

Designing coincidence γ -ray spectrometers with optimized minimum detectable activity

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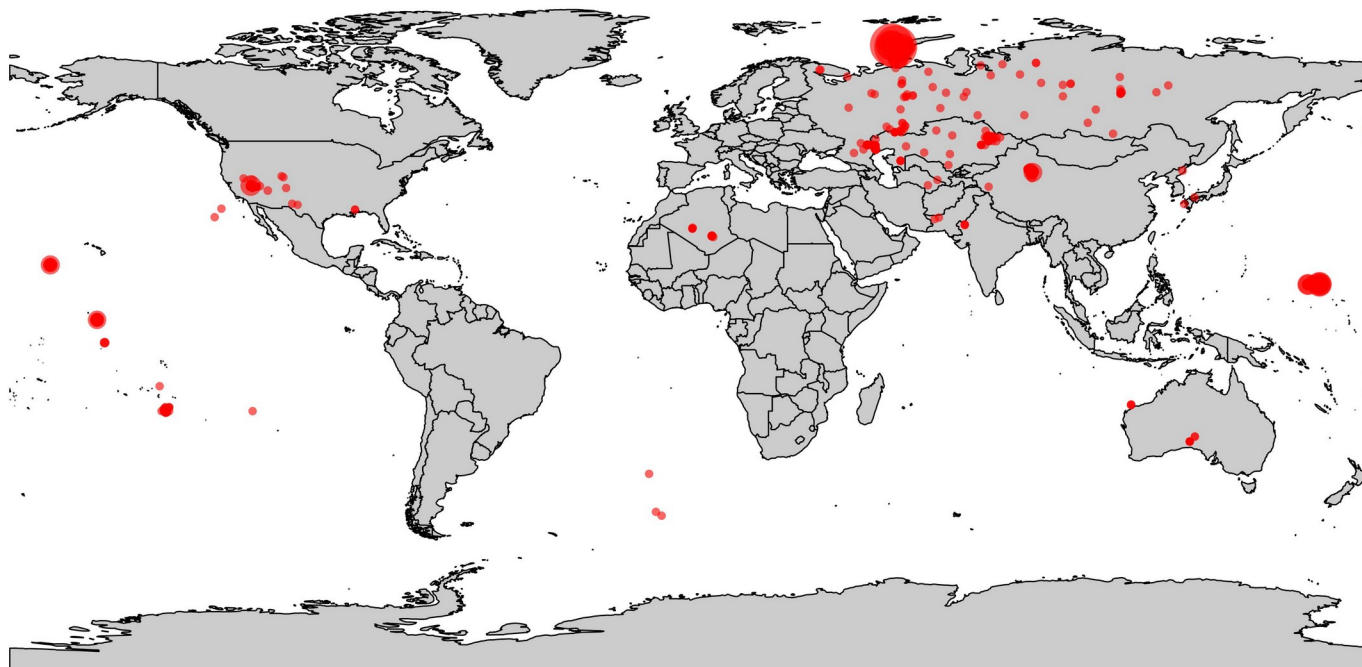
UPPSALA
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Applied Nuclear Physics, Physics and Astronomy, Uppsala University

May 8, 2026

15th Nordic Meeting on Nuclear Physics, Visby, Gotland

>2000 nuclear explosions



How tests are detected

Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)

