GQ 19

Groundwater Quality 2019

EXPERIMENTAL AND MODELLING INVESTIGATIONS OF ^{222}RN PROFILES IN CHEMICALLY HETEROGENEOUS LNAPL CONTAMINATED VADOSE ZONES

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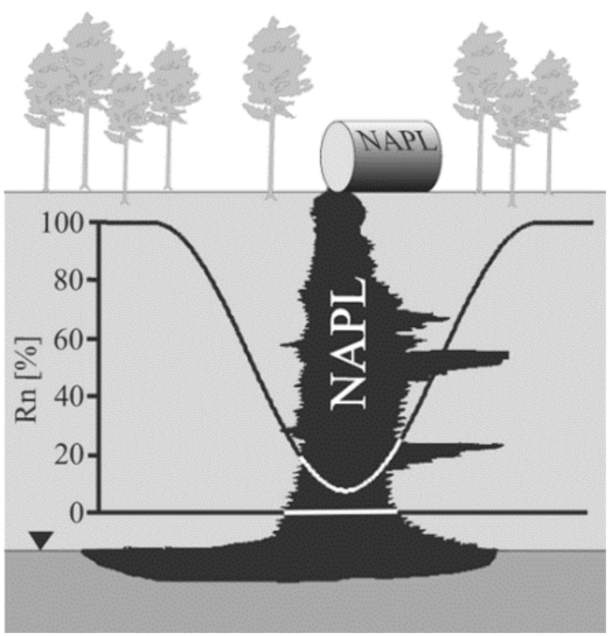
Context

- Groundwater and soil contamination : a widespread environmental problem
- Pollution often related to L and D-NAPL
- Source delineation is crucial to develop improved remediation design
- Usual techniques are costly and time consuming -> Soil gas survey
- Radon-222 (^{222}Rn) : a possible indicator for NAPL localization and quantification

Rn properties

- Naturally emitted by soil matrix with radium-226 bearing minerals
- Chemically inert despite dissolution into NAPL (Nazaroff, 1992)
- Allows NAPL localization and quantification in
  - Saturated zone (Hunkeler *et al*., 1997; Davis *et al*., 2005)
  - Vadose zone (Schubert *et al*., 2001; Höhener et Surbeck, 2004)



(Schubert *et al*., 2002)

Delineation of NAPL contaminated zone in homogeneous aquifers

Project objective

Define the ability of ^{222}Rn gas method to identify LNAPL sources in chemically heterogeneous unsaturated media

- MIN3P enhancement
  - ^{222}Rn production
  - ^{222}Rn dissolution in NAPL
  - ^{222}Rn decay in gas and NAPL phases
- Laboratory experiments
  - Batches
  - Columns

General equations

- Mass balance for a 1D representative volume in vadose zone:

$$\frac{\partial}{\partial t}\left(\theta_g A_g + \theta_w A_w + \theta_n A_n\right) = \frac{\partial^2}{\partial x^2}\left(D_g \theta_g A_g + D_w \theta_w A_w + D_n \theta_n A_n\right) + Q$$

  - g, w, n : gas, water, NAPL
  - θ_i : i phase content (-),
  - A_i : ^{222}Rn activity in phase i (Bq m^{-3}),
  - $D_{i,}$: effective diffusion coeff. in phase i (m^2 s^{-1}),

Diffusion in NAPL ignored

- Source (in-growth) and sink (decay) term *Q* (Bq m^{-3} s^{-1}):

$$Q = E C_{Ra} \lambda \rho_s (1 - \theta_t) - \lambda\left(\theta_g A_g + \theta_w A_w + \theta_n A_n\right)$$

  - *E* : ^{222}Rn emanation coefficient (-),
  - $C_{Ra,}$: solid Ra content (Bq kg^{-1}),
  - ρ_s : solid density (kg m^{-3}),
  - λ : ^{222}Rn decay rate constant (2.1×10^{-6} s^{-1})

