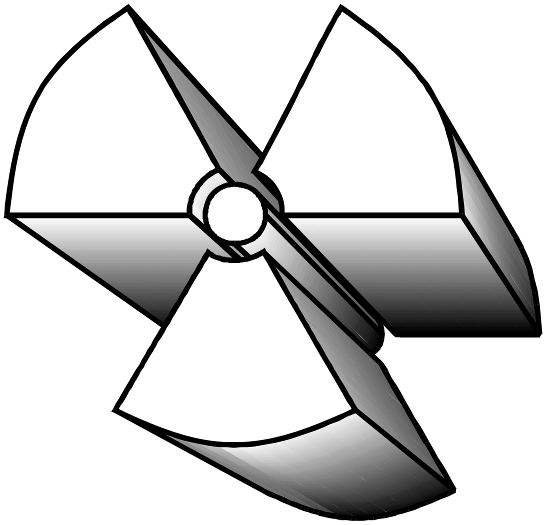
Radionuclide Safety
And
Methodology



Reference Manual

2008

University of British Columbia

Department of Health Safety and Environment

www.hse.ubc.ca

EMERGENCY NUMBERS

UBC CAMPUS

Fire, Police, Ambulance	911
Hazardous Materials Response	911
Emergency First Aid	822-4444
UBC Radiation Safety Office	822-7052
Campus Security	822-2222

VANCOUVER HOSPITAL and HEALTH SCIENCES CENTRE

Vancouver Hospital Site, Jack Bell Research Centre

Fire	88
Hazardous Materials Response	84
Emergency First Aid	84
UBC Radiation Safety Office	822-7052
Security	875-4560

University Site

Koerner, Purdy and Detwiller Pavilions

Fire	0000
Emergency First Aid	0000
Hazardous Materials Response	0000
Security	0000
UBC Radiation Safety Office	822-7052

CHILDREN'S AND GRACE HOSPITALS RESEARCH CENTRE

Fire	33
Emergency First Aid	8400
Hazardous Materials Response	8400
UBC Radiation Safety Office	822-7052
Security	2999

St. PAUL'S HOSPITAL

Fire	5323
Emergency First Aid	3246
Hazardous Materials Response	5323/5042
UBC Radiation Safety Office	822-7052
Security	5323

Foreword

Radiation sources when properly handled represent a minimal risk to research personnel. Accidents and misadventure may result in the loss of scientific information, and of greater concern, possible exposure of laboratory workers. In order to minimize the likelihood of such events, an understanding of the principles of radiation protection is essential. Individuals successfully completing the UBC Radionuclide Safety and Methodology Course will have received a strong foundation in these protection principles as well as the tools necessary to decontaminate and evaluate hazardous situations that may arise.

This manual has been developed over several years, and reflects the needs of the University of British Columbia's research community. The University's Committee on Radioisotopes and Radiation Hazards has endorsed the contents of the manual.

TABLE OF CONTENTS

ADMINISTRATIVE REQUIRMENTS

FUNDAMENTALS OF RADIATION PHYSICS

RADIATION EXPOSURE AND RISK ASSESSMENT

RADIATION DETECTION SYSTEMS

RADIATION SOURCES IN THE WORKPLACE

MANAGEMENT OF RADIOACTIVE WASTE

RADIATION EMERGENCY RESPONSE

APPENDIX I

APPENDIX II

APPENDIX III

APPENDIX IV

APPENDIX V

ADMINISTRATIVE REQUIREMENTS

Safety Policy

The safety of all faculty, staff, students and visitors to the campus is a major concern of the University.

It is an objective of the University to provide a safe environment in which to carry on the University's affairs. All possible preventative measures must be taken to eliminate accidental injuries.

The University shall be administered so as to ensure that health, safety and accident prevention form an integral part of the design, construction, purchase and maintenance of all buildings, equipment, and work processes.

The University Health and Safety Committee shall work to achieve these objectives.

Department Area/Building Safety Committees shall monitor the safety programs within their areas and make recommendations to improve the effectiveness with which the safety objectives of the University can be achieved.

Compliance with the Workers' Compensation Act and related legislation is the minimum standard which is acceptable to the University. The intention is to encourage all faculty, staff, and students to strive to exceed these minimum legal standards.

Application

The successful application of this policy will be achieved by everyone exercising his or her personal responsibility for safety as follows:

The University

It is the responsibility of the University acting through deans, directors and department heads to:

- provide a safe and healthy working environment
- ensure regular inspections are made and take action as required to improve unsafe conditions
- provide first aid facilities where appropriate
- support supervisors and safety committees in the implementation of an effective accident prevention program
- ensure compliance with WCB regulations

The Supervisor

It is the responsibility of the supervisory staff to:

- formulate specific safety rules and safe work procedures for their specific areas of supervision
- ensure that all employees under their supervision are aware of safety practices and follow safety procedures
- provide training in the safe operation of equipment
- regularly inspect their areas for hazardous conditions
- investigate any accidents using the appropriate form
- establish a department safety committee or building safety committee

The Employee/Student

It is each employee or student's responsibility to:

- observe safety rules and procedures established by the supervisors, department heads, the University and the Workers' Compensation Board
- take an active part in practicing safe work habits
- immediately report any accident, injury or unsafe conditions to a supervisor
- properly use and care for personal protective equipment provided by the University

Duties and Responsibilities

Federal legislation created the Nuclear Safety and Control Act and the pursuant regulations, which deal with the handling of radioactive material in Canada. The Canadian Nuclear Safety Commission (CNSC) is the federal body whose agents administer the Act. This agency issues a consolidated licence to the University and has defined the duties and responsibilities of the UBC Committee on Radioisotopes and Radiation Hazards, which administers the licence.

These responsibilities include ensuring that all persons involved in the handling of radioisotopes have adequate training and experience enabling them to perform their duties safely and in accordance with the licensee's radiation safety program and CNSC requirements. Further, the committee is required to ensure that equipment and facilities used with radiation sources are in compliance with CNSC requirements.

The committee is also required to ensure that the doses of ionizing radiation received by any person involved in the use of radioisotopes do not exceed the limits specified in the Canadian Nuclear Safety Regulations.

The UBC radiation safety program is based on the principle that radiation exposure and the associated risk must always be <u>A</u>s <u>L</u>ow <u>A</u>s <u>R</u>easonably <u>A</u>chievable. This ALARA principle is subject to the condition that all exposures must not exceed the regulatory limits.

Further, the policy implies that simply meeting the regulatory limits is not adequate and that every reasonable effort must be made to reduce or eliminate radiation exposure.

The committee is also permitted to grant approval for use of radioisotopes to users only if the use will comply with all the regulatory, environmental and institutional requirements. The committee can ultimately deny the use of radioactive materials given sufficient cause.
The CNSC also defines the roles and responsibilities of the permit holders and radioisotope users as well as the Radiation Safety Officer.

In general terms: The permit holders are personally responsible for radiation safety in all the areas specified on their permits; users of radioisotopes are personally responsible for the safe handling of radioactive materials, and the Radiation Safety Officer is responsible for coordinating and overseeing all aspects of radiation safety within the institution.

Specific Responsibilities of the University

The University can best ensure ionizing radiation sources are handled safely by incorporating the active participation of all faculty, management, staff and students in the radiation safety program. In specific situations, the respective contributions of these parties will depend upon regulatory requirements, organizational structure, and the mandate and responsibilities of management, staff and students.

Licensees must, by law, ensure that they and those activities under their control comply with any applicable regulations and licence conditions. The federal government only licenses entities that have legal capacity and responsibility; that is, individuals, companies or institutions. When a radioisotope licence is granted to an educational, medical or research institution, it issues the licence to the organization. Upon licensing, the institution becomes and remains legally responsible for compliance within the terms of the licence and any other regulatory requirements.

UBC has chosen to delegate, in whole or part, some of the duties to the UBC Advisory Committee on Radioisotopes and Radiation

Hazards (CRRH) and Radiation Safety Officer (RSO).

Composition and Duties of the UBC Advisory Committee on Radioisotopes and Radiation Hazards

The Committee includes faculty members selected or appointed because of their expertise or stake in radiation safety matters. Collectively, these members advise their management and RSOs on radiation safety matters in general, and the effectiveness of Radiation Safety Programs within the University. Other members include governmental radiation safety specialists and a nuclear medicine physician.

As authorized by the University, the Committee may:

(i) Oversee radiation safety on behalf of the University;

(ii) Advise management and RSOs on radiation safety matters, including the safe use of radioactive materials during licenced activities;

(iii) Review all proposed or existing corporate Radiation Safety Programs and procedures to determine whether they assure that radiation exposures will comply with regulatory limits and will be As Low As Reasonably Achievable (ALARA), as described in Regulatory Guides;

(iv) Review all proposed uses of radioisotopes, and their proposed locations of use, to determine whether these proposals comply with corporate procedures and regulatory requirements;

(v) Assess the adequacy, in terms of the contents and schedules for delivery, of the institutions' programs to train staff and workers in the safe use of radioactive materials;

(vi) Assess the results, and determine the effectiveness, of the institutions' programs to train staff and workers in the safe use of radioactive materials;

(vii) Review the results of internal inspections of facilities, premises, equipment, and work practices that assess whether radioisotopes are used safely in CNSC-licenced activities;

(viii) Review annual summaries of the occupational radiation exposures received by staff and workers to determine whether these exposures comply with the ALARA principle of dose limitation;

(ix) Review reports concerning any incidents or unusual occurrences at the institution that involved radioactive materials;

(x) Recommend corrective measures or improvements when their review or assessment identifies deficiencies in a proposal, program, practice, procedure, equipment, record or report;

(xi) Recommend measures or improvements to prevent recurrences of any incidents that exposed staff or workers to excessive radiation, or to prevent recurrence of any other unusual occurrences involving radioactive materials;

(xii) Advise management of any perceived need for additional resources to establish, maintain or improve Radiation Safety Programs; and

(xiii) Maintain written records of their activities, decisions, advice and recommendations concerning radiation safety, including details of meetings and reviews of data, reports, programs, procedures, circumstances, incidents or unusual occurrences.

Duties of the Radiation Safety Officer

The RSO has been assigned lead responsibility to ensure radiation safety at all educational, medical and research sites over which the University has administrative control.

To ensure radiation safety and compliance with regulatory requirements on behalf of management, the RSO is authorized to do the following:

(i) Supervise, advise and consult regarding issues related to the institution’s use of radioisotopes in accordance with regulations and licence conditions;

(ii) Prepare annual reports in accordance with Regulatory Documents, and any pertinent conditions contained in the radioisotope licence(s) issued to the institution;

(iii) Review, either independently or in concert with the CRRH, staff requests for authorization to purchase or use radioactive materials in order to ensure that the proposed uses and locations of use are acceptable and comply with the *Regulations* and licence requirements;

(iv) For radioactive materials, authorize only those purchases, uses, work procedures, and conditions and locations of use that assure compliance with the institution’s Radiation Safety Program, the *Regulations*, and licences;

(v) Assess and designate, as “Basic-level,” “Intermediate-level”, “High-level” or “Nuclear Medicine in accordance with licence conditions, those institution laboratories that use radioisotopes (see Appendix III);

(vi) Maintain a record of all institution laboratories that use radioactive materials, and whether they are designated as Basic-level, Intermediate-level or High-level;

(vii) Develop and implement administrative controls or procedures to ensure radiation safety and compliance with regulatory requirements;

(viii) Assess the qualifications and competence of persons who apply to use or handle radioactive materials to determine whether they can do so safely and in compliance with regulations and licences;

(ix) Ensure that Radiation Safety Programs appropriate to the organization’s undertakings are developed, implemented and maintained;

(x) Ensure that persons who are required to use or handle radioactive materials are adequately trained in radiation safety and the institution’s radiation protection procedures;

(xi) Authorize qualified persons to possess, use or handle radioactive materials;

(xii) Authorize, on an as-required basis, the safe disposal of radioactive materials in accordance with applicable regulations, procedures and licence conditions;

(xiii) Designate Nuclear Energy Workers (NEWs) in accordance with the *Regulations*;

(xiv) Assess, independently or in conjugation with management or the CRRH, the effectiveness of Radiation Safety Programs;

(xv) Ensure that workers such as porters, cleaners, secretaries, and shipping and receiving or other support staff, who may be exposed to radiation as a consequence of their duties, receive appropriate training in radiation safety;

(xvi) Develop and implement programs to inspect and critically review licenced activities, locations of radioisotope use, storage of radioisotopes, and the adequacy of personnel training, safety procedures or physical facilities;

(xvii) Implement remedial actions to correct any deficiencies identified in the inspection programs referred to in (xvi) above;

(xviii) Initiate any revisions to procedures, changes to equipment and facilities, and licence amendments required to ensure on an ongoing basis that the licensee’s operations, equipment and facilities comply with regulatory requirements;

(xix) Communicate with the CRRH, radioisotope users, and management;

(xx) Design and implement in accordance with regulatory requirements, appropriate personnel monitoring and bioassay programs to measure “external” and “internal” exposures to ionizing radiation;

(xxi) Administer or control the issue, use, and maintenance of personnel monitoring devices and equipment within the institution, and the recording of results;

(xxii) Monitor the occupational radiation exposures received by employees by reviewing the records of exposures over each calendar quarter;

(xxiii) Where the above reviews of radiation exposure records indicate that exposures are unnecessarily high, recommend measures to management to reduce these exposures in accordance with the ALARA principle of dose limitation, as described in Regulatory Documents;

(xxiv) Investigate all reports of overexposures to ionizing radiation, of accidents involving radioactive materials, and of losses of radioactive materials, determine pertinent facts or confirm events, and recommend appropriate actions to mitigate the consequences or to prevent recurrences;

(xxv) Ensure that the incidents referred to in (xxiv) above, and the results of related investigations, are reported in accordance with the *Regulations*;

(xxvi) Assess the adequacy of survey programs that measure or control radiation fields and radioactive contamination during licensed activities, such as the use, storage and disposal of radioisotopes;

(xxvii) Ensure, through participation or other measures, that properly-designed radioactive-decontamination programs are implemented as required in the interests of radiation safety;

(xxviii) Ensure that sealed radiation sources are leak-tested in accordance with the institution’s procedures and regulatory requirements;

(xxix) Ensure that all persons who use or handle radioisotopes follow institution procedures, in order to prevent occupational exposures to ionizing radiation that exceed the limits specified in the *Regulations* or that violate the ALARA principle of dose limitation;

(xxx) When an CNSC radioisotope licence authorizes the use of radioisotopes in research, diagnosis or therapy on humans, consult, communicate or cooperate with the responsible physician or body (such as Scientific or Ethical Review Committees) as necessary to assure the safe use of radioactive materials and compliance with licence conditions and regulations;

(xxxi) Prepare or review proposed or existing radiation safety procedures, either independently or in cooperation with the CRRH;

(xxxii) Coordinate, or participate in, emergency responses to accidents involving radioactive materials;

(xxxiii) Ensure that all records and reports that are required by the conditions of the radioisotope licence and the *Regulations* are prepared, maintained and submitted as required; and

(xxxiv) Ensure that any radioisotopes that are to be transported over public roads are packaged in accordance with the *Packaging and Transport of Nuclear Substances* regulations.

Responsibilities of Licence Holders

(1) Ensuring that the conditions stated in the licence are fulfilled and that safe laboratory practices are followed as per posted signs.

(2) Ensuring that all staff and students under their supervision using radioactive materials have been authorized to use these radioactive materials. An up to date list of all such personnel shall be maintained.

