IAEA
International Atomic Energy Agency

13.1 A general introduction to optimization of radiation protection in NORM industries

Optimization and NORMs : Course plan

To illustrate the implementation of optimization in NORMs, the course will be divided into two parts

- Part 1: A general introduction to optimization of occupational radiation protection in NORM industries
- Part 2 : examples of optimization in NORM industries

Part 1: general introduction
What about the ALARA approach implemented in the NORM industries?

- We will not develop the need for regulations and regulatory framework in NORM industries
- We will only consider the situation when the radiological stakes justify a formal implementation of optimization for the workers
- We will address the specificities of occupational exposures to NORM, in particular the importance of inhalation and the problems it raises
- Very often in NORM, many other risks are faced which can overcome the radiological one
- We will therefore also emphasize the relative places of occupational hygiene and radiation protection

Types of Materials concerned

Numerous raw materials containing natural radionuclides are exploited, but two classes of materials can be identified:

- Exploitation of uranium and thorium ores
- Exploitation of other raw materials

Exploitation of Uranium and Thorium Ores (1)

These operations include:

- Exploration, surface prospecting and testing of ore samples
- Excavation of test pits and removal of ore for evaluation
- Siting, construction, operation and maintenance of a mine or of a facility for physical or chemical processing of the ore
- Decommissioning or closure of a mine or facility

Exploitation of Uranium and Thorium Ores (2)

Workers may be exposed to significant gamma dose rates and radioactive dusts

Underground workers may be exposed to high concentrations of radon progeny

Mining and processing facilities are assumed to fall automatically within the scope of regulation: workers exposures have to be formally optimized

Exploitation of other raw materials (3): non-radon exposures

When the raw materials are not excluded or exempted from regulatory control i.e. when concentration in the soil exceeds:

- 1 $Bq.g^{-1}$ for each radionuclide in the U / Th decay chains
- 10 $Bq.g^{-1}$ for 40K

Then exposure levels should be investigated and quantified, and when they are expected to exceed 1mSv a year.

- Gamma radiation and dust exposures may require control
- *workers exposures have to be formally optimized*

Exploitation of other raw materials (4): non-radon exposures (contd.) Criteria for control

All previous prerequisites concern:

- Mineral sands separation and rare earth extraction operations
- Mining and processing of niobium and tantalum ores
- Oil and gas production
- Manufacture of phosphoric acid and phosphate fertilizers
- Manufacture of zirconia and zircon products

Exploitation of other raw materials (5): radon exposures
Criteria for control

- The principles of existing exposure situations are used
- The reference level for intervention in existing exposure situations is determined on the basis of optimization of protection
- Expected reference level is a Rn concentration of 1000 Bq/m3
- Optimization of workers exposures is always required, regardless of Rn concentration
- Above the reference level, remedial action is required

Actual Worker doses Stakes in some of the 12 NORM industries

ALARA has to be formally implemented in:	IAEA EAN ARAN data mSv / year		NORM VI symposium		
			Min	mean	max
1. Mining and processing of uranium ore		3 – 4 (av.)		7.8	40
2. Production of rare earth elements — Separation of monazite from mineral sands — Chemical extraction of REEs		1.5 – 7 3 – 9	0,3		1
3. Thorium extraction & use — Production of thorium compounds — Gas mantle production — Other uses of thorium		~ 10 (max.) 1 – 10 0 – 0.3			82
4. Niobium extraction					
5. Non-uranium mines		0.1 – 8.5 (av.)			
6. Oil and gas		0 – 1.6			0,05 - 3
7. Phosphate industry	0.02 – 1		0,009		2,7
8. Zircon & zirconia — Thermal zirconia production — Other		0.7 – 3.1 0.01 – 1			0,4
9. TiO_2 pigment production		0.03 – 1			0,3 -0,5
10. Metals production (Sn, Cu, Al, Fe, Zn, Pb)		*4 (Av.) 18 (max)*			
11. Burning of coal etc		0.15 (max.)			
12. Water treatment (Rn, solid residue)		*6 - 100*			

Exposure components and NORM

As previously seen when describing the NORM industries, even if the external exposure always exists, the main characteristic of workers' exposure is the existence of internal exposure with the most important component being inhalation *(to gazes such as radon, or dust particles in many cases)*

What has to be optimized?

" Any exposure at work should be included in the occupational exposure " (ICRP 60) and as clearly stated in the BSS, exposure includes automatically the external and internal components.

