Radiation Safety Manual

(Revised March 2010)

Updated December 2012

Stanford University

Veterans Affairs Palo Alto
Health Care System

Environmental Health and Safety, Stanford University, Stanford California

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http://www.stanford.edu/dept/EHS/prod/

Preface

The privilege to use ionizing radiation at Stanford University, Stanford Hospital & Clinics, Lucile Packard Children's Hospital, and Veterans Affairs Palo Alto Health Care System requires each individual user to strictly adhere to federal and state regulations and local policy and procedures. All individuals who work with radioactive materials or radiation devices are responsible for knowing and adhering to applicable requirements. Failure of any individual to comply with requirements can jeopardize the investigation, the laboratory, and the institution.

This manual provides an orientation on ionizing radiation, and describes the radiation safety policies and procedures we have implemented to ensure a safe environment for our patients and students, the public, and ourselves. Our goal is to afford users as much flexibility as is safe and consistent with our policy of as low as reasonably achievable (ALARA) below the limits provided in the regulations.

The Radiation Safety Officer is responsible for managing the radiation safety program subject to the approval of the Administrative Panel on Radiological Safety, and is authorized to take whatever steps are necessary to control and mitigate hazards in emergency situations.

Consult the current Radiation Safety Officer at 723-3201 for specific information.

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Radiation Safety Manual

PREFACE

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Part 1 THE SCIENCE AND TECHNOLOGY OF IONIZING RADIATION

The discovery of x-rays in 1895, and radioactivity in 1896, provided two fundamental foundation stones for the revolution in physical science that occurred in the twentieth century. However, the field of radiation science is sufficiently specialized that it may only be mentioned in passing at the undergraduate level.

This part is a primer on the origins of ionizing radiation, its interaction with matter, its measurement, its potential for adverse health effects, and the measures used to ensure a safe workplace. There are also many unique characteristics related to radioactivity and ionizing radiation; those that are important to radiation safety, specifically time, distance, shielding, and cleanliness in the radiochemistry lab, will be examined. For additional information, consult the references listed at the end of this part.

There are many terms of art specific to ionizing radiation and our administrative structure to ensure its safe use. These terms are defined in the Glossary in Part 4.

SOURCES OF IONIZING RADIATION

We are constantly exposed to ionizing radiation in both the natural and the modern technological environment. This section describes the sources of ionizing radiation used in the research and teaching environment.

Radiochemicals	The evolution of medical research and patient care over the last fifty years was made possible in large part by the use of radioactive atoms to label molecules. This technology provides a simple method by which a chemical compound can be marked, observed, and measured as it is processed by a simple cell culture or a human being. There are applications throughout the life, physical, and engineering sciences. The quantity of a naturally occurring analyte can be measured with isotope dilution analysis. Similar technologies permit the study of, for example, solubility constants of slightly soluble salts. Environmental samples can be analyzed using radiometric titration or by measuring naturally occurring radiotracers.
Sealed Sources	Many devices use sealed radioactive sources because they provide a convenient, inexpensive source of ionizing radiation. Sealed radioactive sources are often made by encapsulating the salt or metal of a radionuclide in a welded metal container whose size typically ranges from smaller than a pencil lead to the size of a golf ball. The encapsulation ensures that there will be no radioactive

	contamination of the laboratory. Alpha "sealed" sources have an open window construction with the source material bonded to the surface of a silver foil mounted in the recess of the plastic disc. Sealed source applications range from low activity alpha sources that are used in home smoke detectors through high activity, self-shielded irradiators that permit the study of dose effects.
X-ray Machines	Any electronic device that has fast-moving electrons is a potential source of ionizing radiation. One is the diagnostic x-ray machine. First used in 1896, it permitted non-invasive imaging of internal human structures. Today, in the US alone, diagnostic radiology accounts for two-thirds of our dose from man-made sources.
X-ray Diffraction and X-ray Fluorescence	Because their wavelength is comparable to the lattice separation in crystals, x-ray diffraction units can be used to study the arrangement of atoms in crystals. X-ray fluorescence permits the chemical analysis of a sample because each element has a unique fluorescent spectrum whose intensity is proportional to that element's concentration in the sample. Both techniques require narrow, intense x-ray beams.
High energy X-ray machines and particle accelerators	High energy x-ray machines, operating in the 4 MV to 25 MV energy range, are used to treat many illnesses, and very-high-energy particle accelerators are used by physicists to understand the internal structure of the elementary particles.
Electron Microscopes	Although they are electronic devices, electron microscopes do not normally present a radiation hazard due to their engineering design and operating parameters. Microscopists who use uranium salts when examining biological specimens should observe hazardous chemical precautions. Persons using uranium salts must work under a controlled radiation authorization (CRA) and submit their protocol to their Health Physicist for review and guidance regarding disposal. See Data Sheets in Part 4, Appendices.
Cabinet X-ray machines	Cabinet x-ray machines are enclosed, self-shielded, interlocked irradiation chambers. The machine can only operate when the chamber door is securely closed. The exposure rates at every location on the exterior meets the rate specified for uncontrolled areas.

RADIOACTIVITY

Radioactivity is the spontaneous emission of charged particles or photons by an atomic nucleus that is in an unstable configuration. This event is called a nuclear transformation, a decay, or a disintegration. Each decay event involves loss of mass or charge. There are a variety of radioactive decay modes. One of the best sources of information on decay modes is the Chart of Nuclides published by the Knolls

Atomic Power Laboratory. Decay schemes for selected isotopes also appear in many texts and reference books. For a more complete introductory discussion, see Alpen ch. 3, Hendee ch. 3, Turner ch. 3, or Bushberg ch. 14.

Alpha

The alpha particle is simply a helium nucleus, comprised of two protons and two neutrons. It is associated with the radioactive decay of elements of high atomic number. For example,

$$^{226}\mathrm{Ra} \rightarrow {}^{222}\mathrm{Rn} + {}^{4}\alpha$$

Each alpha particle has a charge of +2 and a mass of 4. Most have an initial kinetic energy of about 5 MeV. They are frequently accompanied by high energy gamma rays. Almost all radionuclides that decay by alpha emission have atomic number greater than 83 (bismuth). See Krane ch. 8.

Properties of α-particles

Because of their +2 charge and relatively low velocity, alpha particles are densely ionizing, depositing an enormous amount of energy at each collision with an attenuating atom. Thus, they lose all of their kinetic, ionizing energy after travelling a very short distance in any medium. A thin piece of paper, or the layer of dead cells on your skin surface, will completely attenuate a beam of alpha particles. Therefore, alpha particles pose no external hazard. However, if ingested, they can deliver a very large radiation dose to tissue. For example, radium is in the same column of the periodic table of elements as calcium, and is a bone seeker. Ingestion of radium can cause a very large radiation dose to blood-forming cells.

Beta

The beta particle is an electron that has been ejected from a neutron-rich nucleus. It differs from an electron only because it is a product of radioactive decay. This leads us to observe that the neutron is essentially a proton with an attached electron. During the radioactive decay event, the neutron reverts to a proton, an energetic electron and a neutrino that escapes the nucleus. For example,

$$^{14}\mathrm{C} \rightarrow {}^{14}\mathrm{N} + {}^{0}\beta\text{-}\ (0.156\ \mathrm{MeV}) + \nu$$

The maximum kinetic energy of the beta particle, in this example 0.156 MeV, can range from as low as 0.019 MeV for a 3H decay to as high as 1.7 MeV for a 32P decay, or 3.3 MeV for a 214Bi decay. The higher energy particles are more penetrating. See **Table 1.1** for other examples of beta emitters.

Unlike the discrete energies observed for alpha particles and gamma rays, the average kinetic energy of all beta particles from a given isotopic sample is about one-third the maximum energy that is possible for that isotope. See Figure 1.1. The maximum and average are characteristic for the isotope. For a low energy beta particle, we might ask where the missing energy has gone. To explain this, Pauli postulated the existence of a new particle, the neutrino (ν), emitted simultaneously and sharing the energy of the decay event with the beta particle. Neutrinos have little mass and no charge, and do not frequently interact with matter.

Properties of β- particles

As with alpha particles, beta particles are completely attenuated by small thicknesses of common materials. See Figure 1.2. Therefore, they do not pose an external source of radiation dose. Even a high energy beta particle from a P-32 decay event can only penetrate about 8 millimeters of tissue. Our radiation-sensitive organs are typically at least 12 to 25 millimeters below the skin surface. However, a beta emitter can cause radiation dose if ingested. See also Krane ch 9, and Shapiro Part II.

A low atomic number material such as plastic is used for shielding a beta emitter.

The dose rate from a point beta source with energy greater than 0.5 MeV is:

$$X(\text{rad/hr}) = (2.7 \times 10^5 A) / r^2$$

Where X is the dose rate measured in rad/hr, A is activity in Ci, and r is distance in cm. For example, the beta dose rate at 3 cm from a 1 mCi vial of P-32 is:

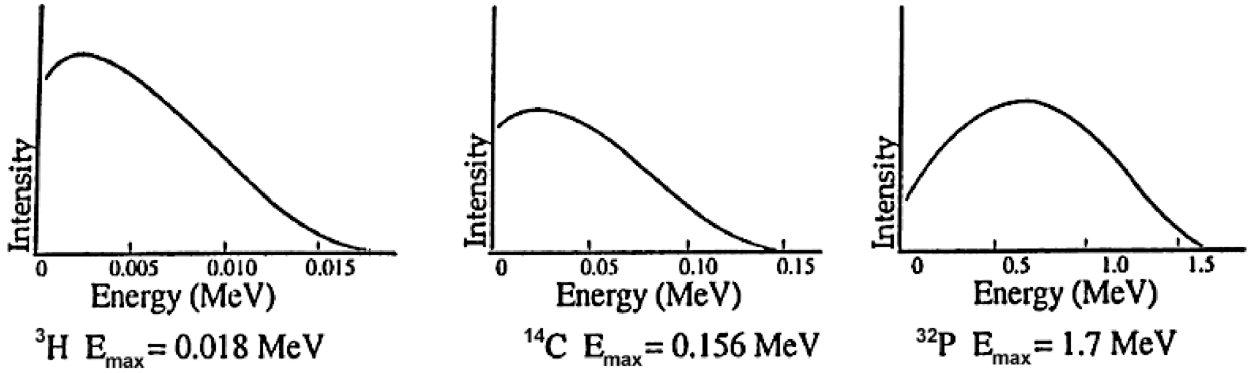
$$2.7 \times 10^5 \times 0.001 / [3]^2 = 30 \text{ rad/hr}$$

Positron

A few isotopes, such as 11C, 13N, and 18F, decay by positron emission. A positron, the anti-particle of a beta particle, is emitted by a proton-rich nucleus. It has the same mass as an electron, but carries a positive charge. During the decay event a proton converts to a neutron and a positive electron, or positron, which is ejected from the nucleus. The positron typically travels not more than a few millimeters before annihilating with an electron to yield two 0.511 MeV photons. That interaction represents a conversion of mass to radiant electromagnetic energy.

Radionuclide	E_{max} in MeV	Half-life
H-3	0.019	12.3 y
C-14	0.156	5730 y
P-32	1.710	14.3 d
P-33	0.249	25.4 d
S-35	0.167	87.4 d
Cl-36	0.709	3E5 y
Ca-45	0.257	163 d
Kr-85	0.687	10.8 y
Sr-90*	0.546	28.6 y
Y-90*	2.28	64.1 h
*Sr-90 and Y-90 are a parent-daughter pair, and are in equilibrium in a source.		

Table 1.1 MAXIMUM ENERGY AND HALF-LIFE OF SELECTED BETA-EMITTERS. The average energy of beta-particle is about one-third of the maximum.



^{3}H $E_{max} = 0.018$ MeV

^{14}C $E_{max} = 0.156$ MeV

^{32}P $E_{max} = 1.7$ MeV

FIGURE 1.1 TYPICAL BETA-SPECTRA. Beta spectra demonstrate two characteristics: maximum beta particle energy; the average beta particle energy (typically about one-third of the maximum).

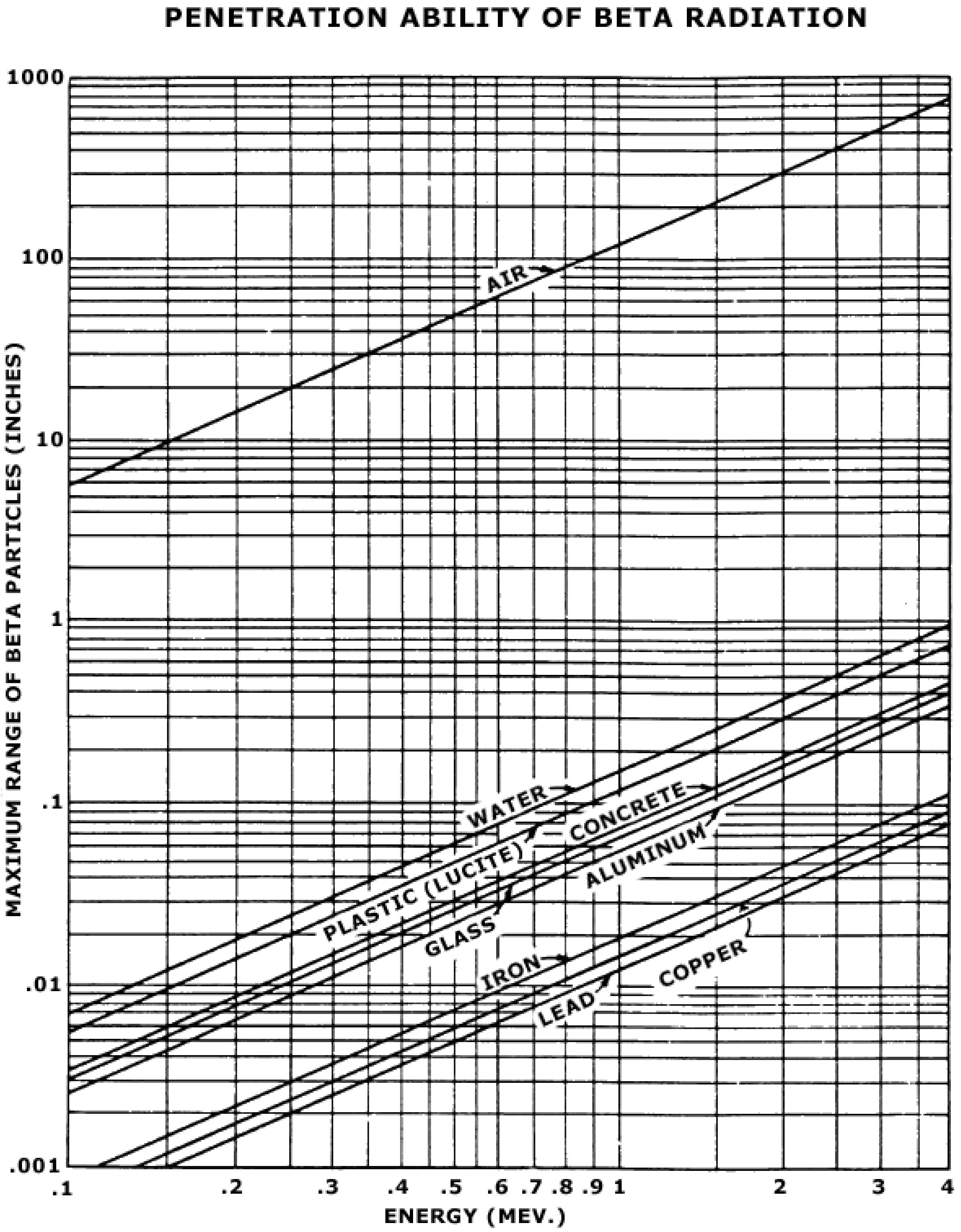


FIGURE 1.2 MAXIMUM RANGE OF BETA-PARTICLES AS A FUNCTION OF ENERGY IN THE VARIOUS MATERIALS INDICATED. From *Radiological Health Handbook, p. 122*.

Beta-Gamma

Most beta emitters decay to an excited daughter state that releases excess energy from the nucleus as a gamma ray. A gamma ray is simply a high energy photon emitted by a nucleus during its transition from a higher energy excited state to a lower energy unexcited state. Gamma rays are always preceded by a charged particle decay, most commonly a beta-event. For example,

$^{137}\mathrm{Cs} \rightarrow {}^{137m}\mathrm{Ba} + {}^{0}\beta\text{-}\ (1.176\mathrm{MeV})$

$^{137m}\mathrm{Ba} \rightarrow {}^{137}\mathrm{Ba} + {}^{0}\gamma(0.662\mathrm{MeV}).$

Although the second decay, called an isomeric transition from the metastable state to the ground state, has a half-life of 2.54 minutes, we seldom chemically separate the 137mBa daughter from the 137Cs parent. Thus, it is not uncommon to colloquially refer to a ".662 MeV cesium-137 gamma ray," although it in fact emanates from a metastable barium nucleus. See Krane ch. 10.

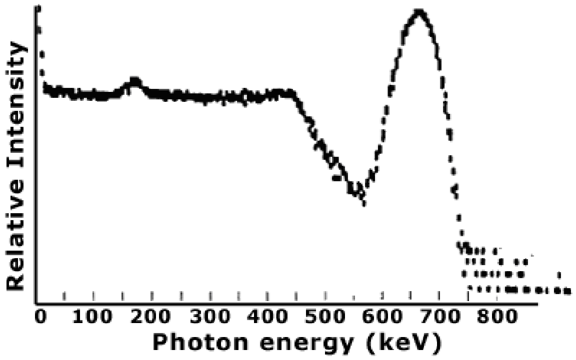


FIGURE 1.3 TYPICAL GAMMA RAY SPECTRUM. The spectrum of gamma rays emitted by a given isotope have distinct, characteristic energy peaks that permit identification of the isotope. This is Cs-137 spectrum taken with a NaI (TI) detector.

Isomeric transition

If a metastable daughter is sufficiently long-lived, it can be chemically separated from the parent, thus yielding a pure gamma emitter. The most important example is

$$^{99}\mathrm{Mo} \rightarrow {}^{99m}\mathrm{Tc} + {}^{0}\beta\text{-}\ (1.214\ \mathrm{MeV})$$

$$^{99m}\mathrm{Tc} \rightarrow {}^{99}\mathrm{Tc} + {}^{0}\gamma\ (0.142\ \mathrm{MeV})$$

The half-lives of the reactions are 2.7 days and 6.0 hours respectively. Thus it is possible to chemically separate ^{99m}Tc from its parent sample of ^{99}Mo, yielding a pure gamma emitter sample with a half-life of 6.0 hours. Tc-99m is the radionuclide of choice for non-invasive nuclear medicine imaging.

Radio nuclide	Γ-Factor	Half-life	Eγ (MeV)	Eγ %	HVL mm Pb
I-125	2.75	60.1 d	.027	113	0.03
Co-57	1.512	270.9 d	.122	86	0.15
Tc-99m	0.612	6.02 h	.140	90	0.3
I-131	2.83	8.0 d	.364	82	3.0
Cs-137	3.82	30.0 y	.662	89	6.5
Mo-99	1.13	66 h	.140	91	7.7
Co-60	13.7	5.3 y	1.17, 1.33	100	13.5
Ra-226*	0.121	1600 y	0.186	3	0.9

TABLE 1.2 Γ-FACTOR, HALF-LIFE, PHOTOPEAK, AND HALF VALUE LAYER (HVL) FOR SELECTED GAMMA EMITTERS. Eγ, the gamma energy is based on the highest percentage abundance; the gamma energy is based on the highest percentage abundance Eγ %. Ra-226*, HVL mm Pb=7.4 with daughter products. The gamma factor indicates dose rate in R/hr at 1 cm from a 1 mCi point source. Its units are R-cm^2/mCi-hr. It can be used to calculate the dose rate at a distance from a point source of the radionuclide by using the equation:

$$X = (A_o\Gamma)/r^2$$

Where X is the dose rate; A is activity in mCi; Γ is the gamma factor; and r distance in cm.

For example, the dose rate at 10 cm from a 2 mCi source of Co-57 is:

$$X = 2 \text{ mCi} \times (1.512 \text{ R cm}^2 / \text{mCi-hr}) \times (10 \text{ cm})^{-2} = 0.03024 \text{ R/hr}.$$

The half value layer, or HVL, is the thickness of shielding material needed to reduce the exposure rate by half.

Internal conversion

If an excited, metastable nucleus goes to its ground state by transferring its energy to a valence electron that is ejected, the process is called internal conversion. This is observed more frequently in heavy nuclei; gamma decay is the preferred mode for lighter nuclei.

Electron capture

Some proton-rich radionuclides decay by electron capture. An orbiting electron, usually from the K-shell, enters the nucleus and combines with a proton to yield a neutron. Its vacancy is filled by a cascading valence electron, which releases its excess energy as a characteristic x-ray. Alternatively, the excess energy can cause the ejection of a valence electron, called an Auger electron.

Spontaneous fission

A few very massive nuclei, such as Cf-252, can decay by spontaneous fission. About 97% of Cf-252 atoms decay by alpha emission. The remaining 3% of the neutron-rich nuclei split into two lighter nuclei, with the release of an average 3.8 neutrons per fission event.

Neutrons

Small neutron sources can be fabricated by mixing an alpha-emitter such as ^{238}Pu or ^{241}Am with ^{9}Be, which has a loosely bound neutron. The nuclear reaction is:

$$^{4}\alpha + {}^{9}\mathrm{Be} \rightarrow {}^{12}\mathrm{C} + {}^{1}\mathrm{n}$$

These sources are commonly used in physics and analytical chemistry experiments when a low-flux neutron source is needed.

PROPERTIES OF RADIOACTIVITY AND UNITS OF MEASURE

Characteristic decay scheme

The modes and characteristic energies that comprise the decay scheme for each radioisotope are specific. If instrumentation is sufficiently sensitive, it is possible to identify which isotopes are present in a sample, or alternatively, to measure only the radioisotope of interest within a sample containing several radioisotopes.

Half-life ($T_{1/2}$)

Probably the best known property of radioactivity is the half-life $T_{1/2}$. After one-half life has elapsed, the number of radioactive decay events in a sample per unit time will be observed to have reduced by one-half. The decay rate or activity A_t at any time t can be described mathematically:

$$A_t = A_0 \; e^{-.693\, t/T_{½}}$$

$e^{-.693}$ is equal to ½, and the exponent t/ $T_{1/2}$ describes the number of elapsed half-lives. Therefore, t and $T_{1/2}$ must be expressed in the same unit. For example, the half-life of I-131 is 8.0 days. If a vial were labeled "29 mCi at 1pm June 3," the activity in the vial at 1am June 6 is:

$$29 \text{ mCi } e^{-.693\,(2.5\,/\,8.0)} = 23 \text{ mCi}$$

Alternatively, if n is the number of elapsed half-lives, then:

$$A_t = A_0 \; (1/2)^{n}$$

$$29 \text{ mCi } (1/2)^{0.31} = 23 \text{ mCi}$$

Half-lives range from billionths of a second to billions of years. The half-life is characteristic of the radioisotope, and cannot be inferred. The half-life is included with the description of the decay scheme.

Decay constant (λ)

The number of decay events in a sample per unit time, or activity A, is proportional to the number of radioactive parent atoms N in the sample; $A = -\lambda N$. For example, the decay constant for 99mTc is 0.115/hour. The half-life is related to the isotope's decay constant; $\lambda = .693 / T_{1/2}$. Thus, we can also write the decay equation:

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

For example, if a vial contains 100 mCi of Tc-99m at 7 am, the activity at 7 pm is:

$100\ \mathrm{mCi}\ e^{-0.115/\mathrm{hr} \times 12\ \mathrm{hr}} = 25\ \mathrm{mCi}$

When using any of these equations, be sure that the same unit of time, whether hours or years, is used to measure both half life $T_{1/2}$, or decay constant ⍰, and elapsed time t.

Measures of activity (A)

The number of disintegrations, or decay events, or nuclear transformations, in a sample per unit time is its activity A. Two common informal units are disintegrations per second and disintegrations per minute.

Curie (Ci)

The US unit of activity is the curie (Ci). One curie is 2.2×10^{12} disintegrations per minute, or 3.7×10^{10} disintegrations per second. Common multiples are the millicurie and microcurie.

Becquerel (Bq)

The SI unit of activity is the becquerel (Bq). One becquerel is 1 disintegration per second. The common multiple is the megabecquerel. Note that 1 mCi = 37 MBq.

ELECTRONIC SOURCES OF IONIZING RADIATION

Production of x-rays

Radioactivity is not the only source of ionizing radiation. Electrons are emitted by a filament heated with an electric current; the process is called thermionic emission. If the electrons are then accelerated through an electric potential of several kV to several MV, and then stopped instantly in a high atomic number metal target anode, some of their kinetic energy can be converted to high energy photons called bremsstrahlung radiation, from the German term for braking radiation. This radiation is more commonly known as x-rays. However, most of the kinetic energy is converted to heat.

For electrons incident on a thick target, the fraction F of energy converted to x-rays is approximately:

$$F = 7 \times 10^{-4}\ Z\ E_k$$

Z is the atomic number of the target, and E_k is the accelerating voltage in MV. Therefore, a 1 MV electron beam accelerated to a tungsten

(Z = 74) target will be about 5% efficient in the production of x-rays.

$$F = 7 \times 10^{-4} \times 74 \times 1 = 0.052$$

The other 95% of the kinetic energy of the electrons is converted to heat.

Because x-ray production is directly proportional to the atomic number of the target and the accelerating voltage of the device, reducing both variables can dramatically reduce the x-ray output of a device. This explains why electron microscopes, cathode ray tubes, and television tubes are not significant sources of x-ray exposure. Although they also have a heated filament and a beam of accelerated electrons, the target is a low Z material, and accelerating voltages are typically 20 kV to 50 kV. Because the maximum x-ray energy cannot exceed the accelerating voltage, most of the x-rays produced cannot penetrate the glass envelope used to contain the vacuum.

