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Exploring bounding parameters for modeling subsurface transport of radioxenon

Carolyn E. Seifert, Christine Johnson, Jana Simo, Paul Eslinger

Pacific Northwest National Laboratory

INTRODUCTION AND MAIN RESULTS

In this work, we use an analytical toy model to explore the phase space of viable subsurface transport conditions that can result in detectable radioxenon from underground nuclear explosions at downwind stations. This analysis demonstrates that a minimum release ~10^8 Bq of ^{133}Xe is needed for downwind detection at 50 km, and that quantity increases to ~10^{11} Bq for 2000 km. We calculate that effective permeabilities less than 10^{-14} m^2 are not likely to result in detectable ^{133}Xe for a 1-kt explosion at 100-m and 200-m depths of burial. Smaller downwind distances, more favorable wind conditions, and the presence of fast subsurface pathways would broaden the range of subsurface conditions that lead to detectable downwind signals.

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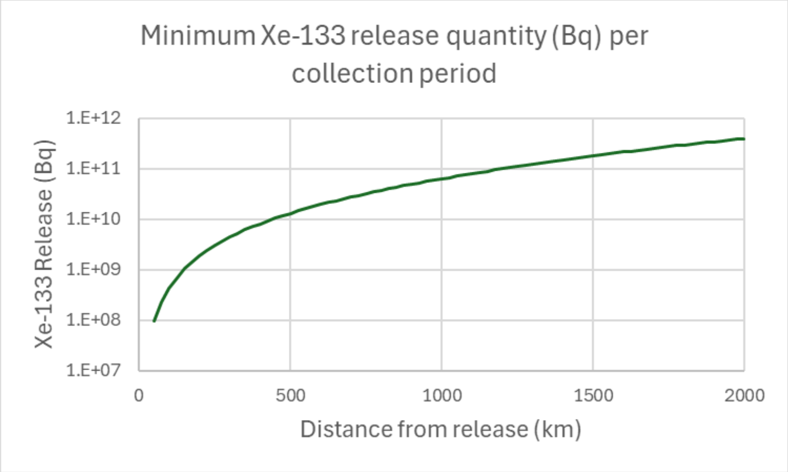
Estimated Minimum ^{133}Xe Release Quantities Required for Downwind Detection

Using the median analytical dilution factors with radioactive decay from Eslinger, et al.[1], and the stated sensitivity of the Xenon International radioxenon collection and analysis system (0.15 mBq/m^3) [2], we calculate the minimum required ^{133}Xe release from an underground nuclear explosion that would result in downwind concentrations above the expected minimum detectable concentration (MDC).

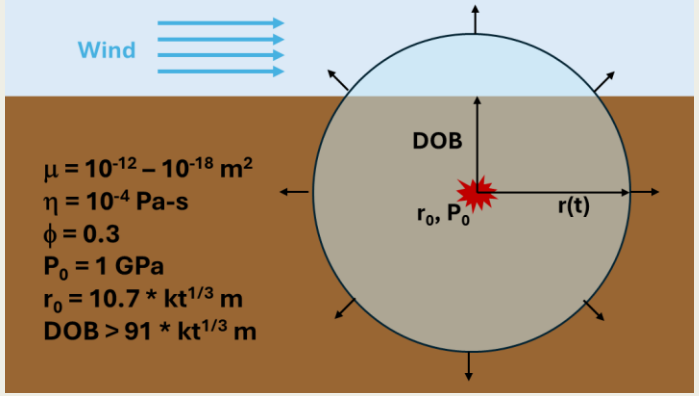


Here we use the median dilution factor, but these factors are observed to vary by several orders of magnitude depending on wind conditions.[1] We also assume that background conditions are such that any measured quantity over the expected MDC is detectable. The required minimum release quantities are used to bound the viable range of subsurface transport conditions.

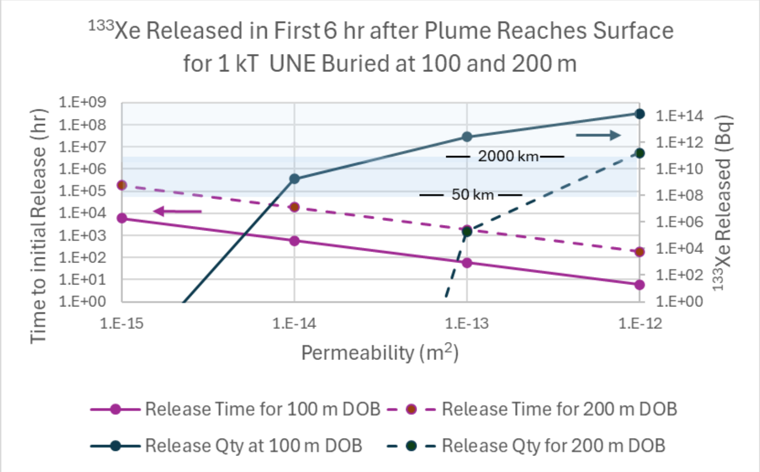
An Analytical Toy Model for Estimating ^{133}Xe Release Quantities from Underground Nuclear Explosions

Calculation steps:

1. Determine initial pressure and radius of cavity based on 1 kt yield [3, 4], assuming sufficiently deep burial.
2. Calculate increased subsurface plume volume and pressure for a fixed step change in plume radius, assuming instantaneous equilibrium conditions.
3. Calculate velocity of pressure front based on 1-D Darcy's Law (constants derived from ref. [5-6]).
4. Calculate time needed for this expansion to occur, given the calculated velocity of the pressure front.
5. Repeat Steps 2-5 until the plume extends beyond the surface for at least one downwind collection period.
6. Calculate the fraction of the plume above the ground in the first collection period after it reaches the surface, estimate total ^{133}Xe release in that period, assuming no subsurface fractionation, and correct for decay during subsurface transport.



