‘Low power, compact, dual mode detectors for nuclear security applications’

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Introduction

- Current technology for detecting neutrons and gammas consists of a combination of a plastic scintillator and a ^{3}He detector.
- There is a need to replace ^{3}He as a method of neutron detection due to cost and decreasing global supply.
- The resulting detector needs to be both low power and robust for field requirements.
- It is possible to detect both gammas and neutrons using pulse shape discrimination (PSD).
- Two dual-mode scintillators are currently under investigation - CLLBC and EJ-276.

Figure 1: A picture of the plastic scintillator EJ-276 (left) and inorganic scintillator CLLBC (right).

Introduction

- Whichever scintillator is used, the light produced needs to be converted into an electrical signal.

- Photomultiplier Tubes (PMT) are currently being used in the lab setup due to their inherent stability.

- However, we aim to use Silicon Photomultiplier (SiPMs) in the future, as these meet the criteria of being low power and robust.

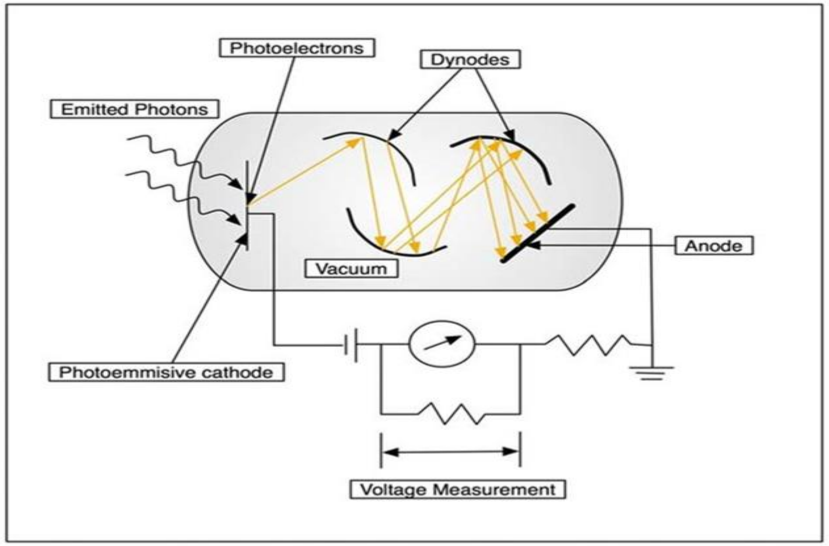

Figure 2: A diagram of a photomultiplier tube [1].

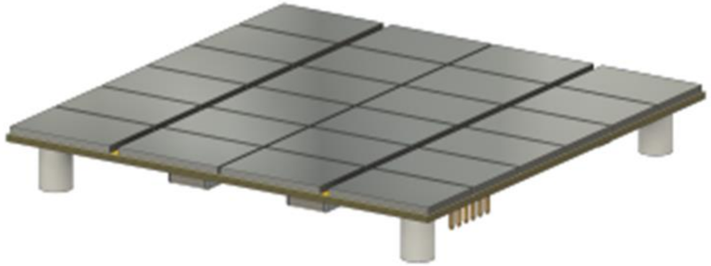

Figure 3: An image of a Silicon Photomultiplier array [2].

Theory – Inorganic Scintillation

- CLLBC (Caesium, Lanthanum, Lithium, BromoChloride) is an inorganic scintillator with a light output of ~45,000 photons per MeV.

- Inorganic scintillators produce photons due to the band gap structure which results from the crystal lattice of the material.

- CLLBC is mainly sensitive to thermal neutrons through thermal capture on ^{6}Li.

