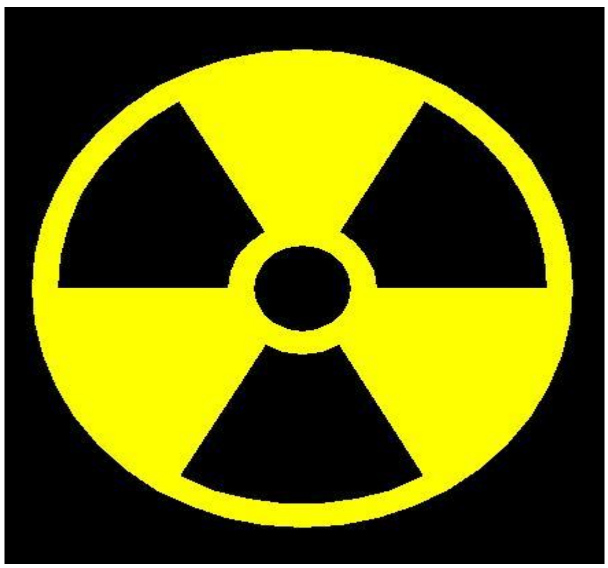
RADIOISOTOPE SAFETY & METHODOLOGY MANUAL

Guidelines and Procedures for Faculty, Staff and Students



UNBC *University of Northern British Columbia*

Prepared by: Committee on Radioisotopes and Radiation Hazards, June 2000

Updated: April 2022

PREFACE

First and foremost, the protection of health and safety is a moral obligation. An expanding array of federal, provincial and local laws and regulations makes it a legal requirement and an economic necessity as well. "In the final analysis, laboratory safety can be achieved only by the exercise of judgement by informed, responsible individuals. It is an essential part of the development of scientists that they learn to work with and to accept the responsibilities for the appropriate use of hazardous substances." [1]

Our organization is responsible for ensuring that all research and related activities are conducted with minimal hazards to employees, students and the community. The procedures described in this manual are elements essential to our program and supersede all pertinent directives issued previously. Anyone using the equipment and facilities of this institution is expected to follow safe and proper procedures, to report all accidents promptly and to bring to their supervisor's attention any unsafe conditions or practices.

This manual provides members of this institution's community with information on the inherent risks associated with laboratory work and suitable safeguards. The guidelines and procedures described have been designed to assist faculty, staff and supervisors in meeting their responsibilities for controlling hazardous situations. Placing these guidelines and procedures into practice is the responsibility of those not only in administrative positions, but also in all positions throughout our organization. It is essential that everyone connected with laboratory activities be thoroughly familiar with this manual and know whom to ask for additional advice and training.

Assistance is available from those responsible for occupational health and safety to all members of our organization in developing procedures for the safe handling, containment and disposal of biological, chemical and radiological agents as well as in designing safe working environments, selecting and using personal protective equipment, and interpreting safety standards.

The organization of the safety program is designed to facilitate knowing the regulations with which we must comply, accepting responsibility for safety on various levels and fulfilling our obligations. For reference and consultation, an overview of this organization is on Page ii.

In addition to those responsible for laboratory operations and occupational health and safety, several committees advise and help to formulate policies and procedures that affect safety. Questions or suggestions can be directed to your supervisor, laboratory manager, those responsible for occupational health and safety or the individuals listed on Page ii when appropriate.

In any emergency, you should dial our emergency contact number, 3333

Disclaimer

The information included in this manual has come from a variety of reliable sources. This manual is intended for use by University of Northern British Columbia personnel as an appropriate starting point for the development of safe and good laboratory practices for working with radioactivity. The material contained within is correct to the best of knowledge of the Committee on Radioisotopes and Radiation Hazards. However, there is no guarantee or warranty that it is without errors or omissions.

[1]National Research Council. 1981. *Prudent Practices for Handling Hazardous Chemicals in Laboratories.* Washington, D.C.: National Academy Press. p. 6.

Duties and Responsibilities

Federal legislation resulted in the creation of the Canadian Nuclear Safety Commission, the Nuclear Safety and Control Act and the pursuant Regulations that deal with the handling of radioactive material in Canada.

The Canadian Nuclear Safety Commission is the federal body whose agents administer the Act. This agency issues licences to the University of Northern British Columbia and has defined the duties and responsibilities of the University of Northern British Columbia Committee on Radioisotopes and Radiation Hazards, which administers the University's licences. These responsibilities include ensuring that all persons involved in the handling of radioisotopes have adequate training and knowledge enabling them to perform their duties safely and in accordance with UNBC's radiation safety program and Canadian Nuclear Safety Commission 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 Nuclear Safety and Control Act and the pursuant Regulations.

The University of Northern British Columbia radiation safety program is based on the principle that radiation exposure, and the associated risk, must always be **A**s **L**ow **A**s **R**easonably **A**chievable. This **ALARA** principle is subject to the condition that all exposures must not exceed the regulatory limits.

Further, the ALARA principle 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 Canadian Nuclear Safety Commission also defines the roles and responsibilities of Internal Radioisotope Permit holders and radioisotope users, as well as the Radiation Safety Officer.

In general terms: Internal Radioisotope 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. For specific details refer to the:

Occupational Health and Safety Policy:
https://our.unbc.ca/sites/Policies/development/Policy/Occupational%20Health%20and%20Safety.pdf#search=occupational%20health%20and%20safety

Radionuclides and Radiation Hazard Policy:

https://our.unbc.ca/sites/Policies/development/Policy/Radionuclides%20and%20Radiation%20Hazard.pdf#search=committee%20on%20radioisotopes

CONTACT NUMBERS

Responsible Individuals (at time of printing):

Radiation Safety Officer	Dispensing Chemist 250-960-6472
Assistant Radiation Safety Officer	Manager, Heath & Safety 250-960-5530
Security:	Director, Safety and Security 250-960-5535
Physical Facilities Management:	Director of Facilities 250-960-5590

Responsible Committees:

Radiation Safety Committee:	Committee Chair 250-960-5530

The Radiation Safety Committee reports to the UNBC Joint Health and Safety Committee. For more information contact safety@unbc.ca or visit the website at https://www.unbc.ca/safety/health-safety

All Emergencies – Dial 3333

FOREWORD

Radiation sources, when properly handled, represent a minimal risk to researchers, staff and students. Accidents and misadventure may result in the loss of scientific information and, of greater concern, possible radiation exposure of laboratory workers. An understanding of the principles of radiation protection is essential. Individuals successfully completing the University of Northern British Columbia Radioisotope Safety and Methodology Course will have received a strong foundation in these protection principles as well as the tools necessary to decontaminate items and evaluate hazardous situations that may arise.

This manual has been developed using well-developed and tested policies and procedures from other highly esteemed and well-established institutions, and reflects the needs of the University of Northern British Columbia's research community. The contents of the manual have been endorsed by the University's Committee on Radioisotopes and Radiation Hazards. This manual is for internal use only and is not intended for external distribution.

TABLE OF CONTENTS

PREFACE .... **ii**

CONTACT NUMBERS .... **ii**

FOREWORD .... **iii**

TABLE OF CONTENTS .... **iv**

1. INTRODUCTION **1**

2. HISTORICAL REVIEW **1**

3. BOHR'S MODEL OF THE ATOM **2**

4. RADIOACTIVITY **3**

4.1 Alpha Emission *3*
4.2 Beta Emission *3*
4.3 Positron Emission *4*
4.4 Orbital Electron Capture *4*
4.5 Gamma Rays *5*
4.6 X-rays *5*
4.7 Other Radiations *5*

5. RADIOACTIVE DECAY **5**

5.1 Physical Half-Life ($t_{1/2}$) *5*
5.2 Biological and Effective Half-Lives *6*

6. UNITS OF RADIATION **6**

6.1 Units of Radioactivity *8*
6.2 Units of Radiation Exposure *8*
6.3 Units of Absorbed Dose *8*
6.4 Units of Relative Biological Effectiveness (RBE) *8*

7. BIOLOGICAL EFFECTS OF IONIZING RADIATION **9**

7.1 Acute Effects *9*
7.2 Delayed Effects *9*

8. RADIATION DOSIMETRY 11

8.1 External Personnel Monitoring 11
8.2 Internal Personnel Monitoring 12
8.3 Exceeding Dose Limits 13

9. LABORATORY RADIATION SURVEILLANCE 13

9.1 Geiger-Mueller Tube 13
9.2 Solid Scintillation Detectors 14
9.3 Liquid Scintillation Counters 14

10. RADIATION PROTECTION PRINCIPLES: SEALED SOURCES 14

10.1 Quantity 15
10.2 Time 16
10.3 Distance 16
10.4 Shielding 17

11. RADIATION PROTECTION PRINCIPLES: OPEN SOURCES 18

11.1 Reasons for Concern Regarding Internal Contamination 18
11.2 Types of Contamination 19

12. CONTAMINATION MONITORING 19

12.1 Wipe-Test Method 20
12.2 Direct-Reading Method 21
12.3 Combined Method 21

13. RADIOISOTOPE LICENCES 21

13.1 Types of Internal Radioisotope Permits 21
13.1.1 Sealed source permits. 21
13.1.2 Open source permits. 21
13.2 Obtaining a University of Northern British Columbia Internal Radioisotope Permit 21
13.3 Amending a University of Northern British Columbia Internal Radioisotope Permit 22
13.4 Renewal of a University of Northern British Columbia Internal Radioisotope Permit 22
13.5 Protocol for Internal Radioisotope Permit De-activation and Laboratory Decommissioning 22
13.6 Internal Radioisotope Permit Re-Activation 23
13.7 Approved Personnel 23
13.8 Non-Compliance 23
13.9 Posting and Labelling 23

14. THE ACQUISITION OF RADIOISOTOPES AND DEVICES CONTAINING RADIOISOTOPES 23

14.1 Ordering Radioactive Materials 23

14.2 Transfer of Radioisotopes To or From the University of Northern British Columbia 24

14.3 Transfers Within the University of Northern British Columbia 24

14.4 Instructions Regarding the Use of the Web-Requisition System for Radioisotope Orders 24

15. RECEIPT OF RADIOACTIVE SOURCES 25

16. RADIATION PROTECTION: PRACTICAL ASPECTS 25

16.1 Justification and Optimization 25

16.2 Locations..26

16.3 Eating, Drinking and Smoking 26

16.4 Refrigerators...26

16.5 Sealed Sources 26

16.6 Open Sources 27

17. PERSONAL PROTECTIVE 28

EQUIPMENT.. 28

18. MANAGEMENT OF RADIOACTIVE WASTE 29

18.1 Radioactive Waste Disposal...29

18.2 Gases, Aerosols and Dusts 30

18.3 Liquid Waste 30

18.4 Solid Waste...30

19. RADIATION EMERGENCY RESPONSE 32

19.1 Dealing with Source Incidents and Accidents 32

19.2 Radioisotope Decontamination/Spill Kit 32

19.3 Sealed Source Leaks..33

19.4 Spills...33

19.5 Personnel Decontamination 34

19.6 Accidents...35

20. RADIOISOTOPE THEFT OR LOSS 36

21. RECORD KEEPING AND DOCUMENTATION 36

21.1 Purchases..37

21.2 Contamination Control *37*
21.3 Usage *37*
21.4 Disposals *37*
21.5 Survey Meter Operability *37*
21.6 Annual Inventory *37*
21.7 Worker Training Records *37*
21.8 Nuclear Energy Worker (NEW) Notification Forms *37*
21.9 Sealed Source Leak Test Records *37*
21.10 Transfer of Nuclear Substances to Another License *38*

22. TRANSPORTATION OF RADIOACTIVE MATERIALS 38

22.1 Protocol for Shipping of Radioactive Materials *38*
22.2 Transport of Dangerous Goods Labelling *38*

REFERENCES 40

RADIATION EXPOSURE FOR WOMEN AT THE UNIVERSITY OF NORTHERN BRITISH COLUMBIA 41

WASTE PREPARATION PROCEDURES 41

FORMS 43

REGULATORY QUANTITIES FOR SELECTED RADIOISOTOPES *43*
CONTAMINATION CONTROL *44*
RADIOISOTOPE DATA *45*
RADIOISOTOPE DISPOSAL *46*
SURVEY METER CHECKS *47*
ANNUAL INVENTORY *48*

DEFINITIONS 49

1. INTRODUCTION

The purpose of this manual is to assist in preparing University of Northern British Columbia personnel and students to work safely with radioactive materials. The topic areas covered include an introduction to ionizing radiation, health effects and dosimetry, use of survey meters, principles of radiation protection, contamination monitoring, legal requirements, practical aspects of handling radioactive materials, waste disposal, emergency response measures and decontamination, record keeping and transportation.

The primary objective of the University of Northern British Columbia radiation safety program is to ensure the safe and knowledgeable use of radiation sources and devices in research, teaching and the environment.

2. HISTORICAL REVIEW

When the earth was formed, much of the constituent matter was radioactive. Over the millennia, this radioactivity has decayed until only those isotopes with extremely long half-lives (e.g. uranium-238; 4.47×10^9 y) 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 radiation of planetary origin and are bombarded with different types of radiation 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 makeup.

Although ionizing radiation has been present from the beginning of time, it was not until 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 exposure (e.g. erythema, skin burns, aplastic) 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 film. In 1898, the element polonium was isolated from tonnes of ore by Marie and Pierre Curie. Intensive research then followed, resulting in the isolation of the radioactive element radium and the discovery, and subsequent investigation of alpha particles.

The labs in which this research was performed were highly contaminated with radium, as up to one 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 cancer.

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 Radiation Protection (now known as the International Commission on Radiological Protection – ICRP) was constituted. Early efforts of the International Commission on Radiological Protection were concerned with establishing radiation units and making some interim protection recommendations. Today the organization 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 agency governing nuclear energy and material is the Canadian Nuclear Safety Commission (CNSC). This agency replaced the Atomic Energy Control Board (AECB) in May of 2000. Radiation-emitting devices, such as x-ray machines and microwave ovens, are regulated by Health Canada.

3. BOHR'S MODEL OF THE ATOM

In spite of years of intense theoretical and experimental work, no completely satisfactory model of the atomic structure has been developed. Many models have been proposed, each capable of explaining some, but not all, of the physical characteristics of the atomic nucleus. Even the most satisfactory 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 negative electrons revolving about the positively-charged nucleus as shown in Figure 1.

The nucleus is the central core of the atom and is primarily composed of two types of particles: the proton, which 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 approximately equal to 1/12th of the mass of a carbon-12 atom, or 1.67×10^{-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 1/1836th that of a proton. There are about 104 different elements, each of which is characterized by two related terms:

> A = *mass number*, which is equal to the sum of the number of protons and neutrons in a nucleus; and,

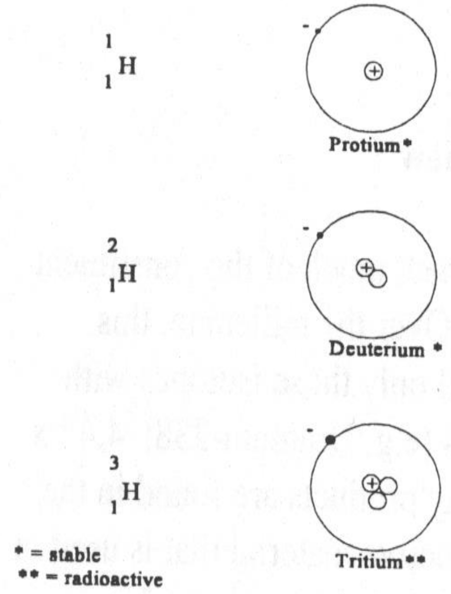


Figure 1. Isotopes of Hydrogen

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

If X represents the chemical symbol of an element, then

$$\text{Atomic Formula} = {}^A_Z X .$$

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.

