Impacts on Characterization of CTBT-relevant Nuclear Events using Isotopic Activity Ratios caused by the Radioxenon Background at IMS Stations

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wosmip Workshop on Signatures of Man-made Isotope Production
WOSMIP IX | December 4 - 7, 2023 | InterContinental Santiago Hotels & Resorts | Av. Vitacura 2885, 7550023 Las Condes, Region Metropolitana, Chile | Pacific Northwest

CTBTO PREPARATORY COMMISSION

Abstract

Radionuclide stations in the International Monitoring System (IMS) network routinely collect air samples and assess activity concentrations. Activities collected in samples are often caused by emissions from nuclear facilities, but they could also indicate a noble gas release from an underground nuclear explosion. A discrimination can be done by estimating and analysing activity ratios of CTBT-relevant radioxenon isotopes under assumed scenarios.

One of the issues in the isotopic ratio estimation is whether the contribution of the radioxenon background at IMS stations needs to be subtracted. This work will investigate the impact of the radioxenon background subtraction on the discrimination of a nuclear release event.

Simulations are performed with atmospheric transport modelling to determine the concentrations originating from hypothetical radioxenon releases of pre-defined underground nuclear explosions distributed over a global semi-regular grid at different times of the day. The latter are studied independently and in the form of synthetic concentrations on top of real observations to account for the radioxenon background.

The ratios of detected radioxenon isotopes are compared between the real IMS observations (typical radioxenon background from 2014), simulated concentrations from hypothetical nuclear explosion sources (pure signals without radioxenon background) and synthetic ones.

Introduction

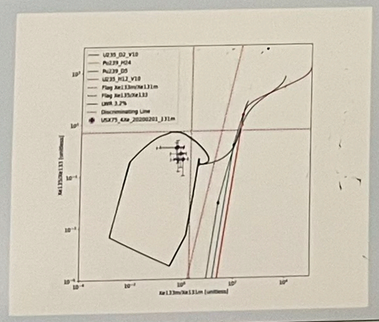
- Radioxenon background at IMS stations might mask the signals from a release of nuclear explosion.
- Concentrations originating from hypothetical releases of nuclear explosion are simulated by atmospheric transport modelling.
- Xenon activity ratios are compared between real IMS observations, simulated concentrations of nuclear explosion and synthetic ones.
- The purpose is to investigate whether subtraction of radioxenon background is necessary for event discrimination.

Event screening and impact by radioxenon background

Screening a nuclear explosion release from nuclear facility releases:

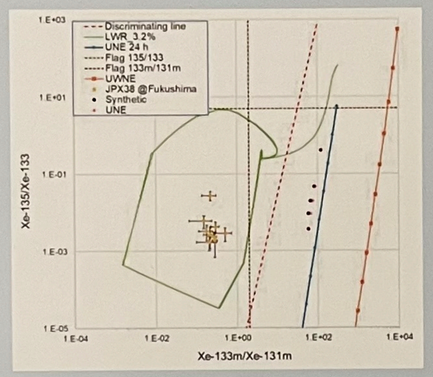
- Estimation of isotopic activity ratios
  - ✓IMS measured activity concentrations
  - ✓Radioxenon background contribution
    - ✓Estimated based on routine IMS measurements
    - ✓Subtracted?
- Screening methods
  - ✓Coverage interval
  - ✓Z-test
  - ✓ML method

Radioxenon background impact:
- Estimation using IMS observation minus atmospheric transport simulations
- Impacts on isotopic ratios and event screening



Four Radioxenon plot (4-Xenon-Plot): Impact of UNE signals > LC

- Data set of 1st Nuclear Explosion Signal Screening Open Inter-Comparison Exercise 2021 is used in this investigation.
  - Real IMS observations,
  - Simulated concentrations of nuclear explosions and
  - Synthetic concentrations, i.e., simulated concentrations of nuclear explosions added on top of IMS observations
- All four radioxenon detected in both synthetic and UNE signals.
  - Only 5 samples (right figure) with IMS activity concentrations < 0.1 mBq/m3.
  - All points locate in the nuclear explosion domain, close to the evolution curve of UNE.
  - Slight differences between IMS observations and Synthetic signals



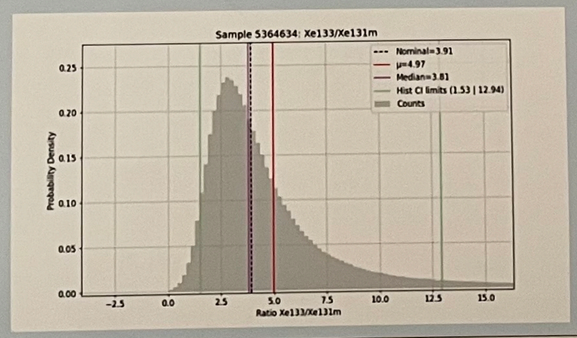
Event screening based on IMS detection(s)

Identifying nuclear explosion source from the radioxenon background:

- *Hypotheses test on nuclear explosion source*
  - ✓*Based on* isotopic ratios detected in the sample, related to *activity concentrations estimated by radioxenon detections at IMS stations*
  - ✓Null hypothesis H_0: radioxenon background
  - ✓Alternative H_1: nuclear explosion source

Screening thresholds
- Limits of the coverage interval with 90% (false positive/negative 5%)
- Based on UNE release scenarios by 5 days, early releases

	True radioxenon background	True nuclear explosion
Do not reject H_0	Correct radioxenon background	False negative
Reject H_0	False positive	Correct nuclear explosion

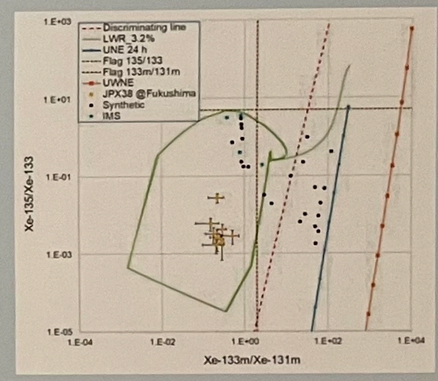


Four Radioxenon plot (4-Xenon-Plot): Impact of UNE signals < LC

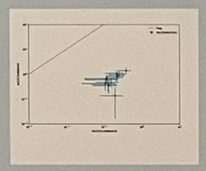
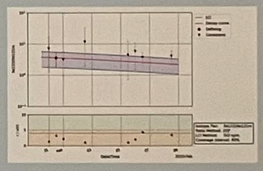
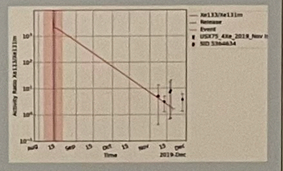
- All four radioxenon detected in synthetic signals.
  - Data points of 23 samples scatter in both domain, crossing the discrimination line.
  - Detections in synthetic signals (> LC)
    - Case 1 and Case 2
- All four radioxenon detected in IMS observations.
  - Radioxenon background
  - Data points of 12 samples (overlapped) locate in the domain of nuclear facility releases.

Case 1:
- Radioxenon background < LC plus
- UNE signal > LC,
- Resulting in a synthetic concentration > LC.

Case 2:
- Radioxenon background < LC plus
- UNE signal < LC,
- Resulting in a synthetic concentration > LC.



From IMS observations to event characterization by isotopic activity ratios

CONCLUSIONS

- Event characterization is performed using the four-xenon plot, 2D plots of activity concentrations and evolution plots of isotopic ratios of paired isotopes, by the coverage interval with a given probability.
- It is necessary to consider the impact on event screening caused by the radioxenon background at IMS stations.

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