

# **UAA Radiation Safety Handbook**

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## RADIATION FUNDAMENTALS

### INTRODUCTION: ISOTOPE REVIEW

For the purposes of this manual, we can use a simplistic model of an atom. The atom can be thought of as a system containing a positively charged nucleus and negatively charged electrons which are in orbit around the nucleus.

The nucleus is the central core of the atom and is composed of two types of particles, protons which are positively charged and neutrons which have a neutral charge. Each of these particles has a mass of approximately one atomic mass unit (amu). (1 amu = 1.66E-24 g)

Electrons surround the nucleus in orbitals of various energies. (In simple terms, the farther an electron is from the nucleus, the less energy is required to free it from the atom.) Electrons are very light compared to protons and neutrons. Each electron has a mass of approximately 5.5E-4 amu.

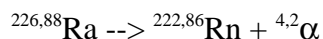
A nuclide is an atom described by its atomic number (Z) and its mass number (A). The Z number is equal to the charge (number of protons) in the nucleus, which is a characteristic of the element. The A number is equal to the total number of protons and neutrons in the nucleus. **Nuclides with the same number of protons but with different numbers of neutrons are called isotopes.** For example, deuterium (<sup>2</sup>H) and tritium (<sup>3</sup>H) are isotopes of hydrogen with mass numbers two and three, respectively. There are on the order of 200 stable nuclides and over 1100 unstable (radioactive) nuclides. Radioactive nuclides can generally be described as those which have an excess or deficiency of neutrons in the nucleus.

### RADIOACTIVE DECAY

Radioactive nuclides (also called radionuclides) can regain stability by nuclear transformation (radioactive decay) emitting radiation in the process. The radiation emitted can be particulate or electromagnetic or both. The various types of radiation and examples of decay are shown below.

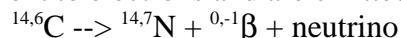
#### **ALPHA (α)**

Alpha particles have a mass and charge equal to those of helium nuclei (2 protons + 2 neutrons). Alpha particles are emitted during the decay of some very heavy nuclides (Z > 83).

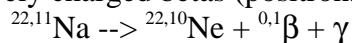


#### **BETA (β-, β+)**

Beta particles are emitted from the nucleus and have a mass equal to that of electrons. Betas can have either a negative charge or a positive charge. Negatively charged betas are equivalent to electrons and are emitted during the decay of neutron rich nuclides.



Positively charged betas (positrons) are emitted during the decay of proton rich nuclides.



## **GAMMA ( $\gamma$ )**

Gammas (also called gamma rays) are electromagnetic radiation (photons). Gammas are emitted during energy level transitions in the nucleus. They may also be emitted during other modes of decay.

## **X-RAYS**

X-rays are photons emitted during energy level transitions of orbital electrons.

**Bremsstrahlung x-rays** (braking radiation) are emitted as energetic electrons (**betas**) are decelerated when passing close to a nucleus. Bremsstrahlung must be considered when using large activities of high energy beta emitters such as P-32 and S-90.

## CHARACTERISTICS OF RADIOACTIVE DECAY

In addition to the type of radiation emitted, the decay of a radionuclide can be described by the following characteristics.

### **HALF-LIFE**

The half-life of a radionuclide is the time required for one-half of a collection of atoms of that nuclide to decay. Decay is a random process which follows an exponential curve. The number of radioactive nuclei remaining after time (t) is given by:

$$N(t) = N(0) \times \exp(-0.693t/T)$$

where

N(0) = original number of atoms

N(t) = number remaining at time t

t = decay time

T = half-life

## INTERACTION OF RADIATION WITH MATTER

### **ENERGY ABSORPTION**

The transfer of energy from the emitted particle or photon to an absorbing medium has several mechanisms. These mechanisms result in ionization and excitation of atoms or molecules in the absorber. The transferred energy is eventually dissipated as heat.

Ionization is the removal of an orbital electron from an atom or molecule, creating a positively charged ion. In order to cause an ionization, the radiation must transfer enough energy to the electron to overcome the binding force on the electron. The ejection of an electron from a molecule can cause dissociation of the molecule.

Excitation is the addition of energy to an orbital electron, thereby transferring the atom or molecule from the ground state to an excited state.

