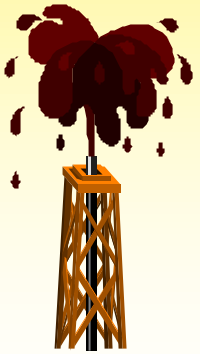
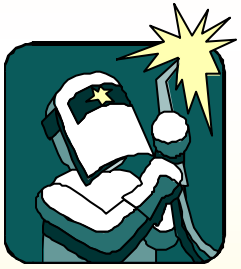
Radiation Protection in NORM Industries



IRPA 11 Refresher Course 5A
27 May 2004
Madrid



J. van der Steen, A.W. van Weers
NRG, Arnhem, The Netherlands

Contents

- Introduction
- Examples of NORM affected industries
- Scope of regulatory control for NORM
- Regulatory requirements
- Process to determine the required regulatory control
- Radiological protection issues

Introduction

- Naturally occurring radioactive materials (NORM) are everywhere
- Problems arise in almost every industry with a large throughput of raw materials
- In all cases unintentional use of radioactivity
- In all cases large quantities

Introduction

- Either the raw material itself has an enhanced concentration of NORM, or the industrial process leads to concentration (TENORM)
- In the latter case, the equilibrium in the decay series can be disturbed. Breaks occur at radionuclides with a long half-life

Introduction

- **Occupational exposure from natural radiation contributes to more than 80 percent of the world-wide annual *collective dose* from occupational exposure, uranium mining excluded (UNSCEAR 2000)**

- **Also, *individual doses* to workers exposed to NORM in industry can be significant**

Introduction

- When the employer is not aware of NORM and when no protective actions are taken, the doses may even exceed the occupational dose limit

- Doses are in many cases due to internal exposure
  - Inhalation of radon in workplaces
  - Inhalation of aerosols in dusty working conditions

Introduction

- Public exposure to environmental radon accounts for half the human exposure to natural sources (UNSCEAR 2000)

- Other environmental problems
  - Mine tailings
  - Phosphogypsum land fills
  - ^{226}Ra bearing produced water

Introduction

- Three main points are relevant to manage and reduce the exposure to NORM
  - awareness
  - regulations
  - guidance
- Specific problem area is the management of large quantities of NORM residues and waste

Introduction

Awareness

- Many studies and conferences during last 15 years
- NORM conferences
  - NORM I - Amsterdam 1997
  - NORM II - Krefeld 1998
  - NORM III - Brussels 2001
  - NORM IV - Katowice 2004
- IAEA Technical Meetings

- But:
  - There is still a backlog in the knowledge of the radiation protection problems with NORM

Introduction

Regulations

- 1996 International Basic Safety Standards (Safety Series 115)
- EU Council Directive 96/29/Euratom (Title VII)
- National legislations

- But:
  - Exemption levels in Directive (and in BSS) are only for practices (moderate amounts)
  - Establishment of exemption and clearance levels for natural radionuclides is left to the EU Member States

Introduction

Guidance

- IAEA Safety Standards and Safety Reports
- Radiation Protection Series of the European Commission

- But:
  - Many data only from Europe and North America
  - Data from less developed countries are scarce
  - Circumstances in these countries lead to particular concern

Introduction

Concern

- Mining and milling mainly in less developed countries
- Protection standards may be less stringent
- Enforcement may be less strict
- Widespread artisanal industries, integrated with family life and potentially leading to public exposure
- Limited resources for upgrading plants, legacy wastes or waste management infrastructure
- Responsibilities for legacy wastes and contamination unclear

Introduction

General conclusion

- **Growing awareness of NORM leads to reduction of collective and individual doses and, generally, to compliance with dose limits**
- **Specific issues of NORM make it difficult to reach compatibility with control of exposure to artificial radiation**
  - **Intrinsic differences in regulating artificial and natural radionuclides**
  - **Backlog in structured approach to introduce radiation protection measures in NORM industries**

Examples of NORM affected industries

Mining and processing

- Gold, copper, nickel, iron, aluminium, rare earths, phosphate, coal, etc
  - Problems: Rn, dust inhalation, mine tailings, residues, waste

Mineral sands

- Zircon, monazite, etc
  - Problems: dust inhalation, external radiation

Thorium industry

- Welding rods, gas mantles, lamps, etc
  - Problems: dust inhalation, residues

Examples of NORM affected industries

Oil and gas production

- Problems: dust inhalation during maintenance, waste

Geothermal energy

- Problems: Rn, waste

Electricity production

- Burning of coal, oil, peat
  - Problems: fly-ash, maintenance work

Examples of NORM affected industries

Workplaces

- Show caves, thermal baths, etc
  - Radon

Recycling and decommissioning

- Scrap, slag wool, etc
  - Dust inhalation, residues, waste

Examples of NORM affected industries

Other processing or manufacturing

- Water purification; Sewage treatment
- Spas
- Paper and pulp
- Ceramics
- Paint and pigment
- Metal foundries
- Optics
- Refractory and abrasive sands
- Electronics
- Building materials
  - Problems: Rn, dust, residues, waste, sludge