In the case of NORM industries, contrarily to nuclear field, the concerned radionuclides do not have very high specific activity that may induce unacceptably very high doses in a very short time of inhalation. Therefore inhalation "does not have to be avoided at any cost".

In the case of NORM inhalation gives rise to doses in the range of low or very low doses (see table in previous slide). The internal exposure will not be considered as "accidental" it will be "predictable".

The internal component has then to be added to the external one within the optimization process.

What has to be optimized?
The sum external and internal

For a specific task " x ", performed by " y " individuals in " h " hours it will be necessary to take care of all the factors contributing to radiation dose . The dose to the individual will therefore be calculated as:

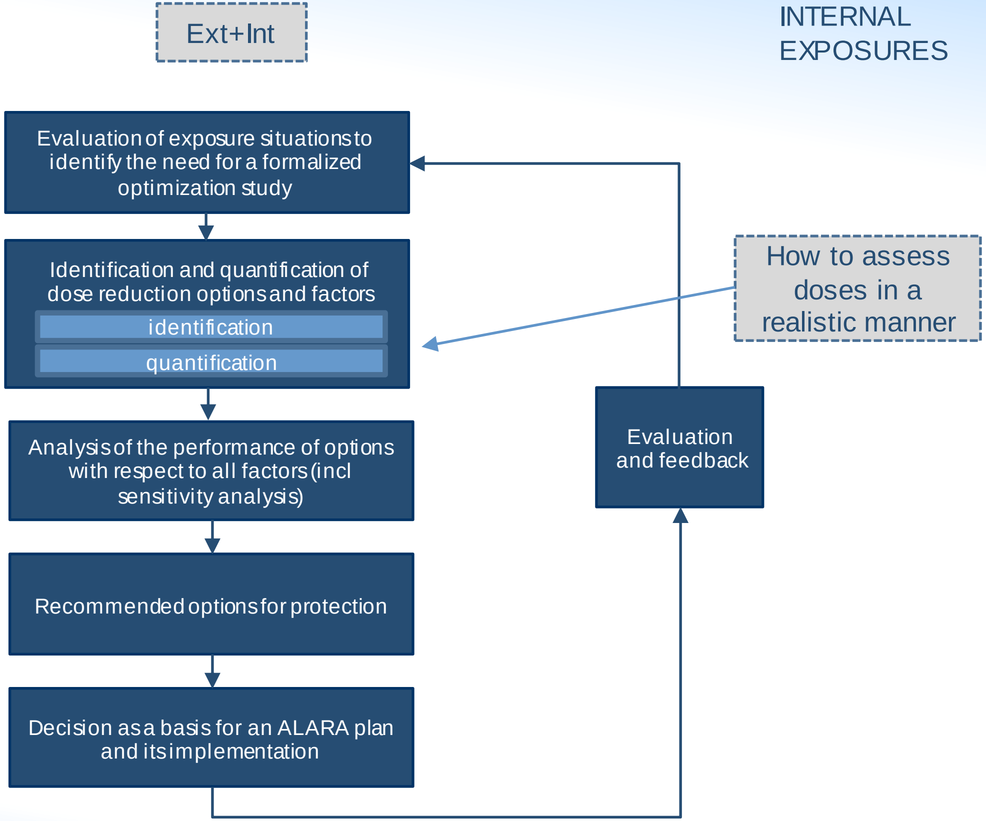
$$E_{y,x} = (E_{external.y,x} + E_{internal,y,x}) = (d_x \;.\; t_{y,x}) + ((V_y \;.\; C_{y,x} \;.t'_{y,x}).\; F)$$

with

- d_x= dose rate (mSv/h)
- $t_{y,x}$= duration of external exposure (h)
- V_y= respiration rate (m^3/h)
- $C_{y,x}$= concentration of air inhaled (Bq/m^3)
- $t'_{y,x}$= duration of inhalation (h)
- **F** = effective dose coefficient (mSv/Bq)

What has to be optimized is $E_{y,x}$

INTERNAL EXPOSURES



How to implement an analytical approach?

For optimizing the protection of workers, it is necessary to be as realistic as possible through an analytical approach.

Therefore one has to try first to answer the following questions

- **What doses have been received by whom?**
- **Where has it been received (work places)?**
- **When has it been received (jobs, tasks)?**

Does the available information allow to answer these questions ?

What tools are available for the monitoring in an optimization perspective ?

