Assessing public exposure from NORM discharges - key parameters and simple approaches to dose estimates

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Learning objectives

- Understand radioactive discharges from NORM industries
  - Which industries may be considered
  - Which discharge pathways are relevant
  - Environmental (non-radiation) protection constraints to discharges
- Understand exposure scenarios
  - Relevant nuclides
  - Relevant exposure pathways
- Dispersion modelling
  - Wet vs. dry deposition
  - Simple model approach
  - Constraints to receptor positions

Why consider radioactive discharges from NORM industries

- Requirement of Art. 23 of the EU BSS 2013/59/Euratom:
  - Member States shall ensure the identification of classes or types of practice involving naturally–occurring radioactive material and leading to exposure of workers or members of the public which cannot be disregarded from a radiation protection point of view.
  - Use White List in Annex VI
- Understand, and put in perspective, contribution of NORM industries to radiation exposure of the public
- Risk communication with the public

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Which industries may need to be considered? („Potentially NORM-affected industries“)

- Rare earths
- Th-containing products
- Processing of Nb/Ta ores
- Oil and gas production and transport
- Geothermal energy production
- Production of TiO_2 pigments
- Thermal phosphorus production
- Zirconium and zirconia industry
- Bauxite processing
- Foundries (foundry sands)
- Radon spas
- Maintenance of klinker ovens
- Production of phosphate fertilizer
- Cement production
- Coal-fired power plants
- Mining, mine water management
- Production of H_3PO_4 and H_2SO_4
- Pig iron production
- Sn-/Pb-/Cu smelter
- Ground water filter plants
- Laboratories, research institutes
- Optical, glass and porcellaine industry
- Production of abrasives
- Production of refractories

A brief excursion: Which processes may lead to the accumulation of radionuclides? A few examples:

- Combustion
  - Mass reduction leads to higher specific activity of ashes and dust than fuel
  - Nuclides of volatile elements are predominantly found in dust
- Chemical reactions
  - Radionuclides are redistributed among various process streams according to their chemical properties
  - Precipitation of radionuclides in scale of oil and gas production equipment
- Adsorption
  - Nuclides of certain elements adsorb better to filter materials than others
  - Low activity from large volumes of water may lead to gradual build-up of nuclides in filters

For a systematic review of NORM types see R. Gellermann: Quantification and characterization of NORM inventories in industrial processes – a comprehensive approach for radiation protection purposes. 1st ENA Workshop, Katowice, 2018

Which processes may actually lead to increased doses for the public?

- For significant public exposure it is not necessarily „typical NORM“ with high specific activity and small amounts, but large activity flows released into the environment:
  - Small amounts can be well contained and their use can be well controlled
  - Control of the use of large areas is difficult
  - Large flows of waste water or off-gas may affect significant areas (e.g., agricultural areas, floodplains)
  - We are talking about several GBq per annum released into the environment
- It is mainly industries with large throughput of raw material that should be expected to lead to increased doses of the public
- Examples include power plants and metallurgical plants (smelters)

Where can we obtain data on radioactive discharges?

