Three-dimensional space analysis of radioxenon isotopic activity ratios for characterizing a nuclear event

Kassoum YAMBA[1] ; Martin B. KALINOWSKI[2]

[1]DE/IRSAT/CNRST Ouagadougou, Burkina Faso ; [2]IDC/CTBTO Vienna, Austria

Corresponding authors: yamba.kassoum@yahoo.com ; martin.kalinowski@ctbto.org

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Introduction

This study on the nuclear release timing aims at analyzing radioxenon isotopic activity ratios in three-dimensional space. When real data from nuclear test are used, the first results obtained are promising for nuclear event zero time determination and nuclear release discrimination. This presentation focuses on the methodological approach considered in this study. Obviously three isotopes are less likely to be detected simultaneously than with only two isotopes. However, if three isotopes are available, making use of all three together offers a much more powerful analysis mechanism than with only two isotopes. In the three-dimensional space the analysis of timing and event screening can be separated. A time-independent screening can be achieved through the projection along the decay axis and the time of the event origin can be determined for each kind of source scenario by projecting the isotopic ratios on the decay axis and scale it in units of time. The time-independent screening is most useful for CTBT monitoring purposes since the time of origin of a remote detection is in general not known. This method may also be of relevance for On-Site Inspection.

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 this virtual time-axis.

When the fission material U235, Pu239 and U238 are considered, the imaginary zero point R_0 is found at the following isotopic activity ratios: R_0(Xe135/Xe133 = 43.03, Xe135/Xe133m = 486.94, Xe133m/Xe133 = 0.089).

Results and Validation

As an example of use, The radioxenon namely Xe135, Xe133m, Xe131m and Xe133 are considered for the following nuclear event: nuclear explosions, Medical Isotopes Production Facility and Nuclear power Plant releases. A parameter giving the usability threshold is defined and evaluated: An angle (alpha) is defined so that the 3D method is usable when alpha <=0.1 degree. This threshold is due to the fact that the time uncertainty is found to be not changing for a certain values of the angle alpha (<=0.099 degree).

