What is the radiological/ecological impact of NORM residues and effluents on the environment

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Examples of industries affected by NORM

- Uranium mining and milling
- Phosphate industry
- Oil and gas
- Coal production and use
- Metal mining and extraction
- Mineral sands mining and extraction
- Water production and purification
- Geothermal power production
- Clay and ceramics
- Use of by-products

Properties of NORM waste: a myriad of cases
Radiological aspects

- Different radionuclides of major concern
  - ^{232}Th series radionuclides (e.g. mineral sands)
  - ^{226}Ra in sludges and scales of oil and gas industry
  - ^{238}U and ^{226}Ra in sludges from P-industry
  - ^{210}Pb in dust from smelting in metal industry
- Variety in radionuclide concentrations
  - ^{226}Ra : 1 Bq/g in phosphogypsum sludge from P-industry
    10^6 Bq/g in scales in tubing of petroleum industry
  - ^{232}Th : <0.1 Bq/g in phosphogypsum sludge
    10^3 Bq/g in refractory bricks
- Element mobility
  - ^{226}Ra has higher availability in phosphogypsum sludge than in scales

Properties of NORM waste: a myriad of cases
Physical forms and quantities

- Different physical forms
  - Waste water from oil and gas production, coal and uranium extraction
  - Sludge from P-fertilizer production, water treatment, metal processing, …
  - Scales in oil industry, P-industry
  - Ashes and slag from metal processing, coal industry
  - Waste rock
  - Miscellaneous waste: filter cloth, filter parts, …
- Large volumes with (relatively) low specific levels of radioactivity
  - Phosphogypsum sludge (160 Mt/a), Al red mud (65 Mt/a), U tailings (20 Mt/a, 1000 Mt legacy)
  - Waste water from industrial processes
- Small volumes containing high levels of specific radioactivity
  - Sludge from water treatment plants; scale from oil and gas tubings (20 to 400 t/a per well head) > 10^3 Bq/g

Properties of NORM waste: a myriad of cases
Non-radioactive hazardous components

- Impacts of non-radiological contaminants as important or even more important than radiological impacts

- Heavy metals (HM), arsenic, toxic organics
  - Oil and gas — Hg, HM, hydrocarbons
  - Phosphate — Cd, Zn, Pb, F, As
  - Iron and steel — Pb, Zn, Cr, Cd, Cu, As, Hg, Ni

- Non-radiological parameters drive the dispersion of radioactive contaminations
  - pH, sulphuric acid content, ground water head

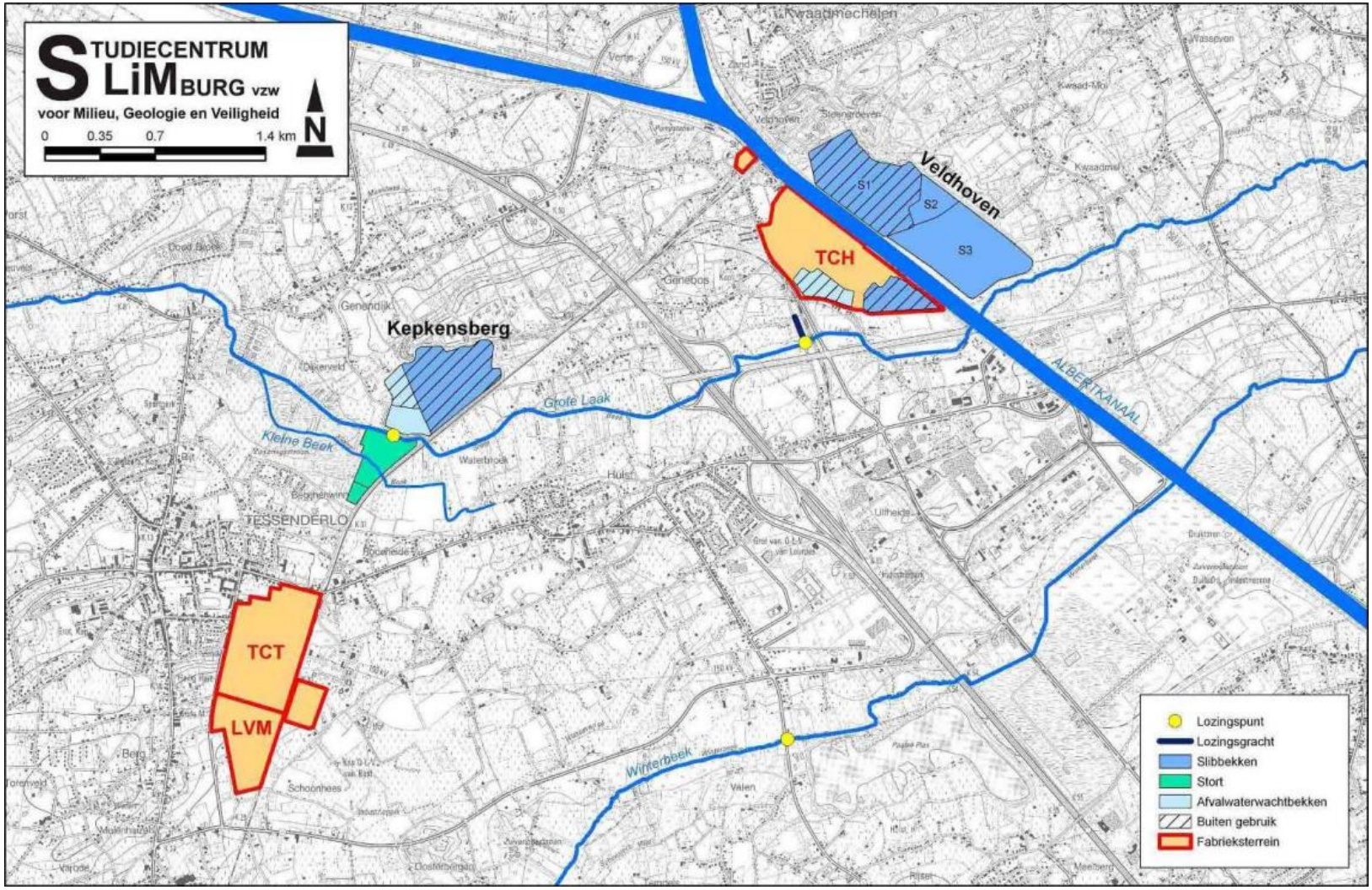
Important release mechanism for pollutants to the environment