X-ray spectra

An x-ray spectrum is continuous, with energies ranging from near 0 keV to the maximum applied voltage. Intensity spikes at energies that are characteristic of the metal used to make the target are superimposed. See Figure 1.3**.** This process forms the basis for radiographic internal imaging in medicine. It is also used extensively in crystallography studies.

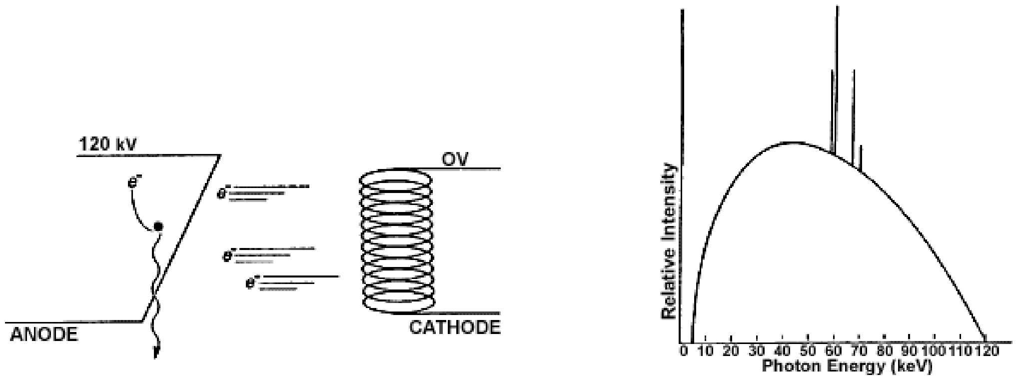


FIGURE 1.4 X-RAYS. (a) x-rays are produced when an electron loses kinetic energy while interacting with a target nucleus. (b) x-rays demonstrate a continuous bremsstrahlung spectrum with spikes that are characteristic of the anode target material, in this case tungsten. The maximum x-ray energy, when expressed in keV, is equal to the voltage applied between the cathode and anode, in this case 120 kV. The average x-ray energy is about one-third of the maximum.

X-ray diffraction and x-ray fluorescence

A special word of caution is appropriate for those who use analytical x-ray devices. Although the beam is narrow, its intensity can be 500 rads per second at the sample, and 10,000 rads per second at the x-ray tube window. Just a few minutes handling a sample with the beam on could cause ulceration that can only be treated by amputation.

The dose rate for your unit can be calculated:

$$X \text{ (rad/sec)} = 50 \times V \text{ (kV)} \times I \text{ (mA)} \times Z_{target} / [r \text{ (cm)}]^2 \times 74$$

For example, the dose rate at 2 cm from a copper target operated at 80 kV and

100 mA is:

$$50 \times 80 \times 100 \times 29 / (2)^2 \times 74 = 39000 \text{ rad/sec}$$

For a further discussion, see Health Physics. 15(6):481-486, December 1968.

Neutrons Neutrons can be created by bombarding targets with high energy photons:

$\gamma + {}^{9}Be \rightarrow {}^{8}Be + {}^{1}n$,

or accelerated charged particles, for example deuterons:

$${}^{2}d + {}^{3}He \rightarrow {}^{4}He + {}^{1}n$$

INTERACTIONS OF PARTICULATE RADIATION WITH MATTER

Alpha particles The alpha particle, comprised of two protons and two neutrons, is very massive, has high kinetic energy, and a charge of +2. Due to its relatively low velocity, it leaves a dense track of ionizations caused by coulumbic interactions. An alpha particle can penetrate about 3 cm of air, but only a few microns of tissue.

Beta particles The beta particle is a high speed electron, with a charge of -1, ejected from a nucleus. The beta particles from a given isotope have a continuous spectrum of energy that is characterized only by the maximum energy associated with the isotope. Depending on the maximum energy, beta particles can penetrate a few microns to a few centimeters of tissue. They also leave a moderately dense track of ionizations caused by coulumbic interactions.

Like the electronic devices described above, beta particles will produce x-rays when absorbed by a target. The fraction of beta energy converted to x-rays is approximately:

$$F = 3.3 \times 10^{-4} Z E_{max}$$

Z is the atomic number of the target, and E_{max} is the maximum beta energy in MeV. This relationship explains why we use low Z materials to shield beta sources. There is less bremsstrahlung production.

Neutrons Depending on their source, neutrons can range in energy from as high as tens of MeV to 0.015 eV. Because they are uncharged, they interact primarily by physical collision with absorber nuclei. The collisions are characterized by conservation of momentum and kinetic energy, and are called elastic.

INTERACTIONS OF PHOTONS WITH MATTER

Gamma rays and x-rays

Gamma rays and x-rays are both forms of electromagnetic radiation. They differ only in their source. A gamma ray emanates from the nucleus of a radioactive atom. An x-ray emanates from outside the nucleus of a radioactive atom, or from an electron as it changes direction when passing an atomic nucleus; this latter type of x-ray is called bremstrahlung. All are collectively referred to as ionizing photons

Photon interactions

Because it is not charged, a photon does not interact by coulumbic force, but rather only by interaction with an electron. The two most common forms of interaction are the photoelectric effect, .Figure 1.5, and Compton scattering, Figure 1.6

The probability of these events depends on the absorbing medium and the photon energy. The photoelectric effect predominates for low energy photons (less than 100 keV). Its probability increases dramatically with Z. The Compton effect predominates for moderate to high energy photons (more than 100 keV). See Hendee ch 4. These facts drive our selection of shielding materials.

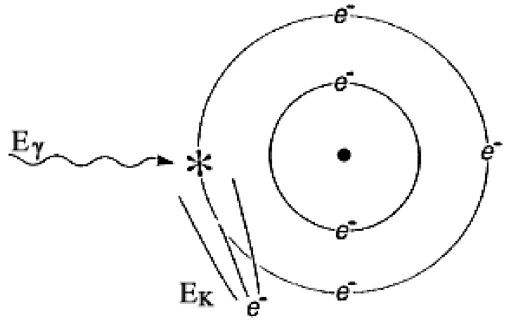


FIGURE 1.5 THE PHOTOELECTRIC EFFECT. The photon is completely absorbed. Its energy E_γ liberates an electron bound with energy E_B, and provides it with kinetic energy E_K. Mathematically, $E_K = E_\gamma - E_B$

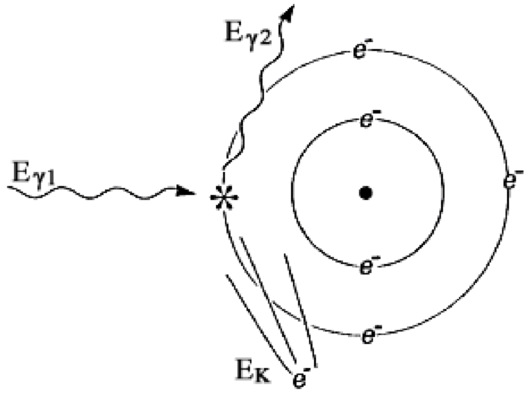


FIGURE 1.6 COMPTON SCATTER. An incident photon with energy $E_{\gamma 1}$ liberates an orbiting electron, yielding a recoil electron with kinetic energy E_K and a lower energy scattered photon with energy $E_{\gamma 2}$ Mathematically, $E_{\gamma 1} = E_K + E_{\gamma 2}$

Other interactions Low energy photons can also interact by coherent scattering. High energy photons can also interact by pair production and photodisintegration. Coherent scattering is generally not of interest in radionuclide laboratory setting and will not be discussed. High energy interactions are of interest in shielding high energy accelerators.

Attenuation The reduction of intensity I of a photon flux is called attenuation. The mathematics of attenuation of ionizing photons in an absorber is identical to the mathematics of half-life. However, we use the terms thickness x, half value layer HVL, and linear attenuation coefficient μ in place of time t, half-life $T_{1/2}$, and decay constant λ. If one half value layer of shielding is added, the dose rate will be reduced by one-half. For a shielding thickness x, the intensity can be described mathematically:

$$I_x = I_0 \ e^{-.693 \ x/HVL}$$

$e^{-.693}$ is equal to ½, and the exponent x/HVL describes the number of half value layers. Alternatively, if n is the number of half value layers, then:

$$I_x = I_0 \ (1/2)^n$$

Half value layers typically range from millimeters to centimeters, depending on the energy of the radiation and the elemental composition of the attenuating medium. Glass, concrete, steel, lead, and depleted uranium are all commonly used as shielding. See Figure 1.9.

As noted before for half-life and decay constant, the half value layer and linear attenuation coefficient are related: $\mu = .693/HVL$. Thus, we can also write:

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

When using either equation, be sure that the same unit of thickness, whether centimeters or millimeters, is used to measure both HVL and attenuation constant, and applied thickness.

MEASUREMENT OF RADIATION AND A UNIT OF EXPOSURE

There are seven basic methods used in the institutional setting for measuring ionizing radiation. The method selected depends on the type and amount of radiation to be measured, the requisite sensitivity, the time available for the measurement, and equipment cost.

Gas detectors One of the oldest methods of measuring ionizing radiation is the gas detector. A simple design would be comprised of no more than an anode and cathode that define a volume in space, a voltage supply, and an ammeter. See Figure 1.7.

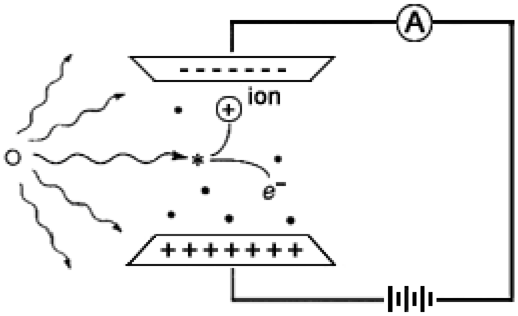


FIGURE 1.7 A SIMPLE GAS DETECTOR. A simple gas detector is comprised of an anode, cathode, voltage supply, and ammeter.

Characteristic curve

Gas detectors demonstrate a characteristic curve of signal strength as a function of applied voltage; see Figure 1.8. In all cases the signal is initiated when a photon or charged particle ionizes a gas molecule in the detector volume.

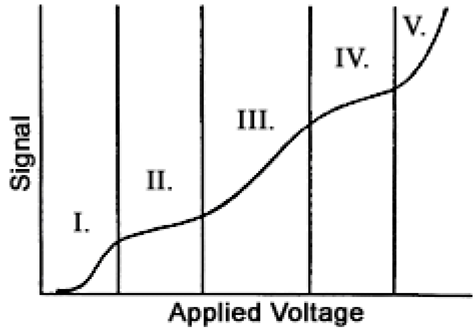


FIGURE 1.8 THE CHARACTERISTIC CURVE FOR GAS DETECTORS. The exact shape of this curve would be different for each detector design, but the five different regions would be observed. They are: I-recombination; II-ionization; III-proportional; IV-GM; and V-continuous discharge.

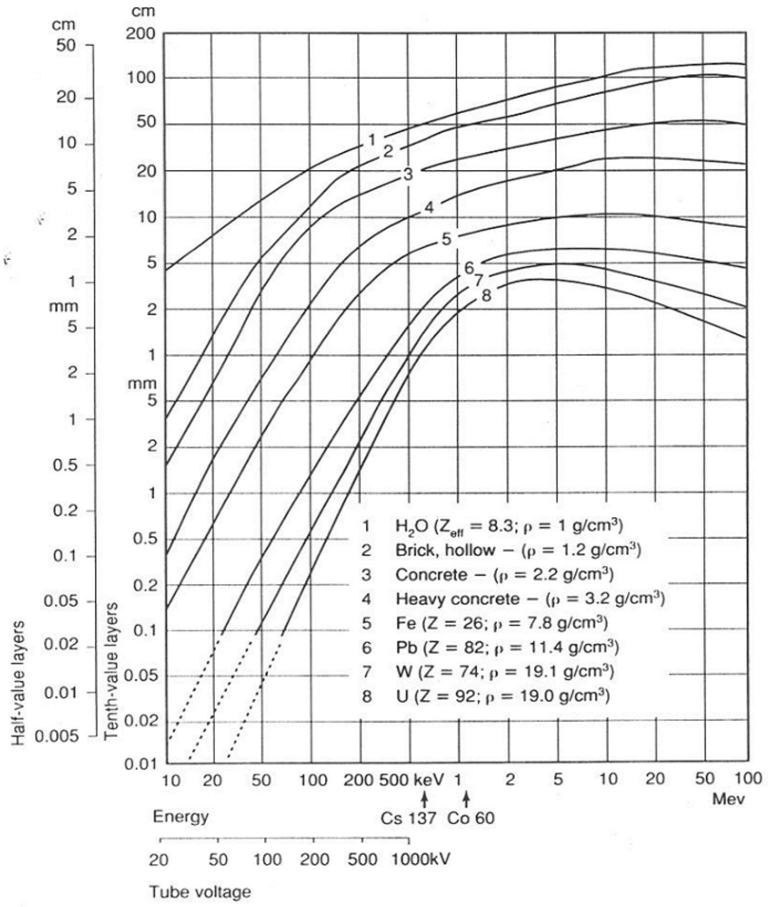


FIGURE 1.9 HALF VALUE LAYER FOR PHOTON ENERGIES FROM 10 KEV TO 100 MEV. SEE *HANDBOOK OF HEALTH PHYSICS AND RADIOLOGICAL HEALTH CHAPTER 6*.

Recombination

If the applied voltage is very low, after an ionization event, the negatively-charged electron and the positively-charged ion will be electrostatically attracted to each other, and will recombine. There will be no signal from the detector.

Ionization

If the applied voltage is just sufficient to collect all the released electrons on the anode, and provide replacement electrons from the cathode, we observe a current that is proportional to the exposure rate. A gas detector operated in this mode is called an ionization chamber. Refer to Knoll ch. 5.

Ionization chamber survey meters are used to measure external radiation dose rate to individuals at levels of about 0.1 millirem per hour or greater. Their use at lower dose rates is limited due to the small electrical signal. The instrument can give false low readings if used to measure intense pinhole beams such as a leak from an x-ray diffraction unit, or intense pulsed radiation, such as from an accelerator.

Small, electrically charged pocket ionization chambers are used to measure whole body dose for individuals who occasionally work in a radiation area, or who may be exposed to a high dose rate while performing a special task.

Roentgen, a measure of exposure

The ionization chamber in Figure 1.7 leads us to the first well-defined unit of radiation exposure, the roentgen (R). The roentgen was originally defined as the amount of ionizing x-ray exposure that would liberate 1 electrostatic unit of negative or positive charge per cubic centimeter of air. Now considered obsolete, it is approximately equivalent to a rad or a rem of radiation dose. Those units are discussed later.

Proportional counter

If the applied voltage is increased, rather than collecting an electrical current, each individual ionizing particle can cause a cascade of secondary ionizing events that are detected as an electrical pulse. The process is called gas multiplication. The magnitude of the electrical pulse is proportional to the energy of the particle that initiated the signal. Thus, for a fixed applied voltage, the signal from a 4.9 MeV ^{241}Am alpha particle will be almost three times larger than the signal from a 1.8 MeV ^{32}P beta particle. See Knoll ch. 6.

Proportional counters are commonly used for measuring environmental and laboratory contamination survey samples.

Geiger-Mueller (GM) tubes

If the voltage is increased further, an individual particle can cause a complete ionization of the gas in the detector. Any ionizing particle, whether high or low energy, whether charged or uncharged, that interacts with the detector gas generates a large electrical pulse. A detector operated in this mode is called a Geiger-Mueller, or GM detector. A GM instrument can become paralyzed and give a false-low reading in continuous high dose rate fields or pulsed fields. See Knoll ch. 7.

GM tubes are commonly used as survey instrument detectors because the complete instrument is relatively inexpensive, lightweight, and rugged. Note that, although a GM survey instrument may have a “millirem per hour” exposure scale, the calibration is valid only for the radiation source used to calibrate the instrument, usually Cs-137. Depending on the type of radiation encountered in the laboratory and its energy, this instrument may indicate low to five- or ten-fold high when used to measure dose rates. Thus, it must be calibrated for the radionuclide of interest if accurate measurements are needed.

GM survey meters are often used to conduct cursory contamination measurements. The meter indicates "counts per minute"; contamination action levels are expressed in "disintegrations per minute." Because the GM detector is energy sensitive, readings must be corrected for the detection efficiency for the radionuclide of interest. Typical efficiencies are provided in Table 3.4.

Continuous discharge

If the voltage in the gas detector were increased further, the positive charge on the anode would pull electrons off the cathode and there would be a continuous signal whether ionizing radiation were present or not. This is referred to as continuous discharge. A detector operating in this region cannot be used as a measuring tool.

Film

The earliest radiation detector was photographic film. The unexpected darkening of photographic plates led Wilhelm Roentgen to the discovery of x-rays in 1895. An ionizing particle disrupts the silver bromide crystals in the film emulsion, allowing the silver to be precipitated onto the film substrate during processing. A greater radiation dose to an area of film results in a darker image.

Film is used for medical imaging; see Bushberg ch. 9 and 13. It is also used in film badge to measure personalwhole body dose. A small film sandwiched between metal and plastic filters in a plastic holder provides a personal monitor that can measure penetrating and non-penetrating dose. See Figure 1.10. The amount of darkening under each filter sandwich is a function of dose. Only higher energy penetrating radiation will darken the film within the metal sandwich; beta dose will darken the film in the open window of the badge. See Cember ch. 9.

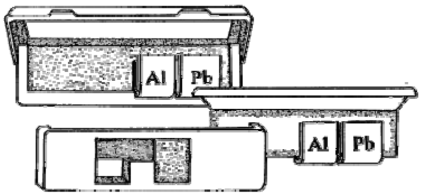


FIGURE 1.10 TYPICAL FILM BADGE. The film badge is comprised of a plastic holder, metal filters, and a film packet with slow and fast emulsions.

Thermo-luminescent dosimeters (TLDs)	Some crystals, such as LiF, store ionizing radiation energy when valence electrons are moved to higher energy "traps" within the crystal matrix. The trapped electrons are released by heating the crystal. When they return to the lower valence energy level, the difference in energy is released as visible light. The amount of visible light released is proportional to the radiation dose absorbed by the crystal. The process is called thermoluminescent dosimetry. TLDs can be used to measure patient dose in diagnostic radiology and radiation therapy. They are also used as extremity dosimeters to measure finger dose for individuals handling small, high activity sources or as a personal monitor.
Scintillation Counting	Some detectors convert a particle's energy to visible light that can be measured with a photomultiplier tube (PMT). This is called scintillation counting. To measure non-penetrating beta radiation, the sample is mixed with a liquid scintillant called a cocktail. To measure penetrating photon radiation, a solid state crystal detector is used. In either case, the charged particles, whether beta particles in liquid scintillation counting or the photoelectrons and compton electrons in x-ray or gamma-ray analysis, interact with the orbital electrons of the scintillator to create flashes of light. See Knoll ch. 8.
Liquid Scintillation counting (LSC)	To measure samples with beta emitters such as ^{3}H, ^{14}C, ^{35}S, ^{32}P, and ^{33}P, the sample is added to a vial of liquid scintillation cocktail comprised of solvent and scintillant. The vial is then mechanically lowered into a light-tight chamber that has two PMTs that detect the individual scintillation events.
NaI(Tl)	To measure samples with gamma emitters such as ^{125}I or ^{99m}Tc, the sample can be placed beside a NaI(Tl) crystal that is optically coupled to a PMT; the entire assembly is enclosed in an aluminum envelope to keep out room light and humidity. The energy of the incident gamma ray is converted to a flash of light in the crystal. The PMT detects the individual scintillation events and their relative intensities.
"cpm" and "dpm"	Many types of radiation detection or measurement instruments indicate "counts per minute"; action levels are usually expressed in "disintegrations per minute." Because all detectors are energy and geometry dependent, cpm readings must be corrected for the detection efficiency for the radionuclide of interest. Mathematically, dpm = cpm / efficiency. Typical efficiencies are provided in Table 3.4**.**

BIOLOGICAL EFFECTS OF RADIATION AND UNITS OF DOSE

Shortly after its discovery, it was recognized that ionizing radiation can have adverse health effects. See Alpen, Introduction. In this section we examine the radiation dose that is a natural part of our environment, and the types of health effects associated with large acute exposures and with low dose rate chronic exposure.

Basic law of radiobiology

Early in the use of ionizing radiation, harmful effects were observed in individuals who had been exposed to large and repeated doses. In 1906 Bergonie and Tribondeau developed a hypothesis, since termed the Basic Law of Radiobiology, regarding biological effects of radiation: Biological effects are directly proportional to the mitotic index and the mitotic future of the exposed cell, and inversely proportional to the degree of differentiation. Mitosis refers to the natural division of a cell nucleus during cell reproduction; differentiation refers to the cell's degree of specialization to perform a specific function in the organism.

Cell sensitivity

Following this law, the most sensitive cells include rapidly dividing, undifferentiated stem cells such as erythroblasts, intestinal crypt cells, primary spermatogonia, and basal cells in the epidermis. Rapidly dividing cells that are more differentiated, including intermediate stage spermatogonia and myelocytes, are less sensitive than undifferentiated cells but are still quite radiosensitive. Irregularly dividing cells such as endothelial cells and fibroblasts demonstrate intermediate sensitivity. Cells that do not normally divide but have the potential for division, such as parenchymal liver cells are relatively radioresistant. Non-dividing cell lines such as muscle cells, nerve cells, mature erythrocytes, and spermatozoa are the most radioresistant. Some cells that would be predicted to be resistant to damage because they do not undergo division and are differentiated, such as the lymphocytes and ova, are nonetheless quite radiosensitive.

DNA as the target

All these cells appear to be affected because of DNA lesions and double strand breaks. The target in the lymphocytes and ova appears to be lipoprotein structures in the nuclear cell membrane rather than in the DNA itself. Damage can be produced directly by the interaction of the radiation with the biochemical target, or by interactions of the free radicals OH, e^{-}_{aq}, and H that are the ionization products of water which have unpaired electrons, with the DNA or other targets. See *Turner* ch. 13.

Age, species, and fractionation

Other factors affect radiosensitivity. As expected, radiosensitivity is greatest during the fetal stage and becomes progressively smaller through adolescence and adulthood. Different species demonstrate different radiosensitivities. A large acute dose delivered at once would have a greater effect than the same dose administered over time as incremental fractions.

Rad and Rem

The US unit of dose is the rad; it is the deposition of 100 ergs of ionizing energy per gram of target material. The US unit of dose equivalent is the rem; for x-, gamma-, and beta-radiation it is numerically equal to the dose in rad. Both are approximately equal to the exposure in roentgen. There are rad-to-rem correction factors as high as twenty to account for the greater radiation damage caused by alpha particles, neutrons, and high energy protons.

Gray and Sievert

The SI units for dose and dose equivalent are the gray (Gy) and sievert (Sv). 1 Gy = 100 rad. 1 Sv = 100 rem. The centigray equal to one rad and the millisievert equal to 100 millirems are commonly used.

Average natural background dose

The amount of radiation an individual receives is called the dose equivalent and is measured in rems. The average individual in the United States accumulates a dose equivalent of 0.3 rem from natural sources each year. Figure 1.11.

Variations in natural background

Natural background radiation levels are much higher in certain geographic areas. A dose of 1 rem may be received in some areas on the beach at Guarapari, Brazil in about 9 days. Some people in Kerala, India get a dose of 4 rems every year. In the US, the dose from natural radiation is higher in some states, such as Colorado, Wyoming, and South Dakota, primarily because of increased cosmic radiation at high elevations and natural high concentrations of uranium and thorium in the soil. Radiation dose can also be received from brick structures, from consumer products, and from air travel.

Medical Dose

Many people receive additional radiation for medical reasons. As of the year 2006, approximately 400 million x-ray radiography examinations are performed in the United States. A typical two view chest x-ray leads to an effective exposure of about 20 mRem. CT examinations deliver much higher doses than standard x-rays. A typical whole trunk CT (chest, abdomen and pelvis) can be 1.5 rem.

Deterministic effects

(also known as nonstochastic effects)

A clinically observable biological effect that occurs days to months after an acute radiation dose is a deterministic effect. Examples are skin reddening or swelling, epilation, or hematologic depression. Deterministic effects require a dose that is greater than a threshold, typically greater than tens or hundreds of rad. Dose limits are set so that occupational exposures will not cause deterministic effects. Examples are dose limits for the lens of the eye (15 rem each year) and for any single organ (50 rem each year).

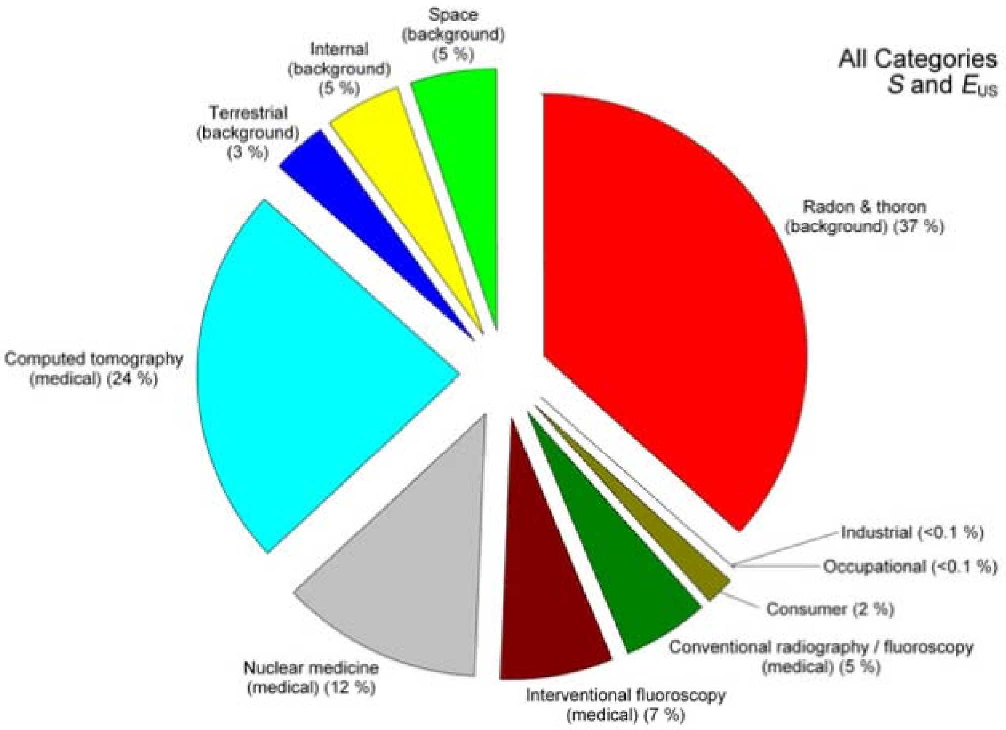


FIGURE 1.11 SOURCES OF RADIATION DOSE IN THE UNITED STATES. From *NCRP 160*, Fig 1.1. Percent contribution of various sources of exposure to the total collective effective dose (1,870,000 person-Sv) and the total effective dose per individual in the U.S. population.