The 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).

There are three or more isotopes for every element, at least one of which is radioactive, the others being either radioactive or stable. Some elements, such as uranium, have no stable isotopes.

4. RADIOACTIVITY

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

(1) the particular type of nuclear instability (too high or too low of a neutron-to-proton ratio in the parent nucleus); and
(2) the mass/energy relationships between the parent nucleus, progeny nucleus and the emitted particle.

4.1 Alpha Emission

An *alpha particle* (α) is a relatively 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 postively-charged helium nucleus, consisting of two protons and two neutrons,

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

For example,

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

as shown schematically in Figure 2.
Because of their size, 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. Consequently, 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 ingestion, inhalation or absorption (through broken or intact skin) suffer severe radiation effects and are likely to be permanently damaged. Hence, alpha radiation is an extreme internal radiation hazard.

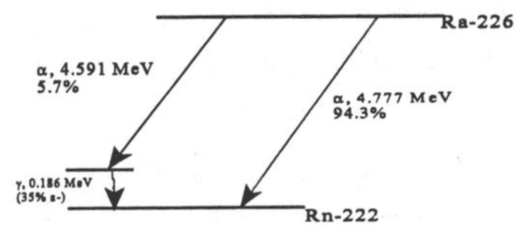


Figure 2. Decay scheme for radium 226

> 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.

4.2 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 atomic mass units). The beta particle is emitted at the instant a neutron undergoes transformation into a proton. Beta decay occurs among those isotopes that have a surplus of neutrons,

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

For example,

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

as shown in Figure 3 below.

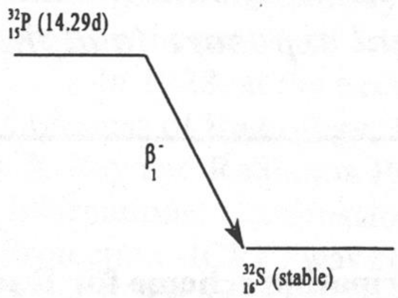


Figure 3. Decay scheme for phosphorus-32

The proton that is created remains in the nucleus, and 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) increases by one. During beta decay, a particle called an *antineutrino*, which has negligible mass and no electrical charge, is also emitted. Beta particles do not penetrate to the body core but can produce significant radiation damage to the cells of the skin and the lenses of the eyes.

Beta particles can damage the lenses of the eyes and produce significant skin doses.

4.3 Positron Emission

A *positron* (β^+) is similar to a beta particle, but possesses a single positive charge ($+1.6 \times 10^{-19}$ C). It has the same rest mass as a negative electron (0.00055 atomic mass units) and is emitted from nuclei in which the neutron-to-proton ratio is very low and alpha emission is not energetically possible,

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

For example,

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

as diagrammed in Figure 4.

During this process, a particle called the *neutrino* having negligible mass and no

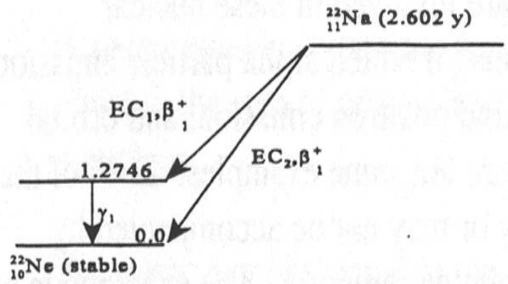


Figure 4. Decay scheme for sodium-22

electrical charge is also emitted. Positrons and antineutrinos are classified as *antimatter*, while beta particles (electrons) and neutrinos are classified as *matter*. Whereas negative electrons freely exist, 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 the gamma radiation.

Annihilation radiation requires lead shielding.

4.4 Orbital Electron Capture

Electron capture or "K capture" is a process whereby one of the K orbital 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 previously occupied by the electron that had been captured,

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

For example,

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

4.5 Gamma Rays

Mono-energetic electromagnetic radiations that are emitted from nuclei of excited atoms following radioactive transformations are called *gamma rays* (γ). In 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.

4.6 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 beta particle, 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-emitting 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. Plexiglas is therefore the shielding of choice.

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

4.7 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.

5. RADIOACTIVE DECAY

5.1 Physical Half-Life ($t_{1/2}$)

Early studies of radioactive materials showed that the radioactivity of each radioisotope decreases at its own characteristic rate. For example, when the radioactivity of phosphorus-32 is measured daily over a period of two months, and the relative amount of the initial radioactivity is plotted as a function of time, the curve shown in Figure 5 is obtained.

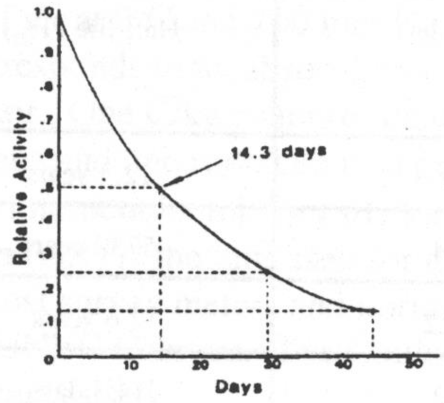


Figure 5. Decay of phosphorus-32

Experimental observation showed that one-half of the initial amount of phosphorus-32 was 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 one-half of the original radioactivity decays is called the *physical half-life* (PHL; $t_{1/2}$). The physical half-lives of some common radioisotopes are listed in Table 1.

When an atom decays, the atomic number (Z) is always altered by either decreasing or increasing the number of protons. Hence, an atom of a specific element can never decay to the same element, as was shown in Figures 2, 3 and 4. This may be of significance in research protocols as the daughter element may have significantly different chemical characteristics than those of the parent.

Given that the half-life of some isotopes is short, it is important to be able to determine the amount of radioactivity at any time. For example, one might need to know how much radioactivity has decayed after purchase but before use, how much will decay over the term of an experiment, or how much will decay if the radioisotope is stored for a period before waste disposal.

The precept, upon which the calculation of radioactivity at any time is based, is that at some observation time (t) there are a given number of atoms (N) of a given radioisotope. The law of constant fractional decay requires that over a short period of time (dt) the number of atoms that shall decay (dN) will be

$$dN = -\lambda N(dt),$$

where the constant of proportionality (λ) is called the *decay constant*. Integrating this equation gives the relationship between N and t,

$$N = N_o e^{-\lambda t}.$$

Given that

$$\lambda = 0.693 / t_{1/2},$$

it follows that

$$N = N_o e^{-0.693t / t_{1/2}},$$

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

Example: a researcher received a shipment of phosphorus-32 labelled adenosine 5'-triphosphate. The supplier's documentation indicated that on the shipping date of March 26 the amount of radioactivity was 555 MBq. The researcher, however, was unable to use the material until April 30. How much radioactivity was present on the day of the experiment?

Data: N_o = 555 MBq,
t = 35 d,
$t_{1/2}$ = 14.3 d.

Result: $N = 555\ MBq \times e^{-0.693 \times 35\,d / 14.3\,d}$,

$N = 102\ MBq.$

5.2 Biological and Effective Half-Lives

The above calculation utilized the physical half-life of the radioisotope in question. However, if one is studying a particular process within a living system, such as an animal, plant or cell line, the physical half-life is not the only determining factor in the clearance of the radio labelled compound. 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 times of both stable and radioactive isotopes of a particular element are the same.

The time required for radioactivity to be reduced to 50% 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 for interpreting experimental results of blood volume and tissue isotope concentration studies.

6. UNITS OF RADIATION

Uranium-238 and a daughter 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} years). Thorium-234, consequently, is decaying 6.8×10^{10} times faster than uranium-238.

When radioisotopes are used, the radiations are often the centre of interest. In this context, 1.5×10^{-7} grams of thorium-234 is about equivalent in radioactivity to one gram of uranium-238.

Obviously, when interest is centred on radioactivity, the mass of a substance is not a very useful quantity.

Table 1. Physical Half-Lives and Radiations Produced by Selected Radioisotopes.

Radioisotope	Physical Half-Life ($t_{1/2}$)	Emission Energy (MeV)		
		Beta (maximum)	Positron (maximum)	Gamma or X-rays
H-3	12.3 y	0.018		
C-14	5730 y	0.156		
Na-22	2.6 y		1.820	0.511; 1.275
P-32	14.3 d	1.710		
S-35	87.9 d	0.167		
Ca-45	165 d	0.252		0.0125
Cr-51[1]	27.8 d			0.320
Co-57[1]	270 d			0.014; 0.122; 0.136; 0.231; 0.340; 0.352; 0.367; 0.570; 0.692; 0.707
Co-60	5.2 y	1.488; 0.663; 0.315		1.17; 1.33; 2.16
Ni-63	92 y	0.067		
Zn-65	245 d		0.327	0.344; 0.771; 0.511; 1.115
Rb-86	18.6 d	1.780; 0.71		1.078
Tc-99m[2]	6 h			0.140
In-111[1]	2.81 d			0.173; 0.247
I-125[1]	60.2 d			0.035
I-131	8.05 d	0.806; 0.606; 0.487; 0.333; 0.257		0.080; 0.177; 0.272; 0.284; 0.318; 0.326; 0.364; 0.503; 0.637; 0.643; 0.723;

[1] Decays by electron capture.
[2] The ‘m’ indicates a meta-stable state, with delayed gamma-ray emission.
$^{99}_{42}Mo \rightarrow {}^{99m}_{43}Tc + \beta^-$; ${}^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc + \gamma$.

6.1 Units of Radioactivity

Under the International System of Units (SI), the *becquerel* (Bq) is defined as one nuclear transformation per second. Prior to the adoption of the SI units by the scientific community, the c*urie* (Ci) was the unit used to quantify radioactivity. Today, one finds that many commercial suppliers provide radionuclides in becquerel or curie quantities, or both, and thus familiarity with both systems is essential. Conversion between the units is as follows:

1 Ci = 3.7 x 10^{10} Bq

and

1 Bq = 2.7 x 10^{-11} Ci

Originally, the curie was defined as the activity of one gram of radium-226, but was later redefined as the activity of radioactive material in which the nuclei of 3.7×10^{10} atoms disintegrate per second (dps). Consequently, one curie is equal to 2.2×10^{12} disintegrations per minute (dpm).

One curie is a large amount of radioactivity; such a quantity would not typically be used for experimental work. Conversely, one becquerel is too little radioactivity for most experiments. Thus, fractions of curies and multiples of becquerels are commonly used. Conversion between the various units is as follows.

1 Bq	60 dpm 27 pCi	
1 kBq	6×10^4 dpm	27 nCi
1 MBq	6×10^7 dpm	27 μCi
1 GBq	6×10^{10} dpm	27 mCi
1 mCi	2.2×10^9 dpm	37 MBq
1 μCi	2.2×10^6 dpm	37 kBq
1 nCi	2.2×10^3 dpm	37 Bq
1 pCi	2.2 dpm	37 mBq

6.2 Units of Radiation Exposure

The *coulomb/kilogram* (C/kg) is the SI unit used to measure the radiation-induced ionizations created in a unit mass. The coulomb/kilogram unit is not widely used.

The *roentgen* (R) is the old unit of radiation exposure. It is defined as the quantity of radiation that produces ions carrying one statcoulomb of charge of either sign per cubic centimetre of air at a temperature of 0°C and 760 mm Hg pressure. One roentgen corresponds to an absorption of 87.7 ergs/g of air.

1 R = 2.58 x 10^{-4} C/kg
1 C/kg = 3876 R

The *milliroentgen* (mR) is the unit used for the display or readout of most survey meters and portable detection instruments on the University of Northern British Columbia campus.

6.3 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 1 J/kg.

1 Gy = 1 J/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 J/kg.

1 Gy = 100 rad

6.4 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 particles, gamma rays and x-rays, the modifying weighting factor (w_r) equals 1. The weighting factor for alpha particles is currently 20.

The sievert replaces the old *rem* (roentgen equivalent man), which was calculated as the numerical product of the absorbed dose (in rads) and the appropriate weighting factor.

1 Sv = 100 rem
1 mSv = 0.1 rem = 100 mrem
1 μSv = 0.1 mrem = 100 μrem

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 radiation, 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.

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 behavioural 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 rad) of mixed neutron and gamma radiation or 5 Gy (500 rad) 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 (200 rad); gastrointestinal syndrome results from a 10 Gy (1000 rad) or greater dose; central nervous system syndrome occurs at a dose of 20 Gy (2000 rad).

Deterministic 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 the magnitude or severity of the effect. 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; the greater the exposure, the greater is the probability 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.

Delayed effects of radiation may be due either to a single large overexposure or to continuing low-level exposures. Given the nature of work performed with radiation sources at the University of Northern British Columbia, 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 delayed effects will therefore deal with low-level long-term exposure.

Epidemiologic 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 may 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 number of excess cancer deaths from exposure to low-level radiation is estimated at 400 per million exposures of 10 mSv.

The Canadian Cancer Society estimates that about half of all cancers are fatal. Thus, the total estimated incidences of cancer would be double that given above – 800 per million exposures of 10 mSv.

Approximately 25% of all adults will develop cancer induced by environmental and genetic factors not associated with work-related radiation sources. Therefore, the increased risk of cancer to an individual exposed to 10 mSv of radiation would rise from 25% to approximately 25.08%.

About 10% of the population suffers from some form of genetic defect leading to a clinically detectable disease some time during their life. It is believed, from animal studies, that the risk may be increased if a person who has been occupationally irradiated subsequently conceives a child. A dose of 10 mSv is estimated to increase the risk to approximately 10.01%.

It is estimated that the risk of serious genetic defects, for all generations subsequent to the irradiation of either parent, is about 100 per million exposures of 10 mSv.

The maximum permissible occupational effective dose for University of Northern British Columbia faculty, staff and students is one millisievert per year (see Table 2)

The maximum permissible whole body (badge) effective dose for University of Northern British Columbia personnel is 1 mSv/y.

The maximum permissible dose to the hands or feet (ring) for University of Northern British Columbia personnel is 50 mSv/y.

Furthermore, the historical mean occupational effective dose for University of Northern British Columbia personnel who work with radioactive materials is <0.1 mSv/y. Thus, the risk of suffering long-term radiation effects from occupational exposure is low.

The estimates of cancer and genetic risks 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.

Current belief is that there is no threshold dose below which there is no risk. Thus a worker who decides to accept this risk, however minimal, should make every effort to keep exposure to radiation **ALARA**. Users of radiation sources have the primary responsibility for protecting themselves from the associated hazards.

Table 2. Maximum Permissible Occupational Doses of Ionizing Radiation[1].

Type of Dose	Members of the Public (incl. UNBC Personnell)	Nuclear Energy Workers
Effective Dose	1 mSv/y [2]	20 mSv/y [3]
Dose to the Lens of an Eye	15 mSv/y	50 mSv/y
Dose to the Skin	50 mSv/y [4]	500 mSv/y
Dose to the Hands and Feet	50 mSv/y	500 mSv/y

[1] During the control of an emergency and the consequent immediate and urgent remedial work, the doses specified in Table 2 may be exceeded, but the effective dose shall not exceed 500 mSv and the dose to the skin shall not exceed 5000 mSv. This exception does not apply to a pregnant nuclear energy worker who has informed her employer of her pregnancy. The dose limits specified in Table 2 and in this paragraph may be exceeded by a person who acts voluntarily to save or protect human life.

