

HANDOUT

for

NEW RADIATION WORKER'S QUIZ

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I. THE PRINCIPLES OF RADIATION SAFETY

Radiation Benefit and Risk

Ionizing radiation is a powerful force of nature which, when channeled wisely, can be used to improve the lives of millions in many ways. When mishandled, radiation can also be a very serious hazard. Because radiation is invisible and its effects may not be immediately recognized, it is easy for a worker to develop too casual an attitude towards it. For this reason, it is in the best interest of all persons who will be working with radiation in any form to educate themselves as fully as possible to the proper work procedures and safety guidelines associated with their particular situation.

ALARA and Radiation Safety

All laboratories using any form of ionizing radiation at UCLA (*e.g.*, radioisotopes, x-ray-generating machines, cyclotrons) are expected to follow the radiation safety principle of ALARA, an acronym for **As Low As Reasonably Achievable**. This principle implies the search for a balance between maximizing benefit and reasonably minimizing risks associated with ionizing radiation. The UCLA Radiation Safety Division (RSD) oversees the implementation of this principle. Regular training of laboratory personnel is one means of reducing unnecessary radiation exposure to one's self and associates. However, training not taken seriously is of little value.

Additional Information

It is hoped that this handout will provide a general outline of the safety concerns to be examined in a research and clinical work environment. No handout can encompass all possible situations one may encounter; however, additional information can be found in the appropriate federal and state regulations Code of Federal Regulations, Title 10, and California Code of Regulations, Title 17, (10 CFR and 17 CCR) or the UCLA Radiation Protection Manual. In addition, the staff of the RSD is available to answer questions of concern.

II. THE NATURE OF RADIATION

The Atom

The atom, classically, consists of a number of negatively-charged electrons orbiting a nucleus of positively-charged protons and chargeless (neutral) neutrons. In a neutral atom, the numbers of electrons and protons are the same. An ion is an atom with charge (*i.e.*, different numbers of electrons and protons).

The atomic mass number, A , is the total number of protons and neutrons in the atom. The atomic number, Z , is the total number of either protons or electrons in the neutral atom. Each element has a specific Z , and each isotope of that element will have a different A . Isotopes of a given element have the exact same chemical properties and may be radioactive (radioisotopes) or stable atoms.

As an example, hydrogen has three isotopes. Each has exactly one proton and one electron, and either zero, one or two neutrons to form simple hydrogen (H-1), a deuteron (H-2) or tritium (H-3), respectively.

Half-Life

Because a radioactive element follows an exponential decay pattern, the percentage of atoms under going decay in any given period of time is constant, with statistical variations only seen with extremely small quantities. The time it takes for some quantity (*e.g.*, number of atoms, number of grams, activity) of a given radioisotope to decay to one-half of its initial value is known as the physical half-life ($T_{1/2}$) for that isotope.

Effective Half-Life

The effective half-life is the time required for a radioactive substance inside the body to diminish to one-half its initial value after entering the body. The effective half-life is the result of the combined action of radioactive decay (radiological half-life) and biological elimination from the body (biological half-life). The biological half-life is the time required for the body to eliminate one-half of any substance by metabolic processes of elimination. The effective half-life is given by the following equations.

$$\frac{1}{T_{1/2eff}} = \frac{1}{T_{1/2rad}} + \frac{1}{T_{1/2biol}} \quad \text{or} \quad T_{1/2eff} = \frac{(T_{1/2rad})(T_{1/2biol})}{(T_{1/2rad})+(T_{1/2biol})}$$

Ionizing Radiation

Radiation is classified as either ionizing or nonionizing. Nonionizing forms of radiation include electromagnetic (wave) radiation of relatively low energy such as radio waves, television signals, microwaves as well as infra-red, visible, and ultra-violet light. Ionizing radiation is the radiation that can create ions through interactions with matter on the atomic level. It is the rate and extent of the formation of ions in tissue that determines the biological effect, along with the sensitivity of tissue. For this reason, it is ionizing radiation that is of primary concern to the health community and the UCLA RSD. Ionizing radiation includes particle radiation (*e.g.*, alpha and beta particles, protons and neutrons) and high-energy electromagnetic radiation (x-rays and gamma rays). It should be kept in mind that modern physics, in the quantum theory on the dual nature of matter, treats particles as possessing some wave properties (*e.g.*, interactions following probability patterns) and waves as possessing some properties associated with particles (*e.g.*, energy deposited in discrete "packets" or quanta).

Particle Radiation

Particle radiation is commonly found in many types of radioisotope work. This radiation includes the charged particles such as protons, beta particles [negatively-charged electrons, or negatrons (Ξ^-), and positively-charged electrons, or positrons (Ξ^+)] and alpha particles which are Helium-4 atoms stripped of electrons (He^{2+} or ∇^{2+}). Neutrons, which are chargeless, are particle radiation that produce ions through atomic collisions.

Electromagnetic Radiation

All electromagnetic waves travel at the speed of light. These waves, known as photons, can be classified by their energies, their frequencies or their wavelengths. The energy of each of these waves is proportional to its frequency and inversely proportional to its wavelength. In order of increasing energies, electromagnetic waves include radio waves, television signals, infrared light, visible light, ultraviolet light, microwaves, and x-rays/gamma rays. Gamma rays originate in the nucleus of atoms during atomic changes while x-rays originate in the electron shells surrounding the nucleus of atoms. Both are referred to as photons and only their origins distinguish them when they have equal energies. Interactions of photons and body tissue cause ions (charged particles) to form in the tissue of the body exposed to them. These ions are related to the radiation dose received by the tissue and, hence, can be of concern to the research and clinical communities.

