Combining Aerosol and Noble Gas Samples in Source-Location Analyses

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Motivation

- Airborne isotopic signatures of nuclear explosions can be obscured by civilian sources:
  - Nuclear power plants
  - Fission-based medical isotope production facilities
- A Bayesian model was recently introduced to use multiple xenon isotopes in a source-term analysis *(doi:10.1016/j.jenvrad.2019.04.004)*
  - Explicitly uses information on the release type (reactor, etc.)
- We extend the model to jointly use radioxenon and aerosol samples
- The new model improves our ability to discriminate between nuclear testing and civilian activities when both radioxenon and radioactive aerosols are sampled in the air

Bayesian Source-Estimation Model

Model Characteristics

- Source parameters: location, release time and duration, magnitude by isotope, release type
- Release type is modeled by isotopic ratios at the time of release
- Different samplers can have different collection periods (i.e., 6 or 12 h for xenon, 24 h for iodine)

Performance Measures

- Distance from release point to the estimated release point
- Probability that the source is within 100 km of the release point
- Probability of the type of release (nuclear explosion, medical isotope production facility, nuclear power plant)

The likelihood function uses data (*D*), subject matter expert information (*I*), and predicted concentrations (*C*).

$$P\left(D \middle| \vec{M}, I\right) \propto \exp\left[-\frac{1}{2}\sum_{i}\frac{\left(D_i - C_i(\vec{M})\right)^2}{\sigma_{D,i}^2 + \sigma_{C,i}^2}\right]$$

Synthetic Data Set for Analysis

Release Types

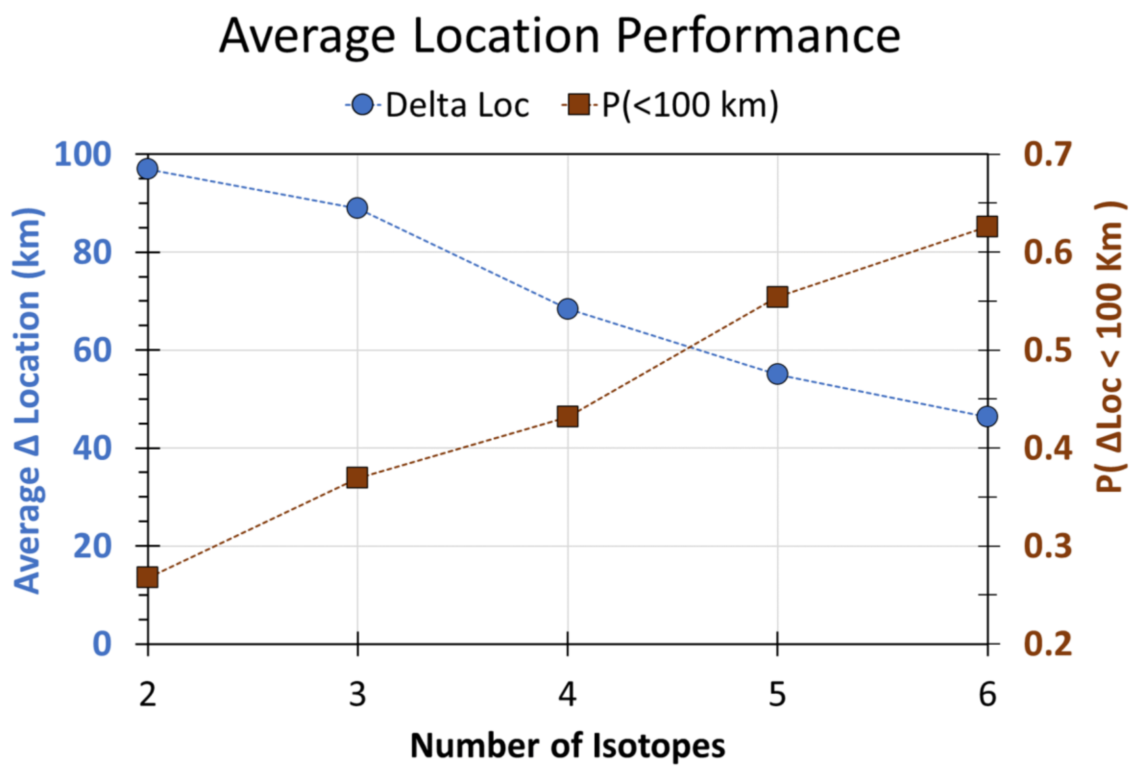
- 10 reactors (historical data)
- 15 modeled MIPF releases (low iodine releases)
- 15 modeled MIPF releases (iodine filter leak)
- 72 types using ^{235}U and ^{239}Pu fission (England & Ryder, 1994).
  - 6 base types
  - Holdups of 0, 1, 2, 3, 4, 5, 6, 7, 8, 12, 16, and 24 h.

