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CFD Simulations for Radon Displacement Detection in UNE Scenarios

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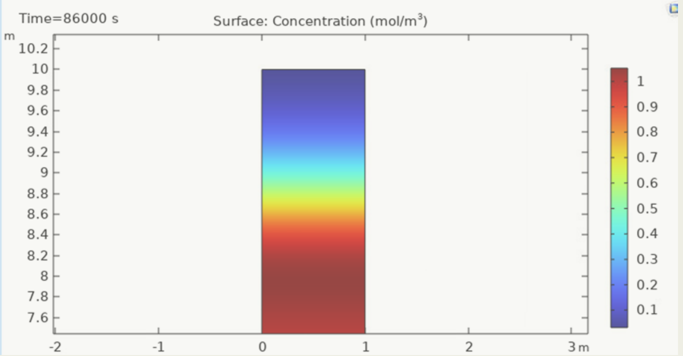
INTRODUCTION AND MAIN RESULTS



This study employs Computational Fluid Dynamics (CFD) to simulate radon (^{222}Rn) transport induced by subsurface pressurization, a potential consequence of underground nuclear explosions (UNEs).

Using COMSOL Multiphysics, we replicate the modeling approach of Burnett et al. (2021), comparing pure diffusion with Darcy-driven advection in sandy soil.

The results closely align with published profiles, confirming the dominant role of diffusion and highlighting the impact of subsurface pressure on radon migration.

These findings support CFD as a valuable tool for interpreting surface-level radon anomalies potentially linked to UNEs.

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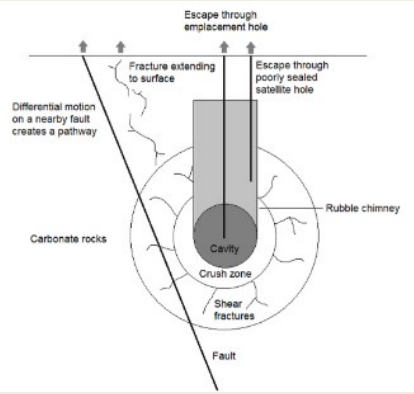
CFD Simulations for Radon Displacement Detection in UNE Scenarios

P2.3-8

Introduction

Radon is a naturally occurring radioactive gas that can serve as a potential indicator of underground nuclear explosions (UNEs). When a UNE occurs, it may cause subsurface pressurization, forcing radon to migrate vertically toward the surface. This study investigates radon (^{222}Rn) transport through soil using Computational Fluid Dynamics (CFD) modeling in COMSOL Multiphysics to replicate Burnett et al. (2021), who explored radon displacement due to pressure buildup. The goal is to understand how diffusion and pressure-driven advection contribute to radon movement and assess the feasibility of using such models to enhance radionuclide monitoring relevant to CTBT verification



Escape paths of radioactive material to the surface (not to scale).
Figure modified after CTBTO (2015), as cited in Burnett et al. (2021).

DISCLAIMER: TBurnett, J.L., Stewart, T.L., Keillor, M.E., & Ely, J.H. (2021). Radon displacement and subsurface pressurization in the aftermath of underground nuclear explosions. Journal of Environmental Radioactivity, 232, 106568. https://doi.org/10.1016/j.jenvrad.2021.106568his presentation has been generated for illustration purposes only.

Methods/Data

To investigate the surface detectability of radon anomalies induced by underground nuclear explosions (UNEs), we reproduced and extended a modeling framework developed by Burnett et al. (2021), using COMSOL Multiphysics®.

A 2D vertical soil column (10 m × 1 m) was simulated under two conditions:

- Pure diffusion, representing passive transport through porous media.
- Coupled advection-diffusion, simulating subsurface pressurization-driven flow.