(3) Ensuring that if required, all staff using radioisotopes have been issued, and wear, a thermoluminescent dosimeter and participate in bioassay programs.

(4) Designating specific work and storage areas for radioactive materials and ensuring that these areas are kept clean, are properly labelled, have adequate ventilation, and are adequately shielded.

(5) Ensuring that all staff using radioactive materials have received adequate radiation protection training from the institution and have been informed of the risks associated with exposure to ionizing radiation. Further, licence holders are responsible for the provision of specific training in radioisotope handling that is necessary for the safe use of the radioisotopes in their laboratories.

(6) Maintaining inventories of all radioactive materials purchased and used as well as storage and disposal records.

(7) Maintaining all area monitoring and/or wipe test records.

(8) Reporting all radiation incidents to the Radiation Safety Officer.

Responsibilities of Radioisotope Users

(1) Every person... shall take all reasonable and necessary precautions to ensure their own safety and the safety of fellow workers.

(2) Every person... shall strictly adhere to all policies and procedures defined by the CNSC regulations, Worker's Compensation Board Regulations and the University Safety Policy as described in this Manual.

Radioisotope Licences

Obtaining a UBC Radioisotope Licence

Any principal investigator wishing to use radioactive material under his/her grant or supervision in activities larger than those listed as exemption quantities in Table 5 (Section 14) must first obtain a radioisotope licence. Research involving radioisotopes may not be conducted under the umbrella of a fellow researchers' licence. The applicant must be a UBC Faculty member and have successfully completed the UBC Radionuclide Safety and Methodology Course. Applications are obtained from the Radiation Safety Office. The form requires a signature of approval from the relevant Department Head. The completed typed form is submitted to the Radiation Safety Office and is reviewed by the UBC Committee on Radioisotopes and Radiation Hazards. The processing of the documents takes several weeks.

Amending a UBC Radioisotope Licence

A modification to any of the defined conditions of a UBC radioisotope licence must be approved and documented through the Radiation Safety Office. An application must be made in writing indicating the specific licence changes that are being requested. The licence must be amended **PRIOR** to any changes being instigated by the licence holder.

Any project in which more than 10,000 EQs (exemption quantities) is used must first be approved in writing by the CNSC and the UBC

Committee on Radioisotopes and Radiation Hazards. Such projects require significant advance planning, capital expenditure and specialized training for laboratory personnel.

Protocol for Licence De-activation and Laboratory Decommissioning

When a researcher acquires a radioisotope licence, they accept personal responsibility for all associated activities. This extends to ensuring that when radioactive material is no longer needed or the researcher wishes to leave the University for any reason, the approved protocol is followed to properly decommission the licence.

<u>Required from the Licencee:</u>

1) Memo stating intent to discontinue the isotope licence.

2) Complete set of wipe tests for all laboratories licenced for isotope use.

3) Record of proper disposal of isotope on hand (this can include a gift of remaining isotope to another researcher that is licenced for that nuclide).

4) Completion of a yearly isotope inventory.

5) If the researcher* is leaving the University, or does not intend to reactivate the licence at some future date, all isotope purchase, usage, disposal and contamination control records must be forwarded to the Radiation Safety Office.

Following the completion of the above steps, members from the Radiation Safety Office will remove all signs. Thereafter, a letter will be issued to the researcher stating that the licence is no longer active. Decommissioning of laboratory space is not complete until verification by the Radiation Safety Office.

*Note: The licencee is responsible for ensuring that the de-activation steps are followed. Failing this, it becomes the responsibility of the Department.

Licence Re-activation

If the researcher wishes to use isotopes again, they need simply to re-apply for a licence by requesting a Licence Renewal Form from the Radiation Safety Office.

Annual Report

At the end of each calendar year, the CNSC requires that the RSO submit for review, a comprehensive report of all the activities related to the Radioactive Materials Safety Program. This annual report must confirm in structure and content to specific criteria. In early January of each year, a request from the RSO is sent to the individual licence holders. The requested summary of radioactive material purchased, disposed and held in the inventory must be submitted in a timely fashion.

INTRODUCTION

The purpose of this manual is to assist in preparing UBC personnel to work safely with radioactive materials. The topic areas covered are as follows: an introduction to ionizing radiation, health effects, record keeping, legal requirements, practical aspects of handling radioactive materials and radiation sources, laboratory and personnel decontamination, the appropriate use of portable survey meters and emergency response measures.

The primary objective of the UBC Radiation Safety Program is to ensure the safe and knowledgeable use of radiation sources and devices in research, teaching and the environment.

FUNDAMENTALS OF RADIATION PHYSICS

1. Historical Review

At the time of the formation of this planet, much of the constituent matter was radioactive. Over the millennia, this activity decayed until only those isotopes with extremely long half-lives (e.g. uranium-238 ; 4.47 x 10^9 years) and their decay products are found in the earth. Most of the radioactive material that is used in scientific research and medicine is generated in particle accelerators or nuclear reactors.

We are continually exposed to atomic radiations from the earth and are bombarded with different types of radiations emanating from the sun, stars and galaxies. As cosmic radiation enters our atmosphere, it generates radioactive atoms, such as carbon-14, that become incorporated into our water and food supplies.

Life on earth has evolved in this inescapable bath of naturally occurring radioactivity and all living organisms, including humans, assimilate this material into their basic chemical make-up. Although ionizing radiation has been present from the beginning of time, it was not until the year 1895 that Wilhelm C. Roentgen discovered X-rays. Interest in this "new ray" was immediate and intense. Within a few months the first cases of injury due to radiation overexposure (erythema, skin burns, aplastic anaemia) were seen by physicians, who knew neither about the origin of these injuries nor of any appropriate therapeutic response.

Within a year after Roentgen's discovery of X-rays, Henri Becquerel discovered that uranium salts emitted radiation capable of exposing photographic films. In 1898, the element Polonium was isolated from tons of ore by Marie and Pierre Curie. Intensive research then followed, resulting in the isolation of the radioactive element radium and the discovery of, and subsequent investigation of alpha particles. The labs in which this research was performed were highly contaminated with radium, as up to a gram of the material was used in some instances.

Some of the initial health effects encountered were skin burns, deformed fingers and cancer. Another group of occupationally exposed workers were women employed in the 1920s as watch dial painters. In the process of their work, they ingested small amounts of radium and many later died of different types of radiation induced cancers.

The first organized step toward radiation protection standards was made in 1915 at the first meeting of the British Roentgen Society, at which a resolution was passed that "...this Society considers it a matter of greatest importance that the personal safety of the operators conducting the roentgen-ray examinations should be secured by the universal adoption of stringent rules...". In 1928, at the Second International Congress of Radiology, an International Committee on X-Ray and Radium Protection (now known as the International Commission on Radiological Protection - ICRP) was constituted. Early efforts of the ICRP were concerned with establishing radiation units and making some interim protection recommendations. Today the ICRP conducts in-depth studies of the many facets of radiation protection, makes recommendations and issues reports which form the basis for legislation worldwide. In Canada, the federal legislation governing radioactivity is the Nuclear Safety and Control Act which is enforced by the Canadian Nuclear Safety Commission. Radiation emitting devices such as X-ray machines, microwave ovens, etc. are regulated by Health and Welfare Canada.

2. Atomic Structure

In spite of years of intense theoretical and experimental work, no completely satisfactory model of the atomic nor nuclear structure has been developed. Many models have been proposed, each capable of explaining some, but not all, of the physical characteristics of the atom and the nucleus. Even the most acceptable of the proposed structures are incomplete and research is constantly posing new questions and finding answers to the basic structure and substance of matter.

For our purposes, Bohr's Model of the atom adequately describes atomic structure. It refers to a simple solar system-like model, with the negative electrons revolving about the positively charged nucleus. See Fig. 1.

The nucleus is the central core of the atom and is composed of two types of particles, the proton that has a positive electrical charge, and the neutron, which is electrically neutral. The mass of each neutron and proton is approximately one atomic mass unit (amu) and is equal to 1/12 of a carbon-12 atom, i.e. $1.66\text{x}10^{-24}$ g.

Electrons revolve around the nucleus at discrete and well-defined orbital distances. Each electron carries a negative electrical charge and has a mass of 1/1836 that of a proton. There are 109 named elements, each of which is characterized by two related terms.

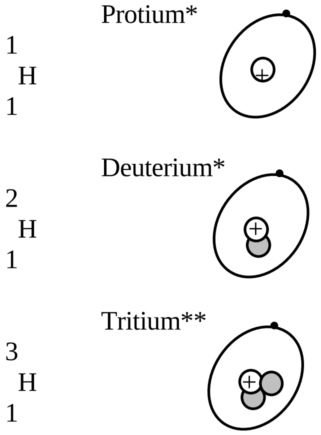
A = *mass number*, equal to the sum of protons and neutrons in the nucleus.

Z = *atomic number*, equal to the number of protons in the nucleus; Z is also equal to the number of electrons attached to the nucleus in a neutral, non-ionized atom.

Atomic Formula = $^{A}_{Z}X$

Given that the number of protons, and hence the atomic number, defines a specific type of atom, the number of neutrons may change without changing the chemical characteristics of that atom. Thus various species or *nuclides* can exist with the same atomic number. These nuclide variants are called *isotopes* and are defined as nuclides having equal numbers of protons but different numbers of neutrons. Isotopes are atoms of the same element that have the same atomic number (Z), but a different mass number (A). An element may have many isotopes, a few of which are normally stable, but most are radioactive. However several heavy elements, such as thorium, uranium and plutonium, have no stable isotopes.

Fig. 1. Isotopes of Hydrogen



* = stable
** = radioactive

3. Radioactivity

Radioactivity can be defined as spontaneous nuclear events that result in the atomic transmutation from one element into a different element. Many distinct mechanisms are involved in these nuclear transformations, of which alpha particle emission, beta particle and positron emission, and orbital electron capture are some examples. Each of these reactions may or may not be accompanied by emission of gamma radiation. The exact mode of radioactive transformation depends on two factors:

- the particular type of nuclear instability (too high or too low neutron to proton ratio).

- the mass-energy relationships between the parent nucleus, progeny nucleus, and the emitted particle.

3.1 Alpha Emission. An *alpha particle* (α) is a massive, highly energetic nuclear fragment that is emitted from the nucleus of a radioactive atom when the neutron to proton ratio is too low. It is a positively charged helium nucleus, consisting of two protons and two neutrons.

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha + \text{gamma rays}$$

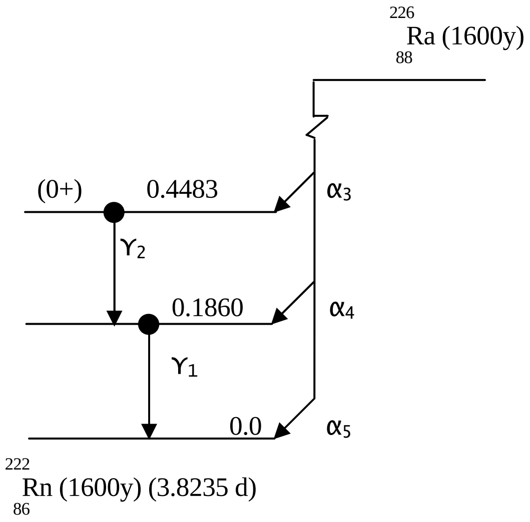
Example:

$${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}\alpha + \text{gamma rays}$$

Because of their mass and charge, alpha particles are extremely limited in their ability to penetrate matter. The dead outer layer of skin covering the entire body is sufficiently thick to stop and absorb all alpha radiation. As a consequence, alpha radiation from sources outside the body does not represent a radiation hazard. However, cells irradiated by alpha particles emitted by atoms that have entered the body by injection, ingestion or inhalation suffer severe radiation effects and are likely to be permanently damaged. Hence alpha radiation is an extreme internal radiation hazard.

> *Alpha particles are extremely hazardous when deposited internally; however the inability to penetrate clothing or the dead surface layer of skin minimizes the risk of external exposure to alpha radiation.*

Fig. 2. Decay Scheme for Radium-226



3.2 Beta Emission. A *beta particle* (β^-) is an electron that is ejected from a beta-unstable radioactive atom. The particle has a single negative electrical charge (-1.6×10^{-19}C) and a very small mass (0.00055 amu). The beta particle, or *negatron*, is emitted at the instant a neutron undergoes transformation into a proton. Beta decay occurs among those isotopes that have a surplus of neutrons.

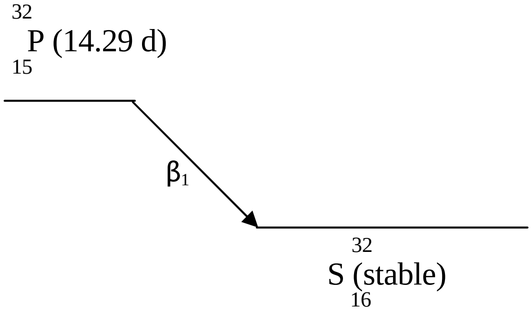
$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^- + \text{antineutrino}$$

Example:

$${}^{32}_{15}\mathrm{P} \rightarrow {}^{32}_{16}\mathrm{S} + \beta^{-} + \text{antineutrino}$$

The proton remains in the nucleus, thus no change in the mass number occurs, but the beta particle is emitted. Since the number of protons has increased by one, the atomic number (Z) has also increased by one. During this process, a particle called the *antineutrino* having negligible mass and no electrical charge is also emitted. Beta particles have a range of a few millimeters in tissue, so external exposure does not penetrate to the body core. It can however, produce significant radiation damage to the cells of the skin.

Fig. 3. Decay Scheme for Phosphorus-32



High energy beta particles can damage the cornea and the lenses of the eyes as well as produce significant skin doses.

3.3 Positron Emission. A *positron* (β^+) is a beta particle with a single positive charge (+ 1.6 x 10^{-19} C). It has the same rest mass as a negative electron (0.00055 amu) and is emitted from nuclei in which the neutron to proton ratio is very low and α emission is not energetically possible. Positrons and antineutrinos are classified as *antimatter*, whereas negatrons and neutrinos are classified as *matter*.

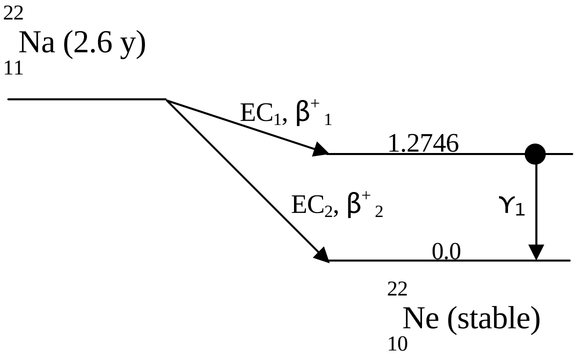
$${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A}_{Z-1}\mathrm{Y} + \beta^{+} + \text{neutrino}$$

Example:

$${}^{22}_{11}\mathrm{Na} \rightarrow {}^{22}_{10}\mathrm{Ne} + \beta^{+} + \text{neutrino}$$

During this process, a particle called the neutrino having negligible mass and no electrical charge is also emitted. Whereas negative electrons freely exist, these antimatter positrons have only a transitory existence. The positron rapidly combines with an electron, which results in the annihilation of both particles and the generation of two 511 keV gamma-ray photons. The hazard associated with positron emission results from this gamma radiation.

Fig. 4. Decay Scheme for Sodium-22



Annihilation radiation requires lead shielding.