[2] Effective dose (mSv) is calculated (for this category of personnel) according to the following formula,

$$Effective\ Dose = E + \frac{[Rn]}{60} + 20\sum\frac{A}{ALI}.$$

In the above formula E (mSv) is the dose received from sources outside the body plus the dose from sources inside the body as measured directly or from excreta, [Rn] is the average concentration of radon-222 in air (Bq/m^3) attributable to a licenced activity, A is the activity of any radioisotope taken into the body (Bq) excluding radon progeny and radioisotopes accounted for in E, and ALI is the 'annual limit on intake' (Bq) for that radioisotope. (Note that an ingestion of one 'annual limit on intake' will result in an effective dose of 20 mSv, which is the maximum permissible dose for a nuclear energy worker, not the maximum permissible dose for UNBC personnel or members of the public.)

[3] Actually 100 mSv per 5 y, with a 1-y maximum of 50 mSv. A pregnant nuclear energy worker is limited to 4 mSv, for the balance of the pregnancy, after informing her employer of the pregnancy.

[4] If the skin of the body is unevenly irradiated, the dose to the skin is considered to be equal to the average received by the 1-cm^2 area that receives the highest dose.

8. RADIATION DOSIMETRY

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

8.1 External Personnel Monitoring

Thermoluminescence and optically stimulated luminescence dosimetry are common methods for accurate monitoring of personal external radiation exposure. When exposed to ionizing radiation, the lithium fluoride detector material contained within thermosluminescent dosimeters (TLDs) 'traps' the energy by shifting electrons to a meta-stable state. Similarly, the aluminium oxide (Al_2O_3) detector in an optically stimulated luminescent dosimeter (OSL) also 'traps' electrons in higher energy states. Radiation exposure is measured by stimulating the detector unit in a dosimeter with heat, in the case of TLDs, or a light source, in the case of OSLs. The light that is emitted from the material is proportional to the amount of exposure.

Thermoluminescent dosimeters are excellent for measuring radiation doses from x-rays, gamma and beta radiation.

Chest badge dosimeters are used to determine whole body radiation dose while ring dosimeters are used to determine extremity dose.

Optically stimulated luminescent dosimeters can measure high- and low-energy photons (x-ray and gamma radiation; 5 keV to 40 MeV) and beta particles (150 keV to 10 MeV).

Any individual working with more than 50 MBq of phosphorus-32, strontium-89, yttrium-90, samarium-153 or rhenium-186 is required to wear a finger 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.

Generally, the badges are changed on a quarterly basis and the results are forwarded to the Radiation Safety Officer for review. All personal exposure data is maintained in the National Dose Registry in Ottawa.

Pocket ionization chambers (PICs) are used in high radiation areas where an immediate estimate of the dose is required after short exposure times. These may be of direct-reading type or with preset alarm signals and are worn in addition to the thermoluminescent dosimeter badge. Under specific circumstances, they can be obtained by the Radiation Safety Officer.

8.2 Internal Personnel Monitoring

Internal doses are more difficult to accurately assess than external doses. In many cases, direct measurement of the amount and distribution of the radioisotope is not possible, especially if the isotope ingested is a beta emitter. In the case of beta emitters (e.g. hydrogen-3, carbon-14, phosphorus-32, sulphur-35, and calcium-45), calculations of internal dose are based on the amounts of these isotopes that may be found in breath or urine, or both.

When working with volatile radioiodines and tritiated compounds, routine bioassays may be required on a specific schedule developed by the Canadian Nuclear Safety Commission. The radioisotopes iodine-125 and iodine-131 concentrate in the thyroid gland and can be quantified using a calibrated sodium iodide crystal monitor. Thus, routine direct thyroid monitoring may be required when working with radioiodine.

Bioassay or thyroid monitoring programs, or both, must be discussed and arranged between the Radiation Safety Officer and the user prior to ordering of and working with radioiodine or tritium compounds. If, through proposed work procedures, the annual committed effective dose is expected to exceed 1 mSv routine bioassays will be required.

Individuals working with radioiodine or tritium may be required to undergo bioassay or thyroid monitoring, or both if expected committed effective dose is greater than 1 mSv/year.

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

8.3 Exceeding Dose Limits

If the University becomes aware that an authorized user exceeds the occupational dose limits (as outline in Table 2) the University will:

1. Immediately notify the authorized user and the CNSC
2. Require the authorized user to immediately cease work activities using radioactive materials
3. Conduct an investigation to determine the magnitude of the dose and to establish the causes of exposure
4. Identify and take any action to prevent the occurrence of such an incident
5. File a full report to the CNSC with the results of the investigation within 21 days of becoming aware of exceeding the dose limit

9. LABORATORY RADIATION SURVEILLANCE

In each area where radioisotopes are handled or radiation hazards exist, 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.

9.1 Geiger-Mueller Tube

The most common alpha, beta and gamma radiation detector is the Geiger-Mueller (G-M) tube, and it is particularly suitable for radiation protection surveys. A Geiger-Mueller counter is a closed hollow tube containing a gas mixture (helium, neon or argon) 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 centre of the barrel insulated from the tube inner wall, 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 a signal of about one volt in a typical Geiger-Mueller circuit, 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 Geiger-Mueller 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 alpha or beta particles that enter the detector will produce a discharge and register as a count on the meter. However, only a small fraction of the gamma or x-ray photons incident upon the counter will interact with an atom of the gas and produce ionizations in the chamber. Most of these photons will pass through without any interaction and will not be recorded; thus, Geiger-Mueller counters are much more proficient in detecting high-energy beta particles than in counting gamma rays or x-rays.

Depending on the energy of the emitted ray, the detection efficiency of a Geiger-Mueller counter may be as low as 1% for x-rays and gamma rays. Counting efficiencies tend to 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 mm of aluminum) is placed in front of the

Geiger-Mueller tube window, it will stop many of 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 Geiger-Mueller tube is solely an ionization event counter, and its output signal cannot be used to provide information on the energy or type of emission nor the identity of the isotope in question.

9.2 Solid Scintillation Detectors

Gas-filled Geiger-Mueller tubes do not detect gamma and x-rays efficiently because most of the photons pass through the gas without interaction. The probability of x-ray and gamma ray detection is increased if a solid detector is used; however, an interaction cannot be registered by collecting electrons and positive ions, as with Geiger-Mueller tubes. Instead, a solid scintillation crystal is used 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. However, sodium iodide crystals are highly hygroscopic and degrade when exposed to moisture. Free iodine is released, which decreases the counting efficiency of the system by absorbing much of the radiation-induced fluorescence.

A low-energy gamma scintillator (LEGS) is an example of this detector type and is used primarily to detect contamination with iodine-125 or other radioisotopes that emit low-energy gamma rays or x-rays. Unlike Geiger-Mueller tubes, LEGS detectors connected to Ludlum survey meters are not calibrated to a standard source and thus any meter reading is inaccurate. They are, however, extremely useful for quickly identifying sites of gamma-isotope contamination.

Most Ludlum survey meter – low-energy gamma scintillator detector combinations are not appropriate for quantifying personal dose rates or the dose rates on waste packages.

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

9.3 Liquid Scintillation Counters

A very sensitive detection system, widely used in research, which can be used to detect minute quantities of almost any alpha-, beta- or gamma-emitting isotope is the liquid scintillation counter (LSC). An instrument of this type is used for counting radio labelled experimental samples and wipe tests of potentially contaminated surfaces.

The liquid scintillation counter is commonly used to quantify hydrogen-3, carbon-14, phosphorus-32 and sulphur-35 samples.

In liquid scintillation counting, instead of utilizing a solid crystal as the primary fluorescence initiator, a scintillating solution (cocktail) which consists of a solvent and one or more chemical fluors, is used. The radioactive source or sample is then added to this liquid and the resultant photons are collected, multiplied and counted.

10. RADIATION PROTECTION PRINCIPLES: SEALED SOURCES

Sealed sources are radioactive materials that are encapsulated or encased in such a way that they are extremely unlikely to be absorbed into the body, and are therefore primarily an external radiation hazard.

Four basic principles ensure that the exposure to radiation is minimized. They are quantity, time, distance and shielding.

Sealed sources are primarily an external radiation hazard.

10.1 Quantity

It is necessary to justify the amount of radioactive material to be used in an experiment. To minimize radiation exposure to laboratory personnel, the quantity of radioactive material should be the minimum that is necessary to successfully conduct an experiment. The radiation dose received during an experiment must never exceed the amount listed in Table 2.

It is possible to calculate the theoretical radiation doses from gamma radiation sources. The calculation 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 common isotopes.

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

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

where

E = dose from an external gamma source (mSv);
Γ = specific gamma ray constant ((mSv·cm²)/(h·MBq));
A = radioactivity of source (MBq);
t = time spent in vicinity of the source (h); and,
d = distance from the source (cm).

Example: What is the gamma radiation dose a graduate student receives when working with 185 MBq of sodium-22 for 2 h every day for 22 days (i.e. a working month) at a distance of 35 cm from the source without using shielding?

Table 3. Specific Gamma Ray Constants ((mSv·cm²)/(h·MBq))

Radioisotope	Γ	Radioisotope	Γ	Radioisotope	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
Cobalt-57	0.29	Manganese-54	1.27	Zinc-65	0.73

Data: Γ = 3.24 (mSv·cm²)/(h·MBq),
A = 185 MBq,
t = 44 h,
d = 35 cm.

Result:

$$E = \frac{3.24\ (mSv \cdot cm^2)/(h \cdot MBq) \times 185\ MBq \times 44\ h}{(35\ cm)^2},$$

$$E = 22\ mSv \quad (an\ unacceptable\ dose).$$

For the calculation of dose from beta-emitting radioisotopes, the theoretical equation is

$$E = 0.8\, mGy/(MBq \cdot h) \times A \times t,$$

where

E = dose from an external beta source at a distance of 10 cm (mGy);
A = radioactivity of source (MBq); and,
t = time spent at a distance of 10 cm from the source (h).

Both the equation for the calculation of the theoretical gamma dose and for the determination of the beta dose include a term for the amount of radioactivity. These equations quantify the intuitive belief that reducing the quantity of radioactive material being used will lessen the radiation exposure.

The amount of radioisotope used should be the minimum quantity that is necessary to conduct the experiment.

10.2 Time

The radiation dose that an individual receives is directly proportional to the length of time spent in a radiation field. This is demonstrated by the following equation,

$$E = It,$$

where E is the dose, I the dose rate and t the time spent in the radiation field. Therefore, to minimize radiation doses, it is necessary to ensure minimum working times when handling radioactive sources.

To minimize working times, 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.

Minimize exposure by minimizing time spent in radiation field.

10.3 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. For point emission sources, the actual relationship follows the inverse square law. If I_1 and I_2 are the dose rates at distances d_1 and d_2 from a point source, the inverse square law states that

$$\frac{I_1}{I_2} = \frac{(d_2)^2}{(d_1)^2};$$

therefore,

$$I_2 = \frac{I_1\,(d_1)^2}{(d_2)^2}.$$

Example: The intensity of the radiation at 2.0 m from a point source is 13 μSv/h (1.3 mR/h) measured with a Geiger-Mueller detector. What is the radiation field at 50 cm?

Data: I_1 = 13 μSv/h,
d_1 = 200 cm,
d_2 = 50 cm.

Result:

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

$$I_2 = 210\ \mu Sv/h.$$

The effect of distance on radiation dose rate is further illustrated in Figure 6, which expands on the example given above. As the distance from the source gets larger, the dose rate gets progressively lower.

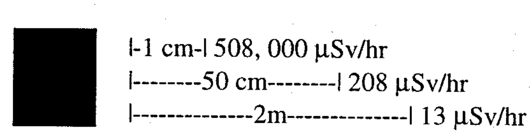


Figure 6. Effect of distance on radiation dose rate.

To increase the distance from radioactive sources, it is best to perform work with radioisotopes in a separate part of the lab (or a different lab) from that used for non-radioactive experimental work and deskwork. Radioactive materials with high dose rates should be stored in areas that are normally unoccupied. To minimize radiation exposure to the hands, forceps and tongs can be used to handle radioactive sources.

Maximize the distance from radioactive materials.

10.4 Shielding

If an individual spends a working year (2000 h) in an area with a dose rate of 0.5 μSv/h (0.05 mR/h), that person would receive a dose of 1 mSv, which is the maximum allowable dose for University of Northern British Columbia personnel.

Exposure at a dose rate of 0.5 μSv/h (0.05 mR/h) for a working year will result in an individual receiving the maximum permissible dose of ionizing radiation.

To avoid exceeding the Canadian Nuclear Safety Commission limit, and to keep exposures **ALARA**, the use of shielding is often prudent. Depending on the type and energy of radiation, different shielding materials are recommended.

Tritium (hydrogen-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-mm-thick Plexiglas, Lucite, or glass shielding is recommended.

Phosphorus-32 is a high-energy beta emitter (1.71 MeV), and consequently most operations require shielding. Thick Plexiglas (1.2 cm) is the material of choice. As described in Section 4.6, lead is not recommended due to the generation of bremsstrahlung. The energy of these secondary x-rays increases with increasing atomic number of the target and the energy of the beta particle. For this reason, when shielding energetic beta emitters, a material such as regular or glass is preferred over lead and steel to minimize x-ray exposure.

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

Sodium-22, chromium-51, cobalt-57, cobalt-60, zinc-65, rubidium-86, technetium-99m, indium-111 and iodine-131 emit gamma radiation (and particle radiation in some cases), 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. For gamma emitters, it is important to measure the dose rate in all directions, and shield appropriately, as the fume hood or building walls may not provide adequate shielding to other areas of the lab or other rooms.

The thickness of any given material 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 its initial value, it is called a *tenth-value layer*. This information is used to calculate theoretical radiation fields. See Table 4 for suggestions as to the type and thickness of shielding appropriate for various radioisotopes.

Use appropriate shielding. Lead is not always best.

Table 4. Shielding Materials for Radioactive Sources.

Radioisotope	Minimum Shielding[1]
Hydrogen-3	None required. Stock vial or any container absorbs all radiation.
Carbon-14	None required for activity up to 370 MBq. Then 3-mm-thick Plexiglas.
Sodium-22	10 cm of lead bricks.
Phosphorus-32	1.2 cm of Plexiglas.
Sulphur-35	None required for activity up to 370 MBq. Then 3-mm-thick Plexiglas.
Calcium-45	None required for activity up to 370 MBq. Then 3-mm-thick Plexiglas.
Chromium-51	2.0 cm of lead.
Cobalt-57	1.7 mm of lead.
Cobalt-60	10.0 cm of lead bricks.
Nickel-63	None required. Electron capture detector housing is adequate.
Zinc-65	10 cm of lead bricks.
Rubidium-86	10 cm of lead bricks.
Technetium-99m	1.2 cm of lead.
Indium-111	2.5 cm of lead.
Iodine-125	1 mm of lead.
Iodine-131	6.0 cm of lead bricks.

