# TABLE OF CONTENTS

## HEALTH PHYSICS REGULATIONS

### A. PURPOSE
- 1. Purpose .................................................................................................................. 1

### B. RESPONSIBILITIES
- 1. Health Physics Advisory Committee (HPAC) .................................................. 1
  - a. Non-Human Use .................................................................................................. 1
  - b. Human-Use ........................................................................................................ 1
  - c. General ............................................................................................................... 1
- 2. Health Physics (HP) .............................................................................................. 2
- 3. Departmental Chairs ............................................................................................ 2
- 4. Project Supervisors .............................................................................................. 2
- 5. Individuals ............................................................................................................ 3

### C. REQUIRED PROCEDURES PERTAINING TO RADIOACTIVE MATERIAL
- 1. Scope ..................................................................................................................... 3
- 2. Permissible Exposures ............................................................................................ 4
- 3. Registration and Authorization ............................................................................. 4
- 4. Medical Examinations ............................................................................................ 4
- 5. Radiation Surveys and Monitoring ..................................................................... 4
- 6. Personal Monitoring .............................................................................................. 4
- 7. Warning Labels and Signs .................................................................................... 4
- 8. Consumption of Foodstuffs .................................................................................. 5
- 9. Use of Radioactive Material ................................................................................ 5
- 10. Storage of Radioactive Material ......................................................................... 5
- 11. Disposal of Radioactive Material ....................................................................... 5
  - a. Disposal into Sewerage System ......................................................................... 5
  - b. Non-Dischargeable Liquid Waste ...................................................................... 5
  - c. Solid Waste Disposal into Containers ............................................................... 6
    - 1) General ............................................................................................................. 6
    - 2) P-32 and Other Short-lived Isotopes .................................................................. 6
- 12. Transfer of Possession of Radioactive Material .............................................. 6
- 13. General Requirements and Precautions ........................................................... 6
- 14. Emergency Procedures ...................................................................................... 6
- 15. Pregnancy and Radiation Work .......................................................................... 7
  - a. Federal Regulations ............................................................................................ 7
  - b. Provincial Regulations ....................................................................................... 7
  - c. Risks .................................................................................................................... 7
  - d. University Policy ................................................................................................ 8
    - 1) External Exposures .......................................................................................... 8
    - 2) Internal Exposures ........................................................................................... 8
- 16. Communicating with the HPAC ......................................................................... 8

### A. INTRODUCTION
- 10

### B. BASIC DEFINITIONS
- 10

### C. RADIATION DOSE UNITS
- 12
  - 1. Absorbed Dose ................................................................................................... 12
  - 2. Equivalent Dose .................................................................................................. 12
  - 3. The Roentgen ..................................................................................................... 12
  - 4. Effective Dose .................................................................................................... 12

### D. ANNUAL DOSE LIMITS
- 13

### E. BACKGROUND RADIATION
- 13

### F. RISKS
- 15

### G. ACUTE EFFECTS
- 18

### H. EXTERNAL RADIATION
- 18
  - 1. Gamma Rays ....................................................................................................... 18
    - a. Radiation Fields from Gamma-emitters .......................................................... 19
    - b. Protection from Gamma-rays .......................................................................... 20
    - c. Summary .......................................................................................................... 21
HEALTH PHYSICS REGULATIONS

A. PURPOSE

This manual incorporates the policies of the Health Physics Advisory Committee designed to:
(a) protect University personnel and the general public from the hazards associated with the University's use of radioactive material or equipment emitting ionizing radiation;
(b) ensure the University's compliance with federal, provincial, and local radiation protection regulations.

The adherence to the rules and regulations contained in this manual is a condition of approval for use of radioactive material or equipment emitting ionizing radiation at McMaster University.

B. RESPONSIBILITIES

1. Health Physics Advisory Committee (HPAC)

The HPAC receives its authority from the Office of the President of McMaster University.

The HPAC is charged with the following responsibilities:
(a) The establishment and continuing review of an adequate radiation protection program at McMaster University.
(b) The University's compliance with radiation protection regulations promulgated by federal, provincial, and local authorities. This responsibility in no way preempts the requirements of the Atomic Energy Control Regulations or any order issued thereunder.

To meet these responsibilities, the HPAC has the following authority:

a. Non-Human Use

(1) To grant authorization and to restrict the use on campus\(^1\) of radioactive material, within the limits of the relevant Atomic Energy Control Board (AECB) licenses.
(2) To suspend the use at McMaster University of radioactive material or equipment that emits ionizing radiation, regardless of the source of authorization.
(3) To provide radiation protection services on a contractual basis at McMaster University to non-McMaster University organizations. Such organizations must obtain a separate AECB license specifying that the handling procedures shall be in accordance with the radiation safety policies of the HPAC.

b. Human-Use

(1) The HPAC has no authority over medical diagnostic and therapeutic procedures involving radioactive material or X-ray units.

c. General

(1) To inform the President of the hazards of equipment emitting radiation and to regulate its use as requested by the President.

\(^1\)For the basis of health physics at McMaster University, the "campus" is defined as those laboratories listed in the license applications by the HPAC to the AECB, as well as those additional laboratories which are approved by the HPAC during the tenure of these licenses.
(2) To produce and continually review radiation protection manuals that incorporate the policies of the HPAC.

2. **Health Physics (HP)**

Health Physics is responsible for:
(a) Implementing the HPAC’s radiation protection program.
(b) Supervising the University's common radioisotope laboratories and storage facilities.
(c) Providing such services as may be required for radiation protection and compliance with government regulations. These services include but are not restricted to the following:
   (1) registration and instruction of workers;
   (2) prescribing medical examinations upon the advice of the Medical Consultant to the HPAC;
   (3) provision of external monitoring devices;
   (4) radioisotope laboratory inspections, radiation surveys, and area monitoring;
   (5) radioactive waste collection and disposal;
   (6) calibration and short-term loan of radiation protection instruments;
   (7) environmental monitoring;
   (8) leak testing of sealed radioactive sources;
   (9) maintenance of records of radioactive sources and materials received by authorized projects;
   (10) supervision of radiation emergencies and special decontamination operations;
   (11) maintenance of radiation protection records;
   (12) provision of bioassay services.

3. **Departmental Chairs**

In regard to use of radioactive material or X-ray units in undergraduate or graduate instruction, each departmental chair is responsible for providing adequate facilities, equipment, instruments, supervision, and instructions to control radiation hazards and to comply with the University's radiation protection requirements. For radioisotopes, a description of the experiment, including the type and quantity of each isotope used, must be submitted to the HPAC. If approval is granted, a permit will be issued and this permit must be posted in each laboratory where the isotopes are used. For both X-ray units and radioisotopes, arrangements may be made with Health Physics for the provision of a safety talk to the students to satisfy the requirement of providing instruction to the students in the fundamentals of radiation protection.

It is the policy of the HPAC that laboratory demonstrators must not prepare open sources of radioactive material unless:
(a) directly supervised by the faculty member responsible for the laboratory or a trained delegate; or
(b) they have been instructed by the supervisor and been provided with written instructions.

4. **Project Supervisors**

Each project supervisor is responsible for providing adequate facilities, equipment, instruments, supervision, and instructions to control radiation hazards and to comply with the University's radiation protection requirements. In addition, each project supervisor possessing or using radioactive material or radiation sources is responsible for:
(a) Assigning a specific person, whose name shall be shown clearly on the laboratory door, the responsibility of enforcing safe practices in work with radioactive material in the laboratory.
(b) Maintaining an up-to-date listing with HP of rooms in which radioactive material is stored or handled, and of rooms in which radiation-emitting equipment is used.
(c) Maintaining an up-to-date listing with HP of the names of personnel who may be handling radioactive material, or who may be exposed to ionizing radiation in excess of any dose specified in column 3 of Table 1, Appendix A (except for prescribed medical treatment).
(d) Allowing only those persons who are registered with HP to handle or use radioactive material, and/or radiation sources.

(e) Ensuring that the permit containing the Conditions of Approval is posted in each laboratory named on the permit and ensuring compliance with the Conditions of Approval.

(f) The maintenance of an adequate inventory of the amount of radioactive material possessed by each of that person's projects, and the establishment of an adequate system to ensure that each project does not exceed its radioactive material possession limits.

(g) Establishing procedures to check the integrity, completeness, and contamination levels of incoming shipments of radioactive material.

(h) Allowing only authorized persons to enter rooms containing radioactive material.

(i) Informing HP of new radioactive-material work, or changes in existing work.

(j) Ensuring that personnel wear assigned personal dosemeters.

(k) Establishing appropriate procedures to ensure compliance with the posting of Warning Labels and Signs as described in the Atomic Energy Control Act Regulations.

(l) Establishing a daily laboratory procedure adequate to ensure that at the end of the workday:

1. Survey-meter measurements have established that external radiation and contamination levels are within permissible limits;

2. Radiation sources are properly labeled and stored;

3. Experiments that will be in progress after normal work-hours will be properly attended;

4. Each laboratory is secured against unauthorized access.

(m) Notifying HP when a woman working under his/her supervision is known to be pregnant.

(n) Immediately informing HP of the loss or theft of any radioactive material.

The HPAC recognizes that during the tenure of the permit, procedures may gradually evolve over time. If the procedures in actual use:

(a) Differ from the original approved procedures such that the potential risk has increased; or

(b) Have resulted in, or could result in radiation doses in excess of the limits for a member of the general public; or

(c) Are to be employed by inexperienced personnel without direct supervision by the project director; then any member of the HPAC or Health Physics can require that written procedures be submitted to the HPAC for consideration and approval before any additional work can be conducted. The supervisor is responsible for ensuring that all workers are familiar with the new approved written procedures.

5. Individuals

Each individual who may use radioactive material or a source of ionizing radiation is responsible for:

(a) Complying with the policies and regulations of the Health Physics Advisory Committee and with the Conditions of Approval established for the project under which the radioactive material work is conducted.

(b) Taking all reasonable and necessary precautions to ensure one's own safety and the safety of one's fellow employees.

(c) Using such devices, wearing such articles of clothing and making use of such equipment as are intended for a person's protection and furnished to that person by the University or required pursuant to the conditions in any authorization issued by the HPAC or by the AECB.

(d) Informing her supervisor and HP when she is known to be pregnant.

C. REQUIRED PROCEDURES PERTAINING TO RADIOACTIVE MATERIAL

1. Scope

These procedures apply to all departments, laboratories, and persons at McMaster University that receive, possess, use, or dispose of radioactive material.
2. **Permissible Exposures**

(a) Exposure to ionizing radiation shall be kept as low as reasonably achievable, taking into account social and economic considerations.
(b) The external and internal exposure from sources of radiation shall be controlled to provide reasonable assurance that no individual shall receive a dose in excess of the value listed in column 2 of Table 1, Appendix A.
(c) For pregnant women, the dose to the abdomen must not exceed the value listed in column 4 of Table 1, Appendix A during the remainder of the pregnancy after the University has been informed.

