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NORM Industries and Regulatory Considerations

Content

- What is NORM ?
- Criteria for regulation
- Graded approach to regulation
- Understanding the project
- Industrial sectors involving NORM
- Key messages

Background

- Natural sources of radiation are present everywhere
- Large throughput of raw materials and when concentrating occurs
- Component of raw materials, products, residues
- Radiation issues are usually not known or not expected or not wanted
- Can have high public profile
- Regulation (and thinking) required when above certain levels

What is NORM?

Naturally Occurring Radioactive Material (NORM)

Radioactive material containing no significant amounts of radionuclides other than radionuclides of natural origin

- Definition of 'significant amounts' is a regulatory decision
- NORM also includes material in which the activity concentrations could have been changed by a process
- NORM refers only to material that is subject to regulatory control

"**If it is not regulated, then it is not NORM !**"

Radioactive material

Material designated in regulation as being subject to regulatory control because of its radioactivity.

(Definitions derived from IAEA Glossary 2018 Edition)

Criteria for regulation

- Excluded exposure situations

  ○ Exposures that are unamenable to control are excluded from the requirements and therefore not subject to regulation

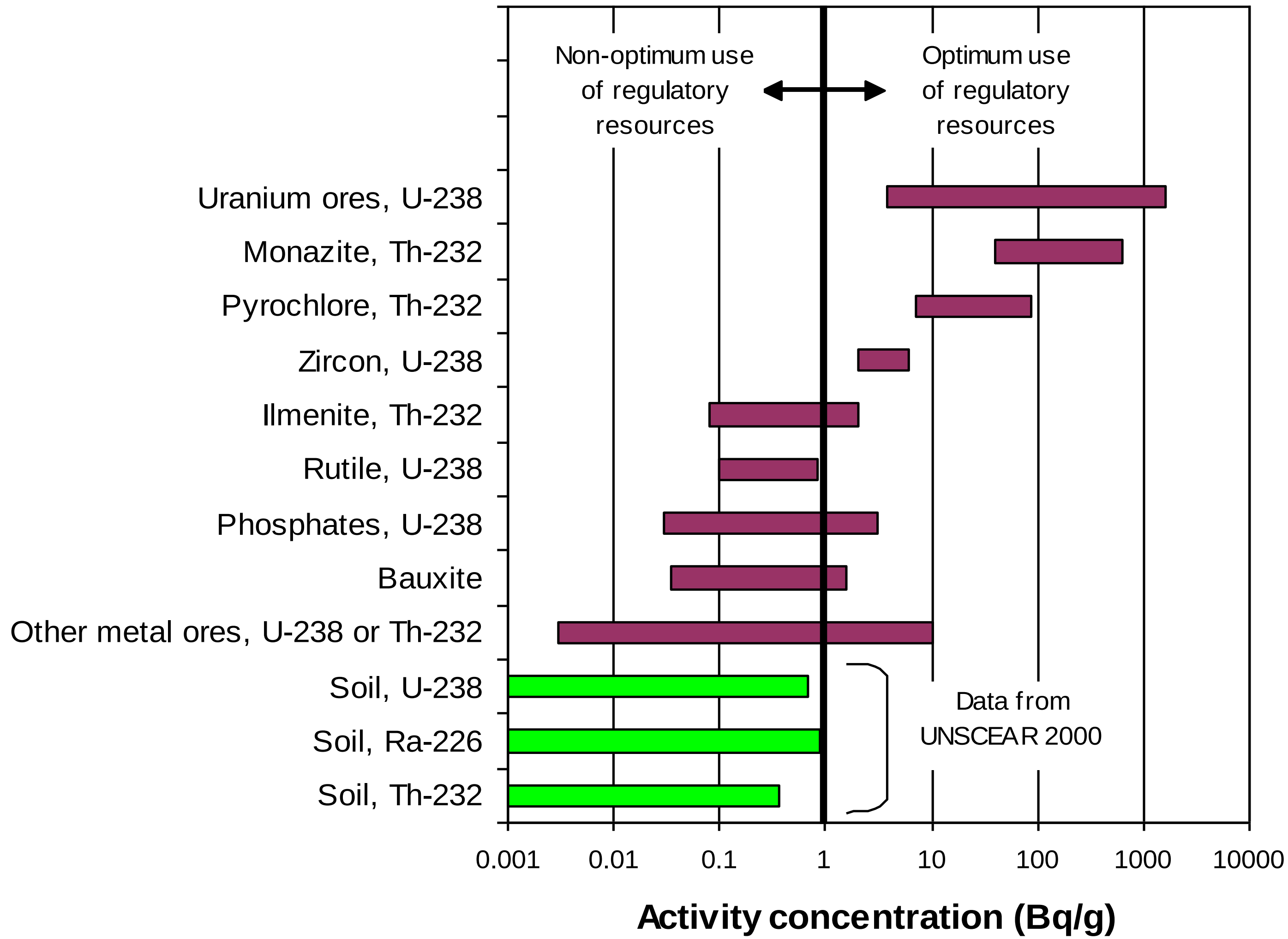
- Non-excluded exposure situations

  – The requirements for planned exposure situations apply if:
    - The activity concentration of any radionuclide in the U or Th decay chains exceeds 1 Bq/g *or* ^{40}K exceeds 10 Bq/g

