SnT 2021
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Three-dimensional space analysis of radioxenon isotopic activity ratios for characterizing a nuclear event in comparison to civilian releases from fission and activation

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

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POSTER

1. CTBTO / IDC – Vienna, Austria (martin.kalinowski@ctbto.org)
2. CNRST / IRSAT / DE – Ouagadougou, Burkina Faso (yamba.Kassoum@yahoo,com)

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ABSTRACT

This study on the nuclear release timing aims analysing radioxenon isotopic activity ratios in three-dimensional space. The methodological approach and the characterization of the 3D usability threshold considered in this study were presented during SnT2019 and INGE2019. This presentation focuses on comparison to civilian sources from fission and activation.

Obviously three isotopes are less likely to be detected simultaneously than two isotopes are. 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. In this projection, event characterization can be achieved without knowledge about the time of the release from the source. 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. In addition, under favorable conditions, the event origin time can also be determined irrespective of the source scenario by projecting the isotopic ratios on the decay axis and scale it in units of time.

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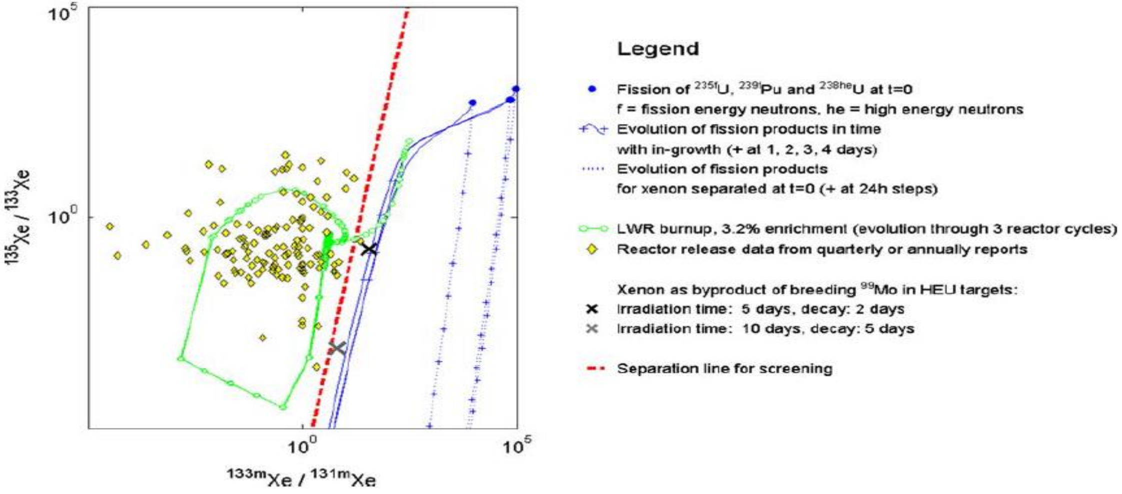
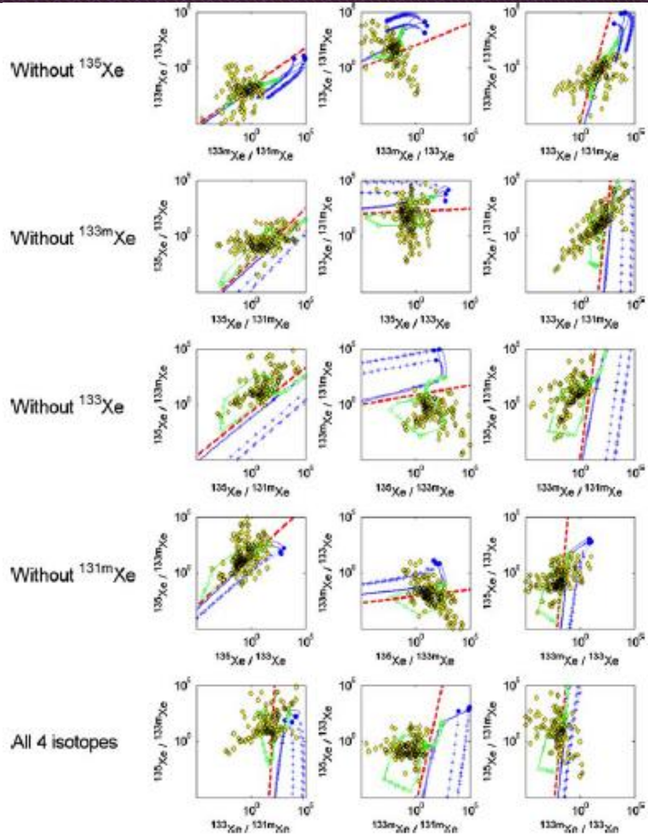
INTRODUCTION

The four isotope plots of radioxenon ratios is well known. Using only two axes is not making full use of the data because none of the possible projection on a 2D space retains all valuable information.

