SnT 2021
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PREPARATORY COMMISSION

A high-resolution laboratory-based β-γ coincidence spectrometry system for radioxenon measurement

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ORAL PRESENTATION

AWE

T3.2-482

A high-resolution laboratory-based β-γ coincidence spectrometry system for radioxenon measurement

M. A. Goodwin, A. V. Davies, R. Britton *et al*.

- The UK CTBT Radionuclide Laboratory (GBL15) is certified for Particulate and Noble Gas measurements as part of the International Monitoring System (IMS)
- To deliver the Noble Gas measurements, a SAUNA II IMS Lab system is used for noble gas re-measurements to quantify ^{133}Xe, ^{135}Xe, ^{131m}Xe and ^{133m}Xe
- GBL15 has the remit to research new detection technologies to improve detection sensitivity and accuracy
- A PIPSBox detector has been configured for coincidence measurements with multiple high-purity germanium (HPGe) detectors to evaluate its performance as an option for a future operational laboratory system
- This work looks to determine the optimal detection limits achievable for this type of system
- This work is in collaboration with scientists from the University of Surrey and the National Physical Laboratory (NPL)

AWE

UNIVERSITY OF SURREY

NPL National Physical Laboratory

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System Overview

- PIPSBox detector with 2x Mirion 6530 carbon-window BEGe detectors
- Acquisition data collected in time-stamped list-mode for each detector (2xPIPS, 2xHPGe) using custom acquisition software
- Data processed using C++/ROOT custom tools
- Advanced coincidence post-processing in Python/ROOT to generate spectral projections
- **Electron-photon coincidences are combined from all four gain-matched detectors to create a near-4π detector geometry and maximise the detection efficiency**

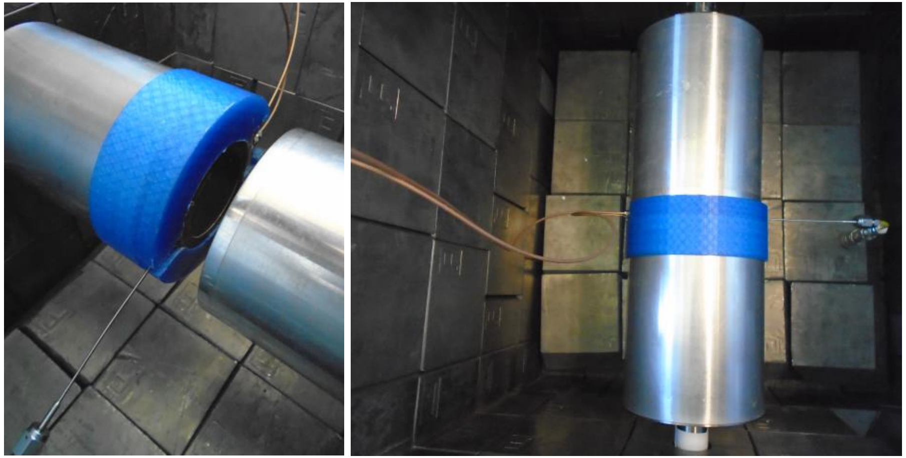

Fig. 1. AWE PIPSBox-HPGe research detector photographs, with detector cables and gas lines

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Measurement & Analysis Overview

- Spike samples prepared by Seibersdorf Laboratories containing ^{133}Xe, ^{131m}Xe, ^{133m}Xe and ^{135}Xe and a separate sample with pure ^{131m}Xe
- Gas injected to the PIPSBox and quantified by HPGe measurements of the gas vial
- Perform acquisition and archive list-mode data
- Determine 4π detection efficiencies
- Extract coincidence projections and generate *energy-gated-coincidence summed spectra*
- Calculate the MDAs

Fig. 2. Glass vial containing radioxenon sample prepared by Seibersdorf laboratories, received by GBL15.

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Straggled/backscattered conversion electrons.
Should we clean out this signal or make use of it?