3. **Registration and Authorization**

(a) Before possessing or using radioactive material, authorization must be obtained from the HPAC. (The procedures for obtaining authorization and procuring radioactive material are described in Appendix B.)
(b) Each person who may handle radioactive material or who may be exposed to external or internal radiation (except prescribed medical treatment) must register with Health Physics and receive a radiation protection instruction-interview.

4. **Medical Examinations**

(a) Each person registered with Health Physics shall be given medical examinations of such a nature and at such intervals as required on the advice of the Medical Consultant to the HPAC. Normally, for Atomic Radiation Workers, this will consist of baseline blood and urine tests and subsequent annual tests.
(b) Any person dealing with radioactive material may be removed from work with ionizing radiation on the advice of the Medical Consultant.

5. **Radiation Surveys and Monitoring**

(a) Each laboratory using radioactive material must provide or have immediate access to suitable radiation detection instruments, unless otherwise authorized by the HPAC.
(b) During and immediately following the use of radioactive material, personnel shall use an appropriate radiation detection instrument to ensure that radiation exposure and contamination are being adequately controlled.

6. **Personal Monitoring**

The HPAC policy is to provide an approved personal dosimeters to the following individuals:
(a) Those likely to receive an effective dose in excess of 2.5 mSv per year;
(b) All pregnant workers;
(c) All Reactor workers regardless of the anticipated annual exposure;
(d) All users of energetic beat-emitters (e.g. $^{32}$P) using more than 0.1 mCi (4 MBq);
(e) Any worker requesting a dosimeter who does not otherwise qualify.

7. **Warning Labels and Signs**

(a) Each container in which is stored or used radioactive material in excess of the scheduled quantity (see Appendix D) shall have a durable, clearly visible label bearing a radiation warning symbol and the words "CAUTION-RADIOACTIVE MATERIAL" together with information as to the nature, form, quantity, and date of measurement. Labeling is not required for laboratory containers such as beakers, flasks, and test tubes used transiently in the laboratory procedures while the user is present.
(b) Each area, room, or enclosure in which
(1) radioactive material in excess of one hundred times the Scheduled Quantity is stored or used,
(2) the dose rate which might be received by a person in normally accessible places is greater than that specified in Appendix A, Table 1, column 2,
shall be clearly marked with durable signs bearing a radiation warning symbol together with the words "CAUTION-RADIATION HAZARD" and an indication of the radiation level. Appropriate signs may be obtained from Health Physics.

8. Consumption of Foodstuffs

There shall be no eating or drinking in any laboratory containing open sources of radioactive material. The visible presence of eating or drinking utensils, or the presence of food or drink packaging in the laboratory waste will be considered as evidence of violation of this policy. Upon the first violation, a verbal warning will be given to the project supervisor by either the Senior Health Physicist or the Health Physics Coordinator. A second violation will result in a formal written warning, with a copy to the Departmental Chair. A third violation will result in immediate suspension of the permit until a meeting of the HPAC can be convened to consider the circumstances and disciplinary action. Flagrant violations may result in one or more steps being bypassed. After one year of exemplary behaviour, a violation will be removed from the record.

9. Use of Radioactive Material

(a) Any laboratory in which radioactive material is used or stored shall be classified by Health Physics as a "Basic Level Laboratory" or "Intermediate Level Laboratory".
(b) The quantity of radioactive material used or stored in laboratory shall not exceed that specified for the laboratory classification. The maximum levels of radioactivity and appropriate modifying factors are given in Appendix C.

10. Storage of Radioactive Material

Radioactive material shall be kept or stored in such a manner that:
(a) the storage container is labeled in accordance with the regulations of C(7) above;
(b) the storage container provides adequate radiation shielding;
(c) the storage container provides adequate protection against fire, explosion, flooding, or accidental breakage of primary storage containers.

11. Disposal of Radioactive Material

a. Disposal into Sewerage System

Radioactive wastes may be discharged into laboratory drains if all the following conditions are met:
(1) the radioactive material is readily soluble in water;
(2) the solution does not contain any material prohibited by law from discharge to the sewer;
(3) the average concentration of the material does not exceed 0.01 Scheduled Quantities per litre. Scheduled Quantities may be found in Appendix D or obtained from Health Physics.
(4) liquid scintillation solutions shall not be discharged into laboratory drains.

b. Non-Dischargeable Liquid Waste

(1) Put organic radioactive waste solutions into containers designated for organic waste.
(2) Put aqueous radioactive waste solutions into containers designated for aqueous waste if the limits specified in C.10.(a)(3) cannot be reached.
(3) Liquid scintillation vials containing liquid scintillation fluid will be disposed of intact. Contact HP
for additional details and costs.

c. Solid Waste Disposal into Containers

(1) General

(a) The total amount of radioactive material put into any container must be controlled so that the radiation level at one foot from the container does not exceed 10 µSv (1 mrem) per hour and the radiation level at contact with any surface does not exceed 0.5 mSv (50 mrem) per hour.
(b) When a container is full or its emitted radiation is approaching the limits specified in the preceding section, Health Physics shall be notified (extension 24226).
(c) Material must not be put into the waste collection containers if there is any possibility of a chemical reaction during storage that might cause fire or explosion, or cause the release of toxic or radioactive gas or vapour.
(d) No biological material shall be placed in the radioactive waste if it could be hazardous to any individual handling the waste, either immediately or after storage for extended periods at room temperature. Such material shall either be rendered inert or be kept frozen until collection.
(e) Powdered material shall be put into a metal or plastic container that is sealed before disposal.
(f) Before disposal, sharp objects or glassware shall be put inside protective containers.
(g) Animal carcasses are shipped off-campus for disposal. A record of the activity disposed of via this route must be maintained. In order to do this, the "In-Vivo Authorization Form" must be completed and submitted to Health Physics before each animal experiment.
(h) Waste of a specified nature containing $^{32}$P shall be placed in a separate labeled container provided by Health Physics.

(2) P-32 and Other Short-lived Isotopes

(a) Only materials approved by Health Physics are permitted in this waste container. A current list of permitted materials will be provided as required to each laboratory.

12. Transfer of Possession of Radioactive Material

No radioactive material may be transferred, transported, or shipped from the approved location unless:
(1) Approval from Health Physics has been obtained.
(2) All regulations concerning the transport, packaging, and supply of radioactive material have been satisfied.
(3) An Export Permit has been obtained through HP if the material is to leave Canada.

13. General Requirements and Precautions

The required procedures and precautions for all workers are described in the Radiation Safety Guide section of this manual.

14. Emergency Procedures

(a) **Accidents involving overexposure to radiation but without physical injury.** Immediately inform Health Physics who will arrange for the care of the patient by the Medical Consultant.

(b) **Accidents involving the ingestion or inhalation of radioisotopes and/or skin contamination without physical injury.** Immediately inform Health Physics. Emergency decontamination procedures will be carried out in the building where the accident occurred, if possible. The Medical Consultant will be advised and will recommend any specific treatment deemed necessary.
15. Pregnancy and Radiation Work

Both provincial and federal regulations place some restrictions upon the radiation exposure allowed during the remaining term of pregnancy. To ensure that the worker is aware of these restrictions as well as the potential risks, the University and the AECB regulations require that the female worker inform Health Physics and her supervisor as soon as she becomes aware of her pregnancy.

a. Federal Regulations

The maximum dose limits for a pregnant worker are given in Appendix A. The worker must inform her employer of her pregnancy as soon as she is aware of her pregnancy.

b. Provincial Regulations

Generally, the Provincial regulations for pregnant X-ray workers are identical to the AECB regulations in regard to external doses to the abdomen.

c. Risks

In 1990, two separate reports reviewed the known effects of radiation on the foetus. One was published by the International Commission on Radiological Protection (ICRP) which is an independent organization of internationally recognized experts whose recommendations are based on the best available scientific data. This report is known as ICRP-60. The other was published by the United States National Academy of Sciences and was entitled "Health Effects of Exposure to Low Levels of Ionizing Radiation" (commonly known as BEIR V) which also reviewed the latest data. There are no significant differences between the conclusions of these two reports.

Both reports suggest that irradiated foetuses seem to be susceptible to childhood leukaemia and other childhood cancers which are expressed during approximately the first decade of life. In the atomic bomb survivors, two cases of childhood cancer have been observed among 1,630 in utero-exposed survivors, both of which occurred in persons who had been heavily exposed (1,390 mSv and 560 mSv). This is consistent with earlier studies which led to the estimate that if each of 100,000 foetuses received an in utero dose of 1 mSv, there would be slightly less than 3 excess childhood cancers among the 100,000 children.

It now appears that the developing human brain is susceptible to ionizing radiation. The effect is absent for irradiations during the first 8 weeks and later than 25 weeks. The effect is maximum between 8 and 15 weeks, and less between 15 and 26 weeks. BEIR V concludes that "In those irradiated between weeks 8 and 15, the prevalence of mental retardation appeared to increase with dose in a manner consistent with a linear, nonthreshold response, although the data do not exclude a threshold in the range of 200-400 mSv". The ICRP concluded that there was a threshold of about 120-200 mSv. There appeared to be a lowering of the IQ by about 30 IQ points per 1,000 mSv.

Thus in summary, it is generally recognized that the foetus is more radiosensitive than an adult and that exposure to ionizing radiation will increase the risk to the foetus. However, as long as the foetal exposures are within the regulatory limits during the remainder of the term, this increased risk is extremely small compared to naturally occurring risks.
d. University Policy

Although each case must be individually assessed, experience has shown that the following generalities normally apply.

(1) External Exposures

For the commonly used isotopes in the quantities normally encountered, external radiation exposures are well below the regulatory limits for pregnant workers. This is also true for the use of analytical X-ray units. If the worker is issued a TLD badge on a monthly period, rather than the normal quarterly period, increased control of radiation exposures can be maintained and compliance with government regulations is better assured. As a result, restrictions on work with radioactive material or X-ray units would normally not be applied because of external exposures.

An exception may be possible for workers using large quantities (mCi or tens of MBq) of $^{32}$P during labeling processes. Based upon the individual's previous exposure history, work with large quantities of $^{32}$P may not be permissible under the current AECB regulations.

(2) Internal Exposures

Internal exposures present a potential hazard greater than external exposures since the radioactive material can be transferred to the foetus. For most isotopes, there seems little reason to expect the radioisotope to have a different metabolic fate in the foetus than in the mother, and so the doses will be similar. The effect may be enhanced, however, because of the increased radiosensitivity of the foetus.

For most work, the inhalation or ingestion of a radioisotope is a remote possibility if proper procedures are followed. That is, work with powdered or dusty material should be conducted in a glove-box, work be conducted in a fume-hood whenever possible, and spills reported promptly to Health Physics. Routine contamination checks of the laboratory should detect the release of particulate radioactive materials to the air well below levels corresponding to any significant hazard.

However, some work is conducted with volatile, or potentially volatile, radioactive material. The most likely isotopes are tritium in the form of tritiated water (HTO), radioiodine, and, to a much lesser extent, sulphur. In addition to limiting the dose to the abdomen, the AECB restricts the intake of radioactive material during the remainder of the term (see Appendix A). This limit would correspond to an intake of approximately one microcurie of either $^{125}$I or $^{131}$I, or a few tens of microcuries of bound $^{3}$H or $^{35}$S. For both $^{3}$H and $^{35}$S, intakes approaching these limits are extremely improbable. However, for the radioiodines, the value is much less than the quantity normally used during radioiodinations, (1,000-2,000 µCi) and so the HPAC has established the policy of not permitting radioiodinations to be conducted by pregnant workers.