[1] Commercially available shielding material. The minimum shielding is calculated as 10 half-value layers

11. RADIATION PROTECTION PRINCIPLES: OPEN SOURCES

Open sources are radioactive materials, in the form of a gas, liquid or solid, that are not in a sealed container. The four principles given in Section 10 (quantity, time, distance and shielding) also apply to work with open sources. To reiterate, the quantity of radioactive material used and the time spent in the vicinity of the source should both be minimized. If possible, the distance between radioisotopes and people should be increased. Lastly, shielding should be used to reduce dose rates.

The greatest concern with open sources is the possibility of internal contamination.

Radioactive contamination is the presence of radioactive material any place where it is not desirable; in particular, where its presence may be harmful.

Open source radioactive material, particularly if its presence is not recognized, can enter the body resulting in *internal contamination*. This material can be inhaled, ingested, absorbed through skin or absorbed through wounds.

> Internal contamination is usually the greatest concern when working with open-source radioactive materials. Radioactive material can enter the body by inhalation, ingestion, absorption through skin or through wounds.

11.1 Reasons for Concern Regarding Internal Contamination

Internal contamination is a serious concern, for a number of reasons, some of which are listed below.

(1) All of the emitted radiation travels through the body and is capable of producing a dose.
(2) Internal alpha particles deposit dose to living tissue.
(3) The exposure continues until the radioisotope is eliminated by decay or excretion. In some cases, this is a very long time.

(4) Certain radioisotopes concentrate in selected tissues or organs. This can result in a high dose to the tissue or organ.

(5) It is difficult to accurately assess the intake and calculate the dose

11.2 Types of Contamination

Radioactive contamination may be located on surfaces or may be airborne. Surface contamination may be loose or fixed. Loose contamination is radioactive dust or liquid that is removed by wiping. Loose contamination easily enters the body, and is therefore a source of internal contamination. Fixed contamination is not easily removed from surfaces, and therefore only contributes to external dose. However, fixed contamination may become loose if the surface is cut, sanded, heated, etc. Therefore, fixed contamination is not tolerated.

Airborne contamination may be particulate, liquid (aerosol) or gas. Loose particulate surface contamination may become airborne if disturbed. Work with dry radioactive powders is very likely to produce suspended particulate and therefore must be done in a fume hood. The same guideline applies to any process that may generate aerosols (suspended microscopic droplets of liquid). Radioactive gases such as tritium gas ($^3H_2$) must be handled in a fume hood. Similarly, volatile materials such as tritium oxide (^3H_2O) or volatile radioiodines can generate radioactive gases and must be handled in a fume hood.

12. CONTAMINATION MONITORING

Following the use of radioisotopes, monitoring of all work surfaces that may have become contaminated during the handling of the material is mandatory. This is essential to minimize the risk of internal contamination. Similarly, all personnel must monitor themselves (hands, feet and clothes) when leaving intermediate-level radioisotope laboratories. It is strongly recommended that personnel leaving low-level radioisotope laboratories check themselves for contamination. The methods used to check for radioactive contamination are described in the next section.

> Good housekeeping is one method to reduce the likelihood of internal contamination.

> Monitoring of work surfaces for loose radioactive contamination is compulsory following any use of radioactive material.

> Personnel must monitor themselves when leaving intermediate-level laboratories, and it is strongly recommended for personnel leaving all radioisotope laboratories.

The Canadian Nuclear Safety Commission requires that the level of loose radioactive contamination on all working surfaces in radioisotope laboratories with limited access not exceed the values given in the column titled 'Contamination in Controlled Area (Bq/cm^2)' in Table 5. In all publicly-accessible areas, the level of radioactive contamination shall not exceed the values given in the column titled 'Contamination in Public Area (Bq/cm^2)' in Table 5. The contamination level may be averaged over an area not exceeding 100 cm^2.

Table 5. Regulatory Contamination Quantities for Selected Radioisotopes

Radioisotope	Contamination in Controlled Area (Bq/cm^2)	Contamination in Public Area (Bq/cm^2)	Garbage (MBq/kg)	Sewer (MBq/y)	Air (kBq/m^3)
Br-82	30	3			
C-14	300	30	3.7	10000	
Co-57	300	30	0.37	1000	

Co-58	30	3	0.37	100	
Co-60	3	0.3	0.01		
Cr-51	300	30	3.7	100	
F-18	30	3	0.01		
Fe-59	30	3	0.01	1	
Ga-67	30	3	0.037	100	
H-3	300	30	37	1000000	37
I-123	300	30	3.7	1000	3
I-125	300	30	0.037	100	0.03
I-131	30	3	0.037	10	0.175
In-111	30	3	0.037	100	
Na-22	3	0.3	0.01	0.1	
P-32	300	30	0.37	1	
P-33	300	30	1	10	
Ra-226	3	0.3	0.01	1	
S-35	300	30	0.37	1000	
Sb-124	3	0.3	0.37		
Sr-85	30	3	0.37	10	0.175
Tc-99m	300	30	3.7	1000	
Tl-201	300	30	0.037	100	
Xe-133	300	30	1		3.7

12.1 Wipe-Test Method

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 radioisotopes. It is good practice to also include surfaces and equipment not normally involved in radioisotope use as part of the laboratory wipe-test program.

Contamination by a radioisotope at the levels set by the Canadian Nuclear Safety Commission is often 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. It is recommended that ethanol-wetted wipe paper be sealed in a vial with scintillation cocktail and shaken well.

For a surface to be considered free of contamination, the amount of radioactivity in the vial containing the filter paper should be no more (within statistical uncertainty) than that in a blank vial. However, assuming a wipe area of 100 cm^2 and a wipe efficiency of 10%, the surface is considered to be free of contamination according to the Canadian Nuclear Safety Commission definition if

$$A \leq WTL \times 100\ cm^2 \times 0.1,$$

where A is the excess radioactivity in the sample vial compared with the blank vial (Bq) and WTL is the wipe-test limit (Bq/cm^2) specified ‘’r the radioisotope of concern. If the liquid scintillation counter is not calibrated for the radioisotope being used, an additional factor is required in the above equation to compensate for the counting efficiency of the instrument.

If a surface is found to have radioactive contamination, it should be cleaned and the wipe test repeated, until the contamination criterion is satisfied. Records of the numerical results of all wipe tests must be maintained.

If the results of a wipe test indicate that the amount of loose contamination is more than permitted, the surface must be decontaminated and re-tested.

12.2 Direct-Reading Method

To supplement wipe testing, portable detectors or survey meters may be used to detect high-energy beta particles, x-rays and gamma radiation. The meter should be set on fast response to detect contamination; the slow response setting should only be used to quantify the contamination after it has been detected.

To scan for contamination, the detector is held approximately 1 cm above the surface to be monitored. To allow sufficient response time, the detector is moved at a rate of about 2.5 cm/s over the area in a paint brush-like fashion.

Some instruments have a shield which is used to distinguish between beta and gamma contamination. The shield should be open or removed and the instrument set on the most sensitive range that is practicable. Note that direct monitoring is the only method that will detect fixed radioactive contamination on surfaces.

The direct reading method is also used for personnel monitoring. The paintbrush technique is used to monitor hands, feet and clothes. Again, the detector should be held about 1 cm from the surface to be monitored and moved at a rate of about 2.5 cm/s.

12.3 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 contamination. Conversely, due to the poor counting efficiency of Geiger-Mueller survey meters for low-energy gamma and x-ray emitters, direct monitoring may result in the underestimation of the amount of radioactive contamination.

13. RADIOISOTOPE LICENCES

The University of Northern British Columbia has been issued licences by the Canadian Nuclear Safety Commission, a federal regulatory agency. Under these licences, individual faculty members are issued Internal Radioisotope Permits that allow radioactive materials to be used for specific purposes in defined locations.

A condition of licensing is that only faculty members are issued Internal Radioisotope Permits and that they, as well as their research personnel, successfully complete the University of Northern British Columbia Radioisotope Safety and Methodology Course, unless otherwise exempted from the course by the Committee on Radioisotopes and Radiation Hazards.

The conditions of the Internal Radioisotope Permits and any licence amendments are in keeping with the legal requirements as defined in the Nuclear Safety and Control Act and pursuant regulations. Breech of the conditions is a criminal offence.

13.1 Types of Internal Radioisotope Permits

13.1.1 Sealed source permits. Sealed sources are radioactive materials that are encapsulated or encased in such a way that they are extremely unlikely to be absorbed into the body, and are therefore primarily an external radiation hazard. Each source (calibration sources, moisture density gauges, electron capture chromatographs, x-ray fluorescence equipment, etc.) must be listed individually on an Internal Radioisotope Permit.

13.1.2 Open source permits. Open sources are radioactive materials, in the form of a gas, liquid or solid, that are not encased. An open source can be absorbed (through intact skin or wounds), ingested or inhaled into the body presenting both an internal and an external radiation hazard.

13.2 Obtaining a University of Northern British Columbia Internal Radioisotope Permit

Any faculty member wishing to use radioactive material in research conducted under his or her grant must obtain an Internal Radioisotope Permit. Research involving radioisotopes may not be conducted under the umbrella of a fellow researcher's permit. The applicant must be a University of Northern British Columbia faculty member and have successfully completed the University of Northern British Columbia Radioisotope Safety and Methodology Course, unless otherwise exempted from the course by the Committee on Radioisotopes and Radiation Hazards.

Applications for Internal Radioisotope Permits are obtained from the Radiation Safety Officer (Room 1097, Administration Building). The form requires a signature of approval from the relevant Department Head. The completed form is submitted to the Radiation Safety Officer and is reviewed by the University of Northern British Columbia Committee on Radioisotopes and Radiation Hazards. The processing of the documents takes several weeks.

A requirement for obtaining an Internal Radioisotope Permit is that the applicant has a training session with Sheila Keith, Purchasing Agent, University of Northern British Columbia (or designate) dealing with using the Radioisotope Requisition Form. Internal Radioisotope Permits will not be issued until Sheila Keith (or designate) has verified that the above training session has occurred.

13.3 Amending a University of Northern British Columbia Internal Radioisotope Permit

A modification of any of the conditions of a University of Northern British Columbia Internal Radioisotope Permit must be approved through the Committee on Radioisotopes and Radiation Hazards. Application must be made in writing indicating the specific permit changes that are being requested. The permit must be amended prior to any changes being instigated by the permit holder.

13.4 Renewal of a University of Northern British Columbia Internal Radioisotope Permit

Each Internal Radioisotope Permit will have an expiry date. The Radiation Safety Officer will initiate procedures for permit renewal approximately one month before this date, by mailing out a permit renewal application. The application is to be completed and returned to the Radiation Safety Officer by the date specified.

13.5 Protocol for Internal Radioisotope Permit De-activation and Laboratory Decommissioning

For an Internal Radioisotope Permit to be de-activated, and the associated laboratory decommissioned, the following are required from the permit holder*:

(1) memo stating intent to discontinue the Internal Radioisotope Permit;
(2) complete set of wipe tests for all laboratories licensed for radioisotope use;
(3) a record of proper disposal of all radioisotopes on hand (this can include a gift of remaining radioisotope to another researcher who is licensed for that radioisotope)
(4) completion of an annual radioisotope inventory;
(5) if the researcher is leaving the University of Northern British Columbia, or does not intend to reactivate the licence at some future date, all radioisotope purchase, usage and disposal records and all contamination control records must be forwarded to the Radiation Safety Officer.

*Note: the Internal Radioisotope Permit holder is responsible for ensuring that the steps are followed. Failing this, it becomes the responsibility of the permit holder's Department Chair.

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

13.6 Internal Radioisotope Permit Re-Activation

If a researcher wishes to use radioisotopes again, they need simply to reapply for a permit by requesting a permit renewal application from the Radiation Safety Officer.

13.7 Approved Personnel

Approved personnel are individuals listed on an Internal Radioisotope Permit that are approved to work with radioisotopes and have successfully completed the University of Northern British Columbia Radioisotope Safety and Methodology Course, or have been exempted from the course by the University of Northern British Columbia Committee on Radioisotopes and Radiation Hazards.

There are two categories of individuals, as defined by the Canadian Nuclear Safety Commission, with different maximum allowable radiation exposures (see Table 2). Approved personnel are considered members of the public unless they have been officially notified by the Radiation Safety Officer of their status as Nuclear Energy Workers. Personnel which may be reasonably expected to receive a radiation exposure greater than 1 mSv will be classified as a Nuclear Energy Worker and will be required to provide specific information under the Canadian Nuclear Safety Commission Act by completing the Nuclear Energy Worker Form.

> Unless notified in writing of their classification as a Nuclear Energy Worker, all University of Northern British Columbia personnel are considered members of the public with respect to the maximum permissible occupational dose of ionizing radiation.

13.8 Non-Compliance

> Strict adherence to the conditions of each and every Internal Radioisotope Permit is critical. Failure to comply could result in cancellation of individual permits.

13.9 Posting and Labelling

A copy of the Internal Radioisotope Permit is to be posted in a prominent place in each location listed on the permit as approved for manipulation and storage of radioisotopes.

All laboratories using open source radioisotopes are to post one of the Canadian Nuclear Safety Commission radioisotope safety posters: ‘Basic Laboratories’ or ‘Intermediate Laboratories’ These posters are available from the Radiation Safety Officer.

Laboratories and storage rooms containing radioisotopes in excess of 100 exemption quantities are to be marked on the entrance door to indicate the presence of radioactive materials. The name of the permit holder and a telephone number in case of an emergency must also be posted.

14. THE ACQUISITION OF RADIOISOTOPES AND DEVICES CONTAINING RADIOISOTOPES

14.1 Ordering Radioactive Materials

Only holders of current University of Northern British Columbia Internal Radioisotope Permits are allowed to procure radioactive materials. The permit clearly indicates which radioisotopes may be purchased, how much radioisotope may be purchased and how much radioisotope may be stored at any given time. It also details the permissible uses of the licensed material.

To order radioactive materials, the permit holder must complete an online request using the University of Northern British Columbia’s Web-Requisition (WebReq) system and submit the request to the Radiation Safety Officer for approval. WebReq training is available for new personnel through the Purchasing, Contract & Risk Management Department.

The Radiation Safety Officer will either contact the permit holder for more information or forward the approved request to the Purchasing Office.

In addition to the fields on the WebReq form, each request should include the following information:

– A current inventory of each radioisotope. The sum of the current inventories plus requests for purchases must not exceed the possession limits of the Internal Radioisotope Permit.

– The Internal Radioisotope Permit number.
– The name of the radioisotope and the quantity of radioactivity ordered, as well as pertinent shipping information, should be written on the form.

A WebReq may also used for standing orders (see Section 14.4 – Instructions Regarding the Use of the Web-Requisition System for Radioisotope Orders).

14.2 Transfer of Radioisotopes To or From the University of Northern British Columbia

The transfer of radioactive materials to or from the University of Northern British Columbia must be coordinated through the Radiation Safety Officer. Radioactive materials must be transferred from one appropriately licensed facility to another, and surface or air transport regulations must be adhered to. Documentation, labelling and placarding may be required.

Table 6. Example of a completed WebReq commodity field.

Item	Commodity Description[1]	Qty/Unit	Unit $	Amount
1	Adenosine-5'-triphosphate, gamma P-32 Catalogue Number: 01-35001X.2 Activity/Unit: 250 μCi[2]	1 EA	$50.00	$50.00

[1] Commodity description should be entered in the format NOUN, CATALOGUE NUMBER, ADDITIONAL INFORMATION.
[2] Activity/unit is to be indicated in kBq, MBq, μCi or mCi (use the units from the catalogue).