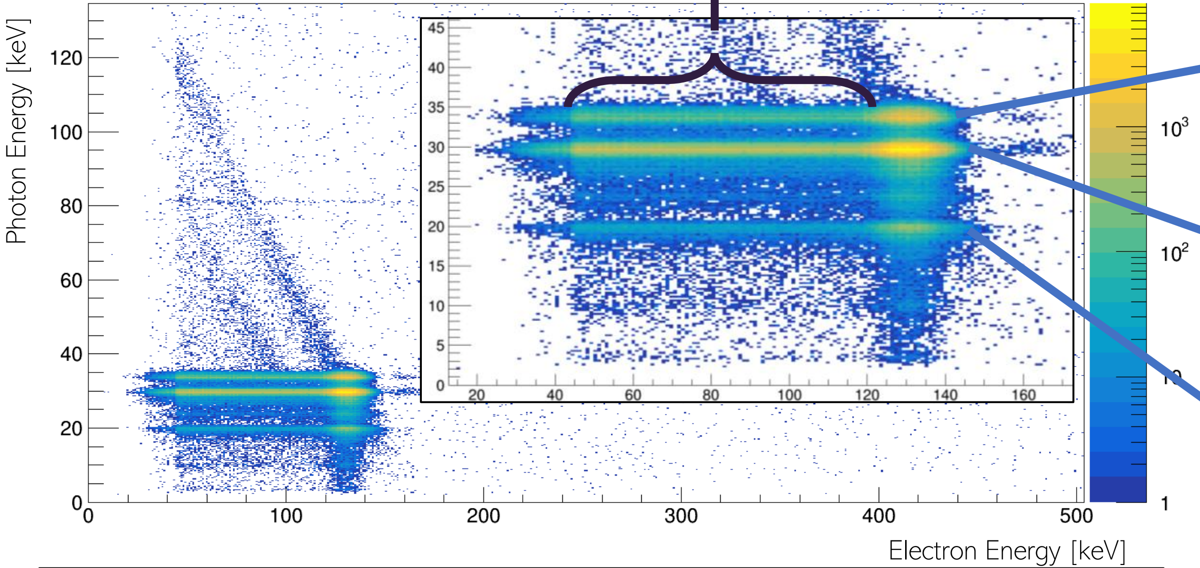
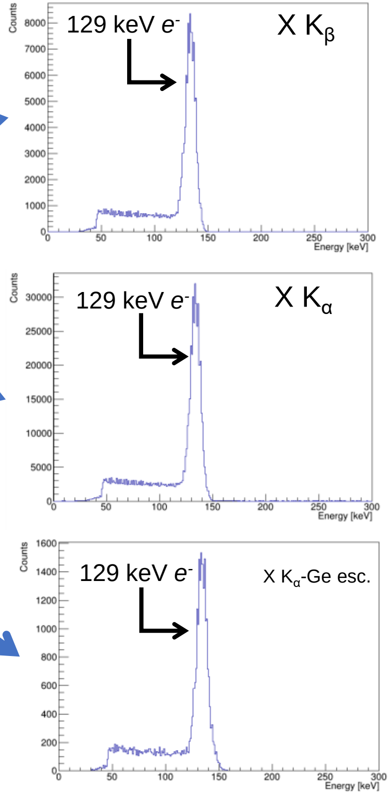


Fig. 3. electron-photon coincidence matrix from a measurement of ^{131m}Xe (with small ^{133}Xe contamination) and inset: zoomed to the X-ray region. Each photon signal energy is used as a gate to project an electron spectrum (see right)



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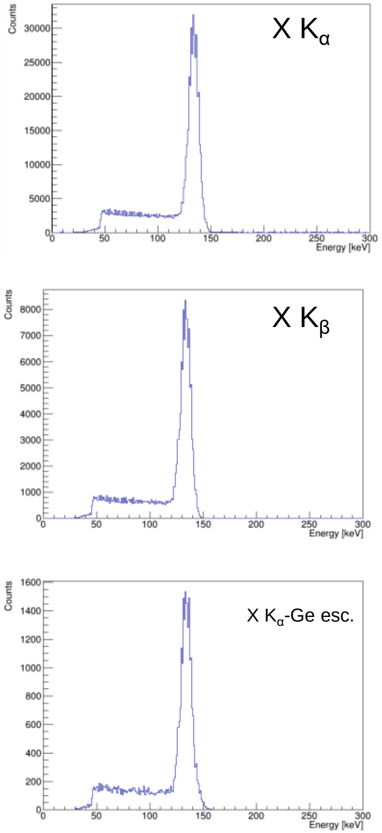