- This determines the monitoring methodology for optimization
  - Bioassays do not allow to answer all the previous questions
  - Only way is by monitoring through air sampling
    - Personal air sampling (PAS)
    - Static air sampling (SAS)
    - Real time dust monitoring (RTDM)

We will not develop here the technical calculation of doses; for doing that one can refer to the IAEA training manual on this issue.

What tools are available for the monitoring in an optimization perspective ?

SAS and RTDM are useful

- to identify specific sources of airborne dust
- to identify specific workstations and tasks
- to assess the effectiveness of countermeasures against such sources

But can SAS replace PAS for dose assessment purposes ?

What tools are available for the monitoring in an optimization perspective? PAS is preferable

- The SMOPIE study has shown that the assessment of internal exposure of workers to industrial natural sources should be preferably based on PAS, which is the preferable tool

    - to identify specific workstations and tasks
    - to assess the effectiveness of countermeasures against such sources

The PAS is more representative of the concentration close to the worker

In some cases in NORMs, the concentration of radionuclide's in the air is mainly due to the worker's operation itself such as the opening of a barrel for example; therefore SAS may underestimate drastically the activity inhaled by the worker in integrating also concentration when no operation occurred.

What tools are available for the monitoring in an optimization perspective? PAS is preferable

As a conclusion dose estimations should be based on *realistic assessments of* the exposures that are likely to be received.

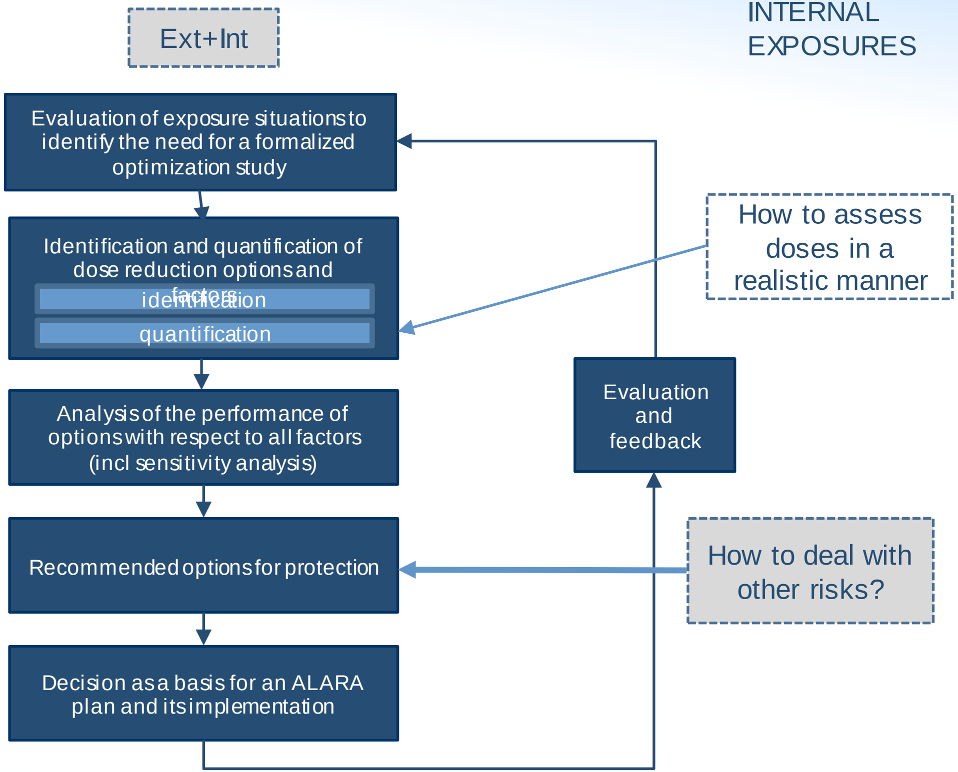
Doses estimated from exposure models are often grossly pessimistic.

Estimates based on actual measurements in the workplace are preferred.

PAS is preferable to SAS or RTDM.

