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NORM AWARENESS

INTRODUCTION

NATURALLY OCCURRING RADIOACTIVE MATERIAL or **NORM**, is a major component of background radiation. NORM consists of long-lived radioactive material which is present throughout the environment in low concentrations. This includes the tissues of every living animal, including humans. **You are naturally radioactive!** This low-level presence has the potential to initiate cancer in persons exposed to it. However, it is generally considered to be negligible.

Higher concentrations of NORM can develop as a result of industrial activities, including the production of petroleum products. These higher concentrations increase the potential for cancer.

Currently, there is no legislation in Canada that deals with NORM. However, provincial governments do have legislation regulating maximum annual exposure limits for radiation.

SOURCES OF NORM

When left in its undisturbed natural environment, NORM exists in very low concentrations and is not a significant problem. However, several industries have production activities that concentrate NORM, sometimes referred to as technologically-enhanced NORM (TENORM) and some of these are:

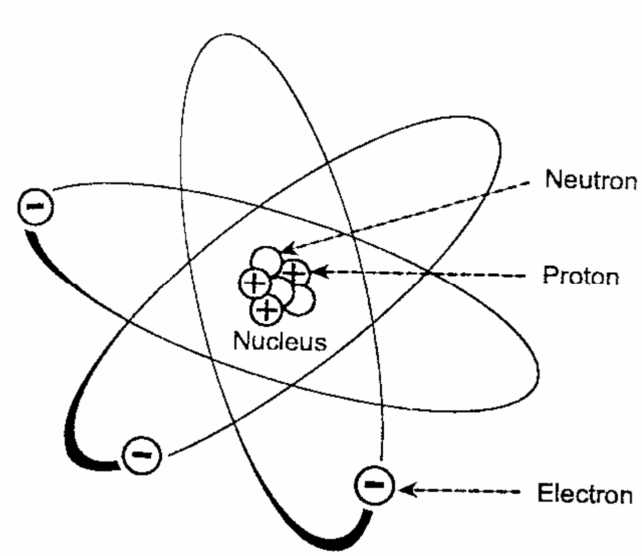
- *Oil and Gas Production* (i.e. radium and radon gas in liquid and gas products)
- *Mining and Ore Processing* (i.e. uranium and thorium deposits)
- *Metal Recycling* (i.e. redistribution of NORM from one industry to another)
- *Forest Product Combustion* (i.e. fly ash form wood products)
- *Thermal-Electric Production* (i.e. fly ash from coal plants/co-generation plants)
- *Water Treatment Facilities* (i.e. filtration systems)
- *Tunnelling or other Underground Industrial Activities* (i.e. radon gas build-up)
- *Phosphate Fertilizer Industry* (i.e. phosphor gypsum)

RADIATION AND RADIATION DECAY

The Atom

The atom is the smallest unit of matter found in nature that can take part in chemical reactions without being permanently changed.

The atom is composed of two parts:
1. the **nucleus**, containing protons and neutrons
2. the **shell**, containing electrons, in the same number as protons, orbiting the nucleus.



Radioactivity

Some atoms are radioactive and breakdown or decay to release radiation. This radiation can be measured with specialized instrumentation.

The quantity of radioactivity within a sample of material is measure in SI (Systemes Internationale) units called becquerels.

1 bequerel = 1 decay event/second or 1 disintegration/second (**1 dps).**

Radioactive Material

When some atoms in a larger group of atoms are radioactive, the material is called **radioactive material**. Radioactive material has important characteristics including radioactive half-life and specific types and amounts or radiation emission from the material.

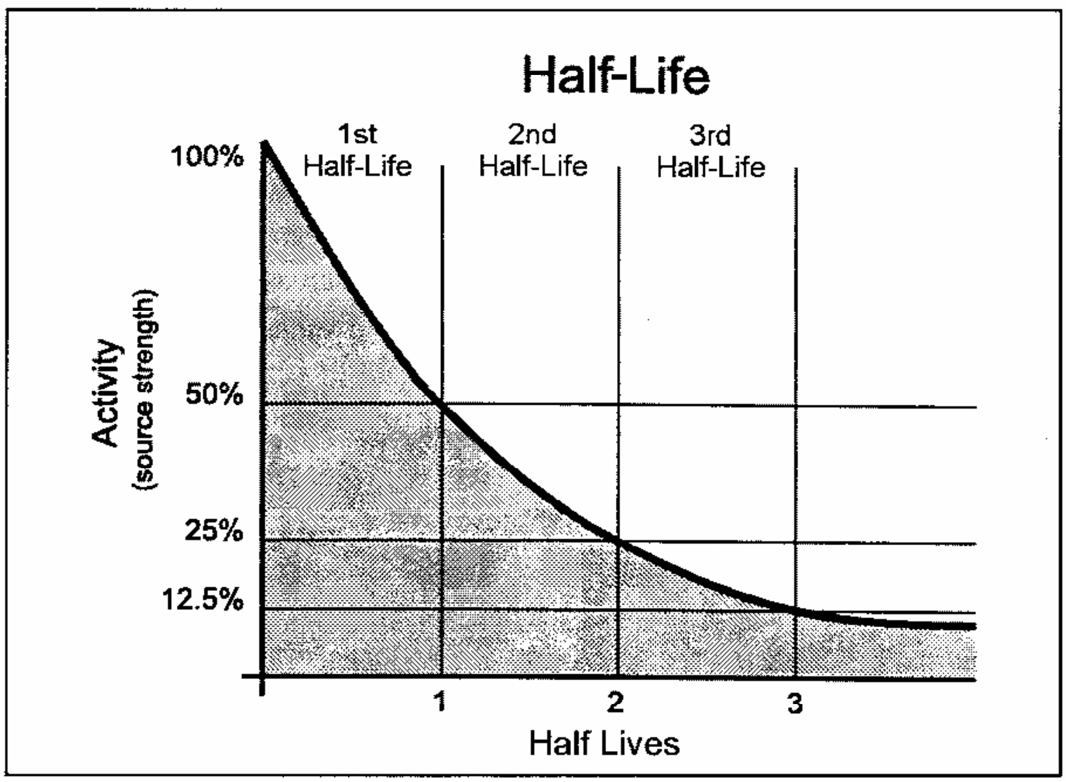
Radionuclide

A radionuclide is a collection of radioactive atoms with identical radioactive properties. Each radionuclide has a unique name and is identified by its chemical name, plus the total number of neutrons and protons contained in its nucleus.

For example, the most common NORM radionuclide of concern in the petroleum industry is Radium^{226}. It has a total of 88 protons and 138 neutrons in its nucleus. Another NORM radionuclide of concern, Lead^{210}, has 82 protons and 128 neutrons.

Radioactive Half-Life

This is the amount of time required for the radioactivity of a particular radioactive sample to decay to ½ its original concentration. The half-life, T½, is a unique identifier of the radionuclide. For example, Radium^{226} has a half-life of 1600 years and Lead^{210} has a half-life of 22.3 years.



NORM RADIATION TYPES AND PROPERTIES

Alpha Particles [Alpha (α) decay]

Alpha decay is a radioactive decay process which results in the emission of an alpha particle. An alpha particle consists of:

- 2 protons and 2 neutrons, and
- is equal to the nucleus of the helium atom.

Exposure of the skin to alpha particles presents no hazard since the particles cannot penetrate the dead surface layer of the skin. However, if the alpha particles emitted from NORM are ingested, inhaled or absorbed into the body, they can be very damaging to internal tissues.

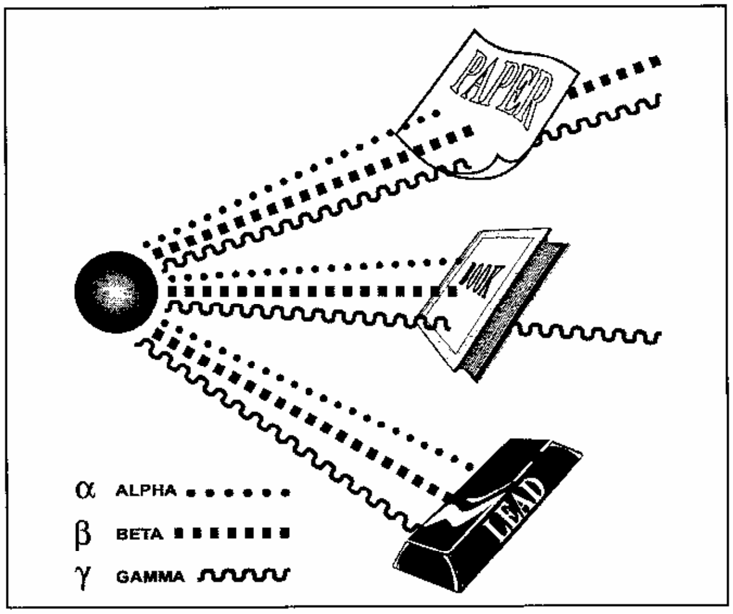
Alpha particles only pose an internal radiation exposure risk.

Beta Particles [Beta (β) decay]

Beta decay is a radioactive decay process resulting in the emission of an electron (i.e. beta particle) from the nucleus. $Lead^{210}$ (PB^{210}) is the most common beta particle in the oil and gas industry.

Beta particles found in NORM generally are quite penetrating. Some beta particles may penetrate skin, but most will be stopped by plywood or heavy gloves. All beta particles will be stopped by metal (i.e. piping).

Beta particles pose, primarily, an internal and to a lesser degree, external radiation exposure risk.



Penetrating Characteristics

Gamma Rays [Gamma (γ) Emission]

Gamma emission is a radioactive decay process resulting in the emission of electromagnetic radiation (i.e. gamma rays). This type of emission promptly follows an alpha or beta decay event.

Gamma rays are highly penetrating and can easily pass through thin layers of steel or concrete.

Gamma rays pose *both* an internal and external radiation exposure risk.

Radioactive Decay Series (NORM decay series)

A radioactive decay series is a number of linked radioactive decays which result in one radionuclide (i.e. the parent), decaying and transforming itself into another radionuclide (i.e. its progeny). If the progeny is radioactive, it behaves as another parent and will decay and transform itself into yet another radionuclide. A radionuclide decay series is named after the first radionuclide in the series. All NORM Decay Series eventually decay into a stable (i.e. non-radioactive) form of lead.

NORM radionuclides of interest to the petroleum industry exist in one of two extremely long-lived radioactive decay series

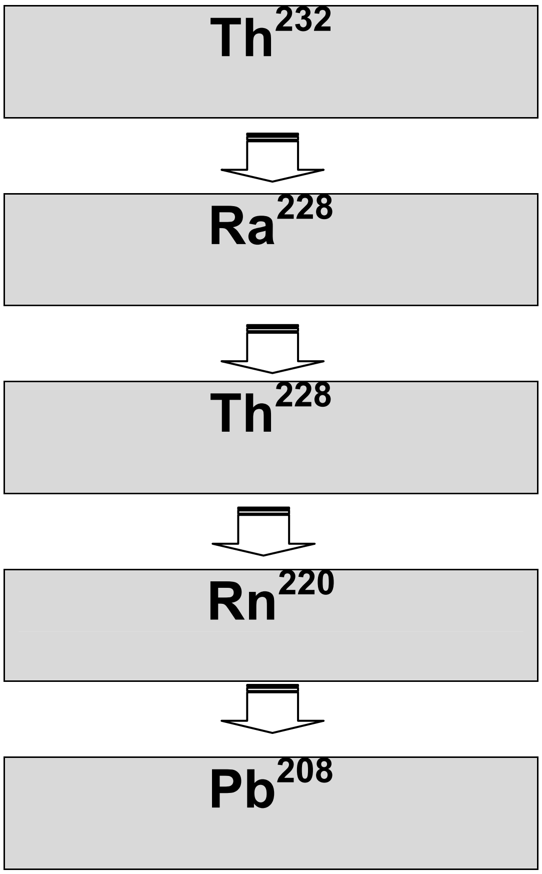
- Uranium^{238} Decay Series (Uranium Series)
- Thorium^{232} Decay Series (Thorium Series)

Within each of these decay series, a number of important radionuclides are present which have very different radioactive properties.

