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*Supplement of*

# Modelling of hydrodynamic and solute transport with consideration of the release of low-level radioactive substances

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# Modelling of hydrodynamic and solute transport with consideration of the release of low-level radioactive substances


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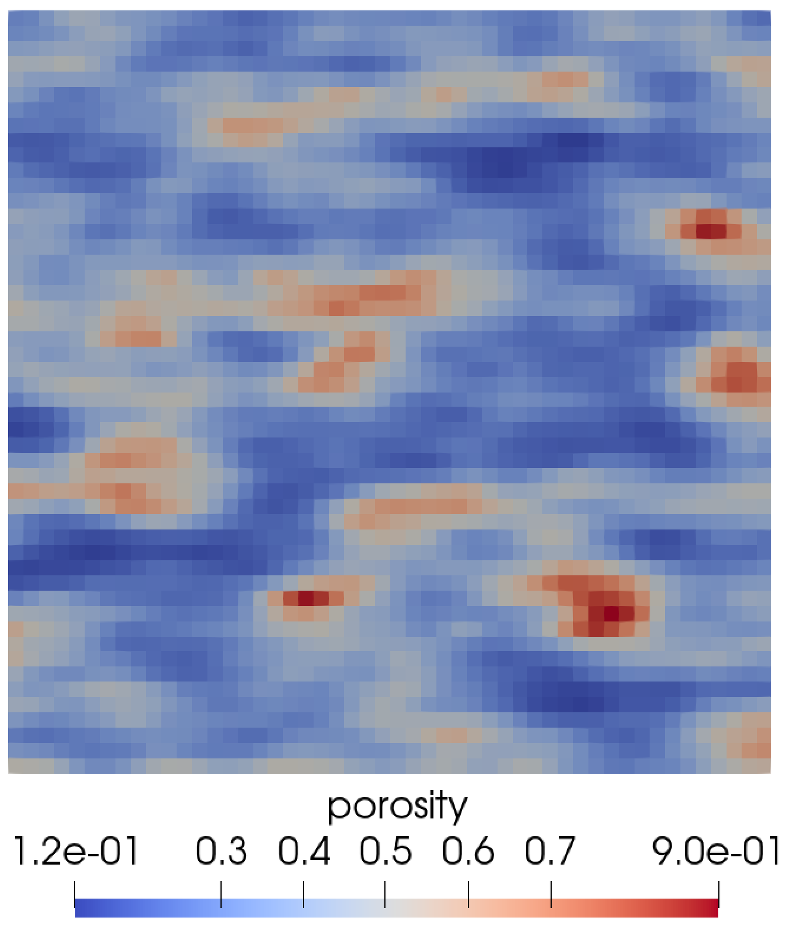
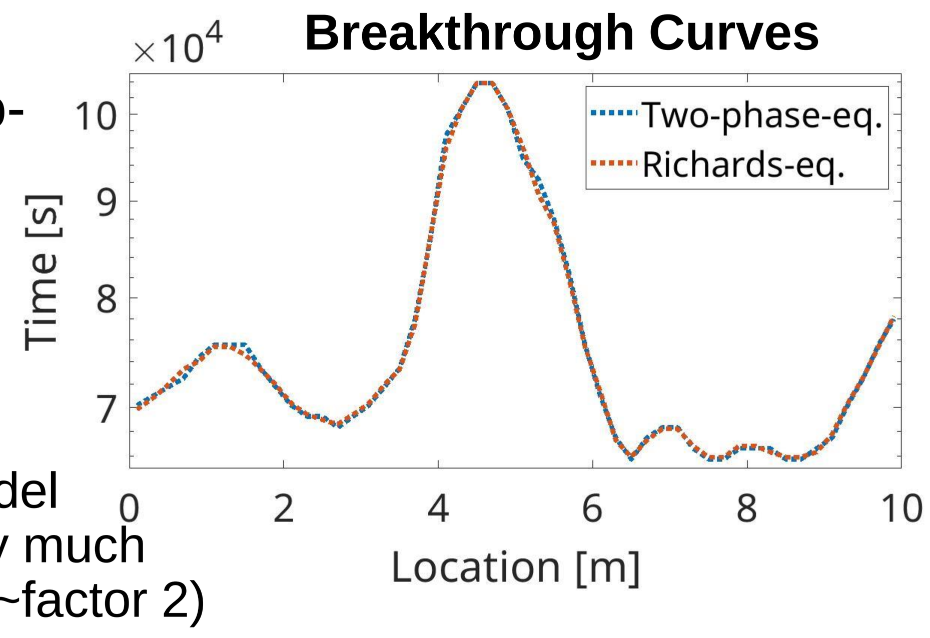
## Different conceptual approaches to the modelling of heterogeneous landfills