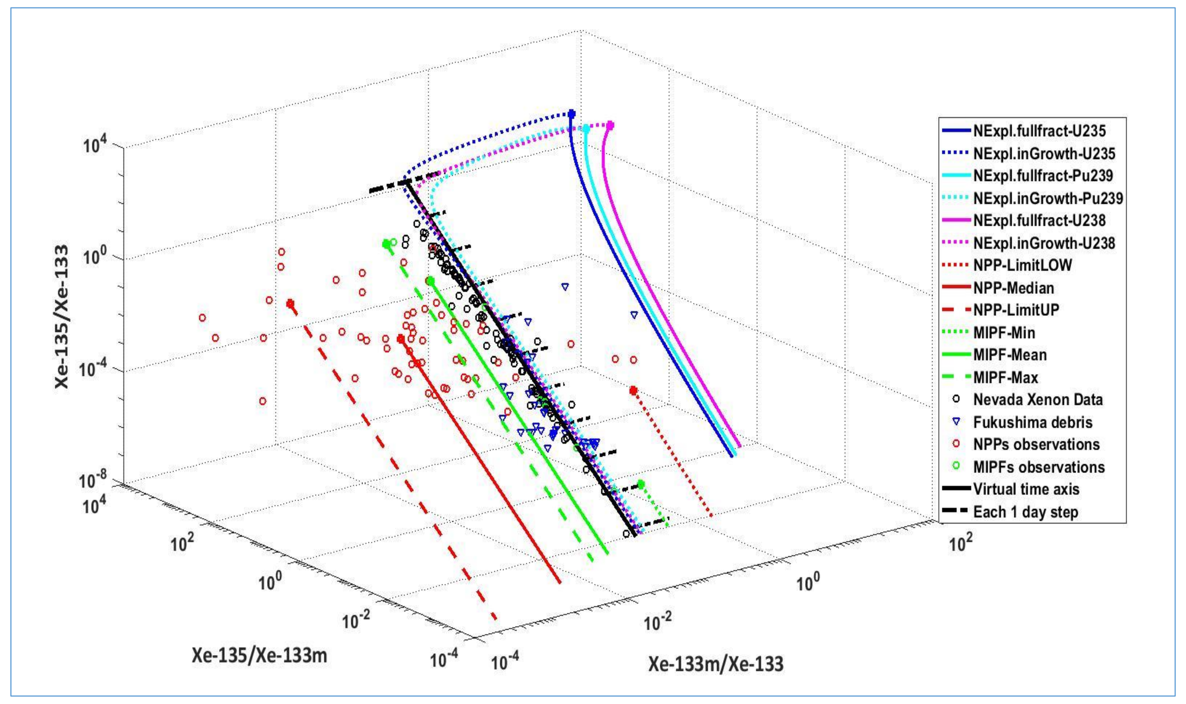

Figure 1: 3-D plotting using radioxenon isotopes Xe135, Xe133m and Xe133. It is found that these implied isotopes are usable after 1 day following the explosion.

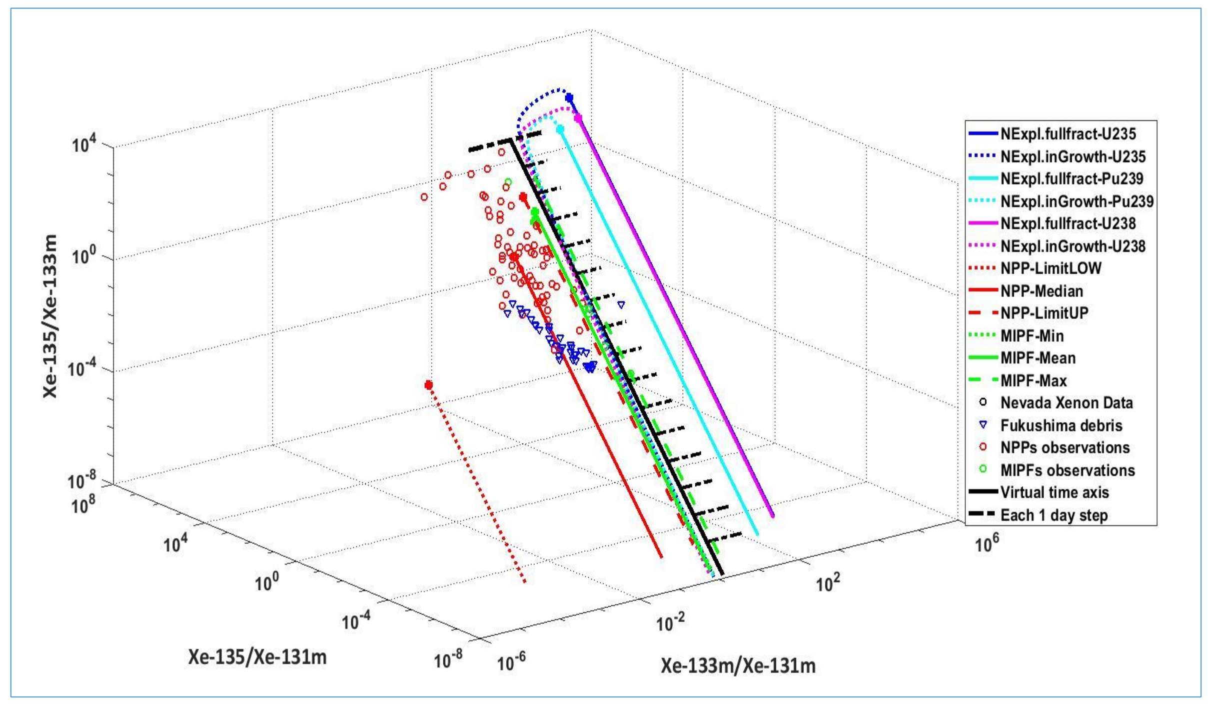

Figure 2: 3-D plotting using radioxenon isotopes Xe135, Xe133m and Xe131m. These isotopes are usable after 10 days following the explosion.