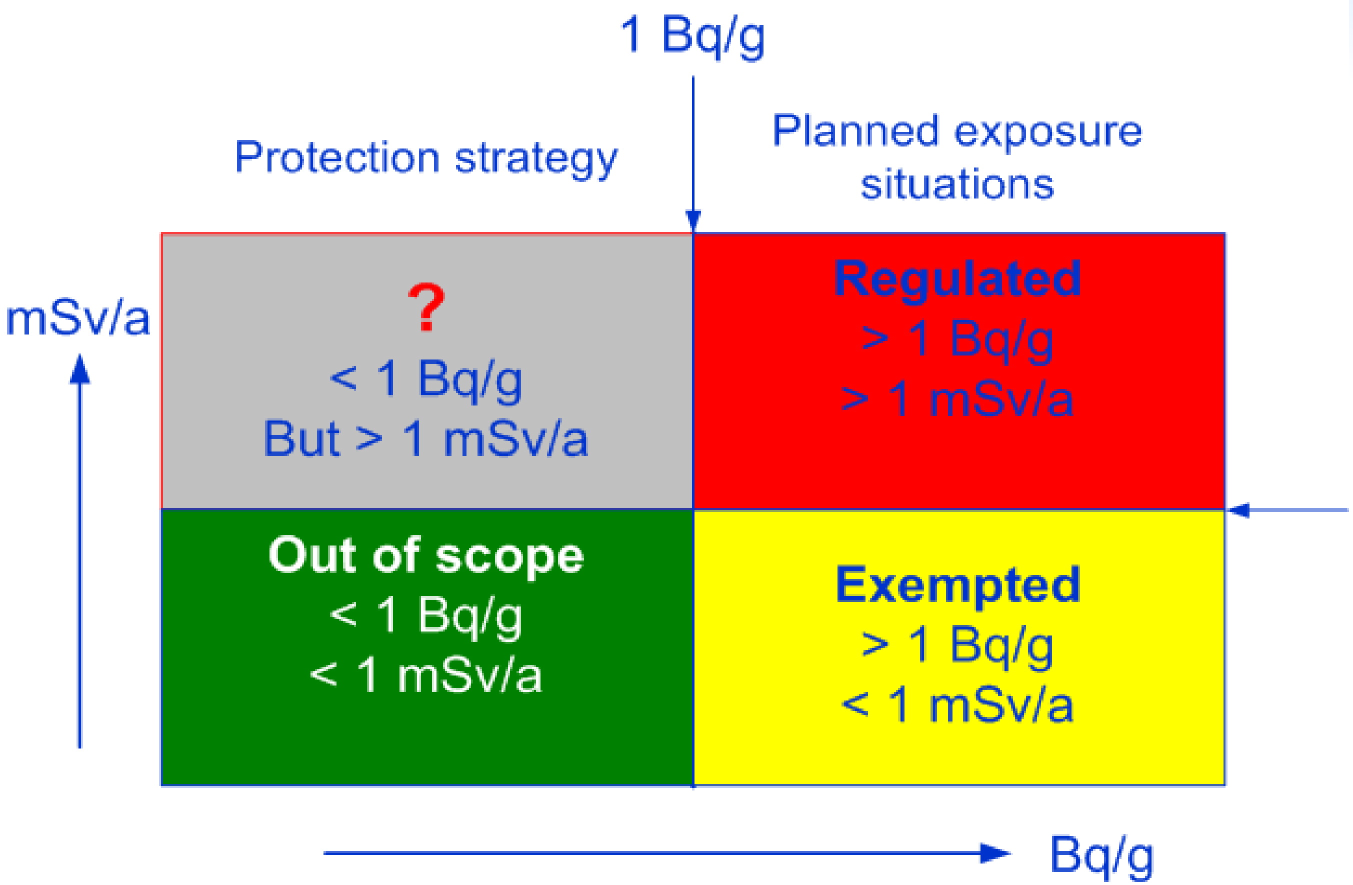
  – These criteria do not apply to radon, for which separate criteria have been established

  – Regulation commensurate with the risk (the graded approach)

