

Introduction

The Marine Biological Laboratory (MBL) is licensed to use radioactive materials by the Massachusetts Department of Public Health (DPH). The authority to regulate most uses of radioactive materials in Massachusetts was transferred from the United States Nuclear Regulatory Commission (NRC) to the Massachusetts Dept. of Public Health (DPH) Radiation Control Division in the spring of 1997. Our use of these materials is therefore controlled by regulations issued by the DPH and by conditions incorporated in our license. Personnel who use radioactive materials at the MBL are required to learn and follow the specific procedures found in this manual.

Because this manual is a part of our Massachusetts license, the MBL is obligated to enforce the regulations contained herein in order to protect our ability to use radioactive materials in our research and teaching programs. Any violation of these regulations is a serious matter that may result in the loss of MBL privileges. If you have questions about any of our requirements or feel that they unnecessarily restrict your ability to use licensed materials please contact the MBL Radiation Safety Office at (508) 289-7424 for assistance. Suggestions for improving our radiation safety program are always appreciated.

There are four reasons why it is important for the MBL to have a strong radiation safety program.

- 1.) High doses of radiation are known to cause many illnesses, including cancer. Although the effect of low doses such as those encountered at the MBL is unknown, it is both prudent and a regulatory requirement for us to keep our exposures as low as reasonably achievable (ALARA).
- 2.) The use of radioactive materials is highly regulated and the MBL is subject to unannounced inspections of our facilities. Inadequate attention to radiation safety requirements could jeopardize our ability to use radioactive materials and have an enormous negative impact on our scientific programs.
- 3.) Regulations reflect an extremely high level of public concern about radiation. No institution can afford the damaging publicity that may result from major incidents or enforcement activities by regulators.
- 4.) Within the MBL community, there is also considerable concern about the safety of working with radioactive materials. All MBL personnel, particularly those who do not work with radioactive materials, are entitled to work in an environment which is free of contamination and free of unacceptable exposures to radiation.

Your cooperation in helping the MBL meet its radiation safety goals is appreciated.

James Marcello
Radiation Safety Officer
April, 2012

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I. Organization, Responsibilities, and Application Instructions

A. The Director of the MBL appoints a Radiation Safety Committee and a Radiation Safety Officer as required by the Massachusetts Department of Public Health when it issues broad scope licenses which give institutions permission to possess relatively large quantities of radionuclides.

B. The MBL Radiation Safety Committee is responsible for:

1. Establishing policies and providing overall guidance for the radiation safety program;
2. Reviewing, approving, and recording safety evaluations of proposed uses of radioactive materials; and
3. Conducting a periodic comprehensive review of the radiation safety program including a review of the activities of the Radiation Safety Officer.

C. The MBL Radiation Safety Officer (RSO) is responsible for the day-to-day management of the radiation safety program and oversees the common use facilities in Whitman. Specific responsibilities include:\

1. Coordinating the Radiation Safety Committee's review of individual proposals for use of radioactive materials;
2. Insuring that all necessary measures are undertaken to achieve compliance with all regulations and special conditions of our licenses;
3. Ordering radioactive materials for researchers and insuring that such materials are received, monitored, and delivered promptly;
4. Conducting routine monitoring and special surveys of areas and equipment where radioactive materials are used;
5. Preparing periodic reports for the Radiation Safety Committee and maintaining all required records;
6. Managing the disposal of radioactive wastes; and
7. Providing training and additional services to researchers to insure that safe use of radioactive materials.

Because many members of the Radiation Safety Committee are visiting researchers, the RSO is authorized to act provisionally on behalf of the Committee pending approval at its next meeting. The RSO has the authority to terminate any activity involving the use of radioactive materials, which she/he believes poses an immediate threat to health, safety, or the environment. Disagreements over policies or the conduct of the radiation safety program will be referred to the Committee or the Director for resolution.

D. A Principal Investigator who wishes to conduct research involving the use of radioactive materials must apply to the Committee to become an Authorized User. A Course Director who wishes to use radioactive materials in an educational program must also apply. Authorized Users are responsible for:

1. Supervising the safe use of radioactive materials in their laboratories;
2. Ensuring that all individuals within their research group are registered with the RSO and have had appropriate training; and
3. Following procedures established by the Committee and enforcing radiation safety program regulations in their laboratories.

Day-to-day responsibilities may be delegated, but the Authorized User is ultimately responsible for the radiation safety program in his or her research group. In exceptional cases where Principal Investigators or Course Directors lack the necessary training and experience or are otherwise not able to exercise direct control over the use of the materials, another qualified scientist within the group may be designated as the authorized User.

Authorized User Application forms, available from the RSO, request a summary of training and experience, an adequate description of the proposed research, and additional information required by the Radiation Safety Committee for its evaluation of the application.

An application may be approved, disapproved, or approved with specific conditions regarding training, procedures, or equipment that must be met. All applications will be evaluated by the Committee at its next meeting, but to avoid delays, they may be temporarily approved by the RSO if the Principal Investigator/Course Director has previously conducted similar radioisotope use at the MBL, or if the RSO judges that the proposed use of materials poses an acceptably small risk. No application will be provisionally approved if it describes new, especially hazardous activities such as the use of radioactive gases or powders, in-vivo animal use, or research, which creates the potential for significant environmental releases. Authorizations are valid only during the calendar year in which they are approved.

Applications for summer investigators should be mailed, but they may also be completed after arrival at the MBL. Each applicant must schedule an entrance interview with the RSO at which time provisional approval may be granted and necessary arrangements made, to permit radionuclide use to begin.

E. All other individuals, students, teaching assistants, and laboratory personnel who are directly involved in the use of radioactive materials must be registered with the RSO as Supervised Users. Supervised Users may be highly qualified, but they are not required to have previous training and experience. They are required to read and comply with applicable sections of this handbook and to comply with any additional requirements which are established by the Authorized User, RSO, or Radiation Safety Committee. Training requirements for Supervised Users will be evaluated when they register with the RSO and also as part of the approval process for the responsible Authorized User. No one under the age of eighteen will be registered as a Supervised User without special permission from the Committee.