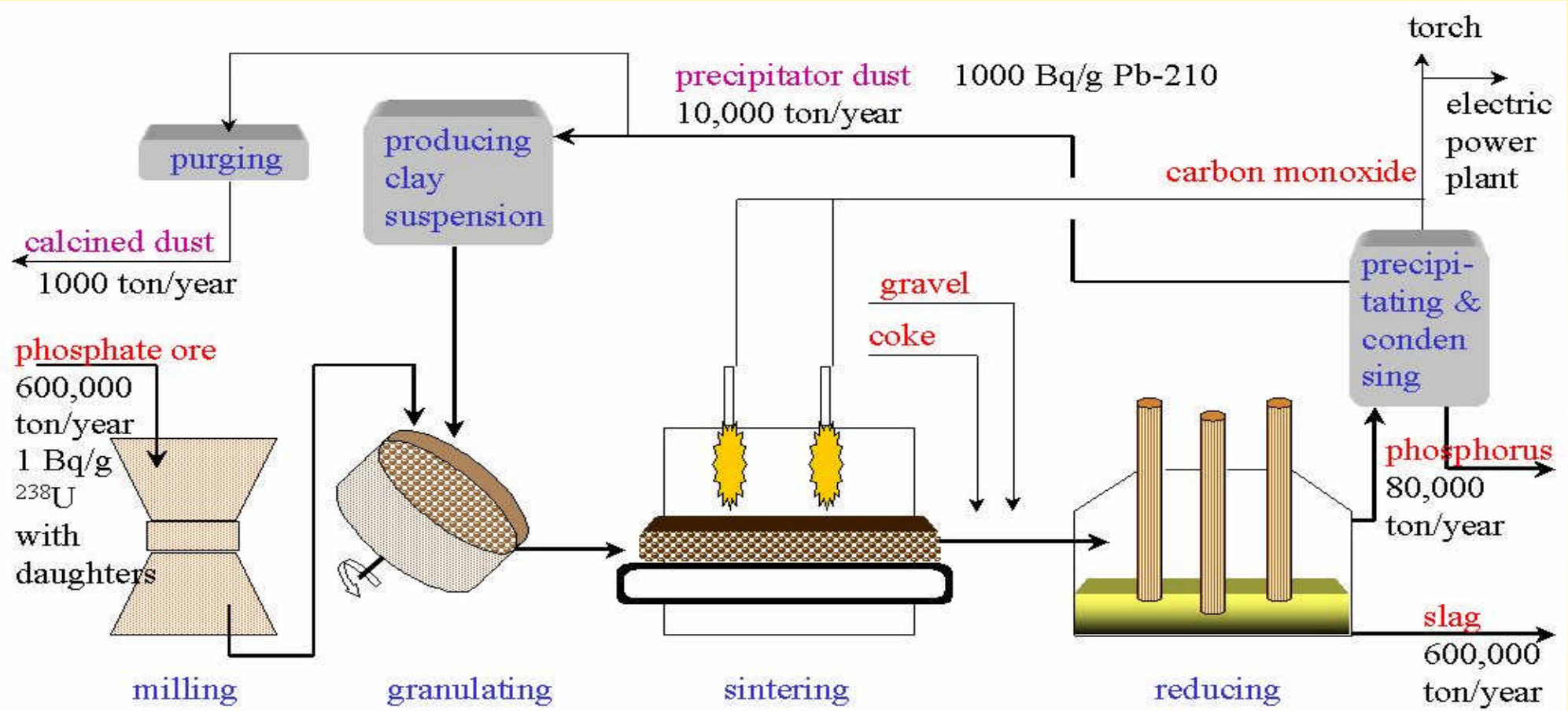
Examples of NORM affected industries

Two typical examples from the Netherlands

- **Elemental phosphorus production**
  - **Thermphos International B.V.**
  - **Problems: Dust, residues, waste**

- **Slag wool from historical tin production**
  - **Variety of installations at dismantling**
  - **Problems: Dust, residues, waste**

Examples of NORM affected industries



$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C \Rightarrow 6CaSiO_3 + 10CO + P_4$$

phosphate ore and gravel and coke => slag and carbon monoxide and phosphorus

PHOSPHORUS PRODUCTION AT THERMPHOS INTERNATIONAL

Examples of NORM affected industries

Examples of NORM affected industries

Examples of NORM affected industries

Examples of NORM affected industries

Optimisation in the workplace at Thermphos

- Large-scale cleaning activities
- New floors in the phosphorus plant, easy to keep clean
- Central vacuum cleaning system (vacuum pipes with vacuum tube connection points)
- Process automation
- Respiratory protection measures in dusty situations

