

Section 3

RADIATION PROTECTION PROCEDURES

A. Introduction

An **accident** is an event that takes place without one's forethought or expectation, especially one of an unfortunate character. Yet, most accidents are predictable, and the occurrence of accidents can be reduced if the causes of accidents are understood and preventive measures taken. An accident is not the result of a purely chance event; totally unexpected; or an unfortunate, unpreventable misfortune. Given a susceptible host, an injurious agent and an unsafe environment, accidents are predisposed.

In each accident, there are varying degrees of the following three factors which contribute to the occurrence of accidents.

1. Human Factors

- a. Lack of knowledge and judgment.
- b. Lack of experience and training.
- c. Fatigue and/or emotional factors.
- d. Responsibility and motivation.

2. Environmental Factors

- a. Improper lighting.
- b. Improper temperature.

Temperatures less than 60 degrees Fahrenheit (F) reduce dexterity and control, while temperatures greater than 75 degrees F allow deterioration of coordination

- c. Improper working conditions which promote fatigue and irritability.

3. Toxic Agents (such as radioactive material)

B. Organizational Plan for Radiation Protection

Organization of procedures and practices in the laboratory should be accomplished in advance of the actual start of laboratory operations.

Good radiation safety practice depends on an effective health and safety organizational plan. Experience shows that even the most competent worker cannot be relied upon to keep in mind all health and safety requirements while preoccupied with the successful performance of his work. Responsibilities and duties must be set out clearly to ensure safety. In the process of applying for radioactive materials (RAM) license, an organizational plan must be presented.

A plan to maintain safety and implement emergency procedures when a major accident has occurred should be in writing and readily available to all of the laboratory personnel. The plan should be discussed with all personnel so each individual is aware of his or her role in the event of an emergency. Such a plan should include the emergency procedures included in the authorized user application. In addition to this outline of emergency procedures, the special hazards peculiar to the operations in the laboratory (i.e. chemical characteristics of the radionuclide and quantities) should be part of the lab plan.

The plan for major emergencies shall list an individual as the Laboratory Radiation Safety Agent who will be in charge of directing emergency procedures, the Principle Investigator, and both of their home phone numbers. For on campus emergencies, dial 911. For off campus emergencies, dial University Police at (206) 543-9331 or 911 (see Appendix 3, Figures 1 and 2).

C. Radiation Lab Protection Procedures

1. Laboratory Layout

The laboratory work plan should include reserving special places for the handling of the radionuclides. These areas should be marked clearly. They should be located, as much as possible, away from the regular traffic patterns in the laboratory. Storage of the radioactive material should be such that the transfer route of the radionuclide to the working area is over as short a distance as possible.

Waste disposal containers should be close to the working area. Record keeping of radionuclide use and disposal should be comprehensive and easily attended to during the work or waste disposal processes without a disruption of the work flow or unnecessary trips to files located elsewhere in the laboratory.

Radiation work should be consolidated both in respect to area allotted to handling of the radioactive materials and to the amount of time spent in handling it. Limiting the area expedites survey and decontamination procedures. Limiting the time spent in handling the radionuclides minimizes external radiation exposure and decreases opportunities for accidents.

In laying out the RAM work area, the possibility of accidental spills and the spread of contamination to adjacent areas and equipment should be kept in mind. Provide working surfaces that are easily cleaned and allow the spill to be easily localized. Manipulations should be carried out over a suitable drip tray or with some form of double container which will minimize the affects of breakages or spills. It is also useful to cover the working surfaces with absorbent material to soak up minor spills.

If external radiation hazard is a possibility, shielding should be provided as near to the RAM container as possible.

The sink designated for radioactive waste disposal should be clearly marked and should be located in the general area designated for radionuclide work. Forms for recording increments of radioactive waste disposal should be right beside the sink to encourage accurate record keeping of this type of disposal.

2. Fume Hoods

Use of radioactive material in a room is permitted if the ventilating rate is such that a spill and total volatilization would result in less than 10% of an annual limit of intake.

If the radionuclide is in a nonvolatile form the amount used can be greater. Work with larger amounts must be done in a fume hood. In particular, work with 500 μCi or more of volatile iodine must be done in a fume hood.

Fume hoods should produce a regular flow of air, as specified by the manufacturer, without any eddies. The speed of the air flow should be such that there can be no escape of air into the working place from the fume hood under typical operating conditions, including opening of windows and/or doors. The suction of other fume hoods or eddies caused by individuals moving quickly across the face of the hood must also be taken into consideration. This can be checked by smoke tests.

Hood sink traps should also be checked periodically because they tend to dry out. The hood should be kept free of clutter and large objects should be located to the rear of the hood to minimize the formation of current eddies. The hood air flow is checked with a calibrated instrument on an annual basis by personnel from the Environmental Health & Safety (EH&S) Department. In between annual checks, the air flow should be monitored with strips of paper or ribbons attached to the bottom of the sash.

The hood sash should be kept clean and lowered as far as practical to increase face velocity. It also protects against splash or explosions.

3. Protective Clothing

No unsealed radioactive sources should be manipulated with the unprotected hand. Rubber or neoprene gloves should be used so that hands will be kept clean and also permit the use of a clean hand for clean work (such as recording data, etc.). It is sometimes useful to use just one hand for "dirty" work and keep the other hand (held behind the back) free of contamination for clean work (hot hand cold hand technique). Tape up sleeves and cuffs to keep them from dragging on potentially contaminated surfaces. Gloves should be removed by turning inside out. Never insert gloved fingers inside the top of glove to assist in removal. Grasp outside surface and strip the glove off inside out. The fingers of the clean hand can be inserted inside the second glove for removal. Remember, the contaminated gloved hand will spread contamination to clean areas and although the individual

remains clean, his fellow workers are exposed to contamination.

Do not blow into glove to return it to its original form or to check for leaks. This practice will spread loose contamination around the room. Saran wrap or similar plastic can sometimes be used as impromptu gloves or protective clothing.

Laboratory coats or aprons worn as protective clothing should remain behind in the laboratory at the end of the day or whenever the individual leaves the laboratory.

4. Storage Security

Radioactive material (including that in animals, patients and equipment/sealed sources) should be prevented from leaving designated controlled areas under circumstances that may subject other persons to unnecessary exposure to radiation. The responsibilities of the Authorized Investigator (AUI) of radiation include the security of the radioactive material against theft or unauthorized use of radiation sources.

Storage of radionuclides should be in a secure and preferably locked place so that unauthorized personnel (casual visitors at the laboratory, custodians, etc.) do not have access to them. Those radionuclides that are external radiation hazards should have adequate shielding to protect individuals working in the vicinity of the storage area.

When the radionuclide laboratory is to be left unoccupied by responsible laboratory personnel for any appreciable length of time (more than a few minutes) it should be kept locked.

Appropriate radiation warning signs or labels should be used to designate radiation areas and to identify radioactive material containers or rooms containing radioactive materials. Regulations stipulating the types, requirements, and locations of these signs or labels are provided in the Radiation Safety Manual - Section 10, Area Classification and Posting.

5. Waste Collection and Disposal

The essential aspects of the radioactive waste program are: 1) proper collection and packaging, and 2) proper labeling and records. These practices are outlined in the Radiation Safety Manual - Section 14 (see Appendix 3, Figure 3).

6. Records

Inventory records should show disposition of radioactive material for each type of disposal so that it is easily discernible as to the amount of activity released to the sewer, the atmosphere, or collected as solid or liquid waste (see Appendix 3, Figure 4).

Packages that are full and ready for collection by the RSO technicians should be securely closed and marked or labeled with the following information: Authorized Investigator's (AUI) name, University box number, budget number, radionuclide and total activity of each radionuclide, laboratory of origin, and radioactive material (RAM) tape or label.

7. Labeling

Custodians occasionally mistakenly collect radioactive waste. A very apparent sign should be attached to each waste container to indicate radioactive waste and forestall accidental pickup by the custodian service. Use the standard radiation sign or a strip of radioactive tape.

Containers that once contained radioactive materials should have labels or signs removed or marked out before the container is discarded or placed in storage. The labels are intended as a warning. When a warning is not necessary, there is a false concern, or worse, a future disregard for the proper warning. When these empty containers appear in public areas or in normal trash, they cause unnecessary alarm.

Standard radioactive waste packages or boxes should be used only for radioactive material.

D. Accident Anticipation

1. Identification of an Accident

The most essential and often the most overlooked problem in coping with a radioactive accident is the recognition that an accident has occurred. This problem can be moderated by frequent and periodic surveying for radioactivity in areas where it does not belong.

2. Habits That May Result in RAM Ingestion

a. Mouth Habits

Anything brought to your mouth while working in a lab may result in ingestion of contaminants. *Do not:*

- 1) Bite fingernails.
- 2) Chew on pencil or pen.
- 3) Think with eyeglasses in mouth.
- 4) Floss teeth.
- 5) Lick labels or stamps.

- 6) Use mouth pipettes.
- 7) Hold stoppers in mouth.
- 8) Open bottles with teeth.
- 9) Blow bubbles with gum.
- 10) Chew hair ends.

b. Food, Drinks, and Smoking

Food, drinks, and smoking are forbidden in labs. This rule is probably the most resisted rule by individuals. *Remember that:*

- 1) Storage of food or drink with lab materials is forbidden. Somebody's apple or sandwich may become contaminated with radioactive material and the end result may be accidental ingestion by a laboratory coworker.
- 2) Preparation of food or drink in a lab is forbidden. The risk of incorporating radionuclides into the cooking or mixing process is great.
- 3) Eating, drinking and smoking in the laboratory are forbidden. Do your eating, drinking and/or smoking in a clean area away from the laboratory.
- 4) Don't use laboratory paper or glass containers for food or drink containers. They may be tagged with radionuclides.
- 5) Before leaving the laboratory, clean your hands and leave your lab coat and gloves behind, along with any radioactive material you may have collected.

c. Pipetting

There should be no mouth pipetting of radioactive materials! It may result in the ingestion of liquid or the inhalation of vapor! Also, mouth pipetting of any liquids is discouraged in the radioactive lab because of possible contamination and subsequently the mouth may be contaminated.