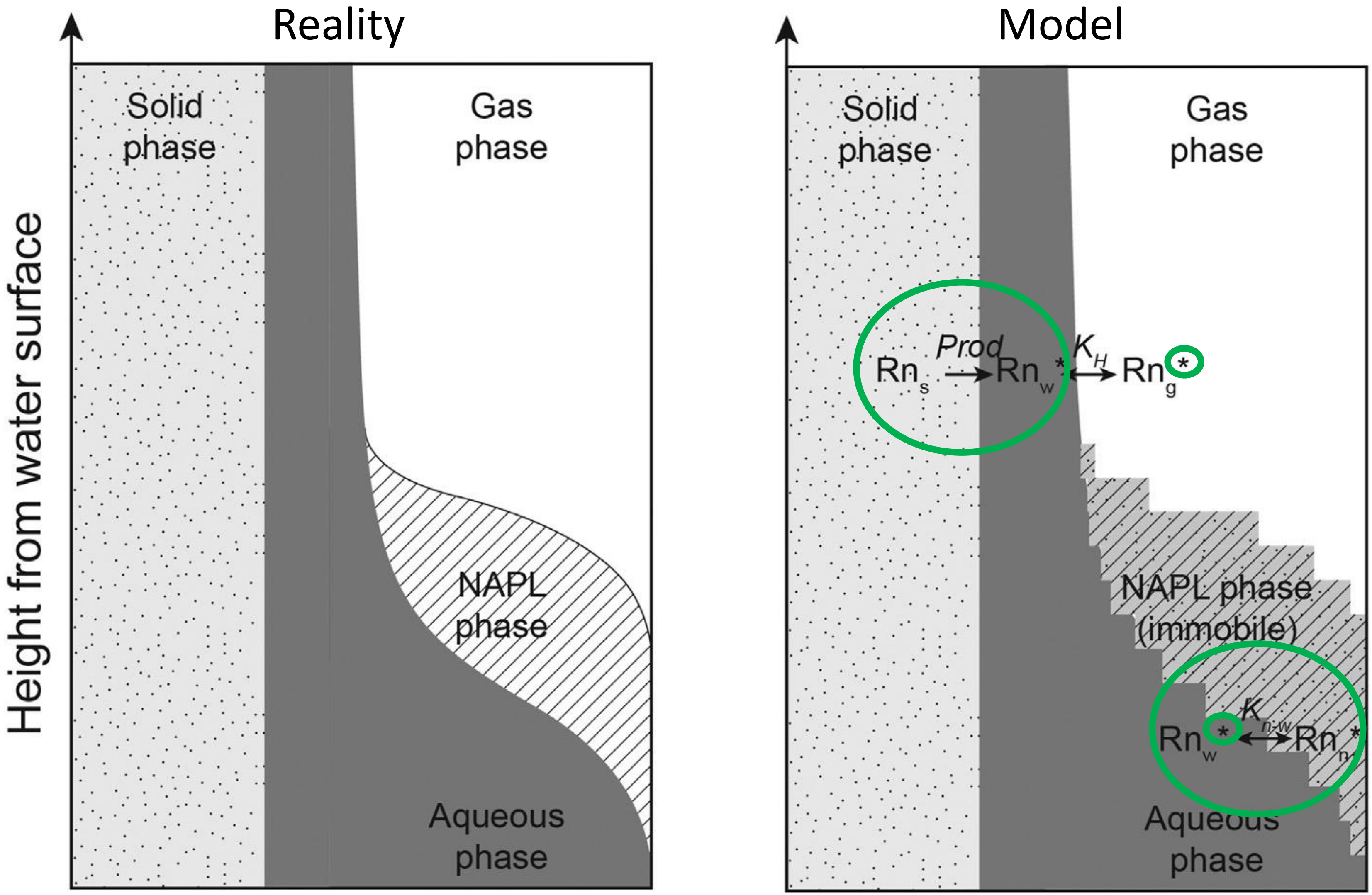
- Assuming instantaneous linear equilibrium between phases:

$$K_H = \frac{A_g}{A_w}$$

$$K_n = \frac{A_n}{A_g}$$

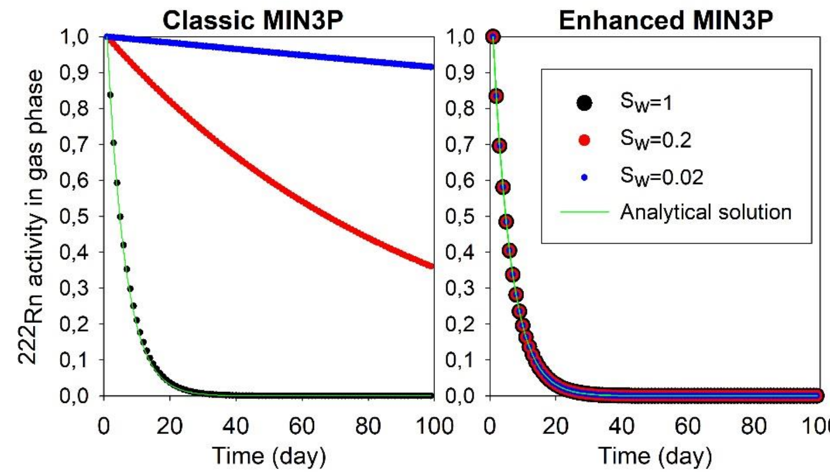
$$K_{n-w} = K_n \times K_H$$

MIN3P conceptual model and enhancement

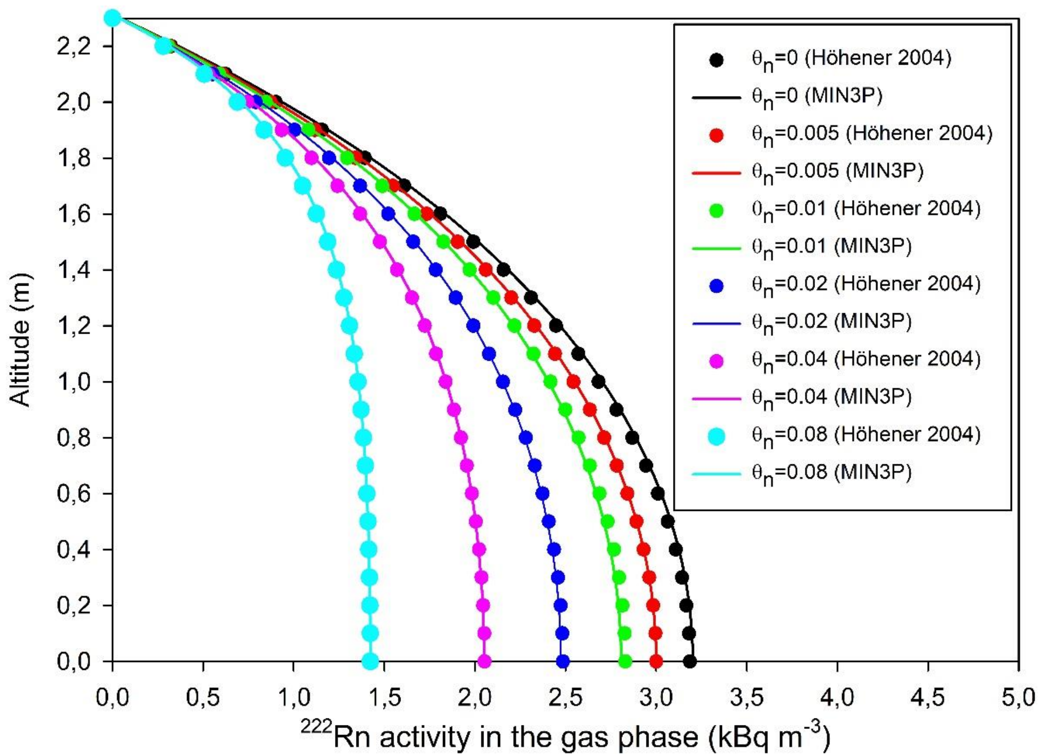


MIN3P enhanced model validation

- ^{222}Rn decay in the gas phase ☑
- ^{222}Rn production ☑
- ^{222}Rn dissolution in NAPL ☑
- ^{222}Rn decay in NAPL ☑



