O3.4-650

Multi-physics Analysis of Nuclear Events at FOI
- the Example of the 2024 CTBTO National Preparedness Exercise

Jon Grumer, Sofie Liljegren, Anders Ringbom, Mattias Aldener, Henrik Olsson, Monika Ivandic, Peter Jansson, Tomas Fritioff

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11 September 2025

SnT 2025 CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE

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Main source signals

Infrasound
- **pressure waves** ~ 0.3 km/s
- acoustics, seismology, meteorology

Electromagnetic radiation
- **light flash, thermal radiation** + subsequent EMP

Radionuclides
- **Particles** ~ 400 km/day (atoms, molecules, particulates)
- nuclear & radiation physics, chemistry, meteorology, …

Seismics
- **pressure** & **shear** waves ~ 2-8 km/s
- seismology, geophysics

Hydroacoustics
- **pressure waves** ~1.5 km/s
- oceanography & fluid dynamics, seismology, …

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A complete picture requires a joint analysis

- Time, place & depth (height)
- Nuclear explosion?
- Source term (yield, materials)
- Scenario timeline

But challenging!

- Communication across several different scientific diciplines
- Completeness of the event scenario space
- Can we quantify the total confidence?
- …

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Towards a well-defined data fusion process

Why do we need a well defined, automated data fusion process?

- Reduce decision bias
- Increased reliability, reproducibility, and traceability
- Easier to identify relevant improvements
- Maybe possible to estimate total uncertainty ($P=P_1P_2P_3\ldots$)
- Possible to make network studies
- Possible to tune false alarm rate
- Easier to discuss results with others

Possible to write a code….

Expert Technical Analysis

Develop standard scientific methods and operational procedures to increase the confidence in an analysis of a specific event.

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Ringbom, SnT 2013

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Criteria example: underground nuclear test (xenon + seismicity)

- Seismic event not screened out in the waveform analysis (explosion, depth, …)
- At least one out of [^{131m}Xe,^{133}Xe,^{133m}Xe,^{135}Xe] detected in one *or* several associated samples
- Background sources not dominating (not from a known background source)
- Xenon isotopic ratios in the nuclear test domain
- Time zero window from xenon agrees with seismic event time
- Position for seismic event covered by estimated location from ATM
- Xenon source term compatible with estimated yield from seismic measurements

The goal is a consistent and coherent picture.
The method should have a low false negative rate.

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Proposed general criteria

Criteria	Fulfilled?
SHI signals from explosion	
SHI and RN not from background source	
RN isotopic ratio(s) in test domain	
Compatible RN & SHI timings	
Compatible RN & SHI locations	
Compatible RN & SHI source terms (release activity & seismic yield)	
= Combined signal is an anomaly?	

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Application to the 2024 NPE

Andlantis

AS.CEN.

Dogga

AS.DOG.

IMS SEX63

IMS DEX33

4x seismic 3C stations

- Andlantis
- 0.5 Hz sample rate?

2x infrasound array data sets

- Andlantis
- 3-element arrays, 20 Hz

3x Xenon stations

- 2x IMS
- 1x Andlantis mobile station

AS.OA1.

IA1.H1-3

Bezores

AS.OA2.