Deterministic effects are possible when using electronic devices such as x-ray diffraction units (XRDs) or linear accelerators. An XRD beam is sufficiently intense to cause skin burns and ulceration that ultimately require amputation. The broad beam of a linear accelerator could cause cataracts or a lethal whole body dose within minutes. Thus it is imperative that interlocks and other safety features never be bypassed.

Stochastic effects

Radiation dose can increase the chance of contracting a cancer. This is an example of a stochastic effect. The increase in chance is assumed to be proportional to the dose, and it is assumed there is no minimum threshold. These two assumptions lead us to low worker and public dose limits. Scientists disagree on whether this conservative linear non-threshold, or LNT, model is the best mathematical representation of the risk of cancer induction. The normal incidence of fatal cancer in an average North American population sample of 10,000 individuals is about 2000. If each individual in the sample were exposed to a 1 rem whole body dose, it is estimated there would be about 4 additional fatal cancers. See BEIR V ch. 3-5.

Tissue weighting factors

In setting limits for doses to individuals, the LNT model also has been used to develop a factor that compares the cancer risk of dose to an individual organ to cancer risk of dose to the whole body. This is of interest when a single organ receives dose after ingestion of radioactivity, or when your body trunk is shielded with a lead apron but the head, neck, and arms are exposed. When the organ dose in rad is multiplied by the tissue weighting factor, the product is the effective dose or effective dose equivalent in rem. This allows a single, risk-based additive dose quantity to be used to limit and record all exposures from penetrating radiation from outside the body and radioactivity inside the body.

Hereditary effects

A hereditary effect is one transmitted to offspring due to the irradiation of the parent egg or sperm cells. Although, it has been estimated based on experimental organisms that the chance of a severe hereditary effect is between 0 and 0.00006 per rem, the UNSCEAR 2001 Report on the hereditary effects of radiation emphasized that no radiation-induced hereditary diseases have so far been demonstrated in human populations exposed to ionizing radiation. The normal chance of a birth defect is 0.03, about one-fourth of which is considered of genetic origin.

Basis for dose limits

Radiation, like many things, can be harmful. A large dose to the whole body (such as 600 rems in one day) would probably cause death in about 30 days; but such large doses result only from rare accidents. Control of exposure to radiation is based on the assumption that any exposure, no matter how small, involves some risk. The 5-rem worker dose limit provides a level of risk of delayed effects that is considered acceptable by the NRC. The dose limits for individual organs are below the levels at which biological effects are observed. Thus the risk to individuals at the occupational exposure levels is considered to be very low. However, it is impossible to say that the risk is zero. See ICRP 60, Sec. 5. Thus our goal is to keep all radiation dose as low as reasonably achievable below the limits; see the discussion on p.23.

Dose limit for radiation workers

As a radiation worker, you may be exposed to more radiation than the general public. California and the Nuclear Regulatory Commission (NRC) have established a basic dose limit for all occupationally exposed adults of 5 rems each year.

Dose limit for minors and public

Because the risks of undesirable effects may be greater for young people, individuals under age 18 are permitted to be exposed to only 10 percent of 5 rem, the adult worker limits.

The limit for members of the general public is 0.1 rem.

Dose limit for pregnant workers

The National Council on Radiation Protection and Measurements has recommended that, because they are more sensitive to radiation than adults, radiation dose to the unborn that results from occupational exposure of the mother should not exceed 0.5 rem. California and the NRC have incorporated this recommendation in their worker dose limit regulations. See Table 2.1.

It is your responsibility to decide whether the exposure you are receiving from penetrating radiation and intake is sufficiently low. Contact Health Physics to determine whether radiation levels in your working areas could cause a fetus to receive 0.5 rem or more before birth. Health Physics makes this determination based on personnel exposure monitor reports, surveys, and the likelihood of an accident in your work setting. Very few work positions would require reassignment during pregnancy.

If you are concerned about exposure risk, you may consider alternatives:

a) If you are pregnant, you may ask to be reassigned to areas involving less exposure to radiation. Approval will depend on the operational needs of the department. Note, however, that no employer is required to provide a work environment that is absolutely free of radiation.

b) You could reduce your exposure, where possible, by decreasing the amount of time you spend in the radiation area, increasing your distance from the radiation source, and using shielding. Increased concern for lab cleanliness will reduce the chance of uptake.

c) You could delay having children until you are no longer working in an area where the radiation dose to your fetus could exceed 0.5 rem.

d) You can continue working in the higher radiation areas, but with full awareness that you are doing so at some small increased risk for your fetus.

Discuss these alternatives with your supervisor and Health Physics. A pregnancy declaration form appears in Part 4, Appendices. There is additional information in the discussion of dose limits in Part 2 of this manual.

ALARA POLICY

Compliance with dose limits ensures that working in a radiation laboratory is as safe as working in any other safe occupation. The goal of the radiation safety program is to ensure that radiation dose to workers, members of the public, and to the environment is as low as reasonably achievable (ALARA) below the limits established by regulatory agencies. The program also ensures that individual users conduct their work in accordance with university, state, and federal requirements.

In the preface to this manual, management has committed to an ALARA policy.

GENERAL WORKPLACE SAFETY GUIDANCE

Education, training, and procedures

Safe use of hazardous materials in the workplace depends on the cooperation of individuals who have been educated in the science and technology of the materials, who have technical training specific to their application, and who follow administrative and technical procedures established to ensure a safe and orderly workplace.

Security

No matter what source of radiation you work with, one way to enhance safety is to allow access only to those with business in the area. If you see unfamiliar individuals in the area, it is important to question them or call security. Regulatory agencies consider a high degree of security to be an important compliance matter.

Time

The less time we spend around a potentially hazardous material, the less the risk. If you are not needed in a work area, or if your task can be done elsewhere, leave.

Distance

Increasing our distance reduces the risk from any potentially hazardous material. For gamma radiation sources, the dose rate goes down rapidly with distance. Mathematically, $I_2 / I_1 = r_1^2 / r_2^2$. This is called the inverse square law.

For example, if the dose rate is 100 mrem/hour at 5 cm from a point source, you can calculate the dose rate at 20 cm from the source:

$$I_{20cm} / I_{5cm} = (5cm)^2 / (20cm)^2$$

$$I_{20cm} = (100 \text{ mrem/hr}) \times (5cm)^2 / (20cm)^2$$

$$I_{20cm} = 6.2 \text{ mrem/hr}$$

When working with high energy beta and gamma emitters, remote handling tools can dramatically reduce your hand dose.

Shielding

If the source is a high energy beta or gamma or x-ray emitter, shielding will reduce the dose rate. For beta emitters, use a low atomic number material such as plastic. For gamma and x-ray emitters, high atomic number materials such as steel or lead are preferred. However, remember that steel and lead pose their own drop and earthquake hazards. Lead is also a toxic material; use gloves when handling it and wash when you finish. Contact the hazardous waste staff to dispose of lead shielding that is no longer needed.

Clean, orderly laboratories

Most laboratories do not use amounts of radiochemicals that pose an external dose risk. However, area contamination can happen even when materials are carefully handled. Have in the work area only those things needed for the task at hand. Wear gloves and lab coat, and wash your hands after working. Use absorbent countertop paper to hold spills.

General guidance

Some detailed guidance on laboratory safety measures is provided in Table 1.3. Unless, due to special circumstances, your group has received an exception, you must follow the guidance in that table.

Plan ahead

Think about what you are going to do. What can go wrong? What can distract you? Have you reviewed the laboratory protocol? Are all the supplies that you need at hand? Have you checked laboratory and protective equipment to ensure they are working correctly? Have you practiced the entire procedure wearing your protective clothing and using the tools you need? Are you wearing gloves, coat, and impervious shoes? Do you know where the safety shower and eyewash are?
Do you know what you are doing, and why?

Before you begin	• Only individuals who have completed Stanford radiation safety training may use radioactive materials. • Review the chemical, radiation, and handling hazards precautions and safety guidance before you prepare for the experiment. • Order only approved radiochemicals and quantities. Log receipts. Completely update the storage log at least annually. • Store materials to cause minimal dose in work areas. Shield photon- and high-energy beta-emitters so that the dose rate at 30 cm is less than 2 mR/hr for low occupancy areas, or 0.2 mR/hr for high occupancy areas. Provide secondary containment. • Do not store food or beverages in work areas, or use refrigerators, hot plates, or ovens that are used for radioactive materials work. • Eat and drink only at desk or lounge areas. No food or beverages are allowed in VAPAHCS laboratories.
Preparing for the experiment	• Set up in a well-ventilated work area. Use a fume hood for volatiles such as I-125 and S-35. • Keep the work area clean, neat, and uncluttered. • Provide secondary containment for spills. • Use plastic-backed absorbent pads or trays to cover work areas. • Do not pipette by mouth. Use manipulators. • Wear your dosimeter (e.g., film badge) and ring if assigned. • Keep a survey meter nearby when using millicurie quantities other than tritium. Use a pancake GM for beta-emitters and a NaI(Tl) for photon-emitters.
During the experiment	• Wear impervious shoes, gloves, lab coat, and safety glasses. • Open and dispense reagents behind a splash shield. • Use capped tubes in centrifuges and agitators. • Use activated charcoal to absorb organic vapors in incubators.
After the experiment	• Label individual containers before placing them in storage. • Change bench covers to avoid cross-contamination. • Survey glassware, apparatus, and central facility appliances. Decontaminate before releasing for house use. • Segregate waste. Solidify iodine liquids. Treat pathogens. Log disposals.
Spills or accidents	• Immediately report injuries or personnel contamination to your supervisor and Health Physics. • Promptly report >QLM spills to Health Physics.

TABLE 1.3 STANDARD WORK RULES FOR RADIOCHEMICAL LABORATORIES.

REFERENCES FOR ADDITIONAL INFORMATION

This part is intended only as a primer on ionizing radiation. The following standard texts provide more information on the topics presented here. Additional publications from the National Council on Radiation Protection and Measurements, the International Commission on Radiological Protection, the National Academy of Sciences, and the Nuclear Regulatory Commission are listed in Part IV, Appendices. All are available for review in Health Physics

Alpen	Alpen, E. L. Radiation Biophysics. Englewood Cliffs: Prentice-Hall; 1990.
BEIR V	Committee on the Biological Effects of Ionizing Radiations, National Research Council. Health Effects of Exposure to Low Levels of Ionizing Radiations. Washington: National Academy Press; 1990.
Bushberg	Bushberg, J. T., et al. The Essential Physics of Medical Imaging. Baltimore: Williams & Wilkins; 1994.
Cember	Cember, H. Introduction to Health Physics. New York: Pergamon Press; 1983.
Chart of Nuclides	Knolls Atomic Power Laboratory
Hendee	Hendee, W. R., and Ritenour, R. E. Medical Physics Imaging. 3rd ed. St. Louis: Mosby-Yearbook; 1992.
ICRP 60	International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. Oxford: Pergamon Press; ICRP Publication 60; Ann. ICRP 21 (1-3); 1991.
Knoll	Knoll, G. F. Radiation Detection and Instrumentation. 2nd ed. New York: John Wiley & Sons; 1989.
Krane	Krane, K. S. Introductory Nuclear Physics. New York: John Wiley & Sons; 1988.
NCRP	National Council on Radiation Protection *Ionizing Radiation Exposure of the Population of the United States* (Report No. 160, 2009)
Radiological Health Handbook	Bureau of Radiologic Health. Radiological Health Handbook. Rockville: Department of Health, Education, and Welfare; 1970.
Shapiro	Shapiro, J. Radiation Protection: A Guide for Scientists and Physicians. 3rd ed. Cambridge: Harvard University Press; 1990.
UNSCEAR 2001 Report	United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2001 Report to the General Assembly, with Scientific Annex- Hereditary effects of radiation
Turner	Turner, J. E. Atoms, Radiation, and Radiation Protection. 2nd ed. New York: John Wiley & Sons; 1995.

Part 2 REGULATIONS FOR THE SAFE USE OF IONIZING RADIATION

During its first fifty years of use, ionizing radiation, whether from x-ray tubes or radioactive materials, was applied in a variety of research, medical, industrial, and consumer products and services. Some applications were well founded and some were frivolous. Some of both resulted in injury or death to radiation workers and members of the public.

By the 1960’s, the state and federal regulatory frameworks governing radiation were established. Their goal was to provide adequate assurance of public health and safety in the presence of ionizing radiation. Today, the use of ionizing radiation is one of the most stringently regulated activities in our society.

The original jurisdiction over most radioactive materials was vested by Congress in the Atomic Energy Commission (AEC), the predecessor of the Nuclear Regulatory Commission (NRC). The NRC has transferred regulatory authority over radioactive materials to several of the states, including California, by agreement between the NRC and the state. The NRC retains regulatory authority over federal facilities, including the VA.

The regulations that apply to the use of ionizing radiation are in Title 10, Parts 19, 20 and 35 of the Code of Federal Regulations and in Title 17 of the California Code of Regulations. The complete texts are available for review in Health Physics. Related portions of the United States Code are also available for review.

In some cases California has adopted NRC regulations by reference, and in some cases it has issued regulatory text that is similar to NRC text. It has also issued regulations on x-ray machines, which are not regulated by NRC.

This part summarizes the regulatory requirements that apply to the institutional use of radiation, using the NRC regulations as an outline. Remember that license documents, supporting correspondence, and orders impose additional requirements that are specific to the licensee.

10 CFR PART 19--NOTICES, INSTRUCTIONS, AND REPORTS TO WORKERS; INSPECTIONS

Part 19--Informed worker

10 CFR Part 19--Notices, instructions, and reports to workers; inspections. This part establishes requirements for notices instructions, and reports by licensees to individuals participating in licensed activities, and options available to those individuals in connection with inspections of licensees.

Notices

§19.11 Posting of notices to workers. The regulations are summarized on forms *RH 2364* and *NRC 3*, which must be posted. You may examine the regulations and any correspondence relating to licensed activities. Call Health Physics to make an appointment.

Instruction

§19.12 Instructions to workers. Anyone who works in a restricted area must be provided training in radiation safety, be instructed to observe regulations and operating procedures, and to report unsafe conditions.

Dosimetry

§19.13 Notifications and reports to individuals. At any time you may request a copy of your radiation exposure history. Indicate if you want an updated report each year. If dosimetry is required by regulations rather than provided in response to the project director's request, you will be given a report each year.

Inspections

§19.14 Presence of representatives..., §19.15 Consultation with workers..., §19.16 Requests by workers for inspections. The Nuclear Regulatory Commission (NRC) and California Department of Health Services (DHS) conduct inspections of licensed activities. You may talk with the inspector privately if you want. If you have identified a radiation safety problem and do not believe it has been properly dealt with, you may request an inspection.

10 CFR Part 20--Standards for Protection Against Radiation

Part 20--Safety standards

ALARA

§20.1101 Radiation protection programs. The radiation protection program ensures compliance with regulations. Its goal is to ensure that doses to workers and members of the public are as low as reasonably achievable (ALARA) below state and federal limits.

Dose limits

§20.1201, §20.1207, §20.1208, and §20.1301. Dose limits for workers and the public. Dose limits have been established for adult workers, minor workers, declared pregnant women, and members of the public. The limits are in Table 2.1.

Table 2.1 DOSE LIMITS FOR ADULT WORKERS, MINOR WORKERS, DECLARED PREGNANT WOMEN, AND MEMBERS OF THE PUBLIC. The dose is the sum of the body dosimeter deep dose plus internal effective dose equivalent from ingested or inhaled radionuclides. Internal dose is uncommon in the institutional setting. Our goal is to keep radiation dose below 10% of these limits.

	Whole body dose in one year	**Other limits**
Adult workers	5 rem	Lens 15 rem each year. Skin, organ, extremities in one year: 50 rem
Minor workers	10% of Adult Limit	10% of Adult Limit
Declared pregnant woman	0.5 rem fetal dose	50 millirem fetal dose each month. Skin, lens, extremities: same as adult worker
Members of the public	0.1 rem	2 mrem in one hour

Surveys

§20.1501 Surveys. Surveys must be made to demonstrate compliance with the regulations and to evaluate the potential for radiological hazard that may be present.

Security

§20.1801 Security of stored material. Radioactive material in controlled or unrestricted areas must be secured from unauthorized removal.

Radiation symbol

§20.1901. Caution signs. The standard radiation symbol appears in Figure 2.1. It is magenta, purple, or black on a yellow background.

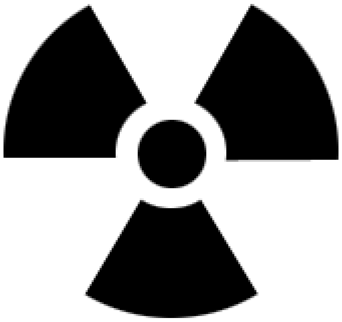


FIGURE 2.1 RADIATION SYMBOL. It is magenta, purple, or black on a yellow background.

Posting requirements

§20.1901 and §20.1902 Posting requirements. The appropriate posting depends on the dose rate or amount of radioactivity in the area or container. Thresholds are provided in TABLE 2.2.

TABLE 2.2 POSTING REQUIREMENTS. Appendix B is in 10 CFR Part 20; DAC means derived air concentration. Appendix C is in 10 CFR Part 20; Quantities of Licensed Material Requiring Labeling; the complete Appendix C is in Part IV, Appendices.

Condition	**Posting**
5 mrem in 1 hour at 30 cm from the source or shield surface	Caution, Radiation Area
100 mrem in 1 hour at 30 cm from the source or shield surface	Caution, High Radiation Area
500 rads in 1 hour at 1 m from the source or shield	Grave Danger, Very High Radiation Area
Air concentrations exceeding the DAC in Appendix B	Caution, Airborne Radioactivity Area
Use or storage of ten times the quantity in Appendix C	Caution, Radioactive Material

Labeling requirements

§20.1901, §20.1904, and 20.1905 Labeling requirements. Containers with greater than Appendix C quantities must be labeled with the radiation symbol, the words "Caution, Radioactive Material," and appropriate precautionary information such as radionuclide, activity, date, dose rate at a specified distance, and chemical form.

Package receipt, opening, and disposal of empty containers

§20.1906 Receiving and opening packages. All non-clinical radioactive materials must be shipped directly to the Health Physics Inspection Station (See Part 3 Ordering and receiving radioactive material for further information). After delivery to the laboratory, review the safety instructions provided by Health Physics and inspect the package for leakage and correctness of contents. If a package appears damaged, promptly contact Health Physics and monitor for dose rate and contamination. If certain thresholds are exceeded, Health Physics must notify the carrier, the Department of Public Health and the Nuclear Regulatory Commission.

If you receive material directly and it has not been inspected, inform Health Physics promptly, and if requested, bring the package to the Inspection Station.

Before discarding empty containers and shipping packages, survey them to ensure that they are not contaminated. Then remove or deface all radiation labels and words. This assures that if the package gets out of the house waste stream it will not be mistaken for a radiation source.

Waste	§20.2001, §20.2003, §20.2005 Waste disposal. Radioactive waste can only be disposed of by transfer to a waste contractor, decay-in-storage, release in effluents, or discharge to the sanitary sewer
Records	§20.2101 Units. Records must have measures recorded in units or multiples of curie, rad, and rem (e.g., mCi, dpm).
Reports	§20.2201, §20.2202, §20.2203 Reports and notifications. Certain types of events require prompt reporting to regulatory authorities. If there is a theft, loss, more than a minor spill, accidental release, or injury involving radioactive material, report it promptly to Health Physics.
Precaution	When making an event report, do not simply leave a recorded message or a note on someone's door. Talk with a member of Health Physics or EH&S, your project director, or the department chair. This assures that there will be prompt, appropriate follow-up.

10 CFR PART 35--MEDICAL USE OF BYPRODUCT MATERIAL

There are extensive regulations governing medical use and human research. They cover general administrative and technical requirements, and prescribe detailed precautions for specific diagnostic and therapeutic clinical procedures. Because they apply only to radiology, nuclear medicine, and radiation therapy, they will not be further discussed here.

TITLE 17--CALIFORNIA CODE OF REGULATIONS

California imposes additional requirements for x-ray installations. These requirements are not under NRC jurisdiction. The radioactive materials requirements are comparable to NRC's byproduct materials requirements.

There are additional engineering and survey requirements for x-ray installations. Because they apply primarily to the design of proposed installations, they will not be discussed.

It is imperative that you do not bypass safety features, and that you report safety features that do not appear to be working.

RESPONSIBILITIES

Safe use of ionizing radiation requires the cooperation of many individuals and committees. Their responsibilities are described below.

Principal investigators	Each Principal Investigator (PI) or project director is responsible for ensuring individuals are trained to do their tasks safely, supervising them, making the lab available for inspection at any work time, and ensuring that the project is managed in accordance with the application, the administrative and technical requirements

in this manual, and the *Hazards Evaluation*.

The PI bears the additional responsibility of setting an example for the project staff. Appropriate attention to details, such as strict adherence to standard work rules, accurate survey records, and timely return of dosimeters (e.g., film badges) can affect the work environment and the attitude of individuals.

Individual users

Each individual user is responsible for following the procedures in this manual and instructions from supervisors and Health Physics, and reporting possible safety problems and incidents.

Administrative Panel on Radiological Safety

The Administrative Panel on Radiological Safety (APRS) oversees the entire institutional radiation safety program for both Stanford and VAPAHCS. It also reviews applications that are outside the jurisdiction of the local control committees.

Local Control Committees

Each Local Control Committee (LCC) is responsible for reviewing applications in its jurisdiction to provide assurance that the work can be done safely and in accordance with the requirements in this manual and the *Hazards Evaluation*. There are two local control committees: Non-Human Use Radiation Safety Committee (NHRSC) and Clinical Radiation Safety Committee (CRSCo) for human use applications. The Radioactive Drug Research Committee (RDRC) is a subset of CRSCo. These committees also oversee VAPAHCS projects.

Health Physics

Health Physics, a division of the Stanford University Department of Environmental Health and Safety (EH&S), is the institutional radiation safety program. It also provides radiation consultation. The Radiation Safety Officer, who is identified on the radioactive materials license, is the manager of Health Physics.

WORDS OF CAUTION

Compliance with requirements

The privilege to use ionizing radiation in medical care, research, and teaching is granted to Stanford and VAPAHCS by the state and federal governments. Health Physics tries to provide users the flexibility needed, consistent with established policy and regulations. There may be some administrative or technical requirements that may not appear necessary in some cases. However, non-compliance jeopardizes not only your project, but the entire community.

Falsification of records is a criminal offense

Do not falsify records, or mislead a state or federal inspector. There are institutional and criminal penalties for such actions. They can have severe adverse effect on your academic or professional career.

If you have made a mistake, request assistance to correct it. If you have failed to make a survey or record of use, note that in the record; do not fabricate records.

Part 3 ADMINISTRATIVE AND TECHNICAL PROCEDURES

Worker and public safety, and orderly conduct of day-to-day business, require a variety of administrative and technical procedures.

Administrative procedures, usually characterized by application forms, supporting documentation, approvals, and other paperwork, help assure that laboratory activities are carefully considered for reasonableness, safety, cost and benefit, and compliance with institutional policy and regulatory requirements. They are not designed to impede your work; their purpose is to protect individuals and the institution from accidents.

Technical procedures, usually characterized by physical measurements or step-by-step instructions, assure that potentially hazardous materials or devices are carefully used and stored.

All uses of ionizing radiation on the Stanford campus are subject to review and approval by the Administrative Panel on Radiological Safety (APRS). The review assures that projects can be conducted safely. The Radiation Safety Officer (RSO) manages the health physics program

This part describes the process for obtaining permission to use ionizing radiation, and applicable safety measures.

GENERAL

Project Directors	Project Directors must qualify as Principal Investigators (PI). This privilege is limited to faculty or certain senior research associates, or their equivalents at the VAPAHCS and the other institutes operating under the university license.
Access for inspection	Health Physics typically schedules inspections to avoid interrupting the laboratory calendar. However Health Physics must have access to laboratories at any time to observe work and perform radiation surveys.
Security	Regulatory agencies require a high degree of security to prevent unauthorized access to and use of radiation sources. At Stanford, radiochemical stock solutions and sealed sources greater than C-level (see Table 3.2) must be stored under lock. In new open architecture buildings, such as CCSR or Clark, all stock vials must be stored under lock. At VAPAHCS, all licensed material, whether it is stock, in use, or waste, must be stored under lock. Radiation devices must be locked out at the console. Do not prop security doors open.
Liquid scintillation cocktail	The APRS recommends biodegradable liquid scintillation cocktail (LSC). Special application and authorization is required for non-biodegradable cocktail. If it a non-biodegradable cocktail is necessary, explain why in the application section that discusses materials or instrumentation.
Mixed waste	Discarding mixed radiologic and chemical hazardous waste is expensive. Make every effort to reduce or eliminate its generation. Special authorization is required prior to generating mixed waste. See pages 36, 55, and 58.

Permitting procedures for radioactive materials

Permitting procedures for radioactive materials require a Controlled Radiation Authorization (CRA) issued by a Local Control Committee (LCC).