(Kalinowski et al., 2010)





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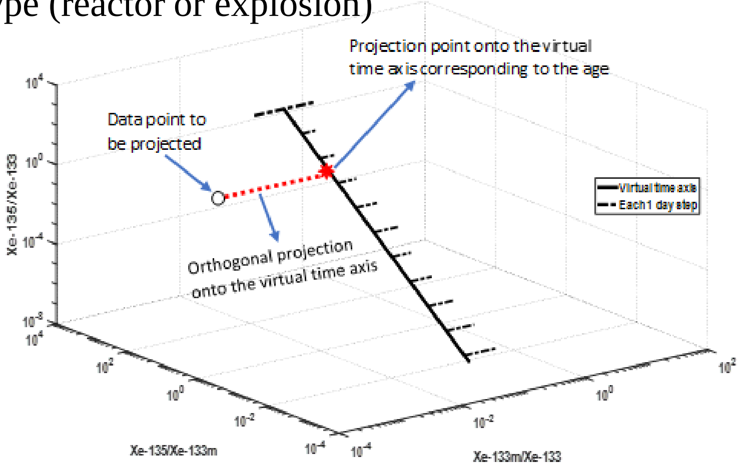
METHODS

3D Approach:

1. An imaginary zero point is defined. The basic application assumes total fractionation at time zero followed by decay, i.e. no in-growth from precursors is taken into account, except for Xe-133m into Xe-133.
2. It can be used for two different applications:
   - A. Determination of the age, i.e. time of a hypothetical nuclear explosion.
   - B. Time-independent characterization of the source type (reactor or explosion)



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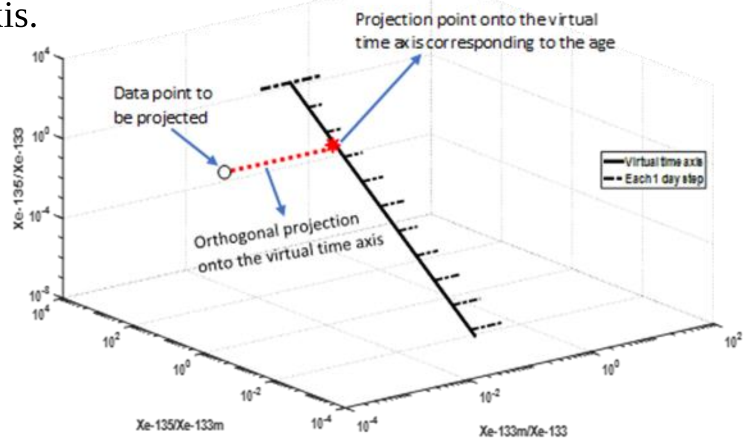
METHODS

3D Approach for event timing:

1. The virtual time axis is introduced with the slope of the trajectories for the explosion scenarios without fractionation at infinity
2. The axis is scaled according to the time required for radioactive decay starting from the imaginary zero point.
3. For any radioxenon measured data, the explosion time is evaluated by projecting its entry in the three-dimensional xenon-ratio-space onto this virtual time-axis.



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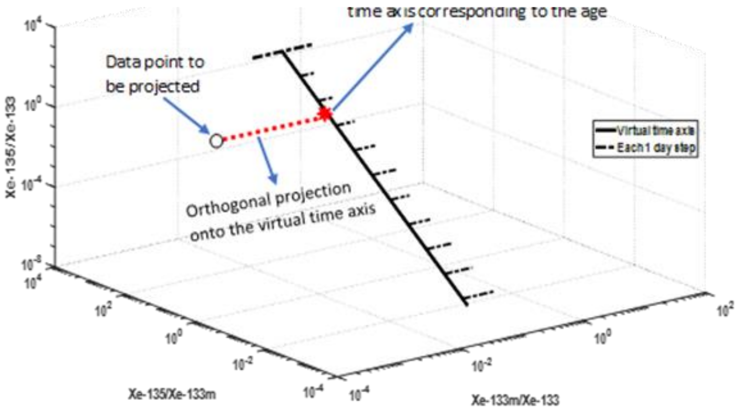
3D Approach for source characterization:

1. The virtual time axis is used as the axis along which all data are projected to a 2D surface that has axes with no defined physical meaning. The time information is lost which means that the plot is independent on any knowledge about the time of the fission event.
2. For any radioxenon measured data, time-independent characterization of the source type (reactor or explosion) is possible by associating it with one of the domains defined by simulated ratios (nuclear reactor vs nuclear test) and reference data from past atmospheric observations at the same IMS station or during special event times like the Fukushima episode.