F. The RSO is responsible for providing appropriate training to Buildings and Grounds employees and other non-research personnel who may visit areas where radioactive materials are used.

G. All personnel should be aware of the special hazards associated with radiation exposure during pregnancy. Exposure levels at the MBL should not exceed the limits considered acceptable for pregnant women. Women who are expecting or planning families should consider contacting the RSO for additional information.

II. Required Procedures

A. Acquisition and Transfer of Radioactive Materials

1. Purchase orders for radioactive materials are placed by the Radiation Safety Office. An order may be initiated by bringing a completed materials requisition to Rowe 401 or by calling extension 7424. Orders will normally be placed the same day and depending on the manufacturer's availability, delivered within three days. The RSO negotiates with manufacturers to ensure that prices paid by MBL researchers are competitive. Pricing policies are complex and researchers should contact the RSO if they anticipate placing repeated orders for the same labeled compound or desire other assistance.
2. Transfers to the MBL. The MBL RSO must be notified by a researcher bringing radioactive materials to the MBL or having them shipped from another institution. Transportation regulations are complicated and regulations require strict control of transfers of materials between licensees. The RSO at the originating institution must also be notified because that institution may face serious problems if materials possessed under its license are transferred from its inventory without following proper procedures. On request, the MBL RSO will provide assistance with packaging, transportation, and resulting paperwork. The MBL RSO may contact the RSO at the originating institution if evidence of improper transfer of materials exists.

To limit the need for transfers:

- a. Radioactive materials may be ordered from a manufacturer for delivery to the MBL RSO before a researcher arrives so that they are immediately available for use after his or her authorization is approved.
- b. The MBL RSO will attempt to match prices paid for labeled compounds by other institutions to eliminate any financial incentive for transfers.

A copy of the current MBL DPH Radioactive Material license is included in this handbook. Transfers of radionuclides from other institutions are discouraged but, if they are necessary, this license must be on file at the originating institution. All materials delivered to the MBL must be marked to the attention of the "HOT LAB" or "Radiation Safety Office."

3. Transfers from the MBL to other institutions will be arranged by the RSO. Personal shipment or transportation of radioactive materials is prohibited. The RSO must obtain a copy of the license of the destination institution before a shipment can be made. Again, transportation and transfer regulations are complex and the MBL is responsible for the legal shipment of any radionuclides in its possession. Researchers who anticipate returning to the MBL within twelve months may arrange to store radioactive materials in the common use radioisotope facilities in Rowe.
4. Transfers between users within the MBL must be reported to the RSO, but these are not discouraged because they may reduce the need to transfer materials from other institutions and also reduce the amount of materials purchased at the MBL. Phosphorus-32 users, or other researchers interested in cooperative purchase arrangements with their MBL colleagues, should contact the RSO.

B. Receipt of Radioactive Materials

The MBL must maintain a current inventory of radionuclides on its premises so it is extremely important that all shipments be addressed to the "HOT LAB" or "Radiation Safety Office" and

that the RSO be notified of pending transfers from other institutions. When a package arrives, the RSO is notified by Shipping and Receiving (S&R), the package is picked-up, tested, monitored, recorded, and delivered to its MBL destination by the RSO. When the RSO is unavailable, S&R has been authorized to release packages directly to laboratory personnel who may check-in their own packages provided procedures in Appendix A are followed.

C. Caution Signs and Labels

1. Labeling of rooms. Each room where radioactive materials are stored or used must prominently display either a “Caution Radioactive Materials” sign or a “Caution Radiation Area” sign on the outside door. Radiation Areas are by definition areas where a major portion of an individual’s body could receive a radiation dose equivalent of 5 millirem or greater in 1 hour at 30 cm from the radiation source. Laboratories and classrooms at the MBL are generally not Radiation Areas and none should be labeled as such without first consulting the RSO. In addition to caution signs, all rooms must be posted with the Authorized User’s name, emergency phone numbers, and a listing of the maximum possible inventory on hand at any time. Suitable signs are provided free of charge at the time of the entrance interview.
2. Labeling of sinks and hoods. All sinks and hoods where radionuclides are discharged shall be clearly labeled with a “Caution Radioactive Materials” sign. The total activity (in millicuries) of each nuclide discharged down laboratory drains must be recorded. Drains should not be used for deliberate discharge of contaminated solutions. Section II E, Disposal of Radioactive Wastes, and Appendix B describe the MBL drain discharge policy.
3. Labeling of refrigerators and cabinets. All refrigerators, freezers, and cabinets used for storage of radioactive materials shall be clearly marked with a “Caution Radioactive Materials” sign. All storage containers, which are not located in secured laboratories where radionuclide inventories are already posted, shall be individually posted with their maximum possible stored inventories.
4. Labeling of glassware and containers. Each container, which holds radioactive materials in excess of the amounts listed in Appendix B, must have a durable, clearly visible, labeling bearing the radiation warning symbol and the words “Caution Radioactive Material.” These labels must indicate the contents of the container including the nuclide, the amount of activity and the date. Containers used temporarily during laboratory procedures (e.g. pipettes) do not require labeling provided the user is present and the room is properly posted. Tape appropriate for labeling containers is available through the RSO. Under no circumstances should the tape be used for any purpose other than for proper labeling of radioactive items. Other caution signs and stickers are also available through the RSO.

D. Required Laboratory Procedures for Handling Radioactive Materials

1. Responsibility- All individuals handling radionuclides are responsible for conducting their work in a manner designed to minimize exposure to ionizing radiation and prevent the spread of radioactive contamination. The RSO is available to help answer any specific questions regarding exposure reduction or shielding.

2. Whole Body Dosimeters and Ring Badges- All personnel who might receive as much as 10% of their maximum permissible radiation doses (summarized in Appendix C) are required to wear whole body film badges at all times when handling gamma or X-ray emitting radionuclides and when handling beta emitters with a maximum energy of greater than 0.2 MeV. Persons regularly handling more than 1 mCi of phosphorus-32 or significant amounts of high-energy gamma emitters must also wear a ring dosimeter. An evaluation of the need for whole body dosimeters and rings will be conducted as part of the evaluation of Authorized User applications.