- During operation
  - Dust emission and release of ^{210}Pb and ^{210}Po from stacks from smelters or furnaces
  - Release of waste streams to river and sea
    - Sea dumping of radium scales in oil and gas industry
    - Sea or river dumping of $CaCl_2$ from P-industry
    - Routine releases of process water
- From tailings or from disposal sites in general
  - Erosion of the cover or embankments
  - Radon emanation
  - Dust
  - Structural failure of tailings embankments
  - Controlled release of contaminated water
  - Seepage
  - Unauthorised removal

General dose delivery pathways to humans

- Atmospheric pathways
  - Inhalation of radon and its daughters
  - Inhalation of radioactive particulates
  - External irradiation (gamma)
- Atmospheric and terrestrial pathways
  - Ingestion of contaminated foodstuffs
  - External irradiation
- Aquatic pathways
  - Ingestion of contaminated water
  - Ingestion of foods produced using irrigation, fish and other aquatic biota
  - External irradiation

Example: Tier 1 impact assessment for phosphate industry



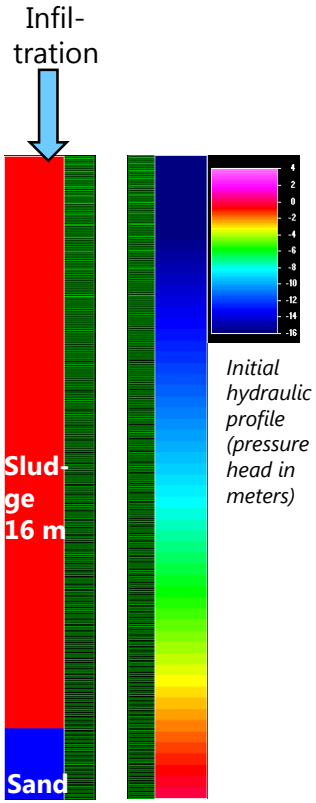
NORM site Veldhoven

- ^{226}Ra in the phosphate ores: 1,2-1,5 Bq /g
- Dissolution with HCl resulted in dicalcium phosphates, CaF_2 sludge and $CaCl_2$ in discharge water, $CaSO_4$ scales
- Veldhoven CaF_2 sludge deposit
  - 9 Mm^3 uncovered sludge over 55 ha
  - ^{238}U, ^{226}Ra and daughters; ^{226}Ra 3.5 Bq/g
  - up to 2.5 µSv/h
  - up to ~ 500 Bq/m^3 radon