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Data used to populate the plot and for validation of 3D methods:

1. Nevada Test Range from 15 September 1961 through 23 September 1992
2. MIPFs signatures from (Gueibe et al., 2017)
3. Fukushima accident data from (CTBTO-CRTool Output, 2018)
4. Radioxenon decay data from DDEP Project (Galan et al., 2018)
5. Analytical formulas from (Yamba et al., 2018)

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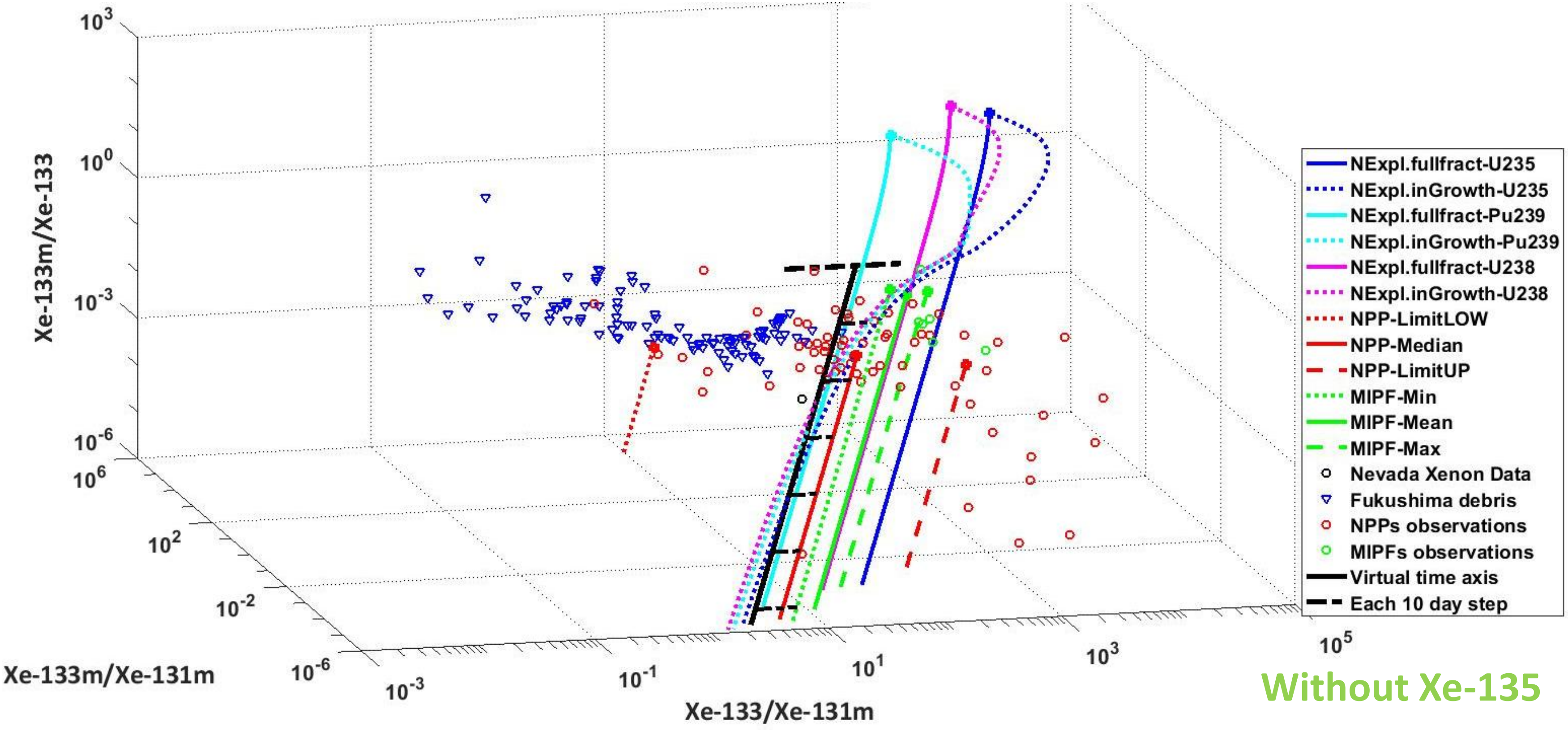
RESULTS



