CHAPTER 4 – RADIATION PROTECTION

The Rhode Island Department of Health's Radiation Control Agency has established regulations governing our use of radioisotopes and x-ray machines. This chapter discusses dose limitations established by those regulations and introduces some basic radiation protection concepts.

DOSE LIMITS: The regulations set dose equivalent limits for radiation workers, minors, the unborn child of a radiation worker and members of the general public. The limits for radiation workers and minors are occupational doses. An occupational dose is the dose received by an individual in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of URI or another person. An occupational dose does not include dose received from background radiation, as a patient from medical practices, from voluntary participation in medical research programs, or as a member of the general public.

The doses to an unborn child and/or a member of the public are "public doses." A public dose is the dose received by a member of the public from exposure to radiation and to radioactive material released by URI, or to another source of radiation. It does not include occupational dose or doses received from background radiation, as a patient from medical practices, or from voluntary participation in medical research programs.

The limits are listed in the following table.

Affected Body Area	Affected Individual	mrem[1]/year
Whole body	Radiation Worker	5,000
Lens of eye	Radiation Worker	15,000
Skin	Radiation Worker	50,000
Hands, wrists, feet, ankles	Radiation Worker	50,000
Thyroid	Radiation Worker	50,000
Whole body	Minor (<18 years old)[2]	500
Whole body	Unborn child of radiation worker	500[3]
Whole body	Members of the general public	100

The whole body doses are total effective dose equivalents. A total effective dose equivalent (TEDE) is the sum of the deep dose equivalent (for external

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[1] The rem is the special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, distribution factor, and any other necessary modifying factors. A millirem (mrem) is one thousandth of a rem.

[2] In this context, a minor is an individual less than 18 years of age, working with radioactive materials (not a member of the general public).

[3] Over entire gestation period for a declared pregnant worker.

exposures) and the committed effective dose equivalent (for internal exposures). The deep dose equivalent applies to external whole-body exposure and is the dose equivalent at a tissue depth of one centimeter (1000 mg/cm^2). The committed dose equivalent is the dose equivalent to organs or tissues of reference man that will be received from an intake of radioactive material by an individual during the 50-year period following the intake. The committed effective dose equivalent is the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues. Reference Man is a hypothetical aggregation of human physical and physiological characteristics arrived at by international consensus used to relate biological insult to a common base.

ALARA: ALARA is an acronym meaning As Low As Reasonably Achievable. It is a requirement of the state's regulations. Any facility possessing a radioactive materials license must have a formal ALARA program. ALARA may be defined as a professional standard of excellence, and is practiced by keeping all doses, releases, contamination and other risks as low as reasonably achievable. We try to stay well below legal limits, such as air and water release limits, exposure limits or contamination limits for radioisotope laboratories.

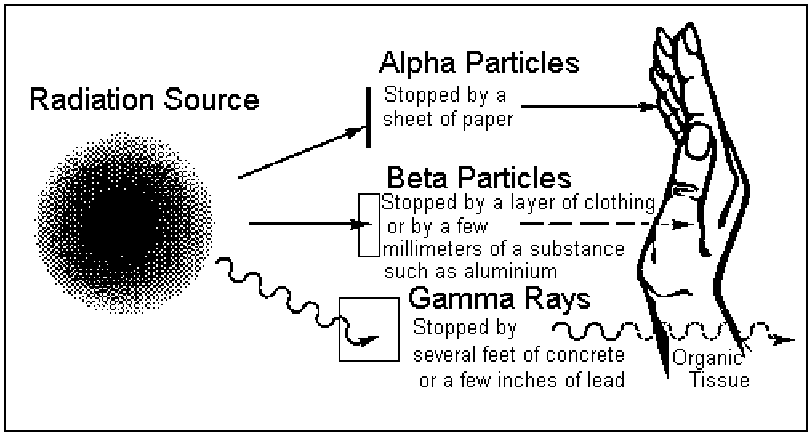
EXPOSURES: There are two potential primary exposure types connected with work involving radioisotopes: external and internal exposure to radiation. The external dose is that portion of the dose equivalent received from radiation sources outside the body. The internal dose is that portion of the dose equivalent received from radioactive materials inside the body. The internal dose is directly related to the intake of radioactive materials. Intake is the quantity of material introduced into the body by inhalation, ingestion or through the skin (absorption, puncture, etc.).