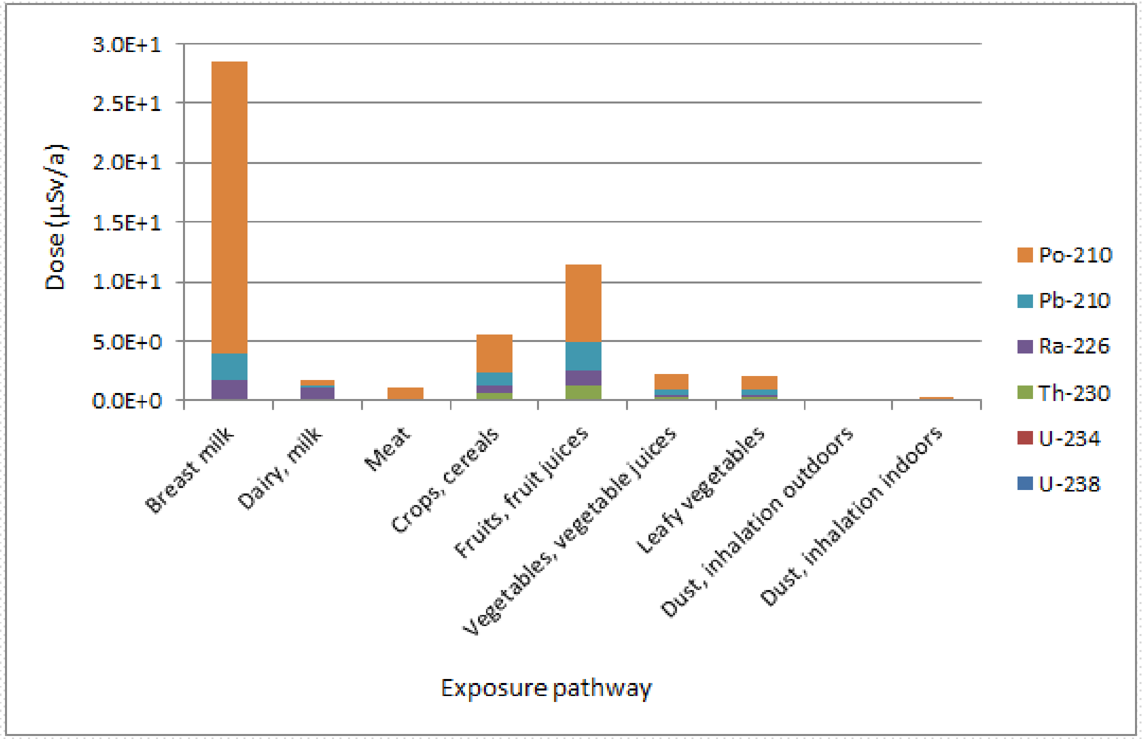
- Literature data on discharges from NORM industries are generally scarce
- National data bases for airborne emissions exist in some countries, e.g., Pollutant Release and Transfer Register (PRTR, Directive 2006/166/EG)
- Constraints and permit conditions may be available for individual plants
- Legal limits, e.g., on dust emissions (tons per year) or water quality
- However, almost none of those data consider the content of natural radionuclides

- But... do we really need all this information complete?
- Can we do without it to assess public doses at least to the order of magnitude?

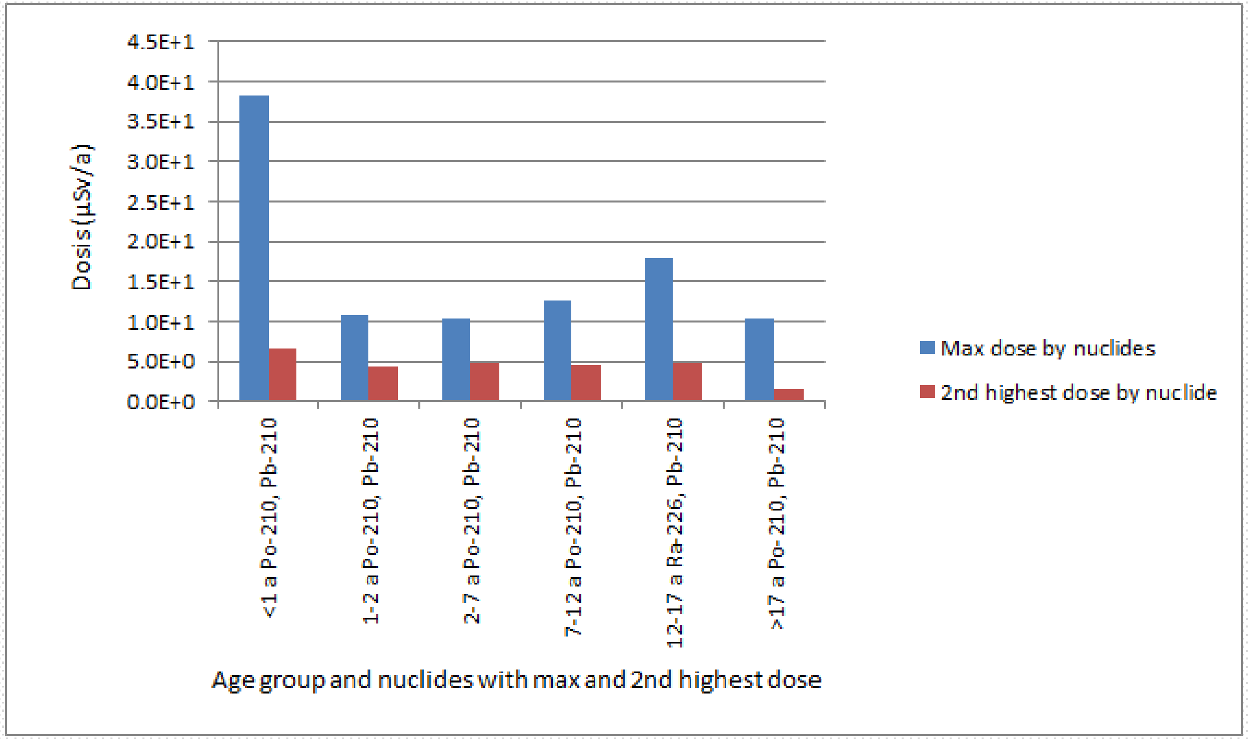
Which exposure pathways are relevant for public doses?