3. Contamination Control- The greatest potential danger to individuals using radionuclide materials at the MBL is the possibility that they may become contaminated. External contamination may be caused directly by spills or indirectly by handling contaminated materials. Internal contamination can result from injection, ingestion, or skin absorption of radioactive materials. Internal contamination can frequently be traced to mouth pipetting, to the failure of individuals to wear disposable gloves, or to the failure to use fume hoods when handling volatile forms of radioactive materials. The following requirements have been established to minimize contamination risks:

- a. Whenever possible, separate areas should be designated in each laboratory for the use of radioactive materials.
- b. No person is permitted to smoke eat, or drink while handling radioactive materials. Furthermore, there should be no consumption of food or drink in the vicinity of areas where radioactive materials are being used. Refrigerators or other containers being used for storing radioactive materials must not be used for storing food or drinks.
- c. All personnel handling liquid or uncontained solid radioactive materials must wear appropriate lab coats and disposable gloves at all times. Personnel performing operations with a high risk of hand contamination should consider wearing two pairs of gloves. Remember that the advantages of wearing gloves are defeated when personnel wearing contaminated gloves indiscriminately handle objects such as doorknobs, pens or telephones.
- d. Trays, available from the RSO, should be used by personnel handling liquid or uncontained solid radioactive materials. Absolutely no mouth pipetting of radioactive solutions is permitted. Pipette bulbs or automatic pipettors must be used.
- f. All operations involving volatile radioactive materials must be performed in fume hoods. Individuals working with dry powders or conducting complex operations or other procedures which may result in aerosol production should consult the RSO prior to beginning work.
- g. Special requirements have been established for the performance of bioassays on individuals handling hydrogen-3 or radioisotopes of iodine. Users of the nuclides are required to read and fulfill the requirements detailed in Appendix D.
- h. Do not return to general usage equipment which has been used with radioactive materials until such equipment has been cleaned and monitored. Equipment must be completely decontaminated prior to servicing or returning to the Apparatus department.

Under special circumstances in which these requirements place undue hardship on laboratory personnel, exceptions may be possible with the prior approval of the Radiation Safety Committee if practices remain in full compliance with DPH regulations and our other license requirements.

4. Monitoring

Regular monitoring of work areas, apparatus, and clothing is required. Prompt detection can reduce the spread of contamination and also aid in the establishment of improved procedures.

The RSO is responsible for conducting regular wipe tests in accordance with the schedule in Appendix E, but wipe tests conducted by the RSO cannot substitute for routine monitoring conducted by personnel using radionuclides who are fully familiar with the research being conducted. Portable survey meters equipped with Geiger-Mueller tubes are sensitive enough to detect significant levels of most gamma and high-energy beta emitters. Iodine-125 can be detected with a portable meter equipped with a sodium iodide scintillation detector. Low energy beta emitters such as hydrogen-3, carbon-14 and sulfur-35 are best detected by conducting wipe tests and scintillation counting the samples. Instructions are included in Appendix E. Researchers using beta emitting isotopes such as phosphorus-32 or calcium-45 with a maximum energy greater than 0.2 MeV or gamma emitting radioisotopes must have access to appropriate portable survey meters and must monitor their hands and clothing before leaving their work area. The RSO will attempt to accommodate requests for temporary use of MBL survey meters but cannot always guarantee that a meter will be available. Researchers visiting the MBL are encouraged to bring portable meters from their home institutions. Meters must be calibrated every six months to a year and researchers should check and try to ensure that meters will not need calibration during their stay at the MBL. Many institutions perform their own calibrations but the MBL uses a commercial firm and calibrations may take several weeks. All meters must be registered with the RSO.

5. Transportation of radioactive materials within the MBL

Must be conducted in a manner designed to limit personnel exposure and the potential for spills. Personnel exposure can be limited by using appropriate shielding and by transporting on carts or in ice buckets to reduce hand exposures. Shielding must reduce doses to less than 1.0 mRem/hr at one meter from the container. Spills can be reduced by using carts, secondary containers, and by traveling on elevators. Many spills occur when individuals are opening doors or traveling on stairs. Individuals transporting materials between Lillie and Rowe or Loeb must use the tunnel that connects Lillie and Rowe, when feasible. No materials may be carried across MBL Street or on any other public property, unless it is performed in such a manner that is approved by the RSO. No materials may be transported outside the MBL or to any area within MBL that is not registered with the RSO for radionuclide usage.

6. All containers for storage must be labeled in accordance with instruction in Section II C. No radioactive materials may be left unsecured after working hours. Any storage cabinets or refrigerators in unsecured areas must be kept locked after hours and during the day when not in use.

7. Special procedures govern the use of radioactive materials which are permanently sealed into holders or instruments in a manner designed to prevent the release of activity.

8. Natural uranium salts, smoke detectors, and certain other special uses of radioactive materials are not regulated by the DPH. The RSO should be consulted for disposal advice and information on hazards associated with their use.

9. Some required procedures have not been included in this handbook. These include regulations governing in vivo animal experiments involving radioactive materials and regulations governing the use of radioactive materials at field research locations. If you need more information on these procedures or have any other questions regarding radionuclide use at the MBL, please contact the RSO.

E. Radioactive Waste Disposal Policy

Disposal procedures are determined based on the half-life of the radioisotope and the physical characteristics of the wastes.

1.0. General Policies

1.1. Labeling

Proper identification of the radioisotope contents of wastes is essential. This is the only way we can assure that our disposal practices are legal and meet the terms of our license. Each waste container is labeled with the names of permissible radioisotopes. You must contact the Radiation Safety Office (x7424) for assistance if you wish to conduct a dual labeled experiment or if you mistakenly discard contaminated materials in the wrong waste container.

1.2. Waste Minimization

Purchases of radiochemicals and the amount of waste generated during the use of these materials must be minimized. Specific procedures for minimizing solid wastes can be found elsewhere in this policy.

1.3. Lead

Shipping containers and other items that contain lead may not be disposed of in the containers provided for radioactive wastes. Contact the Radiation Safety Office for assistance with the disposal of these items.

