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Signal discrimination in CZTS gamma detectors using self-supervised deep learning models

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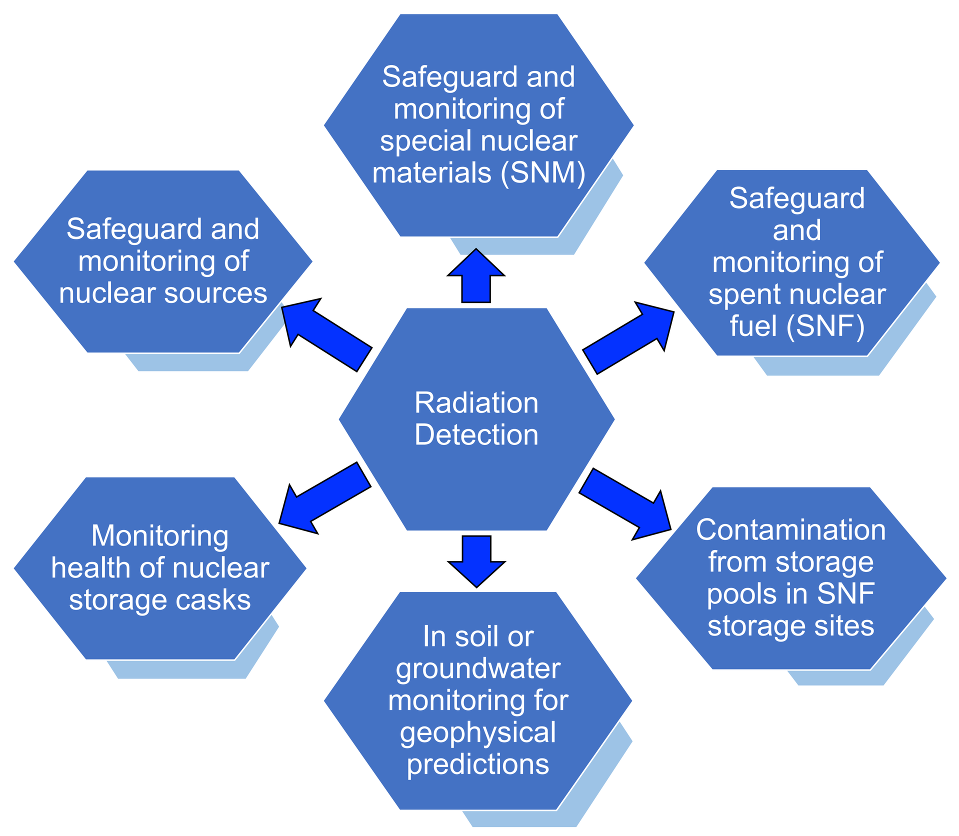
γ-RAY DETECTION AND HIGH-Z SEMICONDUCTORS

High-Z compound semiconductors such as CdZnTe (CZT) have been applied extensively for room temperature detection of high energy gamma rays since a long time.



HIGH-Z SEMICONDUCTORS: CHALLENGES

- Poor Crystal Growth Yield
- Small Detector Volume
- Crystal Defects
- Poor Charge Transport

