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Preliminary screening assessment of the potential impact of the phosphate industry on wildlife

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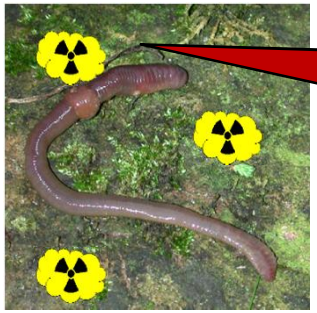
Why look at impact on the environment?

Need for a system to protect environment

- 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
- To date, focus has been on collating relevant information and developing approaches to enable regulatory assessments.
- 3 EU countries have legislation for radiation impact on environment
  England and Wales; Sweden and Finland

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Environmental issues linked with the NORM industry in general or P-industry in particular

- Why look at the NORM industry?
  - Particular regulation? → Generally No
  - Personal curiosity? → Yes
- Why P-industry?
  - Impact from P-industry for human radiological impact rather well studied → info on environmental concentrations likely to be available
- Question?
  - Would environmental concentrations reported in literature lead to a potential impact on reference fauna and flora

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NORM in the P-industry

- Phosphate rocks contain relatively high concentrations of NORM from U and Th decay series
  - Moroccan P-ore: 1500-1700 Bq kg^{-1} ^{238}U and ^{226}Ra; 10-200 Bq kg^{-1} ^{232}Th
- Phosphate ores particularly insoluble. 1st primary step in production process is acid leaching
  - 90% of cases ore treated with sulphuric acid
    - Most U and Th to fertilizers
    - For 1 t of phosphate, 3 t ore extracted and 4-5 t of phosphogypsum formed
    - ~80% of ^{226}Ra, 30% of ^{232}Th and 14% of ^{238}U left in gypsum waste with a mean ^{226}Ra content of 800-1250 Bq kg^{-1}.
  - If hydrochloric acid used to extract phosphate
    - Fertilizers and chemicals free from radioactivity
    - ^{238}U precipitated by lime addition and build up with CaF_2 sludge
    - ^{226}Ra released with liquid $CaCl_2$ liquid effluent

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Environmental contamination linked with P-industry

- Radon emanation and particulate air emissions from the mine areas, phosphogypsum piles, from phosphate ore storage and loading activities in harbours
- Leaching of radionuclides from ore in mining areas and phosphogypsum into groundwater
- Effluent discharges to rivers and marine environments

→ Contamination of the surrounding environment.

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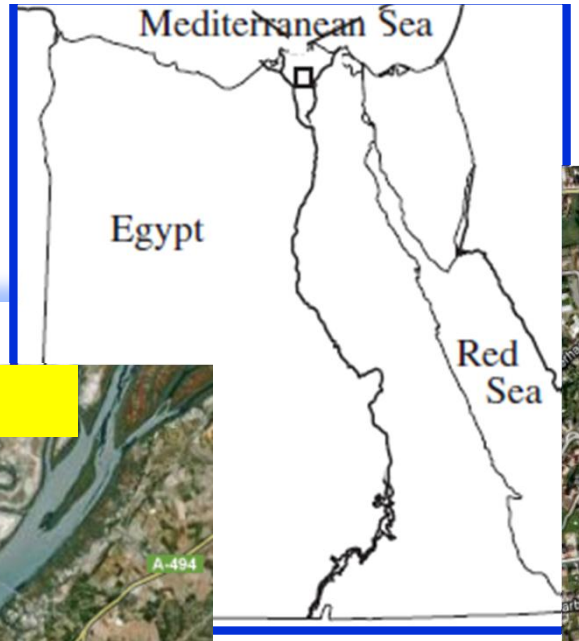
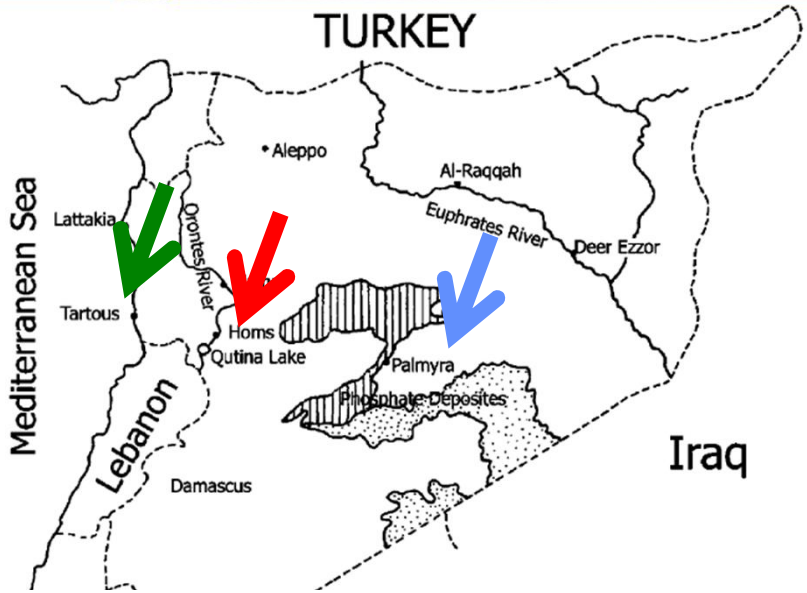
5 P-fertilizer plants
1 P-mine and harbour



Tessenderlo Chemie, Belgium

Huelva, Spain



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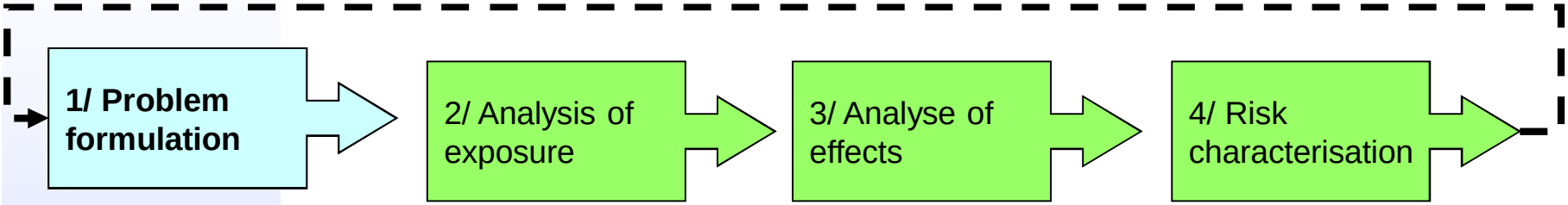
Environmental risk assessment (ERA)
Several steps

ERA
screening



- Source term characteristics
- **Time** and space frame
- Prediction of **environmental concentrations**
- **Reference organisms**

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Environmental concentrations (1)

- Soil, sediment and water concentrations collected from literature
- For soils and sediments in vicinity of P-mines or P-export platforms
  - secular equilibrium for ^{238}U chain
  - for broken chains, equilibrium with most appropriate member
  - assuming 20 % loss due to ^{222}Rn emanation, ^{210}Po and ^{210}Pb conc in soil and sediment 80 % of ^{226}Ra conc
  - If no information available for ^{232}Th chain, ^{232}Th chain not considered
- Releases from phosphogypsum piles (H_2SO_4 wet process)
  - No equilibrium with parent for ^{226}Ra since U mainly retained in fertilizers
- Releases in case of HCl wet process (Tessenderlo Chemie) to the aquatic environment
  - no equilibrium with the parent was supposed for ^{226}Ra released to the rivers since virtually no U and Th in soluble $CaCl_2$ waste streams

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Environmental concentrations (2)

- ^{235}U-series was not considered
- Since the Dose Conversion Coefficients (DCC) of a parent nuclide in the ERICA tool includes all daughters with half-life up to 10 d, only daughter nuclides with half-life >10 d were considered
- If no concentrations in water provided, calculated with default solid-liquid coefficients (K_d) provided by the ERICA tool.