Canadian postal regulations prohibit the use of the postal service for the transfer of radioactive material.

14.3 Transfers Within the University of Northern British Columbia

Transfers of radioisotopes from one Internal Radioisotope Permit holder's control to another must not exceed the recipient's possession limit. Inventory records must indicate if material has been transferred along with the other permit involved. The Radiation Safety Officer must be informed of the transfer in writing before the transfer occurs.

14.4 Instructions Regarding the Use of the Web-Requisition System for Radioisotope Orders

The following instructions referring to the handling of radioisotope requisitions must be observed by all Internal Radioisotope Permit holders. Radioisotopes requisitioned are to be shipped to the user at the University of Northern British Columbia.

(1) Suggested suppliers and estimated costs only may be shown on requisitions. An example is given in Table 6.
(2) Particulars of radioisotopes required should completed in sufficient detail to enable the Purchasing Agent and

Radiation Safety Officer to identify them.

(3) All order requisitions must indicate the current inventory of the requisitioned radioisotope in MBq. The sum of the current inventory plus the quantity ordered must not exceed the possession limit on the Internal Radioisotope Permit for that radioisotope.

(4) Send the WebReq to the Radiation Safety Officer for approval. The Radiation Safety Officer will forward the WebReq to the Purchasing Office.

(5) Standing orders are also to be set up using WebReq and sent to the Radiation Safety Officer for approval.

Payment will not be authorized by the Purchasing Department for items ordered without their knowledge, and without corresponding approval by the Radiation Safety Officer.

15. RECEIPT OF RADIOACTIVE SOURCES

It is the policy of the University of Northern British Columbia that radioactive goods shall be received and inspected by the Radiation Safety Officer or Assistant Radiation Safety Officer and then released directly to the user. A list of other authorized personnel is kept at Shipping & Receiving for when these personnel areare unavailable. Radioactive packages should be received at the laboratory loading dock.

When an order for radioactive material is placed, the Purchasing Office will indicate that the shipment should be delivered to the Lab Receiving Dock. The courier driver must check in with Main Receiving so that Distribution Services staff can contact the Radiation Safety Officer or Assistant Radiation Safety Officer to receive the shipment.

It is necessary to monitor radioactive packages as the shipping boxes can become contaminated internally or externally, or both. Contamination could be 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. The following guidelines are recommended.

(1) Assume that the package may be contaminated until it is proven otherwise. Wear a lab coat and disposable gloves while processing the package. Wear eye protection if the package contains phosphorus-32 or iodine-125.

(2) Place the package in a fume hood within a licensed laboratory.

(3) Check the package to confirm it is properly addressed. Fill out a Receipt of Radioactive Package form.

(4) Wipe test the exterior of the package for contamination. Remove the packing slip and open the outer package.

(5) Inspect the contents for possible damage as indicated by broken seals or discolouration of the packing materials.

(6) Verify that the contents of the package agree with the packing slip. Check that the type of radioisotope, amount of radioactivity and chemical form are what was ordered. Record the pertinent information on a Radioisotope Data form.

(7) Measure the radiation field of the inner container and shield, as required.

(8) Wipe test the inner container.

(9) Remove or deface the radiation symbol on the shipping carton. If the shipping carton is found to be free of contamination, dispose as regular non-radioactive waste.

(10) Notify the Internal Radioisotope Permit holder of any irregularities.

(11) Forward the radioisotope and the Radioisotope Data form to the Internal Radioisotope Permit holder.

16. RADIATION PROTECTION: PRACTICAL ASPECTS

16.1 Justification and Optimization

Prior to commencing a project, it is important to justify the use of radioactive materials. Next, the procedure must be optimized to ensure the most efficient use of radioisotopes.

16.2 Locations

Radioactive materials may only be used in locations specified in an Internal Radioisotope Permit. The total quantity of each radioisotope shall not exceed the possession limits indicated on the permit.

Areas within large multi-purpose laboratories where radioisotopes are used should be clearly indicated. 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 limit the dose rate in all directions from the source.

Any laboratory where radiation fields are in excess of 25 μSv/h, or where more than 100 exemption quantities are stored, shall be posted as a radiation area.

Radioisotope laboratories must be locked when not in use, and radioisotopes must be in a secure storage area within each laboratory.

Dose rates at occupied areas outside storage areas must not exceed 2.5 μSv/hr.

16.3 Eating, Drinking and Smoking

The wording "in this laboratory" on the Canadian Nuclear Safety Commission Radioisotope Safety posters is interpreted as meaning the whole laboratory; consequently no eating, drinking, smoking or storage of food is allowed anywhere in such a laboratory. The intent of this limitation is to minimize the possibility of internal contamination of personnel.

Eating, drinking, smoking and storage of food are prohibited in any laboratory where radioactive materials are handled.

16.4 Refrigerators

If indicated by the manufacturer, store radioisotopes in a refrigerator clearly labelled with a radiation symbol (trefoil). On a routine basis, the refrigerator should be defrosted, cleaned and wipe tested. Ensure that all radioactive samples are labelled with the name of the user, the date, the name of the radioisotope and the amount of radioactivity.

Food or beverages must not be stored in laboratory refrigerators.

16.5 Sealed Sources

16.5.1 General precautions for sealed-source users. Sealed sources are radioactive materials that are encapsulated or encased in such a way that they are extremely unlikely to be absorbed into the body, and they are therefore primarily an external radiation hazard. Prior to beginning work with sealed sources, or devices containing sealed sources, it is important to be familiar with the specific hazards of the radioactive material present.

Following are some suggestions specific to working with sealed sources.

(1) * Pre-plan procedures to minimize the time spent in close proximity to the radioactive material to reduce the time of exposure.
(2) * Utilize procedures that maximize the distance between people and the source.
(3) Follow the manufacturer's directions for storage, leak testing and manipulation of the source. Additional shielding may be required.

*Does not apply to gas chromatographs equipped with electron capture detectors.

16.5.2 Leak-testing schedule and procedures. Except for sealed sources <50 MBq, leak tests shall be performed at least once every six months (whether or not the source is in use) and after any incident which could result in source damage. Leak-test records shall be kept for at least three years.

Sealed sources are to be leak tested by the Internal Radioisotope Permit holder, as required. Prior to leak testing, all leak-test procedures shall be demonstrated to the Radiation Safety Officer for appropriateness. Removable radioactive contamination in excess of 200 Bq is to be reported immediately to the Radiation Safety Officer.

(1) Using forceps or tweezers, wipe all external surfaces of the source container with a cotton-tipped swab or a small piece of ethanol-moistened (50%) filter paper. For tritium foils, wipe adjacent area.
(2) Measure the radioactivity of the wipe by liquid scintillation counting or gamma-well counting.
(3) If the total radioactivity of the wipe exceeds 200 Bq, remove the source container from use and ensure the spread of any leakage or contamination is limited. Report immediately to the Radiation Safety Officer.
(4) Record all results on a Contamination Control form.

16.6 Open Sources

16.6.1 Contamination monitoring. It is necessary to establish a well-planned contamination-monitoring program to maintain levels of contamination **ALARA**. The program should be designed to detect contamination in experimental areas, as well as periodic checks of areas less likely to become contaminated. All rooms where open sources of radioactivity are used should have a decontamination/spill kit prepared (see Section 19.2).

Each area where radioisotopes are handled is to have ready access to a scintillation counter or a survey instrument equipped with an appropriate probe for the type of radioisotope present. The Radiation Safety Officer has specific information on the types of instrumentation required and can provide assistance in training personnel in the use of the devices.

16.6.2 Fume hoods. It is recommended that all work with radioisotopes be done in a fume hood lined with absorbent paper or plastic, or containing a drip tray.

Always use a fume hood or glove box to work with dry powders or volatile substances, or when performing a procedure that may generate an aerosol. Quantities of radioactivity above 100 exemption quantities must be handled in a fume hood. The hood should be labelled with a clearly visible radiation symbol (trefoil).

Should the fume hood not operate correctly, or should servicing be required in the lab, call the Radiation Safety Officer. Perform a complete set of wipe tests in the fume hood and throughout the lab, and remove all hazardous materials. Forward the results of your contamination checks to the Radiation Safety Officer. The Radiation Safety Officer will post a sign that confirms the fume hood and laboratory are free of radioactive contamination and that radioactive work in the lab has ceased. Workers will not enter a radioisotope laboratory without this documented proof. The Radiation Safety Officer will request servicing from the Facilities Department and will remove signs when servicing is complete.

If there is no operational magnehelic gauge on the fume hood, it is a good practice to tape a small piece of tissue paper to the bottom of the sash to give a visual indicator of airflow.

16.6.3 Sinks. Only one sink should be used for the washing of contaminated labware. The sink should be clearly and boldly labelled with radiation warning tape or labels, and they must be replaced immediately if they become obscured or contaminated.

16.6.4 Covering of work surfaces. Working surfaces are required to be covered with an absorbent covering to prevent radioactive contamination. Some options are:

(1) absorbent plasticized paper (e.g. Kay-dry, Benchkote, incontinent pads);
(2) an absorbent-paper-lined tray; or,
(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.

16.6.5 Labelling. Label all material used for radioactive work with radiation symbols (trefoils). Warning signs are essential since visitors, cleaning staff, emergency and 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 labelled 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 radioisotope work.

Vessels containing radioactive materials in excess of one exemption quantity are to be labelled with the standard radiation warning symbol (trefoil), the name of the radioisotope, the amount of radioactivity on a given date, and the name of the Internal Radioisotope Permit holder. The exterior of a fridge, freezer or cabinet used to store such a vessel must be marked to indicate the presence of radioactive material.

The Internal Radioisotope Permit holder shall remove, or not apply, unwarranted radiation hazard stickers.

16.6.6 Procedures when handling open-source materials. Following are some guidelines for the use of open radioactive sources.

(1) For non-routine or new operations, the user should conduct a trial run with non-radioactive or low-radioactivity material to test the adequacy of the procedures and equipment.

(2) Wear disposable gloves that are resistant to the chemicals used in the procedure. Remove or replace the gloves when switching from work with radioisotopes to other laboratory work or deskwork. Wear protective clothing such as lab coats and safety glasses. Always remove protective laboratory apparel before entering public areas.

(3) Implement safe personal practices such as restraining long hair, avoiding loose clothing or jewellery, wearing shoes that cover the entire foot and clothing that covers the entire leg.

(4) When possible, bring necessary apparatus and equipment to your work area instead of carrying radioactive material. Open sources (uncapped) are never to be transported through hallways or public areas. When such transfers are necessary, use sealed shielded containers with adequate volume to contain possible spills.

(5) Work in trays or on benches lined or covered with absorbent material that will contain the total volume of liquid being manipulated.

(6) Use forceps where possible to reduce exposure to hands when working with radioisotopes other than hydrogen-3, carbon-14, sulphur-35 or phosphorus-33.

(7) Radioactive waste containers with foot-pedal operated lids should be used to minimize contamination of the outer surface and lid. These containers must be boldly marked with radioactive labels.

(8) Always wash and monitor hands after a procedure. It is recommended that shoes and clothes also be monitored.

(9) Monitor lab for contamination after each use of radioactive material. It is mandatory to record the results of contamination monitoring.

17. PERSONAL PROTECTIVE EQUIPMENT

Mandatory apparel in a radioisotope laboratory (but never worn outside the radioisotope laboratory) is:

(1) lab coat;

(2) disposable gloves of an appropriate material for the material being handled;

and,

(3) shoes that cover the entire foot.

Additional protective equipment includes:

(1) long pants to provide protection for the lower legs;
(2) safety glasses when there is a possibility of splashing material into the eyes;
(3) safety glasses when working with high-energy beta emitters to reduce the external radiation dose to the eyes;
(4) remote-handling devices such as forceps and tongs when handling stock solution vials or any source that produces a significant dose rate; and,
(5) lead apron, that provides whole-body coverage, in areas where the radiation field cannot be reduced sufficiently with the use of shielding.

18. MANAGEMENT OF RADIOACTIVE WASTE

18.1 Radioactive Waste Disposal

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

Unlike some other hazardous materials, radioisotopes are not degraded by external chemical and physical processes. Dilution of these atoms into the air, landfills or bodies of water simply moves them from one location to another.

However, unlike many hazardous materials which never degrade, radioisotopes decay into stable isotopes (albeit in more than one-step in some cases) and when this occurs the radiotoxicity ceases. Therefore, to minimize the environmental impact of radioisotope disposal, it is incumbent upon all users of radioactive materials to follow the guidelines for radioactive waste management.

The guidelines for radioactive waste management are enforced by law, are administered by the Canadian Nuclear Safety Commission 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 an equal amount of radioactivity of hydrogen-3 (tritium). For this reason, the Canadian Nuclear Safety Commission has set out radioisotope disposal limits that vary with the associated degree of hazard. These limits range (depending on the radioisotope) from 0.01 to 37 MBq/kg for solid waste, 1 to 1×10^6 MBq/y for liquid waste, and 0.03 to 37 kBq/m^3 for air.

Small amounts of radioactive waste may be stored in a radioisotope laboratory but provisions have been made for separate storage areas, controlled by the Radiation Safety Officer, for significant quantities of radioactive wastes. All waste contaminated with radioisotopes must be disposed as radioactive waste, through the Radiation Safety Officer. A simplified schematic drawing of the waste disposal procedure.

Radioactive waste is considered part of the radioisotope inventory, and consequently it is necessary to keep a permanent record of each disposal of radioactive material. A Radioisotope Disposal sheet for recording the following information should be attached to each waste stream:

(1) disposal container identification;
(2) type of radioisotope;
(3) type of waste;
(4) date and time of disposal;
(5) name of user;
(6) source bottle identification; and,
(7) amount/volume of radioactivity.

Note that disposal of radioisotopes must be recorded both on a Radioisotope Disposal sheet and on a Radioisotope Data sheet. When a Radioisotope Data sheet is complete, the total amount of radioisotope disposed should equal the quantity initially received.

It is essential to ensure that there is full and complete documentation of all quantities of radioactivity disposed as solid, liquid or gaseous waste.

18.2 Gases, Aerosols and Dusts

Procedures for which there is a potential to emit radioactive gases, aerosols or dusts must be performed in a fume hood lined with absorbent paper. For radioactive material that may be discharged to the atmosphere via fume hoods, the disposal limit ranges (depending on the radioisotope) from 0.03 to 37 kBq/m^3 of exhausted air, averaged over a one-week period.

18.3 Liquid Waste

Liquid wastes are separated according to solvent and, for each solvent, further separated by radioisotope. Never dispose of non-radioactive liquid in a radioactive liquid waste container, or vice versa.

Liquid waste containers consist of 1-L Nalgene bottles that have a Hazardous Waste tag and a Radioisotope Disposal sheet attached. When full, wipe test the exterior of the waste bottle, ensure the field emitted from the bottle is below 2.5 μSv/h and call the Radiation Safety Officer for waste collection. The Radiation Safety Officer will not remove waste unless it is documented to be free of contamination and meets the dose rate limit given above.

Short half-life aqueous radioisotopes ($t_{1/2} < 100$ d) should be stored in sealed containers, with a separate container for each radioisotope. The containers are held until such time as the radioisotope has decayed and it can be disposed as non-radioactive liquid.