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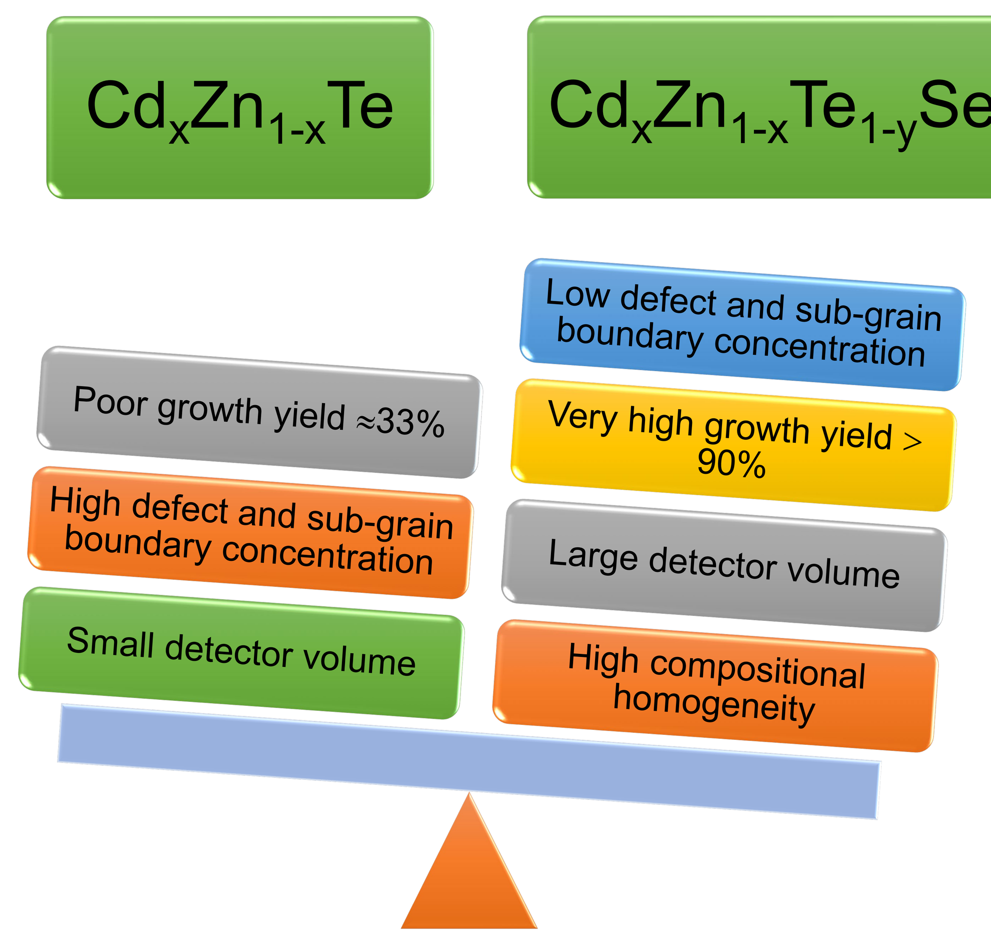
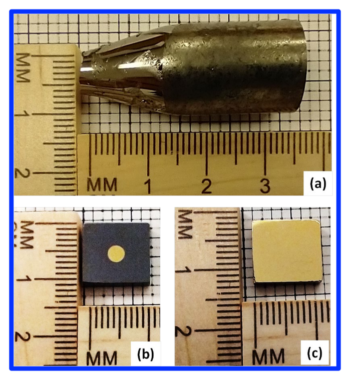
CZTS – THE NEXT GENERATION HIGH-Z DETECTORS

$Cd_xZn_{1-x}Te_{1-y}Se_y$ (CZTS) is an emerging quaternary wide bandgap (≈1.6 eV) semiconductor material for high-resolution gamma-ray detector applications [1-4].

