17th International Workshop on Geological Aspects of Radon Risk Mapping

Radon as environmental tracer for subsurface NAPL contamination and in-situ remediation assessment

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Natural radioactivity – a curse or a blessing?

It is a curse…

"action plan on *radon risk* mapping"

"education in *radon protection*"

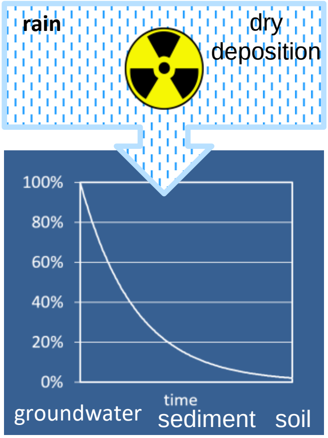
"public *exposure to radiation*"

"*radon entry* into buildings"

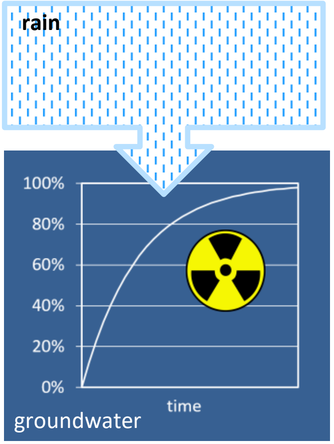
"*anti-radon* membranes"

…but also a blessing!

Cosmogenic

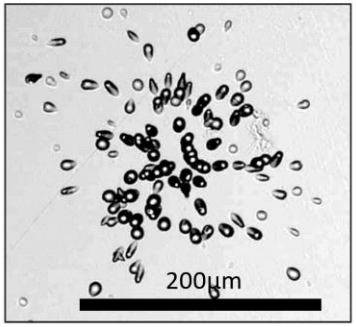


Geogenic



We count single decays, i.e., single atoms!

0.005 Bq/l ^{222}Rn equals 3.3x10^{-18} g/l (0.003 fg/l).



"hot particle" detected with CR39 alpha track detector

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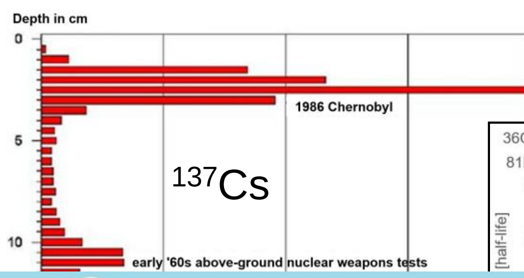
Sediment dating ($^{137}Cs/^{210}Pb$)

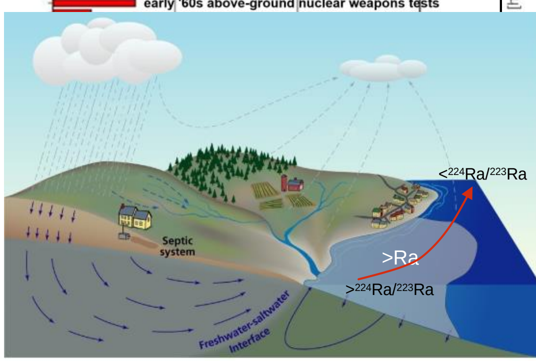
Groundwater dating

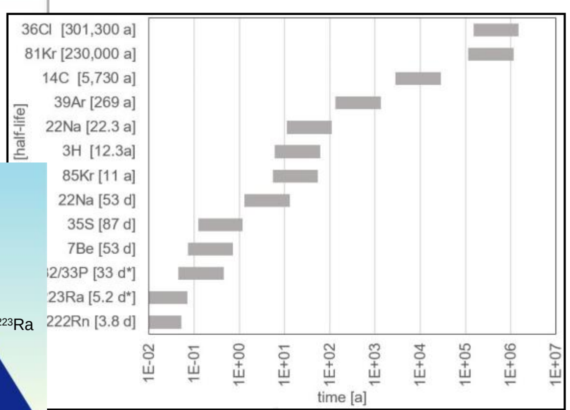
Groundwater tracking

Surface water tracking

NAPL investigation (^{222}Rn)







