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Noble gas signature adsorption in a UNE – bridging the gap between laboratory and field scale models

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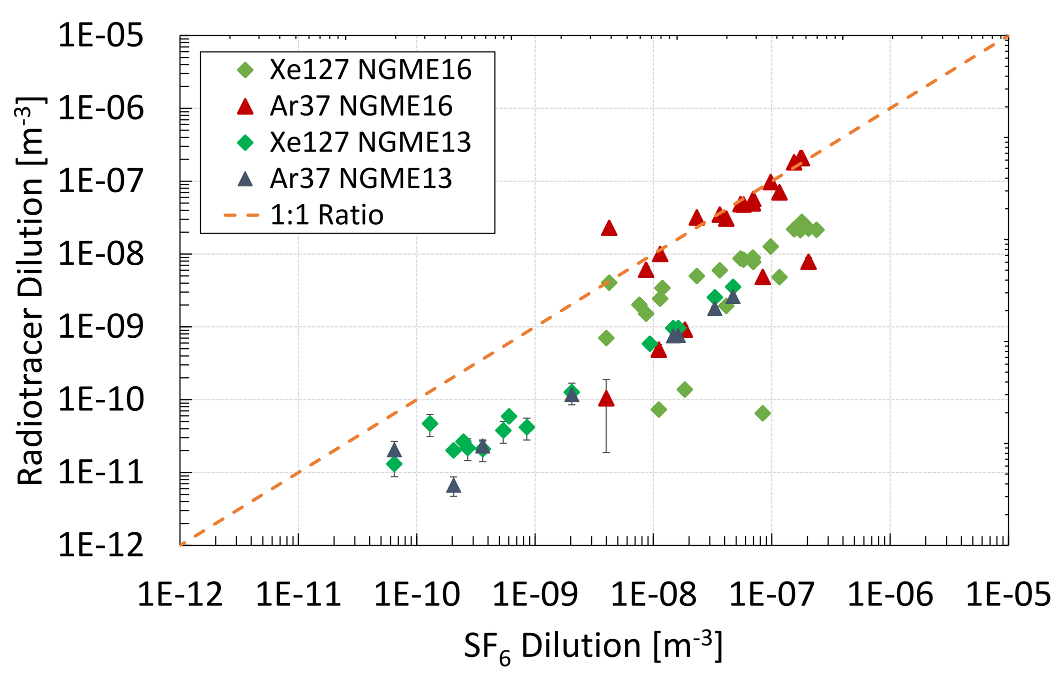
We continue to dispel the notion that UNE-relevant noble gases are "unreactive in the environment" by using a combination of numerical modeling using the STOMP code and results of targeted benchtop-scale gas sorption experiments to interpret seepage in a field campaign.

Problem Statement

In 2013 NGME13 injected ^{127}Xe, ^{37}Ar and SF_6 gas into the Barnwell UNE chimney at NNSS. After 100 days, the chimney was pressurized and resulted in surface measurements that were relatively enriched in SF_6. Similarly, in 2016 NGME16 had the same tracers injected and results of measurements made at depth and at the surface showed differential transport among the tracers.



Plot of measured field tracers in NGME 2013/2016

Differences in tracer dilution seen in NGME13 were unexpected – in particular, xenon and SF_6 were expected to have 1:1 ratios. This motivated laboratory experiments to understand the relative gas behavior. Using such experiments allows for precise environmental control of transport variables and isolation of processes, which is critical for benchmarking numerical models.

Gas Transport Experiments

A variety of experiments have been conducted under UNESE using compacted soil/sand columns and solid core material, exploring:

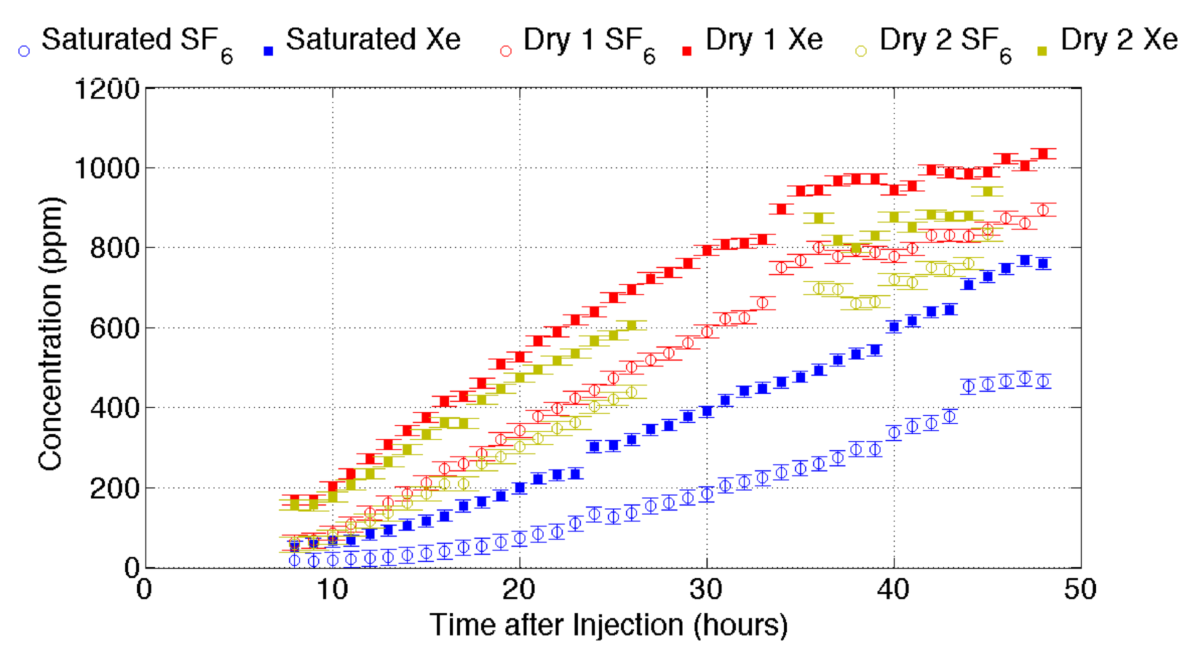
- diffusion rates,
- water saturation,
- surface adsorption, and
- temperature sensitivity.

Results of these experiments were used to benchmark numerical models of simple transport physics, which in turn continue to define relevant parameters in field scale transport models like the Subsurface Transport Over Multiple Phases (STOMP) simulator.

2-bulb gas column located at UT Austin

Results of Column Experiments

Results of one experimental campaign are summarized here. Stable xenon and SF_6 gases were injected at one end of a 1m-long column filled with Ottawa sand and the arrival of the tracer was measured at the other end. Three experiments were run: 2 cases with dry sand and 1 case with water-saturated sand. In the figure below which compares the results of each case, results suggest differential diffusion rates and adsorptive capacities between Xe and SF_6.

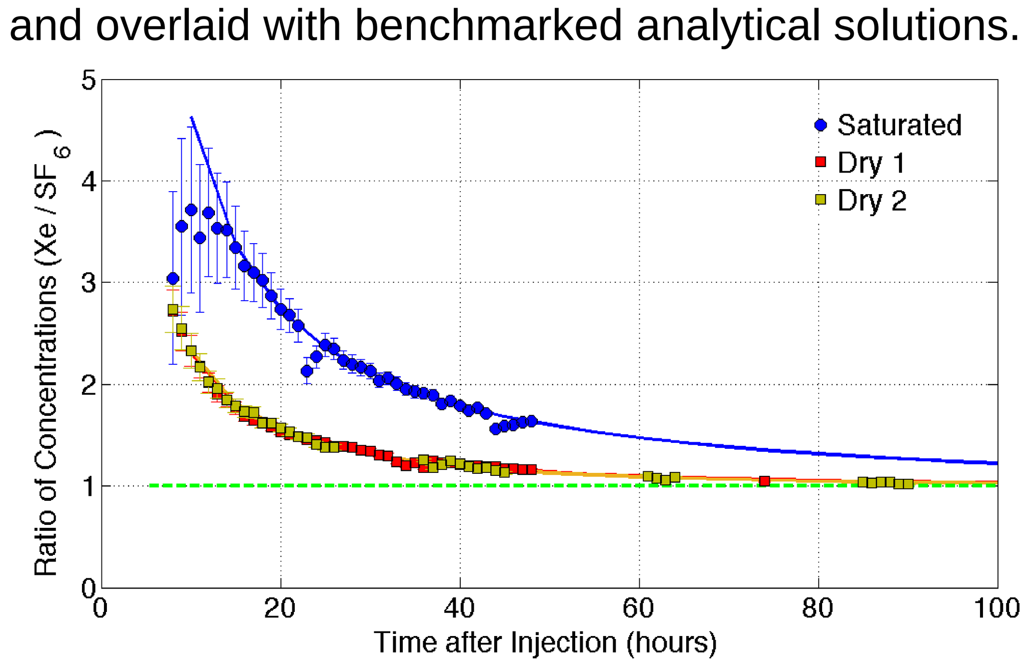


Results of gas transport tests comparing diffusion of Xe and SF_6 in two dry and one saturated porous media scenario test

- In each experiment, xenon concentration increases faster than SF_6
- In each experiment, relative xenon and SF_6 concentrations level off at different values
- The "saturated" test shows a clear effect of water inhibiting transport of both species.

Results of STOMP benchmarking

Experimental lab results were used to benchmark exact analytical solutions of simple1-D transport to estimate diffusion and adsorption rates of Xe and SF_6 gas. Below, the ratio of the two gases are plotted and overlaid with benchmarked analytical solutions.