There are two LCCs. The Clinical Radiation Safety Committee (CRSCo) reviews all procedures that involve administration of ionizing radiation to humans. The Non-Human Use Radiation Safety Committee (NHRSC) reviews laboratory use of radiochemicals and radiation producing machines within Stanford and VAPAHCS.

	μCi			μCi			μCi
H-3	1000		Co-57	100		Tc-99m	1000
C-14	100		Co-60	1		In-111	100
F-18	1000		Ni-63	100		Sn-113	100
Na-22	10		Zn-65	10		I-123	100
P-32	10		Zn-69	1000		I-125	1
P-33	100		Ga-67	1000		I-131	1
S-35	100		Se-75	100		Xe-133	1000
Cl-36	10		Rb-86	100		Cs-137	10
Ca-45	100		Sr-85	100		Hg-203	100
Cr-51	1000		Y-88	10		Tl-201	1000
Fe-55	100		Y-90	10		Ra-226	0.1

TABLE 3.1 QLM QUANTITIES. This table provides the quantities of licensed material (QLM) requiring labeling for the most commonly used radionuclides. For other radionuclides, use the values in Appendix C of10 CFR Part 20; it is duplicated in Part 4, Appendices.

CONTROLLED RADIATION AUTHORIZATIONS (CRAS) FOR RADIOACTIVE MATERIALS

General

To obtain a Controlled Radiation Authorization (CRA) the PI must submit a CRA application and obtain the approval of the appropriate LCC or the APRS. All radioactive materials must be specified.

Application format

Send an application to Health Physics that provides the following information. If the following instructions are not clear, if you need assistance, or if you have special circumstances, please call. You may submit a hard copy, fax, or e-mail. For an application form go to http://radforms.stanford.edu

Facilities

1.a. Facilities. Identify the department, and list receiving, storage, work, and waste areas. Facilities must be adequate for the safe use of the materials. Benches must have impervious surfaces; secondary containment is needed both in work and storage areas; floors must be sealed and waxed if unsealed radioactive materials are handled. Materials must be secured against unauthorized removal; materials in common use areas must be locked when unattended.

A list of rooms is e-mailed out each quarter for updating by the Health Physics contact.

Ventilation

1.b. Ventilation. Describe enhanced ventilation, fume hoods, and biological containment hoods. These must be working and fume hoods must be checked within the last year for flow rate, typically 100 to 180 feet per minute and with the proper sash height marked. An externally-exhausted biosafety cabinet is required for using volatile iodine in conjunction with pathological or infectious agents.

Personnel

2. Personnel. Identify the Project Director, senior staff members who will directly supervise the project, and other personnel participating in the project. Identify the individual who will serve as Health Physics contact; this individual coordinates day-to-day radiation safety activities such as room surveys and reports. Note if individuals under age 18 will be in the lab.

For the PI, key supervisors, and Health Physics contact, provide work telephone, fax, e-mail, mail code, department, building and room, and SUNetID if available.

Lists of personnel, inventory, assigned rooms, sealed sources and instruments are mailed out each quarter for the Health Physics contact to update.

Proposed materials

3. Materials. For each radionuclide that will be used, provide: radionuclide; chemical forms; maximum quantity to be used per experiment and frequency of experiments; maximum quantity to be obtained per order; and maximum to be possessed at any time. For scintillation cocktails, please provide information on whether it is biodegradable, recommended, or has other hazards associated with it. See page 56.

Characterize volumes as milliliters or liters, and identify other hazardous materials such as toxic chemicals, corrosives, or pathogens that might be mixed with radioactivity. See the following web site to identify.

http://nonhazardouswaste.stanford.edu

Proposed uses

4. Laboratory procedure. Characterize the steps in the laboratory procedure by using the form *Worksheet for Radiochemical Protocols.*

Append copies of the experimental protocols. Look for processes that have caused problems in the past: inadequate secondary containment, long-term heating, failed automatic timers, violent vortex mixing, expansion during heating, containment during centrifuging.

Perform a cold run with mock materials to ensure that you can perform manipulations with gloves, handling tools, and shielding in place.

Deliberate introduction of radionuclides into the environment for investigational purposes requires issuance of a special license by the California Department of Health on an experiment-by-experiment basis. To initiate this procedure discuss the environmental impact and include an estimate of risks to the population that may be exposed. Consult Health Physics for details.

Work rules

5. Work rules. State that you will adhere to the standard work rules in Table I.3. If special circumstances make those work rules inappropriate, call Health Physics. In your application you will have to explain why they are inappropriate, and submit alternative work rules for review.

Waste

6. Waste. Normal radioactive waste service is included in overhead charges. Projects that generate large volumes of radioactive waste, or mixed waste that must be disposed of through a special broker, or for projects who do not contribute to Stanford University overhead will be billed for waste services.

Generation of mixed radioactive and hazardous chemical waste must be approved by the LCC before it is generated. All chemical materials are considered hazardous unless specifically tested or otherwise reviewed against specific criteria. An explanation on how to determine whether a chemical is non-hazardous can be found under *Aqueous waste*, p.53 If you must generate mixed waste, explain why the waste must be generated. Describe alternative research methods that have been explored, and explain why they are not suitable for this project.

Instruments and equipment

7. Radiation measurement and safety equipment. Review Table 3.4 under *Surveys*, p.50, to determine which instruments are appropriate. List instruments that are available. Each project must have suitable detection and measurement instrumentation; sharing is permitted. Consult with Health Physics if you need assistance.

Identify any safety equipment that will be used such as splash shields, trays, or remote handling equipment. Shielding, particularly stacked lead bricks, and heavy equipment should be secured for earthquakes. Large volumes of liquid waste must have secondary containment.

Training and experience

8. Training and Experience. If this is an initial application, provide information regarding the previous training and experience of each PI and user. *Training and Experience* forms are available online at radforms.stanford.edu, or may be copied from Part 4, Appendices.

Training and experience are evaluated by Health Physics. Those with little or no experience and previous formal coursework in radiation protection must complete an eight-hour course that is offered by Health Physics. Those who have received comparable training and have laboratory experience must complete an open-book examination on basic principles and institutional procedures.

On-the-job training

In addition to the course or examination, the PI or supervisor must provide specific on-

(OJT)	the-job training for each user on each protocol. The training must include survey techniques, record keeping in the lab and a review of waste requirements. On-the-job training forms are provided for each user after completion of Radiation Safety Training. Training must be logged on OJT forms and filed in the lab's *Radioisotope Journal.*
Refresher training	Each project must hold a staff meeting following a CRA renewal at which radiation safety topics, including the contents of the renewal *Hazards Evaluation*, are reviewed. The *Hazards Evaluation* will include an agenda and signature block for documenting the meeting. The signed agenda must be filed in the *Radioisotope Journal*.
Concurrent review	9. If applicable, confirm that the project has also been submitted for biohazards and animal care review. A project cannot begin until all committees with jurisdiction have approved it.

	C-level	**B-level**	**A-level**
Quantity/Vial	≤200x Appendix C, QLM	≤10,000x Appendix C, QLM	>10,000x Appendix C, QLM
Initial term	1 year	1 year	1 year
Approval	RSO	LCC	APRS
Renewal term	2 years	2 years	1 year
Documented user lab surveys	monthly	monthly	after each use on User Survey Log; complete weekly
User surveys of storage areas	quarterly	quarterly	quarterly
User surveys in shared work areas	after each use on User Survey Log; complete monthly	after each use on User Survey Log; complete monthly	after each use on User Survey Log; complete weekly
HP surveys at Stanford	every 4 months	every 3 months	monthly
HP surveys at VAPAHCS	every 3 months	every 2 months	every two weeks
HP may observe	no	first use	first use and new personnel

TABLE 3.2 CONTROLLED RADIATION AUTHORIZATION (CRA) QUANTITIES AND TERMS. This table defines the CRA categories, which provide the basis for documented survey frequency and renewal term. Users should conduct surveys at the completion of each experiment; these do not require a record unless the experiment is done in a shared work area. Quantities of Licensed Materials (QLM) are found in 10 CFR Part 20, Appendix C, which is duplicated in Part 4, Appendices.

REVIEW AND APPROVAL OF APPLICATIONS; AMENDMENTS

Review

The assigned health physicist will visit before preparing a *Hazards Evaluation*, which is counter-signed by the RSO or designate, and returned to the PI. All affected project staff must review and sign the *Hazards Evaluation* before it is filed in the *Radioisotope Journal*.

Approval

The RSO approves C-level CRAs; an information copy is sent to the LCC chairman. The application and hazards evaluation for B- and A-level CRAs are circulated to the appropriate LCC for approval via fax. Any member can request that the committee convene to discuss items of concern. The initial term of an approval is one year. Shortly after the project has begun operation the health physicist will visit to ensure that administrative and technical procedures have been implemented.

Amendments and Renewals

Substantive amendments undergo the same application, review, and approval process that is applied to new applications. Non-substantive amendments, and renewals of CRAs that have a good safety record, are subject to the same administrative process, but are approved by a single member of the LCC or APRS in the name of the chairman.

Non-substantive amendments include adding radionuclides or changing inventory limits that do not change the C-, B-, or A-level characterization of the CRA, or adding laboratory procedures that are similar to those already approved. Health Physics will add Appendix C QLM quantities to a CRA based on a telephone request.

Renewal period

Projects that do not involve human subjects and that have very good safety and compliance records are usually given a two-year renewal.

Recovery plan

Projects with significant or repeated safety or non-compliance violations receive short-term, provisional renewals and enhanced safety oversight. If significant problems are uncovered during any visit, the PI will be required to meet with the LCC to explain why the problems occurred. The PI and the LCC will develop a recovery plan to correct the problems and to avoid recurrence.

Plan ahead

The administrative process of preparing an application and hazards evaluation for approval can be lengthy. The PI can fax documents to reduce turnaround time. However, committee members will not interrupt their work schedules to accommodate the needs of the PI. It is essential that the work schedule provide adequate time for safety review.

Inspection

During the term of the CRA, Health Physics will conduct periodic surveys and an inspection at the end of the term to assure safety and compliance.

Deficiencies

During the inspection, deficiencies might be uncovered. Deficiencies that are occasionally observed include: incomplete room surveys; lack of on-the-job training; incomplete use records; inadequate security of radioactive materials; violations of waste handling; labeling and disposal regulations; evidence of food or beverages in laboratory work areas; or inadequate attention to work rules. Deficiencies must be corrected. Failure to correct deficiencies, and prevent their reoccurrence, jeopardizes the institutional license.

Suspensions

When necessary, due to overexposure, injury to personnel, survey data that indicate that continued operation poses an unacceptable risk, falsification of records, or multiple or uncorrected deficiencies, the RSO may restrict, modify or terminate the CRA pending review by the appropriate LCC or the APRS.

Moving, modifications, or termination

Project Directors must notify Health Physics at least thirty days before changing laboratory facilities or terminating a project. All radioactive sources must be properly transferred or disposed of. Rooms, facilities and apparatus used by the project must be decontaminated so when measured by Health Physics, they meet the standards for uncontrolled areas. When surveys have been completed, Health Physics will remove signs from rooms and equipment, take custody of project radiation safety records, and terminate the project, if appropriate. Note that PIs or departments are responsible for costs of decommissioning.

HUMAN USE CLINICAL PROCEDURES AND RESEARCH

At Stanford the oversight of human subject research involving radiology devices and radioactive materials is a function of the Clinical Radiation Safety Committee (CRSCo) LCC which is chartered by the Food and Drug Administration. At SHS and VAPAHCS, all uses of radionuclides in humans regardless of quantity or purpose must be approved by CRSCo. Research protocols involving human subjects must also be approved by Stanford's Institutional Review Board (IRB). Reviews may be conducted concurrently. In most cases, according to IRB procedures, only medical faculty and VA staff physicians may apply.

Consultation

Safety policies and instructions for clinical use of radiation sources at SHS and VAPAHCS are available from Health Physics. Additionally, *Guidance for Preparing Research Proposals Involving Ionizing Radiation in Human Use Research,* provides information on administrative procedures and informed consent language. The Health Physics Medical Group is available to assist protocol directors designing studies with radiation. Early consultation will help assure that the proposal will be approved on the first review.

Application

All protocols involving both "research" or *"clinical investigations" and* "human subjects" must be submitted by the electronic Human Subjects "eProtocol" system and be reviewed and approved by the IRB before recruitment and data collection may start. Applications for Human Subjects which include the use of radiation are forwarded to the Health Physics Medical Group for review. Human subject protocols are then approved by the Stanford Clinical Radiation Safety Committee (CRSCo). If the research requires Radioactive Drug Research Committee (RDRC) review as specified by FDA RDRC regulations 21 CFR 361.1, an additional application from Health Physics must be completed.

Review and approval

Your application must be reviewed by the Health Physics Medical Group and may need to be circulated to individual members of the CRSCo/RDRC committee for evaluation and approval. Consult with the Health Physics Medical Group if you have a time-sensitive need.

Human use research approvals are contingent on contemporaneous approval by the Stanford University Research Compliance Office on Human Subject Research.

Renewal

Most human use approvals are for one year.

Amendments

The project director is responsible for informing Health Physics of changes in procedures, personnel, or modifications that might affect radiation safety.

CONTROLLED MACHINE AUTHORIZATIONS (CMAs) FOR RADIATION DEVICES

A Controlled Machine Authorization (CMA) is required for any electronic device that emits ionizing radiation. In the health care setting, radiographic and fluoroscopic units are the most common examples. X-ray diffraction units, cabinet x-ray machines, and accelerators may be found in the university research setting.

The following instructions were developed for the projects that do not involve administration of ionizing radiation to humans. If you have a human use project, consult with Health Physics to determine the appropriate information to submit.

Application to obtain or fabricate a device

Before you acquire, fabricate, or modify a radiation producing device, submit the following information in a memorandum to Health Physics.

1. Description of the device. Specify the type and manufacturer, energy load, and levels of radiation anticipated. Indicate typical energies, beam currents, work load in hours per week and a description of how the device will be used. Submit the manufacturer's brochure and a copy of your purchase request. Provide information about interlock systems, warning devices, and installed monitoring systems.

2. Procedures. Include a copy of operating and safety procedures. These procedures should be posted. Describe how the device is secured against unauthorized use.

3. Sketch of the facility. Include shielding calculations and specifications, and beam directions. Specify occupants of adjacent areas, including areas above and below. If portable shielding is to be used, describe it. Health Physics will provide assistance with shielding calculations.

4. Monitors. Indicate portable monitoring instruments that are available. Each

project must provide necessary survey instruments. Indicate the type of personal monitoring devices, such as film badges or finger dosimeters that will be used. For XRDs, only finger rings are required.

5. <u>Training and experience</u>. Provide a brief but explicit resume of the project director's pertinent training and experience. For the PI and radiation safety contact, provide desk phone, fax, and e-mail information. Note if minors will be in the lab. Each individual user must complete appropriate x-ray device radiation protection training before using the device. Each individual user must also complete hands-on training from a person experienced in the use of the x-ray device. Anyone who performs or supervises x-ray procedures on humans must hold a California Department of Public Health certification.

Conditional Approval

The review and approval process is as described earlier for CRAs. However, initiation of work is contingent on a pre-use survey. Research involving human subjects must be approved by the CRSCo.

Pre-use survey

Depending on the type of device, there will be radiation surveys and checks of warning lights and interlocks. The details of this inspection are specific to the device. After shielding, warning devices, and interlocks are shown to be in order, the final operating approval is issued. Proper posting and labeling are also confirmed during the pre-use survey. A console warning statement, list of authorized users, standard operating procedures, and emergency procedures are required to be posted.

Cabinet x-ray machines

Cabinet x-ray machines are enclosed, self-shielded, interlocked cabinets. The machine can only operate when the opening is securely closed. The exposure levels at every location on the exterior must meet the level specified for uncontrolled areas. Do not operate a machine if the interlocks appear to be malfunctioning. All operators must be trained in the proper operation of the device and be certified by Health Physics in radiation safety associated with the device. Personal dosimetry may be recommended for some operators.

Electron microscopes excepted

Due to their design and operating voltage, electron microscopes do not normally present a radiation hazard. Operators do not need personal dosimeters. Health Physics performs a radiation survey every two years, after alteration, repair or movement of the microscope, or when requested by the project director. Electron microscopes should not be modified in any way to increase the radiation output or reduce the shielding.

These devices are labeled "Caution—this equipment produces ionizing radiation when energized."

Microscopists who use uranium salts when examining biological specimens must receive training and be listed on a CRA before ordering or using radioactive materials.

Medical and veterinary x-ray machines

Medical radiographic units are used for internal imaging of patients and research subjects. Depending on the design, they are capable of making still radiographic or real time fluoroscopic images. In either case localized doses of more than 1 rem to a nearby operator and several rem in the beam are readily attainable. Therefore, training and experience and device safety criteria are stringent.

Registration required

All radiation-producing machines at Stanford whether for research or clinical use must be registered with the State of California within thirty days after acquisition. Health Physics registers machines on behalf of the owner; the user's department pays the associated registration fee. Contact Health Physics prior to ordering. The registration fee is billed after initial registration, and thereafter every two years. This fee is due as long as the machine is in the user's possession, even if it is inactive or broken. Please notify Health Physics (3-3201) if the machine is being sold, transferred or scrapped. We need to notify the state of the new user, or of its dismantling, otherwise the user's department will continue to be billed for the registration fee.

SETTING UP THE RADIOACTIVE MATERIALS LABORATORY

Radioisotope Journal

Each CRA group must maintain a *Radioisotope Journal.* Binders will be furnished by Health Physics to file and keep all required records. The *Radioisotope Journal* must be accessible to all persons who work with radiation sources and must be available for inspection at any time.

General considerations

The work area should provide sufficient space for supplies, work, and waste. Surfaces should be easily cleaned. Reduce contamination by keeping the work area free of unnecessary items. The area should be secured when not supervised.

Food and beverages in work areas

Do not consume, store, heat, or refrigerate food or beverages in radioactive materials work areas. This would provide a direct route for ingestion. Do not discard containers or wrappings in laboratory trash cans as it may be assumed food and beverages were consumed in the laboratory.

Stanford food and beverage policy

Storage or consumption of food or beverage in any laboratory work area is discouraged. However, the Stanford license allows consumption of food and beverages in desk areas within laboratory rooms. The desk area must either be free standing and at least one meter from the radioactive work area, or physically separated from contiguous work surfaces by a physical barrier. The desk area must be posted with a green notice reading "NO RADIOACTIVE MATERIALS ARE PERMITTED IN THIS AREA".

VAPAHCS food and beverage policy

The VAPAHCS radioactive materials license does not allow the consumption or storage of food or beverages in a laboratory room. The NRC considers empty food containers or wrappings to be evidence of use. Food and beverages may only be stored, refrigerated, heated, or consumed in hallways, offices, lounges, or conference rooms.

Records retention

All records generated over the preceding three years should be kept on hand for staff review.

Old records that were submitted to or received from Health Physics (Dosimeter reports, quarterly updates, Health Physics surveys, CRAs and amendments, waste logs, instrument calibrations done by Stanford, and information sheets or newsletters) can be discarded. Health Physics has the original records on file.

Old records that were created by the project staff or outside Stanford (daily use logs, user surveys, on-the-job training records, user incident reports, survey instrument calibrations by contractors) should be retained indefinitely in the lab. They can be transferred to Health Physics if storage space is not available. Health Physics will take custody of them when the CRA is terminated.

Contact Health Physics for a records review before transferring or discarding records.

SETTING UP THE RADIATION DEVICE LABORATORY

The following guidance applies to laboratories that are not administering ionizing radiation to humans. If your application involves special circumstances, please consult with Health Physics.

Radiation device *Operating Log*

Keep a record of results of radiation surveys performed by Health Physics, repair companies, and laboratory staff. When performed by the laboratory staff, specify the date, the person making the survey, the instrument used and the location and levels of radiation.

1. Use log with energy, current, other parameters, date, and user's name.
2. Device calibration records.
3. Surveys, safety bulletins, accident reports, corrective efforts, repairs, and modifications.
4. Start-up, use, and shutdown procedures and precautions.

Operating requirements

Each entrance or access point to a high radiation area must be:

1. Equipped with a control device that upon entry to the area reduces the deep-dose level of radiation to less than 100 millirem per hour at 30 centimeters from the radiation source or from any surface the radiation penetrates;
2. Equipped with a control device that energizes a conspicuous visible or audible alarm in such a manner that individuals are made aware of the entry; or
3. Maintained locked, except during periods when access to the area is required, with positive control over each individual entry.

Dosimetry required

Both federal and state regulations require personal dosimetry for individuals who enter high radiation areas.

Signs and labels

Necessary signs and labels depend on the dose rate around the device. See Table II.2 and the appendices for more information.

Precautions for analytical x-ray devices

X-ray diffraction and x-ray fluorescence units pose a special radiation hazard. They have a one-millimeter diameter beam that has a very high dose rate. Some operators who changed or adjusted samples while the beam was on have received so much radiation dose that their fingers had to be amputated.

These accidents are generally attributable to careless work habits and inadequate instruction. An extract from the 1989 Stanford Radiation Safety Manual, http://www.stanford.edu/group/glam/xlab/Safety/SafetyManual.pdf, and a training film entitled "The Two-Edged Sword" are available for training x-ray diffraction machine operators.

1. All operators must be certified by Health Physics and receive operational safety instructions from the project director. Use only procedures approved by the manufacturer or alternate procedures approved in the CMA.
2. Wear a finger dosimeter.
3. When aligning the camera by eye, be sure that the machine is turned off or that the viewing is done through a properly designed lead glass viewing window.
4. Be sure that the machine is turned off before changing samples. Check the kV and mA meters and the warning light.
5. After turning the unit on, measure the exposure rate at the table edge. It should be less than 0.2 millirem per hour.
6. Use shielding to ensure that the above limits are satisfied. Do not remove or modify the manufacturer's shielding.
7. Maintain direct surveillance of the machine, unless the area is secured. Machines should be kept in a locked room.
8. Check safety apparatus, shutter, warning lights, survey meter, and shields for proper function monthly. Report any malfunction to the PI. Do not operate a machine with a safety defect. Lock out and tag out the device until the problem is corrected.
9. If any changes are made in the machine that might affect radiation output, call Health Physics for a survey.
10. Promptly report any accidental exposures or potential injuries to Health Physics and the project director.
11. Maintain a log of all operations.
12. Never put any part of your body in the beam. Exposure to the primary beam for even a fraction of a second can cause severe damage to tissue.

Interlocks and warning lights

Interlocks and warning lights are essential safety features. Do not bypass them without Health Physics review and approval of alternate safety measures.

SIGNS AND LABELS

Signs and labels provide hazard information and warnings to your co-workers, support staff, and emergency responders. A sign is a notice that applies to an area of use or a work area; a label applies to an appliance, container, shield, pipe, or other equipment. Both are illustrated in Part IV, Appendices. Signs are available from Health Physics.

Signs

Rooms and work areas are posted based on the criteria in Table 2.2. Any information specific to the area, such as user, telephone number, and inventory should be kept up-to-date. There are special signage and log requirements for projects that house animals in DLAM.

Labels

A variety of labels are used to differentiate clean and potentially contaminated surfaces and devices, and radiation machines.

PERSONNEL MONITORING

The purpose of personnel monitoring is to provide early notice if your exposure is not below the limits and ALARA. The monitoring program also provides a permanent record of your exposure.

Types of dosimeters

There are two primary types of dosimeters worn by persons who work with or near sources of radiation. The film badge is film wrapped in light-tight paper and is mounted in plastic. Badges are checked periodically, and the degree of exposure of the film indicates the cumulative amount of radiation to which the wearer has been exposed. Thermoluminescent dosimeters (TLDs) are crystalline solids that trap electrons when exposed to ionizing radiation and can be calibrated to give a reading of radiation level. Film badges are most often worn by hospital staff potentially exposed to x-rays or researchers working with higher energy beta emitters. TLDs are most often worn by persons exposed to a variety of isotopes such as found in nuclear medicine or the cyclotron facility. All dosimeters are processed by a contractor. They are collected the first week of every wear period. Most monitors can read as low as 10 millirem.

Monitoring required

The regulations require monitoring for any worker who might exceed 10 percent of the applicable limit, and any worker entering a high or very high radiation area. Monitors are usually recommended for projects authorized to 5 millicuries of photon- or high energy beta-emitters, and XRD operators. Dosimetry will be issued when evaluation establishes a need for the use of this monitoring technique. Requirements will be stated in the *Hazards Evaluation*. See Table 2.1 for the dose limits.

Records of Prior Exposure

Each individual having a previous or on-going radiation exposure history with another institution is required to submit an "Authorization to Obtain Radiation Exposure History" form.

Use

Body badges and finger rings are worn where the highest exposure is expected; rings are worn underneath gloves to avoid contamination. If you are supplied both types, wear both whenever you are working with radiation. Health Physics can provide alternative guidance in unusual situations.

Precautions

Do not wear for non-work exposures such as a dentist's office.

Store badges in a safe location when not in use, away from sun, heat, sources of radiation or potential damage. Protect badges from impact, puncture, or compression.

Do not store Extremity (finger) rings in lab coat pockets. Storing rings in the lab coat pocket may expose the rings to radiation measured by the whole body badge. Rings are to measure hand exposures only.

A missing or invalid dosimeter reading creates a gap in your radiation dose record and affects the monitoring program's ability to provide accurate exposure readings. For a missing dosimeter a "Lost/Damaged Dosimeter Report" is required.

ALARA Limits

Administrative ALARA Limits Table

Dosimetry Type	***Regulatory Limit***	**Level I (Monthly)**	**Level II (Accumulated)**
Whole Body	*5,000 mrem/yr*	100 mrem (EDE for x-ray)	1,000 mrem (EDE for x-ray)
Lens of the eye	*15,000 mrem/yr*	300 mrem	3,000 mrem
Skin and/or Extremity	*50,000 mrem/yr*	1,000 mrem	10,000 mrem

Level I will be reported to the individual. Level II requires an investigation and will be reported to the appropriate committee. (Refer to HPM 5.5)

Bioassays

Individuals who handle large amounts of volatile radionuclides may be required to participate in a bioassay monitoring program.

