SnT 2023
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
HOFBURG PALACE - Vienna and Online
19 TO 23 JUNE

Radioxenon Isotopes, Ratios, and Discrimination: Challenges and Opportunities

James Ely, Paul Eslinger, James Hayes, Harry Miley, Ramesh Sarathi
Pacific Northwest National Laboratory

Pacific Northwest NATIONAL LABORATORY

INTRODUCTION

Radioxenon in a four-isotope ratio plot used to discriminate backgrounds and nuclear explosions.

What is the potential to measure all four radioxenons from an explosion?

METHODS/DATA

Simulate underground explosion xenon isotope activity production from prompt and delayed releases. Transport out to distances, including decay, and evaluate potential to detect with current capabilities.

START

RESULTS

Xe-131m has low independent production, higher cumulative. Prompt releases challenging to detect at larger distances. Xe-135 has short half-life, decays quickly.
Small time overlap of these two isotopes for detection.

CONCLUSION

Detecting all four radioxenons from an underground explosion at regional distances is challenging at lower yields and release fractions. Other options (2 or 3 isotope ratio plots, additional isotopes) more viable for discrimination.

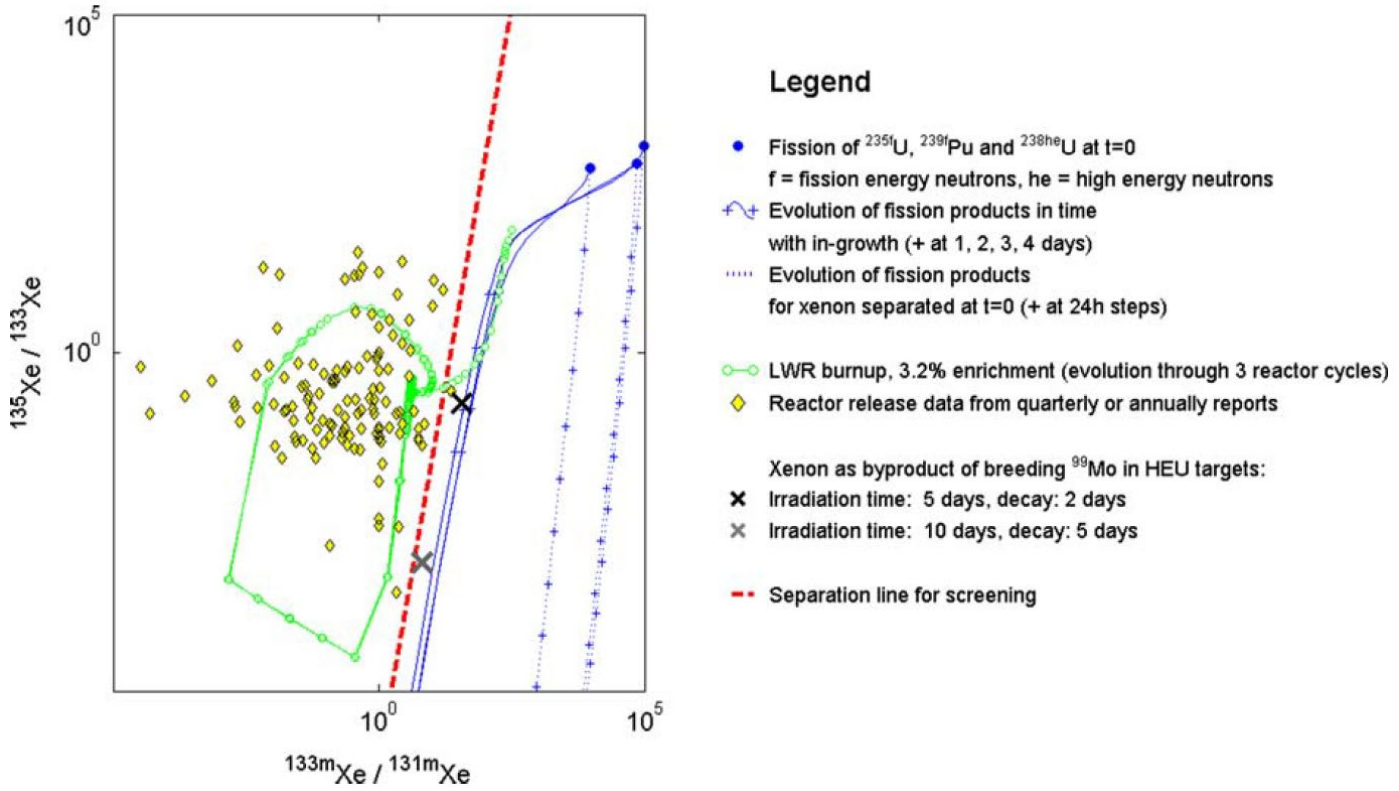
PNNL-SA-186111