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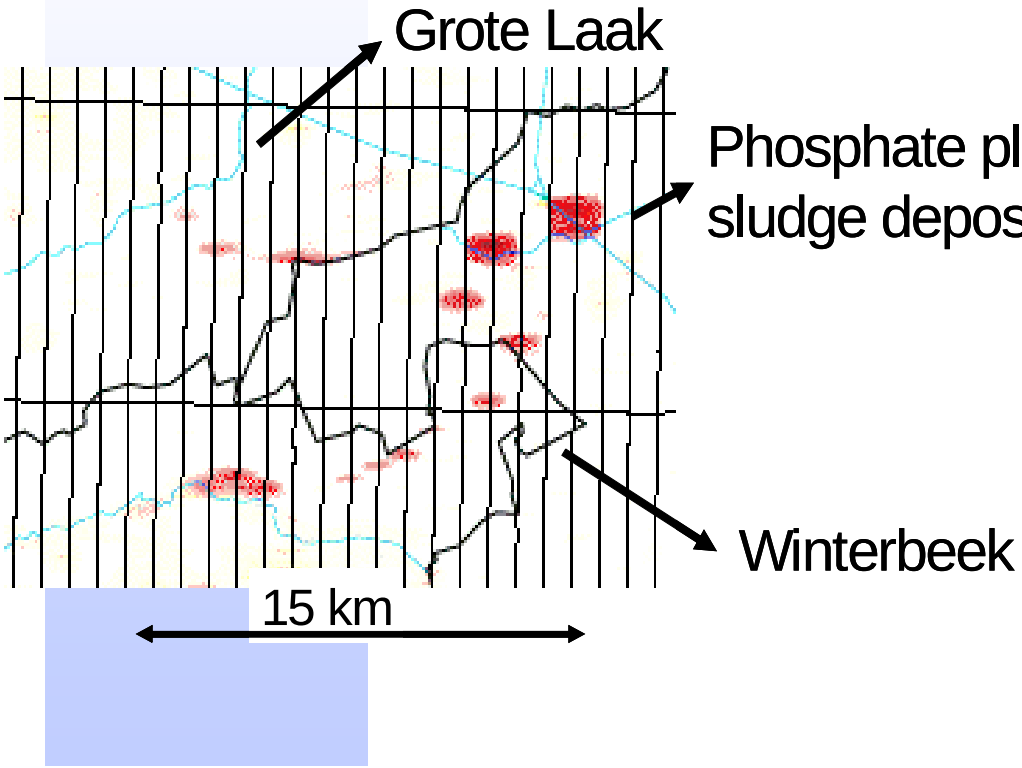
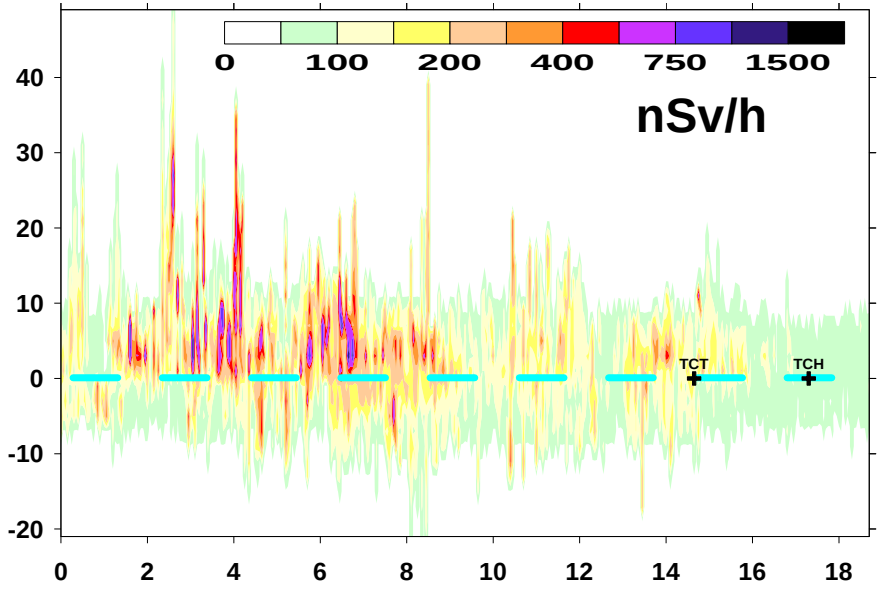
Tessenderlo Chemie (1)





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Tessenderlo Chemie (2)

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	5822	*4658*	*4658*

AQUATIC

^{226}Ra concentrations in river water (Bq L^{-1}) and sediment (Bq kg^{-1}) of Grote Laak and Winterbeek (Average and maxima in period 1998 - 2001)

		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	1200	0.43	902	0.34	629	0.38	461
Winterbeek	average					0.33	676	0.17	523
	maxima					0.63	852	0.34	629

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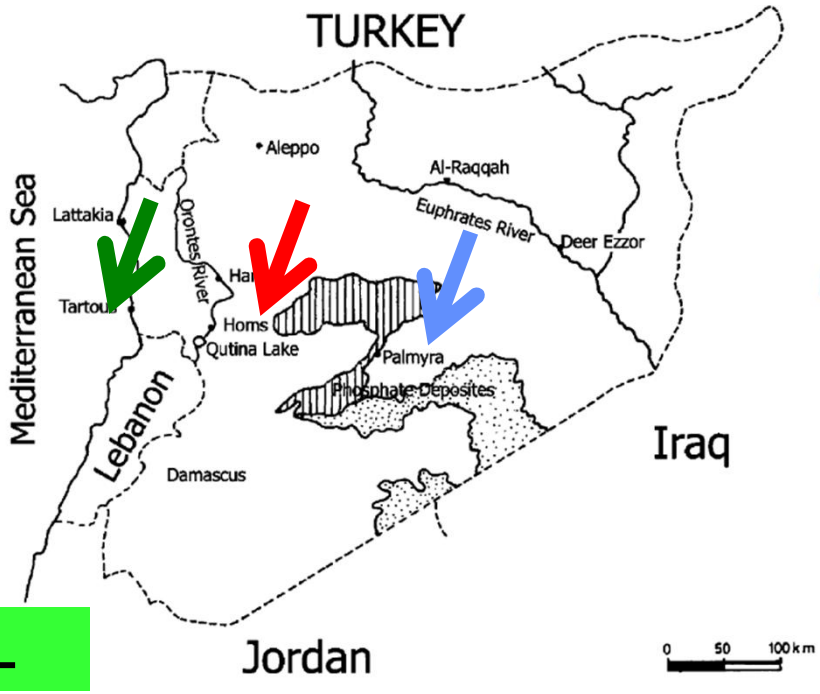
Syria



TERRESTRIAL

Concentrations of natural radionuclides in soil samples (Bq kg^{-1}) collected in the vicinity of the mine

	^{238}U*	^{234}Th	^{234}U	^{230}Th	^{226}Ra	^{210}Po	^{210}Pb
Mine area Village, main gate Table 2 line 6	1168	750	*750*	*750*	820	1557	1184
P-fertilizer plant East of factory Table 5 line 6	38	*38*	*38*	*38*	56	60.6	39.7
Soils collected near load platform Tartuous city, 2 km S. East	159	*159*	*159*	*159*	144	238	224

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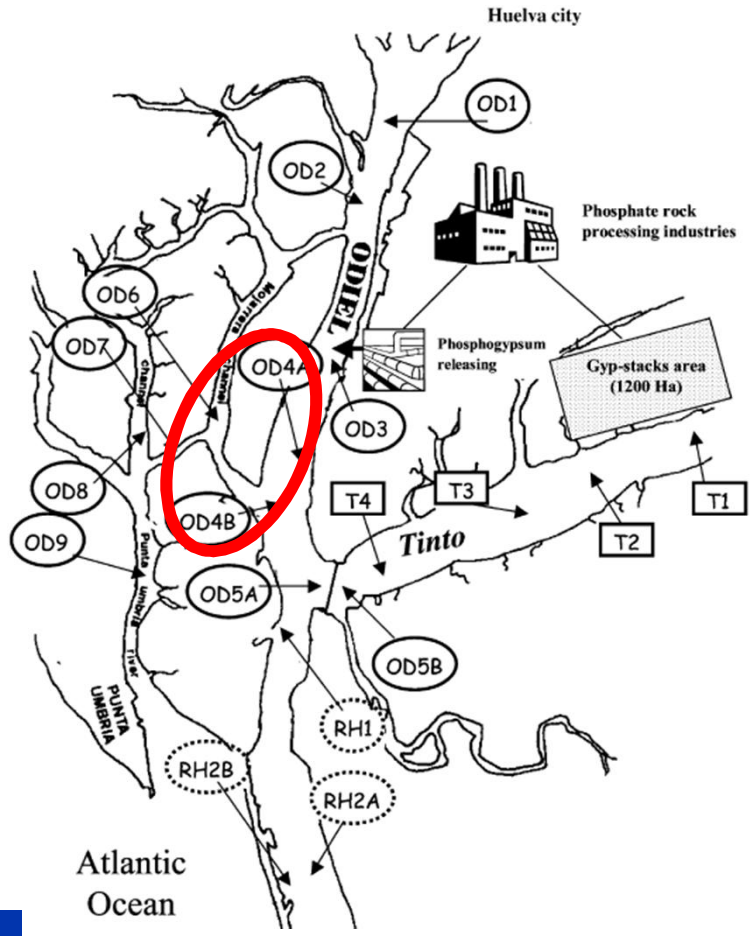
Spain, Huelva