3.4 Orbital Electron Capture. *Electron Capture* or " K Capture " is a process whereby one of the K orbit electrons is captured by the nucleus and unites with a proton to form a neutron. An X-ray, characteristic of the daughter element, is emitted when an electron from an outer orbit falls into the energy level occupied by the electron which had been captured.

$${}^{A}_{Z}X + e^- \rightarrow {}^{A}_{Z-1}Y + \gamma + \text{neutrino}$$

Example:

$${}^{125}_{53}I + e^- \rightarrow {}^{125}_{52}Te + \gamma + \text{neutrino}$$

3.5 Gamma Rays. Mono-energetic electromagnetic radiations that are emitted from nuclei of excited atoms following radioactive transformations are called *gamma rays* (ϒ). In most cases, following alpha or beta decay processes, gamma emission is the mechanism by which a nucleus loses energy in going from a high energy excited state to a low energy stable state.

3.6 X-Rays. *X-rays* are electromagnetic radiations generated outside the atomic nucleus. Both X-rays and gamma rays are highly penetrating and can produce whole body radiation doses. One type of X-ray that is a safety hazard in research laboratories is called *bremsstrahlung*. These photons are emitted when electrons are quickly decelerated when interacting with the electric fields surrounding atomic nuclei. The energy of the resultant photon is related to the energy of the incident electron or β^- as well as the electric field strength. These forces are greater in nuclei with a high atomic number. For this reason lead is not an appropriate shielding material for beta isotopes. Using shielding material composed of atoms with low atomic number, such as hydrogen, carbon and oxygen, the energy and intensity of the bremsstrahlung is minimized. Plexiglass is therefore the shielding of choice.

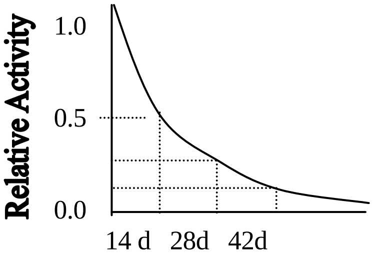
Beta particle interaction with matter results in the production of penetrating bremsstrahlung radiation. Plexiglass shielding is required for beta radiation.

3.7 Other Radiations. Other radiations, such as fast and slow neutrons, mesons, protons, etc. are beyond the scope of this manual, and will not be addressed here.

4. Radioactive Decay

4.1 Physical Half-life ($T_{1/2}$). Early studies of radioactive materials have shown that the activity of each radioisotope decreases at its own characteristic rate. For example, when the activity of P-32 is measured daily over a period of two months, and the percentage of the initial activity is plotted as a function of time, the curve shown in Fig. 5 is obtained. Experimental observation shows that one-half of the initial amount of P-32 is gone in 14.3 days, half of the remainder in another 14.3 days, half of that after another 14.3 days, and so on. This period of time in which half of the original activity decays is called the *physical half-life* (PHL).

Fig. 5. Decay of Phosphorus-32



When an atom decays, the atomic number (Z) is normally altered either by decreasing or increasing the number of protons. Hence, an atom of a specific element rarely decays to the same element, as can be seen in Figures 2, 3 and 4 (Isomers are an exception to this rule). This may be of significance in research protocols as the new element may have significantly different chemical characteristics than those of the original.

Given that the half-life of some isotopes is short, it is important to be able to determine the amount of activity that has decayed after purchase but prior to use, over the term of an experiment, as well as the decay period for waste disposal. The precept upon which the calculation of present activity is based is that at some observation time (t), there are a given number of atoms (N). The law of constant fractional decay requires that over a short period of time (dt), the number of atoms decaying (dN), will be

$$dN = -\lambda N dt$$

where the constant of proportionality (λ), is called the decay constant and $N\lambda$ is called the activity (A). Integrating this equation gives the relationship between N and t:

$$N = N_0 e^{-\lambda t}$$

given that $\lambda = 0.693/T_{1/2}$

then $N = N_0 e^{-0.693t/T_{1/2}}$

where N is the number of atoms at time t, $T_{1/2}$ is the half-life, and N_0 is the number at t = 0.

Multiplying both sides by λ gives:

$$N\lambda = No\ \lambda\ e^{-0.693t/T_{1/2}}$$

Or finally

$$A = Ao\ e^{-0.693t/T_{1/2}}$$

Thus the number of radioactive atoms, and the activity decay away together.

Example: A researcher received a shipment of Phosphorus-32 labeled Adenosine 5'-triphosphate. The supplier documentation indicated that on the shipping date of March 26 the source activity was 555 MBq. The researcher, however, was unable to use the material until April 30. What was the activity on the day of the experiment?

Data:
A = ?
Ao = 555 MBq
t = 35 days
$T_{1/2}$ = 14.3 days

(You may use any unit for the time: sec, hr, day, yr, but it must be the same for t and $T_{1/2}$).

Solution: $A = 555\ \text{MBq} \times e^{-0.693\times35d/14.3d}$

$A = 101.78$ MBq

4.2 Effective Half-life.

The above calculation utilizes the physical half-life of the isotope in question. However, if one is studying a particular process within a living system, such as an animal, plant or cell line, not only is the physical half-life a determining factor in the clearance of the radio-labeled compound, but the natural secretion and excretion rates of the atoms from the organism also affect the length of time radioactivity is present in the system. The time required for the body to eliminate one-half of an administered dosage of substance by the regular processes of elimination is called the *biological half-life* (BHL). The chemical characteristics of all isotopes of an element are identical, hence the elimination time of both stable and radioactive isotopes of that particular element is the same. The time required for radioactivity to be reduced to fifty percent of the original burden as a result of the combined action of radioactive decay and biological elimination is called the *effective half-life* (EHL). This process is of special importance in the calculation of *in vivo* dosimetry and experimental results of blood volume and tissue isotope concentration studies.
The relationship is:

1/EHL=1/PHL + 1/BHL

An example, for iodine-125:
PHL= 60 days
BHL= 138 days

EHL=1/(1/60 +1/138)
So the effective half-life EHL= 42 days

5. Units of Radiation

Uranium-238 and a progeny element, thorium-234, each contain about the same number of atoms per gram, approximately 2.5×10^{21}. Their half-lives however, are greatly different; uranium-238 has a half-life of 4.5×10^{9} years, while thorium-234 has a half-life of 24.1 days (or 6.63×10^{-2} y). Thorium-234, consequently, is decaying 6.8×10^{10} times faster than uranium-238. When radioisotopes are used, the radiations are the centre of interest. In this context, 1.5×10^{-7} grams of thorium-234 is about equivalent in activity to 1 gram of uranium-238. Obviously, when interest is centred on radioactivity, the gram is not a very useful unit of quantity.

5.1 Units of Activity.

Under the International System of Units (SI), the *becquerel* (Bq) is defined as one atomic nuclear transformation per second. Prior to the adoption of the SI units by the scientific community, the Curie was the unit used to quantify radioactivity. Today, one finds that many commercial suppliers provide radionuclides in becquerel and/or curie quantities and thus familiarity with both systems is essential. Originally the *Curie* (Ci) was defined as the activity of 1 g of Ra-226, but was later redefined as the activity of radioactive material in which the nuclei of 3.7 x 10^{10} atoms disintegrate per second (dps). Consequently, one curie is equal to 2.2 x 10^{12} disintegrations per minute (dpm).

Table 1. Half-lives and Radiation Produced by Some Commonly Used Radioisotopes

Nuclide	Half-life ($T_{1/2}$)	Emission Energy (MeV)		
		Beta (maximum)	Positron (maximum)	Gamma
H-3	12.3 years	0.018		
C-14	5730 years	0.156		
Na-22	2.6 years		1.820	0.511 ; 1.275
P-32	14.3 days	1.710		
P-33	28.4 days	0.248		
S-35	87.4 days	0.167		
Ca-45	165 days	0.252		
Cr-51	27.7 days			0.320
Co-57	271 days			0.122
Co-60	5.27 years	1.148;0.3		1.17 ; 1.33
Ni-63	100 years	0.067		
Zn-65	244 days		0.327	0.511 ; 1.116
Rb-86	18.8 days	1.780		1.077
Tc-99m	6 hours			0.141
In-111	2.83 days			0.171 ; 0.245
I-125	60.2 days			0.035
I-131	8.04 days	0.806		0.364 ; 0.637
Cs-137	30.2 years	1.173		0.662
Ra-226	1600 years		4.87α	1.186

Sub-multiples of the becquerel and curie are:

1 becquerel (Bq) =1 dps = 27 pCi
1 kilobecquerel (kBq) =1 x 10^3 dps = 27 nCi
1 megabecquerel (Mbq) =1 x 10^6 dps = 27 µCi
1 gigabecquerel (GBq) =1 x 10^9 dps = 27 mCi
1 terabecquerel (TBq) =1 x 10^{12} dps = 27 Ci

1 millicurie (mCi) =2.2 x 10^9 dpm = 37 MBq
1 microcurie (µCi) =2.2 x 10^6 dpm = 37 kBq
1 nanocurie (nCi) =2.2 x 10^3 dpm = 37 Bq
1 picocurie (pCi) =2.2 x 10 dpm = 37 mBq

5.2 Units of Radiation Exposure. The *coulomb/kilogram* (C/kg) is the SI unit used to measure the radiation induced ionization's created in a unit mass.

The *roentgen* (R) is the old unit defined as the quantity of radiation that produces ions carrying one statcoulomb of charge of either sign per cubic centimetre of air at 0^0 C and 760 mm Hg. One roentgen corresponds to an absorption of 87.7 ergs per gram of air. One C/kg is approximately equal to 3876 roentgens and one roentgen is approximately equal to 258 microcoulomb/kg (µC/kg). The Coulomb/kilogram unit is not widely used.

5.3 Units of Absorbed Dose. The SI unit used to measure the energy imparted to irradiated matter is called the *gray* (Gy). It is defined as the absorbed radiation dose of one joule per kg.

The *RAD* (Radiation Absorbed Dose) is the unit used prior to, and very commonly since, the establishment of the gray, and is defined as an absorbed radiation dose of 100 ergs/g or 0.01 Joules/kg.

1 gray (Gy) = 1 J/kg
1 gray = 100 rads

5.4 Units of Relative Biological Effectiveness (RBE). The *Sievert* (Sv) is the SI unit that takes into account the biological effect of the particular radiation emission into the absorbed dose. It is defined as the numerical product of the absorbed dose in grays, multiplied by the appropriate modifying factors. For beta, gamma and X-rays this quality factor (QF) equals 1. The quality factor for alpha particles and fast neutrons may be 20 or more. The Sievert replaces the old Roentgen Equivalent Man unit or REM (RAD x QF) where:

1 Sv =100 rems
1 mSv = 100 mrems
1µSv = 0.1 mrems

The *microsievert* (µSv) is the unit used for the display or readout of most survey meters and portable detection units on the UBC campus.

RADIATION EXPOSURE AND RISK ASSESSMENT

6. Radiation Dosimetry

All users of radiation sources must follow all internal and external dosimetry protocols as set out in the terms and conditions of the licence that sanctions their specific research project.

Personnel using radioactive material during which they may be reasonably expected to receive a radiation exposure greater than 1 mSv per year shall be classified as Nuclear Energy Workers (NEWs). Personnel using radioactive material during which they may be reasonably expected to receive a radiation exposure greater than 1 mSv shall wear a dosimeter. Under specific circumstances, the Radiation Safety Officer may direct individuals to wear dosimeters.

6.1 External Personnel Monitoring. Thermoluminescent dosimetry is the most accurate method used to determine personal external radiation exposure. The functional components of a thermoluminescent dosimeter (TLD) are lithium fluoride chips that undergo lattice structure changes when ionized by radiation. This structural alteration "traps" the free electrons in a meta-stable state until the chips are heated, at which point light is emitted. The amount of light produced is proportional to the amount of radiation absorbed, and can be measured and recorded. TLDs are excellent dosimeters for X-rays, gamma radiation and bremsstrahlung from high energy betas, such as Phosphorus-32, but do not detect radiation from alpha particles or low energy beta particles such as tritium, carbon-14, or sulphur-35.

TLDs are to be worn only by NEWs who might reasonably expect to receive annual exposures greater than 1 mSv

Any individual working with more than 50 MBq of P-32 is required to wear an extremity dosimeter. This provides an accurate exposure assessment to the fingers and hands. To ensure accurate information is obtained from these devices, it is important that the Mylar coating on the badge holders has no holes or tears, and that exposure to ultraviolet light is minimized during the badge replacement procedure. Most importantly, the badges should always be worn when required and only by the person to whom the badge is issued. Avoid badge contamination and non-personal exposure readings by storing your badge well away from laboratory radiation sources when not in use.

A recent innovation has been the introduction of optically stimulated luminescence (OSL) dosimeters such as those provided by Landauer. The exposure registered with these badges is determined by stimulation using a laser rather than heating the detector. Similar handling precautions to those for TLDs are warranted for this type of detector.

Generally, the badges are changed on a quarterly basis and the results are forwarded to the Radiation Protection Office for review. Regardless of whether the TLD data is generated by Health Canada or the American firm Landauer, all personal exposure data is maintained in the National Dose Registry in Ottawa.

6.2 External Exposures. It is possible to calculate the theoretical radiation fields emitted by gamma radiation sources, thus enabling individuals to determine the required shielding and safe working distances for proposed experiments. The calculation

Table 2. Maximum Permissible Doses per 1 year dosimetry period*

Organ or Tissue	CNSC		UBC Nuclear Energy Workers
	General Public	Nuclear Energy Workers	
Whole body	1 mSv/y	50 mSv per 1 yr period and 100 mSv for 5 yr period	10 mSv/y
Skin	50 mSv/y	500 mSv/y	100 mSv/y
Any tissue of hands and feet	50 mSv/y	500 mSv/y	100 mSv/y
Eye	15 mSv/y	150 mSv/y	30 mSv/y
Abdomen of pregnant worker**	1 mSv/y	4 mSv/y	4 mSv/y **

Note: In determining the dose, the contribution from sources of ionizing radiation both inside and outside the body shall be included.

* The maximum permissible doses specified in this Table do not apply to ionizing radiation that has been:
  a) received by a patient in the course of medical diagnosis or treatment by a qualified medical practitioner; or
  b) received by a person carrying out emergency procedures undertaken to avert danger to human life
** See Appendix I - Radiation Exposure Policy for Women at UBC.

is based on the amount of activity, the time spent in the radiation field, the distance of the individual from the source and a constant that is a reflection of the emission flux of a given isotope. Table 3 lists the gamma ray constants for some of the isotopes commonly found on campus.

The theoretical dose to an individual in the vicinity of a point source of radioactivity is defined as:

$$X = \frac{\Gamma A t}{d^2}$$

where

X = Dose from an external source.
Γ = Specific gamma ray constant in $(\mathrm{mSv} \bullet \mathrm{cm}^2)/(\mathrm{h} \bullet \mathrm{MBq})$ at 1 cm.
A = Activity of source in MBq.
t = time in hours spent in the vicinity of the source.
d = distance from the source in centimeters.

Example: What is the whole body radiation dose a graduate student receives when working with 185 MBq of Na-22 for two hours every day for 22 days (a working month) at a distance of 35 cm from the source and using no shielding?

