# LA-UR-22-23460

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2022 PEGRUM LECTURE SERIES
April 26, 2022

# Geoscience in support of National Security

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Computational Earth Sciences
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# Where we are



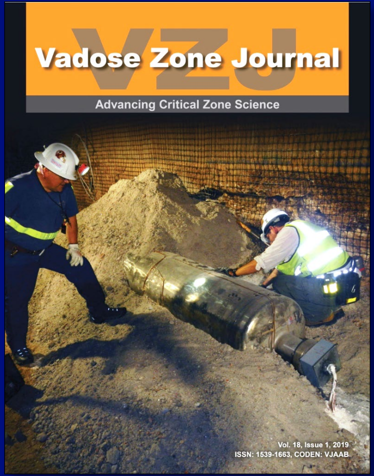

https://www.youtube.com/watch?v=g_QOV3UAjuk?

Los Alamos NATIONAL LABORATORY

# MISSIONS

https://www.lanl.gov/

Energy Security Solutions

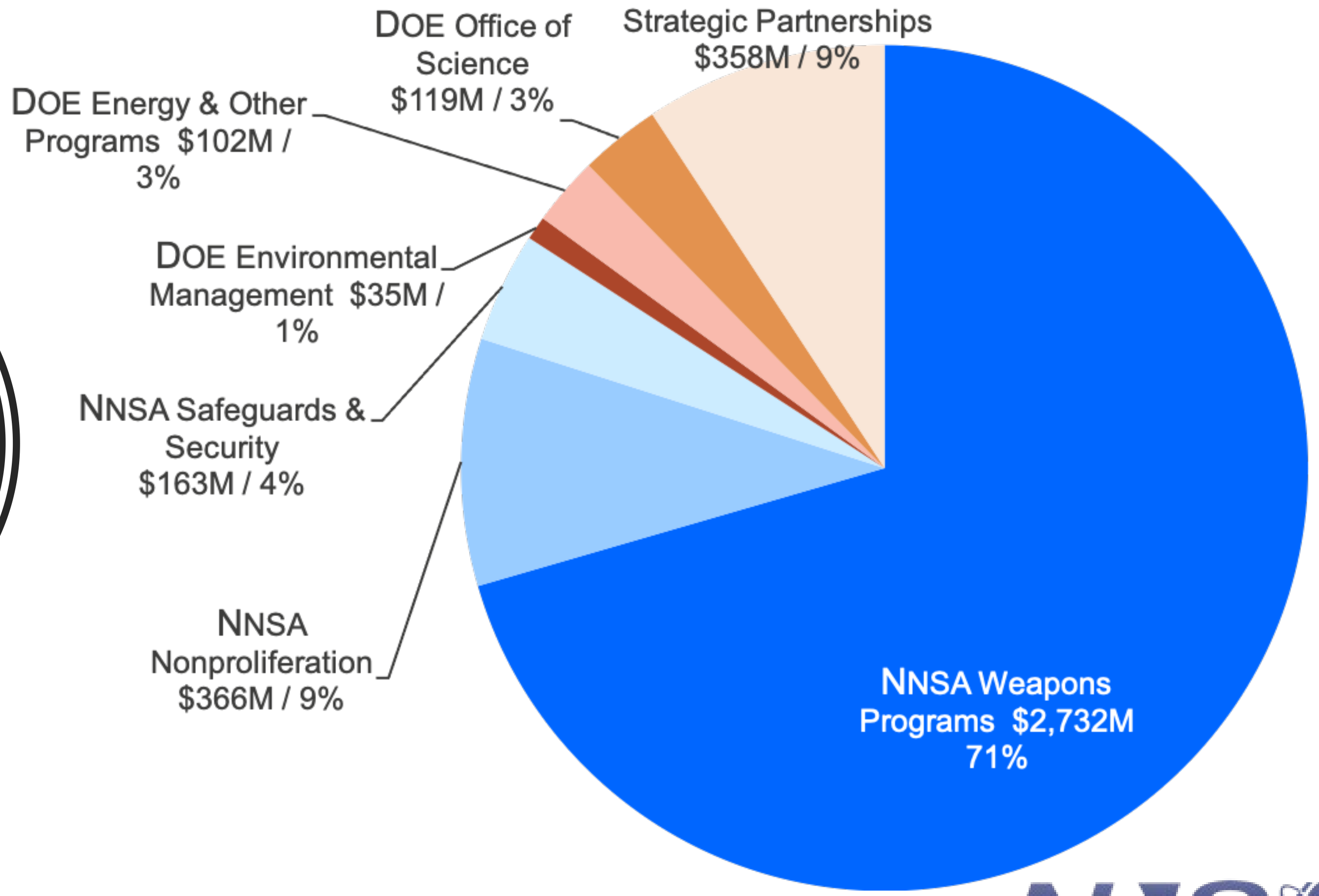



Protecting Against Nuclear Threats

Emerging Threats and Opportunities

Deterrence and Stockpile Stewardship

2021
Los Alamos
BUDGET
3.9B$




https://www.lanl.gov/about/facts-figures/budget.php

# LANL’s Earth and Environmental Sciences Division

- **Earth System Observations**
  - Atmosphere, Climate, and Ecosystem Science
  - Geochemistry and Geomaterials Research
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- **Computational Earth Science**
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- **Geophysics**
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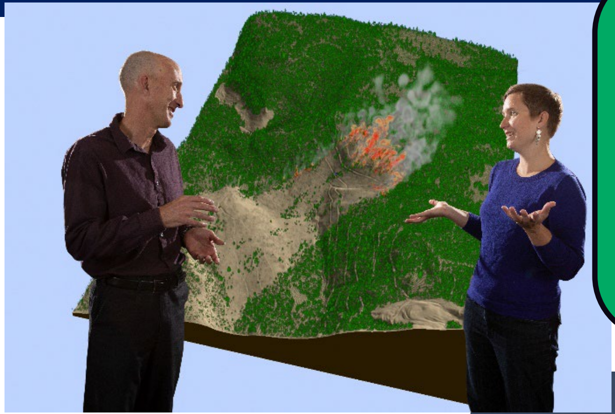

- 17 Undergrads
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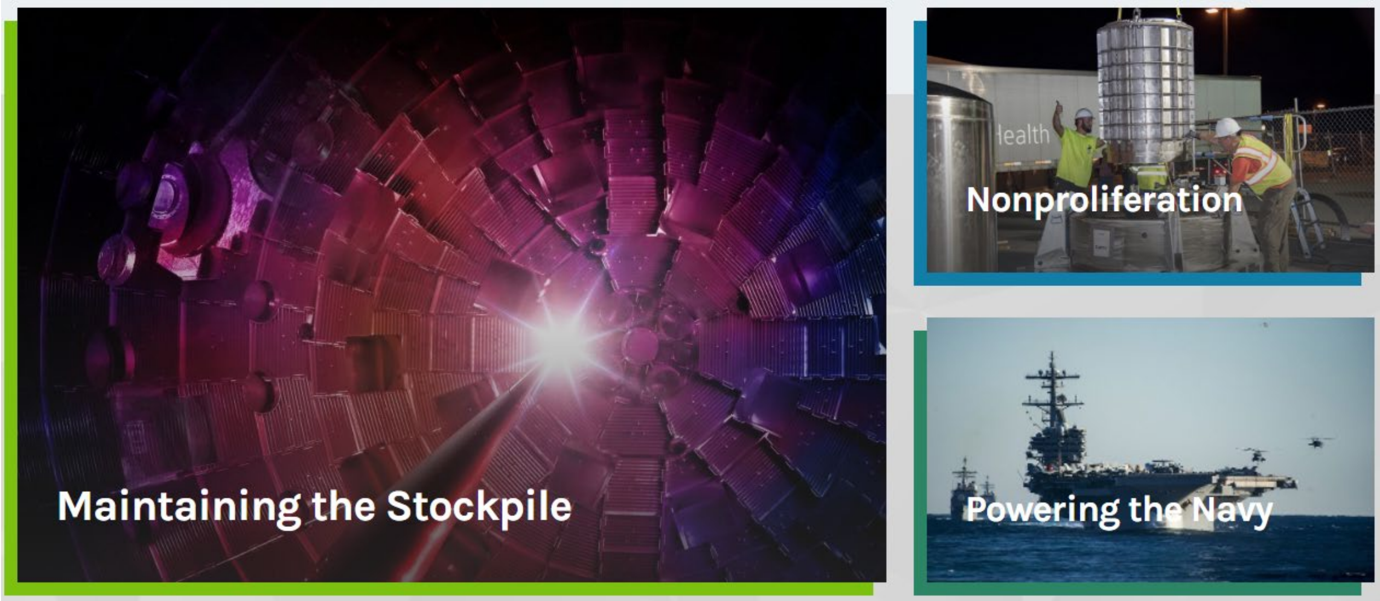
https://www.lanl.gov/org/ddste/aldcels/earth-environmental-sciences/index.php

We provide multidisciplinary solutions to complex problems in climate and environmental change; sustainable energy; and nuclear and global security.

# NNSA : National Nuclear Security Administration

NNSA is a semi-autonomous agency within the U.S. Department of Energy responsible for enhancing national security through the military application of nuclear science.




NNSA

# NNSA Nuclear Monitoring Research

NNSA advances its nuclear threat reduction mission by developing ways to **detect and monitor** foreign nuclear fuel cycle and weapons development activities, special nuclear material movement or diversion, and **nuclear explosions**.

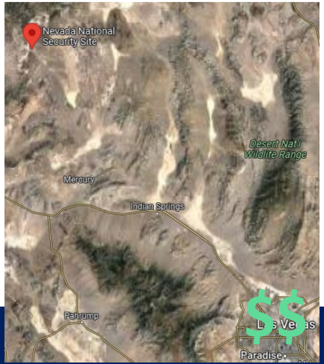
**Workers at Nevada National Security Site prepare for a Source Physics Experiment to improve U.S. capability to detect and discriminate underground nuclear explosions.**

# US Nuclear Explosion History

1945 Trinity Test first nuclear explosion
– White Sands New Mexico
1992 Last US underground test in Nevada

| Test Type | US | WORLD |
|---|---|---|
| Atmospheric | 215 | 528 |
| Underground | 815 | 1528 |
| TOTAL | 1030 | 2056 |