Basis of exclusion criteria



Regulating NORM in Practice



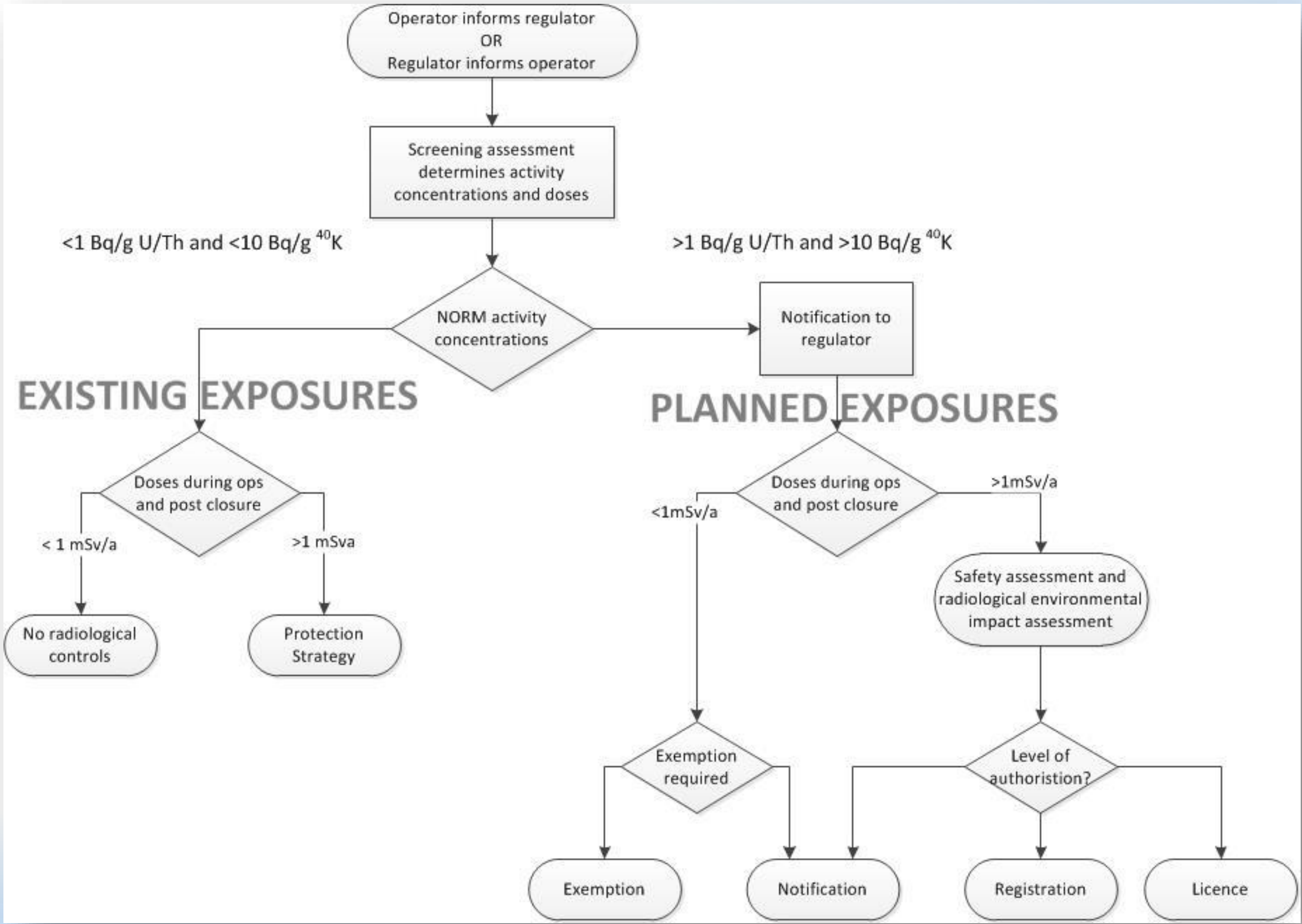
- Generic clearance level <1 Bq/g (U and Th decay chain), 10 Bq/g for ^{40}K
- Specific clearance values derived to meet a dose criterion of the order of 1 mSv/a

Graded approach to regulation

- If criteria exceeded, regulatory control must be considered, based on “the graded approach to regulation”:
  1. Exemption
  2. Notification
  3. Notification + registration
  4. Notification + licensing

- The graded approach is implementation of optimization of protection

- Other forms of industrial regulation may contribute to the control of radiation:
  - Occupational health and safety (OHS) regulation (dust control)
  - Environmental protection regulation (licences)