### Modelling – why and what




- After decomissioning and clearance materials with different properties are deposited
- Rain fall can trigger leakage events and wash out radio-nuclides contained in the material
- [1, 2] used 1D-approaches for contaminated zones with constant properties
- To account for spatial heterogeneity we create a porosity distribution for our domain (above)
- The aim is to identify for differences between the models approaches and to evaluate their relevance

### Two-Phase flow equations vs Richards‘ equation

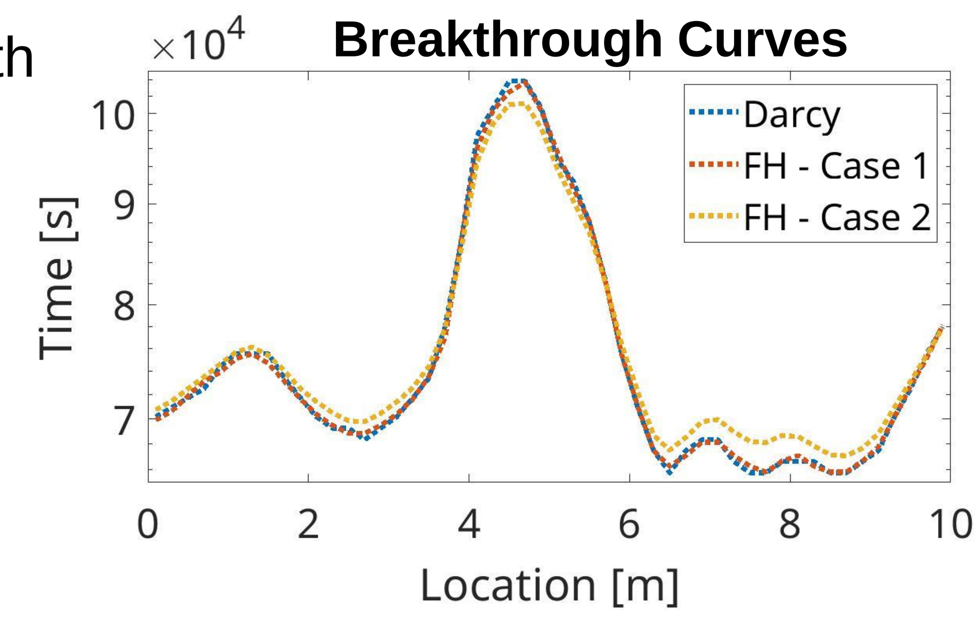



- Richards‘ equation is a simplification of the two-phase flow equations, assuming an infinitely mobile air-phase
- Results:
    - The Richards model is computationally much less demanding (~factor 2)
    - In this case the differences in the results of the breakthrough curves (above) are very small

### Darcy’s Law vs Darcy-Forchheimer

- Forchheimer: extension, which accounts for the inertial effects occurring at higher velocities, i.e Reynolds-No. > 1