AQUATIC

Concentrations of ^{226}Ra, ^{210}Po, ^{210}Pb in water (mBq l^{-1}) and sediment (Bq kg^{-1}) for the Huelva estuary at Odiel-4 (data for 1990 and 1999)

	Water			Sediment		
	^{226}Ra	^{210}Pb	^{210}Po	^{226}Ra	^{210}Pb	^{210}Po
1990	86	29	*29*	432	624	*624*
1999	12	2.3	*2.3*	318	615	*615*

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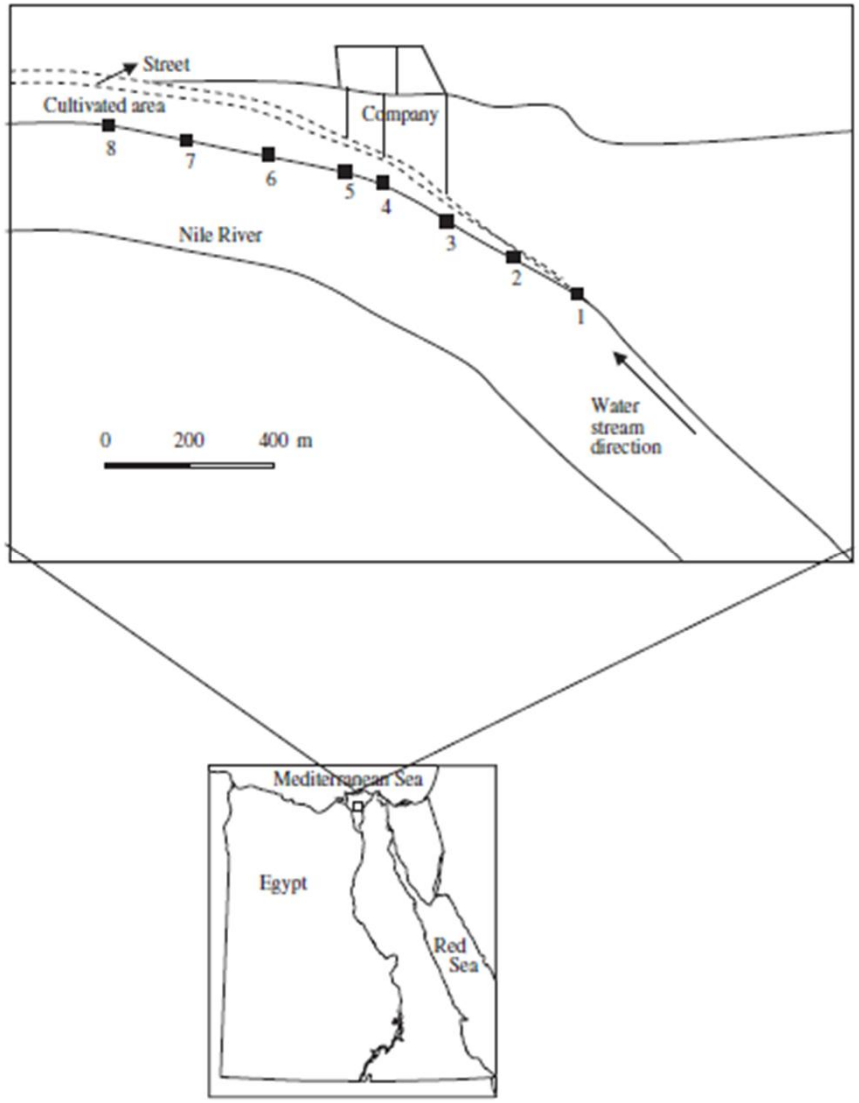
Egypt



AQUATIC

^{226}Ra and ^{232}Th in sediments (Bq kg^{-1}), water (Bq l^{-1}) and *Phragmites australis* (Bq kg^{-1}) in vicinity of outlet of P-fertilizer industry discharging to the Nile

Sample	Position	^{226}Ra	^{232}Th
Sediment	Upstream	17.1	10.9
	Downstream	24.8	16.1
Water	Upstream	0.6	
	Downstream	0.3	
Plants	Upstream	11.8	6.9
	Downstream	17.0	22.5

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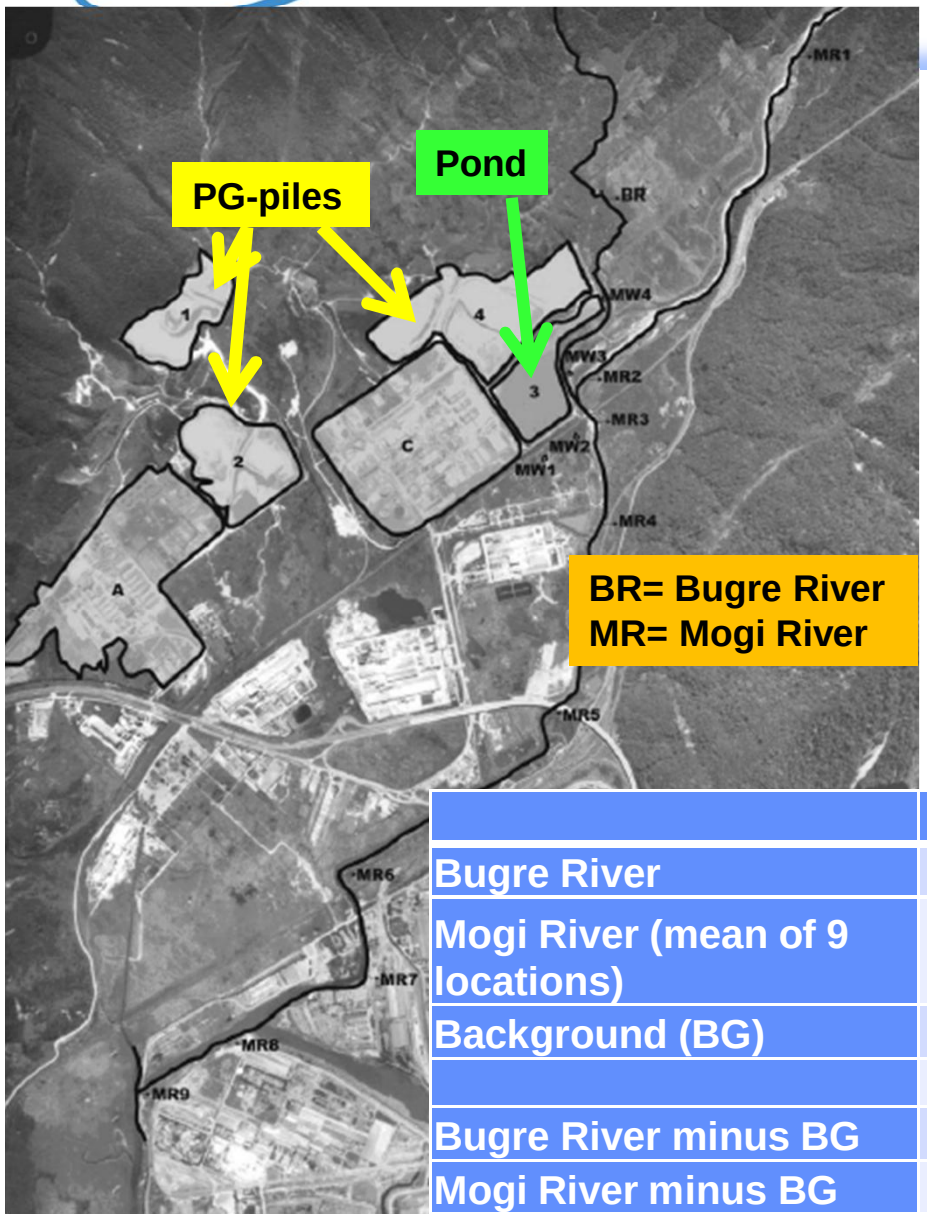
Brazil, State of Goias



Concentrations of ^{232}Th and ^{238}U and daughters in sediments (Bq kg^{-1}) of the Bugre and Mogi River impacted by the Phosphate industry and background (BG – deep core soil profile) in the State of Goiás, Brazil