Yucca Flat – Nevada National Security Site NEVADA.
90 miles from Las Vegas $$

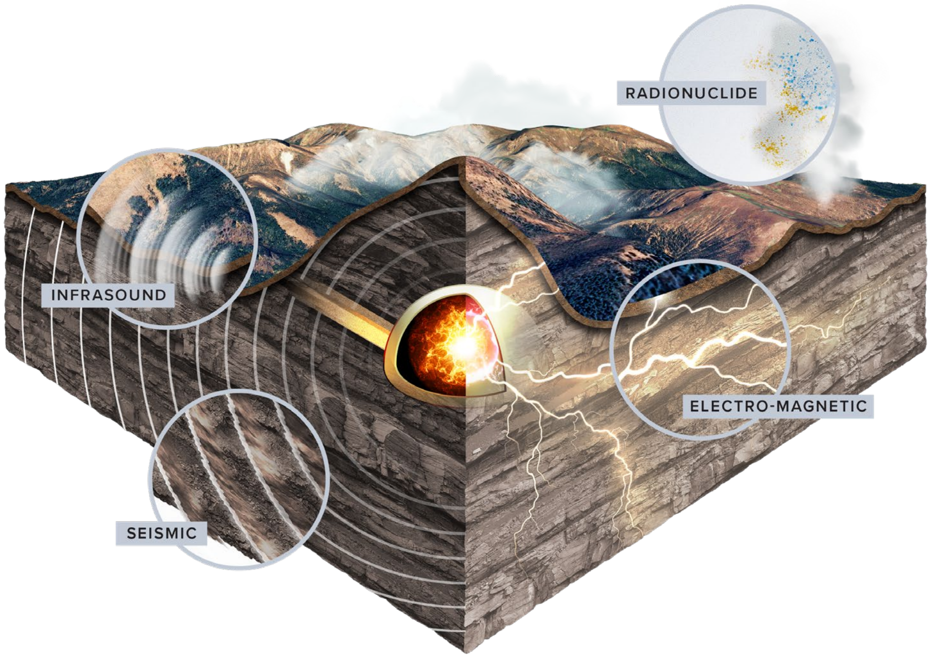



# Los Alamos Research on Nuclear Monitoring

- **Goal:**
  - Enable global detection/measurement of underground nuclear explosions (**UNE**s)
- **Approach:**
  - Comprehensively discover multiple signatures
  - Predictive modeling of signatures
  - Validate against historic test data and new targeted field experiments

**Challenges**

- Complex, emplacement-dependent sources & background signatures
- Validation (e.g., field tests) is complex, expensive, and therefore limited



# Nuclear Nonproliferation Historical Highlights

1957 - The International Atomic Energy Agency (IAEA) was created with the mission of promoting and overseeing the peaceful use of nuclear technology.

1968 - UN General Assembly adopted a resolution endorsing the draft text of the Treaty on the Nonproliferation of Nuclear Weapons

1992 – Last US nuclear test 'Divider' underground at the NNSS, LANL test in a shaft. (DOE, 2015, NV-209 Rev 16)

1996 - Comprehensive Nuclear Test Ban Treaty (CTBT) opened for signature at the United Nations

1997 - The IAEA's Model Additional Protocol is Introduced (more on-site inspections in 136 countries)



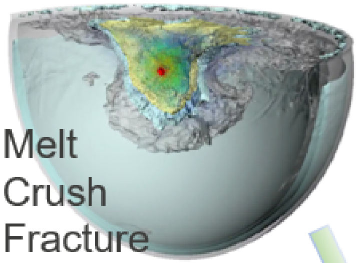
https://world101.cfr.org/global-era-issues/nuclear-proliferation/history-nuclear-proliferation

# Source to Sensor Time Scales

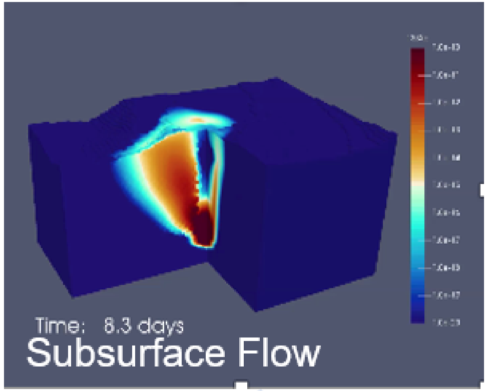
10 Nanoseconds – Microseconds -------- milliseconds ---------------------- days ------------- months

Nuclear Explosion


Nonlinear Wave Propagation
Damage and Melt

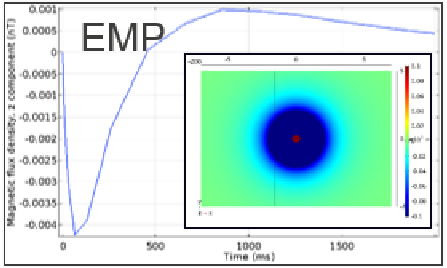



RN and stable isotope transport

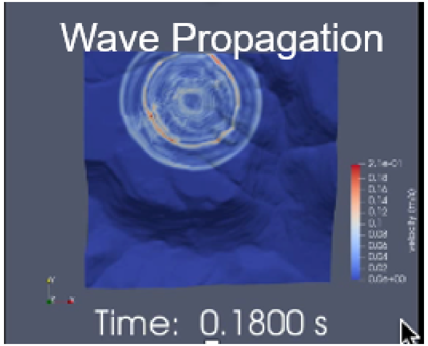


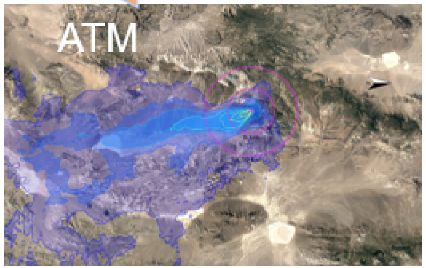

Shakes - Microseconds---------- seconds ------------------ minutes ------------------------------------days

Electromagnetic




Seismic, Acoustic

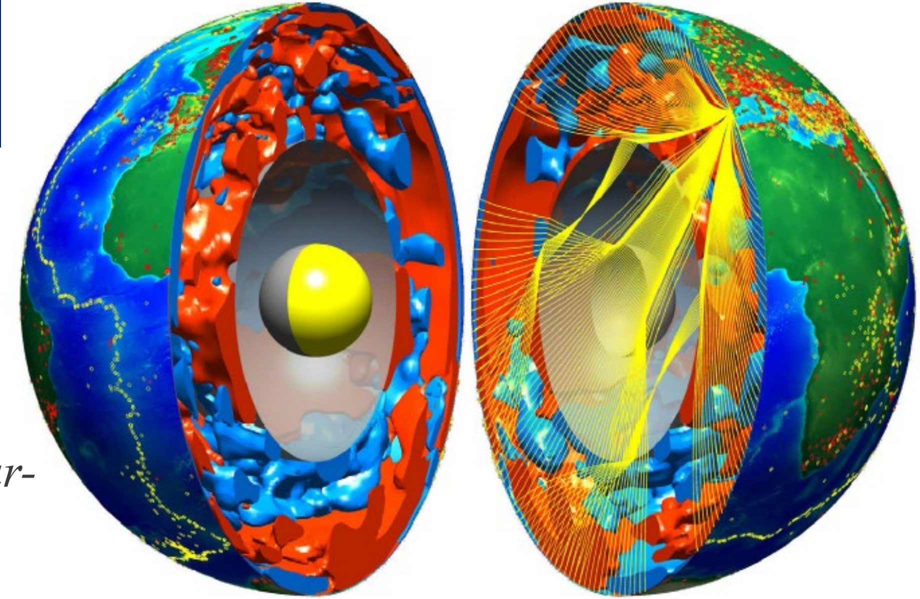


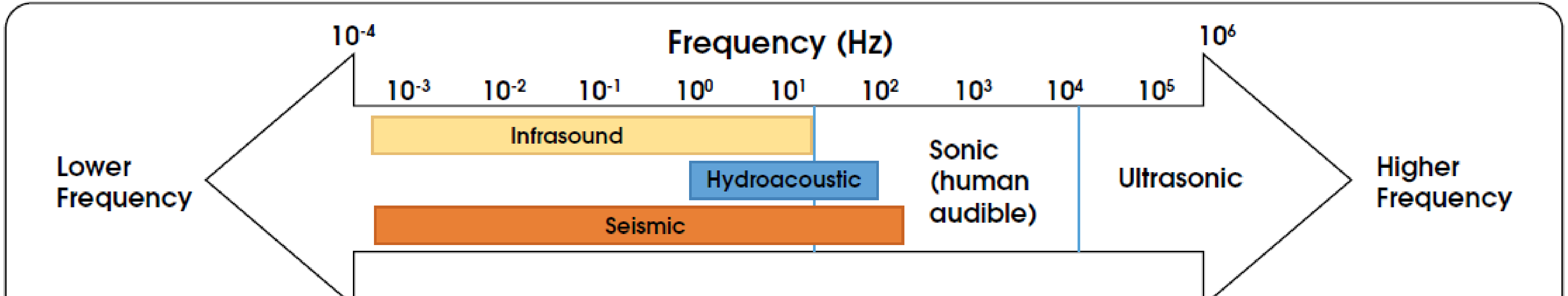

Meteorology & ATM

# Explosions generate immediate signals

- Seismic
- Infrasound
- Electromagnetic pulse
- Radionuclide gases



*fast (blue) and slow (red) shear-wave anomalies in the mantle*

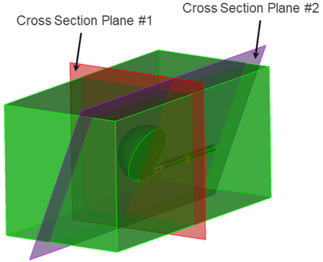


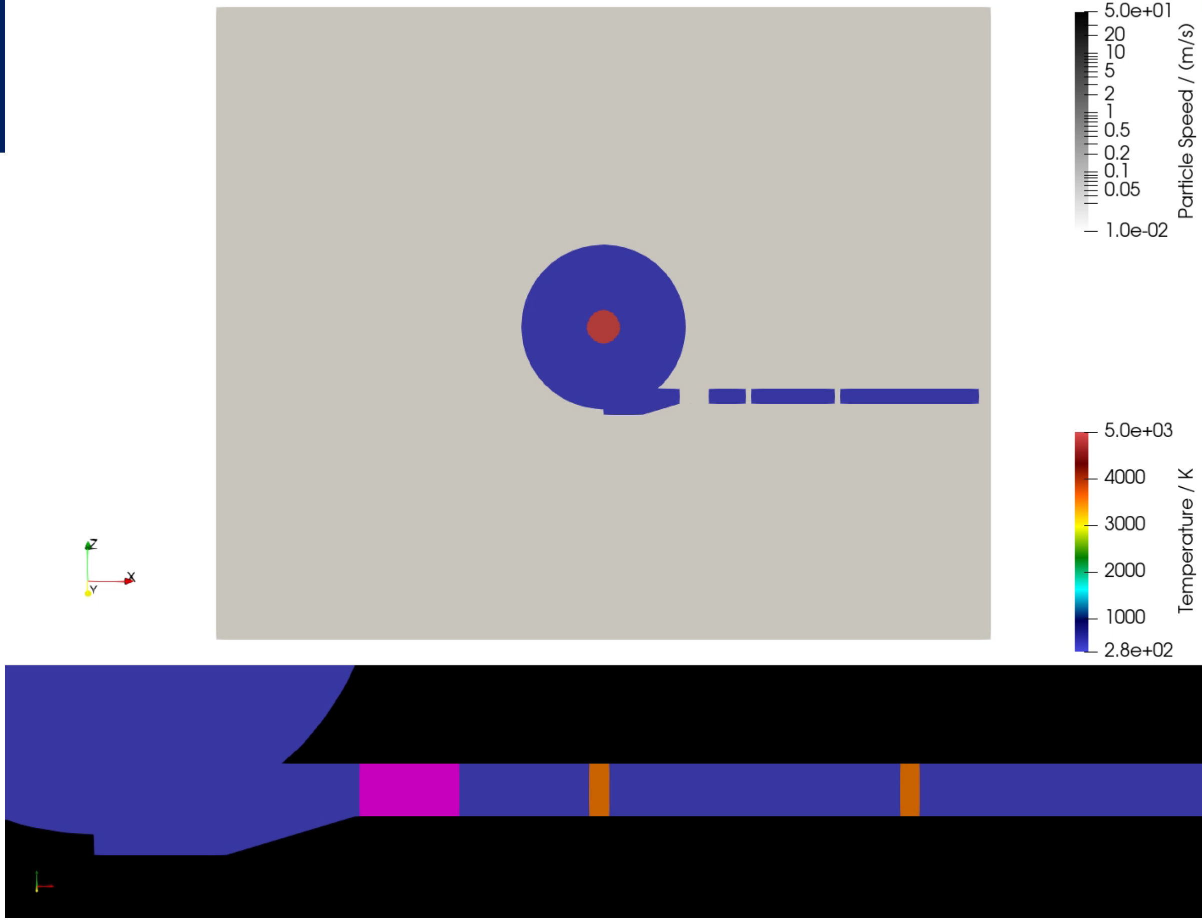

Maceira et al., 2017, LA-UR-17-21274

# Explosion damage

Explosions create changes to the subsurface

- Hydrofractures
- Compressed porosity
- Stress changes
- Destroy manmade structures




