The Characteristic Release Of Noble Gases From An Underground Nuclear Explosion

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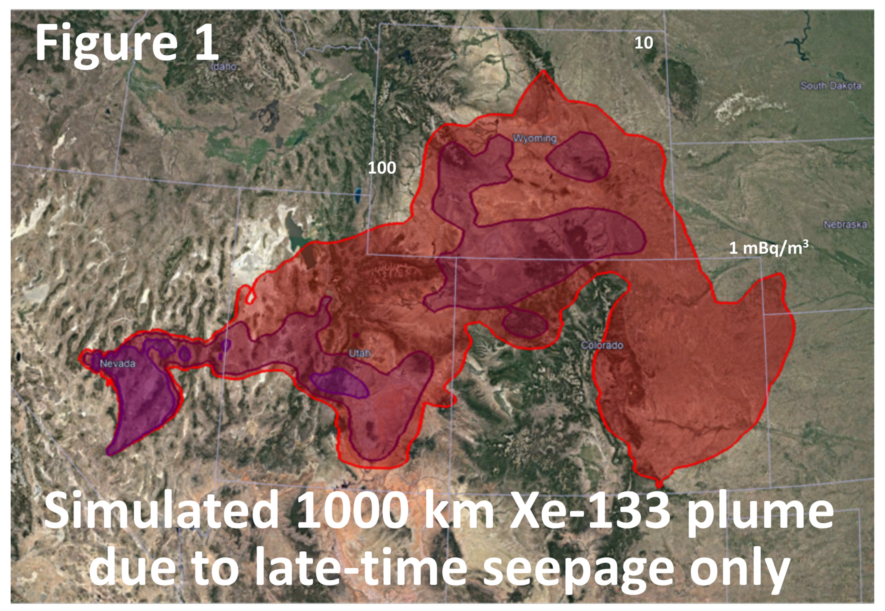
Summary

- Simulations show prompt releases not required for downwind detection at IMS distances (Fig.1)
- Thermo-barometric drive produces detectable xenon levels at tens of km for even small, over-buried events
- Large enhancement of detectability occurs for test site permeability > 1 D
- Larger atmospheric signal may result from low-yield detonation assuming canonical depth-yield relation
- Atmospheric sampling at night may produce larger detections downwind



Introduction

The Pahute Mesa and P-Tunnel sites within Aqueduct Mesa at NNSS are two end-member approaches to containing underground nuclear explosions (UNE). On Pahute Mesa, a 1989 UNE was carried out via a 600 m borehole in permeable volcanic layers while a P-Tunnel UNE was performed about 250 m below the surface of the mesa consisting mostly of a low-fracture density and highly saturated volcanic tuff. Both events were considered contained. How geologic containment is likely to affect radioxenon signatures was the focus of this combined experimental and modeling study.

Approach

• LLNL Smart Samplers deployed at different locations around both sites record barometric pressure changes at the surface and within collapse chimneys. They also monitor a Freon-tracer release into chimneys at both sites, which migrates to the surface.

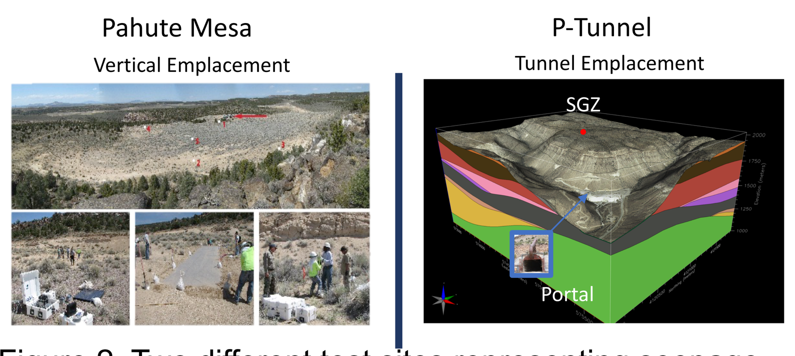


Figure 2. Two different test sites representing seepage or "leakage" endmembers of contained UNEs.

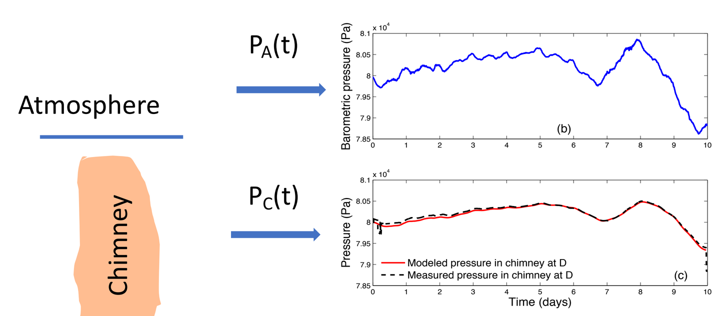


Figure 3. Matching observed cavity pressure changes with simulations allows estimation of leakage parameters for Pahute Mesa and P-Tunnel events.

• Propagation of atmospheric pressure fluctuations at the surface into the subsurface, involving Darcian flow, is analogous to thermal diffusion of diurnal atmospheric temperature variations into the soil. Solving the diffusion equation subject to a fracture-matrix permeability model allows determining "leakage" parameters: bulk permeability, fracture aperture, fracture frequency and matrix permeability.

Major Findings

P-Tunnel "Tight" Site

• Atmospheric pressure fluctuation diffusion model indicates that site has bulk permeability of 0.2- 0.5 D (1D = 1.E-12 m^2).

• Even though geology is "tight", Freon tracer was detected at surface beneath tarp at Surface Ground Zero 3 weeks after injection into the P-Tunnel chimney.