X-ray Production

X-rays are produced when electrons, accumulating at the surface of a cathode due to the effects of an electrical current (the mA, or milli-Amperage of the current), are accelerated by an applied electrical potential (the kVp, or peak kiloVoltage of the treatment) until striking an anode target. In this manner, electrical energy is converted into Electro-Magnetic (EM) energy. The x-ray radiation will be emitted from the target in all directions but is generally shielded and stopped in all but the direction desired for the procedure involved. The amount of radiation a patient receives depends on the current producing the electrons (mA), the accelerating voltage (kVp) and the seconds the beam is

on (s). The product of the current and the time is often used and is known as the mAs of the treatment. The three values chosen for the components of the treatment are known collectively as the technique.

Shielding: The Half-Value Layer

A shielding factor table or Half-Value Layer (HVL) table gives the thickness of a standard shielding material, usually lead, required to attenuate (lessen or reduce) a photon beam (x-rays and gamma rays) of a given energy or frequency by a particular percentage (*e.g.*, 50% for an HVL).

As an example, the 0.5 shielding factor (or HVL) for I-131 (a radioisotope of iodine with mean photon energy of 364 KeV) is 0.3 cm of lead. If 1.5 cm of lead (5 HVLs) are placed in front of the iodine source, we would expect the fraction of I-131 photons penetrating the lead to be reduced to $(\frac{1}{2})^5$, or 1 in 32 photons (~3%) will make it through 1.5 cm of lead.

III. TABLES AND LIMITS

Annual Dose Limits

Occupational dose equivalent limits for adult radiation workers are given in Title 10 of the Federal Code of Regulations (10 CFR) Part 20, Title 17 of the California Code of Regulations (17 CCR), and are described in the UCLA Radiation Protection Manual. These limits are summarized in the following table.

Total effective dose-equivalent *(TEDE)	5 rem/y
Eye dose-equivalent*	15 rem/y
Shallow dose-equivalent*to the skin or to any extremity	50 rem/y

*For definition, see Section V

The annual occupational dose limits for minors (workers under 18 years old) are 10% of the annual dose limits for adult radiation workers. The annual TEDE limit to the general public is 100 mrem.

The dose equivalent to an embryo/fetus during the entire pregnancy (gestation period) due to occupational exposure of a declared pregnant woman is limited to 500 mrem. An effort shall be made to avoid substantial variation above a uniform monthly exposure rate to a declared pregnant worker so as to satisfy the above limit.

Origin of Dose Limits

Annual dose limits are rooted in the biological research outlined in the reports on the Biological Effects of Ionizing Radiation (BEIR Reports) and the International Radiation Protection Association (IRPA). The International Commission on Radiation Protection (ICRP) publishes recommendations based on these reports and the National Commission on Radiation Protection (NCRP) issues recommendations influenced by the BEIR, IRPA, and ICRP reports. Congress enacts laws based largely on the NCRP recommendations and incorporates these laws into the Code of Federal Regulations (10 CFR). Likewise, the State of California incorporates most of these guidelines into the California Code of Regulations (17 CCR). It should be kept in mind that the biological effects outlined in the BEIR reports are only apparent when examining large populations (millions) and the chance of a radiation worker who receives the full annual dose limit (5 rem) experiencing adverse biological effects due to this exposure is extremely small. Needless to say, the principle of ALARA is still in effect and any unnecessary exposure is to be avoided.

IV. PERSONNEL MONITORING

Personnel radiation monitoring at UCLA falls under the categories of External Radiation Monitoring and Internal Radiation Monitoring. External Radiation Monitoring uses personnel dosimeters of two varieties: optically stimulated luminescence dosimeter (OSL) and thermoluminescence dosimeter (TLD) chips that produce measurements to enable the determination of time-integrated radiation dose. OSL dosimeters are worn on the trunk of the body within plastic holders called a badge. TLD dosimeters are worn on the finger in a plastic holder called a ring. Internal Radiation Monitoring is also referred to as the Bioassay Program and applies to the various means for determining the type and amount of radioisotope in the body of a radiation worker.

External Radiation Monitoring

Under current regulations on radiation safety, personnel dosimeters are required for personnel working in areas where they are likely to receive 10% of the regulatory dose limits. These dosimeters should be worn only by the worker to whom they were assigned, as the exposure information becomes a part of the worker's permanent exposure history record. Personnel dosimeters should be stored in dry, low-background areas protected from temperature extremes. They are for occupational exposure only and should never be used when the worker undergoes medical and dental x-ray procedures. In general, dosimetry badges should not be taken off the UCLA campus, unless specifically authorized by the RSD.

These dosimeters are designed to detect gamma and x-ray radiation and beta particles energetic enough to penetrate the dosimeters' external holder. Dosimetry badges are not required for personnel who work in labs that only use H-3, C-14 or S-35 because the low-energy beta emissions from these sources are of insufficient energy to penetrate the dosimetry badge holder and, therefore, will not be detected with sufficient efficiency. An additional plastic chip is used in the badges of personnel working with neutron sources.

Optically Stimulated Luminescence (OSL) Dosimeters

OSL measures radiation through a thin layer of aluminum oxide (Al_2O_3). During analysis, the aluminum oxide is stimulated with selected frequencies of laser light, which cause it to become luminescent in proportion to the amount of radiation exposure. The luminescence measured during analysis is applied to a dose algorithm that relies on the response ratios between different filter positions within the dosimeter to discriminate between beta and photon (x and gamma) radiation fields to determine exposure results. The OSL dosimeters are either exchanged monthly or quarterly, depending on the department.

Thermoluminescent Dosimeters (TLDs)

TLDs are used in rings worn on the finger. When the "chip" of thermoluminescence material is exposed to radiation, the incident energy is stored within the crystal lattice of the material. The chip can then be placed in an enclosed detector system where it is heated until the stored energy is released as light. The amount of released light is recorded and related back to the initial accumulated radiation. The extremity TLDs are exchanged either monthly or quarterly, depending on the department.