In regard to work with trace (<1 µCi) quantities of bound radioiodine, the HPAC allows such work subject to the condition that routine thyroid scans are obtained in consultation with Health Physics. For work with intermediate quantities, each situation must be individually assessed. Much will depend upon the type of work, the individual's exposure history, and the type and quantity of radioisotope in use. The HPAC recommends that, whenever feasible, such work not be conducted by a pregnant worker, but the final decision will depend upon the circumstances.

16. Communicating with the HPAC

If you have any suggestions or complaints which you feel should be brought directly to the attention of the HPAC:

(a) put your submission in writing, address it to the Chair of the HPAC, and mail it c/o Health Physics,
NRB-106.
(b) the name of the current chair and membership of the HPAC can be obtained from Health Physics if you wish to communicate directly with the chair or an individual member.
RADIATION SAFETY GUIDE

A. INTRODUCTION

This section is intended to provide basic principles of radiation protection. It also includes additional HPAC regulations. An understanding of these principles will help you in recognizing and assessing the potential hazards associated with your work involving radioisotopes. It may also help you in the design of the experiment so that the work can be conducted safely. However, this document must of necessity be quite general, and so additional information, instruction, and advice should be sought from your supervisor or Health Physics before initiating work with radioisotopes.

B. BASIC DEFINITIONS

The Nucleus: The nucleus consists of positively-charged protons and neutral neutrons, in more or less equal numbers.

The Atom: The atom consists of a massive, positively charged nucleus around which negatively charged electrons travel in well-defined orbits. In a neutral atom, the number of electrons equals the number of protons. The model is very much like our solar system in which the light planets orbit the massive sun. All matter consists of atoms collected together.

The Atomic Number (Z): The atomic number of a nucleus is the number of protons in the nucleus. Each different atomic number corresponds to a different chemical element. For example, the atomic number for nitrogen is seven; the atomic number for oxygen is eight.

The Mass Number (A): The mass number is the sum of the number of protons and neutrons.

Isotopes: Nuclei having the same atomic number (Z) but different mass numbers are known as isotopes. Isotopes differ only in neutron number, and have the same chemical behavior since they have the same number of protons, and this determines the element.

Nomenclature: The shorthand method of specifying the details of a nucleus is:

\[ ^{14}\text{C} \]

The Mass Number (14 in this example) is given as a left-hand superscript. The Atomic Number is implied by the chemical symbol (6 in this example for carbon). We therefore know that this nucleus has (14-6=8 neutrons). For convenience in typesetting, representation of an isotope may be written as C-14 as well as \(^{14}\text{C}\) in this document. The isotope is called "carbon 14".

Radioactive Decay: For each mass number, there is an optimum ratio of protons to neutrons. To obtain this ratio, the nucleus can convert a proton to a neutron, or vice-versa, or can even eliminate a combination of both. This conversion from one nuclear energy state to another is radioactive decay.

Half-Life: The length of time it takes for one half the original number of nuclei to undergo radioactive decay is known as the half-life. At the end of one half-life, one half of the original atoms are left; at the end of two half-lives, one half of one half, or one quarter, are left.

Alpha-Decay: An alpha particle consists of a helium nucleus, namely 2 protons and 2 neutrons (He-4). The emission of an alpha-particle from the nucleus in an attempt to reach the optimum neutron-to-proton ratio is called alpha decay. This type of decay is common for elements above lead in the periodic table, rare for elements below lead.

Beta Decay: The term beta-decay (\(\beta\)-decay) is applied to any of the processes by which the nucleus alters its atomic number (Z) but not its mass number (A). That is, the number of protons in the nucleus
changes, but the sum of the protons plus neutrons remains constant.

The most common process is the conversion of a neutron to a proton, with the emission of an energetic electron (β⁻-particle) from the nucleus. Isotopes such as $^3$H, $^{32}$P, and $^{35}$S undergo $\beta^-$ decay.

$$^{32}\text{P} \rightarrow ^{32}\text{S} + e^-$$

Another process by which the nucleus can alter the ratio of protons to neutrons is for a proton in the nucleus to capture an orbital electron, thus being converted to a neutron. Isotopes such as $^{51}$Cr and $^{125}$I decay by this process of electron capture.

$$^{125}\text{I} + e^- \rightarrow ^{125}\text{Te}$$

The final process is the conversion of a proton to a neutron by the emission of a positively charged electron (positron) from the nucleus, a process known as positron-decay or $\beta^+$ decay. Isotopes such as $^{22}$Na and $^{65}$Zn decay by this process.

$$^{22}\text{Na} \rightarrow ^{22}\text{Ne} + e^+$$

**Gamma Ray:** Following alpha or beta decay, the nucleus often has residual energy that it dissipates by emitting electromagnetic radiation, called gamma rays. Physically, gamma rays are identical to X-rays, the only difference being that gamma rays result from nuclear changes and X-rays result from atomic (electronic) changes.

**The Joule:** A joule is a unit of work and equals 0.24 gram-calories. It is also the amount of work produced in one second by one watt.

**Electron Volt:** The electron volt is a unit of energy. Chemical bonds are the order of a few electron volts, while nuclear decay energies normally involve thousands (keV) or millions (MeV) of electron volts of energy.

**The Curie (Ci):** The curie is defined as $3.7 \times 10^{10}$ disintegrations per second. More common are the submultiples millicurie (1 mCi = $10^{-3}$ Ci) and microcurie (1 µCi = $10^{-6}$ Ci).

**The Becquerel (Bq):** The Becquerel has replaced the curie as the fundamental unit of activity. It is defined as one disintegration per second. Its common multiples are:

- kilobecquerel (kBq = $10^3$ Bq)
- megabecquerel (MBq = $10^6$ Bq)
- gigabecquerel (GBq = $10^9$ Bq)
- terabecquerel (TBq = $10^{12}$ Bq)

Therefore: $1$ Ci = $37$ GBq $1$ mCi = $37$ MBq $1$ µCi = $37$ kBq

**Atomic Radiation Worker (ARW):** any person who is required, in the course of their work, business, or occupation to perform duties in such circumstances that there is a reasonable probability that, during a year,

1. the sum of the external effective dose and internal committed effective dose may exceed the limit for a member of the public given in Appendix A or
2. the sum of the external organ dose and committed organ dose to that organ may exceed the limit for a member of the public as given in Appendix A.
C. RADIATION DOSE UNITS

1. Absorbed Dose

Radiation resulting from a nuclear transformation is commonly referred to as "ionizing radiation" since it has enough energy to knock an electron out of an atom or molecule, a process known as ionization. This ejected electron, in turn, may collide with other atoms and either eject more electrons or excite the atom. So, as the radiation passes through matter, energy is transferred to the matter by these processes, resulting in a track of ionized and disrupted molecules. These may then recombine in different ways, resulting in structural changes and perhaps ultimately in biological effects. The unit of absorbed dose is related to the energy deposited, and the basic unit is known as the Gray (Gy) in the SIU system.

\[ 1 \text{ Gray} = 1 \text{ joule per kilogram} \]

Another unit of absorbed dose still in widespread use is the rad.

\[ 1 \text{ rad} = 100 \text{ ergs per gram} = 0.01 \text{ joules per kilogram} \]  
\[ \text{(therefore 100 rads} = 1 \text{ Gray)} \]

2. Equivalent Dose

In humans, it is found that the extent of biological damage depends not only upon the amount of energy deposited per unit mass in the system, but also upon how the energy is distributed within that unit mass. For the same total amount of energy deposited, those radiations which produce a dense track of ionized and excited molecules are more effective at promoting biological changes than those radiations which produce a more widespread distribution of ions. To take this into account, the absorbed dose in Grays (or rads) is multiplied by a scaling factor called the Radiation Weighting Factor (once known as the Quality Factor QF). This factor is 1 for the most common radiations (beta particles, X- and gamma-rays) and can range up to 20 for heavy charged particles. A complete list of Radiation Weighting Factors is given in Appendix A. The dose resulting from the product of the absorbed dose in Grays (or rads) and the Radiation Weighting Factor is now a measure of biological damage and not just the energy deposited. This unit of dose is the Sievert (or rem).

Dose in \( \text{Sieverts} \) (Sv) = Dose in \( \text{Grays} \) x \text{Radiation Weighting Factor}

Dose in \( \text{rem} \) = Dose in \( \text{rads} \) x \text{Radiation Weighting Factor}

Example

Assume you had 1 joule of energy per kilogram deposited uniformly throughout your body. Your absorbed dose is 1 Gray. If the radiation depositing the energy were X-rays, gamma-rays, or \( \beta \)-particles, your dose would be 1 Sv since the Radiation Weighting Factor is 1 for these radiations, and so

\[ 1 \text{ Gy} = 1 \text{ Sv} \]

If the radiation depositing the energy were alpha particles with a Radiation Weighting Factor of 20, your dose would be 20 Sv (1 Gy x 20). That is, although the energy deposited was the same in both cases, the biological effect from the alpha particles would be 20 times greater than for the other radiations.

3. The Roentgen

Yet another radiation unit still commonly encountered is the roentgen (r), named after the discoverer of X-rays. For all practical purposes, rads, rems, and roentgens can be used interchangeably when dealing with X-rays or gamma-rays.

4. Effective Dose
What happens when you receive a dose of 1 Sv to your thyroid, and a friend receives a dose of 1 Sv to each of the thyroid and lung? It seems intuitively wrong to claim that you both received identical doses of 1 Sv. It also seems wrong to claim your friend received a total dose of 2 Sv. Obviously your friend has a higher probability of biological damage than you and this should be taken into account when the doses are calculated. We do this by multiplying the dose to each organ by a tissue weighting factor for that organ and add up these weighted sums to obtain the effective dose. Tissue weighting factors are given in Appendix A. These weighting factors are essentially relative radiosensitivities, and are the values adopted by the ICRP in 1990. In your case of the thyroid irradiation, your effective dose is 0.05 x 1 Sv which is 0.05 Sv. Your friend will have received an effective dose of 1 Sv x 0.05 (thyroid) plus 1 Sv x 0.12 (lung) for a total of 0.17 Sv. The effective dose is the dose which, if given uniformly to the whole-body, would put you at the same risk as the non-uniform dose that you actually received. That is, for you, a dose of 1 Sv to the thyroid is equivalent in risk to 0.05 Sv received by each and every organ and tissue in the body. For your friend, the dose of 1 Sv to each of the lung and thyroid resulted in a risk equivalent to a uniform whole-body exposure of 0.17 Sv.

If the whole body is uniformly irradiated, which is the usual case except for an intake of a radioisotope, then the effective dose will be the same as the equivalent dose.