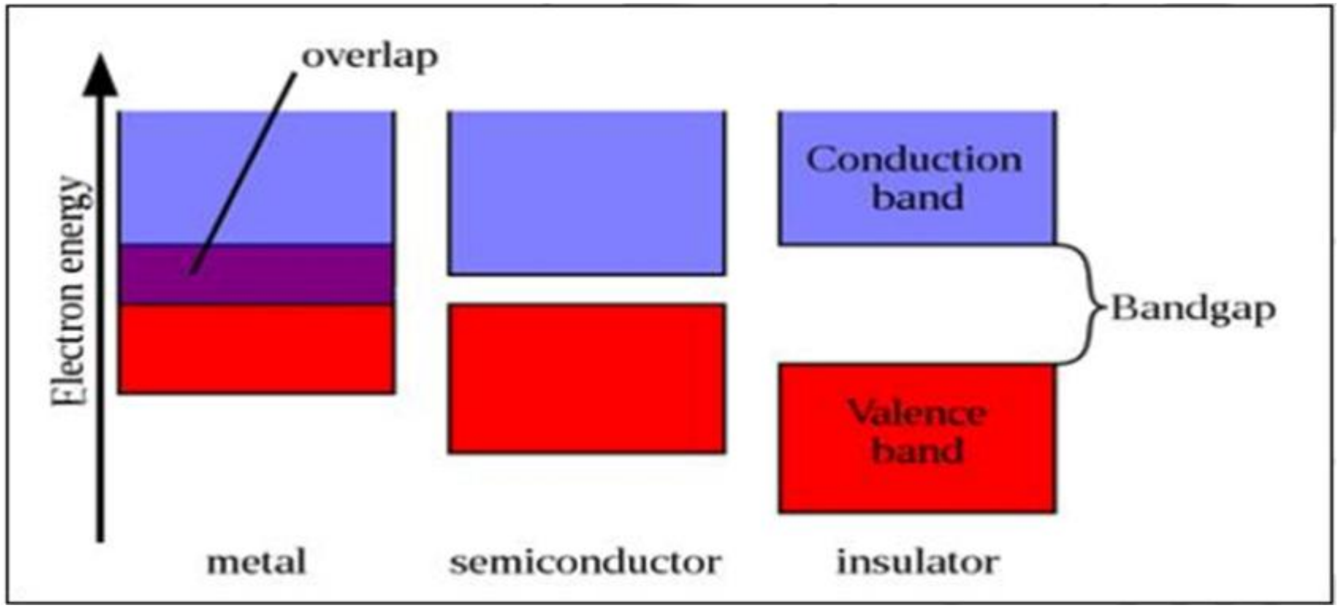

Figure 4: An illustration of the band gap structure that is present in inorganic materials [3].

Theory – Organic Scintillation

- EJ-276 is an organic plastic scintillator with a light output of ~8,000 photons per MeV.

- Photons produced from organic scintillators are a result of the transitions between excited states of single molecules as demonstrated in figure 5.

- Plastic scintillators are better for detecting fast neutrons as they are sensitive to neutrons through elastic scatter on hydrogen.

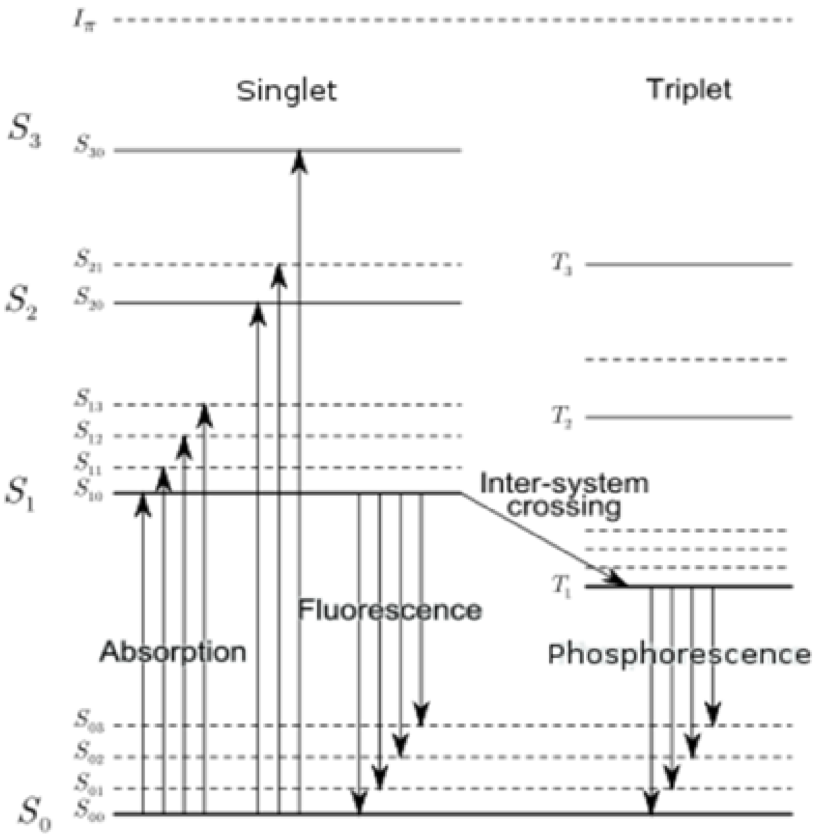

Figure 5: A diagram of the organic scintillation process [4].

Methodology

- Data has been collected using a range of gamma sources of known energies along with some preliminary neutron data.

- This gamma data has been used to perform an energy calibration and to determine the energy resolution.