If you routinely handle one millicurie or more of radioactive iodine, you are required to come to Health Physics to have your thyroid monitored for uptake. The thyroid measurement should be within 72 hours following exposure and every 2 weeks if routine work continues. The bioassay should not be sooner than 6 hours.

The bioassay requirement for each project is described in the Hazards Evaluation. Note that thyroid blocking agents will not be permitted.

If you handle more than 100 millicuries of tritium, you are required to submit a urine sample to Health Physics seven to fourteen days after the experiment. The sample will be measured for tritium content. Please make arrangements with health physics prior to beginning work.

Bioassays may also be ordered by the RSO after a spill, an unusual event, or a procedure that might result in an uptake.

ORDERING AND RECEIVING RADIOACTIVE MATERIAL

Orders

Order all radionuclide shipments for delivery to the following address:

Health Physics Inspection Station (CRA #)
Stanford Medical Center Receiving
820 Quarry Road, Rm. H0321
Palo Alto, CA 94304

Stanford purchases must be made online through Oracle as a Standard Radioactive order. Do not use University Rapid Purchase Orders or University Purchasing Card (PCard) for radioactive materials. Order only through Procurement Services or VAPAHCS Supply Service. The CRA number on the requisition must be included when ordering.

If the vendor requests a copy of the radioactive materials license, forward the request to Health Physics.

Receipt and inspection

When the package arrives, Health Physics checks the exterior for contamination and dose rate, logs the receipt, and checks to ensure you are authorized to receive the radionuclide and amount. Health Physics will then have your package delivered to your lab. You may arrange to pick up a package if it is urgently needed.

Inspect and store promptly

Promptly inspect the package for leakage and correctness of contents. Be sure that you remove each item on the packing list, and carefully sift through dry ice and packing peanuts. Safety instructions may be provided with the package. To ensure it will not be misplaced, store all items promptly after inspection.

Remove package labels

After you remove the radioactive material from the package, remove or deface any “radioactive materials” labels before discarding the empty, uncontaminated package to house waste.

Direct delivery

If you receive material directly and it has not been inspected, inform Health Physics promptly, and if requested, bring the package to the Inspection Station. Special arrangements for direct delivery of radioactive materials from the supplier to the user must be approved by the Radiation Safety Officer (RSO) case-by-case.

USE AND TRANSFER RECORDS

Daily Use Logs

After a package of radioactivity has been inspected by Health Physics, a *Daily Usage Log* is attached. Make an entry each day that the material is used. You may use a different form or format if all the required information is included. Keep the logs in the *Radioisotope Journal* or post them on the refrigerator or storage cabinet. Do not keep these logs in your individual laboratory notebook.

Sealed source storage and use

If several sealed sources are in use, they should be kept in a central location. Sources being used in experiments must be secured, properly shielded, and labeled with the radionuclide, activity, and date. The use log should identify each source, dates of removal and return, and user. If sources are moved to other authorized locations, the use log should indicate this along with the date and the name of the recipient.

Sealed source inventory

A *Sealed Source Inventory* that is e-mailed quarterly lists all sealed sources. The responsible individual must personally examine each source to ensure it is on hand and in its proper place. Verify the location of the sources and return the form to Health Physics. File a copy in the *Radioisotope Journal.*

Leak testing

Most sealed sources must be leak tested twice each year. Health Physics provides this service. Request a leak test when you receive a new sealed source, before transferring it to another CRA, before shipping it to a vendor, or if it appears damaged.

Radionuclide Inventory Summary

An *Inventory Summary* form for unsealed radioactive materials is emailed each January, April, July, and October. The forms must be filled out showing disposition of materials to the nearest microcurie. Use the *Daily Use Log* as the source document. You can remove items that have gone through ten half-lives and contain less than one microcurie. If you have accumulated an inventory of short-lived stock vials, you may have to decay-correct the entries to avoid going over your inventory limit. Indicate the primary vial location if different from the location listed. When completing the October inventory you must also physically examine each container to ensure its location and labeling are accurate.

Fax the forms to Health Physics by the date specified. If it has not been received by the due date, your incoming packages will be held at the Inspection Station until the forms are submitted. File a copy of each summary in the *Radioisotope Journal*.

Transfer to another CRA

Transfers of radioactive materials from one CRA to another must be reported to Health Physics with the quarterly *Inventory Summary* report. Before transferring radioactive material outside your CRA, verify that the person receiving the material is an authorized user of the CRA, and that the material and activity is within the limits of the CRA you are transferring the material to.

Transfer report

If the transfer exceeds ten times the Appendix C QLM, print and complete a transfer form available at http://radforms.stanford.edu. Place the original and one copy into your *Radioisotope Journal* and provide the recipient with two copies. Both the transferor and recipient must attach a copy of the form to their respective quarterly *Inventory Summary* report.

Off-campus transfer

Health Physics is the only campus group authorized to ship radioactive materials off campus. For further details and assistance, call the Inspection Station.

To ensure safety and compliance with transportation regulations, all shipments of radioactive materials from the campus must be prepared under Health Physics supervision. The shipping container must meet the appropriate US Department of

Transportation specifications. The package must not be sealed until Health Physics completes its inspection.

Note that carrying radioactive material with you or in your checked airplane luggage is forbidden under Federal Aviation Administration regulations.

SURVEYS

The purpose of a physical survey is to identify potential problems, such as poor storage or handling practices, before they actually pose a hazard, and to demonstrate that contamination levels and dose rates are well below limits. Surveys should be done the first week of each month to assure they are not inadvertently omitted, and must be done after each use in shared work areas.

Removable contamination surveys

Removable contamination surveys help identify areas where radioactivity has been spilled. Countertops, sinks, floors, refrigerators, centrifuges, fume hoods, and telephone handsets should all be considered for inclusion. Take a sample by making a 100 cm long wipe of the surface with a small piece of paper towel or a filter paper. Count the sample on the same equipment used to count your experimental samples. This is normally done on a Liquid Scintillation Counter.

Instrument surveys

Appropriate instrument surveys (e.g., GM for high energy betas, NaI(Tl) for low energy gammas) help identify areas where radioactivity has been spilled or where it is inadequately shielded. Survey bench surfaces, your hands, clothing, and shoes. Most researchers use a survey instrument with a speaker, which responds more quickly than the meter needle movement. Perform a “battery check,” and use either a radioactive check source or a known radiation area to confirm the instrument is working before you begin. Move the detector slowly to allow the instrument time to respond.

Action Level

If you find occasionally occupied areas with a penetrating dose rate greater than 2 millirem per hour, or continuously occupied work areas with a penetrating dose rate action level greater than 0.2 millirem per hour, corrective action is required. Consult with the PI or Health Physics.

Records

Health Physics will supply a survey form that includes a room sketch. See example in the Appendices. Each survey record must include:

- A sketch of the lab,
- Locations of sample points,
- Measurements in mrem/hr or dpm/100cm^2,
- Identification of the instrumentation used,
- Background and efficiency in the instrumentation,
- Surveyor’s name, and
- Date.

If the instrument (liquid scintillation counter) does not calculate and print dpm, but rather prints just cpm, you must determine the counting efficiency to ensure the counts per minute rate is below the cleanup threshold in Table 3.3 in dpm/100cm^2. Typical counting efficiencies are noted in Table 3.4. Document surveys by completing user survey forms and enter into the Sweeps Program, http://radsurvey.stanford.edu. These surveys must be performed and entered into the Sweeps Program the first week of the month.

Building and equipment repair

Before any potentially contaminated areas or equipment, such as a glove box, hood, refrigerator, sink, or pipeline is turned over for repair, it must be surveyed. Call Health Physics. The equipment will be surveyed, de-labeled, and marked "Cleared for repair or release to uncontrolled area."

Equipment disposal

Notify Health Physics prior to disposal of any radiation device. Special precautions are needed, and the state may require notification.

(Note: action levels are in dpm/100cm^2)	Materials with App. C QLM ≥100µCi[1]	Materials with APP. C QLM <100µCi[2]	All alpha emitters
Unrestricted areas (e.g., desk, hallways)	2,000	200	20
Restricted areas (e.g., work areas, equipment)	20,000	2,000	200

[1] H-3, C-14, F-18, P-33, S-35, Ca-45, Cr-51, Fe-55, Co-57, Ni-63, Cu-64, Zn-65,Ga-67, Se-75, Rb-86, Sr-86, Tc-99m, In-111, Sn-113, I-123, Tl-201.

[2] Na-22, P-32, Cl-36, Fe-59, Co-60, Zn-69, Y-88, Y-90, Cd-109, I-125, I-131, Cs-137.

TABLE 3.3 ACTION LEVELS FOR REMOVABLE CONTAMINATION. This table provides threshold values that require corrective action if exceeded. Action levels are in dpm, not cpm. See Table 3.4. Call Health Physics if removable contamination is more than ten times the action level in unrestricted areas

Radionuclide	LSC[1]	Pancake GM[2]	NaI(Tl) Meter[3]	NaI(Tl) Well[4]
H-3	20%	na[5]	na[5]	na[5]
C-14, S-35, P-33	50%	10%	na[5]	na[5]
Cr-51, Co-57, Tc-99m, I-125	30%	1%	50%	50%
P-32	100%	50%	na[5]	na[5]
LSC[1] : Liquid Scintillation Counter PancakeGM[2] : Hand-held survey meter with pancake GM detector NaI(Tl)[3] : Hand-held survey meter with well-type NaI(Tl) crystal NaI(Tl)[4] : Multichannel analyzer with well-type NaI(Tl) crystal na[5]: not applicable for this group of radionuclides				

TABLE 3.4 APPROXIMATE DETECTION EFFICIENCIES FOR SOME COMMON RADIONUCLIDES AND DETECTORS. This table provides the approximate detection efficiency for the common radionuclide measurement methods. Multiply the action level from Table 3.3 by the detection efficiency to calculate the instrument cpm that indicates need for corrective action

RADIOACTIVE WASTE

It is vitally important that you have accurate data concerning the isotopes and activity present in your waste. Safe disposal of radioactive waste is expensive. When designing a laboratory procedure, minimize waste generation and mixed waste streams as much as practicable.

Definition	Radioactive waste includes any items that contain radioactivity that is distinguishable above background levels using an instrument that is sensitive for the nuclide, and that is set on its most sensitive scale, and with no interposed shielding.
Detecting low energy radionuclides	Many radioactive wastes, such as H-3, C-14, S-35, and I-125 are not readily detectable with GM survey instruments. Hence, items that are in the work area where these or similar unsealed materials are present must be assumed to have been contaminated unless they are surveyed by an acceptable alternative method. For waste contaminated with low energy beta emitters, make smear surveys and measure them with a liquid scintillation counter. For I-125, use a NaI(Tl) scintillation detector to survey potentially contaminated items. If this is impractical, our policy is to assume that the surface is contaminated and discard it as radioactive waste.
Decontamination	Dish detergent, window cleaner, vinegar, bubble bath, waterless hand cleaner, or oven cleaner are all suitable for cleaning surface contamination. Use mild products for skin contamination.

Half-life categories

Separate all radioactive wastes by half-life so that short half-life materials can be held for decay followed by incineration rather than disposal by burial.

Radioactive waste containers and log sheets

All waste containers must be labeled with the radiation symbol and a sign reading "Caution—Radioactive Materials." **For each disposal log, note the radionuclide quantity in microcuries, date of disposal, and your initials**.

Do not use containers other than those provided by Health Physics To ensure radioactive waste is distinguishable from house waste.

Dry waste boxes

Place only dry, non-decomposable wastes such as gloves, paper, and glassware in Dry Waste Boxes. Do not put any liquids, capped vials, lead shields, animals, bedding, or scat into the container. Waste that emits more than 2mrem/hr at 30 cm must be shielded. Do not shield individual items in the box; shield the entire container. Also, bag waste contaminated with volatile materials, especially iodine, prior to disposal.

Waste removal

When a container is almost full, fax a copy of the waste log to Health Physics. Be sure the room number and CRA number are on the form. Leave the pink copy of the log on the box. This will serve to identify the correct box during the pick-up; it can be used as a log for additional disposals prior to pick-up.

Sharps

Discard sharps, such as pipettes, syringes and needles, broken glass, razor blades, and scalpel blades into sharps containers bearing the radiation warning label and log sheet. Use separate containers for isotopes other than C-14 and H-3. For disposal, the full capped sharps container may be placed in a dry waste box containing the same isotope. Enter the contents of the sharps container onto the dry waste log sheet. For separate removal of sharps containers, fax the log sheet to Health Physics.

Large items

Large non-combustible items such as contaminated equipment should not be placed in a Dry Waste Box. Call Health Physics for assistance in the disposal of such items.

Scintillation Vials

See page 56.

Aqueous waste

Material that is readily soluble in water may be disposed of into the sanitary sewer system with adequate flushing, provided that:

The material is not chemically hazardous or containing biohazardous material of BSL-2 or above, or it is not medical waste other than patient urine or feces. See the following web sites to identify:

https://nonhazardouswaste.stanford.edu
http://med.stanford.edu/school/HS/biosafety/bac.html

Contact the manager of the environmental protection program for guidance (725-7529); and

The quantity per laboratory, per day, does not exceed the QLM quantity. Disposal of larger quantities of radioactive wastes via the sewer must be reviewed and have the written approval of Health Physics; and

Log each disposal of radioactivity to the sanitary sewer with the date, activity, form and your name on the *Daily Use Log* in the *Radioisotope Journal*; the properly completed *Daily Use Log* entries constitute the waste disposal record.

Health Physics will post sinks used for disposal of radioactive wastes with proper warning signs to alert plumbers who service the sinks. Use one sink for disposal of radioactive materials in each laboratory.

Human excreta from nuclear medicine procedures

Human excreta containing radioisotopes may be disposed of in the sanitary sewer system.

Cement kits

If you are generating small volumes of liquid waste that cannot be disposed in the sanitary sewer (see *Aqueous waste* above), order a cement kit. This method of disposal is required for radionuclides with a QLM value of 1 microcurie or less, except for I-125 and I-131 which have sewer limits of 100 microcuries per month per project. Cement cans hold about one liter. Use a different kit for each individual radionuclide.

The instructions for use are provided with the kit. For removal of filled cement kits fax the log sheet to Health Physics.

If using a cement kit for mixed waste training is required. Contact the Manager of Environmental Programs (725-7529).

Radiological and biohazardous (BSL≥2) and/or medical waste

Combined radiological and biohazardous (BSL>2) and/or medical waste materials, other than human excreta, must be deactivated prior to disposal as radioactive waste. The project staff should review the potential methods of disinfecting with Health Physics. The deactivation methods must be described by the project and reviewed and approved by the appropriate committee. Methods include autoclaving or treating with chemicals such as formalin, carbolic acid, or bleach. Note that wastes with I-125 or I-131 may be especially difficult to deactivate because heat and strong bleaches may drive off the radioiodine vapors, presenting airborne hazards or contaminating equipment.

Radiological and non-biohazardous and/or non-medical waste

Non-biohazardous biological (BSL 1) or non-medical waste combined with radioactive waste must be handled as radioactive waste in accordance with California regulations.

For BSL levels, check the Biosafety data base at:

http://med.stanford.edu/school/HS/biosafety/bac.html

Liquids. Follow guidance for permissible disposal in the sanitary sewer; this requires approval of Health Physics during the CRA review process. Do not autoclave combined non-biohazardous biological-radioactive liquid waste. Do not bleach or chemically treat combined non-biohazardous biological-radioactive waste to inactivate the biological organisms prior to disposal.

Solids. Dispose of non-biohazardous biological-radioactive waste as radioactive waste. Segregate combined biological-radioactive waste from biological waste that would be red-bagged.

Sharps. Use only the sharps containers provided by Health Physics. Do not discard combined biological (BSL 1)-radioactive sharps in a sharps container that does not have the radiation symbol.

For the safety of waste handlers, please specially annotate disposal of wastes that have been treated for pathogens or infectious agents.

Mixed Waste

Mixed waste is defined as waste that contains radioactivity and chemical wastes as defined in EPA and California regulations (corrosive flammable, oxidizer, air/water reactive, toxic). These “mixed” wastes need to be specially identified and handled. Generation of mixed wastes must be approved by the appropriate local control committee before it is generated. See: http://mixedwaste.stanford.edu

Radiological and hazardous chemical waste

California hazardous waste regulations prohibit disposal of chemical materials to the sewer unless they have been shown to be non-hazardous. EH&S has reviewed many chemical materials such as buffers and salts to determine if sanitary sewer or house waste disposal is allowable. Check the "Non-hazardous Waste List" at:

https://nonhazardouswaste.stanford.edu

Search instructions will help you determine if the chemical is listed and therefore non-hazardous. Be careful to review the conditions; many materials are non-hazardous only below a certain concentration.

If you have a material that is not on the list but you believe it to be non-hazardous, or if the material can be made non-hazardous with simple in-lab treatment, call the Radiological Waste Program. There may be additional applicable data or testing methods. EH&S will make the determination. Treatments must be documented in your *Radioisotope Journal.*

If the half-life is less than 15 days, the material may be stored for decay and then treated as chemical waste.

Mixed wastes, with prior approval, like hazardous chemical wastes may be accumulated in the laboratory for a maximum of 9 months. Submit a pick-up request at 8 months.

Decay-in-storage

Decay-in-storage is one way to handle waste with short half-lives. To store radioactivity for decay in the lab, the CRA application must specify the areas used to store wastes, as well as the methods used to monitor decayed wastes. Decay-in-storage in the lab is limited to radionuclides with half-lives less than 15 days.

Decay-in-storage requires that wastes be stored a minimum of 10 half-lives, then surveyed. The survey must show that the radiation is indistinguishable from background. All radiation warning labels must be removed or obliterated before disposing of waste into house waste, or to chemical waste if it began as a mixed waste. File storage logs and surveys in the *Radioisotope Journal.*

Scintillation vials

The Radiological Waste program provides 5-gallon buckets for liquid scintillation vials. The Stanford Hazardous Waste Label must be completed and dated when first placing an item into the bucket. Different solvents may be added to the same bucket, but you must add the name of each solvent to the label. A trade name may be used i.e. Readysafe, Cytoscint, Optiphase. Note that, under California environmental regulations, even “environmentally safe” cocktails cannot be released to the sanitary sewer.

Send or fax (723-3759) the completed request to Radioactive Waste for pick-up when the pail is full or 8 months old.

The following radionuclides are approved for use in scintillation vials. H-3 and C-14 may be combined in the same bucket.

H-3, C-14, Na-22, P-32, P-33, S-35, Cl-36, Ca-45, Cr-51, Co-57, Fe-59, Zn-65, Ga-67, Ge-68, Se-75, Rb-86, Cd-109, In-111, I-125, I-131, and Hg-203.

If you need to perform liquid scintillation counting for other radionuclides, consult with Health Physics.

Vial Disposal Cost Reduction

Scintillation vials not contaminated with a radioisotope may be managed as chemical waste providing a considerable monetary savings. Please separate the vials containing radioactive contamination from those that do not and dispose of accordingly.

Carcasses, bedding, and scat

Certain freezers have been identified as collection points for carcasses, bedding, and scat. These are located in the Research Animal Facility Room RAF-061 C and D or for imaging isotopes with half-lives of less than 3 days at Clark S035. For other areas, call

Health Physics at 723-3201.

If animals have been etherized, let the carcasses air out thoroughly in a fume hood before placing them in the freezers to avoid the risk of fire or explosion from the ether fumes.

Discard contaminated bedding, carcasses, and scat, segregated by the half-life category, into double plastic bags. In respect of public sensitivities, please use an opaque outer bag. Tag all animal waste on the outside of the bag indicating isotope, activity, date of disposal, and account number to be charged. Tags are available at the freezer. Also, fill in the log sheet on the freezer door.

Note: Always use the log sheets provided with the waste containers.

Charges for radioactive waste at Stanford

Radioactive waste charges are included in laboratory overhead. However, please be careful that you do not needlessly create waste, or mix non-radioactive waste into the waste stream. Projects that generate extraordinary amounts of waste may be billed extra.

PROBLEMS RELATED TO RADIOACTIVE WASTES

Experience over the years has identified several incorrect practices that cause additional cost and time.

Incomplete Waste Log sheets

The incorrect documentation or segregation of waste or incomplete labeling may result in the mismanagement of materials and potential violations.

Radioactive waste in non-radioactive trash cans

Survey items in and around radioactive material work areas prior to disposing of the items into non-radioactive waste. If radioactive waste is improperly released to a sanitary landfill, it will demonstrate a loss of control in the laboratory. This can result in a citation, a civil penalty, and a press release by the regulatory authority.

Mixed half-life categories

External radiation readings found on boxes whose logs have only H-3 or C-14 entries indicates that categories have been mixed. Properly segregate the materials by half-life category and log the materials being disposed of at the time of disposal.

Secondary containment

Place all collection bottles in secondary containment, such as a beaker or bucket. Keep bottle waste in a well-ventilated area such as a fume hood. Observe fire safety practices.

Box flaps and box shields

Do not push waste box flaps down into the box, this makes retrieval of the flap difficult, and increases the potential for contaminating the box, your hands, and the lab. Do not force a box into a shield; it is difficult to remove when it is full. Health Physics can identify manufacturers whose shields easily accommodate our waste boxes.

Mixed waste	Disposal of mixed hazardous waste is a growing problem here and elsewhere. Special permission is required prior to generating mixed waste. Please make every effort to segregate hazardous waste streams such as reactive chemicals and biologics.
Non-radioactive waste	At the VAPAHCS, survey all regular non-radioactive waste to ensure it is free of contamination. Then place it in the corridor for pickup.

RESPONSE TO SPILLS, LOSSES, AND OTHER INCIDENTS

Purpose	Incident response procedures are designed to bring an out-of-control situation to a condition that will minimize the risk to workers and the public. Procedures directed towards containing the source of the risk are not meant to recover the situation, but rather to keep the situation from getting worse. Procedures for personnel decontamination are designed to remove as much contamination as possible without damaging the contaminated skin.
Assistance	If you need assistance to bring an incident under control, or guidance on how to recover from it, call Health Physics. Telephone numbers are on the back cover.
Incident records	After you have recovered from an incident, determine its cause and effects. Consider whether procedures, equipment, facilities, or training should be modified to reduce the chance of recurrence. File a record of this in the *Radioisotope Journal* so that others can learn from your experience.
Surface decontamination	Dish detergent, window cleaner, vinegar, bubble bath, waterless hand cleaner, or oven cleaner are all suitable for cleaning items.
Skin decontamination	Carefully remove contaminated clothing. When cleaning skin, rinse generously, use mild soaps, and take care to not abrade the surface. Simply soaking skin in a mild detergent solution, vinegar, or bubble bath may remove most contamination.
Response procedures	There are ten different incident response procedures provided on the following pages. Select the one that is most appropriate depending on the physical form and source strength of the radiation source.

Small spills: liquids and powders less than the QLM quantity

(Note: see separate discussion below for spills involving positron emitters)

1. Notify persons in the area that a spill has occurred.
2. Prevent the spread of contamination by covering the spill with absorbent paper.
3. Clean up the spill using disposable gloves and absorbent paper. Carefully fold the absorbent paper with the clean side out and place in a plastic bag for transfer to a radioactive waste container. Also put the contaminated gloves and any other contaminated disposable material in the bag.
4. With a low-range radiation detector survey meter, survey the area around the spill, your hands, clothing, and shoes for contamination. Wash contaminated skin. All personnel contamination (e.g. shoes, skin, clothing) must be reported to Health Physics via phone call.
5. Report the spill to the PI.

Moderate spills: liquids and powders ≤ 1000x the QLM quantity

1. Notify persons in the area that a spill has occurred.
2. Prevent the spread of contamination by covering the spill with absorbent paper.
3. Clean up the spill using disposable gloves and absorbent paper. Carefully fold the absorbent paper with the clean side out and place it in a plastic bag for transfer to a radioactive waste container. Also put the contaminated gloves and any other contaminated disposable material in the bag.
4. With a low-range radiation detector survey meter, survey the area around the spill, your hands, clothing, and shoes for contamination. Wash contaminated skin. All personnel contamination (e.g. shoes, skin, clothing) must be reported to Health Physics via phone call.
5. Report the spill to Health Physics via phone.

Large spills: liquids and powders more than 1000x the QLM quantity

1. Clear the area. Order all persons not involved in the spill to vacate the room.
2. If you can do it safely, prevent the spread of contamination by covering the spill with absorbent paper, but do not attempt to clean it up. To prevent the spread of contamination, limit the movement of all personnel who may be contaminated.
3. Shield the source if possible. This should be done only if it can be done without further contamination or a significant increase in your radiation exposure.
4. Notify Health Physics immediately.
5. With a low-range radiation detector meter, survey your hands, clothing, and shoes for contamination. Wash contaminated skin.
6. Health Physics will supervise the cleanup of the spill.

Spill procedures for positron emitters- dose rate < 5 mrem/hour at one meter

1. Notify persons in the area that a spill has occurred.
2. Survey the spill to determine the dose rate.
3. Prevent the spread of contamination by covering the spill with absorbent paper.
4. Clean up the spill using disposable gloves and absorbent paper.
5. With a low-range radiation detector survey meter, survey your hands, clothing, shoes, and the area around the spill for contamination. Wash contaminated skin.
6. Report the spill to the PI.

Spill procedures for positron emitters- dose rate < 20 mrem/hour at one meter

1. Notify persons in the area that a spill has occurred.
2. Survey the spill to determine the dose rate.
3. Survey all who are leaving the area for contamination.
4. If personnel are contaminated, wash the contaminated area with mild soap and water, and contact PI or Health Physics immediately.
5. If the **spill is small in area** place absorbent pad and lead brick at the same time on the spill.
6. If the **spill is too large in area** to be covered by a lead brick, contact Health Physics immediately.
7. After covering, survey the spill area again. If the dose rate is below or equal to 5 mrem per hour at 30 cm from the shield surface, label the top of the brick with the nuclide and time of day. Allow the spill to decay in place. If the dose rate is greater than 5 mrem per hour at 30 cm, then add additional shielding to reach this level.
8. Report the spill to the PI and Health Physics

Spill procedures for positron emitters- dose rate > 20 mrem/hour at one meter

1. Notify persons in the area that a spill has occurred.
2. Survey the spill to determine the dose rate.
3. Order all persons not involved in the spill to vacate the area.
4. Survey all who are leaving the area for contamination. Remove all contaminated clothing.
5. If personnel are contaminated, wash the contaminated area with mild soap and water, and contact Health Physics immediately.
6. If the dose rate is **less than 100 mrem per hour** at one meter and the **spill is small in area** and can be covered by a lead brick, then place absorbent pad and lead brick at the same time on the spill.
7. Report the spill to the PI and Health Physics

Spill proceduresfor positron emitters: When is Health Physics presence required?