Data:

X = Total dose
t = 44 h
Γ = 3.24 $(\mathrm{mSv} \bullet \mathrm{cm}^2)/(\mathrm{h} \bullet \mathrm{MBq})$
d = 35 cm
A = 185 MBq

Solution:

$$X = \frac{3.24 \ \frac{(\mathrm{mSv} \bullet \mathrm{cm}^2)}{(\mathrm{h} \bullet \mathrm{MBq})} \bullet 185\ \mathrm{MBq} \bullet 44\mathrm{h}}{(35\ \mathrm{cm})^2}$$

$X = 21.53$ mSv

Comparing the results with the information in Table 2 we see that this is an unacceptable exposure and shielding will be necessary to perform the experiment safely. Such calculations should be performed before conducting any work with radioactive material to ensure that the prospective work will not be performed in a hazardous environment.

Table 3. Specific Gamma Ray Constants in $(mSv \cdot cm^2)/(h \cdot MBq)$

Nuclide	Γ	Nuclide	Γ	Nuclide	Γ
Arsenic-74	1.19	Cobalt-58	1.49	Radium-226	2.23
Carbon-11	1.59	Cobalt-60	3.57	Rubidium-86	0.14
Cesium-134	2.35	Hafnium-181	0.84	Selenium-75	0.54
Cesium-137	0.89	Iodine-125	0.19	Sodium-22	3.24
Chromium-51	0.04	Iodine-126	0.68	Technetium-99m	0.19
Cobalt-56	4.76	Iodine-131	0.59	Tin-113	0.46
Cobalt57	0.29	Manganese-54	1.27	Zinc-65	0.73

6.3 Internal Exposures. Internal dosimetry is more difficult to accurately assess than external doses, as in most cases direct measurements of the amount and distribution of the radioisotope are not possible, especially if the isotope ingested is a beta emitter. In the case of beta emitters (H-3, C-14, S-35, Ca-45, P-32 and others), calculations of internal dose are based on the amounts of these isotopes that may be found in breath and/or in urine. The radioisotopes iodine-125 and iodine-131 concentrate in the thyroid gland and can be quantified using a calibrated sodium iodide crystal monitor located in the Radiation Safety Office.

Individuals using radioactive iodine are required to report to the Radiation Safety Office for a thyroid scan on a quarterly basis and from one to three days following the experimental iodination of compounds.

Exposure from other gamma isotopes can be assessed mathematically or with the use of whole body counters. The characteristics of the isotope in question, as well as the proposed experimental protocol, are the determining factors for choosing the appropriate method of monitoring personal radiation exposure.

7. Biological Effects of Ionizing Radiation

Radiation is one of the most thoroughly investigated disease causing agents. Although much still remains to be learned about interactions between living organisms and radiations, more is known about the mechanisms of radiation damage at the molecular, cellular, and organ system levels than is known for most other environmental pathogens. The accumulation of dose-response data has enabled health physicists to specify environmental radiation levels that allow the use of radiation sources to be conducted at degrees of risk no greater than, and frequently less than, those associated with other technologies.

To ensure that only true occupational exposures are measured, your TLD must be promptly returned according to the schedule set by the group administrator.

7.1 Acute effects. *Deterministic effects* are those for which there exists a clear causal relationship between the amount of exposure and the observed effect. A certain minimum dose must be exceeded before the particular effect is observed, at which point the magnitude or severity of the effect increases with the size of the dose. For example, a person must consume a certain amount of alcohol before behavioral signs of drinking become evident, after which the effect of the alcohol depends on the amount consumed.

Radiation induced deterministic effects can be specific to a particular tissue: About 2 Gy (200 rads) of mixed neutron and gamma radiation or 5 Gy of beta or gamma radiation will produce cataracts in the lenses of the eyes; cell depletion in bone marrow or hemopoietic syndrome follows a gamma dose of about 2 Gy; gastrointestinal syndrome results from a 10 Gy (1000 rads) or greater dose; central nervous system syndrome occurs at a dose of 20 Gy (2000 rads). These effects tend to be acute in nature, with the symptoms presenting within days, weeks or months after exposure. Because of the minimum-dose that must be exceeded before an individual shows the effect, deterministic effects are also called *threshold effects*.

7.2 Delayed Effects. *Stochastic effects* are those for which the dose increases the probability of an effect occurring, rather than its magnitude or severity. Stochastic effects occur by chance and happen among exposed as well as unexposed individuals. When dealing with radiation exposure, the primary stochastic effects are cancer and genetic effects. Extensive epidemiological studies indicate that these effects occur years after the radiation exposure and have no threshold; that is to say that even at the smallest doses, there is a proportionally small increment in the probability of the effect occurring. Humans develop cancer without having received workplace radiation doses. However, exposure increases the probability of cancer and the greater the exposure, the greater the probability is that the disease will occur. Unlike the causal relationship between alcohol and drunkenness, if an individual does develop cancer, the causal factor cannot be determined. It is, however, possible to estimate the probability that the cancer was caused by radiation induced chromosomal damage.

These delayed effects of radiation may be due either to a single large overexposure or continuing low-level overexposure. Given the nature of the work performed with radiation sources at UBC it is most unlikely that any individual could receive a single large dose of radiation that could induce acute deterministic or delayed stochastic effects. The discussion of late effects therefore, will deal with low-level long-term exposure.

Epidemiological data on the carcinogenicity of low doses of radiation are contradictory and inconclusive. Cancer risk estimates are based on exposure histories of the early martyrs, atomic bomb survivors and the large numbers of individuals who have worked, and are working with radiation sources. Simple extrapolation of the risks of radiation exposure from high dose levels to lower dose levels does not accurately reflect the incidence of delayed exposure effects. These effects are so very low that it is difficult to separate them from the much greater incidence of stochastic effects that result from other environmental and genetic factors.

The Canadian Cancer Society estimates that approximately 25% of all adults will develop cancer induced by environmental and genetic factors not associated with work related radiation sources. Therefore, based on the BIER (1990) report on the biological effect of ionizing radiation, the increased risk of cancer to an individual occupationally exposed to 10 mSv of radiation would rise from 25% to approximately 25.03%.

Given that the maximum permissible exposure for UBC workers is 1 mSv per year (women also see Appendix II) and that the average worker exposure is less than 0.1 mSv per year, the risk of suffering long term radiation effects from occupational exposure is minimal. These estimates are based on current epidemiological evidence and will assist the individual radiation user in making an informed decision concerning acceptance of the risks associated with exposure to radiation. A worker who decides to accept this risk, however minimal, should make every effort to keep exposure to radiation "As Low As Reasonably Achievable" (ALARA). Users of radiation sources have the primary responsibility for protecting themselves from the associated hazards.

U.S. National Academy of Sciences
Report on the Biological Effects of
Ionizing Radiation (BEIR) 1990

230-440 Death per Million Acute
Exposures 10 mSv

RADIATION DETECTION

SYSTEMS

8. Laboratory Radiation Surveillance

In each area where radioisotopes or radiations are utilized there must be functional monitoring equipment available, capable of detecting the types of radiation in use. All personnel should be familiar with the correct operation of these instruments.

8.1 Geiger-Mueller Tube. The most common alpha, beta and gamma radiation detector is the Geiger-Mueller tube (G-M), and is particularly suitable for radiation protection surveys. A G-M counter is a closed hollow tube containing a gas mixture (He, Ne, or Ar) with the interior under one tenth of an atmosphere of pressure, a thin mica or Mylar membrane or "window", a fine wire anode in the and a high voltage potential between the wire and the inner wall of the tube.

An incident particle or photon that ionizes at least one atom of the gas will cause a succession of ionizations in the counter with the resultant electrons captured by the charged centre wire This tremendous multiplication of charge, consisting of perhaps ten billion electrons, will produce, in a typical G-M circuit, a signal of about 1 volt, which is then used to activate a counting circuit. The ionization cascade is stopped or quenched in order that a second event may be detected. A G-M tube requires a certain recovery time after each pulse. If a successive event is initiated by an incident particle before the tube recovers, the discharge will not occur and the event will not be recorded. During the "dead time" the detector is completely unresponsive to additional radiation.

Most beta particles that enter the detector will produce a discharge and register a count on the meter. However, depending on the energy of the gamma or X-ray photons incident upon the counter, only a small fraction may interact and produce ionizations in the chamber. Many of the high energy photons may pass through without any interaction and will not be recorded, thus G-M counters are much more proficient in detecting beta particles than high energy gamma or X rays. Depending on the energy of the emitted ray, the detection efficiency of a G-M counter may be less than 5% for X and gamma rays, but can be much higher for alpha and beta particles that enter the counting volume.

Alpha and beta particles can be readily distinguished from photons by the use of absorbers or shields. If a thin absorber or shield (e.g. 1-3 mm aluminum) is placed in front of the window, it will stop the beta particles but will have relatively little effect on the gamma photons. Thus the counting rate with and without the absorber can be used to distinguish between these two types of radiation. The G-M tube is solely an ionization event counter, and its output signal cannot be used to provide information on the energy or type of the emission nor the identity of the isotope in question.

8.2 Solid Scintillation Detectors. Gas filled G-M tubes do not detect gamma and X-rays efficiently because most of the photons pass through the gas without interaction. The probability of X- and gamma ray detection is increased if a solid detector is used, centre of the barrel insulated from the tube inner wall, however, an interaction cannot be registered by collection of electrons and positive ions, as with G-M tubes. Instead, a solid scintillation crystal is utilized to trap the incident radiation, which causes the emission of photons. This light then impinges upon a photosensitive surface in a photomultiplier tube, resulting in the release of electrons. An electrical signal is created, which the circuitry counts as an event.

Among the alkali halide scintillators, thallium-activated sodium iodide crystals, NaI(Tl), are the most efficient because of the excellent light yield associated with these materials. The efficiency of a crystal for detecting X-ray and gamma-ray photons increases with the size of the crystal. Detectors using solid crystals can also be used to discriminate the various energy-ranges of X-ray and gamma-ray photons and thus can be used to quantify and identify unknown isotope samples. Sodium iodide crystals are highly hygroscopic and must be protected from moisture. If exposed to moisture, the crystal degrades from the resultant free iodine release, which in turn decreases the counting efficiency of the system by absorbing much of the radiation-induced fluorescence.

Most Ludlum Survey Meter-LEGS Detector combinations are not appropriate for quantifying personal exposure fields or waste activity.

A Low Energy Gamma Scintillator (LEGS) is an example of this detector type and is used primarily to detect contamination with I-125 or other isotopes that emit low energy gamma or for soft X-rays. Unlike G-M tubes, LEGS detectors connected to Ludlum survey meters are not calibrated to a standard source and thus any meter reading generated is inaccurate. They are however, extremely useful for quickly identifying gamma isotope contamination sites.

Gamma counters, used mostly in research, also use a solid scintillator. Almost all gamma-emitting isotopes can be counted in this type of instrument.

8.3 Liquid Scintillation Counters. The LSC Scintillation Counter (LSC) is a very sensitive detection system, widely used in research, which can be used to detect minute quantities of almost any isotope. An instrument of this type is used for counting labeled experimental samples and wipe tests of potentially contaminated surfaces. The LSC is commonly used to quantify H-3 , C-14, P-32 or S-35 samples. In liquid scintillation counting, instead of using a solid crystal as the primary fluorescence initiator, a scintillating solution or "cocktail", which consists of a solvent, a primary chemical fluor and, if necessary, a secondary fluor, is used. The radioactive source or sample is then added to this liquid and the resultant photons are collected, multiplied and counted.

Before performing statistical manipulations on LSC data it is necessary to first convert the counts per unit time (CPM) data to disintegrations per unit time (DPM or Bq). To do this one must first determine the counting efficiency of the samples. When counting H-3 or C-14, most LSC systems now are able to make that determination. For other isotopes, this conversion requires the creation of standard reference curves

RADIATION SOURCES IN THE WORKPLACE

9. Basic Principles

Four basic principles ensure that exposure to, and uptake of, radioactive materials is minimized. They are time, distance, and shielding and contamination control.

9.1 Time. The radiation dose an individual receives is directly proportional to the length of time spent in a radiation field. Therefore, in order to minimize radiation doses, it is necessary to ensure minimum working times when handling radioactive sources.

Minimize exposure time.

If possible, practice any new protocol or technique with a non-radioactive blank. The importance of this is two fold. Firstly, you will become aware of any technical difficulties you are likely to encounter and thus avoid handling delays. Secondly, familiarity and practice will reduce the possibility of accidents.

9.2 Distance. It is essential to keep as much distance as possible between a radiation source and the worker. Distance is a very effective factor in reducing the intensity of radiation incident on the body. The actual relationship follows the inverse square law for point emission sources.

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2} \qquad I_2 = \frac{I_1 \cdot (D_1)^2}{(D_2)^2}$$

where I_1 is the intensity of radiation at distance D_1 from the source, and I_2 is the intensity at distance D_2.

Example: The intensity of the radiation at 2 meters from a point source is 13 µSv/h (1.3 mR/h) measured with a G-M detector. What is the radiation field at 50 cm?

Data:

I_1 = 13 µSv/h
D_1 = 200 cm
I_2 = ?
D_2 = 50 cm

Solution:

$$I_2 = \frac{I_1 \cdot (D_1)^2}{(D_2)^2}$$

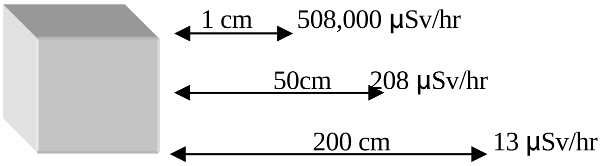
$$I_2 = \frac{13\ \mu\text{Sv/h} \cdot (200\ \text{cm})^2}{(50\ \text{cm})^2}$$

$$I_2 = 208\ \mu\text{Sv/h}\ \ (20.8\ \text{mR/h})$$

Use forceps and tongs to minimize radiation exposure to the hands.

The effects of distance on radiation intensity are illustrated in Figure 7. As the distance from the source gets smaller, the intensity gets progressively larger.

Fig. 6 Effect of Distance on Radiation Intensity



9.3 Shielding. The maximum allowable radiation field for any working area is 2.5 µSv/h (0.25 mR/h). In many instances it will not be possible to keep as far from a source as is required, thus necessitating the use of shielding. Depending on the type and energy of radiation, different shielding materials are recommended.

The maximum allowable radiation field for any working area is 2.5 µSv/h (0.25 mR/h).

Tritium (H-3) produces very weak beta particles with a maximum energy of 18 keV. These electrons travel only a short distance in matter. The range in air of these particles is about 4.7 mm and a glass stock vial or test tube provides complete shielding.

Carbon-14, sulphur-35 and calcium-45 emit beta radiation with maximum energies of 156, 167, and 252 keV, respectively. If kilobecquerel amounts are handled, the glass container will provide adequate shielding. If tens of megabecquerels are being handled, 3 millimetres thick plexiglass, lucite, or glass shielding is recommended.

Phosphorus-32 is a high-energy beta emitter (1.71 MeV), consequently, most operations require shielding. Thick plexiglass (1.2 centimetres) is the material of choice. As described in section 3.6, lead is not recommended due to the generation of bremsstrahlung. The energy of these secondary X-rays increases with the increasing atomic number of the target and energy of the beta particle. For this reason, when shielding energetic beta emitters, a material such as plastic or glass is preferred over lead and steel to minimize X-ray exposure.

Phosphorus-33 is a low-energy beta emitter (0.248 MeV). If kilobecquerel amounts are handled, the glass container will provide adequate shielding. If tens of megabecquerels are being handled, 3 millimetres thick plexiglass, lucite, or glass shielding is recommended.