Please do not use this space, a QR code will be automatically overlayed

P2.4-343

Introduction: Radioxenon Backgrounds and Discrimination

- Radioxenon backgrounds from medical isotope production (MIP) facilities and nuclear reactors are observed frequently and are increasing with new facilities
- These are the same radioxenon isotopes from a nuclear explosion and are difficult to discriminate based on detection and magnitude of activity
- Atmospheric transport can help, but the field of regard can often cover multiple locations (reactors and MIPs) and difficult to determine if a nuclear explosion or just background.
- Multiple radioxenon isotope ratio plots have been demonstrated to provide discrimination power from reactors
- MIP production is more challenging to discriminate (X in plot)
- Four-isotopes plots have the most discrimination power, fewer isotopes provide less discrimination.
- Question: how likely is it to detect all four isotopes at regional distances from prompt and delayed emission from an underground nuclear explosion?

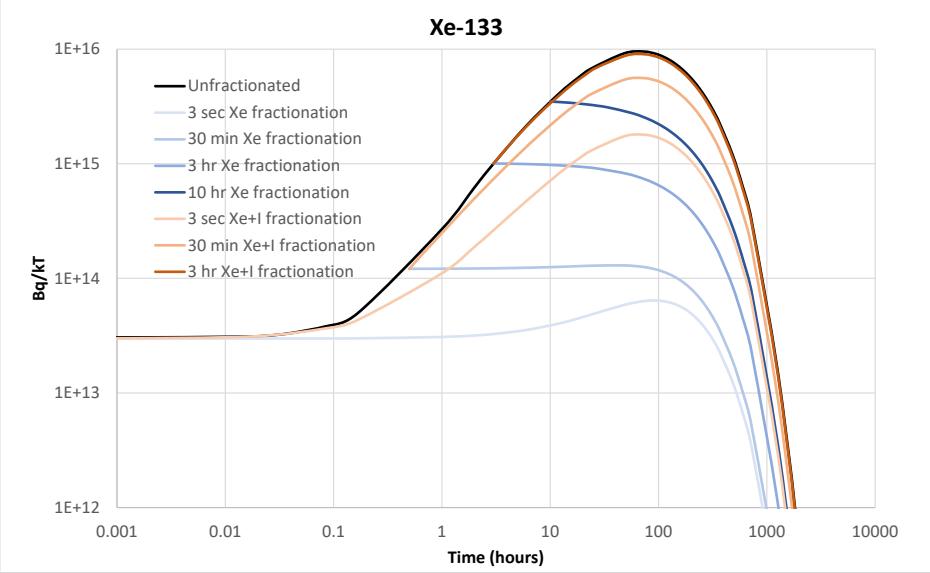


Kalinowski, M.B., *et al*. “Discrimination of nuclear explosions against civilian sources based on atmospheric xenon isotopic activity ratios.” Pure Appl. Geophys. 167 (4–5), 517–539. 2010.