Uranium ^{238} Decay Series

U^{238} ↓	Uranium^{238} is found in geological materials from oil and gas reservoirs.
Ra^{226} ↓	Radium^{226} is found in scales and sludges from treaters and separators.
Rn^{222} ↓	Radon^{222} concentrates in propane and ethane streams.
Pb^{210} ↓	Lead^{210} is found in propane, ethane and LPG (Liqidified Pretroleum Gas) gas handling equipment.
Pb^{206}	Lead^{206} is stable and non-radioactive.

Thorium^{232} Decay Series



Thorium^{232} is found in geological materials from oil and gas reservoirs.

Radium^{228} is found in scales and sludges from treaters and separators.

Thorium^{228} concentrates in propane streams.

Radon^{220} has a very short-lived radioactive state.

Lead^{208} is stable and non-radioactive.

NORM SOURCES IN THE PETROLEUM INDUSTRY

NORM Radionuclides in the Petroleum Industry

Important NORM radionuclides of concern in the petroleum industry have very different chemical properties, physical properties and radioactive half-lives.

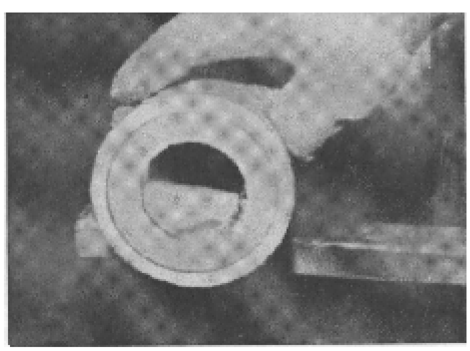
NORM sources in the Uranium^{238} decay series include:

- Uranium^{238} (4.5 billion years),
- Radium^{226} (1600 years),
- Radon^{222} or Radon Gas (3.83 days),
- Radon Progeny – a group of radionuclides found in the decay series immediately following the decay of Radon^{222}, that include:
  - Polonium^{218}
  - Lead^{214}
  - Bismuth^{214}
- Polonium^{214} (less than 1/6,000 of a second to 27 minutes),
- Lead^{210} (22.3 years).

Important radionuclides and their half-lives within the Thorium series include:

- Thorium^{232} (14 billion years),
- Radium^{228} (5.7 years),
- Radon^{220} or Thoron Gas (55.6 seconds).

In terms of potential harm to workers, only the Uranium and Thorium series are found in scales and sludges from produced water.



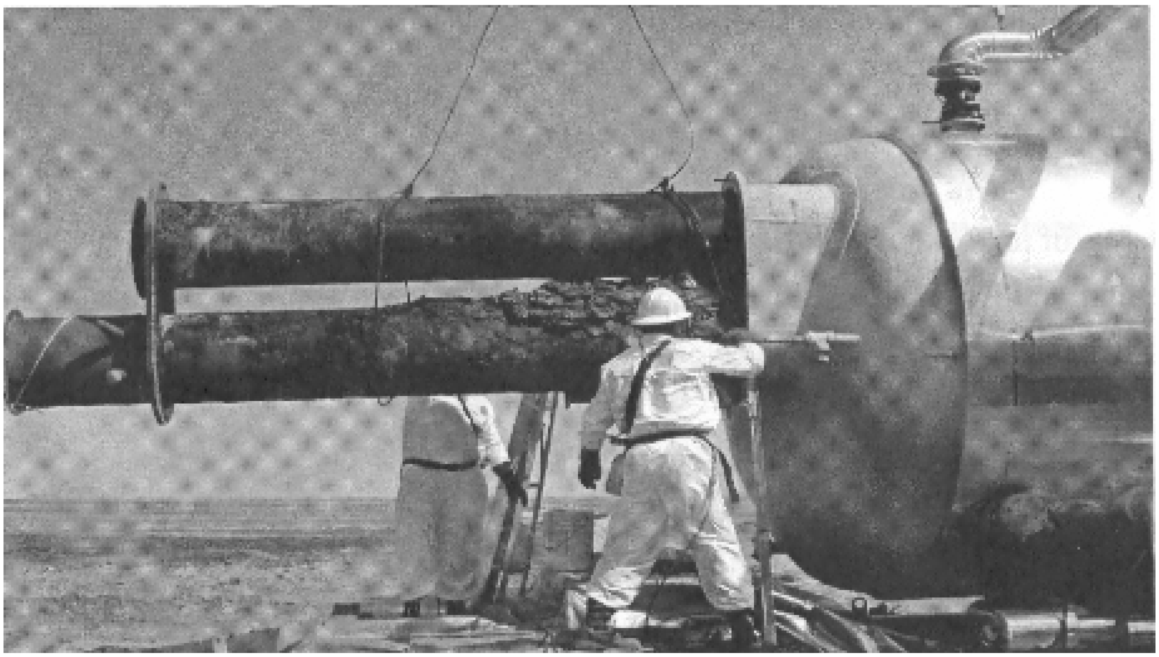
Cross View of NORM Contaminated Scale in Piping

NORM Hazards

NORM hazards are present in the exploration, production, processing and distribution sectors of the petroleum industry.

Exploration and Production

Uranium is found within underground petroleum reservoirs. It is insoluble and presents no significant problem for drilling and extraction. However, $Radium^{226}$, as part of the $Uranium^{238}$ decay series, is somewhat soluble. Under certain chemical conditions, radium can dissolve within the extracted product as a radium salt. These radium salts can then precipitate out as scale or sludge which can accumulate on equipment surfaces (i.e. in elbows, valves, etc.) during the extraction process. This precipitation can build up, leading to concentrated radioactivity levels within the NORM scale or sludge.



NORM Contaminated Bundles

The degree of radiation hazard to upstream operations is highly dependent on the quantity of uranium present within the underground reservoir geology, and the chemical and physical conditions in the extraction process. Concentrations of radioactivity in scale samples can range from 0.05 becquerels per gram (Bq/g) to in excess of 1000 Bq/g.

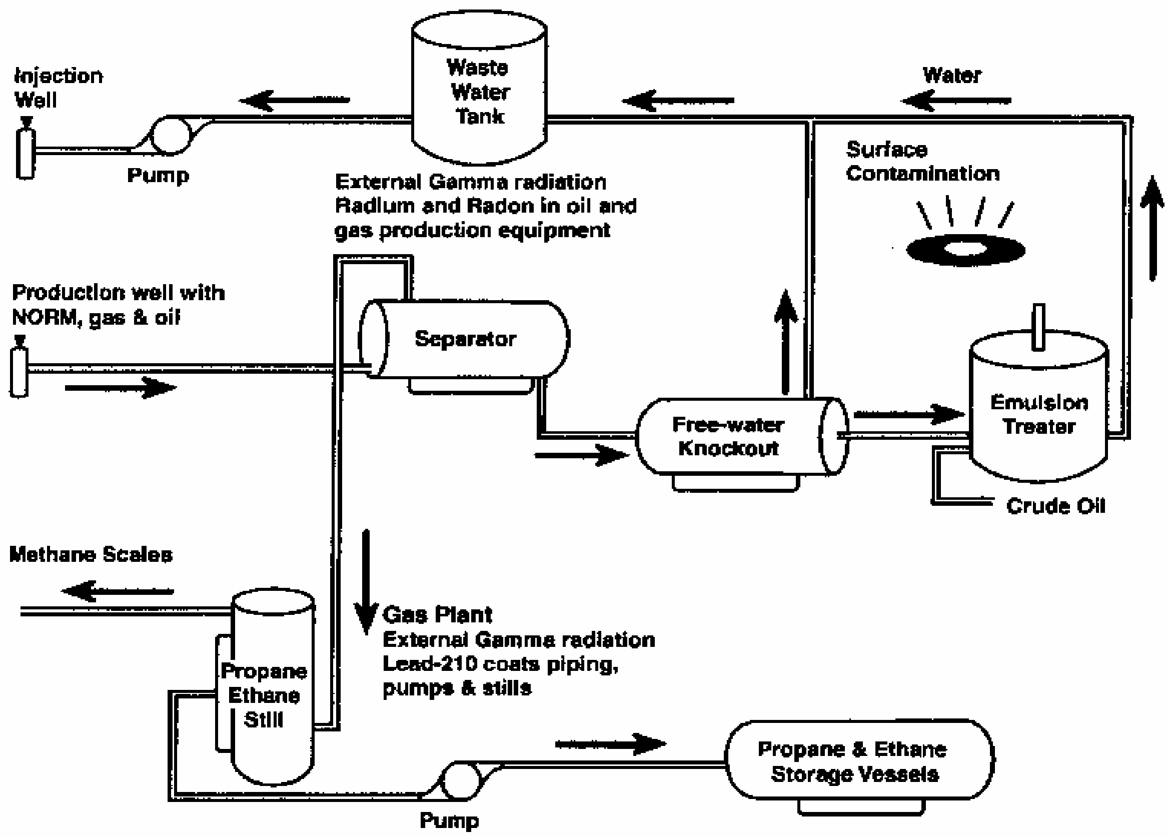
Upstream equipment which may contain NORM scales and sludges include:

- produced water tubulars,
- surface and downhole pumps,
- surface equipment exposed to produces waters,
- enhanced recovery process equipment,
- product holding tanks.

The most common NORM radionuclides include:

- Radium^{226}, as a scale or sludge,
- Radon and radon progeny build-up in storage tanks or within enclosed filtration systems.

Lead^{210} is of potential concern in equipment handling propane, ethane and LPGs. Lead^{210} concentrations may be much higher than Radium^{226}.



Potential Locations of NORM in the Oil and Gas Industry

Processing and Distribution

On the downstream side, natural gas processing plants extract and separate natural gas liquids (NGLs) through a series of distillations. In the NGL stream, radon gas is separated from radium by the distillation process. This results in a concentration of radon gas dissolved in propane, a common consumer product.

With large daily production volumes of propane, even small quantities of dissolved radon gas can lead to large concentrations of radon progeny within various gas plant facilities. In particular, in-line gas filtration systems, extraction and distillation process equipment, and propane handling facilities can concentrate radon gas and radon progeny. High-capacity gas straddle plants are particularly susceptible to this problem.

NORM radionuclides of particular concern include:

- Lead^{210} accumulations in gas processing equipment,
- Radon Progeny accumulations in propane processing equipment and filtration systems,
- Radon gas build-up in storage vessels is normally dissipated through ventilation procedures.

TYPES OF NORM EXPOSURE

External vs. Internal Exposures

Human exposure to NORM sources can occur both externally and internally. Exposure to any source of radiation leads to a radiation dose to tissues. Radiation dose is the quantity that is regulated by government as yearly dose limits. Effective NORM management practices are base on controlling NORM radiation exposures on a day-to-day basis.

External Exposures

External NORM exposures occur when radiation is emitted by a NORM source that exposes the individual from the outside. From these exposures, only gamma rays and beta particles are of concern.