Release of
radioactive fission
products



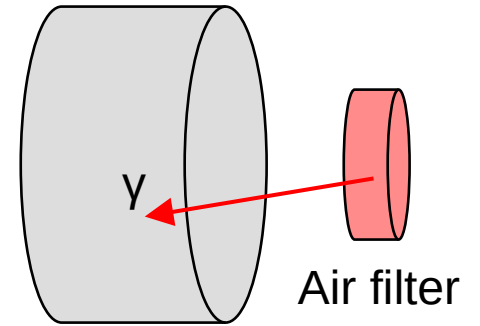
A simple air sampler at UU

How tests are detected

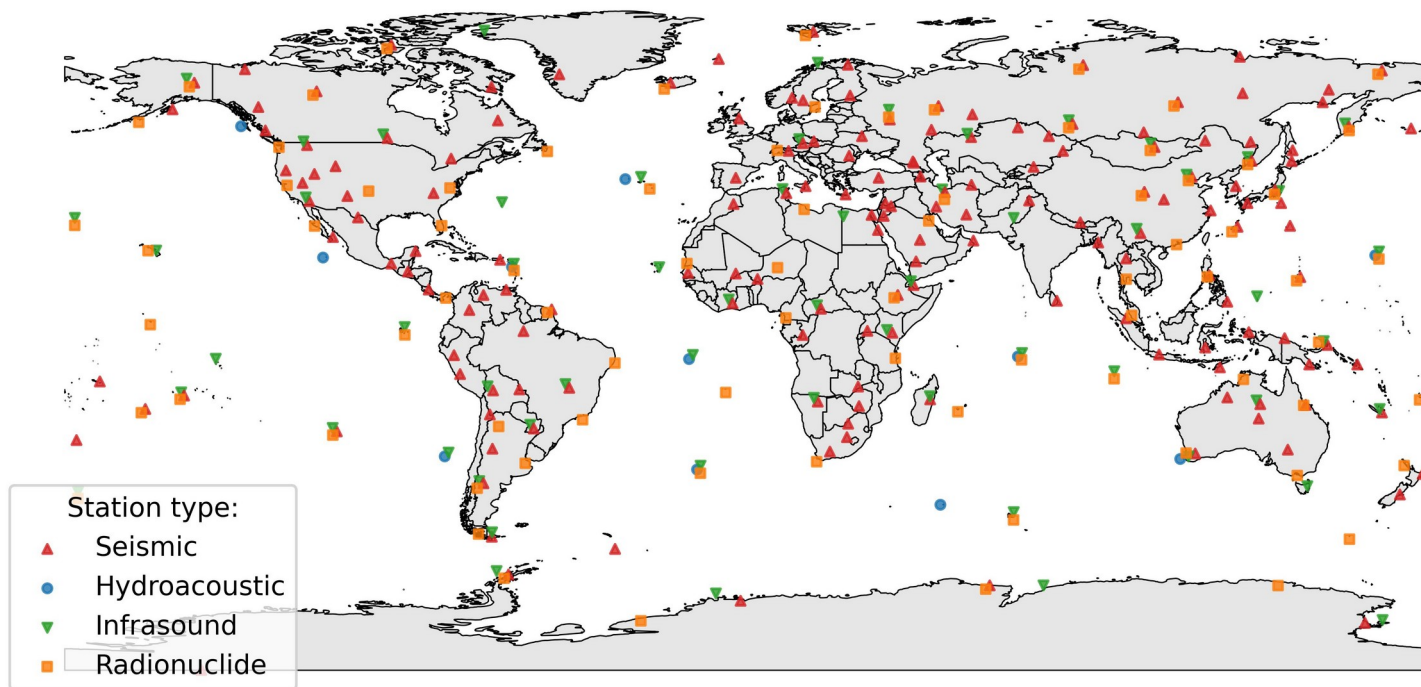


Air sampler at UU

HPGe detector

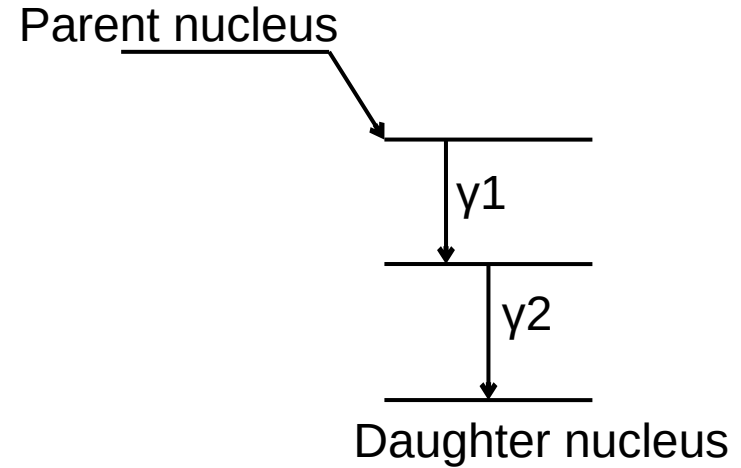
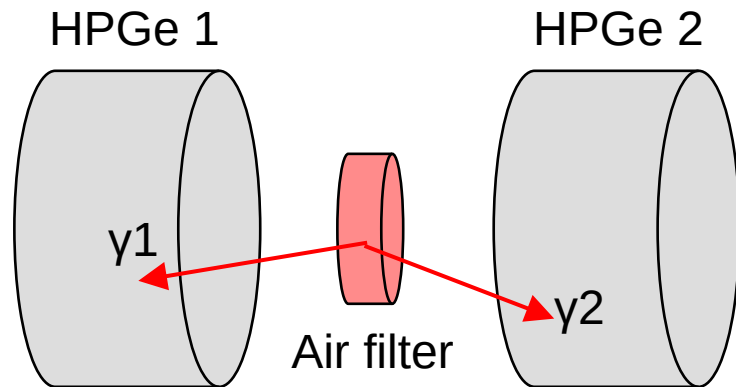
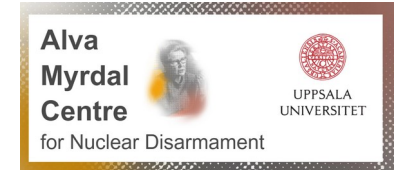


The International Monitoring System (IMS)



The CoSpeR project

CoSpeR: Coincidence Spectrometry for Radionuclide Monitoring



Measuring detector performance

The minimum detectable activity

$$MDA = \frac{L_D}{\varepsilon_{\gamma\gamma} I_{\gamma\gamma} t_M}$$

$$L_D \approx 2.71 + 4.65\sqrt{B}$$

(detection limit)

$\varepsilon_{\gamma\gamma}$ (absolute efficiency)

$I_{\gamma\gamma}$ (intensity)

t_M (measurement time)

MDA

Compared to a
single detector:

Lower

Lower

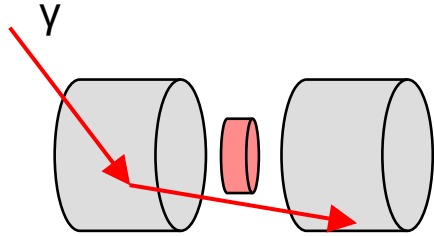
About the same

The same

Lower?

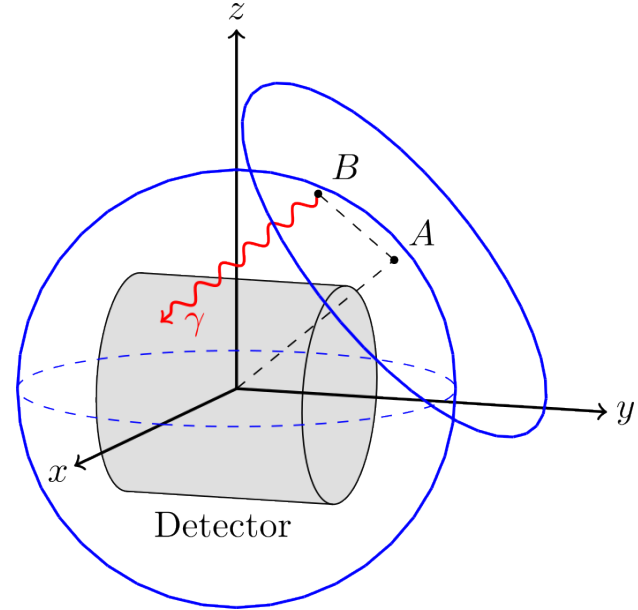
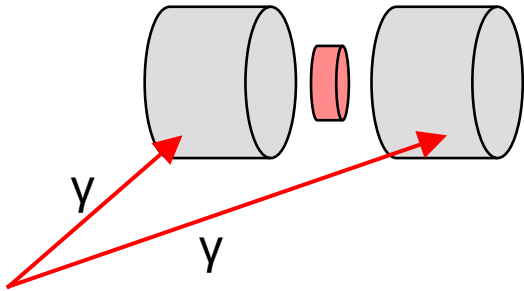
→ Develop method to simulate MDA for coincidence detectors (in Geant4)

Simulating background radiation



Dominant background (usually)