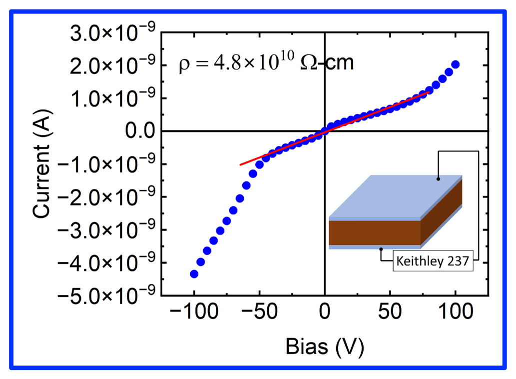


RECENT RESULTS FROM LDRD COLLABORATION

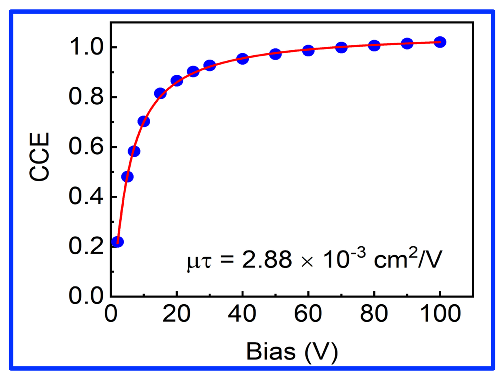
$Cd_{0.9}Zn_{0.1}Te_{0.08}Se_{0.02}$ single crystals have been grown using a Travelling Heater Method (THM) at SRNL. Detectors are fabricated by depositing metal (Au) electrodes with various geometry.



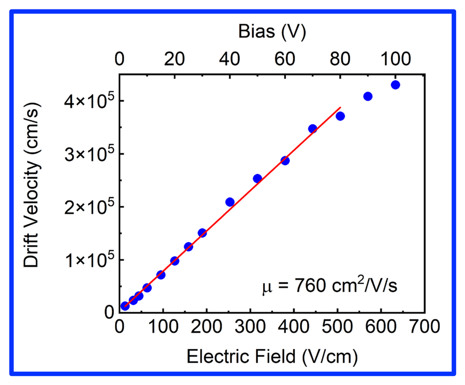
(a) A CZTS ingot. (b) A small pixel detector (c) A planar detector.



Room temperature current-voltage (I-V) characteristics of a THM grown $Cd_{0.9}Zn_{0.1}Te_{0.08}Se_{0.02}$ (CZTS) planar detector.



Hecht plot obtained from alpha pulse height spectroscopy (PHS) of a CZTS planar detector.



Mobility curve obtained from alpha PHS of a CZTS planar detector.

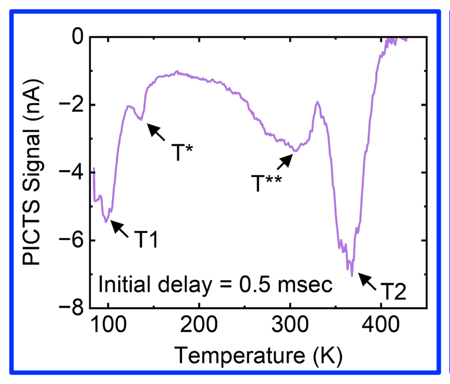
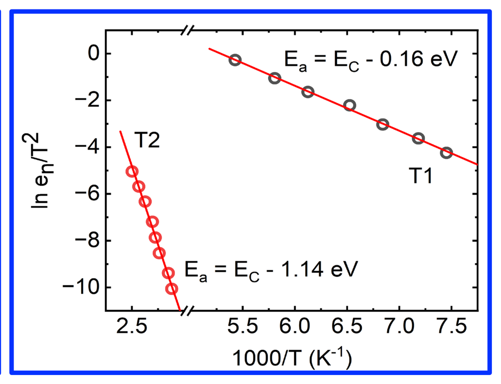


Photo induced current transient spectrum (PICTS) of a CZTS planar detector.



Arrhenius plots for peaks T1 and T2 corresponding to the PICTS plot on left.