- Simulation work has begun to evaluate the detectors performance using GEANT4.

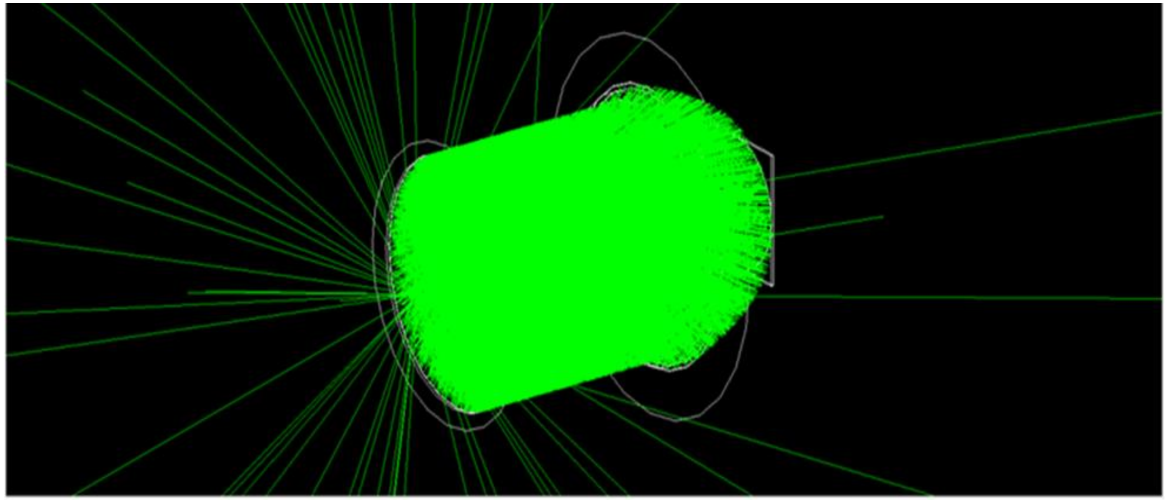

Figure 6: A GEANT4 simulation illustrating the detector interacting with a particle producing scintillation light [5].