### **ALPHA PARTICLES**

Because of their double charge and low velocity (due to their large mass), alpha particles lose their energy over a relatively short range. One alpha will cause tens of thousands of ionizations per centimeter in air. The range in air of the most energetic alpha particles commonly encountered is about 10 centimeters (4 inches). In denser materials, the range is much less. **Alpha particles are easily stopped by a sheet of paper or the protective (dead) layers of skin.**

### **BETA PARTICLES**

Normally, a beta particle loses its energy in a large number of ionization and excitation events. Due to the smaller mass, higher velocity and single charge of the beta particle, the range of a beta is considerably greater than that of an alpha of comparable energy. Since its mass is equal to that of an electron, a large deflection can occur with each interaction, resulting in many path changes in an absorbing medium.

If a beta particle passes close to a nucleus, it decreases in velocity due to interaction with the positive charge of the nucleus, emitting x-rays (bremsstrahlung). The energy of the bremsstrahlung x-rays has a continuous spectrum up to a maximum equal to the maximum kinetic energy of the betas. The production of bremsstrahlung increases with the atomic number of the absorber and the energy of the beta. Therefore, low Z materials are used as beta shields.

### **PHOTONS**

Gammas and x-rays differ only in their origin. Both are electromagnetic radiation, and differ only from radio waves and visible light in having much shorter wavelengths. They have zero rest mass and travel with the speed of light. They are basically distortions in the electromagnetic field of space, and interact electrically with atoms even though they have no net electrical charge. While alphas and betas have a finite maximum range and can therefore be completely stopped with a sufficient thickness of absorber, photons interact in a probabilistic manner. This means that an individual photon has no definite

maximum range. However, the **total fraction of photons passing through an absorber decreases exponentially with the thickness of the absorber.**

## ACTIVITY, EXPOSURE, AND DOSE **DEFINITIONS**

**Activity:** the rate of decay (disintegrations/time) of a given amount of radioactive material.

**Dose:** a measure of energy deposited by radiation in a material, or of the relative biological damage produced by that amount of energy given the nature of the radiation.

**Exposure:** a measure of the ionizations produced in air by x-ray or gamma radiation. The term exposure (with its 'normal' definition) is sometimes used to mean dose. (e.g. 'He received a radiation exposure to his hand.')

## UNITS

### **ACTIVITY**

1 **Curie (Ci)** =  $3.7 \times 10^{10}$  disintegrations per sec (dps). The Becquerel (Bq) is also coming into use as the International System of Units (SI) {<sup>XE</sup> "International System of Units (SI)"} measure of disintegration rate. 1 Bq = 1 dps,  $3.7 \times 10^{10}$  Bq = 1 Ci, and 1 mCi = 37 MBq.

### **EXPOSURE**

The unit of radiation exposure in air is the **roentgen (R)**. It is defined as that quantity of gamma or x-radiation causing ionization in air equal to  $2.58 \times 10^{-4}$  coulombs per kilogram. Exposure applies only to absorption of gammas and x-rays in air.

### **DOSE**

The **rad** is a unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram. (1 erg =  $6.24 \times 10^{11}$  eV) The SI unit of absorbed dose is the Gray (Gy). 1 Gy = 1 joule/kilogram = 100 rad. An exposure of 1 R results in an absorbed dose of 0.87 rad.

A **quality factor (Q)** is used to compare the biological damage producing potential of various types of radiation, given equal absorbed doses. The effectiveness of radiation in producing damage is related to the energy loss of the radiation per unit path length. The term used to express this is linear energy transfer (LET). Generally, the greater the LET in tissue, the more effective the radiation is in producing damage. The quality factors for radiations frequently encountered are:

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|                                     |    |
|-------------------------------------|----|
| Gammas and x-rays                   | 1  |
| Beta particles & electrons          | 1  |
| Alpha particles & fission fragments | 20 |
| Neutrons                            | 10 |

The **rem** is a unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by the quality factor. Dose equivalent determinations for internally deposited radioactive materials also take into account other factors such as the non-uniform distribution of some radionuclides (e.g. I-125 in the thyroid). The SI unit for dose equivalent is the Sievert (Sv). 1 Sv = 100 rem.

