SnT 2021

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Simulations of the long-term evolution of Ar-39 produced in an underground nuclear explosion

Justin Lowrey, Christine Johnson, Signe White, Mark Rockhold

Pacific Northwest National Laboratory

P2.1-474

POSTER

BATTELLE

Pacific Northwest NATIONAL LABORATORY

NNSA National Nuclear Security Administration

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ABSTRACT

Measurements of gas collected from locations surrounding historic underground nuclear tests have identified that Ar-39 produced during a nuclear explosion can remain in the subsurface decades after the event took place. As an activation product produced by the interaction of neutrons with geologic potassium, Ar-39 is produced in significant quantities in almost any underground nuclear explosion. With a half-life of 269 years, the primary loss mechanism for Ar-39 over time is dilution in the atmosphere or the geology surrounding the nuclear detonation. In order to better understand how the transport of Ar-39 affects its viability as a long-lived under nuclear explosion signature, a series of simulations were performed of an initially pressure-driven Ar-39 source with varying the depth and geology type surrounding the source. The evolution of both Ar-37 and Ar-39 were modeled over 30 years and the loss to the atmosphere or to dilution in the surroundings was tracked.

Statement of Contributions to SnT2021 Goals

This work discusses further evaluation of the viability of Ar-39 as a potential long-term indicator of underground nuclear explosions as it compares to Ar-37, with simulations demonstrating persistently detectable subsurface Ar-39 concentrations even decades after events.

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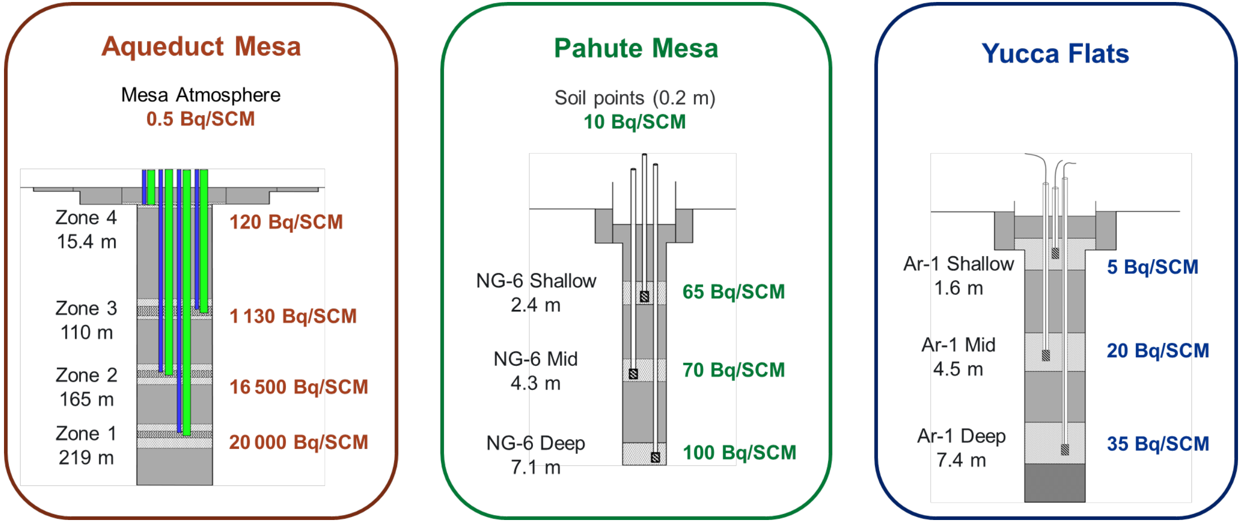
INTRODUCTION

Measurements of gas collected from locations surrounding historic underground nuclear tests have identified that Ar-39 produced during a nuclear explosion can remain in the subsurface decades after the event occurred. (Christine Johnson, PNNL, presented on this at SnT 2019)



Summary of PNNL measurements made of legacy Ar-39 at NNSS (Christine Johnson, INGE 2019)

Can models help us understand why this gas is still around?

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INTRODUCTION

^{39}Ar has a long half-life:

$t_{1/2}$ = 269 years

^{39}Ar is a neutron activation product:

$^{39}K(n,p)^{39}Ar$

K average crustal abundance: 28,650 ppm (93% ^{39}K)

(Wedepohl, 1995)

How surprising are measurements of legacy ^{39}Ar?