Results - CLLBC

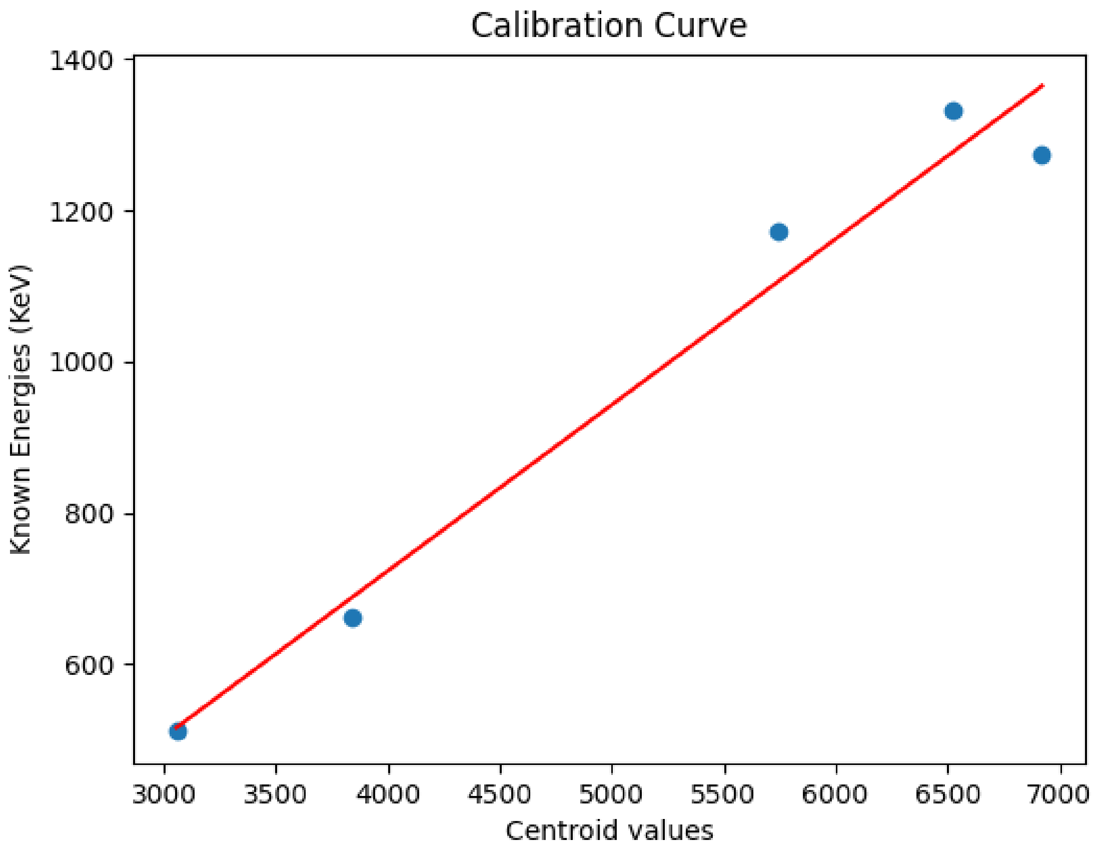

Figure 7: A calibration graph created using ^{137}Cs, ^{22}Na and ^{60}Co sources.

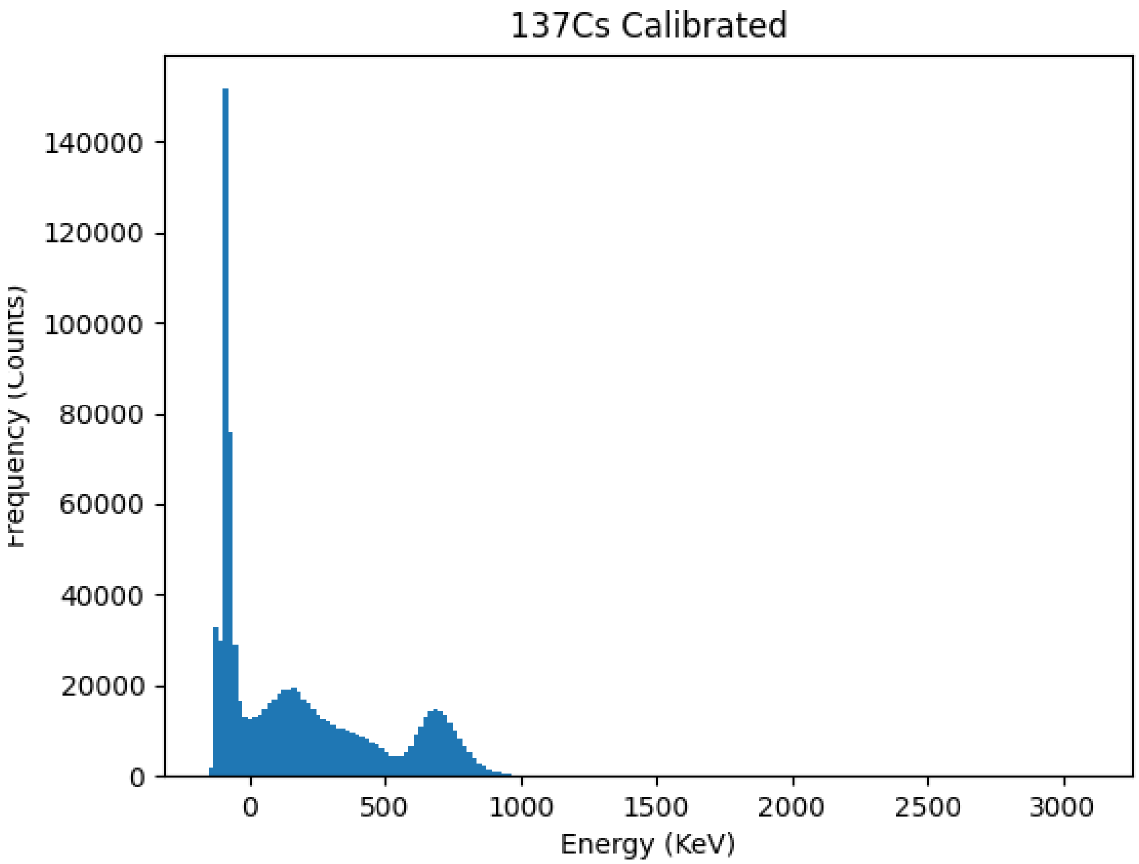

Figure 8: An energy calibrated spectrum of ^{137}Cs.