Personal air samplers

INTERNAL EXPOSURES



Radiation is only one of many hazards in NORM industries

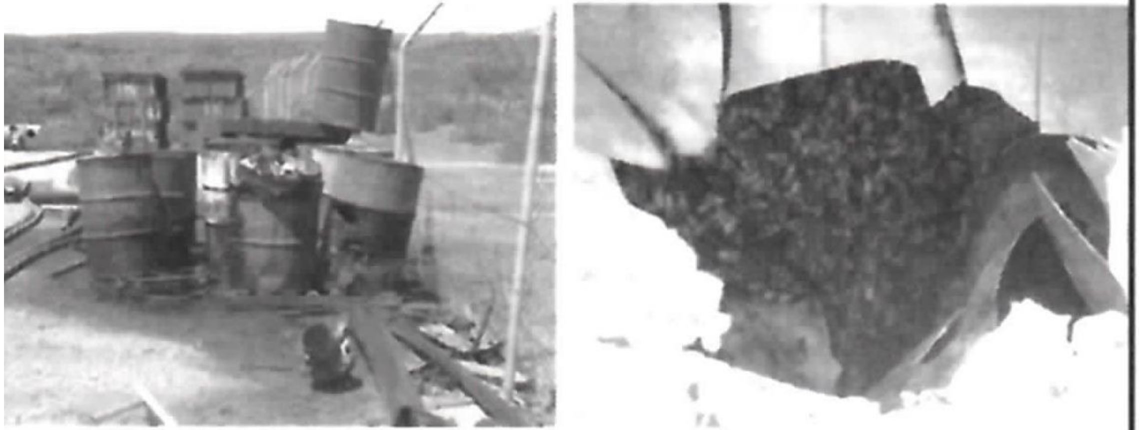
This is the case in mining as well in processing sites; all these should be treated as part of an overall occupational health and safety program

Other parts of health and safety that require specific attention and should be addressed simultaneously:

- *Noise and vibration*
- *Ventilation – other contaminants – dust*
- *Working at heights*
- *High voltage electricity*
- *Heat stress*
- *Etc.*

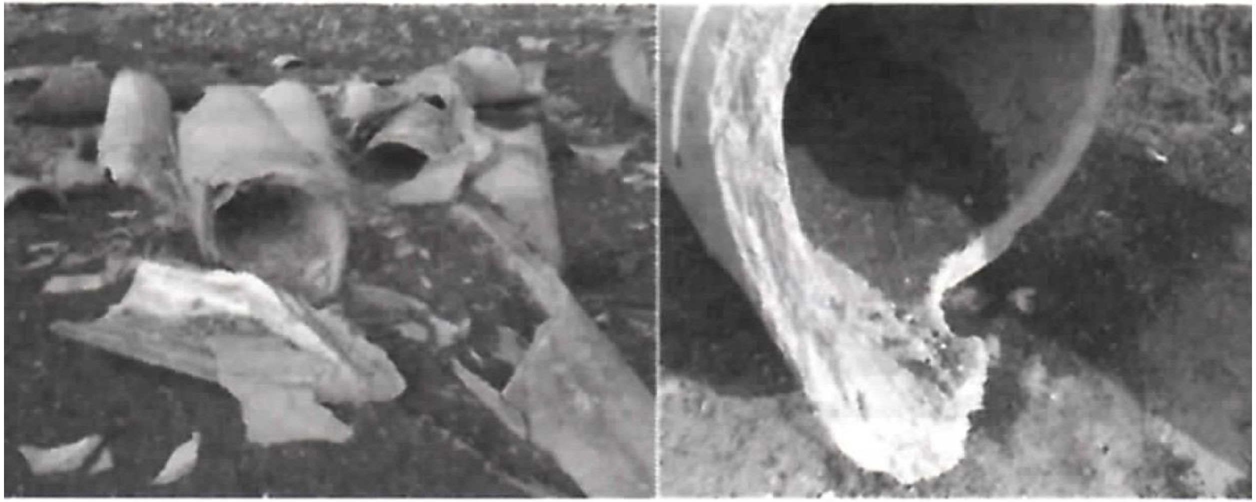
Radiation and other hazards : example 1

Mixed waste, Australia:
Radioactive material + hydrocarbons + biological hazard



Radiation and other hazards : example 2

Mixed waste, Asia:
Radioactive material + asbestos + chemicals



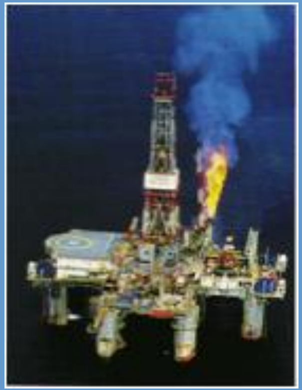
Radiation and other hazards : example 3

Radiation protection and industrial hygiene

Although many NORM industries know little about radiation protection, they are often familiar with worker protection from a wider industrial hygiene perspective.