Results and Implications for Subsurface Transport Modeling and Simulations



Key relationships:

- Time to surface ∝ permeability^{-1}
- Emission rate without decay ∝ permeability^{-2}
- Emission rate with decay
  ~ exp(- C / permeability) / permeability^2

This analysis assumes homogeneous permeability and porosity in the subsurface with no fast fracture pathways. Any subsurface conditions that combine to exhibit the same *effective permeability* would produce similar results. Atmospheric pumping is also neglected, but will be an important contributor to late-time seepage.

With this analytical toy model, we find that subsurface permeabilities below 10^{-14} m^2 do not likely yield sufficient ^{133}Xe to be detected between 50-2000 km downwind.

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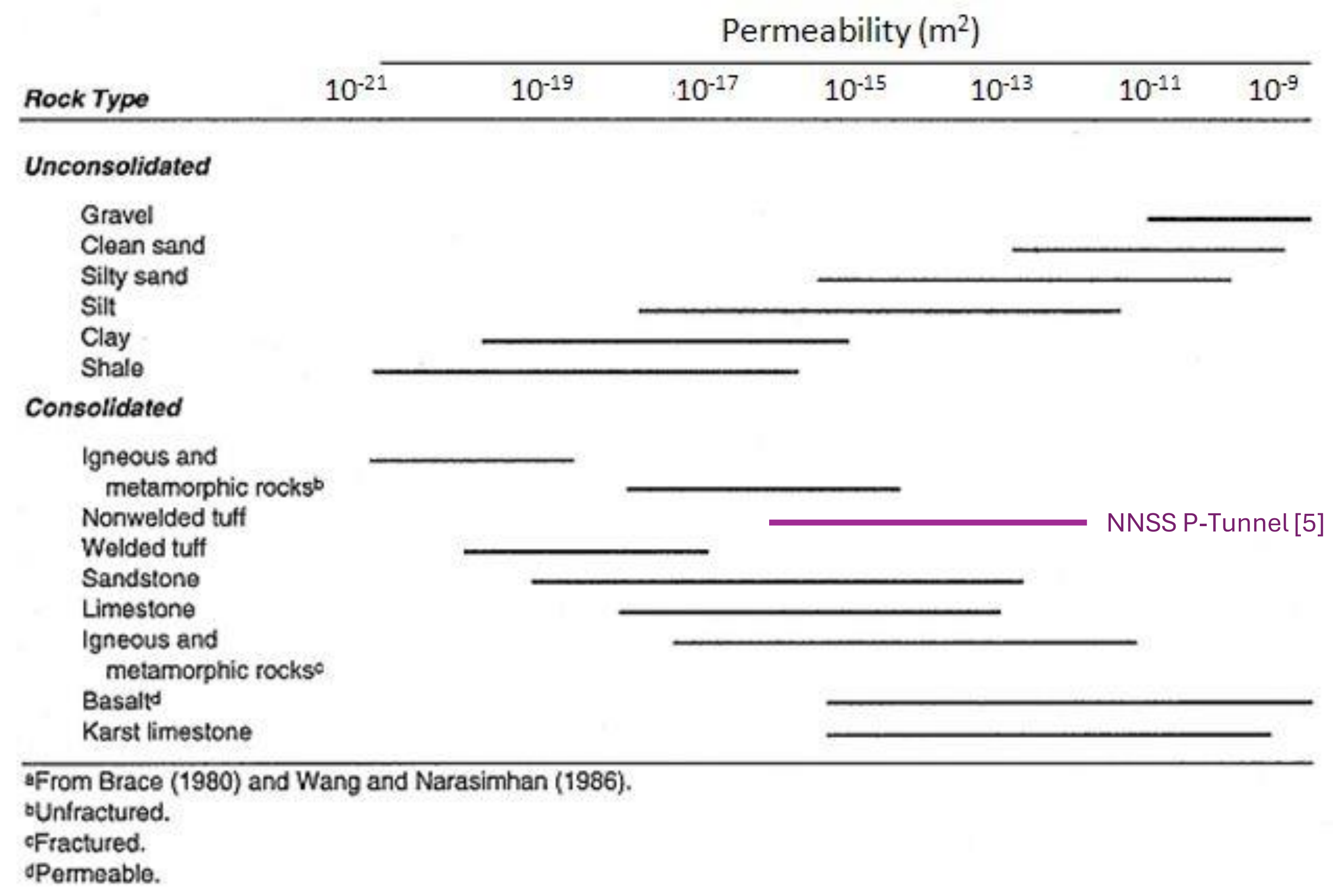
Permeability in Various Geologic Media [7]



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