Negligible background (usually)



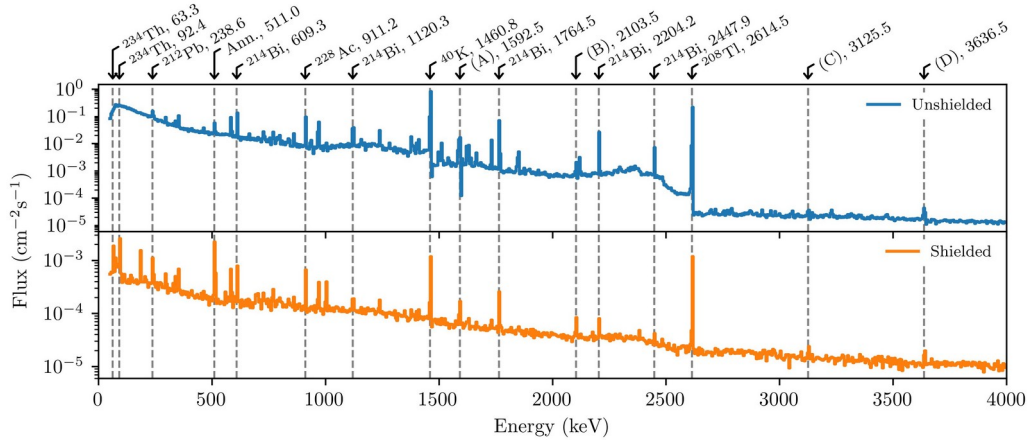
The SURE (Spherical Uniform Radiation Environment) model

$$\psi = \frac{N_{\gamma}}{r^2 \pi}$$

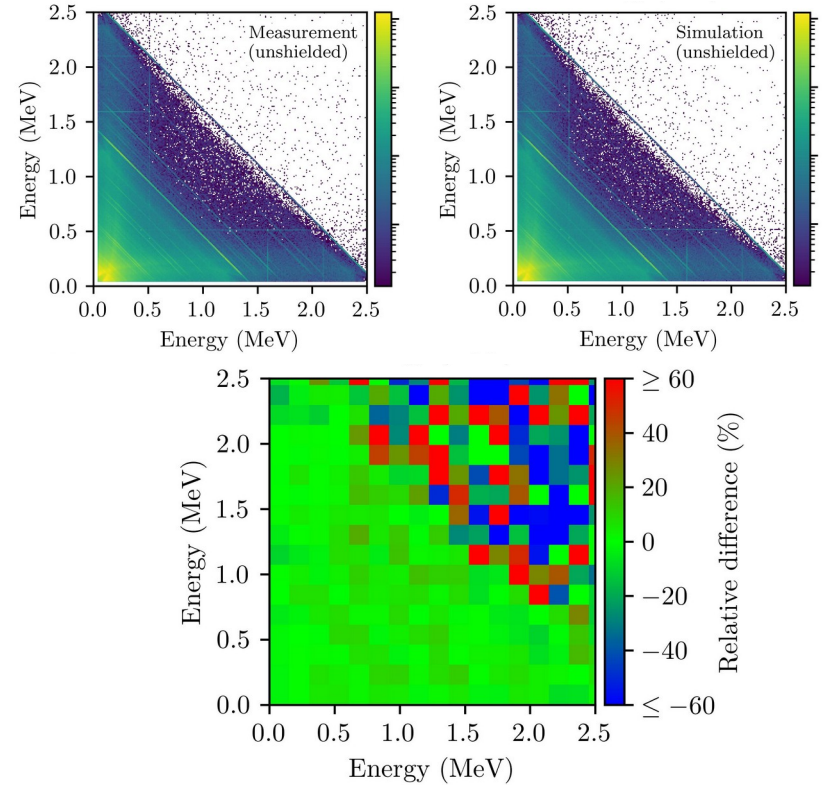
Simulating background radiation



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Unfolded SURE source spectrum from experimental data

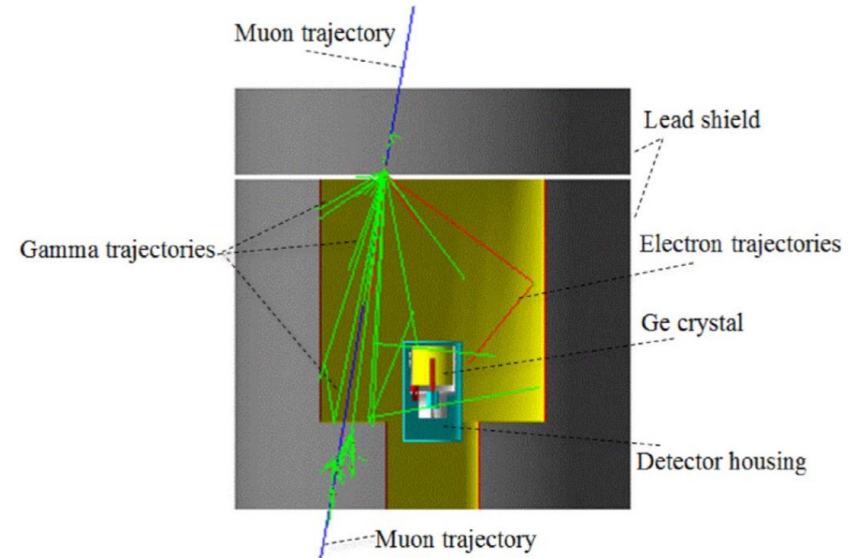
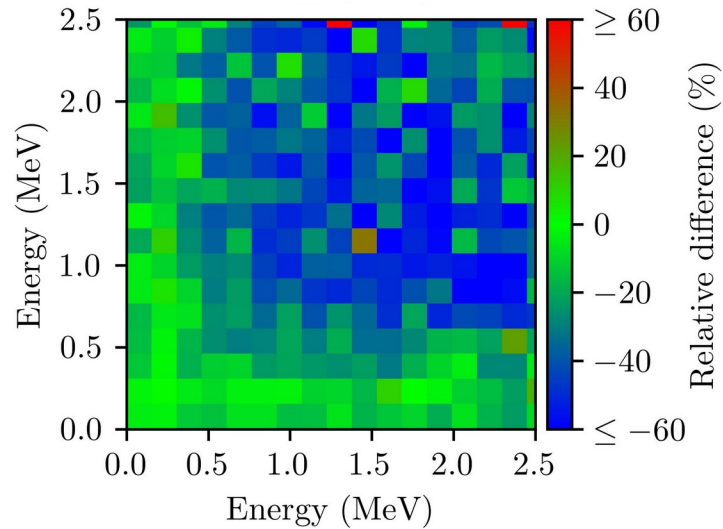


Does the SURE model work?

