NUCLEAR FUEL IMAGING USING POSITION-SENSITIVE DETECTORS

Santeri Saariokari
santeri.saariokari@helsinki.fi
Helsinki Institute of Physics

Peter Dendooven
peter.dendooven@helsinki.fi
Helsinki Institute of Physics

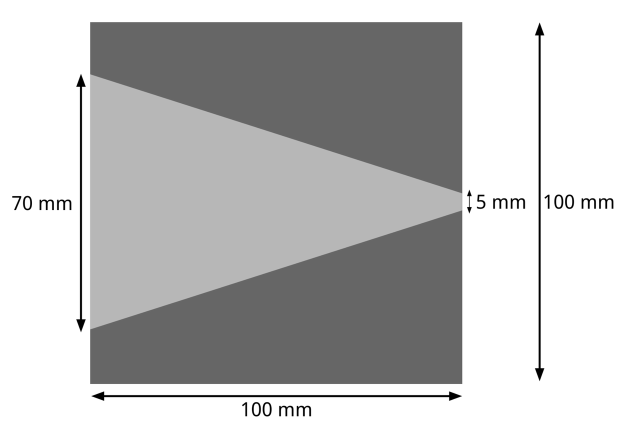
Erik Brücken
jens.brucken@helsinki.fi
Helsinki Institute of Physics

INTRODUCTION

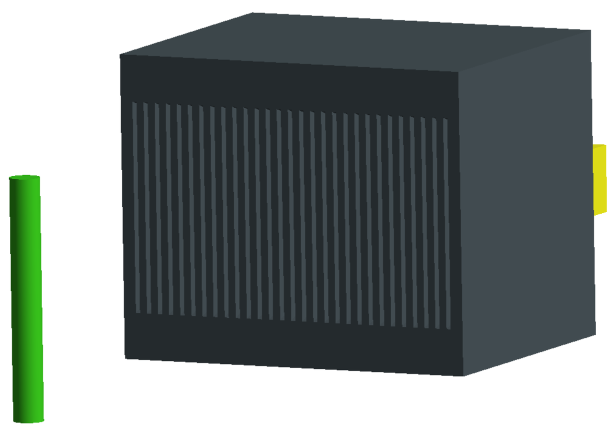
- Finland will start storing its spent nuclear fuel in a deep geological repository in 2025, with Passive Gamma Emission Tomography (PGET) measurements being an integral part of nuclear safeguards at the repository [2].
- The International Atomic Energy Agency (IAEA) approved the PGET device in 2017 for characterizing spent nuclear fuel assemblies (SFAs) for nuclear safeguards purposes.
- Recent advancements in detector technology may offer a method to extend the capabilities of such devices, also beyond standard safeguard applications.
- Employing larger cadmium zinc telluride (CZT) detectors increases the probability of capturing the full energy of gamma rays, enhancing the sensitivity of the PGET device and the quality of the reconstructed images.
- Pixelation improves the spatial resolution of the system, possibly allowing the usage of Compton imaging.

SIMULATION SPECIFICATIONS

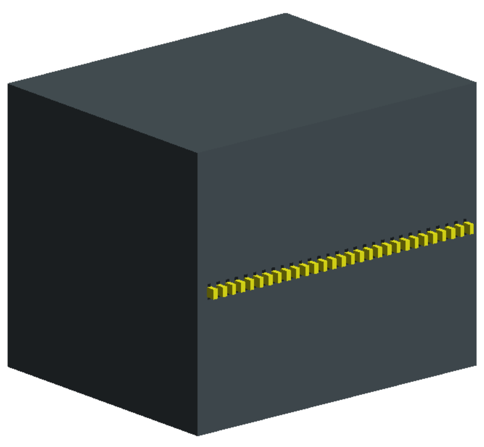
- The simulation geometry consists of
  - Homogenous cylindrical gamma radiation source
  - Tungsten alloy collimator: $_{74}$W (95%), $_{28}$Ni (3.5%), $_{29}$Cu (1.5%)
  - CZT crystals with one of the following sizes:
    - Current device: 3.5 mm x 1.75 mm x **3.5 mm**
    - Proposed configuration 1: 22 mm x 10 mm x **22 mm**
    - Proposed configuration 2: 22 mm x 22 mm x **10 mm**