Synthetic Releases

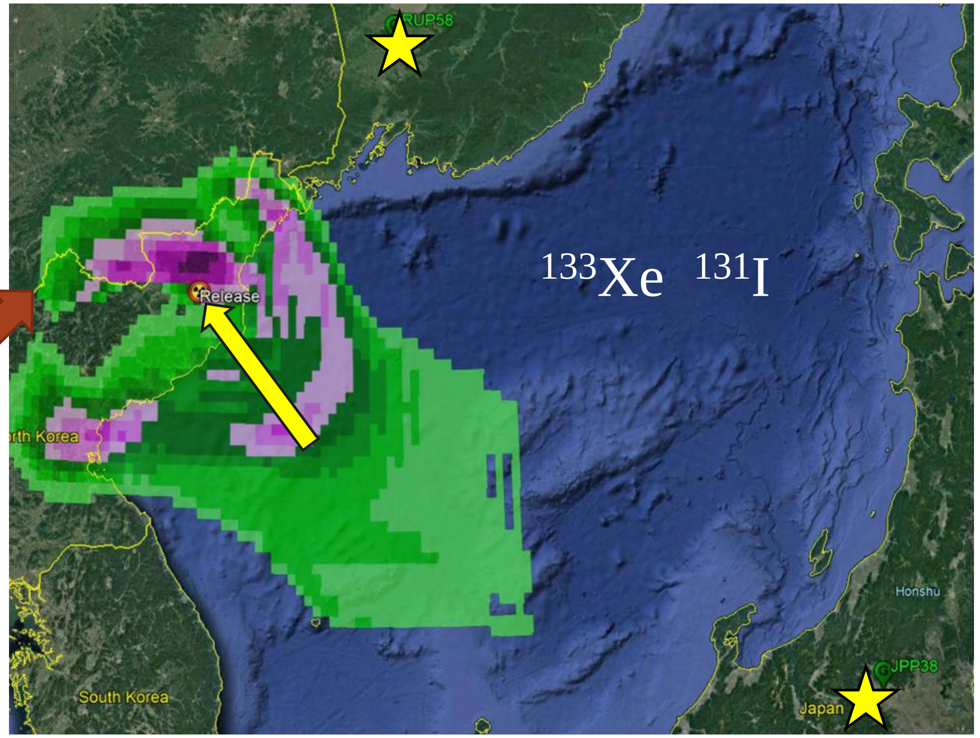
- Extends the data set in Haas, et. al (10.1016/j.jenvrad.2017.08.005)
- ^{235}U fission with a 4 h holdup time
- Xenon: **^{131m}Xe, ^{133}Xe, ^{135}Xe**
- Iodine: **^{131}I, ^{133}I, ^{135}I**
- Location: DPRK test site
- Release times: Selected so plumes cross 2 IMS sampling locations
- Samplers:
  - JPP38 - Takasaki, Japan
  - RUP58 - Ussuriysk, Russian Federation