D. ANNUAL DOSE LIMITS

Dose limitation is based on risk. The underlying philosophy is that the limit on risk should be equal whether the whole body is irradiated or whether there is non-uniform exposure. Therefore, based on the preceding section, the limits will obviously be based on effective dose. The annual permissible exposures are given in Table 1 and in Appendix A. It should be emphasized that the values in Table 1 are limits, not goals. One of the basic radiation protection principles is ALARA -- As Low As Reasonably Achievable. In practice, you should reduce your exposure as much as is reasonable, even if it is already considerably below allowable exposures. Ionizing radiation may cause biological damage, and so there is no justification for receiving any dose that is not necessary.

### TABLE 1

<table>
<thead>
<tr>
<th>Dose Type</th>
<th>Workers (mSv/y)</th>
<th>Public (mSv/y)</th>
<th>Pregnant Woman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Dose</td>
<td>50</td>
<td>5</td>
<td>1 mSv abdomen+ 0.05 ALI</td>
</tr>
<tr>
<td>Lens of the eye</td>
<td>150</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Any single organ</td>
<td>500</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Hands and feet</td>
<td>500</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

* Dose in mrem = mSv × 100 (i.e. Annual Limit for Effective Dose = 2000 mrem)

E. BACKGROUND RADIATION

Our environment contains approximately 10 cosmogenic radionuclides (including $^3$H and $^{14}$C) and 16 primordial radionuclides in addition to the 46 radionuclides in the $^{232}$Th, $^{235}$U, and $^{238}$U chains. These isotopes, which are present in soil, water, air, and minerals, produce an external radiation dose. Isotopes present in the soil, water, and in the air eventually end up in the food chain, and so produce an internal
radiation dose as well. An adult human body contains approximately $0.1 \mu$Ci ($4 \text{ kBq}$) of both $^{14}\text{C}$ and $^{40}\text{K}$. In addition, one of the decay products of natural uranium is radon ($^{222}\text{Rn}$), an inert gas. It diffuses through the soil and can concentrate in dwellings. Its decay products are also radioactive, and they will be inhaled, resulting in a lung dose. Radon is the single largest source of natural radiation for the public.

We are also constantly bombarded by particles originating from outer space. This component of background radiation is called cosmic radiation. The earth's atmosphere acts as a shield and so cosmic radiation is greater at higher altitudes since there is less atmosphere to shield the radiation.

Typical background and medical doses are given in Table 2 and Table 3.

**TABLE 2**

*Average Background Radiation*

<table>
<thead>
<tr>
<th>Source</th>
<th>Dose Equivalent (mSv)</th>
<th>Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon</td>
<td>24</td>
<td>2.0</td>
</tr>
<tr>
<td>Cosmic</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>0.28</td>
<td>0.28</td>
</tr>
<tr>
<td>Internal</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>Total Natural</td>
<td>---</td>
<td>2.94</td>
</tr>
</tbody>
</table>

**TABLE 3**

*Typical Medical Exposures*

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest radiograph</td>
<td>0.02-0.05</td>
</tr>
<tr>
<td>Skull radiograph</td>
<td>0.15</td>
</tr>
<tr>
<td>Thoracic spine radiograph</td>
<td>0.90</td>
</tr>
<tr>
<td>Pelvic/abdominal radiograph</td>
<td>1.3</td>
</tr>
<tr>
<td>Head CT scan</td>
<td>2.0</td>
</tr>
<tr>
<td>PET scan</td>
<td>3.9 (1.0-8.9)</td>
</tr>
<tr>
<td>Intravenous urogram</td>
<td>4.4</td>
</tr>
<tr>
<td>Average Tc-99m scan</td>
<td>5.0 (1.3-8.2)</td>
</tr>
<tr>
<td>Barium examination</td>
<td>3.8-7.7</td>
</tr>
<tr>
<td>Body CT scan</td>
<td>6-16</td>
</tr>
</tbody>
</table>
F. RISKS

There have been many situations in which large numbers of people have been exposed to high levels of radiation, and through studies of these, the health effects of high-level radiation are well known. The most important study is that of the survivors of Hiroshima and Nagasaki. Individual dose estimates have been made for 75,991 survivors through 1985. Of these, 34,272 received minimal doses and act as controls, while the remaining 41,719 received doses of 5 mGy or more. Of these, 3,435 have died from some form of cancer, and this is about 350 above the expected number. At the 95% confidence level, there are no excess cancers below doses of about 200 mSv. The revised dose estimates and the adoption of the relative risk model led to a revision of the risk factor for radiation in 1990. Undoubtedly, the risk factor will be revised in the future as our models improve and as better statistics are obtained.

There is some disagreement in the scientific community concerning how we should extrapolate the data from the A-Bomb survivors to lower levels of radiation and to lower dose rates. The conservative approach is normally taken by assuming that the biological effects are proportional to dose without a threshold. It should be noted that no study has demonstrated a biological effect from ionizing radiation at normal occupational doses. The controversy exists simply because the effect, if any, is so small. If the effect were large, then there would be no disagreement because the effect would be clearly observed.

Table 4 is based on a uniform whole-body dose of 1 mSv per year from gamma- or X-radiation for a population of 1,000 people. Remember that 1 mSv per year is comparable to background.

<table>
<thead>
<tr>
<th>Cancer Mortalities</th>
<th>Continuous exposure to 1 mSv/y from ages 18-65</th>
<th>Continuous exposure to 1 mSv/y for lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Expected number</td>
<td>209.1</td>
<td>177.1</td>
</tr>
<tr>
<td>without radiation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess due to</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td>radiation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%Increase</td>
<td>0.81%</td>
<td>0.95 %</td>
</tr>
</tbody>
</table>

Based on "Health Effects of Exposure to Low Levels of Ionizing Radiation" (BEIR V)

It is natural to be concerned with the genetic effects of ionizing radiation. The International Commission on Radiological Protection is an independent body of international experts in a variety of disciplines which reviews the literature on the effects of ionizing radiation and makes recommendations that are almost universally accepted. (See also section C.14.c. of the Health Physics Regulations.) It concludes "If the damage caused by radiation occurs in the germ cells, this damage (mutations and chromosomal aberrations) may be transmitted and become manifest as hereditary disorders in the descendants of the exposed individual. Radiation has not been identified as a cause of such effects in man, but experimental studies on plants and animals suggest that such effects will occur and that the consequences may range from the undetectably trivial, through gross malformations or loss of function, to premature death". The BEIR V commission concluded that "Results of these careful and very extensive studies, when taken at face value, suggest that humans may be somewhat less sensitive to radiation than mice".
Table 5 is based on the assumption that the doubling dose in humans is the same as for mice, namely 1,000 mSv.

This table shows that the incidence of effects from radiation is very small compared to the natural incidence of genetic effects. BEIR V notes that "the greater current risk (of mutations) seems to result from exposure to chemical mutagens in the environment rather than from the exposure of populations to radiation". The effects of radiation on the foetus are described in section C.14.c. (Pregnancy and Radiation Work: Risks) of the "Health Physics Regulations".

**TABLE 5**

<table>
<thead>
<tr>
<th>Type of Disorder</th>
<th>Current Incidence per Million Liveborn Offspring</th>
<th>Additional Cases per Million Liveborn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First Generation</td>
<td>Equilibrium</td>
</tr>
<tr>
<td>Autosomal dominant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinically severe</td>
<td>2,500</td>
<td>5-20</td>
</tr>
<tr>
<td>Clinically mild</td>
<td>7,500</td>
<td>1-15</td>
</tr>
<tr>
<td>X-linked</td>
<td>400</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Recessive</td>
<td>2,500</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Chromosomal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Unbalanced
translocations | 600                | <5                                    | Very little increase|
| Trisomies         | 3,800              | <1                                    | <1                |
| Congenital
abnormalities | 20,000-30,000      | 10                                    | 10-100            |

Based on BEIR V

In Table 6, the loss of life expectancy due to various causes is given. This table confirms your suspicions that life consists of many risks. The average loss of life expectancy due to an annual exposure of 1 mSv/y (100 mrem/y) is 10 days. This is marginally higher than the loss of life expectancy from drinking coffee.

Table 7 compares the minutes of life expectancy lost from various individual actions. Perhaps the simplest way of putting the loss of life expectancy from radiation is to equate 0.1 mSv with about four cigarettes or to driving 100 miles.

Finally, yet another way of putting your occupational radiation dose in perspective is to look at one-in-a-million risks of death from various causes. In Table 8, we see that if we receive 1 mSv per year of radiation at work, we have to work 50 hours to accumulate one chance in a million of death; in the manufacturing industry, we would have to work 17 hours to accumulate the same risk. To put a one-in-a-million risk in perspective, the lower portion of the table shows that a one-in-a-million risk is equivalent to driving 49 miles or eating 90 pounds of charcoal broiled steak.
### TABLE 6
Loss of Life Expectancy Due to Various Causes

<table>
<thead>
<tr>
<th>Cause</th>
<th>Days</th>
<th>Cause</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living in poverty</td>
<td>3500</td>
<td>Dangerous job-accidents</td>
<td>300</td>
</tr>
<tr>
<td>Being unmarried-male</td>
<td>3500</td>
<td>Motor vehicle accidents</td>
<td>207</td>
</tr>
<tr>
<td>Being unmarried-female</td>
<td>1600</td>
<td>Accidents in home</td>
<td>95</td>
</tr>
<tr>
<td>Smoking-male</td>
<td>2250</td>
<td>Average job-accidents</td>
<td>74</td>
</tr>
<tr>
<td>Smoking-female</td>
<td>800</td>
<td>Alcohol-average</td>
<td>130</td>
</tr>
<tr>
<td>Being 30% overweight</td>
<td>1300</td>
<td>Legal drug misuse</td>
<td>95</td>
</tr>
<tr>
<td>Being 20% overweight</td>
<td>900</td>
<td>Radon in homes</td>
<td>35</td>
</tr>
<tr>
<td>Cancer</td>
<td>980</td>
<td>Radiation-1 mSv per year</td>
<td>10</td>
</tr>
<tr>
<td>Diabetes</td>
<td>95</td>
<td>Coffee</td>
<td>6</td>
</tr>
<tr>
<td>Drowning</td>
<td>41</td>
<td>Smoke alarm in home</td>
<td>-10</td>
</tr>
</tbody>
</table>

### TABLE 7
Some Risks for Individual Actions

<table>
<thead>
<tr>
<th>Individual Action</th>
<th>Minutes of Life Lost</th>
<th>Individual Action</th>
<th>Minutes of Life Lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking a cigarette</td>
<td>10</td>
<td>Coast to coast drive</td>
<td>1000</td>
</tr>
<tr>
<td>Crossing a street</td>
<td>0.4</td>
<td>Coast to coast flight</td>
<td>100</td>
</tr>
<tr>
<td>Driving</td>
<td>0.4/Mile</td>
<td>0.1 mSv radiation</td>
<td>40</td>
</tr>
<tr>
<td>Not using a seat belt</td>
<td>0.1/Mile</td>
<td>Skipping annual PAP test</td>
<td>6000</td>
</tr>
</tbody>
</table>

### TABLE 8
One-In-A-Million Risks

<table>
<thead>
<tr>
<th>Industry</th>
<th>Hours of Work for 1-in-a-Million Risk</th>
<th>Industry</th>
<th>Hours of Work for 1-in-a-Million Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>1.5</td>
<td>Manufacturing</td>
<td>17</td>
</tr>
<tr>
<td>Forestry</td>
<td>1.7</td>
<td>Agriculture</td>
<td>37</td>
</tr>
<tr>
<td>Fishing</td>
<td>2.3</td>
<td>Trade</td>
<td>37</td>
</tr>
<tr>
<td>Construction</td>
<td>4.9</td>
<td>Service</td>
<td>53</td>
</tr>
<tr>
<td>Transport</td>
<td>6.6</td>
<td>Finance</td>
<td>125</td>
</tr>
<tr>
<td>Public Administration</td>
<td>16.0</td>
<td>Radiation - 1 mSv/yr</td>
<td>50</td>
</tr>
</tbody>
</table>

Some Other One-in-a-Million Risks
Motor vehicle accident - Driving 49 miles  Eating 90 pounds broiled steak (benzopyrene)

Drinking 22.5 gallons milk (aflatoxin)  Eating 6 pounds peanut butter (aflatoxin)

**G. ACUTE EFFECTS**

It is highly unlikely that any individual at McMaster could receive a whole-body dose sufficiently large to produce an observable biological effect, although it may be possible to exceed the regulatory limits. However, as we will see, it is quite possible to receive a localized beta- or X-ray exposure large enough to produce observable effects if proper procedures are not followed. The biological effects from massive radiation exposures are described in Tables 9 and 10.

