GUIDELINES
FOR THE HANDLING OF
NATURALLY OCCURRING RADIOACTIVE
MATERIALS (NORM)
IN WESTERN CANADA

Prepared by the Western Canadian NORM Committee

August 1995

ACKNOWLEDGEMENTS

The Western Canadian Committee on Naturally Occurring Radioactive Materials (NORM) comprises government and industry organizations committed to the development of comprehensive controls for the optimum management of naturally occurring radioactive materials (NORM). Organizations that have actively participated in the work of the NORM Committee are:

GOVERNMENT SECTOR
Alberta Environmental Protection
Alberta Health
Alberta Labour
Alberta Public Safety Services
Alberta Energy and Utilities Board
British Columbia Ministry of Health
Saskatchewan Labour

INDUSTRY SECTOR
Alberta Special Waste Management Corporation
Canadian Association of Petroleum Producers
Imperial Oil Resources Limited
Sherritt Inc.
Western Cooperative Fertilizers Limited.

The Committee acknowledges the valuable support provided by the following persons who, over the years, have participated in the activities of the Committee and who contributed particularly to the development of the *Guidelines for the Handling of Naturally Occurring Radioactive Materials (NORM) in Western Canada..*

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ACKNOWLEDGEMENTS (continued)

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$$\text{Bq/l} = \frac{\text{Counts per second}_{net}}{(3 \times DE \times CV)}$$

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In the Regulations: maximum quantity in TBq of radioactivity (total NORM radioactivity) permitted in Type A packaging.
In these Guidelines: maximum quantity in MBq of radioactivity (total NORM radioactivity) permitted in Type A packaging.

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$$Ca_3(PO_4)_2CaF_2 + 10H_2SO_4 + 20H_2O \text{ -------> } 10CaSO_4 \cdot 2H_2O + 6H_3PO_4 + 2HF$$

PART I

FOR THE GENERAL READER

ABOUT THIS DOCUMENT

This document comprises guidelines for detection, classification, handling, transportation and waste management of NORM. Comments or detailed critical reviews will be gratefully received and given careful consideration for future revisions and updates of the guidelines.

Please forward any such input or suggestions to:

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In Canada, legislative control of operations involving radioactive materials rests with the federal Atomic Energy Control Board (AECB). However, naturally occurring radioactive materials (NORM) do not come within the scope of the Atomic Energy Control Act administered by the AECB; rather, jurisdiction for the control of NORM rests with individual provinces.

It has been the practice for companies that encounter problems associated with NORM to seek advice on safety procedures from the relevant provincial Occupational Health or Environmental Protection divisions. Such advice has traditionally been given on an *ad hoc* basis. This has had two undesirable effects:

- Recommendations made have not always been consistent between one operation and another or between provinces because companies experiencing problems with NORM have not been able to refer to generally accepted guidelines to determine what safety precautions may be appropriate.

- The public has not been satisfied that provinces are exercising adequate control over potentially hazardous activities.

The Western Canadian NORM Committee was formed in October 1991 to address these concerns by producing a definitive document that would establish appropriate procedures for the control of NORM. A joint initiative of industry and the governments of the three western provinces, the Committee includes representatives from the provincial governments of British Columbia, Alberta and Saskatchewan, and from the oil and gas, and fertilizer industries C industries that have had concerns about NORM for some time.

The objective of the Committee has been twofold: first, to produce definitive guidance for industries that encounter NORM on a regular basis; and second, to set requirements for the control of NORM that will be acceptable to all regulatory agencies involved.

This publication incorporates industry-specific guidelines for the two industries currently participating in the work of the Committee. The Committee encourages other affected industries to develop their own specific guidelines. It is hoped the publication will develop into a fully comprehensive guide for the control of NORM in all relevant industries.

An attempt has been made to accommodate the needs of three distinct groups of readers:

- The first consists of senior administrators and managers who may need to know what NORM is, what the responsibilities of their company are, and what the budgetary implications of handling NORM may be. Part I of this report has been written specifically for such individuals and contains general background material.

- The second group of readers consists of engineers, environmental specialists, occupational hygienists and safety personnel who may have no experience in dealing with radioactive materials but who could be responsible for preparing detailed plans for handling NORM. Part II is directed towards meeting their needs.

- The third group of readers consists of on-site foremen and supervisors who may encounter NORM problems and need to make immediate decisions on what precautions are required. The industry-specific guidelines in Part III have been prepared primarily to meet the needs of this group.

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NORM AS A RADIATION CONCERN

Background

NORM is an acronym for naturally occurring radioactive materials. These are radioactive elements that have always been present in various concentrations in every part of the Earth's mantle, and that are also present in the tissues of every living animal, including man. Such materials have the potential to initiate cancers in persons who are exposed to them. Although the concentration of NORM in most natural substances is so low that this risk is generally regarded as negligible, higher concentrations may arise as the result of the intervention of man. Some industrial operations may liberate naturally occurring radioactive materials present in the Earth's crust C the plowing of a field, for example, can release radon from the soil. Other industrial processes may act to concentrate NORM C radium, for example, can be concentrated in scales precipitated from contaminated water.

In Canada, radioactive materials associated with the nuclear fuel cycle are licensed and controlled by the AECB; but radioactive materials that are not associated with the nuclear industry are not so controlled. The basic principle of these guidelines is that the same radiation exposure standards that apply to AECB-regulated radioactive materials should also apply to naturally occurring radioactive materials.

The Radiation Dose Associated With Norm

Only a very small part of the radiation dose received by the population of Canada arises through the practices controlled by the AECB. Almost a third of the dose comes from radiation-emitting equipment such as diagnostic X-ray units, which are under provincial jurisdiction. The largest part of the dose is associated with the radioactive isotopes that constitute NORM and these are not regulated federally or provincially.

Figure 1 is a pie chart showing the relative magnitude of each component of the average radiation dose received by an individual. The chart also shows the relative importance, from a public health point of view, of these contributions to the total dose received by the population. Radon inhalation is one of the largest contributors. Two other large contributors are radiation from medical X-ray procedures, which varies considerably but tends to increase as we get older, and background exposure from cosmic radiation, from gamma rays emitted by the natural radioactive material in the soil, in most building materials, and in our own bodies. (Natural radioactivity in the body results primarily from the fact that muscle and fat tissues contain potassium of which 0.5 percent is the natural gamma ray emitter).

By contrast, the total contribution to our radiation dose received from all of the artificial radioactive materials under the jurisdiction of the AECB (nuclear power production) is less than one per cent of the dose we receive. From a public health perspective, efforts to limit exposure to NORM will have more impact than introducing more stringent requirements for the use of licensed radioactive materials or nuclear power stations.

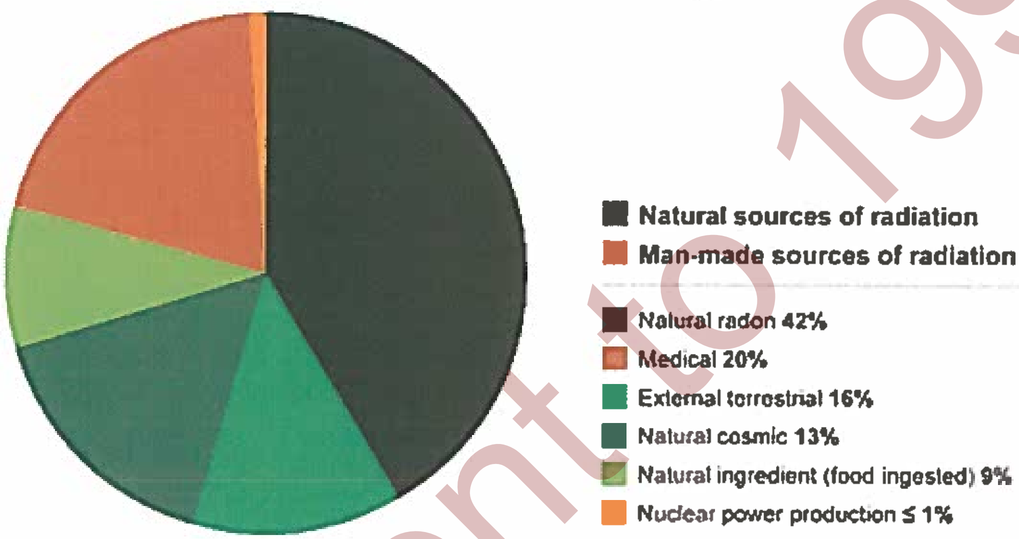
The Sources of NORM

NORM is widespread and though generally very diluted, it can be concentrated either deliberately (nuclear fuel cycle) or unintentionally (NORM). For example, radon in the atmosphere is a very minor concern, but when energy-efficient homes are built, the radon levels indoors may be increased by factors of several hundred. Similarly, radium in production water from an

Figure 1

Radiation Dose Received by Members of the Public

Source of Radiation to Which an Individual is Exposed in Everyday Life – Total Dose: 3.0 mSv/year



Average values for Canadian Residents

The sources of natural background radiation, shown in **green**, include:

- radon
- food and drinks, like bananas which naturally contain potassium-40
- naturally-occurring radioactive metals in the Earth's crust and rocks, like uranium
- cosmic rays from the sun and outer space

Man-made, or artificial, sources of radiation are shown in **orange**. The dominant source is from medical procedures. Controlled releases from nuclear facilities are included in the category of "Other man-made sources" which collectively account for less than one per cent of total radiation exposure.

oil well may not be a serious concern, but it may lead to a buildup of radioactive scale inside pipes that require special handling. It is these kinds of activities these guidelines are intended to address. It is neither practical nor necessary to control naturally occurring radioactive materials that have not been concentrated.

In many resource-based industries, normal industrial practices may increase the concentration of these elements to levels where special precautions are needed for handling, storing, transporting, and disposing of the elements.

Examples of such industries include:

- the mining of non-radioactive minerals
- working or tunneling in areas where small amounts of of indigenous radioactive minerals or gases may be present, such as in underground caverns, electrical vaults, tunnels, or sewer systems
- mineral extraction industries, where trace amounts of NORM may be released from the mineral bearing rock such as in the phosphate fertilizer industry
- oil and gas production, where trace quantities of NORM may be found in the hydrocarbon bearing geological formations
- forest products and thermal-electric production industries where mineral ashes left from combustion may concentrate small amounts of NORM naturally found in plant materials (hog-fuel) and in coal

- water treatment facilities, where fresh or waste water is treated through sorptive media or ion-exchange resins to remove minerals and other impurities from the water being treated.

The NORM Committee Guidelines

A key problem for industries that were aware they had problems with NORM has been the fact that NORM crosses regulatory boundaries. For example, transportation of a NORM waste for disposal involves Occupational Health and Safety (worker exposure), AECB (transport of radioactive material), provincial departments of environment and health (final disposal options). This document was developed to help clarify the jurisdictional confusion by recommending standards to ensure adequate control of problems associated with NORM that may arise during normal industrial operations.

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THE CLASSIFICATION OF MATERIALS CONTAINING NATURALLY OCCURRING RADIOISOTOPES

The Committee believes that the same standards should be applied to all sources of radiation. To that end, materials containing NORM have been classified in accordance with the recommendations of the International Commission on Radiological Protection (ICRP) and the Canadian requirements for other types of radioactive material that are enforced under both the Atomic Energy Control Act (AECA) and regulations issued by the AECB.

In keeping with the philosophy of the ICRP, two categories of NORM have been established. The first defines those radioactivity levels to which the general public is normally exposed; the second defines the radioactivity levels acceptable only in the context of occupational exposure.

Public exposure (*de minimis*) levels

Natural radioactivity is so widespread it cannot be avoided. The public exposure, or *de minimis,* level is the point above which special attention must be paid to radioactivity of any material, including NORM.

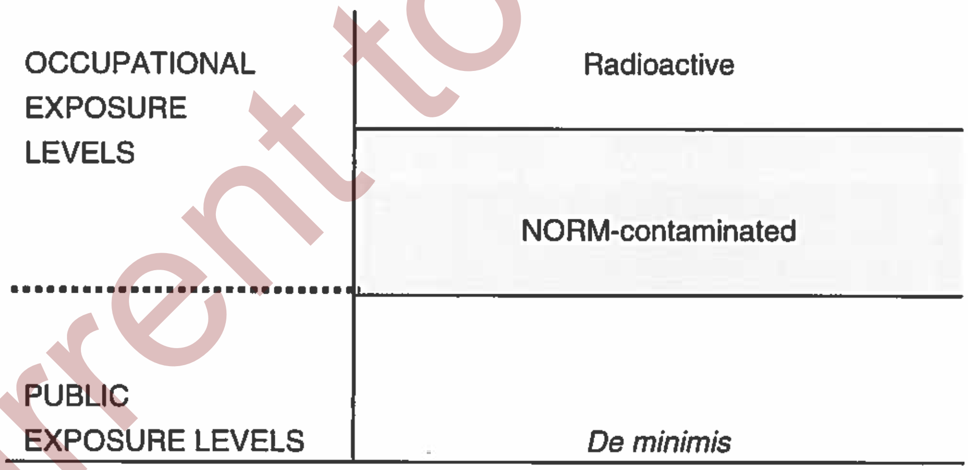
Radioactivity below *de minimis* levels is considered to be of no importance in terms of potential effect on individuals or the ecosystem. Materials whose radioactivity does not exceed these levels do not require any labelling to identify their content of radionuclides.

Occupational Exposure Levels

Occupational exposure may be at two levels depending on the concentration of radioactivity workers encounter C in bulk materials, on the surface of manufactured materials, or in the release of radon gas.

Materials that exceed *de minimis* levels, but do not exceed the levels listed at which they would be classified as *radioactive,* are termed *NORM-contaminated.* Special work procedures must be followed for NORM-contaminated material.

Materials classified as *radioactive* are subject to certain legal requirements and stricter work procedures.



ELEMENTS OF A NORM MANAGEMENT PROGRAM

As has been said, NORM is wide-spread and concentrations can occur unexpectedly in widely differing industries C from mining operations and industries handling large quantities of new materials such as oil and gas to small recycling and repair operations.

If there is reason to suspect a NORM problem, the following steps are recommended:

1. **Identify** if current industrial or commercial processes are concentrating NORM by conducting a survey of the process. This should include radiochemical analysis of feed stock, products and waste materials and a radiation survey of the process equipment.

2. Using the results of the radiochemical analysis and survey, **classify** the equipment and materials as *de minimis, NORM-contaminated* or *radioactive*.

Where all equipment and materials are classified *de minimis*, no further action to manage NORM is needed.

Where equipment or materials are classified as *NORM-contaminated* or *radioactive*, work procedures must be developed to cover the following points:

- take steps to limit the problem, e.g., reduce NORM in plant feed stock, segregate NORM-containing materials

- develop work procedures to limit employee exposure to NORM
- use proper packaging for transportation of radioactive materials
- develop appropriate storage facilities and waste-management options

PART II

TECHNICAL REFERENCE MANUAL

THE NORM STANDARDS – BASIS AND CRITERIA

Recommendations of the International Commission on Radiological Protection (ICRP)

The Western Canadian NORM Committee recognizes that naturally occurring radioactive materials (NORM) do not differ from isotopes that are controlled by the Atomic Energy Control Board (AECB) and the same radiation exposure standards should be applied. Consequently, the control of NORM should be based on the recommendations of the ICRP, which provide the basis for control of radioactive materials in almost all countries of the world. The Committee endorses the recommendations made by the ICRP for the control of radiation exposure of members of the public and occupationally exposed workers. Furthermore, the NORM Committee recommends that the NORM Guidelines be amended in concert with ICRP-based changes in the AECB Regulations in order to provide consistency in the implementation of ICRP recommendations. (Interested readers are referred to ICRP reports 60, 61, 65 and 68 for description and documentation of the ICRP recommendations.)

The recommendations of the ICRP are substantially based on the studies of the Radiation Effects Research Foundation (RERF), which continues to study the Japanese atomic bomb survivors. ICRP also reviews the data on radiation risks from every available source, and in particular it considers in detail the work of two other important agencies C 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 Acceptability of Occupational Risks in Industry

The reports of the ICRP go beyond those made by RERF, UNSCEAR, or BEIR in that the ICRP recommends permissible exposures for workers whereas the other bodies merely estimate the risks associated with radiation exposure. A key part of the work of ICRP is its assessment of the level of risk associated with being a radiation worker.

The ICRP believes that any exposure to ionizing radiation may be potentially harmful to health. They recognize that everybody is subject to a significant background exposure that is largely impossible to control and that, for most people in developed countries, equally significant exposures frequently result from modern medical practices. However, even much smaller exposures that result from occupational practices may be unjustifiable if they can be readily avoided or if there is no associated benefit. The ICRP advocates three fundamental principles for reducing occupational exposures:

- JUSTIFICATION – No use of ionizing radiation for any purpose can be justified unless it is possible to demonstrate that it will lead to positive net benefit.

- OPTIMIZATION – All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into consideration.

- 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.

Recommendation for Radiation Dose Limits

ICRP-recommended dose limits for occupational radiation exposure are all based on a maximum permissible effective dose. The dose limits currently (January 1995) enforced in Canada by the Atomic Energy Control Board (AECB) and most provinces are based on earlier recommendations of the ICRP. However, the AECB and provinces have indicated their intent to implement the most recent ICRP recommendations as soon as possible. The NORM committee recommendations incorporated in these guidelines have therefore been prepared to meet the recommendations of ICRP Publications 60, 61, 65 and 68 as interpreted by the International Atomic Energy Agency (IAEA).

Table 1
NORM Committee
PRIMARY RADIATION EXPOSURE LIMITS[i]

AFFECTED GROUP	ANNUAL LIMIT	5 YR. CUMULATIVE TOTAL
Occupationally exposed workers	50 mSv (20 average)*	100 mSv
General Public	1 mSv	5 mSv

* Additionally, during pregnancy the dose to the foetus of an occupationally exposed worker must be limited to 1 mSv or 2 mSv to the abdomen of the pregnant worker.

Note: These measurements are exclusive of natural background and medical exposures.

Annual Limit on Intake

Primary limits for annual effective dose equivalent provide the basis for many secondary limits of radiation exposure. For internal radiation exposure, the most important of these is the annual limit on intake (ALI). This is the quantity of any radioactive isotope that can be ingested or inhaled each year over a fifty-year working lifetime without that individual receiving an annual effective dose equivalent greater than 20 millisieverts (mSv). The ALI represents the limit for radioactive materials taken into the body by either ingestion or inhalation and is based on ICRP Publication 68. It is the recommendation of the NORM Committee that annual intake by ingestion and inhalation be limited to the ALI values given in ICRP Publication 68.

Table 2
Annual Limit of Intake for NORM Radionuclides[ii]

Radionuclide	Inhalation		Ingestion
	Type*	ALI (Bq)**	ALI (Bq)**
^{226}Ra	M	130	3,000
^{210}Pb	F	900	800
^{228}Ra	M	700	3,500
^{238}U	F M S	2,000 360 130	22,700 132,000
^{232}Th	M S	50 20	800
^{228}Th	M S	20 20	7,000

* 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 in biological systems. Types F, M, and S materials have Fast, Moderate and Slow absorption rates respectively.

** ALI values are based solely on radiological considerations. 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.

Derived Working Limits (DWL) for Concentration of Radionuclides

The Atomic Energy Control Board=s Advisory Committee on Radiation Protection has defined the *de minimis* dose of radiation as 10 microsieverts (□Sv) per year from any one source or procedure[iii]. Based on this concept, the IAEA has developed exempt quantities of radioactivity for various radionuclides.

From the primary exposure limits and from the ALI, other derived working limits or DWLs may derived. DWLs that may be derived in the workplace include:

- the level of activity at which a substance is legally defined as being *radioactive*
- the radiation exposure rate at which work areas would become restricted (i.e., in µSv/h)
- the concentration of radioactive dust above which a respirator must be used
- allowable radioactivity (in becquerels per litre [Bq/l]) in water released to the environment
- allowable levels of radioactivity in recycled materials

NORM Classification

As described in part I, NORM is classified into three categories: *de minimis*, *NORM-contaminated* and *radioactive*.

The classification is based upon two division points recognized by the International Atomic Energy Agency (IAEA), the Canadian Atomic Energy Control Board and the Western Canadian Committee on Naturally Occurring Radioactive Materials.

De minimis

Materials with levels of radioactivity below the *de minimis* decision point are considered for all practical purposes as non-radioactive. Continuous public and occupational exposures to these levels of radioactivity will not result in radiation doses exceeding those stipulated for the protection of members of the public, by the International Commission on Radiological Protection in its recently published report ICRP 60. The concept of *de minimis* proposed by the Western Canadian Committee on

Naturally Occurring Radioactive Materials supports the position of AECB's Advisory Committee on Radiation Protection (ACRP), which advocates the use of a *de minimis* approach in the assessment and control of public risk.

Materials or environments with radioactivity above the *de minimis* level but below the level of radioactive classification require further evaluation to determine the extent of protective measures to be applied.

Table 3

Standards and Guidelines for Classification of Diffuse NORM as *de minimis*

(Maximum activity in bulk materials intended for general releases, e.g., water treatment sludge, phosphogypsum)

BULK MATERIAL	EXEMPTION CONCENTRATIONS	CONDITIONS
Solids	<1 IAEA exempt activity concentration. Units: Bq/g of solid diffuse NORM (see Table 5, column 1)	provided the radioisotopes are uniformly distributed and not readily separable from the host material
Aqueous Solutions	<0.001 IAEA exempt activity concentration. Units: Bq/ml of aqueous NORM released (See Table 5, column 1)	Provided the radioisotopes are water soluble
Gases	Refer to Table 6	Refer to Table 6

Table 4
Standards and Guidelines for Classification of Discrete NORM as *de minimis*

(Maximum activity on equipment, tools or scrap intended for general release)

SURFACE ACTIVITY	CONDITIONS
<0.5 µSv/h at 0.5 metres	Derived from the ICRP 60 public dose limit divided by 2000 work hours per year and set at arms-length from the source.
<1.0 Bq/cm^2	Contamination by removable beta and gamma-emitting radioisotopes averaged over an area <300 cm^2 for non-fixed radioactive contamination[4]

Table 5
IAEA Exempt Activity Levels for NORM Isotopes[5]

ISOTOPE	DIFFUSE NORM Concentration (Bq/g)	DISCRETE NORM Activity (Bq/item)
Uranium-238 (which is allowed to be in equilibrium with thorium-234 and protactinium-234)	10	10 000
Radium-226 (which is allowed to be in equilibrium with its progeny)*	10	10 000
Lead 210 (which is allowed to be in equilibrium with bismuth-210 and polonium-210	10	10 000
Radium-228 (which is allowed to be in equilibrium with actinium-228)	10	100 000
Uranium (natural)	1	1 000
Thorium-228 (which is allowed to be in equilibrium with short-lived progeny)	1	10 000

* The values published by the IAEA relate to the long-lived parent radionuclide in equilibrium with its progeny. The quoted values are specifically titled "Rounded Activity", reflecting the value to the closest power of 10. The use of Uranium (natural) is considered appropriate for NORM-contaminated substances where the natural equilibrium of the material has not been disturbed by physical or chemical partitioning of the Uranium (natural) decay chain, e.g. In natural ore samples.

For materials where the decay chain is not in equilibrium or where *partitioning* has occurred, the activity of each long-lived radionuclide must be found and compared to the appropriate Exempt Activity Level. Where more than one long-lived radionuclide is present in a sample, the appropriate sum of the ratios of the activity or concentration of each long-lived radionuclide and its corresponding exempt activity or exempt concentration, must not exceed 1.0,
e.g.

$$\frac{\text{Activity Radionuclide A}}{\text{Exempt Activity A}} + \frac{\text{Activity Radionuclide B}}{\text{Exempt Activity B}} + \ldots + \frac{\text{Activity Radionuclide N}}{\text{Exempt Activity N}} \leq 1.0$$

Table 6

Radon and Radon Progeny Concentrations for NORM Contamination in Occupied Areas

CONDITIONS	SPECIES	CONCENTRATIONS*
De minimis	Radon-222 Radon progeny	<150 Bq/m^3 <0.020 working levels
NORM-contaminated	Radon-222 Radon progeny	<800 Bq/m^3 <0.10 working levels
Radioactive	Radon-222 Radon progeny	>800 Bq/m^3 >0.10 working levels

*** Assumes an equilibrium factor of 0.5 for radon-222 and its progeny.**

Note: Values for Table 6 are based on Health Canada recommendations for target and action levels of radon in Canadian homes[6]. The radon progeny standard is based on the ICRP equivalency of 1 Working Level Month = 5 mSv (NORM Guidelines, p.34)[7]

Control of radon and its progeny within the values given in Table 6 will concurrently provide for the control of thoron-220 and its daughter products within all applicable limits.

NORM-Contaminated

Materials containing levels of naturally occurring radioactivity in excess of the *de minimis* level, but below the level designated as radioactive, are considered NORM-contaminated. At these levels, exposure, if uncontrolled, has the potential to exceed the public exposure limits recommended in ICRP Publication 60. Workplace exposures at these levels are not expected to exceed the recommended limits for the occupational exposure of adult workers proposed in ICRP Publication 60; however, the ICRP have also formulated the general requirement that all unnecessary exposures should be eliminated or, if this is not possible, maintained As Low As Reasonably Achievable, (ALARA). One of the intentions of this document is to provide specific guidelines that can be applied to help ensure that both public and occupational exposures are always controlled in accordance with this principle.

A radiological evaluation of any work-site containing "NORM-Contaminated" materials will provide guidance on the monitoring of workers who are likely to receive radiation exposures in excess of *de minimis* levels. These workers, who require radiation exposure monitoring, must limit their total annual radiation dose to less than the OCCUPATIONAL DOSE LIMITS, while other workers should meet the PUBLIC DOSE LIMITS.

PUBLIC DOSE LIMITS apply at all facilities and locations to which the public has unrestricted access including most worksites.

OCCUPATIONAL DOSE LIMITS should be applied to facilities meeting the following conditions:

- NORM has been found in excess of *de minimis* levels and workers have received instruction in the use of special work procedures and have been issued protective equipment designed to reduce worker exposure.

- Area monitoring of the worksite is conducted at least annually to identify NORM accumulations and facilitate calculation of workers' radiation dose while in the work area.

- Workers with the potential to exceed an annual radiation dose of 1 mSv/y, are placed on a personal radiation dosimetry program.

Radioactive

Levels of naturally occurring radioactive materials exceeding the *radioactive limits*, if uncontrolled, could cause radiation exposures to occupationally exposed workers to exceed ICRP recommendations. These recommendations require, in addition to the guidance provided above, special procedures for the protection of workers. While the current guidelines will assist in reducing the potential hazard and should be immediately implemented, it is strongly recommended that the specialized expertise of a consultant in health physics should be obtained to assist in the further management of such situations. Criteria are provided for bulk materials, surface contamination of equipment and other items, and the release of radon and its progeny into the air.

Standards and Guidelines for Classification as Radioactive

Bulk materials

Materials containing more than 74 Bq of total radioactivity per gram of isotopes with half-lives of more than 10 days are classified as radioactive*. This is based upon the definition of radioactive given in the AECB Transport Packaging of Radioactive Materials Regulation[8] and comparable to IAEA Safety Series No. 6 (Transportation)[9].

To determine total radioactivity, apply the following rule:

For a single decay chain in which the radionuclides are present in their naturally occurring proportions and in which no progeny nuclide has a half-life either longer than 10 days, or longer than that of the parent nuclide, the activity of the parent nuclide is considered to be the total activity present. If any progeny nuclide has a half-life either longer than 10 days, or longer than that of the parent nuclide, the total activity is the sum of the activities of the parent nuclide and each progeny with a half-life longer than 10 days.

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* Radioactive materials require labelling with the international trefoil radioactive symbol. (Both international and Canadian practice is to require this warning symbol to be printed in magenta on a bright yellow field.) These materials also fall under Transport of Dangerous Goods (TDG) regulations when shipped. (See **Transportation Guideline** in this document.)

In the natural decay chains from U-238 and Th-232, this means only the following nuclides are of concern in classifying material.

Table 7
NORM Isotopes of Concern in Transportation Classification

Uranium-238 Series	Thorium-232 Series
U-238 and U-234	Th-232 and Th-228
Th-234 and Th-230	Ra-228
Ra-226	
Pb-210	
Po-210	

For transport of dangerous goods and for the labelling and disposal of materials, the total radioactivity for the sample is calculated as the sum of the activities of the above nuclides.

In practice, gamma spectroscopy (either directly or by progeny emissions) allows accurate estimation of Th-228, Ra-228 and Ra-226. It is sometimes possible to estimate Pb-210 and U-238 by gamma spectroscopy, and Po-210 can be inferred to be equal in activity to Pb-210. Thus, a single gamma spectrum can adequately characterize a sample for classification purposes. Actual activities of samples are discussed elsewhere in this report.

Surface-contaminated equipment, tools, or scrap materials

Materials are classified as radioactive when measured concentrations exceed any of the criteria given in Table 8:

Table 8

Criteria for the Classification of Areas or Equipment as Radioactive

Radiation Type	Threshold Level for Classification
Gamma	>10 µSv/h at 0.5 m
Beta surface activity[10]	>10 Bq/cm^2, as averaged over 300 cm^2
Alpha surface activity[4]	>1 Bq/cm^2, as averaged over 300 cm^2

Compliance with the beta surface activity value, as measured with a standard β/γ pancake probe will, under most circumstances, indicate compliance with the alpha surface activity value.

These standards are based on the limits allowed on the outside of packages under the Transport Packaging of Radioactive Materials Regulations for alpha- and beta-contaminated packages. The gamma standard is based on an annual dose limit for an occupationally exposed worker of 20 mSv.

