CdTe Detectors for Quantitative X-Ray Fluorescence

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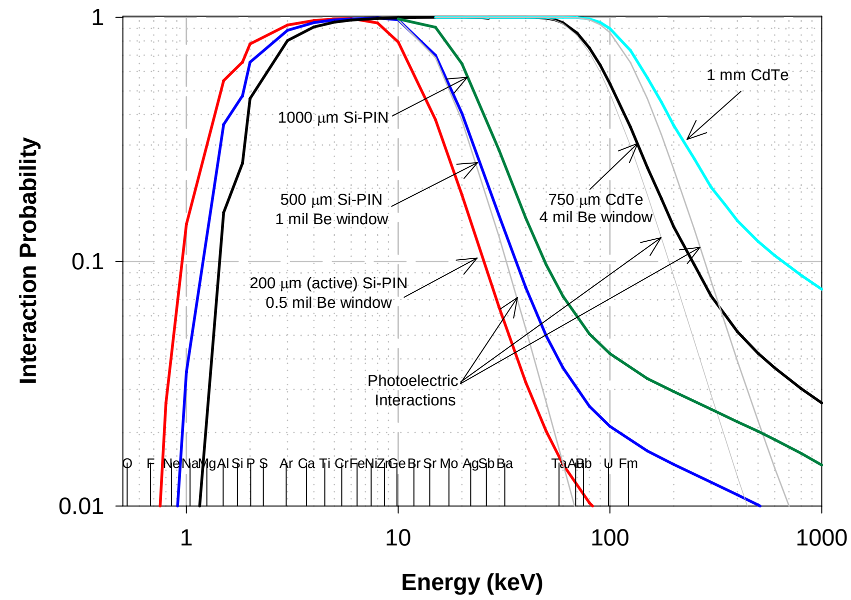
Why use CdTe?

Much higher sensitivity > 20 keV

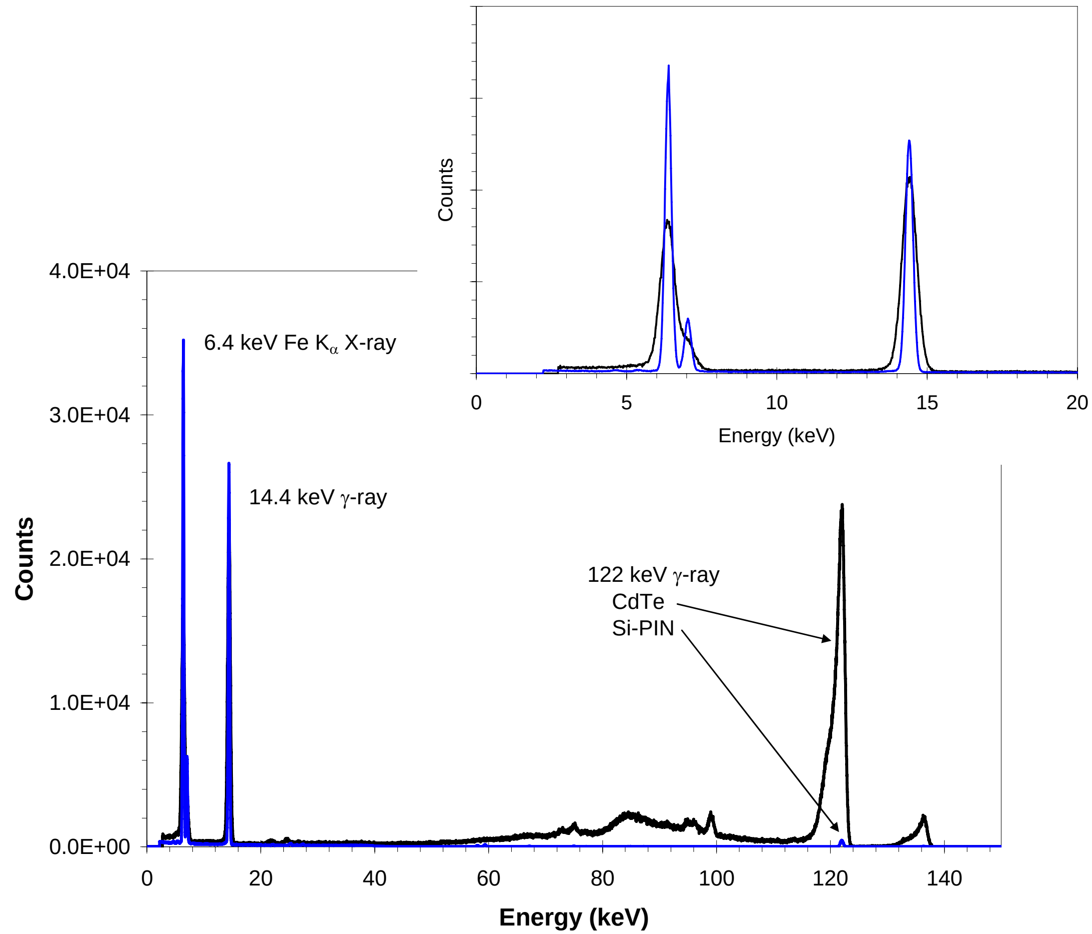
RoHS/WEE demands accurate measurement of metals