Minimum Detectable Value

The great majority of badge users receive exposures of "M" in any month or quarter. "M" signifies a dose below the minimum detectable value. The minimum detectable value is 1 mrem for x-ray and gamma ray, 10 mrem for energetic beta particles and 20 mrem for fast and moderate energy neutrons.

Fines for Lost Whole Body Dosimeters and Finger Ring Dosimeters

The individual is responsible for loss or damage to the dosimeter. Dosimeters are turned in on either a monthly or a quarterly basis, depending on the department. A due date is set for each department to gather all dosimeters and return them to the RSD (*e.g.*, the seventh working day of the month following the wear period). The current fee for a late or "lost" whole body dosimeter is \$11 while the fee for a late or "lost" finger ring dosimeter is \$5. Whole body dosimeters and finger ring dosimeters are considered to be late or "lost" if they are not returned to the RSD on the designated due date. Individuals who "lose" a whole body dosimeter must complete a Notice of Incomplete Dosimetry History form for each dosimeter that is "lost" so a complete exposure history can be maintained. Late or "Lost" dosimeters that are recovered after the due date should be returned to the RSD, even though all fines and charges will still apply.

Double Badging

The UCLA RSD currently conducts a double-badging program for personnel working with angiography and cardiac catheterization procedures where high exposures are sometimes encountered. Personnel must wear protective clothing that includes lead apron, thyroid shield for the neck, and protective leaded glasses for the eyes. A dosimeter is worn outside the protective clothing to record the exposure levels to the radiation worker. A second badge is worn under the protective clothing and gives a more accurate representation of the exposure to the vital organs and regions of the radiation worker.

Internal Radiation Monitoring: The Bioassay Program

The UCLA Bioassay Program includes several different procedures for detecting internal contamination from specific or general groups of radioisotopes. Thyroid bioassays are useful for quantifying the amounts of radioactive iodine present in the thyroid, an organ that uptakes iodine readily when functioning well. Total Body Counting allows the quantification of most gamma contamination. Urinalysis is the method for determining the extent of beta contamination. The types of radioactive sources handled by a radiation worker will determine the Bioassay method best suited for him/her.

Thyroid Bioassay

This procedure is performed on workers who handle or use significant quantities of radioactive iodine. It is a relatively simple assay. A sodium iodide, thallium-doped crystal [NaI(Tl)] mounted in a probe, with appropriate electronics attached, is placed at the area of the throat near the thyroid. The probe will detect, externally, the photons given off by radioiodine if it is present in the thyroid.

A. How is the assay done:

1. For I-125, Health Physics personnel from the RSD take the NaI(Tl) probe and portable scaler directly to the laboratories. They call ahead to make an appointment so that as many lab personnel as possible are there. The RSD technician takes a count on the worker's thyroid noting the results on the notice form. Eligible personnel not present at that time must go to the RSD for their thyroid bioassays. A preset time is set aside for this.
2. For I-131, the assay is performed at the RSD. Prearranging the time assures that there will be a qualified person present to perform the assay and sufficient time to carry out the necessary preoperational checks of the instrument.

B. Notification:

1. For I-125, the notices are generated quarterly based on the amount of radioactive material purchased and possessed during the quarter. ***Unlike the urinalysis notice, RSD does not request that I-125 notices be returned.*** It is used to let the department know ahead of time that RSD will be scheduling an appointment to visit the department's area to perform thyroid bioassays on the appropriate personnel. The personnel list included in the thyroid bioassay notice should be reviewed for accuracy and completeness. A technician from RSD should be notified of any changes that should be made in the listing at the time of the appointment. The technician will then call the lab to schedule an appointment after the notices have been sent out.
2. For I-131, notice for thyroid bioassay is distributed with the radioactive shipment. It is the worker's/lab supervisor's/RU's responsibility to arrange the times for the thyroid bioassay.

Total Body Counting

Total Body Counting (TBC) is required for those authorizations which handle significant quantities of gamma-emitting radioisotopes.

A. When is it done:

Notifications are sent out on a quarterly basis to authorizations which handle significant quantities of gamma-emitting radioisotopes in uncontained form.

There are two important dates: one is the date to return the notice itself to the RSD properly filled out and signed, along with making appointments for personnel to be assayed; the second is the date by which all the assays must be completed.

B. How is it done:

The total body counter is a large iron room, heavily shielded with materials including lead. The shielding is used to minimize background radiation as much as possible. Inside this room is an array of four large NaI(Tl) detectors. The person to be assayed simply rests on a cot with the detectors appropriately positioned above and below the cot. The RSD technician then exits the room closing its door. The detectors accumulate the counts from any emissions for 10 minutes. The attached electronics system, the Multichannel Analyzer, displays the emissions collected in the form of an energy spectrum. This spectrum allows the calculation of how much and which radioisotope is present.

The overall TBC takes about 20 minutes. Thus, the appointments are required to be made early to accommodate all personnel on the schedule. In addition, it will help the personnel working on an authorization prevent delay and penalty for noncompliance and there will be no undesirable gap on the personnel's exposure record.

Urinalysis

Notices are sent to those handling projects that have received or worked with significant amounts of beta emitters.

A. When is it done:

The notices are sent out with the qualifying radioactive shipment. ***The notice indicates two dates for action.*** The ***first date*** is for filling out the notice, marking whether or not individuals have handled/worked with the amounts indicated. The RU or designee must sign the notice and then return it to the RSD. The ***next date*** is the deadline for submitting the samples.

B. How is it done:

A small urine sample from qualifying laboratory personnel is submitted to an RSD technician. A 1-ml aliquot is counted for radioisotopes listed on "Report of Assay of Urine for Radioactive Material" form.

Penalty

Compliance is a requirement in the Bioassay program. There are penalties for "no-show" responses. Noncompliance may affect authorization for using radioisotopes.

V. UNITS AND PREFIXES

Definitions

Absorbed Dose:

Absorbed dose is the energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the Gray (Gy).