Limits and Guidelines for Classification as NORM-contaminated

Materials that exceed *de minimis* limits but do not exceed *radioactive* limits are classified as *NORM-contaminated.*

Endnotes

1. ICRP Publication 60, 1990 *Recommendations of the International Commission on Radiological Protection, Summary of Recommendations* (S25), AnnICRP, 21 (1991)

2. ICRP Publication 68 *1994 Dose Coefficients for Intake of Radionuclides by Workers*, ICRP Volume 24, No.4.)

3. ACRP Publication AC-1, *Recommended De Minimis Radiation Dose Rates for Canada*, AECB Info-0355, July 1990

4. S.H. Ching, *Derived Surface Contamination Limits for the Uranium Mining and Milling Industry*, AECB Info-0138, October 1994

5. IAEA Interim Safety Series No. 115-1, *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources*, 1994.

6. *Radon, You and Your Family - A Personal Perspective*, Health Canada, 1989, Catalogue Number H49-39/1989.

7. ICRP Publication 32, *Limits for Inhalation of Radon Daughters by Workers*, AnnICRP 6 (1) (1989).

8. Canada Gazette, Part II, SOR/83-720, Transport Packaging of Radioactive Materials Regulations Rev SOR/89-426, SOR/90-172, SOR/90-192, SOR/91-304, SOR/92-150.

9. IAEA Safety Series 6, *Regulations for the Safe Transport of Radioactive Materials* 1985 Edition (as amended 1990).

10. AECB Consultive Document c-95, *Policy Statement on Maximum Acceptable Levels of Contamination on Equipment and Materials Leaving Uranium Mine Facilities*, March 1986.

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DETECTION, ASSESSMENT AND MONITORING OF NORM

Introduction

Naturally occurring radioactive materials release energy in the form of alpha, beta, and gamma emissions. These types of radiation are not perceptible to our senses, and instrumentation is required to detect and measure NORM in our environment. Due to our total dependence on instrumentation to detect NORM and quantify the safety of our environment, personnel responsible for assessing NORM must use accepted scientific practises, employ appropriate well-maintained and calibrated monitoring devices, and calculate and interpret the readings accurately.

This section can discuss only the general principles of operating instruments and developing monitoring procedures. It should not be regarded as an adequate substitute for proper reference to equipment manuals or manufacturers= recommended procedures.

An Overview of NORM Radiation

More than 50 naturally occurring radioisotopes exist. The most prevalent, and therefore most likely to be of concern, include isotopes of uranium, thorium, rubidium, potassium, radium, radon, bismuth, and lead.

Radioactive Decay Processes

Atoms contain a dense nucleus of positively charged protons and non-charged neutrons. Surrounding this cluster are orbiting negatively charged electrons.

The ratio of neutrons to protons will determine whether a nucleus is radioactive. Atoms with too many or too few neutrons in the nucleus are unstable (radioactive) and will undergo radioactive decay. This involves the release of an electrically charged particle, either an alpha (α) or a beta (β) particle, from the nucleus. Gamma (γ) radiation is the release of energy from the nucleus in the form of an electromagnetic wave or photon, following the ejection of an alpha or beta particle. The type and energy of the radiation released determines many critical factors: how far the emission may travel, how damaging the radiation is to living organisms, and how best it may be detected and measured.

Alpha Radiation (α)

Alpha radiation is a particle consisting of two protons and two neutrons emitted from the nucleus. The alpha particle, because of its high mass, carries with it a high amount of energy. As a result of its two protons, it has a positive electrical charge that interacts strongly with surrounding matter. It is, therefore, easily stopped, penetrating only a few centimetres of air, or being blocked by thin layers of materials such as paper or the layers of dead cells on the surface of the skin. Since alpha particles do not penetrate to the radiation-sensitive cells in the basal layer of the skin, no health hazard can arise from alpha particles emitted from *outside* the body; however, if alpha-emitting substances are ingested or inhaled, hazardous irradiation of the sensitive cells lining the lungs and digestive tract can take place.

As a result of its low penetration ability, alpha radiation may only be detected if the alpha emitter is exposed on the surface of equipment, or is present in the form of an airborne dust. Alpha radiation contained within enclosed process equipment cannot be detected through equipment walls. However, NORM alpha and beta emitters often release gamma energy coincident with the ejection of these sub-atomic particles. If gamma radiation is found, alpha and/or beta emitters will also be present.

Beta Radiation (β)

In the case of NORM, emitted beta particles are always negatively charged, high-energy electrons. Beta radiation interacts less strongly than alpha radiation with matter. It therefore has greater penetrating power than alpha radiation and is capable of travelling several metres in air and delivering a significant radiation dose to the living cells of tissues below the surface layer of the skin and to the cornea of the eye.

Beta radiation is readily stopped by thin sheets of metal, glass, and plastic; therefore, as with alpha particles, beta radiation may only be detected on the surface of contaminated equipment or when present in airborne dust. Gamma photons can be emitted during beta decay events. Equipment contaminated internally with beta emitters can often be identified by gamma radiation detected during external monitoring surveys.

Gamma Radiation (γ)

Gamma radiation is electromagnetic radiation similar to X-rays. Gamma radiation is a secondary radiation emitted after alpha or beta decay. Like X-rays, gamma radiation is highly penetrating and can pass through the body delivering a radiation dose to all parts of the body. Gamma emissions are frequently used to disclose the presence of alpha and/or beta activity during radiation screening surveys.

A portion of any emitted gamma radiation will penetrate the intact walls of equipment. This is the primary external hazard from NORM accumulations within industrial processing equipment. Because of the penetrating power of gamma radiation, and because detectors that are highly sensitive to it are readily available, gamma ray monitoring is the primary screening tool for the detection of NORM contamination within operating equipment.

In the case of NORM, radioactive decay is frequently a sequential process involving many radioactive decay steps until a stable element is formed. These decay series, or chains are characteristic for each radioactive element. The ^{232}Th and ^{238}U decay series are illustrated on the following page. In any natural sample (for example, uranium ore) all these elements are present. It follows that chemical or physical processes can separate the chemical elements and therefore interrupt the series. Points in the U^{238} series where this often occurs are at radium and at radon.

Radium, Radon and Radon Decay Products

Radium is particularly important in both uranium and thorium decay series as it is the radioactive parent of radon gas.

Radon-222, a chemically inert (noble) gas with a half-life of 3.8 days, is an alpha emitter. Although alpha and beta emitters have been discussed earlier, radon and its progeny merit special attention because they can be dispersed by air and deliver significant amounts of radiation when inhaled, even when well away from their site of origin. Radon is highly soluble in water and frequently travels great distances from where it was originally formed.

Table 1
SOME IMPORTANT CHARACTERISTICS OF THE U-238 AND TH-232 SERIES DECAY CHAINS

	URANIUM 238 SERIES							THORIUM 232 SERIES				
Uranium 92	238_{U} 4.5-10^{9}y		234_{U} 2.5-10^{9}y									
Protactinium 91		234_{pa} 1.2m										
Thorium 90	244_{Th} 24d		230_{Th} 8.0-10^{4}y					232_{Th} 1.4-10^{10}y		232_{Th} 1.9y		
Actinium 89									228_{Ac} 6.1h			
Radium 88			226_{Ra} 1.6-10^{3}y					228_{Ra} 6.7y		224_{Ra} 3.6d		
Francium 87												
Radon 86			222_{Rn} 3.8d							220_{Rn} 55s		
Astatine 85												
Polonium 84			218_{Po} 3.1m		214_{Po} 1.6-10^{4}s		210_{Po} 140d			216_{Po} 0.14s	65%	210_{Po} 3-10^{7}s
Bismuth 83				214_{Bi} 20m		210_{Bi} 61m					212_{Bi} 61m	
Lead 82			214_{Pb} 27m		210_{Pb} 22.3y		206_{Pb} (stable)			212_{Pb} 11h	35%	208_{Pb} (stable)
Thallium 81											208_{Tl} 3.1m	

Both uranium and radium are universally present in soils and rocks. A typical suburban garden plot of 10 m x 40 m, for example, will contain between one and two kg of uranium in the top metre of soil. Radon gas is therefore always released from the surface of the ground and is universally present in trace quantities in the atmosphere over land (concentrations over the sea are very much lower). Once released to the atmosphere the radon quickly disperses and normal concentrations at ground level rarely exceed about 20 becquerels per cubic metre (Bq/m^3).

Radon released from the soil tends to accumulate in caves, natural gas reservoirs, excavations, mines, or tunnels where rapid mixing into the atmosphere does not take place. Wherever high radium concentrations occur in the indigenous soil and rock, radon can be a concern in residential and industrial buildings, particularly those with basements. Heating and ventilating systems generally result in air pressures within buildings that are lower than the ambient pressure, and this can sometimes draw radon into the building from the surrounding soil.

Because Ra-226 has a half-life of 1600 years, Rn-222 emission rates will generally change very slowly. Once formed, radon and its short-lived decay products, can release a significant amount of radiation in a few minutes. Should the radioactive decay products of radon become airborne they may be inhaled and deliver a significant amount of radioactivity directly into the lungs. Any NORM assessment requires an evaluation of radon and its decay products.

Units of Radiation

The System International, or SI, units of measure were introduced in 1975 and will be used throughout this document. Tables of conversion factors from classical units of radiation to SI units are provided in the Appendix.

Activity

The activity of a radionuclide is a measure of the number of atoms of the material undergoing disintegration per unit time. One becquerel (Bq) of activity equals one radioactive decay event per second. Measurements of NORM material activity are typically expressed in terms of becquerels per square centimetre of surface area (Bq/cm^2) or becquerels per gram of material (Bq/g). In the case of radioactive gases such as radon, the activity of the gas is expressed in terms of becquerels per cubic metre of air (Bq/m^3).

Instruments often give readings in counts per minute (cpm) or counts per second (cps) that express the number of radioactive events detected. Field instruments will measure only a fraction of the radioactive decay events present. A correction factor must be applied to the count rate to determine the true activity present. To prevent confusion with the true activity, instrument readings are given in cpm or cps. True activity is reported in becquerels.

The becquerel replaces the classical unit of activity, the curie.

Absorbed Dose

The absorbed dose refers to the energy imparted to any material absorbing radiation. The SI unit of absorbed dose is the gray (Gy). The gray replaces the classical unit, the rad.

Dose Equivalent (Biological Dose)

The dose equivalent is the absorbed dose an organism receives from radiation multiplied by a weighting factor expressing the ability of each type of radiation to damage biological systems. For example, an absorbed dose of alpha radiation is 20 times more damaging to biological systems than the same absorbed dose received from gamma or beta radiation.

The SI unit of dose equivalent is the sievert (Sv), which replaces the classical unit, the rem. Where the weighting factor is one, the biological dose in sievert is numerically equal to the absorbed dose in gray. For example, one mGy of absorbed alpha radiation would produce a biological dose of 20 mSv, but one mGy of absorbed gamma or beta radiation would only produce a biological dose of one mSv.

Human dose rates are usually expressed in terms of microsieverts per hour (µSv/h), while cumulative dose is frequently expressed in terms of millisieverts (mSv).

Working Level

The "Working Level (WL)" is a special unit used to express the concentration of radon progeny in the air.

The "Working Level Month (WLM)" is a measure of personal cumulative dose from radon decay products based on 170 hours of work exposure per month.

The International Commission on Radiological Protection in its latest publication estimated that an inhalation dose of 1 WLM represented about the same health risk as exposure to 5 mSv of whole-body gamma radiation, and recommends an average annual radon daughter exposure of 4 WLM for occupationally exposed workers. This is based on a limit of 20 WLM averaged over any five-year period with a maximum limit of 10 WLM in any one year.

Instrumentation

There is no universal radiation monitoring instrument or technique capable of accurately measuring all forms of radiation. Equipment must be selected based on the type of radiation to be measured, whether alpha, beta or gamma.

In general, a minimum set of instrumentation required for the assessment of NORM consists of the following:

(1) a *radiation survey meter* capable of operating in either rate meter or scaler mode with the following probes:

- a gamma scintillation probe used during screening surveys to identify elevated radiation levels
- an energy compensated Geiger-Mueller (GM) tube to accurately measure gamma radiation dose rates
- a thin-window GM tube (also known as a pancake probe) used to detect surface contamination by alpha and beta emitters

(2) *check sources* used to verify the correct operation of the instruments

If the presence of radon gas and radon decay products is anticipated, the following equipment is needed:

(3) radon gas monitoring equipment
(4) a radon decay product alpha scintillation counter
(5) air sampling pumps capable of drawing at least 5 litres per minute

A listing of major manufacturers of radiation detection equipment and specific instrumentation required for the measurement of naturally occurring radioactive materials is included in the Appendices in the section entitled **NORM Monitoring Instruments and Major Manufacturers**. Also included are listings of the corporate offices of these manufacturers who may be contacted with regard to the locations of distributors nearest to the reader.

NORM Assessment Instrumentation

NORM assessments serve a variety of needs ranging from simple screening surveys to determine whether NORM accumulations are present, to detailed evaluations for comparison against health and safety, environmental management, or transportation guidelines. The type of information required will determine the form of NORM assessments that may be necessary.

The various types of NORM survey are illustrated in Figures 1 to 4 in this section.

The field survey procedures are described later in this chapter under the header *General NORM Survey Procedures.*

Equipment Preparation and Calibration

Equipment used for NORM assessment must be calibrated at least annually by the manufacturer or by a recognized facility. Calibration should be conducted more often if the instrumentation is in frequent service. Prior to each use, inspect monitoring equipment and check its functioning. All such checks and calibrations should be documented and retained to support the validity of measurement results.

Initial Inspection

All individuals performing NORM assessments should be familiar with the instrumentation and how it works. If unfamiliar with the instrumentation or its operation, the user should study the operation manual and become familiar with the correct operation of the equipment.

- Examine all equipment to ensure there is no physical damage.
- Check cables and connectors for signs of corrosion, cuts in insulation, loose connectors, or contamination.
- Examine thin-window probes and alpha-scintillation probes for punctures.
- Ensure that instrument casing gaskets are intact and in good condition.
- Check batteries for leaks and adequate charge. Carry spares.

Field Calibration

Check sources are used to evaluate and document instrument response between calibrations. *Check sources* are typically flat plastic or metallic disks, approximately 2 cm in diameter, that contain a low level of a specified radioisotope. In some instances, the source supplier may indicate an activity level for these *check sources*. These are only very rough approximations to the true activity of the source.

Certified sources, may be used to calibrate instrument readings against true activity. They incorporate three distinct features critical for their use as true calibration sources:

1) distinct identification through a source-specific serial number

2) a certificate of calibration specifying the exact activity level of the source
3) the date of certification, which is essential for determining the actual activity of the certified source at any given time after correction for natural radioactive decay

Although *check sources* contain only low levels of radioactive material, they must always be kept under the control of a responsible person. As with all radioactive materials, take care to avoid unnecessary personal exposure during use. Never leave sources unattended, handle directly or carry in a pocket. Keep sources in their manufacturer's case at all times when not in use and store them in a safe location.

Table 2
Recommended *check sources* for NORM assessments

Isotope	Type of Radiation	Instrument Probe to be Calibrated
^{137}Cesium	Gamma	Energy-compensated GM tube Gamma scintillation probe
^{99}Technetium	Beta	Thin-end window pancake probe
^{230}Thorium	Alpha	Alpha scintillation detectors Thin-end window pancake probe
^{241}Americium	Alpha	Alpha scintillation detectors Thin-end window pancake probe

Procedures

1. Get the meter and probes described under Instrumentation (see also Figure 1)

2. Inspect the probes to ensure that they are clean and have not been contaminated with NORM deposits from the last use.

3. If the probes are contaminated, clean them carefully according to the manufacturer's instructions. Extreme care should be taken when cleaning the surface of thin-window pancake and alpha scintillation probes.

4. Without connecting the probe, turn the instrument on and verify that battery voltage is adequate.

5. Check the probe voltage setting against the recommended voltage for the probe you wish to connect. (Incorrect probe voltages may result in erroneous readings or serious damage to the probe.)

6. Once the correct voltage is established, turn the instrument off, connect the probe, and turn the instrument on again.

7. Measure the background (Recommendation: When using energy-compensated GM probe, count for at least five minutes in the scaler mode.) If abnormally high readings are obtained, verify there are no sources of radiation nearby.

8. Select the appropriate *check source* from Table 2 and apply it to the probe. Ensure that the same geometry (distance from the source to the probe, and position of the source relative to the probe) is used each time the check is done.

9. Take measurements of dose rate or counts per minute. If the instrument has a scaler or integration function, use this during the calibration check. Compare the reading with the reference value obtained in the initial field

calibration. If deviations of greater than plus or minus ten percent compared to the initial reading are obtained, repeat the test and re-examine the procedure.

If it is not possible to obtain reproducible results, return the instrument for service and calibration.

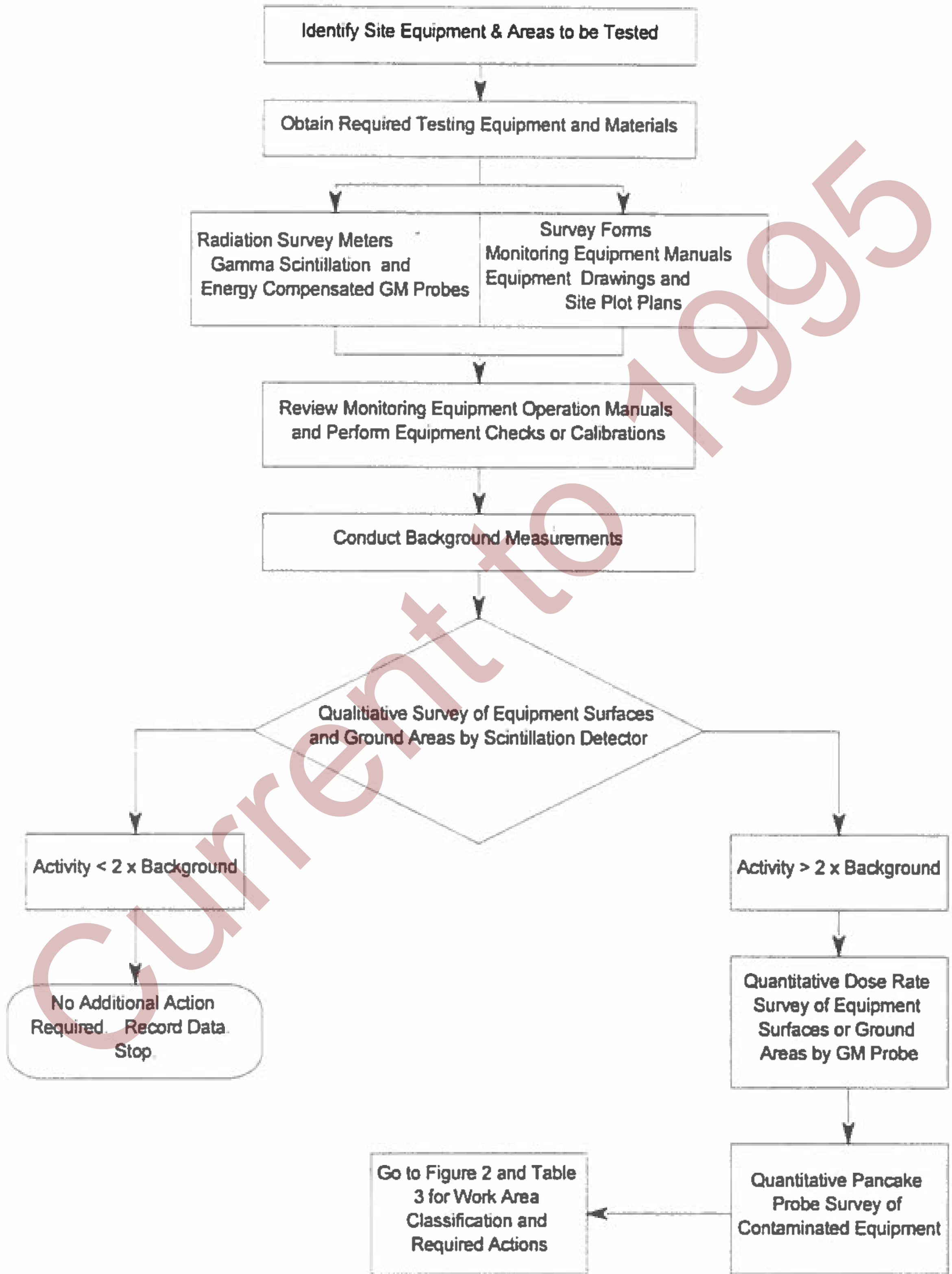
An example of a typical field calibration sheet is provided in the Appendix D, page 201.

NORM Classification

NORM-containing materials may be divided into three classes recognised by the Western Canadian Committee on Naturally Occurring Radioactive Material. These are based on two classification division points developed by the International Atomic Energy Agency (IAEA), and also recognised by the Atomic Energy Control Board (AECB) for all radionuclides under the Boards control. (A description of the three classes begins on page 52.)

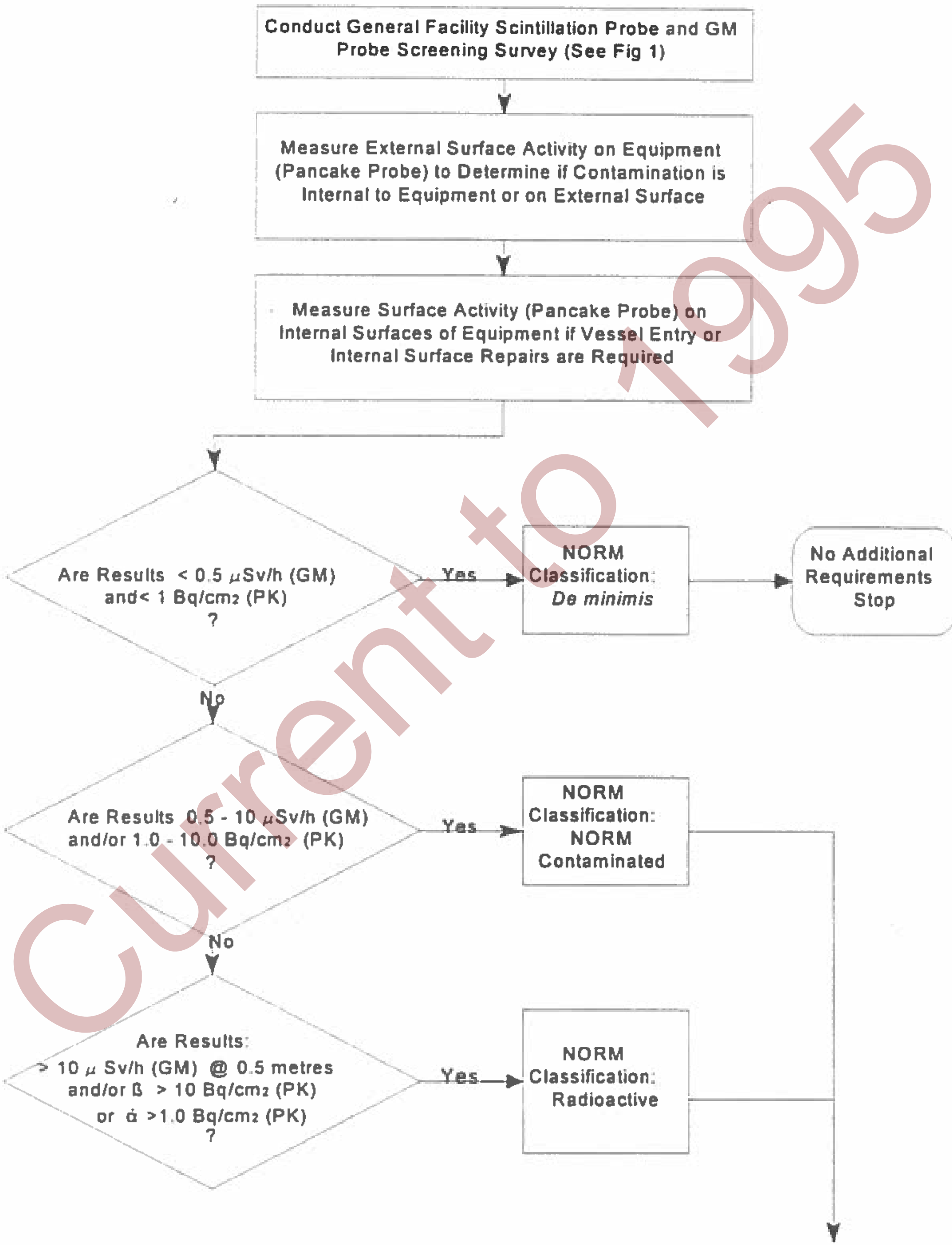
As a minimum, evaluations are necessary to determine to what degree NORM is present and into which of the three classes NORM containing materials should be assigned. An evaluation flow chart indicating the steps necessary for NORM classification is provided on the following page.

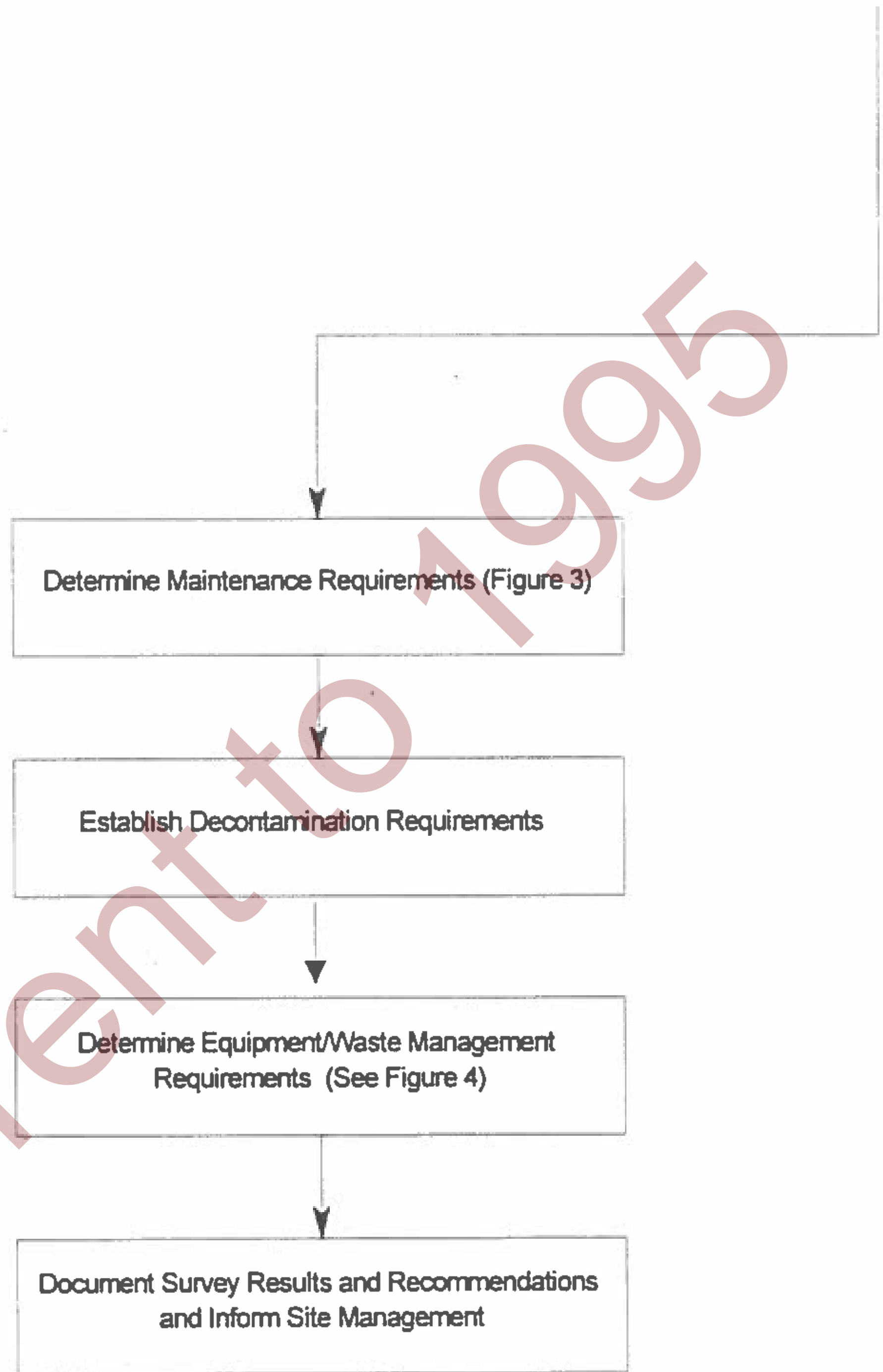
Figure 1: General Facility Screening Survey



The flowcharts on the following pages enable classification and decisions regarding worker protection to be made using field measurements.