1.4 Mixed Wastes

"Mixed wastes" are wastes that meet the definitions of both radioactive and hazardous wastes. Common examples include contaminated solvents and acid cleaning solutions. Generation of mixed wastes is prohibited without the specific prior approval of the Radiation Safety Officer. Generation of mixed wastes containing radioisotopes with half- lives greater than 65 days will also require approval by the Radiation Safety Committee because of the problems associated with the disposal of these materials.

1.5. Radiation Symbols in Laboratory Trash

All radiation symbols and written radioactive designations must be removed or effectively defaced before uncontaminated shipping containers or other labeled items are discarded in regular laboratory trash.

2.0. Procedures for H-3, C-14, Na-22, Ca-45, and All Other Radioisotopes with Half-Lives Greater Than 65 Days except S-35

2.1. Solids

Massachusetts generators currently have access to several radioactive waste burial sites located in the U.S. Burial costs are extremely high and we may lose access to these sites on short notice at any time. Waste volumes must be minimized.

-Whenever possible, non-radioactive assays or short half-lived radioisotopes must be used.

-Use of disposable paper, plastic, and glass products must be minimized. Because drain discharges of radioisotopes are still legal, glass and plastic items must be washed and reused. Use of absorbent paper on trays has been discontinued.

-In the past, we have discarded items in the radioactive waste whenever there was any potential for contamination. This is no longer appropriate. Unless items are known to be contaminated, they must be monitored in an appropriate manner and then discarded in regular trash if no contamination is detected.

-The wearing of disposable gloves while radioisotopes are being used is a requirement of our safety program. However, if there is no detectable contamination on the gloves, you must wash your hands with the gloves on and then discard them in regular laboratory trash.

-Regulations strictly prohibit the disposal of any contaminated items in regular laboratory trash. There are no exemptions or acceptable limits for contamination. Methods used to reduce our volume of solid wastes must be compatible with our regulatory obligations.

Containers for solid wastes are available from the Radiation Safety Office. Because the liquid content of "solid" wastes must be less than 0.5%, all tubes, vials, and other containers must be drained into a liquid waste container prior to disposal.

2.2 Liquids

Containers for aqueous liquids are available from the MBL Chem. Room or the Radiation Labs in the Rowe Building-4th floor. Most liquids containing long-lived radioisotopes will be drain discharged by the Radiation Safety Office in a controlled manner. If there are any hazardous chemicals in the radioactive liquids, an MBL hazardous waste label must be completed and attached to the container.

2.3 Liquid Scintillation Vials (LSVs)

All LSVs are commercially incinerated. Containers for vials are available from the Radiation Safety Office. Non-radioactive vials and vials containing H-3 or C-14 should be segregated from other vials to take advantage of reduced disposal fees.

2.4. Animal Carcasses

All *in vivo* uses of radioisotopes must be approved in advance by the Radiation Safety Committee. Approval of protocols involving long half-lived radioisotopes may be dependent on the availability of a suitable mechanism for disposal of the carcasses.

3.0. Procedures for Sulfur-35 and For All Radioisotopes with Half-Lives Less than 65 Days (Including P-32, I-125, Rb-86, and K-42)

3.1. Solids

Containers for solid wastes are available from the Radiation Safety Office. Because the liquid content of "solid" wastes must be less than 0.5%, all tubes, vials, and other containers must be drained into a liquid waste container prior to disposal.

Contaminated solids (paper, plastic, glass) are stored on site for a minimum of ten half-lives to allow the radioactivity to decay. These materials are then incinerated in a licensed medical waste incinerator.

3.2. Liquids

Containers for aqueous liquids are available from the MBL Chem Room. Liquids are stored in these containers to allow radioactivity to decay and then drain discharged. If there are any hazardous chemicals in the radioactive liquids, an MBL hazardous waste label must be completed and attached to the container.

3.3. Liquid Scintillation Vials (LSVs)

All LSVs are commercially incinerated. Containers for vials are available from the Radiation Safety Office. Non-radioactive vials and vials containing H-3 or C-14 should be segregated from other vials to take advantage of reduced disposal fees.

3.4. Animal Carcasses

All *in vivo* uses of radioisotopes must be approved in advance by the Radiation Safety Committee. Carcasses containing radioisotopes with short half-lives will be frozen, stored for ten half-lives, and shipped to a commercial medical waste incinerator.

III. Emergency Procedures for Incidents Involving Radioactive Contamination

A. Personal Injury with Contamination Involved

In any accident involving a personal injury and radioactive contamination, treatment of the injury has absolute precedence. The following precautions can aid medical response and reduce the spread of contamination.

1. If possible, remove contaminated clothing at the site of the accident.
2. If an ambulance is required, dial “9-911” on any MBL phone or contact the Falmouth Fire Department directly at 548-2323.
3. Notify proper individuals (i.e. RSO) and control contamination as detailed below (Section III B).
4. Inform medical personnel that radioactive contamination may be present so they can take appropriate action. If possible, provide a written report on the isotope and amount of radioactivity.
5. Medical personnel at Falmouth Hospital should contact either Dr. James J. Condon or Dr. Dennis J. Sanidas.

B. General Emergency Procedures

1. Notification

The following personnel should be notified in the order listed in the event of any spill or accidental airborne release of radioactive materials. Do not attempt a clean-up until these people have been contacted. Up-to-date emergency numbers and instructions are posted in each laboratory.

- a. Radiation Safety Officer, at extension 7424. If there is no answer, follow emergency instructions on the recorded message.
- b. The Authorized User or Course Director in whose laboratory the accident occurred. If the Authorized User and the Radiation Safety personnel are not available, attempt to contact the following in the order listed:

- c. Louis Kerr, EM Lab Coordinator, X7273.
- d. Chairman of the Radiation Safety Committee- David Mark-Welch, X7377
- e. Falmouth Hospital Department of Radiology, 548-5300, X347. Ask for Dr. James J. Condon or Dr. Dennis J. Sanidas.
- f. The Massachusetts Nuclear Incident Advisory Team (NIAT), 1-617-566-4500, X237.

2. Containment of Contamination

- a. Volatile liquids or loose powdered activity.