Examples of NORM affected industries

Optimisation in the workplace at Thermphos (2)

- Continuous cleaning operations
- Improved ventilation
- Relocation of the slag beds
- Breathing air network in the sintering plant and in the phosphorus plant

- Measuring and monitoring programs

Examples of NORM affected industries

Examples of NORM affected industries

Examples of NORM affected industries

Examples of NORM affected industries

Examples of NORM affected industries

Two typical examples from the Netherlands

- Elemental phosphorus production
  - Thermphos International B.V.
  - Problems: Dust, residues, waste
- Slag wool from historical tin production
  - Variety of installations at dismantling
  - Problems: Dust, residues, waste

Examples of NORM affected industries

Slag wool in the Netherlands

- Used as thermal insulating material
- Discovered in a wide variety of installations
- Most likely origin: slag from tin production
- Probable production period: 1946 - 1960
- Probably large volumes already disposed as non-radioactive waste

Examples of NORM affected industries

Examples of NORM affected industries

Examples of NORM affected industries

Scope of regulatory control for NORM

Selection of criteria for defining the scope of regulatory control is a critical issue for NORM

- Average concentration of natural radionuclides in earth crust ranges from few hundredths to few Bq/g
- Corresponding terrestrial doses (excl. Rn) ranges from few tenths to few mSv/y
- Applying a trivial dose criterion of 10 μSv/y to NORM activities would bring large areas of the world under regulatory control

Scope of regulatory control for NORM

Therefore:

- Number of industries potentially subject to regulatory control is very large
- Trivial dose criterion of 10 μSv/y cannot be used for natural radionuclides
- Radiation protection standards for natural radionuclides relate to the OPTIMIZATION PRINCIPLE, rather than to trivial dose

Scope of regulatory control for NORM

Distinction between:

Practices

- Subject to requirements of practices, unless:
  - Exposure is excluded
  - Practice is exempted

Interventions

- Action levels to decide on remedial or protective actions to reduce exposure in existing *de facto* situations
  - Radon in workplaces
  - Chronic exposure from past activities

Scope of regulatory control for NORM

Exclusion

BSS:

- *"any exposure whose magnitude or likelihood is essentially unamenable to control…"*

ICRP:

- *"any realistic system … must have a clearly defined scope if it is not to apply to the whole of mankind activities… "*

Euratom Directive:

- *"natural radiation sources that are not amenable to control are excluded"*

Scope of regulatory control for NORM

Exclusion in BSS relates to amenability to control, rather than to the actual magnitude of the exposure

- **Exposure from ^{40}K in the body**
- **Cosmic radiation at the surface of the earth**
- **Unmodified concentrations of radionuclides in *most* raw materials**
  - **< 0.5-1 Bq/g for ^{238}U, ^{232}Th and ^{226}Ra**
  - **< ~4 Bq/g for ^{40}K**

Doses to individuals unlikely to exceed about 1 mSv/y

Scope of regulatory control for NORM

Exemption

- Used only in the context of practices
- Determines *a priori* which practices may be freed from requirements
- Exemption levels for ***artificial*** sources based on trivial dose (10 µSv/y)
- ICRP Publication 60 refers to a second basis for exemption, other than exemption on the basis of trivial dose, namely that:

  "no reasonable control procedures can achieve significant reduction in individual and collective doses"

Scope of regulatory control for NORM

Exemption

- EC has published a guidance document RP122 Part II on the issue of exemption (and clearance) of natural radioactive sources, based on an individual dose criterion of 300 μSv/y
  - Variation of natural background considered as a suitable dose criterion for setting exemption and clearance levels for natural radionuclides

- Most important levels:

^{238}U	0.5 Bq/g	^{210}Po	5 Bq/g
^{232}Th	0.5 Bq/g	^{210}Pb	5 Bq/g
^{226}Ra	0.5 Bq/g		

Scope of regulatory control for NORM

Exemption

- Responsible authority should establish exemption levels, based on a dose criterion somewhere in the range of 0.3-1 mSv/y
  - Taking into account economical, social and political factors
  - Balancing the consequences of regulatory control, in terms of necessary resources and impact on the regulated NORM activity, against the benefit in terms of approved radiation protection

Scope of regulatory control for NORM

Clearance

- **Intended to establish which sources can be removed from regulatory control**
- **Clearance levels defined as:**

  "values, established by the regulatory authority and expressed in terms of activity concentrations and/or total activity, at or below which sources of radiation may be released from regulatory control"