Summed projections for ^{131m}Xe

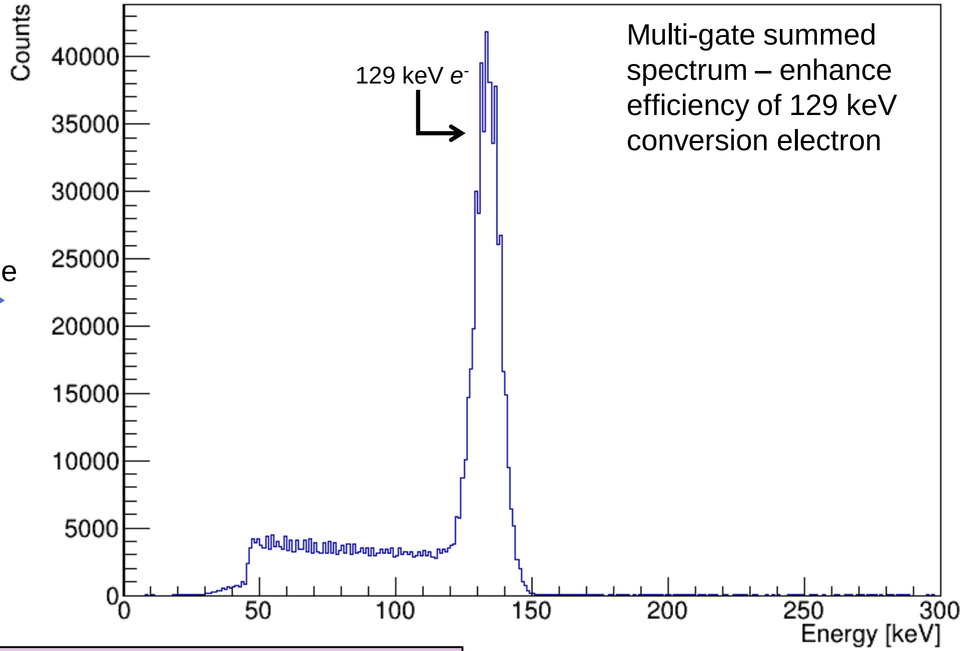

Fig. 4. Summing individual projections to generate a summed projected coincidence spectrum for ^{131m}Xe

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What about when we have a mixed xenon sample? Does this really work?

Can we generate 'optimised' spectra for each signal, using the different X-ray energies of Cs and Xe?