*Mass and energy flow simulation of an explosion in a tunnel complex*

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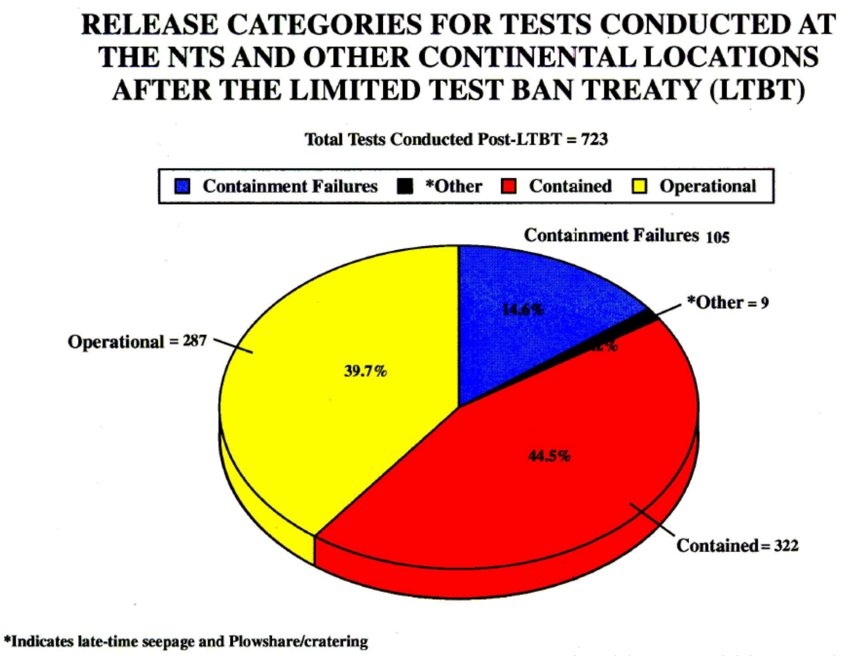
https://www.lanl.gov/orgs/ees/hoss/applications.shtml

Rougier et al., 2021, LA-UR-21-24997

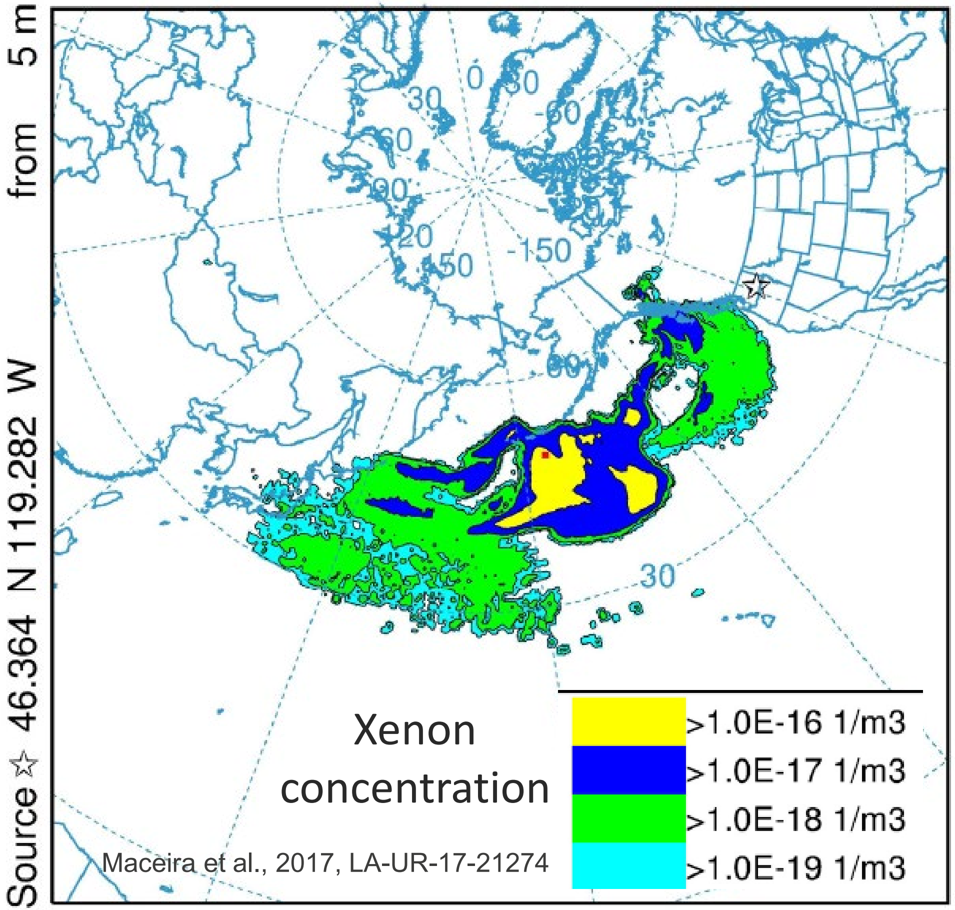
# Atmospheric transport

*ATM model of the Fukushima reactor accident*

Gases escape the underground and move through the atmosphere




DOE, 2015, NV-209 REV 16

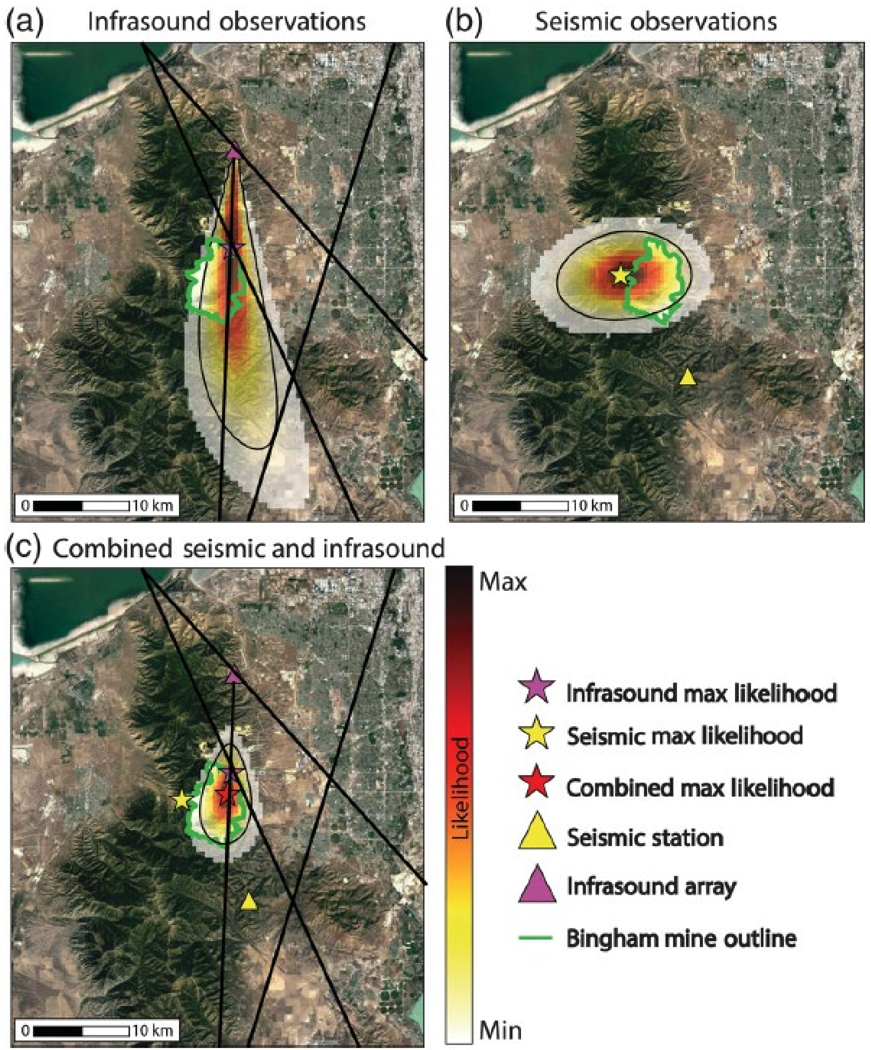



Maceira et al., 2017, LA-UR-17-21274

# Combining data

We can combine signals to
- Lower detection thresholds
- Give more confidence in results

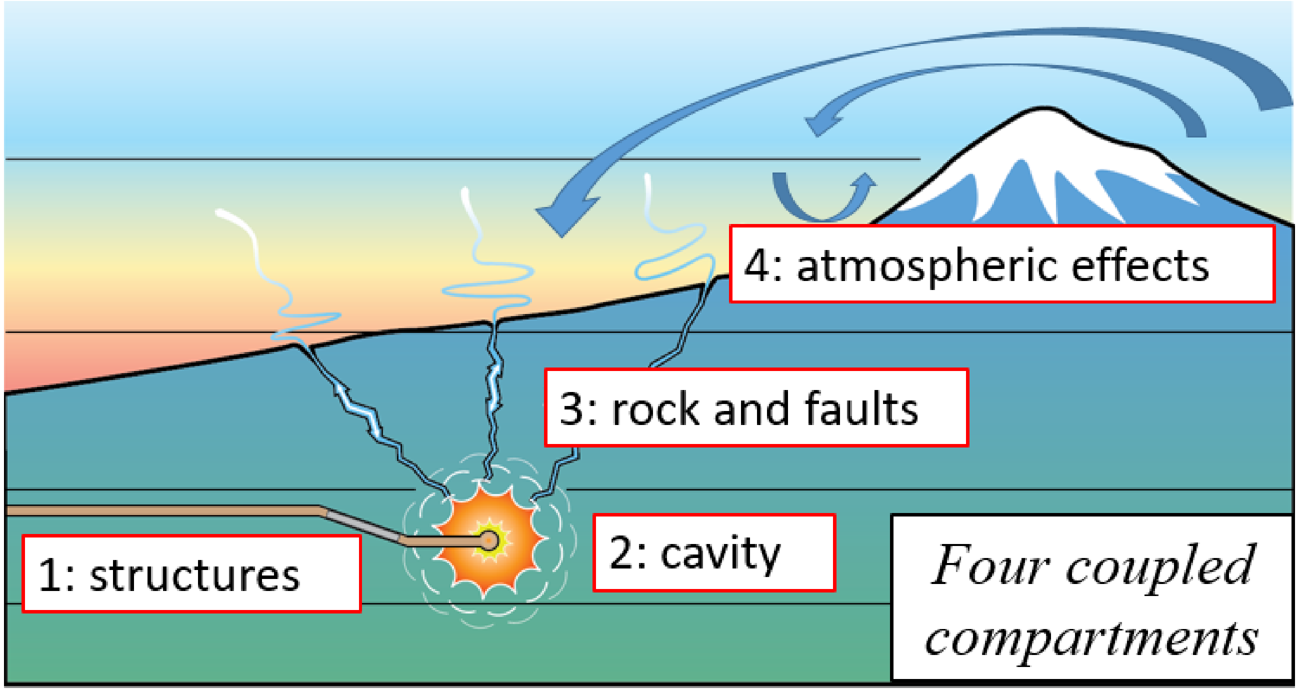
Infrasound + Seismic
does better than either alone
at locating an event