Results - Location

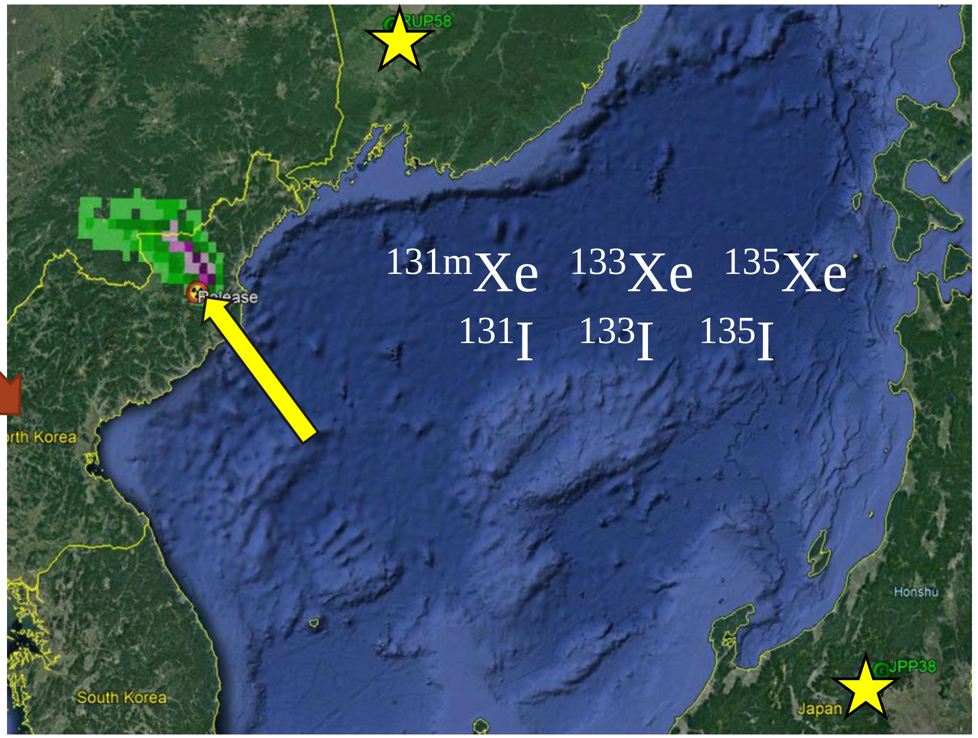
- Model provides point estimate and probability density for the release location
- Location accuracy improves with the number of detected isotopes



The largest improvement in location probability over the five cases when 2 or 6 isotopes are used in the analysis.