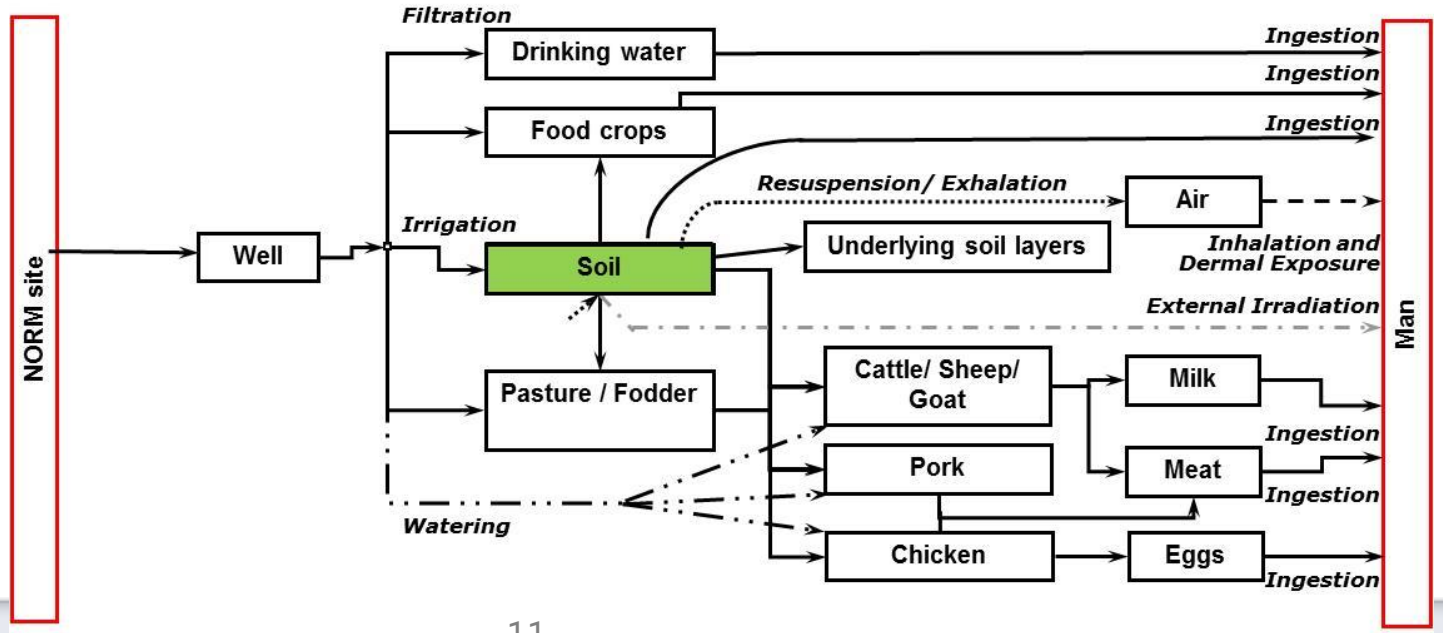
Radiological assessments

- Human impact assessment
  - Sludge heap
    - Well scenario
    - Residence (subsistance) scenario
  - River banks
    - Recreational scenario
    - Residence (subsistance) scenario
- Environmental impact assessment
  - River
  - River banks

Sludge heap
Dose impact due to use of well water



- Leaching through waste heap, leachate diluted in groundwater, and use of well at 50 m
- Representative person: self-sustaining farmer
- Well-water used for drinking water, dredging of cattle, irrigation
- Exposure pathways: inhalation, ingestion, external irradiation



Sludge heap
Well scenario

Well pathway	Dose, mSv/y
Ingestion	
Water	2,72E-03
Crops	6,47E-03
Meat/milk/eggs	1,10E-03
Soil	8,07E-05
Dust + radon inhalation	6,86E-05
External Irradiation	2,01E-04
Total	**1,06E-02**

Conservative approach

'Realistic' doses ~ 10% of conservative values

~100 % dose impact from ^{238}U

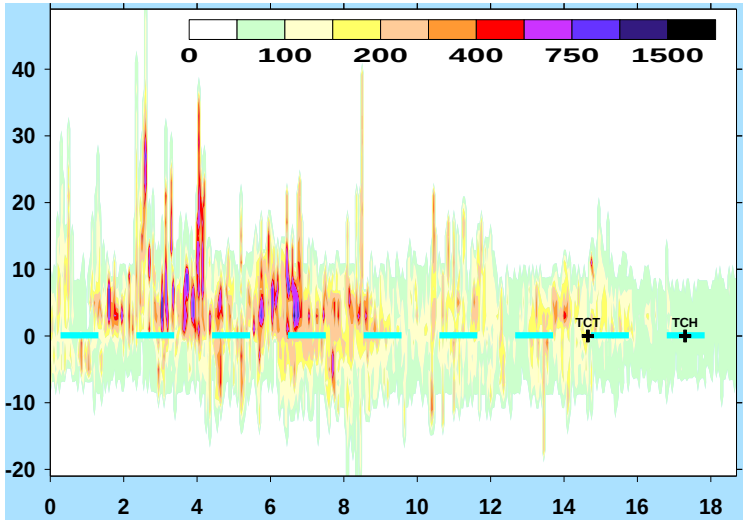
Disposal site
Residence scenario, intrusion scenario

- No cover, people 100 % of time on site (1800 h/a outdoors, 7000 h/a indoors), cellar in waste
- Food grown on site
- U, Ra and daughters: 3,5 Bq/g
- Radon outside: 35 Bq/m³
  Radon inside: 1155 Bq/m³
- Very conservative