Expected ^{39}Ar activity produced in a UNE is 2-3 orders of magnitude less than ^{37}Ar, and many orders less than radioxenon, will we see it?

^{39}Ar is a long-lived noble gas. Shouldn't it leak to the atmosphere or dilute in the ground over 20+ years?

Wedepohl, K. Hans. "The composition of the continental crust." *Geochimica et cosmochimica Acta* 59, no. 7 (1995): 1217-1232.

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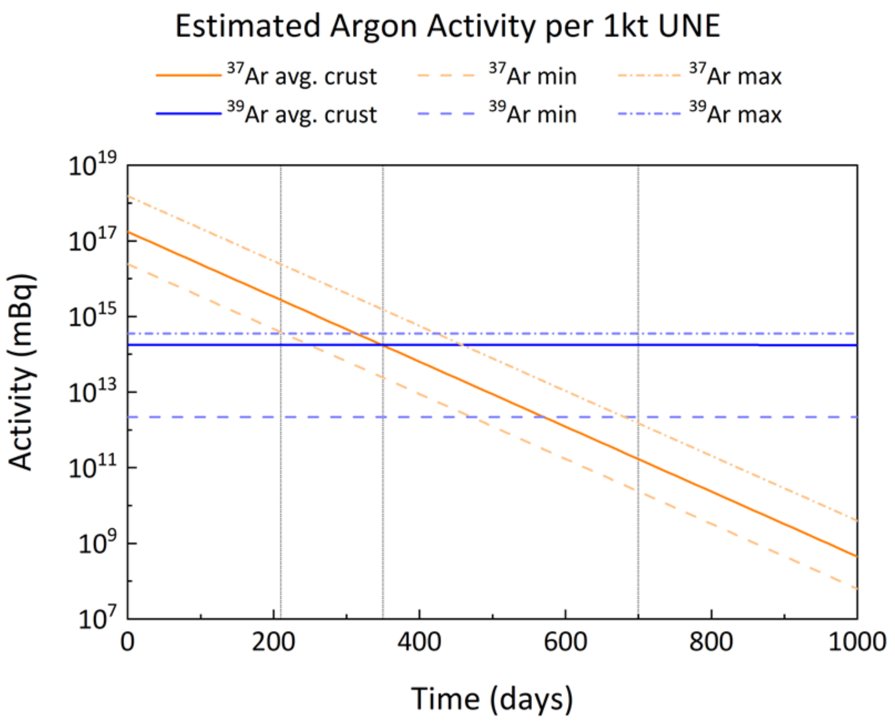
METHODS

For comparison, the inventories of ^{37}Ar and ^{39}Ar produced in a 1 kiloton UNE were estimated assuming several geologies from Taylor (1964) and Parker (1967) having varying potassium and calcium abundances.

The figure summarizes estimated ranges of inventory activities of ^{37}Ar and ^{39}Ar per kiloton UNE over nearly three years of natural decay.

Gray vertical lines denote times where ^{37}Ar and ^{39}Ar have the same total activities for various starting inventories. ***In other words, the shorter-lived ^{37}Ar is likely to fall below ^{39}Ar between 200- and 700-days post-UNE.***



Parker, R.L., 1967. The composition of the earth's crust, Data of Geochemistry, 6 ed, pp. D1-D19.
Taylor, S., 1964. Trace element abundances and the chondritic earth model. Geochimica et Cosmochimica Acta 28, 1989-1998.