Posterior Location Probability

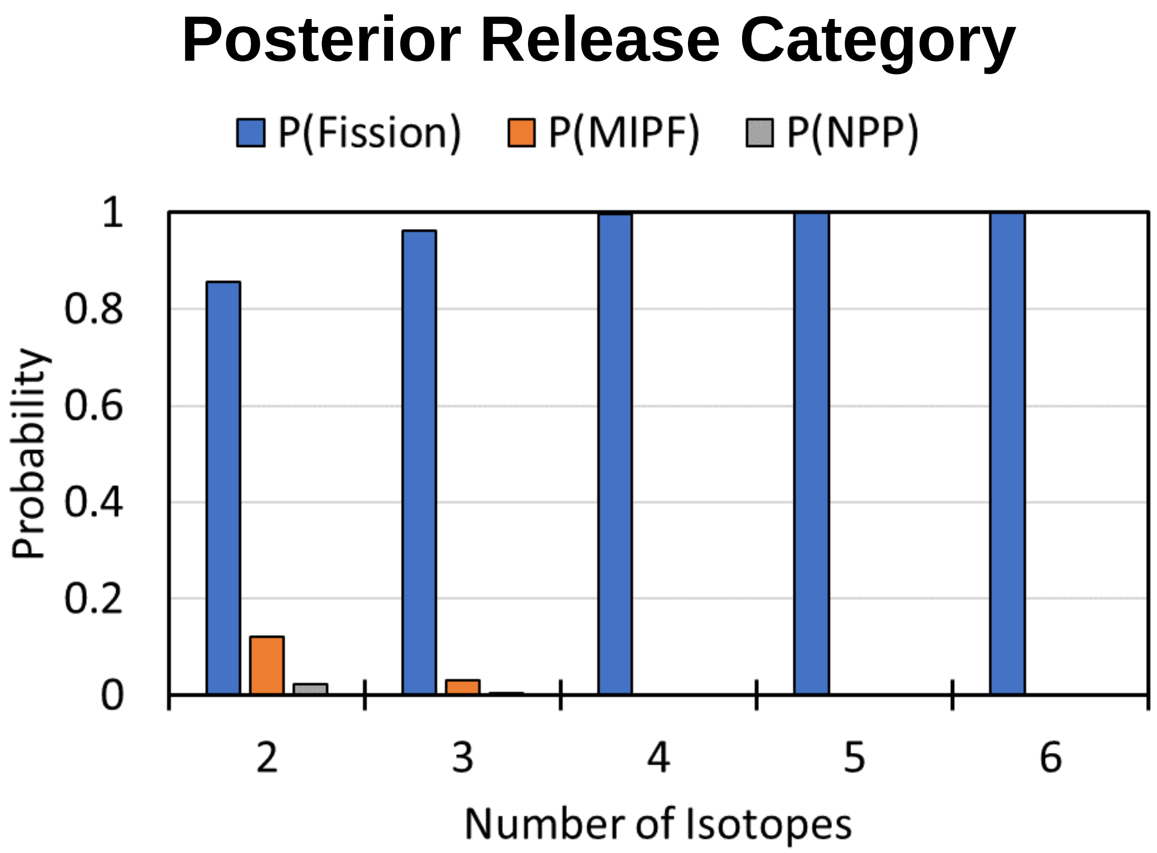


Results – Release Type

- Estimation cases were run with all possible combinations of 2 or more isotopes.
  - ^{133}Xe was always included
- Results are summarized in three categories
  - Fission event (explosion)
  - Nuclear power plant (NPP)
  - Medical isotope production facility (MIPF)

Performance if only have 2 isotopes:

- Worst (0.587) is ^{133}Xe with ^{133m}Xe
- Best (>0.994) is ^{133}Xe with ^{135}Xe or ^{133}I