IA2.H1-3

Mobile Xenon station NPEXE

Madeira

Hydroacoustic observation

- IMS HA10 Ascension Island

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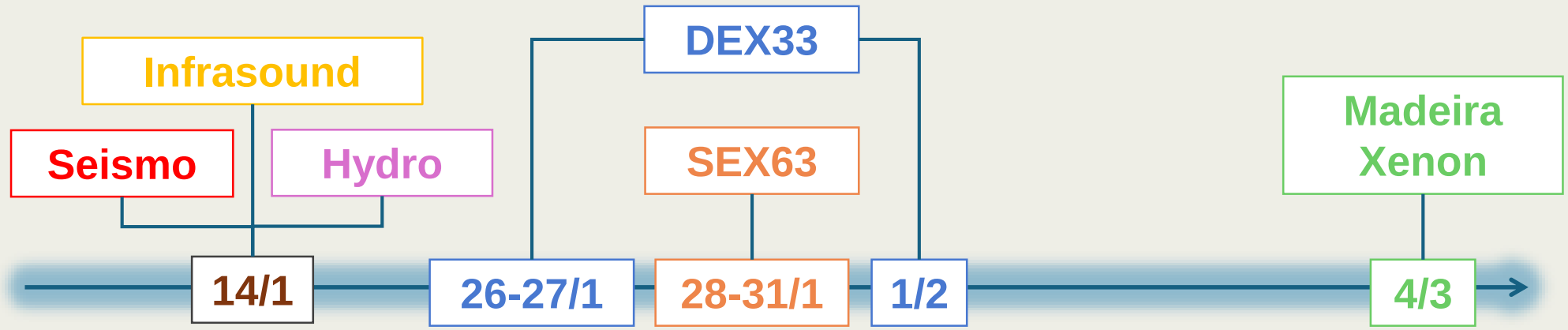
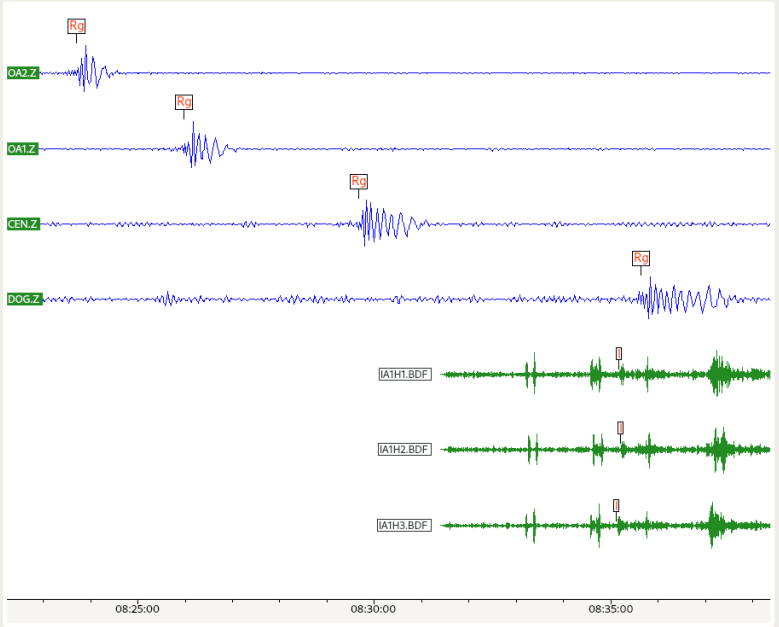
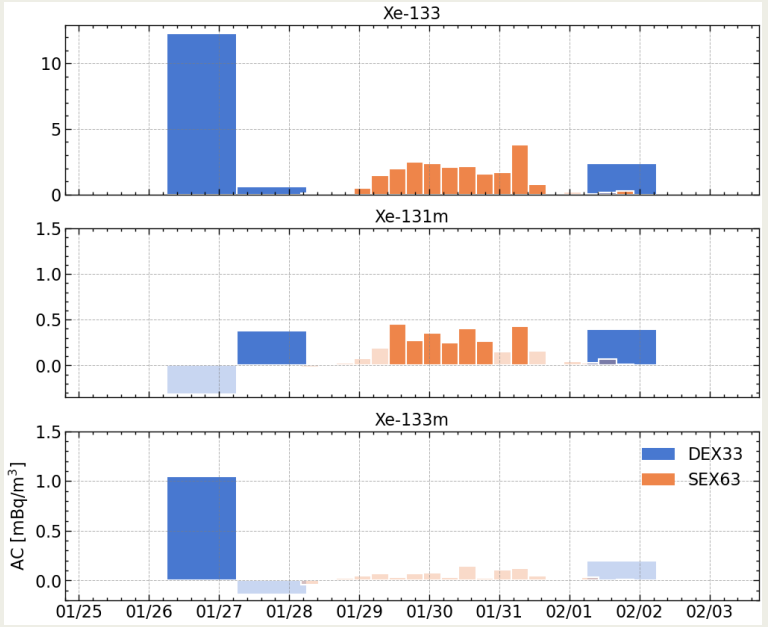
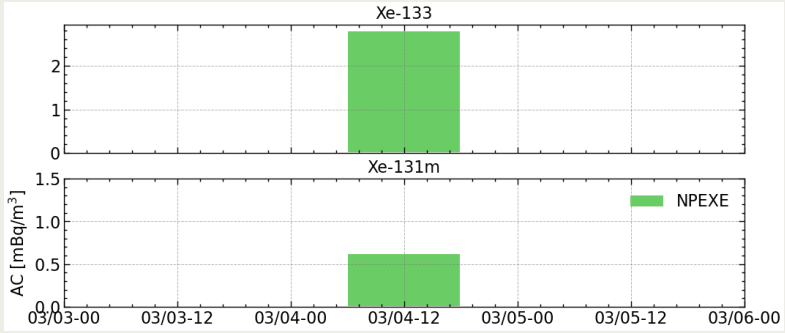
Data timeline