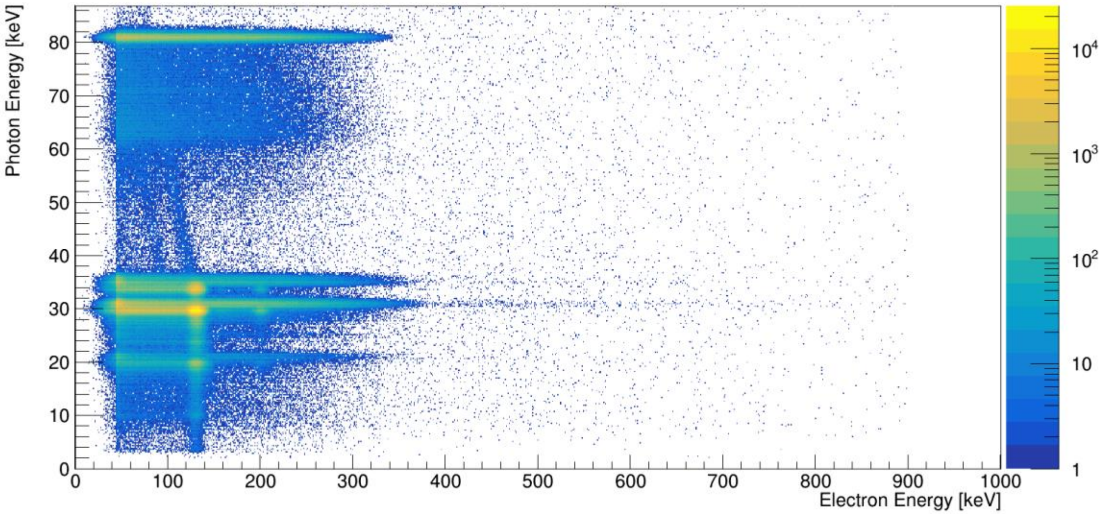

Fig. 5. Electron-photon coincidence matrix for a radioxenon sample containing ^{133}Xe, ^{135}Xe, ^{131m}Xe and ^{133m}Xe

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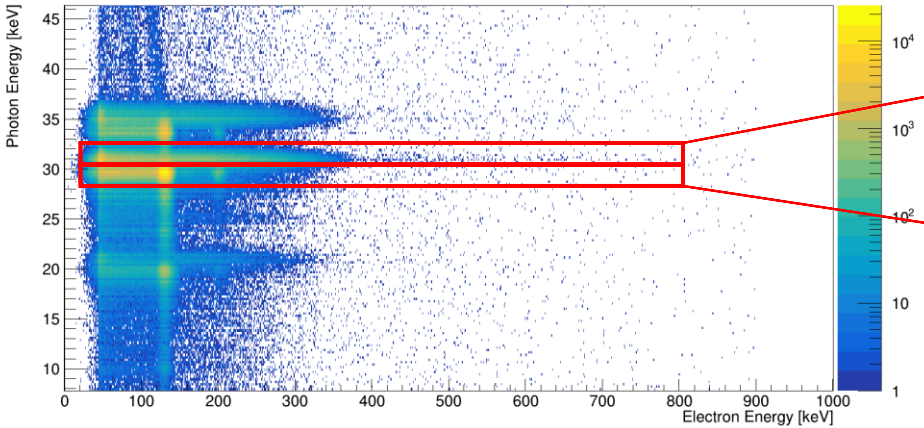
Gating on the Xe X K_α gives a ^{133}Xe β^- continuum 20x lower than that in the Cs X K_α. Most of the contribution is from scattered conversion electrons



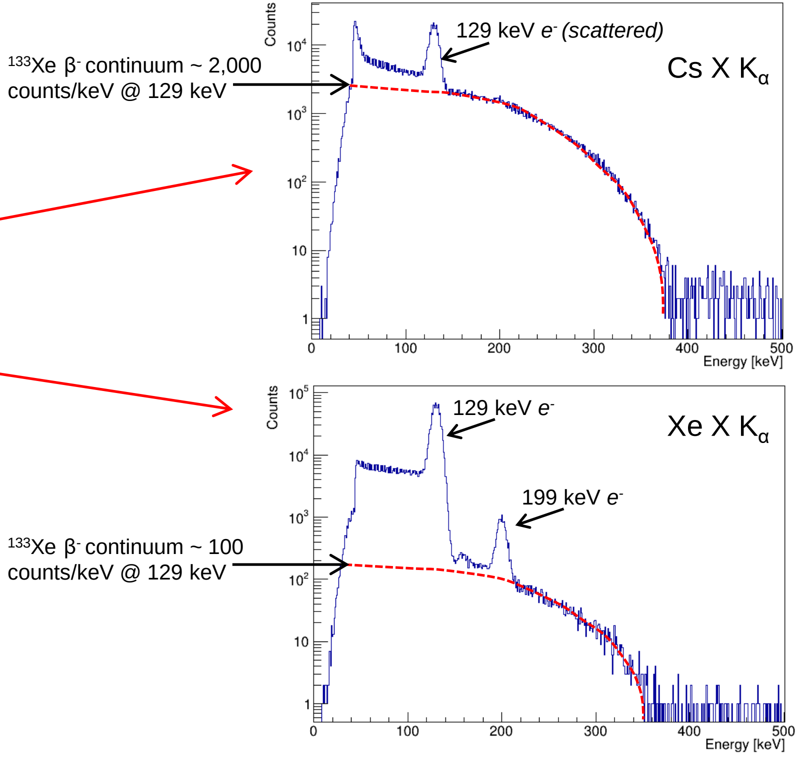


Fig. 6. Coincidence matrix and projected spectra using the X(K_α) energy gate for Cs and Xe