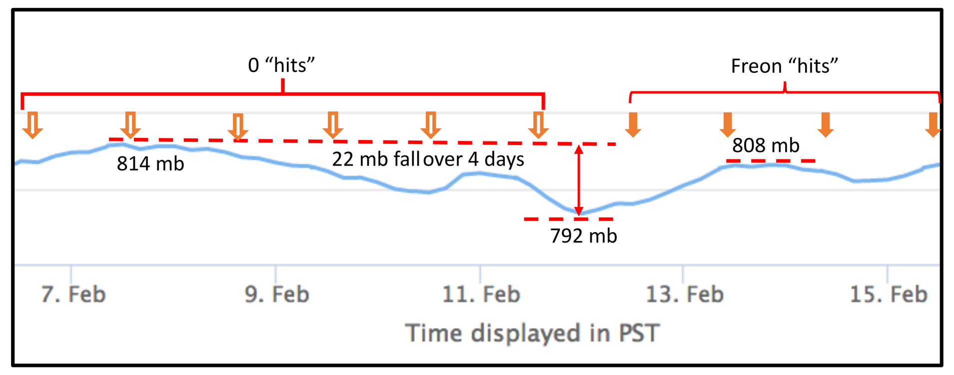


Figure 4. Smart sampler captures arrival of Freon tracer at surface over chimney in P Tunnel.

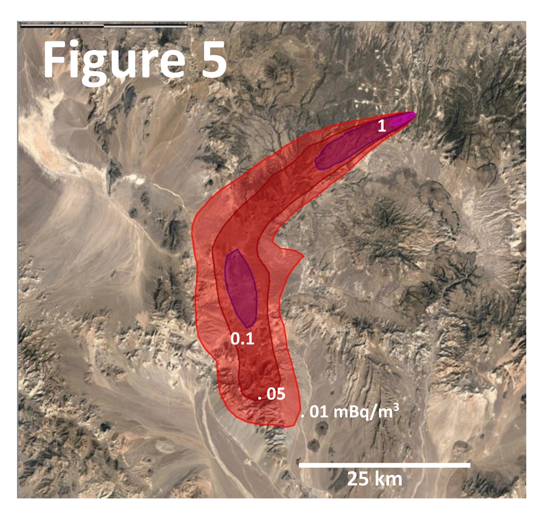
• Gas arrival during a long barometric depression fits classic pattern of gas transport by atmospheric pumping along fracture.

Pahute Mesa Fractured Site

• Very permeable (> 4 D).

• Simulations of deep events are subject to atmospheric detection at 1000 km or more (Fig. 1).

• Seepage rate permits onsite detection of even deep, lower yield events (Fig. 5)



- **Yield** = 2.3 kt
- **Depth** = 323 m (over buried)
- **Plume length** ~ 80 km

Discussion

We have considered the gas transport characteristics of two different types of containment regimes that have significantly different bulk permeabilities.

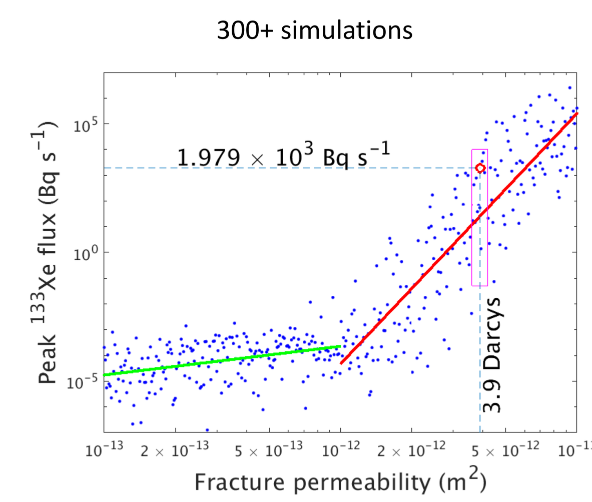


Figure 6. Bulk permeability < 1 D produces low surface flux while greater permeability can result in very high flux detectable at large distances from release point.

Simulations (Fig. 6) show that surface fluxes of radioxenon and hence the strength of an atmospheric plume depend critically on site permeability. Sites with bulk permeability <1 D (1.e-12 m^2) may be very difficult to detect while sites > 1 D may produce large seepage plumes without the need for a prompt vent.

Geology of P-Tunnel falls into the low-detectability category while Pahute Mesa geology has a high potential for detectability based on bulk leakage or permeability analyses.

However, low permeability does not mean that P-Tunnel does not leak at detectable levels. Low permeability containment may permit cavity gas pressures to remain at much higher levels for longer periods than in higher permeability cases. Extended periods of cavity pressurization support seepage along whatever fracture networks exist.

Impact

How does this improve Nuclear Explosion Monitoring?

Pahute Mesa Fractured Site

• Long distance detection possible for late-time seepage fluxes at fractured, higher permeability site.

• A UNE may be more readily detected by standoff atmospheric monitoring of low-level seepage than by on-site radiation surveys.

• Simulations show that monitoring of atmospheric gases during nighttime can increase the distance of detection.

P-Tunnel "Tight" Site (preliminary)

• Sparsely fractured site appears to also produce detectable seeps based on gas sampling results

• P-Tunnel seepage model appears consistent with 2013 DPRK tunnel containment scenario involving drillback and detection after 60 days

• UNE containment designs and operational releases play greater role in determining detection than at fractured sites (e.g., how tunnel is ventilated).

Future Work

Subsurface and atmospheric experiments will evaluate contributions of fracture-based and operational releases to atmospheric signatures produced in P-Tunnel containment geology.

Relevant Publications:

C. Carrigan, Y. Sun & M. Simpson, "The characteristic release of noble gases from an underground nuclear explosion", J. Environ. Rad., 196, 91-97, 2019.

PUTTING AN END TO NUCLEAR EXPLOSIONS

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