**TABLE 9**

<table>
<thead>
<tr>
<th>Dose (mSv)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-250</td>
<td>No detectable effects.</td>
</tr>
<tr>
<td>250-1,000</td>
<td>Slight blood changes with recovery within a few months. Delayed effects possible, but very serious effects very improbable.</td>
</tr>
<tr>
<td>1,000-2,000</td>
<td>Nausea and fatigue. Blood changes with delayed recovery.</td>
</tr>
<tr>
<td>2,000-3,000</td>
<td>Nausea and vomiting on first day. Latent period up to a few weeks, then malaise, sore throat, diarrhea. Recovery likely within 3 months for healthy individuals.</td>
</tr>
<tr>
<td>3,000-6,000</td>
<td>Nausea and vomiting within a few hours. Latent period up to 1 week, then malaise, fever, hemorrhage, loss of weight, sore throat. Death to about 50% of individuals receiving about 3500 mGy (350 rem).</td>
</tr>
<tr>
<td>6,000 +</td>
<td>Symptoms similar to above, but probable death for 100%.</td>
</tr>
</tbody>
</table>

**TABLE 10**

**Effects of Skin Irradiation with βs or Low-energy X-rays**

<table>
<thead>
<tr>
<th>Dose (mSv)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,000-5,000</td>
<td>Reddening of skin (erythema)</td>
</tr>
<tr>
<td>20,000</td>
<td>Skin damage (blisters)</td>
</tr>
<tr>
<td>30,000</td>
<td>Severe skin damage (ulceration)</td>
</tr>
</tbody>
</table>

**H. EXTERNAL RADIATION**

1. **Gamma Rays**
a. Radiation Fields from Gamma-emitters

Most work with gamma-emitters involves the use of 1 mCi (40 MBq) or less. In Table 11, the radiation field at 10 cm (4 inches) from a 1 mCi (37 MBq) unshielded point source is given for some commonly used isotopes. This distance probably represents the closest approach of the hands if appropriate handling tools are used.

**TABLE 11**

*Gamma Ray Dose Rates in Tissue (mSv/h) at 10 cm from a Point 1 mCi Unshielded Source*

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Major Gamma Ray Energies (MeV)</th>
<th>mSv/h at 10 cm</th>
<th>Isotope</th>
<th>Major Gamma Ray Energies (MeV)</th>
<th>mSv/h at 10 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-11</td>
<td>0.511</td>
<td>0.57</td>
<td>Cu-64</td>
<td>0.511, 1.346</td>
<td>0.11</td>
</tr>
<tr>
<td>N-13</td>
<td>0.511</td>
<td>0.57</td>
<td>Zn-65</td>
<td>0.511, 1.116</td>
<td>0.30</td>
</tr>
<tr>
<td>O-15</td>
<td>0.511</td>
<td>0.57</td>
<td>Rb-86</td>
<td>1.077</td>
<td>0.05</td>
</tr>
<tr>
<td>F-18</td>
<td>0.511</td>
<td>0.57</td>
<td>Mo-99</td>
<td>0.181, 0.740</td>
<td>0.08</td>
</tr>
<tr>
<td>Na-22</td>
<td>0.511, 1.275</td>
<td>1.14</td>
<td>Te-99m</td>
<td>0.141</td>
<td>0.06</td>
</tr>
<tr>
<td>Na-24</td>
<td>1.369, 2.754</td>
<td>1.76</td>
<td>In-111</td>
<td>0.171, 0.245</td>
<td>0.20</td>
</tr>
<tr>
<td>Cr-51</td>
<td>0.320</td>
<td>0.02</td>
<td>I-125</td>
<td>0.035</td>
<td>0.16</td>
</tr>
<tr>
<td>Fe-59</td>
<td>1.099, 1.292</td>
<td>0.60</td>
<td>I-131</td>
<td>0.284, 0.365, 0.637</td>
<td>0.20</td>
</tr>
<tr>
<td>Co-56</td>
<td>0.511, 0.847, 1.238</td>
<td>1.33</td>
<td>Cs-134</td>
<td>0.569, 0.605, 0.796</td>
<td>0.81</td>
</tr>
<tr>
<td>Co-57</td>
<td>0.014, 0.122, 0.137</td>
<td>0.09</td>
<td>Cs-137</td>
<td>0.662</td>
<td>0.33</td>
</tr>
<tr>
<td>Co-58</td>
<td>0.511, 0.811</td>
<td>0.52</td>
<td>Au-198</td>
<td>0.412</td>
<td>0.22</td>
</tr>
<tr>
<td>Co-60</td>
<td>1.173, 1.332</td>
<td>1.25</td>
<td>Am-241</td>
<td>0.060</td>
<td>0.02</td>
</tr>
</tbody>
</table>

For radioisotopes not included in Table 11, the following simple approximation can be used:

\[
R = 0.5E_{\gamma}(\text{avg})
\]

where

- \( R \) = radiation field in mSv/hr at 10 centimetres from a one millicurie point source
- \( E_{\gamma}(\text{avg}) \) = average gamma-ray energy per disintegration, in MeV.

For example, \(^{60}\text{Co}\) decays with the emission of a 1.173 MeV gamma and a 1.332 MeV gamma, both of 100% yield. Using our formula, we would predict:

\[
R = 0.5 \times (1.173 + 1.332) = 0.5 \times (2.505) = 1.25 \text{ mSv/hr at 10 cm from 1 mCi.}
\]

It may be convenient to know the radiation field at distances other than at 10 cm. For gamma-rays, we can use the "INVERSE SQUARE LAW". The inverse square law simply states that at half the distance, the field increases by four; at one third the distance, the field increases by nine; and at one tenth the distance, the field increases by one hundred, and so on.

Mathematically, the inverse square law is given by:
\[ R(x) = R(o) \times \left( \frac{d_x}{d_o} \right)^2 \]

where \( R(x) \) = radiation field at distance \( d_x \) and \( R(o) \) = radiation field at distance \( d_o \).

For example, from Table 11, the radiation field at 10 cm from 1 mCi \(^{125}\text{I}\) is 0.16 mSv/hr. During iodinations, it is not uncommon to use 2 mCi \(^{125}\text{I}\), and this will often be at a distance of about 1 cm from the fingers. The dose rate from 1 mCi at 1 cm is

\[ R(1) = 0.16 \times (10/1)^2 = 0.16 \times 10^2 = 16 \text{ mSv/hr} \]

At 1 cm from 2 mCi, the dose rate would be \( 2 \times 16 \text{ mSv/hr} = 32 \text{ mSv/hr} \).

From this dose rate, we can now estimate the total dose received. Typically, the \(^{125}\text{I}\) is at 1 cm from the fingers for 30-60 seconds. Taking one minute as the exposure time, then

\[
\text{Dose} = \text{Dose rate} \times \text{time of exposure} = 32 \text{ mSv/hr} \times 1/60 \text{ hours} = 0.53 \text{ mSv}
\]

b. Protection from Gamma-rays

The three basic methods of reducing radiation fields are: time; distance; and shielding.

**Time:** It is obvious that the less time spent in a radiation field, the less the dose will be. As elementary as this principle is, many researchers tend to overlook it. For example, stock solutions and glassware should be prepared as much as possible before working with radioisotopes, and not when the unshielded isotope is in the work area.

**Distance:** The inverse square law has been discussed and so you should be aware of the role of distance. For example, if a pair of 6" tongs is used to hold a radioactive source rather than a pair of 2" tweezers, the dose is reduced by \((6/2)^2\) or by a factor of 9.

**Shielding:** Generally, the greater the density of the material, the more effective it is as a gamma-ray shield for a given energy. In addition, the thickness of the chosen material required to reduce the radiation field by a fixed amount depends upon the gamma-ray energy. In Table 12, the thickness of lead required to reduce the radiation field by a factor of twenty is given for some common isotopes.

**TABLE 12**

**Thickness of Lead in cm Required to Reduce a Gamma Ray Radiation Field by a Factor of 20**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>1/20\text{th} thickness (cm Pb)</th>
<th>Isotope</th>
<th>1/20\text{th} thickness (cm Pb)</th>
<th>Isotope</th>
<th>1/20\text{th} thickness (cm Pb)</th>
<th>Isotope</th>
<th>1/20\text{th} thickness (cm Pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-11</td>
<td>1.77</td>
<td>Cr-51</td>
<td>0.78</td>
<td>Cu-64</td>
<td>1.85</td>
<td>I-125</td>
<td>0.01</td>
</tr>
<tr>
<td>N-13</td>
<td>1.77</td>
<td>Fe-59</td>
<td>4.25</td>
<td>Zn-65</td>
<td>4.06</td>
<td>I-131</td>
<td>1.24</td>
</tr>
<tr>
<td>O-15</td>
<td>1.77</td>
<td>Co-56</td>
<td>4.66</td>
<td>Rb-86</td>
<td>4.01</td>
<td>Cs-134</td>
<td>2.74</td>
</tr>
<tr>
<td>F-18</td>
<td>1.77</td>
<td>Co-57</td>
<td>0.08</td>
<td>Mo-99</td>
<td>2.57</td>
<td>Cs-137</td>
<td>2.45</td>
</tr>
<tr>
<td>Na-22</td>
<td>3.51</td>
<td>Co-58</td>
<td>2.97</td>
<td>Te-99m</td>
<td>0.11</td>
<td>Au-198</td>
<td>1.29</td>
</tr>
</tbody>
</table>
c. Summary

(1) There is usually a simple relationship between the average gamma-ray energy per disintegration and
the radiation field.
(2) The inverse-square law is valid for gamma-rays.
(3) It can be difficult to shield energetic gamma-rays. For example, well over an inch of lead is required
to reduce the radiation field from $^{22}\text{Na}$ by a factor of 20.
(4) For the procedures, isotopes, and quantities, and normal working distances used in the research
laboratories at McMaster, significant whole body gamma-ray exposures are unlikely. Hand
exposures could be significant if insufficient distance is left between the source and the fingers, or
insufficient shielding is used, or if the time of exposure is unnecessarily long.