Becquerel:

Becquerel is a measure of activity. It is equal to one disintegration* per second.

$$\begin{aligned} 3.7 \times 10^{10} \text{ Bq} &= 1 \text{ Ci} \\ 1 \text{ Bq} &= 2.7 \times 10^{-11} \text{ Ci (Curies)} \\ &= 2.7 \times 10^{-8} \text{ mCi (millicuries)} \\ &= 2.7 \times 10^{-5} \text{ } \mu\text{Ci (microcuries)} \end{aligned}$$

*Actually, one radiological event per second. The most common event is simple disintegration or decay.

Curie:

Curie is a measure of activity. It is equal to 3.7×10^{10} disintegrations per second. Historically defined as the activity from one gram of radium.

$$\begin{aligned} 1 \text{ Ci} &= 3.7 \times 10^{10} \text{ Bq} = 3.7 \times 10^{10} \text{ disintegrations/second} \\ 2.7 \times 10^{11} \text{ Ci} &= 1 \text{ Bq} = 1 \text{ disintegration/second} \end{aligned}$$

Dose Equivalent:

Dose equivalent is a measure of the biological effect or damage caused to tissue by a given radiation dose. It is equal to the product of the absorbed dose in tissue, the quality factor, and all other necessary modifying factors (generally set equal to unity), at the location of interest. The units of dose equivalent are the rem and Sievert (Sv).

Gray:

Gray is the SI unit for absorbed dose. It is equal to 1 joule/kilogram.

$$1 \text{ Gray} = 100 \text{ rad} \qquad 0.01 \text{ Gray} = 1 \text{ rad}$$

Quality Factor:

Quality Factor (QF) is a weighting factor that relates the quality of the energy deposition in tissue (absorbed dose) to the biological effect on the tissue (dose equivalent). The QF for gamma rays, x-rays, and beta particles is 1 rem/rad. The QF for neutrons and heavy charged particles is energy-dependent with values usually ranging between 5 and 20 rem/rad.

Rad:

Rad is a measure of absorbed dose. It is equal to 100 ergs/gram or 0.01 joule/kilogram. The rad is slowly being replaced by the Gray. It has units of energy per unit mass.

$$1 \text{ rad} = 0.01 \text{ Gray}$$

$$100 \text{ rad} = 1 \text{ Gray}$$

Rem:

Rem is a measure of the dose equivalent. The dose equivalent in rem is equal to the product of the absorbed dose in tissue in rad and the QF for the particular type of radiation delivering the dose. Occasionally, additional modifying factors are incorporated into this equation. The rem is slowly being replaced by the Sievert.

$$\text{dose equivalent (rem)} = \text{absorbed dose (rad)} \times \text{quality factor}$$

NOTE: Absorbed dose is in rad (or Gray) while dose equivalent is in rem (or Sievert).

Roentgen:

Roentgen is a measure of radiation exposure. It is defined as the amount of radiation exposure necessary to produce an ionization or charge of 2.58×10^{-4} Coulomb in one kilogram of air.

NOTE: It is defined only in air and for photons.

Sievert:

Sievert is the SI unit for the dose equivalent.

$$1 \text{ Sievert (Sv)} = 100 \text{ rem}$$

$$0.01 \text{ Sievert} = 1 \text{ rem}$$

Committed Dose Equivalent ($H_{T, 50}$):

Committed dose equivalent means the dose-equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

Committed Effective Equivalent ($H_{E, 50}$):

Committed effective equivalent is the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues [$H_{E, 50} = \sum W_T H_{T, 50}$].

Declared Pregnant Woman:

Declared pregnant woman means a woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception.

Deep-Dose Equivalent [H_d]:

Deep-dose equivalent which applies to external whole-body exposure, is the dose equivalent at a tissue depth of 1 cm (1000 mg/cm^2).

Effective Dose-Equivalent [H_E]:

Effective dose-equivalent is the sum of the products of the dose-equivalent to the organ or tissue [H_T] and the weighting factors (W_T) applicable to each of the body organs or tissues that are irradiated Sievert [$H_E = \sum W_T H_T$].

Extremity:

Extremity means hand, elbow, arm below the elbow, foot, knee, or leg below the knee.

Eye Dose Equivalent:

Eye dose equivalent applies to the external exposures of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 centimeter (300 mg/cm²).

Shallow Dose Equivalent [Hs]:

Shallow dose equivalent, which applies to the external exposure of the skin or an extremity, is taken as the dose equivalent at a tissue depth of 0.007 centimeter (7mg/cm²) averaged over an area of 1 square centimeter.

Total Effective Dose Equivalent (TEDE):

Total effective dose equivalent means the sum of the deep dose-equivalent (for external exposures) and the committed effective dose-equivalent (for internal exposures).

Metric Prefixes

METRIC PREFIXES			
Prefix	Meaning	Abbrev.	Example
Giga-	10 ⁹	G	GeV
Mega-	10 ⁶	M	MeV
kilo-	10 ³	k	keV
deci-	10 ⁻¹	d	dl
centi-	10 ⁻²	c	cm
milli-	10 ⁻³	m	mCi
micro-	10 ⁻⁶	μ	μXt
nano-	10 ⁻⁹	n	nCi
pico-	10 ⁻¹²	p	pCi

VI. COMMON SOURCE INFORMATION

Data Tables

BETA SOURCES				
Radioisotope	Max Beta Energy	Maximum Range^a		Half-Life
		Air	Water	
H-3 (Tritium)	18 keV	4.2 mm	5.5 μ m	12.28 yrs
C-14	156 keV	21.8 cm	0.28 mm	5730 yrs
S-35	167 keV	24.4 cm	0.32 mm	87.4 days
P-32	1.71 MeV	6 m	7 mm	14.3 days
Sr-90/Y-90	2.28 MeV	8 m	10 mm	28.6 yrs/64.1 hrs