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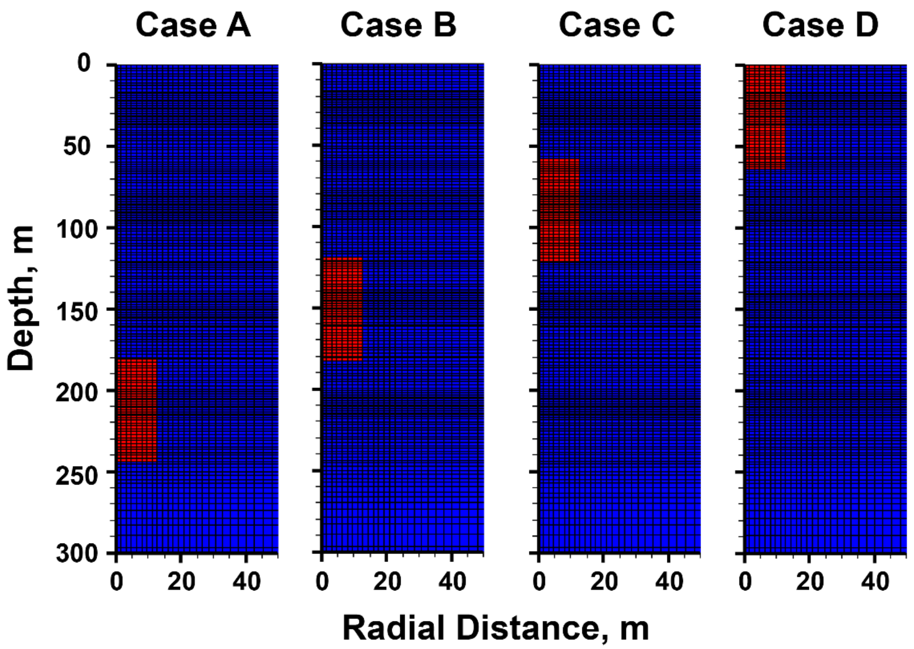
METHODS

The Subsurface Transport Over Multiple Phases – GeoThermal (STOMP-GT) simulator was used to simulate the post-UNE transport of ^{39}Ar and ^{37}Ar gases in the subsurface and any releases to the surface. STOMP-GT solves coupled conservation equations for energy, water, and air (White, 2015).

A cylindrical model was used with radial symmetry of domain size roughly 300 m in the vertical direction and 4500 m in the radial direction. The domain regions consisted of host rock of varying properties as well as a roughly 10m chimney radius. Simulations were run with 4 different depth cases.



Note: only the first 50 meters of radial extent of the model domain is shown

White, M., D. Appriou, D.H. Bacon, Y. Fang, V. Freedman, M.L. Rockhold, C. Ruprecht, G. Tartakovsky, S.K. White, F. Zhang, 2015. STOMP Online User Guide, Pacific Northwest National Laboratory: Richland, Washington

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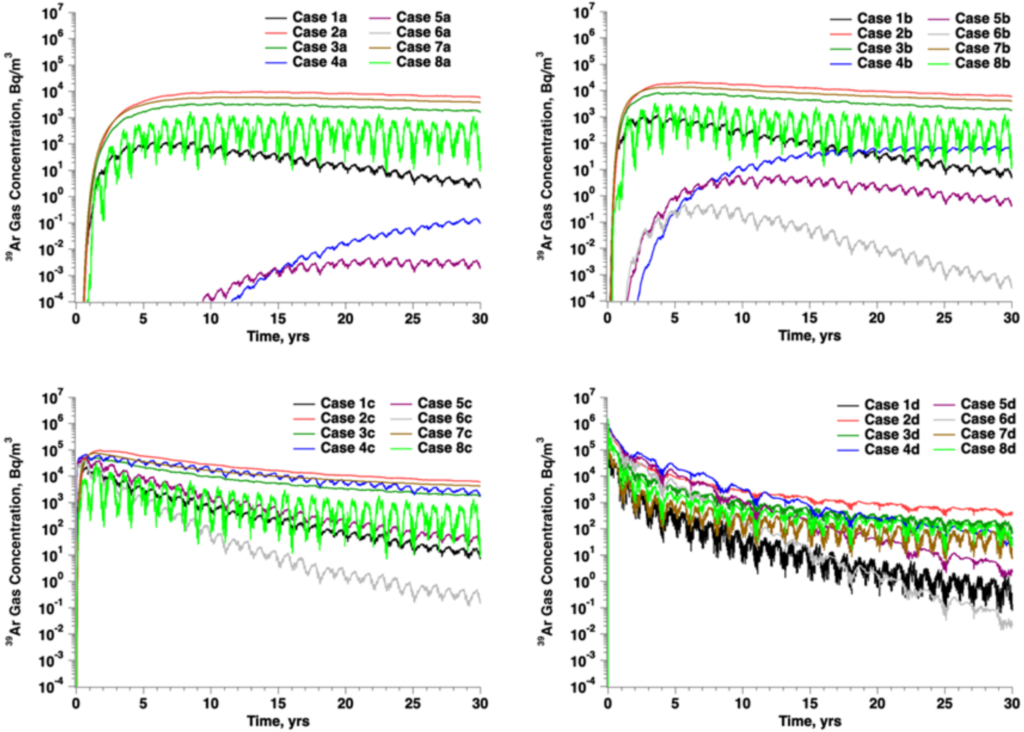
RESULTS

- 8 different geologies with varying permeability, porosity, and fracture characteristic were considered.
- Many of the deeper (A and B) cases show strong, persistent surface concentrations out to 30 years.
- Even in shallower, poorly contained cases (C and D), the long-lived ^{39}Ar remains substantially concentrated over the same time.