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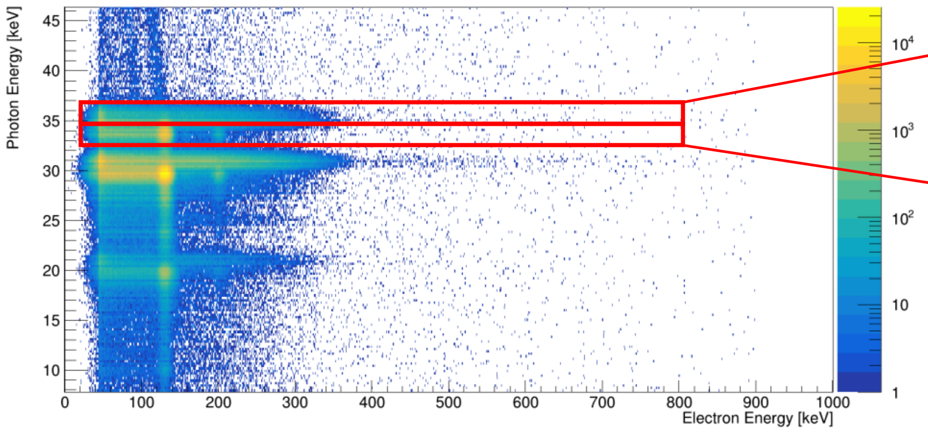
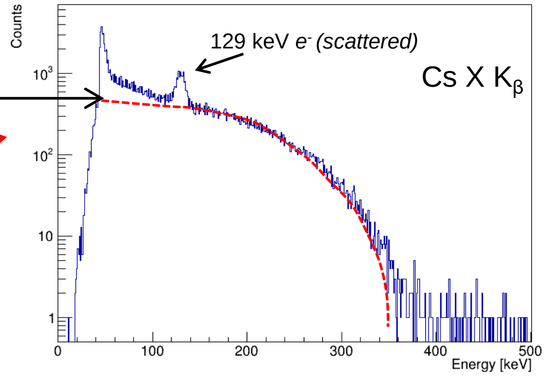
(Same can be applied to K_{β} X rays)





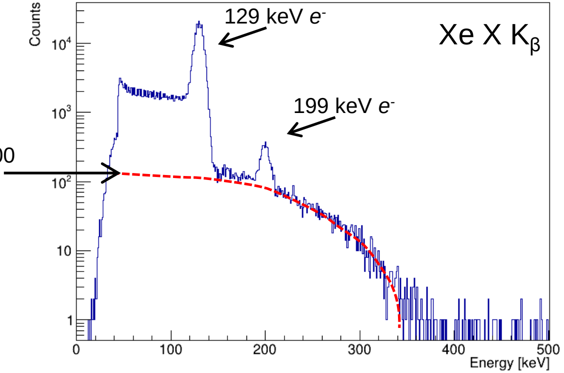


Fig. 7. Coincidence matrix and projected spectra using the $X(K_{\beta})$ energy gate for Cs and Xe