^aRadiological Health Handbook Villforth, J.C. Shultz, G.R. (1970)

GAMMA SOURCES				
Radioisotope	Photon Energy	Abundance^b	Half-Value Layer^c	Half-Life^b
Co-60	1.33 MeV	100%	12 mm	5.27 yrs
	1.17 MeV	100%		
Cr-51	320 keV	9.8%	2 mm	27.7 days
	5 keV	22%		
Cs-137	662 keV	85%	6.5 mm	30 yrs
I-125	35 keV	6.5%	0.02 mm	60.14 days
	31 keV	25.4%		
	27 keV	112%		
I-131	723 keV	2%	3 mm	8.04 days
	637 keV	7%		
	364 keV	81%		
	284 keV	6%		
	80 keV	6%		
Tc-99m	140.5 keV	89%	0.2 mm	6.02 hrs
	21 keV	1%		
	18 keV	6%		

^bRadioactive Decay Data Tables Kocher, P.C. (1981)

^cThickness of Lead

Sealed Radioactive Sources

Sealed beta, gamma-emitting radioisotopes that are <100 ΦCi and alpha- emitting isotopes that are <10 ΦCi in activity are classified as "Small Sealed Sources". These sources may be used in calibrations of certain radiation-detecting devices.

Sealed beta, gamma radioisotopes that are >100 ΦCi and alpha >10 ΦCi in activity are classified as "Sealed Sources". Some of these sources are used in gas chromatographs (Ni-63) and irradiators (Co-60, Cs-137). Sealed sources are swiped every six months by the RSD to assure that the source containers are not leaking.

When purchasing any sealed source, the vendor should be informed of the authorization number assigned by the RSD. All receipts and disposal of radioisotopes have to pass through the RSD. **NO DIRECT RECEIPTS** of isotopes are allowed without prior approval of the RSD.

When using devices that contain sealed sources, ensure that a clear "Radioactive Materials" sign is posted and the emergency numbers are in a visible place. Also, make sure that personnel know whom to contact in case of an interlock failure or some other unusual incident. For irradiators, maintenance at regular intervals should be done by qualified personnel only. When sharing the use between several people, each user should document the use in a log book. Users of large sealed sources and irradiators should receive specific safety instructions on the proper use of the source irradiator from the RU/PI.

Long tweezers, tongs, or other source handling tools should be used as needed to handle sealed sources containing mCi quantities. Maintaining a distance of a few inches with tweezers or tongs can significantly lower exposure to extremities due to the inverse square law. In some cases, the RSD may issue whole-body and/or extremity dosimeter to monitor workers.

The RU should post a copy of the authorization in the lab where the sealed sources are kept. Personnel in the lab should maintain an inventory of all sources present and perform periodic physical inventory to ensure validity of the sealed source inventory. In some cases, the RSD may require the purchase of a radiation-detecting device to be used within the lab.

VII. INSTRUMENTATION

Many different radioisotopes are used by the UCLA radiation community and each one has its own characteristic radiations and associated energies. A survey instrument measures radiation levels and/or contamination levels, therefore, a survey instrument should be chosen such that it matches the specific needs and demands of the laboratory involved. The perfect instrument for the lab next door may be of little or no use to another lab.

Portable Survey Instruments

The portable survey meter widely used at UCLA is the Geiger-Mueller (GM) Counter. GM probes come in many shapes and sizes. They are useful for detecting beta, radiation from C-14, S-35, P-33, P-32, Ca-45, Cl-36 or isotopes with similar radiation emission schemes. Some portable GM instruments come with detachable flat "pancake" probes or cylindrical end-window probes while others come with nondetachable internal probes. GM probes can detect gamma-ray and x-ray radiation but less efficiently than beta radiation.

Another commonly used portable survey meter is the NaI Crystal scintillation meter. Due to extremely low regulatory contamination limits and the decay scheme (low energy) of I-125, the GM counter is not sensitive enough to perform adequate surveys. A thin crystal NaI scintillation probe should be used to survey for I-125.

Contact the RSD before purchasing a portable survey meter. The RSD personnel are familiar with many vendors, instrument types, and radiation safety requirement and can help choose the most appropriate and inexpensive survey meter for a department's needs.

Liquid Scintillation Counter

Because a large percentage of low-energy beta particles are not capable of penetrating the window of a GM probe and being detected, a more efficient method must be used. A beta source placed in a scintillation fluid environment, or "cocktail", will produce secondary flashes of light, or scintillations, which can be detected efficiently by a Liquid Scintillation Counter (LSC). If you work with H-3, C-14, S-35, or isotopes with similar beta energies, an LSC is very efficient in detecting these isotopes.

VIII. TIME, DISTANCE, AND SHIELDING

A radiation worker's exposure to radiation can be reduced by remembering "TDS", the positive effects of Time, Distance, and Shielding. The development of good laboratory practice should include these three principles.

Time

The dose to a radiation worker from a constant source of radiation is directly proportional to the time of exposure. Reduce contact time and the radiation exposure is reduced, too. Careful planning of an experiment prior to actual handling of an isotope or other radiation source can greatly reduce worker's exposure times.

Distance

Exposure decreases with the inverse of the square of the distance from an isotropic point source. Doubling the distance between the source and the radiation worker will reduce the exposure level to one quarter of its initial value. Again, careful planning of an experiment will exploit this fact. Good habits for distance control include stepping away from a secured source when involved in discussions, storing isotope stocks and waste away from main work areas when possible, and using remote handling tools and, thus, avoid picking up sources directly with one's hands unless safety concerns and/or common sense dictate such actions.

Shielding

Proper shielding can significantly lower one's radiation exposure. Placement of shielding is important. In most circumstances, the closer the shielding to the source the better, although the attenuation properties of the shielding will not change, less total mass of shielding material will be required because of geometry. Selecting the proper shielding material is also important and will depend on the type of radiation involved. (Chapter VIII, Section H, Table VIII-5 of the Radiation Protection Manual describes some typical shielding materials for various types of radiation.)