Iodine-125 produces weak photons with a maximum of 35 keV and can easily be shielded using 1 mm thick lead sheets. An alternative to lead sheets are glass or clear plastic that contains lead in concentrations that are equivalent to the appropriate thickness of lead. The advantage to this material is that it permits the experimental apparatus to be viewed at all times. When performing iodinations it is essential to shield the separation column.

Sodium-22, chromium-51, cobalt-57, rubidium-86, tin-113 and cesium-137 emit both beta and gamma radiation, and shielding is always required when these isotopes are used. Good protection is offered by thick lead sheeting, but it is necessary to use a survey meter to check the effectiveness of the shielding. See Table 5.

Half-Value Layer (HVL) and Tenth Value Layer (TVL). The thickness of any given absorber that will reduce the intensity of a radiation field to one-half its initial value is defined as a *half-value layer*. If the absorber reduces the intensity of the beam to one-tenth it is called a *tenth-value layer*. This information is used to calculate theoretical radiation fields.

Use appropriate shielding. Lead is not always best.

9.4 Contamination Control. Following the use of radioisotopes, monitoring of all work surfaces that may have become contaminated during the handling of the radioisotopes is mandatory. The methods used to check for radioactive contamination in a laboratory are determined by the physical characteristics of the particular radiation.

During a compliance inspection, a primary role of the CNSC officers is to review the contamination control records. The inspectors also regularly perform their own wipe tests in order to confirm the research laboratory results.

Table 4 Shielding Materials for Radioactive Sources

Nuclide	Minimum Shielding*
H-3	None required. Stock vial or any container absorbs all radiation.
C-14	None required for activity up to 370 MBq. Then 3mm plexiglass.
Na-22	10 cm (4") 2 layers of 2" lead bricks.
P-32	1.2 cm (1/2") plexiglass.
P-33	None required for activity up to 370 MBq. Then 3mm plexiglass.
S-35	None required for activity up to 370 MBq. Then 3mm plexiglass.
Ca-45	None required for activity up to 370 MBq. Then 3mm plexiglass.
Cr-51	2.0 cm (3/4") lead.
Co-57	1.7 mm (1/8") lead.
Co-60	10.0 cm (4") 2 layers of 2" lead bricks.
Ni-63	None required. Electron capture detector housing is adequate.
Zn-65	10.0 cm (4") 2 layers of 2" lead bricks.
Rb-86	10.0 cm (4") 2 layers of 2" lead bricks.
Tc-99^m	1.2 cm (1/2") lead.
In-111	2.5 cm (1") lead.
I-125	0.4 mm (1/32") lead.
I-131	6.0 cm (2 1/2") lead.

* Commercially available shielding material, based on ten half-value layers.

a. Wipe test method: Low energy beta particles such as those emitted by tritium, carbon-14, or sulphur-35 do not penetrate the detector window of G-M detectors effectively. These emissions are detected poorly or not at all with a hand-held survey meter. Further, any type of emission (α, β, or γ) resulting from contamination at the stringent level set by the CNSC is not readily detected by a survey meter. For this reason, area wipe tests *MUST* be performed when using radioisotopes. To perform this test, a disc of filter paper is wetted with ethanol, rubbed over the surface in question and then counted in a liquid scintillation counter (or a gamma well-counter, as appropriate). **If the results indicate the contamination exceeds *100 COUNTS PER MINUTE GREATER THAN THE BACKGROUND COUNT,* the surface must be decontaminated and re-tested. Records of the numerical results of all wipe tests must be maintained. (Appendix II)**

b. Direct reading method: To ***supplement*** wipe testing, portable detectors or survey meters may be used to detect high energy betas, X- rays and gamma radiation. This is done by holding the detector approximately two centimetres above the surface to be monitored. In order to allow sufficient detector response time, it is moved slowly over the area in a grid-like fashion. Some instruments have a beta shield which is used to distinguish between gamma and beta contamination. It should be open or removed and the instrument set on the most sensitive range that is practicable.

c. Combined method: A combination of the direct reading and wipe test methods provides the best margin of safety. Wipe tests are useful for the detection of loose contamination but will not give any indication of fixed or embedded contamination. The poor counting efficiency of G-M survey meters results in the underestimation of the level of contamination, especially if the levels are low, or if the contaminant is a low energy beta emitter.

Wipe tests are mandatory following the use of radioactive material. Decontaminate any surface that exceeds 100 CPM above background. Numerical results must be documented.

Accidental contamination of work surfaces is a common occurrence in licensed laboratories. It is therefore imperative for the safety of all personnel, that wipe tests be performed following each use of the material. It is good practice to also include surfaces and equipment not normally involved in isotope use as part of the laboratory wipe test program.

10. Record Keeping

CNSC Regulations require each licensed research laboratory to maintain complete records of all radioactive sources. See Appendix III.

10.1 Purchases. Laws that require faculty research scientists to hold a valid UBC Radioisotope Licence prior to obtaining any radioactive substances strictly regulate the acquisition of radioisotopes. An up-to-date record of all purchases, gifts, or donations of radioactive materials must be maintained.

10.2 Usage. It is necessary to record the user's name, date and activity of each aliquot removed from a stock solution vial. It is advisable to have one "usage sheet" per stock vial that is kept near the isotope storage location.

10.3 Disposals. All waste in the laboratory or decay storage area is part of the permanent radioisotope inventory. The activity of radioisotopes that are disposed into the solid waste containers, drains, fume hoods or held for decay must be documented as described in Section 14.3.

10.4 Contamination Control. As described in Section 9.4, it is required that contamination monitoring be performed at the end of each working day in which radioactive materials were used. The results of these checks, *EVEN WHEN NO CONTAMINATION IS FOUND*, must be recorded and held on file for a period of three years. It is advisable to draw a map of the lab and designate areas where monitoring will be performed.

11. Radioisotope Licences

The University of British Columbia has been issued a Consolidated Radioisotope Licence by the Canadian Nuclear Safety Commission, a federal regulatory agency. Under this licence, individual principal investigators are issued licences that permit radioactive materials to be used for specific purposes in defined locations. A condition of licensing is that only faculty members are issued such permits and that they, as well as their research personnel, successfully complete the UBC Radionuclide Safety and Methodology Course. The conditions of the licence, appendix A and any licence amendments are in keeping with the legal requirements as defined in the Nuclear Safety and Control. Breech of the conditions is a criminal offense. The process for obtaining, modifying or decommissioning a radioisotope licence is detailed on page 6 this manual.

11.1 Ordering Radioisotopes. Only holders of current UBC Radioisotope Licences are permitted to procure radioactive materials in quantities that exceed the exemption limits. The Licence clearly indicates which isotopes may be purchased, how much isotope may be purchased and stored on hand. It also details the permissible uses of that material.

At UBC, each licence holder is responsible for ordering and receiving her/his radioactive material. The purchases are arranged with each supplier after establishing the financial linkage through the Purchasing Department. Purchases are made through the web-based purchasing system by the license holder or authorized users. Upon receipt of the radioactive material, the information on the internet site must be updated with the date received, the receivers name, and the vial identifier information.

> Inform the RSO when receiving any isotope shipment through the web-based purchasing system at :
>
> http://www.hse.ubc.ca/rad/Purchasing/login.asp

11.2 Receipt of Radioactive Sources. As packages arrive in the lab it is necessary to carefully monitor each shipment. The fibreboard boxes can be contaminated with loose radioactive material on both inside and outside surfaces. The contamination is caused by poor housekeeping at the place of origin, rough handling, or leaks developing due to material being carried in non-pressurized aircraft. It is therefore necessary to establish regular procedures when receiving radioactive materials, using the following guidelines:

- Wear disposable gloves and a lab coat while processing the package.
- Wear eye protection (goggles) if the package contains P-32 or I-125.
- Verify the labels and transport index (T.I.) See Appendix V.
- Place the package in a fume hood.
- Wipe test the exterior for contamination.
- Remove packing slip and open outer package.
- Verify that contents agree with packing slip. Check that the activity, isotope and chemical form agree with your order.
- Measure radiation of inner container and shield as required.
- Check for damage, broken seals, loss of liquid, change in colour, etc.
- Wipe test inner container.
- Remove or deface the radiation symbol on the shipping label.
- If shipping carton is found to be free of contamination, dispose as regular non-radioactive waste.
- Notify the lab supervisor and the Radiation Safety Officer 822-7052 of any irregularities.
- Amend purchase records in the web- based ordering system.

12. Safety in the Working Environment

12.1 Locations. Radioactive materials may only be used in licensed locations. Busy areas of the workplace should be avoided. When radioisotopes are being used, all personnel in the radiation area should be informed and precautions taken to ensure that the maximum allowable working field of 2.5 µSv/h (0.25 mR/h), in any direction from the source, is not exceeded.

Label all the material used for radioactive work with radiation stickers. Warning signs are essential, since visitors, cleaning staff, emergency or Plant Operations personnel may otherwise be unaware of the presence of the radiation field. Glassware, tongs, and other equipment used to handle unsealed sources should be segregated and labeled to prevent use with non-radioactive materials. Signs and labels should be removed when the equipment has been shown to be free of radioactive contamination and is no longer required for isotope work.

Working surfaces require covering with an absorbent covering to prevent radioactive contamination. Some options are:

1. Absorbent plasticized paper; eg. Kay-dry, Benchkote, incontinence pads.
2. An absorbent-paper lined tray.
3. A glass plate (for very small volumes only).

Should a spill occur, it can then easily be contained and cleaned up, rather than having to remove and dispose of the contaminated bench.

12.2 Fume Hoods. If there is the possibility of producing airborne radioactivity (aerosols, dust, vapours, etc.), work should be performed in an absorbent-paper lined fume hood. The hood should be labeled with a clearly visible radiation sign. The airflow in each hood is checked by the Department of Health, Safety and Environment on an annual basis; however, should the hood not operate correctly, perform a complete set of wipe tests in the fume hood and remove all hazardous materials. Then fax the results to the Radiation Safety Office at 822-7052. The RSO will supply a document to be posted that confirms the fume hood is free of radioactive contamination. Workers will not repair the fume hood without this documented proof. Then call the Campus Plant Operations TROUBLE line at 2-2173 (or other appropriate Environmental Services number) to request servicing of the unit.

If there is not an operational magnehelic gauge on the hood, it is a good practice to tape a telltale (small piece of tissue paper) to the bottom of the sash to give a visual indicator of airflow. Iodine is an extremely volatile isotope and iodination's must always be performed in a fume hood.

12.3 Sinks. If possible, only one sink should be used for the washing of contaminated labware and dilution disposal of aqueous radioactive waste. The sink should be clearly and boldly labeled with radiation warning tape or labels that are replaced immediately if they become obscured.

12.4 Refrigerators. Store the open source radioisotopes in a refrigerator clearly labeled with a radiation sign. On a routine basis, the refrigerator should be defrosted, cleaned and wipe tested. Ensure that all radioactive samples are labeled with the name of the user, date, isotope and activity. Food or beverages *MUST NOT BE STORED* in laboratory refrigerators.

12.5 Radioactive Sources. In order to minimize degradation of a labeled compound it is often good practice to aliquot the stock solution into smaller volumes, which are then shielded and stored. This lessens the number of freeze-thaw cycles of the stock solutions which can cause degradation of your nuclide labeled chemical compound.

12.6 Posting of Signs and Labels. "CAUTION RADIATION AREA" and "In Case of EMERGENCY Call..." labels must be posted at the entrance to each area or laboratory in which radiation hazards may be present. All storage areas, contamination sites, isotope decay cupboards, etc., must be labeled with a "CAUTION RADIOACTIVE MATERIALS" sign. All licensed rooms must display the "NO EATING DRINKING OR SMOKING" and the "RULES FOR WORKING WITH RADIOISOTOPES" signs. These signs and labels may be obtained from the Radiation Safety Office.

12.7 Miscellaneous. Coat hooks should be provided within the laboratory close to the exit, in order to encourage laboratory personnel to remove lab coats prior to leaving the laboratory. Under no circumstances shall provision be made for food or beverage preparation or storage in the laboratory.

13. Personal Protective Equipment

The primary aim of the Radiation Safety Program is to ensure that radioactive materials are used safely and that radiation exposures are minimized. The individuals using radioisotopes can further this objective simply by ensuring that each and every time they use radiation sources, personal protective equipment is utilized. Apart from radiation hazards, the use of personal protective equipment is further necessitated by the myriad of biological, chemical, physical, and ergonomic hazards present in research areas.

a. Gloves. The use of disposable gloves is mandatory when working with open radioactive sources. Gloves should be checked frequently throughout an experiment in order to detect any small punctures that may have developed. Disposable gloves are prone to fail at the fingertips especially if the wearer has long fingernails. Disposable gloves must never be worn outside the laboratory. For iodinations, it is recommended that a minimum of two pairs of gloves be worn, with the outer pair being replaced frequently during the procedure.

b. Laboratory coats. Laboratory coats are designed to offer spill protection to the wearer and their use is mandatory when working with radioactive materials. In order to function properly, the lab coat must be buttoned completely, with the sleeves rolled down fully, thus enabling the wearer to seal the cuffs with gloves. Laboratory coats should not be worn outside the laboratory and may never be worn in areas in which food is consumed.

c. Clothing. It is recommended that laboratory personnel wear long pants. These provide splash protection for the lower legs. Jewelry, especially rings, should not be worn in laboratories as contamination is often trapped under the band and may go undetected. If a ring were to be contaminated, it may be impossible to decontaminate and could not be worn again.

d. Shoes. Wearing shoes that cover the entire foot is required in all research areas. Sandals, thongs, clogs, etc., do not offer adequate coverage in the event of a spill, nor do they offer protection from falling objects. CSA approved safety shoes are recommended.

e. Glasses. A 37 kBq (1 µCi) droplet of phosphorus-32 in the eye will deliver a dose rate of over 20 mSv/cm^2/h (2000 mrem/cm^2/h). Safety glasses, goggles or face guards should be worn when there is a possibility of splashing this material into the eyes. It is also good practice to wear safety glasses as shielding when working with stock solutions of high energy beta emitters in order to reduce the external radiation dose to the eyes.

f. Remote Handling Devices. Forceps and tongs should be used when handling stock solution vials or any source that produces a significant radiation field.

g. Other. In most situations it is preferable to shield the source of radiation rather than the individuals in the laboratory. However, occasions may arise where reduction of the radiation field below the 2.5 µSv/h limit cannot be achieved. In these situations, lead aprons that provide whole body coverage should be worn. The RSO has equipment available to loan for the manipulation and transport of high activity sources.

MANAGEMENT OF RADIOACTIVE WASTE

14. Disposal Procedures

The very nature of scientific research results in the creation of new and varied forms of radioactive waste. If the type of waste you have generated does not fall within the following classification criteria, or if you have any doubts as to the correct waste stream for a given material, please contact the Radiation Safety Office prior to proceeding with disposal.

The protocol for disposing of radioactive waste at off campus sites may vary from the following campus-specific procedures. It is important that the protocol you intend to follow has been approved by the UBC Radiation Safety Office. Regardless of the disposal protocol, the waste disposal **LIMITS** are **UNIVERSAL** across all UBC research sites.

Unlike other hazardous materials, radioactive atoms are invulnerable to degradation by external chemical and physical processes such as oxidation or incineration. Dilution of radioatoms into the air, landfills or bodies of water, simply moves them from one location to another. The only mechanism whereby radioisotopes can be eliminated from the environment is by radioactive decay. Therefore, in order to minimize the environmental impact of radioisotope disposal, it is incumbent upon all users of radioactive materials to strictly follow the guidelines for radioactive waste management.