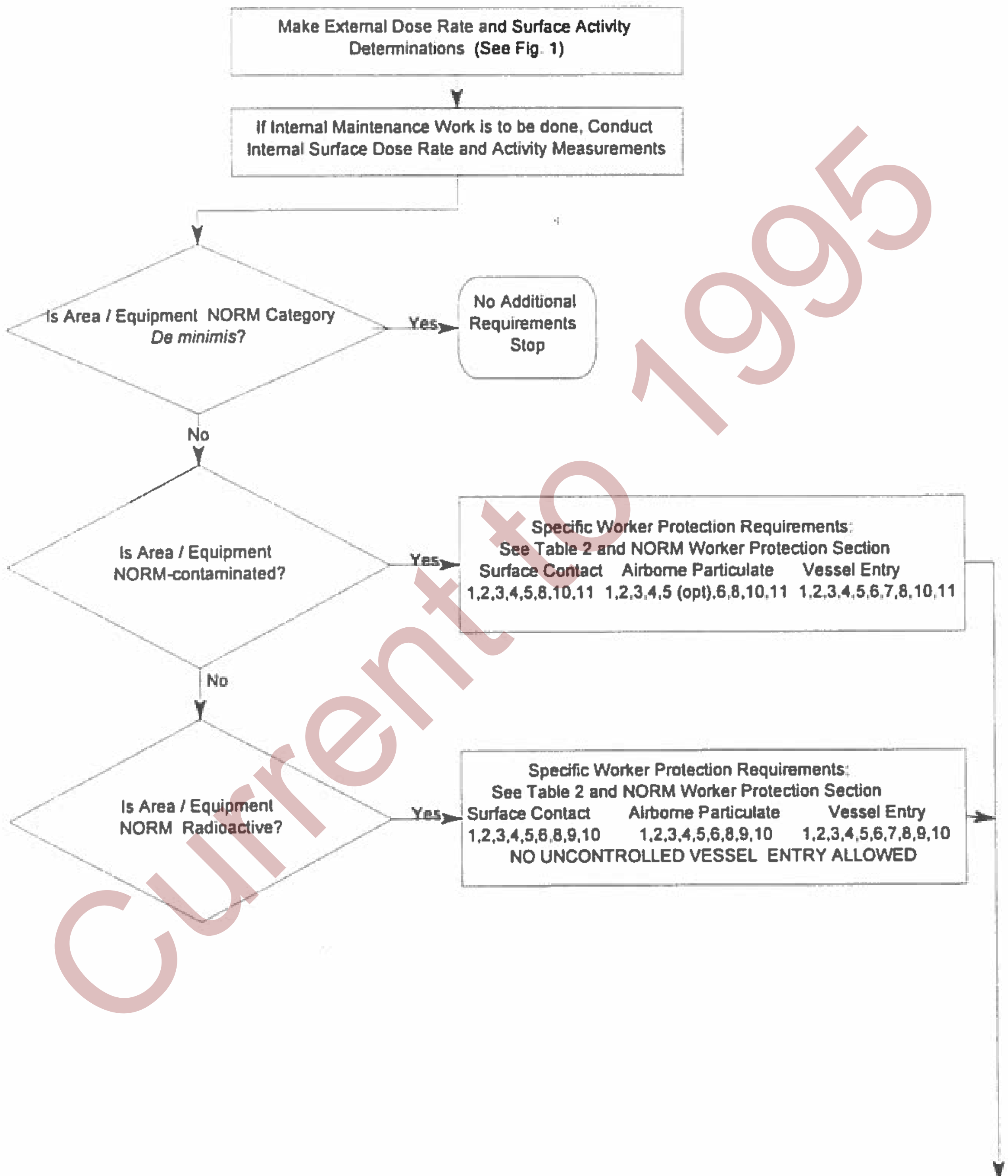
Figure 2: Facility Screening Assessment
Area and Equipment Classification Protocol Flowchart

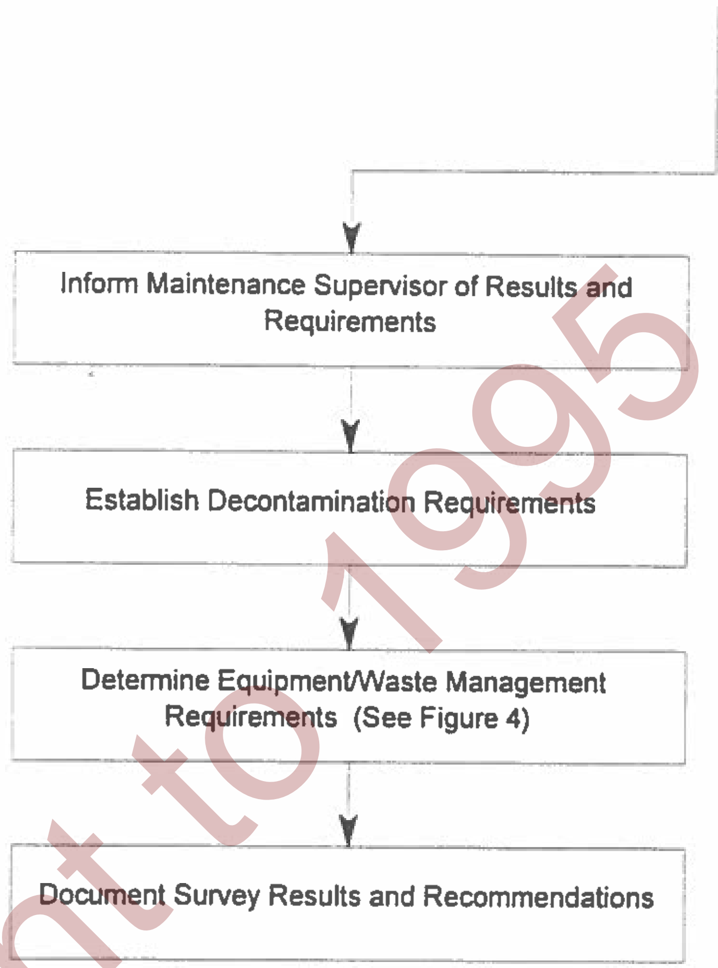




GM = Energy-compensated Geiger-Mueller (GM) Probe
PK = Pancake Probe

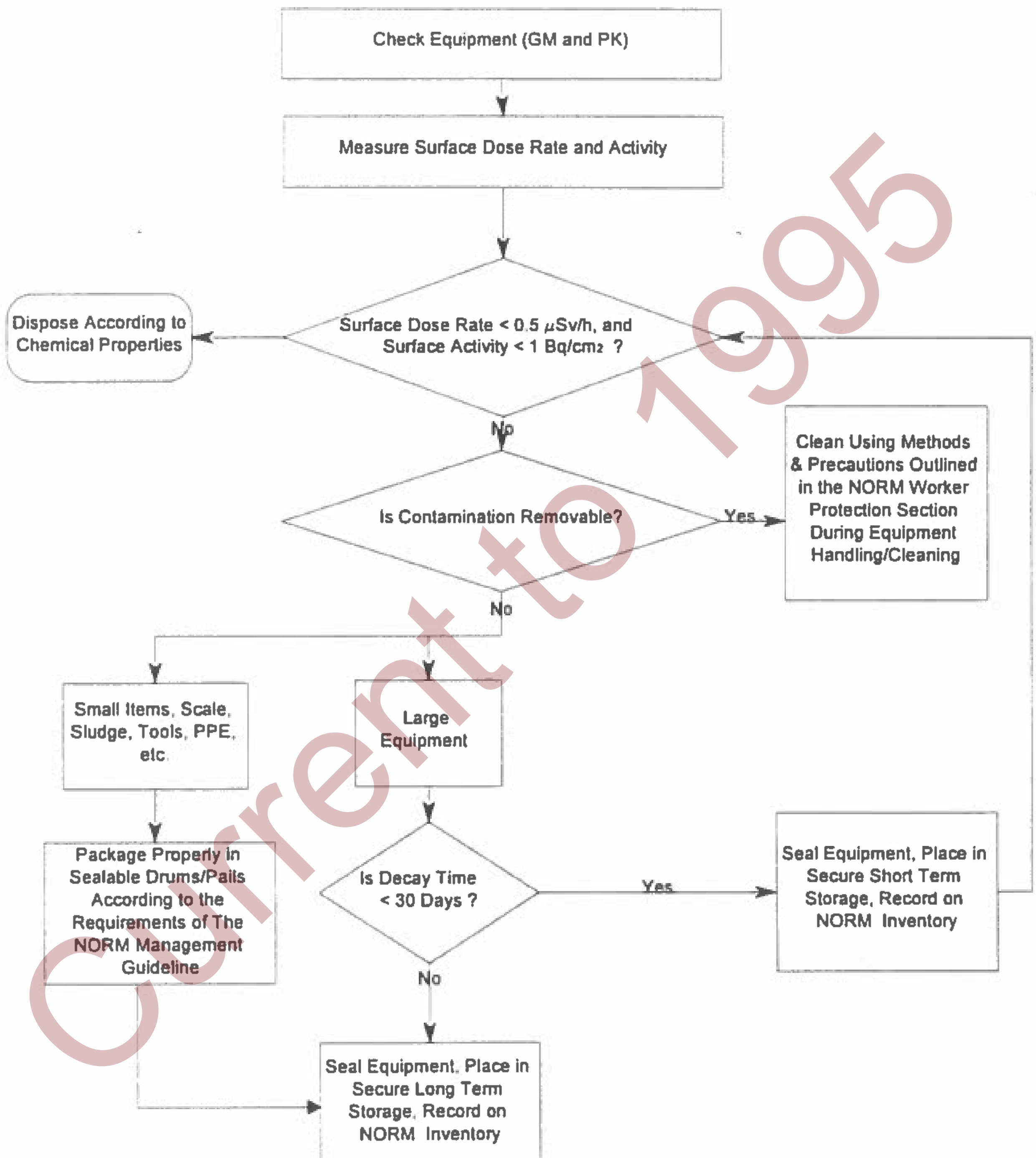
Figure 3: NORM Maintenance Assessment Contaminated Equipment/Vessel Work Requirements





GM = Energy-compensated GM Probe
PK = Pancake Probe

Figure 4: NORM Decontamination Assessment and Management Flowchart



Specific Worker Protection Measures

As indicated in Figures 3 and 4, recommendations are given for the control of exposure to NORM. Site-specific requirements for each workplace may be derived from Figure 3, which refers to the following basic list of recommendations:

Table 2
Key to Specific Worker Protection Requirements from Figure 3

1	**Worker Training**	*All workers must be advised of the presence and potential hazards of NORM, and instructed in the measures for minimizing their exposure. All unauthorized and untrained personnel must stay out of NORM work areas. Supervisors must ensure that workers are properly trained, have necessary protective clothing and equipment, and observe safe work practices.*
2	**Work Site Monitoring**	*Qualified personnel must measure and document radiation levels when working on NORM-contaminated or radioactive equipment.*
3	**Radiation Area Identification**	*Identify or mark equipment that is NORM contaminated. Post radiation signs for areas or equipment exhibiting radiation rates of greater than 10 μSv/h or greater than 1Bq/cm². Encourage workers to minimize their time in posted areas.*

4	**Maintenance Controls**	*a) Preplan work on NORM-contaminated equipment to minimize the time spent in the immediate vicinity of the equipment. Preassemble all necessary tools and equipment.* *b) Minimize manual handling of NORM-contaminated equipment. Keep NORM-contaminated materials as far from the body as feasible.* *c) Equipment dismantled for repair:* ▪ *if remaining on-site with trained tradesmen, remove loose contamination* ▪ *if transported off site to informed person, remove loose contamination and package according to Transportation regulations. (See* ***Transportation Guideline*** *in this document.)* ▪ *if transported offsite to uninformed tradesperson, clean to de minimis levels* *d) Minimize the generation of airborne dusts where the potential exists during handling or mechanical work, by keeping NORM contaminated materials wet, covered and undisturbed.*
5	**PPE - Clothing**	*Wear personal protective equipment, including hooded disposable coveralls, rubber boots and when working on NORM-contaminated equipment.* *Store and launder non-disposable coveralls on site. Discard disposable coveralls, boots or gloves with NORM waste.*
6	**PPE - Respiratory Protection**	*Use respirators with NIOSH-approved High-Efficiency Particulate Air filtering (HEPA) cartridges. Use and maintain respiratory protective equipment in accordance with CSA Standard Z94.4 - 1991.*
7	**Confined Space Entry**	*Follow normal confined space entry procedures, including gas testing for oxygen sufficiency, and elevated levels of flammable and toxic gases. Wear personal protective equipment (Disposable hooded coveralls, gloves, rubber boots and respiratory protection) and evaluate the surface contamination inside the vessel. Refer to Figure 3 for work requirements. Sample for airborne contamination using an air pump and filter.*

8	**Housekeeping And Contamination Control**	*a) Establish a controlled area and equip it with suitable radiation monitors. This requires that people and equipment leaving the controlled area be checked for contamination. Clean the area regularly by wet sweeping, washdown, or HEPA filter vacuuming. Dry sweeping or the use of compressed air must NOT be used for contaminated area cleanup. Segregate NORM-contaminated scale, sludges, solids, and equipment into marked 6 mil plastic bags or other impervious containers and place in controlled storage. DO NOT PLACE NORM WASTE IN GARBAGE OR SCRAP INTENDED FOR OFF-SITE DISPOSAL OR USE.* *b) Securely seal with 6 mil polyethylene any openings in large pieces of internally-contaminated equipment that are being relocated.* *c) Use plastic 6 mil drop sheets on expanded metal gratings, gravel, or other surfaces where the cleanup of loose NORM contaminants would be difficult.*
9	**Transportation Controls**	*NORM-contaminated equipment or waste being transported off-site must be monitored, classified, packaged and labelled as required by the Atomic Energy Control Board's* ***Transport Packaging of Radioactive Materials Regulations****, and the* ***Transportation of Dangerous Goods Regulations****.*
10	**Personal Contamination Controls**	*Do not allow eating, drinking, smoking and applying cosmetics in any area where NORM-contaminated materials are being handled. After work in such areas, personnel must remove any contaminated clothing and wash their hands and face, or shower.*
11	**Provisions for Unrestricted Release**	*Monitor all materials released for unrestricted use or disposal and ensure they meet the de minimis criteria listed in the section of these Guidelines entitled,* ***The NORM Standards c Basis and Criteria****. (See Figure 4 in this section.)*

NORM Classification

Detailed descriptions of the three classes of NORM-containing material follow.

De minimis (*De minimis* quantities are often referred to as "below regulatory concern" or BRC.)

Materials with radioactivity below *de minimis* levels are considered for all practical purposes as *non-radioactive.*

Materials with radioactivity above this level require further characterization, and may require special handling, storage, transport and environmental management requirements. These requirements are discussed in depth in the other sections of these *Guidelines*.

Materials containing less than *de minimis* levels of radioactivity are considered to be of no significance in terms of radioactivity and potential effects on the ecosystem.

At the time of writing, January 1995, the IAEA Basic Safety Standards lists the exempt concentrations and activities of radionuclides that are believed to keep public exposure below the ICRP 60 radiation dose limit of 1 mSv/yr. The Atomic Energy Control Board has stated that it intends to bring its regulations into line with the IAEA safety standard, and we recommend these values for use in Canada.

While activities of individual radionuclides are readily measured in the lab, this analysis is difficult to do in the field. Personnel charged with the evaluation of radiation safety at a facility may obtain measurements using commonly available alpha scintillation, pancake and Geiger-Mueller probes.

Radioactive

Materials with levels of radioactivity greater than 74 Bq/g of total activity are classified as *radioactive*, require labelling with the trefoil symbol, and are subject to special handling, storage, transport and disposal requirements due to the level of inherent radioactivity. This level has been internationally acknowledged as the criterion point for designation of substances as radioactive, and is incorporated into regulations issued by the AECB, the U.S. Nuclear Regulatory Commission (U.S. NRC) and other bodies. Materials above this criterion point also fall under the control of the **Federal Transportation Packaging of Radioactive Materials Regulations** and **Transportation of Dangerous Goods Regulations** when shipped.

For the purpose of determining total activity in the case of a natural radioactive series, the following rule applies:

For a single decay chain in which the radionuclides are present in their naturally occurring proportions and in which no progeny nuclide has a half-life either longer than 10 days or longer than that of the parent nuclide, the activity of the parent nuclide is considered to be the total activity present. For a single decay chain in which the radionuclides are present in their naturally occurring proportions and in which any progeny nuclide has a half life longer than 10 days or longer than the life of the parent nuclide, the total activity is considered to be the sum of the parent nuclide and each progeny with a half-life longer than 10 days.

In the natural decay chains from ^{238}Uranium and ^{232}Thorium this means that the following radionuclides are of concern in total activity classification:

^{238}U and ^{234}U
^{228}Th, ^{234}Th, ^{230}Th, and ^{232}Th
^{226}Ra and ^{228}Ra
^{210}Po, and ^{210}Pb

NORM materials classified as being radioactive, or articles contaminated with NORM at radioactive levels are subject to additional monitoring and classification requirements when shipped. For the purpose of compliance with the Federal **Transportation Packaging of Radioactive Materials Regulations** and **Transportation of Dangerous Goods Regulations**, additional monitoring must be performed in order to permit classification of the shipment as: Excepted, Surface-Contaminated Object (SCO), Low Level Solid (LLS) or, if the activity is greater than that permitted for LLS materials, as Low-Specific Activity (LSA). The following criteria must be met by LSA materials:

1) gamma fields at the surface of the package must be <5 μSv/h, and

2) non-fixed (loosely adhered) alpha emitters must be <0.37 Bq/cm^2 on the surface of the package.

For further information on this matter, the reader is referred to the section in this document entitled **Transportation Guideline** and to the applicable federal regulations.

NORM-contaminated

Materials with levels of radioactivity above the *de minimis* level, but below the criterion level for classification as *radioactive* are classified as *NORM-contaminated* and should be labelled, handled, and managed in accordance with the criteria recommended elsewhere in these *Guidelines.*

The requirements for the safe handling of such materials, as well as for heavily contaminated or radioactive materials are described in the section of these *Guidelines* entitled **Protection of Workers Exposed to NORM.**

Dose Rate Assessments

Dose-rate surveys are usually conducted using an energy-compensated GM probe. Frequently, it is prudent to take this probe in conjunction with the gamma-scintillation probe during the conduct of screening surveys. This allows rapid quantification of dose rates in areas where the scintillation probe has detected elevated gamma intensities. It should be remembered that while giving accurate readings of dose rate, energy-compensated GM probes lack sufficient sensitivity to detect minor accumulations of NORM. It is not uncommon to find that probes of this nature may have a sensitivity of less than 0.1%, meaning that 99.9% or more of the photons emitted may pass undetected. This may fail to flag future problem areas or identify areas that, although insignificant in terms of gamma emission rate, may contain sufficient alpha or beta emitters to present a significant occupational or environmental concern, or require the implementation of special procedures to comply with federal transportation requirements. As a result, GM probes should not be selected as the first choice for screening surveys.

A further limitation presented by the low sensitivity of the energy-compensated GM tube is the length of time required to obtain accurate dose rate measurements in low gamma fields. For example, one popular model of GM probe equates a photon count rate of 120 cpm with a gamma dose rate of 1 µSv/h. In order to obtain a measurement within □ 5% of the true value at this level of dose rate, the measurement must be taken with the survey instrument operating in the integrating scaler mode for a period of 2.5 minutes, then calculating the result according to the following formula:

$$\mu \text{Sv/h} = \frac{N}{CT} \pm \left(\frac{2}{N^{\frac{1}{2}}} \times 100\% \right)$$

rate *uncertainty* (%)

where N is the total counts
C is the count rate per μ Sv/h
T is the total counting period

In the case of typical background dose rates of 0.1 μSv/h, the counting time may need to be extended to 5 minutes per sample in order to achieve an acceptable degree of statistical confidence in the value obtained. This would result in prohibitively long screening surveys where large areas must be examined, whereas the use of the gamma scintillation probe would be able to distinguish any significant emission rate above background with an equal level of statistical confidence in seconds.

Personal Gamma Dosimetry

Routinely occupied workplace areas in which the radiation dose rate exceeds the normal background level by 10 μSv/h present the possibility of worker exposures in excess of the ICRP recommended radiation worker dose exposure limit. At levels in excess of 2.5 μSv/h, area monitoring should be supplemented by personal dosimetry to ascertain the actual dose to personnel within the work area, and to provide a direct measure of the effectiveness of radiation dose reduction efforts. Further discussion on the benefits of personal dosimetry and the concept of maintaining ALARA doses (As Low As Reasonably Achievable) are provided in the section of this publication entitled **Protection for Workers Exposed to NORM.**

Personal dosimetry is accomplished by electronic, film, or thermoluminescence detector chip (TLD) dosimeters worn continuously by individual workers for a period of one or more months, following which the dosimeters are returned for processing. Such procedures generally require the services of qualified radiation dosimetry laboratories; however, with the advent of electronic dosimeters, analysis may be conducted on site by electronic interrogation of data resident in data storage chips by readout units. While film or TLD dosimeters may only be used to obtain the average dose received over the interval worn, electronic dosimeters are able to register the degree of dose received on a minute by minute basis through the use of data logging technology. This allows an assessment of dose rate while conducting specific operations, or while working within specific areas of the work site. An additional benefit is that supervisory personnel can determine critical areas or operations in which remedial measures may be undertaken to reduce personal dose. Furthermore, such dosimeters often have selectable audible alarms that activate when exposed to preselected dose rates, providing further warning of excessive radiation fields to workers, thereby preventing inadvertent exposure.

The old-style quartz fibre pen dosimeters may also be used as an inexpensive backup for the usual TLD dosimeter, to provide ongoing assessment of the extent to which radiation doses are accumulating. They are not suitable for use as a primary dosimeter.

Surface Activity Assessments

Thin-window pancake probes are commonly used to measure the activity of beta-emitting radionuclides deposited on the surface of objects. However, it is a common misconception among inexperienced users that such probes are beta specific, or that they may be used for dose rate measurements. Pancake probes, although incorporating GM tubes with thin end windows for enhanced sensitivity to beta and low-energy gamma emissions, are not energy-compensated and are unsuitable for dose rate assessments. These thin-windows are designed to allow gamma radiation, much of the beta radiation and, in some cases a very little alpha radiation, to penetrate the detector wall and enter the sensitive volume. Results obtained when using pancake probes must always be expressed in cpm.

As stated previously, NORM emissions may be a combination of alpha, and/or beta, and gamma emissions. To determine whether the counts obtained with the pancake probe are due to beta or gamma emissions, the area of interest must be scanned twice – once with the thin-end window of the probe exposed, the second time with a 0.75 cm glass or 1.25 cm plexiglass sheet interposed. The difference between the cpm values of the first and second scan is a measure of the activity of beta particles on the surface being scanned. If there is no appreciable difference between the readings, it may be assumed they are gamma emissions from NORM deposits on the other side of the equipment or surface being scanned, and that any beta emissions present are effectively blocked by that surface.

Alpha Contamination Assessments

Alpha scintillation probes may be used to determine the extent of alpha surface contamination. These probes usually consist of an extremely thin, opaque mylar window, a phosphor- coated scintillator, and a photomultiplier tube that detects the scintillations produced as the alpha particles strike the phosphor, converts these into electrical pulses, and sends the pulses as a signal to the counting instrument. Because of the very thin layer of phosphor used, these probes are insensitive to beta and gamma emissions that normally pass through the phosphor layer without initiating a scintillation.

Areas in which beta particle contamination has been detected will in most, but not all, instances also have alpha emitters present. To determine the presence and activity of alpha emitters, the surface in question should also be scanned using an alpha scintillation probe. The instrument readout will again be in the form of indicated cpm.

Again, due to the limited efficiency of any counting device, the resultant counts will represent only a portion of the true alpha activity on the scanned surface. To provide users of their instruments with an indication of true activity present, manufacturers will frequently provide tables of probe efficiencies for alpha emissions (and beta emissions, in the case of pancake probes) of various energies from different radionuclides. These values may be used as approximate correction factors, that when applied to the cpm results obtained will provide a guide to the true activity present.

Surface Activity Wipe Test Assessments

In radiation protection, it is essential to determine whether NORM surface contamination is fixed (or firmly bound to the surface) or is readily removable. Readily removable surface contamination presents a high risk of contamination being spread during transport through surface contact and wind effects. Should the contaminant become dislodged from the underlying surface, the risk of the material becoming airborne, and thus inhaled, is greatly enhanced. This significantly increases the health risk to exposed persons.

In order to determine whether NORM is readily removable, the surface in question must be subjected to a surface activity wipe test. In this test, a filter paper or other sampling device is lightly wiped across the surface to assess the readiness with which the radioactive material may be dislodged from the contaminated surface.

A second reason for the wipe test involves technical difficulties in monitoring irregularly shaped surfaces. Because particulate emissions can travel only limited distances in open air, scans must be undertaken with the instrument held close to the contaminated surface. This usually means that the probe must be within 1 to 2 cm of the object being surveyed. Scans of highly angular, curved, or irregular surfaces may be impractical with hand-held probes because the curvature of the surface may place too great a distance between the surface in question and the probe for the emissions to bridge the gap. This problem is exacerbated by the fact that contamination tends to collect most readily in hollows or grooves in the contaminated surface. In these cases, wipe test samples of the potentially contaminated surfaces are taken. Measurements are then taken of the surface activity deposited on the wiping media. As transfer of the contaminant onto the sampling device is at best 10% to 20%, a correction factor reflective of this potential source of error must be applied to the resultant readings.

Radon Gas Assessments

Elevated ambient radon gas levels frequently occur in vaults, caverns or buildings. These are often extremely variable and may be influenced by weather conditions and ventilation rates; as well as the radium content and the degree of disturbance or fracturing of the rock or soil surrounding the building or space being monitored. Such high radon concentrations may result from the release of indigenous radon from the surrounding soil, from dissolved radon in a water supply, or from radon released from the processing of radium containing substances handled in industrial processes, such as crushed rock. In the case of the basements of buildings, a major factor is usually a reduction in the ambient air pressure associated with the operation of heating and ventilating systems; this leads to the possibility of significant quantities of radon-rich gas being drawn into the basements concerned from the surrounding soil.

Sampling will determine the presence and quantity of radon that may be present at a specific location, and possibly, but not necessarily, the source of the emanation. In order to determine this source, preferential positioning of samplers in proximity to processing equipment, surrounding soil or aggregate, or possible entry channels may be helpful. Comparison of radon levels in nearby buildings or areas may also help to confirm or eliminate possible causal factors in investigating elevated radon levels.

If it is suspected that the source of radon is emanation from radium containing or radium contaminated soils or aquifers, a variety of soil and water analysis instrumentation is available from many suppliers of radon monitoring instrumentation that will assist in establishing the level of radon activity in the suspect materials. Use of these devices as well as conventional radon in air sampling are discussed in subsequent sections of this document.

Various forms of radon gas monitoring equipment exist, based on a number of different technologies. The most popular of these are alpha scintillometry and solid state detection systems.

Properly used, most detection systems will produce equally valid results; however, it is generally acknowledged that systems based on alpha scintillometry are best suited and of greatest benefit to individuals whose primary monitoring objective is to obtain a large number of samples taken over a few minutes duration (grab samples) during radon surveys. Those who want an indication of average exposure or accumulated dose may choose to use dosimetric samplers such as charcoal canisters or track etch dosimeters, while those who wish to conduct continuous monitoring while obtaining longer-duration trend analysis over a period of several days, weeks or months (long-term sampling) have found solid state detector instruments to be, in general, preferable. Selection of an appropriate monitoring system is therefore dependent upon a variety of considerations including what information must be obtained, the extent of the resources (time, money, manpower) that can be committed, and the degree of technical complexity required to achieve these objectives.

Grab Samples (Alpha Scintillometry)

Grab samples are taken by drawing air for a few minutes through a filter paper that removes radon decay products, into a phosphor-coated sampling flask known as a Lucas scintillation cell. The air sample is then allowed two to four hours to come into equilibrium with any radon decay products that may form. The sample is then counted using a portable photomultiplier tube and scaler, and the result is corrected for volume, cell efficiency, and decay. As Lucas cells are independent of the photomultiplier/scaler, a large number of samples may be collected and sequentially analyzed by one readout device, thus permitting a large scale survey to be conducted efficiently in a minimum of time.

Due to potential changes in air flow patterns, ventilation rates, and even atmospheric conditions, a number of grab samples must be taken over an extended period in order to adequately characterize the level and variability of the radon gas that may be present. A continuous radon monitor that generates a graph of the variation in radon levels over a period of several weeks or months often shows order-of-magnitude, short-term variations over periods of days or hours that may well be superimposed on longer term changes in meterological conditions or seasons. While grab sampling is a useful technique for performing a number of screening assessments over a short period of time, the use of long-term sampling devices is preferable for assessing radon concentrations in facilities where elevated radon concentrations have been shown to exist.

Long-Term Samples

Long-term monitoring is necessary when there is ongoing or continuous occupancy of a work area or location. Furthermore, long-term monitoring is recommended in areas where fluctuations in ventilation rate, or radon release factors may make emission levels variable. Long-term radon assessments may be carried out using either alpha scintillometry or solid state analysis techniques. Air samples for radon, which are to be analyzed by alpha scintillometry, may be collected on activated charcoal sampling canisters that are typically suspended in the area being monitored for a period of several days. The canisters are then returned to a qualified radiological laboratory where a liquid scintillation or gamma spectrum analysis is used to determine the results. Such results are prejudiced towards the last 12 hours of the sampling period, although the average radon concentration over the sampling period is reported.

Long-term sampling of average radon gas concentration may also be accomplished through the use of "track etch" monitors. Track etch monitors typically consist of a piece of plastic film, such as Type II Kodak Pathe LR115 or Kodak Pathe LR2, the surface of which is damaged when hit by an alpha particle. These alpha impact sites are subject to pitting when placed in a caustic solution for processing. The number of pits per unit area per unit of time is then calculated and correlated with the amount of radon exposure damage produced through exposure to a known concentration of radon gas in a standard laboratory calibration chamber. The track etch monitor is typically exposed at the sampling site for a period of three months or longer. It is suitable for use in areas where low radon concentrations may exist, but knowledge of the average radon exposure with time is vital; for example, continuously occupied basement suites in an apartment building suspected of being constructed with contaminated fill.

A third type of integrating radon monitor, available in models suitable for both short-term (48 hour) and long-term (3 month) measurements, is supplied commercially under the trade name E-PERM. These devices are electrets, capacitors that can be charged to high voltages and have such high insulation that their charge can be held with little loss for many months. They are connected so that they apply a voltage across an ionization chamber that is open to the radon rich air. This will cause an ionization current proportional to the radon concentration to pass through the chamber, and will gradually discharge the electret. The loss of voltage experienced over a given time will be a function of the ambient radon concentration to which the E-PERM dosimeter has been exposed.

The electret ion chamber radiometric system (E-PERM™) can be used to make short-duration and long-term radon measurements. The electret ion chamber serves as a collector of ions produced by the radioactive decay of radon. The concentration of radon is determined by the decrease of voltage across the electret.

A limitation of all such integrating types of monitor is the inability of passive monitoring devices to indicate fluctuations in radon activity concentration with time. The result obtained from these devices is strictly the average of the concentration over the time period the samplers were exposed. Changes in radon emission rate in response to process production rate changes, atmospheric conditions, or other variables are simply averaged out with this system. With a reduced knowledge of cause and effect factors, control of radon emission levels becomes less certain. This may be overcome by the selection and use of data logging continuous electronic monitors which obtain direct reading real time sampling data without the need for laboratory analysis, then store the accumulated results in a data logger function which allows sequential printout or downloading of results to a printer or computer for further use. Diffusional silicon detector continuous monitors of this type have recently been marketed by Honeywell Inc. and Sun Nuclear Corporation.

