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Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM)

Canada

Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM)

Prepared by the
Canadian NORM Working Group of the
Federal Provincial Territorial
Radiation Protection Committee

First Edition
October 2000

Our mission is to help the people of Canada maintain and improve their health.

Health Canada

Published by authority of the
Minister of Health

Également disponible en français sous le titre :
Lignes directrices canadiennes pour la gestion des matières radioactives naturelles (MRN)

This publication can be made available in/on (computer diskette/
large print/audio-cassette/braille) upon request.

Cat. H46-1/30-2000E
ISBN 0-662-29448-3

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PREFACE

The NORM Working Group, a working group of the Federal Provincial Territorial Radiation Protection Committee, represents the interests of provincial and territorial regulators and includes affected industries in the petroleum production, fertilizer manufacturing and metal recycling industry sectors. With the support and encouragement of Health Canada and the Canadian Nuclear Safety Commission, these *Guidelines* are the result of their efforts.

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ABBREVIATIONS USED IN THE *GUIDELINES*

ALARA	An acronym for "As Low As Reasonably Achievable", social and economic factors being taken into account. ALARA is a guiding principle in radiation protection, and encourages managers to reduce dose levels as much as possible, even if they are already meeting allowable levels.
ALI	Annual Limit on Intake
BEIR	(the United States National Academy of Science Committee on the) Biological Effects of Ionizing Radiation
CNSC	Canadian Nuclear Safety Commission is the federal agency that licenses and regulates nuclear facilities and materials. The CNSC is the successor to the Atomic Energy Control Board (AECB).
DC	Dose Coefficient
DWL	Derived Working Limit
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection.
NCRP	National Council on Radiation Protection and Measurements
NDR	National Dosimetry Registry
NORM	Naturally Occurring Radioactive Material
SCO	Surface Contaminated Object
TDG	Transportation of Dangerous Goods. A Division of the federal Department of Transport
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

INTRODUCTION

The Canadian Nuclear Safety Commission (CNSC), formerly the Atomic Energy Control Board (AECB), has legislative control of nuclear fuel cycle materials and man-made radionuclides. However, naturally occurring radioactive material (NORM) is exempt from CNSC jurisdiction except for the import, export and transport of the material. Therefore, jurisdiction over use and radiation exposure to NORM rests with each Canadian province and territory.

It has been the practice for companies that encounter challenges associated with naturally occurring radioactive material (NORM) to seek advice on safety procedures from provincial and territorial regulatory agencies. Such advice has been given on an *ad hoc* basis, leading to inconsistencies in the interpretation and application of radiation safety standards across Canada.

The Federal Provincial Territorial Radiation Protection Committee (FPTRPC), a Canadian intergovernmental committee established to support federal, provincial and territorial radiation protection agencies in carrying out their respective mandates, recognizes that the potential radiation hazards from NORM are the same as those from radioactive materials controlled by the CNSC. The basic principle of these *Guidelines* is that where workers or the public are exposed to additional sources or modes of radiation exposure because of activities involving NORM, the same radiation protection standards should be applied as for CNSC regulated activities. This applies to situations where NORM is in its natural state and to cases in which the concentration of NORM material has been increased by processing.

However, in practice there may also be situations where existing natural background radiation is significant quite apart from any activities involving the use of NORM. The issue of whether human intervention is required to reduce such natural radiation levels is quite separate from the issues discussed in these *Guidelines* and the reader is referred to ICRP 65 for a discussion of when such intervention might be warranted.

To that end, the Canadian NORM Working Group has, on behalf of the Federal Provincial Territorial Radiation Protection Committee, produced the *Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM)*. The *Guidelines* are an extension of the work done by the Western Canadian Committee on Naturally Occurring Radioactive Materials (NORM) published in August 1995 as the *Guidelines for the Handling of Naturally Occurring Radioactive Materials (NORM) in Western Canada*.[1] The differences between the Canadian Guidelines and the Western Canadian Guidelines reflect changes in national and international radiation protection practices and consensus standards for NORM classification and management since 1995.

The *Canadian Guidelines* set out principles and procedures for the detection, classification, handling and material management of NORM in Canada, and also include guidance for compliance with federal transportation regulations. These *Guidelines* provide the framework for the development of more detailed NORM management practices and guidelines by regulatory authorities, affected industries and specific workplaces. A separate section outlines the basic science of radioactivity and explains the technical terms and concepts that are used throughout the *Guidelines*. There is also a glossary at the end of the document for quick reference and definitions.

1 NORM AS A RADIATION CONCERN

1.1 Definition

NORM is an acronym for *naturally occurring radioactive materials*, which include radioactive elements found in the environment. Long-lived radioactive elements of interest include uranium, thorium and potassium, and any of their radioactive decay products, such as radium and radon. These elements have always been present in the earth's crust and within the tissues of all living beings.

Although the concentration of NORM in most natural substances is low, higher concentrations may arise as the result of human activities. For example, calcium scale precipitated from oil recovery brine may contain radium at much greater concentrations than the water source itself. The processing of raw materials by many resource-based industries may increase the concentration of radioactive substances in those materials, to levels at which special precautions are needed for handling, storing, transporting, and disposal of material, by-products, end-products or process equipment.

1.2 Purpose of The Canadian NORM Guidelines

As NORM is not part of the nuclear fuel cycle, it does not come under the control of the Canadian Nuclear Safety Commission (CNSC), which licenses and controls radioactive materials associated with the nuclear fuel cycle and artificially produced radionuclides. NORM-related activities therefore fall under the jurisdiction of the provinces and territories. This has lead to inconsistent application of radiation protection standards with numerous agencies involved as materials cross jurisdictional boundaries. For example, transportation of a NORM material for disposal involves:

- Provincial/Territorial Health, Labour and Radiation Regulatory Agencies for worker and public exposure;
- Provincial Environmental Regulatory Agencies for disposal options;
- The Canadian Nuclear Safety Commission for transport of radioactive material.

> **Note**: In its legislation, the CNSC uses the term Naturally Occurring Nuclear Substances instead of NORM.

Accordingly, the *Guidelines* were developed to:

- ensure adequate control of NORM encountered by affected industries;
- harmonize standards;
- reduce jurisdictional gaps or overlap.

The basic principle of the *Guidelines* is that persons exposed to NORM should be subject to the same radiation exposure standards that apply to persons exposed to CNSC-regulated radioactive materials. No distinction is made regarding the origin of the radiation, whether it is NORM in its natural state or NORM whose concentration of radioactive material has been increased by processing (Technologically Enhanced NORM or TENORM). However, because of the ubiquitous nature of NORM, in dealing with situations where natural radiation is significant the cost of any intervention must be taken into account.

A major principle in radiation dose control is that if doses can be reduced by reasonable actions, those actions should be taken. As even low doses of radiation exposure may produce harmful effects, reducing low doses of radiation may be beneficial. The goal is that doses should be *As Low As Reasonably Achievable*, economic and social factors being taken into consideration. This principle is usually referred to by the acronym ALARA.

1.3 Industries with NORM Radiation

There are industries where NORM may be present in amounts sufficient to cause significant radiation doses to workers that require the application of radiation protection practices to reduce radiation doses. Such industries include:

Mineral Extraction and Processing: NORM may be released or concentrated in a process stream during the processing of ore, such as in the phosphate fertilizer industry and the abrasives and refractory industries.

Oil and Gas Production: NORM may be found in the liquids and gases from hydrocarbon-bearing geological formations.

Metal Recycling: NORM-contaminated materials can be redistributed to other industries resulting in the formation of new NORM-contaminated products.

Forest Products and Thermal-Electric Production: mineral ashes left from combustion may concentrate small amounts of NORM present naturally in plant materials and in coal.

Water Treatment Facilities: fresh or waste water is treated through sorptive media or ion-exchange resins to remove minerals and other impurities from the water being treated and may release radon (geothermal sources, fish hatcheries).

Tunnelling and Underground Workings: in areas where small amounts of indigenous radioactive minerals or gases may be present, such as in underground caverns, electrical vaults, tunnels, or sewer systems.

1.4 Description and Sources of NORM

1.4.1 Background Radiation

Life on earth has always been exposed to natural radiation from the environment, also referred to as background radiation. The main sources of this radiation are cosmic radiation from the sun and outer space, and terrestrial radiation from radioactive elements in the earth's crust. A common example of terrestrial radiation source is radon gas, which comes from uranium in the soil and can accumulate in buildings.

1.4.2 Radionuclides and Ionizing Radiation

Chemical elements are characterized by the number of protons in the nucleus of their atoms. Atoms also contain other "sub-atomic particles" such as neutrons and electrons. The number of protons in the atoms of a given element is constant, but the number of neutrons can differ. Atoms of an element that have different numbers of neutrons are called isotopes of that element, though they all behave chemically the same way. Isotopes of an element are referred to by the name of the element followed by the number of the isotope's nucleons (protons + neutrons). Uranium, for example, always has 92 protons, but it has a number of isotopes identified by the number of their nucleons, such as uranium-235 and uranium-238.

Most common isotopes of chemical elements are stable; that is, the balance of protons and neutrons in the nucleus of their atoms never changes. In isotopes of some elements, however, the balance of protons and neutrons in the atom makes the atom unstable, so it ejects one or more particles and excess energy from the nucleus to become more stable. This process is called nuclear disintegration. The particles or high-energy rays are called "ionizing radiation" because they ionize, or change the physical and chemical structure of, other atoms of matter they pass through. Elements that emit ionizing radiation are called radioactive; in some cases, one or more isotopes of an element are radioactive, and are called radioisotopes, or radionuclides.

1.4.3 Half-Life and the Radioactive Decay Series

A radionuclide can be identified by the characteristics of the radiation it emits. These characteristics include the decay rate, or half-life of the radionuclide, and the type and energy of radiation emitted.

The rate at which particles are emitted is expressed by the half-life of the radionuclide. The half-life is the length of time it takes for half of a substance's atoms to 'decay' to a more stable form, or to reduce the radioactivity by half. The half-life can be as short as a fraction of a second or as long as billions of years. As a radionuclide decays, it becomes an isotope of another element. If this new isotope is also radioactive it decays further. Thus there can develop a "decay series." The two most common NORM decay series are the uranium-238 and the thorium-232 series. Figure 1.1 lists the radioisotopes associated with the uranium and thorium radioactive decay series and potassium, and also gives the chemical symbol for each element and isotope.

Figure 1.1
Chemical Symbols and Important Characteristics of the U-238, Th-232 Radioactive Decay Series and K-40

URANIUM 238 SERIES				THORIUM 232 SERIES			
NORM Nuclide	**Symbol**	**Half-Life**	**Major Emissions**	**NORM Nuclide**	**Symbol**	**Half-Life**	**Major Emissions**
Uranium 238	^{238}U	4.5×10^9 y	α	Thorium 232	^{232}Th	1.4×10^{10} y	α
Thorium 234	^{234}Th	24.0 d	β, γ	Radium 228	^{228}Ra	5.7 y	β
Protactinium 234m	^{234m}Pa	1.2 m	β, γ	Actinium 228	^{228}Ac	6.1 h	β, γ
Uranium 234	^{234}U	2.5×10^5 y	α, γ	Thorium 228	^{228}Th	1.9 y	α, γ
Thorium 230	^{230}Th	7.7×10^4 y	α, γ	Radium 224	^{224}Ra	3.7 d	α, γ
Radium 226	^{226}Ra	1.6×10^3 y	α, γ	Radon 220	^{220}Rn	55.6 s	α
Radon 222	^{222}Rn	3.83 d	α	Polonium 216	^{216}Po	0.15 s	α
Polonium 218	^{218}Po	3.1 m	α	Lead 212	^{212}Pb	10.6 h	β, γ
Lead 214	^{214}Pb	27 m	β, γ	Bismuth 212	^{212}Bi	61 m	α, β, γ
Bismuth 214	^{214}Bi	20 m	β, γ	Polonium 212 (65%)	^{212}Po	3×10^{-7} s	α
Polonium 214	^{214}Po	1.6×10^{-4} s	α, γ	Thallium 208 (35%)	^{208}Tl	3.1 m	β, γ
Lead 210	^{210}Pb	22.3 y	β, γ	**Lead 208**	^{208}**Pb**	**Stable**	**none**
Bismuth 210	^{210}Bi	5.01 d	β				
Polonium 210	^{210}Po	138 d	α	**POTASSIUM-40**			
Lead 206	^{206}**Pb**	**Stable**	**none**	Potassium 40	40K	1.3×10^9 y	β, γ

Key:

Example: **Bismuth 212** ^{212}**Bi** **61 m** α, β, γ

212: Mass Number for Bismuth 212

Bi: Chemical symbol for Bismuth

61 m: Radioactive half-life of 61 minutes (y = years; d = days; h = hours; m = minutes; s = seconds)

α: Alpha decay (emission)
β: Beta decay (emission)
γ: Gamma (emission)

1.4.4 Radioactive Equilibrium

The final member of a decay series is stable. The first member (the "parent radionucide") is almost always very long-lived – it has a long half-life. When all the members of a decay series (the parent radionuclide and its "progeny") are "in equilibrium" they all decay at the same rate - the rate at which each in turn is being produced – and every radioactive element or radioactive progeny in the series has the same amount of radioactivity. If such radioactive material is processed chemically or otherwise disturbed, the equilibrium is disrupted.