These guidelines are enforced by law and are administered by the Canadian Nuclear Safety Commission (CNSC) and require detailed accounting of all radioisotope disposals. Each radioisotope poses a unique degree of risk to people and the environment. For example, iodine-125 poses a greater potential risk to the thyroid than does ingestion of the equivalent activity of tritium. For this reason the CNSC has set out isotope disposal limits that vary with the associated degree of hazard. These restrictions are defined as *Exemption Limits* and range from 37 kBq (1μCi) to 37,000 kBq (1mCi). See Table 5.

All radioactive waste is considered part of the radioisotope inventory, consequently it is necessary to keep a permanent record (Appendix II) of each occasion when radioactive material is held for decay, diluted to the drains, exhausted from a fume hood, sent for incineration, or sent to a landfill. These records must be complete and a summary of the activity disposed is required to be sent to the RSO on an annual basis. This information is then collated and sent to the CNSC as a condition of the consolidated licence.

14.1 Gases and Aerosols. Procedures for which there is a potential to emit radioactive gases, aerosols or dusts must be performed in an absorbent-paper lined fume hood. For radioactive material that may be discharged to the atmosphere via fume hoods, the Gas Disposal Limit is 0.001 Scheduled Quantity per cubic meter of air at the point of discharge, averaged over a one-week period. This is a protocol in place at all UBC sites.

14.2 Liquids. Liquid wastes are classified into two groups:

a. Aqueous. If possible, aqueous liquids should be held in sealed containers until such time as the radioisotope has decayed. For large volumes, or for liquid waste containing long-lived isotopes, disposal of aqueous solutions via the sanitary sewer is permissible. In these cases, it will be necessary to meet the Liquid Disposal Limits listed in Table 5. The liquid to be disposed must not contain organic, toxic or hazardous materials. It is essential to continue a flow of water for several hours after meeting the dilution criteria, thereby ensuring that no radioactive waste remains in the building plumbing. This protocol is in place at all UBC sites.

b. Organic. Waste organic solvents, including ALL liquid scintillation cocktails (as well as so-called `Biodegradable cocktail’) with or without radioactivity, are to be collected in approved 5 litre red plastic UBC solvent containers, which are available from the Chemical Waste Processing Facility (822-6306).

The Liquid Disposal Limits listed in Table 5 apply to organic liquids. The tag attached to the container must be completed, and the container placed in the appropriate area for collection.

The red plastic UBC solvent containers are used for the disposal of ALL SCINTILLATION COCKTAILS.

Example: What is the maximum activity of carbon-14 that a red UBC solvent container may contain when sent for disposal?

Data:

Release Limit (RL) = 37 kBq/l

Volume = 5 litres

Solution:

Maximum Activity (MA) = RL x Volume

MA = 37 kBq/l x 5 l/can = 185 kBq/can

14.3 Solids. The maximum concentrations of radioactivity in solid waste are listed in Table 5. All solid waste sent for disposal must emit less than 2.5 µSv/h (0.25 mR/h) at the surface of the bag or box. **Radioactive waste must be placed in designated and labeled containers which are handled only by lab personnel and not by housekeeping staff**. Foot pedal operated lids should be used to minimize contamination of the outer surface and lid. Regardless of research location, be it on-campus or off, the activity/kg and than 2.5 µSv/h (0.25 mR/h) disposal limits must be met.

a. Incineration. The only material that may be sent to the UBC Environmental Services Facility for off-site incineration is biohazardous or animal anatomic waste. This does not include lab waste such as disposable gloves, bench covering material, plastic test tubes, plastic petri dishes and plastic tubing. The waste may not exceed the activity/kilogram limits and must be below exemption quantity prior to incineration. The material should be bagged, and care should be taken to ensure that the package will not rupture when handled.

Exclusive of radioisotope content, biological material, including biohazards, animals, organs or parts thereof, must be sent for incineration. If the biohazardous material contains radioisotopes, autoclaving the waste prior to disposal should be avoided as the process will result in radioactive contamination of the autoclave. In these situations, a waste handling protocol must be approved by both the Biosafety Officer and the Radiation Safety Officer prior to commencing the research.

b. Non-combustible. All low-level radioactive non-combustible waste enters the regular garbage disposal system. See Appendix IV. By ensuring the disposal guidelines are met, the radioactivity in the waste does not pose a health hazard to any individual who may be required to handle it nor does the material pose a hazard to the environment. It is therefore extremely important that the **Activity/kilogram limits and emission levels of 2.5 µSv/h (0.25 mR/h)** are met. Emptied glass scintillation vials and contaminated glassware, pipets, metal, etc. should all be handled as non-combustible waste. Plastic scintillation vials must be emptied prior to disposal. If the vials had contained a toluene based cocktail, they may be left uncapped overnight in a fume hood to allow for the evaporation of the remaining traces of solvent. If, however, the cocktail is the water miscible or 'biodegradable' type, the vials should immediately be sent for disposal as the trace contents will not evaporate to any extent, but may dissolve the waste bags.

*Combustible and Non-combustible solid waste must contain less than the activity listed in Table 5 **AND** emit less than 2.5 µSv/h (0.25 mR/h) at the surface of the disposal container.*

Ensure that all radiation warning labels are defaced when placing material in waste containers.

The bag lining a glass waste container should be sealed and then surveyed with a Geiger- Mueller detector to ensure that the radiation field is less than 2.5uSv/h (0.25 mR/h). The material may not exceed the limits listed in Table 5. There must be no markings, tape, or labeling to indicate that the bag may contain very low activity radioactive waste. The researcher then disposes the material into the regular glass waste stream. By ensuring the disposal guidelines are met, any minute traces of radioactivity in the waste do not pose a health hazard to any individual who may be required to handle it.

14.4 High Activity Waste. Occasions may arise in which the level of radioactive contamination in the waste does not meet the guidelines for radioisotope disposal. Unlike liquid waste that contains isotopes above the disposal criteria, solid waste may not be diluted to meet the disposal limits. Simply adding a lead brick to a bag of solid waste in order to meet the activity per kilogram disposal criteria does not reduce the concentration or the associated hazard of the radioactive material. In these situations there are two options available.

a. Decay. When using radioisotopes with half-lives less than 90 days, all solid waste that exceeds the disposal guidelines must be held until the accepted standard is met. It is recommended that holding aqueous liquid waste containing short-lived isotopes for decay is preferable to diluting the waste into the sanitary sewer system.

Each research space has tackled the problem of decay storage space in a different way. In some buildings, rooms have been made available for all users to leave waste containers for isotope decay. In others, space has been set aside on a departmental basis. In still others, no such space has been allocated, requiring researchers to make space available in their own laboratories for this process. In each situation, it is important to label all containers with the initial holding date, the isotope and activity, researcher, user and anticipated disposal date.

As a general rule, ten half lives will ensure that all isotope has decayed to the acceptable level. Keeping in mind that the radiation fields emitted from these packages may be very high, it is important to print the above information with large bold lettering so that it can be read at a safe distance (Appendix II).

b. Paint Cans. In situations where the activity to be disposed exceeds the solid waste disposal guidelines, and the half-life of the isotope precludes holding the material for decay, the material may be sent by the University for burial in Chalk River, Ontario. The appropriate containers to be used for this process are new empty paint cans, which are available from most commercial paint stores. New empty cans must be used, as the paint from used cans prevents adequate sealing of the lid.

Every effort must be taken to minimize the waste volume as the shipping procedure is very costly. If the absorbent bench cover is heavily contaminated, the whole piece need not be discarded, but the "hot spots" should be cut from the sheet and placed in the paint can. These containers are appropriate for the disposal of stock solution vials containing unused radioisotope, columns and heavily contaminated glassware used in iodination procedures, radioactive metals and geological samples, etc. The activity of all isotope waste that is placed in the paint can must be documented and the disposal records maintained. Arrangements must be made with the Radiation Safety Office (822-7052) to receive, inspect, catalogue and ship the sealed paint cans.

Only material that cannot meet the waste limits by any other means may be placed in paint cans for disposal.

Table 5. Exemption Limits and Maximum Activities for Disposal

Isotope	Licensing Exemption Limits		Disposal Limits					
	(MBq)	(µCi)	Solid Activity/kg		Liquid Activity/l		Air Activity/ m^3	
			kBq/kg	µCi/kg	kBq/l	µCi/l	kBq/m^3	µCi/m^3
H-3	1000	27030.00	3700	100	370.0	10	37.0	1.0
C-14	10	270.30	370	10	37.0	1	3.7	0.1
Na-22	1.0	27.03	1.0	0.027	0.10	0.0027	0.01	0.0003
P-32	0.1	2.70	37	1	3.7	0.1	0.37	0.01
P-33	100	2703.00	100	2.7	10.0	0.27	1.0	0.027
S-35	100	2703.00	37	1	3.7	0.1	0.37	0.01
Ca-45	10	270.30	37	1	3.7	0.1	0.37	0.01
Cr-51	10	270.30	370	10	37.0	1.0	3.7	0.1
I-125	1.0	27.03	3.7	0.1	0.37	0.01	0.037	0.001

If your isotope is not on this list contact the Radiation Safety Office for guidance on disposal options.

RADIATION EMERGENCY RESPONSE

15. Dealing with Source Incidents and Accidents

Accidents can occur even in the best run laboratories, and personnel using radioactive materials must be fully conversant with the appropriate procedures to be followed. In order to ensure the appropriate management of any incident of an emergency nature, especially those involving personal contamination, **the Radiation Safety Officer shall be notified IMMEDIATELY at 604-822-7052.** No person shall resume work at the site of an emergency until authorized to do so by the Radiation Safety Officer. If the volume is greater than one litre, or if you require assistance, call the Emergency Response number for your site.

> IMMEDIATELY notify the Radiation Safety Office (604-822-7052) in the event of any accidental radioisotope release, spill of material or personal contamination.

An accident is defined as any unintended situation or event, which causes injury to personnel or property damage. Incidents are defined as minor occurrences that do not cause injury or damage. The most likely type of radiation incident occurring in a laboratory is a SPILL. The best way to ensure one deals safely with a spill is to prepare in advance. Become familiar with the following procedure and on a regular basis, check that the Radioisotope Spill Kit in your lab is well stocked. It should contain the following items:

- disposable latex gloves (or equivalent)
- plastic bags for waste disposal and foot covers
- radiation tape and cleaning rags
- absorbent material (i.e. paper towels)
- decontamination detergent
    - gritty cleanser (i.e. Ajax)

15.1 Spills. What to do when a spill occurs!

1. IMMEDIATELY notify all other people in the vicinity of the spill. Evacuate the area if necessary.

2. Notify your supervisor and the Radiation Safety Officer (604-822-7052). If the spill is greater than one litre or if your are not able to handle the spill, call the Campus Hazardous Materials Emergency Response number (2-4567) or the number for your site. (see inside front cover of manual for contact numbers)

3. Remove contaminated clothing and assess if any areas of the body have been contaminated. If the individual is contaminated, see Section 16.

4. Assess the characteristics of the isotope (type of emission, energy, half-life) and thus determine potential hazards and clean-up procedures.

5. Put on appropriate protective clothing. A minimum of a lab coat and disposable rubber gloves are required. Solvent spills will require the use of a dual cartridge respirator equipped with acid gas/organic vapour cartridges.

6. Turn off any device, instrument or machine that could enhance the spill.

7. Use appropriate detector to monitor spill, equipment or people to determine extent of spill.

8. Contain the spill and prevent it from spreading.
   LIQUID SPILLS: Absorbent material such as paper towels or incontinent pads.
   POWDER SPILLS: Place dampened absorbent material over spill. Do not use a spray bottle.

9. Mark off contaminated area with masking tape, chalk or rope to restrict traffic.

10. Clean up the spill using a 2-5% solution of decontamination detergent taking care not to spread the spill. If contamination persists, increase the concentration of the detergent. Place contaminated clean-up materials into the Combustible Waste. Wipe test the area carefully to ensure all splatters and spills have been decontaminated.

15.2 Sealed Source Leaks. Radioisotopes such as Ni-63, Cs-137, Ra-226 have to be contained behind shielding at all times. Under some circumstances, sealed sources can leak or be broken. The primary hazard is from external gamma radiation exposure.

1. Evacuate personnel from the area and post signs.

2. Monitor and cordon off the "HOT AREA". Some isotopes like Am-241 are not easy to detect and could produce a false sense of security to personnel with little or no experience. Monitoring will require the use of a Geiger-Mueller survey meter and it may also be necessary to utilize a Low Energy Gamma Scintillator (LEGS) detector.

3. Monitor all personnel.
4. Notify Supervisor and Radiation Safety Officer 604-822-7052. Commence personnel decontamination procedures.

5. Using remote handling devices such as tongs or forceps place the source in a shielded container.

6. Using spill cleanup procedures listed in section 15.1, decontaminate area.

16. Decontamination of Personnel

The individual involved, or their supervisor, shall ensure that an incident/accident report is submitted to the Health, Safety and Environment Office, Room 50 - G.S.A.B., Campus Mail, within 72 hrs.

16.1 External Contamination. If an individual has been contaminated with radioisotope, the following procedure should be used:

1. Determine the extent of the contamination with the most appropriate sensitive detector.

2. Remove contaminated clothing.

3. Flush the affected areas with copious quantities of lukewarm water for several minutes.

4. Monitor contaminated area. Wash with mild soap.

DO NOT USE DECONTAMINATION DETERGENTS SUCH AS 'COUNT-OFF' WHICH ARE INTENDED ONLY FOR EQUIPMENT.

Gently work lather into the contaminated area for 3 minutes. Rinse thoroughly.

5. Monitor, and repeat Step 4 if contamination persists.

6. Monitor, and if contamination persists, use cold cream or baby oil to clean skin.

7. Monitor, and if contamination persists, DO NOTHING MORE. <u>Do Not</u> use abrasives or caustic detergents. At this point the contamination is bound to the skin and any further manipulation could easily result in injuring or defatting the tissue which would result in internal contamination.
8. Immediately notify the Supervisor or Licensee and the Radiation Safety Officer at 604-822-7052.

16.2 Internal Contamination. If an individual has ingested or has been accidentally injected with a radioisotope the Radiation Safety Officer must be immediately contacted at 604-822-7052. If the RSO is unavailable, then the Occupational Health and Safety Office (604-822-2029) or the Campus First Aid (2-4444) should be contacted.

If an individual has ingested *chemically toxic* radioactive material, treat the chemical toxicity first. Dilution of the stomach contents (conscious victim) by drinking copious amounts of water immediately followed by medical attention is often the best response. Refer to the Material Safety Data Sheet (available from the Health Safety and Environment Office at 822-2029) for First Aid information. Contact the Poison Control Centre at 604-682-5050.

17. Accidents

The injured person or their supervisor shall ensure that an incident/accident report is submitted to the Occupational Health and Safety Office. Within 72 hours of an injury requiring medical attention, a Workers' Compensation Board Form 7 must also be completed by the supervisor and sent to the Occupational Health and Safety Office, Room 50 - G.S.A.B., Campus Mail, Zone 1.

17.1 Accidents Involving Personal Injury. In the event of personal injury, the treatment of the injury must take precedence, even with contaminated persons. It may however, be possible to "contain" any contamination by confining all such persons to a restricted area.

a. Minor Injuries

1. Treat immediately at or near the scene of the accident.

2. Rinse contaminated wound under a tap with copious quantities of lukewarm water and encourage bleeding.

3. If the wound is on the face, take care not to contaminate the eyes, nostrils or mouth.

4. Wash the wound with mild soap and lukewarm water (see Sections 16.1 and 16.2).
5. Apply a first aid dressing. The injured areas should be monitored to establish the residual level of radioactivity, if any.