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.

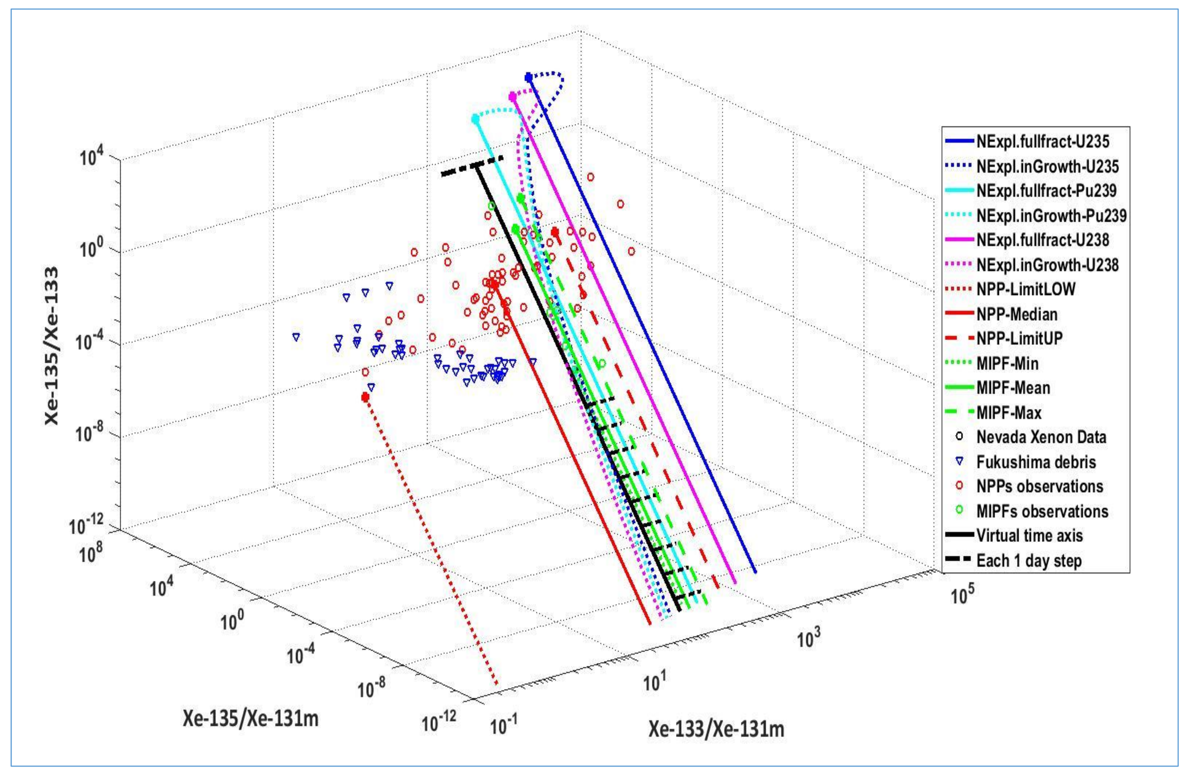

Figure 3: 3-D plotting using radioxenon isotopes Xe135, Xe133 and Xe131m. During the first 2 weeks following the explosion, these isotopes are not useful.