1. If the **spill is too large an area** to be covered by a lead brick.
2. If the dose rate is **greater than 100 mrem per hour**.
3. If personnel are contaminated.

Ensure there is no entry into the area until Health Physics arrives.

Stuck sources in irradiators

1. Jiggle the handle to return the source to the stored position.
2. Activate the manual off control.
3. If area monitors are alarming, stay out of the beam and close the door. Do not attempt to remove your samples.
4. Order all persons to leave the room.
5. Secure the room to prevent entry.
6. Notify the PI and Health Physics immediately.

Loss, theft, or disappearance of radioactive materials or a radiation device

1. Ask co-workers if they know where the material is.
2. If they don't know, promptly call Health Physics. Give your name, the CRA number, and a description of the missing material.
3. Continue to look for the material and interview co-workers pending arrival of Health Physics.

Unusual events

Although there may or may not be personnel exposure, other unusual events, such as unexpected or widespread contamination, missing or unexpected packages, missing or extra waste, indicate a possible breakdown in administrative or technical procedures. Call Health Physics for assistance.

Part 4 APPENDICES

The appendices are a collection of intramural and peer-reviewed information generally applicable to institutional radiation safety. If you have suggestions for additional information that should be included here please contact Health Physics.

Glossary	The glossary is comprised of terms of art from 10 CFR Part 20, other reference works, and acronyms specific to Stanford and VAPAHCS.	63
Safety data sheets	The data sheets provide basic information on some commonly used radionuclides. The data sheets were developed at Stanford based on information in reference works. Data sheets for the radionuclides you use are in your ***Radioisotope Journal***, a more complete set is on our web site: http://radsafetysheets.stanford.edu	69
Reports and Guides	Four organizations have published reports that were used in the preparation of this manual. Those applicable to institutional use of ionizing radiation are listed. The National Council on Radiation Protection and Measurements (NRCP) was chartered by Congress to provide expert guidance on radiation protection; its reports are considered national voluntary standards. The National Research Council provides expert services to the government, the public, and the scientific and engineering communities. The International Commission on Radiological Protection (ICRP) provides guidance on fundamental principles of radiological protection. The US Nuclear Regulatory Commission (NRC) is the lead federal agency on radioactive materials safety; it publishes Regulatory Guides on many topics. All the reports and guides are available for review in Health Physics.	79
10 CFR Part 20 Appendix C – QLM Quantities, Conversion Table	Each radionuclide presents a different relative hazard due to its half-life and decay scheme. 10 CFR Part 20 Appendix C, QLM Quantities of licensed material requiring labeling, provides the basis for categorizing radionuclides according to relative hazard. It is the foundation for our QLM quantities in Table 3.1.	81
Signs and labels	Signs and labels are used to provide information to radiation workers and those who might enter the laboratory occasionally. There is a special purpose for each one.	92
Forms	These forms are used to document receipt, use, transfer, and disposal of licensed material, surveys, and incidents.	95
Index	The key terms used in this manual are included.	106
Phone, fax, e-mail, and web sites	Many Health Physics administrative matters can be handled electronically. If you have a question, please call.	back cover

GLOSSARY

Note: Terms that are institution-specific are marked (Stanford) or (VAPAHCS).

absorbed dose	The energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the gray (Gy).
activity	Rate of disintegration, transformation, or decay of radioactive material. The units of activity are the curie (Ci) and the becquerel (Bq).
ALARA	Acronym for “as low as reasonably achievable.” Make every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical consistent with the purpose for which the activity is undertaken, taking into account the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of ionizing radiation in the public interest.
Annual Limit on Intake (ALI)	The amount of a radionuclide that would result in a committed effective dose equivalent of 5 rems, or a committed dose equivalent of 50 rems to an organ or tissue. See 10 CFR Part 20 Appendix B.
A&MM	Acquisition & Materials Management (VAPAHCS).
APLAC	Administrative Panel on Laboratory Animal Care (Stanford).
APRS	Administrative Panel on Radiological Safety (Stanford). Other organizations may use Radiation Safety Committee or Radiation Control Board, for example.
area of use	A room or suite in which radioactive materials is used. It may have one or more work areas.
background radiation	Radiation from cosmic sources; naturally occurring radioactive materials, including radon (except as a decay product of source or special nuclear material) and global fallout as it exists in the environment from the testing of nuclear explosive devices. “Background radiation” does not include radiation from source, byproduct, or special nuclear materials, or devices regulated by the NRC or DHS. The average United States annual radiation exposure from natural sources is about 310 millirem (3.1 millisieverts or mSv).
becquerel (Bq)	1 nuclear transformation per second (s^{-1}).
bioassay	The determination of kinds, quantities or concentrations, and, in some cases, the locations of radioactive material in the human body, whether by direct measurement, called in vivo counting, or by analysis and evaluation of materials excreted or removed from the human body.

CCR	California Code of Regulations.
CFR	Code of Federal Regulations.
controlled area	An area, outside of a restricted area but inside the site boundary, access to which can be limited by the licensee for any reason.
cpm	Counts per minute. Most radiation detectors display the number of events detected per unit of time. This can be converted to a measure of activity in dpm by dividing by the detection efficiency.
CRA	Controlled Radiation Authorization (Stanford and VAPAHCS). The permit issued by the APRS or RSO that allows the use of ionizing radiation.
CRSCo	Clinical Radiation Safety Committee (Stanford).
curie (Ci)	A unit of activity. 3.7×10^{10} nuclear transformations per second, 3.7×10^{10} becquerels, or 2.22×10^{12} nuclear transformations per minute. The term nuclear transformations is often replaced by the term disintegrations.
DAC	Derived Air Concentration. The concentration of a given radionuclide that, if inhaled continuously during the work year, would cause a dose of 5 rem.
deep dose	The dose from external whole body exposure at a tissue depth of 1 cm.
deterministic effect	Health effects, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a deterministic effect. Also called a nonstochastic effect.
CDPH	California Department of Public Health. The California agency that regulates radioactive materials and radiation devices at non-federal facilities in the state.
DLAM	School of Medicine, Division of Laboratory Animal Medicine (obsolete). Now the Department of Comparative Medicine.
dose or radiation dose	Generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent, as defined elsewhere in this glossary.
dpm	Disintegrations per minute. A measure of activity. See curie.
DTSC	Department of Toxic Substance Control. The California agency that regulates hazardous materials other than radiation.
effective dose equivalent or effective dose	The sum of the products of the dose equivalent to each organ or tissue and multiplied by their respective tissue weighting factors, and then added to the external whole body dose.

EPA	US Environmental Protection Agency.
exposure	Being exposed to ionizing radiation or to radioactive material.
external dose	That portion of the dose equivalent received from radiation sources outside the body.
extremity	Hand, elbow, arm below the elbow, foot, knee, or leg below the knee.
FDA	US Food and Drug Administration.
gray (Gy)	SI unit of absorbed dose. One gray is equal to an absorbed dose of 1 joule/kilogram (100 rads).
Hazards Evaluation	A document prepared by Health Physics that analyzes the potential risk of a project and imposes safety measures (Stanford). Other organizations may use the terms license, authorization, or permit.
High radiation area	An area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.1 rem (1 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.
house waste	Office and lounge waste such as paper and food containers that are normally discarded in a sanitary landfill (Stanford).
ICRP	International Commission on Radiological Protection.
ionizing radiation	Alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of separating a target atom into an electron and a positive ion. As used in this manual, radiation does not include non-ionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light.
IRB	Institutional Review Board (National Institutes of Health). A committee that reviews and approves research projects that involve human subjects. The Stanford University Administrative Panel on Human Subjects performs this function.
LCC	Local Control Committee (Stanford). The LCC oversees radiation safety within a department or school. See CRSCo and NHRSC.
LPCH	Lucile Packard Children's Hospital.
monitoring	The measurement of radiation levels, concentrations, surface area concentrations or quantities of radioactive material and the use of the results of these measurements to evaluate potential exposures and doses.
NCRP	National Council on Radiation Protection and Measurements. A non-profit corporation chartered by Congress to disseminate radiation protection guidance.

nonstochastic effect	Obsolete. See deterministic effect.
NRC	US Nuclear Regulatory Commission. The federal agency that regulates the use of radioactive byproduct materials, source and special nucelar materials. The NRC's regulatory mission covers three main areas: Reactors, Materials and Waste. It does not have authority in California, except at federal agencies; authority over non-federal organizations was transferred to CDPH.
occupational dose	The dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include dose received from background radiation, as a patient from medical practices, from voluntary participation in medical research programs, or as a member of the general public.
photon	A quantum of radiant energy. In this manual, the term usually means gamma rays or x-rays.
PO	Purchase Order.
public dose	Dose received by a member of the public from exposure to radiation and to radioactive material released by a licensee, or to another source of radiation either within a licensee's controlled area or in unrestricted areas. It does not include occupational dose or doses received from background radiation, as a patient from medical practices, or from voluntary participation in medical research programs.
QLM	10CFR20 Appendix C Quantities of Licensed Material requiring labeling. See page IV.23.
quality factor	A modifying factor used to convert dose in rad to dose equivalent in rem. For x-, beta-, and gamma-radiation its value is 1.
rad	Special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joule/kilogram. 100 rads equal 1 gray.
radiation area	An area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.05 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.
RAF	Research Animal Facility (Stanford).
RDRC	Radioactive Drug Research Committee (Food and Drug Administration). The RDRC is chartered by the Food and Drug Administration to review and approve basic research

	projects involving the administration of radioactive drugs to human subjects. CRSCo provides this service.
rem	The special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor. For most forms of radiation, one rem is numerically equal to one roentgen or one rad. One sievert equals 100 rems.
restricted area	An area, access to which is limited by the licensee for purpose of protecting individuals against undue risk from exposure to radiation and radioactive material.
roentgen (R)	The special unit of radiation exposure. The amount of exposure that liberates one esu of charge per cc of air. For most forms of radiation, one roentgen is numerically equal to one rem or one rad. Although considered obsolete, this term and its abbreviation are still commonly used.
RSC	Radiation Safety Committee. This service is provided by the APRS and the LCCs.
RSO	Radiation Safety Officer. The individual responsible for managing the radiation safety or health physics program.
Safety data sheet (SDS)	A one-page information sheet developed at Stanford that provides decay scheme and precautions for a single radionuclide.
SHS	Stanford Health Services. A separate institutional entity that includes the Stanford Hospital and Clinic.
sievert (Sv)	SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the quality factor. 1 sievert equals 100 rems.
SLAC	SLAC National Accelerator Laboratory
stochastic effects	Health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.
SHC	Stanford Hospital and Clinic.
Survey	An evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal or presence of radioactive material or other sources of radiation. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present.
tissue weighting factor	A weighting factor for an organ or tissue relating to the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of

stochastic effects when the whole body is irradiated uniformly.

unrestricted area	An area, access to which is neither limited nor controlled by the licensee.
VAPAHCS	Veterans Affairs Palo Alto Health Care Service.
VMO	Veterinary Medical Officer (VAPAHCS).
VMU	Veterinary Medical Unit (VAPAHCS).
VSC	Veterinary Service Center (Stanford).
work area	A portion of a room or laboratory suite where radioactive materials are stored or handled. It is usually a single countertop.
worker	An individual engaged in activities that are licensed by a regulatory agency and controlled by a licensee. Classification as a worker does not require an employer/employee relationship. Volunteers, students on clinical rotation, residents, staff, faculty, and visiting scientists and physicians whose duties include work in radiation or radioactive materials areas are considered workers.

SAFETY DATA SHEETS FOR COMMONLY-USED RADIONUCLIDES

Introduction	Health Physics has prepared safety data sheets (SDS) for many radionuclides. They provide information about the physical properties of the nuclide such as decay mode, energy, half-life, QLM quantity, and decontamination information. Safety data sheets for the most commonly used radionuclides are provided.
Home page	Other materials used at Stanford are listed on the EH&S-Health Physics home page: http://www.stanford.edu/dept/EHS/prod/researchlab/radlaser/index.html
Additional sources of information	The Health Physics library has reference works on a variety of radiation safety topics. It is available for your use during work hours.

RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: H-3 **FORMS: SOLUBLE, EXCEPT GAS**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 12.35 years TYPE DECAY: $beta^-$

maximum energy 0.0186 MeV

Hazard category: C- level (low hazard): > up to 25 mCi per item to 200 mCi possession

B - level (Moderate hazard): > 25 mCi per item to 10 Ci possession

A - level (High hazard): > 10 Ci

EXTERNAL RADIATION HAZARDS AND SHIELDING:

Because of its low energy, the vial holding the isotope will provide sufficient shielding to stop the betas. If skin is contaminated with tritium, betas will not be able to pass the dead layer of skin. However, H-3 will cause a radiation dose if absorbed into body through cuts in skin or by ingestion.

HAZARDS IF INTERNALLY DEPOSITED:

The Annual Limit of Intake (ALI) based upon a whole body dose of 5 rem per year or upon the maximum recommended (N.C.R.P.) dose to the hematopoietic or spermatogonial stem cell nuclei (from DNA precursors) is as follows:

Whole body	80 mCi (inorganic, soluble) based upon NRC ALI
Stem Cell Nuclei	3.5 mCi (CdR)
Stem Cell Nuclei	7 mCi (other DNA and RNA precursors)

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Film badges and dosimeter rings are not appropriate for monitoring H3 exposure.
Routine urine assays are required after handling 100 millicuries or more of H3. See Radiation Safety Manual Part III.18 for particulars. Spot checks may be required after spills or contamination incidents.

SPECIAL PROBLEMS AND PRECAUTIONS:

1. Always wear protective gloves to keep contamination from skin. Change gloves often.
2. Since the H^3 beta particles have very low energies, the use of G.M. or other survey meters is precluded. Smear surveys are required.
3. All waste in a H^3 work area is considered to be contaminated. Keep work areas free of unnecessary items. Segregate wastes to those with H^3 and C^{14} only.
4. Limit of soluble waste to sewer is 1000 microcuries/ day per lab; and limit of H^3 labeled DNA precursors to sewer as waste is 100 microcuries per day. If the DNA precursors are denatured prior to disposal, the sewer limits would be the same as for soluble forms.

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RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: C-14 **FORMS: SOLUBLE, EXCEPT GAS**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 5730 years TYPE DECAY: beta-

maximum energy: 0.156 MeV

Hazard category: C- level (low hazard): > up to 20 mCi

B - level (Moderate hazard): > 20 mCi to 1.0 Ci

A - level (High hazard): > 1.0 Ci

EXTERNAL RADIATION HAZARDS AND SHIELDING:

The maximum range of these betas is ~1 ft in air and 0.0065 in (0.17 mm) in glass. The external hazard of this isotope is minimal, e.g., the glass vial holding the isotope will provide sufficient shielding to stop the betas. If skin is uniformly contaminated with C14, 1 microcurie/ cm^2 will deliver a dose of 1,100 mrems/hr to basal cells of the skin. (Porter Consultants to NRC)

HAZARDS IF INTERNALLY DEPOSITED:

The Annual Limit of Intake (ALI) which will result in a whole body exposure of 5 rem or maximum recommended doses (by the NCRP) to hematopoietic or spermatogonial stem cell nuclei is as follows:

Whole body	2 mCi (compounds)

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Film badges and dosimeter rings are not appropriate for monitoring C^{14} exposure.

Urine assays may be required after spills or contamination incidents.

SPECIAL PROBLEMS AND PRECAUTIONS:

1. Always wear protective gloves to keep contamination from skin. Change gloves often.
2. C^{14} beta particles have very low energies. G.M. survey meters are not very efficient at such energies. Smear surveys required.
3. All waste in a C^{14} work areas is considered to be contaminated. Keep work areas free of unnecessary items. Segregate wastes to those with H^3 and C^{14} only.
4. Limit of soluble waste to sewer is 100 microcuries/ day per lab.

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RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: P-32 **FORMS: ALL SOLUBLE**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 14.28 days TYPE DECAY: beta-

maximum energy: 1.71 MeV

Hazard category: C- level (low hazard): > up to 2 mCi
B - level (Moderate hazard): > 2 mCi to 100 mCi
A - level (High hazard): > 100 mCi

EXTERNAL RADIATION HAZARDS AND SHIELDING:

The dose rate at 10 cm from an unshielded 1 mCi (dried sample) of P32 (assuming no backscatter or self absorption in the source) is 2.7 rads per hour; the dose at 1 cm is 270 rads per hour. Dose rates vary directly with activity and over short distances inversely with the square of the distance from the source.

Maximum ranges of these betas are 20 feet in air, 1/3 inch in water and tissue and 1/4 inch in plastic.

A spill of 1 µCi of P32 on 1 cm2 skin will deliver a dose of 9200 mrads/hr to the basal cells of the epidermis. (Porter Consultants for NRC)

HAZARDS IF INTERNALLY DEPOSITED:

The Annual Limit of Intake (ALI) (based upon NRC) which would deliver 5 rems to the whole body is 600 µCi.

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Film badges and dosimeter rings are usually required if 5 millicuries are handled at any one time, or if millicurie levels are handled on a frequent (daily) basis. Urine assays may be required after spills or contamination incidents.

SPECIAL PROBLEMS AND PRECAUTIONS:

1. Work behind low Z shielding, preferably transparent materials. Survey frequently. Change gloves often.
2. Segregate wastes to those with half-lives < 19 days.
3. Limit of soluble waste to sewer is 10 microcuries/ day per lab.
4. P^{32} tends to attach to ferrous materials and to glass, weak HCl (~ 0.1 N) can facilitate removal from glass and from some impervious surfaces.

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RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: P-33 **FORMS: ALL SOLUBLE**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 25.4 days TYPE DECAY: beta-

maximum energy: 0.249 MeV

Hazard category:
C- level (low hazard): > up to 20 mCi
B - level (Moderate hazard): > 20 mCi to 1.0 Ci
A - level (High hazard): > 1.0 Ci

EXTERNAL RADIATION HAZARDS AND SHIELDING:

The maximum range of these betas is ~ 19 inches in air and 0.009 inches (0.23 mm) in glass. The external hazard of this isotope is minimal, e.g., the glass vial holding the isotope will provide sufficient shielding to stop the betas. If skin is uniformly contaminated with P33 , 1 microcurie/ cm^2 will deliver a dose of 3,200 mrems/ hr to basal cells of the skin. (Porter Consultants to NRC based upon 0.257 MeV (max.) beta particles.)

HAZARDS IF INTERNALLY DEPOSITED:

The Annual Limit of Intake (ALI, based on NRC) which would deliver 5 rem to the whole body is 6 mCi. Note: The hazards from ingestion or internal deposition of P33 in labeled nucleotide bases may be greater than for inorganic phosphates.

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Film badges and dosimeter rings are of marginal value (inappropriate) for monitoring P33 exposure.

Urine assays may be required after spills or contamination incidents.

SPECIAL PROBLEMS AND PRECAUTIONS:

1. Always wear protective gloves to keep contamination from skin. Change gloves often.
2. P33 beta particles have low energies. G.M. survey meters efficiency for such energies is about 10%. Smear surveys are usually required. (If meter is approved for C14 measurements, it may be used.)
3. All waste in a P33 work areas is considered to be contaminated, unless proved to be clean by appropriate monitoring techniques. Keep work areas free of extraneous items. Segregate wastes to those with half-lives from 19 days to less than 65 days.
4. Limit of soluble waste to sewer is 100 microcuries/ day per lab.

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RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: S-35 **FORMS: SOLUBLE, EXCEPT GAS**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 87.4 days TYPE DECAY: beta-
maximum energy: 0.167 MeV

Hazard category: C- level (low hazard): > up to 20 mCi
B - level (Moderate hazard): > 20 mCi to 1.0 Ci
A - level (High hazard): > 1.0 Ci

EXTERNAL RADIATION HAZARDS AND SHIELDING:

The maximum range of these betas is 43 cm in air, 0.5 mm in plastic and 0.17 mm in glass. The external hazard of this isotope is minimal; the vial holding the isotope will provide sufficient shielding to stop the betas. If skin is uniformly contaminated with S35, 1 microcurie/cm^2 will deliver a dose of 1,200 mrad/hr to basal cells of the skin. (Porter Consultants to NRC).

HAZARDS IF INTERNALLY DEPOSITED:

Although the external hazard associated with S35 is small, it is important to avoid ingestion and/ or skin contamination. Many S35 compounds are volatile or degrade giving off volatile products. Open vials and work in fume hoods.

The Annual Limit of Intake (ALI, based upon the NRC values) that would result in an effective dose equivalent of 5 rem/year is 10 mCi. (Note: A lower ALI is used for insoluble, inorganic sulfides and sulfates- 6 mCi.)

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Film badges and dosimeter rings are not appropriate for monitoring S35 exposure.
Urine assays may be required after spills or contamination incidents.

SPECIAL PROBLEMS AND PRECAUTIONS:

1. Always wear protective gloves to keep contamination from skin. Change gloves often.
2. S35 beta particles have very low energies. GM survey meters are about 10 % efficient at such energies. Smear surveys are generally required.
3. S35 compounds frequently are volatile or produce volatile products; open and handle in a fume hood. When incubating samples use activated charcoal.
4. All waste in a S35 work area should be considered to be contaminated unless proven to be clean by appropriate monitoring techniques. Keep work areas free of unnecessary items. Generally it is very difficult to survey the items because of self-shielding. Segregate wastes to those with half-lives from 65 to less than 90 days.
5. Limit for soluble waste to sewer is 100 microcuries/ day per lab.

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RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: Cr-51 **FORMS: ALL SOLUBLE**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 25.4 days TYPE DECAY: e^- capture

gamma: 0.320 MeV (9%)
X-rays: 0.005 - 0.026 MeV
auger e^-: 0.005 MeV (76 %)

Hazard category: C- level (low hazard): > up to 200 mCi
B - level (Moderate hazard): > 200 mCi to 10 Ci
A - level (High hazard): > 10 Ci

EXTERNAL RADIATION HAZARDS AND SHIELDING:

The exposure rate at 1 cm from 1 mCi is 164 mR/hr. The exposure rate varies directly with activity and inversely with the square of the distance. The tenth value of lead for this radiation energy is 0.7 cm.

HAZARDS IF INTERNALLY DEPOSITED:

The Annual Limit on Oral Intake (ALI) of Cr51 corresponding to a whole-body guideline gamma exposure rate of 5 rem/year is 40 mCi.

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Film badges and dosimeter rings usually required if 5 millicuries are handled at any one time or 1 millicurie level is handled on a frequent (daily) basis.

SPECIAL PROBLEMS AND PRECAUTIONS:

1. When 5 millicuries are used or stored, use lead shielding. Survey frequently. Handle stock solution vials in shields or use tongs or forceps.
2. Survey frequently with a GM monitor. Change gloves often.
3. Segregate wastes to those with half-lives from 15 days to less than 60 days.
4. Aqueous wastes may be disposed to the sewer system in amounts of up to 1 mCi daily per lab.

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RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: I-125 **FORMS: INORGANIC OR FREE IODINE**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 60 days

TYPE DECAY: e^- capture
Gamma rays 0.035 MeV (7 %)
X-rays 0.027-.031 MeV (140 %)

Hazard category:
C- level (low hazard): > up to 200 µCi
B - level (Moderate hazard): > 200 µCi to 10 mCi
A - level (High hazard): > 10 mCi

EXTERNAL RADIATION HAZARDS AND SHIELDING:

Exposure rate at 1 cm from 1 mCi is 1.5 R/hr. (Exposure varies directly with activity and inversely with square of distance from materials.)

Amount of lead required to reduce the exposure rate by a factor of 10 (1 TVL) is approximately 0.1 mm. 1/8 inch of glass would reduce the exposure rate by half. Leaded rubber gloves (0.1 mm lead = 1 TVL) are available from Health Physics.

HAZARDS IF INTERNALLY DEPOSITED:

Contamination on the skin or inhalation will result in internal deposition. Iodide solutions are easily oxidized and the elemental iodine will become airborne. Ingestion of 40 µCi, or inhalation of 60 µCi, will result in the thyroid receiving Annual Limit of Intake (ALI),

Blocking the uptake of radioiodine with the stable nuclide is not permitted. WORK IN PROPER FUME HOODS. (See Radiation Safety Manual, Part 3).

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Badge and ring dosimeters are usually required if 5 millicuries are handled at any one time or if millicurie levels are handled frequently (daily basis). Arrange for a thyroid survey within 24-72 hours after the first procedure; thereafter, every three months.

SPECIAL PROBLEMS AND PRECAUTIONS:

1. GM survey meters have a poor efficiency of detection for I-125. Survey by smear tests or use NaI(Tl) Scintillation probes.
2. Segregate wastes to those with half-lives from 19 to less than 65 days. Assume items in work areas are contaminated unless cleared with a NaI scintillation survey meter. Wrap all waste items in plastic bags prior to placing them in waste.
3. Limit soluble waste to sewer is 100 µCi / month per lab.
4. Wear double gloves. Change gloves often.
5. See separate Radiation Safety Data Sheet for non-volatile or non-cleaving compounds.

4/98

RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: F-18 **FORMS: ALL SOLUBLE**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 109.74 min.

TYPE DECAY: EC e+
gamma: 0.511 MeV (193 %)

Hazard category:
C- level (low hazard) : up to 100 mCi
B - level (Moderate hazard) : > 100 mCi to 10 Ci
A - level (High hazard) : > 10 Ci

EXTERNAL RADIATION HAZARDS AND SHIELDING:

The gamma exposure rate at 1 cm from 1 mCi is 6.95 R/hr. The exposure rate varies directly with activity and inversely as the square of the distance. The 1/10 value layer in lead is 1.6 cm.