Internal Exposures

Internal NORM exposures occur when radioactive material (i.e. the NORM source) is taken into the body by inhalation, ingestion or absorption through the skin. Once inside the body, the material will accumulate in certain body tissues depending on the chemical and physical properties of the NORM source. For example, $Radium^{226}$ (chemically similar to calcium) can accumulate in the bones. From these exposures, gamma rays, beta particles and alpha particles can deliver the greatest potential radiation dose to tissue.

Units of Radiation

Radioactivity (becquerel)

The fundamental SI unit used in Canada for radioactivity for NORM is the bequerel (Bq) which has units of one disintegration per second (1 DPS).

1 Bq = 1 dps

This quantity is a direct measurement of the number of radioactive decay events that will occur in the sample over a 1 second interval. The United States also measures radioactivity in units of curies (Ci). 1 curie = 37 billion bequerels.

$1\ Ci = 3.7 \times 10^{10}\ Bq$

<u>Dose Equivalent (sievert)</u>

Dose equivalent is a measure of the relative extent of tissue damage resulting from the absorption of radiation. The degree of tissue damage ultimately determines the extent of short or long-term biological effects that can develop after exposure to radiation. Dose equivalent is measured in SI units called Sieverts (Sv).

Some radiation survey instruments are calibrated to measure dose equivalent rate in units of millisievert per hour (mSv/H). In the United States, some instruments are calibrated in units of millirem per hour (mrem/h). The conversion between these two doses equivalent rate units is:

1 mSv = 100 mrem

All Canadian regulatory agencies set radiation dose limits based upon the dose equivalent (sievert) in multiples of millisieverts (mSv).

DOSE CONVERSION FACTORS	
Sieverts (Sv)	**Millirem (mrem)**
1 Sv = 1000 mSv 1 mSv = 1000 µSv 1µSv = 1000 ςSv	1 rem = 1000 mrem 1 mrem = 1000 µrem 1 µrem = 1000 ςrem
SI Units to Former Units	**Former Units to SI Units**
1 Sv = 100 rem 1 mSv = 0.1 rem = 100 mrem 1 mSv = 0.1 mrem =100 mrem 1 nSv = 0.1 mrem = 100 nrem	1 rem = 0.01 Sv = 10 mSv 1 mrem = 0.01 mSv = 10 mSv 1 mrem = 0.01 mSv = 10 nSv

RADIATION DOSE LIMITS

In Canada, all levels of government have agreed to a consistent set of radiation dose limits. Workers working with artificial radioactive sources (i.e. radiography) fall under federal jurisdiction and are regulated by the **Canadian Nuclear Safety Commission** (CNSC). Workers working with natural radioactive sources (i.e. NORM) fall under provincial and territorial jurisdictions.

RADIATION DOSE LIMITS

Affected Persons	Annual Limit	5-Year Limit
Occupationally-Exposed Workers (a)	20 mSv	100 mSv
Incidentally-Exposed Workers (b)	1 mSv	5 mSv
Members of the Public	1 mSv	5 mSv

(a) Workers who are regularly exposed to NORM sources as a result of their regular duties. They are classified as workers under provincial jurisdiction, in an occupational exposure environment with a regulatory dose of 20 mSv/a. A formal NORM safety program, including personal dosimetry, is recommended. For the balance of a known pregnancy, an occupationally-exposed worker’s dose is limited to 4 mSv.

(b) Workers whose regular duties do not include exposure to NORM. They are considered members of the public in an occupational exposure environment and have the same regulatory dose limit as members of the public – 1 mSv/a. Most affected workers in the petroleum industry fall within this category.

HEALTH RISKS FROM NORM EXPOSURE

Long term exposure to NORM can lead to increased risk of concern, just as similar exposure to asbestos, coal dust and cigarette smoke can cause lung cancer. **Following the protective measures and safe work practices provided in this course will reduce the risk of cancer to you, as well as the general public!**

A typical Occupationally-Exposed worker in the oil and gas industry is expected to receive an annual radiation dose less than 0.07 mSv per year. This is much less than the annual limit for members of the public. Similar exposure levels include the following:

1. one chest x-ray
2. one 6000 mile flight by jet, or
3. smoking 1.4 cigarettes per day.

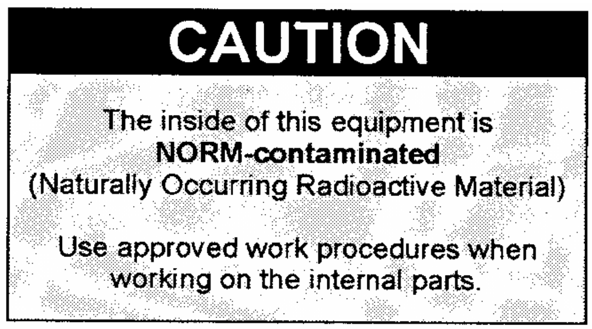
ESTIMATED NON-OCUPATIONAL LOSS OF LIFE EXPECTANCY	
Cause	**Estimated Loss**
Smoking 20 cigarettes per day	6 years
Overweight (by 15%)	2 Years
Alcohol consumption (US average)	1 Year
Accidents (following combined)	1 Year
▪ Accidents in the home	207 Years
▪ Accidents on the road	74 Years
▪ Accidents by drowning	24 Days
All natural hazards (i.e. earthquakes, tornados, etc.)	7 Days
Medical radiation	6 Days
Occupational exposure (1 mSv/yr)	**5 Days**

NORM RADIATION WARNING SIGNS

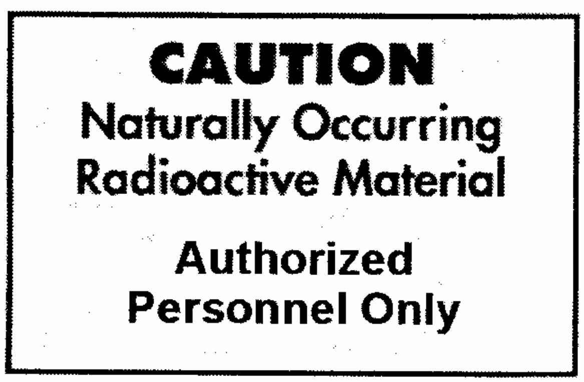
Radiation warning signs assist employers and workers in identifying and avoiding potential radiation exposures. Recognized industry NORM signage is described in the American Petroleum Institute (API) *Bulletin E2, Management of Naturally Occurring Radioactive Material (NORM) in Oil and Gas Production.*

Two types of NORM worksite signage may be encountered in the oil and gas industry:

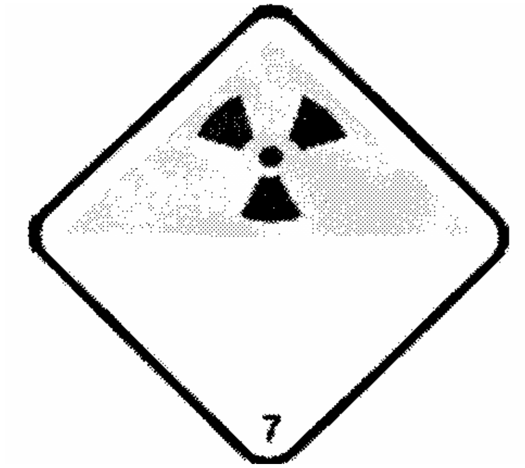
1. For contained or sealed NORM-contaminated material:



2. For areas where NORM is or may contaminate the work area, stay out of the area without appropriate authorization and safety precautions.



Transportation placard/trefoil symbol:



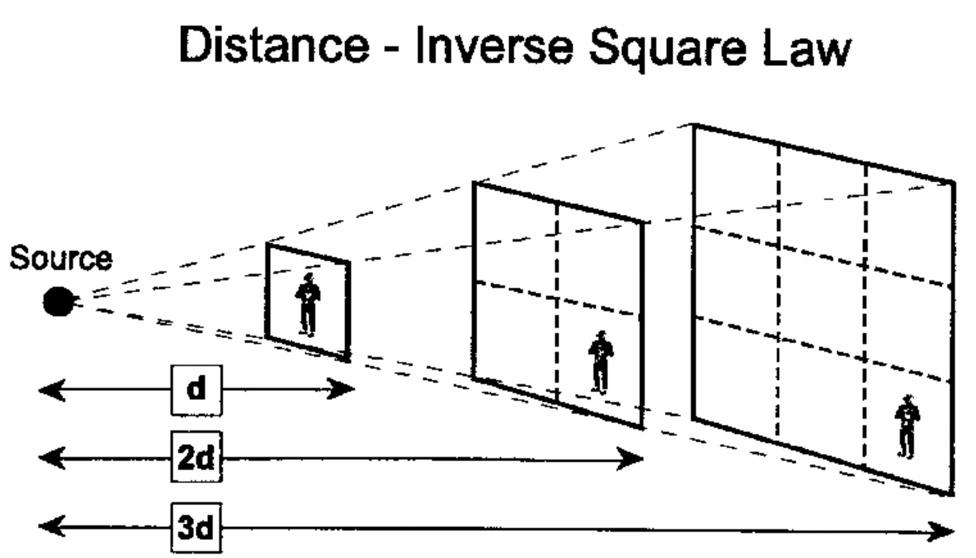
WORKER PROTECTION

PROTECTION FROM EXTERNAL EXPOSURE

Actions to reduce external radiation exposures are:
- Time,
- Distance,
- Shielding.

Time
The amount of exposure time within a radiation field is directly related to the resulting radiation dose received.

Distance
The exposure rate rapidly reduces with distance, utilizing the **inverse square law**. If the distance between you and the NORM source is doubled, the resulting dose is reduced to ¼ of the original expected dose. The distance is tripled, the resulting dose is reduced to 1/9 the original expected dose.



Shielding
The type and thickness of construction materials used in contaminated petroleum equipment (i.e. filter housings, steel tubulars, etc.) provides substantial shielding from radiation arising from NORM accumulations inside the equipment.

Exposure risk will increase when vessels are opened for maintenance and will decrease after contamination.

PROTECTION FROM INTERNAL EXPOSURE

The 3 possible internal exposure pathways for a worker in the petroleum industry are:

1. inhalation of NORM-contaminated dust or radon,
2. inhalation of NORM-contaminated particulates or liquids,
3. absorption of NORM-contaminated particulates or liquids through the skin.

Maintenance activities that present a substantial risk of internal radiation exposure include:

- improper safety procedures for entering pressure vessels due to the build-up of radon gas,
- sanding, grinding or polishing activities that produce airborne NORM particulates on equipment containing NORM scales,
- handling of filters that are heavily contaminated with radon progeny, without wearing protective gloves.

ENGINEERING CONTROLS

Engineering controls use equipment specifically designed to eliminate worker exposures by either containing the NORM source or preventing worker access to its radiation emissions. Engineering controls that will work in various circumstances are as follows:

- dust containment and suppression systems,
- ventilation systems,
- radiation shielding.

ADMINISTRATIVE CONTROLS

Administrative controls are designed to limit worker access to a NORM source (contained or not). Administrative controls will not be needed if the proper engineering controls eliminate all possible internal radiation exposures.

Typical administrative controls are as follows:

- NORM surveys,
- NORM safety policies and procedures,
- Warning signs and barricades,
- Training programs,
- Safe work practices and contamination control procedures,
- Worker exposure assessment/Personal dosimeters,
- Record-keeping.

NORM Surveys

NORM screening surveys are necessary to identify the potential of NORM exposures or to evaluate the effectiveness of existing or planned engineering controls.

NORM radiation surveys are usually conducted on a scheduled basis at a frequency based on results from previous screening surveys. A screening survey is also recommended if changes to the worksite are planned or anticipated which may impact on worker safety. Maintenance of NORM radiation survey records confirms the level of safety at the worksite.