Micro pipette mouth pieces are potential sources of contamination and should not be used since they:

- 1) are often set down on bench,

- 2) are often put into lab coat pocket, and
- 3) must be handled before use.

All the warnings concerning possible ingestion of radionuclides by unconscious mouth habits, eating or drinking in RAM laboratories, apply as strongly to the practice of mouth pipetting.

3. Protective Measures

a. Planning Work

All RAM work should be carried out according to some prearranged plan. Any departure from the plan should be followed by a reassessment of the radiation hazards involved.

b. Knowledge of Radionuclides Being Used

The chemical and physical properties of the radionuclides in the laboratory should be common knowledge to the individuals working in the laboratory so they are prepared to deal with a radioactive spill, should it occur.

c. Lab Procedures

Lab procedures utilizing centrifuging, shaking, or freeze-drying techniques may produce aerosols, gases, powders or dusts in which case the air should be monitored for contamination after an operation. Also in operations of this type, spills or breaks are highly likely. Consequently, adjacent areas may be contaminated along with contamination of the equipment itself. Each time the equipment is used with radioactive material, contamination should be suspected and surveys should be done on a periodic basis.

E. Surveys and Decontamination Procedures

1. Routine Surveys

Monitoring for contamination in a laboratory should be performed with radiation survey instruments and by smear tests. The survey instruments can be used during and after a RAM lab procedure to detect contamination. In making an area survey for beta or weak gamma emitters, the instrument probe should be held close to the surface being surveyed (within two centimeters) and the window on the probe should be open to permit the entrance of beta particles into the detecting media of the probe.

Smear tests for removable radioactive materials contamination are done by wiping pieces of absorbent paper (i.e. Whatman's #2 filter paper) over an area of approximately 100 cm². Number and place the paper swipes in between clean sheets of a scratch pad; note the location where the swipe was taken on a sketch of

the laboratory. The schematic drawing of the laboratory should show recognizable landmarks such as refrigerators, sinks, workbenches, etc. Locations being surveyed should be marked on the drawing with the numbers assigned to the swipes so that a contaminated swipe can be identified as coming from a specific area in the laboratory and steps to clean up the contamination can be identified.

The area survey procedures are explained in the Radiation Safety Manual - Section 13 (see Appendix 3, Figure 5). A swipe may be moistened with water to help remove the contaminant from the work area; however, it should be dried before being counted. Frequency of surveys will depend on the classification of the laboratory in respect to the amount and kind of radionuclide utilized in the laboratory.

Records of each survey taken should be kept (even though the findings are negative). These survey records are periodically audited by the Radiation Safety Office (RSO) to verify that the laboratory personnel are maintaining their prescribed schedule of surveys.

2. Decontamination of Equipment and Work Surfaces

If radionuclide contamination occurs, segregate the area of contamination and stop traffic into that area. Mark the area boundaries with appropriate warning signs or tape. Then proceed to decontaminate the area by cleaning up contaminant from the exterior or outer boundaries of the area and working towards the center (from the least contamination concentrations toward the heaviest concentrations of the radioactive material).

If the half-life of the radionuclide is short (hours or days), simply store the contaminated equipment or restrict ingress for ten half-lives. Then monitor with the appropriate instrument to ensure that no radioactivity above background levels can be detected.

Chromic acid, ammonium citrate, or penta sodium triphosphate solutions are effective in cleaning glassware. Work table surfaces should be cleaned by a wet method to prevent a dust hazard. Use a vacuum cleaner *only if special precautions* have been taken to filter the rejected air. Small liquid spills are easily controlled through judicious use of diatomaceous earth and/or absorbent paper. Remember to treat solutions and absorbent materials used in the decontamination process as radioactive waste. In the event of fixed radionuclide contaminants emitting low energy gammas or betas, a coat of paint or plastic covers may provide adequate protection. Routine washing of moderately contaminated clothing may be carried out according to schedules recommended for commercial laundry practice. The Radiation Safety Office (RSO) may be consulted on this procedure. As noted in the previously discussed emergency plan, any accidents resulting in major contamination (as defined in the emergency plan) should be reported to the RSO so that assistance in handling the situation can be obtained.

3. Personnel Action in Event of Contamination

Except in the case of injury, persons who have left a contaminated area should stay in the vicinity until monitored for contamination. Contaminated shoes or other clothing may have to be removed. If anyone is suspected of suffering an internal intake of radioactive material, the Radiation Safety Office should be notified. If there is an inhalation hazard due to an accidental spill in a laboratory, all persons not involved in carrying out planned safety procedures should vacate the contaminated room immediately and the room should be closed off. Persons directly contaminated by a wet spill should **immediately** remove the clothing affected and thoroughly wash the contaminated areas of the body.

In case of contaminated small open wounds or punctures, wash immediately and encourage bleeding. The danger of loose activity being eventually carried into the body is the most critical hazard. Mild decontaminating procedures should be carried out in the following manner:

Decontamination Procedures

- Use warm water.
- Soap should not be abrasive or highly alkaline.
- Scrub with a soft brush; do not abrade the skin.
- The skin should be washed only for a few minutes at a time, then dried and monitored. The degree of decontamination required will depend on the relative radiotoxicity and the chemical nature of the contaminant. Refer to Appendix A of WAC 246-221-290 for information on internal hazards of radionuclides. Remember that some radionuclides may be extremely hazardous in terms of skin toxicity, i.e. 1 mCi of P-32 spread over a 1 cm² area of skin will deliver 2000 rad/hr to that skin tissue.
- The use of organic solvents or acid or alkaline solutions should be avoided.
- Special attention should be paid to proper decontamination of creases, folds, hair, fingernails, inter-finger spaces and the outer edges of the hands. If there is a risk of spread, mask the non-contaminated adjacent areas of the body.
- After each decontamination period, the treated area should be dried with a fresh towel or swab and monitored. Materials used in the decontamination process should be treated as radioactive wastes.

4. Bioassays

In applying for permits to use radionuclides, the authorized users agree to some

periodic bioassay tests associated with tritium and radioiodine work.

a. Tritium

When there is work with more than 100 mCi of H-3, either as a single one-time procedure or the total amount used in a calendar month (throughput) exceeds 100 mCi, a program must be established to evaluate possible internal dose from H-3. After H-3 enters the body (in most chemical compound forms) it will distribute into body water and will not concentrate. It is eliminated with a biological half-life of 10 to 15 days due to the normal turnover of body water. The internal dose can be calculated if the concentration in any body fluid is determined. Normally an analysis of urine for H-3 contamination is used to determine the body burden.

1) Specific Rules Requiring Urinalysis

- Anyone working with more than 100 mCi of H-3 in a single use must have a urine bioassay within one week of each single use. Normally the personnel using the laboratory can do this analysis.
- Anyone working with a throughput of more than 100 mCi of H-3 in a month must have a urine bioassay once a month.

2) Responsibility for Urinalysis

Arrangements for urine bioassays required by the above rules will be the responsibility of the AUI. Recommended procedures are described in the Radiation Safety Manual, Section 6 Personnel Exposure and Monitoring. The results must be reported to the Radiation Safety Office on RSO Form 202.

3) Authorization

Authorization for more than 100 mCi of H-3 will normally be limited to work that can be done in a hood with face velocity specified by the manufacturer. Proposed work that cannot meet this condition must be supported by a detailed description of alternate protection measures.

b. Radioiodine

Since iodine is very volatile and iodides are easily oxidized to iodine in acid or neutral solution, the use of I-125 or I-131 may necessitate a thyroid bioassay. Anyone working in a laboratory where more than 0.5 mCi of I-125 or I-131 is used or stored during a calendar quarter shall have *in vivo* counts taken of their thyroid gland once during that quarter or within one week after the use of more than 1.0 mCi.

The bioassays are done with a solid sodium iodide crystal probe by Radiation

Safety personnel. The process is simple and involves holding the detector near the person's neck for one minute.

F. Principles of Radiation Detection (see Appendix 3, Figure 6)

1. Methods Classified by Media in Which Ionization or Excitation Interactions Occur

a. Photographic Detection Media

Photographic film was among the first radiation detectors to be identified. Film remains a main detection media, particularly for capturing medical x-ray images. Ionizing radiation causes film emulsions of silver salts to undergo chemical changes nearly identical to changes caused by visible light.

The extent of the change or "exposure" of the film is proportional to the amount of radiation interacting with the emulsion. The film darkness or density can be measured and very accurately correlated with the absorbed dose to the film.

b. Gas Media

A simple radiation detector employs a gas in a hollow tube. A center electrode is placed in the tube and a high voltage is applied between this electrode and the tube wall. Radiation passing through the tube causes ionization in the gas, and the high voltage collects the ions formed. Depending on the voltage applied, the tube will detect radiation by different modes:

1) Ionization Chamber

With a relatively low voltage the tube will collect all the ions created inside the tube by the radiation. This is measured as an electron current. The current is directly related to the radiation energy absorbed in the gas to produce the ionization. The gas filled device operated in this manner is called an ionization chamber (or ion chamber). The ion chamber measures energy deposited and can be calibrated to measure dose or dose rate directly.

2) Proportional Counter

A higher voltage produces an increase or multiplication of the initial ions inside the tube. The initial ions are accelerated with enough energy to cause further ionization. A current pulse proportional to the initial ionization is measured from the tube. This is called a proportional counter. With proper electronics, proportional counters allow measurement of one type of radiation in the presence of other radiation, i.e., alpha in the presence of beta, etc.