An acute exposure is the absorption of a relatively large amount of radiation (or intake of radioactive material) over a short period of time. A chronic exposure is the absorption of radiation (or intake of radioactive materials) over a long period of time, i.e., over a lifetime.

The twin objectives of our radiation safety program are to prevent acute exposures and minimize chronic exposures. Each must be carefully evaluated prior to working with radioactive materials, and precautions must be taken to minimize or prevent these exposures.

EXTERNAL: External hazards arise when radiation from a source external to the body penetrates the body and causes a dose of ionizing radiation. These exposures can be from gamma or x-rays, alpha particles or beta particles. The exposures are dependent upon the type and energy of the radiation.

Alpha and beta particles, and gamma rays and x-rays present differing external hazards based on their ability to penetrate intervening materials. A sheet of paper will stop alpha particles. Clothing or a few millimeters of aluminum will stop most beta particles. Several feet of concrete or several inches of lead may be needed to stop energetic x-rays and gamma rays.



Most beta particles do not normally penetrate beyond the skin, but when sufficiently intense, can cause skin and/or eye damage. Very energetic beta particles, such as those emitted by Phosphorus-32, can penetrate several millimeters into the skin. Shielding is needed in order to reduce the external radiation exposure. Typically, a ½-inch thick sheet of Plexiglas is an effective shield for most beta particles.

Alpha particles, because of higher mass, slower velocity, and greater electrical charge compared to beta particles, are capable of traveling a few inches in air and rarely penetrate the outer dead skin layer of the body. Alpha particles typically are not an external radiation hazard.

X-rays, gamma rays and neutron radiation are very penetrating. They are of primary importance when evaluating external radiation exposure and usually must be shielded. Exposure to external radiation may be controlled by

- Limiting the working time in the radiation field;
- Working at a distance from the source of radiation;
- Inserting shielding between the user and the source; and
- Using no more radioactive material than necessary.

Statistical needs and other considerations usually determine the amount of radioactive material used in an experiment. Thus, the three primary means of eliminating or reducing external radiation exposures are time, distance and shielding.

TIME: You should minimize the time that radioactive materials are handled. Since your absorbed dose is a direct function of the duration of your exposure, less time means less dose. This may be achieved by conducting "dry runs" (practicing the procedures to be performed, with all of the steps and manipulations performed without the radioactive materials). You should conduct the work quickly and efficiently, but do not rush.

DISTANCE: You should maximize your working distance from the radioactive materials. Dose is inversely proportional to distance, therefore, greater distance means less dose. However, you should not increase the distance to a point where dexterity or control of the materials is jeopardized.

SHIELDING: You can use shielding to reduce or eliminate exposure. By placing an appropriate shield between the radioactive source and the worker, radiation is attenuated and exposure may be completely eliminated or reduced to an acceptable level. The type and amount of shielding needed to achieve a safe working level varies with the type and quantity of radioactive material used. The half-value layer (HVL) may be used as a guide to the thickness of the shielding necessary to block the radiation. The HVL is the thickness of the shielding necessary to reduce the radiation dose rate to half of the original or unshielded dose rate.

INTERNAL: Radioactive materials may be internally deposited in the body when an uptake occurs through one of the three routes of entry: inhalation, ingestion and skin contact. These exposures can occur when radioactive material is airborne; is inhaled and absorbed by the lungs and deposited in the body; is present in contaminated food, drink or other consumable items and is ingested; or is spilled or aerosolizes onto the skin and absorbed or enters through cuts or scratches. Internal deposition may also result from contaminated hands, with subsequent eating or rubbing of eyes.