$$A = A_0 \cdot e^{-\lambda t}$$



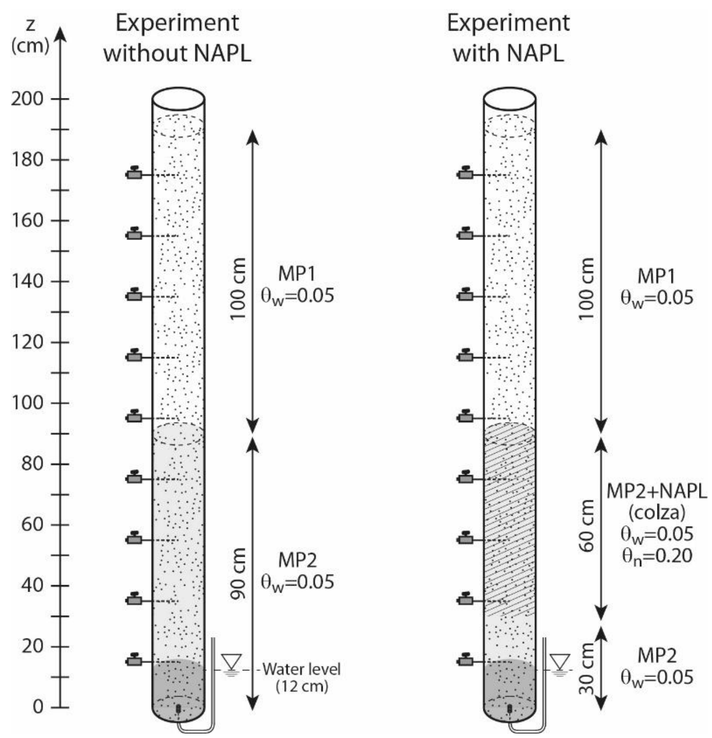
$$A(z) = \frac{f_i S_i}{\lambda}\left\{1 - \left[\cosh\left(\frac{(L-z)}{\sqrt{\frac{f_i D_i}{\lambda}}}\right)\right] \Big/ \left[\cosh\left(\frac{L}{\sqrt{\frac{f_i D_i}{\lambda}}}\right)\right]\right\}$$

$$f_i = \frac{1}{1 + \frac{\rho_s(1-\theta_t)K_d}{H\theta_a} + \frac{\theta_w}{H\theta_a} + \frac{\theta_n}{K_n\theta_a}}$$

(Höhener and Surbeck, 2004)

MIN3P enhanced model validation

- ^{222}Rn decay in the gas phase ☑
- ^{222}Rn production ☑
- ^{222}Rn dissolution in NAPL ☑
- ^{222}Rn decay in NAPL ☑

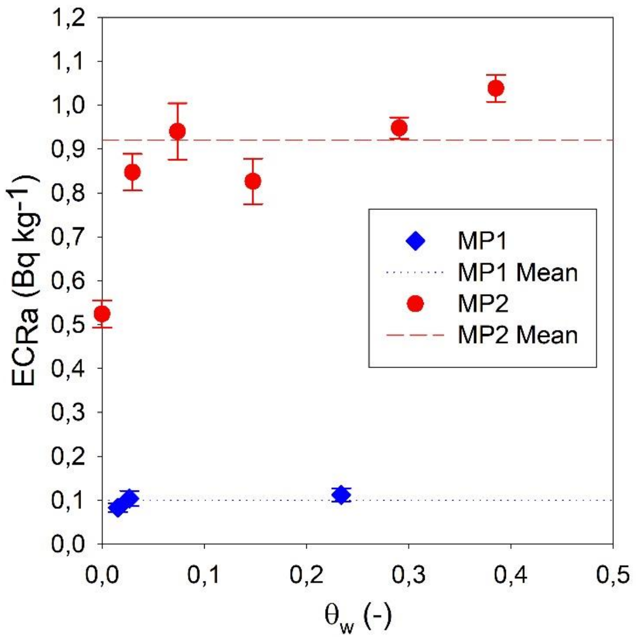


→ **Experimental validation**

- 2 soils selected :
  - MP1 : purified industrial sand
  - MP2 : sieved alluvial sand
- Batches
  - Soils ^{222}Rn production
  - K_n determination (colza oil)
- Column experiments
  - Without NAPL
  - With NAPL