2. Beta Particles

a. Radiation Fields from Beta-emitters

In contrast to gamma-rays, there is no simple relationship between the beta-particle energy and the
radiation field from a point unshielded source. Approximate values of the dose rate as a function of
distance for some commonly used isotopes are given in Table 13. (The commonly used isotopes $^{51}\text{Cr}$,
$^{99m}\text{Tc}$, and $^{125}\text{I}$ decay without the emission of a beta-particle, although electrons may be emitted from the
atom.) There are several important points illustrated in Table 13.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Energy (MeV)</th>
<th>Beta tissue dose rate in mSv/h from unshielded source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.1 cm</td>
</tr>
<tr>
<td>C-14</td>
<td>0.156</td>
<td>1,640,000</td>
</tr>
<tr>
<td>S-35</td>
<td>0.167</td>
<td>1,430,000</td>
</tr>
<tr>
<td>P-33, Ca-45</td>
<td>0.25</td>
<td>1,120,000</td>
</tr>
<tr>
<td>Co-60</td>
<td>0.314</td>
<td>972,000</td>
</tr>
<tr>
<td>Fe-59</td>
<td>0.475</td>
<td>831,000</td>
</tr>
<tr>
<td>Na-22</td>
<td>0.545</td>
<td>910,000</td>
</tr>
<tr>
<td>I-131</td>
<td>0.606</td>
<td>683,000</td>
</tr>
<tr>
<td>Cl-36</td>
<td>0.714</td>
<td>650,000</td>
</tr>
<tr>
<td>Na-24</td>
<td>1.389</td>
<td>476,000</td>
</tr>
<tr>
<td>P-32, Rb-86</td>
<td>1.710</td>
<td>393,000</td>
</tr>
<tr>
<td>Y-90</td>
<td>2.270</td>
<td>276,000</td>
</tr>
</tbody>
</table>
(1) The inverse-square law does not apply for low and medium energy beta-emitters. This is of great significance, and can lead to severe exposures if the inverse square law is mistakenly applied. For example, you could measure the beta radiation field at one meter from 1 mCi (37 MBq) $^{131}$I, and note that it is 0.04 mSv/hr. Applying the inverse square law, you would deduce that the radiation field would be 4 mSv/hr at 10 cm and 400 mSv/hr at 1 cm. The actual fields are more than a factor of ten greater than this. Therefore, you should always apply the following rule:

NEVER ESTIMATE A BETA RADIATION FIELD USING THE INVERSE-SQUARE LAW. WHENEVER POSSIBLE, MEASURE THE ACTUAL RADIATION FIELD AT THE WORKING DISTANCE.

(2) The beta radiation field at short distances is much greater than the corresponding gamma-ray field for most isotopes that emit both beta-particles and gamma-rays. For example, the beta field from 1 mCi $^{131}$I at 10 cm is 61 mSv/hr whereas the gamma-ray field is only 0.20 mSv/hr. This difference arises because we have defined dose as energy deposited per unit weight of material. Beta particles deposit their energy in a relatively short distance in tissue whereas gamma-rays travel much farther. A beam of energetic beta particles hitting an exposed hand may penetrate 1 cm into the tissue. Gamma rays of the same energy would lose only about 2% of their energy while passing through the entire hand. As a result, the betas deposit about 50 times as much energy, and deposit it in less mass, and so the dose (energy per unit mass) is much greater for beta particles than for gamma-rays.

(3) If you need a quick crude rule of thumb, then you could estimate that at one foot from an unshielded point beta source, the dose rate is about 3 mSv/hr per mCi (37 MBq).

DO NOT APPLY THE INVERSE SQUARE LAW TO THIS VALUE.

b. Protection from Beta Particles

The same three factors (time, distance, and shielding) can be used to reduce your exposure when working with $\beta$-emitters.

**Time:** The discussion regarding time as a factor in the section on gamma-rays is equally applicable to $\beta$-particles.

**Distance:** The lack of applicability of the inverse square law has already been discussed. However, the same principle applies and that is to maximize the hand-to-source distance.

**Shielding:** We have seen that beta-particles are "bad news" because they deposit their energy in a relatively small amount of tissue. If you are an optimist, this is also "good news" since they will also deposit their energy in a relatively small amount of shielding material. This is illustrated in Table 14 and Table 15 which illustrate the following points:

(1) Normal laboratory glassware is 1-2 mm thick. For low-energy beta-emitters such as $^{14}$C, $^{35}$S, and $^{45}$Ca this is sufficient to reduce the external radiation fields to zero. As a result, no special handling procedures will normally be required to reduce the external radiation fields for these isotopes.

(2) For energetic beta-emitters, 1 mm glass provides insignificant shielding, and the radiation fields even through 2 mm glass are very significant.

(3) Lucite, plexiglass, or common plastic of at least 1/2" (12.7 mm) thickness is sufficient to completely eliminate the beta radiation field from commonly encountered radioisotopes.

(4) Water is a cheap effective beta shield. If the radioisotope is dissolved in a relatively large volume, the solution itself is acting as a shield. It is good practice to dilute the isotope as soon as possible and as much as possible to take advantage of the shielding value of water.

(5) A dose of 3,000-10,000 mSv produces skin burns from beta radiation. This dose can be obtained by manipulating an unshielded point 1 mCi (40 MBq) source at 1 mm in about 1 minute. This is roughly...
the dose that you would receive if you held a plastic syringe containing 1 mCi \(^{32}\text{P}\) with your fingers on the barrel over the solution. However, at a distance of 10 cm, it would take over a month to accumulate the same exposure from the same source.

**TABLE 14**

**Tissue Dose Rates in mSv/h from an Unshielded 1 mCi Point Source Through 1 mm Air or Glass**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Energy (MeV)</th>
<th>Dose rate in mSv/h through 1 mm air</th>
<th>Dose rate in mSv/h through 2 mm air</th>
<th>Dose rate in mSv/h through 1 mm glass</th>
<th>Dose rate in mSv/h through 2 mm glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-14</td>
<td>0.156</td>
<td>1,600,000</td>
<td>410,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S-35</td>
<td>0.167</td>
<td>1,400,000</td>
<td>360,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>P-33, Ca-45</td>
<td>0.25</td>
<td>1,100,000</td>
<td>280,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Co-60</td>
<td>0.314</td>
<td>970,000</td>
<td>240,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fe-59</td>
<td>0.475</td>
<td>830,000</td>
<td>210,000</td>
<td>45</td>
<td>0</td>
</tr>
<tr>
<td>Na-22</td>
<td>0.545</td>
<td>910,000</td>
<td>230,000</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>I-131</td>
<td>0.606</td>
<td>680,000</td>
<td>170,000</td>
<td>1,400</td>
<td>0</td>
</tr>
<tr>
<td>Cl-36</td>
<td>0.714</td>
<td>650,000</td>
<td>160,000</td>
<td>6,000</td>
<td>3</td>
</tr>
<tr>
<td>Na-24</td>
<td>1.389</td>
<td>480,000</td>
<td>120,000</td>
<td>170,000</td>
<td>5,700</td>
</tr>
<tr>
<td>P-32, Rb-86</td>
<td>1.710</td>
<td>390,000</td>
<td>100,000</td>
<td>260,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Y-90</td>
<td>2.270</td>
<td>280,000</td>
<td>70,000</td>
<td>340,000</td>
<td>40,000</td>
</tr>
</tbody>
</table>

**TABLE 15**

**Maximum Distances Traveled by Beta Particles**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Energy (MeV)</th>
<th>Maximum distance traveled in cm in Air</th>
<th>Maximum distance traveled in cm in Water or polystyrene</th>
<th>Maximum distance traveled in cm in Glass</th>
<th>Maximum distance traveled in cm in Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>0.019</td>
<td>0.5</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>C-14</td>
<td>0.156</td>
<td>20</td>
<td>0.03</td>
<td>0.01</td>
<td>0.003</td>
</tr>
<tr>
<td>S-35</td>
<td>0.167</td>
<td>20</td>
<td>0.03</td>
<td>0.01</td>
<td>0.003</td>
</tr>
<tr>
<td>P-33, Ca-45</td>
<td>0.252</td>
<td>50</td>
<td>0.06</td>
<td>0.03</td>
<td>0.005</td>
</tr>
<tr>
<td>Co-60</td>
<td>0.314</td>
<td>60</td>
<td>0.08</td>
<td>0.04</td>
<td>0.007</td>
</tr>
<tr>
<td>Fe-59</td>
<td>0.475</td>
<td>120</td>
<td>0.15</td>
<td>0.07</td>
<td>0.013</td>
</tr>
<tr>
<td>Na-22</td>
<td>0.545</td>
<td>150</td>
<td>0.19</td>
<td>0.09</td>
<td>0.017</td>
</tr>
<tr>
<td>I-131</td>
<td>0.606</td>
<td>160</td>
<td>0.21</td>
<td>0.10</td>
<td>0.019</td>
</tr>
<tr>
<td>Cl-36</td>
<td>0.714</td>
<td>200</td>
<td>0.26</td>
<td>0.12</td>
<td>0.023</td>
</tr>
</tbody>
</table>
6) Very little lead, less than 1 mm, is required to shield beta particles. A small fraction of the beta energy is converted to X-rays (bremsstrahlung), but this is an insignificant dose compared to the unshielded beta dose. Lead of about 0.8 mm thickness can be obtained from Health Physics. This lead is very pliable, and can be readily shaped to make customized shields.

In this discussion, no mention has been made of tritium (³H). The beta particle from tritium is so weak (0.018 MeV) that it does not penetrate the outer dead layer of skin. It is not possible to receive an external radiation dose from tritium.

c. Summary

(1) At distances of less than 1 meter, the radiation field from an unshielded beta source is normally much greater than from a gamma source of the same strength.
(2) The inverse square law does not work well for beta emitters. Always attempt to measure the radiation field at the working distance and never calculate it from the inverse square law.
(3) Beta particles can be readily shielded.
(4) Extremely large doses can be received at short distances, leading to this fundamental rule: **NEVER HANDLE RADIOACTIVE MATERIAL DIRECTLY WITH YOUR HANDS**

At 1 mm, the radiation field will be at least 100 times greater than at 1 cm.
(5) All beta emitters are not equal. Procedures perfectly acceptable for ³H, ¹⁴C, ³⁵S, or ⁴⁵Ca may be extremely hazardous for energetic isotopes such as ³²P.
(6) If a syringe is used to extract an isotope whose beta particles can penetrate the syringe wall, then a syringe shield MUST be used.

I. EXTERNAL CONTAMINATION

If radioactive material contaminates the outer layer of skin, then the affected skin can receive a significant dose from relatively minor quantities of activity. This is illustrated in Table 16 for skin contaminated at a level of 1 µCi/cm² (37 kBq/cm²).