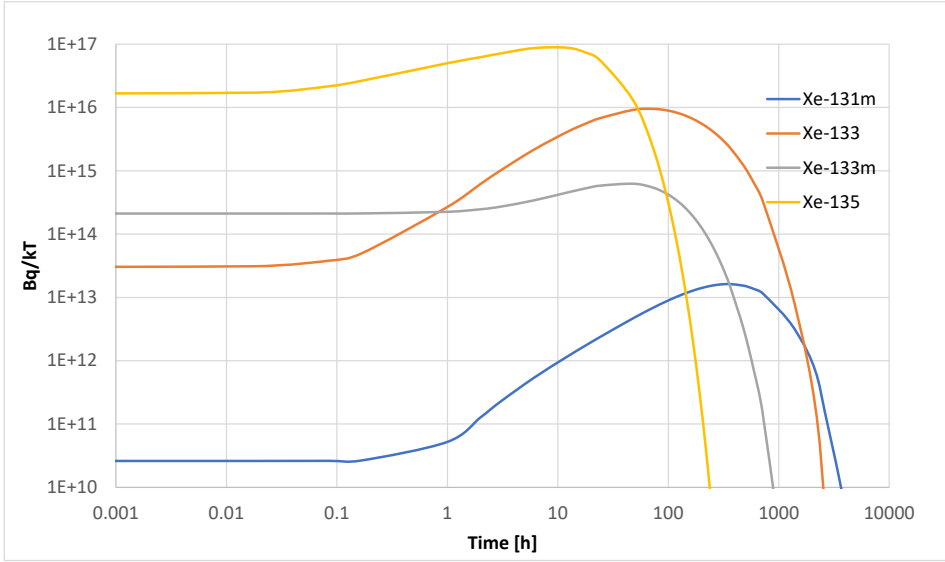
INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Objective: Estimating Detectable Activity from an Underground Nuclear Explosion

- Understanding the radioxenon activity concentrations as a function of distance from an underground nuclear explosion
- Explore simulated fission production as a function of release (and fractionation) time for various release scenarios
- Combine with atmospheric transport to estimate activity concertation as a function of distance



Simulated activities for different releases for ^{133}Xe including unfractionated (everything), xenon, or xenon plus iodine releases



Simulated activities for the four radioxenon isotopes from a one-kiloton nuclear explosion as a function of time (cumulative activity).

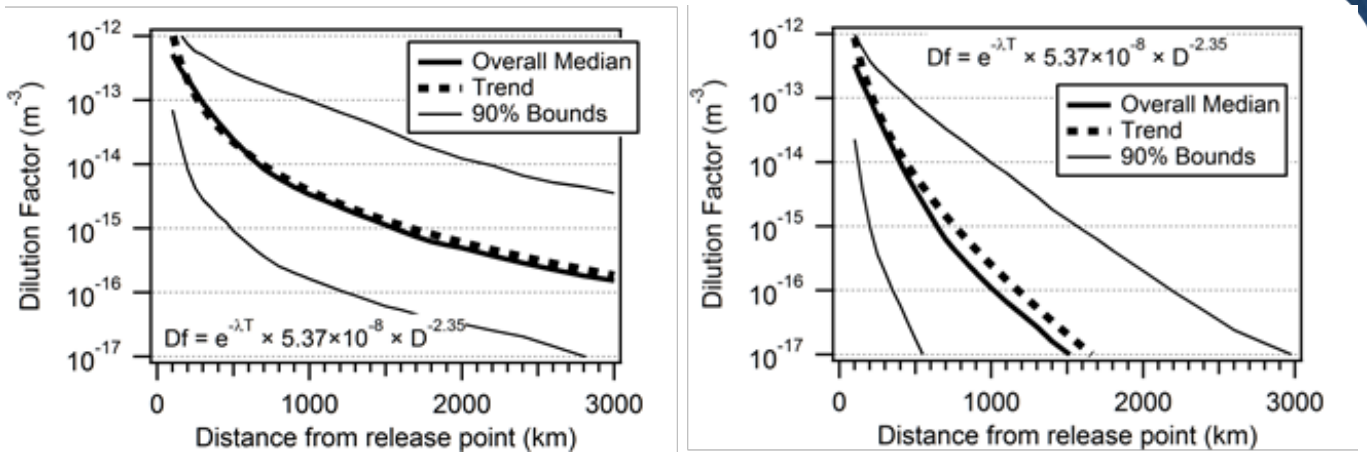
INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Please do not use this space, a QR code will be automatically overlayed