Operator informs regulator
OR
Regulator informs operator
Screening assessment determines activity concentrations and doses
<1 Bq/g U/Th and <10 Bq/g ^{40}K
>1 Bq/g U/Th and >10 Bq/g ^{40}K
NORM activity concentrations
Notification to regulator
EXISTING EXPOSURES
PLANNED EXPOSURES
Doses during ops and post closure
< 1 mSv/a
>1 mSva
No radiological controls
Protection Strategy
Doses during ops and post closure
<1mSv/a
>1mSv/a
Safety assessment and radiological environmental impact assessment
Exemption required
Level of authoristion?
Exemption
Notification
Registration
Licence

1. Exemption

- Exemption is the lowest level of the graded approach
  - Always the first consideration

- Criteria for exemption:
  - “Trivial dose” concept – The radiation risk is sufficiently low as to not warrant regulatory control

    or
  - “No net benefit” concept – No reasonable control measures would achieve a worthwhile reduction in doses
    - Could be important for NORM industries, where the dose may not necessarily be trivial

2. Notification only

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- The requirement for notification (without the need for an authorization) is appropriate when the annual effective dose is small compared to the relevant dose limit
- The responsible person must formally submit a notification to the regulatory body of the intention to carry out the practice
- Similar to exemption, but provides the reassurance that the regulatory body remains informed of all such practices.

3. Notification + Registration

- Registration is the lower of the two levels of authorization
- Appropriate for situations where notification alone is not sufficient for providing an optimized regulatory approach
- The regulatory body may decide that the responsible person has to meet additional (but limited) requirements to ensure adequate protection
- Typical requirements :
  - Measures to keep exposures under review
  - Measures to ensure that the working conditions are such that exposures remain at moderate levels, with little likelihood of doses approaching or exceeding the dose limit

4. Notification + Licensing

- Licensing is the upper of the two levels of authorization
- Appropriate for situations where:
  - Notification alone is not sufficient for providing an optimized regulatory approach
  - An acceptable level of protection can be ensured only through the enforcement of more stringent exposure control measures
- Represents the highest level of the graded approach
- For exposure to NORM, licensing is likely to be appropriate only in those situations involving substantial quantities of material with high activity concentrations (eg; uranium mining)

Removal of regulatory control from material (clearance)

- Criteria for clearance:
  - ‘Trivial dose’ concept or‘ No net benefit’ concept

  Since the dose criterion for exemption is a dose of the order of 1 mSv per year, a similar dose criterion is appropriate for clearance

- Automatic clearance without further consideration:
  - Activity concentration does not exceed
    - 1 Bq/g (U, Th series)
    - 10 Bq/g (^{40}K)

Pre-requisites for decision making

- Successful implementation of a graded approach is possible only if you understand the operation;
  - Processes,
  - Materials involved
  - Exposure pathways
  - Potential exposures and doses
  - The environmental factors

- Requires discussion with industry sector or operator

(see IAEA Safety Guide GSG-7)

Industrial sectors that may require regulatory considerations

1. Mining and processing of uranium ore
2. Extraction of rare earth elements
3. Production and use of thorium and its compounds
4. Production of niobium and ferroniobium
5. Mining of ores other than uranium ore
6. Production of oil and gas
7. The zircon and zirconia industries
8. Manufacture of titanium dioxide pigment
9. The phosphate industry
10. Production of tin, copper, aluminium, zinc, lead, iron & steel
11. Combustion of coal
12. Water treatment