Model Parameters:

- Porous medium: Dry sandy soil
- Porosity: 0.4Permeability: 1×10^{-12} m²
- Radon diffusivity: 1×10^{-6} m²/s
- Fluid: Air (density: 1.2 kg/m³, viscosity: 1.8×10^{-5} Pa·s)

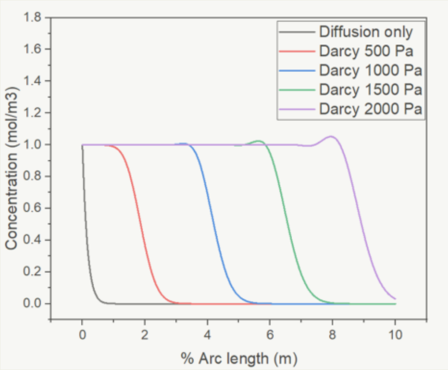
Boundary & Initial Conditions

- Bottom: Constant radon source, top: Outflow ,Boundary Sides: No-flux walls, Initial: Zero radon concentration throughout

Simulation Time the simulation was run over 86,000 seconds (approximately 24 hours).

Results

- Pure Diffusion:The radon profile shows exponential decay with height.
- With Darcy Flow:Pressure-driven advection enhances vertical radon transport, increasing surface concentrations and confirming the effect of subsurface pressurization.



1D line plot Concentration vs height
Diffusion and with darcy (500,1000,1500,2000) Pa

Conclusions

- CFD simulations of radon migration replicate key features of UNE-induced anomalies.These models enhance our understanding of subsurface gas transport and support CTBTO's verification efforts.

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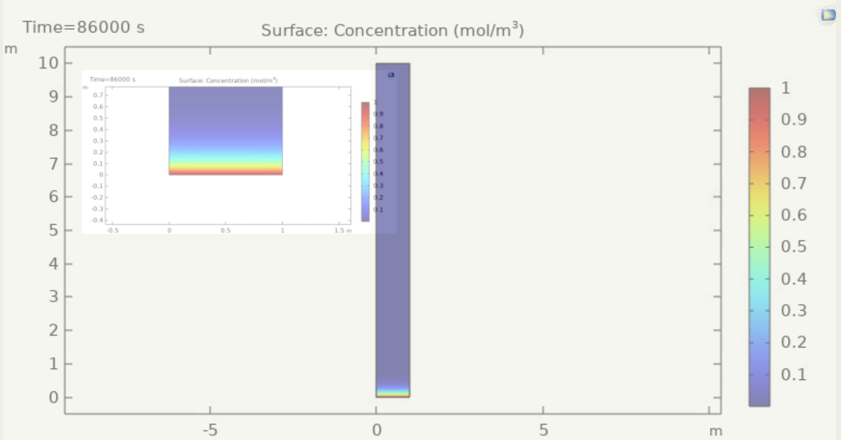
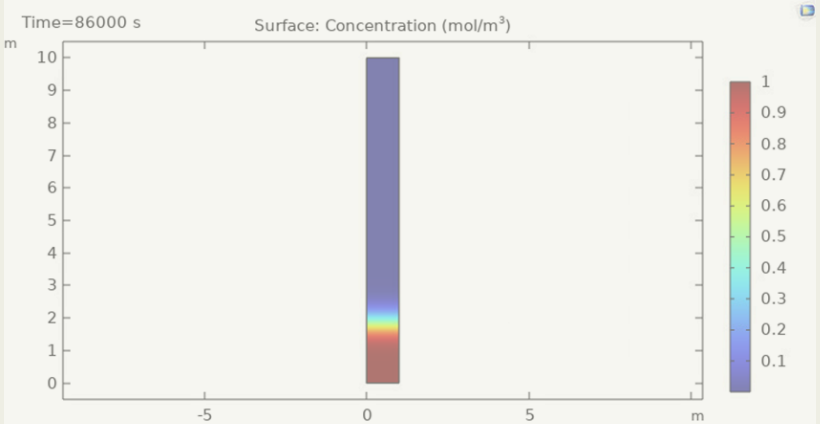
2 D contours Concentration vs height Diffusion and with darcy (500,1000,1500,2000) Pa