Koch & Arrowsmith, 2019, Seismological Research Letters

# Source to Sensor Radioactive Gas Migration

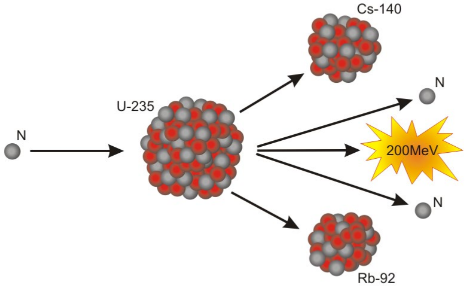
**The international community considers radioactive gases to be a smoking gun indicator of a nuclear explosion**



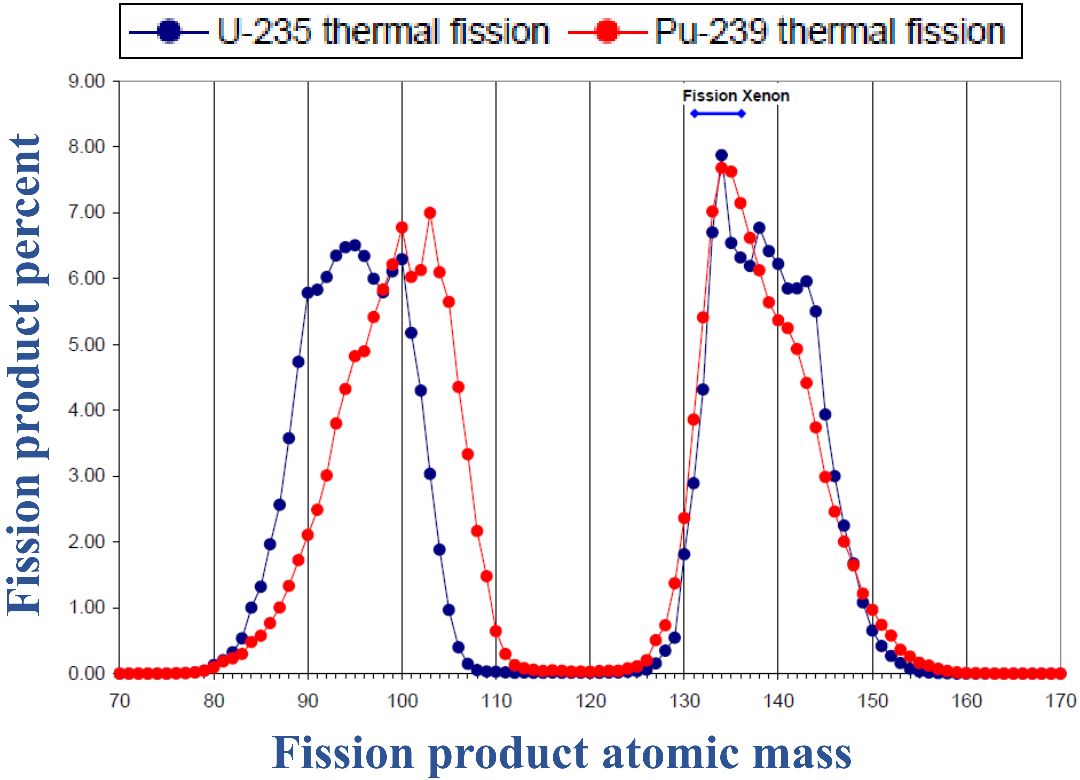

https://www.ctbto.org/specials/testing-times/18-december-1970-the-baneberry-incident

# Source to Sensor Radioactive Gas Migration

## Background on radioactive gas production from nuclear fission




Fission product yields by mass for thermal neutron fission of U-235, Pu-239, typical of current nuclear power reactors.





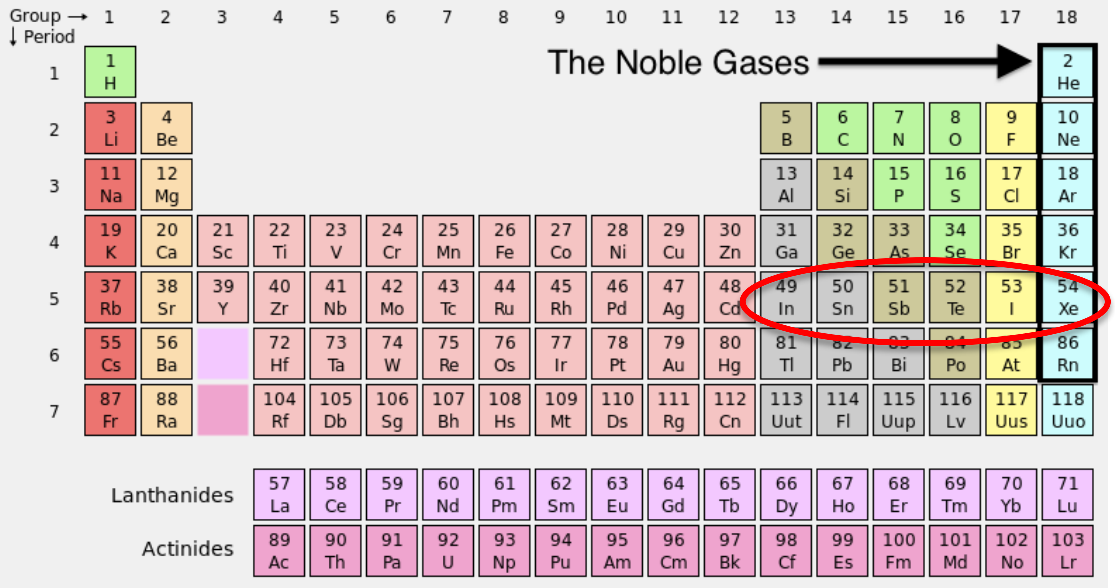

Dresel and Waichler, 2004, PNNL-14617

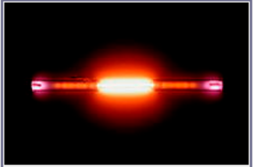
# Source to Sensor Radioactive Gas Migration

## Gases of interest for monitoring

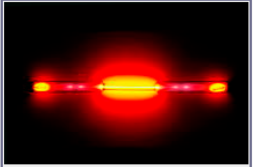
### Noble Gases

- Highly inert
- Half-lives long enough to measure after subsurface transport
- Low atmospheric abundances