Batch experiments results

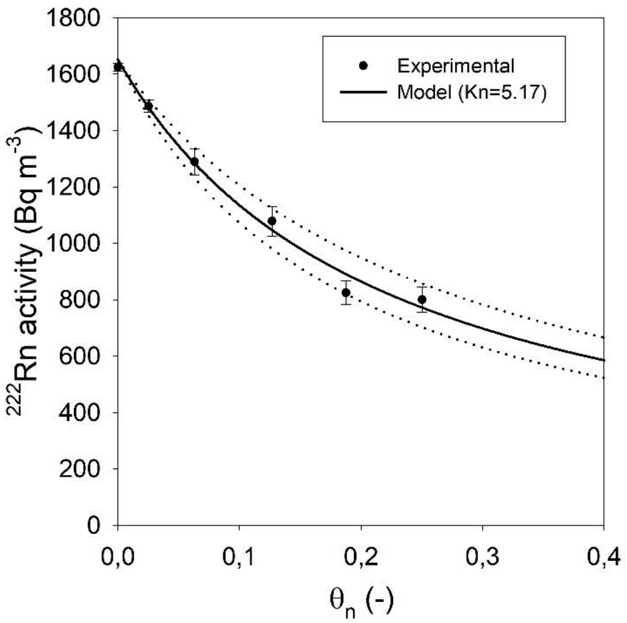
- ^{222}Rn production :
  - MP1 : 0.10 ± 0.01 Bq kg^{-1}
  - MP2 : 0.92 ± 0.08 Bq kg^{-1}



ECRa **relatively stable for environmental application in the relevant range of moisture contents**