- i. Evacuate all personnel from the lab immediately, turning off any apparatus which needs consistent attention. Do not open windows.
 - ii. Gather personnel and wait immediately outside of room until help arrives.
 - iii. Close and lock all entrances to room. Check the direction of air flow underneath doors and seal cracks is air is flowing out towards the corridor.
 - iv. Remove and isolate any contaminated lab coats and outer clothing.
- b. Non-volatile spills.
 - i. Contain spill as much as possible.
 - ii. Remove any contaminated lab coats and outer clothing.
 - iii. Assemble potentially contaminated personnel in one area of lab and monitor contamination.
 - iv. Rope off and guard spill area until help arrives.

IV. Fundamentals of Radiation Protection

A. Definitions and Basic Principles

1. Radiation

The emission and propagation of energy through space of a material medium, may be ionizing or non-ionizing. Ionizing radiations are those which can transfer enough energy to an electron to free it from an atom or molecule. The minimum energy required for an ionization is about 12 electron volts (eV). Non-ionizing radiations such as sunlight, microwaves, and radiowaves do not have enough energy to free orbital electrons.

2. Radioisotopes or radionuclides spontaneously emit ionizing radiation.

This usually occurs when an atom is undergoing a change to correct an imbalance between protons and neutrons. The emitted radiation may directly or indirectly ionize other atoms.

3. Transformation (or decay) is the process by which radioactive atoms become more stable by emitting ionizing radiation. A nuclear change transforms the atom to an isotope of a different element. Each radioisotope has a characteristic rate of transformation, described by its half-life. The half-life is the time required for one half of a given population of radioactive atoms to transform.

4. Quantities of radioisotopes are described by curies or bequerels. A curie equals that amount of material which undergoes 2.22×10^{12} transformations or disintegrations per minute (dpm). A bequerel is equal to one disintegration per second (dps). Dpm and counts per minute (cpm) are not

interchangeable. A cpm is an event observed by a counter; to convert to dpm you must know the counter efficiency for each isotope.

5. The mass of a curie of any specific isotope is dependent on that isotope's half-life. The specific activity describes the relationship between mass and rate of transformation and is usually expressed in curies per gram or per millimole.

6. Amounts of radiation are described by Roentgen, Rad, and Rem.

- a. Roentgen ® is the only exposure unit that is measured against a standard and equals that amount of radiation which produces a charge of 2.58×10 coulombs/kg of dry air. Roentgen does not describe the radiation's effect on tissue.
- b. Radiation absorbed dose (Rad) is a measure of dose and is the amount of energy deposited into a medium, such as skin or bone. One Rad equals 6.25×10^7 million electron volts (MeV) per gram tissue. Compare this to the approximately 12 eV required for one ionization
- c. Roentgen equivalent in man (Rem) describes the biological effect of the radiation and is determined by multiplying the dose in Rads by a quality factor (QF) which measures the relative injury-producing effectiveness of different types of radiation.

For most purposes, these units may be used interchangeably, since one Roentgen of exposure produces approximately one Rad of dose in soft tissue and the quality factor for betas, gammas, and X-rays is one.

Every radioisotope emits a unique, characteristic type and energy of ionizing radiation. Equal amounts of different isotopes as measured in curies can result in very different radiation exposures. Information concerning properties of specific radioisotopes can be obtained from Appendix F or the RSO.

7. Natural Background Radiation is exposure received from cosmic rays, naturally radioactive elements in rocks and soil, and natural radionuclides within your body. Exposure varies widely depending on the environment in which you live, but averages about 0.1 - 0.125 Rem (or 100-125 mRem) per year.

8. In many cases, exposure from ionizing radiation can be prevented by maintaining good lab practices as outlined in Section II D. Time, distance, and shielding must also be considered when working with some of the more hazardous radioisotopes.

- a. Decreasing the time spent handling radioactive materials by careful planning or by performing a practice non-radioactive experiment can significantly reduce exposure.
- b. Ionizing radiation obeys the inverse square law, which states that the dose received varies inversely with the square of the distance from the source. For example, by moving a radioactive sample from 10 to 20 cm from yourself, the dose you receive is reduced to one-fourth its previous intensity.
- c. Shielding requirements vary depending on the isotope involved. Very low emitters such as hydrogen-3 and carbon-14 require no added shielding; air is sufficient. Phosphorus-32 beta particles can be effectively shielded by plastic. Gamma and X-ray emitting isotopes such as iodine-125 or sodium-22 may require denser shielding material such as lead. Contact the RSO if you have any specific shielding questions.

B. Biological Effects of Ionizing Radiation

Exposure to ionizing radiation may be acute or chronic; effects from each type of exposure can vary widely. Biological effects following high dose, acute exposure are well understood. Although chronic low dose occupational exposure has been extensively studied, the data concerning doses required to produce certain known effects are very ambiguous. Several theories concerning the hazards of small radiation exposures have been postulated; the most widely accepted is the "linear non-threshold" theory. It asserts that any exposure to ionizing radiation has some potential effect, though not necessarily detectable or measurable, and that the potential for adverse effects increase linearly with increasing dose.

1. Acute. Very high doses (50 Rads or greater) of ionizing radiation that can lead to rapidly observable symptoms including nausea, changes in blood counts, and skin redness. Acute effects cannot result from radioisotope use at the MBL due to the amounts and methods used.