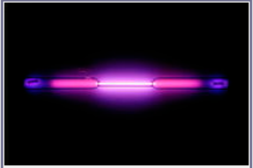


Helium (He)
2

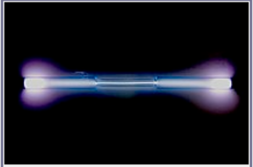


Neon (Ne)
10



Argon (Ar)
18

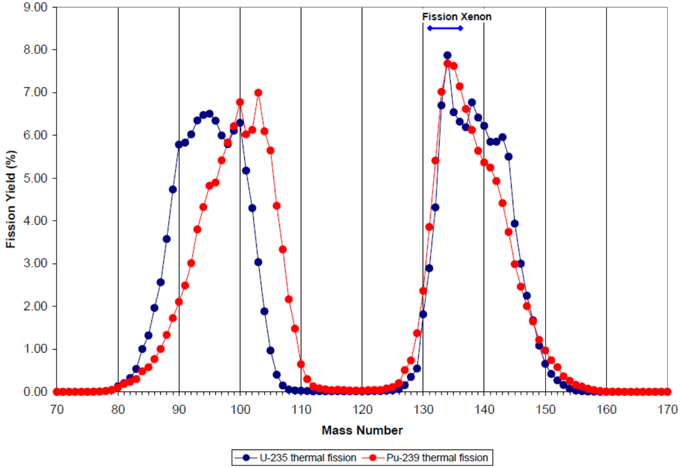
Krypton (Kr)
36

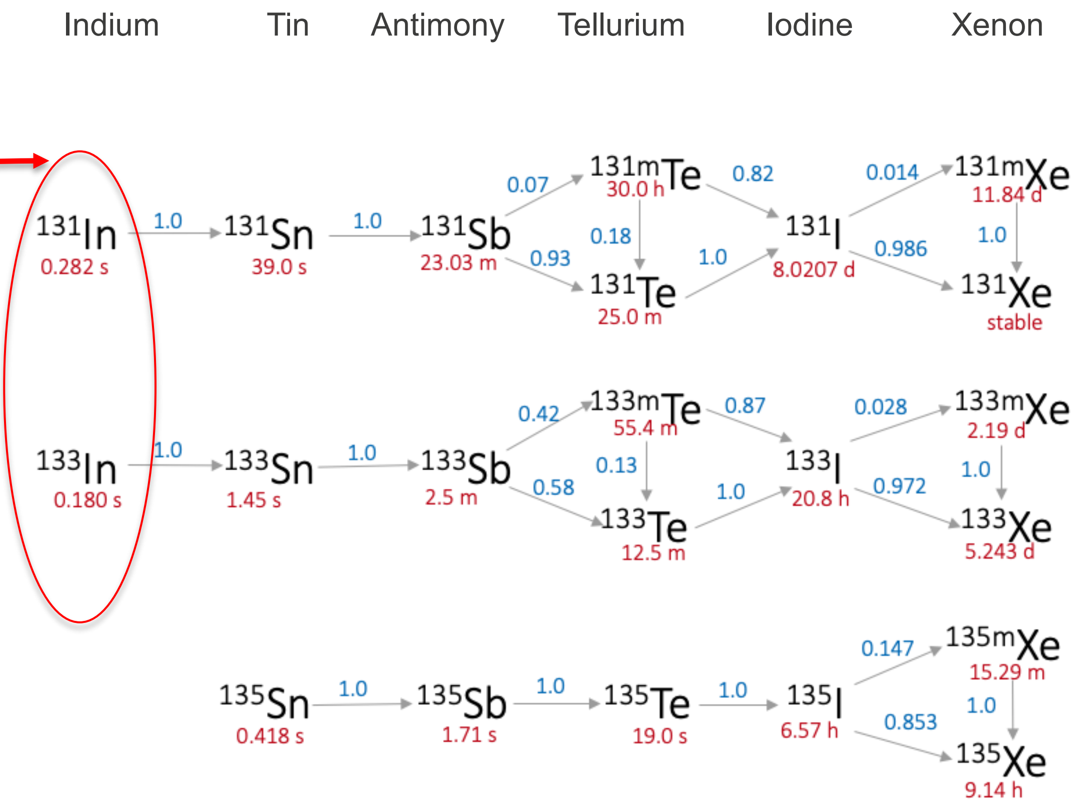


Xenon (Xe)
54

# Source to Sensor Radioactive Gas Migration

**Xenon is created by fission AND decay**
**1/5 of spilt atoms end up as Xenon**



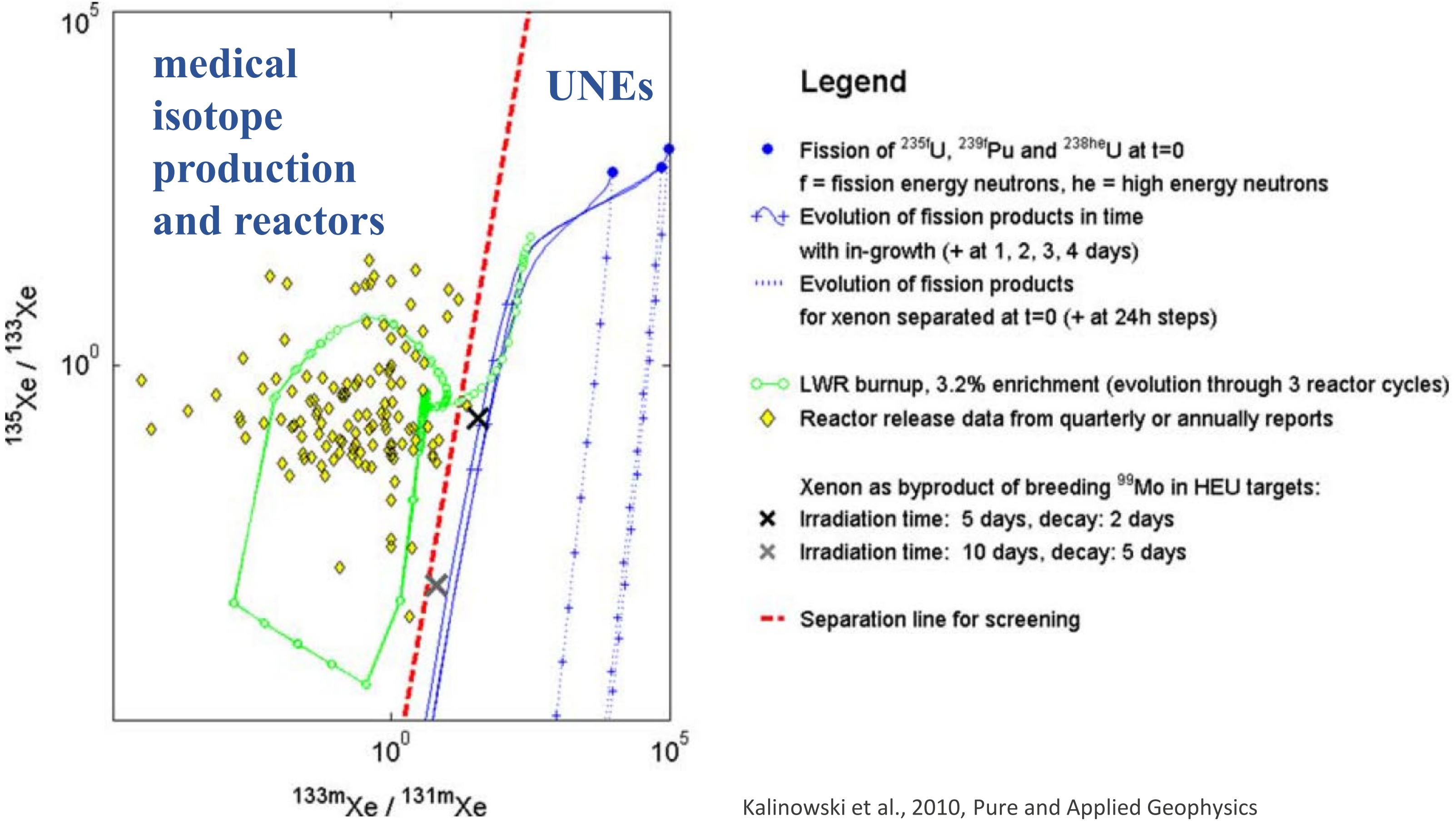



Dresel and Waichler, 2004, PNNL-14617

England and Rider, 1994, LA-UR-94-3106

# Source to Sensor Radioactive Gas Migration

Xenon isotopic ratios can be used to differentiate UNEs from medical isotope production and reactors




Kalinowski et al., 2010, Pure and Applied Geophysics

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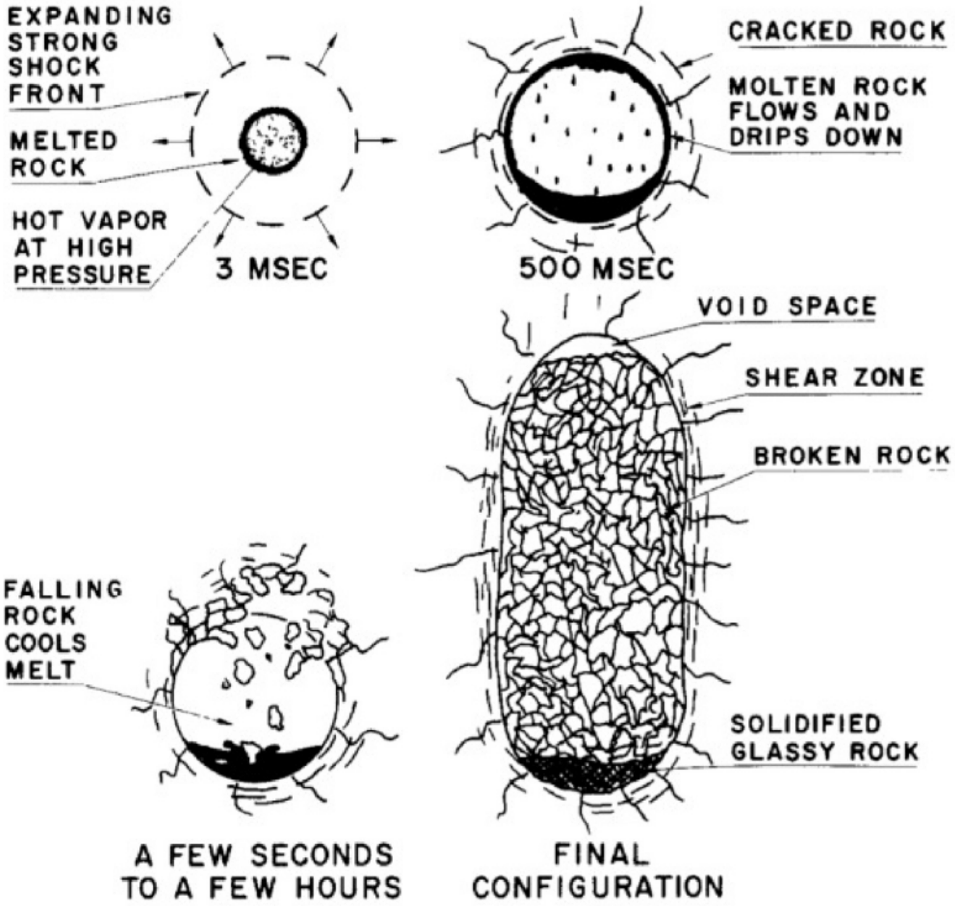
# Source to Sensor Radioactive Gas Migration
# Cavity and chimney formation