HAZARDS IF INTERNALLY DEPOSITED:

The annual limit on oral intake (ALI) of F-18 corresponding to a whole-body guideline gamma exposure rate of 5000 mrem/year is 50 mCi.

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Film badges and dosimeter rings are required for all usage of F-18.

SPECIAL PROBLEMS AND PRECAUTIONS:

1. F-18 syringe shields must be used prior to injection.
2. Store stock material and filled syringes in lead pigs.
3. Unnecessary exposure to personnel and other patients should be minimized by increasing distance from the patient while he is waiting to be scanned. The gamma exposure rate at 1 meter from a patient containing 5 mCi of F-18 will be approximately 2.5 mR/hr.
4. Segregate wastes with those with half-lives less than 4 days (e.g. Tc-99m).
5. Aqueous wastes may be disposed to the sewer system in amounts of up to 1000 uCi daily per lab.
6. Always wear protective gloves to keep contamination from skin. Change gloves often.

02/10

RADIONUCLIDE SAFETY DATA SHEET

NUCLIDE: CU-64 **FORMS: ALL SOLUBLE**

PHYSICAL CHARACTERISTICS:

HALF-LIFE: 12.701 HOURS.

TYPE DECAY: EC e+
gamma: 0.511 MeV (38.6 %)
beta: 0.578 MeV (37.2%)

Hazard category:
C- level (low hazard) : up to 100 mCi
B - level (Moderate hazard) : > 100 mCi to 10 Ci
A - level (High hazard) : > 10 Ci

EXTERNAL RADIATION HAZARDS AND SHIELDING:

The gamma exposure rate 1 cm from 1mCi is 1/32 R/hr. The skin dose for 1 uCi over a 10cm^2 area is 13 mrad/hr for gammas and 320 mrad/hr for betas. The exposure rate varies directly with activity and inversely as the square of the distance. The 1/10 value layer in lead is 17 mm

HAZARDS IF INTERNALLY DEPOSITED:

The annual limit on oral intake (ALI) of Cu-64 corresponding to a whole-body guideline gamma exposure rate of 5000 mrem/year is 10 mCi.

DOSIMETRY AND BIOASSAY REQUIREMENTS:

Film badges and dosimeter rings are required for all usage of Cu-64

SPECIAL PROBLEMS AND PRECAUTIONS:

1. Store Cu-64 behind 2 inch thick lead (Pb) bricks.
2. Use tools to indirectly handle unshielded sources and potentially contaminated vessels; avoid direct hand contact.
3. Segregate wastes with those with half-lives less than 4 days.
4. Aqueous wastes may be disposed to the sewer system in amounts of up to 1000 uCi daily per lab.
5. Always wear protective gloves to keep contamination from skin. Change gloves often.

02/10

REPORTS APPLICABLE TO THE INSTITUTIONAL USE OF RADIATION

The **National Council on Radiation Protection and Measurements** (NCRP) was chartered by Congress to disseminate radiation protection guidance. It has published reports on a variety of topics. The reports are available for review at Health Physics.

111. Developing Radiation Emergency Plans for Academic, Medical or Industrial Facilities (1991).

107. Implementation of the Principle of As Low As Reasonably Achievable (ALARA) for Medical and Dental Personnel (1990).

105. Radiation Protection for Medical and Allied Health Personnel (1989).

100. Exposure of the US Population from Diagnostic Medical Radiation (1989).

99. Quality Assurance for Diagnostic Imaging (1988).

83. The Experimental Basis for Absorbed Dose Calculations in Medical Use of Radionuclides (1985).

73. Protection in Nuclear Medicine and Ultrasound Diagnostic Procedures in Children (1983).

70. Nuclear Medicine—Factors Influencing the Choice and Use of Radionuclides in Diagnosis and Therapy (1982)

65. Management of Persons Accidentally Contaminated with Radionuclides (1980).

58. A Handbook of Radioactivity Measurement Procedures. Second Edition (1985).

57. Instrumentation and Monitoring Methods for Radiation Protection (1978).

54. Medical Radiation Exposure of Pregnant and Potentially Pregnant Women (1977).

37. Precautions in the Management of Patients Who Have Received Therapeutic Amounts of Radionuclides (1970).

30. Safe Handling of Radioactive Materials (1964).

8. Control and Removal of Radioactive Contamination in Laboratories (1951).

The **National Research Council** provides expert services to the government, the public, and the scientific and engineering communities.

BEIR V: Health Effects of Exposure to Low Levels of Ionizing Radiation.

The **International Commission on Radiological Protection** develops reports that provide fundamental principles of radiological protection for use by regulatory and advisory agencies at the national, regional, and international levels. Because of the differing conditions that apply in various countries, it does not provide regulatory text.

ICRP 60: Radiation Protection--1990 Recommendations of the ICRP.

The **US Nuclear Regulatory Commission** (NRC) issues regulatory guides that describe methods of implementing certain regulations or evaluating specific problems, or that provide guidance.

8.9 Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program (1993)

8.10 Operating Philosophy for Maintaining Occupational Radiation Exposure ALARA (1977)

8.13 Instruction Concerning Prenatal Radiation Exposure (1987)

8.18 Information Relevant to Ensuring That Occupational Radiation Exposures at Medical Institutions Will Be As Low As Reasonably Achievable (1982)

8.23 Radiation Safety Surveys at Medical Institutions (1981)

8.29 Instruction Concerning Risks from Occupational Radiation Exposure (1981)

8.32 Criteria for Establishing a Tritium Bioassay Program (1988)

8.34 Monitoring Criteria and Methods to Calculate Occupational Radiation Doses (1992)

8.36 Radiation Dose to the Embryo/Fetus (1992)

8.37 ALARA Levels for Effluents from Materials Facilities (1993)

10.5 Applications for Type A Licenses of Broad Scope (1980)

10.7 Guide for the Preparation of Applications of Licenses for Laboratory and Industrial Use of Small Quantities of Byproduct Material (1979)

10.8 Guide for the Preparation of Applications for Medical Use Programs (1987)

10 CFR PART 20 APPENDIX C- QUANTITIES OF LICENSED MATERIAL REQUIRING LABELING

Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)
Hydrogen-3*	1,000	Calcium-41	100	Iron-55	100
Beryllium-7	1,000	Calcium-45	100	Iron-59	10
Beryllium-10	1	Calcium-47	100	Iron-60	1
Carbon-11	1,000	Scandium-43	1,000	Cobalt-55	100
Carbon-14	100	Scandium-44m	100	Cobalt-56	10
Fluorine-18	1,000	Scandium-44	100	Cobalt-57	100
Sodium-22	10	Scandium-46	10	Cobalt-58m	1,000
Sodium-24	100	Scandium-47	100	Cobalt-58	100
Magnesium-28	100	Scandium-48	100	Cobalt-60m	1,000
Aluminum-26	10	Scandium-49	1,000	Cobalt-60	1
Silicon-31	1,000	Titanium-44	1	Cobalt-61	1,000
Silicon-32	1	Titanium-45	1,000	Cobalt-62m	1,000
Phosphorus-32	10	Vanadium-47	1,000	Nickel-56	100
Phosphorus-33	100	Vanadium-48	100	Nickel-57	100
Sulfur-35	100	Vanadium-49	1,000	Nickel-59	100
Chlorine-36	10	Chromium-48	1,000	Nickel-63	100
Chlorine-38	1,000	Chromium-49	1,000	Nickel-65	1,000
Chlorine-39	1000	Chromium-51	1,000	Nickel-66	10
Argon-39	1,000	Manganese-51	1,000	Copper-60	1,000
Argon-41	1,000	Manganese-52m	1,000	Copper-61	1,000
Potassium-40	100	Manganese-52	100	Copper-64	1,000
Potassium-42	1,000	Manganese-53	1,000	Copper-67	1,000
Potassium-43	1,000	Manganese-54	100	Zinc-62	100
Potassium-44	1,000	Manganese-56	1,000	Zinc-63	1,000
Potassium-45	1,000	Iron-52	100	Zinc-65	10

Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)
Zinc-69m	100	Arsenic-78	1,000	Krypton-87	1,000
Zinc-69	1,000	Selenium-70	1,000	Krypton-88	1,000
Zinc-71m	1,000	Selenium-73m	1,000	Rubidium-79	1,000
Zinc-72	100	Selenium-73	100	Rubidium-81m	1,000
Gallium-65	1,000	Selenium-75	100	Rubidium-81	1,000
Gallium-66	100	Selenium-79	100	Rubidium-82m	1,000
Gallium-67	1,000	Selenium-81m	1,000	Rubidium-83	100
Gallium-68	1,000	Selenium-81	1,000	Rubidium-84	100
Gallium-70	1,000	Selenium-83	1,000	Rubidium-86	100
Gallium-72	100	Bromine-74m	1,000	Rubidium-87	100
Gallium-73	1,000	Bromine-74	1,000	Rubidium-88	1,000
Germanium-66	1,000	Bromine-75	1,000	Rubidium-89	1,000
Germanium-67	1,000	Bromine-76	100	Strontium-80	100
Germanium-68	10	Bromine-77	1,000	Strontium-81	1,000
Germanium-69	1,000	Bromine-80m	1,000	Strontium-83	100
Germanium-71	1,000	Bromine-80	1,000	Strontium-85m	1,000
Germanium-75	1,000	Bromine-82	100	Strontium-85	100
Germanium-77	1,000	Bromine-83	1,000	Strontium-87m	1,000
Germanium-78	1,000	Bromine-84	1,000	Strontium-89	10
Arsenic-69	1,000	Krypton-74	1,000	Strontium-90	0.1
Arsenic-70	1,000	Krypton-76	1,000	Strontium-91	100
Arsenic-71	100	Krypton-77	1,000	Strontium-92	100
Arsenic-72	100	Krypton-79	1,000	Yttrium-86m	1,000
Arsenic-73	100	Krypton-81	1,000	Yttrium-86	100
Arsenic-74	100	Krypton-83m	1,000	Yttrium-87	100
Arsenic-76	100	Krypton-85m	1,000	Yttrium-88	10
Arsenic-77	100	Krypton-85	1,000	Yttrium-90m	1,000

Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)
Yttrium-90	10	Molybdenum-99	100	Rhodium-103m	1,000
Yttrium-91m	1,000	Molybdenum-101	1,000	Rhodium-105	100
Yttrium-91	10	Technetium-93m	1,000	Rhodium-106m	1,000
Yttrium-92	100	Technetium-93	1,000	Rhodium-107	1,000
Yttrium-93	100	Technetium-94m	1,000	Palladium-100	100
Yttrium-94	1,000	Technetium-94	1,000	Palladium-101	1,000
Yttrium-95	1,000	Technetium-96m	1,000	Palladium-103	100
Zirconium-86	100	Technetium-96	100	Palladium-107	10
Zirconium-88	10	Technetium-97m	100	Palladium-109	100
Zirconium-89	100	Technetium-97	1,000	Silver-102	1,000
Zirconium-93	1	Technetium-98	10	Silver-103	1,000
Zirconium-95	10	Technetium-99m	1,000	Silver-104m	1,000
Zirconium-97	100	Technetium-99	100	Silver-104	1,000
Niobium-88	1,000	Technetium-101	1,000	Silver-105	100
Niobium-89m (66 min)	1,000	Technetium-104	1,000	Silver-106m	100
Niobium-89 (122 min)	1,000	Ruthenium-94	1,000	Silver 106	1,000
Niobium-90	100	Ruthenium-97	1,000	Silver-108m	1
Niobium-93m	10	Ruthenium-103	100	Silver-110m	10
Niobium-94	1	Ruthenium-105	1,000	Silver-111	100
Niobium-95m	100	Ruthenium-106	1	Silver-112	100
Niobium-95	100	Rhodium-99m	1,000	Silver-115	1,000
Niobium-96	100	Rhodium-99	100	Cadmium-104	1,000
Niobium-97	1,000	Rhodium-100	100	Cadmium-107	1,000
Niobium-98	1,000	Rhodium-101m	1,000	Cadmium-109	1
Molybdenum-90	100	Rhodium-101	10	Cadmium-113m	0.1
Molybdenum-93m	100	Rhodium-102m	10	Cadmium-113	100
Molybdenum-93	10	Rhodium-102	10	Cadmium-115m	10

Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)
Cadmium-115	100	Tin-127	1,000	Tellurium-123	100
Cadmium-117m	1,000	Tin-128	1,000	Tellurium-125m	10
Cadmium-117	1,000	Antimony-115	1,000	Tellurium-127m	10
Indium-109	1,000	Antimony-116m	1,000	Tellurium-127	1,000
Indium-110 (69.1 min)	1,000	Antimony-116	1,000	Tellurium-129m	10
Indium-110 (4.9 h)	1,000	Antimony-117	1,000	Tellurium-129	1,000
Indium-111	100	Antimony-118m	1,000	Tellurium-131m	10
Indium-112	1,000	Antimony-119	1,000	Tellurium-131	100
Indium-113m	1,000	Antimony-120 (16 min)	1,000	Tellurium-132	10
Indium-114m	10	Antimony-120 (5.76 d)	100	Tellurium-133m	100
Indium-115m	1,000	Antimony-122	100	Tellurium-133	1,000
Indium-115	100	Antimony-124m	1,000	Tellurium-134	1,000
Indium-116m	1,000	Antimony-124	10	Iodine-120m	1,000
Indium-117m	1,000	Antimony-125	100	Iodine-120	100
Indium-117	1,000	Antimony-126m	1,000	Iodine-121	1,000
Indium-119m	1,000	Antimony-126	100	Iodine-123	100
Tin-110	100	Antimony-127	100	Iodine-124	10
Tin-111	1,000	Antimony-128 (10.4 min)	1,000	Iodine-125*	1
Tin-113	100	Antimony-128 (9.01 h)	100	Iodine-126	1
Tin-117m	100	Antimony-129	100	Iodine-128	1,000
Tin-119m	100	Antimony-130	1,000	Iodine-129	1
Tin-121m	100	Antimony-131	1,000	Iodine-130	10
Tin-121	1,000	Tellurium-116	1,000	Iodine-131*	1
Tin-123m	1,000	Tellurium-121m	10	Iodine-132m	100
Tin-123	10	Tellurium-121	100	Iodine-132	100
Tin-125	10	Tellurium-123m	10	Iodine-133	10
Tin-126	10			Iodine-134	1,000

Radionuclide	**QLM** Quantity (µCi)	Radionuclide	**QLM** Quantity (µCi)	Radionuclide	**QLM** Quantity (µCi)
Iodine-135	100	Barium-126	1,000	Cerium-144	1
Xenon-120	1,000	Barium-128	100	Praseodymium-136	1.000
Xenon-121	1,000	Barium-131m	1,000	Praseodymium-137	1,000
Xenon-122	1,000	Barium-131	100	Praseodymium-138m	1,000
Xenon-123	1,000	Barium-133m	100	Praseodymium-139	1,000
Xenon-125	1,000	Barium-133	100	Praseodymium-142m	1,000
Xenon-127	1,000	Barium-135m	100	Praseodymium-142	100
Xenon-129m	1,000	Barium-139	1,000	Praseodymium-143	100
Xenon-131m	1,000	Barium-140	100	Praseodymium-144	1,000
Xenon-133m	1,000	Barium-141	1,000	Praseodymium-145	100
Xenon-133	1,000	Barium-142	1,000	Praseodymium-147	1,000
Xenon-135m	1,000	Lanthanum-131	1,000	Neodymium-136	1,000
Xenon-135	1,000	Lanthanum-132	100	Neodymium-138	100
Xenon-138	1,000	Lanthanum-135	1,000	Neodymium-139m	1,000
Cesium-125	1,000	Lanthanum-137	10	Neodymium-139	1,000
Cesium-127	1,000	Lanthanum-138	100	Neodymium-141	1,000
Cesium-129	1,000	Lanthanum-140	100	Neodymium-147	100
Cesium-130	1,000	Lanthanum-141	100	Neodymium-149	1,000
Cesium-131	1,000	Lanthanum-142	1,000	Neodymium-151	1,000
Cesium-132	100	Lanthanum-143	1,000	Promethium-141	1,000
Cesium-134m	1,000	Cerium-134	100	Promethium-143	100
Cesium-134	10	Cerium-135	100	Promethium-144	10
Cesium-135m	1,000	Cerium-137m	100	Promethium-145	10
Cesium-135	100	Cerium-137	1,000	Promethium-146	1
Cesium-136	10	Cerium-139	100	Promethium-147	10
Cesium-137	10	Cerium-141	100	Promethium-148m	10
Cesium-138	1,000	Cerium-143	100	Promethium-148	10

Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)
Promethium-149	100	Gadolinium-145	1,000	Dysprosium-166	100
Promethium-150	1,000	Gadolinium-146	10	Holmium-155	1,000
Promethium-151	100	Gadolinium-147	100	Holmium-157	1,000
Samarium-141m	1,000	Gadolinium-148	0.001	Holmium-159	1,000
Samarium-141	1,000	Gadolinium-149	100	Holmium-161	1,000
Samarium-142	1,000	Gadolinium-151	10	Holmium-162m	1,000
Samarium-145	100	Gadolinium-152	100	Holmium-162	1,000
Samarium-146	1	Gadolinium-153	10	Holmium-164m	1,000
Samarium-147	100	Gadolinium-159	100	Holmium-164	1,000
Samarium-151	10	Terbium-147	1,000	Holmium-166m	1
Samarium-153	100	Terbium-149	100	Holmium-166	100
Samarium-155	1,000	Terbium-150	1,000	Holmium-167	1,000
Samarium-156	1,000	Terbium-151	100	Erbium-161	1,000
Europium-145	100	Terbium-153	1,000	Erbium-165	1,000
Europium-146	100	Terbium-154	100	Erbium-169	100
Europium-147	100	Terbium-155	1,000	Erbium-171	100
Europium-148	10	Terbium-156m (5.0 h)	1,000	Erbium-172	100
Europium-149	100	Terbium-156m (24.4 h)	1,000	Thulium-162	1,000
Europium-150 (12.62 h)	100	Terbium-156	100	Thulium-166	100
Europium-150 (34.2 y)	1	Terbium-157	10	Thulium-167	100
Europium-152m	100	Terbium-158	1	Thulium-170	10
Europium-152	1	Terbium-160	10	Thulium-171	10
Europium-154	1	Terbium-161	100	Thulium-172	100
Europium-155	10	Dysprosium-155	1,000	Thulium-173	100
Europium-156	100	Dysprosium-157	1,000	Thulium-175	1,000
Europium-157	100	Dysprosium-159	100	Ytterbium-162	1,000
Europium-158	1,000	Dysprosium-165	1,000	Ytterbium-166	100

Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)
Ytterbium-167	1,000	Hafnium-181	10	Tungsten-187	100
Ytterbium-169	100	Hafnium-182m	1,000	Tungsten-188	10
Ytterbium-175	100	Hafnium-182	0.1	Rhenium-177	1,000
Ytterbium-177	1,000	Hafnium-183	1,000	Rhenium-178	1,000
Ytterbium-178	1,000	Hafnium-184	100	Rhenium-181	1,000
Lutetium-169	100	Tantalum-172	1,000	Rhenium-182 (12.7 h)	1,000
Lutetium-170	100	Tantalum-173	1,000	Rhenium-182 (64.0 h)	100
Lutetium-171	100	Tantalum-174	1,000	Rhenium-184m	10
Lutetium-172	100	Tantalum-175	1,000	Rhenium-184	100
Lutetium-173	10	Tantalum-176	100	Rhenium-186m	10
Lutetium-174m	10	Tantalum-177	1,000	Rhenium-186	100
Lutetium-174	10	Tantalum-178	1,000	Rhenium-187	1,000
Lutetium-176m	1,000	Tantalum-179	100	Rhenium-188m	1,000
Lutetium-176	100	Tantalum-180m	1,000	Rhenium-188	100
Lutetium-177m	10	Tantalum-180	100	Rhenium-189	100
Lutetium-177	100	Tantalum-182m	1,000	Osmium-180	1,000
Lutetium-178m	1,000	Tantalum-182	10	Osmium-181	1,000
Lutetium-178	1,000	Tantalum-183	100	Osmium-182	100
Lutetium-179	1,000	Tantalum-184	100	Osmium-185	100
Hafnium-170	100	Tantalum-185	1,000	Osmium-189m	1,000
Hafnium-172	1	Tantalum-186	1,000	Osmium-191m	1,000
Hafnium-173	1,000	Tungsten-176	1,000	Osmium-191	100
Hafnium-175	100	Tungsten-177	1,000	Osmium-193	100
Hafnium-177m	1,000	Tungsten-178	1,000	Osmium-194	1
Hafnium-178m	0.1	Tungsten-179	1,000	Iridium-182	1,000
Hafnium-179m	10	Tungsten-181	1,000	Iridium-184	1,000
Hafnium-180m	1,000	Tungsten-185	100	Iridium-185	1,000

Radionuclide	**QLM** Quantity (µCi)
Iridium-186	100
Iridium-187	1,000
Iridium-188	100
Iridium-189	100
Iridium-190m	1,000
Iridium-190	100
Iridium-192 (73.8 d)	1
Iridium-192m (1.4 min)	10
Iridium-194m	10
Iridium-194	100
Iridium-195m	1,000
Iridium-195	1,000
Platinum-186	1,000
Platinum-188	100
Platinum-189	1,000
Platinum-191	100
Platinum-193m	100
Platinum-193	1,000
Platinum-195m	100
Platinum-197m	1,000
Platinum-197	100
Platinum-199	1,000
Platinum-200	100
Gold-193	1,000
Gold-194	100
Gold-195	10
Gold-198m	100
Gold-198	100
Gold-199	100
Gold-200m	100
Gold-200	1,000
Gold-201	1,000
Mercury-193m	100
Mercury-193	1,000
Mercury-194	1
Mercury-195m	100
Mercury-195	1,000
Mercury-197m	100
Mercury-197	1,000
Mercury-199m	1,000
Mercury-203	100
Thallium-194m	1,000
Thallium-194	1,000
Thallium-195	1,000
Thallium-197	1,000
Thallium-198m	1,000
Thallium-198	1,000
Thallium-199	1,000
Thallium-200	1,000
Thallium-201	1,000
Thallium-202	100
Thallium-204	100
Lead-195m	1,000
Lead-198	1,000
Lead-199	1,000
Lead-200	100
Lead-201	1,000
Lead-202m	1,000
Lead-202	10
Lead-203	1,000
Lead-205	100
Lead-209	1,000
Lead-210	0.01
Lead-211	100
Lead-212	1
Lead-214	100
Bismuth-200	1,000
Bismuth-201	1,000
Bismuth-202	1,000
Bismuth-203	100
Bismuth-205	100
Bismuth-206	100
Bismuth-207	10
Bismuth-210m	0.1
Bismuth-210	1
Bismuth-212	10
Bismuth-213	10
Bismuth-214	100
Polonium-203	1,000
Polonium-205	1,000
Polonium-207	1,000

Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)	Radionuclide	**QLM** Quantity (μCi)
Polonium-210	0.1	Protactinium-227	10	Neptunium-239	100
Astatine-207	100	Protactinium-228	1	Neptunium-240	1,000
Astatine-211	10	Protactinium-230	.01	Plutonium-234	10
Radon-220	1	Protactinium-231	0.001	Plutonium-235	1,000
Radon-222	1	Protactinium-232	1	Plutonium-236	0.001
Francium-222	100	Protactinium-233	100	Plutonium-237	100
Francium-223	100	Protactinium-234	100	Plutonium-238	0.001
Radium-223	0.1	Uranium-230	0.01	Plutonium-239	0.001
Radium-224	0.1	Uranium-231	100	Plutonium-240	0.001
Radium-225	0.1	Uranium-232	0.001	Plutonium-241	0.01
Radium-226	0.1	Uranium-233	0.001	Plutonium-242	.0001
Radium-227	1,000	Uranium-234	0.001	Plutonium-243	1,000
Radium-228	0.1	Uranium-235	0.001	Plutonium-244	0.001
Actinium-224	1	Uranium-236	0.001	Plutonium-245	100
Actinium-225	0.01	Uranium-237	100	Americium-237	1,000
Actinium-226	0.1	Uranium-238	100	Americium-238	100
Actinium-227	0.001	Uranium-239	1,000	Americium-239	1,000
Actinium-228	1	Uranium-240	100	Americium-240	100
Thorium-226	10	Uranium-natural	100	Americium-241	0.001
Thorium-227	0.01	Neptunium-232	100	Americium-242m	0.001
Thorium-228	0.001	Neptunium-233	1,000	Americium-242	10
Thorium-229	0.001	Neptunium-234	100	Americium-243	0.001
Thorium-230	0.001	Neptunium-235	100	Americium-244m	100
Thorium-231	100	Neptunium-236 (1.15×10^5 y)	0.001	Americium-244	10
Thorium-232	100	Neptunium-236 (22.5 h)	1	Americium-245	1,000
Thorium-234	10	Neptunium-237	0.001	Americium-246m	1,000
Thorium-natural	100	Neptunium-238	10	Americium-246	1,000

Radionuclide	**QLM** Quantity (μCi)
Curium-238	100
Curium-240	0.1
Curium-241	1
Curium-242	0.01
Curium-243	0.001
Curium-244	0.001
Curium-245	0.001
Curium-246	0.001
Curium-247	0.001
Curium-248	0.001
Curium-249	1,000
Berkelium-245	100
Berkelium-246	100
Berkelium-247	0.001
Berkelium-249	0.1
Berkelium-250	10
Californium-244	100
Californium-246	1
Californium-248	0.01
Californium-249	0.001
Californium-250	0.001
Californium-251	0.001
Californium-252	0.001
Californium-253	0.1
Californium-254	0.001
Any alpha emitting radionuclide not listed above or mixtures of alpha emitters of unknown composition	0.001
Einsteinium-250	100
Einsteinium-251	100
Einsteinium-253	0.1
Einsteinium-254m	1
Einsteinium-254	0.01
Fermium-252	1
Fermium-253	1
Fermium-254	10
Fermium-255	1
Fermium-257	0.01
Mendelevium-257	10
Mendelevium-258	0.01
Any radionuclide other than alpha emitting radionuclides not listed above, or mixtures of beta emitters of unknown composition	0.01

* H-3 IN THE FORM OF LABELED DNA BASES IS LIMITED TO 100 uCi/DAY.