Long half-life aqueous radioisotopes ($t_{1/2} \geq 100$ d) should be collected in 1-L Nalgene bottles. The bottles will be collected by the Radiation Safety Officer (as described above), who will arrange for disposal. Different types of radioisotope must not be mixed.

All 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 1-L Nalgene bottles, which are available from the Radiation Safety Officer. All short half-life radioisotopes ($t_{1/2} < 100$ d) will be held for decay. A separate bottle must be used for each radioisotope and each solvent.

Long half-life radioisotopes ($t_{1/2} \geq 100$ d) must be collected in 1-L Nalgene bottles, using a separate bottle for each radioisotope and each solvent. The Radiation Safety Officer will collect the bottles and arrange for disposal.

Do not mix radioisotopes and do not mix solvents. Use a separate, properly labelled waste container for each radioisotope and each solvent. Plastic Nalgene containers are used for the disposal of all radioactive liquid waste.

18.4 Solid Waste

Never dispose of non-radioactive solid waste in a radioactive solid waste container, or vice versa. Radioactive solid wastes are classified as combustible or non-combustible. Always separate combustible and non-combustible radioactive solids, and within each of these two categories use a separate container for each type of radioisotope. Furthermore, low- and medium-level radioactive solid waste should be separated. The division between these two categories ranges (depending on the radioisotope) from 0.01 to 37 MBq/kg as described. In addition, the dose rate must not exceed 2.5 μSv/h on the surface of the container for waste to be considered low level.

Exclusive of radioisotope content, biological material including biohazardous material, animals, organs or parts thereof, must be sent for incineration. If the biohazardous material contains radioisotopes, autoclaving the waste before 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 Risk & Safety Coordinator and the Radiation Safety Officer before commencing the research.

18.4.1 Low-level combustible waste. Low-level combustible radioactive solid waste is collected in a receptacle lined with a heavy-duty plastic bag. This includes disposable gloves, paper, plastic, bench-covering material, plastic test tubes, plastic Petri dishes, plastic tubing and empty plastic scintillation vials. A separate bag should be used for each type of radioisotope.

On removal from the receptacle, the material should be double bagged using a second heavy-duty bag, with care taken to ensure that the package does not rupture while being handled. Following double bagging, wipe tests should be made of the exterior of the bag and of the interior of the receptacle. The Radioisotope Disposal sheet for the bag should be retained, with a photocopy attached to the bag of waste. Also, attach records showing the liquid scintillation counter results of the wipe tests.

The bag will be collected by the Radiation Safety Officer. All combustible waste that is contaminated with radioisotopes is either held for decay or sent to an approved facility for disposal, depending on the half-life of the radioisotope. Short half-life ($t_{1/2} < 100$ d) material will be held for decay. The Radiation Safety Officer will make arrangements for the disposal of waste contaminated with long half-life radioisotopes.

18.4.2 Low-level non-combustible waste. Emptied glass scintillation vials and contaminated glassware, pipets, metal, etc. should all be handled as non-combustible waste. The waste should be placed in a white polyethylene pail labelled 'Glass Waste Only'. Each type of radioisotope should have a separate container.

When the pail is full, a wipe test must be conducted of the exterior. The Radiation Safety Officer will collect the pail when contacted. Short half-life ($t_{1/2} < 100$ d) waste will be held for decay before disposal. The Radiation Safety Officer will arrange for the disposal of waste contaminated with longer-lived radioisotopes.

18.4.3 Medium-level combustible waste. Occasions may arise in which the amount of radioactive contamination in the waste, or the dose rate, does not meet the guidelines for low-level combustible radioactive waste disposal. For example, the sorbent material used to clean up a spill of stock solution may contain a significant amount of radioactivity.

When using radioisotopes with short half-lives ($t_{1/2}$ <100 d), solid waste that exceeds the disposal guidelines may be held for decay. Decay storage space is allocated by the Radiation Safety Officer. It is important to label all containers with the type of radioisotope, the amount of radioactive material and the reference date, the radiation dose rate and the name of the Internal Radioisotope Permit holder.

Keeping in mind that the radiation fields emitted from these packages may be >2.5 μSv/h, it is important to print the above information with large bold lettering so that it can be read at a distance.

In situations where the amount of radioactivity to be disposed exceeds the low-level solid waste disposal guidelines, and the half-life of the radioisotope precludes holding the material for decay, the waste will be sent to a licensed facility (AECL, Chalk River, ON) for burial. The appropriate containers to be used for this process are new empty paint cans, which are available from most commercial paint stores. New empty paint cans must be used, as the paint from used cans prevents adequate sealing of the lid. Note that shielding may be required on the inside of the container.

Every effort must be taken to minimize the waste volume, as the shipping procedure is very costly. For example, if an absorbent bench cover is heavily contaminated it may be possible to cut the 'hot spots' from the sheet for disposal as medium-level radioactive waste in paint cans, while the remainder might meet the limit for low-level radioactive waste given.

18.4.4 Medium-level non-combustible waste. Stock solution vials containing traces of unused radioisotope, for example, may not meet the guidelines for disposal as low-level non-combustible waste. Other examples include columns and glassware used in radioiodination procedures, radioactive metals and geological samples.

Waste contaminated with radioisotopes with short half-lives ($t_{1/2}$ <100 d) may be held for decay. If this is the case, white polyethylene pails should be used for the collection of the waste. The pail should be labelled 'Glass Waste Only'. Decay storage space is allocated by the Radiation Safety Officer. It is important to label all containers with the type of radioisotope, the amount of radioactive material and the reference date, the radiation dose rate and the name of the Internal Radioisotope Permit holder.

Keeping in mind that the radiation fields emitted from these packages may be >2.5 μSv/h, it is important to print the above information with large bold lettering so that it can be read at a distance. If necessary, used stock vials can be placed in the lead container in which they were received to reduce the dose rate on the outside of the pail.

If the amount of radioactivity to be disposed exceeds the low-level solid waste disposal guidelines, and the half-life of the radioisotope prevents the material from being held until it decays, the waste will be sent to a licensed facility for burial. The appropriate containers to be used for this process are new empty paint cans. Again, it may be necessary to place used stock vials in the lead container in which they were received to limit the dose rate on the exterior of the paint can.

The amount of radioactivity associated with the waste that is placed in the paint can must be documented and disposal records maintained. Arrangements must be made with the Radiation Safety Officer to receive, inspect, catalogue and ship the sealed paint cans.

19. RADIATION EMERGENCY RESPONSE

19.1 Dealing with Source Incidents and Accidents

Mishaps can occur even in the best-run laboratories, and personnel using radioactive materials must be fully acquainted with the appropriate procedures to be followed. To ensure the appropriate management of any radioisotope mishap of an emergency nature, especially those involving personal contamination, immediately call the emergency response number (ext. 3333) as well as the Radiation Safety Officer (ext. 6472). No person shall resume work at the site of an emergency involving radioactive material until authorized to do so by the Radiation Safety Officer.

An *accident* is defined as any unintended situation or event that 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 to ensure that the radioisotope decontamination/spill kit in the laboratory is fully stocked.

19.2 Radioisotope Decontamination/Spill Kit

A radioisotope decontamination/spill kit should include the following items:

(1) disposable nitrile gloves (or equivalent);
(2) plastic bags for waste disposal and foot covers;
(3) radiation tape and cleaning rags;
(4) absorbent material (e.g. paper towels);
(5) decontamination detergent;
(6) gritty cleanser (e.g. Ajax);
(7) masking tape to fasten shoe covers or plastic bags;
(8) tags for identification of waste;
(9) filter papers to perform wipe tests to check for loose contamination;
(10) a note pad to diagram the area and document the spill and clean up;
(11) chalk to mark off area; and,
(11) a rope or barricade tape to cordon off the area.

19.3 Sealed Source Leaks

Under some circumstances, sealed sources can leak or be broken. If this occurs, the item is essentially an open source and should be handled in an appropriate manner. Follow the procedure below if a leaking or broken sealed source is detected.

(1) Immediately notify all other people in the vicinity. Evacuate the area if necessary.
(2) Monitor all personnel. Remove contaminated clothing and assess if any areas of the body have been contaminated. If any individual is contaminated, proceed to Section 19.5 (Personnel Decontamination) immediately.
(3) Cordon off the area.
(4) If the leak cannot be managed, call the emergency response number (ext. 3333). Otherwise, notify your supervisor and the Radiation Safety Officer (ext. 6472)

If possible, notify anyone who may have unknowingly handled the source while it was leaking.

(5) Use the Radiation Safety Data Sheet to Assess the characteristics of the radioisotope (volatility, type of emission, energy, half-life) and thus determine potential hazards and cleanup procedures.
(6) Put on appropriate protective clothing. As a minimum, a lab coat, safety glasses and disposable gloves are required.
(7) Using remote handling devices such as tongs or forceps, place the source in a shielded container.
(8) Contain the contamination and prevent it from spreading.
(9) Use the appropriate detector to monitor equipment, benches, floors, etc. to determine the extent of the spill.
(10) Mark the contaminated area with tape or chalk.
(11) Clean up the contamination using a 2 to 5% solution of decontamination detergent taking care not to spread the contamination. If contamination persists, increase the concentration of the detergent. Place contaminated cleanup materials in the combustible waste. Wipe test the area carefully to ensure all contamination has been detected and removed.
(12) Monitor all personnel involved in cleaning the leak.
(13) Prepare the necessary Radioisotope Disposal forms and submit to the Radiation Safety Officer immediately.

In the event of a sealed source leak, the Radiation Safety Officer will immediately notify the CNSC duty officer and subsequently submit a full report to the CNSC within 21 days.

19.4 Spills

The procedure to follow in the event of a spill is listed below.

(1) Immediately notify all other people in the vicinity of the spill. Evacuate the area if necessary.
(2) Monitor all personnel. Remove contaminated clothing and assess if any areas of the body have been contaminated. If any individual is contaminated, proceed to Section 19.5 (Personnel Decontamination) immediately.
(3) Cordon off the area.
(4) If the spill is >1 L, or if the spill cannot be managed, call the emergency response number (ext. 3333). Otherwise notify your supervisor and the Radiation Safety Officer (ext.6472).
(5) Assess the characteristics of the radioisotope (volatility, type of emission, energy, half-life) and thus determine potential hazards and cleanup procedures.
(6) Put on appropriate protective clothing. As a minimum, a lab coat, safety glasses and disposable gloves are required. Organicsolvent spills will require the use of a dual cartridge respirator equipped with acid gas/organic vapour cartridges.

(7) Turn off any device, instrument or machine that could enhance the spill.
(8) Contain the spill and prevent it from spreading. For liquid spills use absorbent material such as paper towels or incontinent pads. For powder spills place dampened absorbent material over the spill. Do not use a spray bottle.
(9) Use the appropriate detector to monitor equipment, benches, floors, etc. to determine the extent of the spill.
(10) Mark off the contaminated area with tape or chalk.
(11) Clean up the spill using a 2 to 5% solution of decontamination detergent taking care not to spread the spill. If contamination persists, increase the concentration of the detergent. Place contaminated cleanup materials in the combustible waste.
(12) Wipe test the area carefully to ensure all of the spill, including splatters, have been detected.
(13) Monitor all personnel involved in cleaning the spill.
(14) Adjust Radioisotope Data records and prepare the necessary Radioisotope Disposal sheets.

For major spills (involving more than 100 exemption quantities) the Radiation Safety Officer will immediately notify the CNSC duty officer and subsequently submit a full report to the CNSC within 21 days.

19.5 Personnel Decontamination

19.5.1 Skin contamination.

Remove skin contamination as soon as possible to prevent its spread and to eliminate it as a source of internal contamination by way of ingestion, inhalation, absorption through intact skin or absorption through wounds.

Decontamination procedures should not increase the penetration of radioactivity into the body by excessive abrasion of the skin.

(1) Locate the contaminated area with the most appropriate detector. Record the time of initial contamination and Net counts per minute (CPM).
(2) Remove contaminated clothing.
(3) Flush affected areas of skin with copious quantities of lukewarm water for several minutes.
(4) Monitor the contaminated area and record CPM. If contamination persists, wash with mild soap (non-abrasive). Gently work thelather into the contaminated skin for three minutes. Rinse thoroughly.
(5) Monitor, record CPM and time, and repeat step (4) if contamination persists.
(6) Monitor, record CPM and time, and contamination persists, use cold cream or baby oil to clean the skin.
(7) Monitor, record CPM, and time and if contamination persists, do nothing more. Do not 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) Call the emergency response number (ext. 3333). Then notify your supervisor and the Radiation Safety Officer (ext. 5530) immediately.

In the event of complications, medical assistance is available from:

Manager, Diagnostics, UHNBC
250-649-7505

Chief Technologist
Nuclear Medicine, UHNBC
250-565-2409

It would be of assistance to the Radiation Medical Advisor if the following information could be provided:
(1) the patient's name;
(2) the radioisotope involved;
(3) the total amount of radioactivity involved;
(4) the nature of the material (liquid, powder, etc.);

(5) the extent of the radioactive contamination; and,
(6) any other complications (fractures, burns, etc.).

The individual involved, or their supervisor, shall ensure that an incident/accident report is immediately submitted to the Radiation Safety Officer. The RSO will calculate skin dose based on CPM counts. If the skin dose is determined to be above 5 µSv/hr, the Radiation Safety Officer will immediately notify the CNSC duty officer and subsequently submit a full report to the CNSC within 21 days.

19.5.2 Internal contamination. If an individual has ingested or has been accidentally injected with a radioisotope, call the emergency response number (ext. 3333) immediately.

If an individual has ingested chemically toxic radioactive material, treat the chemical toxicity first. Locate the Safety Data Sheet (available from security) for first aid information. Do not attempt anything further without direction from a First Aid Attendant or the Radiation Safety Officer.

Medical assistance is available from:

Manager, Diagnostics
UHNBC
250-649-7505

Chief Technologist
Nuclear Medicine, UHNBC
250-565-2409

It would be of assistance to the Radiation Medical Advisor if the following information could be provided:

(1) the patient's name;
(2) the radioisotope involved;
(3) the total amount of radioactivity involved;
(4) the nature of the material (liquid, powder, etc.); and,
(5) any other complications (fractures, burns, etc.).

The individual involved, or their supervisor, shall ensure that an incident/accident report is submitted within 24 hours to the Radiation Safety Officer.

The Radiation Safety Officer will immediately notify the CNSC duty officer and subsequently submit a full report to the CNSC within 21 days.

19.6 Accidents

19.6.1 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.

19.6.2 Accidents involving minor injury.

(1) Treat immediately at or near the scene of the accident.
(2) Rinse a 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.
(5) Apply a first aid dressing. The injured areas should be monitored to establish the residual level of radioactivity, if any.
(6) Notify the person's supervisor and the Radiation Safety Officer (ext. 6472).

19.6.3 Accidents involving serious injury.

(1) For situations requiring basic first aid, call the emergency response number (ext. 3333). Describe the injuries, the type and amount of radioactive material involved, as well as the physical and chemical forms of the material. If no phone is available, pull a fire alarm station.
(2) Advise emergency personnel of the

contamination, nature of the injuries and radioisotope handling procedures.