With CdTe, one can measure K X-rays (with few interferences) with much higher sensitivity than Si diodes

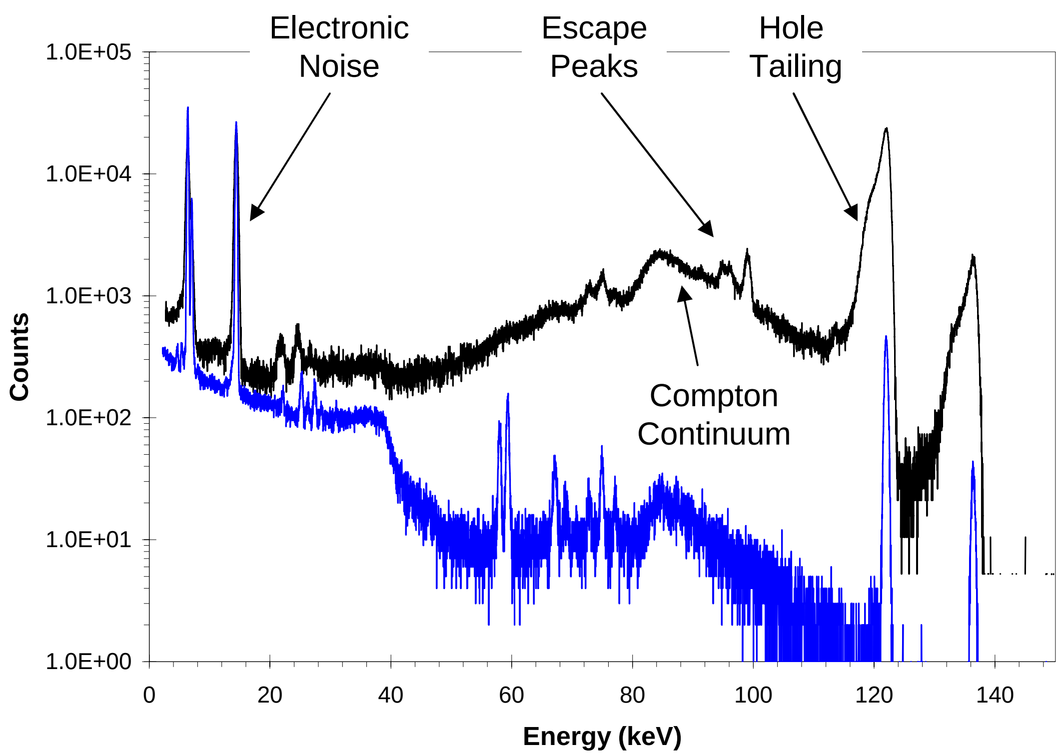


^{57}Co spectra measured with 25 mm^2 Si-PIN and CdTe

- 6.4 keV Fe K_α X-ray
  - Equal photopeak area
- 14.4 keV γ-ray
  - CdTe has 25% more photopeak area
- 122 keV γ-ray
  - CdTe has 140x photopeak area