NORM contamination surveys monitor the worksite for possible contamination of the air, work surfaces or immediate ground area. They are particularly important in jobs that involve cleaning, grinding, sand blasting or milling of equipment surfaces potentially contaminated with NORM scale.

Development of NORM Safety Policies and Procedures

A NORM safety program is needed when a NORM radiation survey indicates the presence of NORM accumulations in sufficient quantities to harm workers.

Use of NORM Warning Signs and Barricades

Signs and barricades restrict access of unauthorized workers or members of the public to certain process areas.

Training Programs

Companies must develop NORM policies and procedures reflecting NORM related activities. All workers who will be engaged in activities involving exposure to NORM must receive training which will include the hazards associated with NORM and the specific engineering, administrative and personal protective equipment controls each worker must follow to safely perform his or her job.

Safe Work Practices and Contamination Control Procedures

Safe Work Practices

Effective NORM safe work practices which will minimize possible internal exposures include:

- Containing potentially dispersible NORM,
- Minimizing production of airborne NORM particulates with dust minimization and suppression procedures,
- Good housekeeping practices.

Personal Hygiene

- Avoid eating, drinking or smoking in restricted access areas with potential for airborne NORM-contaminated dust and particulates, to reduce the chance of NORM ingestion.
- Cover all cuts or wounds to avoid possible absorption of NORM particulates into open skin wounds.
- Upon exiting the NORM-contaminated area, remove protective clothing, properly store or dispose of it, and wash or shower accordingly.
- Conduct personal contamination monitoring.

Worker Exposure Assessments/Personal Dosimeters

Worker exposure assessments involve radiation monitoring of the working environment and assigning a radiation exposure to all affected workers based on each worker's time spent in the area. This type of exposure assessment is common and an acceptable practice where expected annual radiation dose to workers is between 1 and 5 mSv/year.

Where a worker's annual radiation dose is expected to exceed 5 mSv/year, the worker must be assigned a personal radiation dosimeter to measure his/her individual radiation dose. An annual radiation dose greater than 5 mSv for petroleum workers is highly unlikely.

Record-Keeping

Maintain records of all NORM surveys, contamination, decontamination and disposal activities.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

Purpose of Personal Protective Equipment

Personal protective equipment (PPE) represents the last line of defence against internal exposure to NORM. PPE must be used by workers if NORM radiation surveys indicate the presence of NORM. NORM contamination surveys provide information for the possible routes of internal radiation exposure. Internal exposure routes and preventive measures are:

- **Inhalation** of airborne NORM, protected against by using appropriate respiratory protection.
- **Absorption** of NORM, prevented by wearing protective clothing, including gloves, coveralls, show covers, etc.
- **Ingestion** of NORM, prevented through the use of good personal hygiene practices, such as not eating, smoking, or drinking in designated areas.

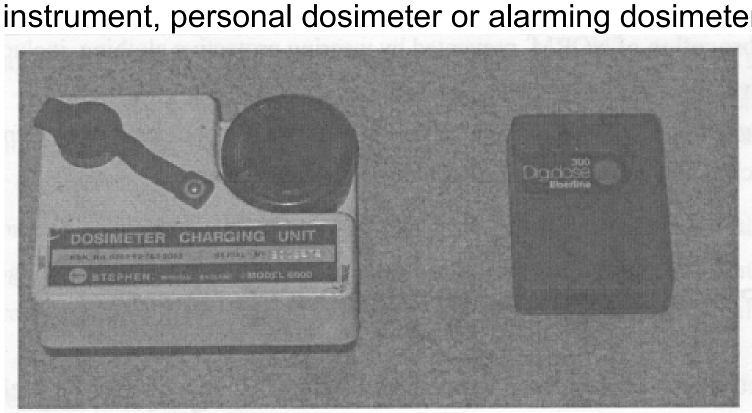
Proper Use of Personal Protective Equipment

Selection

PPE must be widely available and will provide appropriate internal radiation exposure protection for the type of job(s) to be undertaken. PPE requirements are highly dependent upon the task to be performed and on the environment in which the task is to be done.

NORM Exposure Tasks involving selection of PPE are as follows:

- **Respiratory protection**, including air purifying respirators (half face, with goggles, or full face) or full face, self-contained breathing apparatus (SCBA).
- **Protective clothing**, including coveralls (i.e. disposable impervious coveralls or rain gear), gloves (i.e. latex or surgical) and footwear (i.e. CSA-approved safety boots, shoe covers, gum boots, etc.).
- **Radiation monitoring equipment**, including a radiation survey instrument, personal dosimeter or alarming dosimeter.



Pre-Use Inspections for PPE

- Visual inspection of the integrity of the equipment,
- Pre-use review of maintenance records for previously-used PPE, including confirmation of no contamination, general maintenance schedules and operational checks of proper PPE function, as required.

Correct Use

NORM workers must receive appropriate training in the correct use of PPE, prior to its issuance.

Respiratory Protection (follow your company respiratory protection procedures)

- Pre-fit (i.e. fit testing) and adjust (i.e. fit checking) respirators to ensure a good seal.
- Attach filters firmly and never remove them while in the designated work area. Replace filter outside the work area only.

Protective Clothing

- Replace damaged protective clothing as soon as possible.
- Advise your supervisor if the protective clothing creates problems in providing the protection required or if it interferes with completing the intended job (i.e. if the disposable coveralls tear too easily or are too uncomfortably hot).
- Outer workwear may need to be flame-resistant, depending on the nature of the job and/or site-specific policies and procedures.

Radiation Monitoring Equipment

- Only qualified (trained) personnel should operate radiation monitoring equipment.
- Ensure that a radiation survey instrument, assigned to monitor personal worker exposures, remains in the assigned work area. **A survey instrument read-out 20 metres away from any worker provides no useful information to workers of the actual level of radiation exposure.**
- If the instrument readout exceeds the assigned “action level”, stop work and report the occurrence to your supervisor.

Post-Use Inspections –Prior to Restocking for Future Use

<u>*Equipment Function*</u>

- Conduct a visual check of equipment integrity.
- Conduct function tests of correct PPE operation, as applicable.
- Record results of function tests.

Equipment Contamination

- Survey all PPE used in areas of known radioactive contamination immediately after completion of assigned work.
- Ensure disposable PPE, if contaminated, is properly packaged for later disposal.
- Ensure reusable PPE, if contaminated, is promptly decontaminated or safely packaged and stored for subsequent decontamination.
- Survey respirator filters with a sensitive radiation instrument for build-up of radioactivity. Contaminated filters must be either properly disposed or sealed and stored for radioactive decay. This may include placing in a barrel, sealing and labelling the barrel, and keeping it separate from other NORM-contaminated waste.
- **Maintain records of all contamination, decontamination and disposal activities**.

NORM DETECTION

INTRODUCTION

This part of the NORM training deals with contamination, surveys and the selection/use of NORM screening survey instruments.

TYPES OF NORM CONTAMINATION

NORM contamination is classified in one of two general types (diffuse or discrete), according to its physical properties and radioactive concentration. **An internal radiation exposure hazard poses a far greater concern than an external one.**

Diffuse NORM Sources

Diffuse NORM sources are **easily dispersed, difficult to separate, large in volume** and **relatively uniform** in radioactive concentration. These NORM sources tend to pose a greater internal exposure hazard due to their tendency to contaminate the workplace environment.

- Radon gas build-up in storage tanks,
- Suspended airborne NORM particulates,
- Radon gas dissolved in propane,
- Removable NORM surface contamination found throughout storage facilities,
- NORM-contaminated soil,
- Radium^{226} and Radon Progeny contaminated sludge inside storage tanks.

Discrete NORM Sources

Discrete NORM sources are **relatively well-contained, smaller in volume** and **relatively non-uniform** in radioactive concentration. Discrete NORM sources tend to pose a greater external hazard.

- Radium ^{226} scale deposits fixed to interior pipe surfaces,
- Radium ^{226} NORM scale accumulations on high capacity filters,
- NORM scale deposits on interior surfaces of process equipment,
- Radon progeny and/or Lead ^{210} NORM deposits inside propane delivery tanks.

A discrete NORM source can be transformed into a diffuse source by work activities. Descaling of NORM-contaminated wellhead piping without proper engineering controls can create a highly dispersed airborne inhalation hazard from what was once a well contained and controlled discrete NORM source.

FREQUENCY OF NORM SURVEYS

NORM Screening Surveys

NORM screening surveys require the use of highly sensitive instrumentation to detect the presence of any kind of NORM accumulation. NORM screening survey results are used to locate possible NORM hazards and are then compared to background count rates taken, using the same count rate units. The comparative results will indicate if further action is required by the tester and his/her colleagues.

NORM Radiation Surveys

NORM radiation surveys can be used to estimate the amount of radiation exposure resulting from the NORM accumulation. NORM Radiation Surveys are conducted in locations where NORM Screening Survey results exceed a specified "Action Level". NORM Radiation Survey results are used for worker radiation protection planning purposes and for evaluating compliance with regulatory limits.

A rule of thumb for the frequency of NORM screening surveys is: "**The greater the rate of NORM accumulation, the greater the need to conduct NORM surveys.**" Except for the type of instrument used, the methods used to conduct either survey are nearly identical.

NORM Contamination Surveys

NORM contamination surveys monitor the worksite for possible contamination of the air, work surfaces or immediate ground area. They are particularly important in jobs involving cleaning, grinding, sand blasting or milling of equipment surfaces potentially contaminated with NORM scale.

- **Air Contamination Monitoring**

If the initial NORM screening survey and follow-up NORM radiation survey indicate a possible airborne inhalation risk, periodic or continuous air monitoring is required. Radon gas or suspended NORM particulates are potential inhalation risks.

- **Surface Contamination Surveys**

Surface contamination surveys are required for evaluating the possible build-up of NORM particulates on workplace surfaces. Two types of NORM surface contamination are:

1 **Fixed NORM surface contamination** is material that cannot be readily removed from the contaminated surface. This type of contamination can only pose an external radiation exposure hazard.
2 **Removable surface contamination** presents both an external and internal exposure risk. The NORM contaminant can be easily picked up and transferred to other surfaces, be absorbed or ingested, or become re-suspended in the air for subsequent inhalation.

Personal Contamination
Prior to leaving a work area where access is restricted due to possible NORM contamination, all contaminated clothing must be removed and properly stored or disposed. Workers must be checked for NORM contamination with a radiation monitoring instrument (i.e. frisking).

If significant quantities of NORM surface contamination is detected, the surfaces need to be decontaminated, with adherence to proper decontamination procedures and use of personal protective equipment.

TYPES OF NORM SURVEYS

TYPE	DESCRIPTION
Screening Survey	➢ Used to identify NORM exposure potential or evaluate engineering control effectiveness ➢ Should be conducted where NORM-contamination is suspected, but not known to exist
Radiation Survey	➢ Used to assess radiation dose rates ➢ Conducted on a schedule, based on results from previous screening surveys ➢ Recommended where planned or anticipated worksite changes may impact worker safety
Contamination Survey	➢ Used to monitor worksites for possible contamination ➢ Used if cleaning, grinding, sandblasting or milling of NORM-contaminated equipment surfaces occurs ➢ 3 types of contamination surveys: 1) air contamination (i.e. radon gas or suspended NORM particulates) 2) surface contamination (i.e. fixed or removable build-up of NORM particulates on work place surfaces) 3) personal contamination (i.e. frisking workers after decontamination)

SELECTION OF NORM INSTRUMENTS

NORM Screening Surveys

NORM screening surveys involve detecting radiation emissions on the outside of equipment from NORM accumulations found inside the equipment. As a result, the best screening survey instruments are designed to detect very small numbers of gamma emissions that are strong enough to penetrate through steel. Once "exposed" to the outside, these NORM accumulations are much more easily detected permitting the use of different types of radiation detection instruments.