6. Immediately notify the Supervisor or Licensee and the Radiation Safety Officer at 604-822-7052.

b. Serious Injuries

1. For situations requiring basic first aid, call the first aid attendant in your area or call Campus First Aid at 2-4444. In UBC Campus emergencies in which there is serious bodily harm and/or radiation involvement, the Fire Department should be called at 911. Pull the Fire Alarm if no phone is available. Describe the injuries, the isotope and amounts involved, as well as physical and chemical form of the material. Have someone meet the emergency team at an agreed upon entrance to the building in order to lead them quickly to the accident site.

2. Advise emergency personnel of the contamination, nature of injuries and isotope handling procedures.

3. Ensure that the radioactive material does not further contaminate the accident victim.

4. Isolate contaminated body parts as much as possible using any available shielding material.

5. Immediately notify the Supervisor or Licensee and the Radiation Safety Officer (RSO) at 604-822-7052.

18. Radioisotope Losses or Thefts

Losses or theft of radioactive material rarely occurs; however, the Canadian Nuclear Safety Commission treats these situations very seriously and requires immediate reporting of such incidents. Any situation involving the disappearance of radioactive sources *MUST* immediately be reported to the Radiation Safety Office at 604-822-7052

LIST of TABLES and FIGURES

APPENDIX I

Radiation Exposure Policy for Women at UBC

The limit set by the University of British Columbia Committee on Radioisotopes and Radiation Hazards is that the radiation dose to the abdomen of female UBC Nuclear Energy Workers may not exceed that of the population at large 10 mSv/yr).

Further to this requirement is the policy established by the Canadian Nuclear Safety Commission that following declaration of pregnancy the maximum permissible whole body exposure shall not exceed 4mSv.

The following shall apply:

1. Female personnel are encouraged to disclose to their Department Heads or designate, in confidence, at the earliest possible date, all pregnancies or suspected pregnancies.

2. The Department Head, pregnant worker or designate shall notify the Radiation Safety Officer.

3. In cooperation with the worker's supervisor, there shall be prompt review of her schedule and work load to ensure that radiation exposures shall be kept to a minimum.

4. Under certain conditions where it would seem to be prudent to reduce radiation exposures to a substantially lower level and such reductions are not feasible, the worker shall be encouraged to consider termination of any further work within the prescribed radiation area or site.

5. Entry to the prescribed premises shall be denied to persons whose radiation dose approaches the imposed limits.

6. Except where Item 5 applies, it shall be the free choice of the pregnant worker to determine whether she shall continue to work with radioactive nuclides or ionizing radiation producing equipment after she has been made fully aware of the risks involved. If she elects to continue working in a radiation environment, she shall be obliged to acknowledge the statements by signing the requisite form.

7. All actions taken regarding dose-based modification of the pregnant worker's activities as provided in the foregoing shall be reviewed by the U.B.C. Committee on Radioisotopes and Radiation Hazards. This review must include the best interests of the worker and the University. Recommendations of the Committee shall be final.

8. All female employees/faculty/students shall be made aware of the above policy prior to the use of radioisotopes or radiation emitting devices.

APPENDIX II

Radioisotope Inventory, Waste Decay & Contamination Control Forms

The forms on the following four pages contain the information that the Canadian Nuclear Safety Commission requires in order to meet the record keeping regulations. The use of these specific forms is mandatory unless an alternative approved by the CNSC is utilized.

CONTAMINATION CONTROL RECORDS

Wipe tests must be performed immediately following the use of radioactive materials. Results must be saved or recorded in numerical format. Action level for decontamination is **100 CPM above background**. Rewipe results of decontaminated surfaces must be recorded.

Usage Date	**User's Name**	**Control Counts**	**Site** Location or number	**Site** Location or number	**Site** Location or number	**Site** Location or number	**Site** Location or number	**Site** Location or number	**Site** Location or number	**Site** Location or number

Caution Radioactive Material

Low Activity Waste for Decay

Permit Holder(PI)/Lab ___________________

Waste Generator Name ___________________

Lab Contact Phone # ___________________

Box #____

RADIOISOTOPE :

Activity to decay ____ MBq
(FROM YOUR RADIOISOTOPE DATASHEET)

Survey meter reading
at surface of box uSv/hr

Initial Date ________________
Disposal Date ________________
Actual Date of Disposal _______________

Disposed by __________________________

REMOVE THIS SHEET ON DISPOSAL DATE AND SAVE WITH YOUR RECORDS. COMPLETE YOUR ANNUAL INVENTORY WITH DISPOSAL INFORMATION

RADIOISOTOPE DATA SHEET

NOTE: THERE SHOULD BE ONE DATASHEET PER STOCK VIAL **See Over ➔**

ISOTOPE ___________ ACTIVITY________________* VOLUME___________ VIAL IDENTIFIER______________________________

DATE RECEIVED___________________ WIPE TEST Of Outside Of Shipping Container____________CPM Stock vial Stored in Room #__________

Internet Notification sent to Radiation Safety Office YES ☐ Name of person RECEIVING Isotope___________________________________

USAGE DATE	USER	ACTIVITY USED **Also record if**	ACTIVITY REMAINING **isotope is moved**	VOLUME USED **to a secondary**	VOLUME REMAINING **stock vial**	DISPOSAL OF ACTIVITY *			
						DECAY Combust. /NonCombust.	DRAINS or RED CANS	COMBUST.	NONCOMB.

Date Vial Finished______/______/_______ Vial Transferred to Waste Container #_______ for Disposal ***** = UNITS kBq, MBq, µCi or mCi

Waste Packaged in Container(s) #__________ stored in Room #_______ for Decay ☐ **OR** for Immediate Disposal ☐

Waste Container(s) Disposed on _____/_____/______(date) Wipe tests must correspond to Usage records

Fill out the top section when receiving the shipment of radioactive material. Update your order as ‘received’ by accessing your purchasing records on-line.

Fill out the middle section when using the radioactive material. If the main stock vial is separated into secondary stock vials, i.e. to be used under different licences or different researchers, record this information on the original sheet and create a separate inventory sheet for each of the secondary stock vials.

Fill out the bottom section when the waste container(s) is to be disposed and when the stock vial is no longer of use. Ensure that if the waste container is stored in a room other than the room where the stock vial is stored, that the location of the waste container is identified. When a container is held for decay, place a notice on the container indicating, licencee, user, container number, isotope, activity, radiation field on the container surface, initial date and disposal date. These notices are available through the Radiation Safety Office. When the decay date is reached and the material is being disposed, save the notice with your records and note the date on the inventory form.

APPENDIX III

Rules Posters

The following four pages contain the Laboratory Rules (Basic, Intermediate, High and Nuclear Medicine) as defined by the Canadian Nuclear Safety Commission. You are required to post a copy of one of these four posters in each room that is licensed for radioactive work and /or storage.

Canadian Nuclear
Safety Commission

Commission canadienne
De sûreté nucléaire

INFO-0728-1

BASIC LEVEL

Use of Unsealed Nuclear Substances

This room has been classified as "basic level" for the use of unsealed nuclear substances in accordance with Canadian Nuclear Safety Commission guidelines. Below is a list of safe work practices to be followed when working in this room.

24 – hour emergency contact (name and phone number)	Room identification

- **Do not eat, drink, store food, or smoke in this room.**
- **In case of a spill or incident involving a nuclear substance, follow emergency procedures and notify the Radiation Safety Officer.**
- **Clearly identify work surfaces used for handling nuclear substances.**
- **Use protective clothing and equipment when working with nuclear substances.**
- **Check all packages containing nuclear substances for damage upon receipt.**
- **Store nuclear substances in a locked room or enclosure when not in use.**

A room is classified as "basic level" for the use of unsealed nuclear substances when more than one exemption quantity is handled and where the largest quantity (in becquerels) of a substance handled by any worker does not exceed 5 times its corresponding annual limit of intake (in becquerels). Contact your Radiation Safety Officer for a list of annual limits of intake.

For more information, contact: Canadian Nuclear Safety Commission, Directorate of Nuclear Substance Regulation, P.O. Box 1046, Station B, Ottawa, Ontario, K1P5S9. Telephone: 1-888-229-2672. Facsimile (613) 995-5086.

Canada

Canadian Nuclear
Safety Commission

Commission canadienne
De sûreté nucléaire

INFO-0728-2

INTERMEDIATE LEVEL

Use of Unsealed Nuclear Substances

This room has been classified as "intermediate level" for the use of unsealed nuclear substances in accordance with Canadian Nuclear Safety Commission guidelines. Below is a list of safe work practices to be followed when working in this room.

24 – hour emergency contact (name and phone number)	Room identification

- **Do not eat, drink, store food, or smoke in this room.**
- **Wear appropriate dosimeter at all times.**
- **In case of a spill or incident involving a nuclear substance, follow emergency procedures and notify the Radiation Safety Officer.**
- **Clearly identify work surfaces used for handling nuclear substances.**
- **Use protective clothing and equipment when working with nuclear substances.**
- **After working with nuclear substances, monitor work area for contamination.**
- **Wash hands regularly and monitor them for contamination frequently.**
- **Check all packages containing nuclear substances for damage upon receipt.**
- **Store nuclear substances in a locked room or enclosure when not in use.**

A room is classified as "intermediate" for the use of unsealed nuclear substances where the largest quantity (in becquerels) of a substance handled by any worker does not exceed 50 times its corresponding annual limit of intake (in becquerels). Contact your Radiation Safety Officer for a list of annual limits of intake.

For more information, contact: Canadian Nuclear Safety Commission, Directorate of Nuclear Substance Regulation, P.O. Box 1046, Station B, Ottawa, Ontario, K1P5S9. Telephone: 1-888-229-2672. Facsimile (613) 995-5086.

Canada

HIGH LEVEL
Use of Unsealed Nuclear Substances

This room has been classified as "high level" for the use of unsealed nuclear substances in accordance with Canadian Nuclear Safety Commission guidelines. Below is a list of safe work practices to be followed when working in this room.

24 – hour emergency contact (name and phone number)	Room identification

- **Do not eat, drink, store food, or smoke in this room.**
- **Restrict access to authorized workers only.**
- **Wear appropriate dosimeter at all times.**
- **In case of a spill or incident involving a nuclear substance, follow emergency procedures and notify the Radiation Safety Officer.**
- **Work in a fume hood when required by the Radiation Safety Officer.**
- **Clearly identify work surfaces used for handling nuclear substances.**
- **Wear protective clothing and equipment at all times.**
- **After working with nuclear substances, monitor work area for contamination.**
- **Wash hands regularly and monitor them for contamination frequently.**
- **Check all packages containing nuclear substances for damage upon receipt.**
- **Store nuclear substances in a locked room or enclosure when not in use.**

A room is classified as "high level" for the use of unsealed nuclear substances where the largest quantity (in becquerels) of a substance handled by any worker does not exceed 500 times its corresponding annual limit of intake (in becquerels). Contact your Radiation Safety Officer for a list of annual limits of intake.

For more information, contact: Canadian Nuclear Safety Commission, Directorate of Nuclear Substance Regulation, P.O. Box 1046, Station B, Ottawa, Ontario, K1P5S9. Telephone: 1-888-229-2672. Facsimile (613) 995-5086.

Canadian Nuclear
Safety Commission

Commission canadienne
De sûreté nucléaire

INFO-0728-2

NUCLEAR MEDICINE

Use of Unsealed Nuclear Substances

This room has been classified as a "nuclear medicine" room for the use of unsealed nuclear substances in accordance with Canadian Nuclear Safety Commission guidelines. Below is a list of safe work practices to be followed when working in this room.

24 – hour emergency contact (name and phone number)	**Room identification**

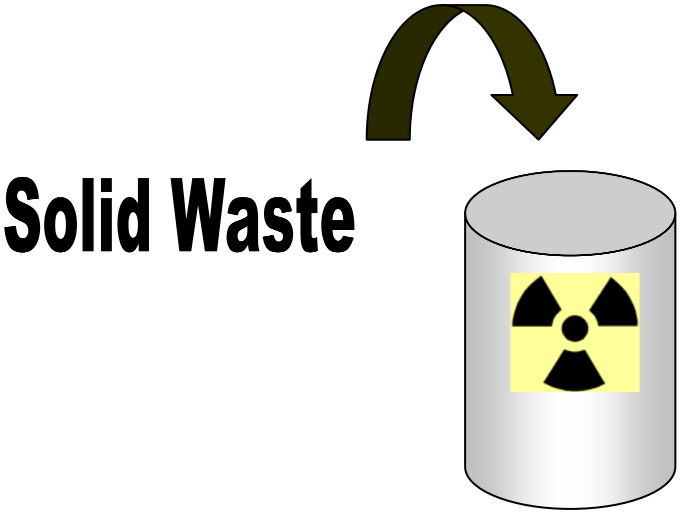
- **Do not eat, drink, store food, or smoke in this room.**
- **Wear appropriate dosimeter at all times.**
- **In case of a spill or incident involving a nuclear substance, follow emergency procedures and notify the Radiation Safety Officer.**
- **Work in a fume hood when required by the Radiation Safety Officer.**
- **Wear protective clothing and equipment at all times.**
- **Wash hands regularly and monitor them for contamination frequently.**
- **Perform thyroid screening or bioassay when required.**
- **Check all packages containing nuclear substances for damage upon receipt.**
- **Store nuclear substances in a locked room or enclosure when not in use.**

A room is classified as "nuclear medicine" for the use of unsealed nuclear substances where *in vivo* related diagnostic or therapeutic nuclear medicine is performed.

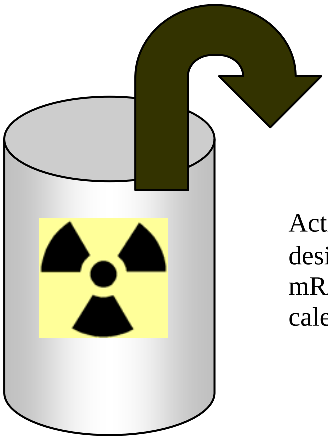
For more information, contact: Canadian Nuclear Safety Commission, Directorate of Nuclear Substance Regulation, P.O. Box 1046, Station B, Ottawa, Ontario, K1P5S9. Telephone: 1-888-229-2672. Facsimile (613) 995-508

APPENDIX IV
SOLID WASTE DISPOSAL

1. Ensure that the waste container displays a radiation warning symbol. Line the container with a plastic bag.
2. As the waste is generated, deface all radiation warning labels on the material to be discarded. Place the solid material in the designated radioactive waste container (Ensure container has a tightly fitting lid).



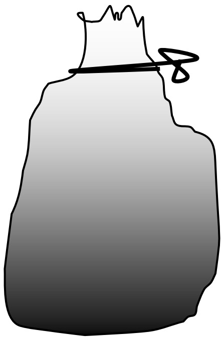
3. Make sure that the radiation field emitted from the walls of the container is less than **2.5 µSv/hr (0.25 mR/hr).**



4. When the container is full - remove the plastic bag - (If the material already meets the disposal criteria for **activity/kg (Table 5)** and emits less than **2.5 µSv/hr (0.25 mR/hr)**, go directly to Step 5). Complete and attach the Low Activity Waste (LAW) form (see page 34 of the manual) to the bag - place the bag in the designated decay storage area. At this point the bag may exceed the 2.5 µSv/hr (0.25 mR/hr) limit in its unshielded state in the storeroom. Note the disposal date on your calendar as a reminder.