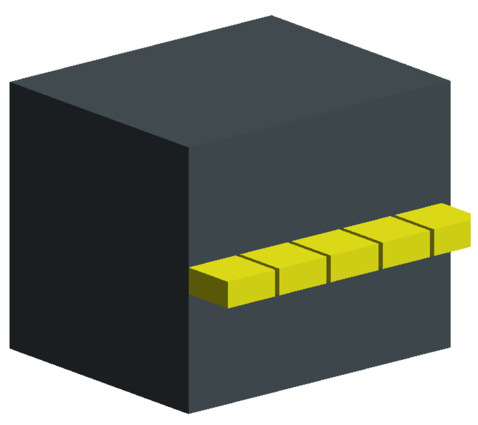
Schematic image of the collimator



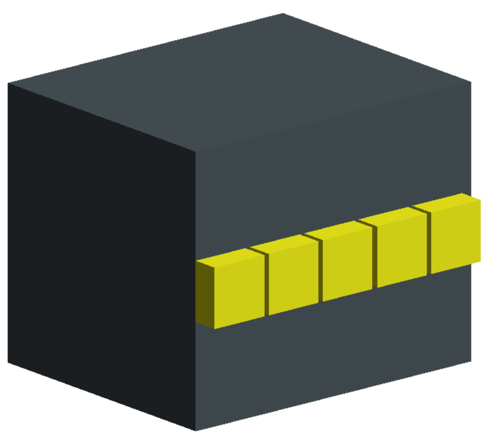
Front view of the collimator and source



Current crystal size



Large crystal, orientation 1

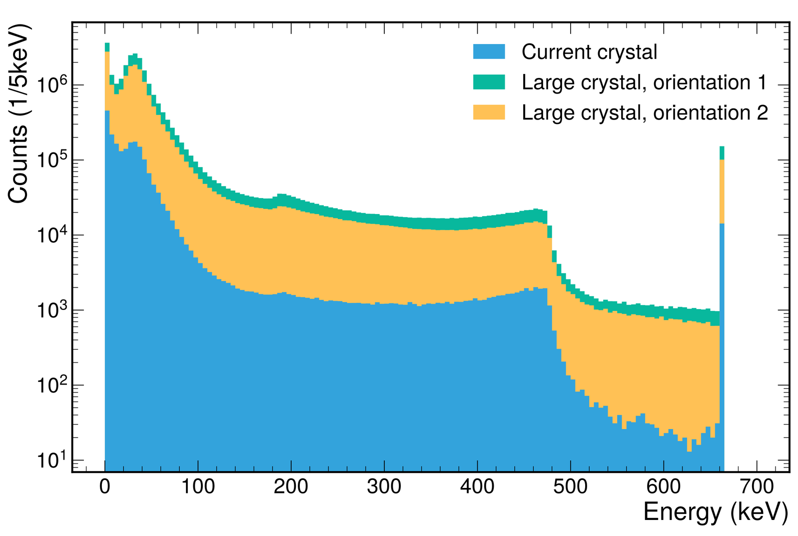


Large crystal, orientation 2

- Implementation using Geant4 with the following physics lists:
  - `G4EmStandardPhysics_option4`
  - `G4DecayPhysics`
- Production cuts:

Material	λ (µm)	E_γ (keV)	E_{e^-} (keV)
CZT	10	2.4	43
Collimator	10	7.2	79
Air	10	0.99	0.99

ENERGY SPECTRA



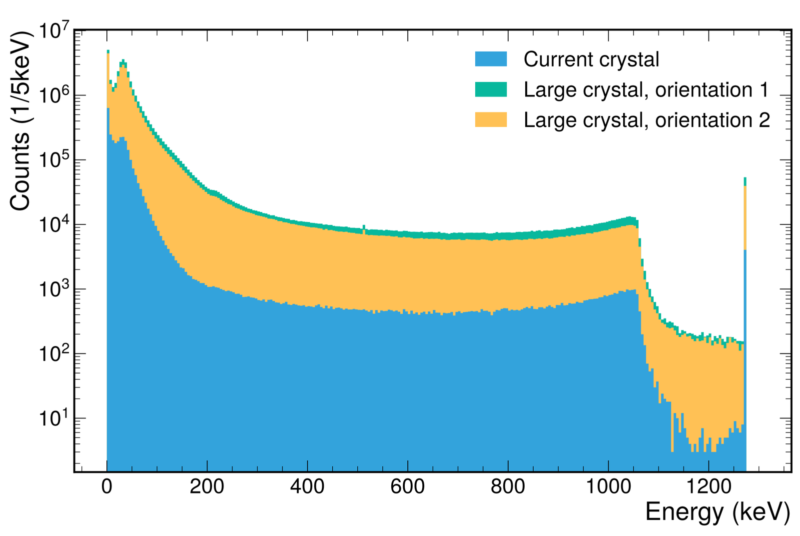


Figure: Deposited energy per event for ^{137}Cs (left) and ^{154}Eu (right)

PROCESS FREQUENCY

- 200 million gamma rays are generated towards the collimator from the cylindrical source.
- Events are categorized by the number of Compton scatterings (CS) and photoelectric effects (PE) in the CZT detectors.
- Only primary events where a ^{137}Cs gamma interacts with the crystal are considered.