Internal exposures arise when radiation is emitted from radioactive materials present within the body. All forms of radiation can cause internal radiation exposures. Alpha particles create a high concentration of ions along their path, and can cause severe damage to internal organs and tissues when they are inhaled, ingested or are present on the skin. Once these particles get into the body, damage can occur since there is no protective dead skin layer to shield the organs and tissues. Internal exposures are not limited to the intake of large amounts at one time (acute exposure). Chronic exposure may arise from an accumulation of small amounts of radioactive materials over a long period of time.

The sustained buildup of radioactive material in the body will eventually reach a body burden. Body burden is the amount of radioactive material, which, if deposited in the total body, will produce the maximum permissible dose rate to the critical organ. The critical organ is the organ or tissue, the irradiation of which will result in the greatest hazard to the health of the individual or his descendants.

Many substances taken into the body will accumulate in certain body organs, called target organs. For example, iodine will accumulate in the thyroid gland. When iodine is inhaled or ingested, the body cannot distinguish stable iodine from radioactive iodine; a significant portion of the inhaled iodine will be deposited in the thyroid gland within 24 hours.

Other elements, such as calcium, strontium, radium and plutonium accumulate in the bones. Here, high doses to bones can occur over very long periods of time, since the body eliminates these materials very slowly once they are incorporated into the bone structure. The blood forming organs, such as the bone marrow, are very radiosensitive, since bone marrow cells are in the S-phase of mitotic activity more often than other cells. Hence, if there is a significant long-term exposure to radioisotopes, chronic diseases such as leukemia and/or osteosarcoma can occur. The induction time for the onset of these types of diseases is typically in excess of 20 years.

The regulatory limits for internal exposure are expressed as an annual activity limit for each radioisotope. The Annual Limit of Intake (ALI) is the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a committed effective dose equivalent of 5 rems or a committed dose equivalent of 50 rems to any individual organ or tissue. Annual Limits of Intake are listed in Appendix B to Part A of the state regulations.

CONTAINMENT: If volatile or dispersible radioactive materials (especially if high levels) are used there may be a potential for an airborne hazard from dust or vapor. Some containment may be required. Partial containment is offered by the use of chemical fume hoods. Biological cabinets, glove boxes and other specialized devices are available commercially. The Radiation Safety Office can provide information about the applicability and procurement of these devices. All systems used in radioisotope work requiring enclosures should be tested and approved before such use, and semi-annually thereafter.

Fume hoods with flow rates of at least 100 linear feet per minute should be used whenever working with radioactive materials where the potential for vaporization/volatilization exists (as is the case during iodination), or in handling stock solutions of radioisotopes, because of the high activity concentration.

AIRBORNE HAZARDS CONTROL: Radioactive materials may be released into the air, causing the user to have an uptake of the material through one or more of the routes of entry into the body. Many situations can cause airborne release of radioactive materials.

Air movement across contaminated areas in a room can create airborne radioactivity. Circulating air can pick up most commonly used radioisotopes and spread them as airborne contamination. This is a good reason to keep areas free of contamination.

Use of volatile forms of radioisotopes, such as I-125 for iodinations or H-3 sodium borohydride may generate airborne radioactivity. Any chemical or physical form that readily volatilizes or evaporates into the air must be considered a potential airborne radioactivity risk.

Chemical reactions may generate radioactive gases or other airborne contaminants. An example is the labeling reaction for S-35 methionine. The reaction generates a methyl mercaptan reaction. The reaction liberates HCl and $^{35}SO_2$ gas. Airborne radioactivity has resulted in unnecessary intakes and area contamination in laboratories where the users were unaware of this risk and had not taken precautions to trap or contain the liberated $^{35}SO_2$.

