

The detection of Ar-39 above underground nuclear explosions decades later as a signature

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UNESE Phase II Noble Gas Migration Experiment



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.

Noble Gas Detection is a Cornerstone of Nuclear Explosion Detection

- For a UNE, it is the noble gases that are most likely to escape to the surface, and thus the most likely radionuclide observables in the atmosphere or near-surface soil
 - They're gases (obviously) and they're chemically inert (so less likely to get bound to something)
- Several radioxenon isotopes have strong fission yields and the presence of multiple isotopes helps with discrimination between nuclear explosions and other sources
 - Xenon-131m, Xenon-133, Xenon-133m, Xenon-135 (9 hour – 12 day half-lives)
- Argon-37 (35 day half-life) is a radioactive activation product from neutrons on Calcium-40
- These are on the CTBT “relevant radionuclides” lists so sensitive equipment has been developed to detect them
- These short-lived radioactive noble gases align with a common desire to detect nuclear explosions quickly

UNESE Noble Gas Migration Experiments

- This project conducted gas migration experiments at two UNE chimneys at NNSS.
- Radioxenon and Argon-37 (10^{10} Bq levels), along with chemical tracers, were injected into the chimneys and then gas sampling occurred in boreholes and the shallow subsurface above the UNEs for months to study the migration of the gases. Samples were analyzed elsewhere with sensitive equipment.
- Experiment Goals:
 - Determine how radioactive noble gases from a UNE transport through the subsurface to the surface
 - Measure and understand the effect of backgrounds
 - Refine subsurface transport models



Borehole being drilled from adjacent tunnel to chimney for experiment's injection

Talk T2.4-O10 by Chris Johnson will provide much more information about these experiments

UNESE Noble Gas Migration Experiment Locations

U20az Testbed

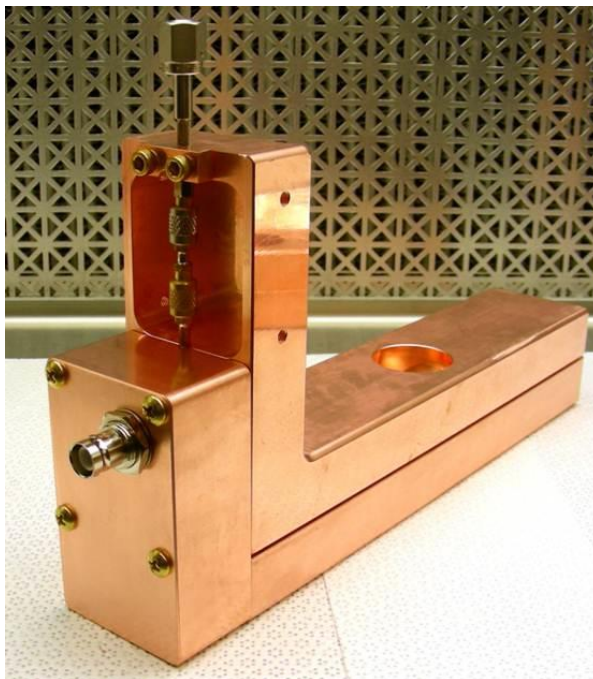
- 20 – 150 kT vertically-emplaced UNE
- Late-time (9 days to 3 months) seepage of radioxenon observed
- Depth of Burial: 686 m
- Estimate depth of chimney top: 176 m
- Surface geology: welded tuff
- Drillback hole to chimney remained for UNESE injections

U12p.03 Testbed

- < 20 kT (a few other similar UNEs were in the same tunnel complex)
- Controlled release of radioactive noble gases
- Depth of Burial: 261 m
- After UNE, reachback holes drilled and later sealed
- Distance from Working Point to nearby tunnel (built after UNE): 60 m
- Geology: Bedded tuff below welded tuft
- Injection hole drilled from tunnel to chimney for experiment

Detecting Argon-37

- Argon-37 is not an easy radioisotope to detect, as its principle signal is 2.8 keV Auger electrons (or x-rays plus Auger electrons)
- Measurement performed using internal source gas proportional counters
- Developing the capability at PNNL to measure Argon-37 was a large effort that took many years, culminating in the recent development of a prototype field system for analysis of samples.