3) Geiger-Mueller Counter

With very high voltages, a discharge or spark occurs within the tube detector when a single ionizing event initiates or triggers the discharge. This tube counts events, but cannot distinguish high-energy from low-energy events. This tube is called a Geiger-Mueller (or GM) Counter, and is normally used to detect or count radiation. It is not usually used to determine absorbed dose; but with very specific calibration it can be used to measure radiation dose, if the radiation is similar to the calibration standard.

c. Scintillation Media

Various materials emit a small amount of light (a scintillation) when they absorb ionizing radiation. The light is "seen" by a very sensitive photomultiplier tube and registered as an electronic pulse. Early physicists actually counted the light flashes in a dark room to measure radiation. The pulse is usually proportional to the total ionization energy from each particle or photon. This property allows the use of scintillation for energy spectrum analysis. Various crystal media, such as zinc iodide or sodium iodide, are used in detector devices, but the scintillation media can also be developed in liquid form. When the scintillation media is a liquid, the radioactive sample can be immersed in the fluid. This provides a geometry that allows a counting efficiency that approaches 100%.

d. Solid State Detector Media

Some newer solid state materials can be used as radiation detectors. Current flow produced in these materials is proportional to absorbed energy. A Germanium Lithium crystal, GeLi, works on this principle and has excellent energy resolution. It is used for identifying very small amounts of radioactive material in samples.

Another type of material stores the excitation energy in a trap within the crystal matrix. When these materials are heated or stimulated optically, the trapped energy is released and emitted as light. The released light is

proportional to the initial dose. These materials are called thermoluminescent dosimeters (TLD).

2. Classifications of Instruments by Use

a. Personnel Dosimeters

For the most part, personnel dosimeters measure cumulative dose rather than acting as rate meters. They serve to give a rough but adequate history of the person's exposure to radiation over a period of time. Personnel dosimetry is required at the University of Washington if the individual is likely to receive 10% of the regulatory limits of occupational dose or if there is frequent contact with external radiation hazards.

1) Ring Badge (TLD)

The ring badge consists of a chip of thermoluminescent material inserted into a plastic ring. The atoms of the thermoluminescent dosimeter (TLD) are excited by radiation interaction and de-excited only when exposed to heat. The de-excitation process results in light photon emissions proportional to radiation doses that are amplified by a photomultiplier tube in a readout instrument. This type of dosimeter is used when individuals are handling radionuclides that present an external radiation risk to the hands, i.e. P-32.

2) Optically Stimulated Luminescence (OSL) Dosimeter

An optically stimulated luminescence dosimeter consists of an aluminum oxide layer coated on a plastic base. After use, the dosimeter is optically stimulated with a laser light causing it to luminesce. The amount of luminescence is proportional to the amount of radiation exposure the dosimeter received. Metal and plastic filters built into the badge can shield portions of the aluminum oxide. This allows differentiation between different types and energies of radiation. These dosimeters have a large dynamic range, increased sensitivity, and long-term stability.

3) Pocket or Self-Reading Dosimeters

These dosimeters are roughly pocket sized and can be clipped to a belt or a pocket. Some of these units are air filled ion chambers and others use a GM counter. These instruments are usually only useful for measuring accumulated gamma or x-ray exposure, but they give immediate output. Self-reading dosimeters often have alarms that inform the user after they accumulate a dose (like every 1/10 mR or 1 mR). They can be quite useful for evaluating which part of a procedure or experiment gives the highest dose to the operator.

4) Population Served by Personnel Dosimeters

Personnel monitoring is used by the following University populations:

- Nuclear Medicine Laboratory personnel - *whole body and ring dosimeters.*
- Individuals working with x-ray units - *whole body dosimeter.*
- Individuals providing brachytherapy - *whole body and ring dosimeters.*
- Nursing staff working with, or around, patients who have millicurie sources in them - *whole body dosimeter.*
- Accelerator site personnel - *whole body plus neutron dosimeter.*
- Open bench work involving 1 millicurie per week of gamma emitting radionuclides and high energy beta emitters - *ring dosimeter.*
- Open bench work involving 10 millicuries gamma and high energy beta emitters - *whole body and ring dosimeters.*

b. Survey Instruments

The survey instrument most commonly used in the laboratory is the Geiger Counter, usually one with a thin window probe to permit beta as well as gamma and x-ray detection.

Survey instruments frequently used at the University of Washington can be used with either scintillation or Geiger-Mueller probes. These instruments have a built-in speaker system for audio response to radiation.

Each survey instrument is energy dependent in one way or another, so periodic calibration is necessary. The Radiation Safety Office will assist in providing proper calibration. Calibrations are made with standard radionuclide sources to:

- 1) determine the energy dependence,
- 2) determine directional effects,
- 3) measure the scale accuracy,
- 4) find rate dependence, and
- 5) determine counting efficiency of standard sources.

Knowledge of the instrument in respect to energy response and geometry is

necessary to properly use the instrument. Energy response and the geometry or directional effects are generally characteristic of the instrument probe and the probe positioning. Scale accuracy and rate dependence of the instrument are adjustable parameters of the instrument itself and must be verified by calibration. One of the most often seen deficiencies in survey instrument use is leaving the instrument on after use and thereby depleting the batteries.

Liquid scintillation instruments and Geiger-Mueller instruments with a thin window probe are the most frequently used laboratory instruments for counting radioactive samples and/or swipes. Care should be taken to locate laboratory counting instruments in low radiation background areas and in clean non-contaminated environments.

G. Mitigating External Radiation Hazards

1. Time

Reduction of exposure time can be used to minimize external radiation hazards through the following mechanisms.

- Reduce radionuclide handling.
- Practice laboratory procedures without the radionuclide dry runs.
- Do your thinking away from the radiation field.

2. Distance

Increasing the distance between you and the radiation source will reduce exposure by the square of the distance. Distance can be increased by the following practices.

- Use tools with long handles.
- Use stands and clamps to hold the radioactive material and place the radionuclide set up as far back from occupied areas as possible.
- Step back or out of the area when not directly working with radiation source.

3. Shielding

Shielding a radiation source can effectively reduce the exposure rate providing the following cautions are observed.

- Know where the edges are for your shadow shielding and that shielding is defeated when scatter radiation (Compton scattering) is a factor.

- Shielding is most effective when it is placed close to the source.
- Plastic shielding (1/4 inch) should be used for P-32.
- Lead is an efficient shield for most gamma emitters. 1/16 inch of lead will shield the weak gamma photons from ¹³⁷Cs; but 1/2 inch to 1 inch lead is needed to reduce most gamma beams to 10% of their original intensity.

It is not always necessary to exactly calculate the shielding properties of a barrier you have erected, simply check out the attenuated beam with a survey instrument.

H. Mitigating Internal Radiation Hazards

1. Good Hygiene

Good hygiene habits and good housekeeping will effectively contain the internal radiation hazards presented by radionuclides. Part of good hygiene is control of mouth habits and eating.

2. Control of Contamination

When contamination does occur, the area of contamination should be limited or contained by isolation, warning signs and subsequent clean up activities. Periodic surveys should be carried out to identify any contamination before it has an opportunity to spread.

3. Airborne Hazards

Initial control of airborne radionuclide contamination is accomplished by recognition of procedures, material and equipment that may result in the production of aerosols, volatile off-gases, dusts, etc. and taking preventive steps (i.e. working with a fume hood, **not working** with RAM in a closed atmosphere cold room).

4. Protective Clothing

The use of gloves, laboratory coats and other protective clothing minimizes the chances for the ingestion or absorption of radioactive materials. The use of suitable respirators when airborne contamination is present will prevent the inhalation of the volatile or airborne radionuclides.

As there are occupational limits for the *external* radiation exposure, so are there limits for *internal* exposure. Internal exposure is slightly more complicated than external exposure, since different radionuclides concentrate in different organs or

areas of the body depending on the nature of the radionuclide itself. (For example, iodine concentrates in the thyroid, whether it is radioactive or not.) The annual intake limits for radionuclides are shown in Appendix 1, Figure 13 “Annual Limits on Intake (ALI) for Occupational Exposure.” These values, shown in μCi and Bq , are the amount of each radionuclide that if ingested or inhaled will result in the annual dose limit for target, or “critical” organs affected by that radionuclide.

Abbreviations

AUI	authorized investigator
Ci	curie
LFM	linear feet per minute
MPC	maximum permissible concentration
RAM	radioactive materials
RSO	Radiation Safety Office
TLD	thermoluminescent dosimeter
WAC	Washington Administrative Code

Glossary

authorized investigator (AUI): A principle investigator authorized by the Radiation Safety Office who becomes legally responsible for the handling of radioactive material under their jurisdiction. The Authorized Investigator (AUI) is usually a faculty member or a medical doctor.

calibrate: To check, adjust, or systematically standardize the graduations of a quantitative measuring instrument.

Compton scatter: The scattering of a photon by an electron. Part of the energy and momentum of the incident photon is transferred to the electron and the remaining part is carried away by the scattered photon.

densitometer: An apparatus for measuring the optical density of a material, such as a negative.

dosimeter: A device that measures and indicates the amount of x-rays or other radiation absorbed.

eddies: Currents of water or air moving contrary to the direction of the main current, especially in a circular motion.

electromagnetic: A magnetic force arising from electric charge in motion.

emulsion: A light-sensitive coating, usually of silver halide grains in a thin gelatin layer on photographic film, paper, or glass.

in vivo: Within living organisms.

laboratory radiation safety agent: Individual appointed by Authorized Investigator to be in charge of radiation safety issues within the laboratory.

phosphor: A substance capable of emitting light when struck by incident radiation.

photon: A quantity of electromagnetic energy, often referring to radiation emitted from the nucleus of an atom. Can also refer to light energy, or other forms of wave energy.

radioisotope: Two or more radionuclides having the same atomic number, hence constituting the same element, but differing in mass number.

radionuclide: A nuclide that has a combination of neutrons and protons which cause the nucleus to be unstable.

scintillation: The emission of light energy by a substance, often a crystalline structure, when struck by incident radiation.

throughput: Output or production over a period of time.

velocity: Rate of motion in a fixed direction.

volatilization: Process of readily evaporating at normal temperatures and pressures.