1.4.5 Types of Radiation

There are three basic types of radiation that may be emitted by NORM:

- **alpha** (α) radiation is made up of heavy, charged particles that cannot penetrate very far, even in air. They can be stopped by a piece of paper.
- **beta** (β) radiation consists of lighter charged particles than alpha particles, that travel faster and are thus more penetrating than alpha radiation. Beta radiation can be stopped by a few centimetres of plywood.
- **gamma** (γ) radiation consists of high-energy rays, and is very penetrating. It can be stopped by a metre of concrete or several metres of water.

1.5 Fundamental Radiation Protection Quantities

There are two fundamental quantities:

Becquerel (= Activity). The becquerel (Bq) measures the quantity of radioactivity present without consideration for what kind of radiation is emitted. 1 Bq = 1 nuclear transformation (disintegration) per second.

Sievert: Effective Dose (= Biological Effect). Different types of radiation have different penetrating power, and different parts of the body have different sensitivities to radiation. Dose assessment therefore requires a knowledge of the type and amount of radiation and the biological sensitivity of the body part exposed.

The sievert (Sv) is the unit of Effective Dose of radiation, and accounts for the total effect of different types of radiation on different parts of the body. Most occupational doses are in the millisievert range, or mSv. Regulations express the dose on a yearly basis, as millisieverts per annum or mSv/a.

An individual may receive an "internal" exposure to a radioactive substance, by inhaling radioactive gas or particles suspended in the air, or by ingesting radioactive dust. The material may remain in the body for some time after the intake, giving a dose. The life-time dose that will be received from an internal exposure is the "committed dose," also expressed in sieverts.

1.6 Background Radiation Dose Summary

Figure 1.2 is a pie chart showing the size in percent of each component of the background radiation dose received by the average Canadian.[(2)] Sources of natural radiation can be classified into three groups: the dose that comes from direct cosmic radiation that arrives at the earth's surface from the sun and outer space; the dose from environmental radiation, which comes from the natural radioactivity at the earth's surface; and internal radiation.

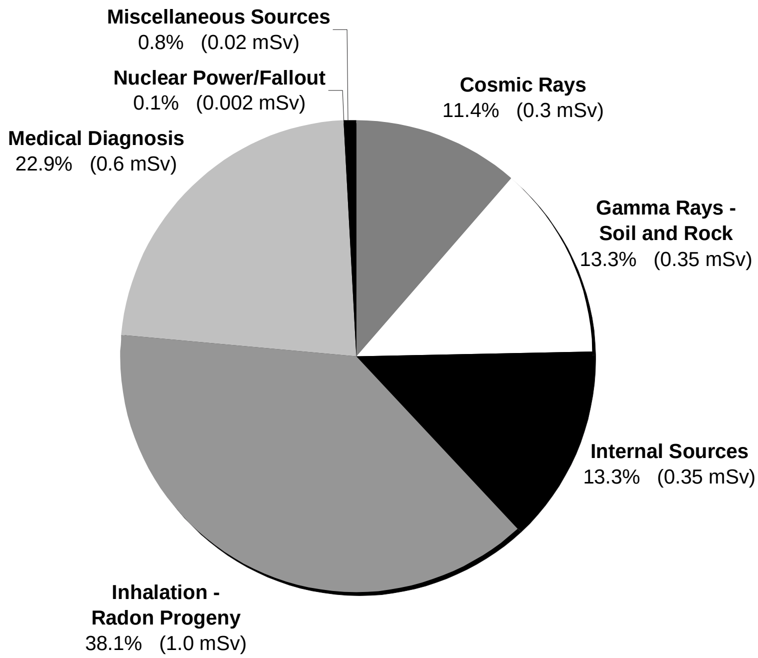
Cosmic radiation varies with elevation above sea level, but contributes about 0.3 mSv/a over most of Canada.

The range of gamma dose rates from naturally occurring radionuclides in the uranium and thorium series, and potassium-40 present in typical soil is:

0.045 - 0.09 mSv/a for the uranium-238 series;
0.09 - 0.15 mSv/a for the thorium-232 series;
0.09 - 0.15 mSv/a from potassium-40.

The typical dose rate from the two series and potassium-40 is 0.35 mSv/a.

Figure 1.2
Average Annual Radiation Dose to Canadians
(Average Total Dose of 2.62 mSv per year)



Source: Canada; Living with Radiation; AECB, 1995.

There is an average internal dose of about 1.0 mSv from the inhalation of radon progeny; but the dose varies greatly with the geological composition of the environment. For example, the average dose from radon progeny in Vancouver is 0.2 mSv/a, but in Winnipeg it is 2.2 mSv/a.

Another source of internal radiation is from a radio-acive isotope of potassium: muscle tissue contains potassium, of which 0.0118 % is potassium-40, a natural gamma and beta ray emitter which contributes about 0.35 mSv per year.

In total, a Canadian may receive a range of annual doses from background radiation from 1.2 mSv/a to 3.2 mSv/a based on geographical location. The average Canadian receives a typical annual dose of approxi-mately 2.0 mSv from background radiation.

Clearly, as radiation doses from NORM cannot be prevented, the question is: **At what incremental dose should we begin to apply radiation protection prac-tices to NORM?** The *Guidelines* have been developed to help answer this question.

2 THE NORM STANDARDS — BASIS AND CRITERIA

2.1 Uniformity of Protection

The basic principle of these guidelines is that the same radiation exposure criteria should be applied where workers or the public are exposed to new sources or modes of radiation from activities involving NORM, as for radiation exposure from CNSC regulated activities. This applies to cases where NORM is in its natural state and to cases in which the concentration of NORM material has been increased by processing.

2.2 Guideline Basis

The *Guidelines* are based on the most recent international standards recommended by the International Commission on Radiological Protection (ICRP) and CNSC regulations. The recommendations of the ICRP represent international consensus on radiation protection standards and provide the basis for regulatory control of radioactive materials in virtually all countries of the world. As these regulations and standards are subject to periodic amendment, the *Guidelines* may also be updated to reflect amendments to accepted national and international radiation protection practices. The ICRP and International Atomic Energy Agency (IAEA) radiation protection philosophy and recommendations of significance for NORM in Canada are contained in ICRP reports 60(3), 65(4), 68(5), 72(6) and 77(7) and IAEA Safety Series 115.(8)

2.3 The Acceptability of Occupational Risks in Industry

The ICRP reviews estimates of radiation risk from every available source, particularly the work of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the United States National Academy of Science Committee on the Biological Effects of Ionizing Radiation (BEIR). The reports of the ICRP go further than these sources, in that the ICRP recommends permissible exposures for workers while the other bodies merely estimate the risks associated with radiation exposure.

The ICRP believes that any exposure to ionizing radiation may be potentially harmful to health, and advocates three fundamental principles for managing radiation exposures:

- **JUSTIFICATION** — No activity involving ionizing radiation for any purpose can be justified unless it is possible to demonstrate that it will lead to a positive net benefit.
- **OPTIMIZATION** — All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into consideration; (the ALARA principle).
- **LIMITATION** — The maximum acceptable occupational exposure of any individual must not involve a radiation risk to that individual greater than the risk that arises in working in what is generally regarded as a “safe” industry.

The ICRP recognizes that everyone is subject to a significant background radiation exposure. However, even smaller-than-background doses from occupational practices are unjustifiable if there is no associated benefit, or they can be readily avoided.

2.4 Recommended Radiation Dose Limits

It is the recommendation of the Federal Provincial Territorial Radiation Protection Committee that the annual incremental effective dose to persons exposed to NORM as the result of a work practice be limited to the values given in Table 2.1.

These dose limits are the foundation for all other radiation protection program recommendations contained in the *Guidelines*; are harmonized with the radiation dose limits recommended by the Canadian Nuclear Safety Commission for Nuclear Fuel Cycle; and incorporate the recommendations of ICRP Publication 60.(3)

2.4.1 Incremental Dose

Dose limits in this document are defined in terms of incremental dose, which is the dose resulting from the work practice in question. The natural background radiation, including radon, is excluded from the dose limitations. Radiation dose arising from the application of medical procedures is also excluded from the dose limitations.

2.4.2 Effective Dose

The ICRP defines the effective dose as the sum of all tissue equivalent doses multiplied by the appropriate tissue weighting factors associated with each respective tissue. The effective dose accumulated over a given period includes:

a. the effective dose from external sources, and
b. the committed effective dose from intakes of radionuclides in that period.

Table 2.1
Radiation Dose Limits

Affected Group	Annual Effective Dose Limit (mSv)[a]	Five Year Cumulative Dose Limit (mSv)
Occupationally Exposed Workers[b]	20[c]	100
Incidentally Exposed Workers and Members of the Public	1	5

Notes:

(a) These limits are exclusive of natural background and medical exposures. Refer to Appendix D for guidance on dose limit calculations.

(b) For the balance of a known pregnancy, the effective dose to an occupationally exposed worker must be limited to 4 mSv as stipulated in the "Radiation Protection Regulations", *Canadian Nuclear Safety Act.* This limit may differ from corresponding dose limits specified in current provincial legislation applicable for exposure to sources of x-rays.

(c) For occupationally exposed workers, a maximum dose of 50 mSv in one year is allowed, provided that the total effective dose of 100 mSv over a five-year period is maintained. This translates into an average limit of 20 mSv/a.

Occupationally Exposed Workers are employees who are exposed to NORM sources of radiation as a result of their regular duties. They are classified as NORM Workers working in an occupational exposure environment, and their average annual effective dose should not exceed 20 mSv (see Table 2.1 note c, for exception).

Incidentally Exposed Workers are employees whose regular duties do not include exposure to NORM sources of radiation. They are considered as members of the public who work in an occupational exposure environment and, as such, the annual effective dose limit for these workers is 1 mSv.

2.4.3 Dose Constraint

A dose constraint is an upper value on the annual dose that members of the public or incidentally exposed workers should receive from a planned operation or single source. To ensure that the public and incidentally exposed workers do not exceed the annual dose limit of 1 mSv, the ICRP[7] and the IAEA[8] suggest the use of a dose constraint. The dose constraint would allow for exposures from other sources without the annual limit being exceeded. The retrospective finding that a dose constraint, as opposed to a dose limit, has been exceeded does not imply a failure to comply with the recommendations of the *Guidelines*. Rather it should call for a reassessment of the effectiveness of the program.

ICRP[7] suggests that for the control of public exposure an appropriate value for the dose constraint is 0.3 mSv in a year. In keeping with this suggestion the *Canadian NORM Guidelines* have adopted 0.3 mSv/a as its first investigation level. Tables 5.1 and 5.2 list the amounts of radioactive materials that if released to the environment without further controls will not cause doses in excess of 0.3 mSv/a.

3 DEVELOPMENT OF A NORM MANAGEMENT PROGRAM

3.1 The NORM Program Classifications

The NORM program classifications summarize the requirements for managing NORM. The worksite classification is set by the maximum annual dose received by both members of the public and workers at the worksite (Figure 3.1). The classification of an individual NORM source is set by the annual dose that may be received by a member of the public from exposure to the shipment or disposal practice.

Estimates should be made of the effective dose to workers and the public resulting from the following exposure pathways:

- External gamma exposure.
- Ingestion of NORM-containing materials.
- Inhalation of NORM-containing dust.
- Inhalation of radon gas and its radioactive decay products.

The highest individual dose determines the NORM Management classification. Guidance on effective dose calculations can be found in Appendix D.

> It is strongly recommended that a person knowledgeable in radiation protection conduct the worksite radiological evaluation. A list of radiation protection consultants can be obtained from the appropriate provincial or territorial government contact. A list of government contacts can be found in Appendix B.