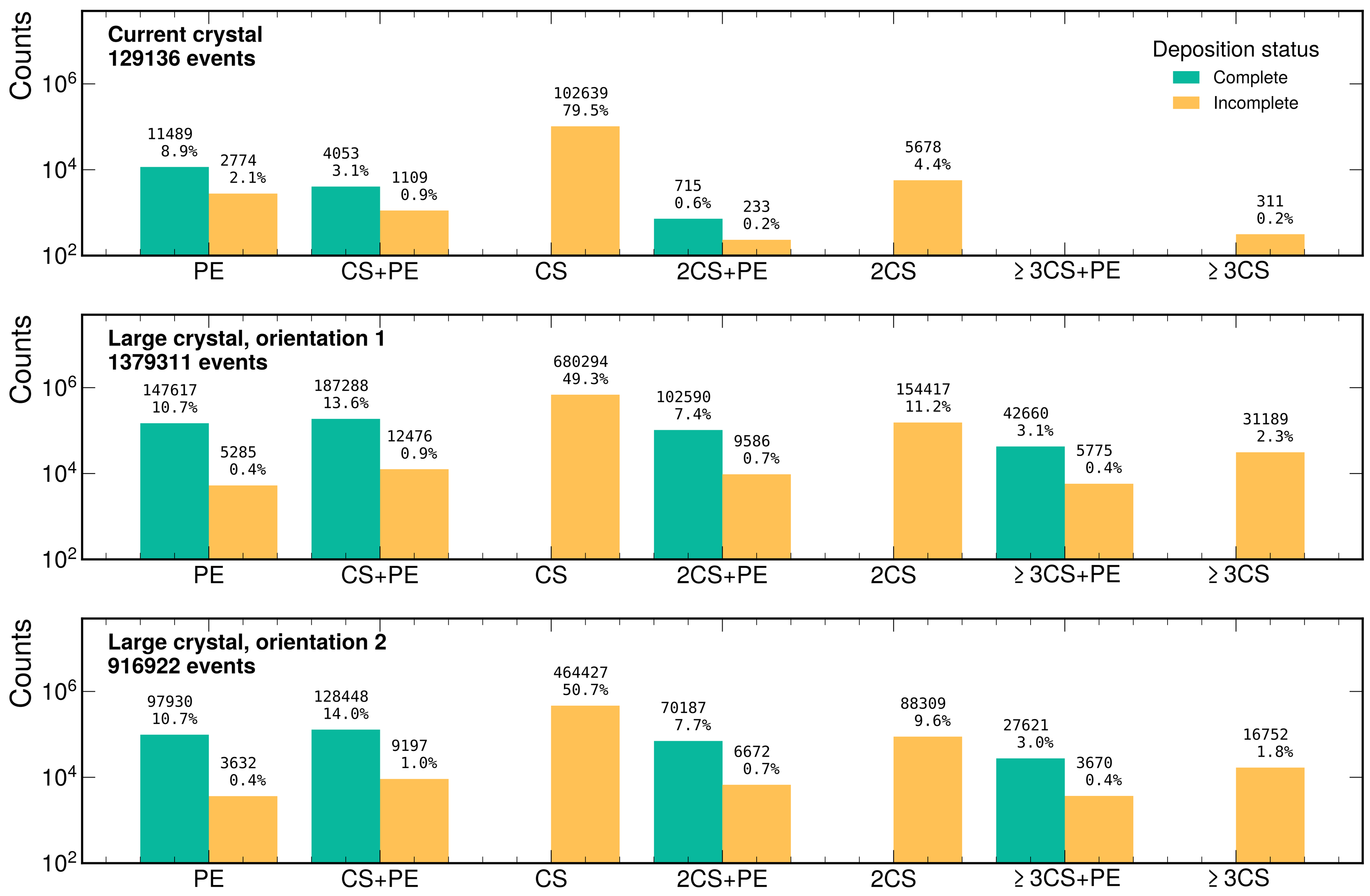


Figure: Number of processes for ^{137}Cs source

COMPTON IMAGING

- Point-like source at $x = 70\,\mathrm{mm}$, $y = 0\,\mathrm{mm}$, $E_\gamma = 661.6\,\mathrm{keV}$
- Large crystal size with orientation 1
- Imaging plane is parallel to the front face of the collimator