2. Chronic. Long-term low dose exposure does not produce immediate effects. A latency period of as much as thirty years may elapse before effects appear. Because of this latency period, effects caused by exposure to ionizing radiation may manifest themselves years after radiation work has ceased, making it very difficult to ascertain whether any particular health problem has been caused by radiation or some other factor.

a. Carcinogenesis. Ionizing radiation in large doses can cause cancer. Ionizations from particles or electromagnetic energy may damage somatic cellular DNA. Any damaged DNA may eventually result in cancerous growth. Certain types of cancer are closely associated with ionizing radiation, but radiation-induced cancers are biologically indistinguishable from those caused by other factors. At the low levels of radioisotope use at the MBL and other research laboratories, no definite correlation can be made between a certain amount of occupational exposure and the development of a certain cancer years later. This uncertainty is compounded by the presence of various other hazardous and carcinogenic materials in the environment.

b. Mutagenesis. Particles or electromagnetic energy can also damage DNA in germ, or reproductive cells. Poorly or non-repaired damage of this type may produce no effect in the lifetime of the exposed individual, but could cause adverse biological effects in the following generation. Mutations occur naturally in human cells; occupational exposure may increase the rate of occurrence. Precautionary measures taken to reduce cancer risks should also reduce the risk of radiation-induced mutations to an acceptable level.

c. Teratogenesis (Birth Defects). Since rapidly reproducing cells are most susceptible to damage by ionizing radiation, a developing fetus is particularly at risk, especially during the first two-to-eight weeks, when the mother may not know she is pregnant. Very high doses during pregnancy may result in developmental problems. The NRC has set an occupational exposure limit for a declared pregnant women at 0.5 Rem over the entire pregnancy, or 10% of the annual dose for other radiation workers. Any woman who is, or expects to become, pregnant should contact the RSO to receive additional information. You are, however, not required by law to do so.

d. Concern has been raised about cataract formation or sterility in radiation workers. Ionizing radiation is capable of causing both, but the doses required are much higher than the maximum occupational limits, which are not approached at the MBL.

C. Radiation Exposure Monitoring

External exposure to radiation can be monitored by portable survey meters, whole body film badges, TLD rings, and pocket dosimeters. Each of these has specific advantages and limitations.

1. Dosimeters are commonly used to monitor whole body exposure to X-rays, gamma rays, and high-energy beta particles. Each badge consists of a small piece of X-ray film in a sealed packet and a plastic holder. The plastic holder contains several shields and is designed to enable the film

processing firm to determine the type and approximate energy of incident radiation. Phosphorus-32 betas can be detected but lower energy beta radiations from hydrogen-3 (tritium), carbon-14, sulfur-35, and calcium-45 are not powerful enough to penetrate the film packet covering.

2. Ring badges contain a more expensive reusable lithium fluoride thermoluminescent dosimeter (TLD) chip. The TLD chip absorbs energy, which is released and measured when the chip is heated during processing. The TLD chip is more sensitive than X-ray film to low energy X-rays and gamma rays but cannot detect low energy beta particles. The ring label of plastic tape covers the TLD chip and should be worn facing incident radiation (usually the palm side of the hand). Gloves should be worn over the ring to prevent contamination.

Both Film badges and rings are processed quarterly; collection and processing usually require one month. The majority of badges receive no exposure; reports are routinely given to personnel if a positive reading is reported. Positive readings on badges returned late for processing are generally not reported, since the reported exposure is usually due to natural occurring background radiation, not occupational exposure. All personnel are entitled to unrestricted access to their exposure histories.

Note: If dosimeter appears or becomes damaged in any manner, contact the RSO (x7424) immediately.

3. Pocket ion chambers or dosimeters can give an immediate measurement of exposure to gamma or X-radiation. An electrically charged ion chamber detects increased radiation levels.

4. Portable survey meters, like pocket dosimeters, give an immediate indication of X-ray, gamma, and medium energy beta radiation in a work area. The Geiger-Mueller (G-M) probe is commonly used at the MBL and can easily detect nanocurie levels of phosphorus-32. Lower energy beta particles can also be detected but with lower efficiency. A G-M probe cannot detect hydrogen-3 betas. Although a G-M probe can detect iodine-125 photons, a low energy gamma scintillation probe is more sensitive. Portable survey meters should not be used for precise quantitative measurements, but they can detect spills and prevent the spread of contamination.

5. Scintillation, gamma, and gas-flow radiation counters are used to measure the very small amounts of radiation present in laboratory samples. They are used by the RSO for detection of surface contamination on radioisotope packages and evaluation of laboratory wipe tests.

Appendix A

Proper Procedures for Receipt of Packages Containing Radioactive Materials

When RSO personnel are not available to check in a shipment, the Shipping and Receiving Department has instructions to release the shipment to the appropriate laboratory. All shipments should be picked-up and monitored within three hours of their arrival.

Laboratories checking in their own packages must have all materials necessary to conduct package wipe tests and may need access to an appropriate portable radiation survey meter. Packages containing potentially volatile materials must be opened in a fume hood. Package contamination and leaks are uncommon but not unprecedented. When checking in shipments, always be careful to use proper shielding to minimize exposure and use care to limit the spread of any contamination.

The following procedures must be followed:

1. While wearing disposable gloves and a lab coat, carefully check all external labels and packing slips to verify that the package contains your order.

2. Most packages do not have external labels because they contain limited quantities of radioactive materials. If the outside of the package does have a 4"x4" diamond shaped category I, II, or III radioactive label, use your survey meter to measure the maximum dose rates in contact with, and one meter from the outer package. Record both results on the packing slip.

Surface dose rate limits are as follows: category I label, 0.5 mR/hr; category II label, 50 mR/hr; category III label, 200 mR/hr. If your measured rate is greater than that permitted for the package label, do not open the package. Complete the external wipe test and contact the vendor or the RSO for assistance.

3. After any required survey meter measurements are complete, wipe approximately 100 square centimeters of the outside of the box with a small piece of filter paper. This will be scintillation counted to test for removable contamination. Then open and remove the packing materials. At each level, check all labels for accuracy and take an additional wipe test. Three to five wipes will be required for each package.

4. As you wipe test the inner container, do not proceed if there are any visible signs of leakage.

5. After all packaging has been opened, set it aside and proceed with scintillation counting the wipes. Notify the manufacturer and the RSO if any contamination is removed from the outside packaging or if more than 0.01 microcuries (22,000 dpm) per square 100 centimeters is removable from the inner container.

6. After wipes have been counted, record the results on the packing list and send a copy to RSO.

7. Uncontaminated gloves and packing materials should be discarded in regular laboratory trash after all radioactive labels have been removed or effectively defaced.

8. After receipt is completed, the radioactive materials and any accompanying shielding must be stored in a secure area in a properly posted laboratory.