- **Concept of clearance differs from exemption, but values should be the same to avoid loops**

Scope of regulatory control for NORM

Action levels

- Refer to interventions
- Schedule VI of BSS gives guidelines for chronic exposure to radon in workplaces
  - 1000 Bq/m^3 yearly average
- ICRP 65 gives range
  - 500-1500 Bq/m^3

Regulatory requirements

Regulatory infrastructure

- Essential is a competent regulatory body, with:
  - Authority to establish regulations
  - Power to enforce compliance
- Regulations should define scope of regulatory control
- Instruments for control of NORM practices
  - Notification
  - Authorization
- Instrument for interventions
  - Action levels

Regulatory requirements

Practices

- Requirements shall be commensurate to characteristics of NORM practice
- GRADED APPROACH is necessary, depending on magnitude and likelihood of exposures
- Simple occupational hygiene control measures often provide sufficient radiation protection

Regulatory requirements

Practices - Notification

- **BSS: *"a document … to notify an intention to carry out a practice …"***
- **Informs the regulatory authority about intentions to carry out a certain practice**
- **Sufficient when the normal exposures are unlikely to exceed a small fraction of relevant limits, specified by authority**

Regulatory requirements

Practices - Authorization

- **BSS**: ***"a permission … to carry out a practice … The authorization can take the form of a registration or a license."***
- **Registration**: ***"a form of authorization for practices of low or moderate risks …"*** **on the basis of a safety assessment, with conditions and limitations as appropriate**
- **License**: ***"an authorization on the basis of a safety assessment, accompanied by specific requirements and conditions to be complied with by the license"***

Regulatory requirements

Interventions

- Protective and/or remedial actions, whenever justified
- Form, scale and duration optimised, taking into account social and economic circumstances
- Allocation of responsibilities between regulatory authority, national or local intervening organizations and operators

- Grey area between practice and intervention:
  long existing industries

Process to determine the required regulatory control

1. National inventory of NORM activities

- Overview of past, present and intended NORM activities
- Information contains process data and radiological data from raw materials, products, residues and waste
- Guidance from many studies, EU and IAEA reports
- Results in an overview of national NORM activities and the associated radiological data

Process to determine the required regulatory control

2. Categorization to radiological concern

- First categorization based on activity concentrations
  - Screening for compliance with exclusion or exemption levels
- Second categorization based on exposure of workers and public
  - Dose assessments
  - Additional data may be needed
- Third categorization based on waste generated
  - Volumes, characteristics, storage sites, legacies
  - Assessment of doses received by the public

Process to determine the required regulatory control

3. Screening against exclusion and exemption criteria

- Compare first list with generic exclusion criteria
- Results in list of not excluded NORM activities
- Compare with exemption criteria
  - Based on dose, but for operational purposes expressed in activity concentrations
  - Also identify if the NORM activity may be considered as being optimised

Process to determine the required regulatory control

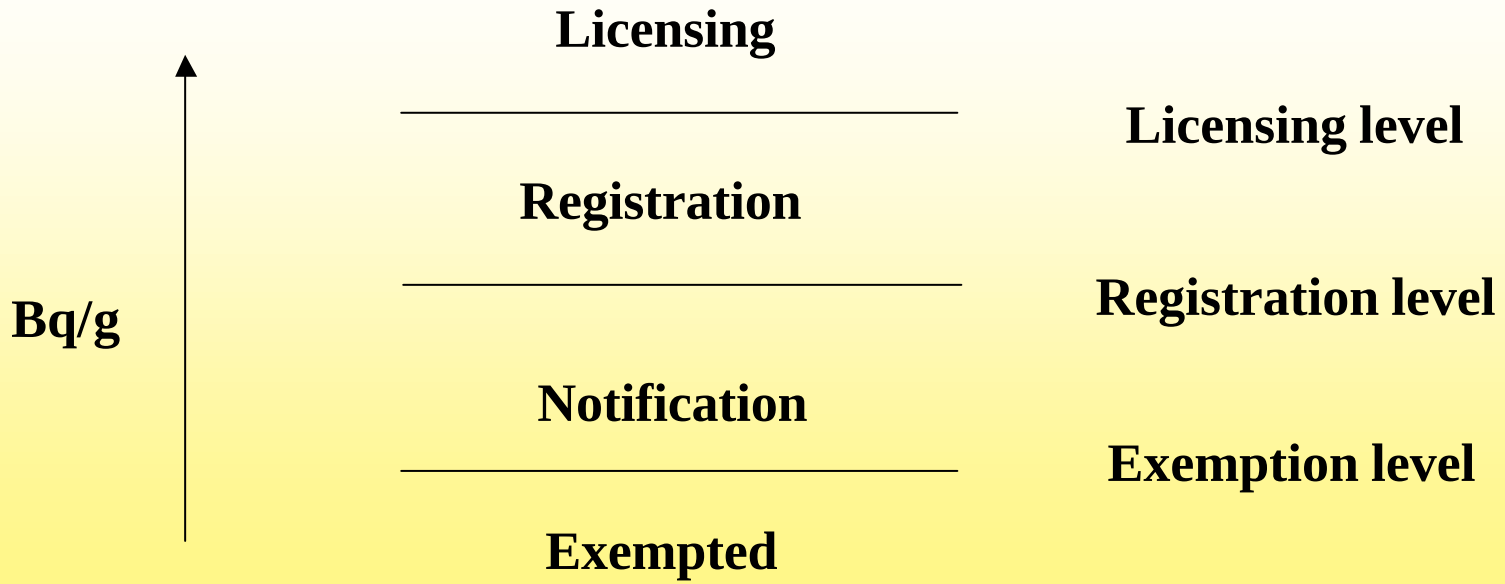
3. Screening against exclusion and exemption criteria (2)