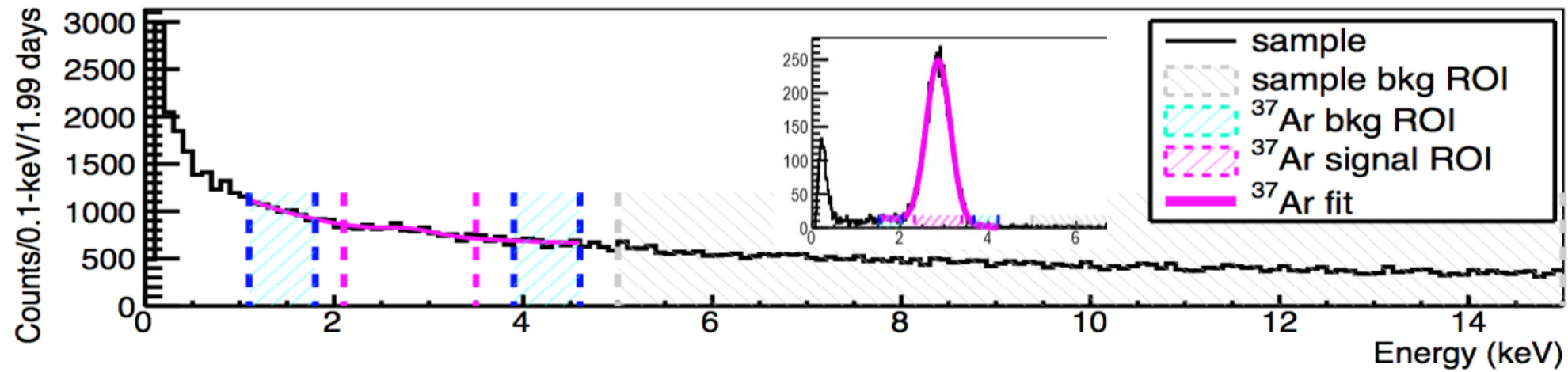
Internal-source
proportional
counter

Argon-37 Analysis
Field System test
at UNESE

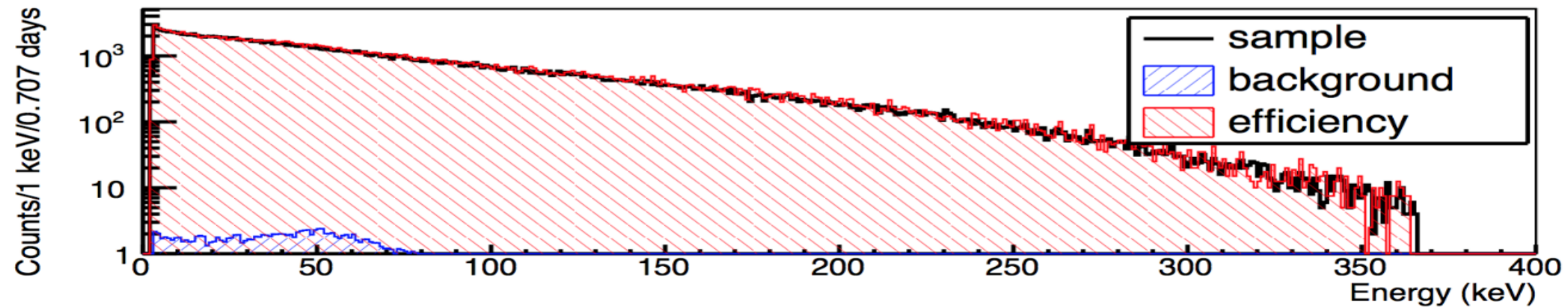


Talk T3.1-O6 by
James Hayes on
Friday will
provide
information
about the Argon-
37 Field System

Discovery of an Argon-39 background at U20az while looking for Argon-37



- Low-energy region showing the location of Argon-37 peak. Inset shows example of Argon-37 sample in P-10 gas.



- Low-gain measurement of the same sample showing more of the Argon-39 beta distribution.

Argon-39 Measured at UNE Sites

- PNNL has subsequently measured Argon-39 at a few other NNSS UNE locations

Sample Description	Ar-39 Conc. (Bq/m ³ whole air)
U20az borehole near chimney	950
U20az surface borehole (2.4 – 8.1 m)	44 - 102
U19c borehole to chimney	> 1580
U2ez surface borehole (1.6 – 8.7 m)	5 - 33
U12p tunnel	0.1 - 23
U12p tunnel just outside entrance	5.9
U12p chimney	1460 - 7182
U12p surface tarp at SGZ	390
U12p surface atmosphere near SGZ	0.5



- U19c is undisturbed drillback hole to 20-200 kT UNE
- U2ez is in alluvium and approximately 300 m from a couple UNEs (20-200 kT)