Results - CLLBC

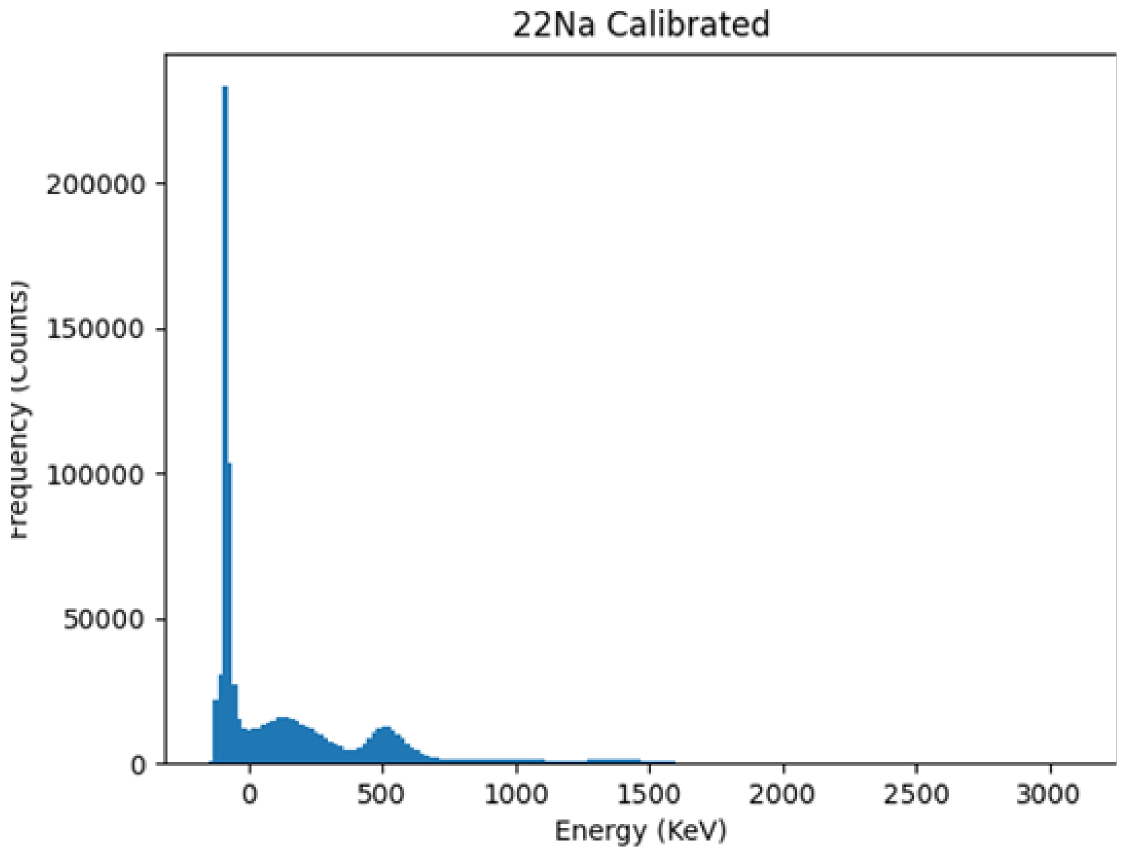

Figure 9: An energy calibrated spectrum of ^{22}Na.