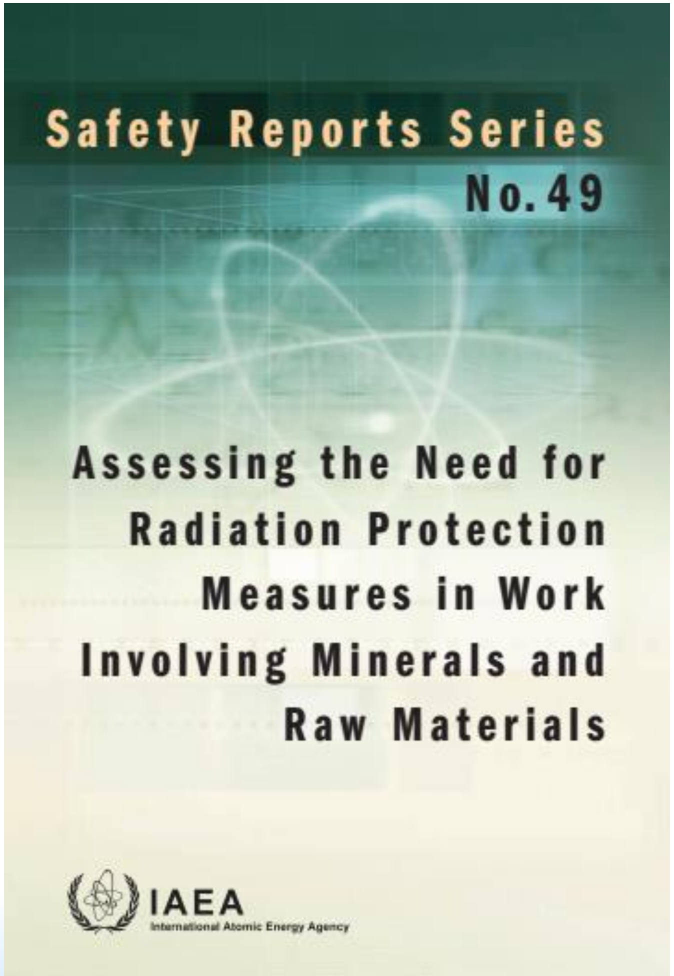
HIGHER CONCERN

Other areas

- Spas
- Paper and pulp
- Ceramics
- Paints and pigments
- Foundries
- Optics
- Refractory and abrasive sands
- Electronics
- Slag wool (insulation)

IAEA Safety Report Series

- Radiation protection and management of NORM residues in the Phosphate industry, Safety Report No. 78, 2013
- Radiation Protection and NORM Residue Management in the Titanium Dioxide and Related Industries, Safety Report Series No. 76, 2012
- Radiation Protection and NORM Residue Management in the Production of Rare Earths from Thorium containing Minerals, Safety Report Series No. 68, 2011
- Radiation Protection and NORM Residue Management in the Zircon and Zirconia Industries, Safety Reports Series No. 51, 2007
- Assessing the Need for Radiation Protection Measures in Work Involving Minerals and Raw Materials, Safety Reports Series No. 49, 2006
- Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry, Safety Reports Series No. 34 , 2003
- Radiation Protection against Radon in Workplaces other than Mines, Safety Reports Series No. 33, 2003
- Monitoring and Surveillance of Residues from the Mining and Milling of Uranium and Thorium, Safety Reports Series No. 27, 2002



2.5.8. Furnace dust

NORM residues in the form of furnace dust are generated by the processing of minerals and raw materials at high temperatures. Most furnace dust is trapped as a condensate in stack filters and electrostatic precipitators and is removed during periodic maintenance operations. Some furnace dust escapes with the stack emissions to the atmosphere, while some may remain within the plant, either contaminating the air in the surrounding workplace or settling out on surfaces, posing a potential inhalation hazard to workers.

The radionuclides of interest in furnace dust are the volatile radionuclides ^{210}Pb and ^{210}Po. Although radium is less volatile than lead and polonium, the presence of radium isotopes may occasionally be of concern.

Occupational exposure to potassium -40

- Potassium-40 (K-40) is present naturally in human body
- Amount in body in metabolic equilibrium so internal exposures not considered
- IAEA Safety Report No 49 considers K-40 exposures
  - Predicted annual dose per unit activity concentration of ^{40}K is 0.02–0.03 mSv per Bq/g (External exposure pathway only; internal exposure excluded)
  - K-40 activity concentration in pure potassium is 30.6 Bq/g
  - For a material containing 100% potassium, the maximum annual dose is therefore

    0.03 x 30.6 = 0.9 mSv/a
- In practice, the potassium content, and hence the annual dose, will be much lower

Examples of industries

Oil and Natural Gas Production

- Oil and gas exist in beds of permeable sandy sedimentary rocks
- Rocks contain naturally occurring uranium (and thorium)
- Radon can be released and caught in gas handling systems
- Radon decays to decay products and Po^{210} and Pb^{210}
- Ra^{226} in water can precipitate as scale when pressures, temperatures or pH changes. Presence of H_2S and CO_2 can change water chemistry causing precipitation
- Exposures can occur;
  - From gamma radiation due to accumulation of scales or sludges
  - During maintenance
- Activity of material can vary widely
- Waste disposal considerations

Bauxite and Aluminium Industry

- Bauxite ores sometimes contain elevated concentrations of natural U and Th
- Two stage processing
- Bauxite to alumina (anhydrous aluminium oxide)
- Electrolysis to metal
- Waste stream from first stage is ‘red mud’ carrying trace elements (and radionuclides)
- Volume is reduce by half, but majority of radionuclides report to mud
- Mud contains radionuclide concentrations above background levels
- Very large volumes of residues

Phosphate Industry

- Natural phosphate usually contains wide range and elevated levels of U (and sometimes Th)
- Ore is processed to produce;
  - Fertiliser
  - Phosphogypsum waste (calcium sulphate)
- Uranium follows fertiliser
- Radium follows waste stream
- Final concentrations depend upon the original ore concentrations
  - U up to 1.5 times in product
  - Ra up to 5 to 15 times in waste