Operations with NORM exposed working surfaces include the descaling of pipes or removal of pump or filter housings for maintenance.

Critical NORM Sources

Three important NORM source emissions are usually sought using these NORM screening survey instruments. They are:

1) NORM containing $Radium^{226}$ in exploration and production activities.
2) NORM containing $Lead^{210}$ found in processing and distribution activities.
3) Radon Progeny arising from exposed NORM-contaminated surfaces.

Radium^{226}

$Radium^{226}$, with a **half-life of 1600 years,** is the **most common NORM contaminant** in the petroleum industry. $Radium^{226}$ and its radioactive progeny emit large quantities of alpha particles and gamma rays that are readily detected.

Lead^{210}

$Lead^{210}$ is a **longer-lived radioactive progeny of radium**. It is considered separately from the other short-lived progeny since it can accumulate over long periods of time. Usually, $Lead^{210}$ sources are only detected in processing and distribution equipment further downstream from radium sources. These sources are often difficult to detect through metal container walls, due to its beta and low-energy gamma emissions. With a half-life of 22.3 years, $Lead^{210}$ takes longer to accumulate insufficient quantities to be reliably detected.

Radon Gas Progeny

Radon gas progeny are **very short-lived radioactive decay products of radon gas** that emit large quantities of high-energy gamma rays, beta particles and alpha particles. Radon progeny are typically found in gas processing equipment handling large quantities of product containing low concentrations of dissolved radon gas. These progeny are solid particulates accumulated in filter media or coat the interior walls of process equipment.

Types of Detectors

There are two types of NORM Screening Survey instruments, named after the type of radiation detector used:

1. Scintillation detectors
2. Pancake Detector

None of those instruments are intrinsically safe.

Scintillation Detectors

Scintillation detectors are the **most sensitive** of all radiation detectors and can detect extremely small quantities of gamma emissions. They are used for screening surveys to provide an "early warning system" for monitoring increased NORM accumulations. This detector is the **preferred instrument** for NORM screening surveys. It is also the only detector that can reliably detect the relatively low energy gamma emissions form $Lead^{210}$.

Pancake Detector

With this configuration, the detector can be placed very close to irregular surfaces of equipment or for scanning large flat surface areas. In these applications, the detector is used to locate surface contamination resulting from the deposition of NORM particulates. It is also used for personal contamination monitoring (i.e. frisking).

Measure detection units are typically counts per minute (CPM).

TYPES OF NORM DETECTORS

TYPE	ADVANTAGES	DISADVANTAGES
Scintillation Detector	➢ most sensitive of all radiation detectors ➢ only detector that reliably detects low-energy Pb^{210} gamma emissions ➢ used for screening surveys to detect presence of NORM	➢ easily damaged by strong impacts ➢ crystal can crack with rapid temperature changes ➢ cannot accurately measure radiation exposure
Pancake Detector	➢ can detect beta and some alpha contamination ➢ large detector surface is good for surface contamination monitoring and personal frisking ➢ good for scanning large flat surfaces and irregular surfaces	➢ cannot be used for measuring dose rates

CAUTION !

- Always follow the manufacturer's instructions for the make and model of detection you are using.
- All radiation monitoring instruments must be calibrated prior to use at least annually by a Canadian Nuclear Safety Commission approved calibration service.

Check Sources

An integral part, of ensuring a radiation detector provides reliable readings, is to ensure it is properly calibrated. A **calibration check** (or *function check*) requires exposure to a radiation source of know strength, or **check source** (*commonly Cesium*^{137}). It is important that the detector response accurately indicates the strength of the check source, not just a positive response. Calibration checks should be recorded in a logbook, dedicated to the specific instrument. Remember, this is not a calibration of the instrument; it is only a check of its proper function. Calibrations should be done only by qualified instrument technicians.

Check sources are generally available from approved radiation detector manufacturers and suppliers.

USE OF NORM DETECTORS

Several steps are required to complete a valid NORM screening survey.

NORM SCREENING SURVEY FORM			
Date:	Site Location:		
Survey Type:			
Survey Instrument Make / Model:			S/N:
Probe Make / Model			S/N:
Last Calibrated Date:			
Natural Background Reading for Area (specify units):			
Survey		Readings	
Location/ Description	CPM (optional)	______@ contact	______ @ 0.5 m (optional)
Comments:			
Area Sketch:			

NORM SCREENING SURVEY PROCEDURE

	STEPS	DESCRIPTION
1	**Perform Pre-Use Checks**	➢ Check equipment calibration records to ensure detector's calibration maintenance records are current. ➢ Check battery level to ensure that detector is connected to the instrument when performing this check. ➢ Check instrument response to verify detector's response to radiation. ***Note:*** *check sources must be licensed.*
2	**Use Survey Form**	➢ Form completion ensures complete gathering of information and provides comparison to previous survey results.
3	**Obtain Background Reading**	➢ Take reading in known NORM-free area, near screening area. ➢ Turn instrument on and select scale multiplier to centre readout on meter display. ➢ Ensure instrument is on for at least 10 seconds prior to reading background level. ➢ Use correct scale on meter display. ➢ Record average reading displayed on meter (*low background levels can vary significantly).*
4	**Record Action Level**	➢ Action level is lowest reading above background level which requires further action. ➢ Lower readings are redeemed 'non-radioactive' or NORM-free. ➢ Higher readings indicate NORM accumulation requiring further investigation. ➢ Twice background rule commonly used as action level. ➢ Action levels are based on total worker exposure less than 1 mSv/year regulated limit.
5	**Conduct Survey**	➢ Conduct survey systematically, recording all locations and readings. ➢ Do not allow detector to directly contact known contaminated surfaces. ***Tip:*** *cover detector with plastic wrap to protect it from contamination.* ➢ Wear thin gloves when conducting survey to prevent inadvertent ingestion or absorption. ➢ Listen for audible output from detector speaker (*radiation level changes can be heard better than seen*). ➢ Do not touch NORM accumulations to avoid internal exposure hazard, ingestion or spreading contamination.

NORM SAMPLE ANALYSIS

There are many situations where samples of NORM require radio-chemical analysis. In most cases, these situations involve decision-making on waste management options or for transport of NORM-contaminated equipment or NORM waste.

Radio-chemical analysis may include:

- Potential NORM contaminated samples of scale or sludge deposits,
- Soil or water,
- Small pieces of NORM-contaminated equipment, such as filter media.

Collection of NORM Analysis

The following guidelines are recommended for collecting NORM samples:

- Perform a radiation measurement in the immediate area of the NORM contamination to confirm previous survey results (i.e. not generally required for environmental sampling).
- Avoid contaminating the sample with extraneous material or contaminating yourself with the sample. Use the appropriate personal protection equipment, including gloves, and use the designated tools to collect the samples.
- Use designated collection containers. For transportation, the collection container is usually constructed of disposable inert plastic that is airtight when sealed.

Transportation of NORM Samples (Off-Site)

CAUTION !

- For off-site transfer of NORM samples for radio-chemical analysis, seek qualified advice.

The transport of NORM is subject to federal transportation regulations if the material has a radioactive concentration greater than 70 Bq/g (70 kBq/kg) and the material is to be shipped off-site. This requires that all NORM consignments be analyzed for radioactive content to determine its transport regulation status.

Federal transportation requirements must meet two sets of regulations:

1. ***Transportation of Dangerous Goods Regulations*** *(TDG)*, administered by the provinces, territories and the federal government.

2. ***Packaging and Transport of Nuclear Substance Regulation***, administered by the Canadian Nuclear Safety Commission (CNSC). This regulation adopts many sections of the International Atomic Energy Agency's Safety Series 6 document, *Regulations for the Safe Transport of Radioactive Materials*. Compliance with the Safety Series 6 document automatically meets federal transportation of radioactivity regulation requirements. Other TDG requirements must still be met to comply with all transportation regulations.

The above regulations should be referenced when preparing a NORM consignment.

SAFE WORK PRACTICES

INTRODUCTION

NORM minimization practices are the ultimate control to limit radiation exposures to all exposure groups. These practices are designed to prevent NORM accumulations from occurring. An effective NORM minimization practice begins with a review of the complete petroleum production process to identify opportunities for reducing NORM accumulations.

A feasible NORM minimization practice is then determined through application of the ALARA principle (as low as reasonably achievable). The costs associated with implementing feasible minimization practices must be balanced against the benefits of the avoided radiation dose to workers and the public, plus the savings associated with the reduced costs for radiation protection practices.

CONTROL OF EXTERNAL RADIATION EXPOSURE

Radium^{226} (Ra ^{226}), Lead^{210} (Pb^{210}), Radium^{228}, (Ra^{228}) and Radon progeny pose a potential external radiation exposure risk to workers.

Ra^{226} and Ra^{228}

The control of external radiation exposure from existing NORM accumulations is limited to all worker who are exposed to gamma emissions from equipment containing NORM deposits of Ra^{226}, Ra^{228} and/or the short-lived Radon gas progeny. These two types of NORM deposits each contain sufficient numbers of highly energetic gamma emissions to enable the rapid survey of equipment while it is on-line. The preferred detector for external surface surveys is the **Sodium Iodide scintillation detector**, which is highly sensitive to the gamma emissions from Ra^{226} and the short-live radon gas progeny.

Pb^{210}

The gamma emissions from Pb^{210} are usually too low to successfully penetrate most gas process equipment walls. However, the beta radiation can present an external exposure to persons entering a vessel. Therefore, Pb^{210} NORM deposits on internal equipment surfaces, can only be reliably detected after the equipment is taken off-line and the internal surfaces exposed. The preferred detector for Pb^{210} surveys is a beta/gamma gas-filled detector that is scanned over the exposed internal working surfaces that contain the NORM deposits.

Effective controls to limit external radiation (i.e. gamma) exposures include:

- Conducting a **screening survey** of suspect equipment using a gamma scintillation detector to confirm the presence or absence of NORM accumulations (readout in units of cpm or cps).

- Conducting a **radiation survey** of equipment with elevated counts to determine the gamma dose rate (µSv/h) on contact and at 50 centimetres distance from the equipment (*usually done at the same time as the screening survey).*
- Immediately informing the supervisor if radiation levels greater than 0.50 µSv/h at 50 cm distance, have measured on previously unidentified equipment.
- Where measurements are to be made on gas handling equipment, the equipment must be running at the time of the measurement in order to detect the radon gas progeny.
- Prior to operating suspected NORM-contaminated gas handling equipment, the equipment must have been shut down for at least two hours to permit the short-lived radon progeny to decay away.
- Determining the "**maximum daily recommended time**", or calculated value based upon a number of work factors including:
  - Measured radiation exposure rate at a typical working distance from the equipment (µSv/h).
  - Company 'Action Level' for annual worker radiation dose from a known NORM source (µSv/h).
  - Expected number of work hours per year at that work location under the assumed exposure conditions (h/yr).
- Labelling of production equipment having radiation levels in excess of 0.5µSv/h at 50 cm distance from the exterior surface. The labels should contain the following information:
  - The words, "Naturally Occurring Radioactive Materials"
  - Radiation level measurement above background (µSv/h)
  - Date when radiation survey completed
  - Date of next scheduled radiation survey
  - Maximum daily recommended time (i.e. hours) spent near equipment, as applicable.