Methods: Assumptions and Approach

Assumptions for Simulated Data

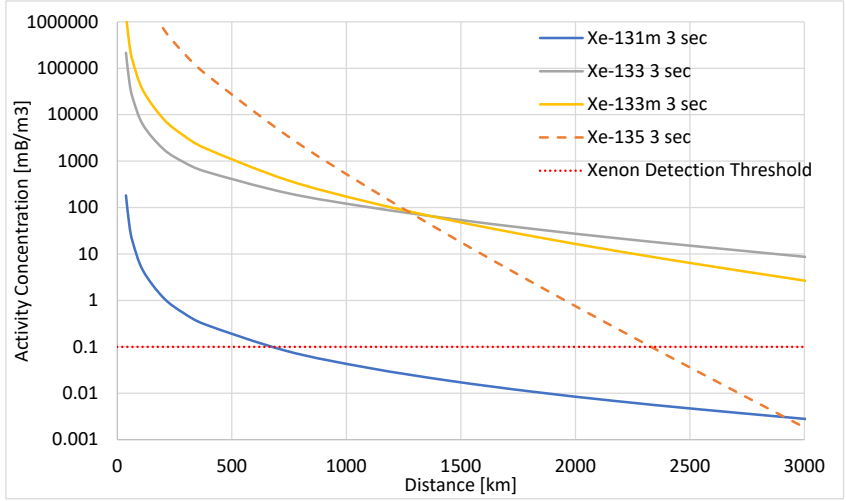
- One-kiloton yield (plutonium) simulated nuclear explosion
- 0.1% release of produced isotope
- Detection sensitivity of 0.1 mBq/m3
  - Above three assumptions can be scaled
- Single release time (puff type release)
- Xenon gas release



Comparison of dilution factors in modeled ^{133}Xe (left) and ^{135}Xe (right) as a function of distance. Eslinger, P.W., T.W. Bowyer, I.M. Cameron, J.C. Hayes, H.S. Miley, "Atmospheric plume progression as a function of time and distance from the release point for radioactive isotopes." J. Environ. Radioactivity, 148, 123-129. 2015.

Approach

- Fission production simulated; cumulative growth until release time
- At release time, xenon is separated (fractionated) from parent isotopes
- Iodine is also released in some simulations
- At each time step, dilution factor calculated and converted into distance, using the mean dilution factor
- Focus on ^{131m}Xe and ^{135}Xe; other isotopes in the middle



Simulated activity concentration versus distance at 3 second release time

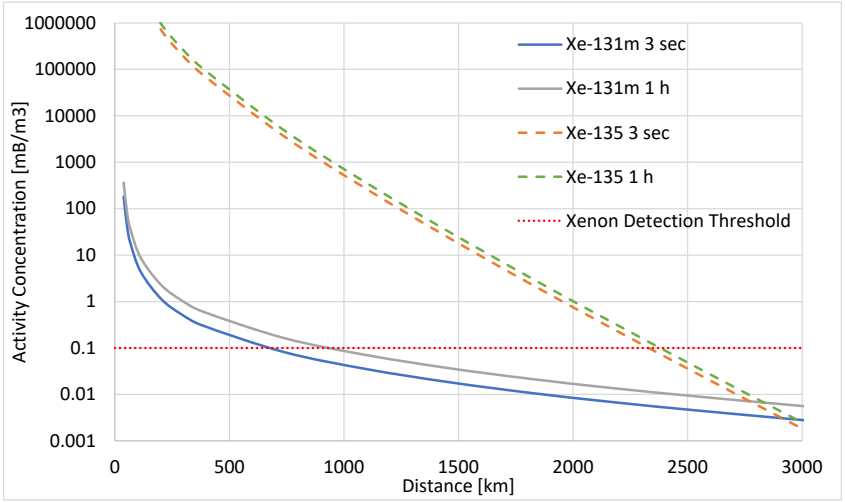
INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Results: ^{131m}Xe and ^{135}Xe Simulations

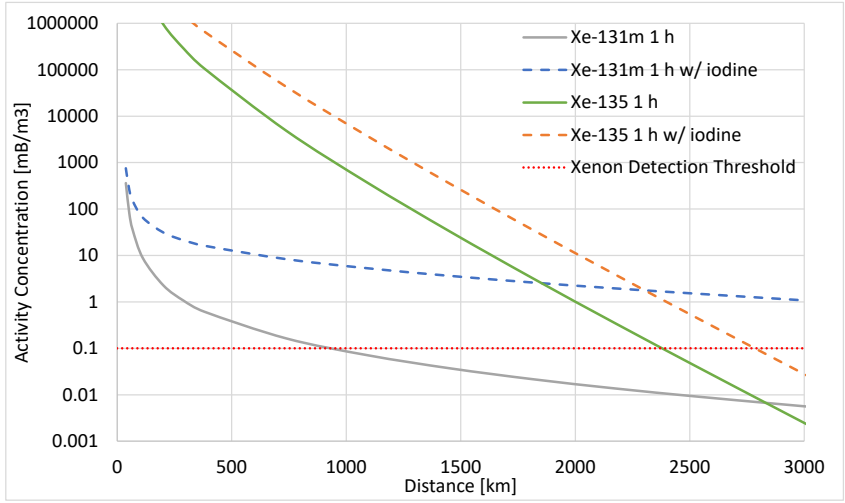
For the studied scenario (1 kt; 0.1% xenon release)