### **CALCULATION OF ACTIVITIES**

The half-life of a radionuclide is the time required for one-half of a collection of atoms of that nuclide to decay. This is the same as saying it is the time required for the activity of the sample to be reduced to one-half the original activity. This can be written as:

$$A(t) = A(0) \times \exp(-0.693t/T)$$

where

A(0) = original activity

A(t) = activity at time t

t = decay time

T = half-life

#### *EXAMPLE*

P-32 has a half-life of 14.3 days. On January 10, the activity of a P-32 sample was 10 uCi. What will the activity be on February 6? February 6 is 27 days after January 10, so

$$A(\text{Feb } 6) = A(\text{Jan } 10) \times \exp[-0.693(27/14.3)] = 2.7 \text{ uCi}$$

A quick estimate could also have been made by noting that 27 days is about two half-lives. So the new activity would be about one-half of one-half (i.e. one-fourth) of the original activity.

### **BIOLOGICAL EFFECTS OF IONIZING RADIATION**

#### **RADIATION HAZARDS**

The hazards associated with the absorption of radiation in mammalian systems and tissue are related to both the type of radiation and the nature of the absorbing tissue or organ system.

#### **ALPHA**

Alpha particles will be stopped by the dead layers of skin, so they are not an external hazard. However, many alpha emitters or their daughters also emit gammas which are penetrating and therefore may present an external hazard. Internally, alphas can be very damaging due to their high linear energy transfer (LET). That is, they deposit all of their energy in a very small area. Based on their chemical properties, alpha emitters can be concentrated in specific tissues or organs.

## **BETA**

Externally, beta particles can deliver a dose to the skin or the tissues of the eye. Many beta emitters also emit gammas. A large activity of a high energy beta emitter can create a significant exposure from bremsstrahlung x-rays produced in shielding material. Internally, betas can be more damaging, especially when concentrated in specific tissues or organs.

## **PHOTONS**

Externally, the hazard from low energy (< 30 keV) gammas and x-rays is primarily to the skin or the tissues of the eye. Higher energies are more penetrating and therefore a whole body hazard. Internally, gamma emitters can affect not only the tissues or organs in which they are deposited, but also surrounding tissues.

## **MECHANISMS OF DAMAGE**

As discussed earlier, radiation causes atoms and molecules to become ionized or excited. These ionizations and excitations can result in:

- Production of free radicals.
- Breakage of chemical bonds.
- Production of new chemical bonds and cross-linkage between macromolecules.
- Damage to molecules which regulate vital cell processes (e.g. DNA, RNA, proteins).

## **EFFECTS OF ACUTE HIGH RADIATION DOSES**

A whole body radiation dose of greater than 25 to 50 rem received in a short time results in the clinical 'acute radiation syndrome.' This syndrome, which is dose related, can result in disruption of the functions of the bone marrow system (>25 rem), the gastro-intestinal system (>500 rem), and the central nervous system (>2000 rem). An acute dose over 300 rem can be lethal.

## **EFFECTS OF LOW RADIATION DOSES**

There is no disease uniquely associated with low radiation doses.

Immediate effects are not seen below doses of 25 rem. Latent effects may appear years after a dose is received. The effect of greatest concern is the development of some form of cancer.

The National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (BEIR) issued a report in 1990 entitled Health Effects of Exposure to Low Levels of

Ionizing Radiation, also known as BEIR V. A typical whole body dose limit for planned exposures is 500 mrem/year (5 mSv/yr). If a worker were to receive the maximum allowable planned dose each year for twenty years, the total dose received would be 10 rem (0.1 Sv). According to the BEIR V report, the worker's chance of death from cancer would increase by approximately 0.4%. This is fairly small compared to the normal chance of death from cancer in the U. S. of about 20%.

## RADIATION DOSIMETRY PROGRAM

### **FILM BADGE**

The film badge is used to measure whole body dose and shallow dose. It consists of a film packet and a holder. The film is similar to ordinary photographic film but will be exposed by radiation. (It will also be exposed by light, so if the packet is opened or damaged, the reading will be invalid.) The holder has several filters which help in determining the type and energy of radiation. The badge will detect gamma and x-rays, and high energy beta particles. It does not register radiation from low energy beta emitters such as H-3, C-14, and S-35, since their betas will not penetrate the paper covering on the film packet.

The badge is usually worn at the collar or chest level to measure the radiation dose received by the trunk of the body. When not in use, the badge should be left in a safe place on campus away from any radiation sources.