- Results in overview of NORM activities that are:
  - Excluded from regulatory control
  - Exempted from regulatory control
  - Subject to regulatory control

Process to determine the required regulatory control

4. Use GRADED APPROACH for imposing regulatory control

- Define what is necessary and sufficient for an optimal level of radiation protection for practices
  - Define exemption, registration and licensing levels



Process to determine the required regulatory control

5. Interventions

- Radon in dwellings and workplaces
  - Guidance by ICRP, IAEA and EC
  - Use of building materials: guidance by IAEA and EC
- Old NORM activities and waste storage sites
  - Guidance by ICRP
  - Benefits of actions should be carefully judged against disadvantages
  - Costs in many cases considerable, if not prohibitive

Radiological protection issues

- Internal exposure most dominant pathway
  - Radon in workplaces
  - Large volumes of NORM in industry
  - Dusty work conditions
- Large differences in exposure situations
  - Type of industry
  - Workplace conditions
  - Radionuclides involved
- Need for guidance, specific for the type of industry
  - Appropriate protection measures
  - Monitoring strategies and methods

Radiological protection issues

Radon in workplaces

- Well known in mining industry
- Other underground workplaces
  - Tunnels, stores, show caves, spas
- Above-ground workplaces
  - Factories, shops, schools, offices, laundries
  - From soil gas, building materials, ground water