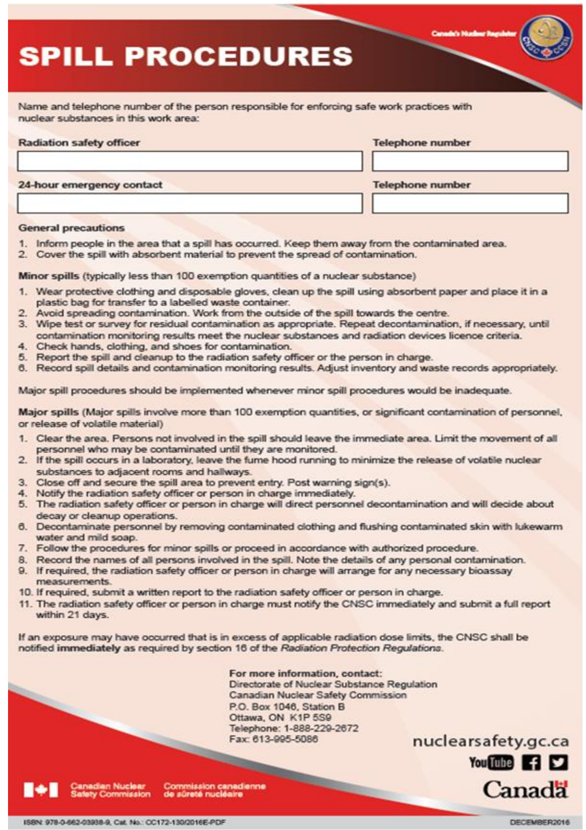
(3) Ensure that the radioactive material does not further contaminate the accident victim.

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

(5) Notify the person's supervisor and the Radiation Safety Officer (ext. 6472).

19.6.4 Reporting. For injuries requiring medical attention, the injured person or their supervisor shall notify the Radiation Safety Officer of the accident immediately as well as ensure that an incident/accident report is submitted within 24 hours. A WorkSafe BC Form 7 must also be completed by the supervisor and sent to the Health and Safety Office.

19.6.5 Natural Disaster. In the event a situation or event (such as a fire or earthquake) occurs in which an emergency action plan in enacted or a results in the further inspection to verify the structures or the University, the Radiation Safety Officer will immediately notify the CNSC duty officer and subsequently submit a full report to the CNSC within 21 days



SPILL PROCEDURES

Canada's Nuclear Regulator

Name and telephone number of the person responsible for enforcing safe work practices with nuclear substances in this work area:

Radiation safety officer	Telephone number
24-hour emergency contact	**Telephone number**

General precautions

1. Inform people in the area that a spill has occurred. Keep them away from the contaminated area.
2. Cover the spill with absorbent material to prevent the spread of contamination.

Minor spills (typically less than 100 exemption quantities of a nuclear substance)

1. Wear protective clothing and disposable gloves, clean up the spill using absorbent paper and place it in a plastic bag for transfer to a labelled waste container.
2. Avoid spreading contamination. Work from the outside of the spill towards the centre.
3. Wipe test or survey for residual contamination as appropriate. Repeat decontamination, if necessary, until contamination monitoring results meet the nuclear substances and radiation devices licence criteria.
4. Check hands, clothing, and shoes for contamination.
5. Report the spill and cleanup to the radiation safety officer or the person in charge.
6. Record spill details and contamination monitoring results. Adjust inventory and waste records appropriately.

Major spill procedures should be implemented whenever minor spill procedures would be inadequate.

Major spills (Major spills involve more than 100 exemption quantities, or significant contamination of personnel, or release of volatile material)

1. Clear the area. Persons not involved in the spill should leave the immediate area. Limit the movement of all personnel who may be contaminated until they are monitored.
2. If the spill occurs in a laboratory, leave the fume hood running to minimize the release of volatile nuclear substances to adjacent rooms and hallways.
3. Close off and secure the spill area to prevent entry. Post warning sign(s).
4. Notify the radiation safety officer or person in charge immediately.
5. The radiation safety officer or person in charge will direct personnel decontamination and will decide about decay or cleanup operations.
6. Decontaminate personnel by removing contaminated clothing and flushing contaminated skin with lukewarm water and mild soap.
7. Follow the procedures for minor spills or proceed in accordance with authorized procedure.
8. Record the names of all persons involved in the spill. Note the details of any personal contamination.
9. If required, the radiation safety officer or person in charge will arrange for any necessary bioassay measurements.
10. If required, submit a written report to the radiation safety officer or person in charge.
11. The radiation safety officer or person in charge must notify the CNSC immediately and submit a full report within 21 days.

If an exposure may have occurred that is in excess of applicable radiation dose limits, the CNSC shall be notified **immediately** as required by section 16 of the *Radiation Protection Regulations*.

For more information, contact:
Directorate of Nuclear Substance Regulation
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B
Ottawa, ON K1P 5S9
Telephone: 1-888-229-2672
Fax: 613-995-5086

nuclearsafety.gc.ca

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20. RADIOISOTOPE THEFT OR LOSS

Loss 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 Security Office or the Radiation Safety Officer (ext. 6472).

The Radiation Safety Officer will immediately notify the CNSC duty officer and subsequently submit a full report to the CNSC within 21 days.

21. RECORD KEEPING AND DOCUMENTATION

Canadian Nuclear Safety Commission regulations require each licensed research laboratory to maintain complete records of all radioactive sources. This is accomplished by using the forms described in this section. Disposal of any records must be preceded by the notification of the CNSC 90 days prior to the disposal.

21.1 Purchases

The acquisition of radioisotopes is strictly regulated, as described in Section 14. An up-to-date record of all purchases, gifts or donations of radioactive materials must be maintained.

Records will be retained for a minimum of 1 year after the expiry of the CNSC licence.

21.2 Contamination Control

It is required that contamination monitoring be performed at the end of each working day in which radioactive materials were used. The numerical results of these checks, even when no contamination is found, must be recorded on a Contamination Control form. This form is shown in Appendix V. These records must be kept on file for a minimum of three years.

Leak test records shall also be maintained using the Contamination Control form.

Records will be retained for a minimum of 1 year after the expiry of the CNSC licence.

21.3 Usage

It is necessary to record the user's name, date, amount of radioactivity removed and amount of radioactivity remaining each time an aliquot is removed from a stock solution vial. A Radioisotope Data sheet, an example of which is shown in Appendix V, must be maintained for each stock solution. Radioisotope disposals should be recorded on both Radioisotope Data and Radioisotope Disposal sheets.

Sealed-source inventory records shall also be maintained using the Radioisotope Data sheet.

Records will be retained for a minimum of 1 year after the expiry of the CNSC licence.

21.4 Disposals

All waste in the laboratory or decay storage area is part of the permanent radioisotope inventory. The amount of radioactivity that is disposed must be documented. Note that disposals should be recorded on both Radioisotope Data and Radioisotope Disposal sheets.

Records will be retained for a minimum of 1 year after the expiry of the CNSC licence.

21.5 Survey Meter Operability

The first time a survey meter is used each day, its correct operation must be verified. Three items are to be checked: validity of calibration sticker, satisfactory battery/high voltage reading (as applicable) and meter response to a check source. A meter that fails any of these checks is not to be used.

Records will be retained for a minimum of 1 year after the expiry of the CNSC licence.

21.6 Annual Inventory

An physical inventory is performed for a sealed sources on annual basis.

Records will be retained for a minimum of 1 year after the expiry of the CNSC licence.

21.7 Worker Training Records

The radiation safety program will retain all worker training records for a period of at least 3 years after the end of employment.

21.8 Nuclear Energy Worker (NEW) Notification Forms

If a worker is determined to be a Nuclear Energy worker, all records pertaining to this (including notification forms and annual dose data) will be retained for 1 year after the expiry of the CNSC license.

21.9 Sealed Source Leak Test Records

Wipe tests that are performed for the purpose of determining if a sealed source is leaking will be retained by the Radiation Safety Program for a period of three years.

21.10 Transfer of Nuclear Substances to Another License

Records of the transfer of nuclear substances to another licence will be retained by the Radiation Safety Program for 1 year after the expiry of the CNSC license.

22. TRANSPORTATION OF RADIOACTIVE MATERIALS

22.1 Protocol for Shipping of Radioactive Materials

No person shall ship any radioactive prescribed substances unless the shipment complies with the requirements respecting the packaging, labelling and safety marking described in the Packaging and Transport of Nuclear Substances Regulations. The Transportation of Dangerous Goods act, consolidated in 1985, is consistent with the Packaging and Transport of Nuclear Substances Regulations. According to the Transportation of Dangerous Goods Act, all "products, substances or articles containing a product or substance with activity greater than 74 kBq/kg are radioactive materials," and therefore are subject to the Act. This means that the consignor must ensure that the goods are properly classified, packaged, labelled and documented before they are shipped. In addition, vehicles carrying Category III articles must be placarded on all four sides. If further classification or assistance is required, please contact the Radiation Safety Officer.

Transportation of any radioactive material can take place only if the following conditions are met:

(1) the material is being shipped from one licensed individual to another individual who is licensed for that type and quantity of radioisotope;
(2) the recipient of the material has been advised, and reasonable arrangements for receipt have been made; and,
(3) the shipment includes all necessary labelling, documentation and placarding.

> Canada Post regulations do not permit the shipment of radioactive material through the mail system.

22.2 Transport of Dangerous Goods Labelling

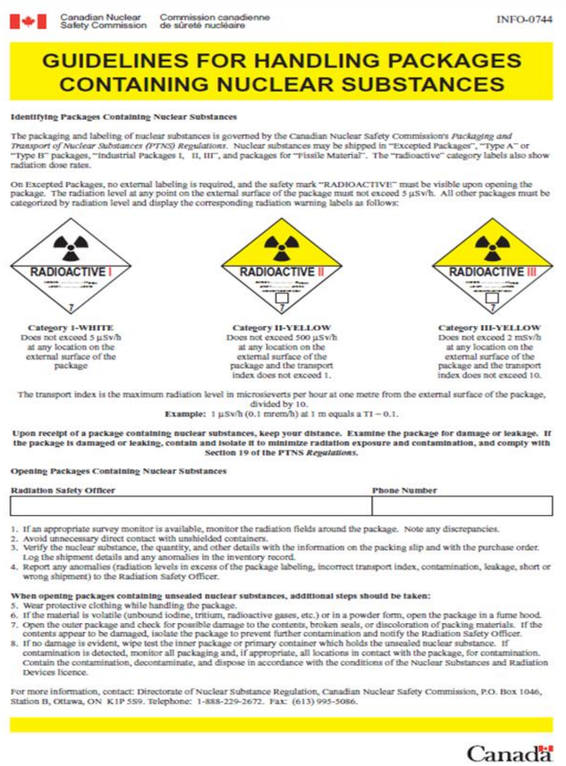
Containers for shipping radioactive material may display different labels depending on a number of factors. The requirements for shipping radioisotopes are defined in the Packaging and Transport of Nuclear Substances Regulations. The four categories of labelling are: excepted package, I – white, II – yellow and III – yellow (see Canadian Nuclear Safety Commission poster Radioisotope Safety – Identifying and Opening Radioactive Packages).

The markings on a package in the first classification indicate that the package meets the criteria for an excepted package. This means that the amount of radioisotope 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 symbol (trefoil) and one red bar on a white background. This indicates that on any surface of the package, the maximum radiation field is ≤5 μSv/h (0.5 mR/h).

The third category is the II – yellow label displaying the radiation symbol (trefoil) and two red bars. This indicates that on any surface of the package the maximum radiation field is between 5 μSv/h (0.5 mR/h) and 500 μSv/h (50 mR/h). The top half of the label is yellow and the bottom half is white. Further, the number in the small box in the bottom corner of the label indicates the Transport Index. The Transport Index restricts the radiation field to a maximum of 10 μSv/h (1 mR/h) at a distance of 1 m from the package.

The fourth category is the III – yellow label displaying the radiation symbol (trefoil) and three red bars. This indicates that on any surface of the package the radiation field is between 500 μSv/h (50 mR/h) and 2 mSv/h (200 mR/h). The top half of the label is yellow and the bottom half is white. The Transport Index restricts the radiation field to a maximum of 100 μSv/h (10 mR/h) at a distance of 1 m from the package.



Canadian Nuclear Safety Commission   Commission canadienne de sûreté nucléaire   INFO-0744

GUIDELINES FOR HANDLING PACKAGES CONTAINING NUCLEAR SUBSTANCES

Identifying Packages Containing Nuclear Substances

The packaging and labeling of nuclear substances is governed by the Canadian Nuclear Safety Commission's *Packaging and Transport of Nuclear Substances (PTNS) Regulations*. Nuclear substances may be shipped in "Excepted Packages", "Type A" or "Type B" packages, "Industrial Packages I, II, III", and packages for "Fissile Material". The "radioactive" category labels also show radiation dose rates.

On Excepted Packages, no external labeling is required, and the safety mark "RADIOACTIVE" must be visible upon opening the package. The radiation level at any point on the external surface of the package must not exceed 5 μSv/h. All other packages must be categorized by radiation level and display the corresponding radiation warning labels as follows:

Category I-WHITE
Does not exceed 5 μSv/h at any location on the external surface of the package

Category II-YELLOW
Does not exceed 500 μSv/h at any location on the external surface of the package and the transport index does not exceed 1.

Category III-YELLOW
Does not exceed 2 mSv/h at any location on the external surface of the package and the transport index does not exceed 10.

The transport index is the maximum radiation level in microsieverts per hour at one metre from the external surface of the package, divided by 10.
Example: 1 μSv/h (0.1 mrem/h) at 1 m equals a TI – 0.1.

Upon receipt of a package containing nuclear substances, keep your distance. Examine the package for damage or leakage. If the package is damaged or leaking, contain and isolate it to minimize radiation exposure and contamination, and comply with Section 19 of the PTNS *Regulations*.

Opening Packages Containing Nuclear Substances

Radiation Safety Officer	Phone Number

1. If an appropriate survey monitor is available, monitor the radiation fields around the package. Note any discrepancies.
2. Avoid unnecessary direct contact with unshielded containers.
3. Verify the nuclear substance, the quantity, and other details with the information on the packing slip and with the purchase order. Log the shipment details and any anomalies in the inventory record.
4. Report any anomalies (radiation levels in excess of the package labeling, incorrect transport index, contamination, leakage, short or wrong shipment) to the Radiation Safety Officer.

When opening packages containing unsealed nuclear substances, additional steps should be taken:

5. Wear protective clothing while handling the package.
6. If the material is volatile (unbound iodine, tritium, radioactive gases, etc.) or in a powder form, open the package in a fume hood.
7. Open the outer package and check for possible damage to the contents, broken seals, or discoloration of packing materials. If the contents appear to be damaged, isolate the package to prevent further contamination and notify the Radiation Safety Officer.
8. If no damage is evident, wipe test the inner package or primary container which holds the unsealed nuclear substance. If contamination is detected, monitor all packaging and, if appropriate, all locations in contact with the package, for contamination. Contain the contamination, decontaminate, and dispose in accordance with the conditions of the Nuclear Substances and Radiation Devices licence.

For more information, contact: Directorate of Nuclear Substance Regulation, Canadian Nuclear Safety Commission, P.O. Box 1046, Station B, Ottawa, ON K1P 5S9. Telephone: 1-888-229-2672. Fax: (613) 995-5086.

Canada

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RADIATION EXPOSURE FOR WOMEN AT THE UNIVERSITY OF NORTHERN BRITISH COLUMBIA

The recommendation of the University of Northern British Columbia Committee on Radioisotopes and Radiation Hazards is that the radiation dose to the abdomen of pregnant workers not exceed that of the population at large.