Appendix 3

Figure 1 (On Campus Use)

EMERGENCY PROCEDURES

RSO Form.39 (12/99)

*MUST BE POSTED IN EACH CERTIFIED LABORATORY IN A CONSPICUOUS LOCATION***Emergency Phone Numbers:** (Fill in)

Radiation Safety Officer

206-543-0463

University Police

9-911

Principal Investigator (Name & Home Phone) _____

Lab's Radiation Safety Agent (Name & Home Phone) _____

Radionuclides in Use: (Circle radionuclides being used in lab) (ALI = Annual Limit on Intake)						
GROUP I ALI > 10 mCi	GROUP II 1 mCi < ALI ≤ 10 mCi			GROUP III 0.1 mCi < ALI ≤ 1 mCi		GROUP IV 0.01 < ALI ≤ 0.1 mCi
H-3	C-14	Mn-54	Mo-99	Na-22	Sr-89	Sr-90
F-18	Na-24	Fe-55	In-111	P-32	Cd-109	I-125
Cr-51	P-33	Co-57	I-123	Cl-36	Ag-110m	I-131
Cu-64	S-35	Co-58	Hg-197	Ca-47	Cd-115m	
Tc-99m	K-42	Ga-67	Au-198	Fe-59	Ir-192	
In-113m	Ca-45	Hg-203 (inorganic)		Zn-65	Hg-203 (organic)	

MAJOR SPILLS: Group I > 10 mCi / Group II > 1 mCi / Group III > 0.1 mCi / Group IV > 0.01 mCi

- CLEAR THE AREA.** Notify all persons not involved in the spill to vacate the room.
- PREVENT THE SPREAD.** Cover the spill with absorbent pads or diatomaceous earth, but do not attempt to clean it up. Confine the movement of all personnel potentially contaminated to prevent the spread.
- SHIELD THE SOURCE.** If necessary, the spill should be shielded, but only if it can be done without further contamination or without significantly increasing your radiation exposure.
- CLOSE THE ROOM.** Leave the room and lock the door(s) to prevent entry.
- CALL FOR HELP.** Notify the Radiation Safety Officer immediately.

MINOR SPILLS: Spills less than major spill quantities.

- NOTIFY.** Notify persons in the area that a spill has occurred.
- PREVENT THE SPREAD.** Cover the spill with absorbent paper or pads or spread absorbent diatomaceous earth.
- CLEAN UP.** Use disposable gloves; remote handling tongs should also be used whenever possible. Carefully fold the absorbent paper or pads. Scoop up absorbent diatomaceous earth with cardboard. Insert into a plastic bag and dispose in the radioactive waste container. Also insert into the plastic bag all other contaminated materials such as disposable gloves.
- SURVEY.** With a low-range, thin-window G-M survey meter, check the area around the spill, hands, and clothing for contamination. Survey H-3 and C-14 spills with wipes counted in LSC.
- REPORT.** Report incident to the Radiation Safety Officer.
- PERSONNEL DECONTAMINATION.** Contaminated clothing should be removed and stored for further evaluation by the Radiation Safety Officer. If the spill is on the skin, flush thoroughly and then wash with mild soap and lukewarm water.

Figure 2 (Off Campus Use)

EMERGENCY PROCEDURES

RSO Form 39 (12/99)

MUST BE POSTED IN EACH CERTIFIED LABORATORY IN A CONSPICUOUS LOCATION

Emergency Phone Numbers: (Fill in)

Radiation Safety Officer

206-543-0463

University Police

9-911

Principal Investigator (Name & Home Phone) _____

Lab's Radiation Safety Agent (Name & Home Phone) _____

Radionuclides in Use:		(Circle radionuclides being used in lab)					(ALI = Annual Limit on Intake)
GROUP I ALI > 10 mCi	GROUP II 1 mCi < ALI ≤ 10 mCi			GROUP III 0.1 mCi < ALI ≤ 1 mCi		GROUP IV 0.01 < ALI ≤ 0.1 mCi	
H-3	C-14	Mn-54	Mo-99	Na-22	Sr-89	Sr-90	
F-18	Na-24	Fe-55	In-111	P-32	Cd-109	I-125	
Cr-51	P-33	Co-57	I-123	Cl-36	Ag-110m	I-131	
Cu-64	S-35	Co-58	Hg-197	Ca-47	Cd-115m		
Tc-99m	K-42	Ga-67	Au-198	Fe-59	Ir-192		
In-113m	Ca-45	Hg-203 (inorganic)		Zn-65	Hg-203 (organic)		

MAJOR SPILLS: Group I > 10 mCi / Group II > 1 mCi / Group III > 0.1 mCi / Group IV > 0.01 mCi

- CLEAR THE AREA.** Notify all persons not involved in the spill to vacate the room.
- PREVENT THE SPREAD.** Cover the spill with absorbent pads or diatomaceous earth, but do not attempt to clean it up. Confine the movement of all personnel potentially contaminated to prevent the spread.
- SHIELD THE SOURCE.** If necessary, the spill should be shielded, but only if it can be done without further contamination or without significantly increasing your radiation exposure.
- CLOSE THE ROOM.** Leave the room and lock the door(s) to prevent entry.
- CALL FOR HELP.** Notify the Radiation Safety Officer immediately.

MINOR SPILLS: Spills less than major spill quantities.

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- SURVEY.** With a low-range, thin-window G-M survey meter, check the area around the spill, hands, and clothing for contamination. Survey H-3 and C-14 spills with wipes counted in LSC.
- REPORT.** Report incident to the Radiation Safety Officer.
- PERSONNEL DECONTAMINATION.** Contaminated clothing should be removed and stored for further evaluation by the Radiation Safety Officer. If the spill is on the skin, flush thoroughly and then wash with mild soap and lukewarm water.

Figure 3

Radiation Safety Manual – Section 14

Radioactive Waste

Contents

- A. Proper Collection, Disposal, and Packaging
 - 1. Dry Waste
 - 2. Liquid Waste
 - 3. Liquid Scintillation Counting (LSC) Waste
 - 4. Animal Carcasses and Putrescible Animal Waste
 - 5. Possible Infectious Wastes
 - 6. Fumes and Vapors
 - 7. Incineration
 - 8. Storage for Decay
 - 9. Mixed Waste
 - 10. Lead
 - 11. Uranium and Thorium Compounds
- B. Records and Labeling
 - 1. Waste Disposal Records
 - 2. Marking Packages for Collection
- C. Other Items of Importance
 - 1. Designation of Radioactive Waste Containers
 - 2. Radioactive Material Labels
 - 3. Security
 - 4. High Exposure Level Waste
 - 5. Waste Containers
 - 6. Ventilation of Containers
 - 7. Radioactive Material Waste Fees

Tables

- Table 14-1 Characteristics of Hazardous Waste
- Table 14-2 Catalog Numbers for Ordering Waste Supplies

A. Proper Collection, Disposal, and Packaging

1. Dry Waste

a. Acceptable

Dry waste consists of paper, gloves, glass, plastics, and other forms of solid waste.

b. Unacceptable

It is forbidden to put the following items in dry waste

- 1) Uranium and thorium compounds.
- 2) Liquid in any form.
- 3) Lead.
- 4) Animal carcasses.
- 5) Putrescible waste.
- 6) Human blood or tissue.

c. Disposal:

- 1) Dry Waste

Dry waste is collected in the standard Low Specific Activity (LSA) box that has been lined with a plastic bag. See Table 14-2, at the end of Section 14 of the UW Radiation Safety Manual, for catalog numbers for ordering LSA boxes and plastic bags.

- 2) Sharps

Sharps include glass pipettes, broken glass, and needles. They should be placed in a strong inner package, which is placed in the LSA box.

2. Liquid Waste

a. Sewer Allowance

The UW is allowed to dispose of material that is soluble or readily dispersible in water into the sanitary sewer, as long as quantities are restricted. A portion of the UW's allowance for sewer disposal is allocated to each lab. Each registered radioactive materials (RAM) laboratory may have a sink or drain designated for liquid radioactive waste disposal.

1) Single Laboratory

The single laboratory allowance for each calendar quarter is as follows:

H-3	1000	μCi
C-14	200	μCi
I-125	100	μCi
All other radionuclides combined	200	μCi

2) Multiple Laboratories

When a group of RAM laboratories are assigned to one Authorized Investigator, the allowance for the group is the sum of the allowance for each lab. For example, if you have six labs assigned to your use, you may dispose of a total of six times the limit given above. **Records of all sink disposals must be maintained by each Authorized Investigator** to show compliance within the limits. Radiation Safety Office (RSO) Form 170, Quarterly Sink Disposal Record for Radioactive Material, is available for this purpose.

3) Release

The soluble or readily dispersible material must be released into a strong flow of water to allow complete purge of traps. Consult the UW Environmental Health and Safety (EH&S) website or call the Radiation Safety Office at 543-6328 for the current list of approved sewer disposable liquid scintillation fluids.

4) Restricted or Not Allowed

a) Restricted Liquid Scintillation Fluids

This restriction includes soluble liquid scintillation fluids that are not approved for sewer disposal.

b) Not Sewer Disposable

Organic solvents or other hazardous materials are not to be disposed of into the sewer.

5) Special Projects

A portion of the University's licensed sewer disposal allowance is held in reserve for special projects, which generate unusual quantities of liquid waste. Permission to make these nonroutine disposals should be requested from the RSO.

b. Aqueous Liquid

Aqueous liquids that exceed the sewer allowance are not candidates for sewer disposal and must be absorbed and transferred to Radiation Safety (RS) staff for disposal.

1) Waste Collection Procedures

Only properly packaged aqueous waste will be accepted for disposal by the RS staff.