Without Xe-135

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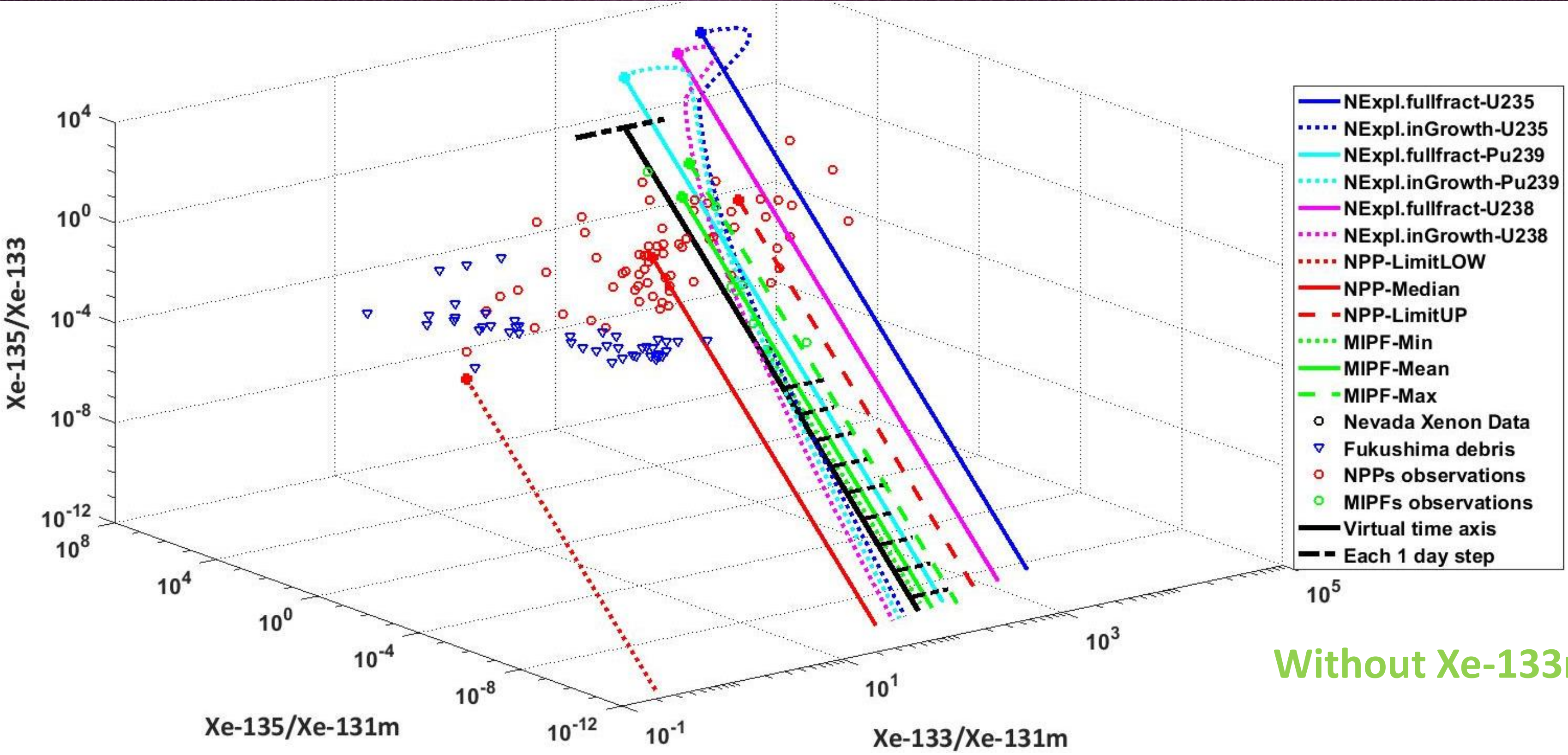