Figure shows simulated concentrations of ^{39}Ar at a surface location directly above the center of the chimney with time.



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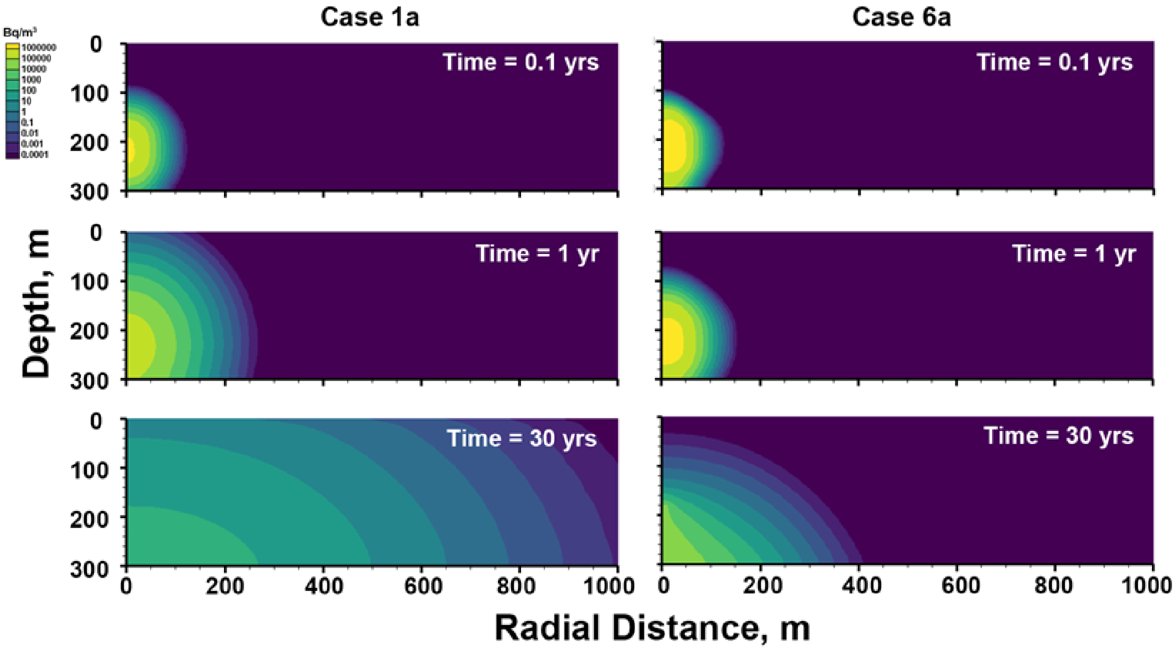
RESULTS

Predicted ^{39}Ar concentrations in the model domain at various times. This illustrates the influence that a much more highly-permeable host rock (1a) can have compared to a lower-permeable host rock (6a).



Note that only the first 1000 meters radial extent of the model domain is shown.

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CONCLUSIONS

- Results from this study clearly illustrate how and why ^{39}Ar from legacy UNEs at the NNSS and other sites can be expected to persist in the subsurface for decades
- Results suggest that in certain geologic environments ^{39}Ar and other noble gases resulting from UNEs might never be detectable at ground surface depending on emplacement, low gas permeability of the host rock, and other factors.
- The variability of the simulation results, and sensitivity to factors such as the nature and extent of fracturing, point to the importance of site characterization and use of controlled field experiments to provide test beds for improving our understanding and ability to characterize and accurately model complex subsurface environments.

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The Underground Nuclear Explosion Signatures Experiment (UNESE) was created to apply a broad range of research and development (R&D) techniques and technologies to nuclear explosion monitoring and nuclear nonproliferation. It is a multi-year research and development project sponsored by NNSA DNN R&D, and is collaboratively executed by Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Mission Support and Test Services, Pacific Northwest National Laboratory, and Sandia National Laboratories.

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