3.2 NORM Classification/Thresholds

3.2.1 Investigation Threshold

An incremental dose of 0.3 mSv/a, the dose constraint value set in section 2.4.3, is adopted as the NORM Investigation Threshold. Where doses to workers or members of the public may exceed this value, a site-specific assessment should be carried out.

3.2.2 NORM Management Threshold

An assessed incremental dose to the public or workers of greater than 0.3 mSv/a, the dose constraint value set in section 2.4.3 and the Investigation Threshold, is adopted as the NORM Management Threshold.

3.2.3 Dose Management Threshold

An assessed incremental dose of 1 mSv/a to a worker is adopted as the Dose Management Threshold.

3.2.4 Radiation Protection Management Threshold

An assessed or measured incremental worker dose of 5 mSv/a is adopted as the Radiation Protection Management Threshold.

3.3 Introduction of a NORM Program

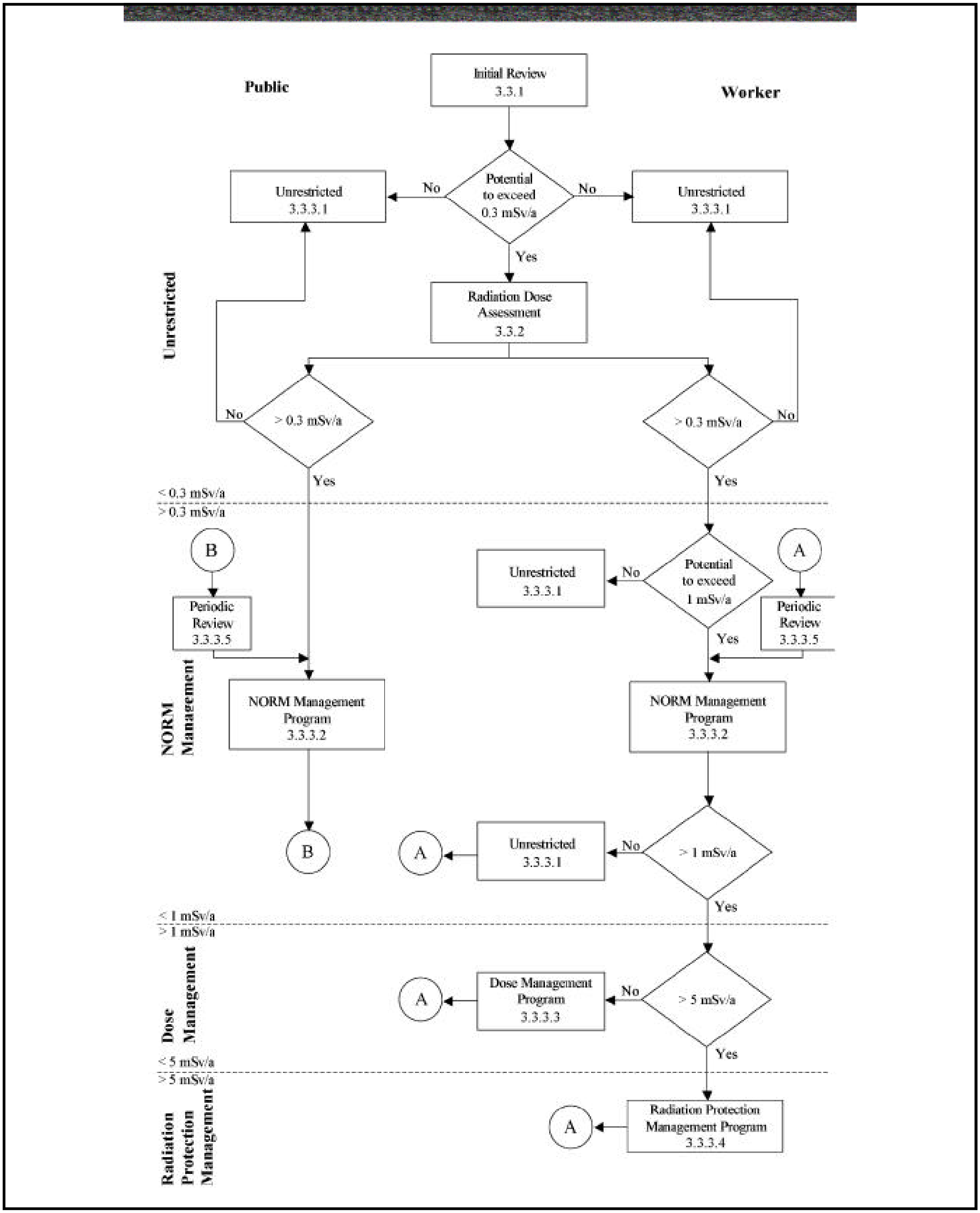
The steps to determine the type of NORM Management program at a workplace are given below. Figure 3.1 summarizes the process in a flow-chart.

3.3.1 Initial Review

If a workplace falls in one of the NORM-prone industries noted in Section 1.3:

- stores, handles or disposes of materials containing amounts of natural radioactive substances in excess of amounts in Tables 5.1 for diffuse NORM or 5.2 for discrete NORM; or

Figure 3.1
NORM Classification Flowchart



- has suspected incremental effective dose rates in excess of 0.3 mSv/a;

the NORM Investigation Threshold may be exceeded. A dose assessment should be carried out.

3.3.2 Radiation Dose Assessment

Estimate doses to members of the public, and workers by conducting a radiation survey of the workplace/ worksite. The survey should include evaluations of both gamma dose-rates and airborne radioactivity as required.

Workers with estimated doses in excess of 1 mSv/a are classified as occupationally exposed workers.

Estimate doses to members of the public from feed-stock, product and waste transport, storage and disposal. Radiochemical analysis of feed stock, products and waste materials may be needed.

3.3.3 Evaluation and Program Classification

3.3.3.1 Unrestricted Classification

Where the estimated incremental annual effective dose to the public is less than 0.3 mSv/a and to the worker is less than 1.0 mSv/a, the NORM program classification is ***Unrestricted***. No further action is needed to control doses or materials.

3.3.3.2 NORM Management Classification

Where the estimated incremental annual effective dose to members of the public or incidental workers is greater than the investigation threshold of 0.3 mSv/a, the NORM classification is ***NORM Management***. Public access would need to be restricted. However, worker access would be unrestricted. Depending on the circumstances and the source of the dose, the NORM Management Program may include:

- Introduction of incidentally exposed worker access restrictions.
- Introduction of shipping and/or material management.
- Changes in work practices.

Where the work site, feed and waste materials are subject to change, the work site, feed and waste material should be reviewed periodically to verify that conditions have not changed.

3.3.3.3 Dose Management

Where the estimated incremental annual effective dose to an occupationally exposed worker is greater than the dose management threshold of 1 mSv/a, the NORM classification is ***Dose Management***.

The program should include:

- Worker notification of radiation sources.
- Consideration of work procedures and protective clothing to limit worker dose from NORM.
- Application of engineering controls where appropriate (see 4.3.3).
- Training to control and reduce worker dose.
- Introduction of a worker radiation dose estimate program. Doses may be estimated from the dose rate in each working area and the time spent in each area or by personal monitoring.
- Reporting of worker doses to the National Dose Registry (NDR) (see address in Appendix B).

Assess the work site periodically to measure changes in conditions and to facilitate worker dose calculations.

3.3.3.4 Radiation Protection Management

Estimated Annual Effective Dose

Where the estimated annual effective dose to an occupationally exposed worker is greater than 5 mSv/a, the NORM classification is ***Radiation Protection Management***. In addition to the requirements of the Dose Management Program, the following should be included:

- Introduce a formal radiation protection program as described in Appendix G. This program is similar to the formal program required by the CNSC for nuclear energy workers exceeding 5 mSv/a.
- Place those workers estimated to exceed 5 mSv/a in a personal radiation dosimetry program meeting the requirements of S-106, Technical and Quality Assurance Standards for Dosimetry Services in Canada.[9]
- Provide protective equipment, clothing and work procedures to reduce worker dose and the spread of contamination.

Measured Annual Effective Dose

Where the measured annual effective dose reported by personal radiation dosimetry program is greater than 5 mSv/a, the NORM classification is ***Radiation Protection Management***. The program should include the following additional steps:

- Use engineering controls and provide protective equipment designed to reduce worker dose as required.
- Ensure that workers do not exceed the five-year average occupational dose limit of 20 mSv/a.

Assess the work site periodically to measure changes in conditions and to facilitate worker dose calculations.

3.3.3.5 Periodic Review

Whenever a NORM Management, Dose Management or Radiation Protection Management Program has been implemented, a periodic review is needed . The review is to determine if there have been changes to the system that may affect the radiation dose, to monitor the effectiveness of the NORM program and to determine if modifications are required. The frequency of the periodic review will depend on the ability of conditions to change and the NORM program.

3.3.4 ALARA

The goal is that doses should be As Low As Reasonable Achievable, economic and societal factors being taken into account. From the time a NORM accumulation is expected to the implementation of a NORM Program, the ALARA principle should be the prime decision making criterion used to ensure minimal public and worker radiation dose.

4 DERIVED WORKING LIMITS (DWLs) FOR NORM

Derived Working Limits (DWLs) have been determined from the annual radiation dose limits to assist in dose assessment. The DWL's provide an estimate of dose from the quantities that may be directly measured in the workplace. A Radiation Assessment program may compare measurement results to derived working limits (DWLs).

4.1 Gamma Radiation Dose Rate

4.1.1 Investigation Threshold

The occupational dose-rate that will give an incremental gamma radiation dose of 0.3 mSv/a is 0.15 µSv/h. The DWL for the gamma Investigation Threshold is an incremental dose-rate above off-site background of 0.15 µSv/h.

4.1.2 Dose Management Threshold

The occupational dose-rate that will give an incremental gamma radiation dose of 1 mSv/a is 0.5 µSv/h. The DWL for the gamma Dose Management Threshold is an incremental dose-rate of 0.5 µSv/h.

4.1.3 Radiation Protection Threshold

There is no DWL for the gamma Radiation Protection Threshold as doses are expected to be derived by dosimetry measurement/estimation.

4.2 Radon Concentration

4.2.1 Introduction

Radon is a radioactive gas produced by the decay of radium isotopes in both the uranium and thorium radioactive decay series (see Figure 1.1). As it is a gas, radon can be carried away from its origin by air or water flows, and released into workplace air. Usually radon-222 is the only isotope present in high enough concentrations to provide a significant dose, but radon-220 (thoron-220) can be present where thorium is handled or stored.

Although elevated radon concentrations from natural causes are common in buildings, it is not the intention of these *Guidelines* to provide guidance on the management of radon in other than workplace settings. Information on public/residential radon exposure guidelines can be obtained from *Radon – A Guide for Canadian Homeowners*(10) published by Canada Mortgage and Housing Corporation and Health Canada.

Radon released from soil beneath a building gives rise to an average indoor background concentration of about 50 Bq/m^3, but much higher values are possible in some areas. This concentration is so variable with time, that short-term assessment measurements are unlikely to distinguish convincingly between background radon and that released by an industrial practice. In excavations and tunnelling the industrial practice releases radon from the soil, so there can be no distinction between background radon and that introduced or released by the industrial practice (practice radon).

> As a result, the recommendations for radon are modified to take practical constraints into account. As background radon generally cannot be distinguished from practice radon, the dose limits given here are based on TOTAL dose from radon exposure, not the INCREMENTAL dose from the practice as used elsewhere in these *Guidelines*.

The dose from radon can be estimated either from the radon gas concentration (Bq/m^3), or from the progeny energy concentration (joules per cubic metre (J/m^3)). On grounds of cost and convenience, it is recommended that radon-222 concentration be the preferred measurement method for screening measurements where dose estimates are less than 5 mSv/a. The only approved personal dosimetry system measures progeny concentration (J/m^3), therefore dose rates over 5 mSv/a must be evaluated on that basis. The dose from thoron can only be estimated from progeny concentration.

Conversion factors relating dose from exposure to radon from radon gas concentration and from progeny energy concentration are given in Appendix C. The assumptions and uncertainties in these conversion factors are described in ICRP Publication 65.(4) Other relationships between gas and progeny measurements are also given in Appendix C.

4.2.2 Investigation Derived Working Limit for Radon

The occupational radon concentration that gives a dose of 0.3 mSv/a is about 50 Bq/m^3, which is comparable to the background concentration of radon in buildings. However, as the background radon concentration can vary considerably, the Derived Working Limit for radon is 150 Bq/m^3. The Unrestricted Classification therefore applies to all circumstances where the average radon concentration is less than 150 Bq/m^3. Where the annual average concentration of radon gas is expected to be above 150 Bq/m^3, measurements should be made to estimate the average annual radon gas concentration.