Without Xe-133m

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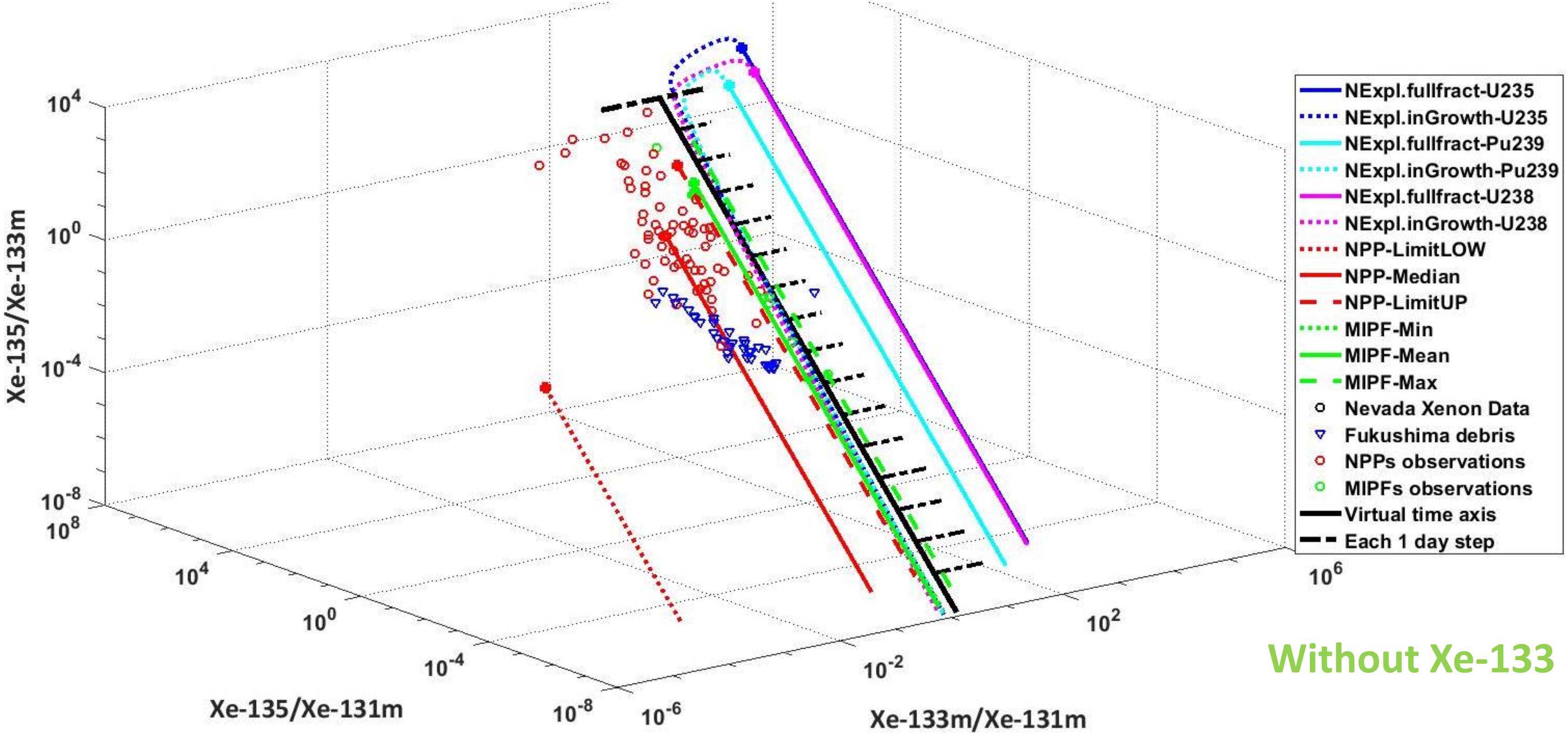

Without Xe-133

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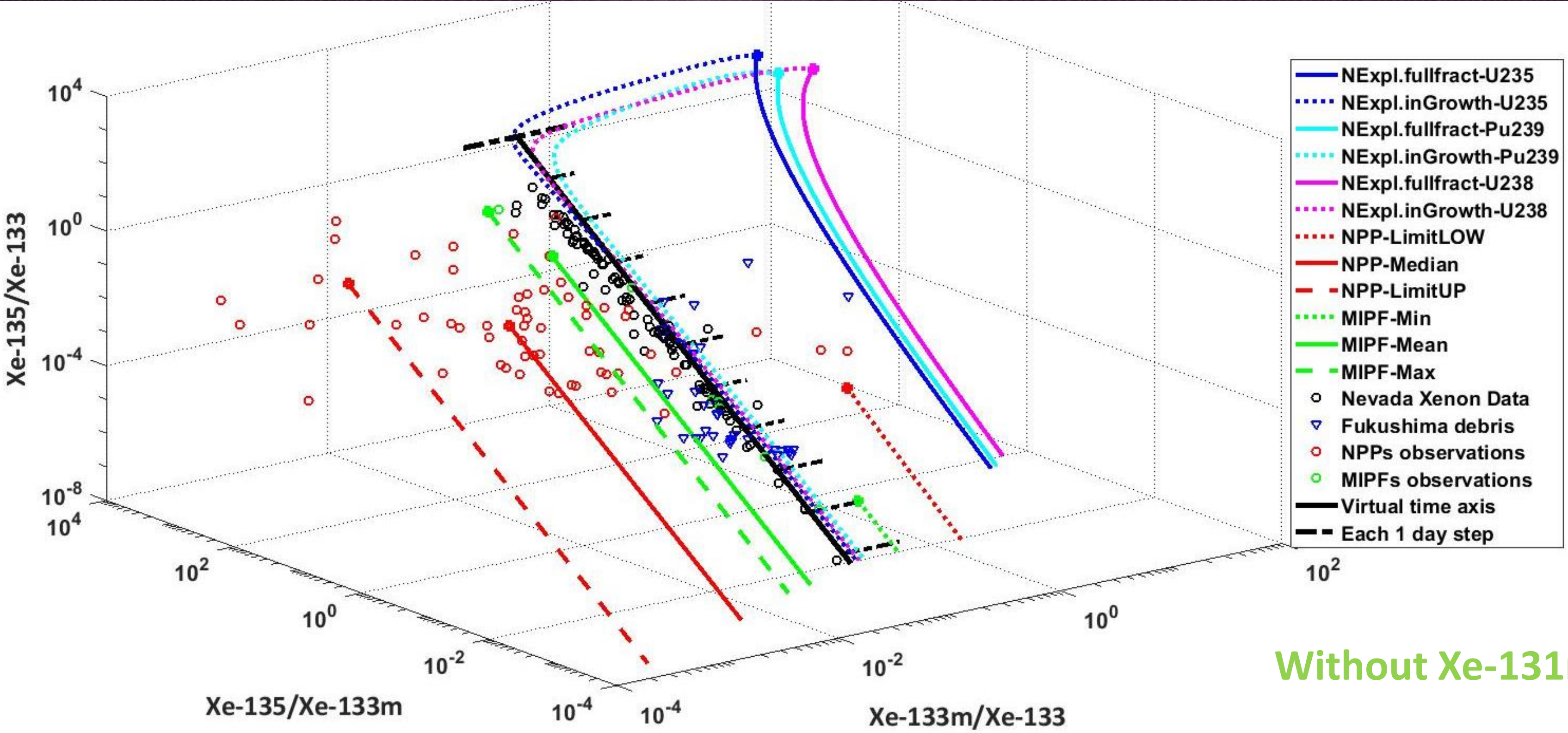