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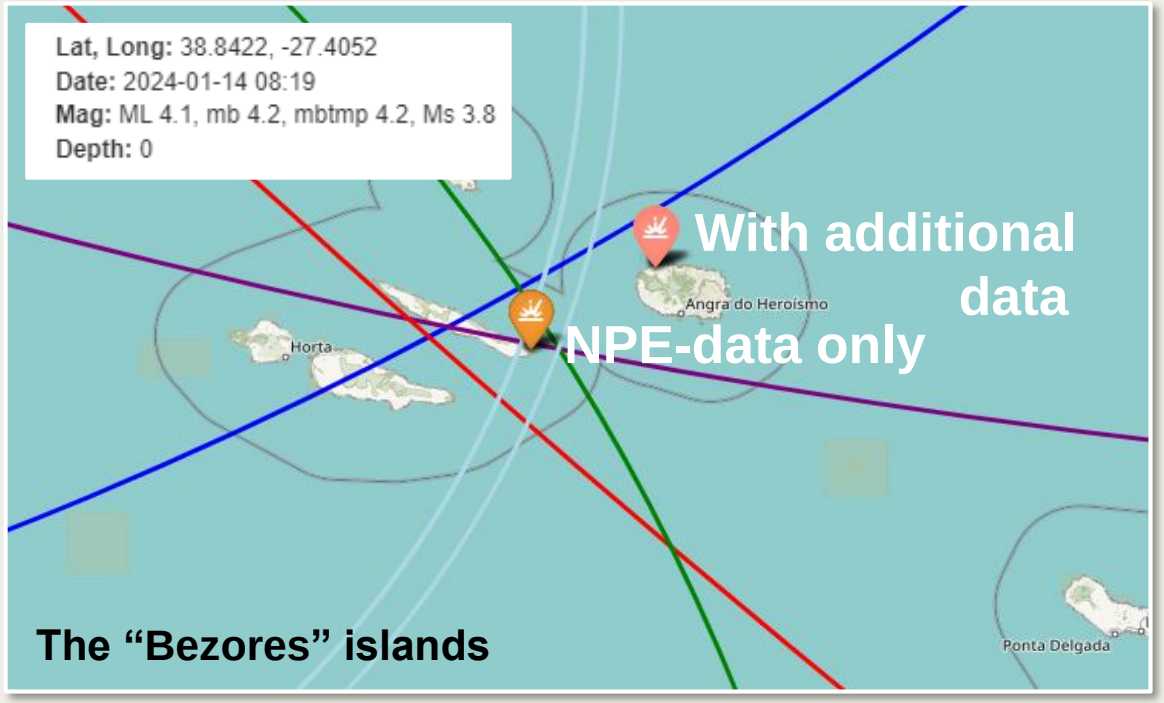
NPE 2024