Metal Mining and Processing

- U and Th concentration varies with geologic formation and region.
- Metals (Cu, Sn, Au, Ag)
- Potential radioactive materials include;
  - Ores
  - Intermediate streams
  - Metal concentrates
  - Waste rock, Tailings, Smelter slags
- Exposures pathways;
  - Gamma
  - Inhalation of radioactive dusts
  - Radon and decay products
- Exposures during; mining, processing, recycling and closure

Metal Mining and Processing

- Where concentrating of metals occurs
- Extraction processes is an enriching process
- Radionuclides are also found in some final products
- Large bulk waste streams (e.g., copper, aluminum, iron, steel)
- Usually in low concentration and high volume waste streams
- Some processes concentrate specific radionuclides
  - Actinium follows Lanthanum
  - Radium follows Ba, Ca
  - Polonium follows Te, Se
  - Some radionuclides are acid soluble

Coal Mining and Processing

- Coal is mined, pulverised, mixed with hot air and burnt to produce steam.
- Wastes are fly ash and bottom ash and slag
- Radionuclides in coal remain in waste – enhanced by a factor or 3 to 20
- Volatile radionuclides accumulate in the fly ash or stack emissions
- Radon emitted as a gas
- Potential issues with remediation

Iron and Steel Production

- Raw materials are; iron ore, coal and limestone
- Waste is 2 to 4 t per tonne of steel
  - Therefore, enhancing of radionuclides into waste (0.5Bqg -> 2Bq/g)
- Waste contains radionuclides (and other heavy metals)
- Volatile radionuclides (Po^{210} and Pb^{210}) are in exhaust system and can accumulate in dust handling systems
- Radionuclides can accumulate in other waste streams

Rare Earths and Mineral Sands

- Lanthanide rare earth metals – 16 elements
- Mineral sands operations are well understood
- Gravity processes concentrate the heavy minerals
- Monazite in mineral sands contains about 6% thorium
- Cracking uses concentrated H_2SO_4 – can mobilize radionuclides
- Ilmenite, rutile, zirconia material
- Rare earths used in electronics, super magnets and technology
- Generally Th decay chain radionuclides
- Selective concentrating of rare earth metals can also act to concentrate radionuclides

Water Treatment

- Some water supply systems treat water containing elevated levels of NORM
- Radionuclides may be present in potable groundwater and surface water
- Removing impurities tends to concentrate them in waste streams
- Radium in groundwater (Ra^{226} and Ra^{228})
- Wastes include sludges and solids
  - Filter sludges
  - Ion-exchange resins
  - Activated charcoal
  - Radium-selective resins - discrete wastes
- Waste stream concentrates impurities

Building Industry

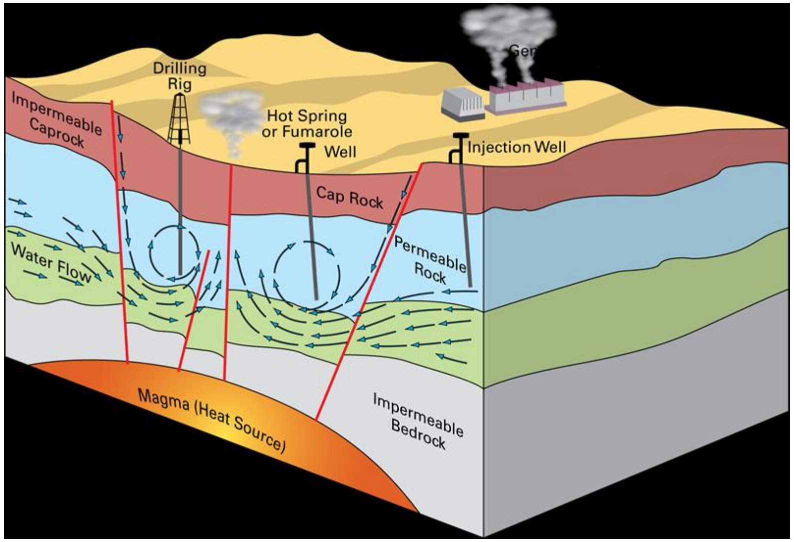
- Extensive use of recycled materials;
  - Fly ash used as a concrete extender
  - Bottom ash sometimes used in concrete
  - Smelter slag used as filler for foundations (eg; roads)
  - Steel recycling
- Wastes and residues used as filler material
- NORM in materials is source of gamma radiation (up to 0.4μSv/h per Bq/g)
- Radon exhalation also potential source of exposure
- Exposure scenarios (longer times)

Underground Activities

- Radiation impacts in enclosed spaces
- Includes;
  - Tunnelling
  - Underground Mining
  - Caving
- Exposure pathways
  - Gamma exposure
  - Build up of radon with time
  - Low ventilation rates leading to ingrowth
- Radiation protection considerations for mines and excavations