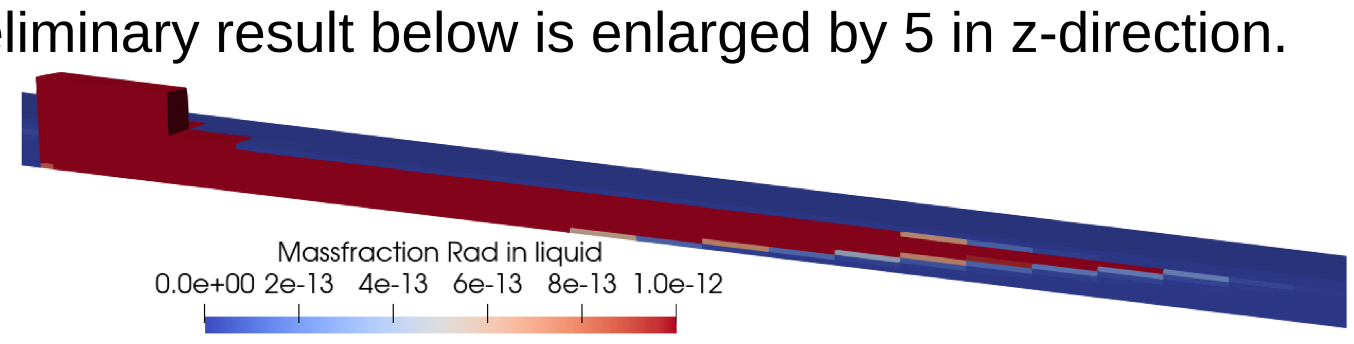
$$-(\nabla p_\alpha - \rho_\alpha \mathbf{g}) = \frac{\mu_\alpha}{\mathbf{K} k_{r\alpha}} \mathbf{v}_\alpha + \beta_\alpha \rho_\alpha \mathbf{v}_\alpha |\mathbf{v}_\alpha|$$




- Two coefficients, with different complexity:
- Case 1:
$$\beta_\alpha = \frac{c_F}{\sqrt{\mathbf{K} k_{r\alpha}}}$$
- Case 2:
$$\beta_\alpha = \frac{c_\beta \tau}{(\mathbf{K} k_{r\alpha})(\phi S_\alpha)}$$
- Results:
    - With increasing complexity the runtime increases (Case 1: x4; Case 2: x20)
    - Case 1 shows minor differences in the breakthrough curves to Darcy (above)
    - Case 2 differs more, thus has higher inertial effects.

## Modelling of landfill and aquifer

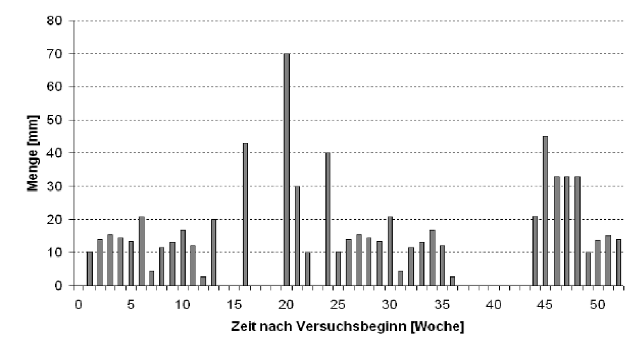
- Imitation of the domain from [1, 2]:
    - Landfill is contaminated with a radioactive substance
    - Neumann inflow boundary condition on the top
    - Radioactive substance dissolves in the water and is transported with the water and subject to adsorption and desorption bewteen solid and liquid phase
    - Eventually the contamination reaches the aquifer and is transported with the water
- Reproducing the results of the 1D model in [1] with our modeling software DuMu$^X$
- Increasing the complexity step by step:
    - Model approaches in terms of governing equations
    - Increase the dimensions to 3D
    - Add more realistic form of the landfill and more natural rainfall (not only on the landfill)
- Preliminary result below is enlarged by 5 in z-direction.