These devices, available in various configurations for air, soil, and water testing operate on the following basis. Radon enters a counting chamber by diffusion through a 1 micron membrane which excludes the solid radioactive radon daughter particles. Radon decay while in the chamber results in the production of ^{218}Polonium and ^{214}Polonium, both of which decay with the release of alpha radiation. It is this decay event that is detected by a solid state (diffused junction) photovoltaic detector. An analog pulse of specific voltage characteristics for ^{218}Po and ^{214}Po alphas is generated, and is then counted by a signal processor and the result displayed (in pCi/L) and stored in memory.

A user-selectable count integration period ranging from four to 24 hours and data-logging capability is built in allowing the user to download period-by-period, integrated averages to a printer, in addition to the cumulative average over the sampling duration which may last from several hours to 96 days. Although the monitor is designed to operate from mains power through a converter, the supply of 18 volts DC from external or internal batteries permits the device to be used as a portable field instrument. However, such instruments are subject to problems from dust resulting in diffusional membrane plugging if not adequately protected against this possibility.

Radon Daughter Assessments

It is the short-lived decay products of radon that are of particular health concern due to the potential for inhalation and retention of the daughter radionuclides in the lungs. (The radon gas itself is normally exhaled before radioactive decay can take place). However, these decay products are more difficult to measure due to their short half lives. It is, therefore, not uncommon to find that radon alone is measured and the concentration of radon decay products is derived by calculation. Such calculations must be based on assumptions of air exchange rates and the corresponding equilibrium conditions established between radon and its daughters. They are therefore less reliable than measured values. Radon decay products may be directly assessed by grab sampling, or through the use of short-term or continuous-working-level monitors. The Modified Kusnetz Method described in the section on grab sampling continues to remain the standard reference method for the measurement of radon decay products.

Grab Sampling

In grab sampling, air is drawn at a rapid rate (usually 5 to 8 litres/min) through a glass fibre or membrane filter for a five-minute sampling period. The alpha emitters collected on the filter are then counted with an alpha scintillation counter at a specified number of minutes after sampling. From this data, the working-level concentrations of radon decay products are calculated. The Modified Kusnetz method, and Modified Tsivogolu method are the best known of the radon daughter grab sampling techniques. In the Modified Kusnetz method, the filter is counted 40 to 90 minutes after its collection using a portable alpha scintillation counter. The recorded counts are then converted to working levels using Kusnetz decay factors.

In the Modified Tsivogolu method, air is drawn through a membrane filter for a five-minute sampling period. The filter is then counted three times using a portable alpha scintillation counter (at 2 to 5 minutes, 6 to 20 minutes, and 21 to 30 minutes post sampling). The concentrations of ^{218}Po (RaA), ^{214}Pb (RaB), and ^{214}Bi (RaC) are then determined by solving three differential equations. The working level is then determined by summing the total alpha energy results obtained.

Short-Term Monitoring

Short-term monitoring generally consists of using an integrating monitor that may be placed in the area being examined for a period of several days to several weeks. These devices generally use a cellulose nitrate or CR-39 plastic film detector (often called track etch or track damage detectors). Samples may be taken by pumping air through a filter that collects the radon progeny. The filter is placed adjacent to the track etch material. Readout of the dosimeter is accomplished by etching the film at a qualified radiological laboratory and counting the total number of tracks produced by exposure under a microscope. The integrated average is determined from the total number of tracks over the exposure time.

Continuous Monitors

Working-level monitors designed to continuously sample the air provide an opportunity to obtain long term radon daughter results. In this technology, a silicon surface barrier detector is used to make a series of sequential counts of the alpha particles from radon decay products deposited on a filter paper over time periods ranging from several minutes to several hours. Through pulse height analysis and spectral discrimination, the concentrations of individual radon and thoron daughters may be determined and used to calculate the working levels present.

General NORM Survey Procedures

The first step in assessing NORM at a site is to plan a systematic facility-wide survey to determine if NORM is present above normal background level. If necessary, follow-up measurements may then be taken to determine the dose rate at specific locations, determine the type of radiation present, evaluate the amount of activity, and determine whether the contamination is fixed or distributable. During these latter activities don't hesitate to ask for help from a skilled radiation consultant if you need it.

In the initial assessment of a site, conduct a gamma scintillation survey of all areas and equipment. Don't assume where NORM contamination may be found. Past history relative to waste disposal, industrial equipment placement, and even the type and extent of NORM contamination may be limited, or incorrect, particularly in regards to abandoned sites or those that have been converted to alternate uses. Erroneous assumptions may have far-reaching consequences.

Personal Protection for Survey Personnel

The use of standard radiological safety precautions and personal protective equipment may be required to perform NORM contamination assessments as hands and other parts of the body may come into direct contact with NORM contaminated materials. See the section **Protection of Workers Exposed to NORM** for additional detail.

In areas of high NORM contamination, survey personnel should follow standard radiological safety precautions and not place their hands in close proximity to equipment if surface dose rate levels exceed 50μSv/h at 0.5 metres from the equipment. The simple expedient of taping probes to a wooden dowel or other device which they hold will allow survey personnel to place the probe against the surface to be measured while maintaining a safe distance and avoiding unnecessary and avoidable exposures.

It is good practise to ensure that NORM scale and dust are not allowed to settle directly on the body surface or clothing from which they may continue to deliver alpha, beta and gamma exposures until removed. For this reason, the use of hooded disposable spunbonded polyolefin coveralls, disposable rubber gloves, and washable rubber boots are recommended when conducting tasks that may lead to the generation of airborne NORM.

Inhalation or ingestion of alpha emitters may present a significant radiological concern in highly contaminated areas. The use of high efficiency particulate air filtering (HEPA) respirators are therefore recommended if NORM containing dusts are likely to be encountered. These cartridges are approved by the National Institute for Occupational Safety and Health (NIOSH) for use with radionuclides, hence, are colour coded with the magenta often used for the radiation trefoil symbol.

Attention to good personal hygiene, such as frequently washing hands will prevent inadvertent ingestion, while showering after conducting a NORM survey on contaminated equipment or surfaces will reduce the exposure risk from radionuclides that may be present on the skin or hair.

Gamma Scintillation Surveys

Gamma scintillation surveys provide a rapid and efficient means of screening a facility for the presence of NORM. Naturally occurring radioactive materials are primarily alpha and beta emitters. Gamma radiation is also present and indicates that NORM is present, whether on the interior or exterior of an object. Gamma surveys can be used to evaluate the internal areas of operating equipment without taking the equipment out of service.

Screening evaluations compare readings taken from the area under investigation with background readings from a nearby uncontaminated area. Gamma scintillation assessments are done in the rate-meter mode. Surveys can be conducted at a scan rate of 10 metres per minute over the surface of suspect equipment.

A gamma scintillation detector is constructed of a 1-inch or 2-inch sodium iodide (NaI) crystal that produces a flash of light, called a scintillation, when struck by a gamma photon. This scintillation is detected by an integral photomuliplier tube that produces pulses of current that are then counted by a pulse counter or "scaler."

Gamma scintillation instruments are extremely sensitive to small changes in gamma radiation intensity. The probe response is dependent on the energy of the radiation. Although they are excellent screening tools, gamma scintillation detectors should *not* be used to measure dose rates from a mixture of radioisotopes with varying gamma radiation energies – a situation characteristic of most forms of NORM. The readings should be expressed in *cpm* or *cps*, and should *not* be used for dose-rate assessment. These detectors are insensitive to alpha and most beta emissions.

If radiation levels greater than twice background are found, further assessment is required to determine the nature and extent of the NORM accumulation, and to determine the extent of any hazard presented to individuals or the environment. Refer to Figure 2: *Area and Equipment Classification Protocol Flow chart.*

Obtain a current map or plot plan of the area to be surveyed. In industrial facilities, obtain information on the location of:

- idle equipment storage areas
- locations where maintenance is or has been performed
- waste storage areas

- equipment washdown or cleaning areas
- control rooms, lunch rooms, and change room facilities

Carry out the survey following the procedure outlined below and illustrated in Figure 1.

1. Assemble all necessary gamma scintillation survey equipment and perform all previously specified pre-survey equipment checks and field calibrations.

2. Obtain background measurements in an area near the facility known to be free of possible NORM contamination and record this value as the background activity level.

3. Flag areas displaying count rates greater than twice the background activity level for possible further examination. If the survey meter has a user-selectable audible alarm, preset it to the twice background value. (This makes it easier to conduct the survey by eliminating the need to constantly view the meter response.)

4. Conduct the survey in a systematic manner.

5. For outdoor surveys in relatively open areas, use a grid search procedure based on 10 x 10- metre squares.

6. For process equipment surveys of industrial facilities, scan the processing equipment in sequential order, beginning with the start of the process and concluding with the finished product storage area. Don't overlook waste treatment areas in industrial facility NORM surveys.

7. Flag areas of elevated count rates for further investigation.

8. Survey process equipment, paying particular attention to places where process fluids may be constricted, and entrained solids may precipitate. (Examples of such places are in tankage, at process piping elbows or valves, filters and along low-velocity pipeline runs.)

9. Place the face of the scintillation probe within 10 cm of surface being surveyed.

10. Conduct scanning surveys at a rate of 10 metres/min or less in order to allow for instrument response and counting time.

11. Conduct soil or ground contamination surveys with the probe positioned 1 metre above the soil surface.

12. Flag areas where activity count rates exceed twice the background level measured at 1 metre above the ground for further investigation.

Dose-Rate Surveys

Dose-rate surveys are conducted with energy-compensated GM probes in the scaler mode. Such probes may be equipped with openable beta windows. Ensure that these windows remain closed during the course of the survey.

Because gamma radiation intensity drops off rapidly with distance, measurements should be taken with a probe at 0.5 metres from the surface. Ensure the selected instrument has the sensitivity to respond to exposure rates of concern.

Measure areas or equipment previously flagged during gamma scintillation surveys as twice background for gamma dose rate. Obtain measurements at 0.5 metres and on contact with the surface. If high dose rates are measured, survey personnel should follow the radiological safety precautions outlined elsewhere in this publication. Place a disposable plastic bag over the probe to prevent probe surface contamination. Change bags if the bag surface becomes contaminated by NORM or if persistent high readings are obtained.

In addition to surface contact readings, take measurements to demarcate the 0.5, 10, and 50 µSv/h contour lines around the area of NORM accumulation. Refer to the section **Protection for Workers Exposed to NORM** for interpretation of the significance of these values. Immediately restrict access to areas where gamma levels exceed 50 µSv/h.

Surface Activity Pancake Probe Surveys

The next step in the Figure 1 sequence is to conduct a surface activity survey using pancake probe in the scaler mode. Before beginning, put on disposable coveralls and gloves. Under dusty conditions or when doing internal vessel surveys, use a high-efficiency particulate air filtering (HEPA) respirator.

1. Reset the instrument voltage and perform a field calibration as discussed earlier under Instrumentation.

2. Obtain the background dose rate. The calibration factor for the probe must be known to convert counts to Bq/cm^2.

3. Position the probe within 1 cm of the surface being measured. The probe can easily become contaminated

with NORM materials. Inspect and clean the probe as often as necessary.

The purpose of the survey is to identify alpha and beta contamination. Because gamma radiation may interfere, two measurements are needed.

4. Take the first measurement with no shield between the surface and the probe and the second with a 1/4-inch plexiglass or glass shield in place. The difference between the two readings is the contamination attributable to beta and alpha emissions.

The objective of the surface contamination survey is to identify surfaces contaminated above 1 Bq/cm^2. The measurements are used to classify equipment and areas as in Figure 2. Restrict access to areas where surface contamination exceeds 10 Bq/cm^2.

Surface Activity Wipe Sample Surveys

Wipe sampling is used for evaluating the surface activity of an irregularly shaped or curved item when an instrument cannot reach the surface or its necessary to determine the amount of removable surface NORM activity. A limitation of wipe tests is that firmly bonded NORM deposits cannot be removed from the surface and hence, go unmeasured.

Survey personnel should note the safety precautions already discussed in the preceding sections and the section **Protection of Workers Exposed to NORM**. In addition to the survey probes and equipment described in the preceding section on pancake probe surveys, the following equipment will also be required:

- precut 17cm x 17 cm (300 cm^2) paper templates
- 5 cm diameter filter paper or medical throat swabs
- a sample holder
- zip lock storage bags

The procedure for taking wipe samples is as follows:

1. Place an unused filter in a storage bag to be used as a blank. This blank, known as the field blank, should be carried with the actual wipe test samples.

2. Place the pre-cut template on the surface to be wipe tested.

3. Wipe the open area of the template with the filter paper using moderate pressure. Hold the filter paper so that only a small portion of the total filter contacts the surface being tested. The area of the filter paper in contact with the surface should be no larger than the window of the pancake probe.

4. Place the filter paper flat in a zip lock bag and seal it.

5. Mark the bag with a sample number or other unique identifier. Do not write over top of the filter paper or in any other way compress the filter, to minimize the possibility of transferring any radionuclides onto the surface of the bag.

6. Repeat the procedure for all remaining areas. Never allow your fingers to touch the area of the filter in contact with the test surface. To prevent cross contamination of samples, it is good practise to use disposable surgical

gloves and remove and dispose of the old pair after each sample is taken.

Note: Medical throat swabs may be used instead of a filter paper, for highly irregular or difficult-to-reach surfaces. Use the same procedure as before.

7. Measure the filters using a pancake probe in the scaler mode:

   - Take all measurements using a sample holder.
   - Calibrate the instrument by counting a certified beta source.
   - Count an unused filter fresh from the pack, for five minutes.
   - Count the field blank for five minutes. These should agree within plus or minus 20 per cent. If they do not agree, discard samples and repeat sampling.
   - Count the samples for five minutes each
   - Apply a correction factor to convert from counts to becquerels and divide the Bq by 300 cm^2 (the area wiped) to give removable surface activity in Bq per cm^2. Total activity is assumed to be 10 times this level.

$$\text{Contamination (Bq/cm}^2\text{)} = \frac{\text{Counts}}{\text{Correction Factor}} \times \frac{10}{300}$$

8. Dispose of all wipe test materials, templates, and gloves following standard procedures for the disposal of NORM wastes. For further information on this matter, refer to the section of this publication dealing with NORM Management.

The objective of the surface activity survey is to identify surfaces with removable contamination above 1 Bq/cm^2 and above 10 Bq/cm^2. The measurements are used to classify equipment and areas as in Figure 2.

Airborne NORM Dust Surveys

During operations where airborne NORM-containing dusts may be generated, exposure by inhalation to alpha emitters presents a significant potential health risk that requires assessment. The quantitative assessment of exposure requires the collection of either area or personnel dust samples that may then be analyzed in a similar fashion to wipe samples as described in the preceding section. The following dust sampling equipment, available through most major safety equipment supply companies in Canada, is required to perform this type of assessment:

Portable Air Sampling Pumps
Compact battery-powered pumps that will draw air at a precisely regulated rate through a dust sampling filter for periods of up to 12 hours.

Dust Sampling Filters
Sampling for airborne NORM particulates is achieved by drawing air through matched weight 5-micron pore size, polyvinyl chloride or glass fibre air-sampling filters.

Air Sampling Pump Calibrator
This is essential to ensure an accurate measurement of the flow rate of air through the pump to minimise a potential source of error because (unless freshly calibrated) rotameters on pumps so equipped will only read, at best, an approximation of the actual air flow rate. NORM particulate air-sampling equipment

should be assembled to ensure that the plastic plugs have been removed and that the "spider web" filter support end of the cassette is attached to tubing connecting the cassette to the pump. Ensure that sampling pump batteries are fully charged prior to sampling. Adjust the air flow drawn through the pump for a rate of 2.0 - 4.0 litres/min. Follow the instructions provided with the calibrator and accurately record the air-sampling rate. Label the air-sampling cassette with a unique sample number.

1. For sampling the dust level in an area, place the sampler in the location of interest. If personnel exposures to NORM-containing dusts are to be assessed, use the belt clip on the pump to secure the sampling pump to the worker's belt, then clip the air filter to a location near the worker's collar.

2. Turn on the sample pump noting the exact time at which the pump is turned on. Samples should be collected over a period of eight to 12 hours.

3. At the completion of the sampling period, turn the pump off, again noting the exact time.

4. Recalibrate the pump to determine the air flow rate at the completion of sampling.

5. Calculate the volume of air sampled by multiplying the average air flow rate drawn through the pump (L/min) by the number of minutes the pump was operating.

6. Remove any external dust adhering to the dust filter cassette with a damp paper towel.

7. Slit the white plastic band holding the top and bottom of the air sampling cassette together.

8. Carefully remove the top of the cassette and set aside for later use.

9. Without removing the filter media from the cassette, centre the pancake or alpha probe over the rim of the cassette and obtain activity measurements.

10. Reseal the cassette and arrange for the following analyses from a competent radiological laboratory:

    a) **Mass of dust collected**
    Accomplished by weighing the mass of the dust and filter, then weighing and subtracting the mass of a matching filter, free of dust, that underlies the dust-collection filter to yield the net weight of dust collected. Measurement of the amount of dust present requires the use of a laboratory balance capable of measurements to 0.1 mg.

    b) **Gamma spectroscopy**
    Used to identify and quantify each radionuclide present.

Activity measurement values obtained either through gamma ray spectroscopy or through filter counting may then be divided by the mass of dust collected to give the specific activity, in Bq/g, of dust obtained.

Radon Gas Surveys

Radon gas may be monitored by either the grab sample or long-term sampling techniques discussed earlier. In either case, it is essential to first review the placement of the monitoring or sampling device. In any structure, radon gas enters at basement level, whether directly from the surrounding soil or dissolved in water. It mixes with the air already present and escapes through normal ventilation. Natural air currents are normally upwards and outwards so radon concentrations will be highest where it enters the building and least in the upper stories. In general, therefore, except when it is suspected that radon is being released directly from building materials or contaminated substances within the structure, samplers or monitoring instrumentation should always be placed in the lowest level of the structure being monitored. Locations where radon may be preferentially released include drainage sumps, ground water pumping stations, rock crushing facilities, propane or LPG handling facilities, tunnels, caverns, and other subsurface installations.

Due to the variety of instruments available for radon gas detection, detailed instruction suitable for each is not possible, however, the use of Lucas cell samplers in conjunction with alpha scintillometers will be discussed, as the standard reference method. Lucas cells must be counted for background (residual radiation) prior to being used for sampling. The cells are typically placed in the counting chamber and are counted for a period of one hour under the same instrument settings as will be used for the analysis of the sample.

Lucas cells used for such surveys are typically fitted with two swagelock ports on top of the cell. Filtered air is drawn through the Lucas cell for five minutes at a minimum flow rate of 5 lpm or greater. After collection, the sample is left for two to three hours for the radon decay products to reach equilibrium with the radon present. At equilibrium, each radon decay is associated with three alpha particles. The Lucas cells are then placed in the scintillation chamber and are counted for typically 30 minutes to one hour. The radon concentrations are calculated from the formula:

$$Bq/l = \frac{\text{Counts per second}_{net}}{(3xDExCV)}$$

Where:

3 = number of alphas produced and counted per ^{222}Rn

DE = detector efficiency of the alpha scintillometer

CV = cell volume of the Lucas cell in litres

While used as the standard reference method for radon gas detection, the procedure is slow and cumbersome. For many applications, it has been supplanted by electronic detector technology that provides continuous real time activity results.

Radon Decay Product Surveys

As with radon gas monitoring, a variety of instruments are currently on the market allowing grab and long-term sampling of radon decay products. The standard reference method for radon decay product analysis is the Modified Kusnetz method discussed earlier. This requires a similar air filter assembly to that used for radon gas measurements and described in the preceding section. Air is drawn through the filter (1 micron pore size or less) at a rate greater than 5 lpm for five minutes. If both radon and radon daughter measurements are being made, the filter used to filter out the radon decay products from the air being analyzed for radon gas can often be used. However, radon decay products are highly charged and tend to adhere to the surface of dust particles, samples should therefore be taken in areas where the highest dust levels may be expected, as well as those where radon gas may be released. Areas combining both a high potential for radon release and a high dust level, together with little air movement or exchange provide the greatest potential for high concentrations of radon and its progeny.

After sampling, the filter paper is placed on a ZnS scintillation counter tray so that the dust-collecting surface faces the scintillator, and is left to age for a specified period of time, usually 45 or 55 minutes. The result is calculated from the formula:

$$\text{Working level} = \frac{\text{Counts per second}_{net}}{(V x DE x K)}$$

where:

V = volume of air sampled in litres
DE = detector efficiency of the alpha scintillometer
K = Kusnetz factor.

K = 132 for a 45 min wait
K = 112 for a 55 min wait

As with radon gas monitoring, electronic instrumentation is now capable of providing significantly greater monitoring capability with reduced labour; however, the results obtained may not be as accurate or as precise; hence, electronic monitoring instrumentation should periodically be tested against this standard Kusnetz method.

Surface Activity Alpha Scintillation Probe Surveys

As indicated in earlier sections, personal protective equipment may be required to perform this assessment when hands or other parts of the body may come into direct contact with NORM materials. As a minimum, survey personnel should wear disposable coveralls and gloves. The use of high- efficiency particulate air filtering (HEPA) respirators is also recommended if NORM dust is a likely to be encountered.

1. Assemble and inspect the necessary equipment, having first ensured that operating voltages are set in accordance with the probe requirements.

2. Perform a field calibration using the ^{241}Am *check source.* Ensure that the probe response is within +/- 10% of the reference value recorded for this particular check source.

3. Obtain background measurements in an area near the facility known to be free of possible NORM contamination. Record this value as the background activity level.

4. Obtain measurements by holding the window of the probe slightly above the surface being surveyed. Distance from the surface should be maintained at approximately 1 cm or less due to the extremely limited ability of alpha particles to penetrate air. For example, the maximum distance in air that any alpha particle ejected from radionuclides in the uranium decay chain is capable of traversing is 7 cm. Most betas emitted from these nuclides are incapable of traversing 4 metres of air, although the highest energy beta particles may travel 12 metres.

5. It is not uncommon for the surface of the probe to become contaminated with NORM materials. Inspect and clean the probe according to the manufacturer's instructions as often as necessary during the survey.

6. Move the probe slowly over the surface being measured.

7. Record the highest values measured.

PROTECTION OF WORKERS EXPOSED TO NORM

An Overview of Radiological Hazards

Control of naturally occurring radioactive materials does not differ in principle from the control of artificially produced radioisotopes or nuclear fuels cycle materials regulated by the Atomic Energy Control Board. Consequently, as with licensed radioactive materials, the control of NORM in Canada should be based on the recommendations of the International Commission on Radiological Protection (ICRP) as interpreted by the AECB for the control of radiation exposure of members of the public and occupationally exposed workers.

A brief summary of the research on which the ICRP has based its latest recommendations (ICRP Publications 60 and 61) follows.

Quantitative studies of radiation effects are carried out on groups of people who have been exposed to abnormal amounts of ionizing radiation for various reasons. Several such groups are:

- patients who were subjected to high dose medical diagnostic procedures in the early days of radiology
- the survivors of the Hiroshima and Nagasaki atomic bombs in Japan
- radium dial painters in luminising works
- early uranium miners

The latter two groups received internal radiation doses from inhaled or ingested radioactive materials. This is of greater concern because the dose of radioactivity delivered is more intense, and unlike external exposures, does not cease when the individual has left the contaminated area.

The most important data on the effects of whole body radiation exposure comes from studies of the Japanese atomic bomb survivors that have been undertaken by the Radiation Effects Research Foundation (RERF) since 1950. In 1993 about 60 percent of the survivors were alive. On average, the incidence of cancer among the survivors is two percent greater than among a comparable Japanese population. Detailed risk calculations have been carried out on the basis of this fairly small difference. RERF has concluded that the actual doses of radiation received were much less than originally thought. This has led to the conclusion that the risk per unit dose must be greater.

The recommendations of the ICRP are based substantially, but not entirely, on the RERF studies. The ICRP also reviews the data on radiation risks from every available source, and in particular considers in detail the work of two other important agencies. These are the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the US National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR).

UNSCEAR was established after the Second World War and consists of leading scientists from all countries of the world. It studies data on human radiation exposure including populations subject to unusually high background radiation from natural sources.

The BEIR Committee, while studying similar reports, focuses on the production of risk models from which future health effects may be predicted. Recently, the BEIR Committee has concluded that the risk of radiation-induced cancer increases with age in a manner similar to the natural cancer risk. Such a model predicts a greater risk of developing a radiation-related cancer following any given radiation dose.

The latest ICRP recommendations (60 and 61), issued in 1990-91, accept both the RERF conclusion that doses were less than originally thought, and the BEIR Committee risk model. This has led the ICRP to recommend a large reduction in permissible dose limits both for the general public and for exposed workers. These recommendations are intended to ensure the same level of safety for radiation workers as for workers in the safest types of industry where radiation is not a factor.

ICRP 60 recommends total dose limits based on external whole body exposure and total dose to organs due to internal exposure.

Table 1
NORM COMMITTEE PRIMARY RADIATION EXPOSURE LIMITS

AFFECTED GROUP	ANNUAL LIMIT	5 YR. CUMULATIVE TOTAL
Occupationally exposed workers	50 mSv (20 average)*	100 mSv
General Public	1 mSv	5 mSv

* Additionally, during pregnancy the dose to the foetus of an occupationally exposed worker must be limited to 1 mSv or 2 mSv to the abdomen of the pregnant worker.

Note: These measurements are exclusive of natural background and medical exposures.

The rate at which the annual dose is accumulated has not been specified as health effects depend primarily on the total dose for subacute exposures and not the rate of accumulation.

The annual limit on intake (ALI) is the quantity of any radioisotope that may be ingested or inhaled each year without exceeding the annual dose limit. The greater the internal dose received, the less external dose is allowed.

Table 2
Annual Limit of Intake for NORM Radionuclides

Radionuclide	Inhalation		Ingestion
	Type*	ALI (Bq)**	ALI (Bq)**
^{226}Ra	M	130	3000
^{210}Pb	F	900	800
^{228}Ra	M	700	3,500
^{238}U	F M S	2,000 360 130	22,700 132,000
^{232}Th	M S	50 20	800
^{228}Th	M S	20 20	7,000

*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 in biological systems. Types F, M, and S materials have Fast, Moderate and Slow absorption rates respectively.

** ALI values are based solely on radiological considerations. 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.

The values given in Tables 1 and 2 are considered primary limits. Secondary limits, which are generally known as derived working limits (DWLs), may be obtained from the primary limits. The most important of these include specific activity limits below which substances may be classified as non-radioactive, and limits for radioactivity that may be present in air, soil, and water. These secondary limits are discussed in the section of these *Guidelines* entitled **Criteria for the Classification of NORM.**

Basic Principles of Worker Protection

Protection from External Radiation

The basic philosophy of worker protection from all radioactive materials, including NORM, is to maintain all exposures "As Low As Reasonably Achievable" (ALARA). In other words, if it is feasible to avoid all unnecessary exposures above normal background levels, that is the preferred objective.

In keeping with the principles of ALARA, external radiation doses above background should, if possible, be eliminated; and, if not, be minimized. Radiation dose is determined by the amount of time spent in the radiation field, and the strength of the radiation field. Exposures may be reduced by three specific approaches that can be used either independently or conjointly:

1. **Time** - Minimize the duration of exposure.
   Reducing the time of exposure in an area where radiation is present will reduce the overall dose proportionately. Elevated radiation fields must be identified so people may limit their time in these areas. Warning signs must be posted in areas exceeding 10 microsieverts/hour (μSv/h).

2. **Distance** - Maximize the distance between the source of radiation and the person(s).

   Increasing the distance, combined with limiting exposure time is the most effective and economical way of minimizing radiation dose. When the source of radiation is small the level of radiation drops very quickly with the square of the increasing distance. A general formula for the dose rate at any distance is:

$$DR_2 = \frac{d_1^2}{d_2^2} \times DR_1$$

Where:

DR_2 = dose rate at location 2

DR_1 = dose rate at location 1

d_2 = distance from the source at location 2

d_1 = distance from the source at location 1

If the source of radiation is large, the dose rate drops off more slowly.

3. **Shielding** - Reduce the intensity of radiation by providing shielding.

Shielding is the most expensive method for minimizing radiation exposure. For NORM, shielding is a method of last resort.

For any NORM deposits inside equipment, all alpha and beta radiation will be shielded. Alpha particles are readily absorbed by thin layers of any material, such as paper, placed in their path. Beta particles are readily absorbed by materials such as plastics, glass, or metal foils.

Gamma radiation is difficult to stop and may require significant thicknesses of very dense materials, such as lead, for adequate shielding. Considerations of size, weight, and cost set a practical limit to the amount of shielding that can be used.

For the uranium-238 decay series of radionuclides, shielding of 0.9 inches of steel will reduce the intensity of gamma radiation by one-half.

Prevention of Internal Radiation Exposure

Internal radiation exposure occurs when NORM gets into the body and is of far greater concern than external radiation exposure. Some radioactive isotopes may not be eliminated from the body for several decades, and a very large cumulative dose may build up.

Internal contamination is prevented by avoiding inhaling, ingesting, or absorbing radioactive materials.

- *Inhalation* is the most common route of entry. All feasible measures must be taken to prevent NORM particles from becoming airborne. Industrial operations, such as welding, grinding or cutting can create an inhalation hazard. Possible controls include using engineered ventilation controls, air filtration, good housekeeping, and closure of emission points. If the dust cannot be controlled through these measures, workers must use respiratory protection.

- *Ingestion* of NORM may occur when contaminants are deposited on food, drinks or smoking materials. Possible controls include good housekeeping, restrictions on eating, drinking, smoking or applying cosmetics in the workplace areas where contamination may be present, and good personal hygiene.

- *Absorption* of NORM into the body is limited to entry through open cuts or abrasions. Thoroughly clean and cover any cuts or abrasions.

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TRANSPORTATION GUIDELINE

Introduction

In Canada, the regulation of dangerous goods transport is federally and provincially administered. The federal Transportation of Dangerous Goods Act and Regulations has a counterpart in each province and territory. These Acts and Regulations cover nine classes of dangerous products including **Class 7 (Radioactive Material)**.