Key Spectral Characteristics of CdTe



- Resolution
  - Electronic Noise
  - Hole tailing
- Escape peaks
- Continuum
  - Compton
  - Dead layer
- Other
  - Stability
  - Linearity

Apparatus

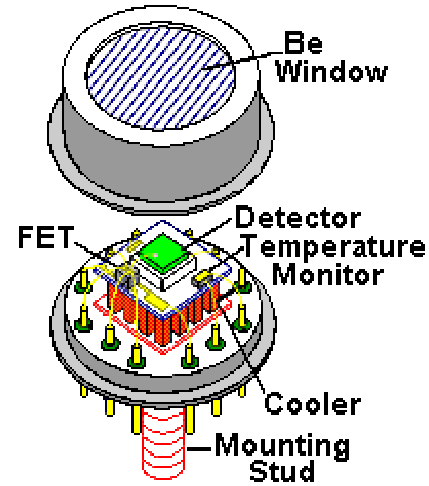
Detectors

- CdTe
  - Compound semiconductor with wide bandgap (4.4 eV), high density (6.2 g/cm^3), and high atomic number (48,52)
  - Charge transport better than most alternatives $\mu\tau_h = 2x10^{-4}$ cm^2/V
  - Studied and used for γ-ray spectroscopy since late 1960s
- Amptek detectors
  - Schottky (blocking) contacts to reduce leakage current
  - $I_{dark} \approx 5$ nA/cm^2 at 500V and 300K
  - Mπn structure from Acrorad, Inc
- Good yield, reproducible properties

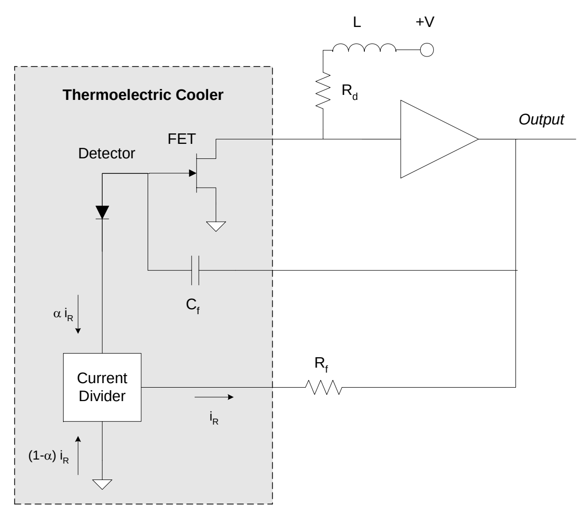
- Amptek diodes are 0.5 to 1 mm thick from 3x3 to 7x7 mm^2
- Results here are for 0.75 x 5 x 5 mm^3 unless otherwise stated

Apparatus

Thermoelectrically Cooled Solid State Detector



- Reasons for thermoelectric cooling
  - Reduces shot noise and thermal noise
  - Cooling invisible to user
- Two stage cooler for >80˚C differential
  - 215K for lab use
  - 240K for field use (at ambient of 45˚C)
- FET and feedback components on cooler
  - Leakage currents as low as 5 fA
  - Low stray capacitance, reduced EMI pickup
- Continuous feedback preamp using current divider



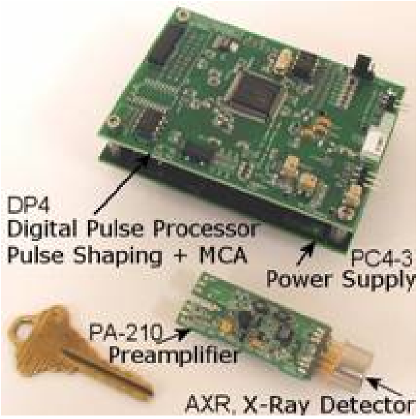
Apparatus

X123, PX4, DP4

- All are complete spectroscopy systems
- All share core technologies
  - Digital pulse processor for pulse shaping, selection logic, and multichannel analyzer
  - Power supplies, including 1.5 kV bias supply and closed loop temperature control
  - USB interface, +5V power input
- Targeted at different applications