* 100 uCi OF I-125 AND I-131 CAN BE DISPOSED OF TO THE SEWER WITH PRIOR APPROVAL OF HEALTH PHYSICS.

RADIATION

DOSE

rem	sievert
0.1 mrem	1 µSv
1 mrem	10 µSv
10 mrem	100 µSv (0.1 mSv)
100 mrem	1mSv
500 mrem	5 mSv
1 rem	10 mSv
5 rem	50 mSv
10 rem	100 mSv
25 rem	250 mSv
50 rem	500 mSv
100 rem	1 Sv

AMOUNT

curie	becquerel
1pCi	37mBq
27 pCi	1 Bq
1 nCi	37 Bq
27 nCi	1kBq
1 µCi	37 kBq
27 µCi	1 MBq
1 mCi	37 MBq
27 mCi	1 GBq
1 Ci	37 GBq
27 Ci	1 TBq
1 kCi	37 TBq
27 kCi	1 PBq
1 MCi	37 PBq

GUIDE TO SI UNITS

TEMPERATURE

Celsius	Fahrenheit
3000°C	5432°F
2500°C	4532°F
2000°C	3632°F
1500°C	2732°F
1000°C	1832°F
800°C	1472°F
600°C	1112°F
400°C	752°F
200°C	392°F
100°C	212°F
50°C	122°F
0°C	32°F
-17.8°C	0°F

PRESURE (Pascal)

1 Pa = 1.45 x 10^{-4} psi

1M Pa = 145 psi

SPEED

1 m/s ≃ 2 mph

VOLUME

$1\ m^3 = 10^3 \ell$

1 cc (cm^3) = 1 mℓ

1 cc ≃ 1 gram water

3785 cc/gal   7.48 gal/ft^3

AREA

$1\ km^2 = 10^6\ m^2$

$1\ m^2$ ≃ 11 ft^2

ABSORBED ENERGY

100 rad = 1 Gy (gray)

SI UNITS PREFIXES:

E	exa	10^{18}	M	mega	10^6	µ	micro	10^{-6}
P	peta	10^{15}	k	kilo	10^3	n	nano	10^{-9}
T	tera	10^{12}	c	centi	10^{-2}	p	pico	10^{-12}
G	giga	10^9	m	milli	10^{-3}			

Prepared By U.S. NRC AEOD/IRB   1/90

SIGNS AND LABELS

Most of these signs and labels are available from Health Physics. Be sure names and telephone numbers are up-to-date.

CAUTION

RADIOACTIVE MATERIAL
WORK AREA

SURFACES AND ITEMS IN THIS AREA MAY BE CONTAMINATED!

NO SMOKING, EATING,
OR DRINKING PERMITTED

FOR HEALTH PHYSICS ASSISTANCE AT ANY TIME, CALL 723-3201

Work area. Mark bench tops and other surfaces where open radiochemicals are handled. Red on yellow.

CAUTION

RADIOACTIVE
MATERIAL

FOR HEALTH PHYSICS ASSISTANCE AT ANY TIME, CALL 723-3201

General notice. Mark the doors to areas where devices and radiochemicals are handled or stored. Red on yellow.

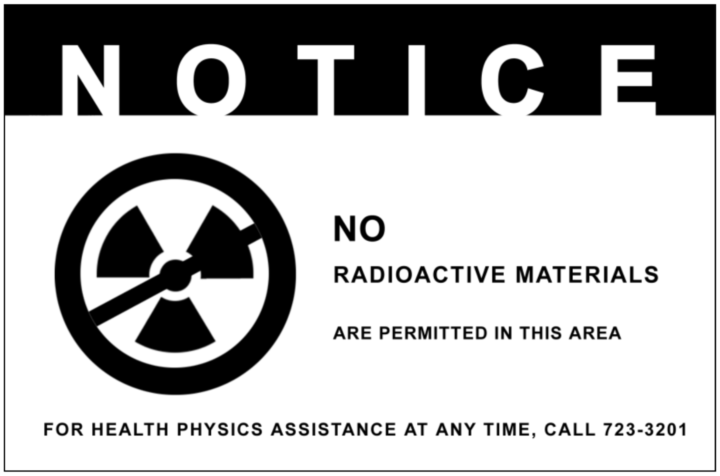
CAUTION
RADIOACTIVE MATERIAL

ITEMS AND SURFACES
INSIDE THIS ENCLOSURE
MAY BE CONTAMINATED

BEFORE DISPOSING OF THIS
APPLIANCE REQUEST A RADIATION SURVEY
BY HEALTH PHYSICS

PHONE 723-3201

Appliances, hoods, and cabinets. Mark equipment that has held radiochemicals. Red on yellow.



NOTICE

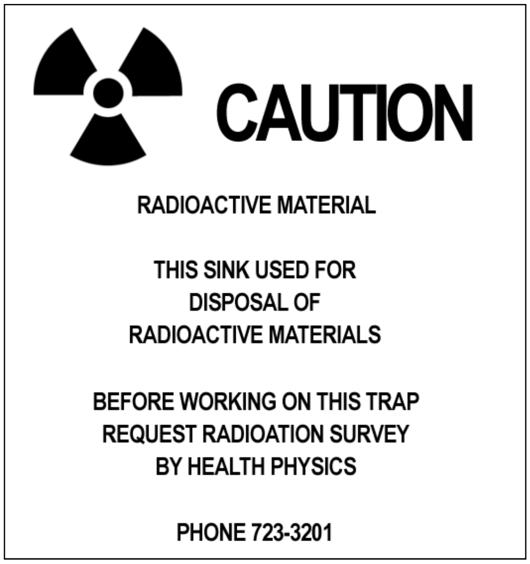
NO

RADIOACTIVE MATERIALS

ARE PERMITTED IN THIS AREA

FOR HEALTH PHYSICS ASSISTANCE AT ANY TIME, CALL 723-3201

Desk area. Mark areas dedicated to office work where there will be no radiochemicals. Black on green.



CAUTION

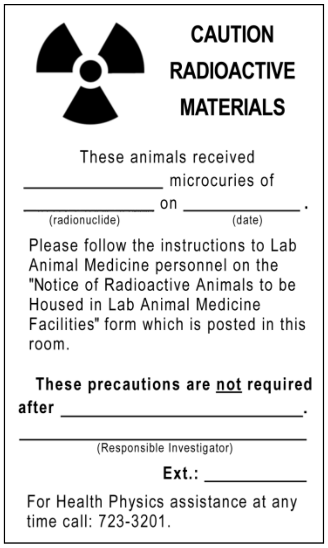
RADIOACTIVE MATERIAL

THIS SINK USED FOR
DISPOSAL OF
RADIOACTIVE MATERIALS

BEFORE WORKING ON THIS TRAP
REQUEST RADIOATION SURVEY
BY HEALTH PHYSICS

PHONE 723-3201

Sink for disposal. Mark the inside of the cabinet door of a sink that has been used for radiochemical disposal. Red on yellow.



CAUTION
RADIOACTIVE
MATERIALS

These animals received
_______________ microcuries of
_______________ on _____________ .
(radionuclide) (date)

Please follow the instructions to Lab Animal Medicine personnel on the "Notice of Radioactive Animals to be Housed in Lab Animal Medicine Facilities" form which is posted in this room.

These precautions are <u>not</u> required after ___________________________.

____
(Responsible Investigator)

Ext.: ___________

For Health Physics assistance at any time call: 723-3201.

Animal cages. Mark individual cages or cage racks if animals have been administered radiochemicals. Red on yellow. Also post the room with an animal care instruction form.

Electronic equipment.
Label the control panel.
Burgundy on yellow.

X-ray diffraction units.
Label the control panel and
the sample chamber door.
Red on yellow.

FORMS

This section provides comments on frequently used forms. If a full sized blank is provided you may photocopy it.

STATEMENT OF TRAINING AND EXPERIENCE FOR USE OF RADIONUCLIDES AND RADIATION DEVICES

Instructions: All individuals must complete formal radiation safety training before using ionizing radiation. The training that is required depends on the type and amount of materials to be used, and the individual's current training and experience. Most individuals must attend an eight-hour course given by Health Physics, and then be provided on-the job training by the laboratory supervisor. You will receive specific instructions after Health Physics evaluates your training and experience. If you have any questions, please call Health Physics at 723-3201. Fax this completed form to Health Physics at 723-0632. Complete ALL fields!

(CRA #) CONTROLLED RAD. AUTH >> REQUIRED! <<		LAST NAME		FIRST NAME		**MI**
M or F	DEPARTMENT	POSITION*	MAIL CODE	WORK PHONE	FAX NUMBER	
EMAIL ADDRESS		**SUNet ID**	**BUILDING AND ROOM**			

*** POSITION: Faculty, Post-Doc; Visiting Scientist; Student; Staff**

Duration at Stanford: ☐ 30 days ☐ ≤ 6 months ☐ > 6 months

What sources will you use here: ☐ unsealed radiochemicals ☐ sealed radioactive sources ☐ XRD ☐ irradiator ☐ XRF ☐ medical x-ray ☐ non-medical x-ray ☐ cabinet x-ray

TRAINING AND EXPERIENCE WITH RADIATION SOURCES

INSTITUTION	BEGAN (MM/YY)	ENDED (MM/YY)
INSTITUTION	BEGAN (MM/YY)	ENDED (MM/YY)

ESTIMATE THE NUMBER OF CLASSROOM CONTACT HOURS FOR EACH TOPIC

Topic	Hours
Physics of ionizing radiation and radiation units	
Bioeffects of ionizing radiation	
Radiation hazards and protection methods	
Regulations and standards	
Monitoring and survey methods	

OFFICE USE ONLY

CLASS	COMPQ	PROQ	XRD
	Score		
	Date		
	By		
	___ SHP	___ OJT	
	Notes ___/___/___		
	Cd Reqs ___/___/___		

NOTE TYPICAL RADIONUCLIDES YOU HANDLED AND LENGTH OF EXPERIENCE IN THE APPROPRIATE BOX, E.G. H-3 5 DAYS; 1-125 6 MONTHS; CS-137 3 YEARS

Type of Sources	MICROCURIES	MILLICURIES	CURIES	KILOCURIES
Sealed sources or neutron emitters				
Unsealed beta and gamma emitters				

WHAT DEVICES HAVE YOU USED: ☐ XRD ☐ self-shielded irradiator ☐ XRF ☐ medical x-ray ☐ non-medical x-ray ☐cabinet x-ray ☐ ________________________________

___________________________________ ____________________

Signature Date

ON THE JOB TRAINING FORM (OJT)

Health Physics
Stanford University

(650) 723-3202 **fax (650) 723-0632**

Date:

Memo to:
CRA:
Department:
From: ***Training Coordinator***
Health Physics Training Coordinator

Subject: Completion of Radiation Safety Training for ____________________

This individual completed formal radiation safety orientation on (date of training). This two-day, eight contact-hour course was designed for scientists using radioactive materials in the biochemistry environment. It provided a condensed survey of radiation safety fundamentals. The course, comprised of two four-hour sessions taught by two senior health physics staff, provided 3 hours physics, 1 hour biology, 2 hours hazards and protection, 1 hour regulations, and 1 hour monitoring. Students were evaluated by multiple-choice homework after session 1 and multiple-choice open-book quiz after session 2.

Will you please complete the training by providing On-The-Job training in all the indicated tasks, plus demonstration of each radioactive materials protocol this individual will perform. Document this training on this form, and file it in your Radioisotope Journal at Tab 6.

Please call for additional information on irradiator training.

Training was provided by ____ on _______.

☐ Ordering radioactivity
☐ Defacing packages
☐ Lab surveys
☐ Receiving, checking, and storing new material
☐ Radioisotope Use Log and Waste Log
☐ Personnel monitoring
☐ Project records and the Radioisotope Journal

Nuclide	µCi / run	Protocol Title	Date	Instructor

WORKSHEET FOR RADIOCHEMICAL PROTOCOLS

Instructions: Please complete a separate worksheet for each radiochemical protocol. The purpose of the worksheet is to identify hazardous or regulated chemicals, operations, and waste streams that might pose safety problems or unanticipated costs. Attach an abstract or copy of the protocol. If this is an amendment to an existing CRA, you may fax this completed form and that attachment to Health Physics at 723-0632.

PI LAST NAME	FIRST NAME	MI	CRA NUMBER

DEPARTMENT	E-MAIL	MAIL CODE	PHONE	FAX

NUCLIDE	µCI PER EXPT	µCI IN VIAL*	CHEMICAL FORM	VOLATILE ☐ Yes ☐ No	PHYSICAL FORM ☐ Powder ☐ Liquid ☐ Solid ☐ Gas

*At Stanford, if >100 QLM, vial must be locked. At VAPAHCS, all vials must be locked.

PROTOCOL TITLE

SIMPLE HANDLING

☐ Weighing ☐ Pipetting ☐ Type ____ ☐ µL's ☐ mL's

PROCESSING THAT MIGHT GENERATE MIST, VAPOR, OR SPILL

☐ Heating to ________ °C ☐ Open flame heating ☐ Stirring ☐ Vortex mixing for ☐minutes ▣ hours

☐ Centrifuging for ☐ minutes ☐ hours ☐ Chromatography__________________________________

IDENTIFY ADDED HAZARDS ☐ None

☐ Flammable solvent ☐ Toxic ☐ Corrosive ☐ Reactive ☐ Pathogen ❒________________________

ANIMALS ☐ None ☐ Applied for animal committee approved on _____ -- _____ -- _____

SPECIES	NUMBER	GRAMS EACH	µCI ADMIN'D	µCI AT EUTH	EUTH ❒ Ether ❒ ____	CAGES CLND ❒ CRA staff ❒ VSC	µCI IN URINE 48 HRS: ___ 7 DAYS:___	µCI IN SCAT 48 HRS:___ 7DAYS:___

Where will animals be housed; who will care for them: ____

Where will carcasses and excreta be disposed: ____

PROTECTIVE ITEMS THAT WILL BE USED

☐ Shielding type __________________________ ☐ Interlab transport container ____________________________

☐ Fume hood in room _____ ☐ Splash shield ☐ Dosimetry badges ☐ Rings

☐ Survey meter ☐ GM ☐ Ionization ☐ NaI(TI) ☐ ____

RADIOACTIVE WASTE GENERATION

☐ Liquid Scintillation Cocktail trade name ____

☐ Dry waste cubic feet per month ___________ ☐ Sharps ☐ Liters per month for solidification ___________

MIXED WASTE GENERATION ☐ None ☐ Mark on an attachment, all reagents that are not on the "Non-hazardous Waste List" at http://www.stanford.edu/dept/EHS/prod/enviro/waste/nohaz.html

_______________________________________ ___________________

PI Signature Date

☐ No follow-up needed ☐ ____

____ ____________________

Signature Date

DECLARATION OF PREGNANCY

Instructions: It is our responsibility to ensure that the dose to an embryo/fetus, during the entire pregnancy, due to occupational exposure of a declared pregnant worker, does not exceed 0.5 rem [§20.1208]. Our policy is to examine your work environment and job responsibilities to assure that you will avoid substantial variation above 0.05 rem each month during your pregnancy. If you have questions, please call Health Physics at 723-3201. Fax this completed form to Health Physics at 723-0632. We will schedule an interview with you to review safety measures and answer your questions.

LAST NAME	FIRST NAME	MI	DELIVERY DATE	☐ STANFORD ☐ VAPAHCS

DEPARTMENT	POSITION*	MAIL CODE	PHONE	**EMAIL**

* POSITION: Faculty, Post-Doc; Visiting Scientist; Student; Staff

Describe the sources of radiation that you personally work with day to day. For radioactive materials, describe the radionuclides and activities, and hours of use each day. For devices, identify the type of device and hours of use each day. Also describe the level of use for other individuals in your work area.

In accordance with 10 CFR 20.1208, I am voluntarily declaring, in writing, that I am pregnant. I understand that it is my sole and fundamental responsibility to inform Stanford Health Physics, in writing, of my pregnancy, it I choose to do so. I also recognize that I am now subject to dose-limit restrictions to ensure that occupational prenatal radiation exposure does not exceed 0.5 rem during the duration of the pregnancy.

Signature ______________________ Date ______________

REVIEW 10 CFR 20.1208 AND RADIATION SAFETY MANUAL, PART 1.

OFFICE USE ONLY

Attach Wearer's dose for the past 12 months

Workplace interview scheduled for date: ______________; time: _____________; room:____________

Do you anticipate a change in your workload or uses? ______________________

Will there be a change in co-workers' workload or uses? ______________________

Note other questions and answers ______________________

Health Physicist ______________________ Date ______________

RADIATION DOSIMETRY SERVICE REQUEST

Please complete form & send with attachment(s) to: Dosimetry Coordinator, Health Physics, MC 8007 or fax to Health Physics at 650-723-0632.

For the online version go to http://radforms.stanford.edu

DEPARTMENT: ________________________________ **DATE:** ____________________

CONTACT (OR PI) RESPONSIBLE
FOR EXCHANGING DOSIMETERS: ________________________ **PHONE #:** _________________

DOSIMETRY ACCT.# & LOCATION CODE: ________ /________ **EMAIL:** ___________________

START / STOP SERVICE EFFECTIVE DATE: _______________

TYPE OF SERVICE:
X-RAY, BETA, GAMMA, NEUTRON
☐ ☐ ☐ ☐

If applicable: CONTROLLED RADIATION AUTHORIZATION (CRA) #: ___________ (example: SMN011)

PLEASE PRINT CLEARLY:

(1) NAME (Last, First)	(2) Action	(3) Position	(4) Gender (M/F)	DATE OF BIRTH	(5) HISTORY		BODY BADGE	RING SIZE (S-M-L)	(6) USE
					None	Attach			

(1) All personnel working under CRA's must complete formal basic radiation protection training provided by Health Physics, and on-the-job training provided by the project, PRIOR to using ionizing radiation. Please complete a "STATEMENT OF TRAINING AND EXPERIENCE" for each new person listed who will use radionuclides, and append it to this request.

(2) Acton: **(A)** - add; **(D)** - delete; **(C)** - corrections

(3) Position: **(F)** - faculty; **(P)** - post-doc; **(V)** - visiting scientist; **(S)** - staff; **(G)** - student; **(O)** – other

(4) Gender: **(M)** – Male / **(F)** - Female

(5) Each person having a previous or ongoing radiation exposure history with another facility, as required by regulations, must submit an **Authorization to Obtain Radiation Exposure History** form, or must check "**None**" to indicate there is no radiation exposure history. It is each person's responsibility to inform Health Physics of historical or concurrent radiation exposures from other facilities.

(6) Use: **(N)** - not using radiation but works in a radiation lab; **(C)** - radiochemicals; **(S)** – small sealed sources;
(XRD) - x-ray diffraction; **(XRF)** - x-ray fluorescence; **(XRM)** - x-ray medical; **(XRN)** - x-ray non-medical;
(XRC) - cabinet x-ray; **(XI)** –X-ray irradiator; **(SI)** – Sealed Source irradiator **(O)** - other

LOST / DAMAGED DOSIMETER REPORT

Instructions: It is our responsibility to estimate your dose if your dosimeter is lost or damaged. Our estimate is based on your usual dose and activities, and your activities during the monitor period. Please complete the top half of this form and fax it to Health Physics at 723-0632.

LAST NAME	**FIRST NAME**	**MI**	☐ **STANFORD** ☐ **VAPAHCS**

DEPARTMENT	**POSITION***	**EMAIL**	**PHONE #**	**CRA/PI**

*POSITION: Faculty, Post-Doc, Visiting Scientist, Student, Staff

DOSIMETRY ACCOUNT #	**LOCATION #**	**WB DOSIMETER #** _________ **RING DOSIMETER #** _________	**WEAR PERIOD**

Describe the sources of radiation that you personally worked with day to day during the monitor period. For radioactive materials, describe the radionuclides and activities, and hours of use each day. For devices identify the type of device, room number, and hours of use each day. Also describe the level of use for other individuals in your work area.

____

____

____

Was the level of use greater, similar to, or less than usual? ☐ **Greater** ☐ **Similar** ☐ **Less**

To the best of my knowledge, I believe the above statements are true and the estimated radiation dose may be entered into my exposure record.

________________________________ ____________________

Signature Date

OFFICE USE ONLY

Attach wearer's dose for the past 12 months

☐ Telephone ☐ Email ☐ Workplace interview conducted date: ____________ time: ___________

____

____

Millirem to be assigned: Deep ________ Eye _________ Shallow _________ Notify Processor: Y ☐ N ☐

_____________________ ___________ _____________________ ___________

Health Physicist Date Radiation Safety Officer Date

Distribution: Original: HP dose record Copy: Monitored Individual Copy: Dosimetry Contact

PLEASE COMPLETE FORM & SEND TO HEALTH PHYSICS, FAX: 723-0632, M/C 8007

AUTHORIZATION TO OBTAIN RADIATION EXPOSURE HISTORY

PURPOSE: In order to comply with regulations pertaining to radiation exposure, it may be necessary for Stanford University to obtain your occupational exposure history if you have been exposed to ionizing radiation.

INSTRUCTIONS: Please complete the form below giving the information requested. List only those organizations where you were exposed to radiation such that personnel monitors (dosimeters) were worn. If you have never worn dosimeters write "none".

INFORMATION: ____

Name

____

Soc. Sec. No. Date of Birth

____

Department

FORMER AFFILIATIONS HAVING RECORDS OF RADIATION EXPOSURE

Name of Company or Institution______________________________________

Department or Division: ______________________________________

Address: ______________________________________

Time of Affiliation: From: ____________________ To: ____________________

I authorize the release of past radiation exposure information to Stanford University.

Signature: ______________________________ Date: ____________________

……

Name of Company or Institution: ______________________________________

Department or Division: ______________________________________

Address: ______________________________________

Time of Affiliation: From: ____________________ To: ____________________

I authorize the release of past radiation exposure information to Stanford University.

Signature: ______________________________ Date: ____________________

……

USER RADIATION SURVEY REPORT

CRA #: ____________ Building/Room #: ____________ Date: ____________ Use Level: A ☐ B ☐ C ☐

Contamination Survey (dpm) - Working surfaces and floor areas are smear tested for removable radioactive contamination in a random fashion. An area of approximately 100 cm sq. is covered by each smear. Results are reported as net (background corrected) disintegrations per minute (dpm) on the sketch below. Printed results are appended where appropriate.

Area Survey (mrem/hr) – Radiation dose rates are measured at work areas and storage areas. The readings are reported as millirems per hour (mrem/h) on the sketch below. Except where noted readings are for beta and/or gamma radiation at 1 foot. Known sources of external radiation are noted on the sketch.

Enter the survey date into the "Sweeps online system "http://radsurvey.stanford.edu, and file the copy in the "Radioisotope Journal".

Area Survey: (Instrument Used)		**Contamination Survey:** (Instrument Used)	
Manufacturer:	____________	Manufacturer:	____________
Model:	____________	Model:	____________
Serial Number:	____________	Serial Number:	____________
Date Calibrated:	____________		
Background:	____________	Surveyor's Name:	____________

Inspection Check

General Lab Deficiencies	N/A	Yes	No	Comments
a. Rad waste logs current?	☐	☐	☐	____________
b. Rad waste containers over filled or >2mR/hr at 1 foot?	☐	☐	☐	____________
c. Rad waste in the general trash baskets?	☐	☐	☐	____________
d. If "A" levels on hand, is the isotope secured?	☐	☐	☐	____________
e. Refrigerator and other storage area logs current?	☐	☐	☐	____________
f. Refrigerators/freezers in corridors unlocked?	☐	☐	☐	____________
g. Food and Drink physically separated from contiguous radioactive work area, or by 1 meter from non-contiguous rad work area?	☐	☐	☐	____________

**** RADIOISOTOPE USE LOG ****

If the package is Crushed, Wet, or Damaged, IMMEDIATELY secure it and call Health Physics at 723-3201.
Otherwise, continue your inspection following the "Safety Instructions."
CRA:
Vial #:

Nuclide: __________ Chem. Form: ____________ Date Rec.: __________ Amount : _______

Purchase Order #: __________ Vendor: ___________ Location of Storage: ______________

ALWAYS remove/obliterate all Radioactive package markings and survey prior to disposal.

Amount On Hand [uCi]	Amount Removed [uCi]	Name	Date

WASTE DISPOSAL		
To Sewer [uCi]	To Health Physics [uCi]	Other Explain [uCi]

Long Term Retention † [uCi]	Transfer To uCi/CRA #

† Nuclides incorporated into samples or in the process of an experiment – Disposal date is indefinite.
This log sheet must be kept in a readily retrievable manner for inspection; and after the shipment is used up this is to be filed in the lab journal as a long term record.

Take balance to zero showing final disposal of the stock vial to ________ on _______ (date).

TRANSFER OF RADIOACTIVE MATERIAL

RADIOACTIVE MATERIAL TRANSFER AND USE LOG

NUCLIDE: __________
CHEM. FORM ______________
DATE REC: ________
AMOUNT TRANSFERRED: __________

FROM CRA: _______
FROM NAME: ________
TO CRA: _________
TO NAME: _________
TRANSFER DATE: ______

Amount On Hand [uCi]	Amount Removed [uCi]	Name	Date

WASTE DISPOSAL		
To Sewer [uCi]	To Health Physics [uCi]	Other Explain [uCi]

Long Term Retention * [uCi]	Transfer To uCi/CRA #

*Nuclides incorporated into samples or in the process of an experiment – Disposal date is indefinite.

This log sheet must be kept in a readily retrievable manner for inspection, and after the shipment is used up this it to be filed in the lab journal as a long term record for 3 years.

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Shortcut Web Address for Health Physics

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