Residence, waste heap		Dose, mSv/y
Ingestion		
	Crops	2,53E+00
	Soil	2,23E-01
External Irradiation		
	Outdoors	1,57E+00
	Indoors	2,03E+00
Dust inhalation		
	Outdoors	2,18E-03
	Indoors	2,65E-03
Radon		
	Outdoors	3,87E-01
	Indoors	3,45E+01
Total		**4,12E+01**

Contaminated river banks of Grote Laak

- Liquid discharges in Grote Laak resulted in contamination of riverbanks due to flooding
  - ^{226}Ra: 0.8 Bq/g
  - ^{210}Pb, ^{210}Po : 0.6 Bq/g (derived from ^{226}Ra levels considering ^{222}Rn exhalation)



Contaminated riverbanks
Recreation and subsistance scenario

- Recreational scenario (2h/d on river bank)

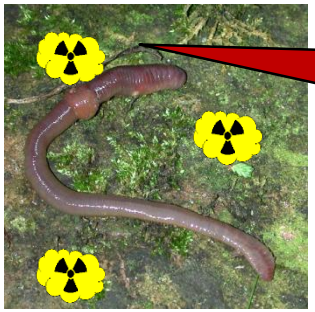
Residence, banks Grote Laak	Dose, mSv/y
Ingestion	
Crops	5,85E-01
Soil	5,16E-02
External Irradiation	
Outdoors	3,63E-01
Indoors	4,72E-01
Dust inhalation	
Outdoors	5,06E-04
Indoors	6,15E-04
Radon	
Outdoors	8,96E-02
Indoors	9,58E-01
Total	**2,52E+00**

Recreational, river banks	Dose, mSv/y
External Irradiation	4,71E-02
Inhalation	7,83E-05
Radon	2,08E-02
Total	**6,80E-02**

- Subsistance scenario (cfr scenario waste heap)
- Measured Rn indoors: 38 Bq/m^3
  CalculatedRn outdoors: 7,3 Bq/m3

Impact on wildlife: Why look at it?

- Paradigm contested: “If man is protected, the environment is protected”

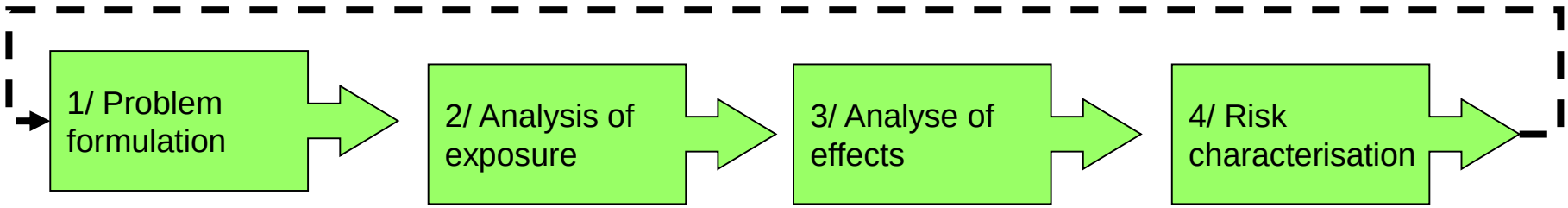


I may be less radiosensitive but I stay all the time in or on the contaminated soil

- Over last decade, considerable international and national effort with environmental protection now being referred to in the IAEA Fundamental Safety Principles and Recommendations of the ICRP

Environmental risk assessment (ERA): Several steps

ERA
screening



$$RQ = \frac{PEDR}{PNEDR}$$

$$\frac{\text{Predicted environmental dose rate}}{\text{Predicted no effect dose rate}}$$

PNEDR -PROTECT-ERICA Screening Value: 10 µGy/h

Tessenderlo Chemie – Grote Laak

TERRESTRIAL

Concentrations (Bq kg^{-1}) on right river border of Grote Laak

	^{226}Ra	^{210}Pb*	^{210}Po*
Mean concentrations	811	*649*	*649*
Mean concentration for soil sampled at highest dose rate locations	5,822	*4,658*	*4,658*

