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 (^{2}H) and tritium (^{3}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

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.

$^{14,6}C \text{ --> } ^{14,7}N + ^{0,-1}\beta + \text{neutrino}$

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

$^{22,11}Na \text{ --> } ^{22,10}Ne + ^{0,1}\beta + \gamma$

GAMMA (γ)

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.

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.

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)** = 3.7E10 disintegrations per sec (dps). The Becquerel (Bq) is also coming into use as the International System of Units (SI){XE "International System of Units (SI)"} measure of disintegration rate. 1 Bq = 1 dps, 3.7E10 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 2.58E-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 = 6.24E11 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:

Radiation	Q

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

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

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 paricles 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

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

where
Io 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.

- 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^2 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, 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, 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.

- 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, 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.

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

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.

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, RadioactiveWaste," 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 aboutthe contents as well as the name of the person or area responsiblefor the sample. They must also carry the words "Caution Radioactive Materials."