Specific federal requirements for the transport of radioactive materials including NORM, are stipulated and administered by the Atomic Energy Control Board or AECB. The AECB intends to amend its regulations to incorporate the International Atomic Energy Agency (IAEA) publication, Safety Series No. 6, *Regulations for the Safe Transport of Radioactive Material 1985 Edition (as amended 1990)*, as part of its regulation for the transport of radioactive material anywhere in Canada.

An internationally recognized standard first published in 1961 and amended five times since, IAEA Safety Series No. 6 is one of many IAEA publications identified as either Safety Series *Standards* or Safety Series *Guidelines.* Safety Series No. 6 is a Safety Series *Standard.*

The NORM *Guideline* adopts IAEA Safety Series No. 6, as the recommended reference for the transportation of NORM or NORM-contaminated material. Given the AECB's intention to adopt Safety Series No. 6 as a Regulation, the balance of this *Guideline* will refer to Safety Series No. 6 as a Regulation.

Background on the Development of the IAEA Regulation

A total of 112 countries including Canada are member states of the IAEA. In conjunction with 12 other international organizations, representatives from all parties reviewed and amended the 1985 edition of this Regulation.

The major international organizations involved in amending or incorporating this regulation as one of their own include:

- World Health Organization (WHO),
- International Labour Organization (ILO),
- Nuclear Energy Agency (NEA).

Basis of the IAEA Transportation Regulations

IAEA Safety Series No. 6 contains transportation requirements based on another IAEA standard, Safety Series No.115-1 entitled*: International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources,* Interim Safety Series, 1994.

No.115-1 adopts maximum annual radiation dose limits as specified in recommendations from the International Committee on Radiological Protection (ICRP) in its latest 1990 report *ICRP Report 60.* These recommendations describe the rationale for revising radiation dose limits based on probable risk to health associated with an assigned radiation exposure. These risk-based dose limits as adopted in Safety Series No. 115-1 have been incorporated into the development of Safety Series No. 6.

Appendix 3 provides names and addresses for purchase of any of the IAEA documents referenced in Table 1.

Figure 1

TRANSPORTATION REGULATION DEVELOPMENT SUMMARY

ICRP
(Recommendations on Risk vs. Radiation Dose Limits Developed)
Report 60

↓

IAEA
(General Radiological Safety Standards/Dose Limits Adopted)
Safety Series No. 115-1

↓

IAEA
(Regulations for Safe Transport of Radioactive Materials)
Safety Series No. 6

Table 1

It is recommended that the following IAEA publications also be acquired. They provide additional supportive information:

Title	Description
Transport of Radioactive Material IAEA, Dec. 1992	provides a history and general overview of the regulations and their development
Safety Series No. 7 IAEA Safety Guides *Explanatory Material for IAEA Regulations for Safe Transport of Radioactive Material (1985 Edition); Second Edition (amended 1990)*	describes the basis for the regulatory requirements to transport radioactive material It provides answers to WHY
Safety Series No. 37 IAEA Safety Guides; *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (1985 Edition); Third Edition (amended 1990)*	provides examples of ways that certain regulatory requirements can be met. It provides answers to HOW.
It is highly recommended that the following IAEA publication be acquired:	
Safety Series No. 80 IAEA Safety *Guides, Schedules of Requirements for the Transport of Specified Types of Radioactive Material Consignments; (As Amended 1990*	lists requirements for specific types of shipments It provides specific answers to WHAT.

The IAEA Transport Regulations

Introduction

The balance of this section of the *Guideline* will address specific requirements of **Safety Series No. 6**, *Regulations for the Safe Transport of Radioactive Material 1985 Edition (as amended 1990)*, IAEA Safety Standards.

The reader is *strongly advised* to obtain a copy of the Regulations. Where there is discrepancy between the NORM *Guideline* and this Regulation, the Regulation shall prevail.

In preparing this section of the NORM *Guideline*, the NORM requirements specified in Safety Series No. 80, *Schedules of Requirements for the Transport of Specified Types of Radioactive Material Consignments (as amended 1990)* was heavily referenced. It is highly recommended that the reader acquire this document.

The overall approach to take when classifying and preparing a NORM shipment is presented in the flow chart on the following page.

Figure 2
Overview Of NORM Shipment Preparation

NORM Material Description

- Form of material (solid/liquid)
- Specific activity (radioactive concentration) (Bq/g)
- Total *package* radioactivity (Bq)
- Total transport *container* radioactivity (Bq)

NORM Packaging Options

- Excepted package
- Industrial package
- Type A package

Selection Criteria For Package Type

- NORM material specific activity (Bq/g)
- Total shipment activity (Bq)
- Material package limits: *excepted* or *LSA*
- Maximum radiation intensity limits (ΦSv/h): package surface, transport index
- Surface-contaminated objects (SCO) limits (Bq/cm^2)
- Contamination limits:
  - fixed versus non-fixed contamination
  - surface-contaminated objects
  - package surfaces
- Exclusive use or non-exclusive use transport
- Mode of transport: air, land or inland water

Packaging Design Specification/Compliance Test Procedures

- General packaging requirements
- Additional requirements c air transport
- Excepted packaging requirements
- Industrial packaging types 1, 2 or 3
- Type A packaging requirements

Packaging Label Requirements

- Radioisotope(s) and total radioactivity (Bq): *excepted* or *LSA*
- Radiation intensity levels: package surface, transport index
- Transport category: I-WHITE, II-YELLOW, or III-YELLOW

Table 2 presents some critical reference values that are required to classify, package and ship "EXCEPTED" and "LSA" NORM consignments.

Table 2

Radionuclide	A_2	Excepted		LSA		
		Solid	Liquid/Gas	I	II	III
		0.01 x A_2	0.001 x A_2	Ores	10^{-4} x A_2/g	$2x10^{-3}$ x A_2/g
	(MBq)	(MBq)	(MBq)	Unlimited	(MBq/g)	(MBq/g)
Uranium Series						
Uranium Ore (U-ore)	Unlimited	Unlimited	N/A	Unlimited	N/A	N/A
Radium-226 (Ra-226)	20000	200	20	N/A	2	40
Radon-222 (Rn-222)	4000	N/A	4	N/A	0.4	8
Lead-210 (Pb-210)	9000	90	9	N/A	0.9	18
Polonium-210 (Po-210)	20000	200	20	N/A	2	40
Thorium Series						
Thorium Ore (Th-ore)	Unlimited	Unlimited	N/A	N/A	N/A	N/A
Thorium-232 (Th-232)	Unlimited	Unlimited	N/A	Unlimited	Unlimited	Unlimited
Radium-228 (Ra-228)	40000	400	40	N/A	4	80

Notes:

1. For ease of interpretation, the specified units in the Regulations, terabecquerels (TBq) have been converted to units of megabecquerels (MBq) in this guideline.
   1 TBq= 10^6 MBq
2. SI Units to Traditional Units
   1 TBq (10^6 MBq)= 27 Ci
   Therefore:
   0.1 MBq = 2.7 uCi   100 MBq= 2.7 mCi
   1.0 MBq = 27.0 uCi   1,000 MBq= 27.0 mCi
   10.0 MBq = 270.0 uCi   10,000 MBq= 270.0 mCi

For the balance of this guideline, all formulas and reference to A_2 values will be to TABLE 2 A_2 VALUES, which are presented in units of megabecquerels (MBq).

NORM Shipment Preparation

This section of the NORM *Guideline* will provide more specific guidance on the steps required to prepare and transport a NORM consignment. The following information, is presented in the same format as IAEA Safety Guide No. 80 but is edited, where appropriate, to specifically address NORM consignments.

I. Excepted Packages (Limited Quantities of NORM Material)

- Shipments involving the possible transport of radium-contaminated materials, (e.g., scale deposits or phosphogypsum tailings).
- Transport of limited quantities of a NORM inventory (a NORM sample) for analysis to determine NORM concentrations.
- Transfer of instrument check sources

1. Materials

- NORM solids (not including ores) in amounts not exceeding radioactive limits of 10^{-3} A_2 MBq
- Liquid NORM in amounts not exceeding radioactive limits of $1x10^{-4}$ A_2 MBq
- Radon not exceeding $1x10^{-3}$ A_2 MBq

2. Package

- Must meet general packaging requirements specified in the Regulations (Safety Series No. 6, paragraphs 505-514, pages 61 to 62)
- No leakage of package contents during normal conditions encountered while in transport.
- Other dangerous goods properties of the material (eg. flammable), taken into account.
- Transport of unpackaged NORM material prohibited.

3. **Maximum Radiation Level**
   - Maximum of 5 μSv/h at any surface of the package.

4. **Package Non-fixed Contamination Limits**
   - Less than 0.04 Bq/cm^2 on:
     - external *package* surfaces
     - internal surfaces of *freight containers*, *overpacks* and *conveyances*.

5. **Use and Decontamination of Conveyances, Parts of Conveyances and Tanks**
   - Decontaminate as soon as possible after use
   - Non-fixed contamination limit:
     - 0.04 Bq/cm^2 when not in use
     - 0.4 Bq/cm^2 while in use for radioactive and excepted packages
   - Fixed contamination limit of 5 μSv/h at the surface.

6. **Mixed Package Contents/ Mixed Loading**
   - No specific requirements.

7. **Labelling and Markings**
   - Packages
     - marked "radioactive" on an *internal* surface.
     - no labelling requirements on the *external* surfaces
     - other dangerous properties are labelled as such on the package surface.

8. **Placards**
   - No requirement for radioactive nature of the contents.
   - Placard for other dangerous properties, as appropriate.

9. **Transport Documents**
   - Describe contents in documents as:
     RADIOACTIVE MATERIAL, EXCEPTED PACKAGE, UN 2910, LIMITED QUANTITY OF MATERIAL

10. **Storage and Dispatch**
    - Transport by post:
      - Transport by Canadian post is not recommended.
      - International Post, AECB authorization (usually by air), may be required.
    - Other transport modes
      - No specific requirements.

11. **Carriage of Packages, Freight Containers and Tanks**
    - No specific requirements.

12. **Other Provisions**
    - Refer to applicable sections of the Regulations (IAEA Safety Series No. 6) on:
      - Accident Provisions
      - Compliance Assurance
      - Contamination Surveys
      - Customs
      - Damaged or leaking packages
      - Determination of the Transport Index
      - Quality Assurance
      - Radiation Protection Principles
      - Undeliverable Packages

II. Excepted Packages: NORM-Contaminated Instruments and Articles

Shipments involving the possible transport of radium-contaminated items (e.g., filter media or conveyor belts).

1. Materials

- Instruments, equipment and manufactured articles with NORM either as a component part or with NORM as a fixed contaminant.
  - solids: A_2
  - liquids: 0.1 x A_2
  - radon: 0.01 x A_2
- Total NORM radioactivity not to exceed for:
- The radiation level at 10 centimetres from external surfaces of an unpackaged item is less than 0.1 mSv/h.

2. Packaging

- General packaging requirements (see I-.2. above).
- All items securely packed.
- Other dangerous goods properties taken into account.
- Transport of unpackaged NORM items prohibited.

3. Maximum Radiation Levels

- Maximum of 5 µSv/h at any surface of the package.

4. Package Non-fixed Contamination Limits

- Less than 0.04 Bq/cm^2.

5. Use and Decontamination of Conveyances and Parts of Conveyances

- Decontaminate as soon as possible after use.
- Non-fixed contamination limit of 0.04 Bq/cm^2.
- Fixed surface contamination limit of 5 µSv/h.

6. **Mixed Package Contents/ Mixed Loading**
   - No specific requirements.

7. **Labelling and Marking**
   - International post packages:

     On one external package surface:
     - consignor's name and address
     - the words **RADIOACTIVE MATERIAL Quantities Permitted for Movement by Post**

     On internal package surface:
     - consignor's name and address and contents of consignment
   - Other transportation modes:
     - no internal or external labelling required for NORM
     - other dangerous properties specified on labelling as appropriate
   - Freight containers, tanks and overpacks:
     - no specific requirements

8. **Placards**
   - No requirement for radioactive properties of NORM.

9. **Transport Documents**
   - Describe package as:

     RADIOACTIVE MATERIAL, EXCEPTED PACKAGE, UN 2910, ARTICLES or **RADIOACTIVE MATERIAL, EXCEPTED PACKAGE, UN 2910, INSTRUMENTS** as appropriate.

10. Storage and Dispatch

- Domestic post (not recommended).
- International post - AECB authorization (usually by air), may be required.
- Other transport modes - no specific requirements.

11. Carriage of Packages, Freight Containers and Tanks

- No specific requirements.

12. Other Provisions

- Refer to Section **I-12** above

III. Empty Packages As Excepted Packages

Shipments involving the transport of:

- empty NORM transport packaging, containers or empty tanks
- descaled tubulars or other decontaminated equipment used as industrial type transport containers.

1. NORM Material

- Empty *packaging* previously containing radioactive material or NORM
- Internal fixed contamination levels shall not exceed 40 Bq/cm^2.

2. Packaging/Package

- See Section **I-2**.

3. Maximum Radiation Levels

- See Section **I-3**.

4. Contamination on Packages
- See Section I-4.

5. Use and Decontamination of Conveyances, Equipment and Parts
- See Section I-5.

6. Mixed Package Contents/ Mixed Loading
- No specific requirements

7. Labelling, Marking or Placarding of Packages, Freight Containers, Tanks and Overpacks
- See Sections I-7, I-8.

8. Transport Documents
- Describe package contents.

9. Storage and Dispatch
- See Section I-10.

10. Carriage of Packages, Freight Containers, Tanks and Overpacks
- No specific requirements

IV. Low Specific Activity NORM (LSA-I, LSA-II, or LSA-III)

LSA-I: Shipments involving transport of NORM containing ores or core samples.

LSA-II: Shipments involving the transport of NORM scale samples or filters contaminated with LSA-II NORM material.

LSA-III: Shipments involving the transport of NORM at concentrations, higher than for LSA-II materials.

1. NORM Materials

LSA-I NORM

- ores of uranium, thorium and other NORM
- physical concentrates of uranium or thorium ores containing NORM
- other radioactive material with an A_2 value that is *unlimited.*

LSA-II NORM

- NORM solids and radon gas with a radioactive concentration no greater than 10^{-4}x A_2/g.
- NORM liquids with a radioactive concentration no greater than 10^{-5}x A_2/g.

LSA-III NORM

- NORM solid, uniformly distributed or solid compacted within a binding agent AND,
- NORM is relatively insoluble or bound in a relatively insoluble matrix AND,
- NORM concentration is less than 2 x 10^{-3} A_2/g.

2. Packaging/Package

LSA-I

- can be shipped with no packaging if:
  - only *exclusive use* transport
  - no loss of NORM contents or shielding loss during routine transport.
  - for natural ores, no specific shielding requirements

LSA-I, LSA-II and LSA-III

- LSA II and III *must be packaged* where:
  - packaging meets industrial packaging (IP-1) or (IP-2) design requirements
  - packaging can be a tank or freight container

- no loss of NORM contents under routine transport
- industrial package requirements (See Table 3)

Table 3
Industrial Packaging Requirements C LSA NORM Shipments

State of NORM - Type of Transport	Type of Industrial Packaging		
	LSA-I	LSA-II	LSA-III
Solids:			
Exclusive use	IP-1	IP-2	IP-2
Non-exclusive use	IP-1	IP-2	IP-3
Liquids			
Exclusive use	IP-1	IP-2	IP-2
Non-exclusive use	IP-2	IP-3	IP-3

Note for Table 3: For industrial package requirements, refer to the Regulations - Safety Series No. 6, paragraphs 518 to 523, pp. 63 to 64

- for all LSA NORM shipments
  - other dangerous goods properties accounted for in packaging type selected

3. Maximum Radiation Levels

All LSA shipments:

- 10 mSv/h or less at 3 metres distance (no package/overpack/shielding)
- with package/overpack C exclusive use transport
  - road/rail 2 mSv/h external surface OR
  - road/rail 10 mSv/h if packaging used:
    - secured from unauthorized access
    - immobile during transport
    - no loading or unloading operations in transit

- air
  - 2 mSv/h external surface OR
  - 10 mSv/h if shipped under **special arrangement**
- with package/overpack non-exclusive use transportroad/rail/air
  - 0.1 mSv/h one metre from the surface
  - 2 mSv/h on the external surface

4. Non-fixed Contamination Limits (Packages, Freight Containers, Tanks, Overpacks)
(See Tables 4 and 5)

Table 4
External Surface Contamination Limits
IP-1 And IP-2 Packages

Content Description	Contamination Limit
LSA material (I, II or III)	0.4 Bq/cm²
LSA material (I, II or III) plus excepted material/non-radioactive goods	0.04 Bq/cm²

Table 5
External Surface Contamination Limits
Freight Containers/ Tanks And Overpacks

Content Description	Contamination Limit
LSA material (I, II or III)	0.4 Bq/cm²
LSA material (I, II or III) plus excepted material/non-radioactive goods	0.04 Bq/cm²

Note For Table 5: Overpacks/freight containers dedicated to LSA-I, II, or III NORM, are exempt from these limits only for *internal surfaces* and only while under *exclusive use*.

5. **Use and Decontamination of Conveyances, Equipment and Parts**
   - Decontaminate immediately when non-fixed contamination limits are exceeded OR
   - When surface radiation levels exceed 5 µSv/h.
   - Decontaminate until contamination and radiation levels are below specified limits.

   Note: Conveyances dedicated to LSA-I, II, or III NORM, are exempt from these limits only for *internal surfaces* and only while under *exclusive use.*

6. **Mixed Contents**
   - LSA NORM can be transported with other materials or items if no unsafe interactions can occur.

7. **Mixed Loading**
   - Mixing of LSA-I, II, or III NORM with other radioactive and non/radioactive packages is permitted.
   - Consignments must be segregated from other dangerous goods. If transport is exclusive use, other goods may be carried if:
     - consignment arrangements are under the direct control of the consignor, and
     - other regulations do not prohibit the arrangement.

8. **Labelling and Marking of Packages, Freight Containers, Tanks and Overpacks**
   - Packages
     - completed WHITE or YELLOW labels affixed to two opposite external sides of packages
     - completed WHITE or YELLOW labels affixed to all four sides of freight containers or tanks when used as packages

Note: For guidance on selection of I-WHITE, II-YELLOW, III-YELLOW, III- YELLOW (exclusive use) labels, refer to the *Regulations*:

- Paragraphs 432-435 (page 43),
- TABLE IX: *CATEGORIES OF PACKAGES* (page 44) and
- TABLE X: *CATEGORIES OF OVERPACKS INCLUDING FREIGHT CONTAINERS WHEN USED AS OVERPACKS*, (page 44).

- Labels:
  - are marked with maximum radioactivity (total becquerels) of NORM contents
  - Transport Index (TI) is specified for yellow labels
  - exterior package is clearly and durably marked with the *permissible gross mass* when package gross mass *exceeds 50 kilograms*
  - other dangerous properties are indicated on the label as appropriate

- Freight containers and overpacks (and non-packaged LSA-I shipments):
  - completed WHITE or YELLOW labels are affixed:
    Freight containers – to all four sides
    Overpacks – to two opposite sides.
  - contents described as **LSA-I, LSA-II or LSA-III**
  - maximum radioactivity (total becquerels) of the entire NORM contents during transport, is specified
  - YELLOW labels indicate the Transport Index for either the loaded freight container or overpack
  - other dangerous properties are indicated on the label as appropriate

9. Placarding of Vehicles, Freight Containers and Tanks

- All placards affixed in a vertical orientation on:
    - rail vehicles
        - two external lateral walls.
    - freight containers and tanks
        - two external lateral walls and both end walls
        - alternative enlarged labels can be used (para. 443 of the *Regulations*, page 50)
    - required for:
        - unpackaged LSA-I Material OR
        - packaged LSA Material (I, II or III) in freight containers or tanks, where **RADIOACTIVE MATERIAL UN 2912 , LOW SPECIFIC ACTIVITY (LSA), NOS** is displayed on all four sides of the freight container or tank on the lower half of the radioactive placard, (See Fig. 3).
- Additional placards may be required for other dangerous goods properties in the shipment.

Figure 3

RADIOACTIVE PLACARD SPECIFICATIONS
(Reproduced from Figure 5 of the *Regulations*)

Minimum dimensions are given; when larger dimensions are used, the relative proportions must be maintained. The figure 7 shall not be less than 25 mm high. The background colour of the upper half of the placard shall be yellow and the lower half white. The colour of the trefoil and the printing shall be black. The use of the word "RADIOACTIVE" in the bottom half is optional to allow the alternative use of this placard to display the appropriate United Nations Number for the consignment.

10. Transport Documents

- Refer to paragraphs 447 to 454 of the *Regulations*.

11. Storage and Dispatch

- Segregate from other dangerous goods during storage.
- LSA-I NORM:
  - no limit on Transport Index (TI)
- LSA-II and LSA-III NORM:
  - total TI of the storage group is less than 50 with a minimum of 6 metres distance between storage groups
  - total TI of the storage group is less than 50 with a minimum of 6 metres distance between storage groups
  - individual packages, overpacks, or freight containers with a TI greater than 50 must be separate storage groups

12. Carriage of Packages, Freight Containers, Tanks and Overpacks

- Unpackaged LSA-I Material can *only be transported* under *exclusive use*.
- LSA-II and LSA-III NORM *must* be packaged.
- Segregate packages from other dangerous goods during transport.
- No limit on Transport Index (TI)
- If TI is greater than 10, then only transport under *exclusive use*
- No total radioactivity limit for any conveyance of LSA-I NORM consignments.
- Conveyance activity limits for LSA-II and LSA-III NORM shipments (see Table 6).

Table 6
Norm Conveyance Activity Limits

Physical State of NORM	Road/Rail/Air	Inland Waterway Craft
Combustible solids	100 A_2	10 A_2
Noncombustible solids	Unlimited	100 A_2
All liquids and gases	100 A_2	10 A_2

- Maximum radiation limits for conveyances, large freight containers and tanks
  - 2 mSv/h on surface of conveyance 0.1 mSv/h at 2 metres from the surface of the conveyance
  - 0.02 mSv/h at occupied positions within a road vehicle unless persons occupying those positions are provided with personal radiation monitoring devices
- Transport by air is prohibited except by *special arrangement* (Refer to paragraph 211 of the *Regulations* - page 15) for packages with surface radiation levels greater than 2 mSv/h.
- Transport by post prohibited.

13. Other Provisions

- See section **I-12**.

V. Surface-Contaminated Objects (SCO-I and SCO-II)

NORM Shipments involving the transport of solid non-radioactive items with NORM contamination distributed on its surfaces, e.g., pipes coated with NORM scale deposits.

1. Materials

Two classes of NORM surface-contaminated objects

(SCO) for transportation (see Table 7)

- Surfaces in question must be accessible.

Table 7
Norm Surface Contamination Limits
For SCO-I and SCO-II

Class	Nonfixed	Fixed	Fixed and Nonfixed
SCO-I	0.4 Bq/cm^2	4 x 10^3 Bq/cm^2	4 x 10^3 Bq/cm^2
SCO-II	40 Bq/cm^2	8 x 10^4 Bq/cm^2	8 x 10^4 Bq/cm^2

- Contamination limits are averaged over 300 cm^2 or less if the surface area of interest is less than 300 cm^2.

2. Packaging/Package

- SCO-I can be transported *unpackaged* and *non-exclusive* if there is:
  - no escape of contents from the conveyance
  - no loss of shielding
  - no likelihood of non-fixed contamination on inaccessible surfaces
- Unpackaged SCO-I *must* be transported exclusive use when it is suspected that non-fixed contamination in excess of SCO-I contamination limits exists on inaccessible surfaces
- SCO-II cannot be transported unpackaged.
- SCO-I items *may* be transported in IP-1 industrial packages. (See *Regulations*, para. 518, page 63).
- SCO-II items *must* be transported in IP-2 industrial packages. (See *Regulations*- para. 519, page 63)
- Other dangerous goods properties must be accounted for.

3. **Maximum Radiation Levels**
   - Requirements for both SCO-I and SCO-II are identical to those for LSA NORM shipments.

4. **Non-fixed Contamination Limits**
   - Requirements for SCO-I and SCO-II are identical to those for LSA NORM shipments.

5. **Use and Decontamination of Conveyances, Equipment and Parts**
   - See LSA requirements.

6. **Mixed Contents**
   - See LSA requirements.

7. **Mixed Loading**
   - See LSA requirements.

8. **Labelling and Marking of Packages, Freight Containers, Tanks and Overpacks**
   - Packages:
     - see LSA requirements
     - labels are marked **SCO-I** or **SCO-II** as appropriate
   - Freight containers and overpacks:
     - see LSA requirements
     - labels are marked **SCO-I** or **SCO-II** as appropriate

9. **Placarding of Vehicles and Freight Containers**
   - See LSA requirements.
   - Where SCO is the only type of NORM present in the consignment, display the following on each placard on all four sides of the freight container: **UN 2913: RADIOACTIVE MATERIAL, SURFACE-CONTAMINATED OBJECTS (SCO)**

10. Transport Documents

- See LSA requirements.

11. Storage and Dispatch

- See LSA requirements.

12. Carriage of Packages, Freight Containers and Overpacks

- SCO-I may be transported:
  - *unpackaged* C if total NORM contamination on accessible and inaccessible surfaces is less than or equal to 0.4 Bq/cm^2
  - by *exclusive use* C when total NORM contamination is greater than 0.4 Bq/cm^2.
- SCO-II *must* be packaged
- Segregation from other danger goods is required during transport.
- Total Transport Index (TI) limits. (See Table 8)

Table 8
Total Transport Index Limits For Freight Containers And Conveyances

	Nonexclusive Use	Exclusive Use
Freight container	50	No limit
Vehicle	50	No limit
Aircraft - passenger	50	Not applicable
- cargo	200	No limit
Inland waterway vessel	50	No limit

- Individual packages and Overpacks with TI greater than 10, must be transported *exclusive use.*
- Maximum radiation levels - see LSA requirements

- Total NORM radioactivity in a single conveyance (see Table 9)

Table 9
Total Norm Radioactivity In A Single Conveyance

Type of Conveyance	NORM Radioactivity Limit
Inland watercraft	10 A_2
Other conveyances	100 A_2

13. Other Provisions

- Refer to Section I 12

VI. Other NORM Shipments

The majority of NORM consignments fall under one of the above categories. Should a NORM consignment require Type A packaging, the reader is referred to the *Regulations* and to *IAEA Safety Series No. 80 Schedules of Requirements for the Transport of Specified Types of Radioactive Material Consignments (as amended 1990).* A realistic example of a NORM consignment, complete with classifying steps, is provided in Appendix 2. For unusual consignments or other information, additional assistance can be sought from the list of contacts listed in Appendix 4 of this section of the NORM *Guideline.*

APPENDIX 1
NORM Transportation Glossary

A_2
In the Regulations: maximum quantity in TBq of readioactivity (total NORM radioactivity) permitted in Type A packaging.
In these Guidelines: maximum quantity in MBq of radioactivity (total NORM radioactivity) permitted in Type A packaging.

carrier
Any individual, organization or government undertaking the carriage of **NORM** by any means of transport.

consignee
Any individual, organization or government that receives a **consignment**.

consignment
Any **package** or **packages**, or load of radioactive material including **NORM**, presented by a **consignor**, for transport.

consignor
Any individual, organization or government that presents a **consignment** for transport and is named the consignor in transport documents.

containment system
The assembly of components of **packaging** specified by the package designer intended to **retain** the NORM contents during transport.

contamination
Radioactive material present on the surface of an object
Fixed contamination: NORM contamination that can=t be removed from the surface of an object.
Non-fixed contamination: NORM contamination that can be removed from the surface of an object.

conveyance
Transport by:

- road c any vehicle
- water c any vessel or hold, compartment or specific deck area of a vessel
- air c any aircraft
- rail

exclusive use

The **sole use**, by a **single consignor**, of a **conveyance** or large freight container with a minimum length of 6 metres where all loading and unloading is performed under the direction of the **consignor** or **consignee**.

freight container

An article of transport equipment design to carry goods that are packaged or unpackaged by one or more means of transport, without intermediate reloading.

- It must be permanent, enclosed, rigid and strong enough for repeated use.
- It must be fitted with **handling devices** to facilitate transfer between conveyances and from one mode of transport to another.
- It can be used as **packaging** and can be used as an **overpack.**

Small freight container: A freight container with any overall outside dimension less than 1.5 metres in length or an internal volume less than 3.0 m^3

Large freight container: Any other freight container that does not meet the requirements for a small freight container.

Low Specific Activity (LSA)

Any NORM that has a limited specific activity (concentration) such as natural ore samples, or other NORM where limits for specific activity can be applied.

The non-radioactive objects surrounding or incorporated into the NORM must not be considered in determining the specific activity.

One of three categories of LSA NORM:

(a) LSA-I

- NORM **ores** and uranium and thorium **concentrates** of those ores
- other NORM for which the $\mathbf{A_2}$ value is **unlimited**

(b) LSA-II

NORM with a specific activity (concentration) less than or equal to:

- 10^{-4} A_2/g (MBq/g), A_2 values in units of MBq in this guideline, for solids and radon,
- 10^{-5} A_2/g (MBq/g), A_2 values in units of MBq in this guideline, for liquids.

(c) LSA-III

- radioactivity uniformly distributed within the NORM or is uniformly distributed within a solid compact binding agent AND
- the NORM is relatively insoluble or the material is bound within a relatively insoluble binding matrix such that the loss of radioactivity due to leaching by water, is less than or equal to 0.1 A_2 (MBq), A_2 values in units of MBq in this guideline, over a one week period AND
- the estimated specific activity (concentration) of the solid is less than 2 x 10^{-3} A_2/g (MBq/g), A_2 values in units of MBq in this guideline.

overpack — An enclosure that may not meet the requirements of a freight container and that is used by a single consignor to **consolidate the handling** of two or more packages into one handling unit or for the purpose of stowage and carriage.

package — The packaging and its NORM contents as presented for transport.
Performance standards for Packaging depend on the quantity and nature of NORM transported and are graded to account for three severity levels (transport conditions):

- routine transport conditions (accident free)
- normal transport conditions (minor mishaps)
- accident transport conditions.