Wastes from Geothermal Energy Production

- Using the natural heat, pressure and liquid from within the earth
- Hot rock technology also a potential source of NORM
- Minerals that precipitate out of solution forming scale or sludge on the inside surfaces of equipment
- Contain barium, calcium, and strontium salts (carbonates, sulfates, silicates) as well as silica
- Can contain significant concentrations of radium and radium decay products



Practical Considerations

- Identify sources;
  - Understand radionuclide distributions
  - Where are the radionuclides in the materials and processes ?
- Identify exposure pathways to workers, the public and the environment
- Understand natural background levels
- Management measures; training, monitoring and safe work practices
- Systems of Protection are generally standard for all industries
- Excellent guidance exists (IAEA and from industry experts)
- Radiation is only one of a number of hazards

Key Messages

- NORM present in many industries
- Graded approach to NORM industries necessary
- Application of graded approach requires understanding of industry dynamics
- Each industry has unique characteristics and set of exposures
- Important to have good understanding of industry

Backup Slides

1. Mining and processing of uranium ore

^{238}U activity concentration	Ore: 4 – 1600 Bq/g Product: 10000 Bq/g
Exposure pathways	Gamma, dust, radon Potential for significant worker exposure Potential for significant public exposure Contamination of water bodies – discharges, mine residues
Occupational dose	2 mSv average (12000 mine workers) 1 mSv (3000 ore processing workers)
Regulatory approach	Notification & Licensing

2. Extraction of rare earth elements

(IAEA Safety Report Series No. 68)

^{232}Th activity concentration	Monazite concentrate: 6–400 Bq/g Bastnäsite concentrate: 0.15–7.8 Bq/g Xenotime concentrate: 13–200 Bq/g Rare earth clays: <1 Bq/g Process residues: 0.2–1000 Bq/g (up to 5000 Bq/g ^{228}Ra)
Exposure pathways	Gamma, dust, thoron Potential for significant worker exposure Potential for significant public exposure Contamination of water bodies – discharges, process residues
Annual Effective dose (Occupational)	0.3 - 10 mSv (mining) 0.6 - 9 mSv (chemical processing)
Regulatory approach	Notification & Licensing

3. Production and use of thorium and its compounds

(IAEA Safety Report in publication)

^{232}Th activity concentration	Th concentrate: 500–1000 Bq/g Th compounds: Up to 2000 Bq/g *Industrial Products:* Gas mantles: 500–1000 Bq/g Thoriated glass: 200–1000 Bq/g Th-containing optical polishing powders: 150 Bq/g Thoriated welding electrodes: 30–150 Bq/g Th alloys: 47–70 Bq/g
Exposure pathways	Gamma, dust, thoron Potential for significant worker exposure
Annual Effective dose (Occupational)	< 1 - 15 mSv
Regulatory approach	Notification & Licensing Solid wastes and effluents may need to be controlled.

4. Production of niobium and ferroniobium

Activity concentrations	Extracted from pyrochlore, columbite, tantalite Pyrochlore concentrate 80 Bq/g ^{232}Th Slag: 20–120 Bq/g ^{232}Th Furnace dust: 100–500 Bq/g ^{210}Pb, ^{210}Po Residues from columbite and tantalite processing: 300 Bq/g ^{238}U, 100 Bq/g ^{232}Th, 500 Bq/g ^{226}Ra Other residues: 200–500 Bq/g ^{228}Ra
Exposure pathways	Gamma, dust, thoron Potential for significant worker exposure
Residues/wastes	May need to be monitored and controlled
Regulatory	Use of slag for construction may have to be restricted (potential for gamma, radon and thoron exposures in buildings).

5. Mining of ores other than uranium ore

Activity concentrations	Activity in most ores are not elevated. In some cases ^{238}U may range upto 10 Bq/g.
Exposure pathways	Radon main concern Potential for significant worker exposure. Worker doses could exceed dose limits if radon not properly controlled. (Radon influenced by properties of rock, e.g. porosity, inflow of Ra-rich water, ventilation)
Residues and wastes	Scales and sediments can have ^{226}Ra, ^{228}Ra concentrations up to 200 Bq/g Discharge of contaminated water can have significant environmental impact.

6. Production of oil and gas

(IAEA Safety Report Series No. 34)

Source	Formation water contains ^{228}Ra, ^{226}Ra and ^{224}Ra and decay progeny dissolved from the reservoir rock.
Changes in temperature and pressure at the well-head can cause	Scales rich in Ra & progeny inside pipes, valves, vessels Sludges rich in Ra & progeny in separators and skimmer tanks Deposits containing ^{210}Pb & progeny in wet parts of gas production equipment
Exposures	Potential for significant exposure of maintenance workers to gamma and dust during maintenance and exposure to gamma of other workers spending time near pipes etc.
Residues and wastes	Activity concentrations are difficult to predict: Scales 0.1–15 000 Bq/g ^{226}Ra Sludge 0.05–800 Bq/g ^{226}Ra Disposal has to be controlled.