The Problem

Conventional survey approach:

- soil / aquifer material sampling
- soil gas / groundwater sampling
- *direct* analysis of samples for NAPLs

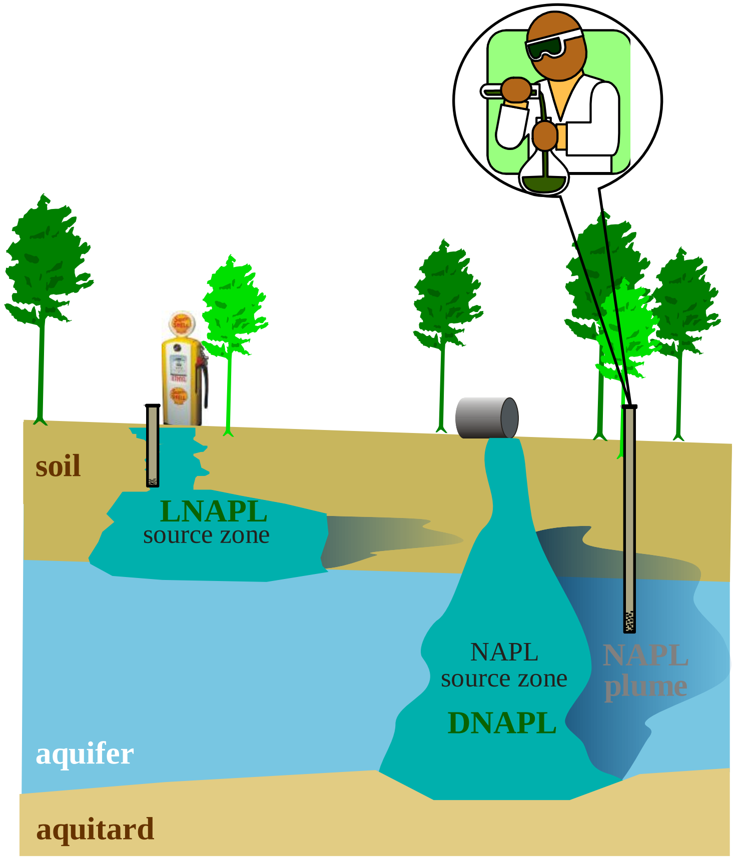
Shortcomings:

Soil and aquifer material samples only provide <u>point values</u>.

Soil gas samples only allow the localisation of contamination with <u>volatile NAPLs</u>.

GW samples only allow the localisation of contamination with <u>soluble NAPLs</u>.

GW samples do not allow to differentiate between source zone and plume.



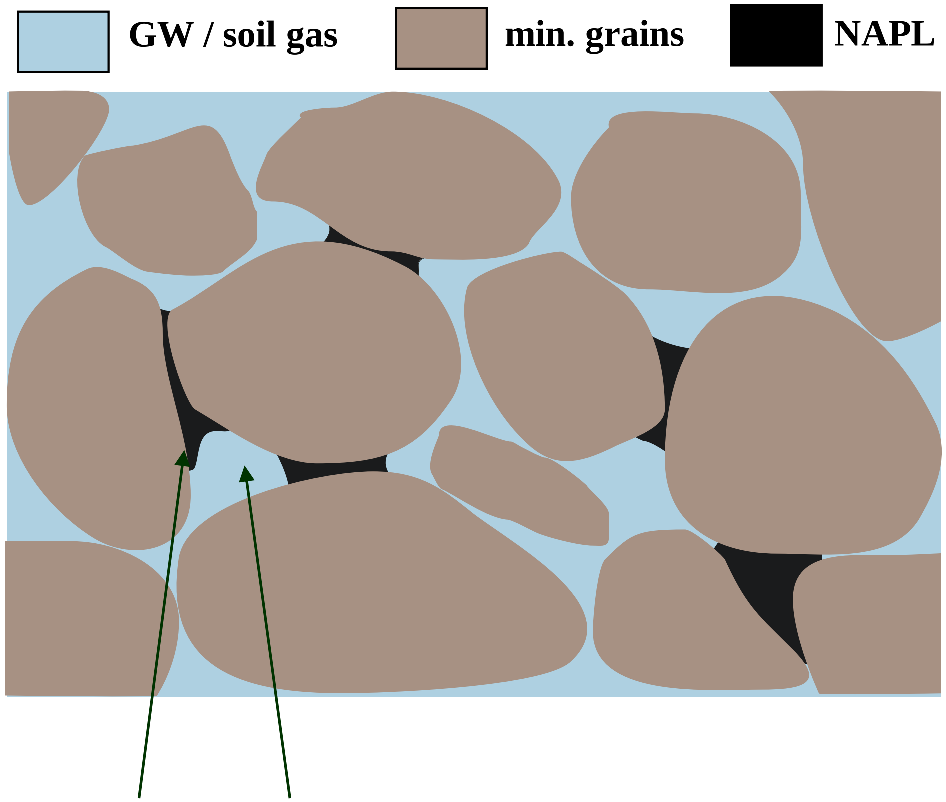
The Approach: Radon-222 as NAPL-Indicator