- **Dust deposition on agricultural areas, fruit and vegetable plants (ingestion)**
- Less or not relevant
  - Dust deposition on soil
  - Inhalation of dust
  - External radiation (soil, gamma submersion)
- Potentially relevant: Radon and radon progeny
  - From underground mines
  - Close to residential areas
- Potentially relevant: Water from underground mines, but rather hypothetical use scenarios
  - Sorption on sediments
  - Sedimentation of contaminated particulates on floodplains

Relative contributions to effective dose



Settling rate: 1 Bq/m² a



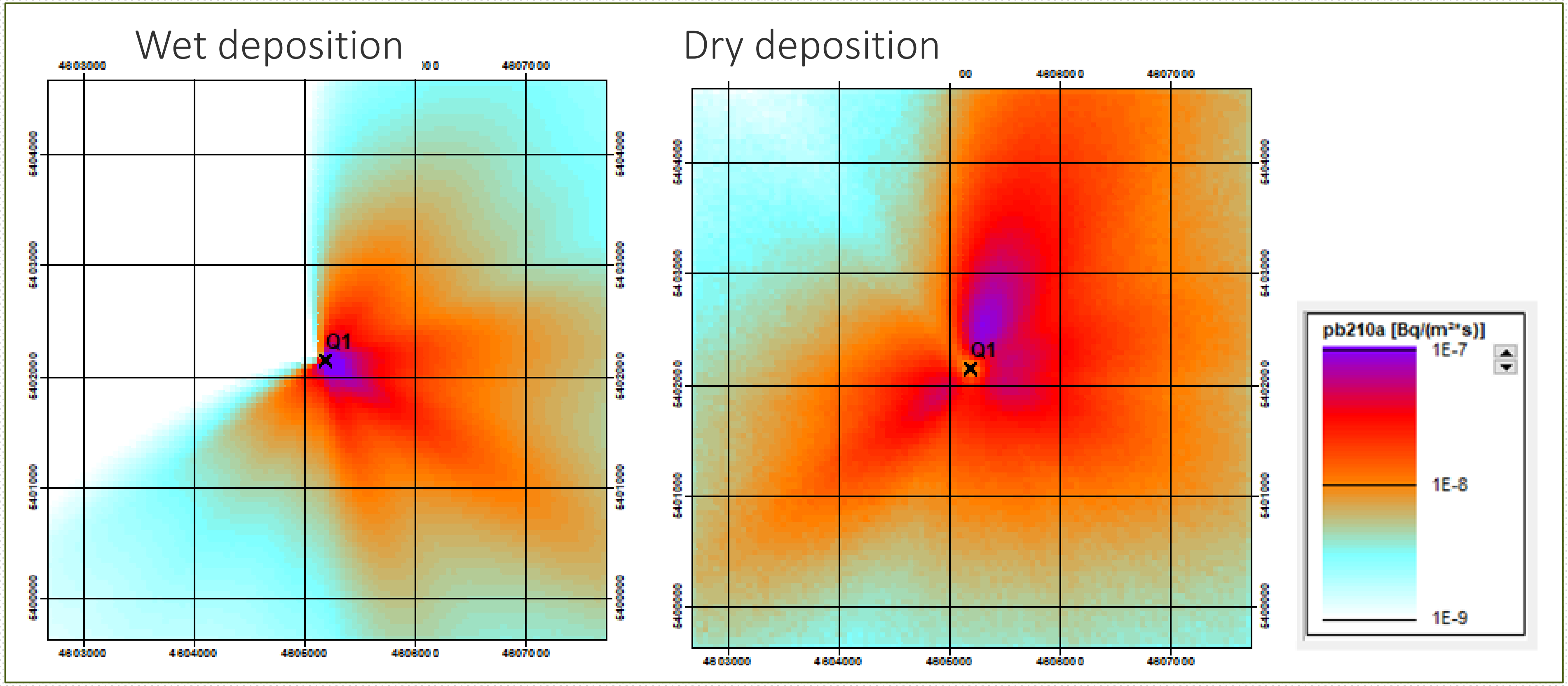
Specific Activity: 1 Bq/g

We need to focus on infants (< 1 year old) and Po-210 (+ Pb-210)