Appendix B

Exposure and Environmental Standards for Selected Radionuclides

Isotope	Limits for Removable Surface Contamination		Occupational Exposure Limit-Oral Ingestion ALI (μCi)	Occupational Exposure Limit- Inhalation		Effluent Concentration Limit-Air (μCi)
	Unrestricted Areas (μCi/cm ²)	Restricted Areas (μCi/cm ²)		ALI (μCi)	DAC (μCi/mL)	
H-3	10 ⁻⁵	10 ⁻⁴	8 X 10 ⁴	8 X 10 ⁴	2 X 10 ⁻⁵	1 X 10 ⁻⁷
C-14 (Dioxide)	10 ⁻⁵	10 ⁻⁴	-	2 X 10 ⁵	9 X 10 ⁻⁵	3 X 10 ⁻⁷
C-14 (Compound)	10 ⁻⁵	10 ⁻⁴	2 X 10 ³	2 X 10 ³	1 X 10 ⁻⁶	3 X 10 ⁻⁹
Na-22	10 ⁻⁶	10 ⁻⁵	4 X 10 ²	6 X 10 ²	3 X 10 ⁻⁷	9 X 10 ⁻¹⁰
P-32 (most compounds)	10 ⁻⁶	10 ⁻⁵	6 X 10 ²	9 X 10 ²	4 X 10 ⁻⁷	1 X 10 ⁻⁹
P-33 (most compounds)	10 ⁻⁶	10 ⁻⁵	6 X 10 ³	8 X 10 ³	4 X 10 ⁻⁶	1 X 10 ⁻⁸
S-35 (most compounds)	10 ⁻⁵	10 ⁻⁴	1 X 10 ⁴	2 X 10 ⁴	7 X 10 ⁻⁶	2 X 10 ⁻⁸
Cl-36 (NaCl)	10 ⁻⁶	10 ⁻⁵	2 X 10 ³	2 X 10 ³	1 X 10 ⁻⁶	3 X 10 ⁻⁹

Ca-45	10^{-6}	10^{-5}	2×10^3	8×10^2	4×10^{-7}	1×10^{-9}
Cr-51 (chloride)	10^{-5}	10^{-4}	34×10^4	2×10^4	1×10^{-5}	3×10^{-8}
I-125 (all compounds)	10^{-6}	10^{-5}	4×10^1	6×10^1	3×10^{-8}	-
I-125 (thyroid)			1×10^2	2×10^2	-	3×10^{-10}

The “limits for removable surface contamination” are adapted from the NRC Regulatory Guide 8.23 “Radiation Surveys at Medical Institutions.” In practice, contamination levels in all areas within the MBL will be kept as low as reasonably achievable (ALARA).

Removable contamination is assessed using wipe tests.

ALI and DAC are defined in Appendix C.

Appendix C

Dose Concepts and Occupational Dose Limits

“Dose” is a generic term. To fully understand occupational dose limits it is helpful to understand a number of different terms related to radiation doses.

The occupational limits take into account the different biological effects of different types of radiation, the different modes of exposure, and the differing responses of organs exposed to radiation.

Absorbed dose refers to the amount of energy imparted by ionizing radiation per unit mass of irradiated material. The units are the gray (Gy) and the rad. The gray is the International System (SI) unit equal to an absorbed dose of 1 joule per kilogram. One gray is equal to 100 rads which is the traditional unit for absorbed dose.

Dose equivalent is the product of the “absorbed dose” and the quality factor assigned to the type of radiation present. The units for dose equivalent are the sievert (Sv) and the rem. The sievert is the SI unit and is equal to 100 rem which is the traditional unit for the dose equivalent.

Quality factors (Q) account for the fact that the biological effects of different types of radiation can differ dramatically for any given absorbed dose. Alpha particles have Q values of 20 and

neutrons have Q values of 10. Since x-rays, gamma rays and beta particles all have Q values of 1, the absorbed dose and dose equivalent they produce are equal.

The deep dose equivalent for external exposures is the “dose equivalent” at a tissue depth of 1 centimeter received from radiation which is “external”, that is radiation which originates from a source outside of the body.

The committed dose equivalent for internal exposures is the dose equivalent to an organ or tissue which will be received in the first fifty years following any intake of radioactive materials.

Many internal exposures are limited to the organs or tissues where the radioactive materials are deposited. Weighting factors are used when internal organ exposures and external whole body exposures are summed. The “weighting factor” for radiation exposures to the lung is 0.12. A 20 mSv “committed dose equivalent” for the lungs would be equal to a whole body committed effective dose equivalent of 2.4 mSv (20 x 0.12).

Total effective dose equivalent (TEDE) is the sum of the “deep dose equivalent” for external exposures and the “committed effective dose equivalent” for all internal exposures from intakes of radioactive materials.

C.2. Occupational Dose Limits for Adults

Affected Organ	Maximum per Year
Whole body	5 rem (.05 Sv) TEDE
Any individual internal organ or tissue*	50 rem (0.5 Sv)*
Lens of the Eye	15 rem (0.15 Sv) dose equivalent
Skin or extremity	50 rem (0.5 Sv) shallow dose equivalent

* Organ limits are the sum of the “deep dose equivalent” and the committed effective dose” to any individual organ or tissue other than the lens of the eye.

The annual occupational dose limits for minors are 10% of those for adult workers.

The limit for exposure to members of the general public from each license holder is 100 mrem per year (1 mSv) at a rate not to exceed 2 mrem (0.02 mSv) per hour from external sources.

C.3. Annual Limits on Intake (ALIs)

ALIs are the limits on the amount of radioactive material which may be taken into the body of an adult worker in one year. The ALI for any radioactive compound is the smaller of the amounts which would produce a committed effective dose equivalent of 5 rems or a committed dose equivalent of 50 rems to any individual organ or tissue.

The ALI for inhalation is used to calculate a DAC (derived air concentration) which is the concentration of a radionuclide in air which would result in the intake of one ALI over the course of a standard 2000 hour work year.

Several ALIs may exist for any radionuclide depending on its chemical form and the rate at which inhaled material is removed from the lung.

Tables of ALIs and DACs are published in the Massachusetts DPH regulations. Selected ALIs are listed in Appendix D. Others are available from the RSO.