4.2.3 NORM Management for Radon

Where the estimated annual average concentration of radon gas in an occupied area is more than 150 Bq/m^3 but less than 800 Bq/m^3, the NORM Classification is NORM Management. Depending on the source of the radon, application of ALARA may include:

- introduction of public and incidentally exposed worker access management;
- changes in work practices.

The work site should be reviewed periodically to verify that conditions have not changed.

4.2.4 Radiation Protection Management for Radon

The DWL for the radon-222 Radiation Protection Management threshold is an average annual radon concentration of 800 Bq/m^3. Where the estimated annual average concentration of radon gas is more than 800 Bq/m^3, the NORM Classification is Radiation Protection Management. A Radiation Protection Management program as described in section 3.3.3.4 should be implemented. The program should include steps to reduce the radon levels to below 800 Bq/m^3.

4.3 Annual Limit on Intake (ALI)

The Annual Limit on Intake is the amount of radioactive material a worker can ingest or inhale each year, that will deliver an annual effective dose of 20 mSv. ALI values are derived from dose coefficient (DC) values, developed by the ICRP. They are based on a critical review of available research on the estimation of radiation dose delivered to specific organs and tissues which arise from an intake of a given quantity of the radionuclide.

Intake parameters (breathing rate, particle size, etc.) are different for occupational or public exposure conditions so there are different DC values for occupational (DC_w) or public (DC_p) exposure.

4.3.1 Occupational ALIs

Two groups of workers must be considered in assigning ALIs:

- **Occupationally Exposed Workers** are employees who are exposed to NORM sources of radiation through their regular duties. They are classified as NORM Workers working in an occupational exposure environment, and their average annual effective dose must not exceed 20 mSv.
- **Incidentally Exposed Workers** are other employees whose regular duties do not include exposure to NORM sources of radiation. They are considered as members of the public who work in an occupational exposure environment and, as such, the annual effective dose limit for these workers is 1 mSv.

Table 4.1 shows DC_w and ALI values for NORM workers for significant NORM radionuclides. The DC_w values are from ICRP Publication 68,(5) and are based on an average effective dose limit of 20 mSv per year.

Appropriate ALI values for incidentally exposed workers are 1/20 of the ALI values listed in Table 4.1.

Figure 4.1
Radon and NORM Program Classifications[a]

ANNUAL DOSE	NORM PROGRAM CLASSIFICATION
3000 Bq/m^3	(20 mSv/a Occupational Dose Limit: five year Avg.)[b]
	RADIATION PROTECTION MANAGEMENT
800 Bq/m^3	(5 mSv Radiation Protection Management DWL)[c]
	NORM MANAGEMENT
150 Bq/m^3	(Investigation DWL)[c]
	UNRESTRICTED
Background	

Notes:

(a) Control of Radon 222 and its progeny within the values given in Figure 4.1 will concurrently control Radon 220 and its progeny within applicable limits.

(b),(c) An equilibrium factor of 0.4 for Radon-222 and its progeny and 2000 hours per year occupational exposure duration are assumed. (Reference 4).

4.3.2 Public ALIs

Instead of specifying ALI values for public dose, the *Guidelines* present Derived Release Limits which specify the maximum total NORM radioactivity (Bq) and radioactive NORM concentration values (Bq/g; Bq/L; Bq/m^3) for unconditional releases into the public domain in Tables 5.1, 5.2 and 5.3. This is a more practical method of providing NORM material management guidance and is consistent with other related environmental release standards.

These release limits are based on the dose arising from all the radiation exposure pathways arising from the release, and are based on a maximum annual dose limit of 0.3 mSv as recommended by ICRP 77.[7]

4.3.3 Inhalation Control Measures

Inhalation can deliver most of the dose in some NORM work environments. Where annual intakes exceed 1/20 of the ALI, engineering control of the source of airborne radioactive material is the preferred management method. Controls include capture ventilation at the source to prevent escape into the air, and room ventilation rate increase.

If intakes exceed 25% of the ALI (equivalent to 5 mSv/a) after engineering controls are applied, a respiratory protection program and/or limiting worker access should be considered as part of the radiation protection program. Respiratory protection must follow the standards requirements specified for other hazardous dusts under the local jurisdiction.

Respirator Program

A high protection factor can only be obtained if there is an effective respirator selection, service and fitting program.[11]

Table 4.1
Annual Limits on Intake for Occupationally Exposed Workers

NORM Radionuclide	Inhalation (5 μm AMAD)[a]			Ingestion		
	Type[b]	DC_w (Sv/Bq)	ALI (Bq)[c]	f_1[d]	DC_w (Sv/Bq)	ALI (Bq)[c]
Lead-210	F	1.1e-06	18,000	0.2	6.8e-07	29,000
Polonium-210	F M	7.1e-07 2.2e-06	28,000 9,000	0.1	2.4e-07	83,000
Radium-226	M	2.2e-06[g]	9,000	0.2	2.8e-07	71,000
Radium-228	M	1.7e-06	12,000	0.2	6.7e-07	30,000
Thorium-228	M S	2.3e-05 3.2e-05	900 600	0.0005 0.0002	7.0e-08 3.5e-08	290,000 570,000
Thorium-232	M S	2.9e-05 1.2e-05	700 1,700	0.0005 0.0002	2.2e-07 9.2e-08	91,000 200,000
Uranium[e] (all progeny)	Mixed	7.1e-06	2,800	Composite	1.2e-07	170,000
Uranium (par) (U-238, U-234)[f]	F M S	5.8e-07 1.6e-06 5.7e-06	34,000 13,000 3,500	0.02 0.002	4.4e-08 7.6e-09	450,000 2,600,000

Notes:

(a) Activity Mean Aerodynamic Diameter. An average inhaled aerosol size of 5 microns (5µm).

(b) The column "Type" reflects the relative rate of absorption of deposited material from the respiratory tract into the blood stream hence the probability of uptake of the material into biological systems. Types F, M, and S materials respectively have; Fast, Moderate and Slow rates of absorption into blood from the respiratory tract.

(c) ALI values are based solely on radiological considerations where the intake of 1 ALI corresponds to an annual effective dose of 20 mSv. For incidentally exposed workers multiply the ALI values by 1/20. For some long-lived NORM radionuclides, chemical toxicity may be more restrictive. Chemical and radiological toxicity should be reviewed prior to setting workplace exposure limits.

(d) The retained fraction of the initial intake. The fraction absorbed versus total intake quantity. The rest passes through the GI Tract and is excreted.

(e) From "Interim Annual Limits on Intake for Long-lived Radioactive Dust", Atomic Energy Control Board (CNSC), January 1995.

(f) The residual uranium nuclide remaining after the chemical or physical separation of its progeny.

(g) From "Age Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 – Compilation of Ingestion and Inhalation Coefficients, ICRP Publication 72, Annals of the ICRP, Vol. 26, number 1, 1996.

5 NORM MATERIAL MANAGEMENT

5.1 Non-radioactive Hazards of NORM Materials

The *Guidelines* provide recommendations based on the radiological properties of NORM. In determining an acceptable material management option, other hazardous properties such as chemical toxicity must be considered. In many cases, the non-radiological hazardous properties of NORM materials are the critical selection criteria for the preferred NORM material management option.

5.2 NORM Derived Release Limits

To assist in NORM material management, Derived Release Limits (DRLs) have been determined from the annual radiation dose limits. The DRL's provide an estimate of public dose from measured releases of NORM. A Radiation Assessment or Material Management program may compare measurement results to Derived Release Limits (DRLs).

5.2.1 Unrestricted Classification

The control of public exposure to radiation from NORM disposal is constrained to less than the public dose limit to allow for exposures from multiple sources. The *Guidelines* recommend that NORM may be released with no radiological restrictions when the associated dose is no more than 0.3 mSv in a year. The radioactive hazard associated with this dose is considered insignificant, and no further control on the material is necessary on radiological protection grounds. It may be necessary to consult and obtain approval from Provincial waste disposal regulatory agencies regarding non-radiological properties.

Derived Release Limits for the amount and concentration of NORM materials that meet this criteria have been calculated, and are presented in Tables 5.1, 5.2 and 5.3 as Unconditional Derived Release Limits.

5.2.2 Release with Conditions

NORM quantities in excess of the Unconditional Derived Release Limits may, after a specific site review, be released without further consideration. In such instances, the basic premise is that the material, in its final disposition, will not contribute a dose to an individual that is greater than 0.3 mSv/a. Outside those situations or conditions, the material falls within a more restrictive NORM classification.

5.3 Derived Release Limits for NORM Materials

5.3.1 Diffuse NORM

Diffuse NORM is generally large in volume, with a relatively low radioactive concentration that is uniformly dispersed throughout the material. Diffuse NORM by-products from industrial activity are usually stored close to the point of generation as the cost of long distance transportation is prohibitive. Phosphogypsum, a by-product of fertilizer production, is an example of diffuse NORM.

Disposal of diffuse NORM sources requires consideration of the effects of dilution, possible re-concentration of the material in the environment, and the manner in which the material may deliver radiation doses to the public.

Table 5.1 shows the Unconditional Derived Release Limits for Diffuse NORM. Unrestricted release of NORM at the listed concentrations will deliver a maximum effective dose of 0.3 mSv/a under conservative scenarios. The calculations are given in Appendix E. Actual effective doses arising from releases of NORM at Unconditional Derived Release Limits are expected to be substantially less than the 0.3 mSv/a.

Table 5.1
Unconditional Derived Release Limits – Diffuse NORM Sources

NORM RADIONUCLIDE	Derived Release Limit[a]		
	AQUEOUS[b] (Bq/L)	SOLID (Bq/kg)	AIR (Bq/m^3)
Uranium-238 Series (all progeny)	1	300	0.003
Uranium-238 (U-238, Th-234,Pa-234m, U-234)	10	10,000	0.05
Thorium-230	5	10,000	0.01
Radium-226 (in equilibrium with its progeny)	5	300	0.05
Lead-210 (in equilibrium with bismuth-210 and polonium-210)	1	300	0.05
Thorium-232 Series (all progeny)	1	300	0.002
Thorium-232	1	10,000	0.006
Radium-228 (in equilibrium with Ac-228)	5	300	0.005
Thorium-228 (in equilibrium with all its progeny)	1	300	0.003
Potassium-40	n/a[d]	17,000[c]	n/a

Notes:

(a) Pathways Considered:

Aquatic

1. Value 10X Guideline for Canadian Drinking Water Quality.

Terrestrial

1. External groundshine from soil contaminated to infinite depth.
2. Soil-veg-ingestion//soil ingestion.
3. Inhalation of resuspended material.

Air

1. Inhalation at concentration resulting in 0.3 mSv.
2. Exposure factor of 25% assumed.

Assumptions:

- All radionuclides and compartments in equilibrium.
- Typical values for uptake and transfer factors.
- No allowance for hold-up time.
- 25% “occupancy” factor for solid source (groundshine, soil ingestion, resuspension), 25% ‘occupancy’ factor for air, and 50% of vegetable intake grown on soil.
- No correction for shielding, surface roughness.

Where more than one long-lived radionuclide is present in a sample, the appropriate sum of the ratios of the activity of each long-lived radionuclide and its corresponding Release limit, must not exceed 1,

e.g., $\frac{\text{Concentration NORM Isotope A}}{\text{Derived Release limit A}} + \frac{\text{Concentration NORM Isotope B}}{\text{Derived Release limit B}} + \ldots + \frac{\text{Concentration NORM Isotope N}}{\text{Derived Release limit N}} \leq 1$

(b) Aqueous Release limits ~10x Guidelines for Canadian Drinking Water Quality. Subsequent dilution of the release is assumed. Refer to the Provincial Drinking Water Standard where planned diffuse NORM releases must meet provincial drinking water standards. (See reference 16)

(c) Natural abundance of Potassium 40 in potassium chloride.

(d) No aqueous release limit is needed as potassium content of the body is under homeostatic control, and is not influenced by environmental levels.

5.3.2 Discrete NORM

Discrete NORM sources are small in size and exceed the concentration criteria for a diffuse source. Because of the possibility of high radiation dose-rates close to the source, the Unconditional Derived Release Limits are lower than for diffuse NORM.

Table 5.2 lists the Unconditional Derived Release Limits for discrete NORM sources. The material must also meet the applicable radioactive surface contamination values, shown in Table 5.3.