### TABLE 16

*Approximate Skin Beta Dose Rates from Surface Contamination of 1 µCi/cm²*

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Energy (MeV)</th>
<th>mSv/h per µCi/cm²</th>
<th>Isotope</th>
<th>Energy (MeV)</th>
<th>mSv/h per µCi/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>0.019</td>
<td>0</td>
<td>Na-22</td>
<td>0.545</td>
<td>800</td>
</tr>
<tr>
<td>C-14</td>
<td>0.156</td>
<td>90</td>
<td>I-131</td>
<td>0.606</td>
<td>700</td>
</tr>
<tr>
<td>S-35</td>
<td>0.167</td>
<td>100</td>
<td>Cl-36</td>
<td>0.714</td>
<td>700</td>
</tr>
<tr>
<td>P-33, Ca-45</td>
<td>0.252</td>
<td>300</td>
<td>Na-24</td>
<td>1.389</td>
<td>1000</td>
</tr>
<tr>
<td>Co-60</td>
<td>0.314</td>
<td>400</td>
<td>P-32, Rb-86</td>
<td>1.710</td>
<td>900</td>
</tr>
</tbody>
</table>
Note that although $^{14}$C, $^{35}$S, and $^{45}$Ca do not normally present an external radiation hazard, but they can lead to a significant skin dose through contamination.

Although exercising good technique will minimize the possibilities of external contamination, some contamination is unavoidable. Therefore, disposable gloves and laboratory coats are required when working with radioactive material.

At the end of each working day, you should monitor yourself to ensure that no contamination is present. Be sure, in addition to monitoring your hands and feet, to monitor your hair. Most people have a habit of running their hands through their hair, and if the hands or gloves are contaminated, the hair will become contaminated.

### J. INTERNAL RADIATION

Radioactive material can enter the body by inhalation, ingestion, or through intact or wounded skin. Once the radioactive material is in the body, it normally cannot be removed simply except by a combination of radioactive decay and normal biological elimination.

#### 1. Doses from Internal Exposures

The annual intake required to produce a dose of 1 mSv for some commonly used radioisotopes is given in Table 17. These are the values adopted in 1990 by the ICRP.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Intake for 1 mSv</th>
<th>Intake for 1 mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ingestion (µCi)</td>
<td>Inhalation (µCi)</td>
</tr>
<tr>
<td>H-3 (water)</td>
<td>1400</td>
<td>1400</td>
</tr>
<tr>
<td>H-3 (organic)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>C-14</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Na-22</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Na-24</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td>P-32</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>P-33</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>S-35</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>Cl-36</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Ca-45</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Cr-51</td>
<td>500</td>
<td>300</td>
</tr>
</tbody>
</table>
For the intake of more than one isotope, the requirement is that the sum of the fractional intakes should not exceed 1. For example, if you should ingest 0.6 of the permissible annual intake of $^3$H, then only 0.4 of the permissible annual intake of any other isotope would be permissible. Again, remember that the values in Table 17 are limits, not goals, and the ALARA principle should apply for internal exposures as well as external exposures. The values are for the most restrictive compound of the element.

2. Protection from Internal Radiation

To prevent the ingestion of a radioisotope, the following rules should be obeyed:

(a) Good personal hygiene should be established to prevent the transfer of contamination from hands to food, cigarettes, pencils, etc., from where it can be transferred to the mouth. The use of disposable gloves is required for this reason.

(b) In a laboratory containing radioactive material, nothing should be placed in the mouth. The obvious hazard is ingesting radioactive solutions while pipetting. The more subtle hazard of mouth-pipetting is that the glassware may be externally contaminated. This hazard will exist even if the material pipetted is non-radioactive.

(c) **There shall be no eating, drinking, or smoking in a laboratory area containing radioactive material.**

To prevent the inhalation of radioactive material:

(a) When performing work that may produce airborne contamination (e.g. boiling, evaporating, oxidizing), work shall be conducted in a fume hood.

(b) A glove box should be used for such work involving dry radioactive powdered material. Glove boxes are available in NRB-112 for such work.

(c) Spills involving radioactive material should be cleaned up as soon as possible before the material has the opportunity to dry and become airborne.

All spills should be reported immediately to Health Physics. To protect against absorption of radioactive material through the skin, any cut, abrasion, or wound must be adequately protected. Even through intact skin, tritium oxide or iodine as a vapour or in solution in an unbound form (e.g. iodide) can be absorbed. We have found at McMaster that researchers have received thyroid exposures from absorption of iodine or iodide through the surface of intact skin. Special protective clothing is available from Health Physics to prevent this absorption when conducting iodinations.

K. SPILLS

When working with radioactive material, good technique will minimize the number of spills. However, a spill is inevitable even with good technique. When the spill occurs, the following procedures should be followed:

1. Inform all the personnel in the room and delineate the area of the spill to eliminate traffic through the contaminated area.
2. Inform Health Physics immediately.
3. In the event of a dry spill, wet absorbent paper should be placed over the affected area. Dry absorbent paper should be placed over a wet spill. The papers should be placed in the radioactive waste container and the area monitored.
4. Decontamination should be carried out until the area is free of contamination. Cleaning should always be done inwards toward the center of the spill. Areas of lesser contamination should be cleaned first so that cross-contamination does not occur from areas of high contamination to areas of lower
contamination. Gloves should be worn and care taken to prevent contamination of the skin or ingestion or inhalation of the radioactive material.

(5) Before resuming work, Health Physics must conduct a survey and determine if the contamination has been removed. In addition, the personnel involved in the cleanup must be monitored to ensure that they have not become contaminated.

L. RADIATION DETECTION INSTRUMENTS

Since we cannot detect ionizing radiations with our senses, special instrumentation must be used. There are various types of instruments available, and it is absolutely vital to ensure that the instrument used will actually detect the radiation of interest. For example, $^{14}$C cannot be detected with a standard Geiger tube; an end-window tube must be used. It is also important that the readings be interpreted properly.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Radiation Detected</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>End Window GM</td>
<td>$\beta, \gamma &gt; 20$ keV</td>
<td>Fragile window</td>
</tr>
<tr>
<td>GM (Thin Wall-30 mg/cm$^2$)</td>
<td>$\beta &gt; 200$ keV, $\gamma &gt; 40$ keV</td>
<td>Not for $^{14}$C or $^{35}$S or $^{125}$I</td>
</tr>
<tr>
<td>Ionization Chambers</td>
<td>$\beta &gt; 20$ keV, $\gamma &gt; 20$ keV</td>
<td>Relatively low $\beta$ sensitivity</td>
</tr>
<tr>
<td>Scintillation</td>
<td>$\beta &gt; 10$ keV</td>
<td>Good for $^{125}$I</td>
</tr>
</tbody>
</table>

DO NOT USE A SURVEY INSTRUMENT WITHOUT PROPER INSTRUCTION

To ensure that the instrument is suitable for the intended purpose and to ensure that the readings are interpreted correctly, refer to the manufacturer's manual or consult Health Physics. None of the above instruments will detect tritium.

M. RULES AND PROCEDURES

1. General Rules for All Radioisotope Users

The following rules have been formulated to reduce your radiation exposure and must be obeyed since they represent the policy of both the University and the AECB.

These rules will assist in reducing internal exposures:

(a) There shall be no smoking, eating, drinking, or storage of food in a laboratory containing radioactive material.
(b) Do not mouth pipette radioactive solutions.
(c) When performing work that might produce airborne contamination (e.g. boiling, grinding, oxidizing, iodinations) work must be conducted in a fume hood.
(d) A glove box should be used for work involving dry powdered radioactive material.
(e) Do not work with radioactive material if you have open cuts or abrasions.

These rules will assist in reducing your external exposures:
(f) Whenever possible, perform a trial experiment using stable or low activity material to establish the adequacy of the procedures and equipment.

(g) Never handle radioactive material directly with your hands.

(h) Measure the external radiation fields, using suitable instruments during your initial experiment. Health Physics will be glad to do this, and in the case of $^{32}$P users, Health Physics must do this.

These rules will assist in reducing personal contamination:

(i) Use protective gloves and clothing whenever hand or clothing contamination is possible.

(j) After working with unsealed radioactive material:
   (i) hands shall be washed before leaving the laboratory;
   (ii) clothes, shoes and hands monitored for contamination.

To reduce laboratory contamination:

(k) Use disposable absorbent liners on trays or bench surfaces.

(l) Objects and equipment used for work with radioactive material should not be used for other purposes and should be monitored before removal from the laboratory.

(m) Immediately inform Health Physics if there is a spill of radioactive material.

2. **Special Rules for P-32 Users and Users of Other Energetic Beta-Emitters (e.g. $E_{\text{max}} > 0.6$ MeV)**

Because of the great potential for skin exposures from $^{32}$P and other energetic beta emitters, it is a requirement that your initial experiment with these isotopes be monitored by Health Physics regardless of the quantity in use. At this time, you will see the radiation fields monitored at actual working distances and so hopefully will appreciate the potential hazards. Also, your procedures will be reviewed and means of reducing your exposures brought to your attention. If necessary, additional shielding will be recommended and subsequent experiments monitored until a satisfactory protocol is established.

3. **Procedures for Radioiodine Users**

For those workers using more than 1.35 mCi unbound radioiodine per quarter as an open source, the following AECB regulations apply for $^{125}$I use:

(a) **Routine Status**
   An individual is in routine status and shall undergo bioassay after each use of $^{125}$I or monthly (whichever is the less frequent),
   (i) for the first three months he or she is in the bioassay program,
   (ii) following an observed burden above 27 nCi (1 kBq),
   (iii) following any significant change to radioiodine handling procedures, or
   (iv) following any significant increase in the amount of radioiodine used.

(b) **Maintenance Status**
   Bioassay for $^{125}$I shall be performed at quarterly intervals if each observed thyroid burden during the previous quarter was less than 27 nCi (1 kBq); if any burden was greater than 27 nCi, the worker remains in "Routine Status".

The regulations for $^{131}$I use are identical except that in the first quarters, scans must be conducted weekly or after each iodination, whichever is less frequent.

When radioiodinations are conducted, the quantity used, typically 1000-2000 µCi (40-80 MBq), is much greater than the permissible annual intake of 1 µCi (40 kBq) by inhalation. Since iodinations normally
involve oxidation of the iodide, the potential for a significant intake is great. Also, experience at
McMaster has shown that thyroid exposures can be received from I$_2$ vapour in contact with exposed skin
or from contamination of exposed skin. As a result, the following additional rules have been established
by the HPAC for radioiodine users:
(a) The initial iodination must be monitored by Health Physics. Subsequent iodinations may be monitored
if deemed necessary.
(b) The iodination must be conducted in a fume hood.
(c) The protective clothing supplied by Health Physics must be worn.
(d) Prior to and subsequent to the initial iodination, thyroid scans must be obtained. After each subsequent
iodination, a thyroid scan is strongly recommended.
(e) It is the responsibility of the user to arrange for the scans at the required frequency.
(f) A completed "Request to Acquire Unbound Radioiodine" form must be submitted along with the
purchase order if unbound radioiodine is to be obtained.