Without Xe-131m

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RESULTS

Overview of the usability threshold for each radioxenon isotope set

	Age Error [Days]	*Angle Alpha [° Degree]*	*Time axis start [Days]*
Xe135/Xe133m/Xe133	[5E-3, 0.0832]	0.0876	1
Xe135/Xe133m/Xe131m	[1E-3, 0.2722]	0.1	10
Xe135/Xe133/Xe131m	[1.7E-4, 0.2746]	0.0964	11
Xe133m/Xe133/Xe131m	[3.5E-3, 0.7437]	0.1	61

The 3D space without Xe-131m can best be used for event timing.

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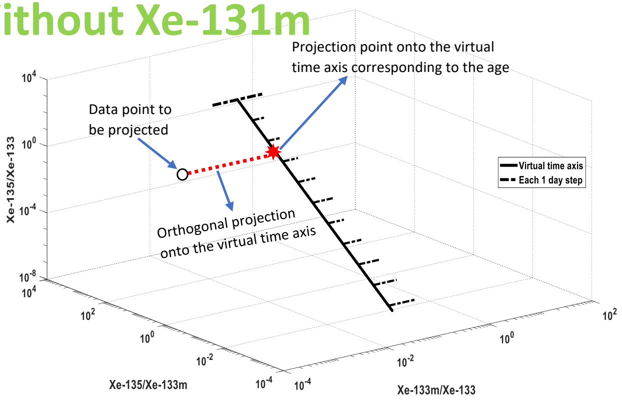
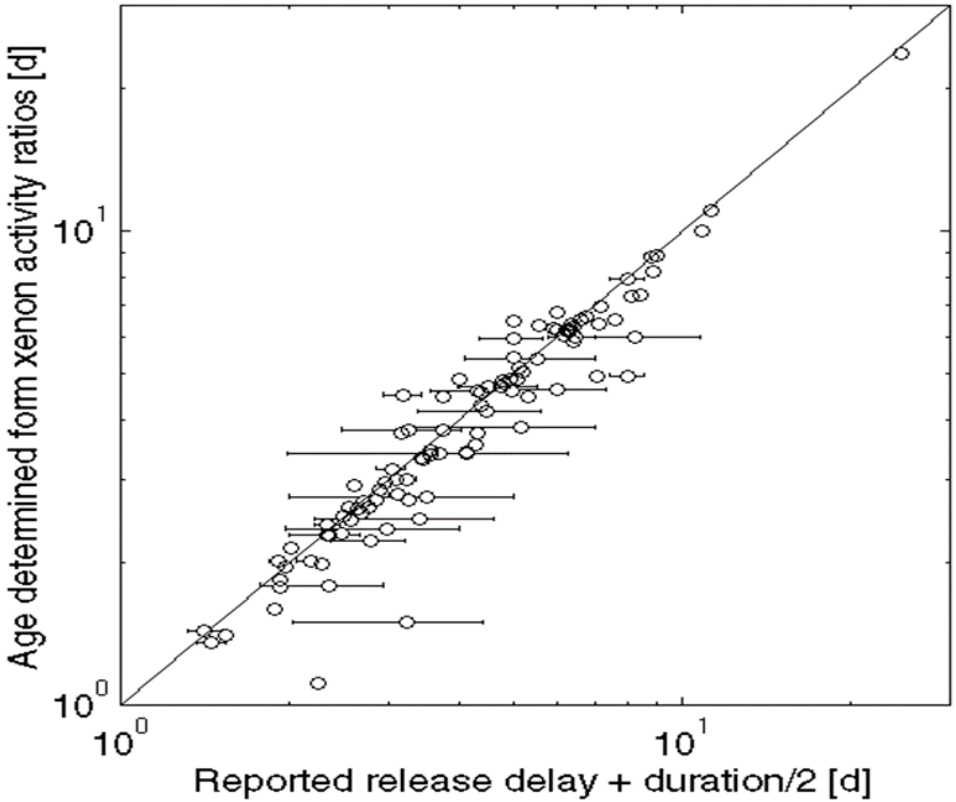
Without Xe-131m



Age determined from 3D activity ratios versus the reported delay time at the middle of the release period (delay+duration/2) for 102 UNE at Nevada. Release durations are marked by horizontal bars.