- A) Prompt release time
  - ^{131m}Xe detectable out to ~1000 km (release at 1 h)
- B) Co-releasing precursors helps extend detectable distance
  - Likely only volatile at early times
- C) Maximum distance ~2500 km at optimal release time of 10 h

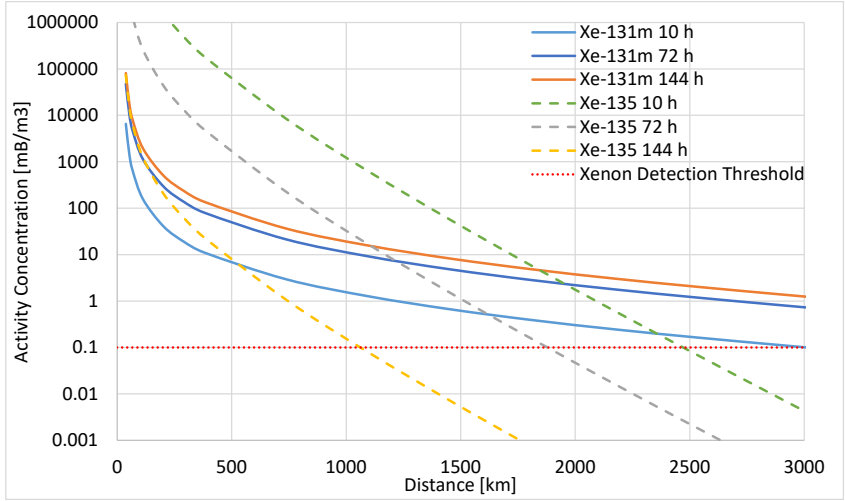
Further distance detection requires increased release amount or yield



A) Prompt release times for ^{131m}Xe and ^{135}Xe



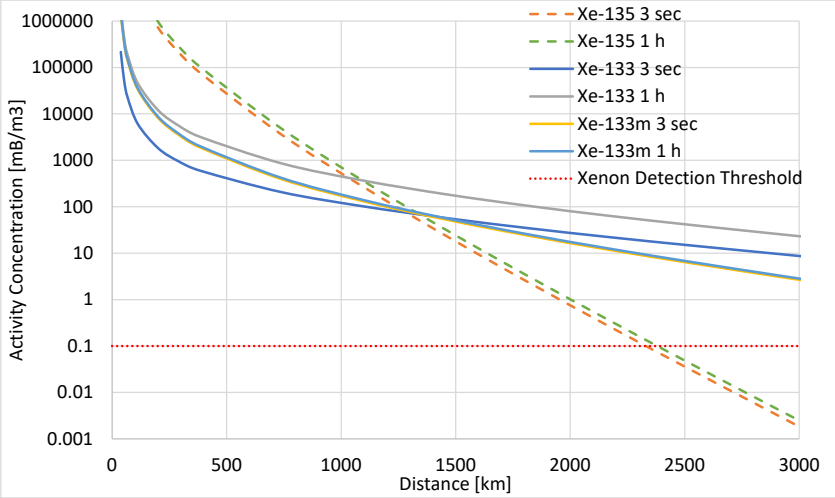
B) Prompt release times for ^{131m}Xe and ^{135}Xe; co-release of iodine



C) Delayed release times for ^{131m}Xe and ^{135}Xe

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Results: Three isotopes without ^{131m}Xe