Appendix D

Special Bioassay Requirements for Users of Hydrogen-3, Phosphorus-32, and Radioisotopes of Iodine

I. General

Bioassay requirements described in this appendix are minimum standards adopted by the MBL. Requirements may be established for additional isotopes and activity limits may be reduced when the RSO or the Radiation Safety Committee believes that an experiment has a high potential for creating contamination. Bioassays will be conducted for any MBL personnel on request regardless of the amount of activity used. Sample containers for urinalysis are available in the RSO.

II. Hydrogen-3 (Tritium)

An individual handling 10 millicuries or more of hydrogen-3 must submit urine samples to the RSO for analysis. Samples must be submitted before research at the MBL begins and either following each experiment or on a weekly schedule.

III. Radioisotopes of Iodine

All iodination's must be conducted in the RSO hood in Whitman which is equipped for the required air sampling. Thyroid monitoring must be conducted before the initial iodination and either on the day following each iodination or on a weekly basis. All monitoring will be conducted by RSO personnel using either a Ludlum Model 3 survey meter with a Model 44-3 probe or the multichannel analyzer and sodium iodide detector located in Whitman 423. Iodinations using less than 100 microcuries are exempt although monitoring following all iodinations is strongly recommended.

IV. Phosphorus-32

Urinalysis may be recommended for individuals conducting experiments involving one millicurie or more of phosphorus-32, which pose a significant risk of producing airborne activity.

Appendix E

Laboratory Surveys

The following table shows the minimum frequency used by the Radiation Safety Office for its survey of radioisotope laboratories.

Isotopes	Required Frequency		Comments
	Monthly	Weekly	
³ H	<1 Ci	1Ci – 100 Ci	
¹⁴ C, ³⁵ S	<100 mCi	100 mCi – 1 Ci	Simple Operations
	<10 mCi	10 mCi – 100 mCi	Complex Operation Powders
³² P	<2 mCi	2 mCi – 100 mCi	All Operations
²² Na, ³³ P, ⁴⁵ Ca, ¹²⁵ I	<1 mCi	1 mCi – 100 mCi	Protein Bound ¹²⁵ I
Na, ¹²⁵ I	<0.1 mCi	0.1 mCi – 10 mCi	Volatile

Typical surveys consist of two components:

-a survey of external radiation exposure levels using an appropriate portable survey meter whenever gamma, x-ray, or beta doses could exceed 1 mRem/hour at one meter from any unshielded source

-a survey of removable surface contamination using wipe tests. A wipe test is conducted by rubbing a surface with a piece of dry filter paper and then measuring the amount of contamination transferred to the filter in an appropriate gamma or scintillation counter. Results are reported as dpm or μCi per 100 cm^2 . Limits for acceptable levels of removable surface contamination are shown in Appendix D.

Exceptions

- 1) Whenever feasible, all laboratories used for teaching purposes will be surveyed on a weekly basis.
- 2) Laboratories where radioactive materials are stored but not in active use will be surveyed on a quarterly basis.
- 3) Laboratories containing sealed sources will be surveyed biannually.
- 4) Areas where inventories exceed the weekly limits will be surveyed on a daily basis. The RSO may require daily surveys in any area with a history or high potential for contamination.

Appendix F

Properties of Common Radioisotopes

Properties of “Pure” Beta Emitters

Isotope	Half-Life	Decay Product	Decay per Month	Max/Ave Beta Energy (MeV)	Max Range in Air (ft)	Max Range in Tissue (cm)	Percent Transmitted to Live Skin Cells	Dose Rate to Live Skin Cells from a 1 $\mu\text{Ci}/\text{cm}^2$ spill
${}^3_1\text{H}$	12.3 y	${}^3_2\text{He}$	0.5%	.018/.005	0.02	0.0005	0 %	0
${}^{14}_6\text{C}$	5730 y	${}^{14}_7\text{N}$	-	.158/.049	1	0.029	11 %	1400 mR/hr
${}^{32}_{15}\text{P}$	14.3 d	${}^{32}_{16}\text{S}$	77.1%	1.71/.694	20	0.8	95 %	9200 mR/hr
${}^{33}_{15}\text{P}$	24.4 d	${}^{33}_{16}\text{S}$	57.8%	.249/.076	2	0.6	~35 %	N/A
${}^{35}_{16}\text{S}$	87.4 d	${}^{35}_{17}\text{Cl}$	21.4%	.167/.048	1	0.032	16 %	1800 mR/hr
${}^{36}_{17}\text{Cl}^*$	3×10^5 y	${}^{36}_{18}\text{Ar}$	-	.714/.252	9	0.27	N/A	N/A
${}^{45}_{20}\text{Ca}$	165d	${}^{45}_{21}\text{Sc}$	12%	.254/.075	2	0.06	37 %	4000 mR/hr

*Cl-36 produces gamma or x-rays ~ 2 % of the time when it transforms to S-36 through electron capture.

Properties of Common Gamma and X-Ray Emitters

Isotope	Half-Life	Decay Product	Decay per Month	Type of Decay	Principle Radiations Emitted (MeV)	Γ^*	Half Value Layer of Lead**
${}^{22}_{11}\text{Na}$	2.6 y	${}^{22}_{10}\text{Ne}$	2.2%	Positron emission and electron capture	0.545 Max β^+ (90%) 1.275 x-ray (100%) 0.511 γ (180% from β^+)	12.0	0.4 cm
${}^{51}_{24}\text{Cr}$	27.7 d	${}^{51}_{23}\text{V}$	53.3%	Electron capture	0.32 γ (9.8%) V x-rays	0.16	2-3 mm
${}^{125}_{53}\text{I}$	60.2 d	${}^{125}_{52}\text{Te}$	29.7%	Electron capture	0.035 γ (7%) 0.027 – 0.032 Te x-rays (140%) 0.005 – 0.030 e^- (93%)	1.5	0.02 mm

* Γ is the dose rate in R/hr at 1 cm from 1 mCi of a radioisotope. $\Gamma/10$ is the dose rate in mR/hr at 1 m from 1 mCi.

** Half Value Layer refers to the amount of lead required to reduce the intensity of the radiation by a factor of 2. These are approximations because of the complicated spectra of these radioisotopes.