Heating or incubating may cause evaporation or chemical reactions that release radioactive materials into the air. Aerosols (tiny droplets or particles) are present with all materials, and pose an increased risk when handling stock solutions or other high concentrations of radionuclides. You should use chemical fume hoods or biological safety cabinets for high activity, concentrated or potentially volatile radioactive materials manipulations.

Frozen materials may release substantial quantities of aerosols or gaseous radioactive material when the containers are opened. There have been incidents at other institutions where this has occurred and has caused significant contamination of work areas, equipment and clothing of the worker opening the containers.

Media or solutions containing cells, bacteria or other living organisms are another cause of airborne radioactivity. The living organisms metabolize the radioactive substrates and may produce radioactive gases or vapors as a byproduct.

When hazardous chemical forms of the radioisotopes are used, such as labeled carcinogens or toxins, the vapors, aerosols or gases present or generated in the use present additional risks. In this instance, the risks are both radioactive and chemical.

In order to prevent uptake in these increased risk situations, the operation should be conducted in fume hoods, biological safety cabinets or other containment to protect the user from uptake and internal deposition.

Tissue culture hoods should not be used for radioactive materials, or any other hazardous material. These hoods blow the hazardous material present in the sterile culture into the face of the user and into the room. Tissue culture hoods provide no protection for the user.

In certain rare cases, respiratory protection may be necessary for certain radioisotope uses. However, respiratory protection should only be used when other means of control and containment do not provide enough protection. Respirators must be chosen carefully to ensure the proper fit and type of cartridge, and the use must be monitored carefully. For this reason, Radiation Safety must pre-approve, document and monitor the use of respirators for radioactive materials. Fit testing and medical monitoring are required before using respirators.

If you are concerned that an intake has occurred, contact the Radiation Safety Office. Bioassays (urine samples) or other internal counting methods may be employed to determine whether an intake has actually occurred and to recommend ways to avoid such undesirable situations in the future.

A properly functioning fume hood or equivalent approved enclosure should be used whenever there is a possibility of airborne radioactivity. Fume hoods in radioisotope laboratories are surveyed annually by the Radiation Safety Office. The survey consists of measuring airflow velocity at the face opening of the hood and visually checking air containment using visible smoke.

The hood airflow velocity test uses a velometer to measure the average face velocity with the sash at its normal operating height. If the airflow is less than 80 fpm at a reasonable working height (generally about 20 inches), an increase in airflow is required.

Air containment is visually checked using smoke sticks[4]. The hood face is traversed with the smoke source to observe air flow patterns. Back flow or air eddies which result in release of smoke into the room are not permitted.

HEPA is an acronym for “high efficiency particulate arresting”. HEPA filters effectively remove particulate radioactivity from the exhaust stream.[5] The HEPA filter component is essentially an accordion of very fine paper-like material. The material is loaded in this accordion or zig-zag manner so that a very large surface area is available for air to be pulled through by the exhaust fan. Over time (usually about three to five years) the filter may plug and air will no longer be able to move through the filter. The annual hood tests will detect significant plugging by the associated reduced airflow. In addition, differential pressure gauges may be used to monitor the ΔP across the HEPA filters.

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[4] Standard smoke sticks generate titanium dioxide particles.

[5] HEPA filters remove 99.95-99.97%.

To use the safety features of a fume hood effectively, the following procedures should be used:

1. Never remove sashes or alter a hood.
2. Always check with a piece of tissue to see if the hood is operating prior to use.
3. Remove all unnecessary items from the hood to prevent their contamination.
4. Cover stationary objects not to be used.
5. Keep the materials in use away from the sash openings to insure containment.
6. Always wear a lab coat, gloves and safety glasses (further protection is available for arms and face).
7. Never enter the sash opening without protection; avoid placing your head inside the plane of the hood opening.
8. Further protection can be achieved by working around a sash or shield and doing certain manipulations inside a plastic bag in the hood.
9. Dry runs are advisable for unfamiliar procedures.
10. Keep volatile wastes in the hood.
11. Close, mark and bag the container before removal.