Initial blast creates a cavity

Sometimes the cavity collapses and forms a chimney above

Can lead to a surface crater

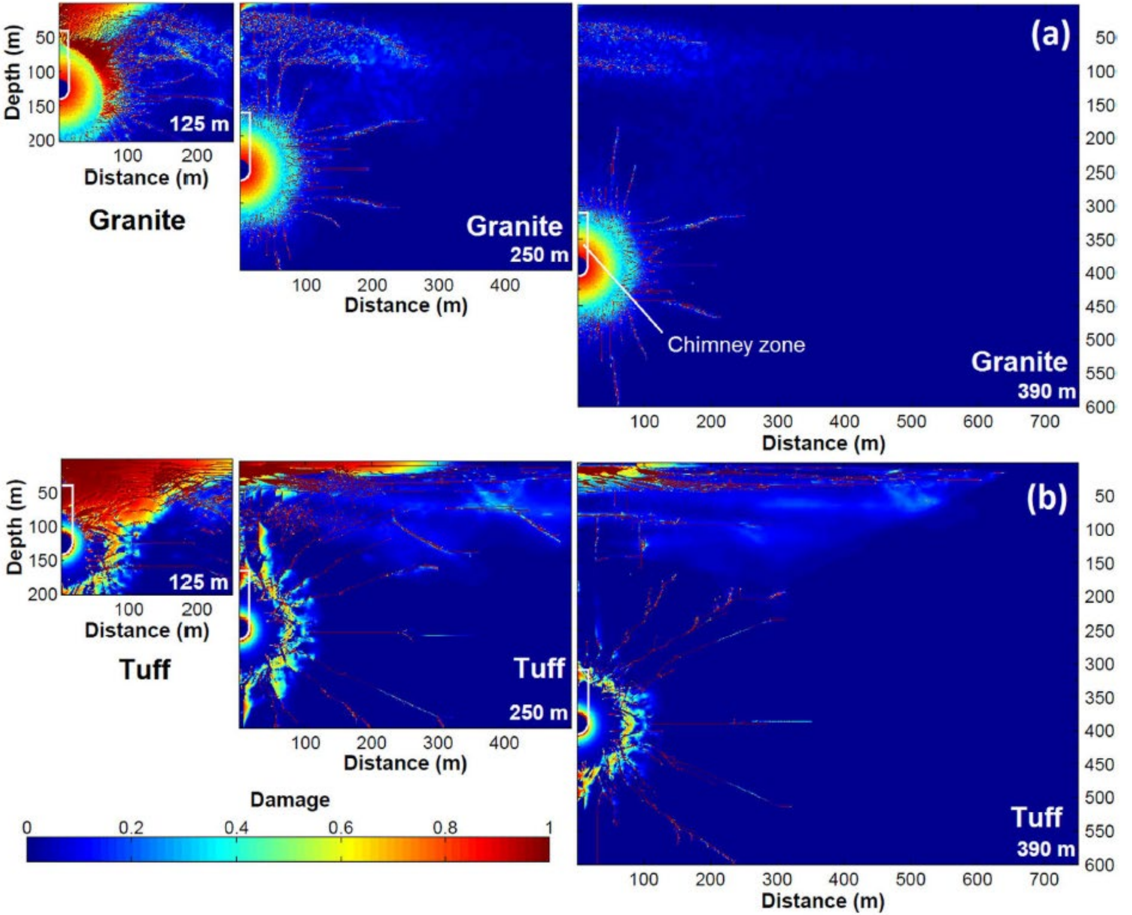





Schwartz et al., Journal of Non-Crystalline Solids, 1984

# Source to Sensor Radioactive Gas Migration
# Cavity and chimney formation

## Damage is dependent on geology and depth

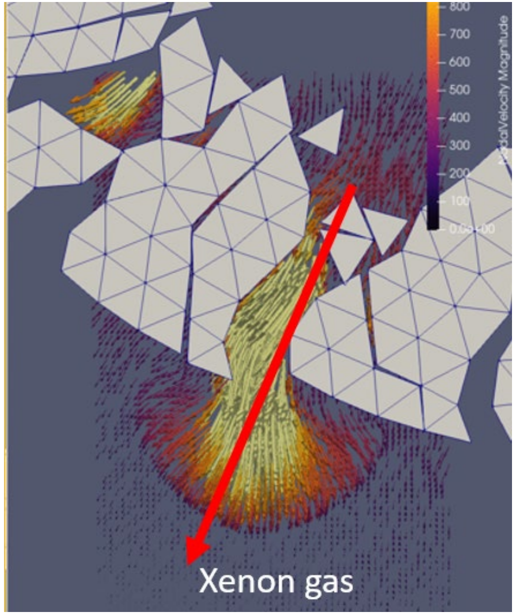


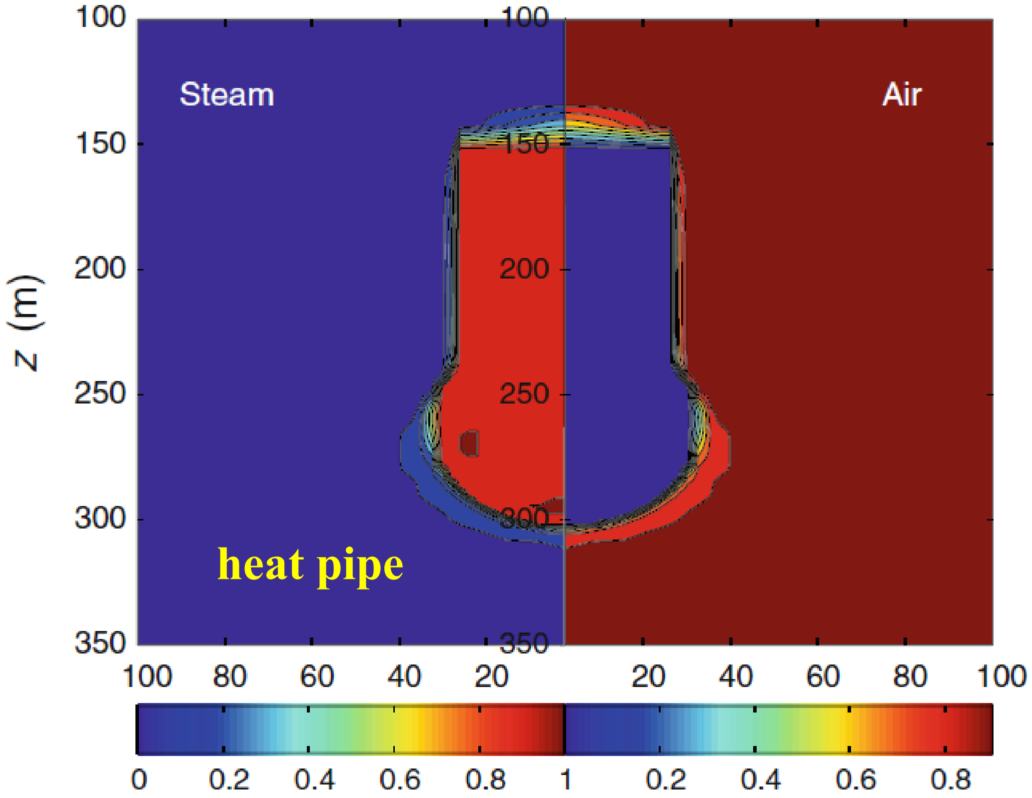



Jordan et al., 2015, Scientific Reports

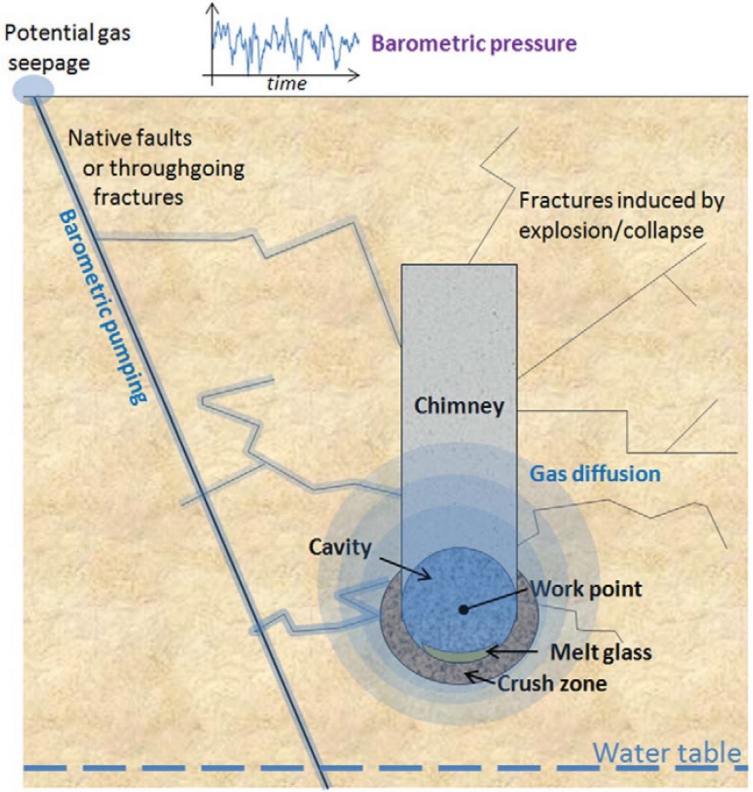
# Source to Sensor Radioactive Gas Migration
# Processes impacting gas migration to the land surface : Early Time

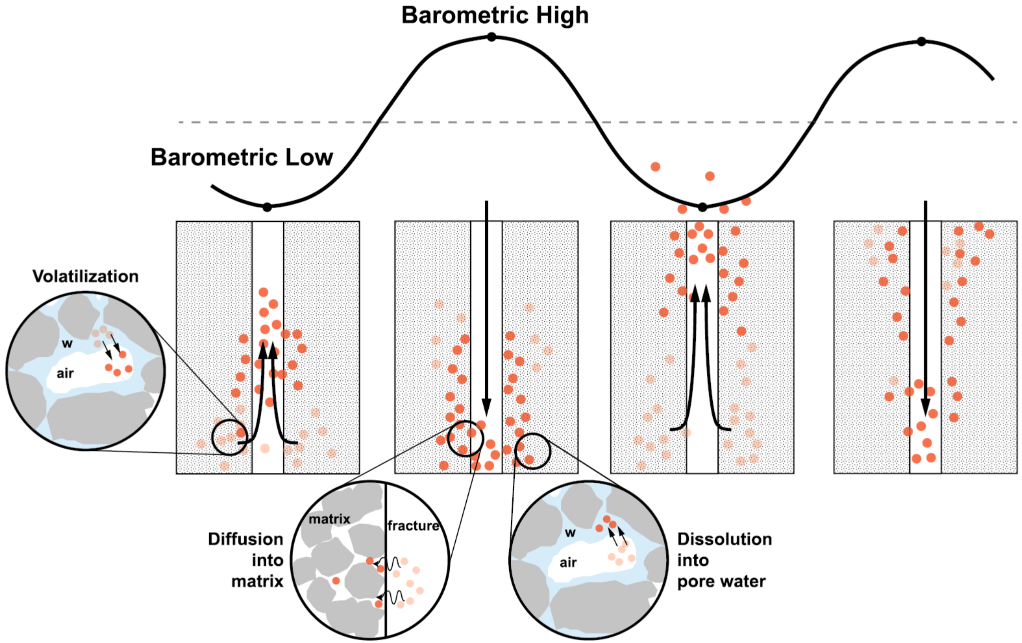
**Pressure and temperature from the explosion can drive flow**



# Source to Sensor Radioactive Gas Migration
# Processes impacting gas migration to the land surface : Late Time



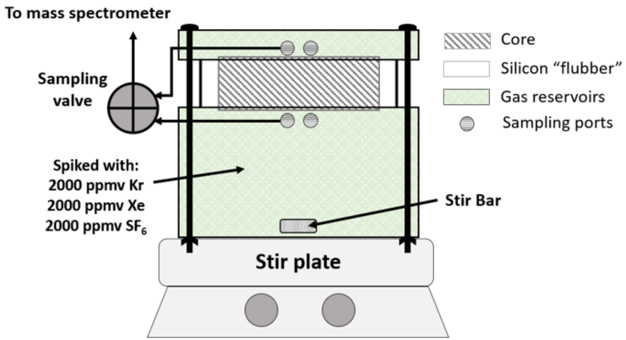


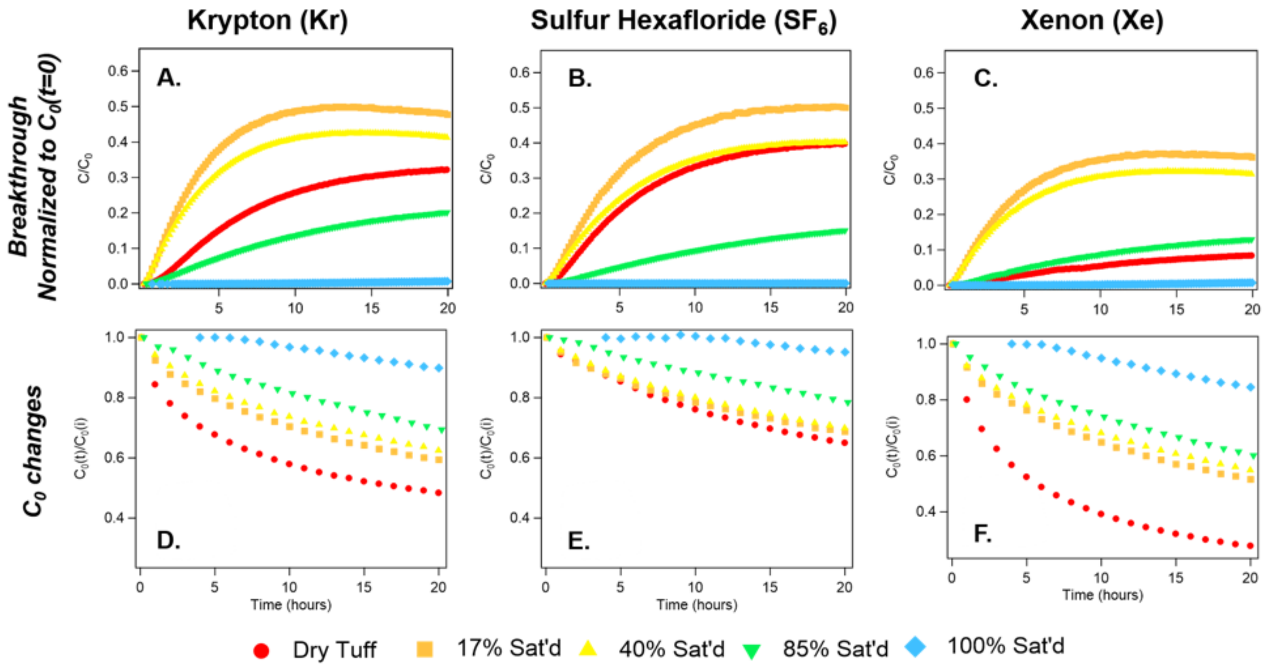

Jordan et al., 2014, Vadose Zone J.