- a) Use plastic pails and lids, which are available from **Radiation Safety**. See Table 14-2, at the end of Section 14 of the UW Radiation Safety Manual, for catalog numbers for these supplies.
- b) Pails should be labeled with a radiation label and filled only **half-full** with diatomaceous earth, an absorbent. See Table 2 for the catalog number for diatomaceous earth.
- c) The lid can be secured and liquid added through the bung hole, or the lid can be left loose.
- d) Add liquid waste until it will no longer "soak in."
- e) Fill the remaining half volume with diatomaceous earth. **Do not add more liquid.** This will assure the legal disposal of approximately 1.5 gallons of aqueous solution in a 5-gallon pail. Fill the bucket as full as possible with dry absorbent to minimize the void space in the pail.
- f) Secure the lid and the bung hole plug.
- g) Wipe any spilled waste from the top, sides and bottom of the pail.
- h) **No items other than aqueous liquid and diatomaceous earth are allowed in pails.**

2) Maximum Allowed Pail Weight:

- a) 5-Gallon Pail - maximum pail weight is 38 lbs.
- b) 3.5-Gallon Pail - maximum pail weight is 26 lbs.
- c) Pails over the appropriate weight or that contain materials other than absorbed aqueous liquid and diatomaceous earth will be returned to the lab of origin for repackaging.

3) Removing Lid

It is not possible to remove the lid from a plastic pail once it has been secured without breaking the binding ring. If a secured lid is removed, it must be replaced with a new lid.

4) Cautions

a) Inhibit Biological Growth

A pail of absorbed liquid waste can serve as an ideal growth chamber and may generate gas when cell culture media or other nutrients decompose. Waste may need to be treated prior to disposal by adding an appropriate growth inhibitor.

b) Biohazard Control, Decontamination

Consult the UW Biohazard Safety Manual, Chapter IV Procedures for Biohazard Control, Part C Decontamination.

c) Possible Side Reactions

An example of a possible side reaction is chlorine bleach releasing chlorine gas or stimulating the volatilization of radioactive iodine.

5) Liquid Scintillation Fluid

This is not considered aqueous liquid, and must be handled separately. See Item 3 - Liquid Scintillation Counting Waste below.

3. Liquid Scintillation Counting (LSC) Waste

a. Bulk LSC Waste

1) Cost

The most economical method of disposing LSC waste is in bulk form.

2) Bulking

LSC waste can be emptied from vials and consolidated into tight-lidded, labeled containers.

3) LSC Bottles

The original LSC bottles in the original cardboard carton are recommended for packaging waste LSC fluid.

b. Vials and Contents

1) Disposal

Vials containing LSC fluid can be accepted by the RS staff for disposal; however, the cost is greater than for disposal of bulk LSC waste.

2) Packaging

LSC vials and contents should be packaged in the original "egg crate" cartons, because loose vials in boxes are prone to leakage. Also, do not use LSA boxes to package vials. An LSA box full of scintillation vials is too heavy for pickup.

c. Safe Handling of LSC Waste

1) Caution During Handling

- a) LSC waste may contain several solvents, including toluene, dioxane, xylene, and/or trimethylbenzene.
- b) Many LSC fluids contain chemicals that are suspected carcinogens.
- c) Inhalation, skin contamination, and fire hazards must be considered in handling LSC waste.

2) Protection during Handling

- a) Filling and emptying LSC vials may require the use of an operating fume hood.
- b) During work individuals should wear gloves, eye protection, and a lab coat.

3) Handling Empty Vials

- a) Empty vials can be re-used or properly disposed.
- b) If vials are to be disposed, they should either be evaporated to dryness or rinsed in a pail of warm detergent water within a ventilated space to eliminate residual solvent vapors, and checked for contamination.
- c) Empty glass vials should be discarded with lab glassware. Empty plastic vials may be discarded in normal trash.

4) Storing Bulk LSC Waste

Bottles of LSC waste should be stored until collected in cabinets approved for flammable materials.

5) Exceptions

- a) Some newer types of LSC fluid may be safer to use and, therefore, require fewer precautions.
- b) Be sure to consult manufacturer's recommendations before you deviate from the above procedures.

4. Animal Carcasses and Putrescible Animal Waste

a. Non-Radioactive Animal Waste

1) Below Regulatory Limits

Animals contaminated with H-3 or C-14 at a concentration less than 0.05 $\mu\text{Ci}/\text{gram}$, or other radionuclides at a concentration below 0.005 $\mu\text{Ci}/\text{gram}$ can be disposed as non-radioactive waste.

2) Specific Organs

Organs with concentrated radioactivity may be removed and treated separately as radioactive waste if the remainder of the animal is below regulatory limits. See Item b.1) for handling of those specific organs.

b. Radioactive Animal Waste

1) Organs with Higher Levels

If certain organs with H-3 or C-14 concentrated radioactivity at or above 0.05 $\mu\text{Ci}/\text{gram}$ or other radionuclides at or above 0.005 $\mu\text{Ci}/\text{gram}$, these parts can be removed for radioactive waste disposal.

2) Animal Waste above Limits

Putrescible animal waste containing radionuclides greater than the levels listed in Item a.1) above must also be treated as radioactive waste. This includes blood, excreta, tissue samples, animal bedding, and similar materials.

3) Disposal

Animal carcasses, animal organs, or putrescible animal waste containing long-lived radionuclides above the exempt limits **must be transferred to RS staff** for disposal.

4) Packaging for Disposal

To package radioactive animal carcasses, animal organs, and putrescible animal waste, do the following. Waste presented in an incorrect form or which becomes putrid will jeopardize the authorization to use radioactive materials. Putrid packages will be returned to the originating laboratory for proper packaging.

a) Seal into two layers of plastic bags.

b) Take to Comparative Medicine, Health Sciences D607 (freezer section).

- c) Label with a RAM tag provided in HSB D607. The tag should be filled out with all information required for disposal.
- d) Large Animals

When the disposal of large animals is anticipated, arrange with RS staff to have a 30-gallon drum delivered to your work area. The carcass can then be placed in the drum before it becomes rigid. When notified, the RS staff will pick up the drum and take it directly to the freezer in Health Sciences B122.

c. Animal Carcasses Containing Short Half-Lived Materials

- 1) Holding for Decay

Animals containing only radionuclides with short half-lives can be held for radioactive decay, provided the average activity concentration will be less than 0.005 $\mu\text{Ci}/\text{gram}$ within six months, to prevent long term storage.

- 2) Storage

These animals are stored without charge. Make arrangements with the Radiation Safety Office.

- 3) Labeling

This waste **must be labeled** by the researcher to indicate the date at which the activity of the waste will be below 0.005 $\mu\text{Ci}/\text{gram}$.

5. Possible Infectious Wastes

a. Type of Infectious Wastes

- 1) Human blood.
- 2) Human tissues.
- 3) Human wastes of any kind.
- 4) Animal carcasses or wastes that contain active pathogens.

b. Processing

- 1) Sterilization

These materials need to be processed in an appropriate manner to sterilize any biological agent.

2) Incompatible Processing

Some sterilization procedures, such as treatment with chlorine bleach, may be incompatible with control of radioactive materials. Contact the RSO for special review, if you have questions or are uncertain about the appropriate procedure.

6. Fumes and Vapors

a. Atmospheric Releases

The UW is allowed to emit small quantities of radioactive materials to the atmosphere. An evaluation of the potential release, the exhaust stacks, and the exhaust rates must be made and included with other University releases.

- 1) The Radiation Safety office will assist with this evaluation.
- 2) Atmospheric release, as part of ongoing research projects, needs to be evaluated by Radiation Safety staff. You must present a detailed discussion of your plans in the application to use radioactive materials or in an application for amendment to your authorization.

7. Incineration

At present, there is no provision in the University license or local pollution prevention laws to permit incineration of radioactive materials.

8. Storage for Decay

a. Waste That Can Be Stored for Decay

1) Short-Lived Radionuclides

Short-lived radionuclide waste can include almost all radionuclides on campus with a half-life of 100 days or less. Radionuclides, such as tritium and carbon-14, have a half-life greater than 100 days, and, therefore, cannot be held in storage for decay.

2) Acceptable Locations for Storage

Short-lived radioactive materials may be stored for decay in the User's facilities or transferred to RS staff for a storage and handling fee. **Putrescible material** is not allowed and should not be included.

b. Length of Storage

1) Time Held

Waste must be held for at least 10 half-lives.

2) Decay Limit

Waste must be decayed to less than 0.0001 $\mu\text{Ci}/\text{gram}$ (100 pCi/gram).

c. Prior to Disposal of Decayed Materials into Normal Trash

1) Package Survey

Packages must be surveyed to assure no long-lived contaminants are present.

2) Decay Calculations

The current activity must be determined using appropriate decay equations or tables. Packages must be weighed to enable calculation of final concentration.

3) Labels

All radionuclide labels and radiation symbols must be removed or defaced.

4) Internal Labels

Waste given to the RS staff for decay must be properly labeled on the outside, but internal labels and radiation symbols must have been removed or marked out.

d. Record Keeping

1) Required Data

Careful records must be kept of original activity, time of decay, final concentration of radionuclides, and the radiation survey prior to disposal.

2) Records Retention

You must keep these records for three years.

9. Mixed Waste

The University currently does not have a means of disposal for mixed waste. Review laboratory procedures to eliminate the production of mixed wastes. Processes that use or generate materials that could potentially become mixed wastes will not be authorized.

a. Definition

Mixed waste is radioactive waste that has a hazardous waste component.

b. Characteristics and Examples of Mixed Waste

Table 14-1 is a list of characteristics and examples to help you avoid generating mixed waste. Contact the RSO, 206-543-6328, to assist in researching questions concerning this issue.