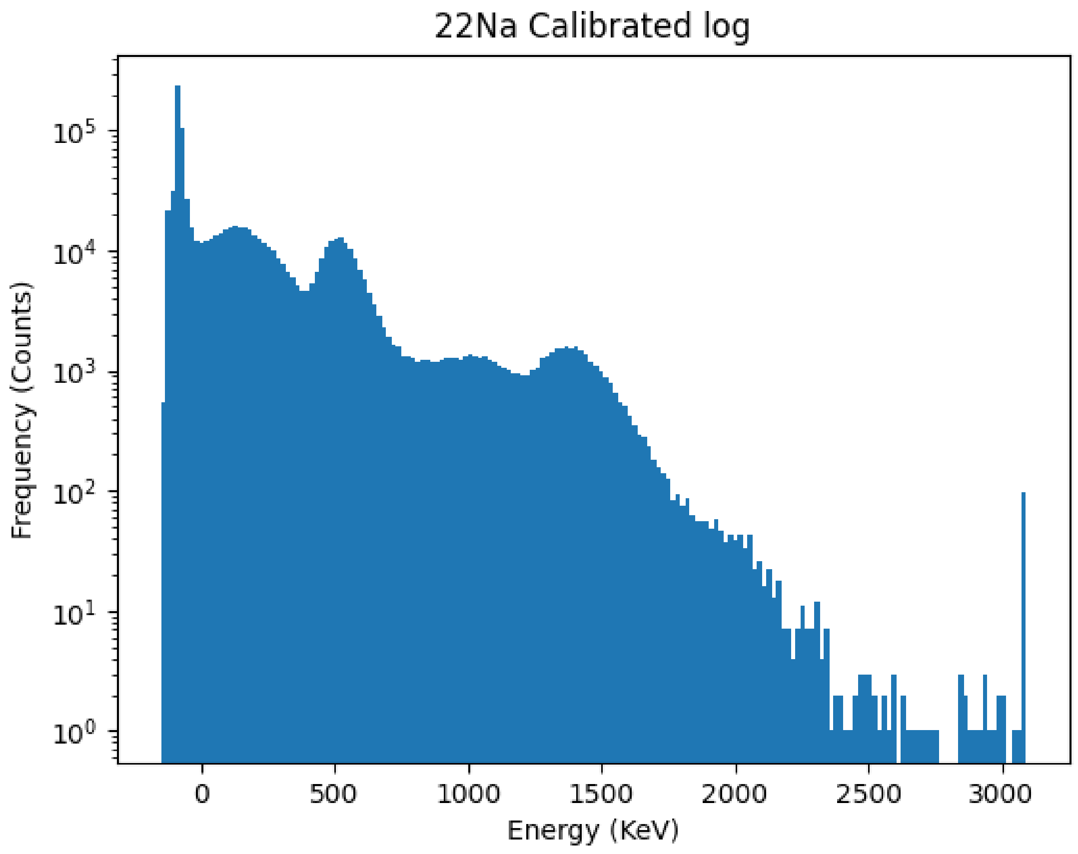

Figure 10: An energy calibrated log plot of ^{22}Na.

Results - CLLBC

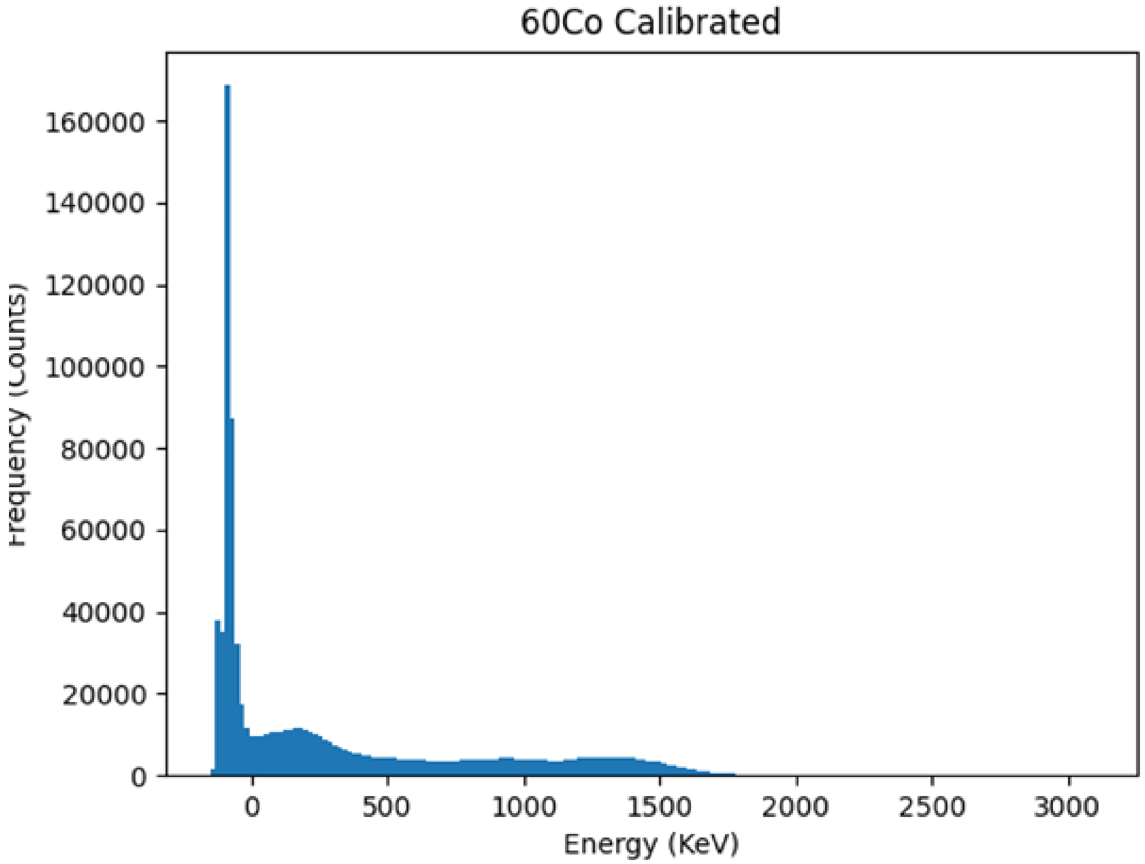

Figure 11: An energy calibrated spectrum of ^{60}Co.