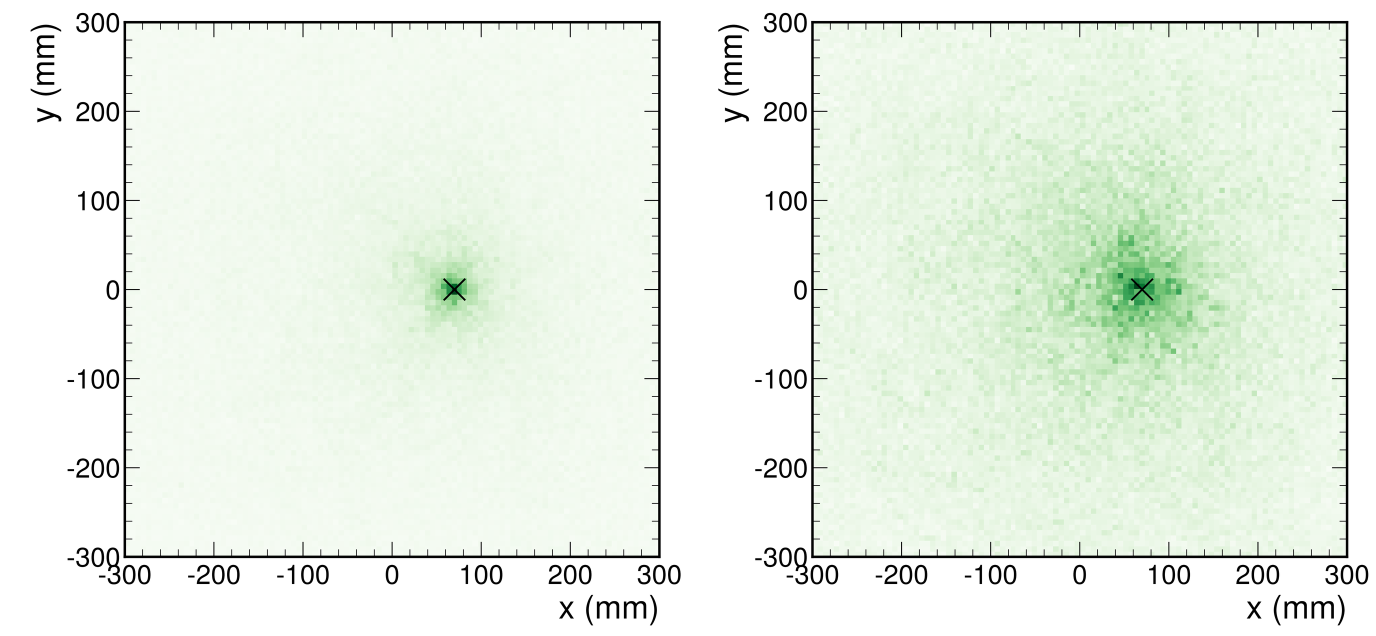


Figure: Compton image derived using the MC truth (left) and after implementing the detector energy and spatial resolution (right)

- The used smearing resolution is compatible with a commercial device supporting the simulated crystal sizes [1].
  - Location 0.635 mm RMS, depth 0.357 mm RMS, energy 2 % RMS

CONCLUSIONS

- We compared the energy absorption of larger CZT crystals to presently installed small crystals. Results show an enhanced probability for full absorption of gamma rays.
- Fraction of "golden events" for ^{137}Cs is increased from 3.1 % to 13.6 % and 14.8 % for orientations 1 and 2, respectively. For ^{154}Eu, the similar increase is from 1.3 % to 7.4 % and 7.6 %.
- Interaction probability is higher for orientation 1 when measuring ^{137}Cs, but higher for orientation 2 when measuring ^{155}Eu.

REFERENCES

[1] *GDS-100*. URL: https://ideas.no/products/gds-100.
[2] *Posiva Oy*. URL: https://www.posiva.fi/en.

UNIVERSITY OF HELSINKI
FACULTY OF SCIENCE