CONTROL OF INTERNAL EXPOSURES

The control of internal radiation exposure requires limiting the amount of **radioactive material** that can be taken into the body via inhalation, ingestion or absorption.

NORM presents a potential internal radiation exposure hazard from:

- Creation of airborne NORM particulates through equipment descaling activities
- Handling of accessible surface-contaminated equipment without proper PPE
- Build-up of radon gas inside vessels.

Two general approaches are used to limit internal radiation exposures:
1. Engineering Controls, which contain the source
2. Administrative Controls, to protect the worker.

Engineering Controls

Examples of engineering controls used to contain NORM contamination include:
- Dust suppression and containment systems and controls,
- Packaging of exposed surface-contaminated equipment prior to handling or transport,
- Ventilation systems to divert and/or filter airborne particulates and radon gas.

Engineering controls result in the prevention or reduction of internal worker exposure by avoiding the development of the worker exposure risk. The feasibility of an engineering control is dependent on the costs of its introduction and negative impact on productivity, vs. the benefits of avoided worker radiation dose plus the associated reduction in required radiation protection program costs (i.e. the reduced costs associated with the use and maintenance of PPE).

Administrative Controls

While engineering controls are generally consistent between work sites, administrative controls may vary considerably. Five categories of administrative controls will be discussed:
1. NORM surveys,
2. NORM safety policies and procedures,
3. warning signs and barricades,
4. training programs,
5. safe work practices and contamination control procedures,
6. record-keeping.

NORM Surveys and Record-Keeping

NORM radiation surveys are necessary if there is a potential for NORM accumulations. A radiation survey is required:
- on a scheduled basis at a frequency that depends on results from previous surveys,
- if changes to the worksite are either planned or anticipated to occur which may impact on worker safety.

The maintenance of current and accurate NORM radiation surveys records confirms the level of safety at the worksite.

NORM Safety Policies and Procedures

The development of NORM safety policies and procedures is only required when a NORM radiation survey indicates the presence of NORM accumulation in sufficient quantities to warrant development of the program. **In general, measured NORM accumulations that exceed recommended Canadian NORM Guideline Derived Release Limits (DRLs) for solids, liquids and gases, warrant further consideration of safety policies and procedures.** DRLs taken from the Canadian NORM Guidelines include:

- **solids** including scales, contaminated soils, filters, etc. (Ra^{226}/Pb^{210} = 300 Bq/kg),
- **liquids** including sludges, process waters, etc. (Ra^{226} = 5 Bq/L, Pb^{210} = 1 Bq/L),
- **gases and suspended particulates** (Radon gas = 150 Bq/m^3, Ra^{226}/Pb^{210} = 0.05 Bq/m^3).

Warning Signs and Barricades (Unauthorized Workers)

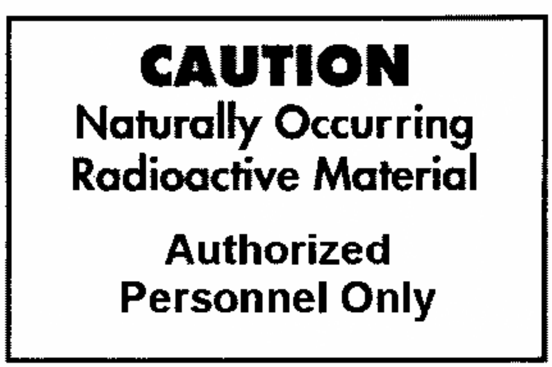
Not all workers may need to be fully trained in the management of NORM. Signs and barricades restrict access of unauthorized workers of members of the public to certain areas in order to avoid meeting the specified cumulative worker exposure time within the restricted area.

Maximum acceptable daily or weekly worker exposure times should be designed to meet worker action levels that are below the regulatory annual dose limits. A figure of 0.3 mSv/yr is often used as the reference action level.

Warning sign specifications for the establishment of a restricted access area include:

- that it be **prominently displayed**,

- the optional use of the **radiation warning symbol** (black “trefoil” on white background).



Training Programs

Authorized workers must receive training on the hazards associated with NORM and the specific administrative controls they must follow in order to safely complete their job.

Safe Work Practices and Contamination Control Procedures

There are several inter-related elements that are essential for the successful implementation of safe work practices and contamination controls.

- **Safe Work Practices**
  Effective safe work practices will minimize possible internal exposures by:
  - Containing dispersible NORM sources,
  - Separating workers from diffuse NORM sources,
  - Minimizing the production of airborne NORM particulates through dust minimization and suppression procedures.

- **Contamination Control Procedures**
  Contamination control procedures are required if Engineering Controls and Safe Work Practices fail to completely avoid the creation of dispersible NORM contaminants.

- **Personal Hygiene Requirements**
  Personal hygiene requirements in designated 'NORM-Contaminated" locations include:
  - No eating, smoking or drinking in designated locations.
  - All open cuts must be covered.
  - Upon exiting the NORM-contaminated location, remove protective clothing and properly stored or dispose.
  - Wash or shower accordingly.

- **Worker Radiation Exposure Assessment/Personal Radiation Dosimeters**
  - *Expected Annual Dose between 1.0 and 5.0 mSv per year.*
    Worker Radiation Exposure Assessments involve radiation monitoring of the working environment and assigning a radiation exposure to all workers in that environment based upon each worker's time spent in the area. This type of radiation exposure is most common and is an acceptable practice.

  - *Expected Annual Dose greater than 5.0 mSv per year*.
    The worker must be assigned a personal radiation dosimeter to record his or her individual radiation dose.

NORM Contamination Surveys

Two types of NORM contamination surveys shall be conducted contingent upon the nature of the NORM contaminants:

1. ***Air Contamination Monitoring***

   If the initial NORM Screening Survey and follow-up NORM Radiation Survey indicate a possible airborne inhalation risk, periodic or continuous air monitoring is required. Specialized assistance is required to conduct air monitoring activities. Workers may be required to wear respiratory protective equipment. Radon gas or suspended NORM particulates are the potential inhalation risks. If average air contamination levels in a work location exceed the applicable Canadian NORM Guideline Derived Release Limit (DRL), precautions must be taken to limit worker and public exposure to this inhalation risk. The three most important airborne DRLs are:

   1) Radon Gas (150 Bq/m^3)
   2) $Radium^{226}$ (0.05 Bq/m^3)
   3) $Lead^{210}$ (0.05 Bq/m^3)

2. ***Surface Contamination Surveys***

   Surface contamination surveys are required to evaluate the possible build-up of fixed and removable NORM surface contaminants.

   - ***Fixed Surface Contamination***

     Fixed NORM surface contamination on equipment can only pose an external radiation exposure hazard. Special handling of equipment with fixed contamination is warranted if:
     - A radiation dose rate measurement at 50 cm distance from the surface is greater than 0.5 µSv/h, or
     - An estimate of the fixed surface contamination level is greater than 1 Bq/cm^2.

     Grinding or sanding operations may convert **fixed** surface contamination to **removable** surface contamination, creating an internal exposure hazard.

   - ***Removable Surface Contamination*** (breathable)

     Removable surface contamination presents both an external and internal exposure risk:
     - For resale or commercial recycling of used equipment, there must be **no removable surface contamination,**
     - For reuse or in-house recycling, acceptable levels of removable contamination are dependent on the affected NORM workers and/or Incidentally Exposed workers.

If significant quantities of NORM surface contamination is detected:

- Decontaminate surfaces following proper decontamination procedures,
- Use appropriate personal protective equipment (PPE).

WASTE MANAGEMENT

NORM WASTE CATEGORIES

The effective management of NORM waste requires the proper segregation of the wastes into appropriate categories based upon a number of properties of the NORM waste. Four categorization criteria that are used to segregate NORM waste are:

1. physical form of the waste,
2. volume of NORM waste,
3. radioactive content within the NORM waste,
4. co-contaminants (i.e. *physical, chemical, toxicological*, etc.).

Each of these categorization criteria, in turn, affects the specific procedures that are required to manage the waste and the associated costs of its handling, storage and ultimate disposal. Therefore, the proper categorization of NORM waste will minimize handling, storage and disposal costs by ensuring that only the more radioactive and potentially hazardous NORM wastes accrue the majority of the costs.

Physical Forms

There are two physical forms of NORM waste:

1. ***solids***, such as:
   - fixed scale deposits (inside process equipment and filters),
   - liberated scales (generated after decontamination),
   - tank bottom residues,
   - contaminated soils,
   - contaminated filter media,
   - contaminated PPE and clothing.

2. ***liquids**,* such as:
   - sludges in storage tanks,
   - production waste waters.

Although not considered a waste, radon gas and other airborne particulates pose a hazard in terms of their migration into other areas.

Volume of NORM Waste (Diffuse vs. Discrete)

The volume of NORM waste establishes its capacity to contaminate the environment and the potential risk of internal exposure to workers. Two types of NORM have been defined that are based on the degree to which the material is contained (or the ease with which the material can be dispersed into the local environment).

- **Diffuse NORM Waste**
  Diffuse NORM Waste (Bulk Waste) is typically large in volume, more difficult to separate and more uniformly dispersed. Handling and disposal of diffuse NORM wastes poses an environmental concern to the public and to workers at the worksite due to the relative ease with which the material can contaminate the air, water and soil. Such contamination increases the risk of internal radiation exposure to workers and the public.

  Examples of diffuse NORM wastes include:
  - Contaminated Ra^{226} and Pb^{210} soils,
  - Ra^{226} sludge accumulations in storage tanks,
  - Ra^{226} production (brine) waste waters,
  - Radon gas accumulations in enclosed vessels.

- **Discrete NORM Waste**
  Discrete NORM waste is usually found in the form of contamination fixed to internal surfaces of process equipment. This waste is generally much smaller in volume and with relatively non-uniform concentrations of radioactivity and not uniformly dispersed. The handling and disposal of discrete NORM sources poses a much reduced environmental concern vs. diffuse sources and is limited to the risk to workers form external radiation exposure.

  Examples of discrete NORM wastes include:
  - Fixed Ra^{226} scale deposits inside process equipment such as steel tubulars and pump filters/housings,
  - Radon gas progeny and/or Pb^{210} accumulations inside propane pumps, filters and tank trucks,
  - Fixed surface (film) deposits of Pb^{210} inside propane storage vessels.

Quantity of Radioactivity (radioactivity levels)

The final NORM waste categorization criteria is the quantity of radioactivity contained within the waste material. The Canadian NORM Guidelines contain **Unconditional Derived Release** (UDRLs), for NORM wastes based on the two categorization criteria previously discussed and on the following radioactive quantities:

- The concentration of radioactivity within diffuse NORM sources,
- The total radioactivity within discrete NORM sources,
- The radioactive contamination level on accessible surfaces of discrete NORM sources.

NORM wastes whose radioactive content is less than the applicable URDL can be treated as non-radioactive. Chemical, physical and toxicological properties must still be considered.

DISCRETE AND DIFFUSE NORM SOURCE DRLs				
Major NORM Nuclide	Diffuse DRLs	Diffuse DRLs		
	Item/Equipment	Aqueous (Bq)	Solid (Bq/L)	Air (Bq/m^3)
Uranium^{238} Series	1,000	1	300	0.003
Uranium^{238}	10,000	10	10,000	0.05
Thorium^{230}	10,000	5	10,000	0.01
Radium^{226}	10,000	5	300	0.05
Lead^{210}	10,000	1	300	0.05
Thorium^{232} Series	1,000	1	300	0.002
Thorium^{232}	1,000	1	10,000	0.006
Radium^{228}	100,000	5	300	0.005
Thorium^{228}	10,000	1	300	0.003

DISCRETE NORM SOURCES	
Fixed Surface Contamination Property	DRL Limit
Dose Rate	0.5 µSv/h (50 cm distance)
Surface Contamination Level	1 Bq/cm^2 (100 cm^2 area)

NORM wastes containing radioactivity levels above the applicable Unconditional DRL, can be either decontaminated or disposed as radioactive waste.