The two approaches are complementary, and compliance with traditional health and safety controls may be sufficient to ensure that radiation exposures are also adequately controlled.

Even where this is not the case, any additional radiation protection controls should, where practicable, follow the industrial hygiene ethos.



Conclusions to part 1

Main characteristics of the implementation of Optimization in the NORM industries are therefore:

- The need, when implementing the Optimization "procedure" to assess the stakes for both external and internal components of the exposure, to quantify and to assess the efficiency of the protections actions taking care of both components
- The need to be as realistic as possible when estimating individual internal doses per inhalation, making use when possible of PAS
- The need to "merge" the Optimization programmes into more global industrial hygiene programmes, where any decision dealing with radiation protection will be taken following a multi criteria proc

Annex 1 : Where to get more information (1)

ICRP Publications:

- Protection against Radon-222 at Home and at Work (ICRP Publication 65, 1994)
- ICRP 2001,"The Optimization of Radiological Protection-Broadening the process", ICRP Publication 101b, Ann.ICRP 36 (3)
- "The 2007 Recommendations of the International Commission on Radiological Protection", ICRP Publication 103, Ann.ICRP 37 (2-4)
- ICRP Statement on Radon (Porto Statement, November 2009)

Annex 1: Where to get more information (2)

IAEA Publications

- “Fundamentals Safety Principles”, IAEA, Safety Fundamentals SF-1, Vienna, 2006)
- “Optimisation of Radiation Protection”, Safety Reports Series No 21, IAEA, Vienna, 2002 (under revision)
- “Occupational Radiation Protection”, General Safety Guide, GSG-7,IAEA, Vienna, 2018
- “Radiation Protection and Safety of Sources: International **B**asic **S**afety **S**tandards”, IAEA Safety Standards, GSR Part 3, Vienna, 2014

Annex 1: Where to get more information (3)

IAEA SAFETY GUIDES

- Safety Guides recommend actions, conditions or procedures for meeting the IAEA's Safety Requirements, and reflect current internationally accepted principles and recommended practices:
- Application of the Concepts of Exclusion, Exemption and Clearance (IAEA Safety Standards Series RS-G-1.7, 2004)

IAEA SAFETY REPORTS

- "Assessing the Need for Radiation Protection Measures in Work Involving Minerals and Raw Materials", Safety Report No 49, IAEA, 2006)
- IAEA NORM training manual

Annex 1: Where to get more information (4)

IAEA SAFETY REPORTS

- “Assessing the Need for Radiation Protection Measures in Work Involving Minerals and Raw Materials”, Safety Report No 49, IAEA, 2006)
- IAEA NORM training manual

Other references on *Optimization of Radiation Protection*

Optimisation of Radiation Protection - ALARA: A Practical Guidebook, European ALARA Network, First publication, 2019

A less recent reference, but still useful is the European Commission book: “ALARA from theory towards practice”, EC Report EUR 13796 EN, DG Science, Research and Development, 1991

Annex 2: NORM 6

TABLE 1. DOSES RECEIVED BY WORKERS, AS REPORTED AT THE SYMPOSIUM
(Excluding doses from inhalation of radon and thoron, except where stated otherwise)

	Annual effective dose (mSv)			
	Minimum	Mean	Maximum	Distribution
Uranium ore mining		7.8	40–45	
Processing of thorium concentrate[a]	3.0		7.8	
Production of thorium compounds[b]			82	67% < 1
Mining of rare earth ore[c]		0.24–1		
Beneficiation of rare earth ore[c]		0.28–0.61		
Handling of monazite			0.3	
Rare earth separation and purification			0.3	
Decommissioning of a rare earths plant[d]	0.2	7.2	8.94	
Mining of ore other than uranium ore			<1	
Oil and gas production, offshore			0.5	
Oil and gas production, onshore			0.05	
Oil production, cleaning of pipes[c,e]		0.6	3	80% < 1
Titanium dioxide pigment production			<0.5	
Titanium dioxide pigment production			0.27	
Phoshate ore storage			0.28	
Phosphate fertilizer production			0.5	
Phosphate industry facilities[f]	0.009		2.7	
Zircon production			0.4	

symposium are summarized in Table 1. The annual effective doses given in Table 1 include the contributions from external exposure to gamma radiation and internal exposure to inhaled dust but (except where stated otherwise) not the contributions from the inhalation of radon and thoron, which are usually treated separately. The