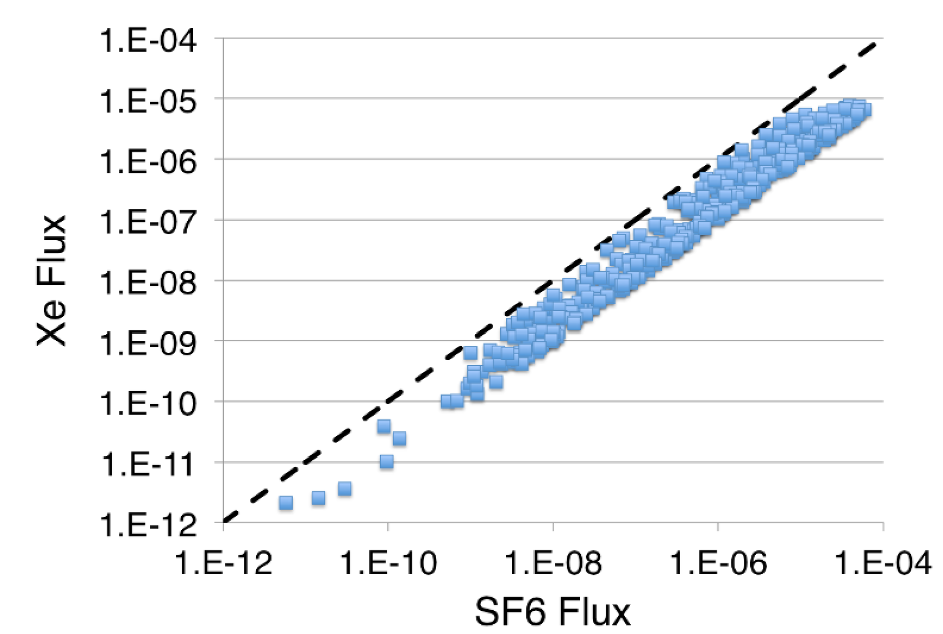


Measured ratios of Xe to SF_6 gas collected from the top of the experimental column with fitted curves

Extrapolation to Field Scale

Estimates of effective diffusion and adsorption rates for xenon and SF6 obtained by benchmarking simple analytical solutions against the laboratory experiment data were then next into simple field scale simulations of the gases in STOMP.

Results of this very simplistic extrapolation from benchmarked numerical models to field scale transport scenarios is plotted below for comparison with the data from NGME 2013/2016 and does indeed suggest differences in dilutions at the field scale.



Xe versus SF_6 fluxes resulting from the simple gas migration scenario modeled in STOMP

Initial results indicate that a combination of diffusive and adsorptive differences can at least partially explain dilution differences seen in NGME 2013/2016. Some major things to note:

- **Diffusion rates**: D(Ar) > D(Xe) > D(SF6); in fractured flow, higher D means greater losses out of fractures
- **Sorption rates**: S(Xe) > S(Ar) > S(SF6); higher S means greater loss
- NGME13 – Pressurization of chimney means surface measurements were indicative of bulk gas that had largely been stagnant in chimney.
- NGME16 – Measurements indicative of natural seepage at depth and surface.
- Lab results are consistent with noble gases being more diluted than SF6, but the Xe vs. Ar differences in NGME2016 are more complicated.

Abstract

In an effort to better understand the processes that impact noble gas transport in the subsurface, the Underground Nuclear Explosion Signatures Experiment (UNESE) conducted multiple field campaigns in which tracers such as Xe-127, Ar-37 and chemical surrogates were released underground and monitored as they migrated toward the surface. A significant result was that the tracers reached sampling locations with different dilutions, indicating that these "largely non-interacting" gases were being differentially influenced by the environment. These results have spurred a number of laboratory scale experiment efforts to improve models of how UNE-relevant noble gases and common surrogates interact with geologic material under variable conditions. This presentation focuses on bridging the gap between models based on small-, even pore-scale transport physics and field-scale radionuclide signature migration models. Specifically, laboratory experiments demonstrating the capacity of volcanic tuff to variably adsorb xenon and argon gas versus chemical surrogates are used to inform field-scale models and ultimately depict how even small effects can result in large radionuclide signature discrepancies over large distances.

Conclusions

- ➢ The combination of field results in NGME 2013/2016 with results of laboratory experiments demonstrates how small transport effects can have large, aggregate impacts on surface arrival time and relative concentration of UNE signature gases.
- ➢ Site-specific geologic conditions can have enormous impact on expected gas seepage.
- ➢ Understanding such impacts are critical to further building and interpreting of models of UNE signature transport.

References

Johnson et al., Noble gas migration from the site of an underground nuclear explosion at the Nevada National Security Site (anticipated 2019)

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