Hazardous waste disposal must be consistent with the University's Hazardous Waste Program. Call 206-685-2848 for questions concerning disposal of hazardous waste.

c. Neutralization and Deactivation

In some cases, the hazardous aspect can be neutralized and/or deactivated. The generating laboratory, if appropriate, must do this process.

d. Lead

Lead in any form is not permitted in radioactive waste, since its inclusion with radioactive materials constitutes mixed waste. This includes lead shielding.

10. Lead

Disposal - A laboratory wishing to dispose of lead must segregate it from their radioactive waste, and the RS staff will collect it at no charge.

Table 14-1
Characteristics of Hazardous Waste

Characteristic	Description	Examples
Flammable	Liquids with a flash point less than 140° Solids which spontaneously ignite in air or can ignite through friction or absorption of moisture	Methanol, xylene, other solvents Zinc dust, pyrophoric organometallic compounds
Oxidizer	Compounds which promote combustion	Potassium, permanganates, chromic acid
Corrosive	Liquid with a pH less than 2 or greater than 12.5 Solids which, when mixed with an equal part water, will form solutions with a pH less than 2 or greater than 12.5	Sulfuric acid, ammonium hydroxide Ferric Chloride
Reactive	Unstable compounds which may explode Compounds which react violently with water Compounds which may produce toxic gases when in contact with water or acids	Picric acid, perchloric acid, lead azide Metallic sodium and potassium Acetyl chloride, sodium cyanide
Toxic	High acute toxicity to mammals by ingestion, inhalation, or skin absorption (measured by median lethal doses in laboratory animals) High toxicity to fish (measured by laboratory aquatic toxicity tests) Compounds possessing high organ-specific toxicity	Phenol, mercury salts, lead, organophosphates Chromic acid, silver salts Carbon tetrachloride
Environmentally Persistent	Halogenated hydrocarbons 4-, 5-, and 6-ring polycyclic aromatic hydrocarbons	Trichlorethylene Benzo (a) pyrene, 3-methylcholanthrene

11. Uranium and Thorium Compounds

a. Separation

Uranium and thorium compounds may **not** be mixed with other radioactive waste forms.

b. Disposal

Uranium and thorium waste must be collected separately by the RS staff.

B. Records and Labeling

The University's license requires that we maintain records of inventory and control on all aspects of work with radioactive materials.

1. Waste Disposal Records

a. Radioactive Material Delivery and Usage Record (Form 160)

A Form 160 is provided with each shipment of radioactive material. Indicating the disposal methods of the radionuclide on the Form 160 and returning it to the RSO reduces your inventory. The Authorized Investigator should retain copies of these records, for at least three years, to be available for inspection and to verify disposal of inventory.

b. Disposal Log

To establish how much radioactive waste is involved in the following processes, the Authorized Investigator should maintain a log for each mode of disposal.

- 1) You may use RSO Form 150 to record how much activity is in each container. This form is optional and available from the Radiation Safety Office. Form 150-type records should be totaled to determine the approximate values for labeling the contents of each filled waste container. This information should be consistent with that on Form 160, but scrupulous correlation is not necessary.
- 2) Use RSO Form 170 to record the amount of radioactive waste released to the sewer.
- 3) You must also keep track of the amount of radioactive materials released to the atmosphere. This may be recorded on RSO Form 160.

2. Marking Packages for Collection

Packages that are full and ready for collection must be securely closed and marked or labeled to show the following information:

- Authorized Investigator's name
- Phone #
- Budget #
- Mail Box #
- Radionuclide(s)
- Total activity of each radionuclide
- Laboratory of origin
- RAM tape or label (see C.2.b. - Marking Waste Containers)

C. Other Items of Importance

1. Designation of Radioactive Waste Containers

Clearly label each waste container with a sign to indicate radioactive waste. Use the standard radiation sign or a strip of radioactive tape.

Since custodians occasionally collect radioactive waste by mistake, handmade hazard signs and handwritten messages are not adequate. Some custodians may not be able to read or interpret them correctly. Also, do not use "Laboratory Glassware" tape to secure radioactive waste boxes closed.

2. Radioactive Material Labels

a. Purpose of Labels

Do not misuse RAM labels. RAM labels are intended as a warning. Improper use of labels causes unnecessary alarm and leads to disregard for the proper warning.

b. Removal of Labels

A container that once contained radioactive material should have labels or signs removed or marked out before the container is discarded or placed in storage.

3. Security

Radioactive waste containers **should not** be placed in hallways or unsecured areas.

4. High Exposure Level Waste

a. "Hot Project" Waste

Waste from a special project that involves high radiation activity (hot project) should be sealed up immediately for early removal from the work area. Smaller packages can be used if normal packages are too large.

b. Disposition

Prior arrangements may be made to schedule the early collection of "hot" packages. However, researchers must be prepared to store it in their laboratory until collection is possible.

5. Waste Containers

Standard radioactive waste containers should be used **only** for radioactive materials.

6. Ventilation of Containers

a. Proper Ventilation

Vapor and fumes may accumulate above waste containers. Therefore, waste receptacles should be in or near a fume hood or other ventilated space.

b. Adding Waste

Partially full containers should be allowed to ventilate "down wind" when opened to add more waste.

7. Radioactive Material Waste Fees

a. Determination of Waste Fees

The Washington Utilities and Transportation Commission determines the fees for radioactive waste disposal in our state.

b. Changing Rates

In general, disposal rates can be expected to rise. Waste disposal costs fluctuate depending on market factors such as:

- 1) Broker costs.
- 2) Total disposal volumes from the entire northwest region.
- 3) Taxes.
- 4) State and waste-site license fees.

c. University Costs

The disposal prices charged to individual researchers are equal to University of Washington costs. Call the RSO for specific price information (206-543-0463).

Table 14-2
Catalog Numbers for Ordering Waste Supplies

#	Item	Central Stores Catalog #
Section – Food Services & Janitorial Supplies		
1	LSA Box	0737042
2	Plastic Liner	0060132
3	5-Gallon Plastic Pail	0737237
4	3.5-Gallon Plastic Pail	0737240
5	Diatomaceous Earth	0737236
Section – Hardware, Electrical, Plumbing		
	Lead	6451030

Figure 4

FORM 160 RADIOACTIVE MATERIAL DELIVERY AND USAGE RECORD (10/04)

AUI Name _____ PO # _____

AUI # _____ Item # _____

Order Date _____ Order # _____

Radionuclide (Chemical Form) _____ Definition # _____

Description _____ Activity _____ mCi

Comments _____ Delivery Date _____

INVESTIGATOR'S RESPONSIBILITY UPON RECEIPT OF PACKAGE (WAC 246-221-160(5)):

Regulations require individuals receiving shipments of radioactive materials to monitor the inside of packages in order to detect a leaking container. After opening the package, wipe the outside of the smallest inner container (or alternatively, the packing materials immediately adjacent to the innermost container) and count the wipe sample with an appropriate instrument. Record results below. If contamination is found, take appropriate steps to control and remove contamination. Further ensure that packaging materials are free of contamination and that radioactive labels are defaced prior to their disposal into the normal waste stream.

RESULT OF WIPE SAMPLE:

Survey performed by _____ (Initials)

- No contamination found
- Contamination above background _____ cpm

Contact Person _____ (Print Name)

DISPOSAL RECORD

Summarize estimated activity for each type of use or disposal. Retain a copy of this form for 3 calendar years after disposal of material!

Collected by RSO	mCi
A. Animal Carcasses & Waste	_____
B. Solid Dry, LSA Box	_____
C. Absorbed Aqueous Liquid	_____
D. LSC Vials	_____
E. LSC Bulk Fluid	_____
Released to Environment	
F. Sewer	_____
G. Released to Atmosphere (Requires prior approval from Radiation Safety Office)	_____
Other	
H. Administered to Humans	_____
I. Decayed	_____
J. Holding for Decay (For at least 10 half-lives, only if half-life < 100 days.)	_____
K. Other (describe or circle type) Not received; Returned to vendor; Long lived unusable storage	_____
Transferred To AUI _____	_____
Date of Transfer _____	
To: Tech Contact _____	
Bldg _____ Room _____	
Transferred To Non-UW Entity _____	_____
Subtotal	_____
Activity Remaining and/or Reusable Product	
<input type="checkbox"/> Started New Form 160	_____
Total	_____

Must equal activity received as shown above

Date _____ Box # _____ Phone _____

RETURN TO: Radiation Safety Office, Box 354400

UW EH&S Radiation Safety Office Box 354400 201 Hall Health Seattle WA 98195-4400 206-543-0463

Figure 5

Radiation Safety Manual - Section 13

Laboratory Survey Procedures

Contents

- A. Purpose of Surveys
- B. Frequency
 - 1. Surveys After Use
 - 2. Required Monthly Surveys
 - 3. Working Surveys and Self-Monitoring
 - 4. Surveys of Common Use Areas
 - 5. Radiation Safety Staff Surveys
- C. Survey Methods
 - 1. Method 1 - Wipes / Scintillation Counting
 - 2. Method 2 - Portable Detector
 - 3. Method 3 - Portable Detector with Wipes
- D. Method for Specific Radionuclides
 - 1. Hydrogen-3
 - 2. Carbon-14 and Sulfur-35
 - 3. Iodine-125
 - 4. Phosphorus-32, Chromium-51, Iron-55, Iron-59, Iodine-131, and Other High-Energy Beta or Gamma Emitters
 - 5. Combinations of Radionuclides
- E. Where to Survey
 - 1. General Rule
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- F. How to Record Surveys
 - 1. Survey Form
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- G. General Laboratory Practices
 - 1. Poor Laboratory Housekeeping
 - 2. Food and Drink
 - 3. Radioactive Waste
 - 4. Laboratory Security
- H. Inspection of Records

Tables

Table 13-1 Radionuclides Arranged in Hazard Groups According to Annual Limit on Intake (ALI)

A. Purpose of Surveys

The safe use of radioactive materials requires frequent surveys in each area where unwanted contamination or external radiation may exist. In laboratories where handling practices are good, the results of the survey will usually show no evidence of contamination. Good practices cannot be assured without these survey results.