Table 5.2
Unconditional Derived Release Limits

NORM RADIONUCLIDE	Unconditional Derived Release Limit [(a)] (Bq)
Uranium Ore (in equilibrium with all progeny)	1,000
Uranium-238 (partitioned) (in equilibrium with thorium-234 and protactinium-234)	10,000
Thorium-230 (no progeny)	10,000
Radium-226 (in equilibrium with its progeny)	10,000
Lead-210 (in equilibrium with bismuth-210 and polonium-210)	10,000
Thorium-232 (in equilibrium with all progeny)	1,000
Radium-228 (in equilibrium with actinium-228)	100,000
Thorium-228 (in equilibrium with its short-lived progeny)	10,000
Potassium-40	1,000,000

Notes:

(a) Unconditional Derived Release Limits, DRLs, (Activity and Concentration) relate to the long-lived parent radionuclide in equilibrium with its progeny. The use of Uranium Ore is considered appropriate for NORM-contaminated substances where equilibrium has not been disturbed by partitioning of the Uranium decay series. Where partitioning has occurred, the activity of *each* long-lived radionuclide must be found and compared to its appropriate *Unconditional Derived Release Limit*. Where more than one long-lived radionuclide is present in a sample, the appropriate sum of the ratios of the activity of each long-lived radionuclide and its corresponding Unconditional Derived Release Limit, must not exceed 1,

e.g., $$\frac{\text{Activity NORM Isotope A}}{\text{Unconditional DRL A}} + \frac{\text{Activity NORM Isotope B}}{\text{Unconditional DRL B}} + \ldots + \frac{\text{Activity NORM Isotope N}}{\text{Unconditional DRL N}} \leq 1$$

5.3.3 Surface Contamination

Limits for surface radioactive contamination on equipment, tools or scrap surfaces intended for unconditional release are based on the analysis of personal radiation exposure pathways to a maximum annual dose of 0.3 mSv. Discrete NORM sources with surface contamination less than the Table 5.3 Surface Contamination Unconditional Derived Release Limits can be released without further investigation.

Table 5.3
Surface Contamination Unconditional Derived Release Limits – Discrete NORM Sources

Property	Limit
Dose Rate	0.5 µSv/h at 50 cm
Surface Contamination	1 Bq/cm^2 averaged over a 100 cm^2 area

Notes:

1. A thin window radiation detector is recommended when monitoring beta/gamma sources of surface contamination.
2. Table 5.3 release limits are only applicable to fixed surface contamination. Loose surface contamination must be completely removed or all accessible surfaces stripped to ensure complete removal.
3. In most cases, decontamination efforts which meet beta surface contamination limits will concurrently provide for the control of mixed alpha/beta/gamma sources.

6 STANDARDS FOR THE TRANSPORT OF NORM

The transport of radioactive material, including NORM, with radioactivity below 70 Bq/g is not subject to federal transportation regulations. All NORM consignments must initially be analyzed for radioactive content to determine whether the material meets Unconditional Derived Release Limits, and if it does not, whether federal transport regulations apply.

NORM with activity above 70 Bq/g falls under federal jurisdiction and is therefore subject to the requirements of federal regulations, including the CNSC's *Packaging and Transport Regulations* (12) and the *Transport of Dangerous Goods Regulations* (13) for all dangerous goods shipments. The CNSC Packaging and Transport Regulations have been harmonized with the IAEA's Safety Series 6, Regulations for the Safe Transport of Radioactive Materials, 1985 Edition (amended 1990) (14) with future plans to harmonize with IAEA's Regulations for the Safe Transport of Radioactive Materials, 1996 Edition, Report ST-1.(15)

6.1 Unrestricted NORM Shipments

Materials meeting all of the following criteria under this classification do not require any special considerations for transportation.

- **General exclusion:** Material has a total specific activity less than or equal to 70 Bq/g; and
- **CNSC exemption:** there are no regulatory requirements for its possession or use under the *Nuclear Safety and Control Act,* and the Packaging and Transportation Regulations pursuant to that Act; and
- meets the Unconditional Derived Release Limits of section 5.3.

6.2 NORM Shipments Subject to the *Canadian Guidelines*

For NORM packaging having less than 70 Bq/g total specific activity and NORM quantities above the Unconditional Derived Release Limits, the following are recommended:

- Ensure that the transport manifest contains the descriptor "*Naturally Occurring Radioactive Material – NORM*".
- Ensure that the consignment is securely packaged in a manner that effectively prevents release of any NORM contamination during transport.
- Do **not** affix radioactive placards or labels on the transport vehicle or on the exterior surfaces of the packaging.

6.3 NORM Shipments Governed by the Federal Transport Regulations

For NORM transport shipments with greater than 70 Bq/g total specific activity, the reader is referred to the CNSC regulations and the IAEA Safety Series regulation on transportation. Access to a copy of the regulations is essential. Preparation of these shipments for transport involves several steps. As a result, lead times from four to six weeks prior to shipment should be planned. For more information concerning transportation requirements, contact the appropriate Federal, Provincial or Territorial government agency. A list of government contacts is provided in Appendix B.

6.4 NORM Surface Contamination Exclusions

A surface contaminated object (SCO) is a solid object which is not itself radioactive but which has radioactive material distributed on its surface. An object with external contamination is exempted from the CNSC Packaging and Transport Regulations if :

(a) the non-fixed contamination when averaged over each 300 cm^2 of all surfaces is less than 0.4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters*, and is less than 0.04 Bq/cm^2 for all other alpha emitters; and

(b) the object itself has an average specific activity less than 70 Bq/g.

*Low toxicity alpha embitters are : natural uranium, depleted uranium, uranium-235 or uranium-238, thorium 232, thorium -228 and thorium-230 when contained in ores or physical and chemical concentrates, or alpha emitters with a half life less than 10 days.

6.5 Additional Information

Refer to the Transportation of Dangerous Goods Regulations, the CNSC Packaging and Transportation Regulations and the IAEA Regulations for the Safe Transport of Radioactive Material for additional information on requirements for the transport of NORM.(12,13,14,15)

REFERENCES

1 *Guidelines for The Handling of Naturally Occurring Radioactive Materials (NORM) In Western Canada*, Western Canadian NORM Committee, Aug. 1995.

2 *Canada: Living With Radiation*, Atomic Energy Control Board, Canada Communication Group-Publishing, 1995.

3 *1990 Recommendations of the International Commission on Radiological Protection,* ICRP Publication 60, Annals of the ICRP, Vol. 21, No. 1-3, 1991.

4 *Protection Against Radon-222 at Home and at Work*, ICRP Publication 65, Annals of the ICRP, Vol. 23, No. 2, 1993.

5 *1994 Dose Coefficients for Intake of Radionuclides by Workers*, ICRP Publication 68, Annals of the ICRP, Vol. 24, No. 4, 1994.

6 *Age Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 – Compilation of Ingestion and Inhalation Coefficients*, ICRP Publication 72, Annals of the ICRP, Vol. 26, No. 1, 1996.

7 *Radiological Protection Policy for the Disposal of Radioactive Waste.* ICRP Publication 77, Annals of the ICRP, Vol. 27, Supplement 1997.

8 *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources*, IAEA Safety Series No. 115, 1996.

9 *Technical and Quality Assurance Standards for Dosimetry Services in Canada*, S-106, A Joint Federal-Provincial Standard, Published by the Atomic Energy Control Board, March 20, 1998.

10 *Radon – A Guide for Canadian Homeowners*, Canada Mortgage and Housing Corporation and Health Canada, 1997.

11 *Selection, Care and Use of Respirators*, Canadian Standards Association, Z94.4-93, August 1994.

12 *Packaging and Transport Regulations*, Canadian Nuclear Safety Act, Canada Gazette Part I, Oct. 1998.

13 *Transportation of Dangerous Goods Regulations*, Canada Gazette Part II, July 1980.

14 *Regulations for the Safe Transport of Radioactive Material* — 1985 Edition (As Amended 1990), Safety Series No. 6, IAEA 1990.

15 *Regulations for the Safe Transportation of Radioactive Material*, IAEA Safety Series No. ST-1, 1996.

16 *Guidelines for Canadian Drinking Water Quality*, 6th Edition, Health Canada, 1996.

A APPENDIX

Publications Address List

Canadian Nuclear Safety Commission

Office of Public Information
Canadian Nuclear Safety Commission
280 Slater Street, P.O. Box 1046
Ottawa, Ontario K1P 5S9

Health Canada

Radiation Protection Bureau, AL 6302D1
775 Brookfield Road
Ottawa, Ontario K1A 1C1

International Atomic Energy Agency (IAEA)

Bernan Associates
4611-F Assembly Drive
Lantham, MD. 20706-4391

Division of Publications
International Atomic Energy Agency
Wagramerstrasse 5, P.O. Box 100
A-1400 Vienna, Austria

International Commission on Radiological Protection (ICRP)

Pergamon Press Inc.
Maxwell House, Fairview Park
Elmsford, New York, U.S.A.

Pergamon Press plc
Headington Hill Hall
Oxford, U.K. OX3 0BW

Guidelines for the Handling of Naturally Occurring Radioactive Materials (NORM) in Western Canada

Alberta Human Resources and Employment
Information Services
2nd Floor, 10808 – 99 Avenue
Edmonton, Alberta, Canada T5K 0G5

B APPENDIX

Government Contacts

Federal Government Agencies

Canadian Nuclear Safety Commission
(formerly the Atomic Energy Control Board)

P.O. Box 1046
Ottawa, Ontario K1P 5S9
1-800-668-5284 or (613) 992-2915

Health Canada

Radiation Protection Bureau
Environmental Radiation Hazards Division
775 Brookfield Road
Ottawa, Ontario K1A 1C1
(613) 954-6671

National Dose Registry

Health Canada
Radiation Protection Bureau
775 Brookfield Road
Ottawa, Ontario K1A 1C1
(613) 954-6663

Provincial Government Agencies

Alberta

Workplace Health and Safety
Alberta Human Resources and Employment
9th Floor, 10808- 99 Avenue
Edmonton, Alberta T5K 0G5
(780) 427-6971

British Columbia

Radiation Protection Branch
BC Ministry of Health
4940 Canada Way, Suite 210
Burnaby, British Columbia V5G 4K6
(604) 660-6630

Manitoba

Radiation Protection Section
Manitoba Cancer Treatment and Research Foundation
100 Olivia Street
Winnipeg, Manitoba R3E 0V9
(204) 787-2213

New Brunswick

Public Health Management Unit
Health and Community Services
P.O. Box 5100
Fredericton, New Brunswick E3B 5G8
(506) 453 2638

Newfoundland

Employment and Labour Relations
Fall River Plaza, P.O. Box 8700
270 Torbay Road
St. John’s, Newfoundland A1C 4J6
(709) 729-0218

Northwest Territories

Department of Health and Social Services
Government of the Northwest Territories
7th Floor, Centre Square Tower
P.O. Box 320
Yellowknife, Northwest Territories X1A 2L9
(867) 920-3293

Nova Scotia

Department of Environment and Labour
P.O. Box 697
Halifax, Nova Scotia B3J 2T8
(902) 424-4077 or -4300

Nunavut Territory

Department of Health and Social Services
Government of the Northwest Territories
7th Floor, Centre Square Tower
P.O. Box 320
Yellowknife, Northwest Territories X1A 2L9
(867) 920-3293

Ontario

Ontario Ministry of Labour
Radiation Protection Service
81 Resources Road
Weston, Ontario M9P 3T1
(416) 326-1403

Prince Edward Island

Division of Environmental Health
Department of Health and Social Services
Government of Prince Edward Island
P.O. Box 2000
Charlottetown, P.E. I. C1A 7N8
(902) 894-2277

Quebec

Service de la Promotion de saines habitudes de vie et de dépistage
Ministère de la Santé et des Services sociaux
1075, chemin Ste-Foy
Québec, Québec G1S 2M1
(418) 646-2515

Saskatchewan

Radiation Safety Unit
Occupational Health and Safety Division
Saskatchewan Labour
1870 Albert Street
Regina, Saskatchewan S4P 3V7
(306) 787-4538

Yukon Territory

Workers Compensation Health & Safety
Government of the Yukon Territory
401 Strictland Street
Whitehorse, Yukon Territory Y1A 5N8
(780) 667-5450

C APPENDIX

Radiation Unit Conversion Factors

PREFIXES

T: Tera	10^{12}	M: Mega	10^{6}	m: milli	10^{-3}	n: nano	10^{-9}
G: Giga	10^{9}	k: kilo	10^{3}	μ: micro	10^{-6}	P: pico	10^{-12}