Central Facts:

1. Radon is a naturally occurring component of groundwater and soil gas.

2. Radon exhibits a very good solubility in a wide range of NAPLs.

3. The radon inventory available in the pore space is preferentially accumulated in the residual NAPL.



$$C_{NAPL} / C_{w} = K_{NAPL/w} = 40$$

$$C_{NAPL} / C_{gas} = K_{NAPL/gas} = 10$$

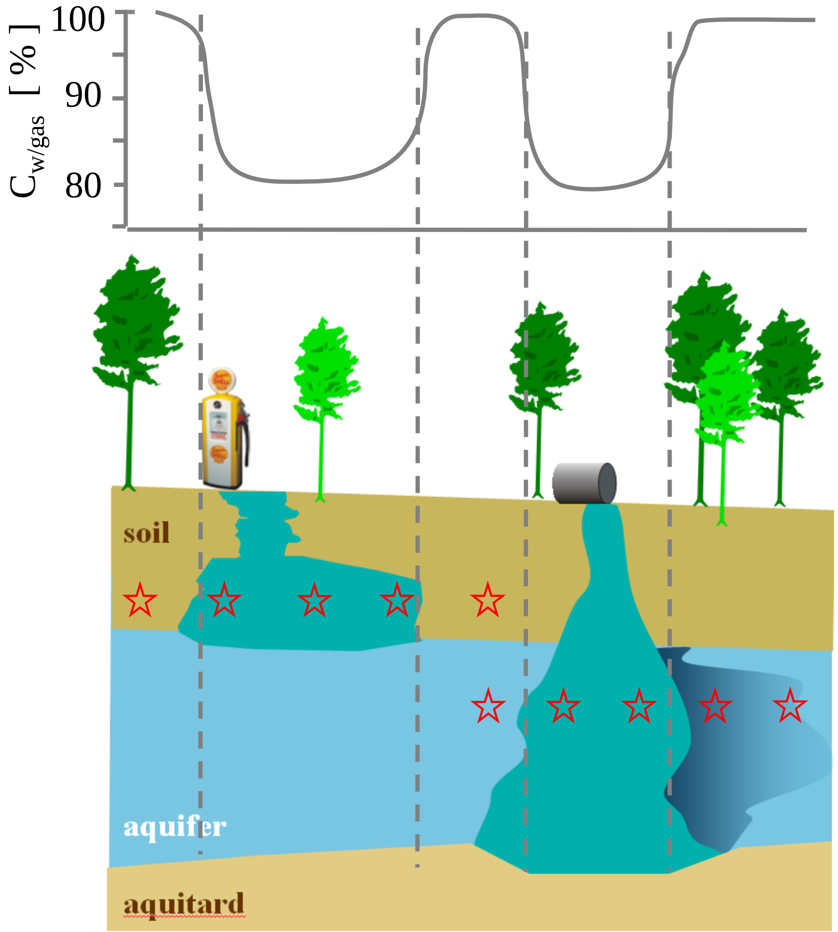
Rn partition coefficient

The Approach: Radon-222 as NAPL-Indicator

Central Idea:

Any residual NAPL causes locally reduced radon concentrations in the surrounding pore space.