Photon Shielding (Gammas and X-Rays)

A shielding factor table (*e.g.*, table for Gamma Sources, Section VI of this handout) gives the thickness of a shielding material, usually lead, required to attenuate a photon beam from a given isotope by a given percentage (*i.e.*, [HVL (Half Value Layer) table attenuates by 50 percent]). Lead bricks are good for high energy photon emitters (for example, Co-60, Cs-137), while lead foil is adequate to shield I-125.

Charged Particle Shielding (e.g., Beta and Alpha Sources):

The Problem of Bremsstrahlung

When a charged particle is deflected and decelerated by the nucleus of an atom, the loss in energy is balanced by the appearance of electromagnetic radiation called bremsstrahlung, German for "braking radiation". The energy of the photons can range from nearly zero for slight-charged particle deflections, to a maximum value equal to the full energy of the incident particle for extreme deflections. This will mean that the higher the energy of the incoming charged particle, the greater the average bremsstrahlung photon energies.

The percentage of bremsstrahlung interactions increases with the atomic number of the absorber or shielding material. A shielding material with a low atomic number or low effective atomic number (wood, plexiglass, plastics) will produce less bremsstrahlung than one with a high atomic number (lead). Plexiglass is the most commonly used shielding material. The fraction of the beta energy converted into photons is given by $F_{\beta} = 3.5 \times 10^{-4} Z E_m$:

where Z = atomic number of the absorber
 E_m = maximum energy of beta particle, MeV

The amount of bremsstrahlung production is inversely proportional to the mass of the incident-charged particle. Therefore, protons, alpha particles and heavier-charged particles will produce little bremsstrahlung relative to beta particles with similar energies.

One can see that bremsstrahlung production will be highest for high energy beta particles (*e.g.*, P-32: Max Beta Energy of 1.7 MeV) interacting with shielding materials of high atomic number (*e.g.*, Pb: $Z = 82$).

A question that may arise is why UCLA's P-32 shipments occasionally come in lead containers? Actually, P-32 is often shipped in plastic-lined lead containers. The plastic stops the majority of the beta particles emitted by the source. The small number of bremsstrahlung x-rays are then attenuated by the lead itself. The primary (first contact) shielding material is the plastic.

IX. LAB SURVEYS

Frequency

As described in Chapter V, Section F, and Chapter X, Section D, of the Radiation Protection Manual, routine radiation surveys of laboratory areas must be performed by the RU or a qualified designee, and the surveys must be documented for audit by RSD personnel. It should be noted that the usual frequency given is once per month. The inspection frequency for a particular laboratory may be changed by the RSD as necessary.

Records

Survey records must be developed and maintained by the RU. The information should include the following:

1. Authorization number and exact location – by building and room
2. Signature of surveyor and date of survey
3. Sketch of laboratory showing locations surveyed
4. Identification (with serial numbers) of survey instrument(s) used
5. Radioactivity counting results of swipes, *i.e.*, both gross count, background count, and standard sample count
6. Results of survey instrument measurements including background
7. Actions taken to correct off-standard conditions. This may include follow-up survey results

Common errors in recordkeeping are: failure to include background survey instrument count-rates, background swipe results (from a clean swipe run with other swipe samples), or results from rechecks/reswipes of corrected conditions (*e.g.*, following clean up of minor hot-spots).

X. INVENTORY

Inventory records of radioactive materials for each laboratory room under an authorization need to be maintained and kept current. A well-planned inventory record should follow an isotope shipment from its receipt to its depletion. A running total of the amount of isotope present is very useful, with quantities being subtracted from the total as they are moved to other rooms, used in experiments or disposed as waste.

XI. RADIATION SAFETY DIVISION AUDITS

When a RSD representative inspects a laboratory or work area, he/she checks more than just required records and surveys lab benches. Among other items, the lab personnel should be aware of the following:

1. *Notices/Signs* – When the RSD grants an Isotope Authorization, a copy of the Authorization or Renewal Notice is sent to the RU. A copy of this notice must be posted prominently in each lab room under the authorization. In addition, appropriate caution signs and labels bearing the standard magenta three-bladed caution symbol or propeller on a yellow background, along with appropriate messages must be posted, as specified in 10 CFR 20.1901 and described in Section C, Chapter X of the Radiation Protection Manual. Emergency Procedures should be posted near the telephone.

2. *Food and Drink* – Food and drink are not to be stored or consumed in any area where radioactive material is stored or used except for emergency kits. Beverage containers or evidence of food can result in findings by the RSD and citations by the State regulatory agencies.
3. *Instrument Calibration* – Every survey instrument in a lab needs to be calibrated by qualified personnel (*i.e.*, RSD) annually. A survey instrument that is not calibrated must be labeled to ensure that it will not be used.
4. *Waste Segregation and Management* – see Section XIII of this handout.
5. *Fume Hood and Iodination Hood Operation* – see Section XII of this handout.
6. *Decommissioning of Laboratory Facilities* – Chapter V, Section I of the Radiation Protection Manual describes the procedures for terminating work with radioisotopes in a particular authorized location.
7. *Proper Removal of Equipment* – Any equipment used or merely kept in a laboratory or work area where unsealed radiation sources have been used must be shown to be essentially free of contamination before removal from the work area.

XII. FUME HOODS AND IODINATION CABINETS

Title 17 of the California Code of Regulations (17 CCR) and Title 10 of the Federal Code of Regulations (10 CFR) Part 20 set forth series of limits for controlling exposure to both radiation workers in controlled areas and the general public in uncontrolled areas. These limits are based on Derived Air Concentrations (DACs) and Annual Limits on Intake (ALIs) where a hypothetical reference man is used to determine the applicable concentration limits.