### **PRECAUTIONS**

The radiation doses recorded by your dosimeters become part of your occupational radiation dose record. Make sure that this record is valid and accurate by observing the following precautions:

- Always wear your badge when using radioactive materials or radiation producing machines.
- Keep your dosimeters away from radiation sources when not in use. Do not deliberately expose a dosimeter to radiation or wear your badge when receiving medical or dental x-rays.
- Do not tamper with the film packet or remove it from the holder.
- Never wear someone else's dosimeter or let someone else wear yours.
- Avoid subjecting the badge to high temperatures or getting it wet.

Notify the RSO if your badge has been damaged or lost, or if you have reason to believe that you or your dosimeter has received an accidental high dose.



## RADIOACTIVE MATERIAL HANDLING AND LABORATORY SAFETY

### **REDUCTION OF DOSE TO PERSONNEL**

The following are ways in which radiation doses can be reduced.

#### **TIME**

Carefully plan your activities in order to minimize the time spent handling or in the vicinity of radiation sources.

#### **DISTANCE**

Increasing the distance from a radiation source by the use of handling devices will reduce the dose received, since exposure rate decreases as  $1/r^2$ , where  $r$  is the distance from a point source. For example:

At 10 cm, a 5 mCi I-125 source has an exposure rate of 75 mR/hr. Moving to 30cm would reduce the exposure rate to

$$(75 \text{ mR/hr})(10/30)^2 = 8.3 \text{ mR/hr}$$

Note: The  $1/r^2$  formula (also known as the inverse square law) does not take into account shielding provided by air. This can be significant for particulate radiation. Even the most energetic alpha particles commonly encountered have a range in air of about 4 inches. A beta from the decay of S-35 has a maximum range in air of about 12 inches.

#### **SHIELDING**

As gammas and x-rays pass through an absorber their decrease in number is governed by the energy of the radiation, the density of the absorber medium, and the thickness of the absorber. This can be expressed approximately as

$$I = I_0 \exp(-ux)$$

where

$I_0$  is the intensity of the initial radiation,

$I$  is the radiation intensity after it has passed through the absorber,

$u$  is a factor called the linear absorption coefficient (The value of  $u$  depends on the energy of the incident radiation and the density of the absorbing medium.), and

$x$  is the thickness of the absorber.

## TVL & HVL

The thicknesses of an absorber needed to reduce the radiation intensity by a factor of two and by a factor of ten are called the half-value layer (HVL) and the tenth-value layer (TVL), respectively. Approximate lead TVL's, HVL's, and linear attenuation coefficients for some radionuclides are listed below.

| Nuclide | Gamma Energy(MeV) | HVL(mm) | TVL(mm) | $\mu(\text{cm}^{-1})$ |
|---------|-------------------|---------|---------|-----------------------|
| I-125   | 0.035             | 0.05    | 0.16    | 150                   |
| Am-241  | 0.060             | 0.14    | 0.45    | 51                    |
| Co-57   | 0.122             | 2.0     | 6.7     | 3.4                   |
| Cs-137  | 0.662             | 6.5     | 21      | 1.1                   |
| Na-22   | 1.28              | 9.6     | 32      | 0.72                  |
| Co-60   | 1.17 & 1.33       | 12      | 40      | 0.58                  |

*Example:* At 30 cm, a 10 mCi Co-60 source produces an exposure rate of about 150 mR/hr. How much lead shielding is needed to reduce the rate to 4 mR/hr?

40 mm (one TVL) will reduce the rate to 15 mR/hr. Adding 12 mm (one HVL) will make it 7.5 mR/hr. One more HVL will put the rate at about 4 mR/hr. So the total lead shielding needed is  $40 + 12 + 12 = 64$  mm.

## SHIELDING CONCERNS

When designing shielding there are several points to be kept in mind.

- Persons outside the shadow cast by the shield are not necessarily protected.
- A wall or partition may not be a safe shield for people on the other side.
- Radiation can be "scattered" around corners.

## BREMSSTRAHLUNG

The absorption of high energy beta radiation (e.g. P-32 and Sr-90) in high Z materials such as lead and tungsten may result in the production of electromagnetic radiation (bremsstrahlung) which is more penetrating than the beta radiation that produced it. Low Z materials such as plastics and glass minimize the production of bremsstrahlung.