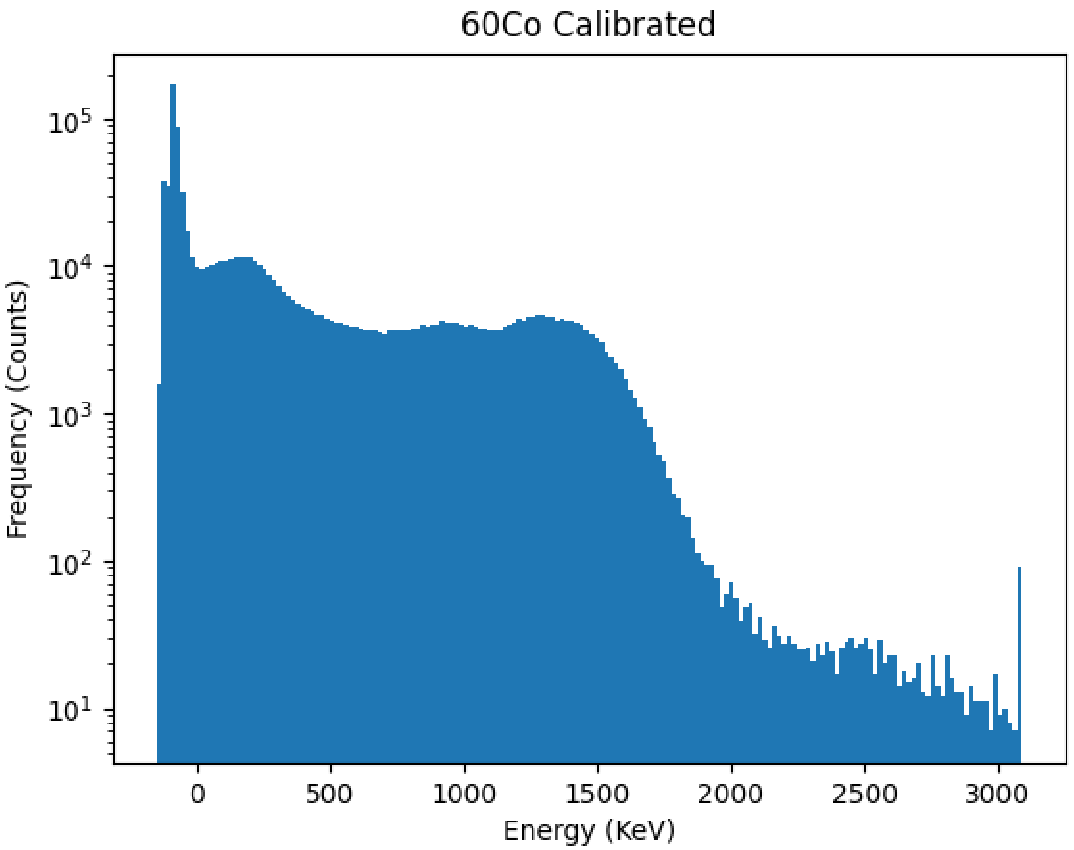

Figure 12: An energy calibrated log plot of ^{60}Co.

Results – EJ-276

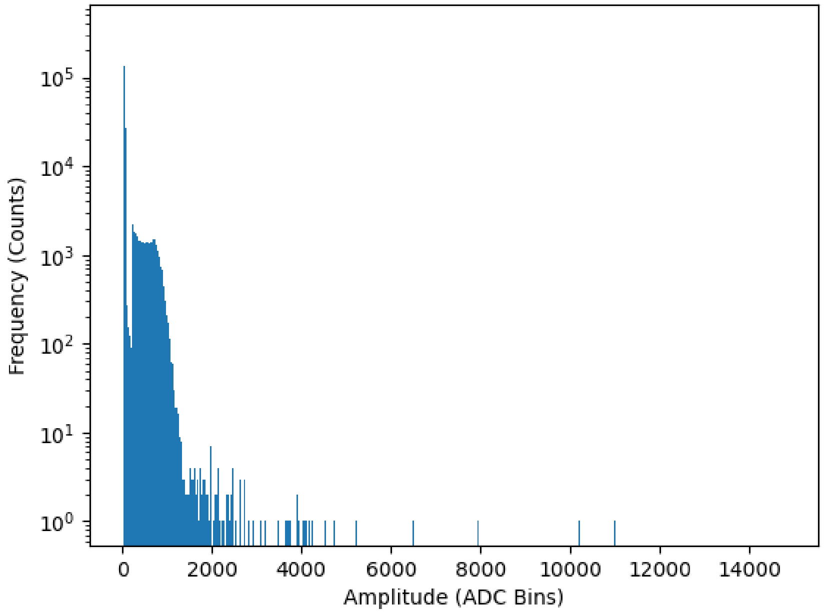

Figure 13: An uncalibrated spectrum of ^{137}Cs produced by EJ-276.