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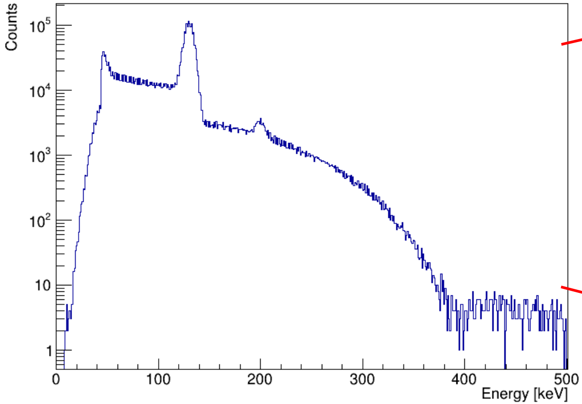
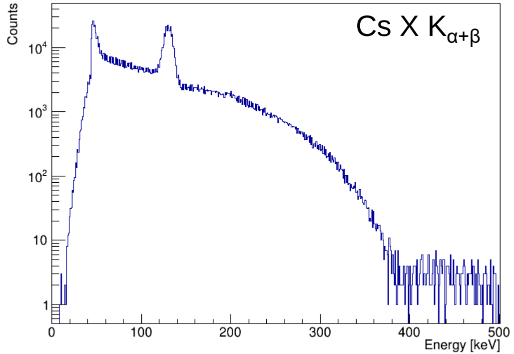
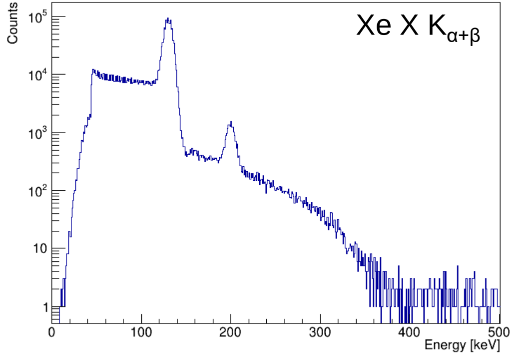
Total X-ray gate: 20-40 keV (a low resolution photon spectrometer)



‘Optimised energy-gated coincidence spectra’





More selective signals means less interference.

Summing projections means greater detection efficiency.

Fig. 8. Optimising the signal by summing spectra from multiple photon energy gates

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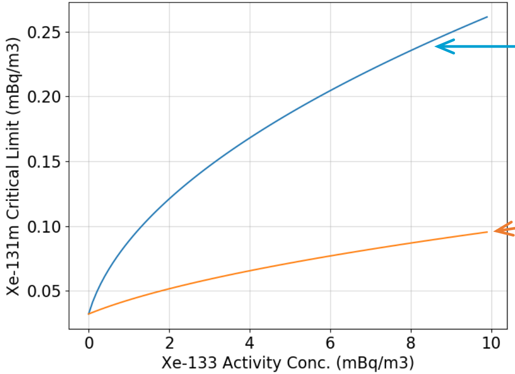
- ^{133}Xe is prevalent in the atmosphere due to civil nuclear processes contributing to the global radioxenon background, and high-activity ^{133}Xe samples are often measured on the IMS.
- ^{131m}Xe is an important radionuclide - because the 3-isotope ratio plots do NOT allow for clear discrimination between a nuclear explosion and a civil source in many cases
- On the 4-isotope ratio plot, ^{133m}Xe/^{131m}Xe is the most effective way to determine the possible source 'type' from IMS radioxenon measurements
- High-resolution spectroscopy means the effect from ^{133}Xe on the detection limit of ^{131m}Xe and ^{133m}Xe is reduced.
- Both metastable isomers are more readily detected using β-γ coincidence, rather than γ-singles



Isotope	4π MDA (mBq)
^{133}Xe	1.0
^{131m}Xe	1.0
^{133m}Xe	1.0
^{135}Xe	4.0

Fig. 9. Detection limit (critical limit - L_c) of ^{131m}Xe as a function of the ^{133}Xe measured activity concentration

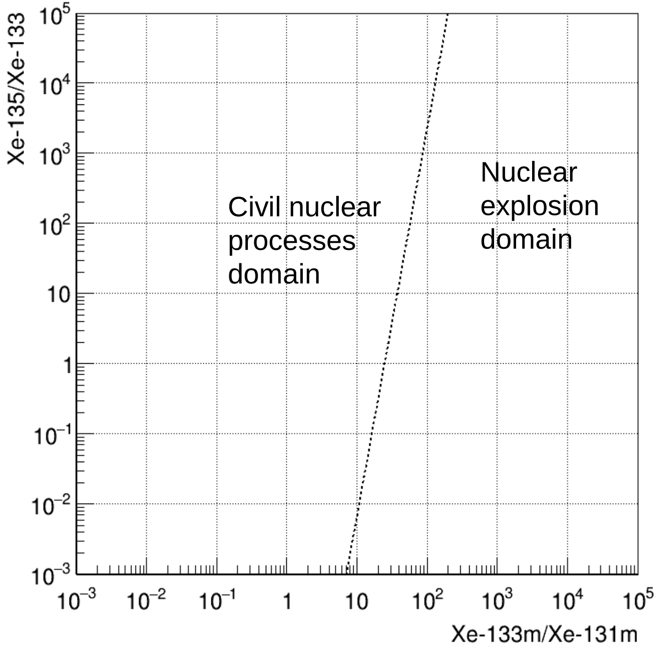


Fig. 10. 4-isotope ratio plot showing the civil nuclear domain and explosion domain.