Rn deficit in GW or soil gas can be used as qualitative indicator for the *indirect* localization of residual NAPLs.



☆ GW / soil gas samples for on-site Rn detection

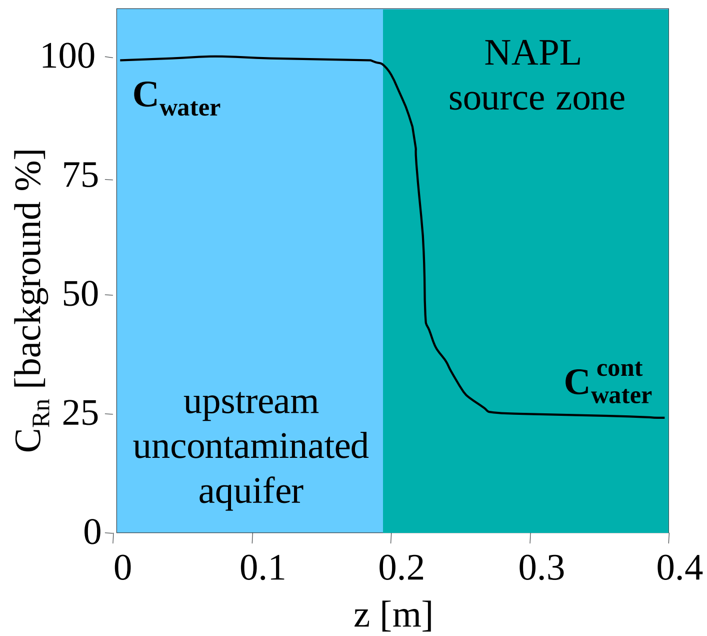
The Approach: Radon-222 as NAPL-Indicator

Central Idea:

Any residual NAPL causes locally reduced radon concentrations in the surrounding pore space.

Rn deficit in GW or soil gas can be used as qualitative indicator for the indirect localization of residual NAPLs.

If K is known, the Rn deficit is also a quantitative indicator for estimating the NAPL saturation of the pore space (S_{NAPL}).