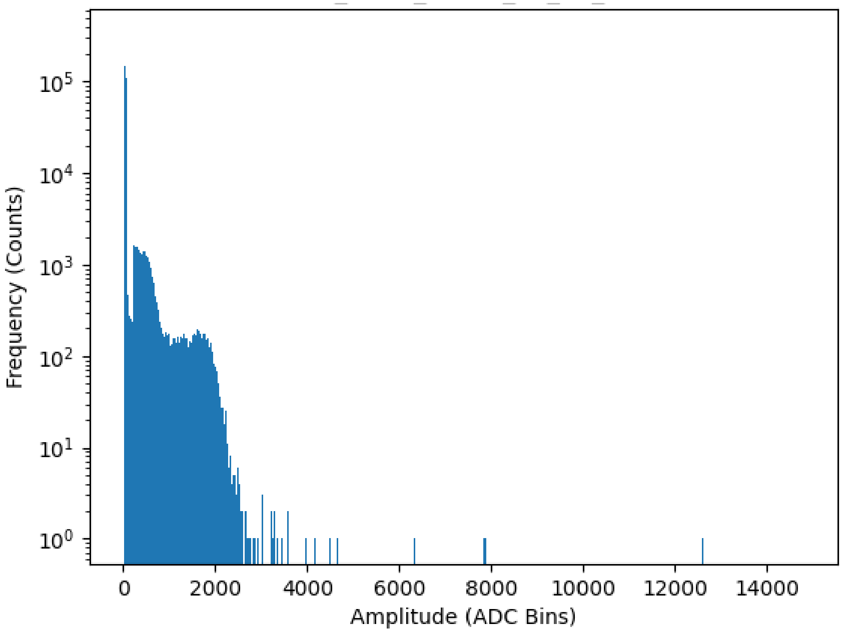

Figure 14: An uncalibrated spectrum of ^{22}Na produced by EJ-276.

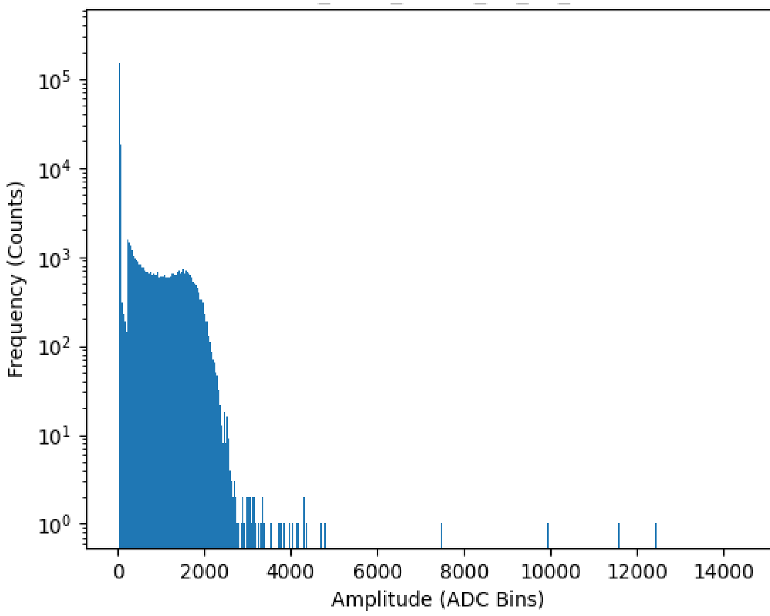

Figure 15: An uncalibrated spectrum of ^{60}Co produced by EJ-276.

Future

- Collection of further neutron data and optimisation of PSD analysis.
- Further GEANT4 simulation to allow for comparison to experimental data.
- Transition from PMTs to SiPMs to replicate expected final setup.
- Development of both analog and digital circuits to determine optimal design choice.

References

- [1] J. R. Quinn et al, "*Development of a Pattern Recognition Approach for Analyzing Flow Cytometric Data*", 2006
- [2] A Razeto et al, "*Very large SiPM arrays with aggregated output*", 2022
- [3] M. A. Bilya et al, "*Determination of the Band-Gap of a Semiconductor: Germanium Chip using Four Probe Set-Up*", 2016
- [4] A. Baitenov et al, "*Technical manual: a Survey of Scintillating Medium for High-Energy Particle Detection*"
- [5] F. Thomson, "*Development of a Radiation Detector with Particle Discrimination for Nuclear Security Applications*", 2019