Argon-39 Measured at non-UNE Sites

- Atmospheric air concentration of Argon-39: $\sim 0.016 \text{ Bq/m}^3^*$
- Measurement from shallow subsurface air in the Cascades (Chinook Pass) – 9 samples from three different holes at depths from 1 – 3.5 m: $0.016 - 0.057 \text{ Bq/m}^3$
- Measurement from shallow subsurface air in Death Valley National Park – 3 samples from two different holes at depths from 1 – 4 m: $\sim 0.016 \text{ Bq/m}^3$

*P. Benetti et al., NIM A vol. 574, p. 83-88 (and we have measured this)
-concentrations are in whole air



Implications

- Argon-39 has a half-life of 269 years and is produced in a UNE by neutron capture on Potassium-39 at $\sim 10^{12}$ Bq/kT. Exceeds Argon-37 activity after approximately 1 year.
- Reduces sensitivity to detect Argon-37. At about 1 Bq/m³ of Argon-39, measuring Argon-37 to background levels (0.001 – 0.1 Bq/m³) starts to be affected.
- **Argon-39 appears to be easily detectable in shallow subsurface gas samples at UNEs for decades and beyond.**
 - It might be that Argon-39 makes UNE detection relatively easy for a long time, and UNE detection may even be easier at late times (years?) than at some earlier times. This represents a paradigm shift from current nuclear explosion verification techniques based on observables that disappear quickly due to decay, dispersion, and possible concealment efforts.
 - Would not distinguish between UNEs happening before and after Treaty signing.
 - May also help to identify appropriate tunnel adits.

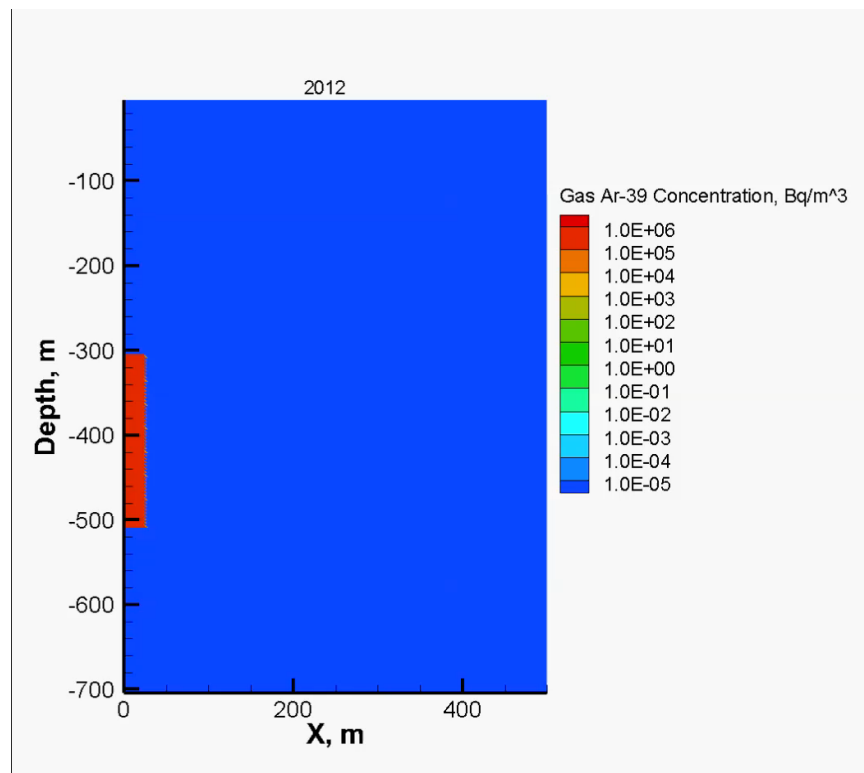
Further Studies Needed

- Much of this effort was ad-hoc on the sidelines of the Noble Gas Migration Experiments.
- Need to do dedicated measurement campaigns involving UNEs with published yields, different geologies, unused tunnel complexes without running ventilation, and chimneys not undergoing injection experiments.
- A dedicated measurement campaign to measure backgrounds in non-UNE subsurface soils is also needed.
- Need to ascertain how robust observable is with time, yield, and spatial extent from Surface Ground Zero. Also, how are observables affected by tunnel complexes?
- Are there other isotopes that are better?

Thank you

Initial Modeling Efforts at PNNL

- Subsurface Transport over Multiple Phases (STOMP) Geo-Thermal (GT)
- Model of a “well contained” (moderate fracture density) vertically-emplace UNE implies considerable amount of gas stays at UNE chimney



Initial modeling agrees with concept of the chimney serving as a source for observables reaching the surface for decades.