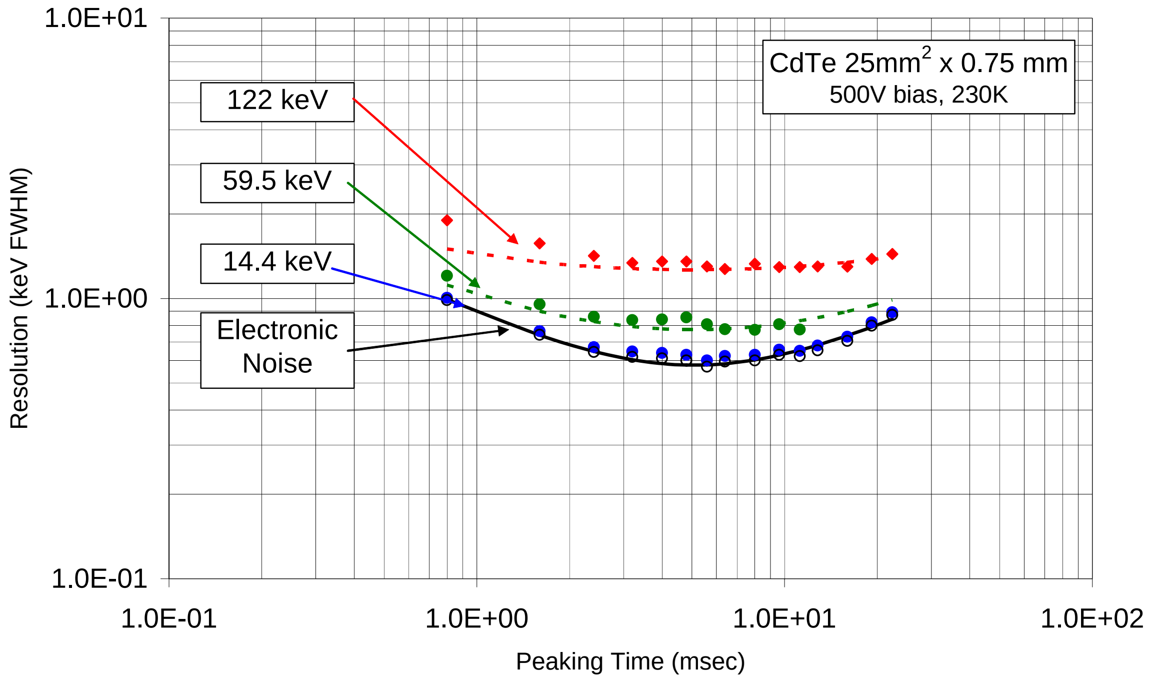
X123 for compact, packaged system

PX4 and XR100 for benchtop & laboratory



DP4 and PA210 for embedding in instruments

Electronic Noise



CdTe Noise Components

- Typical results with a 25 mm^2 x0.75 mm detector
- Noise corner <600 eV FWHM near 6.4 μsec peaking time
- Noise dominates below 30-50 keV, Fano broadening above