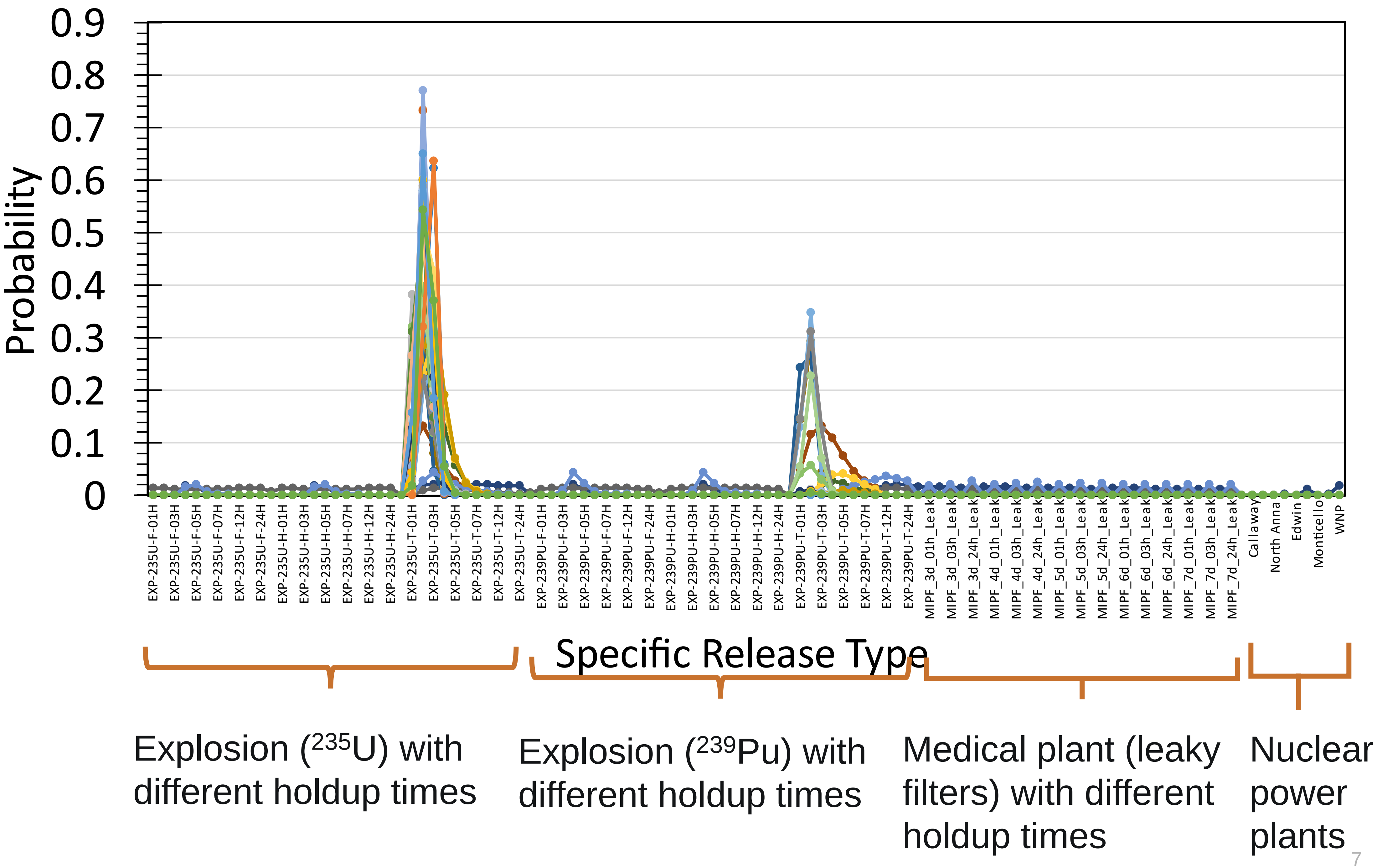


Performance if have 3 isotopes:

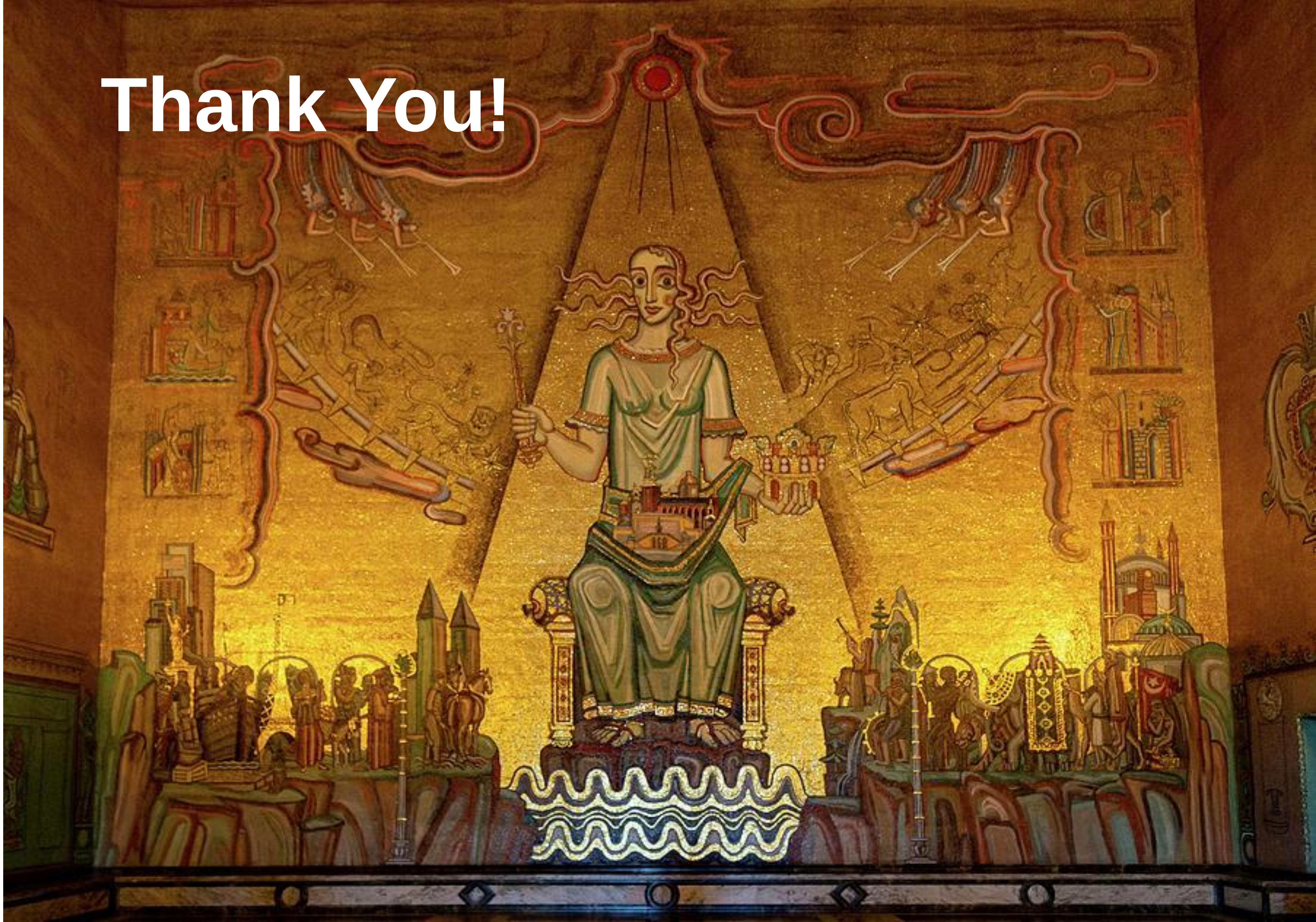
- Worst (0.731) is ^{133}Xe with ^{133m}Xe and ^{131}I
- Then (0.949) is ^{133}Xe with ^{133m}Xe and ^{135}I
- Then (0.966) is ^{133}Xe with ^{131}I and ^{135}I
- Rest are 0.995 or higher

