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Nuclear event timing with three-dimensional spatial analysis of radioxenon isotopic activity ratios

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INTRODUCTION AND MAIN RESULTS

3-D analysis would be a promising tool for nuclear explosion zero time determination, with a condition that at least three radioxenon isotopes are detected.

A precision less that 1 hour can be achieved if an immediate (less than 1 hour) release occurs following an underground nuclear test

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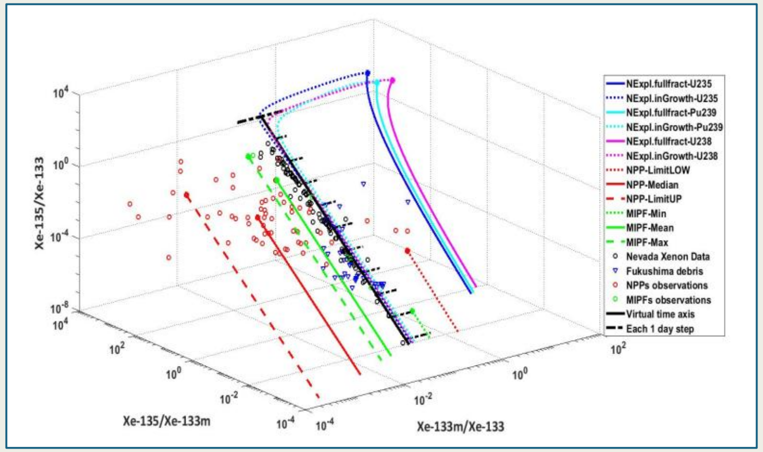
Introduction

The three-dimensional (3D) spatial analysis of radioxenon isotopic activity ratios is a powerful approach for the determination of the time of a nuclear event. In contrast to the 2D planar analysis, this method requires at least a triple detection from the same sample among the four CTBT-relevant radioxenon isotopes, which are ^{131m}Xe, ^{133m}Xe, ^{133}Xe, and ^{135}Xe. One method of the 3D spatial approach applies a virtual time axis. This starts from an imaginary zero point and is used for determining the age by taking decay into consideration. For any measurement entered in the 3D plot, time zero can be determined by projecting it on this virtual axis, if it would be caused by a nuclear explosion. The valid range of the virtual time axis is determined by requiring the angle alpha ≤ 0.1° and for a relative age error ≤ 10%. A more sophisticated method can avoid the age error and be applicable for the whole age range. This uses the trajectories of nuclear explosion scenarios in 3D space rather than a virtual time axis. The age of any data point is determined by a perpendicular projection on the nuclear explosion trajectory.



3-D analysis: methodology

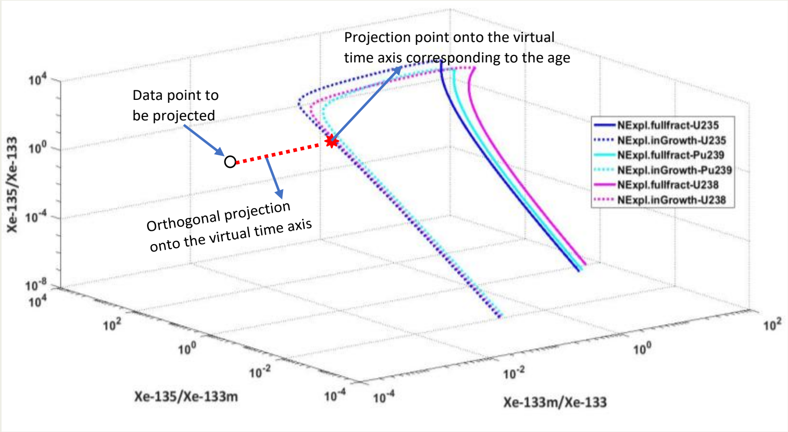
The 3-D analysis using radioxenon isotopic activity ratios presented in this work is based on the approach as follow:

1- The trajectories of all realistic explosion scenarios converge within 24 hours to a narrowly defined band within the three-dimensional xenon-ratio-space.

2- An imaginary zero point is defined. It is used for determining the age by ignoring in-growth and taking decay into consideration.

3- A virtual time axis is introduced by calculating the radioactive decay starting from the imaginary zero point and going parallel to the trajectories for the explosion scenario without fractionation. The zero point is defined by going 24 hours back from the crossing of the time axis with the notional line that connects the first 24-hour marks of the trajectories for the explosion scenario without fractionation.

4- For each radioxenon measured data, the explosion time is evaluated by projecting its entry in the three dimensional xenon-ratio-space onto the nuclear explosion trajectory.



References

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Results and Validation

Real observations plotted in the figures 1, 2, 3 and 4 are from (Kalinowski, 2005) for Nevada test site data where an analysis of atmospheric radioactivity release information for 433 nuclear tests conducted on the Nevada Test Range from 15 September 1961 trough 23 September 1992 can be found, (Gueibe, C. et al. 2017) for MIPFs signatures and (CTBTO-CRTool Output, 2018) for Fukushima accident data. All radioxenon decay data used in this work are from (Galan, M. et al. 2018) where new re-evaluated decay data (DDEP Project) for some xenon isotopes can be found.

	All Data	Data/release duration<1h	Data/release duration>1d
Precision/mean age error	3.22 hours	0.76 hours	13.26 hours
Median/age error	0.88 hours	0.31 hours	10.99 hours
Accuracy /standard deviation	15.43 hours	11.06 hours	22.93 hours
Number of Nevada data entries	102	42	19

In **conclusion**, it is found from this work that the 3-D analysis would be a promising tool for nuclear explosion zero-time determination, with a condition that at least three radioxenon isotopes to be detected. A precision less that 1 hour can be achieved if an immediate (less than 1 hour) release occurs following an underground nuclear test, as demonstrated in the above table. According to the detected isotopes, the lower border of the usability domain of this 3D method varies from 1 to 70 days following the explosion.