Hole Tailing: Origins

Lifetimes

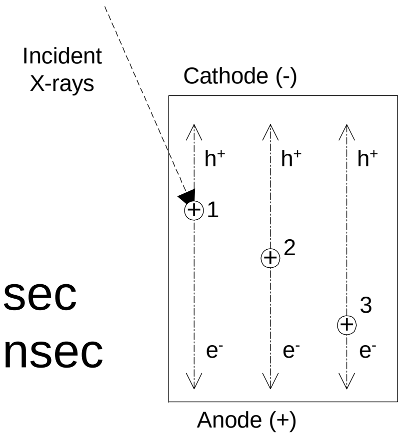
τ_e = 3 μsec

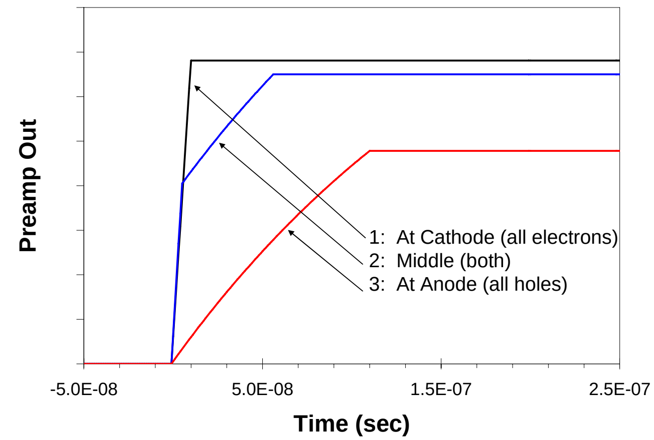
τ_h = 1 μsec

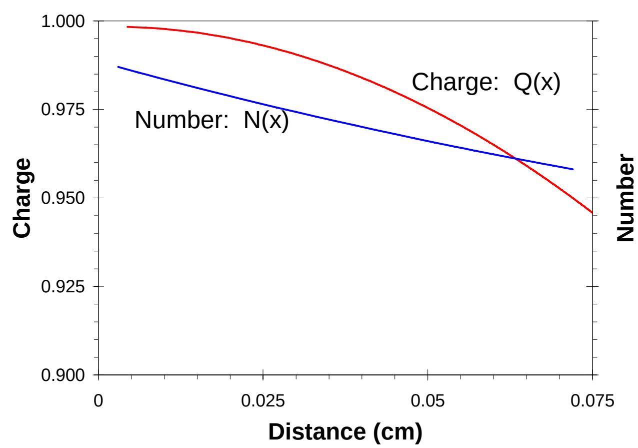
Transit time

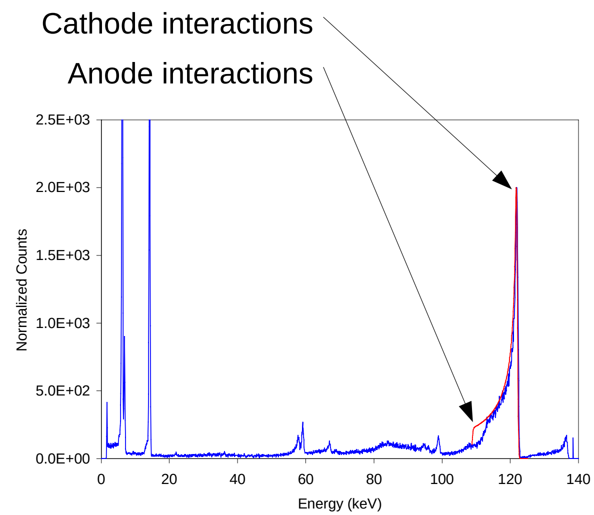
T_e (max) = 10 nsec

T_h (max) = 110 nsec





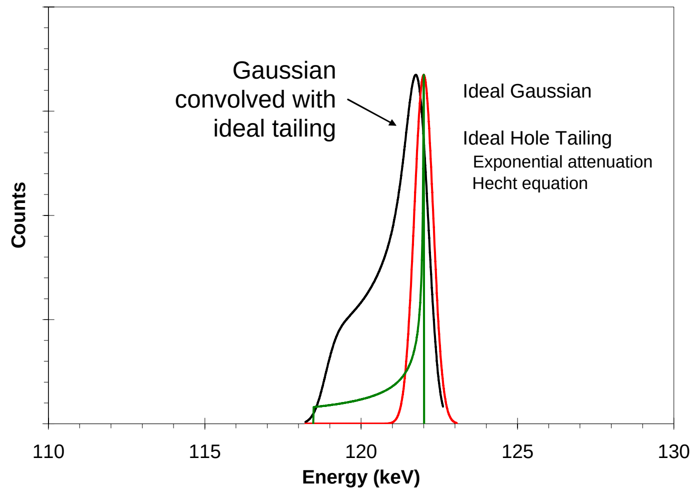




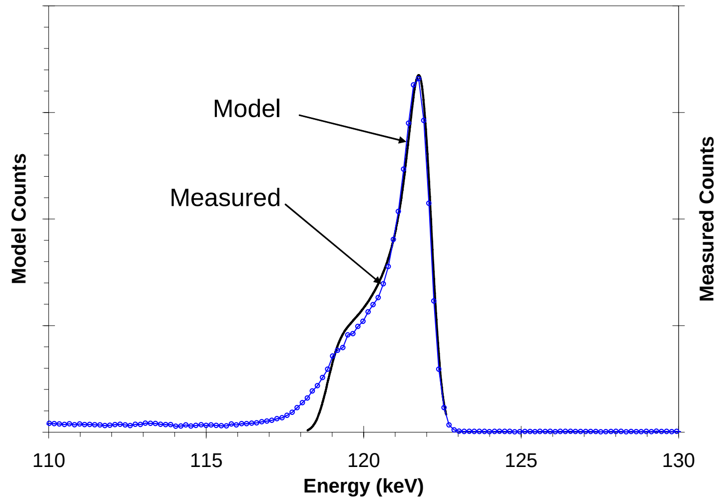
Hole Tailing: Effects