- Colza oil K_n determination : K_n = 5.17

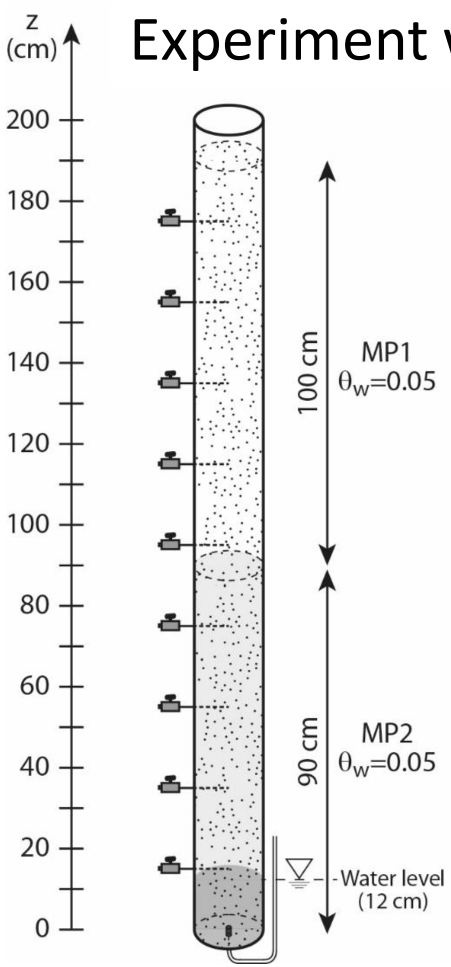
  -> $K_{n\text{-}w}$ = 22.7

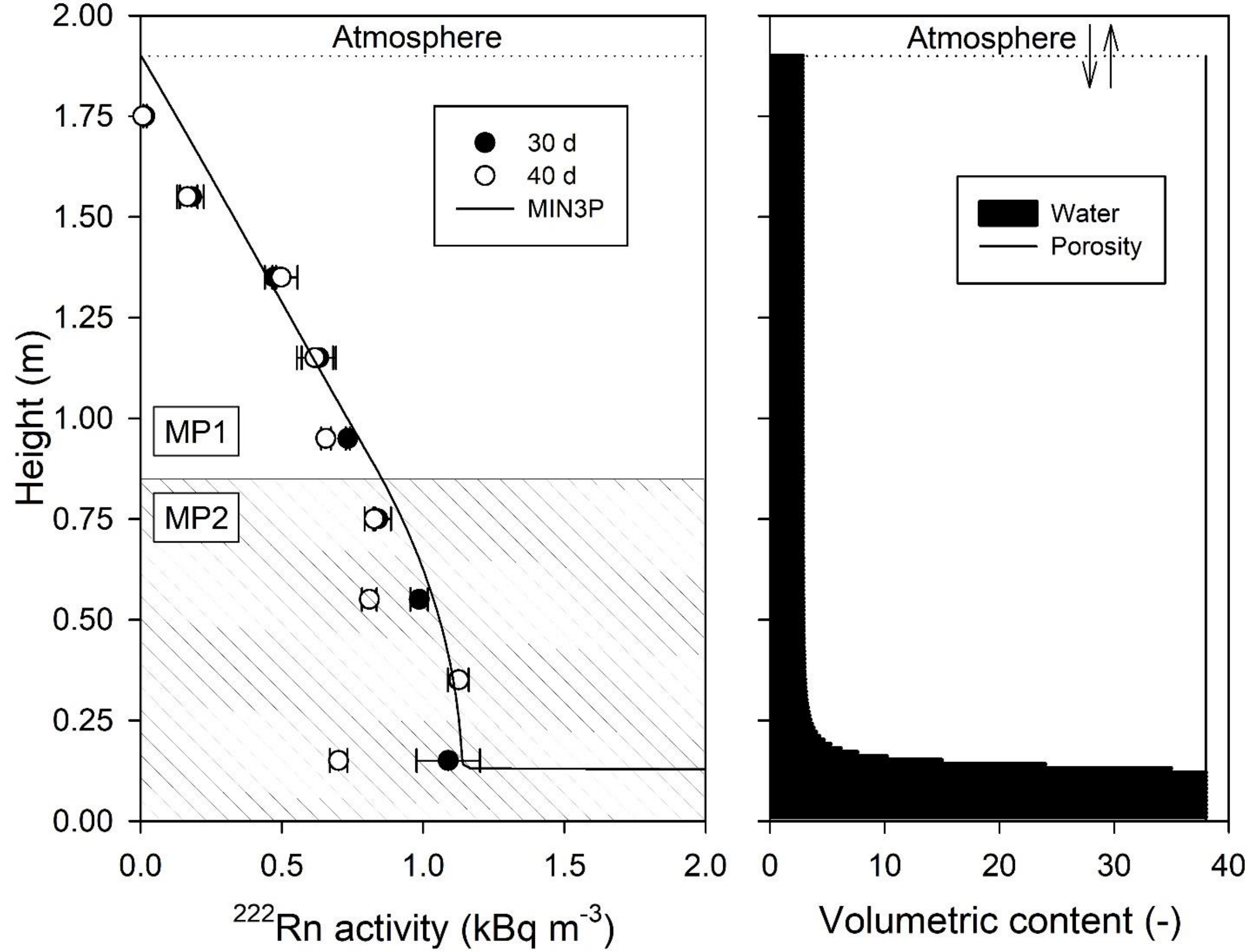


Good accordance with partitioning coefficients found in the literature for colza oil (Clever, 1979)