Harp et al., 2018, Transport in Porous Media

# Source to Sensor Radioactive Gas Migration

**Lab experiments are used to measure diffusion and sorption**



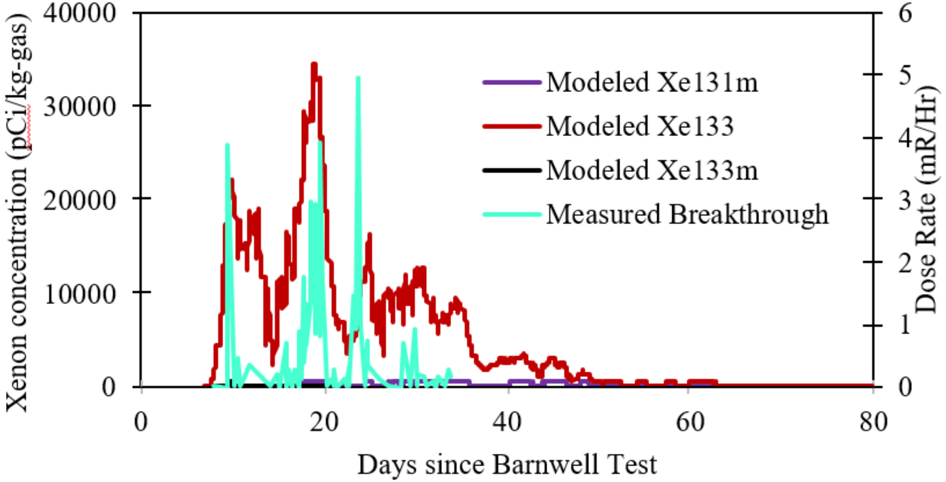

**Here, for the first time, impacts of saturation on Xenon diffusion in zeolitic tuff are measured**



Neil et al., 2022, J. Environmental Radioactivity (submitted)

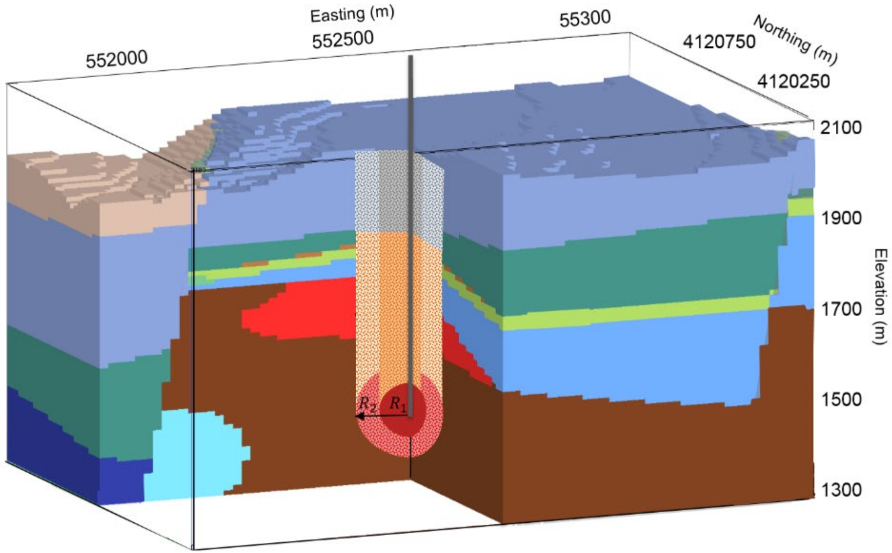
# Source to Sensor Radioactive Gas Migration Simulations can match historic gas release data

## Simulated Xenon breakthrough matches surface rad detector measurements




*Comparison of model results at SGZ with measured dose at ground surface 134 m north of SGZ. Dose data are from Hudson (1990).*

## Simulations calibrated to 2013 Nobel Gas Migration Experiment



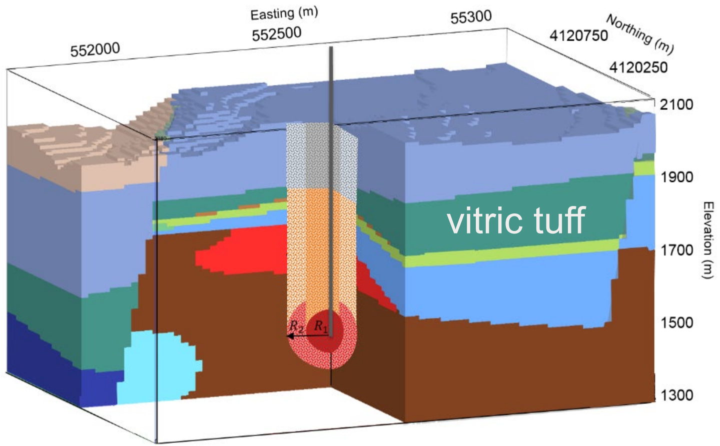

Barnwell (1989) Simulation Domain

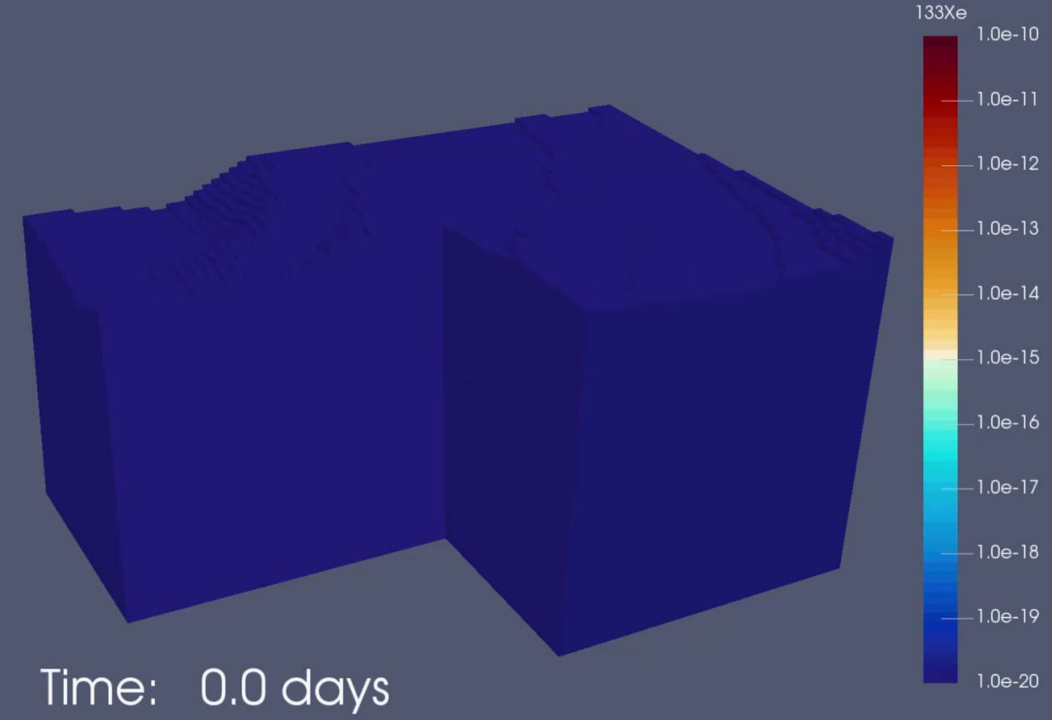


Bourret et al., 2019, Vadose Zone Journal

# Source to Sensor Radioactive Gas Migration
# 3-D effects result in gas moving to interesting places

Topography and geology affect gas migration behavior.
Fault provides offset on high porosity (high gas storage) vitric tuff layer



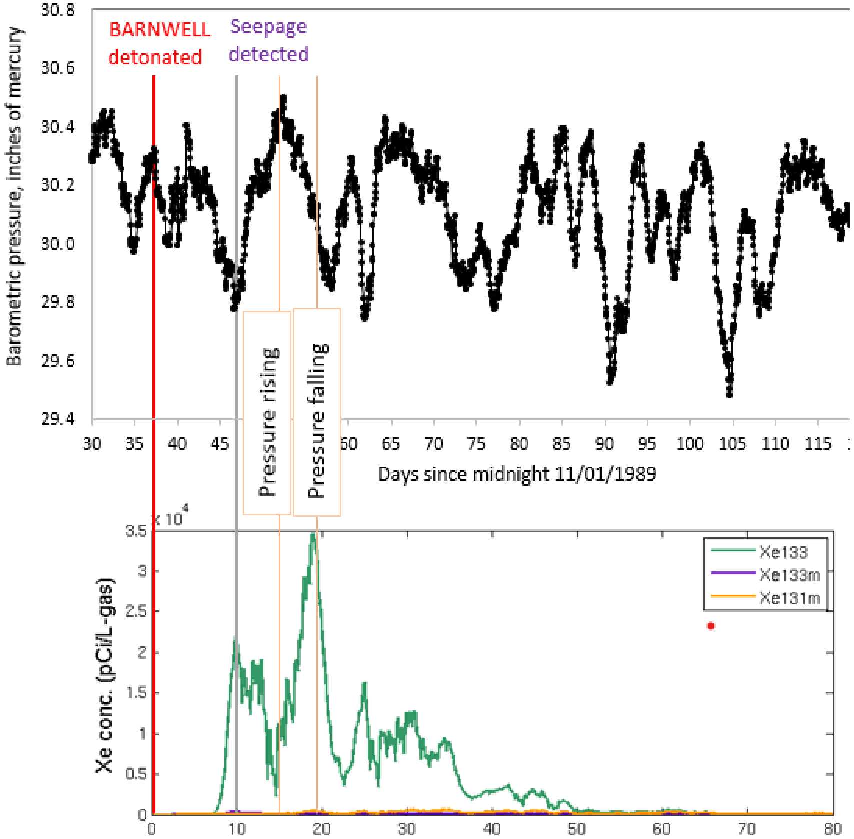


Bourret et al., 2019, LA-UR-19-29343

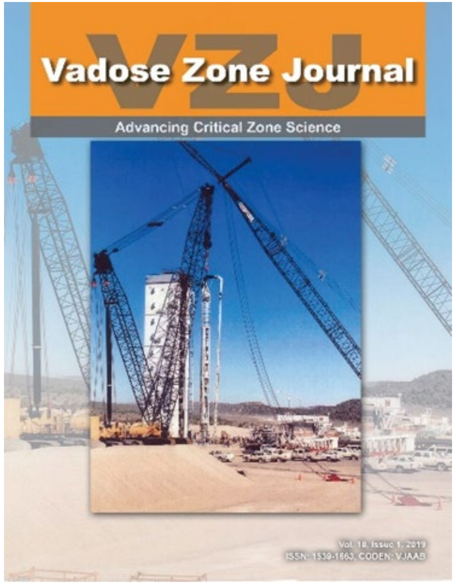
# Source to Sensor Radioactive Gas Migration
# Atmospheric pumping pulls gas to the surface