## HANDLING PRECAUTIONS

Here are some of the radiological characteristics of and special precautions associated with some radionuclides commonly used on campus. In addition to the specific precautions for each nuclide, the following general precautions should always be followed when applicable to your work.

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- Whenever practical, designate specific areas for radioactive material handling and use. Clearly label the area and all containers. Minimize and confine contamination by using absorbent paper and spill trays. Handle potentially volatile materials in certified fume hoods.
- Do not smoke, eat, or drink in rooms where radioactive materials are used. Do not store food or drink in refrigerators, freezers, or cold rooms used for radioactive material storage.
- Use an appropriate instrument to detect radioactive contamination. Regularly monitor the work area. Always monitor yourself, the work area, and equipment for contamination when your experiment or operation is completed. Decontaminate when necessary.
- Use appropriate shielding when handling gamma emitters or high energy beta emitters.
- Wear the dosimeters issued to you while using radioactive materials.
- Wear two layers of gloves; in case of contamination one layer can be discarded without losing protection
- Wash your hands before leaving the lab, using a telephone, or handling food.

### P-32 INFORMATION

|                          |                                     |
|--------------------------|-------------------------------------|
| Radioactive half-life    | 14.3 days                           |
| Decay mechanism          | Beta emission                       |
| Contamination monitoring | Thin window Geiger-Mueller detector |
| Shielding                | 1 cm Lucite (plexiglass)            |
| Dosimetry                | Film badge                          |

- The dose rate on contact on the side of a 1 mCi delivery vial will be on the order of 1000 mrem/hr. If possible, avoid direct hand contact with vials and sources. When working with 50 uCi or more of P-32, work should be done behind a 1 cm lucite shield.
- One microcurie of P-32 in direct contact with 1 cm<sup>2</sup> of bare skin gives a dose rate to the skin of about 8 rem/hr. Always protect your skin when handling unsealed materials. Wear gloves, lab coats, and shoes.
- A thin window G-M survey meter should always be available. A survey should be made immediately after use and any 'hot spots' should be decontaminated.
- Film badges must be worn for all P-32 work.
- Handle and store your radioactive waste carefully. The bottles for liquid waste should be placed in a secondary container (e.g. a bucket or tray) to contain spills or leaks. When more than a millicurie is involved, place 1 cm lucite around the

container for shielding. The metal barrels for dry waste provide sufficient shielding but be sure to keep the lid on.

### S-35 INFORMATION

|                          |   |
|--------------------------|---|
| Radioactive half-life    | 87.4 days   |
| Decay mechanism          | Beta emission   |
| Contamination monitoring | Thin window Geiger-Mueller detector,<br>liquid scintillation counter for wipe surveys |

- Radiolysis of S-35 labelled amino acids may lead to the release of S-35 labelled volatile impurities. Delivery vials should therefore be opened in a fume hood.
- The addition of stabilizers (buffers) will reduce, but not eliminate, the evolution of S-35 volatiles from tissue culture media. Incubators should be checked for contamination after using S-35 methionine or other volatile compounds.
- S-35 may be difficult to distinguish from C-14. If both nuclides are being used in the same laboratory, establish controls to ensure they are kept separate. If 'unknown' contamination is found, treat it as C-14.

### I-125 INFORMATION

|                          |   |
|--------------------------|---|
| Radioactive half-life    | 59.6 days   |
| Decay mechanism          | Electron capture (gamma and x-ray emission)                                 |
| Contamination monitoring | Thin crystal NaI detector,<br>liquid scintillation counter for wipe surveys |
| Shielding                | Thin lead   |
| Dosimetry                | Film badge  |

- The dose rate at 1 cm from a 1 mCi point source is about 1.5 rem/hr The dose rate is inversely related to the square of the distance from the source. Thus while a small amount of I-125 held for a short time can result in a significant dose to the hands, a relatively short separation distance reduces the dose rate to an acceptable level.
- The volatility of iodine requires special handling techniques to minimize radiation doses. Solutions containing iodide ions (such as NaI) should not be made acidic or be frozen. Both lead to formation of volatile elemental iodine. Once bound to a protein, the volatility of the radioiodine is tremendously reduced.
- Always work in a fume hood with a minimum face velocity of at least 125 linear feet per minute when working with NaI. The sash should be below the breathing zone.
- Use shoulder length veterinary gloves with short vinyl gloves on top to minimize skin absorption.
- Avoid opening the septum on delivery vials. It is preferable to remove radioiodine using a hypodermic needle and syringe.