See Kalinowski *et al*. for more information on the 4-isotope ratio plot. https://doi.org/10.1007/s00024-009-0032-1

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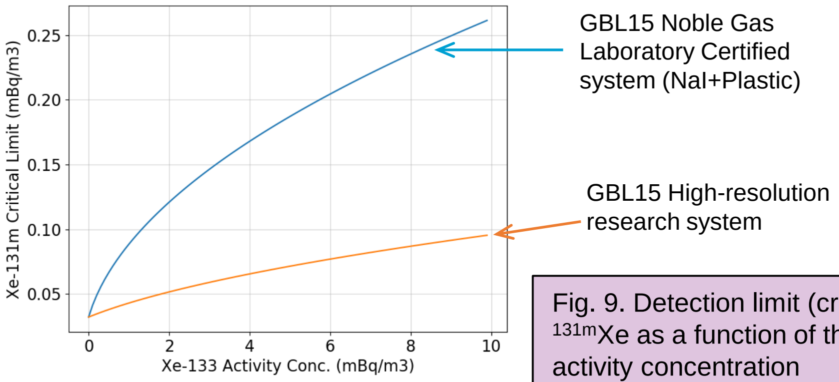
- Improved sensitivity of ^{131m}Xe in real/environmental samples can enhance our dataset during an event of interest. Re-measurement at a laboratory could IMPROVE the sensitivity compared to the station, for some isotopes. With delayed re-measurements, perhaps the laboratories can detect isotopes that *were not* detected in the station measurement…



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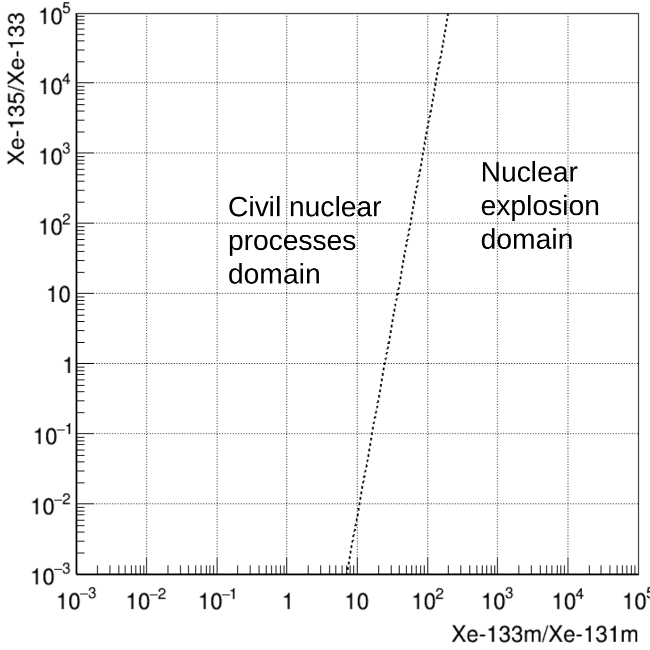