In accordance with the above recommendation, the following shall apply:

(1) female personnel are encouraged to disclose to their Department Head or designate, in confidence, at the earliest possible date, all pregnancies or suspected pregnancies;
(2) the Department Head 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 the 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 regulatory 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 materials 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 pregnant workers as provided in the foregoing shall be reviewed in confidence by the University of Northern British Columbia Committee on Radioisotopes and Radiation Hazards. This review must include the best interests of the worker and the University of Northern British Columbia. Recommendations of the Committee on Radioisotopes and Radiation Hazards shall be final; and,
(8) all female employees and faculty and students shall be made aware of the above policy prior to the use of radioisotopes or radiation-emitting devices.

WASTE PREPARATION PROCEDURES

(1) When a waste container (the bottle, bag or other container that holds radioactive waste, not the receptacle that holds a waste bag) is getting full, seal it and ensure that it has the appropriate Chemical Safety tag as well as the appropriate Radiation Safety tag. Combustible waste requires a red incineration label available from the Radiation Safety Officer.
(2) Wipe test the exterior of each waste container for possible radioactive contamination. If contaminated, decontaminate and repeat the wipe test; continue until decontamination is successful. Label all wipes taken from the exterior of a container with that container's identification on the liquid scintillation counter printout. This enables the Radiation Safety Officer to visually see from the liquid scintillation counter printout that the wipes taken from the waste container are satisfactory.
(3) Attach a photocopy of each disposal sheet to the respective waste container. There should be an original disposal sheet for each waste container. Hold the originals on file for 3 y and then forward to the Radiation Safety Officer.
(4) Monitor the field coming from the waste container to ensure it is <2.5 μSv/h.
(5) Wipe test the interior of any receptacle that held a waste bag. If the receptacle is found to be

contaminated, decontaminate and repeat the wipe test. Once proven to be free of contamination, place a new bag in the container.

(6) Contact the Radiation Safety Officer (ext. 6472; cell 778-349-8758) for pick-up of waste. For waste that will not be held for decay, discuss waste preparation procedures with the Radiation Safety Officer.

If the above procedures have not been followed, the waste cannot be removed from the laboratory. These procedures protect the individuals who will be handling the waste from internal and external contamination or unnecessary exposure, or both. Additionally, records required by the Canadian Nuclear Safety Commission are generated by this procedure.

FORMS

REGULATORY QUANTITIES FOR SELECTED RADIOISOTOPES

Radioisotope	Exemption Quantity (MBq)	Annual Limit on Intake by Ingestion[1] (MBq/y)	Basic Level Lab (MBq)	Intermed. Level Lab (MBq)	High Level Lab (MBq)	Contamination in Controlled Area (Bq/cm^2)	Contamination in Public Area (Bq/cm^2)	Garbage (MBq/kg)	Sewer (MBq/y)	Air (kBq/m^3)
Br-82	0.1	37	185	1850	18500	30	3			
C-14	100	34	170	1700	17000	300	30	3.7	10000	
Co-57	0.1	95	475	4750	47500	300	30	0.37	1000	
Co-58	0.1	27	135	1350	13500	30	3	0.37	100	
Co-60	0.1	6	30	300	3000	3	0.3	0.01		
Cr-51	1	530	2650	26500	265000	300	30	3.7	100	
F-18	0.01	400	2000	20000	200000	30	3	0.01		
Fe-59	0.1	10	50	500	5000	30	3	0.01	1	
Ga-67	1	100	500	5000	50000	30	3	0.037	100	
H-3	1000	1000	5000	50000	500000	300	30	37	1000000	37
I-123	10	95	475	4750	47500	300	30	3.7	1000	3
I-125	1	1	5	50	500	300	30	0.037	100	0.03
I-131	0.01	1	5	50	500	30	3	0.037	10	0.175
In-111	0.1	70	350	3500	35000	30	3	0.037	100	
Na-22	0.01	6	30	300	3000	3	0.3	0.01	0.1	
P-32	0.01	8	40	400	4000	300	30	0.37	1	
P-33	1	80	400	4000	40000	300	30	1	10	
Ra-226	0.01	0.07	0.35	3.5	35	3	0.3	0.01	1	
S-35	100	26	130	1300	13000	300	30	0.37	1000	
Sb-124	0.01	8	40	400	4000	3	0.3	0.37		
Sr-85	0.1	36	180	1800	18000	30	3	0.37	10	0.175
Tc-99m	10	900	4500	45000	450000	300	30	3.7	1000	
Tl-201	1	210	1050	10500	105000	300	30	0.037	100	
Xe-133	100000					300	30	1		3.7

[1]Note that an ingestion of one 'annual limit on intake' will result in an effective dose of 20 mSv, which is the maximum permissible dose for a nuclear energy worker, not the maximum permissible dose for UNBC personnel or members of the public.

CONTAMINATION CONTROL

Date of Use	Initials of User	Background (cpm)	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

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 given in Section 12.1 of the Radioisotope Safety & Methodology manual. Following decontamination, wipe tests must be repeated and the results recorded.

RADIOISOTOPE DATA

Radioisotope: __________________ Quantity*: _____________________ Starting Volume: _________________ Vial Identifier: _____________

Date Received: _________________ Reference Date: _________________ Wipe Test of Outside of Shipping Container: _________________ cpm

Date of Use	Initials of User	Volume Used	Volume Remaining	Activity Used*	Activity Remaining*	Disposal of Radioactivity*			
						Decay	Liquid	Combust.	Non-Comb.

*Units = kBq, MBq, μCi or mCi

Date Vial Finished: _________________ Vial: (1) Held for decay; (2) Combustible Waste; (3) Non-Combustible Waste_________________

Note: wipe tests must be performed immediately following the use of radioactive material.

RADIOISOTOPE DISPOSAL

Disposal Container I.D.:____________________________**Radioisotope:**______________________

Type of Waste: ____

Date of Disposal	Time of Disposal	Initials	Source Bottle Bar Code	Volume Disposed (mL)	Activity Disposed*

Units = kBq, MBq, μCi, mCi

Do not correct for decay; calculate the activity based on the initial activity in the stock vial. Keep these records on file for inspection purposes. Also record all disposals on the appropriate Radioisotope Data sheet.

SURVEY METER CHECKS

Meter Model and Serial Number: ____

Probe Model and Serial Number: ____

Location: ____

Date	Calibration Check	Battery/ High Voltage Check	Check Source I.D.	Background (cpm)	Check Source Reading (cpm)

ANNUAL INVENTORY

Name of Internal Radioisotope Permit Holder: __________________________ Licence Number: _____________________ Year: _______________

Name of Individual Completing Form: ____ Phone: ________________________________

Radioisotope	Total Amount Carried Over from Previous Year	Total Amount Acquired in Current Year	Disposed Radioactivity					Total in Possession at End of Current Year
			1[1]	2[2]	3[3]	4[4]	5[5]	

[1]Reduction of inventory due to radioactive decay of radioisotopes in laboratory (including liquid and solid waste in lab at year-end).
[2]Disposed as short half-life ($t_{1/2} < 100$ d) liquid waste that is being held for decay in room 4-223
[3]Disposed as long half-life ($t_{1/2} \geq 100$ d) liquid waste that is being held for disposal in room 4-223.
[4]Disposed as short half-life ($t_{1/2} < 100$ d) solid waste that is being held for decay in room 4-223.
[5]Disposed as long half-life ($t_{1/2} \geq 100$ d) solid waste that is being held for disposal in room 4-223.

Please forward by January 31 to Radiation Safety Officer, Room 4-333, Laboratory Building or fax to 960-5587.

Note: if you have not used radioisotopes recently, or are not intending to use such materials in the near future, you can surrender your licence until such time as your research priorities change. It is a quick and simple process to reactivate your licence at that time.

DEFINITIONS

A: mass number of a given radioisotope.

ABSORPTION: transfer or deposition of some or all of the energy of radiation travelling through matter.

ABSORPTION COEFFICIENT: since the absorption of x-rays or gamma rays is exponential in nature, these radiations have no defined 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 required to induce this effect is 10 MeV), by nuclei thereby producing a new isotope.

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

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

ANNUAL LIMIT ON INTAKE (ALI): the amount of a radioisotope that, upon ingestion, results in an exposure equal to the annual maximum permissible dose for a nuclear energy worker.

ATTENUATION: the reduction of the intensity of a beam of x-rays or gamma rays as it passes through some material. Beam energy can be lost by deposition (absorption) or by deflection (deflection attenuation), or both. 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 rate of radioactive decay, defined as one nuclear disintegration per second.

BETA PARTICLE (β^-): negatively-charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to that of an electron.

BRANCHING: the occurrence of two or more modes by which a radioisotope can undergo radioactive decay to the ultimate stable state. An individual atom of a radioisotope 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 nuclear force fields. The energy of the resultant photon is proportional to the mass of the nucleus of the absorber.

CARRIER: a non-radioactive or non-labelled material of the same chemical composition as its corresponding radioactive or labelled 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’.

CONTAMINATION (RADIOACTIVE): unwanted radioactive material in or on any medium or surface.

COULOMB (C): the quantity of electricity transported in 1 s by a current of 1 A.

COUNTER, SCINTILLATION: an instrument for measuring the rate of radioactive decay in a sample. Scintillation detection is based on the interaction of radiation with substances known as fluors (solids or liquids) 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 pre-SI unit for the rate of radioactive decay, defined as 3.7×10^{10} disintegrations per second.

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

DECAY, RADIOACTIVE: transformation of the nucleus of an unstable isotope by spontaneous emission of charged particles or photons, or both.

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, infrared radiation, visible light, ultraviolet light, x-rays, gamma rays and cosmic radiation) having no charge or mass, often called photons or quanta.

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 between the mass of the sum of the component parts and the actual mass of a 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 of cross-sectional area per unit time.

ENERGY LEVELS: discrete set of quantized energy states within a given atomic nucleus.

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

EXPOSURE (C/kg): a measure of the ionization produced in air by x-rays or gamma rays. 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 C/kg replaces the roentgen (R) unit.

GAMMA RAY (γ): electromagnetic radiation originating from changes in the energy level of the nucleus of an atom.

GEIGER-MUELLER TUBE: the detector 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 ionization events.

GENERATOR: device from which a progeny isotope is eluted from an ion-exchange column containing a parent radioisotope that 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 1 J/kg. The gray replaces the pre-SI unit rad.

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

HALF-LIFE, EFFECTIVE (EHL): the time required for a radioactive element in a living organism to be diminished by 50% as a result of the combined action of radioactive decay and biological elimination,

$$EHL = \frac{BHL \times PHL}{BHL + PHL}.$$

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

HALF VALUE LAYER: the thickness of a specified substance which, when introduced into the path of a given beam of x-rays or gamma rays, reduces the intensity of the beam by one-half.

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

IRRADIATION: subjection to radiation.

ISOTOPES: atoms with the same atomic number (i.e. same chemical element) but different atomic mass numbers (i.e. different numbers of neutrons).

JOULE (J): the work done when the point of application of a force of 1 N is displaced a distance of 1 m in the direction of the force.

LABELLED COMPOUND: a compound consisting, in part, of molecules made up of one or more atoms distinguished by a non-natural isotopic composition (either stable or radioactive 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): that rate at which an incident particle transfers energy as it travels through matter. The unit is keV/μm.

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

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

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 composition 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 the atomic mass.

PHOTON: a quantized amount of electromagnetic energy, which at time displays particle characteristics.

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

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

RADIOISOTOPE: a radionuclide of a specific element.

RADIONUCLIDE: a radioactive nuclide.

RADIORESISTANCE: relative resistance of cells, tissues, organs and organisms to damage induced by radiation.

RADIOSENSITIVITY: relative susceptibility of cells, tissues, organs and organisms to damage induced by radiation.

REFERENCE MAN: compilation of anatomical and physiological information defined in the report of the International Commission on Radiological Protection 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 linear energy transfer ranges to produce a specific biologic response; the comparison of a dose of test radiation to a dose of 250 keV x-rays that produces the same biologic response.

ROENTGEN (R): the pre-SI unit of exposure that has been replaced by the SI unit C/kg. One roentgen equals 2.58×10^{-4} C/kg of air.

ROENTGEN EQUIVALENT MAN (rem): the pre-SI dose equivalent unit that is numerically equal to the absorbed dose (rads) multiplied by the radiation weighting factor (w_r) and, if appropriate, by the tissue-weighting factor (w_t). The rem has been replaced by the sievert (100 rem = 1 Sv).

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

SHIELD: material used to prevent or reduce the passage of ionizing radiation. See also ‘half layer value’ and ‘tenth value layer’.

SI: International System of scientific nomenclature.

SIEVERT (Sv): the SI unit of dose equivalent that is numerically equal to the absorbed dose (in Gy) multiplied by the radiation weighting factor (w_r) and, if appropriate, by the tissue-weighting factor (w_t). The sievert replaces the rem (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 radioisotope following intake of that radioisotope.

SPECIFIC ACTIVITY: the rate of radioactive decay of a given radioisotope per unit mass of a compound, element or radioisotope.

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

SURVEY METER: a hand-held radiation detection instrument. See also ‘Geiger-Mueller tube’.

TENTH VALUE LAYER: the thickness of a specified substance which, when introduced into the path of a given beam of x-rays or gamma rays, reduces the intensity of the beam by a factor of ten.

THERMOLUMINESCENT DOSIMETER (TLD): a small badge worn by workers, which is used to monitor personal radiation doses. Within certain materials such as lithium fluoride or aluminium oxide, the functional unit in the badge, 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 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.

WATT: unit of power that produces energy at the rate of 1 J/s.

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

Z: atomic number of a given radioisotope.

NUCLEAR ENERGY WORKER
Acknowledgement

In accordance with the Nuclear Safety and Control Act and Regulations of Canada, this is to inform you that you have been notified as a Nuclear Energy Worker (NEW). Users of nuclear substances (radioactive material) at the University of Northern British Columbia are notified as Nuclear Energy Workers when there is reasonable probability that the user will receive a dose of radiation that is greater than the prescribed limit for the general public (1 mSV per calendar year for the whole body) while working with radioactive substances through the course of their research or occupation at the University.

You are required to provide specific information under the Canadian Nuclear Safety Commission Act.

==

I verify that I have been informed in writing of:

1) The risks associated with radiation to which I may be exposed to during the course of my work, including the risk associated with the exposure of an embryo and fetus
2) For females, my rights and obligations should I become pregnant or are breastfeeding. Pregnant NEWs are strongly suggested to notify the RSO once pregnancy is determined. Once declared, regulatory requirements will apply
3) Applicable dose limits. NEWs cannot exceed 50 mSv for a one-year dosimetry period as well as 100 mSv for a five-year dosimetry period. For pregnant NEWs the dose limit for the remainder of the pregnancy cannot exceed 4 mSv
4) The obligation that the University must inform me of my occupational dose on an annual basis in written format
5) The expected dose levels for my current position

I understand the risk, my obligations, and the radiation dose limits and levels that are associated with being notified as a Nuclear Energy Worker.

Signature: ________________________________ Date ________________

(Nuclear Energy Worker)

Signature: ________________________________ Date ________________

(Radiation Safety Officer)

Name: ____

first name middle name last name

UNBC Number ____________ Gender: Male _____ Female_____

Supply Dose Record(s) if received anywhere other than at the University of Northern BC:

Date Location Dose Estimate (History)

____

____

All information will be kept confidential

ACKNOWLEDGEMENTS

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