AQUATIC

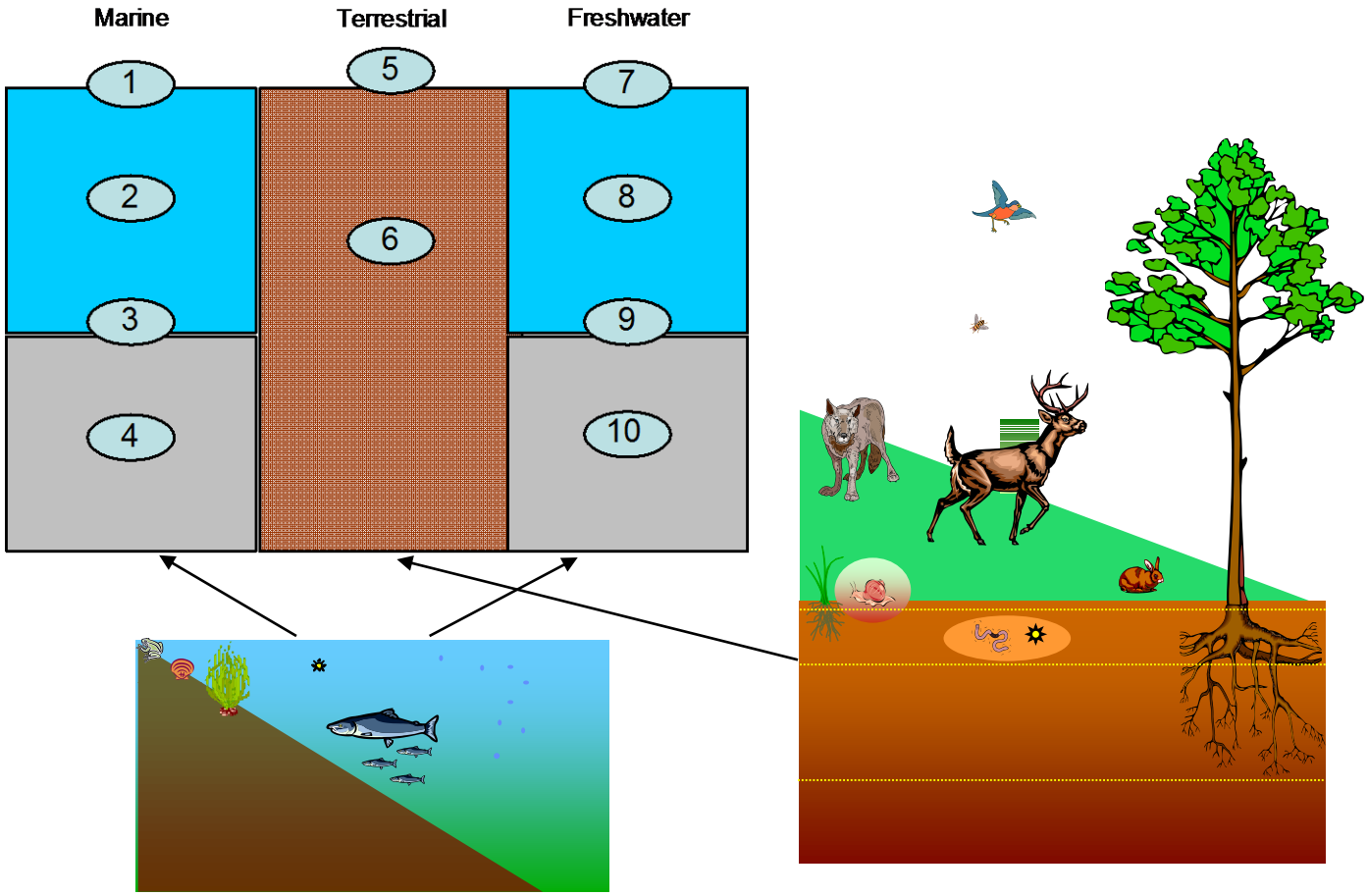
^{226}Ra concentrations in river water (Bq L^{-1}) and sediment (Bq kg^{-1}) of Grote Laak

		1998		1999		2000		2001	
		Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment
Grote Laak	average	0.14	818	0.18	528	0.21	475	0.13	327
	maxima	0.37	1,200	0.43	902	0.34	629	0.38	461