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- A radiation survey instrument should be available in the immediate area. A low energy scintillation detector is preferable to a G-M detector. You should do a wipe survey in your work areas after each use.
- Film badges must be worn for all radioiodine work.
- Use lead to shield quantities of 1 mCi or more. 1 mm of lead will essentially absorb all of the radiation emitted from I-125.

### H-3 (TRITIUM) INFORMATION

|                          |   |
|--------------------------|---|
| Radioactive half-life    | 12.4 years                                    |
| Decay mechanism          | Beta emission                                 |
| Contamination monitoring | Liquid scintillation counter for wipe surveys |

- Because the beta emitted has a very low energy, tritium cannot be detected with the usual survey meters found in the lab. Therefore, special care is needed to keep the work area from becoming contaminated. Tritium can be detected by doing a wipe survey and counting the wipes in a liquid scintillation counter.
- Many tritiated compounds readily penetrate gloves and skin. Wearing two pairs of gloves and changing the outer pair every fifteen or twenty minutes will reduce the chances of cross contamination and absorption through the skin.

### C-14 INFORMATION

|                          |   |
|--------------------------|---|
| Radioactive half-life    | 5730 years  |
| Decay mechanism          | Beta emission   |
| Contamination monitoring | Thin window Geiger-Mueller detector,<br>liquid scintillation counter for wipe surveys |

- Some C-14 labelled compounds can penetrate gloves and skin. Wearing two pairs of gloves and changing the outer pair every fifteen or twenty minutes will reduce the chances of absorption through the skin.
- C-14 may be difficult to distinguish from S-35. If both nuclides are being used in the same laboratory, establish controls to ensure they are kept separate. If 'unknown' contamination is found, treat it as C-14.

## RADIATION SURVEY METERS

There are several types of portable radiation survey instruments. Various types have different qualities and can therefore have very different detection capabilities.

As a user of radioactive materials or radiation producing machines, you are expected to be able to use the survey meters in your laboratory. During your initial training, you will learn how to operate the instruments in your lab. You should know their capabilities and limitations and be able to interpret the meter readings.

## GEIGER-MUELLER DETECTOR

The Geiger-Mueller (G-M) counter is the most common radiation detection instrument on campus. In this type of meter, an ionization in the detector results in a large output pulse that causes meter and audio responses. Because of the inherent characteristics of the detector, all initial ionizing events produce the same size output pulse. Therefore, the meter does not differentiate among types or energies of radiation.

Most G-M detectors have a thin mica film 'window' at one end. This window is very fragile. Always use the thin end window for detecting pure beta emitters and low energy photons (e.g. P-32, S-35, C-14, Fe-55, I-125, and x-rays less than 40 keV).

Very low energy beta emitters such as H-3 and Ni-63 are not detectable since their betas do not have enough energy to penetrate the window. They are best detected by using liquid scintillation counting techniques. C-14 and S-35 emit betas energetic enough to pass through the thin window. However, covering the window with plastic wrap or paraffin film will stop most or all of their betas from entering the detector.

The efficiency of a meter for a specific source of radiation is given by the ratio of the meter count rate to the actual disintegration rate of the source (cpm/dpm). Some examples of approximate G-M efficiencies through the end window at 1 inch from a point source are given below:

|            |                |
|------------|----------------|
| H-3        | not detectable |
| C-14, S-35 | 0.2% - 0.8% *  |
| P-32       | 3% - 8%        |
| I-125      | 0.01% - 0.03%  |

\* Not detectable if the detector window is covered with paraffin film, plastic wrap, or other material.

*Example:* Your G-M counter reads 5000 cpm at one inch from a small spot of P-32 contamination on the bench. What is the total activity of the contamination?

$$\begin{aligned} \text{actual disintegration rate} &= (5000 \text{ cpm}) / (0.05 \text{ cpm/dpm}) = 100,000 \text{ dpm} = 1700 \\ \text{dps} &= 1700 \text{ Bq} = 45 \text{ nCi} \end{aligned}$$

Because of the randomness of radioactive decay, the meter reading at low count rates often fluctuates widely. For this reason, the audio speaker is sometimes a better indicator of small amounts of radioactivity than the meter reading. At higher count rates, the speaker response is often faster than the meter reading. It is better, therefore, to have the speaker on when using a G-M counter.