It is difficult to define a "safe" or "allowable" level of contamination or external radiation. The important word is unwanted. If radiation is unwanted, efforts should be made to reduce it or eliminate it completely. Otherwise, it poses an unnecessary risk, however small.

Beyond the safety issue, contamination or external radiation can interfere with experimental sensitivity and results. Radiation levels that would cause these types of concerns are often far more limiting than what might be defined as safe for personnel.

B. Frequency

1. Surveys After Use

It is the responsibility of the Authorized Investigator and his/her laboratory personnel to assure that radioactive material is contained after each use. In order to assure this, monitoring in University of Washington laboratories must be conducted by lab personnel soon after the time of use. These "after use" surveys must be recorded. They do not need to include the entire laboratory, but may be limited to the particular portion of the laboratory where the work took place.

2. Required Monthly Surveys

In addition, laboratory personnel must perform a "monthly" survey of the entire laboratory. The monthly survey must be performed even if there was no known use of radioactive materials in the laboratory during that month-long period. The surveys must be made with instruments or wipes as appropriate for all the radioactive materials the laboratory is authorized to use. These "monthly" surveys must also be recorded.

3. Working Surveys and Self-Monitoring

Frequent surveys while using radioactive materials are encouraged. In addition, good practice necessitates a working survey or self-monitoring in certain situations. Examples of situations where working surveys would be necessary would be when use or process is interrupted by a distraction, and whenever contamination is suspected. Self-monitoring must be done before leaving the area,

for example when taking a break or leaving for lunch. Working surveys and self-monitoring do not need to be documented.

4. Surveys of Common Use Areas

When more than one authorized group uses a lab or space, the responsibility for doing monthly surveys may be shared. Each group should be responsible for doing their own surveys after each use, but the monthly survey only needs to be done once. It is less confusing and survey compliance is better assured if someone is assigned to perform the monthly survey of the entire lab for all groups.

In common use areas, it is especially important to communicate to everyone involved when contamination is found.

5. Radiation Safety Staff Surveys

Radiation Safety staff will also survey your labs to satisfy Department of Health requirements for administrative oversight. However, these surveys are conducted relatively infrequently.

C. Survey Methods

In general, surveys can be carried out in one of three ways. The preferred method depends on the radionuclides being used and the background level in the lab at the time of the survey. Below are more detailed explanations of the three methods.

1. Method 1 - Wipes / Scintillation Counting

The most significant radiation hazard in most laboratories is the potential ingestion or inhalation of transferable radioactive materials, rather than from external exposure. Ingestion or inhalation results in internal dose.

The main method for evaluating the ability for contamination to be transferred is to take a series of wipes from surfaces with small filter paper disks or squares of tissue and then evaluate the wipes with an appropriate detector. Wipes may be taken and counted in a counting device appropriate for the radionuclide(s) expected to be present.

Many investigators find it convenient to take wipes of their work areas immediately after preparing their research samples and running these wipes along with their samples. This gives immediate verification of the cleanliness of the lab and does not require an additional time allotment for lab survey measurements.

a. Choice of Counting System

The same counting system that is used in the experimental work will usually serve to evaluate the wipes, for example, liquid scintillation counting or gamma counting.

1) Liquid Scintillation Counting (LSC)

Low energy beta particles, like those emitted by H-3, C-14, and S-35,

have a very short range and detection can be difficult. Liquid scintillation counting has an advantage in this situation since the wipe is mixed intimately with the fluids of the liquid scintillation cocktail. Radiation does not need to travel far to interact with the scintillation media and radiation interactions with extraneous material are reduced to a minimum. Therefore, radiation with short range is detected with reasonable efficiency. LSC also works with higher energy beta emitters as well as alpha and gamma emitters. However, as the energy of gamma rays increases, detection efficiency diminishes.

2) Gamma Counting

Gamma counting is most convenient for detecting the presence of gamma emitters on wipes. The detector in a gamma counter is usually a sodium-iodide crystal, but a semiconductor detector system (such as a germanium-lithium detector) can also be suitable for measuring wipe counts of gamma emitters. Gamma counters are also often used to check wipes for the presence of positron emitters by detecting the annihilation radiation.

b. Wipes

The typical wipe survey method utilizes dry filter papers being wiped over potentially contaminated surfaces, and then counting these filter papers in a liquid scintillation counter (LSC) or gamma counter.

1) Performing Wipes

The papers are wiped over a surface using moderate finger pressure so that about 100 cm² of surface is covered on each wipe. The wipes should be held so that your fingers will not touch the surfaces being wiped

2) Large Area Wipes

Certain surfaces (hood-lip, bench area, floor in front of work area, etc.) could be checked using just one wipe per surface. The advantage of this method is that results are obtained without counting multiple samples. The drawbacks are the potential to spread contamination and subsequent identification of the exact spot of the contamination.

3) Wipes near Radioactive Work

When wiping near radioactive work where contamination is expected, use extra care to avoid contaminating your hands and thereby cross-contaminating subsequent wipes.

c. Liquid Scintillation Counter (LSC)

1) LSC Wipes

- a) The most convenient wipes for Liquid Scintillation Counting are filter papers, with a 4 to 5 cm diameter.
 - b) The papers should be dry when placed into the LSC fluid, or counting efficiency in the LSC will be greatly reduced.
- 2) Processing
- a) Each wipe would then be put into a vial and scintillation cocktail added.
 - b) Sufficient cocktail should be added to completely wet the wipe. In a large 20 ml vial, at least 10 ml of cocktail should be used.
 - c) To check for background, you should run a clean wipe with each set of survey wipes.
 - d) All wipes should be counted twice.

d. Results

- 1) Wipe results greater than twice the background may indicate that there is a problem with containment in your laboratory and the situation should be investigated.
- 2) Levels of contamination greater than 0.5 nCi on a wipe must be reported on the survey form and action taken to clean the area(s).

e. Resurvey after Cleanup

To ensure that cleanup was successful, the area must be resurveyed and the results reported on the survey form. If radioactive materials have spread beyond controlled areas, the control procedures should be questioned and reviewed to prevent further contamination.

2. Method 2 - Portable Detector

For some radionuclides, discussed in more detail below, surveys may be done without taking wipes by using a hand-held detector. This is only feasible if the background level in the lab is sufficiently low.

If the background in the lab is more than three times the natural background, the sensitivity of the detector is reduced and low levels of contamination will not be detected. In this case, Method 1 or 3 should be used. To check for natural background, measure the radiation level using your particular instrument in some location that is certain to not be contaminated or influenced by nearby radiation sources.

When working with radionuclides that may be detected with portable instruments, it is extremely important to monitor your hands, clothing, and work areas while doing the work.

a. Sensitivity of Instrument

Your instrument should be sensitive enough to detect the following radiation levels. See Table 1 for a list of radionuclides classified into Hazard Groups.

- 1) For Group I radionuclides, 10 nCi at a distance of 1 cm from the surface.
- 2) For Group II radionuclides, 1 nCi at a distance of 1 cm from the surface.
- 3) For Group III and above radionuclides, 0.1 nCi at a distance of 1 cm from the surface.

b. Calibration

Your instrument must be calibrated annually. The UW Radiation Safety Office operates an instrument calibration facility. Costs of meter calibration at the UW facility are comparable to other calibration facilities. Advantages of using the UW calibration facility are shortened turn-around time and avoidance of shipping charges for on-campus users.

c. Operation

When using a hand-held detector, do the following:

- 1) Check battery.
- 2) Remove the protective plastic or metal cap from your probe.
- 3) Make sure instrument responds to a check source. This can be a commercial check source, stock solution, or other source the detector is known to respond to when properly working.
- 4) Check background in known low background area.
- 5) Survey within 2 or 3 cm of surfaces. If contamination is suspected, measure the level with the probe within 1 cm of the surface.
- 6) Go slowly so your detector has time to respond to contamination.
- 7) To guard against contamination of your probe, you could cover the probe with plastic wrap.

d. Results and Follow-Up

If instrument readings indicate contamination at more than 500 cpm above background, the contaminated areas or items should be cleaned, labeled, or disposed and the area resurveyed.

3. Method 3 - Portable Detector with Wipes

Even when a hand-held detector is available for survey purposes, there may be situations where wipes must be taken.

a. Background Level Too High

When the background level in a laboratory is too high (more than three times the natural background level as discussed in Method 2 above) wipes must be taken as described in Method 1 above. However, these wipes may be counted with the hand-held detector in an area with low background.

b. After Cleaning of Contamination Areas

Another situation where wipes must be taken would occur after some contaminated areas have been thoroughly cleaned and radiation levels are still observed with the hand-held detector. In this situation, wipes must be taken and counted to verify that the remaining contamination is not removable and would not be transferable to other areas.

c. Performing the Count

1) Screening Wipes

Counting each wipe for 10 seconds is usually long enough to obtain a consistent response and determine whether contamination is present.

2) Counting Contaminated Wipes

If contaminated wipes are suspected, count them for at least 30 seconds each to document the contamination level; and if the instrument has a fast/slow response setting, it should be set to "slow" for this purpose.

Action required when contamination is found is the same as discussed in Method 2.

d. Results and Follow-Up

If instrument readings indicate contamination at more than 500 cpm above background, the contaminated areas or items should be cleaned, labeled, or disposed and the area resurveyed.

D. Method for Specific Radionuclides

1. Hydrogen-3

Hydrogen-3 emits a very low energy beta radiation that will not penetrate the walls of most portable instrument probes. It must be surveyed by using Method 1 as described above.

2. Carbon-14 and Sulfur-35

Both Carbon-14 and Sulfur-35 are very low energy beta emitters and are not easily detected using a portable survey instrument. Therefore, the preferred method for surveying laboratories where these radionuclides are used is with wipes counted in a liquid scintillation counter.

