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Examining Changes in Radioxenon Isotope Activity Ratios during Subsurface Transport

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The Non-Proliferation Experiment (NPE) has demonstrated and modelled the usefulness of barometric pumping induced gas transport and subsequent soil gas sampling during On-Site inspections. Generally, gas transport has been widely studied with different numerical codes. However, gas transport of radioxenons and radioiodines in the post-detonation regime and their possible fractionation is still neglected in the open peer-reviewed literature.

Atmospheric concentrations of the radioxenons Xe-135, Xe-133m, Xe-133 and Xe-131m can be used to discriminate between civilian releases (nuclear power plants or medical isotope facilities), and nuclear explosion sources. It is based on the multiple isotopic activity ratio method. Yet it is not clear whether subsurface migration of the radionuclides, with eventual release into the atmosphere, can affect the activity ratios due to fractionation. Fractionation can be caused by different mass diffusivities due to mass differences between the radionuclides. Cyclical changes in atmospheric pressure can drive subsurface gas transport. This barometric pumping phenomenon causes an oscillatoric flow in upward trending fractures or highly conductive faults which, combined with diffusion into the porous matrix, leads to a net transport of gaseous components - a so-called ratcheting effect.

We use a general purpose reservoir simulator (Complex System Modelling Platform, CSMP++) which is recognized by the oil industry as leading in Discrete Fracture-Matrix (DFM) simulations. It has been applied in a range of fields such as deep geothermal systems, three-phase black oil simulations, fracture propagation in fractured, porous media, and Navier-Stokes pore-scale modelling among others. It is specifically designed to account for structurally complex geologic situation of fractured, porous media. Parabolic differential equations are solved by a continuous Galerkin finite-element method, hyperbolic differential equations by a complementary finite volume method. The parabolic and hyperbolic problem can be solved separately by operator-splitting. The resulting system of linear equations is solved by the algebraic multigrid library SAMG, developed at the Fraunhofer Institute for Algorithms and Scientific Computing, Germany. CSMP++ is developed at Montan University of Leoben, ETH Zuerich, Imperial College London and Heriot-Watt University in Edinburgh.

This study examines barometric pumping-driven subsurface transport of Xe-135, Xe-133m, Xe-133, Xe-131m including I-131, I-133 and I-135 on arrival times and isotopic activity ratios.

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