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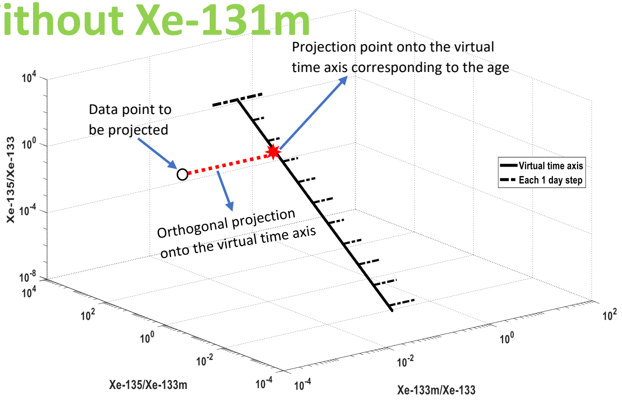
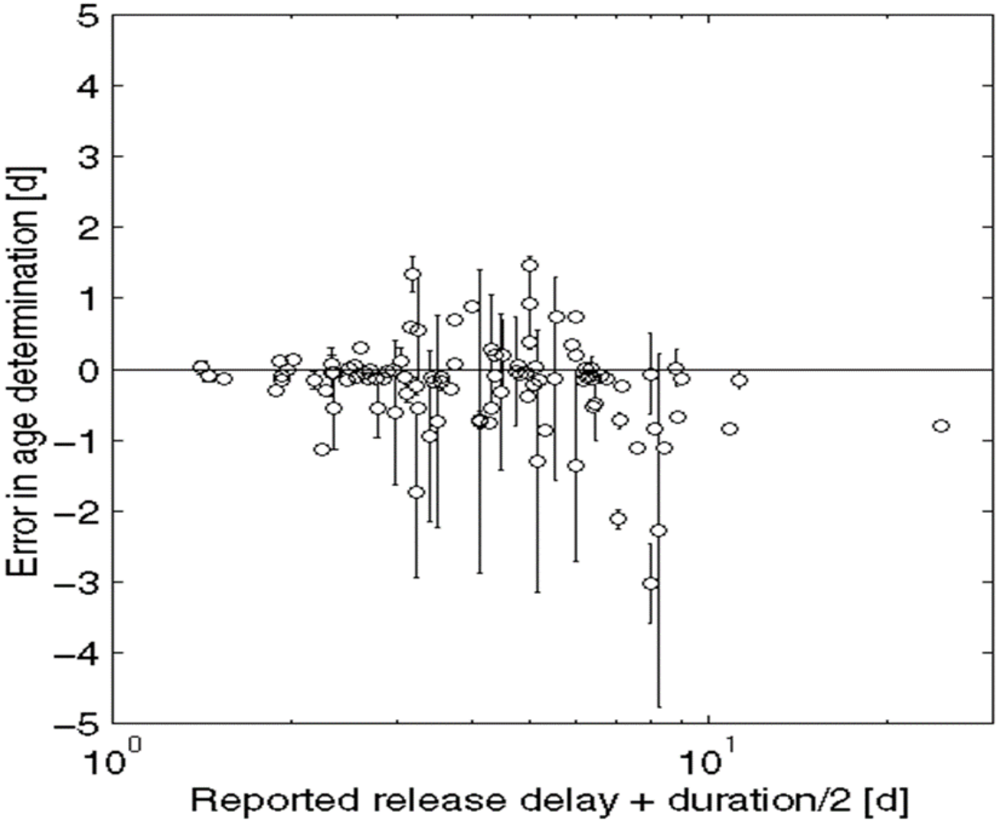
Without Xe-131m



Absolute error in age determination as a function of the delay at the middle of the release period (delay+duration/2). The total lengths of the error bars are indicating the release duration.