	^{232}Th	^{228}Ra	^{228}Th	^{238}U	^{234}Th	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Bugre River	198	86	*86*	118	*118*	*118*	*118*	43	56	*56*
Mogi River (mean of 9 locations)	93	73	*73*	72	*72*	*72*	*72*	43	60	*60*
Background (BG)	61	71	*71*	54	*54*	*54*	*54*	45	57	*57*
Bugre River minus BG	137	15	*15*	64	*64*	*64*	*64*	-	-	-
Mogi River minus BG	32	2	*2*	18	*18*	*18*	*18*	-	3	*3*

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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)

ERICA reference organisms

- Selected on the basis of – radiosensitivity, ecological relevance
- Bias towards European species

All **default** information on transfer and dose-rate estimation relate to these entities

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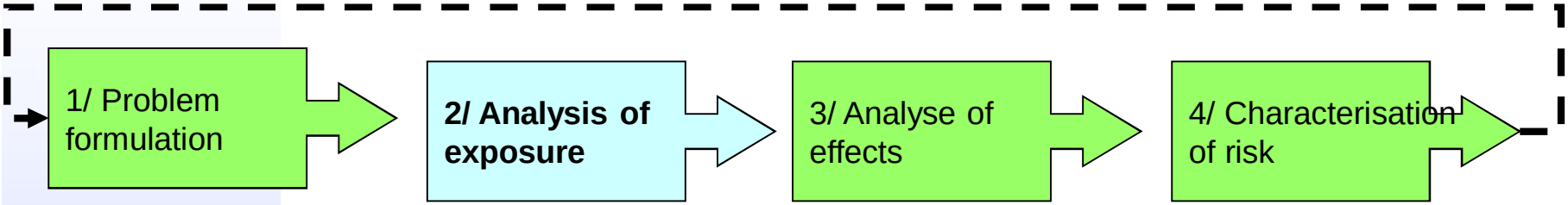
ERA

screening



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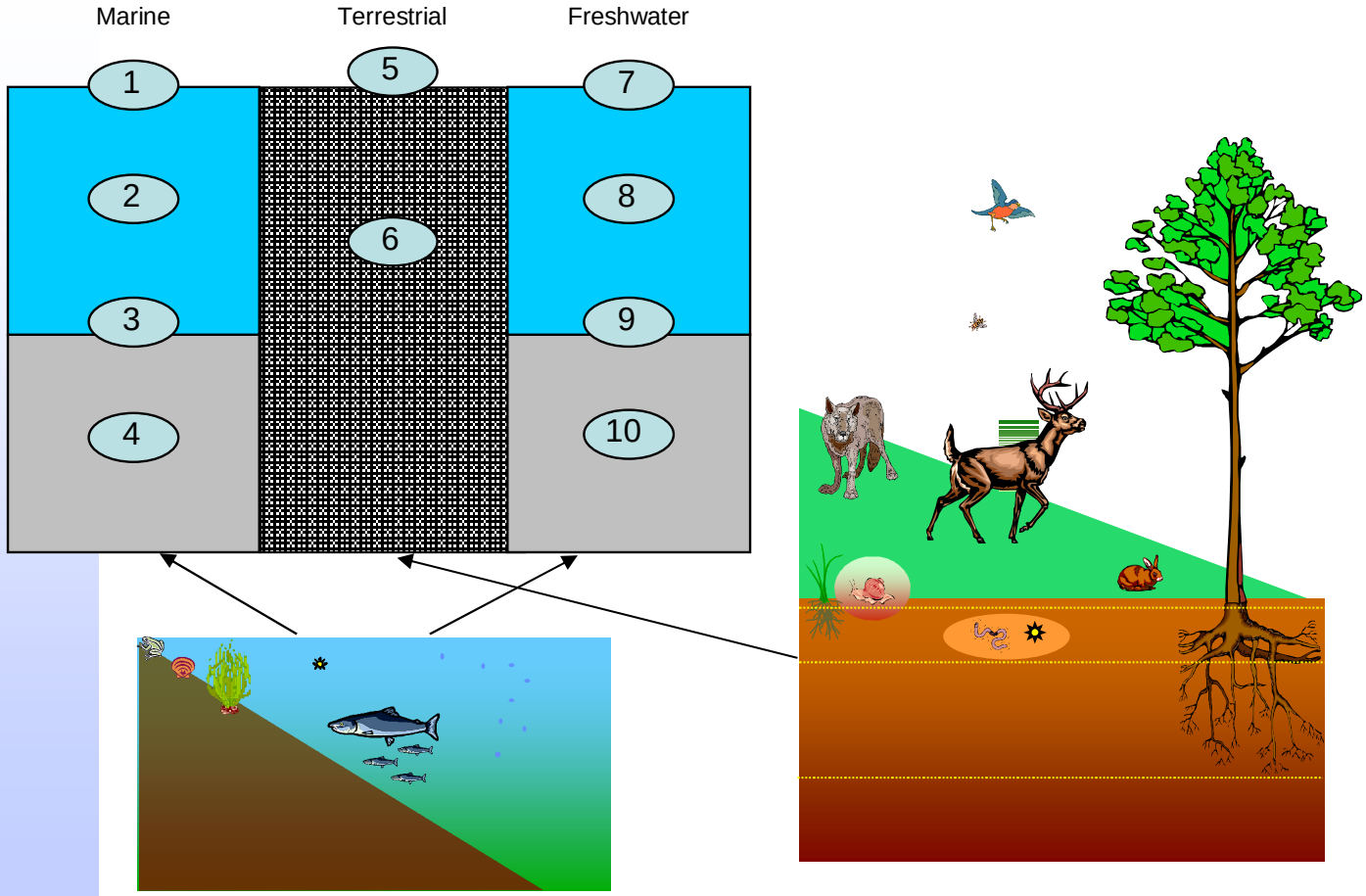
The ten ERICA habitats



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2/ Analysis of exposure

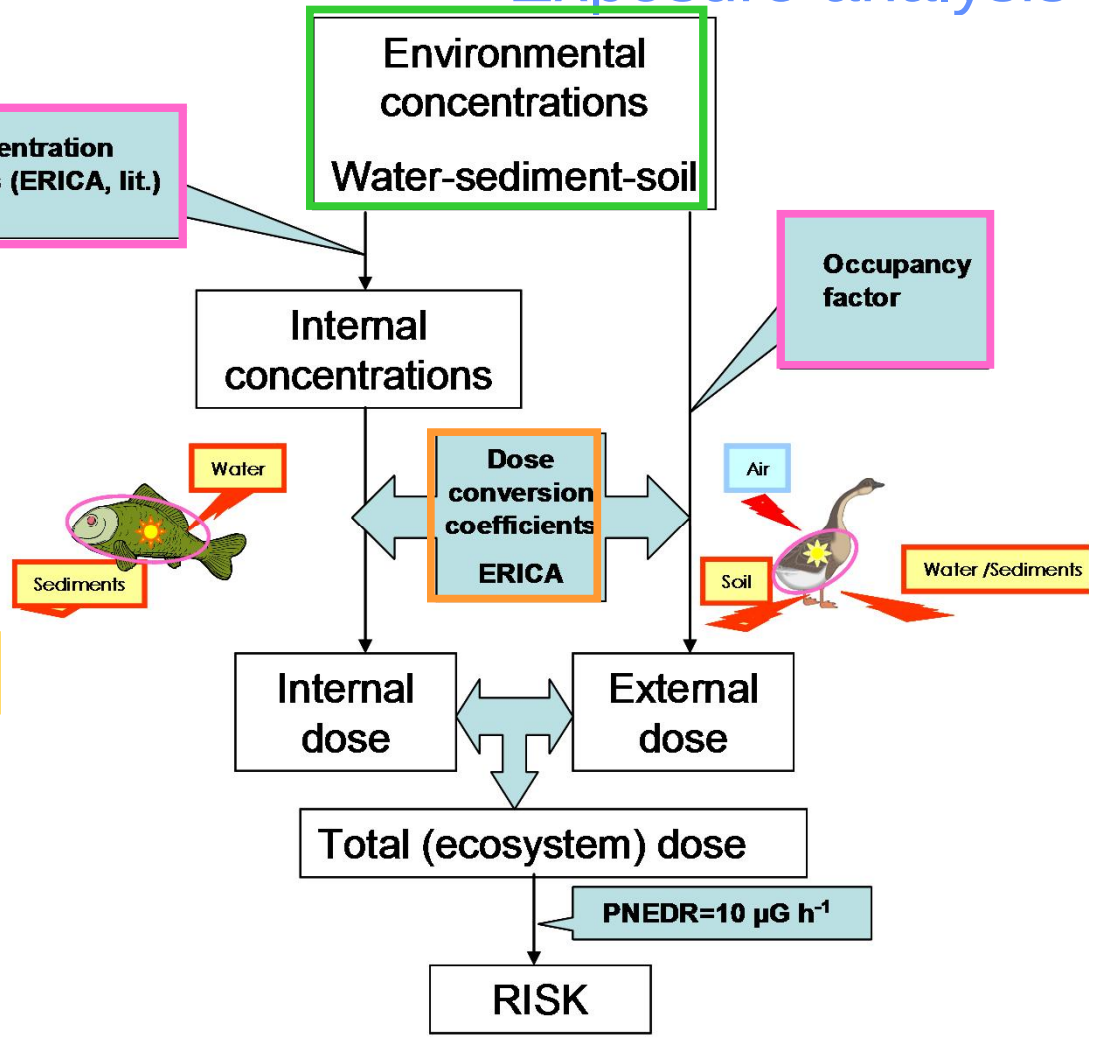
Exposure analysis

With information on
•RN conc. in water and sediments

•RN in biota of interest (via CRs)
•Biota occupancy factors (OF)