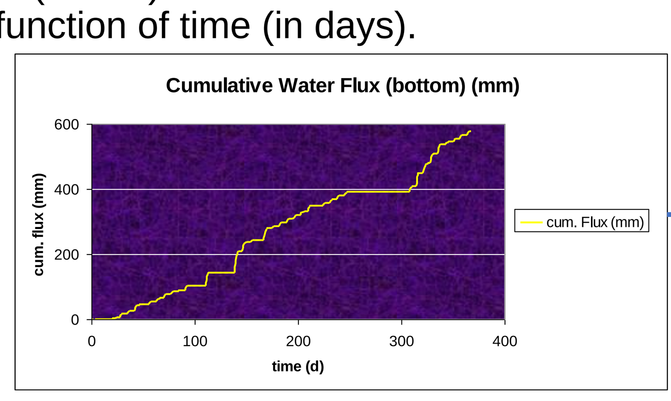

## BfS research in the area of clearance

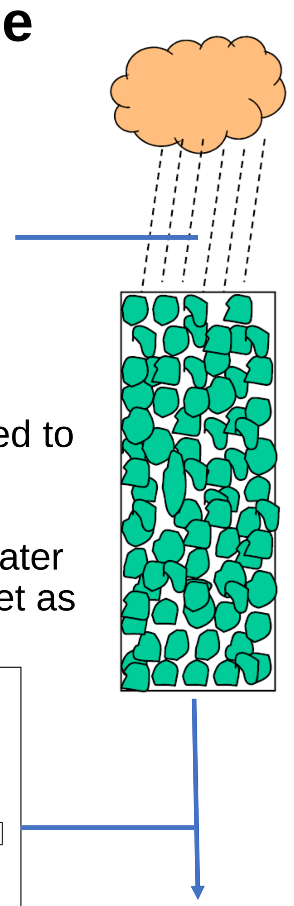
- The Federal Office for Radiation Protection (BfS) supports the present project as part of its own research activities in the field of **clearance of materials with negligible radioactivity**.

*Example:* The present work by University of Stuttgart was initiated by BfS research activities on water and radionuclide transport in porous media such as aquifers. For example, extreme meteorological conditions (flooding, drought) were not yet studied by BfS and might affect clearance levels due to the radioecological *water pathway* of radionuclides.



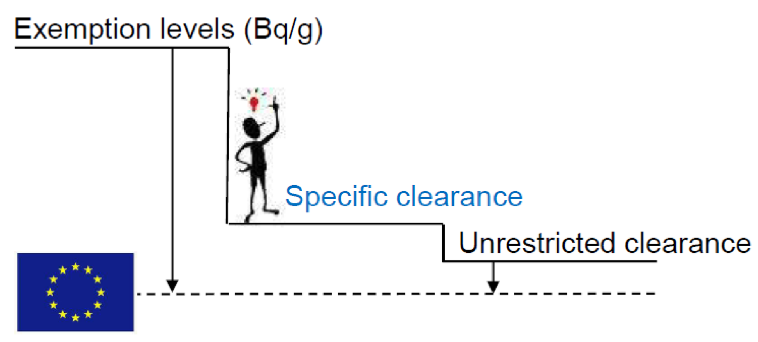
Top: Lab profile of amount of water applied to radioactive concrete rubble (in mm) as a function of time (in weeks). Bottom: BfS Computer simulation of the cumulative water flux (in mm) determined at the water outlet as a function of time (in days).



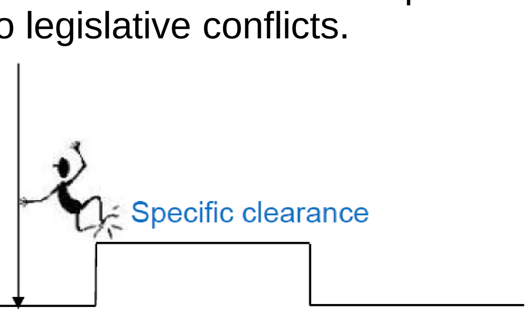



- Part of the BfS research is conducted in cooperation with external consultants.

*Example:* Compliance of the *“Specific Clearance”* with the new Council Directive *2013/59/Euratom* was demonstrated as part of an external research project organized and evaluated by the BfS.




Top: Exemption and clearance levels in Germany before implementation of Council Directive *2013/59/Euratom*. Bottom: Unsystematic implementation of new exemption levels could have led to legislative conflicts.





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[1] IAEA. SR 44: Derivation of Activity Concentration Values for Exclusion , Exemption. Technical report, International AtomicEnergy Agency, Vienna, 2005.
[2] Merk, R. Numerical modeling of the radionuclide water pathway with HYDRUS and comparison with the IAEA model of SR 44.Journal of Environmental Radioactivity 2012,105, 60–69. doi:10.1016/j.jenvrad.2011.10.014


LH² DuMu$^X$ ENWAT International Doctoral Program Environment Water