$$C_{water}^{cont} = \frac{C_{water}}{1 - S_{NAPL} - K_{NAPL/W} S_{NAPL}}$$

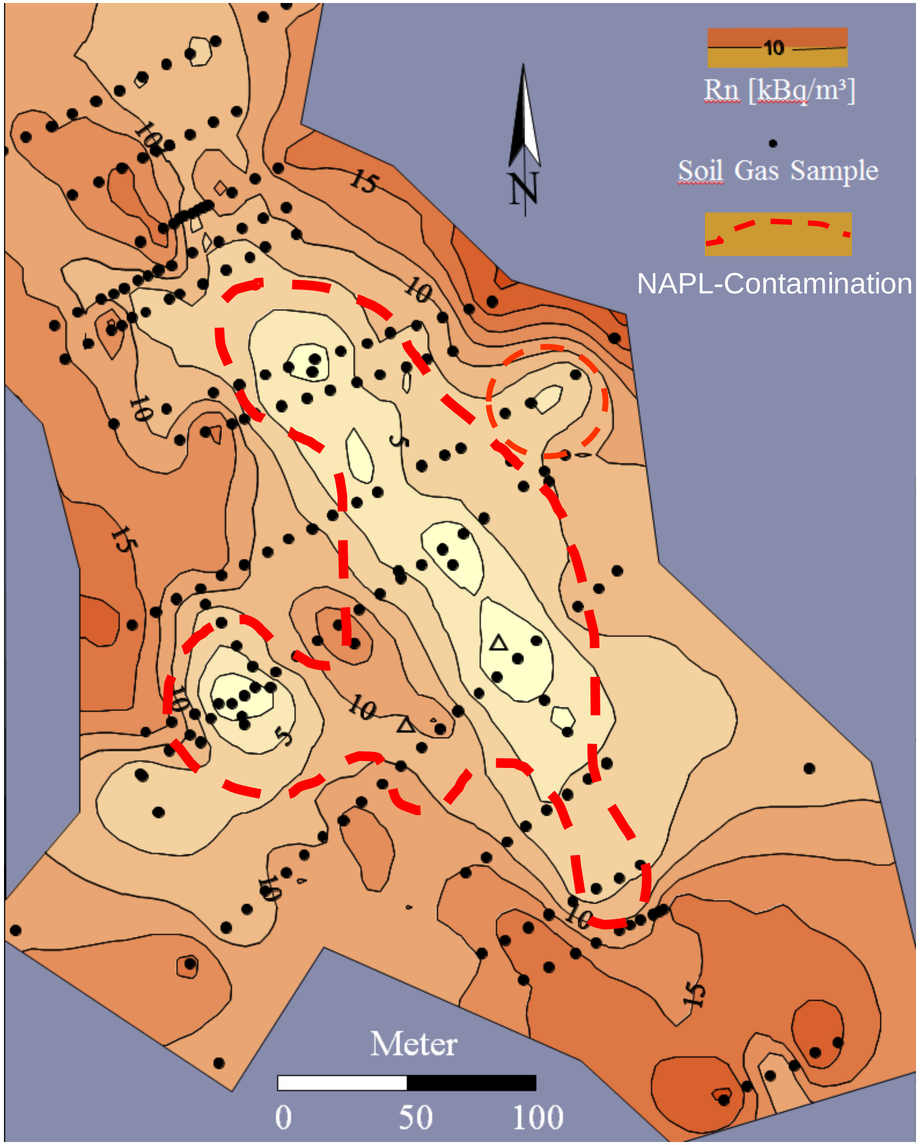
Example 1 - Soil Contamination

- abandoned airport
- geology: sand
- soil contamination with kerosene
- contamination covers ca. 1500 m²
- 200 soil gas samples taken
  by one technician in five days

➡ good correspondence

➡ less expensive / time-consuming than the conv. drilling + lab survey

➡ results show contaminated zone in higher resolution



Schubert, M., Freyer, K., Treutler, H.C., Weiß, H. (2001): Using soil gas radon as an indicator for ground contamination by non-aqueous phase-liquids. Journal of Soils and Sediments 1, 217-222.

Example 2 - GW Contamination

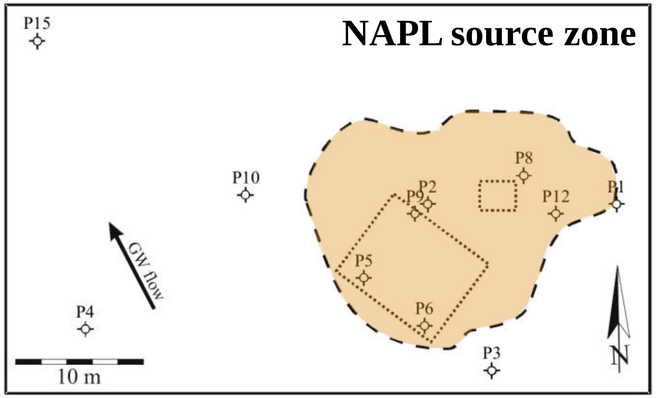
- abandoned gas station
- geology: sandy gravels
- residual contamination with diesel fuel
- source zone covers ca. 400 m²
- GW samples from 11 monitoring wells analysed for Rn and BTEX
- BTEX plume down gradient of source zone