•Dose Conversion Coefficient (DCC)

→ radiation exposure (**predicted environmental dose rate, PEDR**, µGy/h) for the selected reference organisms is assessed.



External exposure

$$PEDR_{ext}(o) = OF(o,m) \times DCC_{ext}(i,o) \times C(i,m)$$

Internal exposure

$$PEDR_{int}(o) = CR(i,o,m) \times DCC_{int}(i,o) \times C(i,m)$$

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Data gaps for environmental transfers

Terrestrial ecosystem

	Amphibian	Bird	Bird egg	Detritivorous invertebrate	Flying insects	Gastropod	Grasses & Herbs	Lichen & bryophytes	Mammal (Deer)	Mammal (Rat)	Reptile	Shrub	Soil Invertebrate (worm)	Tree
Po							1.24E-01	6.28E+00	2.78E-03	2.78E-03		9.85E-02		3.84E-02
Pb	1.20E-01	6.15E-02		7.53E-01	6.09E-02	7.27E-03	6.65E-02	6.00E+00	3.88E-02	3.88E-02		3.08E-01	2.85E-02	7.59E-02
Ra		3.62E-02		9.00E-02		4.77E-02	3.94E-02	2.12E-01	2.65E-02	2.65E-02		2.40E-02		6.75E-04
U		5.41E-04					1.46E-02	7.09E-02	1.06E-04	1.06E-04		7.06E-03	8.84E-03	6.79E-03
Th		3.89E-04					4.37E-02	1.03E-01	1.22E-04	1.22E-04		1.60E-02		1.08E-03

Freshwater ecosystem

	Amphibian	Benthic fish	Bird	Bivalve mollusc	Crustacean	Gastropod	Insect larvae	Mammal	Pelagic fish	Phytoplankton	Vascular plant	Zooplankton
Po			22000		38000	9900			240	27000	4000	
Pb												
Ra			940	80	1500	1500			80	1100	1800	
U				30		500			30	120	2900	48
Th				110					110		1260	

Marine ecosystem

	(Wading) bird	Benthic fish	Benthic mollusc	Crustacean	Macroalgae	Mammal	Pelagic fish	Phytoplankton	Polychaete worm	Reptile	Sea anemones or true corals - colony	Sea anemones or true corals - polyp	Vascular plant	Zooplankton
Po	17000	60000	10000	17000	26000		76000		35000	1000	20000			
Pb		10000	19000		490000		26000		1700	1000				
Ra	280	150		280	1000		81		65	89				
U	14			14	140	230			32	120			1000	1000
Th	600			600	730000		7500		510	2000				

IAEA-EMRAS-2: Biota working group

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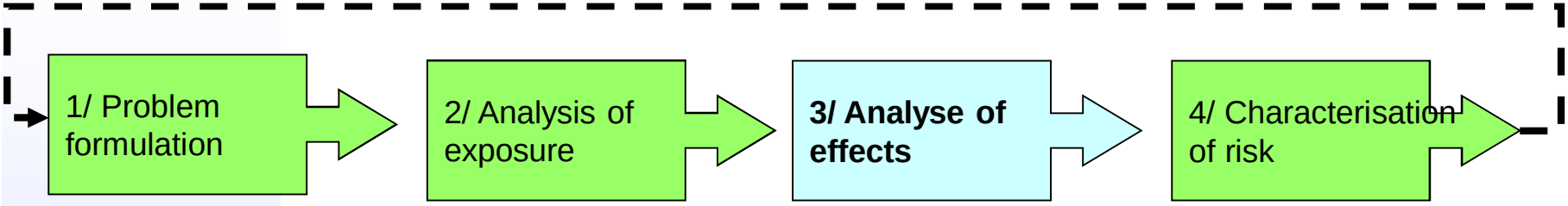
Effects analysis



- Derivation of **Predicted No Effect Dose Rate (PNEDR)**
  - Values derived following different approaches and have different protection level e.g.
    - IAEA: 40-400 µGy/h
    - ICRP: 4-4000 µGy/h
    - **EC-ERICA and PROTECT: 10 µGy/h** (~100 mSv/y)
      - Assumed to protect ecosystems
      - Screening dose rate → to screen out sites

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Risk assessment

- Deterministic approach
- Risk Quotient (RQ) is ratio of two values

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

Predicted environmental dose rate

Predicted no effect dose rate

PROTECT-ERICA SV: 10 µGy/h

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Using the ERICA tool

Welcome to the ERICA Assessment Tool
To start a New Project select 'File', 'New'

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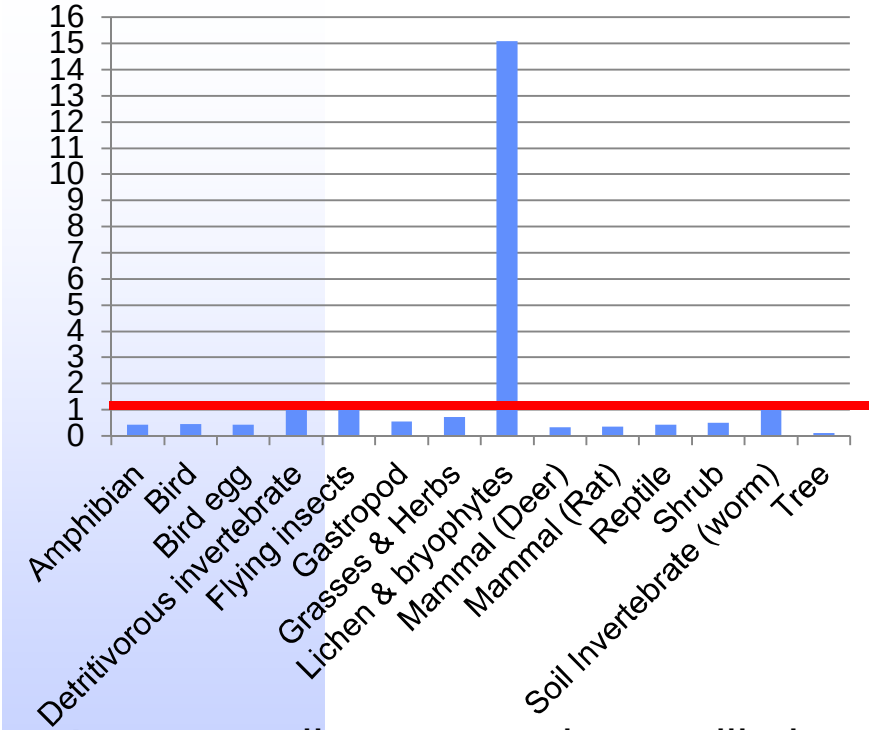
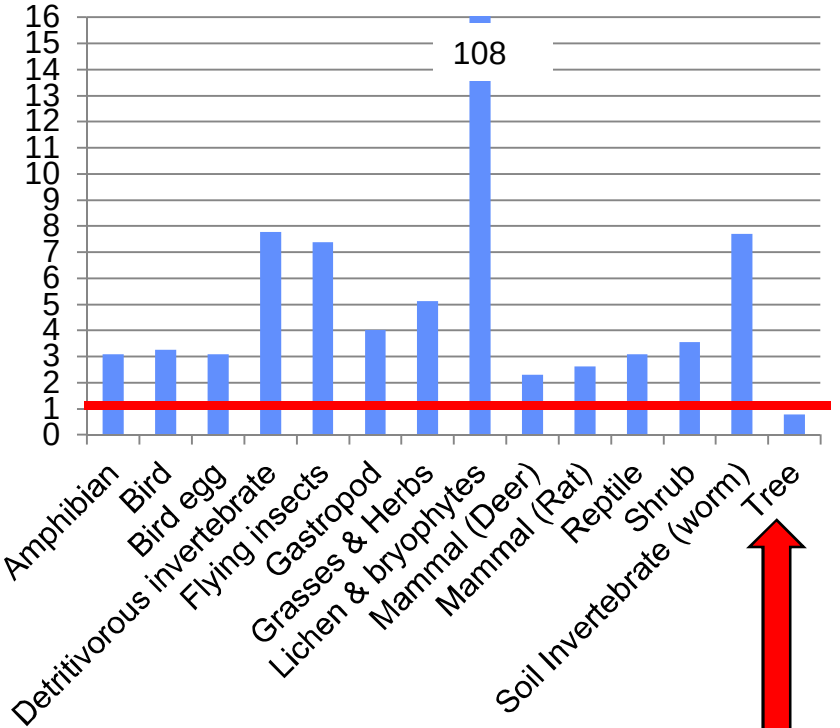
RQ for Tessenderlo – Grote Laak river banks