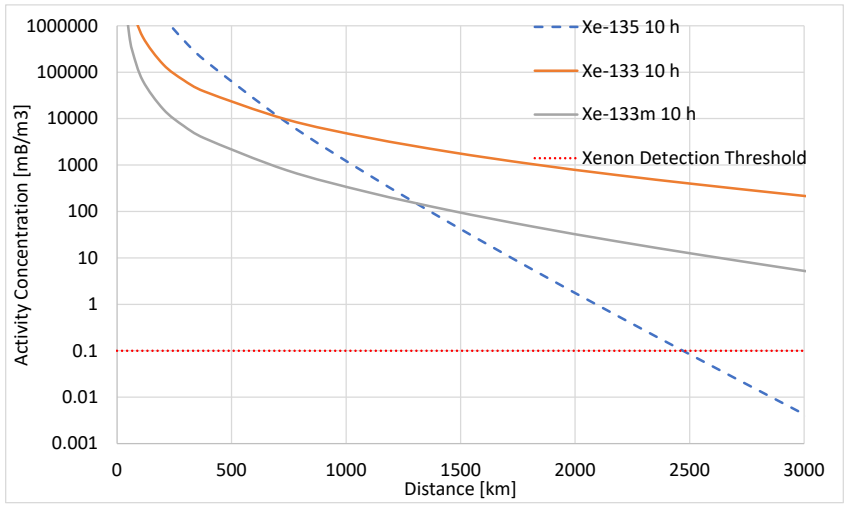
A) Prompt release times for ^{133m}Xe, ^{133}Xe, and ^{135}Xe

Three isotopes (no ^{131m}Xe) provides greater detection distances

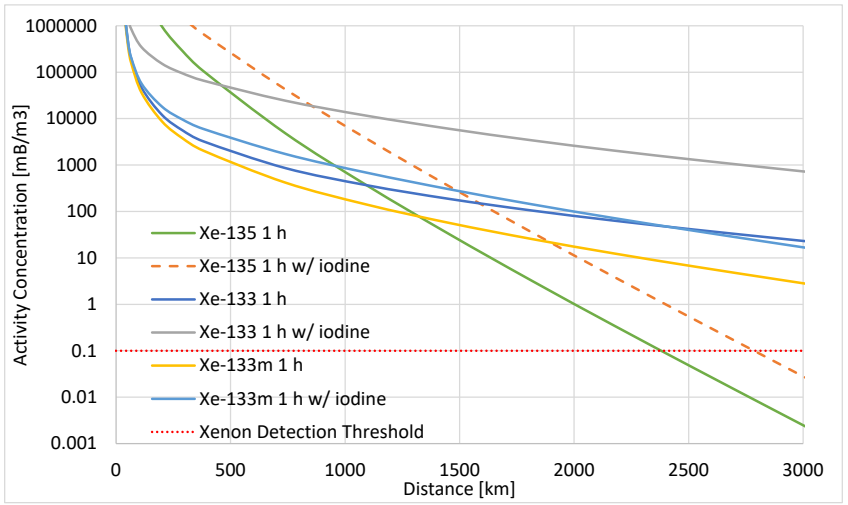
- A) 1 and 3 second prompt releases all 3 xenon isotopes detectable out to ~2300 km, limited by ^{135}Xe
- B) 10 hours increases the distance to ~2500 km
- C) 3-hour release with co-release increases out to ~2800 km

Three isotope ratio plots do not have the discrimination power of four, approaches beyond ratio plots may provide additional discrimination

- Algorithms: Eslinger, P.W., J.D. Lowrey, H.S. Miley, W.S. Rosenthal, B.T. Schrom, “Source type estimation using noble gas samples.” J. Environ. Radioactivity, 225, 106439 (2020). https://doi.org/10.1016/j.jenvrad.2020.106439
- Additional isotopes, for example ^{37}Ar



B) 10 release times for ^{133m}Xe, ^{133}Xe, and ^{135}Xe



C) 1 h release time for ^{133m}Xe, ^{133}Xe, and ^{135}Xe; iodine co-release

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Please do not use this space, a QR code will be automatically overlayed