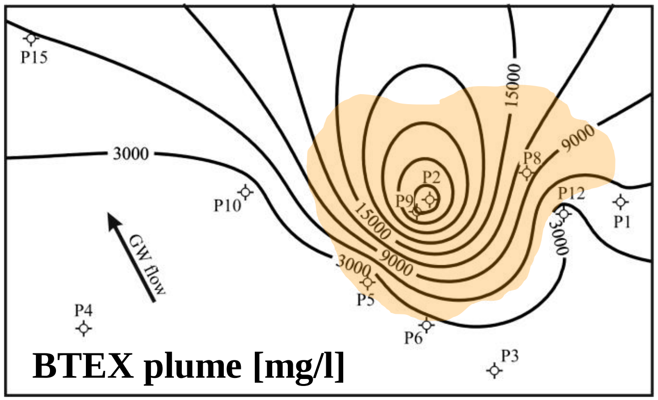
➡ good correspondence

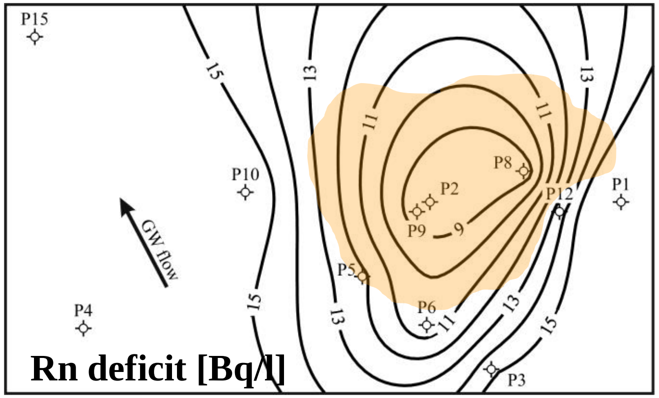
➡ differentiation between source zone and NAPL plume was possible

➡ quantitative assessment revealed a NAPL saturation of about 3%.

Schubert, M., Paschke A., Lau, S., Geyer, W., Knöller, K. (2007): Radon as a Naturally Occurring Tracer for the Assessment of Residual NAPL Contamination of Aquifers. Environmental Pollution 145, 920-927.

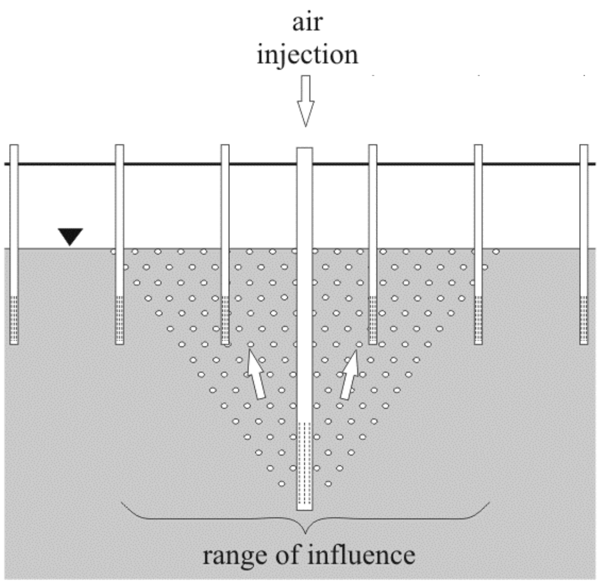






Example 3 - GW Remediation

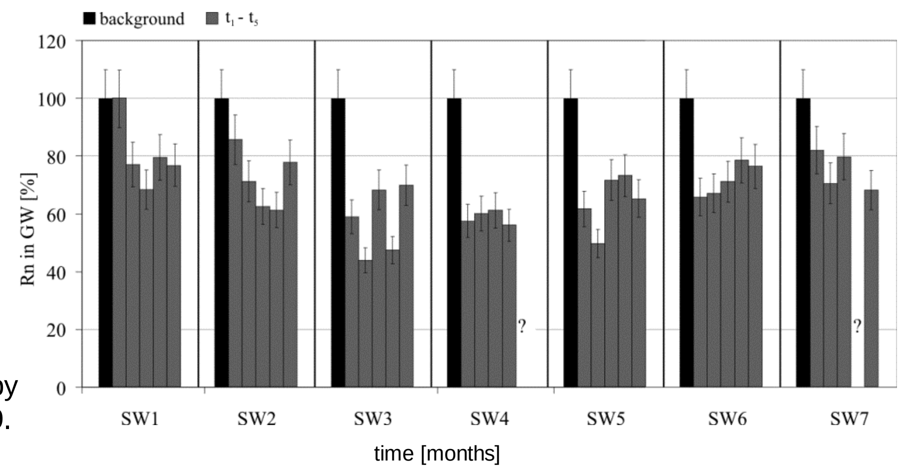
- abandoned hydrogenation plant
- geology: mainly sand
- large-scale GW contamination (VOC)
- GW remediation by means of *in situ* air sparging (IAS) for five months.