Terrestrial - average



Terrestrial – average hot spots



- Average soil concentrations unlikely to impact terrestrial wildlife living on the river banks 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 …

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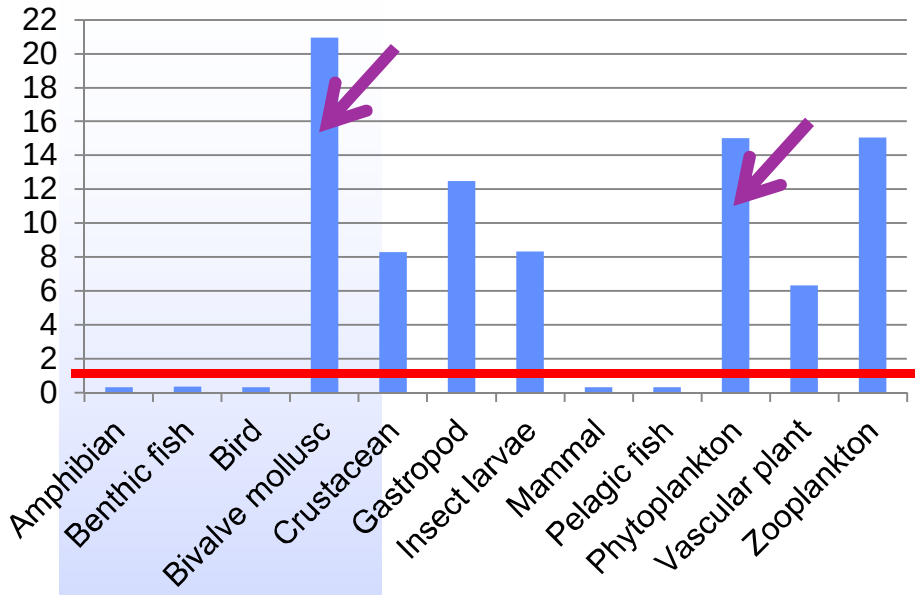
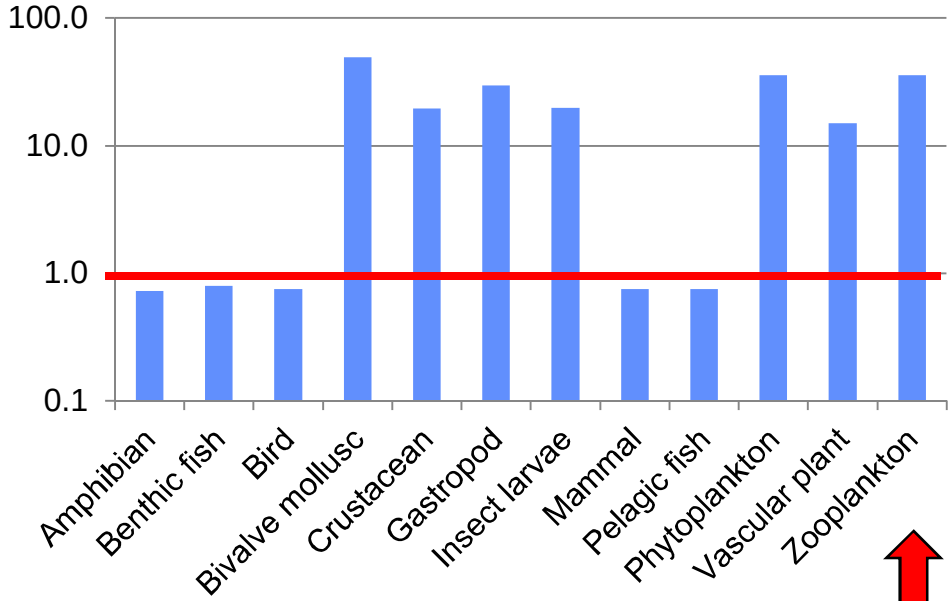
RQ for Tessenderlo Grote Laak - Aquatic 1999

Aquatic - average



Aquatic - maxima



- 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
- Under PROTECT project, organism group specific SV derived
  - Plants: SV = 70 µGy h^{-1} ; Invertebrates: SV = 200 µGy h^{-1}
- However, for screening assessment conservative approach should be used …

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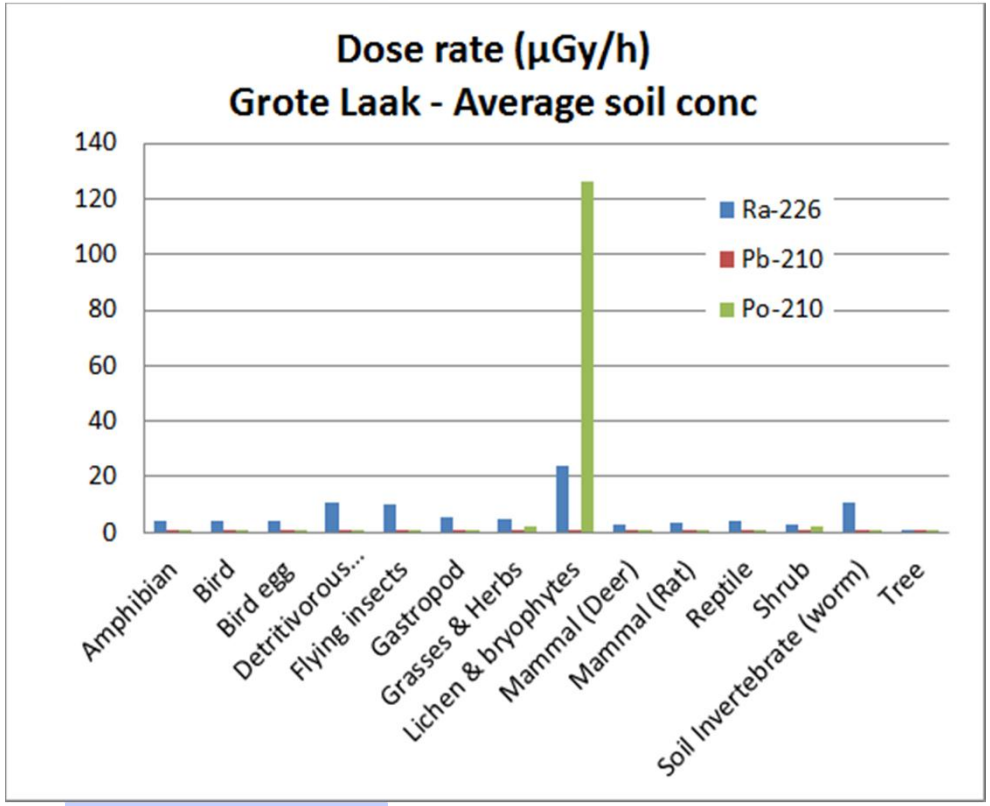
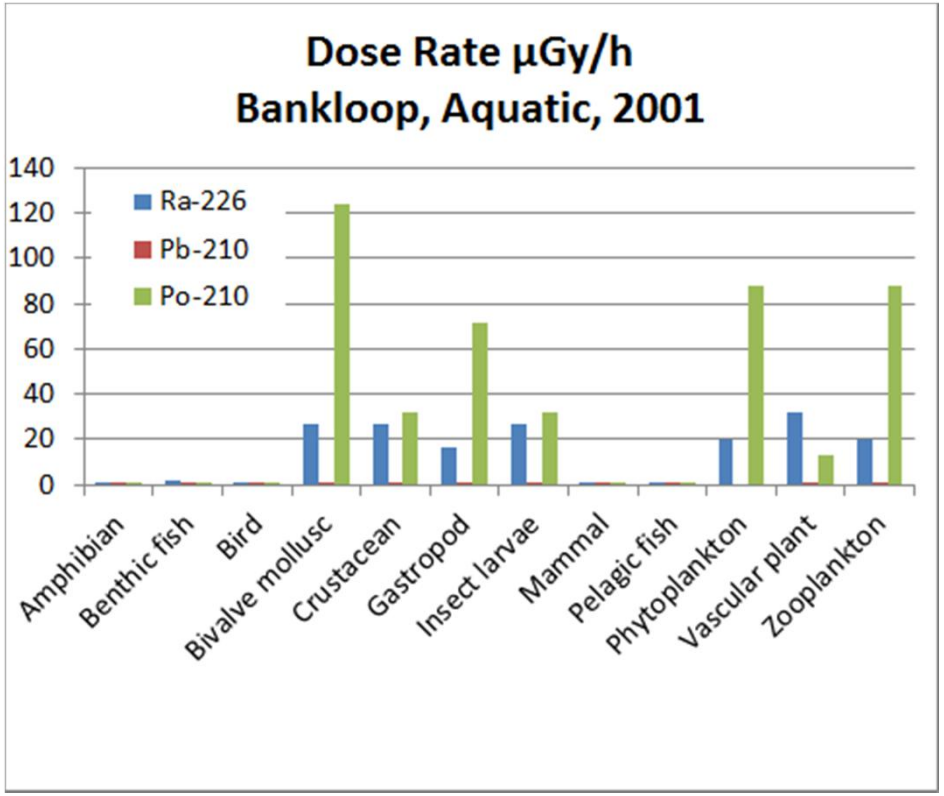
Dose contributing radionuclides