For NORM wastes, containing **less than 70 Bq/g** (70,000Bq/kg) radioactive concentration, the material is classified as non-radioactive *for transport purposes only* and can be shipped off-site without special consideration of its radioactive properties.

NORM wastes, containing **greater than 70 Bq/g** (70,000Bq/kg), fall under federal transport regulations and must be treated as *radioactive material* for off-site transport.

Co-Contaminants

NORM-contaminated waste may have other non-radioactive properties needing to be considered. These include:

- physical,
- chemical or
- toxicological properties,

which may require additional work practices, precaution or environment considerations.

NORM WASTE MANAGEMENT PROGRAM

To control public and environmental exposures from NORM, requires the successful management of the NORM waste. NORM waste management encompasses all aspects of handling NORM waste materials from beginning to end. A NORM Waste Management program involves three major handling stages:

- Stage 1: Temporary NORM Storage,
- Stage 2: Interim NORM Storage,
- Stage 3: Permanent NORM disposal.

Stage 1: Temporary NORM Storage (On-Site)

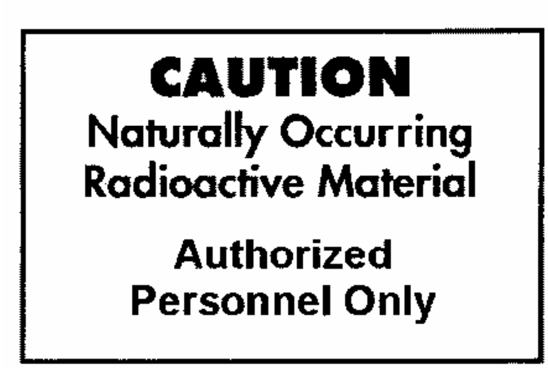
Temporary NORM storage is defined as the on-site holding and preliminary processing of NORM waste for future transport to an Interim Storage Facility. Some preliminary NORM waste processing could include:

- Waste minimization activities,
- Waste packaging,
- Basic waste segregation,
- Site waste transport/relocation.

Since the site is under the direct control of the company, Incidental Workers and NORM Workers are the only affected exposure groups. Therefore, only occupational radiation exposure controls are required.

Occupational Radiation Exposure Controls

- **Access Control**
  Access control procedures are designed to limit Incidentally Exposed Worker access and restrict Public access and to the Interim Waste Storage Facility. Access controls including signs and barricades would be used. Suggested wording on warning signs have the optional use of the **radiation warning symbol** (black "trefoil" on white background).



- **External Radiation Exposure Controls**
  Standard external radiation protection controls should be employed to protect all workers. These include:

  - *Screening and Radiation Surveys*
    Periodic screening and radiation surveys are recommended to monitor the integrity of NORM waste packaging and to verify access control action levels

  - *Access Control Procedures* (see above)

  - *Cumulative Worker Exposure Time Estimate*
    Cumulative exposure time estimates for NORM Workers and/or Incidentally Exposed Workers may have to be repeated as the inventory of NORM waste changes within the facility. Additions or subtractions to existing inventories could alter radiation levels at designated access points and at work locations.

  - *Radiation Exposure Assessments/Personal Dosimeters*
    Corporate radiation exposure monitoring policies for Incidentally Exposed Workers and NORM Workers should be applied at the waste storage facility.

- *Internal Radiation Exposure Controls*
  Key internal radiation exposure controls employed to protect NORM Workers include:
  - Ensuring integrity of containers and packaging,
  - Sealing containers to prevent dispersal of dusts,
  - NORM sampling for Radio-chemical Analysis.

Stage 2: Interim NORM Storage

Stage 2 of NORM waste management involves the storage of previously segregated NORM waste at a facility that is designed to protect workers, any unauthorized employees and the public who gain access to the location.

It is anticipated that all types and concentrations of NORM waste could be present at interim storage locations which are situated on properties under the direct control of the NORM waste generator, or under the direct supervision of a NORM waste management contractor off-site who acts as an agent for the NORM waste generator.

Interim storage of NORM waste is intended for longer periods of time and may be on-site or off-site. General NORM waste handling guidelines and storage criteria are based upon universally accepted radioactive material handling procedures and derived radiation exposure criteria contained within the Canadian NORM Guidelines.

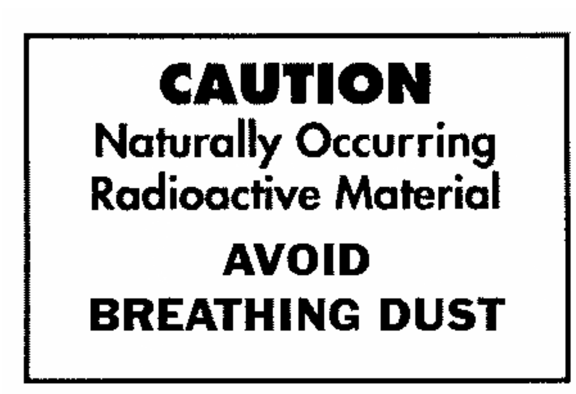
The following guidelines address NORM material packaging and Interim NORM waste storage facility requirements.

- **NORM Material Packaging**
  Sort all generated NORM wastes according to the NORM Waste Categorization criteria previously discussed. After classification, separate all NORM wastes into lower and higher radioactivity levels. Disposal options are different for the two categories and mixing may increase high activity waste volume and disposal costs.

  Minimum recommended radioactivity classification criteria will be provided by the waste control company. As a minimum, the waste should be segregated based on the following guidelines:
  - *Diffuse NORM Sources*
    Trigger value of 70 Bq/g (70,000 Bq/kg), for liberated scales, sludges and contaminated soils.
  - *Discrete NORM Sources* (Contaminated Equipment)
    NORM-contaminated equipment should be classified on the basis of maximum measured surface dose rate. A trigger value of 0.15 µSv/h is recommended. As well, representative samples of the contaminant should be taken for quantitative analysis.

Liberated scales, sludges and NORM-contaminated soils should be stored in polyurethane barrels, or equivalent corrosion-resistant impervious containers to prevent rain or snow from entering.

For equipment with contamination limited to interior surfaces, open ends must be capped or sealed. Where contamination is present on interior and exterior surfaces, the equipment must also be sealed in 6 ml plastic or equivalent. All sealed equipment, packages or containers must be labelled with the wording shown in the diagram and marked to ensure that the contents and/or contamination levels are readily identifiable from the outside. This prevents unnecessary handling or opening of packages for identification at a later date. Equipment and containers should be inspected monthly ensure packaging integrity.



- **Interim NORM Waste Storage Facility Requirements**

If the storage area is outdoors, it **must** be secured by fencing. The fencing line should be set so that annual exposure to members of the public does not exceed 0.3 mSv/yr at the perimeter. Siting considerations and time calculations should be used to establish the storage area perimeter and the derived dose rate limits used to establish the perimeter boundaries.

Access to the storage area must be managed and work practices established to ensure that annual exposure to incidentally exposed workers does not exceed 1.0 mSv/yr. Incidentally exposed workers are considered members of the public who work in an occupational exposure environment, but whose regular duties do not include exposure to NORM sources of radiation.

Additional design criteria for the interim storage facility include:

- Materials with higher radioactivity should be stored near the centre of the storage area.
- Materials and containers must be stored above ground on adequately designed storage racks or pallets or on a contained concrete floor.

- The Storage Area should be protected from exposure to the elements, either indoors or containers, and wrapped and sealed with heavy-duty tarpaulins.
- The Storage Area must be properly posted with the wording as shown here.

CAUTION
Naturally Occurring
Radioactive Material

Authorized
Personnel Only

If the storage area contains any NORM material with a radioactive concentration greater than 70 Bq/g, the material is considered radioactive. In this case, signage must contain the radioactive trefoil symbol.

- **Interim Storage Documentation**

All NORM material stored in the interim waste storage facility must have the following documentation:

- Container identification (ID number and type of container),
- Type of waste (scale, sludge, contaminated soil, etc.),
- Source of waste (original location),
- Surface dose rate of container/equipment,
- Radionuclides present (e.g. Ra^{226}, Pb^{210}, U^{238}, etc.),
- Radioactive concentration of diffuse NORM waste (Bq),
- Total radioactivity estimates of discrete NORM waste (i.e. scale in equipment),
- Removable surface contamination (Bq/cm^2),
- Date stored and date removed (to final disposal),
- Final destination of waste, if known.

- **Interim Storage Monitoring**

Waste inventory documentation must be kept current and accessible for inspection. The following radiation protection activities are recommended:

- Containers and equipment should be inspected monthly to ensure packaging integrity.
- Leaking or corroded containers and equipment must be repackaged or resealed immediately.
- The Interim Storage area should be surveyed biannually to ensure gamma dose rates are not exceeded at the perimeter and that workers entering the area are not overexposed.

Stage 3: Permanent NORM Waste Disposal

An important reason for categorizing NORM waste is to contain NORM waste management costs. Categorization also determines which permanent NORM waste disposal options are viable and therefore meet the government's waste disposal approval criteria. Discussions here will consider only NORM waste whose radioactive content exceeds the applicable Unrestricted DRL.

Some potential permanent disposal options that have been considered to date include:

- Salt cavern disposal,
- Abandoned well disposal,
- Well injection disposal,
- Land fill disposal.

➢ **Salt Caverns**

Salt caverns, hundreds to thousands of feet below ground level, permit the permanent disposal of highly concentrated radioactive materials. Caverns can accommodate very large volumes of slurried waste. It is expected that a salt cavern failure will not occur over geologic time frames.

Selection Criteria:

- Large volume slurries of solids and liquids,
- Economical Feasibility.

➢ **Abandoned Wells**

Disposal into abandoned wells requires the packaging of diffuse NORM into tubulars or canisters and lowering of the packages into abandoned wells. The material is interred more than 100 metres into deep wells with the tubular string placed well below the groundwater. The string is then sealed with several hundred metres of cemented casing string. Liberated scales resulting from decontamination activities, small-volume contaminated equipment and scale-contaminated pipes can be considered for this option. Certain sludges may not be viable, given the possible chemical incompatibility with the concrete. The well is finally capped to prevent inadvertent intrusion.

Selection Criteria:

- Small volume solids (packaged in tubular strings),
- High (unlimited) Radioactive concentration Limits,
- Economic Feasibility.

➢ **Well Injection**

Well injection consists of injecting a slurry of sludges and/or scales into a deep permeable formation below the ground water which has no economic petroleum value nor is a viable source of drinking water. The injection is conducted under pressure, which causes the slurry to flow into horizontal fracture lying between impermeable layers. The slurry is therefore locked within the permeable layer. The well is plugged with concrete and subsequently capped or sealed. The long-term monitoring of groundwater for leakage will possibly be a requirement.

Selection Criteria:
- Large volume slurries of solids and liquids,
- High (unlimited) Radioactive Concentration Limits,
- Economic Feasibility,
- Appropriate geological zone.