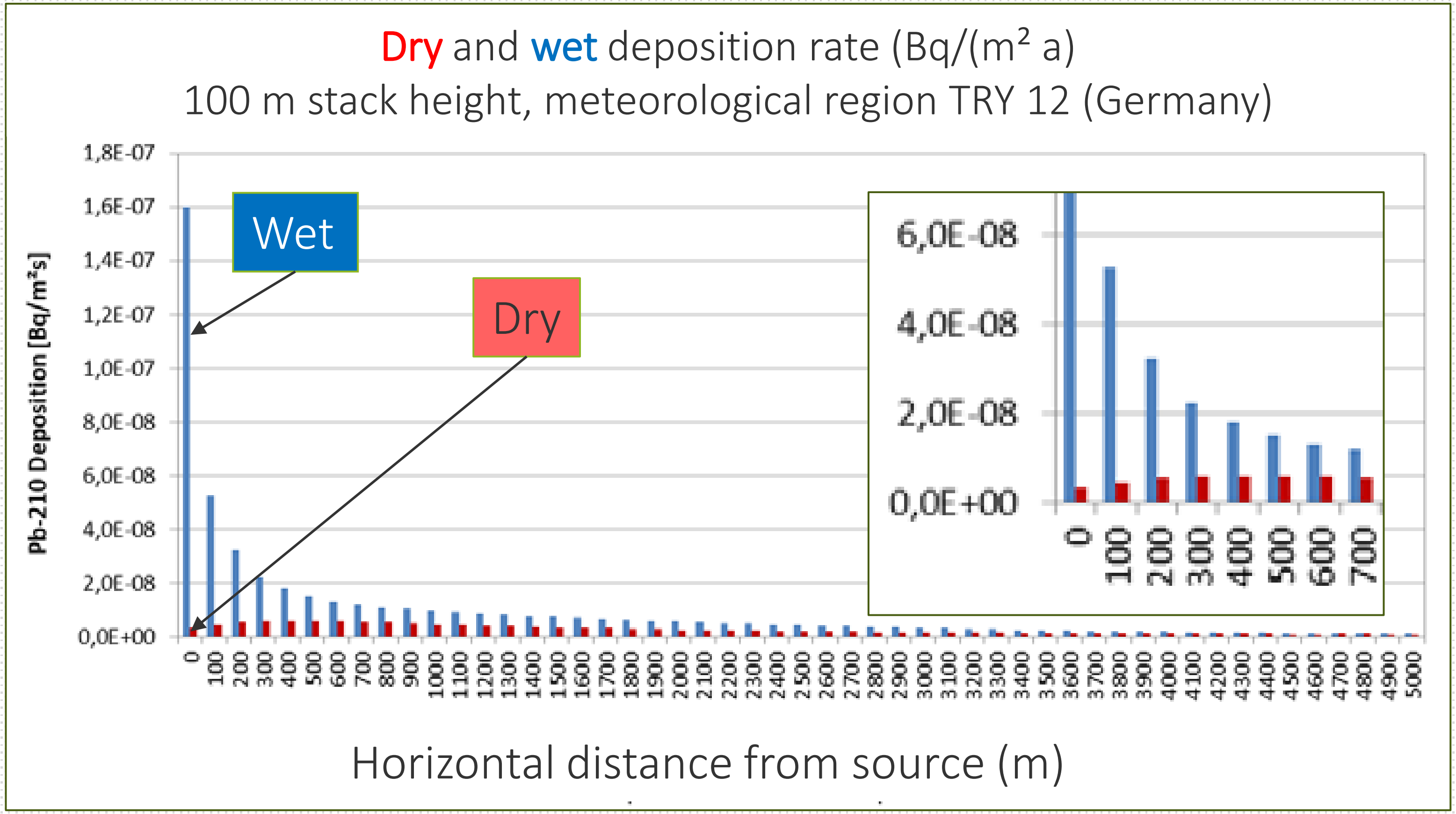
Po-210 (and Pb-210) are the relevant nuclides for public doses resulting from discharges

- Po-210 and Pb-210 are volatile in high-temperature processes and transferred into the off-gas/dust.
- Deposition of dust on vegetables/crops leads to an ingestion dose of
  - Po-210: 38 µSv/a per Bq/(m^2 a)
  - Pb-210: 7 µSv/a per Bq/(m^2 a)
- All we need to know for an estimate is the release rate of Po-210 from a smoke stack
  - Assume 100 % volatilisation of nuclides in raw material
  - 95...99 % retention efficiency of dust filters
- Activity source term = mass flow [t/h] x specific activity [Bq/g] x (1 - filter retention)