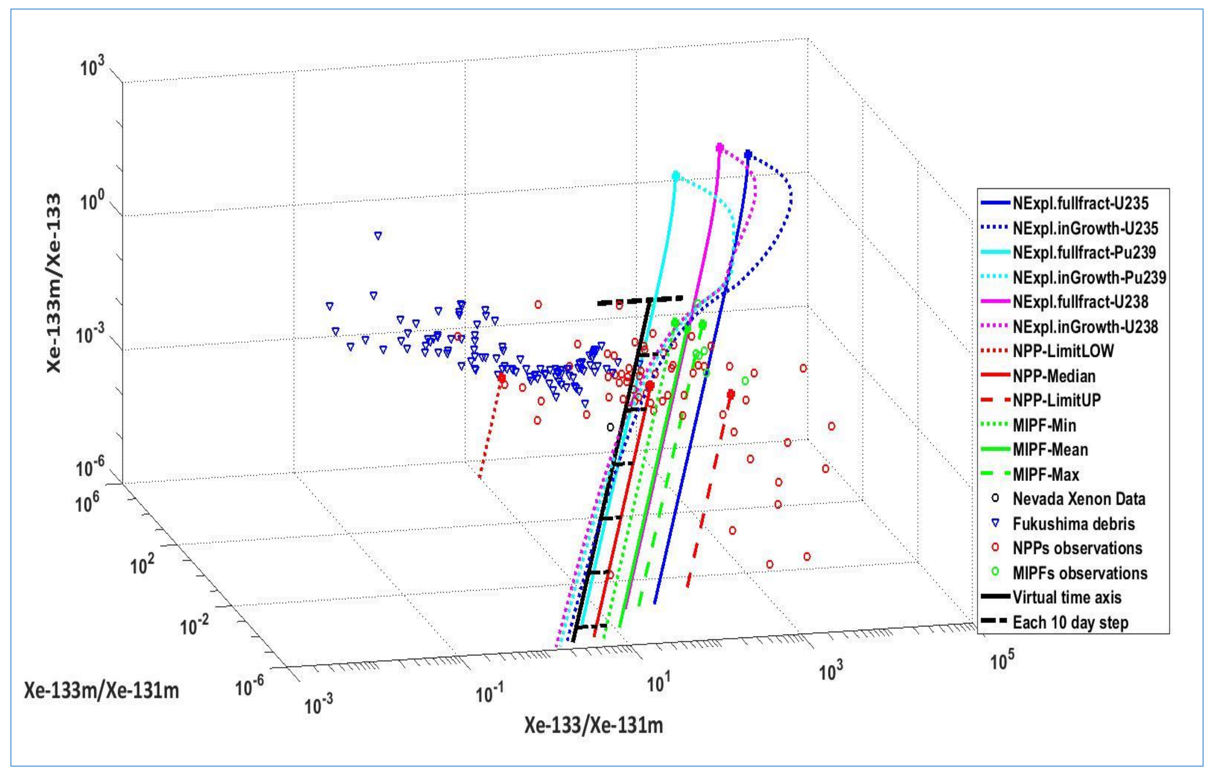

Figure 4: 3-D plotting using radioxenon isotopes Xe133, Xe133m and Xe131m. These isotopes are usable for this 3D method after 10 weeks following the explosion

Discussion & Conclusion

This work is based on a paper done by Martin Kalinowski a few years ago on "*Nuclear explosion time assessment based on xenon isotopic activity ratios*". The advantage of this method for event time calculation based on three xenon isotopes is that it can be applied without knowledge about any technical details of the explosion and for any above-ground test as well as for underground explosions.

Table 1: Event zero time uncertainty result from 3-D analysis when Nevada data are used. Radioxenon isotopes investigated are Xe135, Xe133m and Xe133.

	All Data	Data/release duration<1h	Data/release duration>1d
Precision/mean age error	3.55 hours	0.76 hours	13.59 hours
Median/age error	1.20 hours	0.63 hours	11.31 hours
Accuracy /standard deviation	15.43 hours	11.06 hours	22.93 hours
Number of 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 table 1. 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.

The analytical formulas used for plotting curves are from (Yamba, K. et. al. 2018) where the MATLAB script giving the analytical solutions describing the change over time of the radioxenon isotopic activities in the nuclear explosion context can be found.

References

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