Summary and Conclusions

Summary

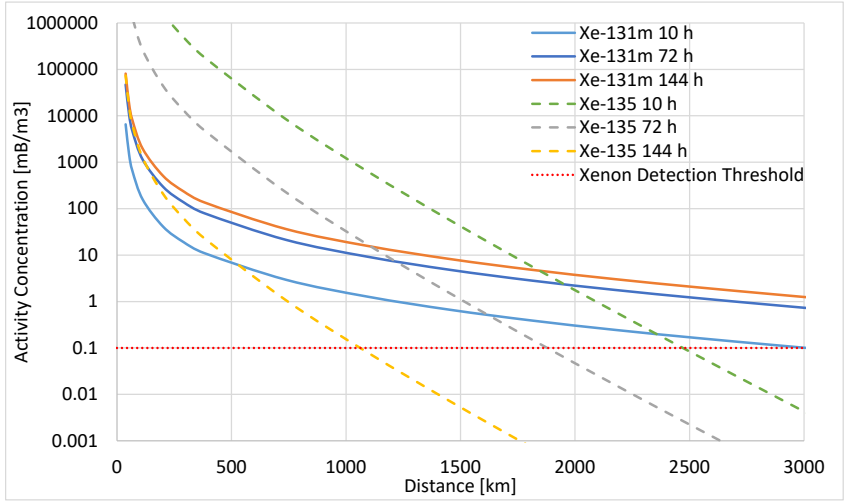
Combining radioxenon produced activity with atmospheric transport modeling provides a more direct understanding of the detectability as a function of distance

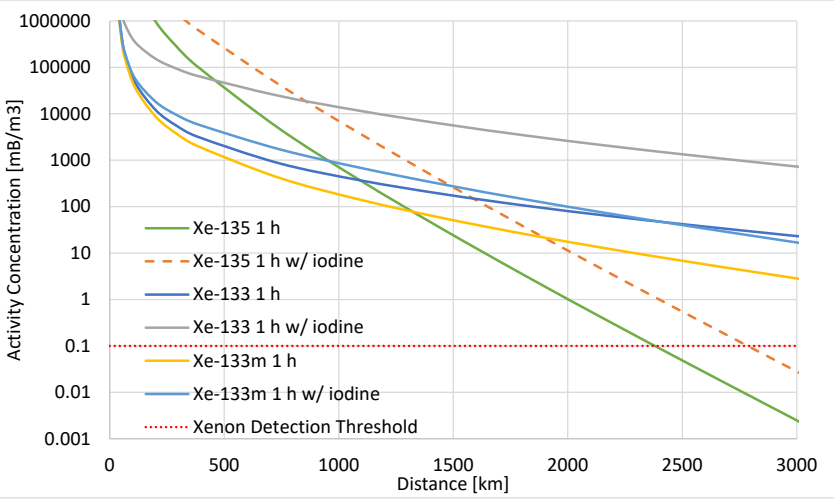
- ^{131m}Xe has low independent yield, comparatively less activity in prompt releases
- ^{135}Xe decays quickly, delayed releases are less detectable

Specific scenario explored
- 1 kt yield, 0.1% release, 0.1 mBq/m3 detection threshold

Four isotope detection for specific scenario
- Prompt release: detectable to ~1000 km (> 3000 km with iodine co-release)
- Optimal detection at ~10 h release time out to ~2500 km

Three isotope (without ^{131m}Xe)
- Prompt release: detectable to ~2300 km
- Optimal detection at ~1 hour release time (with co-release) out to ~2700 km





Conclusions

Four isotopes may not be detectable in many cases and distances
- For prompt releases longer distances (>1000 km) may require:
  - Higher yield (>1 kT); higher xenon release (>0.1%), specific release time (-5 days), or co-releases of iodine

Three isotopes (without ^{131m}Xe) detectable at much further distances for releases
- 3-isotope plots have less discrimination power
- Other approaches needed - other algorithms or additional isotopes to provide discrimination

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Please do not use this space, a QR code will be automatically overlayed

References

Kalinowski, M.B., *et al*. “Discrimination of nuclear explosions against civilian sources based on atmospheric xenon isotopic activity ratios.” Pure Appl. Geophys. 167 (4–5), 517–539. 2010.

Eslinger, P.W., T.W. Bowyer, I.M. Cameron, J.C. Hayes, H.S. Miley, “Atmospheric plume progression as a function of time and distance from the release point for radioactive isotopes.” J. Environ. Radioactivity, 148, 123-129. 2015.

Eslinger, P.W., J.D. Lowrey, H.S. Miley, W.S. Rosenthal, B.T. Schrom, “Source type estimation using noble gas samples.” J. Environ. Radioactivity, 225, 106439 (2020). https://doi.org/10.1016/j.jenvrad.2020.106439

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

This Low Yield Nuclear Monitoring (LYNM) research was funded by the National Nuclear Security Administration, Defense Nuclear Nonproliferation Research and Development (NNSA DNN R&D). The authors acknowledge important interdisciplinary collaboration with scientists and engineers from LANL, LLNL, NNSS, PNNL, and SNL.