Monitoring of radon distribution pattern allows assessment of:

➡ spatial range of the IAS influence

➡ temporal variations of the IAS efficiency



Schubert M., Schmidt A., Müller K., Weiß H. (2011): Using radon-222 as indicator for the evaluation of the efficiency of groundwater remediation by in-situ air sparging. Journal of Environmental Radioactivity, 102: 193-199.

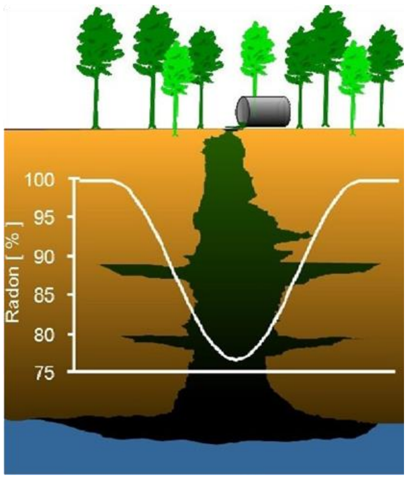
Radon-222 as NAPL-Indicator

Conclusions 1

- ^{222}Rn naturally occurring in soil gas and natural waters.
- ^{222}Rn exhibits a very good solubility in a wide range of NAPLs.
- ^{222}Rn can easily be detected in water and soil gas on site.

➡ ^{222}Rn minima can be used for:

- Localization of residual NAPL contamination in soils.
- Localization and assessment of NAPL source zones in aquifers.
- Distinguishing between source zone and plume in aquifers.
- Efficiency evaluation of GW remediation activities.



Schubert M. (2015): Using radon as environmental tracer for the assessment of subsurface Non-Aqueous Phase Liquid (NAPL) contamination – A review. Eur. Phys. J. Special Topics 224, 717–730.

Radon-222 as NAPL-Indicator

Conclusions 2

- The use of ^{222}Rn as NAPL indicator is understood in theory.

  However, in the practical application errors can occur that
  lead to misinterpretation of the results.

- These possible errors include:

  - neglect spatial inhomogeneity of the geology (i.e. the ^{222}Rn background)
  - neglect temporal fluctuations of air pressure, temperature or soil moisture
  - accidental sampling of outside air
  - accidental radon loss from water samples
  - incorrect error propagation

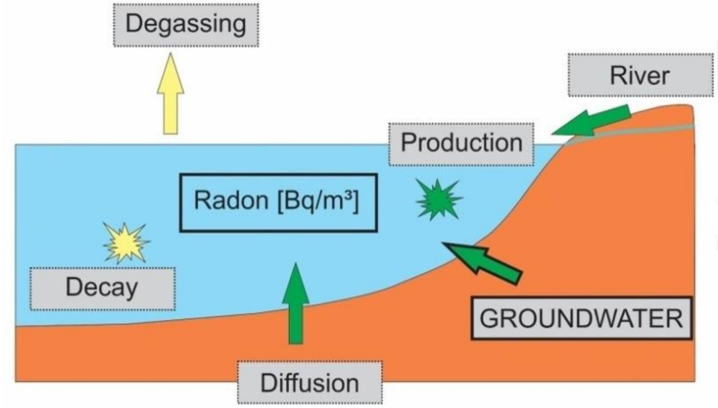
➡ Survey results should not only be published as success stories.
It would be more helpful to discuss possible errors.

A review paper addressing these possible errors might be advisable.

Radon-222 as tracer in hydrogeology

Conclusions 3

- ^{222}Rn can be used as “age” tracer for natural waterbodies.
- ^{222}Rn can be used for tracking groundwater and surface water flow paths.
- ^{222}Rn mass balance can be used for estimation of GW discharge into lakes.



➡ If you are using a mobile radon monitor for radiation protection purposes, think of other applications.

Schubert M., Lin M., Clark J.F., Kralik M., Damatto S., Copia L, Terzer-Wassmuth S., Harjung A. (2024): Short-Lived Natural Radionuclides as Tracers in Hydrogeological Studies – A Review. Science of the Total Environment 920, 170800