ACTIVITY

SI Units				Former Units		
1 Bq	=	1 dps	=	27 pCi	=	2.7×10^{-11} Ci
1 kBq	=	1×10^{3} dps	=	27 nCi	=	2.7×10^{-8} Ci
1MBq	=	1×10^{6} dps	=	27 μCi	=	2.7×10^{-5} Ci
1 GBq	=	1×10^{9} dps	=	27 mCi	=	2.7×10^{-2} Ci
1 TBq	=	1×10^{12} dps	=	27 Ci	=	2.7×10 Ci
37 mBq	=	0.037 dps	=	1 pCi	=	1×10^{-12} Ci
37 Bq	=	37 dps	=	1 nCi	=	1×10^{-9} Ci
37 kBq	=	3.7×10^{4} dps	=	1 μCi	=	1×10^{-6} Ci
37 MBq	=	3.7×10^{7} dps	=	1 mCi	=	1×10^{-3} Ci
37 GBq	=	3.7×10^{10} dps	=	1 Ci	=	1 Ci

ABSORBED DOSE

SI Units to Former Units	Former Units to SI Units
1 Gy = 100 rad 1 mGy = 0.1 rad 1 μGy = 0.1 mrad	1 rad = 10 mGy 1 mrad = 10 μGy 1 μrad = 0.01 μGy

DOSE EQUIVALENT "BIOLOGICAL DOSE"

SI Units to Former Units	Former Units to SI Units
1 Sv = 100 rem 1 mSv = 0.1 rem 1 μSv = 0.1 mrem	1 rem = 10 mSv 1 mrem = 10 μSv 1 μrem = 0.01 μSv

RADON

Radiation Exposure Domain	**Radon Gas** (Bq/m^3)		**Radon Progeny** (WLM)		**Radon Progeny** (mJ h/m^3)		**Annual Radiation Dose** (mSv/a)
Occupational (2000 hours per year)	150	=	0.2	=	0.67	=	1

D APPENDIX

Effective Dose Calculations

1. Effective Dose Categories

The total Effective Dose, E_T, is calculated from three categories of radiation exposure:

a. External gamma and beta dose

This dose category, personal dose equivalent from penetrating radiation, is symbolized by "**$H_p(10)$**" and represents the beta/gamma dose received in a dosimetry period. A one-year dosimetry period is defined as the dosimetry period commencing January 1 and having one calendar year duration. The five-year dosimetry period means the period of five calendar years beginning January 1 of the year after these guidelines are published, and every period of five calendar years thereafter.

b. Internal dose from the intake of radionuclides

This dose category is symbolized by "**I**" and represents the one-year or five-year dosimetry period estimate of NORM nuclide intake (inhalation and ingestion) other than from radon and its progeny.

c. Inhalation of radon gas and its progeny

This dose category is defined by cumulative exposure to radon progeny symbolized by "**RnP**" with units of WLM. RnP represents the one-year or five-year dosimetry period estimate of cumulative radon progeny inhalation by workers.

For dose recording purposes, each dose category can be measured and recorded separately. For compliance to these *Guidelines*, or, federal, provincial or territorial dose limit regulations, these categories must be combined to calculate one effective dose for each individual. This combined dose, the effective dose, is then compared to the radiation dose limits found in Table 2.1 of the *Guideline*.

2. Effective Dose and Dose Limit Compliance Calculations

For worker dose compliance purposes, the *Guidelines* require dose calculations over a one-year and a five-year dosimetry period. One-year dosimetry period calculations are necessary for compliance with one-year maximum effective dose limits, while five-year dosimetry period calculations demonstrate compliance with the cumulative dose limits for a five-year period. The five-year cumulative limit also implies an average annual dose limit.

For workers, the implied average annual limit over a five-year period is an annual effective dose of 20 mSv versus the 50 mSv maximum in any single one-year dosimetry period. For the public, including the incidentally exposed worker, the annual limit is 1 mSv and the five-year limit is five times the annual limit. The following dose calculation methodology is recommended for determining one-year and five-year dosimetry period results.

A. One Year Dosimetry Periods

Step 1

Calculate the annual dose received from each dose category.

External Gamma and Beta Exposures	Annual dose received from all external sources, $H_p(10)$.
Radionuclide Intake (Internal Exposures)	Annual dose received from all internal sources, $I = \sum A_n \times DC_{wn}$ where A_n is the activity intake of radionuclide n and DC_{wn} is the appropriate worker dose coefficient specified for NORM nuclide, n (refer to Table 4.1 entries). For inhalation, the DC_{wn} selected from Table 4.1 will depend on the chemical form of the radionuclide, which will determine

whether it is fast (F), moderate (M) or slow (S) absorption from the lungs.

Radon-222 Inhalation Annual dose received from radon-222 progeny inhalation, $Rn_d = 5(RnP)$, where for workers the dose conversion from WLM to mSv is 5 for radon-222 progeny. Radon-220 progeny must be treated separately.

Step 2. One-Year Dosimetry Period Compliance

Determine the effective dose by adding the dose contributions from the three categories. To determine whether the annual total effective dose received complies with the *Guidelines* compare it to the appropriate one-year dose limit from Table 2.1.

Compliance: $E_T = H_p(10) + I + Rn_d \leq$ the appropriate value from Table 2.1

Example 1: During the year, a worker has been exposed to external gamma radiation, has ingested radium in dust and was exposed to radon-222 progeny. The workers recorded dose/intake are as follows:

Source	Recorded Dose/Intake	Effective Dose
External Radiation $H_p(10)$	12 mSv	$H_p(10)$ = 12 mSv
Internal Radiation (radium-226) I_n	9,000 Bq	I = 2.5 mSv
Radon RnP	0.4 WLM	Rn_d = 2 mSv

This worker's internal dose component (I) can be calculated using table 4.1. The ingestion DC_w for ^{226}Ra is 2.8 e-7 Sv/Bq.

Therefore $I = (9{,}000 \text{ Bq})(2.8 \text{ e-7 Sv/Bq})$
$= 0.0025 \text{ Sv} = 2.5 \text{ mSv}$

This worker's radon dose component (Rn_d) can be calculated by multiplying the dose in WLM by 5 to convert to mSv.

Therefore $Rn_d = (0.4 \text{ WLM})(5 \text{ mSv/WLM})$
$= 2 \text{ mSv}$

The Effective Dose:

$$E_T = H_p(10) + I + Rn_d$$
$$= 12 \text{ mSv} + 2.5 \text{ mSv} + 2 \text{ mSv}$$
$$= 16.5 \text{ mSv}$$

Conclusion: The worker has not exceeded the annual dose limit of 50 mSv. However, the worker is getting close to the average annual dose limit implied by the five-year limit (20 mSv/a).

B. Five-year Dosimetry Period

Step 1

Calculate the dose received in the five year period, or portion thereof, from each dose category.

External Gamma and Beta Exposures Total dose received during the five year period, or portion thereof, from all external sources = $H_p(10)$.

Radionuclide Intake (Internal Exposures) Total dose received during the five year period, or portion thereof, from all internal sources = $I = \sum A_n \times DC_{wn}$, where A_n is the activity intake of radionuclide n and DC_{wn} is the worker dose coefficient specified for that NORM nuclide (Refer to Table 4.1 entries). For inhalation, the DC_{wn} selected from Table 4.1 will depend on the chemical form of the radionuclide, which will determine whether it is fast (F), moderate (M) or slow (S) absorption from the lungs.

Radon-222 Inhalation Total dose received during five year period, or portion thereof, from radon-222 progeny inhalation, $Rn_d = 5(RnP)$, where for workers the dose conversion from WLM to mSv is 5. Radon-220 progeny must be treated separately.

Step 2. Five Year Dose Limit Compliance

Determine the effective dose by adding the dose contributions from the three categories. To determine whether the effective dose received complies with the *Guidelines* compare it to the appropriate five-year dose limit from Table 2.1.

Compliance: $E_T = H_p(10) + I + Rn_d \leq$ the appropriate value from Table 2.1

Example 2: During a five-year period, a worker has been exposed to external gamma radiation, has ingested radium in dust and was exposed to radon-222 progeny. The workers recorded doses are as follows:

Source	Recorded Dose/Intake	Effective Dose
External Radiation $H_p(10)$	30 mSv	$H_p(10)$ = 30 mSv
Internal Radiation (radium-226) I_n	26,000 Bq	I = 7.3 mSv
Radon RnP	1 WLM	Rn_d = 5 mSv

This worker's internal dose component (I) can be calculated using Table 4.1. The DC_w for ^{226}Ra is 2.8 e-7 Sv/Bq.

Therefore $I = (26{,}000\ Bq)(2.8\ e\text{-}7\ Sv/Bq)$
$= 0.073\ Sv = 7.3\ mSv$

This worker's radon dose component (Rn_d) can be calculated by multiplying the dose in WLM by 5 to convert to mSv.

Therefore $Rn_d = (1\ WLM)(5\ mSv/WLM)$
$= 5\ mSv$

The Effective Dose:

$$E_T = H_p(10) + I + Rn_d$$
$$= 30\ mSv + 7.3\ mSv + 5\ mSv$$
$$= 42.3\ mSv$$

Conclusion: The worker has not exceeded the five-year dose limit of 100 mSv.

E APPENDIX

Derivation of Diffuse NORM Unconditional Derived Release Limits

The Unconditional Derived Release Limit for diffuse NORM sources (solid, air, and water) is the concentration of the parent radionuclide (Bq per unit mass or volume), in equilibrium with its progeny, that could result in a dose of 0.3 mSv per year from those pathways considered in the assessment, based on conservative exposure assumptions (conservative assumptions are those that are least likely to understate exposure). The pathways, assumptions, and other related information are supplied below for the calculation of the limits for the decay chains listed in Table 5.1.

Unconditional Derived Release Limits have been calculated for ^{40}K, and for the ^{238}U and ^{232}Th decay series. Values for the two decay series are given for the various sub-chains that can be assumed to be in equilibrium, i.e., the parent radionuclide in equilibrium with its shorter-lived progeny. For example, within the ^{238}U series, a release limit is given for ^{210}Pb in equilibrium with its progeny, ^{210}Bi and ^{210}Po.

Exposure Pathways for Diffuse NORM Sources

Solid NORM

For diffuse solid NORM, the release limit is the concentration in soil (Bq/kg) ***at the receptor*** that would result in a dose of 0.3 mSv/a to a reference adult. Based on a modification to the screening methodology recommended by the National Commission for Radiation Protection (NCRP) for disposal of radionuclides in the ground (NCRP 1996), it is assumed that the radioactive material is uniformly distributed in soil to infinite depth, and that the reference individual resides on this soil and consumes produce grown on the soil. The following exposure pathways and assumptions were considered:

- The parent radionuclide and its progeny are in equilibrium.
- The reference adult is exposed to direct external irradiation from the soil, which is assumed to be homogeneously contaminated to infinite depth.
- The individual receives an internal dose from the inhalation of resuspended dust, contaminated to the same level as the soil.
- Half of the individual's annual supply of vegetables is grown on contaminated soil. It is assumed that the land does not support livestock, so there is no dose from the consumption of animal products.
- The individual ingests contaminated soil from unwashed produce, dirt on hands, etc.
- The reference individual is assumed to occupy the site for 25% of the year, affecting the direct irradiation, inhalation, and soil ingestion pathways.

Airborne NORM

For airborne NORM, the unconditional release limit is the concentration in air (Bq/m^3) ***at the receptor*** that would result in a dose of 0.3 mSv/a to a reference adult from inhalation. The following assumptions apply:

- Only the inhalation pathway is assumed.
- The parent radionuclide and its progeny are in equilibrium (very conservative).
- The reference individual is assumed to occupy the site for 25% of the year.

Aquatic NORM

For aquatic NORM, the Unconditional Derived Release Limit is the concentration in water (Bq/L) ***at the point of release*** that would result in a dose of less than 0.3 mSv/a to a reference adult consuming water for an entire year assuming a four to ten-fold dilution in concentration between the NORM release point and a drinking water intake point. Equilibrium between the parent and its progeny is not assumed. The release limit is therefore 10 times the maximum acceptable concentration given in the Guidelines for Canadian

Drinking Water Quality, 6th edition (Health Canada 1996), which is based on a dose of 0.1 mSv/a. Regardless of the NORM guideline, in all cases, provincial drinking water standards would apply to the water as released.

Discussion of Parameters Used in the Derivation of Unconditional Release Limits

Soil to plant uptake factors, Bv_x, for the various radionuclides of interest are taken from Zach and Sheppard (1992), Table 6. These were selected by Zach and Sheppard, based on a review of available data, as being appropriate mean values for the Canadian Shield.