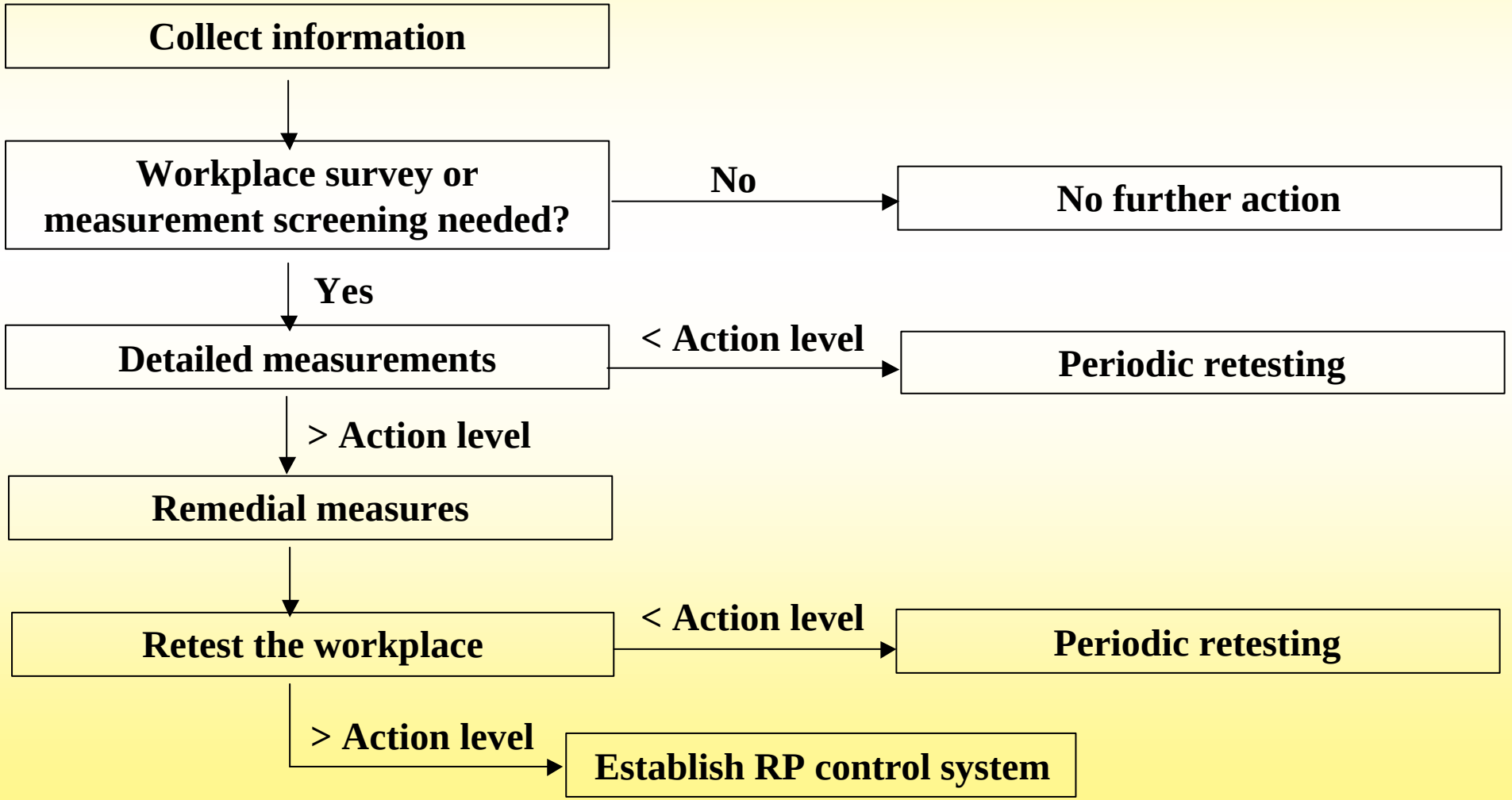
Radiological protection issues

Radon in workplaces

- Make surveys to assess the geographical variation of radon exposure in buildings and the variations between different types of workplaces
- Determine radon prone areas
- Establish action levels

Radiological protection issues

Radon in workplaces - Scheme for control



Radiological protection issues

Radon in workplaces – Remedial actions

Cost-effectiveness

Method	Cost	Effectiveness
Sub-floor depressurisation	Moderate	High
Sub-floor ventilation	Moderate/ Low	Variable
Floor sealing	Moderate	Moderate
Increased ventilation	Moderate	Low
Subsoil removal	High	High
Water treatment	Moderate	High

Radiological protection issues

Number of exposed workers in industry

- SMOPIE project (EC project under FP5) summarized available information in Europe
  - Severe lack of information
  - Not possible to evaluate the problem in a scientifically sound way
  - No mining included

Radiological protection issues

Exposed workers in EU industry (from SMOPIE)

NORM industry / work activity	Number of exposed workers	Basis for estimate
Thoriated electrodes Production, grinding, use	70,000	Dutch and German data
Phosphate fertilizer Trade and use	10,000	German data
Oil and gas production Maintenance work	2,000	1,000 production units; 2 persons per unit
Other industries	~3,000	

- Area for further research!

Radiological protection issues

General considerations for dose assessment

- Generic exposure scenario calculations make use of conservative parameters
- For specific dose assessments it is necessary to set up monitoring programs (air sampling)

Radiological protection issues

General considerations for dose assessment

- Air sampling strategy must be representative for the worker's exposure
  - Spatial and temporal variation of dust concentrations
  - Variation in time of the exposure
  - Mobility of workers
  - Multiple dust sources
  - Non-uniformity of dust composition

Radiological protection issues

General considerations for dose assessment

- PAS should be preferred above SAS
- Available sampling equipment has been designed for industrial hygiene, not for radiation protection
- Not possible to sample the true ambient aerosol required for radiation protection purposes
  - Affects assessment of activity concentration in air
  - Affects assessment of effective dose

Radiological protection issues

Aerosol characteristics

- Information needed about AMAD and GSD

Lung clearance

- Information needed about compounds (F, M, S)

Dose coefficients

- Not available for all combinations of natural radionuclides, AMAD, GSD and F, M, S
- Calculations made in SMOPIE project
- Also for low Rn emanation rate!

Radiological protection issues

Dose coefficients, ^{238}U chain, AMAD = 5 μm, GSD = 2.5

Chain (segment) Nuclide,	Fast	Moderate	Slow	Ratio S/F	Ratio S/M
^{238}U	5.9E-07	1.7E-06	5.7E-06	**9.8**	3.5
^{238}Usec	1.2E-04	3.7E-05	3.4E-05	**0.28**	0.92
^{238}Usec *)	1.2E-04	4.8E-05	6.5E-05	**0.53**	1.36
^{226}Ra	4.4E-07	2.2E-06	6.9E-06	**16**	3.2
^{226}Ra *)	4.4E-07	1.4E-05	3.8E-05	**87**	2.8
^{226}Ra+	2.3E-06	5.1E-06	1.4E-05	**6.1**	2.7
^{226}Ra+ *)	2.3E-06	1.6E-05	4.5E-05	**20**	2.8
^{210}Pb	1.1E-06	7.4E-07	4.3E-06	**3.8**	5.7
^{210}Po	7.3E-07	2.2E-06	2.7E-06	**3.7**	1.25