Little excursion: dry and wet deposition rate
Normalised to a 1 GBq/a source strength, Lagrangian model



Settling rate (dry & wet) for a source, dust borne acitivity strength of 1 GBq/a, main wind direction

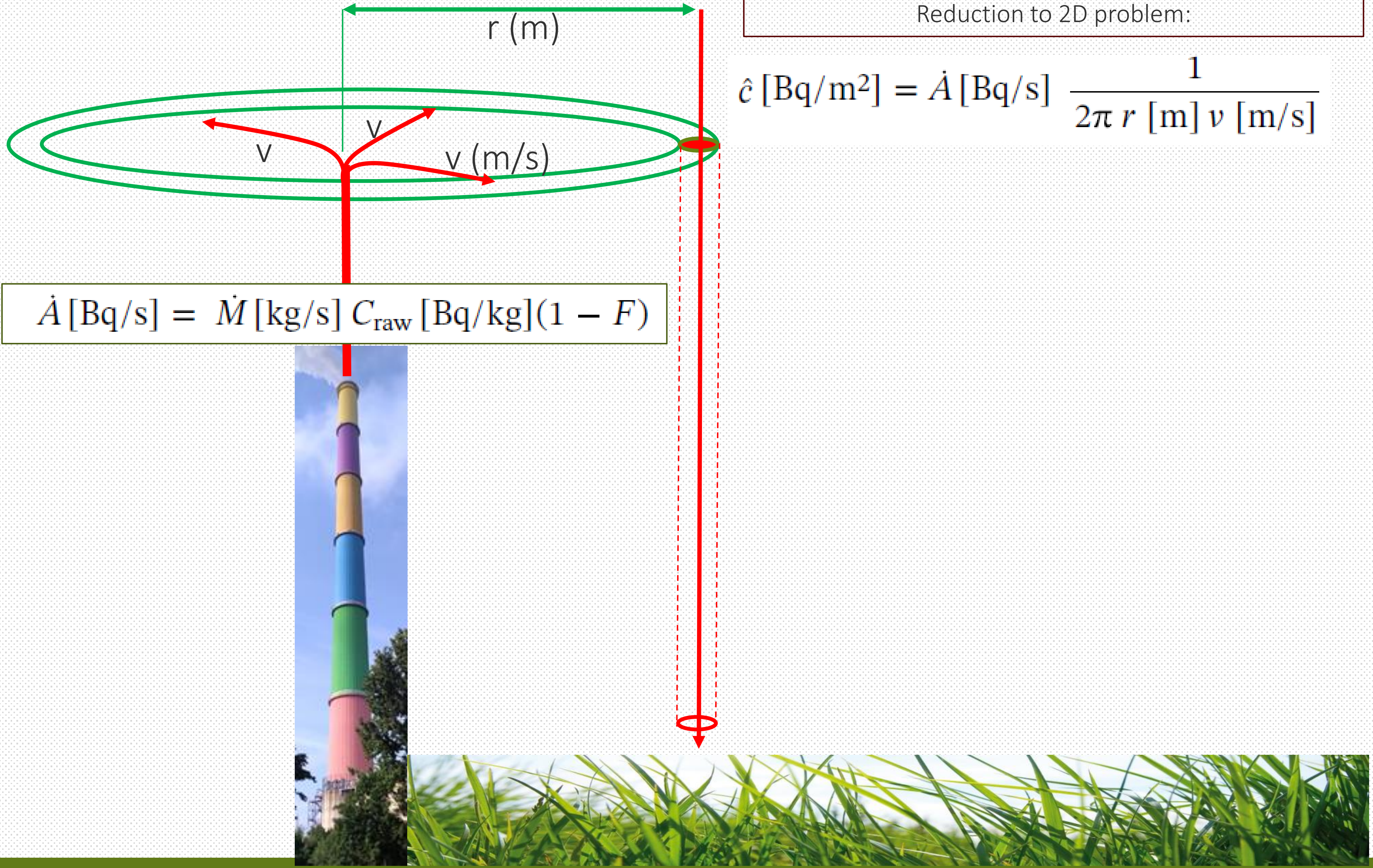


Dose estimate algorithm for dust-borne NORM discharges

- Discharges from typical high-temperature processes are radiologically dominated by Po-210
- For an order-of-magnitude estimate, assume that 100 % of the Po-210 content in the raw material (coal, ore) are volatilised
- For dust filter retention, assume something like 95...99 %
- Under typical European climate conditions with annual precipitation of approx. > 500 mm, wet deposition dominates overall dust deposition
- „Conservative-realistic“ dust deposition estimate
  - Move the receptor as close to the source as realistically possible
  - Realistically, the distance between an industrial dust source (i.e., large smoke stack) and receptor (agricultural areas) is typically 2...4 times the height of the smoke stack