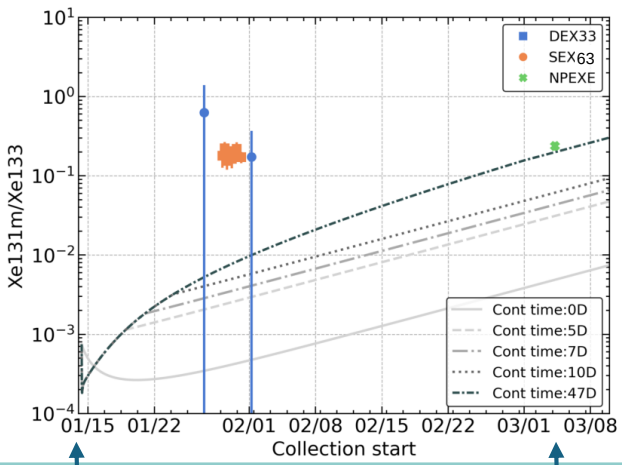
Analysis

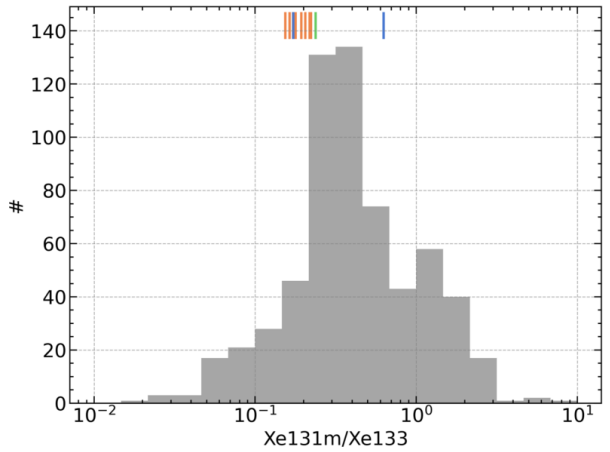
SHI



RN & ATM

- SEX33 and DEX33 are not NW candidates
- Madeira xenon measurement agrees with NW release after 47D (containment time found from weather simulations)
- The ratio is commonly found in IMS





SHI event time
Jan 14 2024

Madeira Xe
ca 1.5 months

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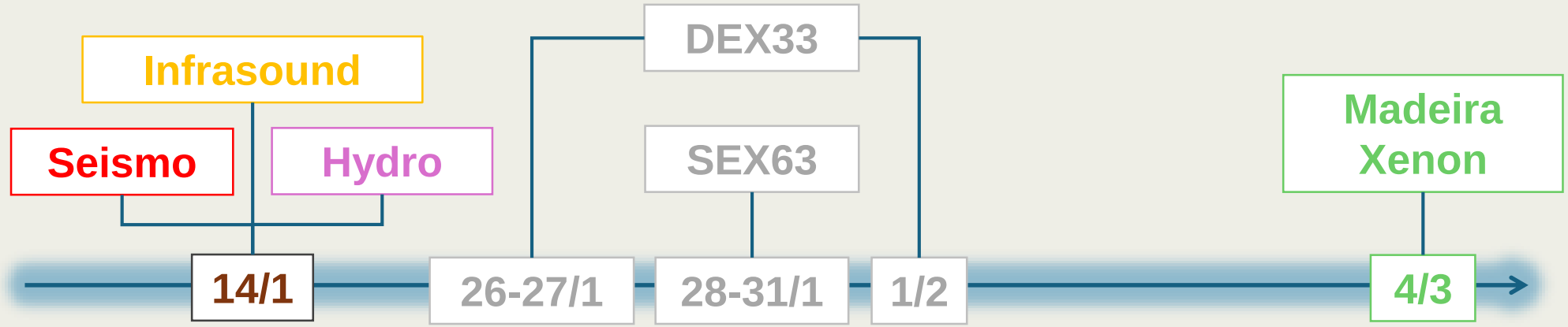
NPE 2024