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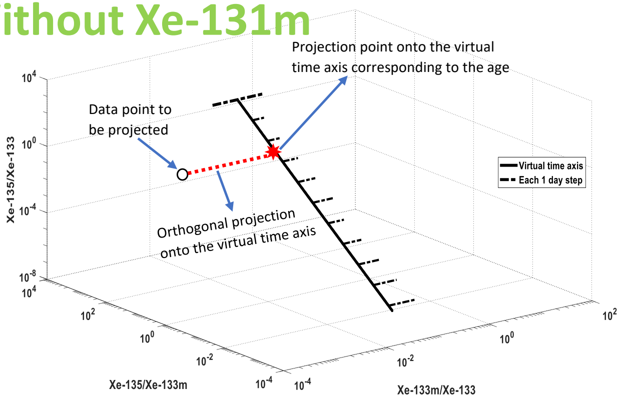
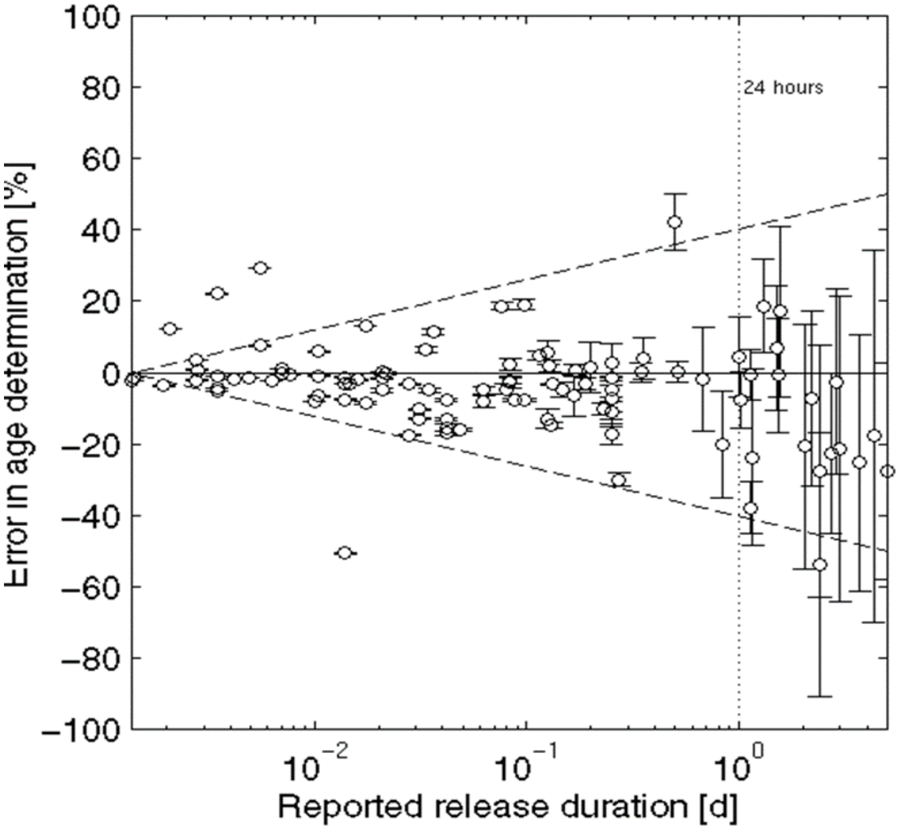
Without Xe-131m



Relative error in age determination as a function of release duration. The total lengths of the error bars are indicating the release duration



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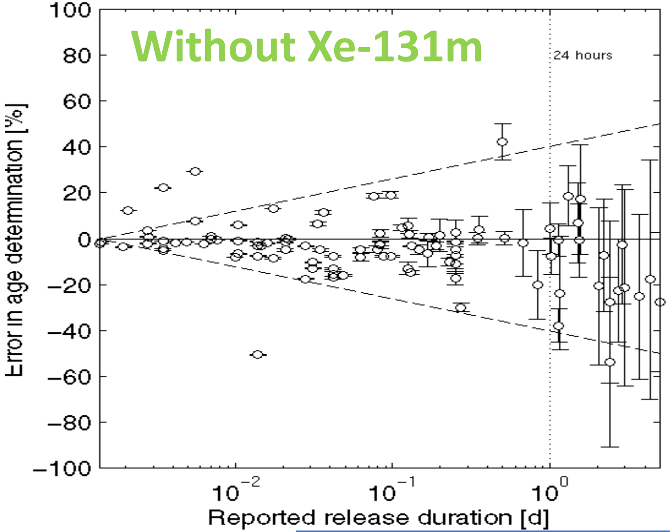

	All Data	Data/release duration<1h	Data/release duration>1d
Precision/mean age error	3.55 hours	0.76 hours	13.59 hours
Median/age error	1.20 hours	0.63 hours	11.31 hours
Accuracy /standard deviation	15.43 hours	11.06 hours	22.93 hours
Number of entries	102	42	19

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CONCLUSIONS

- The 3D timing can be applied for prompt releases with early detections only with the combination of Xe135/Xe133m/Xe133 and for detections later than 11 days, the two other combinations with Xe-135 can be used as well.
- Due to the short half-life of Xe-135 the practical use is limited to short times after the release.
- The combination being most likely of practical relevance is the one without Xe-131m. This happens to be the one for which a large Nevada data set of about 100 observations is available.
- For short release durations (< 1 hour), the timing error is less than one hour when these three isotopes are used for event zero time determination.