*) Low Rn emanation rate

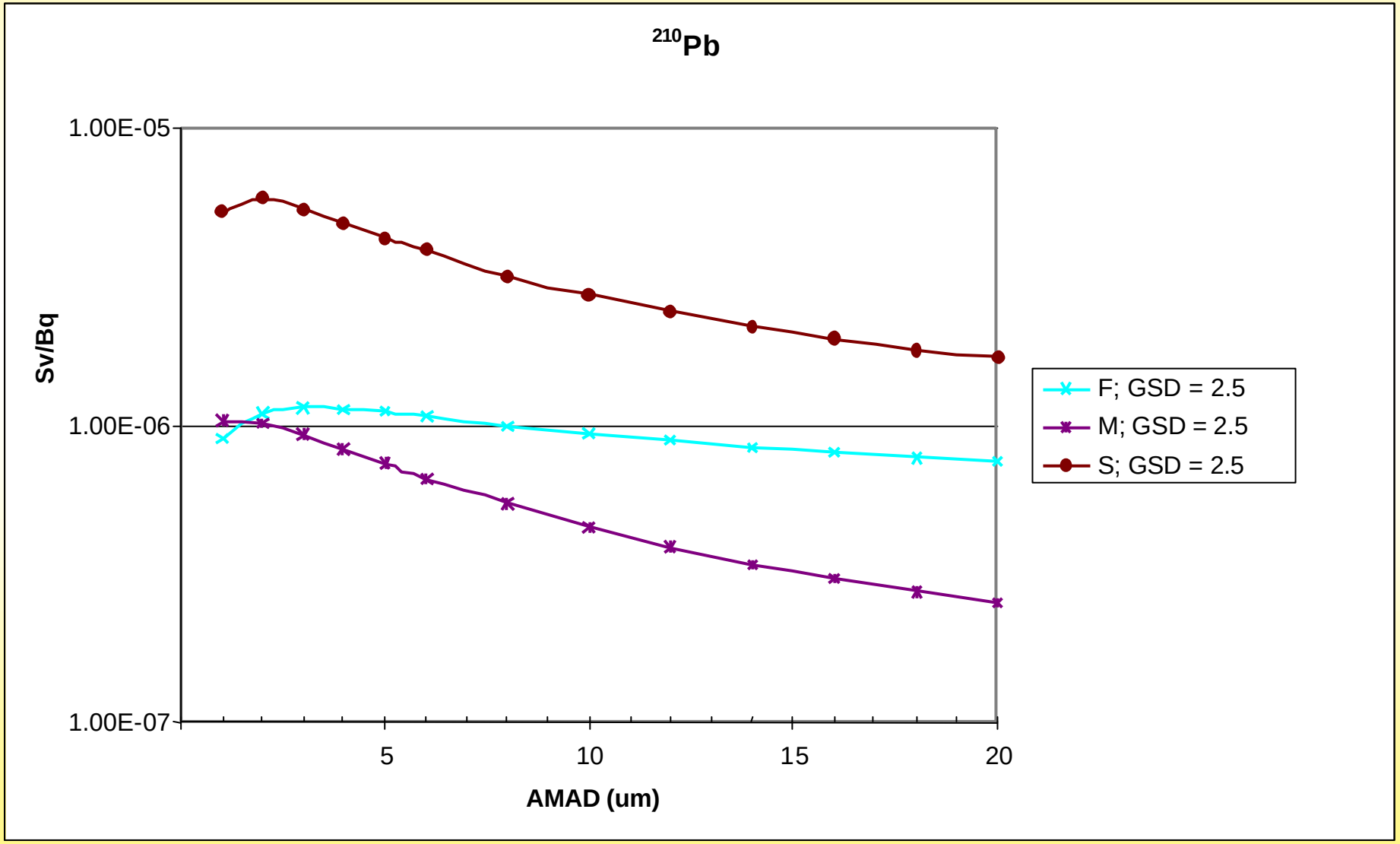
Radiological protection issues

Dose coefficients, ^{232}Th chain, AMAD = 5 μm, GSD = 2.5

Chain (segment) nuclide	Fast	Moderate	Slow	Ratio S/F	Ratio S/M
^{232}Th	1.3E-04	2.9E-05	1.2E-05	**0.09**	0.41
^{228}Ra	1.1E-06	1.7E-06	1.1E-05	**10**	6.7
^{228}Th	3.4E-05	2.2E-05	2.5E-05	**0.74**	1.14
^{232}Thsec	1.6E-04	5.3E-05	4.9E-05	**0.30**	0.92