Certain laboratory procedures can lead to the release of radioactive materials into the air. Expected levels of airborne concentrations of an isotope or mixture of isotopes (expressed in $\Phi\text{Ci/ml}$) must be evaluated carefully. Fume hoods and related devices are designed to reduce the exposure due to airborne contaminants and will be stipulated in many laboratory authorizations.

Many types of laboratory hoods exist, including sterile hoods and laminar-flow biosafety hoods. For most laboratory procedures involving volatile radioisotopes or more than minimal quantities of radioisotopes, only a qualified, certified chemical fume hood is appropriate. In addition, for iodination with I-125 or I-131, an iodination cabinet or minihood, operating within the larger fume hood is required.

Fume Hoods

Chemical fume hoods are checked at least annually by the Environment, Health and Safety Office (EH&S). A qualified hood will include a strip of tape along its side delineating the level at which the hood sash or window should be maintained to ensure adequate air flow.

Fume hoods rely on sufficient air flow to minimize worker exposure to contaminants such as radioisotopes. Because excessive clutter inhibits air flow and reduces overall efficiency, fume hoods are not meant to be used as storage areas and should be kept as clear as reasonably possible.

Minihoods

Iodination cabinets or minihoods are designed to increase the control of hood ventilation and also minimize the potential release of radioactive iodine into the environment. They must be used inside the confines of a functioning fume hood that has been accepted by EH&S, with the minihood in place.

Each minihood includes a pump that draws air through a roughing filter to remove coarse particulates, and an activated charcoal filter to remove airborne iodine. The filtered air is then removed from the hood through the exhaust duct system. These filters must be changed and disposed of as dry radioactive waste in each of the following instances:

1. When the exposure rate from the filter is 0.6 mR/hr or above, at the nearest accessible external point.
2. When the charcoal filter shows a loading from dust or debris which could slow the flow of air.
3. Since it is difficult to assess the continued efficiency of the charcoal filter under the various use conditions experienced, it should be replaced at least annually, before it no longer functions properly.

III. WASTE HANDLING AND DISPOSAL

Dry Radioactive Waste

Segregation Requirements

All dry radioactive waste must be segregated into one of the following categories prior to acceptance by the RSD.

1. Alpha emitters
2. Sealed sources, including check sources
3. Sr-90, I-129
4. Stored for decay waste
 - a. $T_{1/2}$ # 15 days (P-32, Ga-67, Tc-99m, In-111, Tl-201, etc.)*
 - b. 15 days < $T_{1/2}$ # 61 days (Cr-51, I-125, etc.)*
 - c. 61 days < $T_{1/2}$ # 90 days (S-35, etc.)*
5. $T_{1/2}$ > 90 days (H-3, C-14, Na-22, Ca-45, Co-57, etc.)
6. Lead

NOTE: *Remove/Deface all Radiation Labels. Package all stock vials separately.

Radioactive waste mixed with biohazardous, infectious, or hazardous waste cannot be accepted without prior permission by the RSD.

Options:

1. Biohazardous or infectious waste can be sterilized. After sterilization, delete biohazardous or infectious warning signs. Place sterilized bag inside radioactive waste collection. Cold sterilization techniques which use ethylene oxide or formaldehyde are not authorized.
2. Store for decay (minimum of seven to ten half-lives) and dispose as biohazardous, infectious, or hazardous. Radiation reading should not be distinguishable from low background radiation levels with the appropriate survey instruments.

Handling, Packaging, and Transportation

1. All segregation waste must be accumulated in strong transparent plastic bags, within a rigid support container.
2. Double-bagging is recommended whenever containment integrity is in question.
3. If accumulating high energy beta or beta/gamma emitters, the support container should be constructed of a material that will provide shielding.
4. High energy beta and beta/gamma emitters require shielding at all times.
5. Any objects considered "sharps" (needles, broken glass, etc.) must be packaged in an appropriate rigid plastic container.
6. The "sharps" container must be properly sealed and labeled separately.
7. Attach a completed "Dry Radioactive Waste" tag with the following:
 - Activity in millicurie or microcuries for each radioisotope listed (**Do not use "Less Than"**).
 - Lead pigs (containers) do not require activity unless contaminated.
 - RU, department, and date.
8. If a transportation cart is used, it must have side rails, or some means of securing the waste.
9. Use freight elevators; not patient or public elevators.
10. If elevator use is required, try to use one that is not already occupied.
11. Properly packaged waste will contain all contamination. Therefore, use of gloves during transport is not recommended. However, gloves should be taken along for use in the unlikely event of a spill.
12. All animal carcasses and excreta must be securely packaged in opaque plastic bags.
13. All animal carcasses and excreta may be delivered to the CHS RSD during normal working hours.
14. Accurate accounting of radioisotope, radioactivity, and date radioactivity was calculated is very important for all animal carcasses and excreta. Therefore, include these data on a completed "Dry Radioactive Waste" tag.

Disposal Practices

Short-lived contaminated laboratory trash is placed in cardboard boxes and stored for a minimum of seven to ten half-lives. The waste is then surveyed to ensure that it is indistinguishable from background and disposed as ordinary trash. Needles are biohazardous by definition and will be sent for incineration. Long-lived waste is compacted into Department of Transportation-approved 55-gallon drums. The dry radioactive waste is reduced to approximately 30% of its original volume. Uncontaminated lead shielding is recycled.

Liquid Radioactive Waste

Segregation Requirements

All liquid radioactive waste must be readily soluble or dispersible in water. Radioactive liquid waste mixed with biohazardous, infectious, or hazardous waste cannot be accepted without prior permission by the RSD.