Barnwell Atmospheric pressure data

Barnwell simulated $^{133}Xe$ using NGME permeability calibration

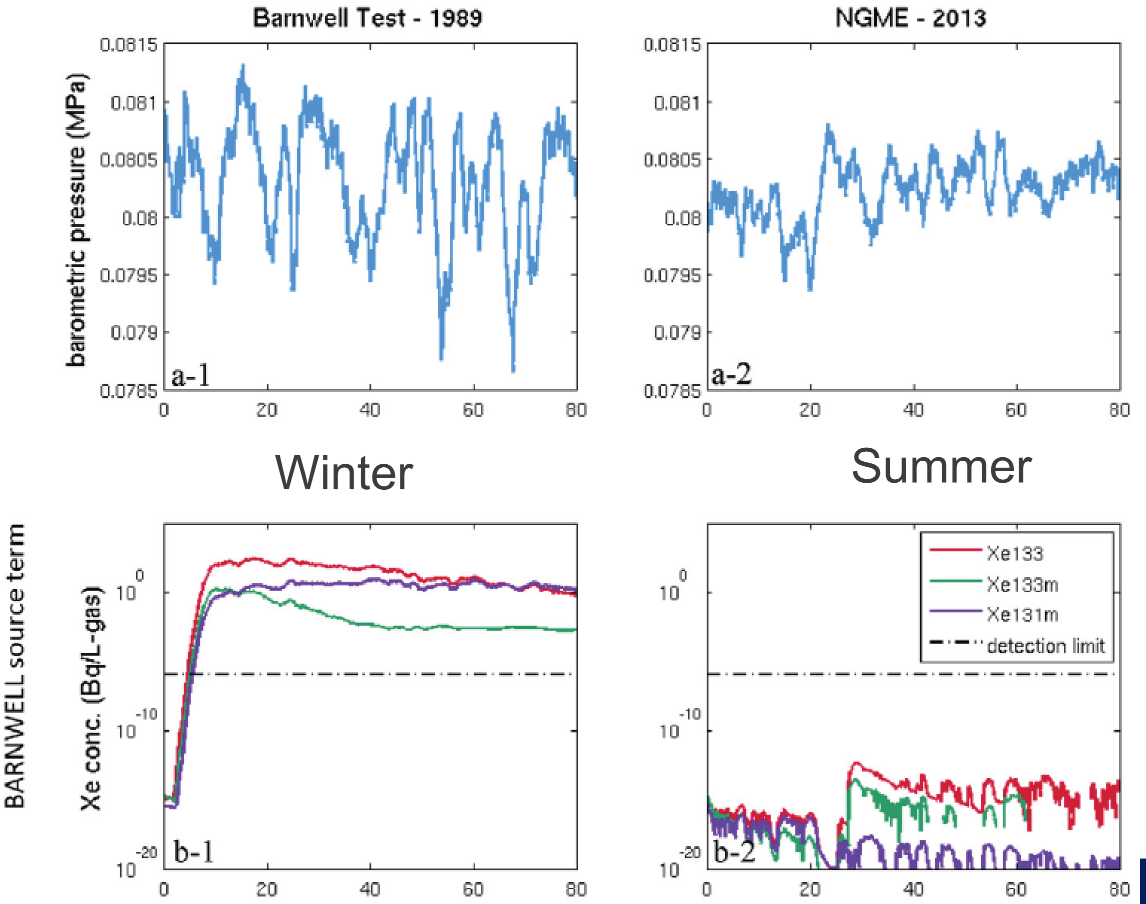



Gas releases from some historic UNEs can be explained by pumping due to barometric pressure changes pulling gases to the surface



# Source to Sensor Radioactive Gas Migration
# Season of the year really matters!!

Winter storms are more efficient at pulling gas from the subsurface

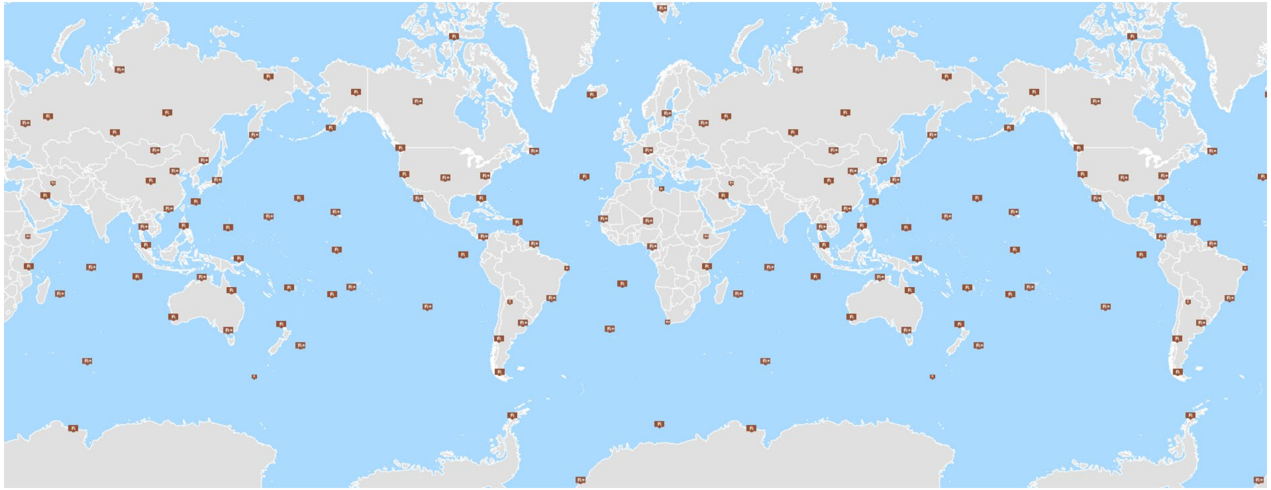



Bourret et al., 2019, Vadose Zone Journal

# Nuclear Nonproliferation Monitoring

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) bans nuclear explosions everywhere: on the Earth's surface, in the atmosphere, underwater and underground.

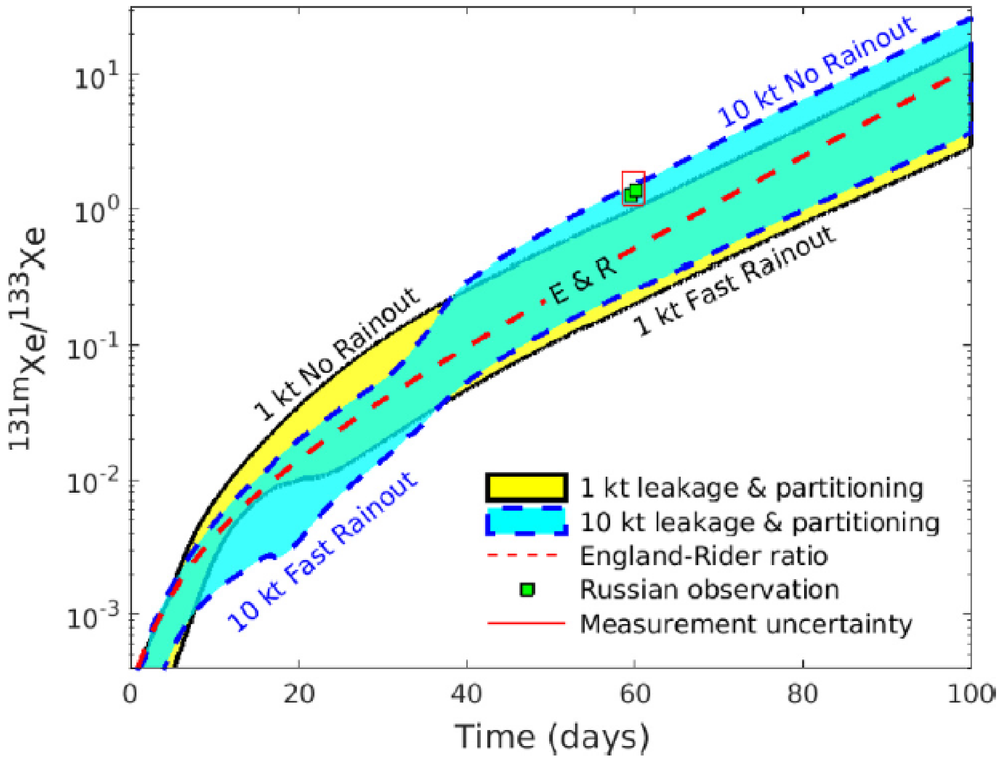
**Radionuclide**: 80 stations are planned to measure the atmosphere for radioactive particles; 40 of them will also pick up noble gas. Only these measurements can give a clear indication as to whether an explosion detected by other methods was nuclear.



# Source to Sensor Radioactive Gas Migration
# Atmospheric detections

Xenon ratio plots help to explain measured data

Russian measurements of the isotopic ratio resulting from the 2013 DPRK UNE are interpreted as a sample released from the cavity






Carrigan et al., 2020, Journal of Environmental Radioactivity

# Acknowledgements

The work presented here spans many dozens of researchers at both Los Alamos and other US National Laboratories

# Questions

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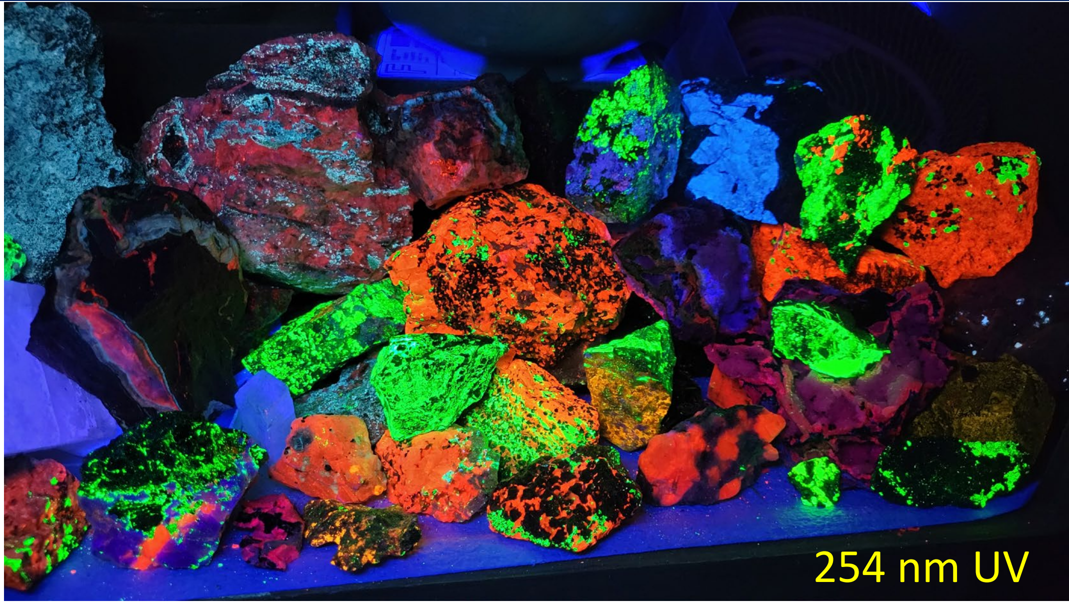
Computational Earth Science EES-16
Earth and Environmental Sciences
Los Alamos National Laboratory




https://www.lanl.gov/expertise/profiles/view/philip-stauffer

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