ERICA reference organisms for terrestrial and aquatic environments

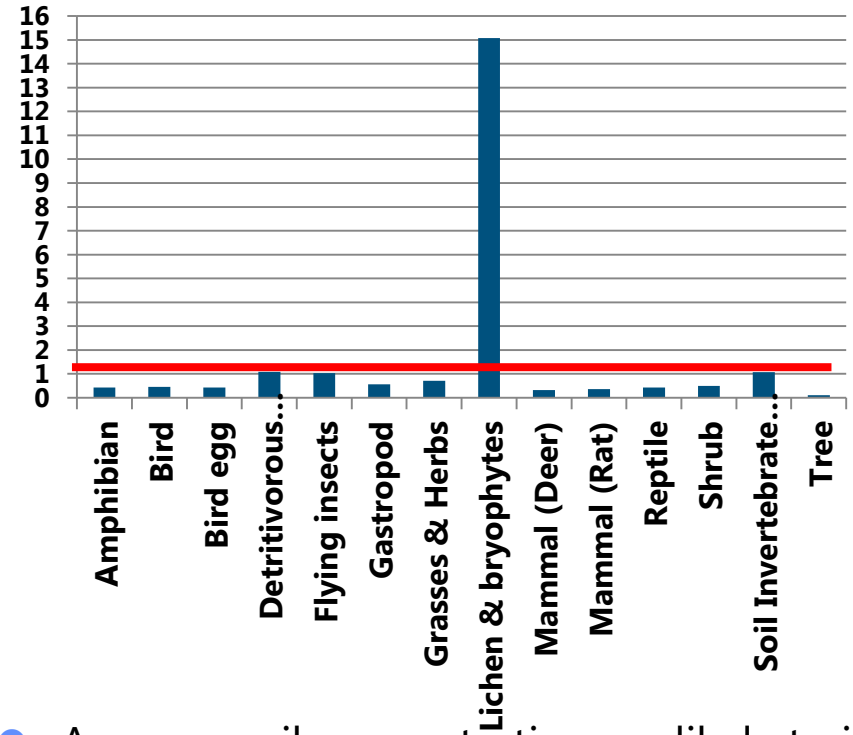
Freshwater	Terrestrial
Amphibian (frog)	Amphibian (frog)
Benthic fish	Bird (duck)
Bird (duck)	Bird egg (duck egg)
Bivalve mollusc	Detritivorous invertebrate
Crustacean	Flying insects (bee)
Gastropod	Gastropod
Insect larvae	Grasses & herbs (wild grass)
Mammal	Lichen & bryophytes
Pelagic fish (salmonid/trout)	Mammal (rat, deer)
Phytoplankton	Reptile
Vascular plant	Shrub
Zooplankton	Soil invertebrate (earthworm)
	Tree (pine tree)