Simulating background radiation



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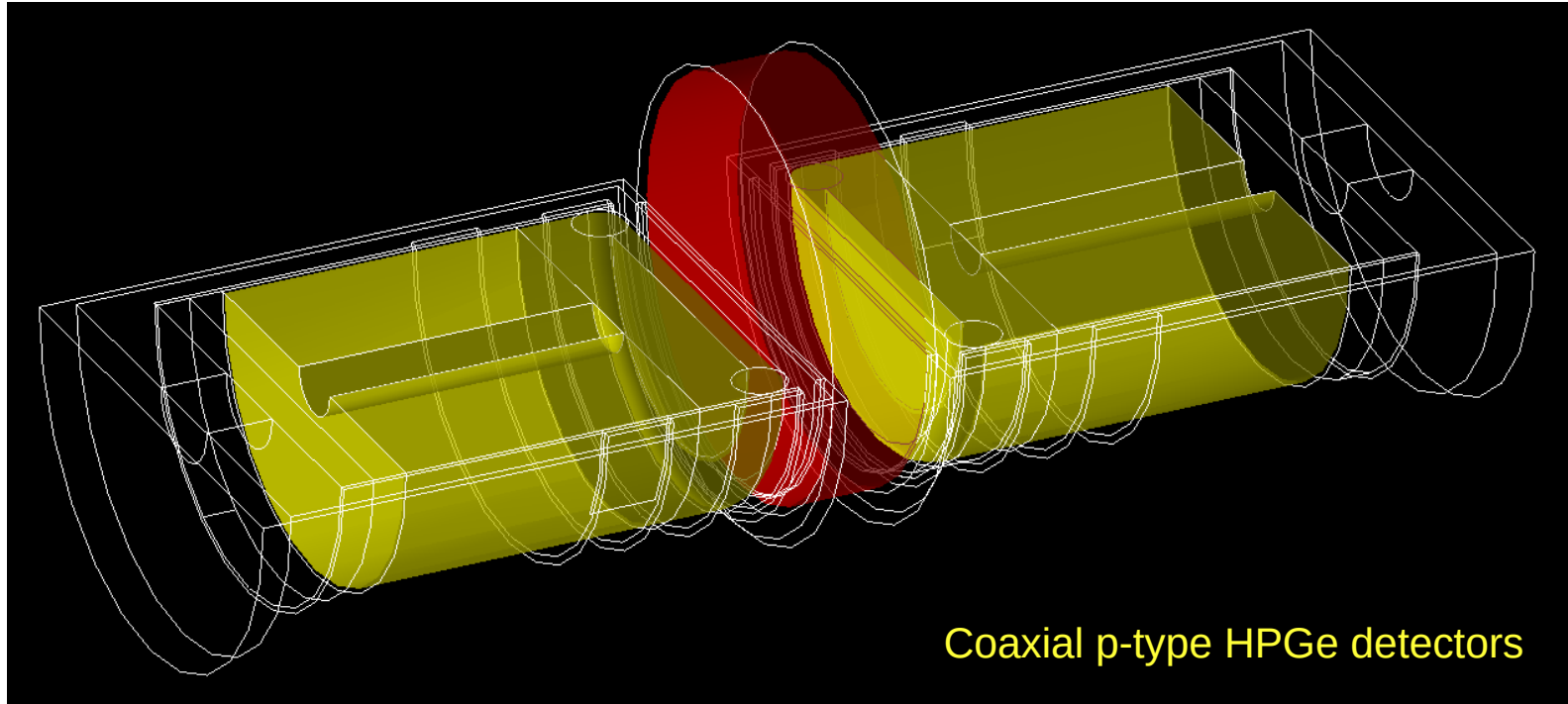


N.Q. Hung *et al.*

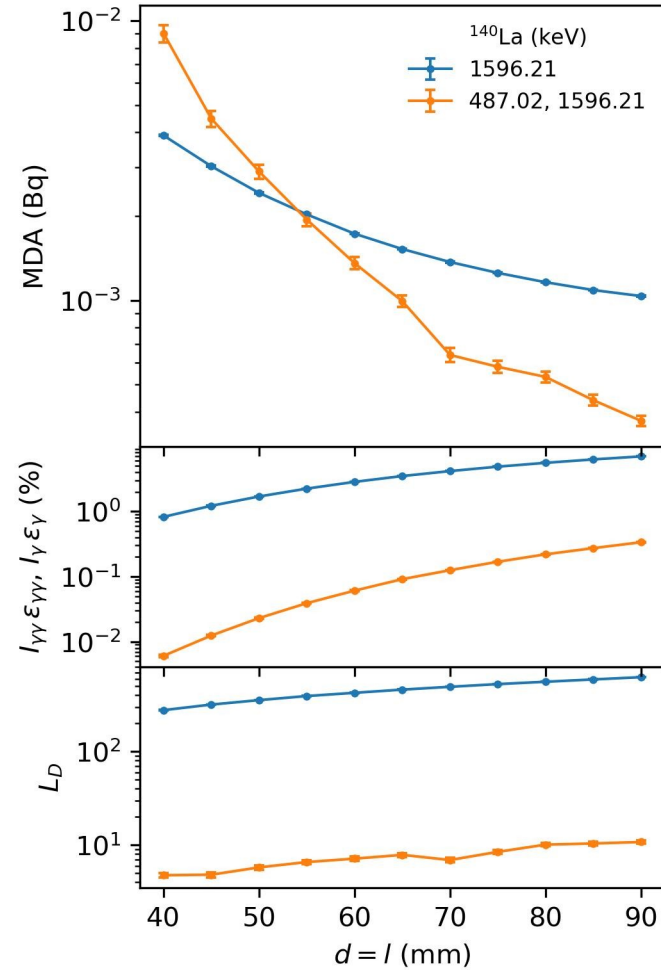
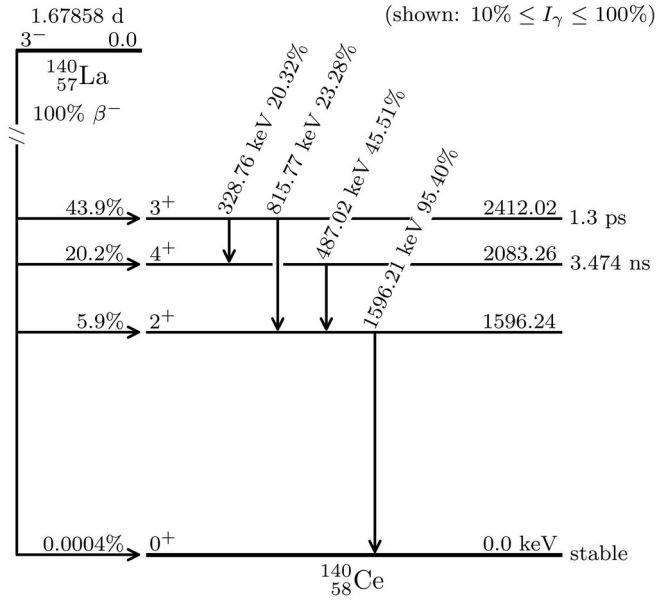
<http://dx.doi.org/10.1016/j.apradiso.2016.12.047>