CHALLENGES IN FIELD APPLICATIONS

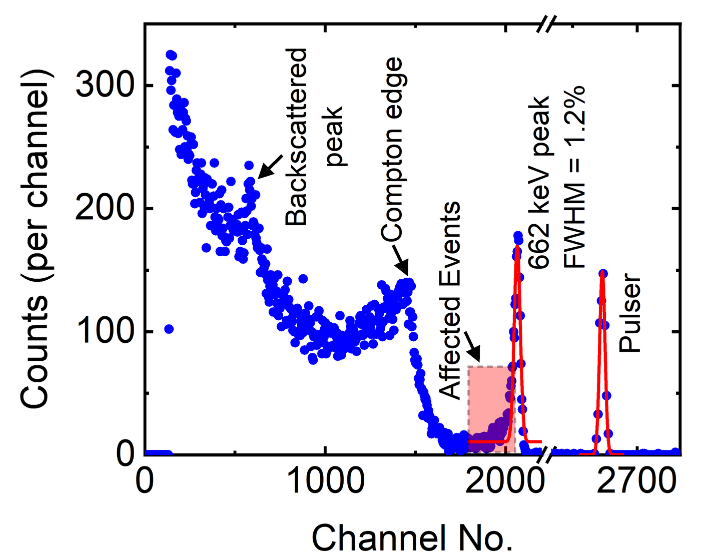
- Background radiation
- Attenuation and scattering from shielding
- Weak source strength
- Variation in source-detector geometry

MACHINE LEARNING IN γ - RAY DETECTION

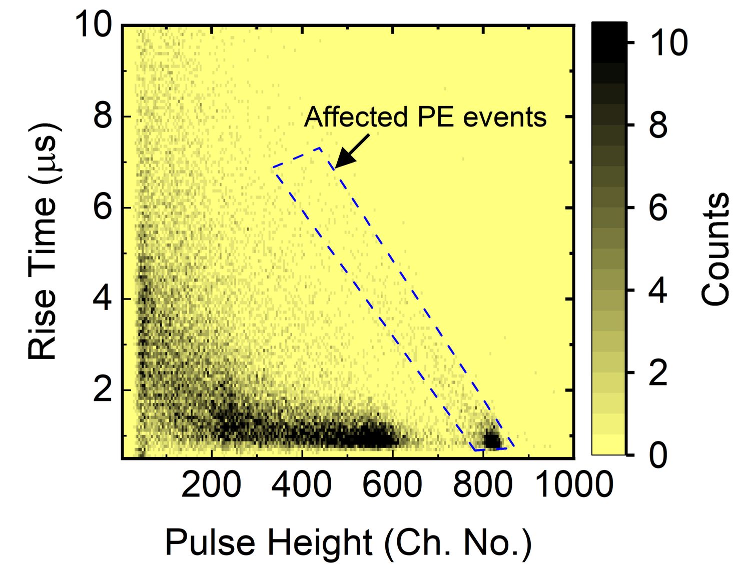
- Radiation detection in field applications cannot rely on simple peak detection algorithms due to uncertainties and requires trained spectroscopists to manually analyze the detector signals.
- A fast, efficient, and cost-effective alternative is to employ trained algorithms coupled to high resolution gamma detectors.
- In our previous work, machine learning (ML) models based on pattern recognition convolutional neural network (CNN) was successfully employed to identify incident gamma energies with high efficiency in CZTS detectors [5,6].
- The CNN was trained on the equivalent of 90% of the simulated data and validated on 10% simulated data. The predictions of the CNN were within 0.2% of the actual energy [6].

PRESENT APPROACH: EFFICIENCY ENHANCEMENT

- Due to charge trapping, the energy read out by a detector interacting with a monoenergetic gamma-rays decreases substantially.
- This causes overlap of photoelectric and Compton events which leads to poor energy resolution and poor peak-to-background and peak-to-Compton ratios.