Very high radiation fields may temporarily overload the detector circuit resulting in a partial or complete loss of meter or audio response. If this happens, remove the meter and yourself from the area and push the reset button or turn the meter off then back on. The meter should resume normal operation. Always turn on a survey meter before entering an area that might have high radiation fields.

### RADIOACTIVE WASTE DISPOSAL

UAA stores radioactive waste to allow time for the decay of short-lived radionuclides and to facilitate the proper disposal of all radioactive waste.

### **WASTE MINIMIZATION**

Since all radioactive waste must be stored on campus until it decays or until it can be shipped to an authorized disposal facility, it is important that the amount of waste generated be kept to a minimum. We have a limited area to store radioactive waste. Some ways to minimize waste are listed below.

- Design experiments to use as little radioactive material as possible.
- Use proper handling techniques. This will reduce the chance of contamination.
- When practical, use techniques which do not involve radioactive materials. There are many new techniques and products available which can be used in place of radioactive materials.
- Monitor for contamination and dispose of as little as possible. If there is a spot of contamination on a piece of absorbent paper, cut out that spot and dispose of it rather than the whole piece. Don't automatically place your gloves in the radioactive waste. Monitor them. If there is no detectable contamination, throw them in the regular trash.
- Liquid radioactive waste includes the radioactive material and the first rinse of its experimental container. After the first rinse, the container can be washed in the sink.

### **SEGREGATION BY HALF-LIFE**

All radioactive waste must be segregated according to radionuclide half-life. The three categories for segregation are:

Half-life less than 15 days (P-32)

Half-life between 15 and 90 days (S-35, Cr-51, I-125)

Half-life greater than 90 days (H-3, C-14, Ca-45)

Waste containers are marked with the category of waste they are intended for. It is very important that waste is placed in the proper container.

If waste contains two different radionuclides, place it in the container appropriate for the longer half-life.

## RESPONSIBILITIES OF THE LABORATORY SUPERVISOR (AUTHORIZED USER)

In addition to assuming all the responsibilities of an individual radiation user, the Laboratory Supervisor shall:

1. Be responsible that all personnel, particularly new personnel, who have access to radiation sources under his/her jurisdiction are properly instructed and that they possess the necessary skills and disposition to cope with radiation safely. S/he must ensure that people in his/her area know what they need to know about:
  - a. This manual as it applies to their work.
  - b. Applicable Federal, State, and local regulations.
  - c. The nature of his/her radiation sources and their particular hazards.
  - d. Proper use of instruments in the area--especially their limitations.
  - e. Routine procedures for handling work safely.
  - f. Emergency procedures.
2. Determine the types of radiation sources, equipment and facilities and procedures needed for his/her work.
3. Prepare for his/her personnel specific written routine and/or emergency procedures applicable to his/her operations when necessary or desirable.
4. Ensure that the procedures for purchase, acquisition, use, and transfer of radioactive materials are followed in work under his/her supervision. This includes keeping accurate records of inventory and disposal of sources or portions thereof.
5. Routinely check protective equipment and instruments to ensure they are working properly and adequately performing their intended functions.
6. Actively seek the assistance of and cooperate with the Radiation Safety Officer in solving radiation safety problems unique to his/her situation and in correcting violations of the rules and regulations imposed by federal, state or local regulatory agencies.
7. Provide whatever action and information necessary with respect to his/her operations to assist the Radiation Safety Officer in complying with existing laws and license requirements (maintenance of records, preparation of reports, etc.).



8. Complete a Radiation User checklist form for every worker in the laboratory, whether or not they use radioactive materials directly. File copies of checklists with RSO.