Limited performance in shielded environments:
SURE model underestimates by about 40%

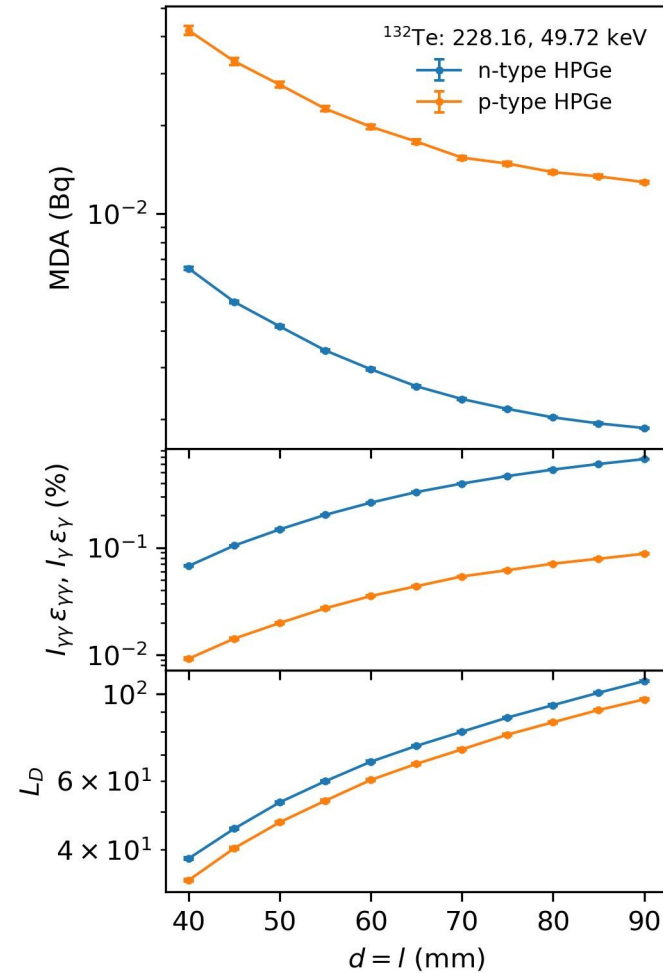
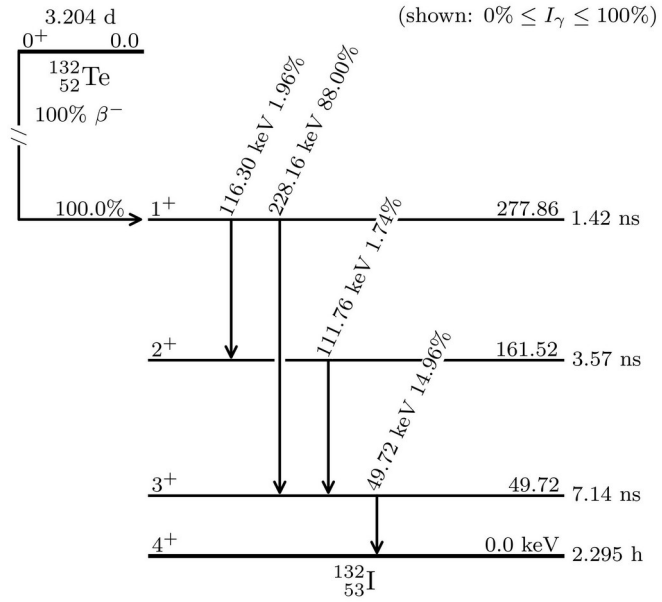
A dual-detector setup