N. USEFUL REMINDERS AND HINTS

(a) the radioactive work area should contain all appropriate signs.
(b) non-radioactive areas must be clearly defined and signed.
(c) refrigerators containing radioactive material must NOT contain foodstuffs.
(d) the work area should be covered with absorbent paper.
(e) when conducting an experiment, it is often useful to have a small waste container adjacent to the work
area. This can be easily shielded and then emptied into the main waste container at the end of the
experiment. This procedure minimizes traffic and reduces the probability of spreading
contamination.
(f) have long tweezers or tongs handy.
(g) when working with large volumes of solutions (say 100 ml or more), conduct the work in a tray.
(h) have shielding apparatus handy and use it.
(i) areas in which radioactive stock solutions are stored should be clearly labeled and the radiation field
posted.
(j) use lab coats. Check frequently for contamination, particularly sleeves and pockets. Do not wear these
lab coats into eating areas such as cafeterias and lounges.
(k) an inventory of radioactive material in the laboratory must be maintained.
(l) the following must be prominently displayed in the laboratory:
   - the permit to use radioactive material
   - a copy of the AECB regulations
   - spill emergency procedures
   - $^{32}$P posters if this isotope is used

O. WHEN TO CALL HEALTH PHYSICS

You must inform Health Physics:
(a) if it is known or suspected that exposures to external radiation in excess of the values in Table 1
(Appendix A) have been received.
(b) when there is accidental contamination of the laboratory or an accidental release of radioactive
material to drains, ventilation system, or laboratory atmosphere.
(c) when you suspect an exposure due to inhalation, ingestion, or injection of radioactive material.
(d) when it has been confirmed that you are pregnant.
(e) before you use a new isotope for the first time, especially $^{32}$P, $^{125}$I, or $^{131}$I.
(f) when your exposure report is inconsistent with the frequency and type of work conducted.
(g) if you suspect you are still contaminated after attempts to decontaminate yourself.
(h) when you are unsure of a radiological hazard in your area or if you suspect that proper procedures are
not being followed by colleagues.
(i) before you use radioisotopes in animals for the first time.
APPENDIX A

TABLE 1  MAXIMUM ANNUAL DOSE LIMITS IN mSv*

<table>
<thead>
<tr>
<th>Dose Type</th>
<th>Workers</th>
<th>Public</th>
<th>Pregnant Woman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Dose</td>
<td>50</td>
<td>5</td>
<td>1 mSv abdomen+ 0.05 ALI</td>
</tr>
<tr>
<td>Lens of the eye</td>
<td>150</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Any single organ</td>
<td>500</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Hands and feet</td>
<td>500</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

* Dose in mrem = dose in mSv x 100

TABLE 2  RADIATION WEIGHTING FACTORS

<table>
<thead>
<tr>
<th>Type and Energy Range</th>
<th>Radiation Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photons, all energies</td>
<td>1</td>
</tr>
<tr>
<td>Electrons, all energies</td>
<td>1</td>
</tr>
<tr>
<td>Neutrons, energy &lt;10 keV</td>
<td>5</td>
</tr>
<tr>
<td>10 keV to 100 keV</td>
<td>10</td>
</tr>
<tr>
<td>&gt;100 keV to 2 MeV</td>
<td>20</td>
</tr>
<tr>
<td>&gt;2 MeV to 20 MeV</td>
<td>10</td>
</tr>
<tr>
<td>&gt;20 MeV</td>
<td>5</td>
</tr>
<tr>
<td>Alpha Particles</td>
<td>20</td>
</tr>
</tbody>
</table>

TABLE 3  TISSUE WEIGHTING FACTORS

<table>
<thead>
<tr>
<th>Tissue or Organ</th>
<th>Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>0.20</td>
</tr>
</tbody>
</table>
APPENDIX B

PROCEDURES FOR AUTHORIZATION AND PROCUREMENT OF RADIOACTIVE MATERIAL

B1. PROCEDURES FOR OBTAINING APPROVAL TO POSSESS AND USE RADIOACTIVE MATERIAL:

1. Complete the form entitled "Application for Authorization to Possess and Use Radioactive Material" and send to Health Physics, NRB-106. The quantity of radioactive material in use per experiment, relative to the limits for a "Basic Level Laboratory" as described in Appendix D, determines the manner in which approval is granted.
   (a) For quantities less than 10% of the limits for a "Basic Level Laboratory" Health Physics may grant immediate conditional approval.
   (b) For quantities between 10% and 100% of the limits for a "Basic Level Laboratory", the application must be circulated to all members of the HPAC. If no objections are received, approval may be granted seven days after circulation.
   (c) For quantities greater than the limits for a "Basic Level Laboratory", the application must be considered at the next regular meeting of the HPAC. Normally the applicant is requested to attend this meeting to clarify any questions the members of the HPAC may have.

2. Upon approval, a copy of the application will be returned to the supervisor along with a Permit containing the Conditions of Approval and the "Project Number". A copy of this permit must be posted in each laboratory listed on the application to use radioactive material.

3. If any changes are to be made to an authorized project, the research supervisor should apply in writing to Health Physics for an amendment to their project.

B2. POLICY AND PROCEDURES FOR PROCURING RADIOACTIVE MATERIALS:

1. Orders from McMaster University for radioactive material must be placed by the University Purchasing office. This includes standing orders. Before Purchasing can place the order, approval must be obtained from Health Physics. This is most efficiently obtained by submitting all purchase orders for radioactive material to Health Physics, NRB-106.

2. Any amendment to the type or quantity of isotope in a single order must be approved by Health Physics. This approval can be sought by either contacting Health Physics directly at extension 24226 or by contacting Purchasing who in turn will contact Health Physics. Changes must not be made by the researcher dealing directly with the supplier.

3. Any amendment to a standing order must also be approved by Health Physics. This approval can be sought by either contacting Health Physics directly at extension 24226 or by contacting Purchasing who in turn will contact Health Physics. This means, for standing orders:
   (a) the duration of the standing order cannot be extended.
   (b) neither the frequency of shipments or the quantity of isotope shipped can be altered. The only exception is that a shipment can be skipped without obtaining University approval. However, a skipped shipment cannot be used to extend the term of the standing order by adding it on at the nominal expiry of the order, nor can the quantity of isotope in the skipped shipment be...
shipped at a future date to complete the quantity originally ordered.

4. If this policy is violated, the researcher will be barred from purchasing any radioactive material from that supplier for a period of up to six months for the first offense. The order will be immediately canceled regardless of the financial consequences to the researcher.

5. Procurement from a McMaster supplier (Reactor, Cyclotron, or Radiopharmacy):
   (a) Complete a Requisition Request form and forward to room 106, Nuclear Research Building. This must be signed by the Project supervisor or by an individual authorized in writing by the supervisor.
   (b) A copy of this form will be retained by Health Physics. A copy of the approved form must be presented to the McMaster supplier before you can receive any isotopes.
**APPENDIX C**

PERMISSIBLE QUANTITIES OF ISOTOPES IN LABORATORIES

<table>
<thead>
<tr>
<th>Type of Laboratory</th>
<th>Maximum Number of Scheduled Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Handled on Open Bench</td>
</tr>
<tr>
<td>Basic</td>
<td>&lt;100 SQ</td>
</tr>
<tr>
<td>Intermediate</td>
<td>100-1,000 SQ</td>
</tr>
<tr>
<td>High</td>
<td>&gt;1,000 SQ</td>
</tr>
</tbody>
</table>

**APPENDIX D**

SCHEDULED QUANTITIES OF SOME COMMON ISOTOPES

<table>
<thead>
<tr>
<th>Single Isotope</th>
<th>µCi</th>
<th>kBq</th>
<th>Single Isotope</th>
<th>µCi</th>
<th>kBq</th>
<th>Single Isotope</th>
<th>µCi</th>
<th>kBq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au-198</td>
<td>10</td>
<td>370</td>
<td>Fe-55</td>
<td>100</td>
<td>3700</td>
<td>Mo-99</td>
<td>10</td>
<td>370</td>
</tr>
<tr>
<td>C-14</td>
<td>100</td>
<td>3700</td>
<td>Fe-59</td>
<td>10</td>
<td>370</td>
<td>Na-22</td>
<td>10</td>
<td>370</td>
</tr>
<tr>
<td>Ca-45</td>
<td>10</td>
<td>370</td>
<td>H-3</td>
<td>1000</td>
<td>37000</td>
<td>Na-24</td>
<td>10</td>
<td>370</td>
</tr>
<tr>
<td>Cd-109</td>
<td>10</td>
<td>370</td>
<td>Hg-197</td>
<td>100</td>
<td>3700</td>
<td>Ni-63</td>
<td>10</td>
<td>370</td>
</tr>
<tr>
<td>Cl-36</td>
<td>10</td>
<td>370</td>
<td>Hg-203</td>
<td>10</td>
<td>370</td>
<td>P-32</td>
<td>10</td>
<td>370</td>
</tr>
<tr>
<td>Co-57</td>
<td>10</td>
<td>370</td>
<td>I-123</td>
<td>100</td>
<td>3700</td>
<td>P-33</td>
<td>27*</td>
<td>1000*</td>
</tr>
<tr>
<td>Co-58</td>
<td>10</td>
<td>370</td>
<td>I-125</td>
<td>1</td>
<td>37</td>
<td>Rb-86</td>
<td>10</td>
<td>370</td>
</tr>
<tr>
<td>Co-60</td>
<td>10</td>
<td>370</td>
<td>I-131</td>
<td>1</td>
<td>37</td>
<td>S-35</td>
<td>100*</td>
<td>3700*</td>
</tr>
<tr>
<td>Cr-51</td>
<td>100</td>
<td>3700</td>
<td>In-113</td>
<td>100</td>
<td>3700</td>
<td>Tc-99</td>
<td>10</td>
<td>370</td>
</tr>
<tr>
<td>Cs-134</td>
<td>10</td>
<td>370</td>
<td>K-42</td>
<td>10</td>
<td>370</td>
<td>Tc-99m</td>
<td>100</td>
<td>3700</td>
</tr>
<tr>
<td>Cs-137</td>
<td>10</td>
<td>370</td>
<td>Mn-54</td>
<td>10</td>
<td>370</td>
<td>Y-90</td>
<td>10</td>
<td>370</td>
</tr>
<tr>
<td>Cu-64</td>
<td>100</td>
<td>3700</td>
<td>Mn-56</td>
<td>10</td>
<td>370</td>
<td>Zn-65</td>
<td>10</td>
<td>370</td>
</tr>
</tbody>
</table>

* For laboratory classification only. For waste disposal and shipping, the Scheduled Quantities for $^{33}$P and $^{35}$S are 1 µCi (37 kBq) and 10 µCi (370 kBq), respectively.

For two or more isotopes, the following inequality must be satisfied:

$$\sum_{i=1}^{n} \frac{A_i}{SQ_i} \leq 1$$

where $A_i$ is the quantity of isotope $i$ and $SQ_i$ is the Scheduled quantity for isotope $i$. 

33