Dose estimate algorithm for dust-borne NORM discharges

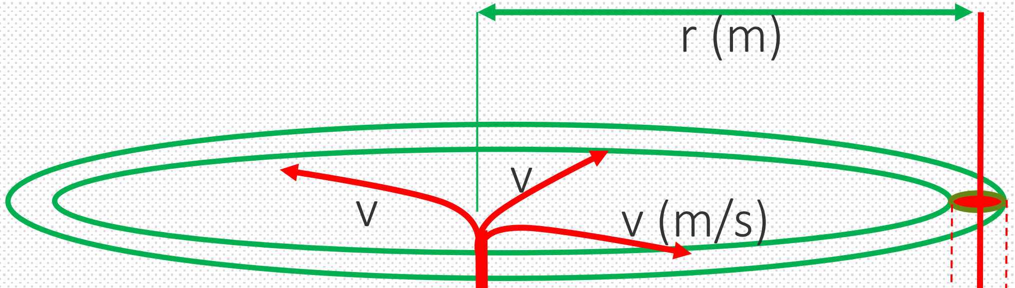
$$\dot{A}\,[\mathrm{Bq/s}] = \dot{M}\,[\mathrm{kg/s}]\,C_{\mathrm{raw}}\,[\mathrm{Bq/kg}](1 - F)$$



$$\dot{A}\,[\mathrm{Bq/s}] = \dot{M}\,[\mathrm{kg/s}]\, C_{\mathrm{raw}}\,[\mathrm{Bq/kg}](1 - F)$$

Reduction to 2D problem:

$$\hat{c}\,[\mathrm{Bq/m^2}] = \dot{A}\,[\mathrm{Bq/s}]\;\frac{1}{2\pi\, r\,[\mathrm{m}]\, v\,[\mathrm{m/s}]}$$



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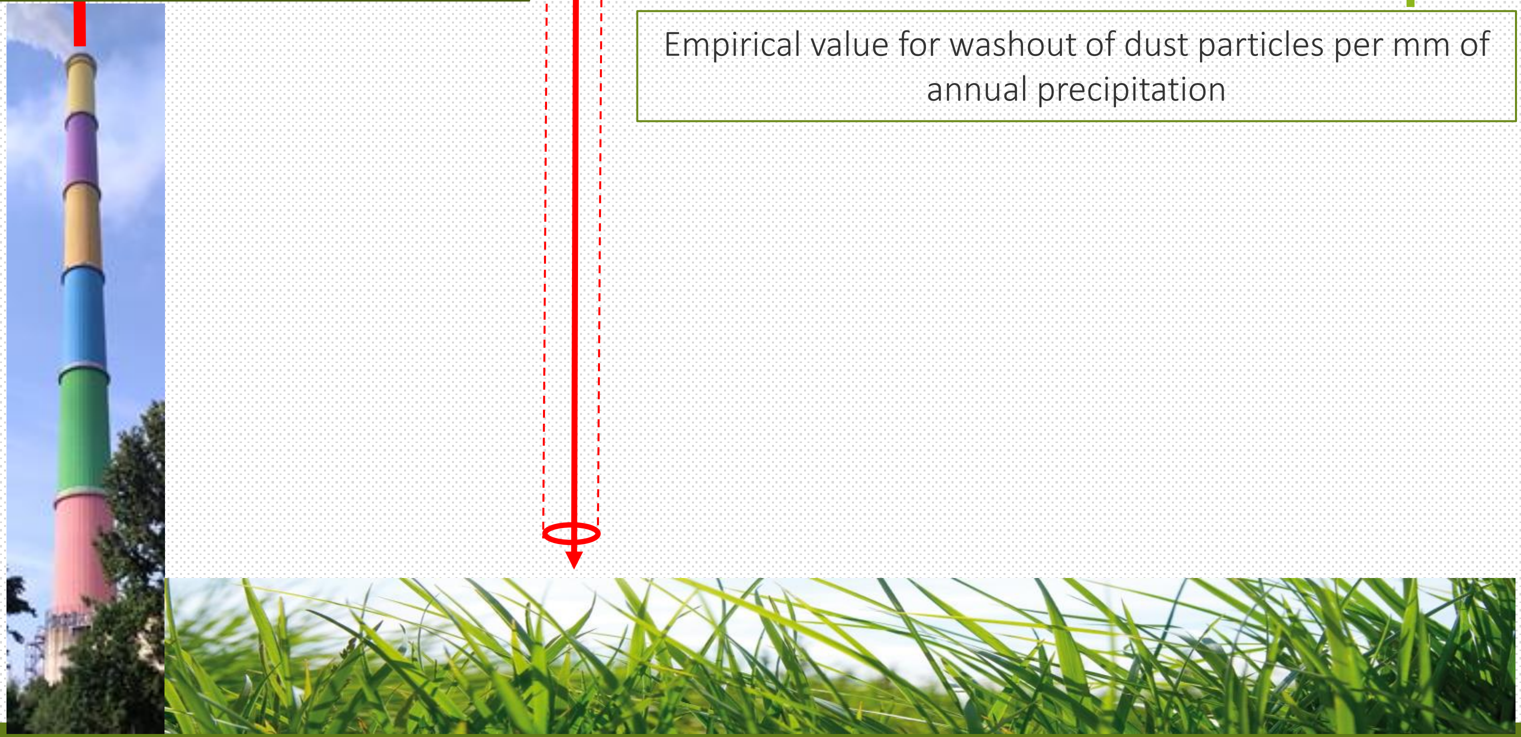