➢ **Landfills**

Landfill disposal should be the option of **last resort.** It involves the burial of NORM wastes into designated landfill sites with at least a one-metre cap of clay. Lower radioactive concentrations of NORM in the form of liberated scales, sludges, contaminated soils or NORM-contaminated equipment can be considered for this option if non-radioactive waste properties are acceptable. Liquid forms of NORM are **not** acceptable.

Computer modelling of environmental pathways indicates the need to specify landfill NORM inventory limits based upon the total radioactive inventory of the different forms of acceptable NORM waste described in the previous section of the course.

This option requires on-going environmental monitoring of ground water and analysis of landfill leachate samples.

Inhalation of radon gas is only a concern if the landfill site is to be reclaimed as a residential complex. Radon gas generated from Ra^{226} NORM contamination within the surrounding soil can diffuse through basement walls and increase the amount of radon gas inhaled by the occupants (i.e. radiation from the ground).

Exposure to groundshine is only significant if the landfill site were to be reclaimed as a residential complex since a portion of the protective clay cap may be inadvertently removed during residential construction. Removal of the clay cap exposes the underlying NORM-contaminated soil. This reduced ‘shielding effect’ results in increased gamma exposure to the occupants.

Selection Criteria:
- Large and small volume solids only,
- Maximum Radioactive Concentration Limits (pending),
- Economic Feasibility.

In all four NORM disposal options, **ingestion of groundwater** is a theoretically possible public exposure pathway. Public radiation exposure pathways are dependent on the environmental impacts of the waste over a period of at least 2,000 years. Additional public radiation exposure pathways associated with decommissioned landfill sites have also been modelled due to the various site reclamation options (subsequent land use).

TRANSPORT OF CONTAMINATED WASTE AND EQUIPMENT

The final work activity of NORM waste management is waste transport to the permanent NORM disposal site.

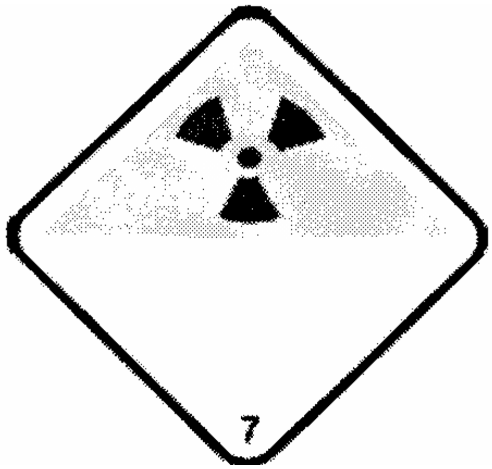
NORM shipments with **greater than 70 Bq/g** radioactive concentration, fall under federal jurisdiction and are subject to the following federal regulations:

- *Packaging and Transport of Nuclear Substances Regulations, Nuclear Safety and Control Act,*
- *Transportation of Dangerous Goods Regulations, Transportation of Dangerous Goods Act,*
- *A manifest should be used when transporting NORM waste.*

NOTE:

The previously described package labels and vehicle placarding requirements should conform to these regulations.

For transportation of materials with an activity level **greater than 70 Bq/g**, only the Class 7 radioactive materials placard is permitted for transport vehicles under the *Transportation of Dangerous Goods (TDG) Regulations.*



Waste Package Label Information should include:

- Package Identification Number
- Radionuclides present (e.g. Ra^{226}, Pb^{210}, U^{238}, etc.)
- Estimate of total package radioactivity (Bq, kBq or Mbq)
- Radioactive Label (I-White, II-Yellow or III-Yellow)
- Maximum Surface Radiation Level (µSv/h)
- Transport Index – maximum radiation level at one metre distance (µSv/h)

Access to copies of the federal transportation regulation is essential. Preparation of these shipments for transport involves several steps. As a result, lead times from four to six weeks prior to shipment should be planned.

For NORM packaging containing material with radioactive concentrations between applicable Canadian NORM Guidelines URL and 70 Bq/g, the following is recommended:

- Ensure that the shipping document contains the descriptor below:
  Naturally Occurring Radioactive Substance – NORM
- Ensure that the consignment is packaged in a manner that effectively contains the possible release or redistribution of any NORM contamination during transport.
- Do not affix radioactive placards or labels on the transport vehicle or on the exterior surfaces of the packaging.

APPENDIX 1

CONVERSION FACTORS

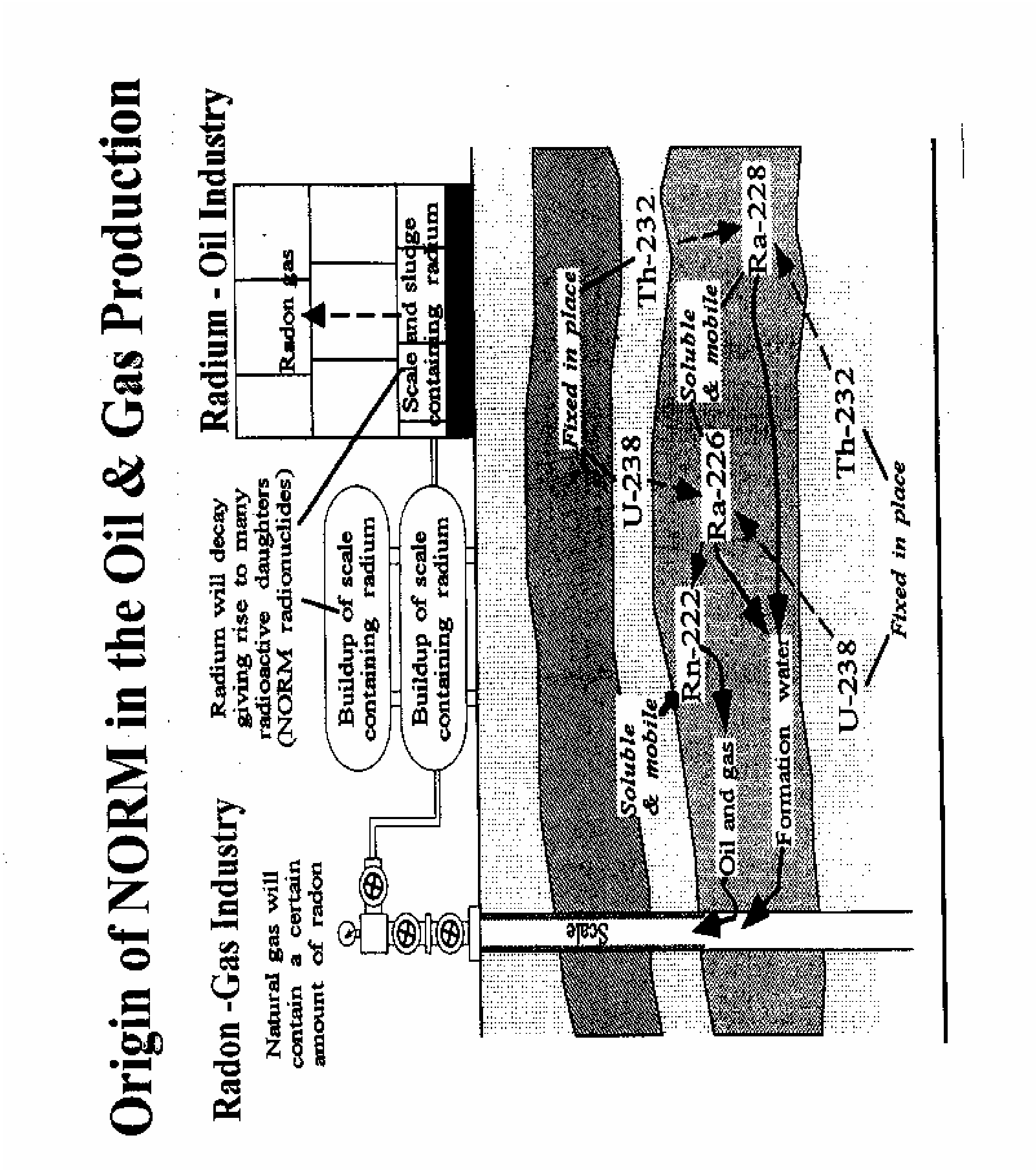
RADIATION UNIT CONVERSION FACTORS

PREFIXES			
T: Tera 10^{12}	M: Mega 10^{6}	m: milli 368^{-3}	Ç: nano 368^{-9}
G: Giga 10^{9}	K: kilo 10^{3}	µ: micro 368^{-6}	P: pico 368^{-12}

ACTIVITY							
SI Units				Former Units			
1 Bq	0	1 dps	=	27 pCi	=	2.7×10^{-11} Ci
1kBq	=	1×10^{3} dps	=	27 nCi	=	2.7×10^{-8} Ci
1MBq	=	1×10^{6} dps	=	27 µCi	=	2.7×10^{-5} Ci
1GBq	=	1×10^{9} dps	=	27 mCi	=	2.7×10^{-2} Ci
1Tbq	=	1×10^{12} dps	=	27 Ci	=	2.7 X 10 Ci
37 mBq	=	0.037 dps	=	1 pCi	=	1×10^{-12} Ci
37 Bq	=	37 dps	=	1 nCi	=	1×10^{-9} Ci
37 kBq	=	3.7×10^{4} dps	=	1 µCi	=	1×10^{-6} Ci
37 MBq	=	3.7×10^{7} dps	=	1 mCi	=	1×10^{-3} Ci
37 GBq	=	3.7×10^{10} dps	=	1 Ci	=	1 Ci

DOSE		
SI Units to Former Units		**Former Units to SI Units**
1 mSv = 0.1 rem 1µSv = 0.1 mrem		1 mrem = 10 µSv 1µrem = 0.01 µSv

APPENDIX 2:


Origin of NORM in the Oil & Gas Production
Radon -Gas Industry
Natural gas will contain a certain amount of radon
Radium - Oil Industry
Radium will decay giving rise to many radioactive daughters (NORM radionuclides)
Radon gas
Scale and sludge containing radium
Buildup of scale containing radium
Buildup of scale containing radium
Scale
Fixed in place
Th-232
U-238
Soluble & mobile
Ra-228
Ra-226
Rn-222
Soluble & mobile
Oil and gas
Formation water
Th-232
U-238
Fixed in place

APPENDIX 3: IMPORTANT DEFINITIONS

GLOSSARY OF RADIATION TERMINOLOGY

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

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

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

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

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

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

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

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

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

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

Beta Radiation (Beta Decay): the ejection of a high-energy negatively charged subatomic particle from the nucleus in mass and charge to an electron.

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

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

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

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

Decay series (Radioactive Decay Series): a succession of radionuclides, each member of which transforms by radioactive decay into the next member until a stable nuclide results. The first member is called the "parent", the intermediate members are called "progeny" and the final stable member is called the "end product". In the two NORM decay series; $Uranium^{238}$ and $Thorium^{232}$ are the "parents", and $Lead^{206}$ and $Lead^{208}$ are the "end products".

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

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

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

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

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

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

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

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

Equivalent Dose: the absorbed dose multiplied by a "radiation weighting factor" (W_R) which accounts for the different potential for adverse effects of the different types of radiation. Unit: sievert (Sv).

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

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

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

Groundshine: radiation detectable on the earth's surface from radioactive substances on or beneath the surface.

Half-Life, Biological: the time required for a radioactive material to lose half of its activity through radioactive decay.

IAEA: International Atomic Energy Agency

ICRP: International Commission on Radiological Protection

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

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

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

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

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

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

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

Photons (X-Ray or Gamma Rays): see gamma radiation.

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

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

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

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

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

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

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

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

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

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

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

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

Specific Activity (Radioactive Concentration): the number of becquerels per unit of mass of a material.

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

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

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

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