Results – Release Type (cont'd)

The highest probabilities of the release type for the individual cases are for ^{235}U near 4 h separation time, lower probabilities for ^{239}Pu near 4 h separation time. This generally agrees with the synthetic data (^{235}U explosion with a 4 h separation time).



Thank You!



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Abstract: Recently, Eslinger et al. (2019) introduced a new Bayesian algorithm that makes discrimination between possible types of releases (e.g., nuclear explosion, nuclear power plant, or medical isotope production facility) an integral part of a source-location analysis for samples that contain multiple xenon isotopes. The method can be applied to data sets containing both aerosol and noble gas samples that are measured with different frequencies. Using synthetic data, the method is applied to five estimation cases with IMS radionuclide station separation distances where each release plume crosses two sampling stations. Releases for three xenon isotopes, ^{133m}Xe, ^{133}Xe, and ^{135}Xe, and three iodine isotopes, ^{131}I, ^{133}I, and ^{135}I, are simulated for ^{235}U fission. The average location discrepancy (estimated release location versus the simulated release location) decreases from 100 km (with all pairs of isotopes) to 45 km with six detected isotopes. The posterior probability of selecting the right class of release type increases with the number of detected isotopes and approaches 1 when four or more isotopes are detected.

Eslinger, P.W., Lowrey, J.D., Miley, H.S., Rosenthal, W.S., Schrom, B.T., 2019. Source term estimation using multiple xenon isotopes in atmospheric samples. *J. Environ. Radioact. 204, 111-116. doi:10.1016/j.jenvrad.2019.04.004*

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Isotopes Present						Performance		
Xe133	Xe133m	Xe135	I131	I133	I135	Δ Dis.	P(100 km)	P(EXP)
X	X					103	0.161	0.587
X		X				100	0.322	0.998
X			X			86	0.207	0.762
X				X		102	0.350	0.995
X					X	94	0.297	0.944
X	X	X				76	0.434	0.999
X	X		X			100	0.241	0.731
X	X			X		92	0.341	0.995
X	X				X	94	0.296	0.949
X		X	X			87	0.444	0.998
X		X		X		73	0.434	1.000
X		X			X	109	0.370	1.000
X			X	X		99	0.400	0.996
X			X		X	87	0.288	0.966
X				X	X	72	0.447	0.999
X	X	X	X			73	0.462	0.998
X	X	X		X		61	0.392	1.000
X	X	X			X	90	0.438	1.000
X	X		X	X		86	0.381	0.996
X	X		X		X	56	0.308	0.977
X	X			X	X	57	0.452	0.999
X		X	X	X		46	0.515	1.000
X		X	X		X	83	0.371	1.000
X		X		X	X	60	0.543	1.000
X			X	X	X	73	0.457	1.000
X	X	X	X	X		46	0.536	1.000
X	X	X	X		X	74	0.476	1.000
X	X	X		X	X	47	0.586	1.000
X	X		X	X	X	58	0.553	1.000
X		X	X	X	X	50	0.619	1.000
X	X	X	X	X	X	46	0.626	1.000

Performance of P(Explosion) if only have 2 isotopes:

- Worst (0.587) is ^{133}Xe with ^{133m}Xe
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Performance of P(Explosion) if have 3 isotopes:

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