Annual adult consumption rates for vegetables and soil are taken from Health Canada (1993). A factor of 0.5 has been applied to the intake of produce to reflect the assumption that one-half of the annual intake is grown on contaminated soil. The adult water consumption rate is from Health Canada (1996). The inhalation rate is from ICRP Publication 71 (1995), Table 6. Soil density (for conversion of groundshine dose coefficients) is taken from CSA (1987). The soil resuspension factor is from Davis *et al* (1993). An occupancy correction factor of 0.25 has been applied to exposure to airborne NORM sources by inhalation, and to exposures to solid NORM sources by:

- direct groundshine irradiation;
- ingestion of soil; and
- inhalation of resuspended dust.

Committed effective dose coefficients for internal exposure (inhalation, ingestion) are from ICRP Publication 72 (1996). External dose rate coefficients for soil contaminated to infinite depth are taken from Eckerman and Legett (1996); Eckerman and Ryman (1993). These are consistent with ICRP 60 methodologies. Parameters values used in the calculation of unconditional release limits are summarized in Table 1.

It is assumed that:

- All radionuclides in the defined parent-progeny group are in equilibrium for both solid and airborne NORM sources.
- For aquatic NORM, equilibrium is not assumed, and the unconditional release limit is based on each separate radionuclide released.
- All compartments are in equilibrium, and at steady-state.
- No allowance is made for transfer times between compartments, or hold-up time of food (for example between harvest and consumption).
- No corrections are made for reduction in external irradiation due to shielding, surface roughness, etc.

Methodology and Equations

Solid and Airborne NORM

For a given decay chain in equilibrium (e.g., $^{238}U \rightarrow {}^{234}Th \rightarrow {}^{234m}Pa$), the doses resulting from a unit concentration of *each* radionuclide, *x*, by each relevant exposure pathway, *y*, referred to as $D_{x,y}$ (mSv y^{-1}) were calculated as follows, where $DC_{x,y}$ is the radionuclide- and pathway-specific effective dose coefficient:

For Solid NORM:

- External groundshine

$$D_{x,ext/gnd} = \text{soil conc'n}_x\ (\text{Bq/kg}) \times DC_{x,ext/gnd}\ (\text{Sv m}^3\ \text{Bq}^{-1}\ \text{s}^{-1}) \times \text{soil density (kg m}^{-3}) \times \{3.16 \times 10^7\ (\text{s y}^{-1}) \times \text{occupancy factor (0.25)}\} \times 1000\ (\text{mSv Sv}^{-1})$$

- Internal, ingestion of vegetables

$$D_{x,ingest/veg} = \text{soil conc'n}_x\ (\text{Bq/kg}) \times DC_{x,ingest}\ (\text{Sv Bq}^{-1}) \times \{\text{Plant uptake factor} \times \text{veg. Consumption rate (kg y}^{-1}) \times 0.5\} \times 1000\ (\text{mSv Sv}^{-1})$$

- Internal, ingestion of soil

$$D_{x,ingest/soil} = \text{soil conc'n}_x\ (\text{Bq/kg}) \times DC_{x,ingest}\ (\text{Sv Bq}^{-1}) \times \{\text{soil ingestion rate (kg y}^{-1}) \times \text{occupancy factor (0.25)}\} \times 1000\ (\text{mSv Sv}^{-1})$$

- Internal, inhalation of resuspended material

$$D_{x,inhal/resus} = \text{soil conc'n}_x\ (\text{Bq/kg}) \times DC_{x,inhal}\ (\text{Sv Bq}^{-1}) \times \text{dust loading factor (kg m}^{-3}) \times \{\text{inhalation rate (m}^3\ \text{y}^{-1}) \times \text{occupancy factor (0.25)}\} \times 1000\ (\text{mSv Sv}^{-1})$$

Table E.1
Parameter Values

Parameter	Value		Reference
Plant/Soil Uptake, Bv_x	Element	Bv_x	(Zach and Sheppard, 1992)
(Bq/kg wet / Bq/kg dry)	K	2.5E-01	
	Pb	1.1E-02	
	Bi	8.8E-03	
	Po	6.3E-04	
	Ra	3.3E-03	
	Ac	8.8E-04	
	Th	2.1E-04	
	Pa	6.3E-04	
	U	2.1E-03	
Soil density (kg m^{-3})		1.6E+03	(CSA 1987)
Food consumption: Veg (kg y^{-1})		2.5E+02	(Health Canada 1993)
Soil ingestion rate (kg y^{-1})		7.3E-03	(Health Canada 1993)
Dust loading – resuspension (kg m^{-3})		6.0E-08	(Davis, *et al.*, 1993)
Adult breathing rate (m^3 y^{-1})		8.1E+03	(ICRP 1995)
Occupancy Factor		2.5E-01	(NCRP 1996)
External dose coefficients (Sv m^3 Bq^{-1} s^{-1})		Note (a)	(Eckerman and Legett 1996)
Internal dose coefficients (Sv Bq^{-1})		Note (a)	(ICRP 1996)

(a) Dose coefficients are radionuclide dependent. Refer to listed references for specific values.

For Airborne NORM:

- Internal, inhalation of airborne material

$D_{x,inhal/air}$ = conc'n_x in air (Bq m^{-3}) × $DC_{x,inhal}$ (Sv Bq^{-1}) × {inhalation rate (m^3 y^{-1}) × exposure factor (0.25)} × 1000 (mSv Sv^{-1})

Calculation of the
Unconditional Derived Release Limit

The total dose per unit concentration (solid or airborne) is given by a double sum over each radionuclide and pathway:

$D_{total,\ soil/\ air}$ (mSv y^{-1} per Bq/kg (or m^{-3}))
= $\sum\sum D_{x,y}$ for each radionuclide, x in each exposure pathway, y

The Unconditional Derived Release Limit, URL, for the parent radionuclide in equilibrium with its progeny is:

URL (Bq/kg (or m^{-3}))
= 0.1 mSv y^{-1} / $D_{total,\ soil/air}$ (mSv y^{-1} per Bq/kg (or m^{-3}) for solid (or airborne))

Aquatic NORM

As discussed above, the unconditional derived release limit for aquatic NORM is 10 times the maximum acceptable concentration given in the Guidelines for Canadian Drinking Water Quality, 6th edition (Health Canada 1996) for the parent radionuclide. Equilibrium between parent and progeny is not assumed.

Unconditional Derived Release Limits

Table 5.1 of the *Guidelines* provides a summary of the Unconditional Derived Release Limits calculated for the significant NORM nuclides in the Uranium and Thorium decay series and for potassium-40.

References

CSA (1987). CAN/CSA-N288.1-M87, Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities (1987).

Davis P.A., *et al*., (1993) The Disposal of Canada's Nuclear Fuel Waste: The Biosphere Model, BIOTRAC, for Postclosure Assessment, AECL-10720, COG-93-10. AECL Research, Whiteshell.

Eckerman K.F. and Ryman J.C. (1993). Federal Guidance Report No. 12: External exposure to radionuclides in air, water, and soil. EPA 402-R-93-081. U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, DC.

Eckerman K.F. and Leggett R.W. (1996). DCFPAK: Dose coefficient data file package for Sandia National Laboratory, ORNL/TM-13347. Oak Ridge National Laboratory, Oak Ridge, TN.

Health Canada (1993). Reference values for Canadian populations. Health Canada, Environmental Health Directive, Ottawa.

Health Canada (1996). Guidelines for Canadian Drinking Water Quality, 6th edition. 96-EHD-196. Ottawa.

ICRP (1995). Age-dependent doses to members of the public from intake of radionuclides: Part 4 Inhalation dose coefficients. Publication 71. Ann. ICRP 25 (3-4), Pergamon Press, Oxford.

ICRP (1996). Age-dependent doses to members of the public from intake of radionuclides: Part 5 Compilation of ingestion and inhalation dose coefficients. ICRP Publication 72. Ann. ICRP 26 (1), Pergamon Press, Oxford.

NCRP (1996). Screening models for releases of radionuclides to atmosphere, surface water and ground. NCRP Report No. 123I. NCRP Publications, Bethesda, MD.

Zach R., Sheppard S.C. (1992). The Food-Chain and Dose Submodel, CALDOS, for the Assessment of Canada's Nuclear Fuel Waste Management Concept, AECL-10165, COG-91-195. AECL Research, Whiteshell.

F APPENDIX

Elements of a Formal Radiation Protection Program

Radiation Protection Program

Employers that implement a radiation protection program should, as part of that program, keep the exposure to radon progeny and the effective dose received by and committed to persons as low as reasonably achievable through the implementation of:

(i) management control over work practices;

(ii) personnel qualification and training;

(iii) control of occupational and public exposure to radiation; and

(iv) planning for unusual situations.

An employer should ascertain the exposure to radon progeny and the effective dose by direct measurement as a result of monitoring; or by expert estimates.

Provision of Information

(1) The employer shall inform each occupationally exposed worker, in writing:

- (a) that he or she is an occupationally exposed worker;
- (b) of the risks associated with radiation to which the worker may be exposed in the course of his or her work, including the risks associated with the exposure of embryos and foetuses to radiation;
- (c) of the applicable radiation dose limits for occupationally exposed workers shown in Table 2.1; and
- (d) of the worker's radiation dose levels.

(2) The employer should inform each occupationally exposed female worker, in writing, of the applicable effective dose limits shown in Table 2.1.

(3) The employer should obtain from each occupationally exposed worker a written acknowledgement that the worker has received this information.

Use of Licensed Dosimetry Service

Employers should use a dosimetry service, meeting the requirements of S-106, Technical and Quality Assurance Standards for Dosimetry Services in Canada,[9] to measure the radiation doses to occupationally exposed workers who have a reasonable probability of receiving an effective dose greater than 5 mSv in a one-year dosimetry period.

Occupationally Exposed Workers

An occupationally exposed worker should on request of the employer provide the worker's:

- (a) given names, surname and any previous surname;
- (b) Social Insurance Number;
- (c) gender;
- (d) date, province or state and country of birth; and
- (e) dose record for the current one-year and five-year dosimetry periods.

Pregnant Occupationally Exposed Workers

Every occupationally exposed worker who becomes aware that she is pregnant should immediately inform the employer in writing.

On being informed by an occupationally exposed worker that she is pregnant, the employer should make accommodation to comply with Note (b), Table 2.1, that will not constitute undue hardship to the employer.

When Dose Limit Exceeded

When an employer becomes aware that a dose of radiation received by and committed to a person may have exceeded an applicable dose limit shown in Table 2.1, the employer shall:

(a) immediately notify the person and the Provincial Authorities of the dose;

(b) require the person to leave any work that is likely to add to the dose;

(c) conduct an investigation to determine the magnitude of the dose and to establish the causes of the exposure;

(d) identify and take any action required to prevent the occurrence of a similar incident; and

(e) within 21 days after becoming aware that the dose limit has been exceeded, report the results of the investigation to the appropriate government authority (reference Appendix B) or on the progress that has been made in conducting the investigation.

Return to Work

If a person has received or been committed to an equivalent dose that exceeds an equivalent dose limit given in Table 2.1, and Provincial Authorities agree that the person can return to work, the authorization may specify conditions and prorated dose limits.

For the purpose of this section a prorated effective dose limit is the product obtained by multiplying the applicable dose limit given in Table 2.1 by the ratio of the number of months remaining in the dosimetry period to the total number of months in the dosimetry period.

Labelling and Signs

Labelling of Containers and Devices

Containers that store NORM radioactive material should be labelled with:

(a) the radiation warning symbol set out in Figure G-1 and the words “RAYONNEMENT – DANGER – RADIATION”; and

(b) the name, quantity, date of measurement and form of the radioactive material in the container.

This does not apply to a container used to hold radioactive material for current or immediate use or in which the quantity of radioactive material is less than or equal to the amounts shown in Table 5.1. For transporting radioactive materials refer to Section 6, Standards for the Transport of NORM.

Posting of Signs at Boundaries and Points of Access

The employer should place a durable and legible sign that bears the radiation warning symbol shown in Figure G-1 and the words “RAYONNEMENT – DANGER – RADIATION”, at the boundary, and at every point of access to the area, room or enclosure:

where,

(a) there is radioactive material present in an activity greater than 100 times the value shown in Table 5.1 in an area, room, or enclosure;

or,

(b) there is a reasonable probability that a person in the area, room or enclosure will be exposed to a radiation dose rate greater than 25 µSv/h.