Classes of packaging applicable to NORM include:

- Excepted
- Industrial c Type 1, Type 2 and Type 3
- Type A.

packaging

- An assembly of components necessary to completely enclose the NORM materials and can consist of:
  * receptacles, absorbent materials, spacing structures
  * radiation shielding, filling/emptying/venting/pressure release equipment
  * rolling, mechanical shock, absorption, thermal insulating
  * devices to provide handling and tie-down capability.
- The assembly can also be a box, drum, freight container or tank that meets the applicable performance standards for the package classification required for transport.

radiation level — The dose equivalent rate expressed in millisieverts per hour (mSv/h).

radioactive material — Any material with a specific activity greater than 70 kBq/kg. (70 Bq/g).

shipment — The specific movement of a consignment from origin to destination.

special arrangement — Provisions specified by the Atomic Energy Control Board and/or Transport Canada and the provinces to transport a consignment that doesn=t satisfy all regulation requirements.

specific activity

- Radioactivity per unit mass of a particular radionuclide OR
- Radioactivity per unit mass of material (NORM) when the radioactivity is uniformly disbursed throughout the material.

surface-contaminated object (SCO)

A solid non-radioactive object that has radioactive material distributed on its surfaces. Two types of SCO are:

(a) SCO-I

- *Non-fixed contamination* levels averaged over a 300 cm^2 accessible surface area less than or equal to:
  - * 4.0 Bq/cm^2 (beta, gamma, low toxicity alpha emitters)
  - * 0.4 Bq/cm^2 (high toxicity alpha emitters including most NORM consignments)
- *Fixed contamination* levels averaged over a 300 cm^2 accessible surface area are less than or equal to:
  - * 4×10^4 Bq/cm^2 (beta, gamma, low toxicity alpha emitters)
  - * 4×10^3 Bq/cm^2 (high toxicity alpha emitters including most NORM consignments)

(b) SCO-II

- *Non-fixed contamination* levels averaged over a 300 cm^2 accessible surface area less than or equal to:
  - * 400 Bq/cm^2 (for beta, gamma, low toxicity alpha emitters)
  - * 40 Bq/cm^2 (high toxicity alpha emitters including most NORM consignments)
- *Fixed contamination* levels averaged over a 300 cm^2 accessible surface area are less than or equal to:
  - * 8×10^5 Bq/cm^2 (for beta, gamma, low toxicity alpha emitters)
  - * 8×10^4 Bq/cm^2 (high toxicity alpha emitters including most NORM consignments)

tank A tank container, portable tank, road tank vehicle, rail tank wagon any other receptacle:

- with a capacity greater than or equal to 450 litres and capable of containing liquids, powders, granules, slurries, solids or solidified liquids and gases.
- with a capacity greater than or equal to 1000 litres and capable of containing gases.
- that is capable of being carried on land or sea and can be loaded and discharged without the need to remove structural equipment
- that must possess stabilizing members and tie-down attachments external to the shell and can be lifted when full

Transport Index (TI) A single number assigned to a package, overpack, tank or freight container or to unpackaged LSA-I or SCO-I materials. (See section IV of the Safety Series No. 6 Regulations)

To determine the TI number, use one of the following:

TI= 100 x [Reading (mSv/h) at one metre distance]

or

TI= [Reading (mrem/h) at one metre distance]

uranium *Natural Uranium* – Chemically separated uranium containing the natural distribution of approximately 99.28% U-238 and 0.72% U-235.

Depleted uranium – uranium containing a lesser per cent U-235 than is present in natural uranium.

Enriched uranium – uranium containing a greater per cent U-235 than is present in natural uranium.

vehicle A road vehicle, railroad car or railway wagon. Trailers are considered separate vehicles.

vessel Any seagoing vessel or inland watercraft used to carry cargo.

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APPENDIX 2
A Worked Example of a NORM Consignment

Let's take an example of the kind of information you must gather for a realistic NORM shipment. You work at a gas processing plant. You have been given the task of preparing a shipment of NORM for disposal. The shipment inventory includes 40 kilograms of contaminated filters and 10 kilograms of contaminated scrap pump housing coated with 1/8 inch (0.32cm.) thick of radioactive (NORM) scale. You would like to ship this material inside a 45 gallon steel drum.

a. FORM OF THE MATERIAL:
Solid

b. RADIOISOTOPES PRESENT:
A 2-gram sample of filter and 5 grams of scale were sent to a laboratory for radiological analysis. Results showed three radioisotopes as both filter and pump contaminants:

Radioisotope	**Symbol**	**A_2 (MBq)**
Radium-226	Ra-226	20,000
Lead-210	Pb-210	9,000
Polonium-210	Po-210	20,000

c. TOTAL WEIGHT OF FILTERS:
A total of 40 kilograms of filter material are to be packaged and transported.

d. TOTAL WEIGHT OF SCALE:
As well, a 5 cubic centimetre (5 cm^3) sample of scale was carefully removed from the pump and sent to an analytical lab. Lab analysis showed that 2 cm^3 of pump scale weighed 1 gram.

You have estimated the total volume of **pump scale** to be 40 cm^3. Therefore the total weight of pump scale is:

$40 \text{ cm}^3 \times 1 \text{ gram}/2 \text{ cm}^3 = 20 \text{ grams}$

Note: Both scale and filter samples qualify as a LIMITED QUANTITY shipment that must be appropriately packaged, labelled and shipped.

e. TOTAL RADIOACTIVE CONTENT (each radioisotope) IN THE SHIPMENT:

Filter Concentration: The laboratory analysis indicates that a 2 gram sample of *filter* contained:

Ra-226	220 Bq
Pb-210	40 Bq
Po-210	10 Bq

Pump Scale Concentration: Analysis also showed that one gram of *pump scale* contains:

Ra-226	500 Bq
Pb-210	11 Bq
Po-210	4 Bq

Therefore, for each radioisotope, there will be a total radioactive content (shipment) of:

Total Filter Radioactivity:

Ra-226	220 Bq/2 grams x 40 kilograms	= 4.4 MBq
Pb-210	40 Bq/2 grams x 40 kilograms	= 0.8 MBq
Po-210	10 Bq/2 grams x 40 kilograms	= 0.32 MBq
TOTAL FILTER RADIOACTIVITY		**5.52 MBq**

Total Scale Radioactivity:

Ra-226	500 Bq/gram x 20 grams	= 10 kBq
Pb-210	11 Bq/gram x 20 grams	= 0.220 kBq (220 Bq)
Po-210	4 Bq/gram x 20 grams	= 0.080 kBq (80 Bq)
TOTAL SCALE RADIOACTIVITY		**10.3 kBq (0.010 MBq)**

Total Shipment Radioactivity (each radioisotope/ scale and filters)

Ra-226	4.4 MBq + 10 kBq (0.010 MBq)	= 4.41 MBq
Pb-210	0.8 MBq + 0.220 kBq (0.00022 MBq)	= 0.80022 MBq
Po-210	0.32 MBq + 0.080 kBq (0.00008 MBq)	= 0.32008 MBq

f. TOTAL SHIPMENT RADIOACTIVITY (all radioisotopes/ scale and filters)

Ra-226	4.41 MBq
Pb-210	0.80 MBq
Po-210	0.32 MBq
GRAND TOTAL	**5.53 MBq**

g. TYPE OF FILTER CONTAMINATION:
Filters qualify as *contaminated solids* if they have uniformly distributed contamination. This means that radioactivity is part and parcel of the filter. The amount of removable contamination should be checked to verify this. From the laboratory analysis we learned that the total radioactive content of a 2-gram sample of filter is:

Ra-226	220 Bq
Pb-210	40 Bq
Po-210	10 Bq
TOTAL	**270 Bq**

Therefore, there is a total radioactive concentration of:

270 Bq/2 g = 135 Bq/g (135 kBq/kg) filters

It is reasonable to assume that the *fixed NORM contaminant* on the filters will be dispersed throughout the 45-gallon drum, if we assume that the *filters* are also dispersed throughout the drum.

h. TYPE OF SCALE CONTAMINATION:
Scale is a radioactive *surface contaminant*. We must find the radioactive concentration of the NORM scale. For this NORM scale, the total radioactive concentration of one

gram of scale contaminant is:

Ra-226	500Bq
Pb-210	11 Bq
Po-210	4 Bq
TOTAL	**515 Bq**

Therefore, there is a total radioactive scale concentration of: **515 Bq/g (515 kBq/kg)**. In our example, the following steps are required:

(i) Compare A_2 values with total radioactive content for each radioisotope and the total radioactive shipment content. Is the shipment (package or drum):
- excepted?
- low specific activity?
- surface-contaminated object?

(ii) Perform the removable surface contamination measurement for both filters and scale for comparison to Table 6 limits. Is the removable contamination limit of 0.04 Bq/cm^2 exceeded?

(iii) Package the material with attention to general packaging requirements stipulated in the Regulations and perform a series of radiation intensity measurements from all external surfaces of the drum. Compare results with the 5 μSv/h limit.

(iv) If drum contents qualify as radioactive material of limited quantity; place an indication (usually a label/sign) *inside* the drum that is readily seen upon opening the drum with the word **RADIOACTIVE.**

i. SHIPMENT CLASSIFICATION
In our example, the following steps are required to determine the classification of NORM material and the requirements for transport of that material.

1. Compare the A_2 values for each identified radioisotope with the corresponding TOTAL RADIOACTIVE VALUE for each radioisotope

Radioisotope	Total Activity	A_2 (MBq)
Ra-226	4.41 MBq	20,000
Pb-210	0.80 MBq	9,000
Po-210	0.32 MBq	20,000
TOTAL	**5.53 MBq**	**A_2(All/Mixed Sample)**

For EXCEPTED SHIPMENTS individual and total activities for all identified radioisotopes cannot exceed 0.001 x A_2 values.

By inspection, we can see that each radioisotope *individually*, meets this criteria.

2. Calculate the combined A_2 (all/ mixed sample) value and compare it to the total shipment activity (5.53 MBq). Refer to TABLE 1, pg. 30 of the Regulations to calculate A_2 for mixtures of radioisotopes.

Radioisotope	Total Activity	Fraction Of Total
Ra-226	4.41 MBq	4.41/5.53 = 0.80
Pb-210	0.80 MBq	0.80/5.53 = 0.14
Po-210	0.32 MBq	0.32/5.53 = 0.06
ALL	**5.53 MBq**	1

$$A_2\text{ (total)} = \frac{1}{\frac{0.8}{20,000} + \frac{0.14}{9,000} + \frac{0.06}{20,000}} = \mathbf{17,080\ MBq}$$

EXCEPTED ACTIVITY LIMIT:

A_2 (total) x 0.001= **17.1 MBq**

TOTAL SHIPMENT ACTIVITY: **5.53 MBq**

j. CONCLUSION:

This shipment contains excepted quantities of NORM and can be shipped *excepted* as long as all other excepted packaging provisions are met. Refer to the section of the

Guidelines on *excepted packages (limited quantities of NORM material).*

3. Review other requirements to ensure compliance with all other *excepted* criteria.
    a) general packaging requirements
    b) maximum radiation level on all package surfaces (5 μSv/h)
    c) package non-fixed contamination limits (0.04 Bq/cm²)
    If greater, then compare to the LSA contamination limits
    d) internal package labeling requirement
    e) transport documents are complete and accurate and, most importantly, include the statement:
    RADIOACTIVE MATERIAL, EXCEPTED PACKAGE, UN 2910, LIMITED QUANTITY OF MATERIAL
    f) mode of transport
        - road/rail? C no special requirements
    g) carriage requirements
        - no special requirements
    h) other provisions (Regulations)
        - accident provisions/compliance assurance
        - contamination surveys/customs
        - damaged or leaking packages/quality assurance
        - radiation protection principles/undeliverable packages

APPENDIX 3
IAEA Documents Address

To obtain IAEA documents, place purchase requests through:

UNIPUB
4611-F Assembly Drive
Lantham MD. 20706-4391

OR

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

APPENDIX 4
Contacts For Further Information

Provincial government agencies:

Refer to appropriate provincial department contact listings

Atomic Energy Control Board:

Western Regional Office (Calgary)	(403) 292-5181
Ottawa (24 hour emergency)	(613) 995-0479

Transport Canada (CANUTEC):

Information	(613) 992-4624
Emergency	(613) 996-6666

ENVIRONMENTAL PROTECTION AND NORM WASTE MANAGEMENT

Naturally occurring radioactive materials (NORM) may be liberated or concentrated by many industrial processes. Where NORM are liberated or concentrated, good environmental management practices should be employed to protect the workers, the public and the environment. The following principles are provided to assist industry, government regulators and the public to better understand and cost-effectively manage NORM.

Environment Management Principles

Radionuclides associated with NORM can enter the environment by essentially three means: through the air by dissemination, through radon gas emissions from radioactive decay, or through surface or groundwater migration. Other heavy-metal ion contamination can sometimes occur at the same time as radiation.

Principle 1
Be aware of the presence of NORM and develop a monitoring system to ensure the level and amount of NORM are well understood.

Principle 2
Ensure that the appropriate employee training and signage are in place at the site.

Principle 3

Ensure that NORM are properly contained in an engineered fashion that minimizes the quantities of NORM entering the environment.

Principle 4

Provide appropriate community awareness to those members of the public who may potentially be affected by NORM management. Radioactivity issues cause the public to have emotional as well as technical and political concerns regarding the presence of NORM. (It is crucial to ensure that detailed and accurate information is provided to the public and that their concerns and fears are addressed in an empathetic manner.)

Principle 5

Clearly understand whether the NORM is to be contained or condensed, or whether it may be more appropriate to disperse and dilute it. Each NORM and its site has unique characteristics that need to be assessed. A management plan reflecting these characteristics must be developed and communicated with the regulators and the potentially affected public.

Principle 6

Clearly define when a NORM becomes a waste material, i.e., a material that is no longer used for its original purpose and that is recyclable material or that is intended for treatment or disposal.

Resource recovery may be accomplished in a multitude of ways depending on the source of the NORM. Two quite different examples for consideration are:

1) the descaling of oil field production tubing that allows for the decontaminated tubing to be recycled

2) the possible use of gypsum from a fertilizer plant stack as a soil amendment

In each example, the timing and the risk to affected public or environmental health and safety are quite different, and the mechanisms to be developed with the regulators and the public will likely be quite different.

Waste management of NORM must also be done in conjunction with the first five of the environmental management principles. Once a NORM is considered to have no further value to society, it can then be designated a NORM waste. Waste management must be engineered on the basis of long-term managed storage (condense and contain), or other techniques that may be appropriate to the specific industrial source of the NORM. There may be some specific sources and locations that dictate the use of disperse-and- dilute as the most cost-effective and environmentally responsible means of handling NORM waste.

The development of an appropriate environmental management plan for NORM from the various sources requires a site-specific approach with regulatory approval and public consultation. This document provides individual industry sector chapters to assist in the identification of the types of radiation sources of NORM, and site-specific considerations that will go into the development and communication of the most appropriate environmental management plan.

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PART III

OPERATIONAL GUIDELINES

NORM OPERATIONAL GUIDELINES: INTRODUCTION

Introduction

Naturally occurring radioactive material (NORM) is a part of our natural environment and cannot be prevented or eliminated, however, it can be managed safely. Experience has shown that the generation of radioactive waste and byproducts by many non-nuclear industries is usually the result of:

- a naturally high concentration of NORM in their feedstocks and/or
- physical or chemical processes which enrich the concentration of naturally occurring radioactivity, usually incidentally.

The NORM OPERATIONAL GUIDELINES provide information and guidance on the types of NORM found, the potential for worker exposure, and the NORM management options available in specific industries. The initial industry guidelines covered are:

- the fertilizer industry
- the upstream oil and gas industry

It is anticipated by the Committee that future guidelines may be produced which would be specific to the following industries:

- the fossil fuel utilities industry
- the mineral processing industry (non-uranium mining)
- the metals processing industry
- the forest products industry

- the water treatment industry
- others

These industry-specific guidelines form Part III of the complete publication prepared by the Western Canadian Committee on the Management of NORM. Part I comprises basic information about NORM, while Part II comprises more detailed scientific and technical guidance on the procedures that must be followed regardless of the industry in which NORM-contaminated material(s) are found. These companion documents will be referenced where appropriate by the industry specific guidelines which follow, and form an integral part of the total NORM management concept. Among the subjects covered in Parts I and II of the complete document are:

- NORM Classification Guidelines
- NORM Measurement Guidelines
- NORM Transportation Guidelines
- NORM Worker Protection Guidelines

To help industries that will develop industry-specific guidelines in the future, a list of potential topics is given below:

Introduction:

Overview of the issue

Definitions and general principles

Types of NORM

Characteristics: type composition, distribution

Inventory and rate of generation

The Worker and NORM

Workers likely to be exposed

- Worker protection practices

General Management Options

- Byproduct options.
- Waste minimization:
  - reduction
  - recycle
  - reuse
  - recovery
- Treatment and pretreatment:
  - consolidation
  - storage
- Waste Disposal
- Site selection criteria
- Decommissioning, reclamation, closure and post closure care

Specific Management Information

NORM management sheets

- Hazard data sheets
- References

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NORM IN THE UPSTREAM OIL AND GAS INDUSTRY

In the following section, the numbers in brackets refer to references listed at the end of the section.

Introduction

Both uranium and thorium and their progeny are known to be present in varying concentrations in underground geological formations from which oil and gas are produced (1),(2), (3). The presence of these naturally occurring radionuclides in petroleum reservoirs has been recognized since the early 1930s and has been used as one of the methods for finding hydrocarbons beneath the earth's surface (4).

Uranium and thorium are highly insoluble and, as oil and gas are brought to the surface, remain mostly in place in the underground reservoir. However, radium and the radium daughters are slightly soluble, and under some conditions may become mobilized by the liquid phases in the formation. When brought to the surface with liquid production streams, radium and its daughters may remain dissolved at dilute levels, or they may precipitate because of chemical changes and reduced pressure and temperature. Since radium concentrations in the original formation are highly variable, the concentrations that precipitate out on the surfaces of oil and gas production and processing equipment are also variable and may exhibit elevated radioactivity levels. Scales and sludges that accumulate in surface equipment may vary from background to elevated levels as high as **hundreds of becquerels per gram**, depending on the radioactivity and chemistry of the geologic formation from which oil and gas are produced and on the characteristics of the production process.

Since the radioactivity in oil and gas production and processing equipment is generally low and of natural origin, its accumulation and significance have only recently begun to be studied in Western Canada. The problem is now known to be widespread, occurring in oil and gas production facilities throughout the world, and has become a subject of attention in the United States and in other countries. In response to this concern, facilities in the US and in Europe have been characterizing the nature and extent of NORM in pipe scale, evaluating the potential for exposures to workers, and developing methods for properly managing these low specific activity wastes (5), (6), (7), (8).

In 1982, radium and thorium in measurable quantities were found in mineral scales on British oil and gas production facilities in the North Sea. Because large quantities of materials were being handled in the confined working area of offshore platforms, operators developed special work procedures for protection against possible harmful effects of radioactivity. After a review of the situation, the British government and oil industry representatives issued guidelines governing worker safety, material handling, and waste disposal (9).

The American Petroleum Institute (API) has conducted an industry-wide survey of radiation exposure levels associated with NORM in oil production and gas processing equipment (10). The purposes of the study were (a) to identify the geographic areas of petroleum producing and gas processing facilities having the greatest occurrence of NORM, and (b) to identify items of equipment at these facilities which have the highest NORM activity levels. More than 36,000 individual observations were made in 20 states and two offshore areas by participating petroleum companies using similar equipment and data collection protocols. Radiation exposure levels were measured in units of µrem/h, and the results were reported on survey data sheets provided to all participants. Background radiation levels were also measured and reported for each site in order to differentiate the background effects from contamination effects.

Radium and other radioactive constituents are also known to be present in elevated concentrations in waters released during oil production operations. In general, these produced waters are re-injected into deep wells. The impacts of elevated concentrations of radionuclides in produced waters are not considered in this risk assessment.

This assessment is limited to NORM in oil and gas production equipment. NORM in gas plant processing equipment is described but is not included in the risk assessment for this sector category because the NORM is generally in the form of Pb-210 surface contamination on the gas plant equipment. Consequently, it does not have a strong radon or gamma emission component.

In the following sections, descriptions are given of the oil and gas production industry and of the properties of oil and gas scale and sludge waste from production equipment. Descriptions of NORM management options and the workers most likely to be exposed to NORM are also provided.

Overview of NORM in the Oil and Gas Industry

The amount of NORM material generated by a producing field generally increases with the amount of water pumped from the formation. The natural formation water will undergo changes in temperature and pressure as it is brought to the surface with the oil and gas and may, under certain conditions, deposit scale and sludge within the oil production system. This scale consists principally of barium, calcium and strontium compounds (sulphates, silicates and carbonates). Because the chemistry of radium is similar to barium, radium may also precipitate to form complex sulphates or carbonates. The NORM accumulated in production equipment scales typically contains radium coprecipitated in barium sulphate ($BaSO_4$).

It appears that the geological location of the oil reserve and the type of production operation strongly influences the prevalence of NORM accumulations. From US studies, NORM materials are very prevalent in eastern gulf states and decrease significantly for more westerly sites across to the Rocky Mountains.

The highest concentration of radium appears to occur in the wellhead piping and in production piping near the wellhead. The concentration of radium deposited in separators is about a factor of ten less than that found in wellhead systems. There is a further reduction of up to an order of magnitude in radium concentration in heaters/treaters and in sludge holding tanks.

Types of NORM (11)

The US EPA has reported that concentrations of NORM radionuclides in scale and sludge collected by oil and gas production equipment can range from background (i.e., about 0.04 Bq/g) to thousands of becquerels per gram; depending on the production facility location, the type of equipment, the period of time during which the production well has been in operation, and changes in temperature and pressure during the extraction of petroleum from underground reservoirs (US EPA, 1991).(12). In Western Canada, a survey of 63 scale samples from 19 oil and gas production locations has been conducted by Esso Resources Canada Limited (personal communication, 1991, I. Drummond). Most of the samples (i.e., more than 78%) contained less than 0.1 Bq/g of radium, about 14 percent contained between 0.1 and 1 Bq/g, two percent contained between 1 and 30 Bq/g, and about six percent contained more than 30 Bq/g.

Typical equipment that may contain NORM sludges and scales includes:

- produced water pipe, tankage, treaters, surface and downhole pumps; or the equipment itself as a result of exposure to produced water

- propane piping, pumps, storage vessels as a result of radon gas daughter products produced in these systems

- turnaround wastes such as tank bottoms, cleaning materials or exposure to radon if working inside tanks or vessels

A number of other organizations have also carried out measurements in Canada. For example, the Alberta Occupational Health and Safety department has reported that measurements of the content of radium in radioactive scale have ranged from 96 Bq/g to 260 Bq/g. The following measurements were reported by the Radiation Protection Services Branch of the Environmental Health Protection Service in British Columbia:

Material	Service	Activity
pipe scale	scrap steel - unknown source	200 to 250 (Bq/g)
barium sulphate	gas pipe scale - Ft. St. John	200 (Bq/g) of Ra-226
pipe scale	gas pipe scale - Peace River	similar activity to area above

There is also potential for Pb-210-contaminated equipment to act as a discrete NORM source. This results from the radioactive decay of natural radon present in the gas. Concentrations of radon in natural gas at production wells in Canada were reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1977) and are given below:

Radon Concentration (Bq/L)

Well Location	Average	Range
Alberta	2.3	0.37 to 4.0
British Columbia	17.8	14.4 to 20
Ontario	6.3	0.15 to 30

The first work on NORM was conducted in the late 1980s on the occurrence of radon-222 and its progeny in natural gas processing plants in Western Canada (19). The study evaluated 24 gas plants operated by seven companies. Trace quantities of radon-222 were found in the inlet streams and were concentrated in streams rich in propane. These findings indicate a substantial flux of radon-222 and progeny passing through the plants, but little accumulation of radionuclides. In no case was there evidence of significant exposure of plant operators or maintenance personnel to ionizing radiation.

The Canadian Association of Petroleum Producer's Industrial Hygiene Subcommittee conducted a survey in 1991 using radiation measurement dosimeters provided by the Atomic Energy of Canada Limited Laboratories of Pinawa, Manitoba. These dosimeters were provided to five companies who installed them on process equipment in twenty oil fields in Northeast B.C., Alberta and Southern Saskatchewan. The dosimeters were placed on about 200 various pieces of oil field equipment expected to concentrate NORM scale in produced water and oil production (i.e., inlet separators, bottoms of treaters, pig traps, produced water tank and a control badge).

The precision of the measurement technique was not as good as had been hoped (standard deviation 0.4 μSv/h when trying to detect a contamination level of 0.5 μSv/h). As none of the dosimeters were exposed to known levels of radiation, the results can only be described as illustrative. The control dosimeters were used to provide a measure of background radiation due to factors other than oil field equipment (cosmic radiation, soil radiation, or accidental exposure to radiation). There were no samples that were significantly contaminated, which confirms the theory that contaminated $BaSO_4$ scales are randomly and infrequently distributed.

The Alberta Energy and Utilities Board (AEUB), the B.C. Ministry of Energy, Mines and Petroleum Resources and the Saskatchewan Department of Energy have little or no reported information to date. It is believed that steel recycling facilities located in Alberta have radiation detectors to check all scrap steel coming into their facilities. The IPSCO steel plant in Regina also has monitoring equipment to check all incoming steel. Any radioactive material is turned back to the originator. Some oil field pipe refurbishing companies are now acquiring radiation-detection equipment in order to provide an indication of NORM when they work on oil and gas leases.

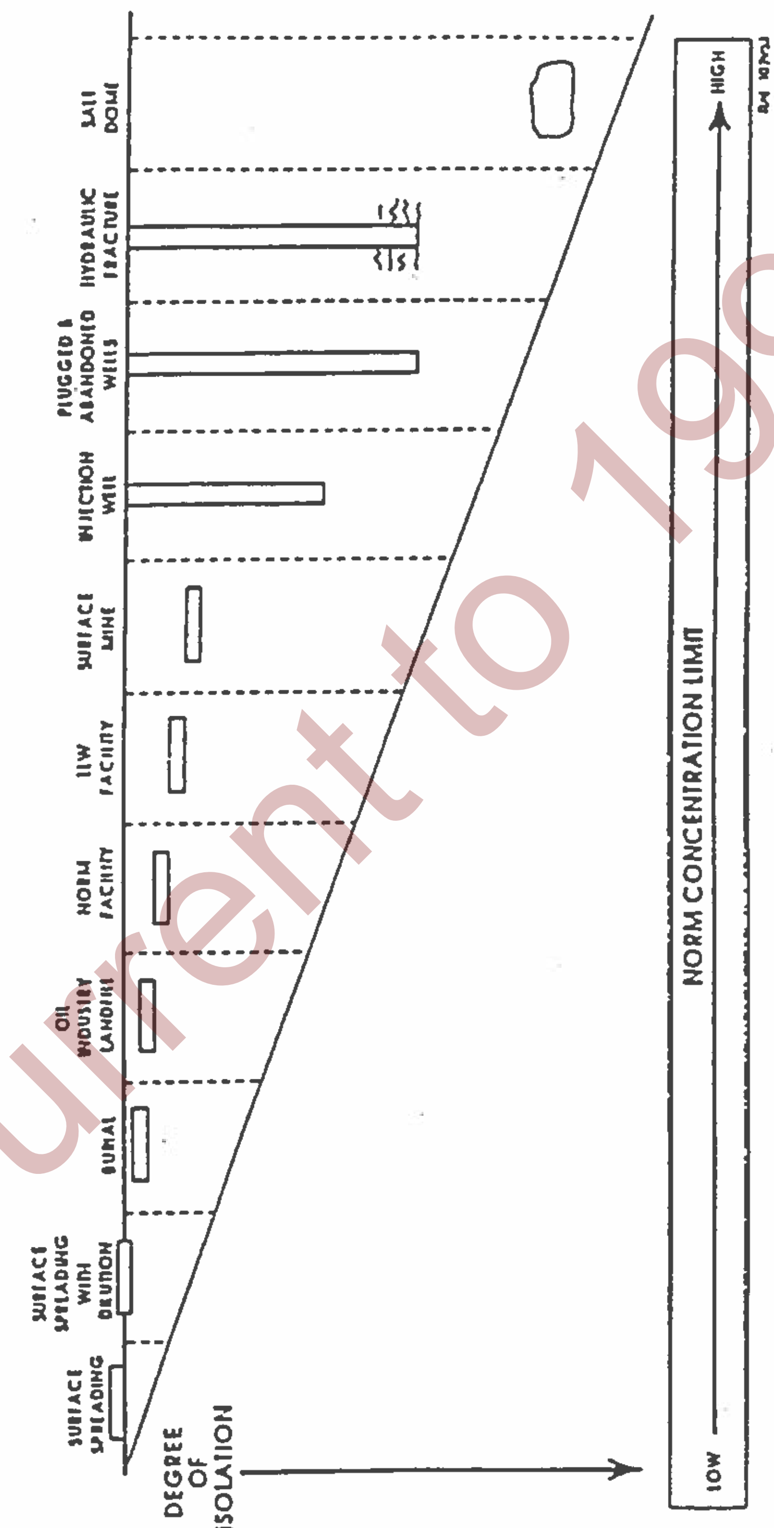
Workers Most Likely to be Exposed to NORM

The oil and gas field operators, maintenance crews or contractor employees that do well servicing, and equipment cleaning and contracted maintenance workers, comprise the groups of employees most likely to be exposed to NORM.