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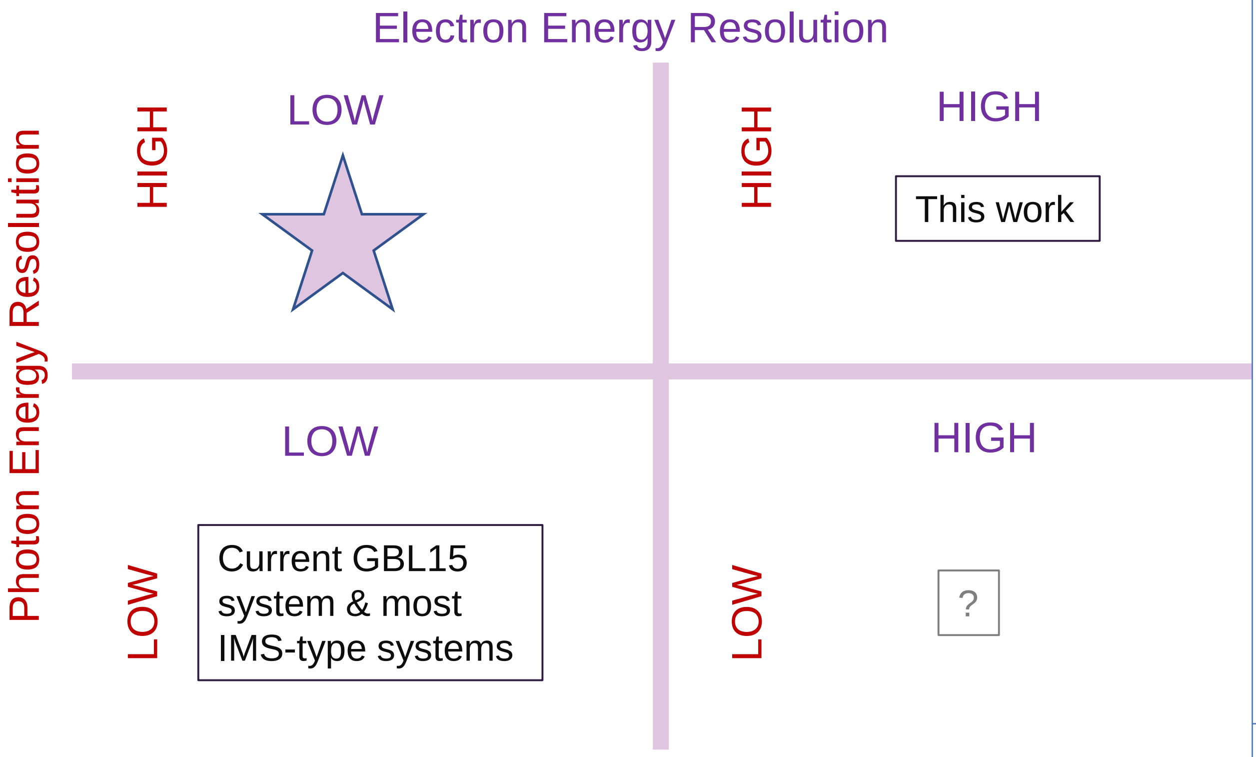

- High-resolution photon detectors provides the signal discrimination required (Cs X-rays / Xe X-rays)
- High-resolution electron detectors improve discrimination of ^{131m}Xe and ^{133m}Xe but this is not the most important interference
- Low-resolution electron detectors are more efficient
- Beginning GEANT4 simulations of HPGe+Plastic scintillator coincidence setup
- New measurements with SAUNA/Xe-I beta-cell and GBL15 HPGe detectors

New measurements have recently been published:
Qi Li et *al.* Nuclear Inst. And Methods in Physics Research, A 988 (2021) 164939

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Conclusions and Future Work

- Detector geometry has been optimised to improve detection efficiency by enclosing the PIPSBox with two HPGe detectors.
- High-resolution β-γ coincidence spectrometry can improve sensitivity to metastable isomers ^{131m}Xe & ^{133m}Xe with a high background signal of ^{133}Xe, when compared to a NaI(Tl)+Plastic set up.
- High-resolution γ-ray detector means it is possible to resolve Cs and Xe X-rays and create separate projections
- Signals from K_{α} and K_{β} can be used selectively and the projections summed
- PIPSBox geometry is excellent for getting near-4π geometry.
- More work required to determine whether the drop-off in detection efficiency is worth the enhanced electron energy resolution – *Testing plastic+HPGe system* with measurements and GEANT4 simulations.

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Thanks to those that have contributed to this project:

Marc Abilama (NPL), Rob Shearman (NPL), John McLarty (AWE), Graham Galvin (AWE), Phill Scivier (AWE)

Please visit the corresponding poster:
Measurement of gaseous fission products on an electron-photon coincidence detector system
(P3.1-485)