However, in situations where a liquid scintillation counter is not readily available, either an end-window or pancake probe Geiger-Mueller counter could be used. The efficiency is low, but a slow, deliberate survey, with the probe held near the surface, can detect C-14 and S-35 in amounts of 0.5 nanocurie or less. This level of detection can be achieved when the count rate is twice background. This also is the level that must be reported on the survey form, and action must then be taken to clean the area.

3. Iodine-125

Iodine-125 emits very low energy gamma radiation. A Geiger-Muller (G-M) detector is not very effective for this type of radiation. Instead, a portable detector with a special low-energy gamma scintillation probe must be used. This probe contains a thin sodium iodide crystal and is particularly efficient for low-energy gamma radiation. Using this probe and depending on the background radiation in the lab, survey Methods 2 or 3 could be used. If it is more convenient, Method 1 may be used instead of or in addition to Methods 2 or 3.

4. Phosphorus-32, Chromium-51, Iron-55, Iron-59, Iodine-131, and Other High-Energy Beta or Gamma Emitters

These radionuclides are readily detected using a hand-held portable G-M detector with a thin window not more than 2 mg/cm² in thickness. Depending on the background activity in the lab, the above Methods 2 or 3 would usually be used for surveys. If it is more convenient, Method 1 may be used instead of or in addition to Methods 2 or 3.

5. Combinations of Radionuclides

In situations where laboratories are using various combinations of several different radionuclides, the required surveys will include a combination of techniques. For instance, if a lab uses H-3 and P-32, the after use surveys may be specific for the radionuclide used (Method 1 for H-3 and probably Method 2 is preferred for P-32). However, the monthly survey should employ LSC counted wipes, which are capable of detecting both types of emitters.

E. Where to Survey

1. General Rule

Surveys should be conducted in all areas where radioactive materials is used or stored. Areas where contamination is more likely should be surveyed with greater attention.

2. Particular Areas of Importance

a. Floors and Storage Areas

- 1) Floors near storage of radioactive materials, including waste.
- 2) Floors in front of hoods and workbenches.
- 3) Floors near exit from lab.
- 4) Interiors of storage areas.

b. Equipment

- 1) Hood lip and sash.
- 2) Handles on refrigerators and freezers where radioactive materials are stored.
- 3) Telephones.
- 4) Computers/data entry devices.
- 5) Doorknobs.
- 6) Instrument dials.
- 7) Centrifuges.
- 8) Other miscellaneous items that could be contaminated.

c. Work Surfaces

- 1) Areas on work bench where work is done.
- 2) Desks.

F. How to Record Surveys

Monthly and after use surveys must be recorded. In labs where the locations surveyed and the instruments used are always the same, this information can be typed onto the standard form and copies used for each survey.

1. Survey Form

The following information must be recorded for any survey form.

a. Identification

- 1) Room and building surveyed.
- 2) Name of surveyor.
- 3) Date of survey.

b. Survey Map

Diagram or map showing facilities surveyed.

c. Instrument

Instrument used to perform survey, including serial number.

d. Results

- 1) Results of background count.
- 2) Results of wipe tests and portable instrument surveys.

e. Action Taken

Actions taken for any contaminated areas or items.

2. Mapping Work Space

A sketch of the floor plan of the work area should be used when making surveys, with a number corresponding to each survey location. If wipes are used for taking contamination measurements, the wipes should be numbered with the survey location. This allows easy mapping and evaluation of contaminated areas and aids in locating the source of the contamination.

An alternative to producing a sketch of the floor plan for each survey is to make a detailed drawing with several numbered locations. Then, survey documentation can be attached on subsequent sheets of paper. These subsequent sheets would specify the actual survey locations (by number) and survey results, with inferred reference back to the original drawing.

G. General Laboratory Practices

When performing your required laboratory surveys, it is a good practice to be alert for unsafe laboratory practices or conditions in the lab that could lead to the loss of radioactive materials or to uncontrolled contamination. These are discussed more completely in Section 9 of this manual, Radiation Protection Procedures. Some conditions that should be noted and corrected are:

1. Poor Laboratory Housekeeping

If laboratories are messy and housekeeping is especially poor, these conditions could contribute to the uncontrolled release of radioactive materials.

2. Food and Drink

a. Consumption Not Allowed

- 1) Food and drink must not be consumed in laboratory space.
- 2) The presence of food and beverages in radioactive material laboratories at the University of Washington is strictly prohibited, unless in enclosures dedicated only to storage of food and drink.
- 3) Laboratory glassware/equipment should not be used for food or drink.
- 4) Food or drink containers should not be used for chemicals or radioactive materials.
- 5) Avoid creating the misleading appearance that food or beverage was consumed in a laboratory. For example, do not discard drink containers or food in laboratory trash receptacles.

b. Food Storage

- 1) Refrigerators or enclosures that protect food from radioactive contamination may be used for the storage of food or drink in laboratories. Refrigerators used for this purpose must be clearly marked with an "Only Food and Drink" label.
- 2) Food or drink must not be stored in enclosures, refrigerators, or cold rooms that contain radioactive materials.

3. Radioactive Waste

a. Proper Disposal

Radioactive waste receptacles should be clearly identified with the proper warning labels, tape, or stickers.

b. Improper Disposal

- 1) Radioactive waste should not be placed in the hallways.
- 2) Radioactive waste must not be mixed with normal trash or placed in ordinary wastebaskets.

4. Laboratory Security

Radioactive material laboratories must not be left open and unattended while radioactive materials is accessible.

H. Inspection of Records

Survey records will be inspected periodically by Radiation Safety staff. Laboratories in which records are found to be incomplete or missing will be checked during the next survey. If the records are still missing, further action will be determined at this time.

Table 13-1
Radionuclides Arranged in Hazard Groups
According to Annual Limit on Intake (ALI)

Group I	Group II		Group III		Group IV	Group V	Group VI & Above
ALI > 10	10 > ALI > 1		1 > ALI > 0.1		0.1 > ALI > 0.01	0.01 > ALI > 0.001	0.001 > ALI
H-3	C-14	Ru-103	Na-22	Ag-110m	Sr-90	I-129	Po-208 * (VI)
Be-7	Na-24	In-111	P-32	Sn-113 *	Ru-106 *	Ra-228	Po-209 * (VI)
C-11	P-33	I-123	Cl-36 *	Ba-133 *	Cd-109 *		Po-210 *(VI)
F-18	S-35	Sm-153	Ca-45 *	Cs-137	In-114m *		Pb-210 (VI)
Cr-51	K-42	Re-186	Sc-46	Ce-139 *	Cd-115m		Ra-226 * (VI)
Cu-64	Fe-55	Hg-193m	Ca-47	Ce-141 *	I-125		Th-228 * (VII)
Ga-68	Co-57	Hg-195m	V-48	Gd-153 *	I-131		Th-229 * (VIII)
Br-77	Co-58	Hg-197	Mn-54 *	Ho-166	Cs-134		Th-230 * (VII)
Rb-81	Ni-63	Tl-204	Fe-59	Yb-169 *	Eu-155 *		U-233 * (VI)
Kr-85	Ga-67		Co-60	Ir-192			U-236 * (VI)
Tc-99m	Ge-68		Zn-65	Hg-203 **			Pu-238 * (VII)
Ag-104	As-73		As-74	Bi-207 *			Pub-239 * (VII)
Ag-106	Br-82		Se-75	Pa-233 *			Am-241 * (VIII)
In-113m	Sr-85		Sr-82				Am-243 * (VIII)
Xe-122	Nb-95		Rb-86				Cm-244 * (VII)
Xe-127	Tc-95m		Y-88				Cf-252 * (VII)
Xe-133	Tc-99		Sr-89				
Tl-201	Mo-99		Y-90				

Groups are based on Annual Limits on Intake (ALI) Values (mCi) from EPA Federal Guidance Report No. 11.

* Group classification based on inhalation ALI - all others based on ingestion ALI

** Organic form - inorganic form in Group II

Radiation Detecting Devices

(Information from NCRP Report 48, *Radiation Protection for Medical and Allied Health Personnel*)

Detector	Type of Radiation Detected	Purpose	Minimum Energy Measured	Directional Dependence	Advantages	Possible Disadvantages
Geiger-Müller (GM) counter	Beta, x-ray, gamma	Survey	20 keV for x-rays, 150 keV for beta	Low for x-ray or gamma	1. Rapid response	1. Strong energy dependence 2. Possible paralysis of response (saturation) at high count rates. 3. May be affected by ultraviolet light
Scintillation counter	Beta, x-ray, gamma, neutrons	Survey	20 keV for x-rays, variable for beta	Low for x-ray or gamma	1. High sensitivity 2. Rapid response	1. Fragile 2. Relatively expensive
Liquid scintillation counter	Beta, gamma, alpha	Survey	<6 keV for beta	None	1. Relatively high efficiency 2. Distinguishes between radionuclides	1. Expensive 2. Not portable
Ionization chamber	Beta, x-ray, gamma	Survey, dose rates	20 keV for x-ray, variable for beta	Low for x-ray or gamma	1. Low energy dependence	1. Relatively low sensitivity 2. May be slow to respond
Alpha counter	Alpha	Survey	Variable	High	1. Designed specifically for alpha particles	1. Slow response 2. Fragile window
Film	Beta, x-ray, gamma, neutrons	Personnel and environmental monitoring	20 keV for x-ray, 200 keV for beta	Moderate	1. Inexpensive 2. Estimates integrated dose 3. Provides permanent record	1. False readings possible 2. Variations with film type and batch 3. Strong energy dependence For low energy
Pocket ionization chamber (PIC)	X-ray, gamma	Personnel and environmental monitoring	50 keV	Low	1. Relatively inexpensive 2. Estimates integrated dose 3. Small size	1. Subject to accidental discharge
Gamma counter	Gamma	Survey	15keV	None	1. Designed specifically for gamma rays	1. Expensive 2. Not portable

Figure 6