Norm Management Options

A broad range of waste disposal alternatives were analysed to characterize safety precautions ranging from simple to extensive, and to provide potential flexibility in disposal decisions. Separate disposal alternatives were considered for solid residues and for equipment. The technical nature of each disposal alternative defined in this chapter provides a basis for radiation exposure analyses by providing the detailed scenario under which the disposal would occur. The scenarios include typical disposal depths, dimensions, and other characteristics needed to subsequently estimate radiation exposures via different environmental pathways. As the disposal alternatives provide increasing isolation of the NORM, they allow the disposal of increasing concentrations of Ra-226 and Pb-210. This is illustrated in Figure 1. **Not all options are currently available in Canada.**

FIGURE 1
COMPARISON OF ISOLATION PROVIDED BY NORM DISPOSAL ALTERNATIVES



Disposal of Solid or Liquid Residue

The following sections consider the disposal of solid sludges and scales removed from petroleum product equipment by each of twelve alternatives. Many apply only to sludges and scales that have been removed from equipment. These include landspreading, landspreading with dilution, injection into inactive wells, hydraulic fracturing into unused formations, and injection into salt domes. Others also accommodate sludges and scales remaining in equipment as well as those that have been removed. These include burial at unrestricted sites, disposal at commercial oil-field waste sites, disposal at licensed NORM disposal sites in the United States, disposal at licensed low-level radioactive waste sites, and burial in surface mines. Two of the alternatives apply only to residues remaining in equipment. These are placement into wells being plugged and abandonment (non-retrieval) of surface pipelines.

The AEUB will entertain applications to dispose of NORM scale into wellbores that are being abandoned.

Landspreading

Disposal by landspreading involves minimal precautions, and simply consists of spreading sludges and scales that do not exceed 74 Bq/g on the surface of open lands in a prescribed area. A minimum thickness of one-quarter inch (0.6 cm) is assumed to be the smallest particle layer thickness that can be applied, and applications of layers up to eight inches (20 cm) are considered. The area covered may become arbitrarily large for disposal of a given quality of material. Analyses of landspreading are based on incremental increases of radium concentrations above background levels, and thus are restricted to one-time disposal in a given area. This suggests record keeping to avoid repeated spreading in a given area, and possible radiation surveys to characterize pre and post spreading radiation levels. In the US, subsequent uses of the affected land are not restricted, permitting home construction, agricultural food production, or any other land uses. The Western Canadian NORM Committee believes that the above guideline for one-time landspreading of NORM sludge or scales that do not exceed 74 Bq/g are appropriate to protect public health and the environment.

Abandoned Pipelines

Produced water and propane pipelines containing scales and sludges are typically buried to depths of two metres or greater. Upon retirement from active service, the pipes may be cleaned of produced water and petroleum products but left abandoned in place. Currently, the Alberta Energy Resources Conservation Board and other stakeholders are developing pipeline abandonment guidelines that will determine whether there may be circumstances where these pipelines will be removed from the ground. It is expected that the main reasons for requiring removal would be concerns around subsidence, not the potential for health risks due to the possibility of NORM being left in the pipeline.

Disposal at a Commercial Oil Field Waste Site

Disposal at a commercial oil field waste site involves burial with other wastes that may not contain NORM. NORM containing 74 Bq/g or less is acceptable in AEUB-approved commercial oil field waste facilities. The completed waste site should have an earthen cover that is level with surrounding terrain to minimize erosion. This is not currently a Canada-wide option, but should be considered a proposed option.

Disposal at a Licensed NORM Waste Disposal Site (Currently USA only)

A NORM waste disposal site is defined by the EPA regulations as suitable for the disposal of uranium and thorium mill tailings and related byproduct materials (13). Sites are designed to meet engineering criteria for 1000 years to the extent reasonably achievable, or in any event, for at least 200 years. It is designed to limit radon fluxes to the atmosphere to 740 $mBq/m^2/s$ (20 $pCi/m^2/s$), averaged over the disposal area and over any one year period. The impoundment usually is designed with an earthen or clay cover for radon control, and suitable liners and siting criteria to protect local groundwater from contaminant leaching and migration. After closure, the site is deeded to the state for permanent monitoring and restricted future use. No intrusive activities or construction of occupiable structures on the site are permitted. For estimating exposures from transporting wastes to the disposal site, a distance of 500 kilometres is assumed. Canadian operators using these facilities must consider their long-term liability in sending these NORM wastes to the USA

Disposal at a Licensed Low-level RadioactiveWaste Disposal Site (USA only)

The low-level radioactive waste (LLW) disposal site is defined and licensed under the US Nuclear Regulatory Commission regulations (14) with numerous protective features and restrictions that ultimately restrict the feasible locations and numbers of such facilities. Currently, there are only three LLW facilities in the United States (Hanford, WA; Beatty, NV; and Barnwell, SC), although others are being considered by some states and interstate compacts. There are no low-level waste sites approved in Canada, but arrangements may be made through Atomic Energy of Canada Limited for storage at one of their sites. Due to the limited number of LLW sites, transportation of wastes to the site may make this option very expensive.

Burial in Surface Mines (US only)

Burial of NORM-contaminated sludges and scales in surface mines involves placement at the bottom of mine excavations and subsequent burial by accumulated earthen overburden. Typical burial depths are 15 m (50 feet) or greater, and areas are sufficient to accommodate relatively large volumes of wastes. Because of the significant burial depths, the potential for erosion or intrusion into the wastes is remote. No land use restrictions are applied related to the NORM content of the wastes buried.

The Western Canadian NORM Committee is not aware of this option currently being assessed by any Canadian jurisdiction, but believe this to be an option to evaluate.

Plugged and Abandoned Wells

Well tubing with accumulated scale may be left in place or placed in a well being plugged and abandoned. Scales in the tubing remain nearly completely inaccessible from surface intrusion. Reclamation of the well site includes sealing the well with cement, precluding significant access to materials at greater depths or surrounding formations. The well is capped, preventing inadvertent intrusion into the well. This practice is approved by the AEUB in Alberta and Energy, Mines and Petroleum Resources in British Columbia on a site-specific basis.

Well Injection (US only)

Well injection consists of injecting slurries of the sludges or scales into a deep permeable formation below underground sources of drinking water (USDW) with no fresh water or mineral value. The formation is confined by impermeable layers that are likely to remain intact. Therefore formations selected for injection are limited to areas and horizons in which deeper formations also have little or no economic value. The injection is consistent with EPA standards for underground injection controls for Class II wells (15). During operations and at closure, the injection facility is monitored for leakage, and at closure, cement and clay are used to seal the top region of the well. The well is cut below the ground surface and capped, preventing inadvertent intrusion into the injection well. Canadian regulators allow for injection of liquids containing NORM that are 74 Bq/g or less, and may consider approving injection of liquids with greater than 74 Bq/g on a case-by-case basis, depending on the volume and radioactivity of the material and the specific reservoir destined for use.

Injection into Salt Domes

Salt dome cavities have been used to store petroleum products, and have been proposed for disposal of intermediate and high level radioactive wastes due to the inherent isolation of the wastes from groundwater and from the surrounding environment. The salt provides impermeable containment of the wastes at depths of hundreds to thousands of metres. The salt formation tends to self-anneal any containment defects that may occur, further assuring containment of the wastes. Sludges, scales, and equipment containing NORM can be placed in the salt domes. Injection into salt domes in Alberta is allowed if the NORM is under 74 Bq/g, and may be considered on a case-by-case basis, depending on the volume and the radioactivity of the material if greater than 74 Bq/g.

NORM Landfill

Proper design and operation of a NORM landfill or a separate cell in an existing municipal or industrial landfill, if the site has appropriate design and monitoring, is considered to be an acceptable means of disposing of NORM. Application of the current Alberta Environmental Protection or AEUB landfill design criteria, particularly focusing on the groundwater protection portion, is considered by the Western Canadian NORM Committee, to provide appropriate protection. While this is a technically appropriate solution, obtaining the necessary approvals may prove to be politically difficult.

Alternatives for Equipment Containing NORM

Alternatives for disposal or use of equipment containing NORM residues include release for general use, release for re-use within the petroleum industry, storage in an oil-field equipment yard, release for smelting, and burial with NORM scales and sludges. Selection among these alternatives depends in part on the quantity of NORM remaining in the equipment. For example, release for unrestricted use requires that any residual NORM is at very low levels, while burial with NORM scales and sludges permits potentially higher concentrations of NORM residues.

1. Release for General Use

General use of petroleum equipment could occur under a variety of conditions. A conservative but plausible scenario for exposure to NORM remaining in former petroleum equipment is that of residential use of the equipment. If it is assumed that a piece of larger pipe or other equipment containing scale is used inside the house for structural support of a floor, ceiling, etc., and the residents in the house are assumed to spend 2.2 hours per day within one metre of the structural pipe or equipment containing NORM, they may be exposed 800 hours/year to gamma emissions from the indoor NORM as well as continually to any radon gas generated. Rate of exposure would be a function of the radioactivity of the scales. This is not considered to be a good practice and should be discouraged.

2. Release for Re-use Within the Petroleum Industry

Simple release of equipment containing NORM for re-use within the petroleum industry constitutes a non solution, since continued use constitutes non-disposal, and makes the new owners responsible for either cleaning or appropriately disposing of the equipment. Once the buyer is informed of the presence of NORM in the equipment, it is his or her responsibility to ensure the appropriate use and worker protection are implemented.

3. Storage in an Oilfield Equipment Yard

Oil-field equipment removed from service frequently is stored in oil-field equipment yards pending cleaning, refurbishing, transfer to other fields, sale to other companies, or disposal as scrap or for other uses. As a result of this storage and the associated handling of equipment, both equipment yard employees and offsite residents will be potentially exposed to gamma emissions and respirable dusts from NORM in the equipment. The equipment may be capped to contain any sludges and scales, or may be left open. Yard workers spend about 500 hours per year near, or working on, the equipment. Adjacent residents may also be exposed to gamma radiation and dusts from the yard. It is recommended that any NORM-contaminated material in a storage yard be segregated and clearly marked with appropriate signage indicating the material is potentially radioactive, and advising what, if any, worker-protection equipment should be used if work is being done in the immediate area.

4. Release To a Smelter

Although some smelting operations may produce steel for new oil-field equipment from old equipment that contains NORM, other operations may produce consumer products in which residual NORM is more significant. When separated by smelting, residual NORM mainly accumulates in the slag. This use of iron-containing radioactive materials is specified by the US Nuclear Regulatory Commission in the IMPACTS-BRC methodology (17). From an occupational perspective, the smelting process produces airborne dust that is respirable by both onsite workers and offsite residents. Slag from the smelting process is within gamma exposure proximity to workers and also produces respirable dust.

Release to a smelter is not considered to be an appropriate option.

5. Burial With NORM Sludges and Scales

Equipment containing residual NORM scales may be buried under any of several disposal alternatives with sludges and scales that contain NORM. When NORM is still deposited in equipment, however, the waste is considerably more bulky than the separated sludges and scales. Equipment that could be buried with NORM wastes has been categorized and estimated to result in a disposed bulk density of 4 g/cm^3, with a porosity of 0.5. Production equipment included in this estimate included flow lines, manifolds, meters, pumps, separators, stock tanks, vapor recovery units, injection wells and pumps, production wells, tubing, heater treaters, sump equipment, water lines and storage tanks. Gas plant equipment was estimated to have similar bulk disposal densities and porosities. The dilution of scale by the metal equipment mass was estimated to amount to a factor of 15.

NORM Concentration Limits for Disposal

The following material is taken from US EPA documents to provide additional information for the reader

Radiation exposures can be calculated for upstream oil and gas wastes based on disposal at either arid or humid disposal sites. The resulting maximum radium concentrations that correspond to the radiation exposure limits are given in the Appendix, Rogers and Associates Engineering Corporation (for API)(18), for all disposal alternatives, NORM waste types, pathways and geohydrologic settings. The maximum NORM concentration for each waste disposal or equipment disposition alternative was then chosen from the critical pathway (the pathway with the lowest maximum NORM concentration) for each alternative and waste type. These NORM disposal limits are presented in Tables 1 and 2 for humid and arid sites, respectively. The NORM disposal limits have been presented in terms of maximum concentrations of radium-226, since this is the dominant isotope controlling all limiting radiation exposures.

The radium concentration limits range from 1 Bq/g for burial in an arid permeable region to more than 3,700 Bq/g for plugged and abandoned wells, well injection, hydraulic fracturing and salt dome disposal in any region. The radium concentration limits were generally set by the radon, gamma or groundwater pathways. The radon and gamma pathways dominate for disposal alternatives with less than two metres (6.6 feet) of cover below the intrusion zone, and the groundwater pathway dominates for alternatives with more than two metres of cover.

Table 1

US RADIUM SOURCE CONCENTRATION LIMITS FOR DISPOSAL AT A HUMID PERMEABLE SITE (Bq/g)

Disposal Alternative	Sludge	Scale	Equipment and Scale
1. Landspreading[a]	5	5	NA[b]
2. Abandoned pipelines	200	500	NA
3. Commercial oil industry waste facility[c]	185	1,000	3,700
4. NORM disposal facility	1340	740	3,700
5. Commercial LLW disposal facility	1,850	1,850	3,700[d]
6. Surface mine	130	3700	3,700
7. Plugged and abandoned well	3,700	3,700	3,700
8. Well injection	3,700	3,700	NA
9. Salt dome disposal	3,700	3,700	3,700
10. NORM landfill			

a. Four barrels per 100 m^2 (33 ft x 33 ft) giving a 0.25 inch (0.63 cm) average layer thickness.
b. NA = Not Applicable
c. For 6.6 feet (2 m) of depth beneath the intrusion zone.
d. If the limit is greater than 3700 Bq/g it is reported as 3700 Bq/g.

Table 2

US RADIUM SOURCE CONCENTRATION LIMITS FOR DISPOSAL AT AN ARID PERMEABLE SITE (Bq/g)

Disposal Alternative	Sludge	Scale	Equipment and Scale
1. Landspreading[a]	5	5	NA[b]
2. Abandoned pipelines	100	250	NA
3. Commercial oil industry waste facility[c]	15	67	230
4. NORM disposal facility	37	167	2,500
5. Commercial LLW disposal facility	1,850	1,850	3,700[d]
6. Surface mine	3,700	3,700	3,700
7. Plugged and abandoned well	3,700	3,700	37,000
8. Well injection	3,700	3,700	NA
9. Salt dome disposal	3,700	3,700	3,700
10. NORM landfill			

a. Four barrels per 100 m^2 (33 ft x 33 ft) giving a 0.25 inch (0.63 cm) average layer thickness.
b. NA = Not Applicable
c. For 6.6 feet (2 m) of depth beneath the intrusion zone.
d. If the limit is greater than 3,700 Bq/g, it is reported as 3,700 Bq/g.

REFERENCES

1. Bell, K.G., 1960, Uranium and Other Trace Elements in Petroleums and Rock Asphalts, US Geological Survey, Professional Paper 356-B.

2. Johnson, R.H., D.E. Bernhardt, N.S. Nelson, H.W. Calley, Assessment of Potential Radiological Health Effects from Radon in Natural Gas, Environmental Protection Agency, EPA 520/1-73-004, Washington, D.C., 1973.

3. Pierce, A.P., J.W. Mytton, and G.B. Gott, Radioactive Elements and Their Daughter Products in the Texas Panhandle and Other Oil and Gas Fields in the United States, Geology of Uranium and Thorium, International Conference, 1955.

4. Martin, J.C., Regulation and Licensing of Naturally Occurring Radioactive Materials (NORM) in Oil and Gas Exploration and Producing Activities, Proceedings of Conference of Radiation Control Program Directors Annual Meeting, Boise, Idaho, May 21, 1987, American Petroleum Institute, Dallas, Texas, June 1987.

5. E & P Forum, Low Specific Activity Scale Origin, Treatment and Disposal E & P Forum, UK, London Report No. 6 March 1987.

6. McArthur, A., Development and Operation of a NORM Processing and Disposal Facility for the US Oil and Gas Industry, published in CRCPD Publication 88-2, 19th Annual National Conference on Radiation Control, May 18-21, 1987, Boise, Idaho, Conference of Radiation Control Program Directors, Frankfort, KY, 1988.

7. Miller, H.T., Radiation Exposures in Crude Oil Production Chevron Corp., San Francisco, CA, presented at the Annual Meeting of the Health Physics Society, July 5-9, 1987, Salt Lake City, Utah.

8. Miller, H.T., Disposition of Naturally Occurring Radioactive Material in Crude Oil Production Equipment, Chevron Corp., San Francisco, CA, presented at the Annual Meeting of the Health Physics Society, Boston, MA, July 4-8, 1988.

9. Guidelines for Operators on Naturally Occurring Radioactive Substances on Offshore Installations, UK Offshore Operators Association Limited, Series No. 5, July, 1985.

10. Otto, G.H., A National Survey on Naturally Occurring Radioactive Materials (NORM) in Petroleum Producing and Gas Processing Facilities, American Petroleum Institute, Dallas, Texas, July 1989.

11. Low-Level Management of Radioactive Waste Produced on an On-Going Basis: Wastes Generated From Non-Nuclear Industry Activities, by SENES Consultants Limited, 52 West Beaver Creek Road, Unit 4, Richmond Hill, Ontario, L4B 1L9, March 1992.

12. United States Environmental Protection Agency (US EPA), 1991. Diffuse NORM - Waste Characterization and Preliminary Risk Assessment. Draft.

13. Texas Department of Health, Bureau of Radiation Control, Texas Regulations for Control of Radiation, Part 21, 1985.

14. Texas Department of Health, Texas Regulations for Control of Radiation, Part 21, Sec. 307, 1987.

15. Merrell, G.B., E.S. Murphy and V.C. Rogers, "Preliminary Endangerment Assessment for Contaminated Residential Properties Near Friendswood, Texas", Rogers and Associates Engineering Corp. Report RAE-8729-1 to Texas Low-Level Radioactive Waste Disposal Authority, October 1987.

16. US Environmental Protection Agency, Draft of Proposed Environmental Protection Standards for Low-Level Radioactive Waste and Naturally Occurring and Accelerator-Produced Radioactive Materials Disposal, Title 40, Code of Federal Regulations, Part 193, and supporting background information document.

17. US Environmental Protection Agency, Underground Injection Control Program, Title 40, Code of Federal Regulations, Part 146.

18. Rogers and Associates Engineering Corporation for the American Petroleum Institute, Management and Disposal Alternatives for NORM Wastes in Oil Production and Gas Plant Equipment, May 1990.

19. Drummond, I., el al, Occurrence of ^{222}Rn and Progeny in Natural Gas Processing Plants in Western Canada, Health Physics, Vol 59, No 1 (July), pp. 133-137, 1990.

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NORM MANAGEMENT IN THE FERTILIZER INDUSTRY

In the following section, the numbers in brackets refer to references listed at the end of the section

Introduction

Naturally occurring radioactive materials (NORM) are found in igneous and sedimentary rocks throughout the world. NORM found in fertilizer operations originates in rock containing phosphates that is used as the raw material for the production of ammonium phosphate fertilizers.

This *phosphate rock* is mined in the U.S.A. (Florida, Western United States) and Africa (Togo, Morocco) and is shipped by ocean or rail transport. The rock contains oxides of phosphorous and calcium, with trace levels of heavy metal impurities and trace levels of naturally occurring radioactive impurities such as uranium-238 and thorium-232 and their various decay products.

Uranium is a naturally occurring radioactive material found in the environment including soil, rock and some geological formations such as marine phosphate deposits, the source of phosphate rock. Radium-226 and radon-222 are of particular interest.

In the production of ammonium phosphate fertilizers (commonly referred to as mono or diammonium phosphate [MAP or DAP], 12-51-0, 11-51-0, 11-48-0, etc.), two key feed ingredients are required: anhydrous ammonia and phosphoric acid. The phosphoric acid is produced by reacting phosphate rock with sulphuric acid and water. The chemical reaction that takes place between the phosphate rock, sulphuric acid and water can best be represented by the following equation:

$$Ca_3(PO_4)_2CaF_2 + 10H_2SO_4 + 20H_2O \text{ -------> } 10CaSO_4 \cdot 2H_2O + 6H_3PO_4 + 2HF$$

(Calcium Phosphate/ Calcium Fluoride) (Sulphuric Acid) (Calcium Sulphate) (Phosphoric Acid) (Hydrogen Fluoride)

The main reaction produces calcium sulphate dihydrate (also referred to as phosphogypsum) and phosphoric acid. The phosphoric acid is then neutralized with ammonia to form the solid ammonium phosphate fertilizer.

The minor reaction products include barium sulphate, radium sulphate and fluorosilicates, which are insoluble solids. These are carried out with the phosphogypsum byproduct to the phosphogypsum stack. (The term phosphogypsum stack refers to the storing of phosphogypsum byproduct in large piles at the production site.) Thus, the naturally occurring radionuclides in the phosphate rock are redistributed in the reaction such that radium-226 goes with the calcium and is found in the phosphogypsum byproduct, while trace levels of uranium-238 and thorium-232 are found primarily in the phosphoric acid.

Approximately 800,000 tonnes of ammonium phosphate fertilizer are used annually in Western Canada. Prairie soils are deficient in phosphorus and, as a result, phosphate-containing fertilizers were among the first agricultural amendments applied in the region. Phosphate significantly increases crop yield and enhances crop maturity, which is critical in the short prairie-growing season. Thus, phosphate fertilizers are an essential component in the sustainability of prairie agriculture.

Phosphate fertilizer is currently manufactured in Alberta and New Brunswick. In the past, phosphate fertilizer was produced in six of Canada's ten provinces (Newfoundland, New Brunswick, Quebec, Ontario, Alberta, and British Columbia). The result is a total Canadian inventory of byproduct phosphogypsum of approximately 70 million tonnes (1).

In the U.S.A. there are 63 phosphogypsum stacks located in 12 different states with a total inventory of more than 800 million tonnes. Florida has the highest concentration of stacks with nearly 400 million tonnes. (2).

Overview of NORM in the Fertilizer Industry

Typical levels of NORM found in phosphate fertilizer products, intermediate products, and byproducts in the United States are given in the following table (3), (4).

Mean Concentrations (Bq/g)

	Ra-226	*U-238*	*Th-232*
phosphate rock	1.10	1.20	<0.06
phosphoric acid	0.03	0.94	0.11
phosphogypsum	1.22	0.12	<0.01
diammonium phosphate fertilizer	0.21	2.33	<0.01
monoammonium phosphate fertilizer	0.19	2.04	<0.06

NORM is also found in scales, sludges and filters in the production of phosphoric acid.

Note: Equivalent data from the Alberta Fertilizer industry is provided under "NORM Characterization" later in this Section.

The following classification is based on data from the Alberta fertilizer industry.

Classification

NORM can be categorized as either diffuse or discrete. Diffuse NORM is defined as large in volume with a low relative radioactivity level that is uniformly dispersed throughout the material. Diffuse NORM from industrial activity is usually stored close to the point of generation as the cost of long distance transportation is prohibitive. Phosphogypsum is an example of diffuse NORM.

Discrete NORM is defined as lower volume material with higher radioactivity levels non-uniformly dispersed throughout the material. An example of discrete NORM is pipe scale that builds up on the inside of some processing pipes and tubing and is characterized by sometimes high, non-uniform concentrations of naturally occurring radioactivity. The pipe is then classified as NORCOM, i.e., equipment that is contaminated by naturally occurring radioactive material. For further information regarding NORM classification, refer to **The NORM Standards C Basis and Criteria.**

Of the radionuclides present in NORM-containing materials, the most significant is radium-226 due to its abundance, its rate of radioactive decay, and its presence at the head of the radium decay chain that spawns the formation of radon-222 gas and progeny products.

By comparison, the presence of uranium-238 in NORM-containing materials is of much less significance. With a half-life of 4.5 billion years, its rate of decay (hence the rate at which it emits damaging energy) is much less than radium-226 whose half-life is 1600 years. The US National Research Council in its BEIR IV Report (5), indicated that the health aspects of natural uranium appear to be entirely related to its chemical toxicity as a heavy metal and specifically to its nephrotoxicity, rather than to its radioactive properties.

Phosphate Rock

The radium-226 content of the phosphate rock currently used in Alberta ranges from 0.4 to 1.3 Bq/g, although in the past, activities of up to 1.9 Bq/g were present (6). Levels of uranium-238 activity in the phosphate rock are equivalent to those of radium-226.

IAEA exempt activity levels have been adopted by the NORM Committee as the standard for classification as *de minimis.*For natural uranium in which the radiological equilibrium has not been disturbed by physical or chemical partioning, the IAEA has adopted a total exempt activity of 1 Bq/g. For phosphate rock that has been physically and/or chemically partioned, IAEA exemption limits of the dominant long-lived parent radionuclide for each partioned decay series can be found in Table 5, page 21 of these *Guidelines.* When applied to phosphate rock currently or formerly used within the province of Alberta, the combined activity values have ranged from 0.2 to 0.6 Bq/g, well below the *de minimis* limit of 1 Bq/g.

Phosphogypsum Byproduct

Alberta phosphogypsum contains radium-226 concentrations of 0.4 Bq/g to 1.9 Bq/g and uranium-238 concentrations of <0.02 - 0.05 Bq/g (7). The activity of phosphogypsum is below the *de minimis* level of one IAEA exempt concentration for uranium-238 (10 Bq/g) and for radium-226 (10 Bq/g) in equilibrium with its specified progeny. Below these exemption concentrations, no special handling or precautions are required.

Outside of Canada, phosphogypsum had in the past been used in large quantities in the construction industry (cement, plasterboard) and the agricultural industry (fertilizer, soil remediation). Because of the abundance of inexpensive natural gypsum in Canada, very little phosphogypsum has been used here. Currently, a number of independent research studies in Western Canada are investigating the potential uses of phosphogypsum that meets *de minimis* levels.Completed research indicates that phosphogypsum meeting IAEA exempt activity levels, may be beneficially used in various applications including the restoration and conditioning of soils, as a fertilizer, as a road base material, and as a mine tailing flocculant. Based upon these findings, phosphogypsum stockpiles at production sites may be made available by industry for these purposes.

Fertilizer

Fertilizer currently produced or imported in Western Canada typically contains 0.10 to 0.30 Bq/g of radium-226. Uranium-238 concentrations in fertilizers produced in Western Canada are in the range of 0.4 to 0.6 Bq/g, while imported material may range up to 2.6 Bq/g (8). Again no special handling or precautions are required as these concentrations are below the *de minimis* level.

Phosphoric Acid

Phosphoric acid may also be used for a variety of other purposes as a commodity product of its own. Currently, the mean activity of uranium-238 in phosphoric acid produced in Alberta is 0.5 Bq/g, while the mean activity of radium-226 is 0.2 Bq/g. Thorium-232 content is at or below the lower limit of detection, 0.02 Bq/g (9). For all three species, the concentrations meet the IAEA exemption concentration, i.e., the *de minimis* criteria.

Scale and Sludge (NORCOM)

In the phosphoric acid production process, processing facilities become contaminated with NORM scale and sludge that tend to build up inside processing equipment. Sludge tends to accumulate in reaction vessels and acid storage tanks. Scales, which are very hard precipitates, tend to build on the inside surfaces of phosphoric acid piping, valves, filter pans and filter cloths. Radium-226 concentrations tend to be significantly higher and more variable than that found in the phosphate rock raw material or phosphogypsum. In phosphoric acid filtration equipment, radium-226 scale concentrations can range from 4 Bq/g to 2800 Bq/g (10).

Special attention and precautions are required with respect to sludge and scale produced within the operating equipment and piping. Thus, the scale and sludge material falls in the *NORM-contaminated* and *radioactive* classifications and must be managed as such.

In the following sections, information is given for the types of NORM found in the phosphate fertilizer industry, the potential for worker exposure, and the NORM management options available.

Characterization

Phosphate Rock

The phosphate rock imported to Western Canada has come from the southeastern and western United States and West Africa. It is usually stored at the operating sites in amounts of 10,000 to 40,000 tonnes prior to processing. This generally provides a 20- to 30-day supply of raw material for phosphoric acid manufacture.

The uranium-238 and radium-226 radionuclide concentration for the major phosphate rock sources used in Alberta, typically resembles the following (6):

Uranium-238	0.4 - 1.9 Bq/g
Radium-226	0.4 - 1.9 Bq/g

The thorium concentration is typically <0.05 Bq/g and in most instances is indistinguishable from background levels.

Phosphogypsum

Phosphogypsum is currently produced at a rate of 1.8 million tonnes per year. In Alberta, approximately 50 million tonnes of phosphogypsum are currently stored in phosphogypsum stacks at four locations (two stacks near Edmonton, one at Calgary, and one at Medicine Hat).

For Alberta phosphogypsum, the specific activities of uranium, radium and thorium are generally of the following concentrations (7).

Uranium-238	< 0.02 - 0.05 Bq/g
Radium-226	0.4 to 1.9 Bq/g
Thorium-232	Not detected, < 0.02 Bq/g

This information confirms data from the Florida phosphate industry in which radionuclide concentrations ranged as follows (11).

Uranium-238	< 0.02 - 0.19 Bq/g
Radium-226	0.34 to 2.0 Bq/g
Thorium	Typically <0.25 Bq/g

Alpha decay of radium-226 in phosphogypsum leads to the formation of the noble gas radon-222. Radon-222 is a short-lived radioactive element with a half-life of only 3.8 days.

Further radioactive decay leads to the formation of radon progeny, highly charged metallic isotopes of polonium, bismuth and lead that firmly affix to the gypsum crystal structure. The amount of radon-222 released from phosphogypsum stacks is very limited relative to the amount of radium-226 contained within the stack for several reasons.

Radium-226 is uniformly dispersed and locked within the crystal matrix of the phosphogypsum. Only a small fraction of the radon-222 formed can physically escape the crystal. Typically, this is only 14 to 15 percent (12). If released from the crystal, radon-222 can only travel a limited distance within the gypsum stacks through the interstitial spaces to the surface to escape. The diffusion coefficient of radon-222 in air is 1×10^{-5} meters/sec and 10,000 times less, 1×10^{-9} metres/sec in water (13). Only the radon-222 produced near the surface and able to get out of the crystal is released from the stack (Health Canada - Environmental Health Directorate). Typically, the rate of release ranges from 0.04 Bq/m^2 to 1.1 $Bq/m^2/s$. (14)

The radon-222 emission rate from the phosphogypsum stacks is extremely variable. The emissions depend upon factors such as climatic conditions, crust depth, moisture content and soil cover. The U.S. National Emission Standard for Hazardous Air Pollutants (NESHAP), developed by the Environmental Protection Agency (EPA), limits average radon-222 emissions from phosphogypsum stacks to 0.74 $Bq/m^2/s$ in order to provide an ample margin of safety (15). In Alberta, emission rates averaging 0.50 $Bq/m^2/s$ have been measured. Air quality studies are currently under way to verify the emission rates of radon-222 from phosphogypsum stacks at a number of Alberta locations.