#### RESPONSIBILITIES OF THE INDIVIDUAL USER

The individual user is the one ultimately responsible for the safe use of the radiation sources to which s/he has access. S/he shall:

1. Keep his/her exposure as low as practical.
2. Wear assigned personnel monitoring devices in an approved manner.
3. Be familiar with and comply with all sections of this Manual applicable to his/her work.
4. Be familiar with the nature of his/her area's radiation sources, the extent of their potential risk and use the proper means of coping with them safely.
5. Monitor his/her area frequently for contamination. No person or object should leave the laboratory without being monitored.
6. Clean up minor spills immediately.
7. Dispose of radioactive waste in an approved manner.
8. See that sources, containers, and the area are properly labeled and posted.
9. Assist his/her supervisor in maintaining required records and inventories.
10. Prevent unauthorized persons from having access to radiation sources in his/her area.
11. Protect service personnel, allowing no maintenance or repairs of area facilities or equipment unless approved by the area supervisor and/or the Radiation Safety Officer.
12. Notify his/her supervisor and the Radiation Safety Officer of unexpected difficulties.
13. Be prepared to handle accidents or injuries with common sense. S/he shall notify and seek the assistance of his/her immediate supervisor and Radiation Safety as soon as possible in emergencies.
14. When entering an unfamiliar posted area, it is wise to monitor the radiation levels with an appropriate instrument to establish the need for limiting stay time, supplementing shielding, etc.

## LABORATORY PROCEDURES

1. To prevent accidental entry of radioactive materials into the body, high standards of cleanliness and good housekeeping must be maintained in all laboratories where radioactive material is present.
2. Visitors are not allowed without approval of laboratory supervisor.
3. Wash hands and arms thoroughly before handling any object which goes to the mouth, nose, or eyes (e.g., cigarettes, cosmetics, foods).
4. Smoking and eating in radioisotope laboratories is strongly discouraged. Refrigerators will not be used jointly for foods and radioactive materials.
5. One or more trial runs beforehand with non-radioactive materials are recommended for new procedures and new personnel to test effectiveness of procedures and equipment.
6. Use shielding when desirable.
7. Do not work with radioactive materials if there is a break in the skin below the wrist.
8. Always use gloves when handling more than a few hundred counts per minute. Wear protective clothing (lab coats, masks, shoe covers) as needed.
9. Tritium workers: change gloves every hour when working with 50 millicuries or more.
10. Never pipette by mouth. Use rubber bulbs, syringes, or mechanical devices.
11. Clean up minor spills immediately. For major spills follow emergency procedures.
12. Whenever possible, operations with radioactive materials should be conducted in a hood, dry box, or some other type of closed system. Operations with materials susceptible to atmospheric distribution, such as boiling, evaporating, distilling or ashing, must be done in a hood with an air flow of approximately 100 linear feet per minute. Work with activities of more than a few hours half-life should be done over a tray. Work with finely divided powder must be done in a hood or closed system.
13. Table and bench tops should be of a non-porous, chemical resistant material. Working surfaces shall be covered with absorbent paper regardless of the type of surface.
14. When work is completed each person will clean up his own work area and arrange for disposal or proper storage of all radioactive materials and equipment.

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15. Vacuum pumps used in systems containing radioisotopes must not be permitted to exhaust into room air or out windows.
16. Laboratories shall provide special radioactive waste containers. These shall bear the words "Caution, Radioactive Waste," and a warning to janitors against handling.
17. Cleaning crews should not touch benches and instruments, etc., but are permitted to clean floors and windows only. Laboratory personnel are responsible for the rest of the housekeeping.
18. Repairs such as plumbing, etc., should not be undertaken unless the Radiation Safety Officer has been notified.
20. When use and storage of radioactive materials is to be terminated at a facility, notify the Radiation Safety Officer who must make a terminal survey before an area can be released for other uses.

### STORAGE OF RADIOACTIVE MATERIALS

1. Radioisotope laboratories and storage areas (rooms, cabinets, safes, etc.) must be locked at all times when not in actual use to prevent theft and unauthorized use of radioactive materials.
2. Radioactive materials stored in occupied areas shall be shielded in accordance with ALARA. A good rule for selecting storage containers and in designing equipment is that the radiation level be less than 200 mR/hr at accessible surfaces and less than 10 mR/hr at one meter from the source, provided the normal operating distance to frequently occupied areas is such that no one is likely to exceed 10% of the permissible radiation doses.
3. Unbreakable containers are recommended for storage of radioactive liquids. Bottles and other breakable containers used for storage must be kept in non-breakable, leak-proof containers or trays capable of containing the entire volume of liquid waste stored therein.
4. Radioactive gases and volatile forms of radioisotopes should be stored in a well ventilated area, preferably in a hood or dry box.
5. All active samples including calibration sources regardless of strength should be clearly labeled giving accurate information about the contents as well as the name of the person or area responsible for the sample. They must also carry the words "Caution Radioactive Materials."