Radiological protection issues

Dose coefficients, dependence of lung clearance and AMAD



Radiological protection issues

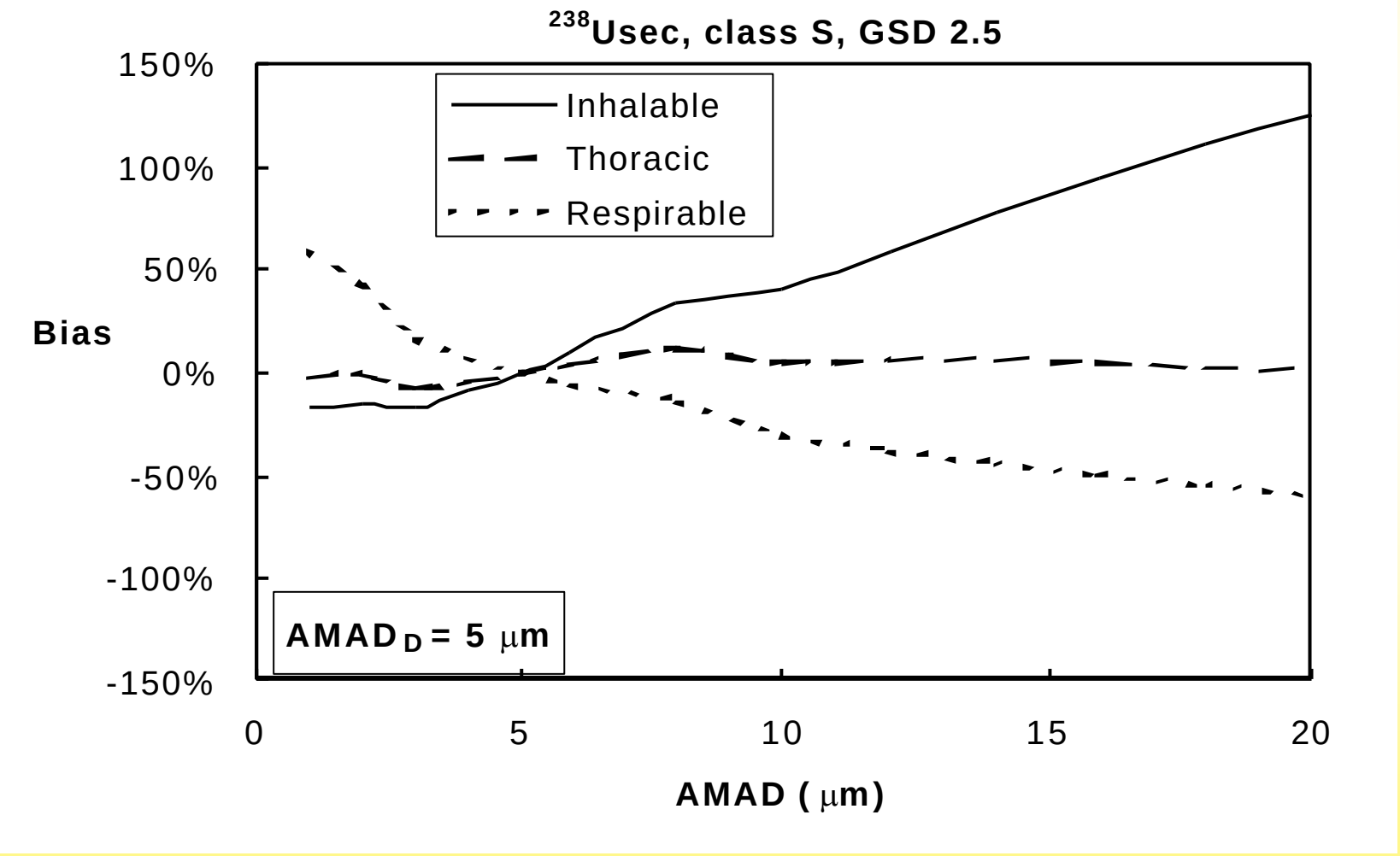
Requirements for monitoring techniques

- Sensitivity
  - Able to assess doses well below 1 mSv/y
- Accuracy
  - Avoid bias and minimize uncertainty
- ALARA information
  - Provide information about exposure patterns
- Equipment suitability
  - Equipment with appropriate sampling characteristics
  - Practical use

Radiological protection issues

Requirements for monitoring techniques

Sampling characteristics



Radiological protection issues

Graded approach for establishing a monitoring programme

- Nine steps procedure, from first screening to detailed assessments and monitoring programme