Terrestrial - average



Aquatic - average



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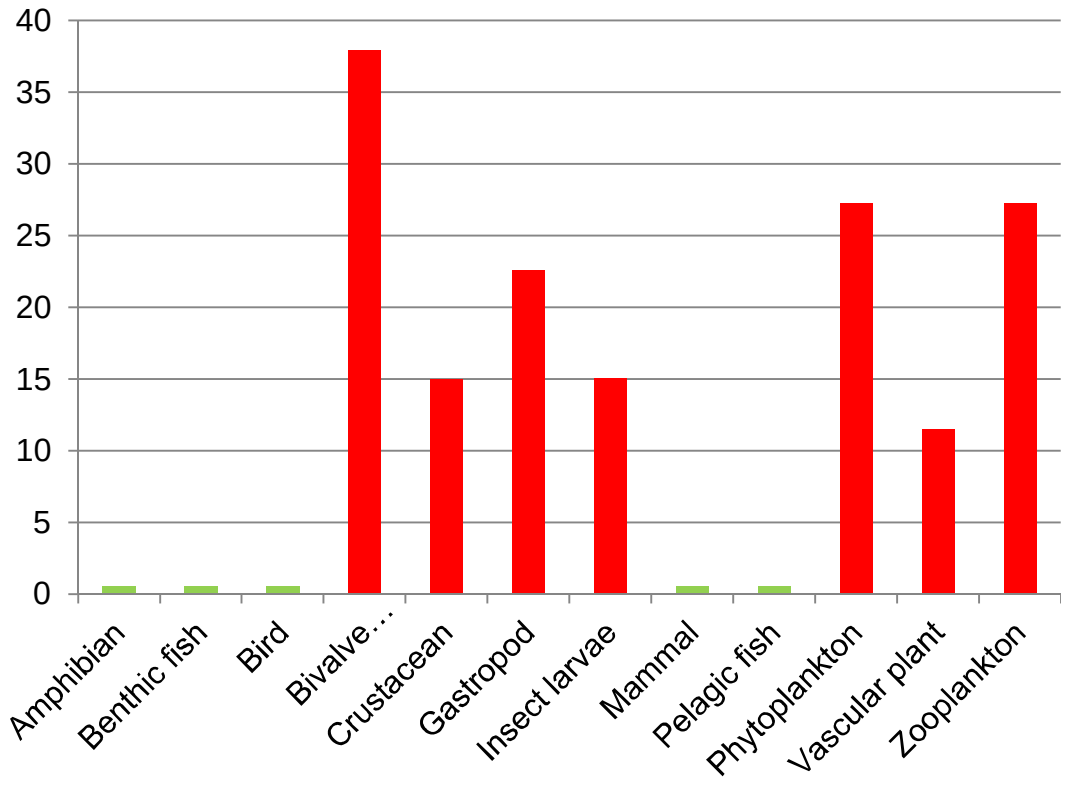
RQ for Tessenderlo Winterbeek- Aquatic Average 2000

Aquatic - average



- Same picture as Grote Laak but higher doses
- For many organisms even the PROTECT organisms specific SV exceeded (red bars)

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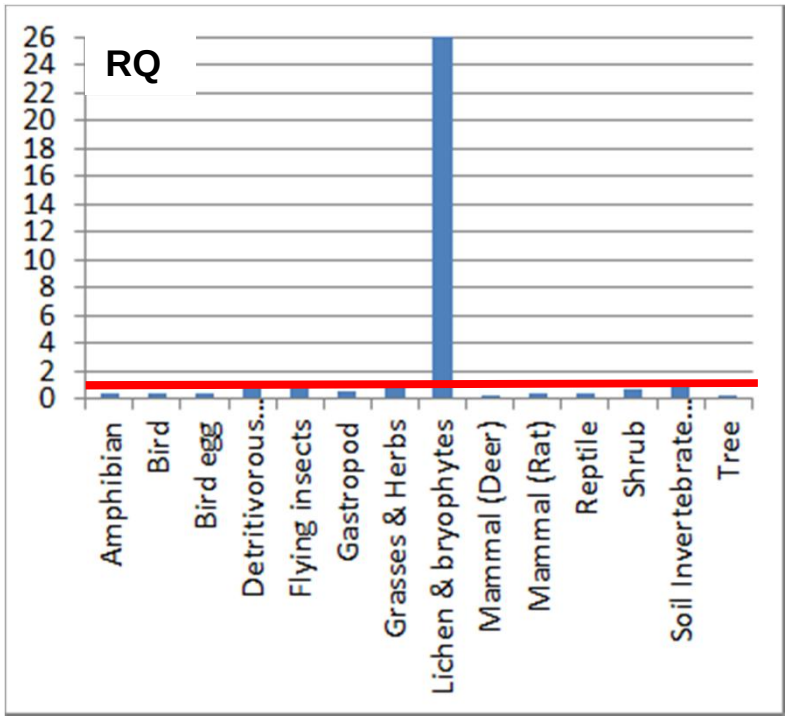
Syria
P-fertilizer plant, P-platforms and P-mine

TERRESTRIAL

- RQ < 1 for terrestrial wildlife in vicinity of P-fertilizer plants and P-loading platforms in harbour
- Palmyra P-mine



- Detritivorous invertebrates, flying insects, grasses&herbs, trees: RQ just above 1
  - No effects observed at related dose rate
- Lichens and bryophytes: RQ ~25 or dose rate ~250 µGy h^{-1}
  - No effects data available for this dose rate