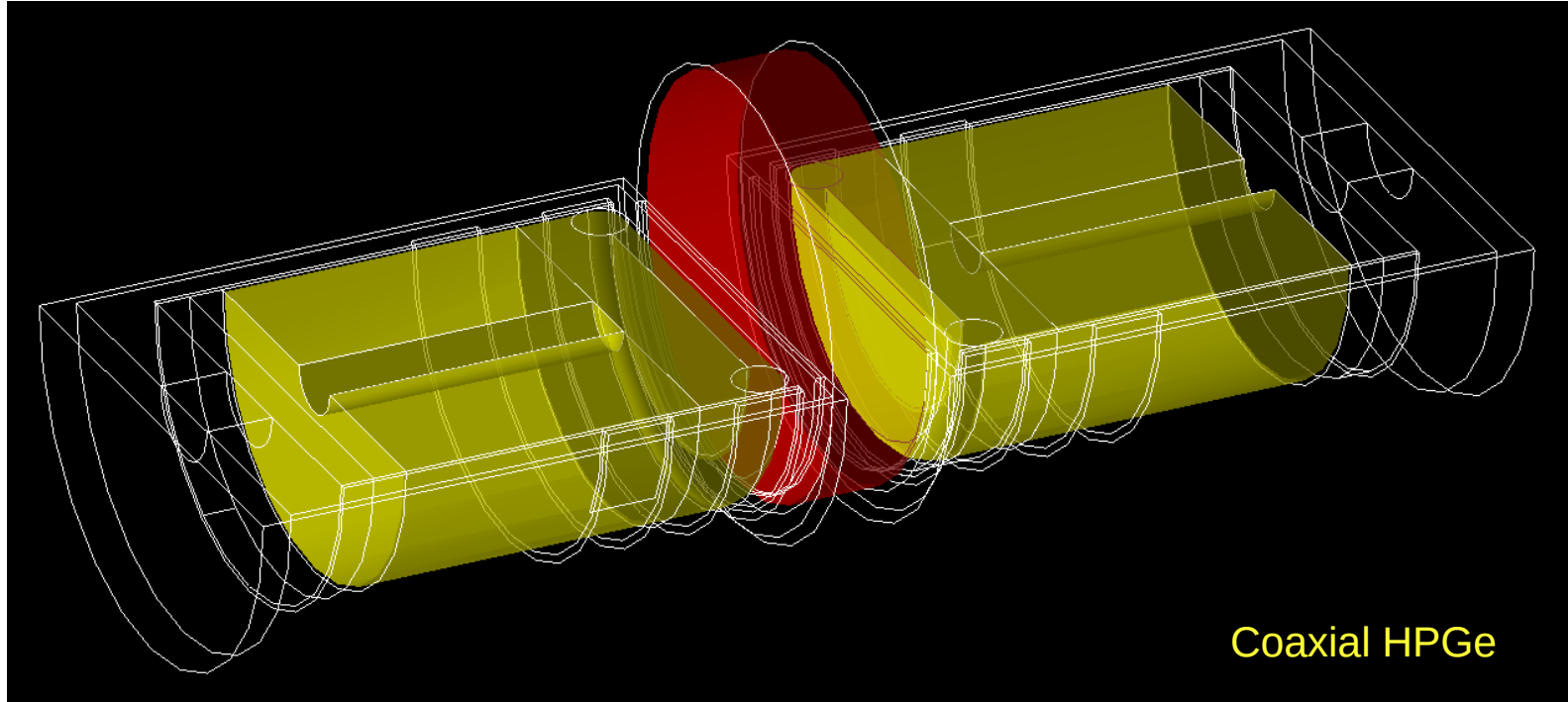
A dual-detector setup



A dual-detector setup

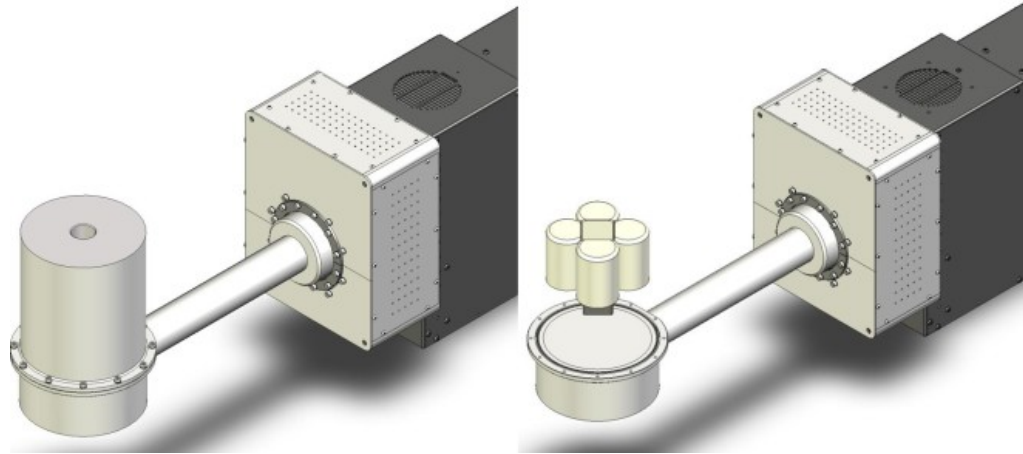


A dual-detector setup

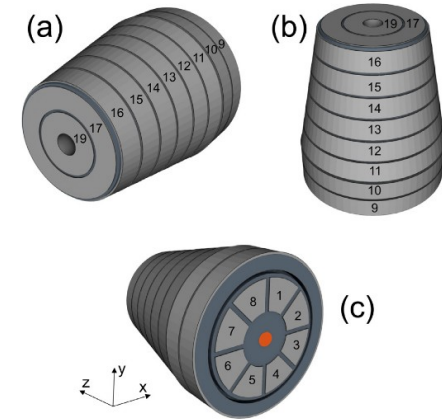


Coincidences are (usually) better.
Bigger is (usually) better.
An n-type is (usually) better.

Next: more complex detectors



Mirion Technologies



F.J. Pearce *et al.*
<https://doi.org/10.1016/j.nima.2021.166044>

Thank you for your attention!

Summary

- CoSpeR: coincidence spectrometry for radionuclide monitoring
- Simulate MDA (background and efficiency)
- The SURE background model seems to work well in unshielded environments
- Parametric design optimization of detector designs

Advertisement for 5 ECTS PhD course:

Register by email: peter.andersson@physics.uu.se

Advertisement for PhD position:

Active neutron interrogation for nuclear disarmament verification

<https://www.uu.se/en/about-uu/join-us/jobs-and-vacancies/job-details?query=932444>



The course *Verification of nuclear test explosions* is provided by Uppsala University in collaboration with the Swedish Defence Research Agency (FOI).