The ten ERICA habitats

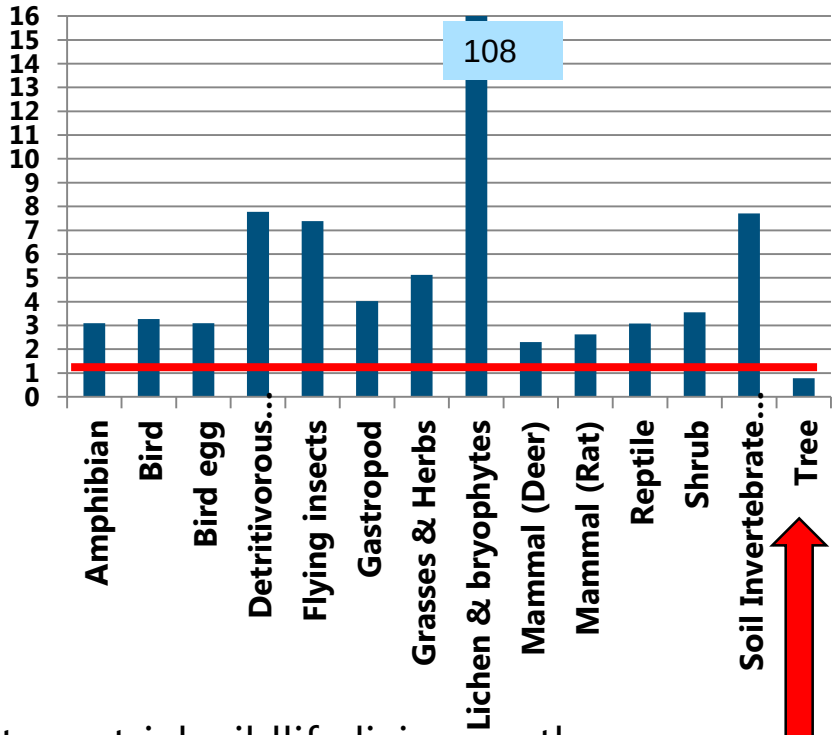


RQ for Tessenderlo – Grote Laak riverbanks

Terrestrial - average

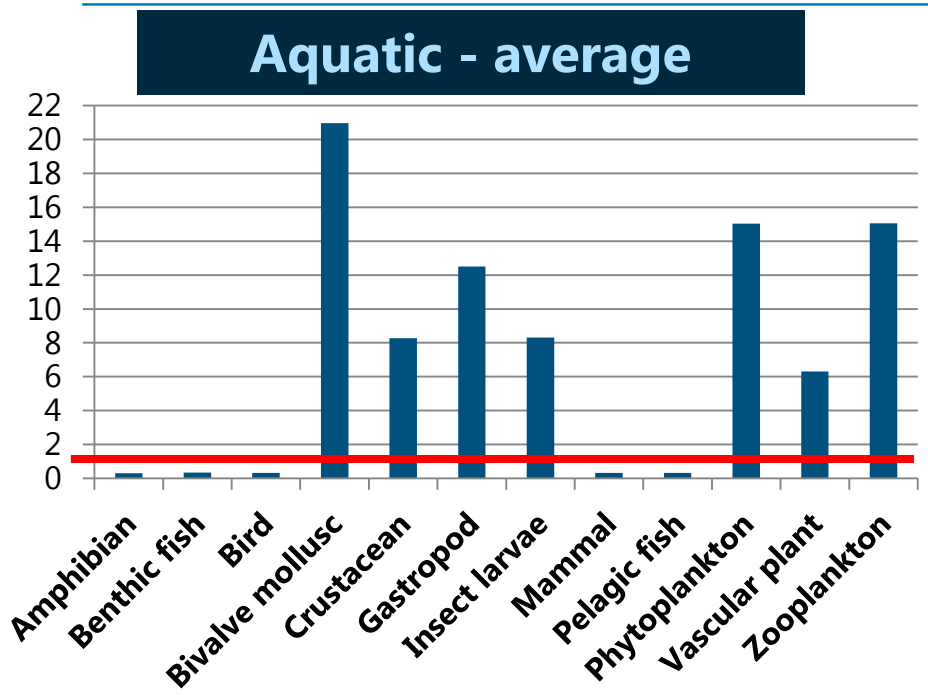


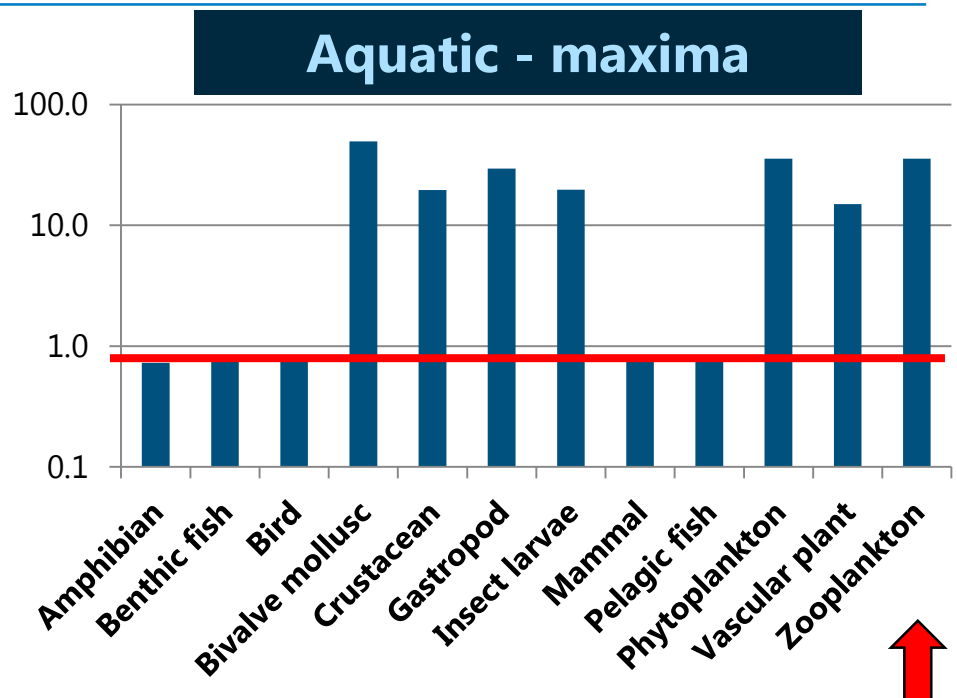
Terrestrial – average hot spots



- Average soil concentrations unlikely to impact terrestrial wildlife living on the riverbanks of Grote Laak
- No effects dose rates available for organism for which RQ>1
- Dose rates were almost entirely due to internal exposure
- However, for screening assessment conservative approach should be used …