"Physics" based model

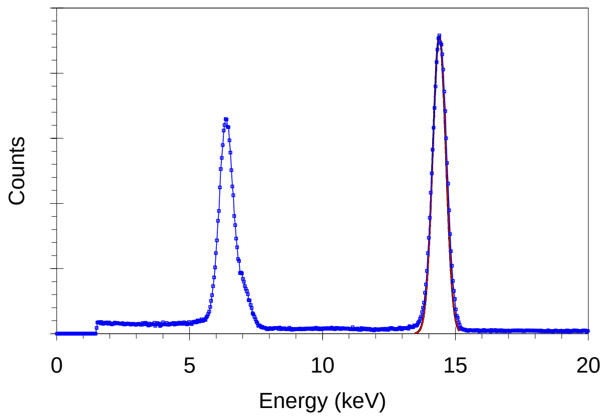
- Charge collection ⇒ Q(x)
- Photoelectric absorption ⇒ N(x)
- Combination ⇒ N(Q)
- Convolve with Gaussian
  ENC and Fano

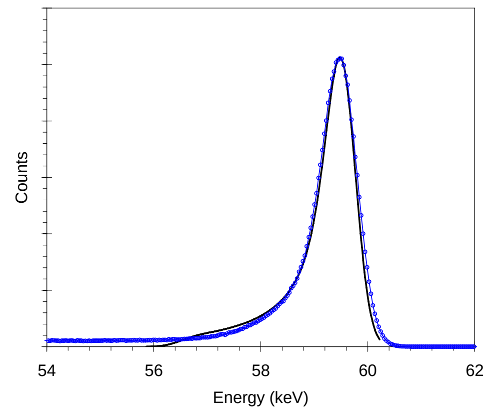


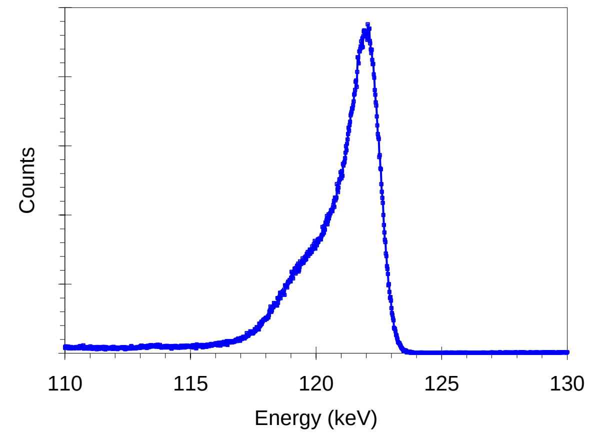
- Fairly accurate representation
- Estimate performance
- Not in analytical form, so difficult to use for spectra fitting