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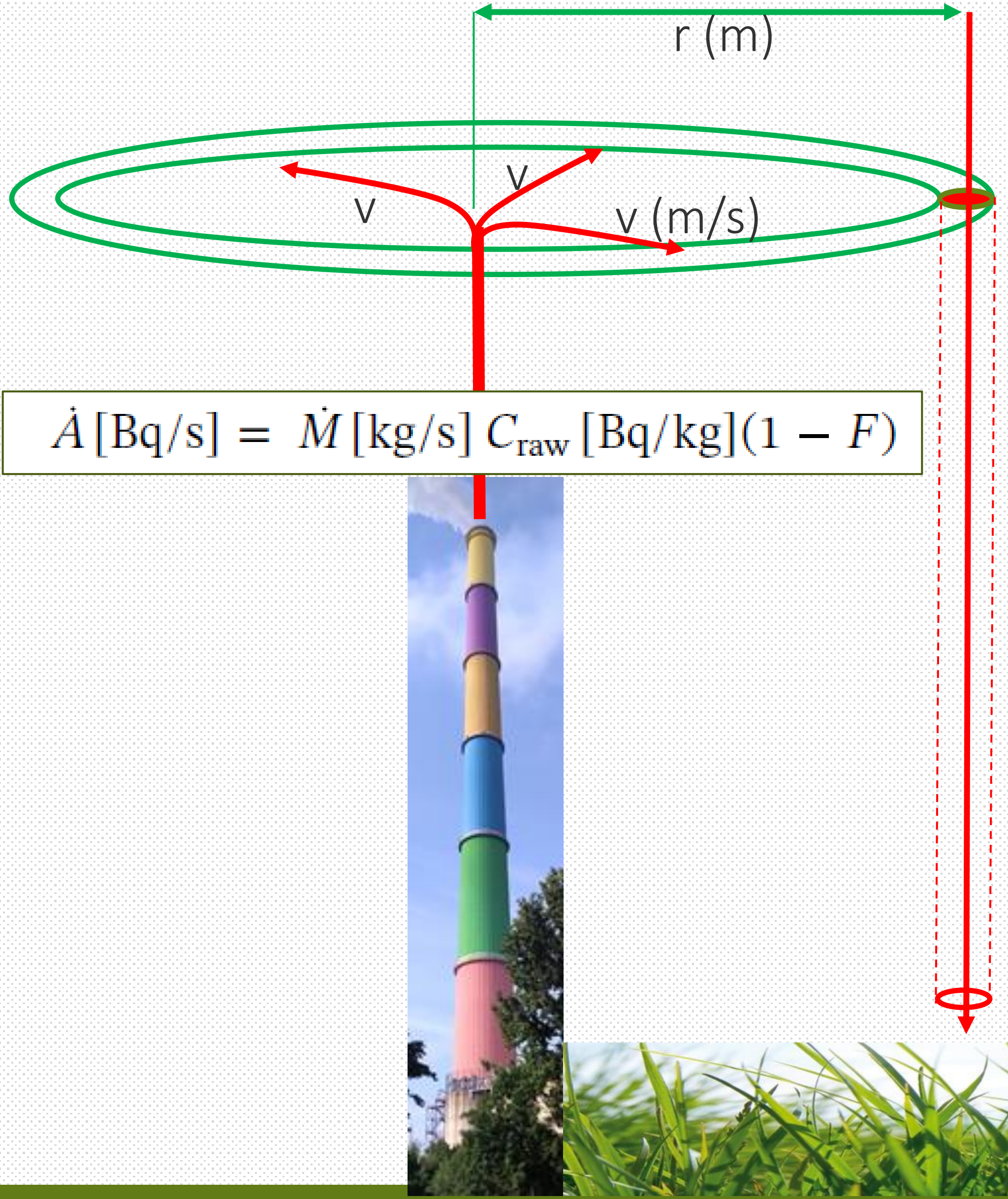
Rotational symmetric wind field:

$$D\,[\mathrm{Bq/(m^2a)}] = \hat{c}\,[\mathrm{Bq/m^2}]\; I\,[\mathrm{mm/a}]\;\; 0.19\,\mathrm{mm^{-1}}$$

Empirical value for washout of dust particles per mm of annual precipitation



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Empirical value for washout of dust particles per mm of annual precipitation

Correction for preferential wind direction & r = 2 H

Dose rate: ingestion of Po-210, agricultural products

$$H_{eff} \cong \dot{M} \cdot C_{raw} \cdot [1 - F] \cdot \frac{0.19\ mm^{-1}}{4\,\pi\, H\, v} \cdot I \cdot \frac{38\ \mu Sv/a}{Bq/m^2 a}$$

Po-210 source strengths of high-temperature processes

Industry branch	Typical production capacity	Discharge of Po-210 (GBq/a)	Normalised discharge
Cement production	0,7 Mt/a	1	1.4 GBq/a per Mt/a
Hard-coal-fired power plant	1 GW(e)	2.4	2.4 GBq/a per GW(e)
Pig iron production	5 Mt/a	7.5	1,5 GBq/a per Mt/a
Lead smelter	0,1 Mt/a	0.5	5 GBq/a per Mt/a

Notes:

- Generic source term estimate, filter retention of 97%
- For detailed industry data see Kunze, Ettenhuber, Schellenberger (2018)
- Differences between detailed and generic data are within 50%
- Examples selected from Germany, situation in other countries may differ

Results: effective doses due to dust emissions from typical NORM-affected industrial plants

Sector	Production or generation capacity of an average facility	Simplified approach using a 2d dispersion model			
		$\dot{M}$ [kg/s]	C_{raw} [Bq/kg]	$\dot{A}$ [Bq/s] $\dot{M}\ C_{raw}$	H_{eff} [µSv/a]
Cement production	0.7 Mt/a	22	40	26.4	17
Power plants (hard coal)	1 GW_{el}	42	25	31.5	20
Primary iron production	5 Mt/a	158	50	237	146
Lead smelting	0.1 Mt/a	1.6[a]	100	4.8	3

Recommended reading and other useful sources

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Research paper

Discharges of dust from NORM facilities: Key parameters to assess effective doses for public exposure

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Discharges from NORM industries in Germany: estimate of doses to members of the public

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Calculation Guide Mining

Calculation Guide for the Determination of Radiation Exposure due to Environmental Radioactivity Resulting from Mining

Department
Radiation Protection and Environment

Bundesamt für Strahlensch

Ressortforschungsberichte zum Strahlenschutz

Ermittlung von potentiellen Strahlenexpositionen durch Ableitungen aus NORM-Industrien
- Vorhaben 3615S12232

Auftragnehmer:
IAF-Radioökologie GmbH

Dr. C. Kunze
Dr. E. Ettenhuber
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Bundesamt für Strahlenschutz

Conclusions

- For dust-borne discharges from NORM-affected industries, deposition of Po-210 on agricultural products is the dominant exposure pathway
- Po-210 is easily volatilised
- A simple generic algorithm with normalised quantities is enough to estimate doses to an order of magnitude
- All we need is input of **raw material**, **specific activity**, **filter retention**, **stack height**, some typical weather parameters (**wind speed**, **washout coefficient**)
- Common-sense assumptions for sufficiently conservative but realistic estimates (**distance of receptor to source**)
- Processing/combustion of large amounts of raw materials/fuel even with specific activity at natural background levels can lead to <u>moderate</u> effective doses to the public
- Annual doses are in the range from several **10's to 100's of µSv** even for large plants