Use of Radiation Warning Symbol

Whenever the radiation warning symbol is used it should be:

(i) prominently displayed;
(ii) of an appropriate size for the size of the container to which it is attached, or of the area, room, enclosure or vehicle for which it is posted;
(iii) oriented with one blade pointed downward and centred on the vertical axis;
(iv) no wording shall be superimposed on it.

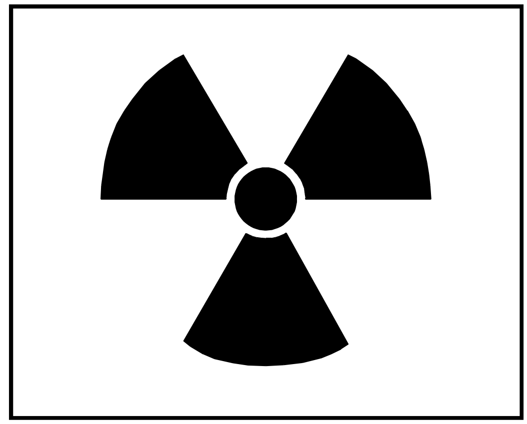
Frivolous Posting of Signs

A radiation warning sign should not be posted at a place where the radiation dose rate or radioactive material indicated on the sign is not present.

Records to Be Kept by Employer

Every employer should keep a record of the name and job category of each occupationally exposed worker.

Figure G-1
Radiation Warning Symbol



Note:

The three blades and the central disk of the symbol shall be:

(a) magenta or black; and

(b) located on a yellow background.

G APPENDIX

Glossary of Radiation Terminology

Absorbed Dose: The mean energy deposited by ionizing radiation per unit mass of the body or organ or tissue of the body. Unit: gray (Gy), 1 Gy = 1 joule per kilogram.

Activity (Radioactivity): The number of nuclear transformations that occur in a quantity of material per unit of time. Unit: becquerel (Bq), 1 Bq = 1 disintegration per second.

ALARA: A principle of risk management according to which exposures are kept as low as reasonably achievable, economic and social factors being taken into consideration. A guiding principle of radiation protection.

Alpha Radiation (Alpha Decay): A high-energy positively charged particle ejected from the nucleus of an unstable (radioactive) atom, consisting of two protons and two neutrons. An alpha particle is a helium nucleus.

Annual Limit on Intake (ALI): The intake by inhalation, ingestion or through the skin of a given radionuclide in a year by a reference man which would result in a committed dose equal to the relevant dose limit. The ALI is expressed in units of activity.

Atomic Number: The number of protons contained in the nucleus of an atom. This number gives each atom its distinct chemical identity.

Atomic Mass (Mass Number): The total mass of protons and neutrons contained in the nucleus of an atom.

Background Radiation: The radiation to which an individual is exposed arising from natural radiation sources such as terrestrial radiation from radionuclides in the soil, cosmic radiation from space, and naturally occurring radionuclides deposited in the body from foods, etc.

Balance of Pregnancy: The period from the moment an employer is informed of the pregnancy to the end of the pregnancy.

Becquerel (Bq): An SI unit of radioactivity, equivalent to 1 nuclear transformation per second. Used as a measurement of the quantity of a radionuclide since the number of radioactive transformations (disintegrations) is directly proportional to the number of atoms of the radionuclide present. Replaces an earlier unit, the curie (Ci).

Beta Radiation (Beta Decay): The ejection of a high-energy negatively charged subatomic particle from the nucleus of an unstable atom. A beta particle is identical in mass and charge to an electron.

Contamination (Radioactive Contamination): Radioactive material present in excess of natural background quantities in a place it is not wanted.

Committed Dose: The total dose received from a radioactive substance in the body during the remainder of a person's life (assumed as 50 years for adults, 70 years for children) following the intake of the radionuclide.

Curie (Ci): A unit of activity equivalent to 3.7×10^{10} disintegrations per second. Replaced in international usage by the Becquerel.

Decay (Radioactive Decay): A process followed by an unstable nucleus to gain stability by the release of energy in the form of particles and/or electromagnetic radiation. NORM materials decay with the release of alpha particles, beta particles and/or gamma photons.

Decay Series (Radioactive Decay Series): A succession of radionuclides, each member of which transforms by radioactive decay into the next member until a stable nuclide results. The first member is called the "parent", the intermediate members are called "progeny" and the final stable member is called the "end product”. In the two NORM decay series; uranium-238 and thorium-232 are the “parents,” and lead-206 and lead-208 are the “end products”.

Derived Working Limit (DWL): A practical working limit derived from regulatory limits. Derived Working Limits can be compared to measured values at the work site to assess compliance with regulatory limits.

Diffuse NORM: NORM-contaminated material in which the radioactive concentration is uniformly dispersed. It is generally low in radioactive concentration, and relatively large in volume.

Discrete NORM: NORM-contaminated material in which radioactive substances are concentrated, or not uniformly dispersed throughout the material. It generally has much higher levels of radioactive concentration in a localized volume than diffuse NORM.

Dose Coefficient (DC): A factor that relates the amount of radiation dose (Sv) delivered to the body per unit of activity (Becquerel) taken into the body. Unit: (Sv/Bq).

Dose Constraint: An upper bound on the annual dose that members of the public or incidentally exposed workers should receive from a planned operation or single source.

Dosimeter: A device for measuring a dose of radiation that is worn or carried by an individual

Effective Dose: Radiation dose for primary radiation dose limits. It represents the sum of the equivalent doses received by different tissues of the human body, each multiplied by a “tissue weighting factor” (w_T). Unit: sievert (Sv).

Equilibrium (Radioactive): In a radioactive decay series, the state that prevails when the rate at which progeny are produced is equal to the rate at which they are decaying. This form of equilibrium may be attained only if the precursor is very long-lived relative to any member of the decay chain. All members of a NORM radioactive decay series in equilibrium have the same radioactivity.

Equivalent Dose: The absorbed dose multiplied by a “radiation weighting factor”, (w_R), which accounts for the different potential for adverse effects of the different types of radiation. Unit: sievert (Sv).

Five Year Dosimetry Period: The period of five calendar years beginning on January 1 of the year following the year in which the Radiation Protection Management Program is started, and every period of five calendar years thereafter.

Gamma Radiation (Gamma Rays or Gamma Photons): Electromagnetic radiation or photon energy emitted from an unstable nucleus in the process of ridding itself of excess energy. Highly penetrating, gamma rays lose energy as they pass through atoms of matter.

Gray (Gy): Radiation damage is dependant on the absorption of radiation energy and is approximately proportional to the concentration of absorbed energy in tissue. The gray is the SI unit of absorbed radiation dose corresponding to the absorption of 1 joule of radiation energy per kilogram of material. For gamma and beta radiations, the gray is numerically equal to the sievert.

Groundshine: Radiation detectable on the earth’s surface from radioactive substances on or beneath the surface.

Half-life, Biological: The time required for the body to eliminate half the quantity of a substance taken into the body. A major factor in determining a radionuclide’s Dose Coefficient.

Half-life, Radioactive: The time required for a radioactive material to lose half of its activity through radioactive decay.

IAEA: International Atomic Energy Agency.

ICRP: International Commission on Radiological Protection.

Incidentally Exposed Workers: Employees whose regular duties are not expected to result in exposure to NORM radiation. The public annual dose limit of 1 mSv applies to this category of workers in an occupational exposure environment – the occupational domain.

Incremental Dose: Radiation dose found in excess of the local background radiation dose.

NORM (Naturally Occurring Radioactive Materials): NORM is an acronym for naturally occurring radioactive materials comprising radioactive elements found in the environment. Long-lived radioactive elements of interest include uranium, thorium and potassium and any of their respective radioactive decay products such as radium and radon. Some of these elements have always been present in the earth's crust and within the tissues of all living beings. Although the concentration of NORM in most natural substances is low, higher concentrations may arise as the result of human activities.

One-year Dosimetry Period: The period of one calendar year beginning on January 1 of the year following the year in which the Radiation Protection Management Program is started, and every period of one calendar year thereafter.

Occupationally Exposed Workers (NORM Workers): Employees who expect to receive exposure to sources of NORM radiation as a result of their regular duties. The annual occupational dose limit of 20 mSv applies to this category of workers in an occupational exposure environment.

Personal Dosimetry Threshold: The annual effective dose above which radiation dosimetry of individual workers is required.

Phosphogypsum Stack: Phosphogypsum stack refers to the storing of phosphogypsum, a byproduct of fertilizer production, in large outdoor stockpiles.

Photons (X-ray or Gamma rays): See gamma radiation.

Rad: A historical radiation unit for measuring radiation energy absorption (dose), equivalent to 100 ergs per gram in any medium. RAD is an acronym for Radiation Absorbed Dose. Now replaced in international system of units by the "gray" (Gy).

Radiation Weighting Factor (w_R): A value recommended by the International Commission on Radiological Protection, and usually adopted by national regulatory agencies, to convert absorbed dose from various types of ionizing radiation into its dose equivalent in terms of biological harm from alpha, beta or gamma radiation. For gamma rays and beta particles, $\mathbf{w_R = 1}$. For alpha particles and fast neutrons, $\mathbf{w_R = 20}$.

Radiochemical Analysis: Analysis of the radioactive content of a NORM sample. Radiochemical analysis will identify and quantify the concentration of various radionuclides in the NORM sample.

Radionuclide or Radioisotope: A particular form of an element, characterized by a specific atomic mass and atomic number, whose atomic nucleus is unstable and decays or disintegrates with a statistical probability characterized by its physical half-life.

Radium-226: A radioactive element with a half life of 1600 years. It is a particularly hazardous decay product of natural uranium, and is frequently the dominant NORM nuclide. It decays into the radioactive gas Radon-222.

Radon: The only radioactive gas generated during natural radioactive decay processes. Two radioisotopes of radon are present – radon and thoron – each a decay product of radium. Radon (Rn-222) is found in the uranium decay series while thoron (Rn-220) is found in the thorium decay series.

Radon Progeny: The products of radon (radon-222) or thoron (radon-220) decay with short half-lives. Radon decay products include; Polonium-218 (RaA), Lead-214 (RaB), Bismuth-214 (RaC), and Polonium-214 (RaC'). Thoron decay products include; Polonium-216 (ThA), Lead-212 (ThB), Bismuth-212 (ThC), Polonium-212 (ThC'), and Thallium-208 (ThC").

Rem: A historical unit of human dose equivalent. Rem is an acronym for roentgen equivalent man and was replaced in 1977 by the sievert in the international system of units.

Roentgen (R): The classical unit of radiation ionization in air, frequently misapplied as a unit of exposure in humans. Replaced in international system of units by the "coulomb per kg in air".

Shielding: The reduction of radiation beam intensity by interposing, between the source and an object or person that might be exposed, a substance that absorbs radiation energy, either by collision, in the case of particulate radiation, or by absorption of waveform energy, in the case of gamma photons.

SI (International System of Units): The “metric” system of units generally based on the metre/kilogram/second units. Special quantities for radiation include the becquerel, gray and sievert.

Sievert (Sv): The sievert is the unit of radiation equivalent dose, H, that is used for radiation protection purposes, for engineering design criteria and for legal and administrative purposes. The sievert is the SI unit of absorbed radiation dose in living organisms modified by radiation type and tissue weighting factors. The unit of dose for the terms “equivalent dose” and “effective dose”. It replaces the classical radiation unit the rem. Multiples of sieverts (Sv) used in the *Guidelines* include millisieverts (mSv) and microsieverts (μSv).

Specific Activity (Radioactive Concentration): The number of becquerels per unit of mass of a material. Units: Bq/g and kBq/kg.

Tissue Weighting Factor (w_T): A weighting factor developed by the ICRP that assigns a relative share of total radiation dose detriment to specific organs and tissues. Risks from localized radiation exposures to specific organs and tissues can be quantified.

Unconditional Derived Release Limits: Within the Unrestricted classification, the radioactive activity of NORM below which NORM can be released into the public domain without restrictions.

Working Level (WL): A unit for potential alpha energy concentration, (PAEC), resulting from the presence of radon progeny equal to the emission of 1.3×10^5 MeV of alpha energy per litre of air. In SI units the WL corresponds to 2.08×10^{-5} joules per cubic metre (J/m^3).

Working Level Month (WLM): A measure of the cumulative exposure to radon progeny in air. One Working Level Month is defined as the exposure received by an individual inhaling air containing a radon progeny concentration of one WL for a period of 170 hours, the assumed number of hours in a working month. One working level month is equivalent to 3.54 mJ h m^{-3}.