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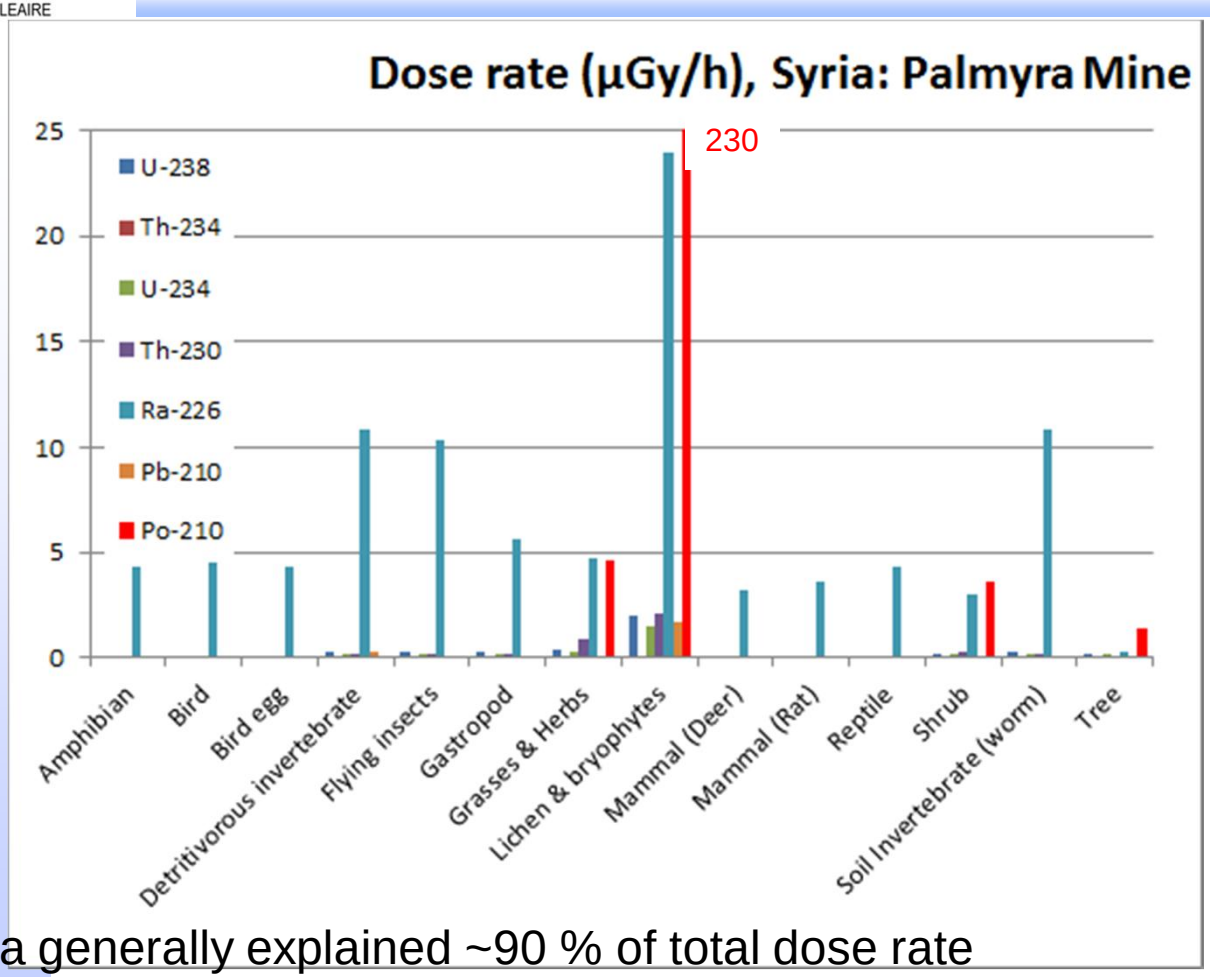
Syria



- ^{226}Ra generally explained ~90 % of total dose rate
- Grasses and shrubs: equal contribution of ^{226}Ra and ^{210}Po
- Trees: 70 % of dose rate by ^{210}Po ; Lichens and bryophytes: 90%
- No role of ^{232}Th chain

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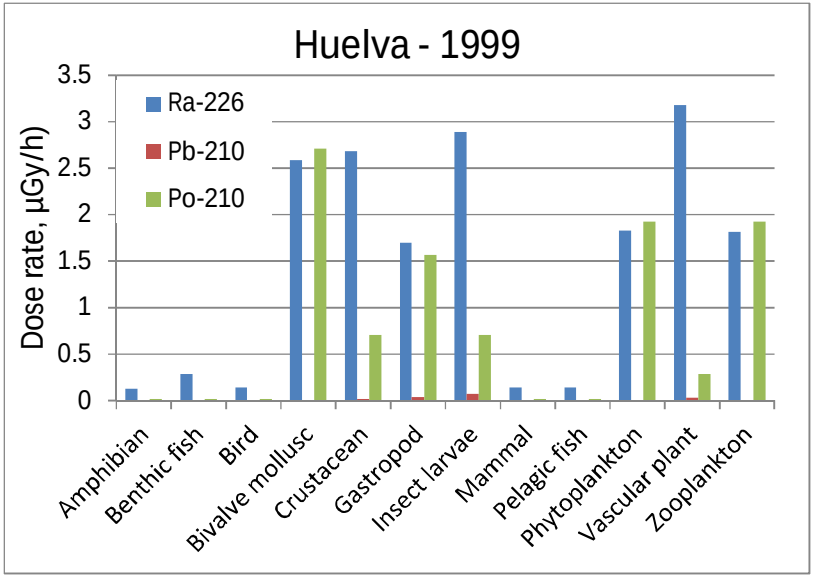
Spain – P-fertilizer plant Huelva – very high RQ
Effects expected

Aquatic

RQ	1990	1999
Amphibian	0.11	0.01
Benthic fish	0.14	0.03
Bird	0.12	0.02
Bivalve mollusc	*5.18*	0.53
Crustacean	*2.70*	0.34
Gastropod	*3.13*	0.33
Insect larvae	*2.73*	0.37
Mammal	0.12	0.02
Pelagic fish	0.12	0.02
Phytoplankton	*3.74*	0.38
Vascular plant	*2.52*	0.35
Zooplankton	*3.74*	0.37



Dose rate entirely due to water concentration, because internal dose is most important contributor and CR based in water concentrations

FACTOR 10 but ± no difference in sediment conc

		Water			Sediment		
		^{226}Ra	^{210}Pb	^{210}Po	^{226}Ra	^{210}Pb	^{210}Po
1990	FACTOR 10	86	29	*29*	432	624	*624*
1999		12	2.3	*2.3*	318	615	*615*

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Egypt – impact on wildlife of Nile River

Aquatic

	Downstream	Upstream	Downstream-upstream
Amphibian	*1.03*	0.57	0
Benthic fish	*1.07*	0.59	0.0007
Bird	*1.07*	0.59	0
Bivalve mollusc	***70.30***	**37.85**	0.0008
Crustacean	***27.60***	**14.53**	0.0010
Gastropod	***41.86***	**22.54**	0.0008
Insect larvae	***27.60***	**14.54**	0.0021
Mammal	*1.07*	0.59	0
Pelagic fish	*1.07*	0.59	0
Phytoplankton	***50.90***	**28.63**	0
Vascular plant	0.34	0.75	0.4125
Zooplankton	***50.74***	**27.91**	0

Additional risk due to released from P-fertilizer industry to Nile River is negligible

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Brazil – P-fertilizer plant

	Bugre River	Mogi River	Background	Bugre River minus BG	Mogi River Minus BG
Amphibian	0.37	0.23	0.17	0.20	0.06
Benthic fish	0.38	0.23	0.18	0.20	0.06
Bird	0.37	0.23	0.17	0.20	0.06
Bivalve mollusc	***2.28***	***1.41***	***1.08***	***1.20***	0.34
Crustacean	***6.21***	***3.81***	***2.88***	***3.33***	0.94
Gastropod	***2.26***	***1.39***	***1.06***	***1.20***	0.34
Insect larvae	***6.22***	***3.83***	***2.89***	***3.33***	0.94
Mammal	0.37	0.23	0.17	0.20	0.06
Pelagic fish	0.37	0.23	0.17	0.20	0.06
Phytoplankton	***1.52***	0.94	0.72	0.80	0.22
Vascular plant	***35.67***	***21.80***	***16.37***	***19.30***	***5.43***
Zooplankton	0.63	0.40	0.31	0.32	0.09

- Bugre River: RQ>1 for 6 Reference Organisms
  - At associated dose rates no effects reported or no data available (except for insect larvae: moderate effects (cytogenic) observed)
- Mogi river **and Control**: RQ> 1 for same Reference Organisms except phytoplankton
- Incremental RQ>1 for Bugre River for 5 Reference Organisms; for Mogi River RQ_{inc}>1 only for vascular plant RQ

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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
  - Higher TIER ERA recommended for aquatic ecosystems of Tessenderlo, Huelva, Brazil and terrestrial ecosystem in vicinity of P-mine in Syria
- Higher TIER ERA may include
  - Less conservative assumptions
  - More in depth site monitoring for environmental concentrations or radionuclide concentrations in biota
  - Effects studies on species concerned in lab and/or in field
- If field tests established: non-radioactive contaminants should be evaluated since effects observed may not be caused by RNs
- Importance to have info on BG concentrations

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- Thanks for your attention
- Questions?

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