RQ for Tessenderlo Grote Laak - Aquatic 1999

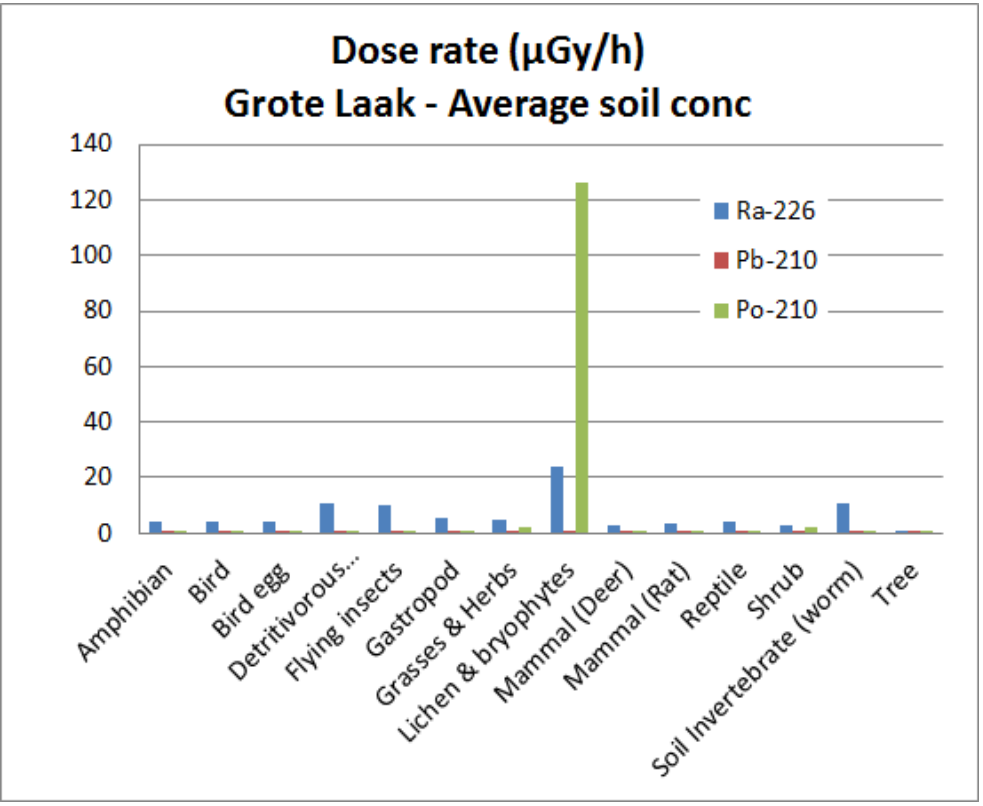




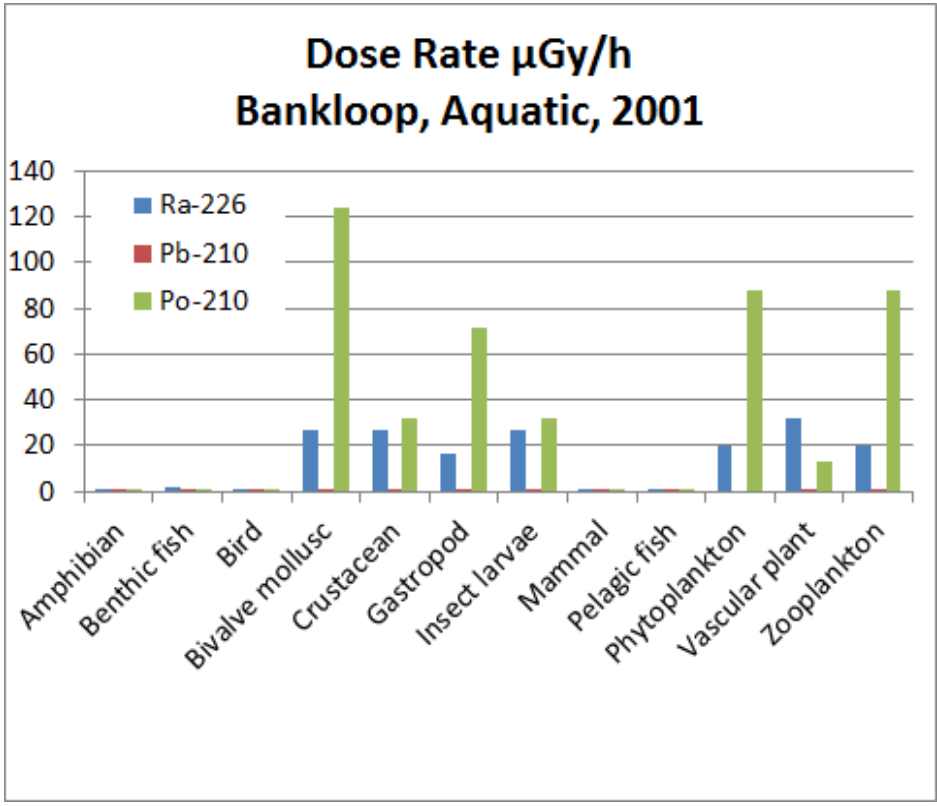
- At dose rates predicted for bivalve molluscs, crustaceans & gastropods, some effects observed
- For insect larvae, no effects observed up to a dose rate of 200 µGy h-1
- For all other organisms for which RQ>1, either no effects were observed for dose rates obtained or no effects data provided by ERICA
- However, for screening assessment conservative approach should be used …

Dose contributing radionuclides

Terrestrial - average



Aquatic - average



Conclusions

- Screening ERA for some P-industry case studies show that
  - ^{226}Ra and ^{210}Po are the most important contributors do the dose
  - Dose rate is almost fully determined by internal dose rate
  - (past) Activities may lead to environmental contamination resulting in dose rates >PNEDR (RQ> 1)
  - Higher TIER ERA recommended for aquatic ecosystems of Tessenderlo

Long term impact

- Impact assessment of NORM liabilities → tailored to the needs
- Not many dedicated studies on public exposure, though some exposure situations need critical evaluation of risk
- NORM is extremely long lived, impacts cannot only be considered in short term but must include the potential effects on future generations
  - Long-term impact assessment, stewardship, memory, long-term efficacy of remedial options