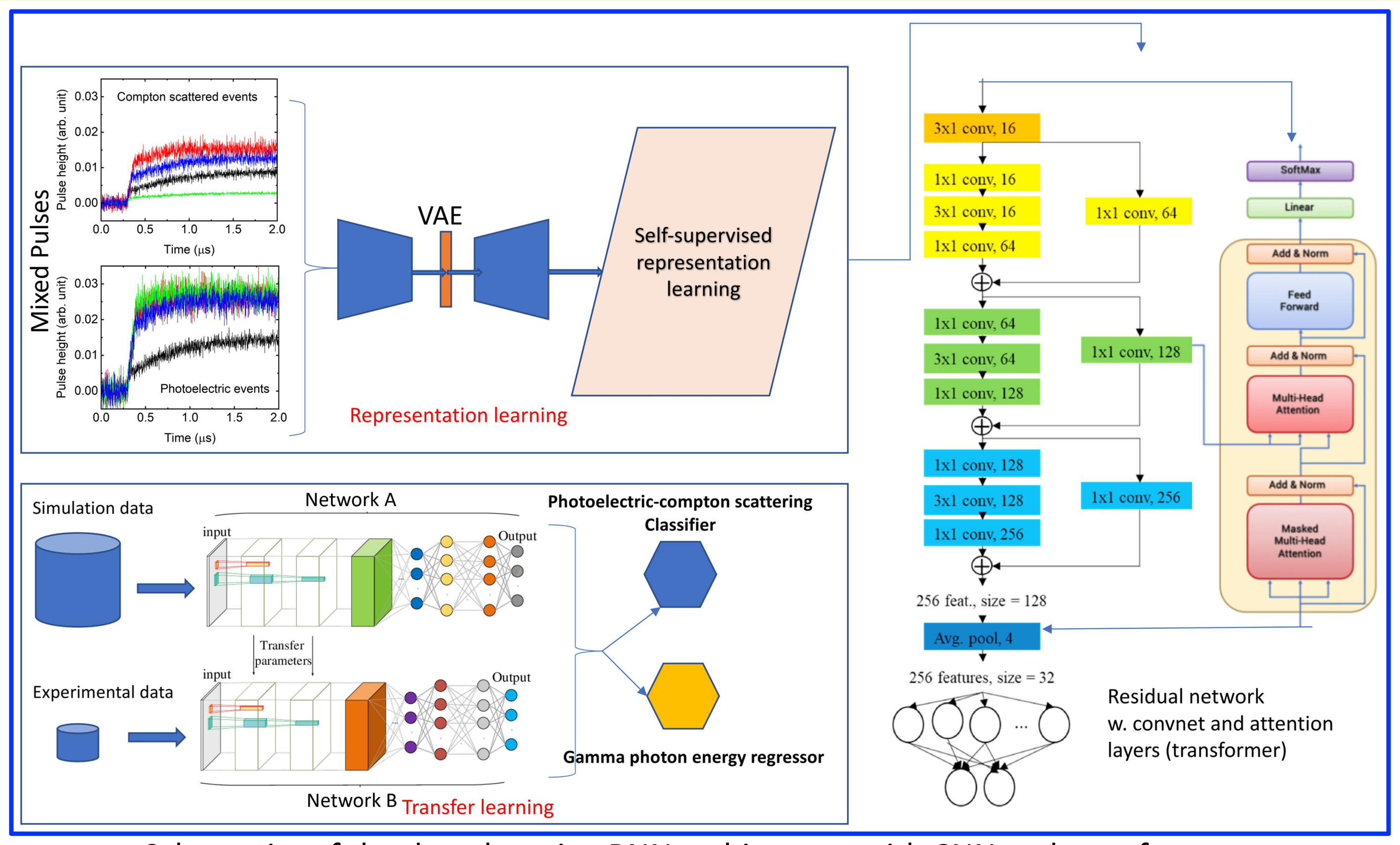


A PHS obtained using a virtual Frisch grid CZTS detector when exposed to a 662 keV γ-photons.



A biparametric correlation plot showing the overlap of photoelectric and Compton events.

- In the present approach we attempt to differentiate Compton scattered and photoelectric events on an event-by-event basis by training two different neural networks using detector pulses simulated for a CZTS detector generated through photoelectric absorption and Compton scattering separately.
- A recurrent neural network (RNN) for time series analysis and a convolutional neural network to analyze the pulse signal image are being developed.
- The CNN is aimed to pick up or recognize any behavioral pattern between the detector pulses generated due to Compton scatter and photoelectric absorption.



Schematics of the deep learning RNN architecture with CNN and transformers.

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