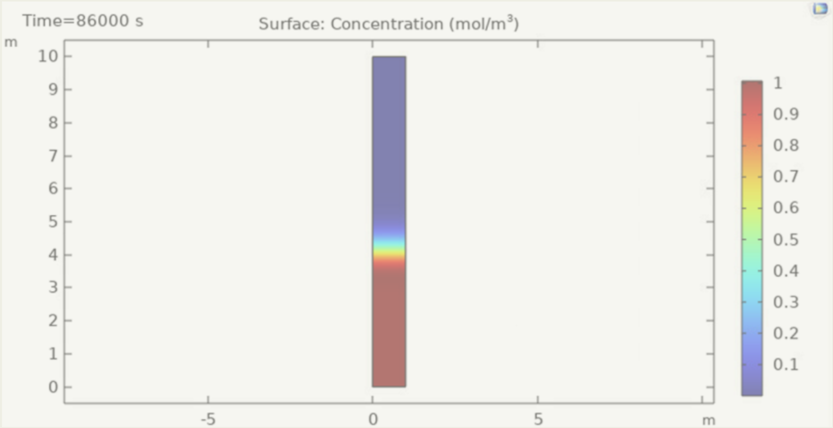
Diffusion



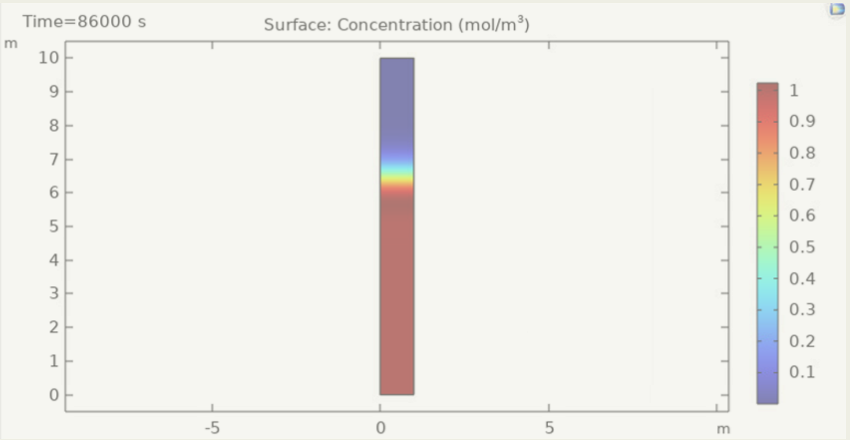
Darcy 500 Pa



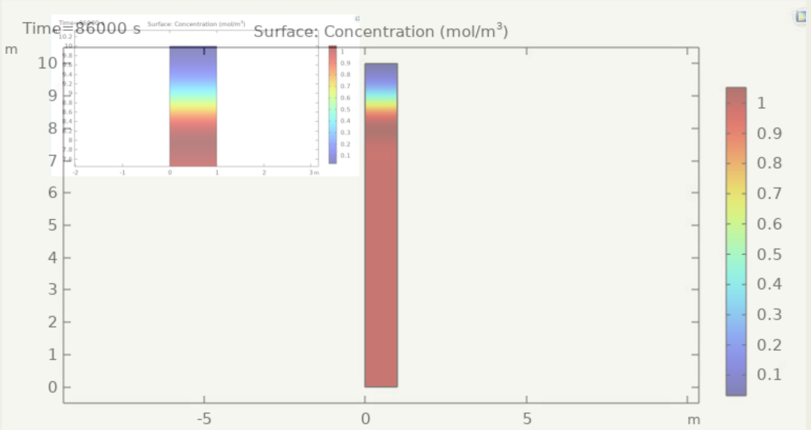
Darcy 1000 Pa



Darcy 1500 Pa



Darcy 2000 Pa



- Remarkable notice : The diffusion show slow spread of the radon compare with diffusion with darcy which also showed a rapid spread of the radon with the increase of the pressure .