When the disposal date arrives and the material meets the disposal criteria –

for **activity/kg (Table 5)** and emits less than **2.5 µSv/hr (0.25 mR/hr) Note: At all VGH locations the disposal limit is 'equal to background'.**



- Remove the LAW form and place it in the records binder
- Enter the date of disposal on the associated Isotope Inventory Sheet
- Check to ensure there are no radiation warning labels or tape on the bag
- Place bagged waste in outside lab waste dumpster.

APPENDIX V

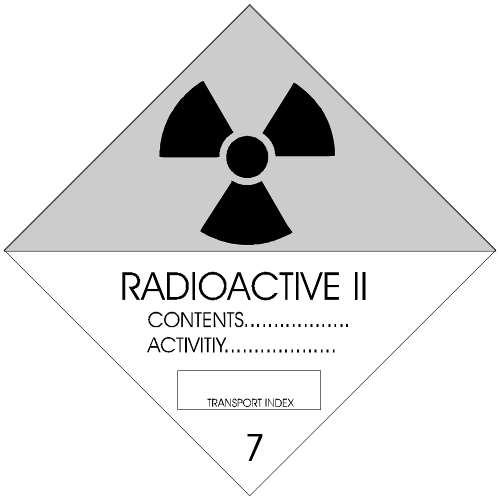
Transport Packaging

Containers for shipping radioactive material may display different labels depending on a number of factors. The requirements for shipping radioisotopes are defined in the Transport Packaging of Radioactive Materials Regulations. The four categories of labeling are: excepted package, I-white, II-yellow and III-yellow.

The marking on a package in the first classification indicates that the package meets the criteria for an *excepted package.* This means that the amount of isotope being shipped does not pose an external radiation hazard to anyone handling the package. There is no specific symbol for this classification.

The second category is the I-white label displaying the radiation trefoil and one red bar on a white background. This indicates that on any surface of the package the maximum field strength may not exceed 5µSv/h (0.5 mR/h).

The third category is the II-yellow label displaying the radiation trefoil and two red bars. This indicates that on any surface of the package the maximum field strength is greater than 5µSv/h (0.5 mR/h) but may not exceed 500 µSv/h (50 mR/h). The top half of the label is yellow, the bottom half is white. Further, the number in the small box in the bottom corner of the label indicates the Transport Index (TI). The TI restricts the radiation to a maximum of 10µSv/h (1 mR/h) at one meter from the package.



The fourth category is the III-yellow label displaying the radiation trefoil and three red bars. This indicates that on any surface of the package the maximum field strength is greater than 500µSv/h (50 mR/h) but may not exceed 2 mSv/h (200 mR/h). The top half of the label is yellow, the bottom half is white. The TI restricts the radiation field to a maximum of 100µSv/h (10 mR/h) at one meter from the package.

GLOSSARY OF TERMS

A: Mass number of a given nuclide.

ABSORPTION: Transfer or deposition of some or all of the energy of radiation traversing matter.

ABSORPTION COEFFICIENT: Since the absorption of gamma or X-rays is exponential in nature, these radiations have no clear cut range. The fractional decrease in the intensity of such a beam per unit thickness of the absorber is expressed by the linear absorption coefficient.

ACCELERATOR (PARTICLE): A device that accelerates charged sub-atomic particles to very great energies. These particles may be used for basic physics research, radioisotope production or for direct medical irradiation of patients.

ACTIVATION: Absorption, usually of neutrons or charged particles (the minimum energy to induce this effect is 10 MeV) by nuclei thereby making them radioactive.

ACTIVITY: Is the number of nuclear transformations occurring in a given quantity of material per unit time. The SI unit for the transformation rate is the becquerel, which is defined as one disintegration per second.

ALPHA PARTICLE (α): A positively charged highly energetic nuclear fragment, comprised of two neutrons and two protons (helium nucleus).

ANNIHILATION RADIATION: Positrons interact with negative electrons resulting in the disappearance of both particles and the release of two annihilation 511 keV photons.

ANNUAL LIMIT ON INTAKE (ALI): The activity of a radionuclide which, upon ingestion, results in an exposure equal to the annual maximum permissible dose.

ATTENUATION: The reduction of the intensity of a beam of gamma or x-rays as it passes through some material. Beam energy can be lost by deposition (absorption) and/or by deflection (deflection attenuation). The three primary mechanisms by which energy is transferred from the beam to the material through which it passes are the photoelectric effect, the Compton effect and pair production.

BEAM: A flow of electromagnetic or particulate radiation that is generally unidirectional or is divergent from a radioactive source but is confined to a small angle.

BECQUEREL (Bq): The SI unit of activity defined as one nuclear disintegration per second.

BETA PARTICLE (β): Negatively charged particle emitted from the nucleus of an atom. It is just an energetic electron.

BRANCHING: The occurrence of two or more modes by which a radionuclide can undergo radioactive decay to the ultimate stable state. An individual atom of a nuclide exhibiting branching disintegrates by one mode only. The fraction disintegrating by a particular mode is the branching fraction for that mode. The branching ratio is the ratio of two specified branching fractions (also called multiple disintegration).

BREMSSTRAHLUNG: Secondary electromagnetic radiations produced by the rapid deceleration of charged particles in strong electromagnetic fields. The likelihood of emission is proportional to the mass of the nucleus of the absorber.

CARRIER: A quantity of non-radioactive or non-labeled material of the same chemical composition as its corresponding radioactive or labeled counterpart.

CARRIER-FREE: A preparation of radioisotope to which no carrier has been added and for which precautions have been taken to minimize contamination with other isotopes. Material of high specific activity is often loosely referred to as "carrier-free" but is more correctly defined as "high isotopic abundance".

COMMITTED DOSE EQUIVALENT: The total dose equivalent averaged throughout a tissue 50 years after body uptake of the radionuclide.

CONTAMINATION, RADIOACTIVE: Unwanted deposition of radioactive material in or on any medium or surface. UBC policy permits no contamination greater than 100 Counts Per Minute above background.

COULOMB (C): The quantity of electricity transported in one second by a current of one ampere.

COUNTER, SCINTILLATION: Scintillation detection is based on the interaction of radiation with substances known as fluors (solid or liquid) or scintillators. Excitation of the electrons in the fluor leads to subsequent emission of light (scintillation) which is detected by a photomultiplier tube and converted into an electronic pulse. The pulse magnitude is proportional to the energy lost by the incident radiation in the excitation of the fluor.

CURIE (Ci): The outmoded unit used to quantify activity of radioactive material. Defined as 3.7×10^{10} disintegrations per second.

DECAY CONSTANT: The fraction of atoms undergoing nuclear disintegration per unit time.

DECAY, RADIOACTIVE: Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons.

DOSE EQUIVALENT (H): The product of the absorbed dose, the quality factor (Q) and the product of any other modifying factors (N). For most laboratory purposes N = 1.

DOSIMETER, POCKET: A small pocket-sized ionization chamber used for monitoring radiation exposure of personnel.

ELECTROMAGNETIC RADIATION: A spectrum of discrete energy emissions such as radio waves, microwaves, ultraviolet light, visual light, X-rays, gamma rays, etc, having no charge or mass, often called photons or quanta.

ELECTRON CAPTURE: A type of radioactivity in which an atomic electron is absorbed by the nucleus, and is often followed by γ-ray emission.

ENERGY, AVERAGE PER ION PAIR: The average energy expended by a charged particle in a gas per ion pair produced. For most radiological calculations, this value has been normalized to 33.73 eV.

ENERGY, BINDING: The energy represented by the difference in mass between the sum of the component parts and the actual mass of the nucleus.

ENERGY, EXCITATION: The energy required to change a system from its lowest energy state (ground state) to an excited state.

ENERGY FLUENCE: The sum of the energies, exclusive of rest energies, of all particles passing through a unit cross-sectional area.

ENERGY FLUX DENSITY (ENERGY FLUENCE RATE): The sum of the energies, exclusive of rest energies, of all particles passing through a unit cross-sectional area per unit time.

ENERGY LEVELS: Discrete set of quantized energies states within a given atomic nucleus (or atom itself).

ERYTHEMA: An abnormal redness of the skin due to distention of the capillaries with blood. It can be caused by many different agents of which heat, drugs, ultraviolet rays, and ionizing radiation (dose of 10 Sv) are the most common.

EXPOSURE (C/kg): A measure of the ionization produced in air by X or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The SI unit of Coulombs per kilogram replaces the outmoded Roentgen unit.

GEIGER MUELLER TUBE: The major component of laboratory survey meters, which function as incident radiation detectors. A Geiger-Mueller tube is composed of a gas filled hollow tube containing two coaxial electrodes that discharge and recharge following ionizing events.

GENERATOR: Device from which a progeny nuclide is eluted from an ion exchange column containing a parent radionuclide, which is long-lived compared to the progeny.

GENETIC EFFECT OF RADIATION: The radiation induced change in the DNA of germ cells resulting in the passing of the altered genetic information to future generations.

GEOMETRY FACTOR: The fraction of the total solid angle about a radiation source that is subtended by the face of the sensitive volume of a detector.

GRAY (Gy): The SI unit of absorbed dose that is equal to one joule per kilogram. Replaces the RAD.

HALF-LIFE, BIOLOGICAL (BHL): The time required for the body to eliminate one half of an administrated dosage of any substance by regular process of elimination.

HALF-LIFE, EFFECTIVE (EHL): Time required for a radioactive element in a living organism to be diminished 50% as a result of the combined action of physical half-life (PHL) and biological elimination (BHL).

HALF-LIFE, PHYSICAL (PHL): Time required for a radioactive substance to lose 50% of its activity by decay. Each radionuclide has its own unique half-life.

HALF VALUE LAYER (HVL): The thickness of a specified substance which, when introduced into the path of a given beam of X or gamma radiation, reduces the intensity of the beam by one half.

IONIZATION ENERGY: The energy required to remove one electron from an atom giving rise to an ion pair. In air, the average ionization energy is 33.73 eV.

IONIZING RADIATION: Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Examples include alpha particles, beta particles, gamma rays or x rays, and cosmic rays. The minimum energy of ionizing radiation is a few electron volts (eV).

IRRADIATION: Subjection to radiation.

ISOTOPES: Nuclides with the same atomic number (same chemical element) but different atomic mass numbers.

ISOMER: An excited state of a nucleus which is long-lived. It often de-excites by γ-ray emission, but sometimes by β or α decay.

JOULE (J): The work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force.

LABELLED COMPOUND: A compound consisting, in part, of molecules made up of one or more atoms distinguished by non-natural isotopic composition (either radioactive or stable isotopes). See also Carrier.

LATENT PERIOD: The period or state of seeming inactivity between the time of exposure of tissue to an injurious agent such as radiation, and the presentation of the associated pathology.

LINEAR ENERGY TRANSFER (LET): The rate at which an incident particle transfers energy as it travels through matter. The unit is keV per micron of path traveled.

LOW ENERGY GAMMA SCINTILLATOR (LEGS): A detection system that utilizes an alkali halide crystal photomultiplier arrangement to detect low energy gamma and x-ray radiation.

MAXIMUM PERMISSIBLE CONCENTRATION (MPC): Limits set on water and air concentrations of radionuclides, for 40 or 168 hours per week, which yield maximum permissible body burden values and their corresponding organ dosages.

NON-STOCHASTIC EFFECTS: Induced pathological changes for which the severity of the effect varies with the dose, and for which a threshold must be exceeded, i.e. eye cataracts.

NUCLIDE: A species of atom in which the nuclear constitution is specified by the number of protons (Z), number of neutrons (N), and the energy content; or alternately by the atomic number (Z), mass number A = (N + Z), and atomic mass.

PHOTON: A quantized amount of electromagnetic energy, which at times displays particle characteristics.

POSITRON: A particle equal in mass to an electron and having an equal but positive charge.

POST-CARD: A card (free from RSO) sent to the UBC Radiation Safety Office upon receipt of radioactive sources purchased on a standing order.

QUALITY FACTOR (Q): The principal dose modifying factor which is based on the collision stopping power of an incident particle and is employed to derive the dose equivalent from the absorbed dose.

RADIOACTIVITY: The property of certain unstable nuclides to spontaneously undergo nuclear transformations that result in the emission of ionizing radiations.

RADIOISOTOPE: A synonym for radionuclide.

RADIONUCLIDE: A radioactive nuclide.
RADIORESISTANCE: Relative resistance of cells, tissues, organs and organisms to damage induced by radiation.

RADIOSENSITIVITY: Relative susceptibility of cells, tissue, organs and organisms to damage induced by radiation.

RED CAN: Five- litre capacity plastic container used for disposal of organic solvents. Obtained from the UBC Chemical Waste Processing Facility (822-6306).

REFERENCE MAN: Compilation of anatomical and physiological information defined in the report of the ICRP Task Group on Reference Man (ICRP Publication 23) that is used for dosimetry calculations.

RELATIVE BIOLOGICAL EFFECT (RBE): A term relating the ability of radiations with different LET ranges to produce a specific biologic response; the comparison of a dose of test radiation to a dose of 250 keV x-ray that produces the same biologic response.

ROENTGEN (R): The outmoded unit of exposure that has been replaced by the Si unit Coulombs per kilogram. One roentgen equals 2.58 x 10^{-4} Coulombs per kilogram of air.

ROENTGEN EQUIVALENT MAN (REM): The outmoded dose equivalent unit that is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor and any other necessary modifying factor. It has been replaced by the Sievert.
100 rem = 1Sv

SCATTERING: Change of direction of subatomic particles or photons as a result of atomic collisions.

SCHEDULED QUANTITY (SQ): A regulated amount of radioactivity of an isotope, the level of which is determined by the relative risk associated with that isotope during shipping or disposal.

SHIELD: Material used to prevent or reduce the passage of ionizing radiation. See also Half Value Layer.

SI (Syteme International): International System of scientific nomenclature.

SIEVERT (Sv): SI unit of dose equivalent that is numerically equal to the absorbed dose in grays, multiplied by the quality factor, the distribution factor and other necessary modifying factors. 1 Sv = 100 rem.

SOMATIC INJURY: Radiation induced damage to cells other than germ cells.

SOURCE TISSUE: Tissue (which may be a body organ) containing a significant amount of a radionuclide following intake of that radionuclide.

SPECIFIC ACTIVITY: Total activity of a given nuclide per gram of a compound, element, or radioactive nuclide.

STOCHASTIC EFFECTS: Induced pathological changes for which the probability of an effect occurring, rather than the severity, is regarded as a function of dose without threshold (i.e. cancer).

SURVEY METER: A hand held radiation detection instrument. See also Geiger-Mueller Tube.

TENTH VALUE LAYER (TVL): The thickness of a specified substance which, when introduced into the path of a given beam of X or gamma radiation, reduces the intensity of the beam by a factor of ten.

THERMOLUMINESCENT DOSIMETER (TLD): A small badge worn by workers, which is used to passively monitor personal radiation doses. Lithium fluoride crystals are the functional units in the badge. In which a small fraction of the energy absorbed from ionizing radiation is stored in a metastable energy state. This energy is later recovered as visible photons, when the material is heated.

TRACER, ISOTOPIC: An isotope or mixture of isotopes of an element or elements that which may be incorporated into a sample to permit observation of the course of that element, alone or in combination, through a chemical, biological or physical process. The observation may be made by measurement of radioactivity or of isotopic abundance.

X-RAY: Electromagnetic radiation originating from the orbital electrons of an atom.

Z: Atomic number of a given nuclide.

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