Course information

- **Level:** Ph.D. course in physics, equivalent to 5 ECTS
- **Duration:** Week 36-44, 2026
- **Location:** Flipped classroom and an optional radionuclide detection lab in Ångström Laboratory, Uppsala
- **Format:** Lectures (≈14x90 min) and a laboratory exercise
- **Examination:** Oral examination, hand-ins



Castle Bravo Test, Image: U.S. Department of Energy, via Wikimedia Commons (public domain)

Prerequisites

- Fundamentals of nuclear physics
- Basic programming skills, preferably in Python

After completing the course, the participant shall be able to

- Account for treaties and verification regimes governing nuclear weapons,
- Identify remote signatures from nuclear explosions and account for techniques used to detect such signatures,
- Have basic understanding of seismic detection for nuclear explosion monitoring,
- Account for processes that give rise to atmospheric radioactivity and techniques used to measure it,
- Analyze data of atmospheric radioactivity in order to discriminate between natural sources, contributions from civil nuclear power and nuclear test explosions,
- Perform calculations of particle diffusions in the atmosphere using dedicated software tools, and
- Perform a cross-disciplinary analysis of a nuclear test explosion scenario, where incoming information is analyzed and evaluated using statistical analysis.

Register to peter.andersson@physics.uu.se no later than August 1st,

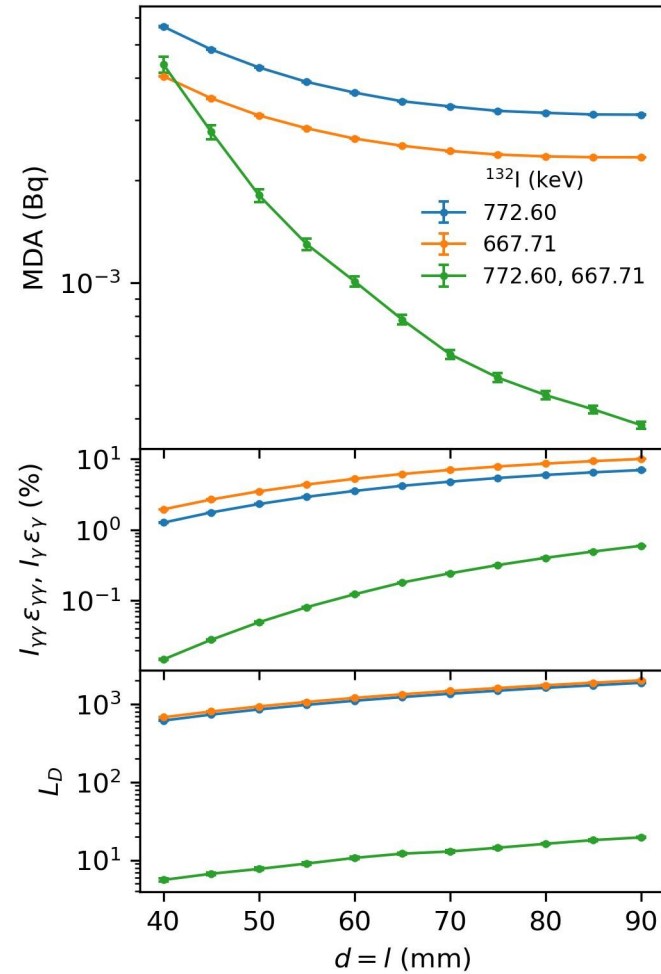
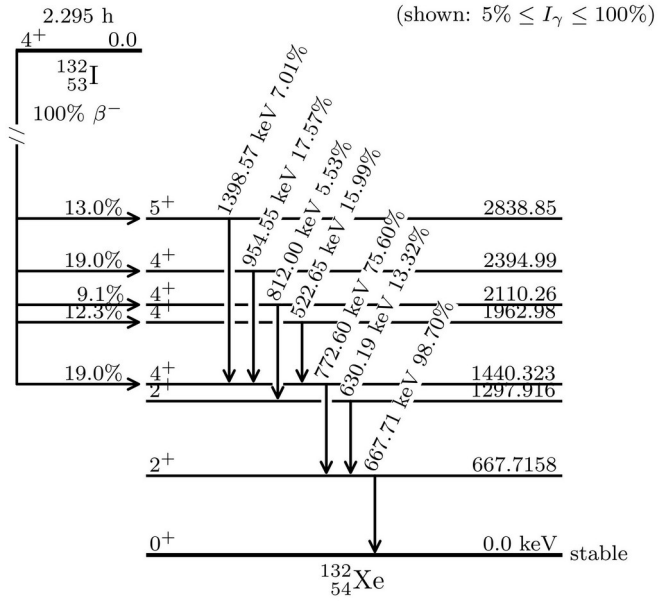
- with the topic Nuclear Verification
- and including your name and affiliation
- Personal number (Swedish citizens), passport number (others).

Use the same email address for questions about the course.



Backup slides

A dual-detector setup



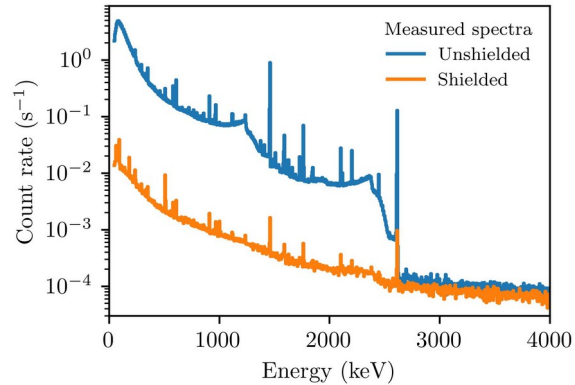
Simulating background radiation

Response function:

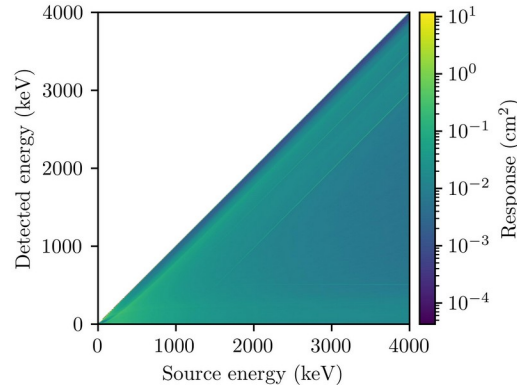
$$c(E) = \int_0^{\infty} R(E, E') s(E') dE'$$