Column experiments results

Experiment without NAPL

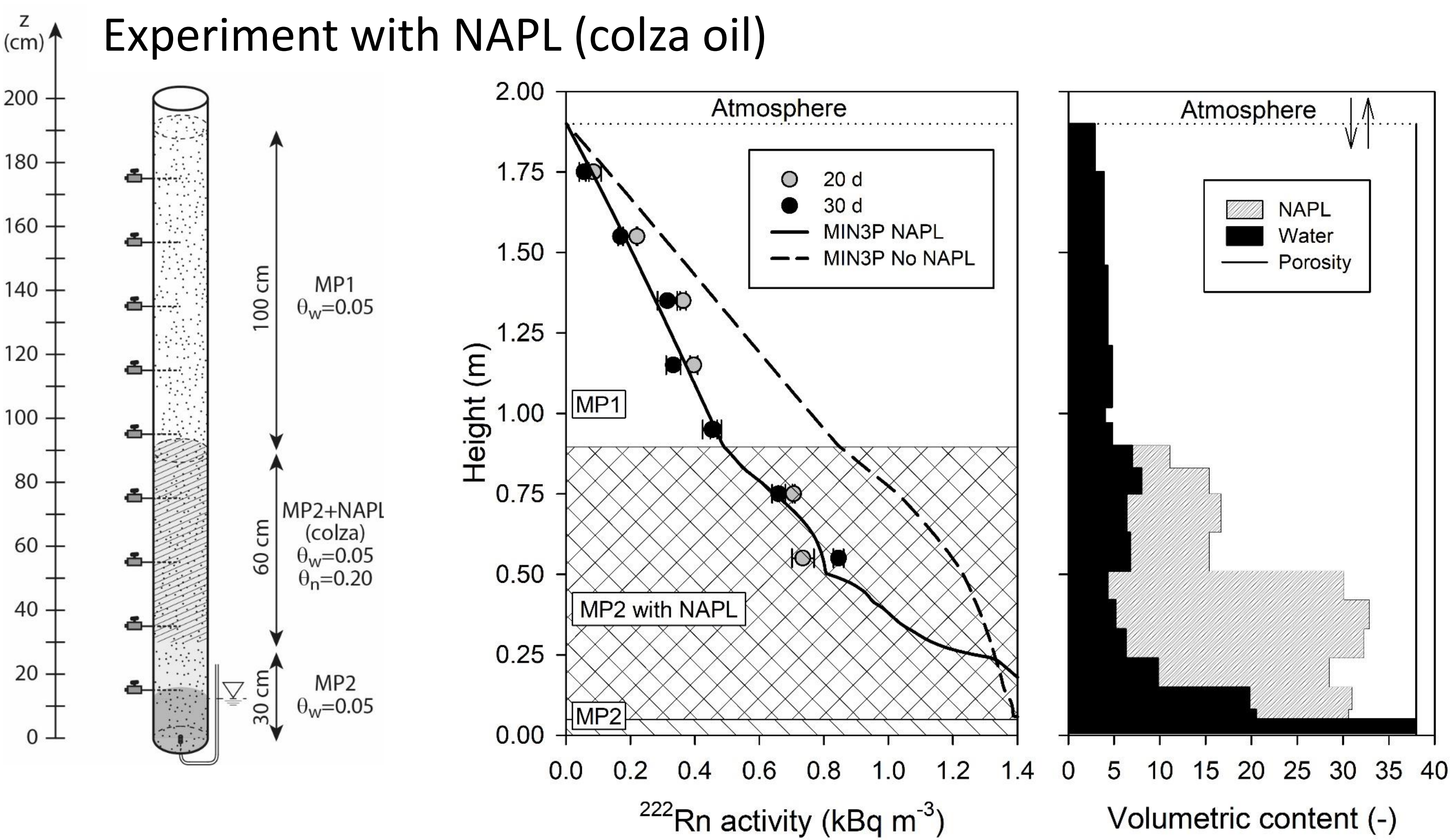




Good agreement between experimental and numerical results

Column experiments results

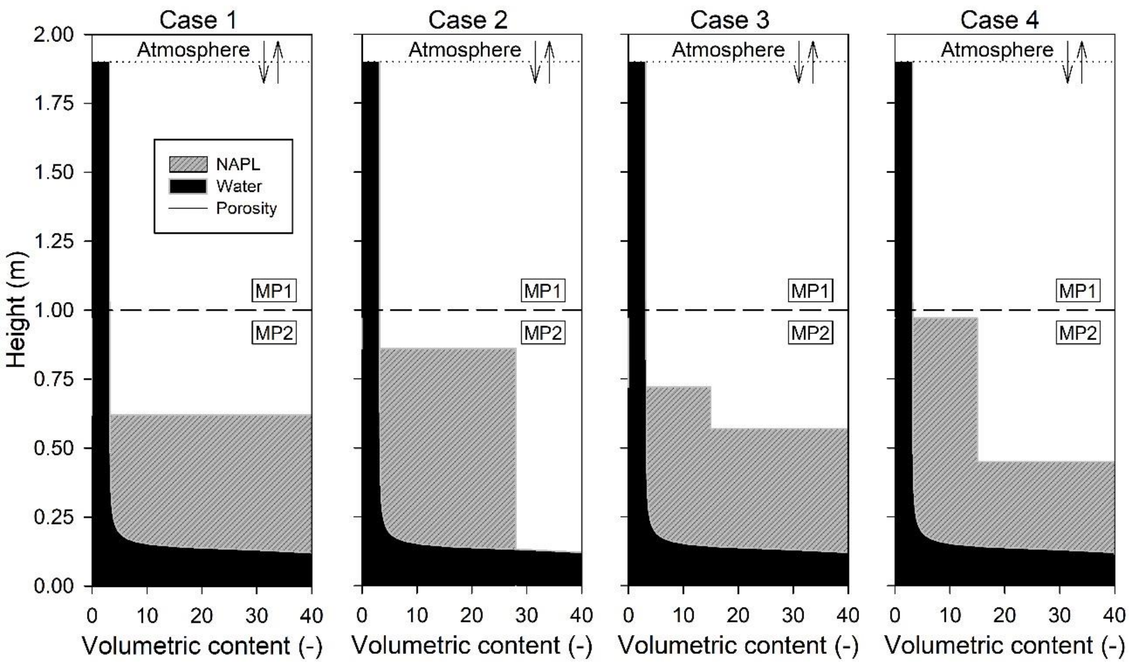
Experiment with NAPL (colza oil)