Handling, Packaging, and Transportation

1. Liquid wastes must be accumulated in strong leak-proof containers.
 - Polyethylene is acceptable; glass containers are no longer acceptable.
2. Liquid waste containers will not be accepted if they contain solids or laboratory trash such as pipettes and vials.
3. Container volume is limited to 10 liters.
 - Fill volume should not exceed 75% of the total volume
4. Containers must be capped when not in use.
5. Secondary container must be used at all times.
6. Secondary container volume must exceed liquid waste volume.
7. Attach a completed "Liquid Radioactive Waste" tag with the following:
 - Activity (millicuries or microcuries) for each radioisotope listed (take a sample and count in a liquid scintillation counter to calculate activity or keep running total of activity as liquid is added)
 - Chemicals present
 - RU, department, and date
8. If a transportation cart is used, it must have side rails, or some means of securing the waste.
9. Please use freight elevators; not patient or public elevators.
10. If elevator use is required, please try to use one that is not already occupied.
11. Properly packaged waste will contain all contamination. Therefore, use of gloves during transport is not recommended. However, gloves should be taken along for use in the unlikely event of a spill.
12. Shielding must be provided for storage and transportation of high energy beta (P-32, Sr-90), and beta/gamma emitters (Fe-59, I-131, Na-22).

Disposal Practices

Liquids which are readily soluble or dispersible in water may be disposed of by release into the sanitary sewer system. This must be done by qualified RSD personnel, at a designed site, so that the conditions and provisions outlined in the UCLA Radioactive Material License and California Code of Regulations, Title 17, are met. This means that the primary radioactive solution should be poured into the liquid waste container. If the solution is highly concentrated, the first rinse should also be placed in the waste container. All subsequent rinsings/washings may be released into the sink drain.

Liquid Scintillation Vial

Segregation Requirements

All liquid scintillation vials must be segregated into the following categories prior to acceptance by the RSD.

1. Radioisotope
 - Exempt fluids (H-3 and/or C-14 not exceeding 0.05 Φ Ci/gm.)
 - Regulated radioisotopes (P-32, I-125, S-35, etc.)
2. Composition
 - Plastic (a recharge will be assessed)
 - Glass
3. Size
 - Mini
 - Standard (–20 ml)
 - Other
4. Liquid scintillation fluid used
 - Environmentally benign or biodegradable
 - Organic solvent-based (a recharge will be imposed)

Handling, Packaging, and Transportation

1. Vials must be accumulated in:
 - Stacked cardboard racks within two transparent bags
 - Cardboard box lined with a plastic bag
 - Any sturdy sealed container with prior RSD approval
2. Contents limited to vials and containers will not be accepted with solids or laboratory trash.
3. Vials must be capped.
4. Attach a completed "Liquid Radioactive Waste" tag with the following:
 - Activity (millicuries or microcuries) for each radioisotope listed
 - RU, department, and date
 - Scintillation fluid brand name and type must appear on the tag
5. If a transportation cart is used, it must have side rails, or some means of securing the waste.
6. Use freight elevators; not patient or public elevators.
7. If elevator use is required, try to use one that is not already occupied.
8. Properly packaged waste will contain all contamination. Therefore, use of gloves during transport is not recommended. However, gloves should be taken along for use in the unlikely event of a spill.

Disposal Practices

All organic solvent-based (*e.g.*, p-dioxane, xylene, or pseudocumene) liquid scintillation cocktails are subdivided into the exempt and regulated categories and are sent off campus for disposal.

Environmentally benign or biodegradable liquid scintillation cocktails use long-chain and multi-ringed aromatic compounds (*e.g.*, linear alkylbenzenes) as solvents. These have not been identified as hazardous by the Environmental Protection Agency (EPA). These cocktails have lower toxicities and higher flash points than the organic solvent-based type. Vials with these cocktails are run through a vial crusher separating the cocktail and the vials. The crushed vials (shards) are rinsed and disposed as ordinary trash. The cocktail is disposed by release to the sanitary sewer system. This must be done by qualified RSD personnel, at a designated site, so that the conditions and provisions outlined in the UCLA Radioactive Material License and California Code of Regulations, Title 17, are met.

Mixed Waste and Lead

Mixed waste is a category of radioactive waste that is controlled by both the Nuclear Regulatory Commission and the EPA because of chemical or otherwise hazardous properties besides radiotoxicity. Title 40, Sections 260-266 of the Code of Federal Regulations (40 CFR) lists several substances which may fall under the category of mixed waste.

The relevance of this to the UCLA research community is that radioactively-contaminated hazardous waste is classified as mixed waste. Typical mixed wastes are radioactively contaminated lead, toluene, xylene, acetone, waste oils, acids, bases, and uranyl nitrate. All mixed wastes need to be separated from other radioactive or hazardous chemical wastes before being delivered to RSD personnel at designated waste pick-up times.

A sample of the waste pick-up schedule is shown on the following page.

UCLA RADIATION SAFETY DIVISION HANDOUT

RADIOACTIVE WASTE PICK-UP SCHEDULE

Effective January 12, 2007

Monday:

0910 to 0930 Warren Hall
0945 to 1030 CHS Loading Dock, 1st Floor

Tuesday:

0850 to 0910 Rehabilitation Center* See Notes
0915 to 0930 Medical Plaza* See Notes
0945 to 1030 MRL/GRL B-726

Wednesday:

0900 to 0930 MBI/Boyer Hall Loading Dock
0935 to 1000 Molecular Sciences Building Loading Dock
1005 to 1025 Life Sciences Loading Dock (C.E.Y. Drive South)
1030 to 1040 Botany* See Notes

Thursday:

0900 to 0915 Brentwood Facility (1st and 3rd Thursdays of the month)
0945 to 1030 CHS Loading Dock, 1st Floor

Friday:

NO PICK-UPS

Notes:

* Pick-up by Appointment Only. Call the Isotope Desk @ x5-5396 at least 24 hours in advance.

Radioactive wastes may not be transported outside your complex

Call x5-5396 to request a radioactive waste container return