Studies on both Alberta and Ontario phosphogypsum stacks indicate that this level of flux resulted in radon-in-air concentrations indistinguishable from the normal variability of natural background levels within 100 meters of the stacks tonnes (1). Background radon concentrations in areas of Alberta, Ontario, and Florida have been measured ranging from 4.8Bq/m^3 to 17.4 Bq/m^3. Typically, concentrations of radon in air directly above phosphogypsum stacks have been on the order of 24Bq/m^3(1), (16), (17). Studies in Canada by Western Research Limited and Senes have indicated that phosphogypsum tailings ponds were not a significant source of environmental radon and that radon in air concentrations in the vicinity of dry inactive stacks are unlikely to have a measurable environmental impact (1).

To place these results within context, measurements of radon-222 taken in 14,000 homes in 19 Canadian communities have determined that the mean concentrations of radon-222 from natural sources ranges from 5.2 Bq/m^3 to 57.0Bq/m^3 depending on the location of the community (18), (19). Health Canada has recommended a maximum exposure limit of 800 Bq/m^3 with a mitigation target of 150 Bq/m^3. These limits are compared to the averaged radon concentration evaluated over a one-year measurement period in normal residential living areas.

Fertilizer

Phosphate fertilizer produced in Alberta is typically mono-ammonium phosphate (MAP). As mentioned previously, specific activities are typically (8):

Uranium-238	0.40 - 0.60 Bq/g
Radium-226	0.10 - 0.30 Bq/g
Thorium-232	<0.02 Bq/g

Phosphoric Acid

As previously mentioned, filtered 42 wt% phosphoric acid (P_2O_5) contains only trace quantities of uranium-238, radium-226, and thorium-232. (9) The precipitate from the filtered acid is sent to the phosphogypsum stack. Accumulation in the form of scale and sludge minimizes the amount which is passed on in the production of the fertilizer product.

Scale and Sludge - NORCOM

Typical radionuclide concentrations in scales and sludges associated with process equipment is extremely variable. Data from Alberta phosphate fertilizer industry facilities verifies the data taken from the Florida phosphate industry (10).

Equipment	Ra-226 Activity - Bq/g
Filter cloths, mats and scales (Alberta)	4 to 2800
Industry data (Florida)	
• Filter pan scales	980 to 2450
• Miscellaneous scales	2 to 131
• Scrap materials (cloths, etc.)	12 to 17

Workers Most Likely to be Exposed to NORM

Phosphoric acid operations technicians, maintenance technicians and contractors who operate and service the process equipment and who also do contract maintenance, are the workers most likely to be exposed to sludges and scales contaminated with NORM. Health risk to workers can be minimized through the use of the proper protective equipment, sound operating procedures and precautions.

Radiation dosimetry monitoring of phosphoric acid workers has measured annual exposure dosages ranging from background to as high as 0.5 mSv/y above background.

Exposure rates, measured at 1 metre directly above a phosphogypsum stack are typically from 0.1 µSv/h to 0.52 µSv/h above background. This is equivalent to a maximum worker exposure of 0.2 to 1 mSv/y assuming continuous exposure for 2000 working hours per year, and is comparable to the average exposure rate of 0.33 µSv/h determined by Horton et al in the Florida phosphate industry (17).

The above-measured exposure levels for workers are well below the NORM Worker exposure guideline value of 20 mSv/y. Should phosphogypsum be used as a soil amendment, road base construction material, or as a source of fertilizer, worker exposure is expected to be well below guideline levels. The health risk for phosphogypsum workers, with exposure levels of less than 0.5 µSv/h, is significantly less than the increased exposure to cosmic radiation in airplanes, with levels up to 2.5 µSv/h (22).

Direct radiation exposure and inhalation of phosphogypsum associated radionuclides were evaluated for agricultural applicators and road construction crew members (23). For agricultural workers, exposure to direct gamma emissions would amount to 0.05 mSv/y, while committed dose from inhalation would amount to 0.008 mSv/y under maximum exposure conditions. For roadway construction workers, exposures to direct gamma emissions would amount to 0.4 mSv/y, while committed dose from inhalation would amount to 0.025 mSv/y under maximum exposure conditions. In both scenarios, the exposure levels for workers are well below the NORM worker exposure guideline value of 1 mSv/y above background.

Worker Protection

Refer to **Protection of Workers Exposed to NORM** in Part II.

NORM Management Options

Phosphogypsum Byproduct

There are potentially a number of uses for the phosphogypsum byproduct:

- as a soil amendment for solonetzic soils (hard-pan soils)
- as road base construction material
- for remediation of land impacted by brine spills from oil and gas well operations
- as a fertilizer
- as a source of chemical raw material (e.g., sulphur)
- as a mine tailings flocculant

Currently, a number of research studies are exploring the use of phosphogypsum. In Western Canada, the University of Alberta is conducting research to better understand the environmental issues associated with phosphogypsum including potential use as a soil amendment; the University of Saskatchewan is studying remediation of brine spill lands; and the Alberta Environment Centre, Vegreville is investigating biorecovery of selective chemical components. In the U.S.A., the Florida Institute of Phosphate Research (FIPR) is studying road base construction, recovery options and soil amendment.

The six environmental management principles are adhered to by the Alberta fertilizer industry using the following waste management approach.

In the fertilizer industry, *diffuse NORM* is defined as large in volume with a low radioactivity level uniformly dispersed throughout the material. Diffuse NORM in the fertilizer industry is classified as *de minimis* as outlined in **The NORM Standards - Basis and Criteria**.

Waste management principles apply to *discrete NORM*, i.e., lower-volume material with higher radioactivity levels non-uniformly dispersed throughout the material. Discrete NORM is generally above *de minimis* and is classified as *NORM-contaminated (NORCOM)* as outlined in **The NORM Standards - Basis and Criteria.**

Waste Minimization

The fertilizer industry is committed to waste minimization using the 4 Rs (Reduce, Reuse, Recycle and Recover). In practice, this includes NORM-contaminated materials (NORCOM).

Scales and Sludges – NORCOM

There is a broad range of options for the minimization of scales and sludges contaminated with NORM. Each option has built into it safety precautions that must be taken to limit exposure of the worker and ensure health and environmental protection. Within the operating facilities, worker exposures are regularly monitored to ensure that dose limits are not exceeded.

As sludge and scale builds up in the phosphoric process, it often becomes necessary to remove as much of the scale as possible, while operating, in order to maintain operating efficiency. Scale removal can be accomplished by using a 5 percent sulphuric acid solution boil-out at elevated temperatures for an extended length of time. The accumulated scales go into solution and the resultant boil-out slurry is sent to the phosphogypsum stack where the NORM contaminants settle out and the water can be returned to the process. This method eliminates most of the sludge and scale that has built up and allows the phosphoric acid plant to continue to operate. No special precautions are necessary, other than monitoring the NORM levels of the piping and vessels, where the scale and sludge build-up occurs, ensuring that worker protection is maintained through good practices and procedures and that the appropriate signage is displayed.

Equipment and Piping

Where equipment or piping must be taken out of service for desludging or descaling or for replacement, two options are available. Either the NORM sludge/scale contaminants can be removed from the equipment or the contaminated equipment (or piping) can be removed from service. The volume of NORM-contaminated material can be reduced through segregation of the uncontaminated portions from the contaminated portions.

If the equipment or piping sludge and scale is to be removed, workers must use the correct personal protective equipment to prevent inhalation, ingestion or skin contact. The type of personal protective equipment required is described in detail under the section entitled **Protection of Workers Exposed to NORM**.

Release of NORM-contaminated materials (NORCOM) for reuse is limited to informed and knowledgeable purchasers within the fertilizer industry. Simple release of equipment containing NORM for re-use outside the fertilizer industry is not a reasonable option, as this would make the new owners responsible for either cleaning or disposing of the equipment, e.g., release of NORCOM to a smelter.

Waste Characterization

When it becomes necessary to remove NORM-contaminated material, one of the first steps taken is to determine its level of radioactivity. The procedures used to determine the level of radioactivity are outlined in **Detection, Assessment and Monitoring of NORM** in Part II, Technical Reference.

The NORM-contaminated material is also assessed to determine whether it is diffuse NORM or discrete NORM (volume or mass of the material versus the radioactivity level).

A Materials Management Sheet is generated each time a quantity of NORCOM is removed. The NORCOM is inventoried and placed in a secured interim storage location. The Materials Management Sheet shows the waste characterization, waste classification, storage and disposal for each quantity of NORM waste removed (*chain of custody documentation*).

Waste Classification

NORM waste is classified as per the procedures outlined in **Detection, Assessment and Monitoring of NORM**. The three waste classifications are: *de minimis*, NORM-contaminated (NORCOM) and radioactive.

Interim Storage

Storage of the NORCOM material can be accommodated either by burial in the phosphogypsum stack or in an above-ground, secured structure, as an interim measure. Equipment, non-salvageable filter cloths and piping that has reached the end of its effective life and cannot be descaled or desludged because of its size, magnitude or the practicality of the operation, can be handled by one of two methods:

Burial in the phosphogypsum stack

Equipment (rubber and metal parts), non-salvageable filter cloths and piping are wrapped and secured in several layers of polyethylene and buried in a well-marked surveyed pit (10 to 15 feet deep) located within the phosphogypsum stack at the operating site.

Storage in a secure, aboveground facility

Equipment (rubber and metal parts), non-salvageable filter cloths and piping are wrapped and secured in several layers of polyethylene and placed in an aboveground storage facility at the operating site.

The interim storage facilities must be properly maintained to ensure a controlled, secured temporary storage of two to 50 years. Interim storage provides a means of containing the material at the operating sites until there is a permanent, environmentally acceptable, economically attractive facility for permanent disposal. The volume of NORCOM stored in this manner varies with each plant site (size of plant, age of plant), however, the annual accumulation ranges from 5 m^3 30 m^3 based on Alberta fertilizer plant information.

Waste Disposal

At present, there are no commercial NORM waste disposal sites in Canada. In the United States, the EPA has defined criteria for NORM waste disposal sites for uranium and thorium mill tailings and related byproduct materials. The waste disposal site must be capable of providing effective storage for at least 200 years and ideally for 1000 years. This is consistent with the criteria for disposal of wastes from the nuclear industry. Radon fluxes to the atmosphere must be limited to 740 $mBq/m^2/s$ or 20 $pCi/m^2/s$(averaged over the disposal area and over any one-year period) (15).

While there are no low-level waste sites approved in Canada, arrangements may be made through Atomic Energy of Canada Ltd. for storage at one of their sites.

In the United States, the only licensed low-level radioactive waste (LLW) disposal sites are found in Hanford, Washington; Beatty, North Virginia and Barnwell, South Carolina.

Due to the limited number of LLW sites and the extreme distances from these sites, transportation of low-level radioactive wastes is too costly to be a practical option.

Pending further studies including risk assessments, phosphogypsum stacks may be considered an acceptable option for permanent NORM waste disposal sites.

The disposal design criteria for permanent long-term NORM storage sites remains to be determined. This would involve approvals from regulatory agencies. Appropriate standards and regulatory approval protocols would have to be developed and in place.

REFERENCES

1. Senes Consultants Ltd., An Analysis of the Major Environmental and Health Concerns of Phosphogypsum Tailings in Canada and Methods for Their Reduction, published November 1987, prepared for Ontario Ministry of Environment, Alberta Environment and Environment Canada.

2. United States Environmental Protection Agency (EPA), Risk Assessment Methodology, Environmental Impact Statement for NESHAPS Radionuclides, Volume 1, Background Information Document, EPA 520/1-89-005, September 1989.

3. Guimond, R.J., The Radiological Aspects of Fertilizer Utilization, Radioactivity in Consumer Products, NUREG/CP-0001 (GUI78), Nuclear Regulatory Commission, Washington, DC., 1978.

4. Guimond, R.J. and Windham, S.T., Radioactivity Distribution in Phosphate Products, By-Products, Effluents and Wastes, Technical Note ORP/CSD-75-3 (GUI78), Environmental Protection Agency, Washington, DC., August 1975.

5. U.S. National Research Council, National Academy of Science Committee on the Biological Effects of Ionizing Radiation (BEIR), 1988.

6. Actual data taken from Florida Phosphate Rock and Togo Phosphate Rock used at the Sherritt - Redwater Plant.

7. Dudas, M.J. and Rutherford, P.M., AERT Final Report - Leachate Chemistry of Phosphogypsum Byproduct, University of Alberta, December 1994.

8. Personal Communications (#1), current and former Western Canada Phosphate Producers.

9. Personal Communications (#2), current and former Western Canada Phosphate Producers.

10. Actual data taken from the Alberta Phosphate Producers' operations.

11. Rutherford, P.M., Dudas, M.J., and Samek, R.A., Environmental Impacts of Phosphogypsum, University of Alberta, September 1992, Table 5.

12. Rutherford, P.M., Dudas, M.J., and Samek, R.A., Environmental Impacts of Phosphogypsum, University of Alberta, May 1993.

13. Rutherford, P.M., Dudas, M.J., and Samek, R.A., Environmental Impacts of Phosphogypsum, University of Alberta, May 1993.

14. Rutherford, P.M., Dudas, M.J., and Samek, R.A., Environmental Impacts of Phosphogypsum, University of Alberta, May 1993.

15. US EPA, 40CFR 61, R(54FR51654, December 15, 1989), as amended (57FR23305, June 3, 1992).

16. Roessler, C.E., Radon Emissions from Phosphogypsum Stacks, paper presented to the Proceedings of the Eighteenth Midyear Topical Symposium of the Health Physics Society, Colorado Springs, January 6-10, 1985.

17. Horton, T.R. et al, A Long Term Study of Radon and Airborne Particulates at Phosphogypsum Stacks in Central Florida, U.S. EPA Report EPA520/5-88-021, October 1988.

18. MacGregor, R.G. et al, Background Concentrations of Radon and Radon Daughters in Canadian Homes, Health Physics 39, 285 - 29, 1980.

19. Letourneau, E.G. et al, Design and Interpretation of Large Surveys for Indoor Exposure to Radon Daughters, Radiation Protection Dosimetry, 7, 303 - 308, 1984.

20. Federal - Provincial Conference of Deputy Ministers of Health, December 1988.

21. Krewski, D. et al, Managing Environmental Radon Risks: A Canadian Perspective, Health Protection Branch, Health Canada, 1989.

22. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Sources, Effects and Risks of Ionization Radiation, United Nations, New York, 1991.

23. U.S. EPA, Potential Uses of Phosphogypsum and Associated Risks, Background Information Document for 40CFR 61 Subpart R - National Emission Standards for Radon Emissions from Phosphogypsum Stacks, EPA520/1-91-029, April 1992.

Note: References 1 through 23 are also covered within the EPA Document ANR-460 (Air and Radiation): 'Draft' - Diffuse NORM - Waste Characterization and Preliminary Risk Assessment.

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APPENDICES

Appendix A
Glossary Of Radiation Terminology

Abandonment	This refers to the approved plugging of a wellbore and the safe removal of surface equipment.
Absorbed dose	The energy imparted by radiation to any substance per unit of mass. Use of the term "dose" does not imply human radiation exposure.
Activity	The number of nuclear transformations that occur in a quantity of material per unit of time.
Alpha radiation	A high energy positively charged particle ejected from the nucleus of an unstable (radioactive) atom, consisting of two protons and two neutrons. Alpha particles are, effectively, a helium nucleus. Due to its large size, an alpha particle is readily stopped by collisions with other atoms.
Annual Limit on Intake (A.L.I.)	The amount of the annual uptake of a specific radionuclide by all routes, which, if never exceeded, would ensure that the maximum permissible occupational radiation dose being received by a person each year is not exceeded.
Atomic Number	The number of protons in the nucleus of an atom. This number gives each atom its distinct chemical identity.
Background Radiation	The amount of radiation to which an individual is exposed from natural sources such as terrestrial radiation from radionuclides in the soil, cosmic radiation, and naturally occurring radionuclides deposited in the body from foods, etc.
Becquerel (Bq)	SI unit of radioactivity, equivalent to 1 disintegration 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.

Beta radiation The emission of a high energy negatively charged subatomic particle ejected from the nucleus of an unstable atom. A beta particle from a naturally occurring radioactive substance is identical in mass and charge to an electron.

Consolidation (1) Consolidation refers to increasing the concentration of the radioactive material in NORM, through the reduction of volume by the removal of less radioactive materials.
(2) Consolidation refers to the concentration of NORM, which may increase its activity while reducing volume.

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

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

Decommissioning Decommissioning refers to the removal of surface, or abandonment of downhole, operating equipment.

Gamma radiation Photon energy emitted from an unstable atomic nucleus in the process of ridding itself of excess energy. Highly penetrating, it dissipates by transferring energy to incident atoms.

Geiger-Muller (GM) Probe A radiation detector whose output is proportional to the number of radioactive events present, but is relatively independent of the energy of that radiation.

Gray (Gy) The SI unit of absorbed radiation dose corresponding to the absorption of 1 joule of radiation energy per kilogram of material.

Half-life, biological The time required for the body to eliminate half the quantity of a substance taken into the body.

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

MPCa	Maximum Permissible Concentration in air. The concentration of radionuclide in air which, if inhaled continuously throughout a year would lead to a total inhaled activity equal to the annual limit on intake.
Monitor	Any instrument used to measure radiation levels.
NORCOM	(Naturally Occurring Radioactive Contaminated Materials) Refers to equipment, such as tubing, piping, filters, and vessels contaminated by NORM.
NORM	(Naturally Occurring Radioactive Materials) Refers to radioactive materials and chemicals in their natural form, such as scale, deposits, solids or solutions with elevated radionuclide concentrations.
NORM residue	(1) NORM residue refers to the material remaining, which requires final treatment and disposal, after all waste minimization efforts have been applied. (2) NORM residue is the material remaining requiring final treatment and disposition after all waste minimization efforts, such as reduction, recycling and reuse have been applied.
Phosphogypsum Stack	Phosphogypsum stack refers to the storing of Phosphogypsum byproduct in large outdoor stockpiles.
Prescribed Substance	Radioactive materials regulated under the Atomic Energy Control Act, requisite for the production, use or application of atomic energy.
Pre-treatment	Pre-treatment is a process, which reduces or concentrates NORM residue before final treatment or disposition.

Quality Factor (QF) (Radiation Weighting Factor)
: A weighting factor which represents the degree of biological damage inflicted by various forms of radiation on living organisms. This damage is a function of the linear energy transfer to tissue of each form of radiation as it penetrates the tissue. For x rays, gamma rays and beta particles the quality factor is 1, while for alpha particles and fast neutrons, the quality factor is 20.

RAD
: An obsolescent unit for measuring radiation energy absorption (dose), equivalent to 100 ergs per gram in any medium. RAD is a contraction of Radiation Absorbed Dose. Now replaced in international usage by the gray.

Radioactive Equilibrium
: A condition in which the activities of the members of a radioactive decay chain decrease exponentially in time with the half-life of the decay chain precursor, leading to an equilibrium between the precursor and progeny. This form of equilibrium may only be attained if the precursor is very long lived relative to any member of the decay chain.

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 present in significant quantities in NORM. It decays into the radioactive gas radon.

Radon
: The only radioactive gas generated during natural radioactive decay processes. Two isotopes of radon are present – radon and thoron – each a daughter 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 decay products
: The products of ^{222}Rn decay having short half-lives, namely ^{218}Po (RaA), ^{214}Pb (RaB), ^{214}Bi (RaC), and ^{214}Po (RaC').

Reclamation
: (1) Reclamation refers to the re-establishment of the land surface area for its original equivalent land capability.
(2) Reclamation is the reestablishment of the land surface area to its original; or approved, land capability.

Recovery Recovery refers to the use of NORCOM for one of its chemical or physical properties, such as the recovery of sulphate from phosphogypsum.

Recycling (1) Recycling refers to the use of NORM for one of its chemical or physical properties such as, phosphogypsum as a soil amendment.
(2) Recycling refers to the reconstitution of NORCOM into new products, such as cleaned steel into new steel.

Reduction (1) Reduction refers to the reduction of the volume or weight of NORM generated by any particular process.
(2) Reduction refers to a process of reducing the amount of NORCOM generated in terms of volume or weight.

REM A classical unit of human dose equivalent. REM is a contraction of Rad Equivalent Man. Now replaced in international usage by the sievert.

Reuse (1) Reuse refers to the reuse of NORM materials in their original context, such as tubing being cleaned and reused.
(2) Reuse refers to the use of NORCOM in its original context such as tubing after being cleaned and put back into similar service.

Roentgen (R) An obsolescent unit of radiation ionization in air, frequently misapplied as a unit of exposure in humans. Replaced in international usage by the coulomb per kg.

Scaler A radiation measurement instrument that counts the number of radioactive events detected by a suitable probe.

Scintillation Detector A radiation detector, which counts the pulses of light produced when a phosphor is bombarded by ionizing radiation.

Shielding The reduction of radiation beam intensity by interposing a substance, which absorbs radiation energy, either by collision, in the case of particulate radiation, or by absorption of waveform energy, in the case of gamma or x-radiation.

Sievert (Sv) — SI unit of absorbed radiation dose in living organisms, usually people. The product of the absorbed dose in gray and the radiation weighting factor for the form of radiation in question. Replaces the obsolescent unit, the rem.

Specific Activity — The number of decays per unit time of a radionuclide per gram of a material.

Storage — Storage refers to both the interim and long-term retention of NORM. It falls into three categories:

- short-term: less than two years storage
- interim: two to fifty years storage
- permanent: greater than fifty year storage

Treatment — (1) Treatment refers to the final treatment and disposition in a permanent storage location or facility.
(2) Treatment refers to the application of waste minimization to NORCOM prior to disposition in a permanent approved storage facility.

Waste Minimization — Waste minimization refers to the activities of reduction, recycling, reuse or recovery of NORM residues (NORCOM).

Working Level — A measure of the alpha energy released by the decay of radon decay products in equilibrium with 3.7 becquerels per litre of radon. One Working Level (WL) is defined as any combination of radon decay products in one litre of air that will result in the ultimate emission of 1.3×10^5 Mev of alpha energy.

Working Level Month — An expression of the cumulative energy release from radon daughter decay. One Working Level Month is defined as the exposure received by an individual inhaling air containing a radon daughter concentration of one WL for a period of 170 hours. (The assumed number of hours in a working month.)

Appendix B
NORM Monitoring Instruments And Major Manufacturers

This appendix provides a listing of suppliers and instrumentation suitable for the measurement of NORM. This list is not intended to be all inclusive or to imply any endorsement of the listed instruments or manufacturers over any others. It is provided solely for the convenience of the reader in identifying potential sources of instrumentation which meet the technical demands of NORM monitoring.

NORM Assessment Instrumentation

Eberline Instrument Corporation
504 Airport Road
Santa Fe, New Mexico
USA, 87504-2108
Phone: (505) 471-3232

Survey Meter	Probe or Accessory
ESP-2 Survey Ratemeter/Scaler	HP-270 Energy-compensated GM probe HP-210 T or 260 Pancake Probes SPA-3 or SPA-8 NaI gamma scintillation probes AC3 Alpha scintillation probe.
DD-100 Electronic Dosimeter	DR-200 Dosimeter Readers Dose record-keeping software Electronic access control systems

Ludlum Measurements, Inc.
P.O. Box 810
501 Oak Street
Sweetwater, Texas
USA, 79556
Phone: (915) 235-5494

Survey Meter	**Probe or Accessory**
Ludlum 3-97 with mSv/h and CPM meter face.	1" X 1" internally mounted Model 44-2 NaI gamma scintillation detector (the external M44-38 energy-compensated GM probe is included in this unit) Model 44-9 Pancake Probe.

Victoreen, Inc.
6000 Cochran Road
Cleveland, Ohio
USA, 44139-3395
Phone: (216) 248-9300

Survey Meter	**Probe or Accessory**
Thyac IV Model 290-SI Meter	Energy-compensated GM probe Model 489-4 Gamma scintillation probe, Model 489-55 Pancake GM probe, Model 489-110c Alpha scintillation probe, Model 489-60

Honeywell, Inc.
Minneapolis, Minnesota
USA,
Phone: (612) 951-1001

Survey Meter	**Probe or Accessory**
Honeywell Professional Radon Monitor Model A9000A	Data Logger Printer Model Q9010A

Sun Nuclear Corp.
Pineda Products
425-A Pineda Court
Melbourne, Florida
USA, 32940
Phone: (407) 254-7785

Survey Meter	Probe or Accessory
Model 1023 Radon Monitor	
Model 1081 Radon Soil and Water Monitor	Water Aeration Pump 9 Pin Male x 25 Pin female
Model 1025 Radon Surveyor	RSU-232 Adapter

EDA Instruments Inc.
1 Thorncliffe Park Drive
Toronto, ON, M4H 1G9
(416) 425-7800

Survey Meter	Probe or Accessory

Suppliers of a variety of instrumentation designed especially for the monitoring of radon and thoron gas and daughter products.

Scintex
222 Snidercroft Road
Concord ON L4K 1B5
(905) 669-2280

Survey Meter	Probe or Accessory
RDA-200 Portable Radon Detector	Radon daughter measurement option Radon in soil gas measurement option RDU-200 radon in water degassing option

Pylon Electronics Inc.
147 Colonnade Road
Nepean ON K2E 7L9
(613) 226-7920

Survey Meter	**Probe or Accessory**
AB-5 Radon/Thoron Detection System	Continuous passive radon detection system
	High-sensitivity continuous radon system
	Continuous working level system
	Grab sample working level system
	Radon-in-soil system
	Radon-in-water system
	Certified radon and radon thoron gas standards

Thompson & Nielsen Electronics Ltd.
4019 Carling Avenue
Kanata ON K2K 2A3
(613) 592-3019

A variety of instrumentation designed especially for the monitoring of radon and thoron gas and daughter products.

Appendix C
Radiation Unit Conversion Factors

Prefixes

T	Tera	10^{12}	m	milli	10^{-3}
G	Giga	10^{9}	μ	micro	10^{-6}
M	Mega	10^{6}	0	nano	10^{-9}
k	kilo	10^{3}	Δ	pico	10^{-12}

Activity

		SI Units	to	Classical 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
1 MBq	=	1×10^{6} dps	=	27 μCi	=	2.7×10^{-5} Ci
1GBq	=	1×10^{9} dps	=	27 mCi	=	2.7×10^{-2} Ci
1 TBq	=	1×10^{12} dps	=	27 Ci	=	2.7 x 10 Ci
0.037 Bq	=	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 Classical Units

1 Gy = 100 rad

1 mGy = 0.1 rad

1 μGy = 0.1 mrad

SI Units to Classical Units

1 rad = 10 mGy

1 mrad = 10 μGy

1 μrad = 0.01 μGy

Equivalent "Biological Dose"

SI Units to Classical Units

1 Sv = 100 rem

1 mSv =100 mrem

1 μSv = 0.1 mrem

SI Units to Classical Units

1 rem = 10 mSv

1 mrem = 10 μSv

1 μrem = 0.01 μSv

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Appendix D
Radiation Monitoring Instrumentation
Field Calibration Form

Instrument:

Make and Model #:______________________________Serial #:_____________

Factory Calibration Date:____

Probe:

Make and Model #:______________________________Serial #:_____________

High Voltage:_________Dead Time:______Calibration Constant:___________

Factory Calibration Date:____

Check Source:

Check Source Isotope:____________Activity:_________Serial #:___________

Source Holder Make/Model:____

Source/Probe Geometry Specifications:_________________________________

Field Calibration Data:

Date	Background Reading	Source Reading	Net Reading	Is Source Result Within +/- 10% of Reference Value? (Y/N)?

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Appendix E
NORM Assessment Survey Form

Date:____________________ Site/Location:____________________

Survey Type:____________________

Survey Instrument Make and Model:____________________ S/N:__________

Probe Make and Model:____________________ S/N:__________

Natural Background Reading for Area: ____________________

α: __________ β:__________ γ:__________

Survey	Surface Contact Readings			
Location/Description	CPM	Bq/cm^2	μSv/h @ 0.5 m	μSv/h @ 1.0 m

Comments:

Area Sketch:

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Appendix F

Airborne NORM Dust Radiological Survey Form

Date:____________________ Sample Number:____________________
Site / Location:____

Sample Description:____

Pump Number:____________________ Time On:________________
Time Off:____________________ Pump Run Time:____________ min
Flow Rate, Initial:____________ lpm Flow Rate, Final:____________1 pm
Ave Flow Rate: ____________lpm

Filter Wt, Initial:____________ mg Filter Wt, Final:____________ mg
Wt Gain:____________ mg

Air Volume Sampled:____________ litres Dust Concentration:____________ mg/m^3

a Count Rate:________ cps / Probe Effic:________ = α Activity: ________ Bq
a Activity:________ Bq / Air Vol Sampled:________ = α Conc: ________ Bq/l

b Count Rate:________ cps / Probe Effic:________ = β Activity:________ Bq
b Activity:________ Bq / Air Vol Sampled:________ = β Conc: ________ Bq/l

Area Sketch:

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Appendix G
Radiological Laboratory and Consultant Listing

The reader is advised to contact the appropriate provincial government agency for a list of radiological laboratories and consultants.

British Columbia: B.C. Centre for Disease Control, Radiation Protection Services
655 West 12th Avenue (Main Floor), Vancouver, BC V5Z 4R4
Phone: (604) 660-6633

Alberta: Alberta Human Resources & Employment, Workplace Policy and Standards
8th Floor, 10808 - 99 Avenue, Edmonton, AB T5K 0G5
Phone: (780) 427-2687

Saskatchewan: Saskatchewan Labour, Occupational Health and Safety Branch
1870 Albert Street, Regina, SK S4P 3V7
Phone: (306) 787-4538