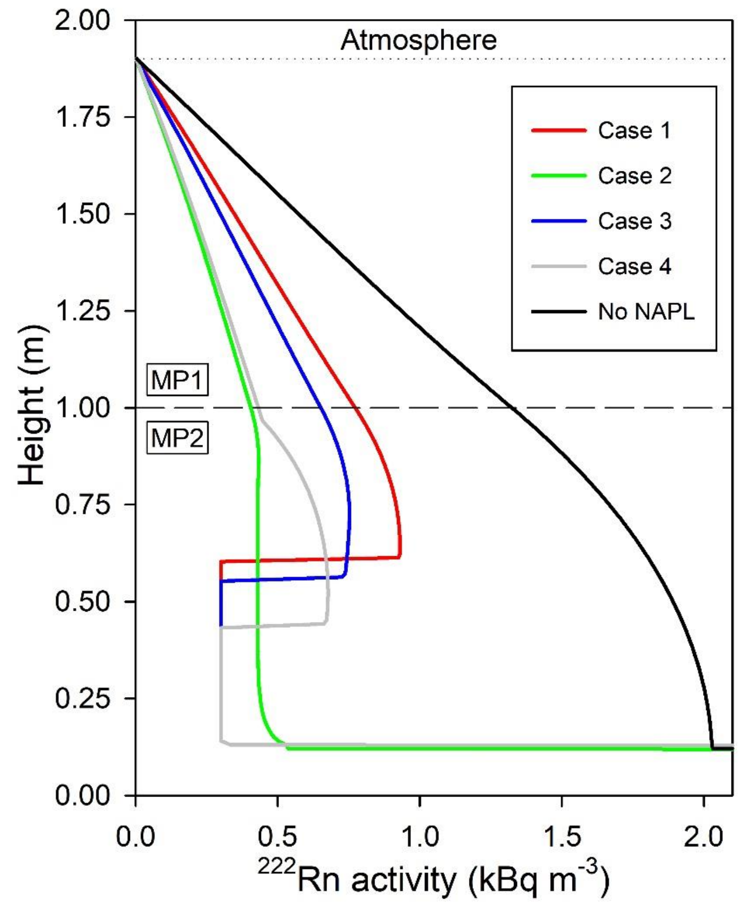


Good agreement between experimental and numerical results

Influence of NAPL distribution on ^{222}Rn activity profile

- 4 configurations :
  - Same NAPL amount
  - Different NAPL distribution





➡ **Influence of NAPL distribution on ^{222}Rn profiles**

Conclusions and perspectives

- Enhancement and validation of MIN3P model

-> Ability to simulate ^{222}Rn transport in heterogeneous vadose zone

- Possibility of LNAPL contamination delineation by ^{222}Rn soils gas monitoring in chemically heterogeneous unsaturated media

- ^{222}Rn activity profile mainly controlled by:
    - Porous media ^{222}Rn production rate,
    - Vadose zone fluid saturations and
    - NAPL type and distribution in the contaminated regions

- Future studies need to be carried out to evaluate the potential of this modeling method on real industrial contaminated sites

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Thank you for your attention

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Laboratory-scale experimental and modelling investigations of ^{222}Rn profiles in chemically heterogeneous LNAPL contaminated vadose zones

Check for updates

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