7. The zircon and zirconia industries

(IAEA Safety Report Series No. 51)

Activity concentrations	Zircon: 2–4 Bq/g ^{238}U Baddeleyite: 3–13 Bq/g ^{238}U, 0.1–26 Bq/g ^{232}Th Zirconia from fusion: 1.9–8 Bq/g ^{238}U Zirconia from chemical processing: 0.001–1 Bq/g ^{226}Ra SiO_2 residue from zircon fusion: 1.5–6 Bq/g ^{226}Ra, 0–10 Bq/g ^{210}Pb, ^{210}Po Furnace dust from baddeleyite fusion: 600 Bq/g ^{210}Po Effluent treatment tank deposit: >5000 Bq/g ^{226}Ra Chlorination residues: 0.3–48 Bq/g ^{226}Ra
Annual effective doses received by workers:	Fusion or chemical processing of zircon or baddeleyite: 0.015–5.5 mSv All other processes: 0.0003–1 mSv
Exposures	Potential for significant exposure of workers if good OHS practices not adopted.

8. Manufacture of titanium dioxide pigment

(IAEA Safety Report Series No.76)

Activity concentrations	Ores: 0.001–2 Bq/g ^{232}Th TiO_2 product, $TiCl_4$ intermediate product: <0.1 Bq/g By-products: <0.01–1 Bq/g ^{232}Th Scale: <1–1600 Bq/g ^{228}Ra Filter cloths: 2–1000 Bq/g ^{228}Ra Other residues: 0.02–24 Bq/g ^{232}Th
Annual effective doses received by workers:	<0.01–1 mSv
Exposures	Potential for significant exposure of workers to gamma and dust.

9. The phosphate industry

(IAEA Safety Report Series No.78)

Activity concentrations	Ore: 0.1–3 Bq/g ^{238}U Process residues: Mine tailings: 0.01–2 Bq/g ^{238}U Scale: 0.03–4000 Bq/g ^{226}Ra Sediment, sludge: 1.3–4.3 Bq/g ^{226}Ra Sludge from dicalcium phosphate production: 8–13 Bq/g ^{210}Po Fertilizer and animal feed products: 0.04–3 Bq/g ^{238}U Phosphogypsum by-product: 0.01–3 Bq/g ^{226}Ra Slag from thermal phosphorus production: 1 Bq/g ^{238}U Furnace dust from thermal phosphorus production: 1000 Bq/g ^{210}Pb
Annual effective doses received by workers:	0.1–0.7 mSv
Exposures	Potential for moderate exposure of workers to gamma and dust.
Environmental	Bulk storage of phosphogypsum in stacks has the potential for significant environmental impacts, mostly non-radiological. Decay storage of precipitator dust has to be controlled.

10. Production of tin, copper, aluminium, zinc, lead, iron and steel

Activity concentrations	Feedstocks: Usually close to background levels Bauxite 0.035–1.4 Bq/g ^{232}Th Furnace dust (smelting and refining): Up to 200 Bq/g ^{210}Pb, ^{210}Po Tin slag: 0.07–15 Bq/g ^{232}Th Copper slag: 0.4–2 Bq/g ^{226}Ra Sludge from iron smelting: 12–100 Bq/g ^{210}Pb Red mud (from aluminium production): 0.1–3 Bq/g ^{238}U, ^{232}Th
Exposures	Potential for moderate exposure of workers to dust.
Environmental	Use of tin slag may need to be restricted.

11. Combustion of coal

Activity concentrations	Coal: Typically at background levels, but sometimes higher Ash: Typically 0.2 Bq/g, but sometimes higher Fly ash contains the volatile radionuclides ^{210}Pb, ^{210}Po Flue gas desulphurization residues (sludges, gypsum): Lower than ash Scales inside burner kettles: Can exceed 100 Bq/g ^{210}Pb
Exposures	Limited potential for worker exposure, doses < 1 mSv/a
Environmental	Bulk storage/disposal of residues have potential environmental impacts, mostly non-radiological — engineered containments required The use of fly ash and gypsum as by-products for construction materials does not usually need to be restricted

12. Water treatment

Activity concentrations	Radionuclides can accumulate in water treatment residues, e.g. sludges, ion exchange resins 0.1–14 Bq/g ^{226}Ra. Usually at the low end of this range, except when treating groundwater
Exposures	Limited potential for worker exposure
Environmental	Control of residue disposal needed for non-radiological reasons Measures may be needed to prevent the buildup of radon in underground facilities where groundwater is treated