Suggested scenario



POSSIBLE UNDERGROUND EXPLOSION @ BEZORES

UNRELATED

XENON RELEASE AFTER CA 2 MONTHS

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O3.4-650

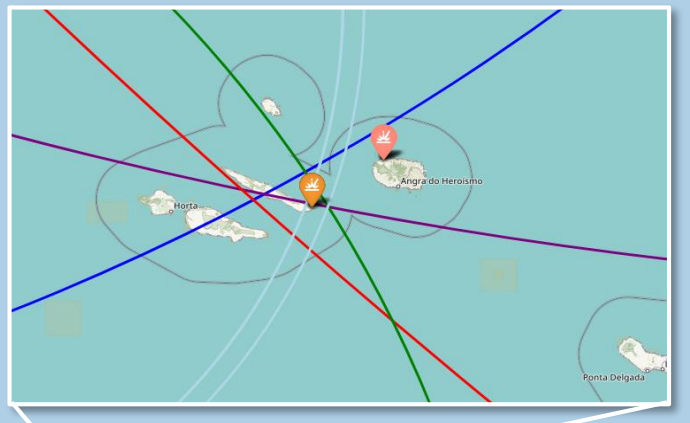
Suggested scenario

NPE 2024

Andlantis

AS.CEN.

UNDERGROUND EXPLOSION



AS.OA1.

IA1.H1-3

Rezores

AS.OA2.

XENON RELEASE
AFTER CA 2 MONTHS

IA2.H1-3

Mobile Xenon station NPEXE

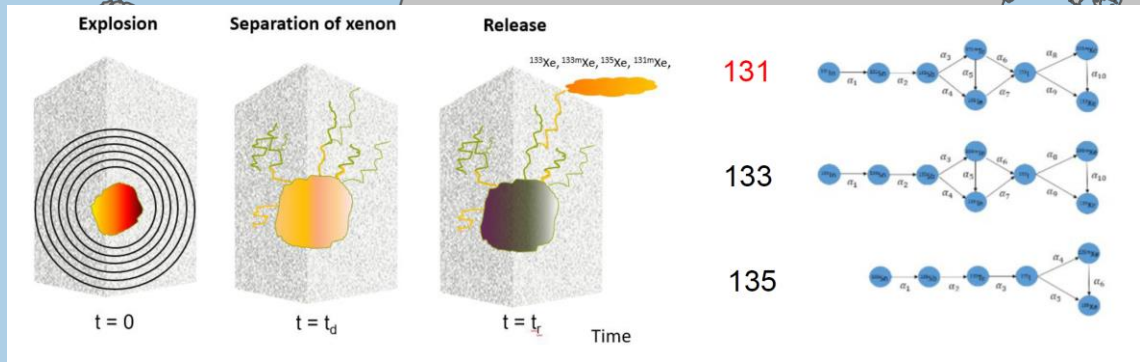
Madeira

Dogga

AS.DOG.

IMS
SEX63

IMS DEX33



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NPE 2024

Application to FOI criteria

Criteria	Fulfilled?
SHI signals from explosion	?
SHI and RN not from background source	? ✓
RN isotopic ratio(s) in test domain	✓
Compatible RN & SHI timings	✓
Compatible RN & SHI locations	✓
Compatible RN & SHI source terms (release activity & seismic yield)	?
= Combined signal is an anomaly?	✓

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Conclusions

- A **systematic** and **well-defined** approach to data fusion → **pre-defined criteria to avoid bias**
- **Independent analysis from raw data,** if possible
- **RN – SHI scientific communication** can present a challenge
- **NPE's** are great for learning and testing – improves the work at our NDC
- **RN sample association** and **signal extraction** from background is challenging (and related!)
- **Auto-fusion** tools in dev. (Ringbom SnT 2013 & ETA Workshop 2024)
- **FOI NPE report** (open access) coming in 2025 (Liljegren & Grumer et *al.*)

Some related FOI presentations @ SnT2025

- ML method for RN sample association is under development (**P3.6-559** Liljegren *et al.*)
- A tool for simulating sensor network response from a nuclear event: NEMOS (**P3.4-517** *Ringbom et al.*)
- Improved automatic Xe alarms **P3.6-625** (*Kimstrand et al.*)