Matrix form: $c = R s$

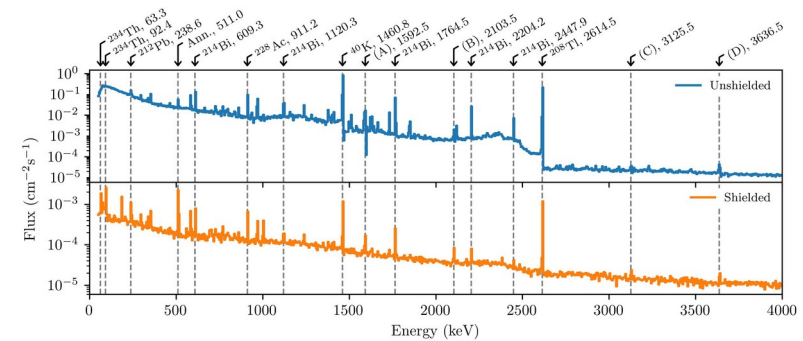
Measured spectrum



Simulated response function



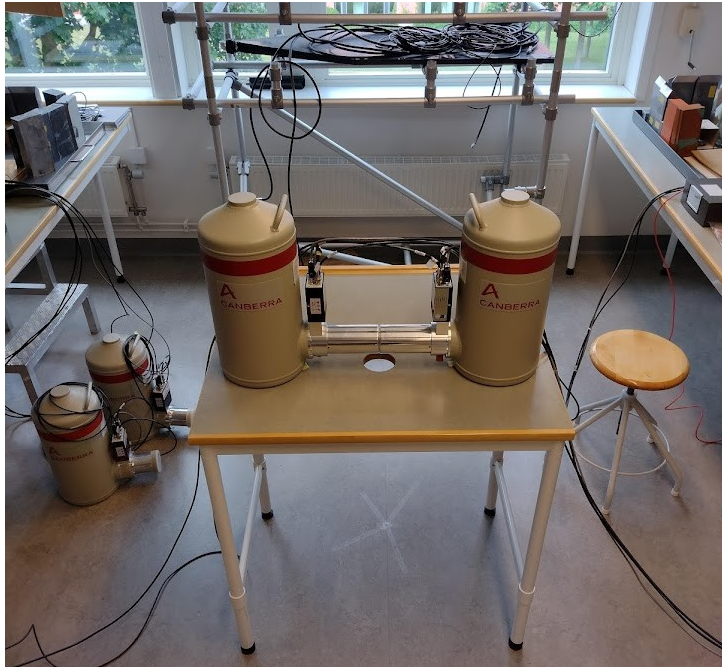
Solve for source spectrum



Simulating background radiation

Background in two cases:

Unshielded at UU

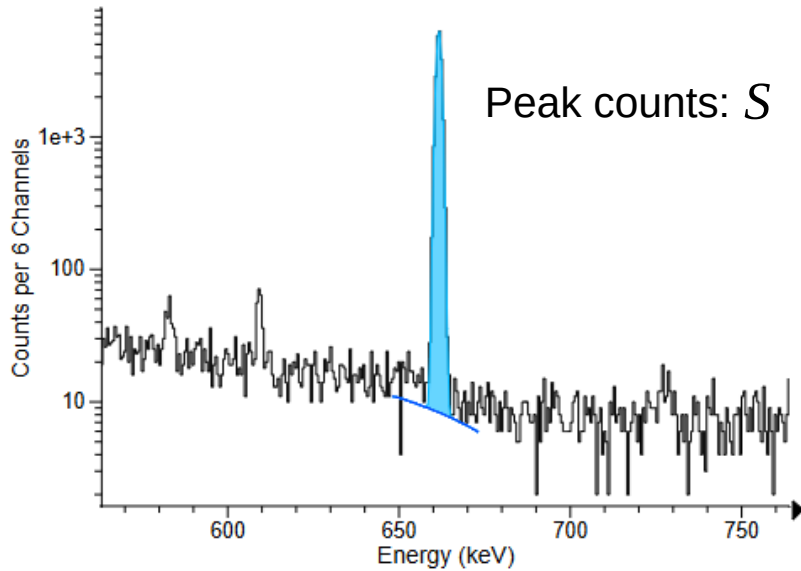


Shielded at FOI



Introduction

Quantifying detector performance



$$S/t = A I_\gamma \epsilon_\gamma$$

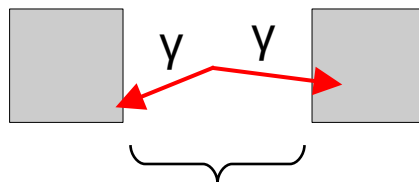
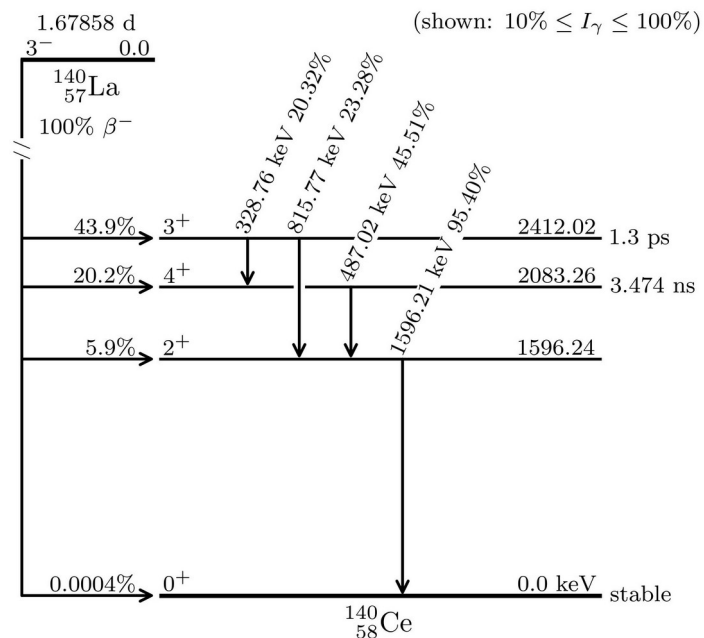
Peak count rate Activity Gamma intensity Detection efficiency

$$A = \frac{S}{I_\gamma \epsilon_\gamma t}$$

$$MDA = \frac{L_D}{I_\gamma \epsilon_\gamma t}$$

Minimum detectable activity Detection limit

Example



Distance d

$$MDA = \frac{L_D}{\epsilon_{\gamma\gamma} I_{\gamma\gamma} t}$$