Hole Tailing: Effects







Photopeak shape

<20 keV: All interactions near cathode, no tailing, Gaussian

≈50 keV: Small asymmetric correction to Gaussian

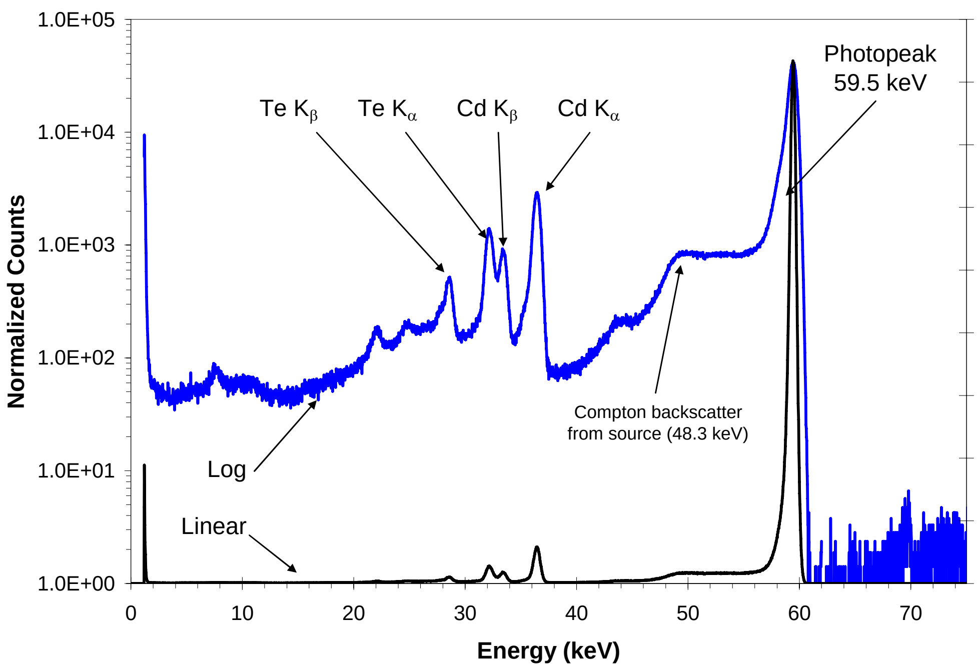
≈100 keV: Interactions uniform, tail important, shape complex

Can model using Van Espen type tail but truncate at Q_{anode}

Escape Peaks

Much more important in CdTe than in Si

– Cd & Te $\omega_K \approx$ 85%, 5% in Si
– K X-ray attenuation lengths 0.1 to 0.2 mm



	X-ray energy (keV)
Te K_β	31.0
Te K_α	27.5
Cd K_β	26.1
Cd K_α	23.2

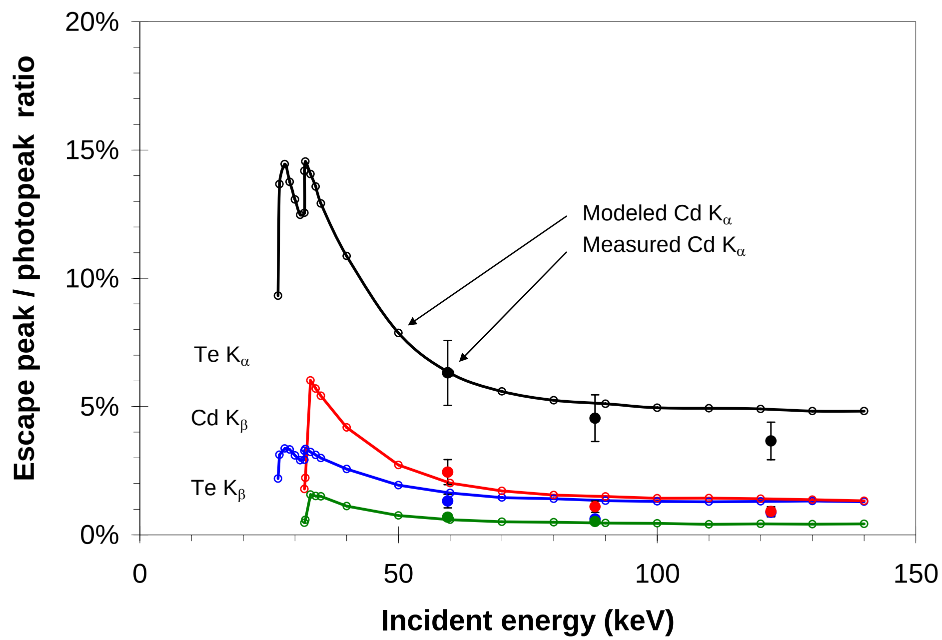
Escape Peaks: Correction

Intensity vs energy

- Computed using EGS4 Monte Carlo software

  Carried out by Paul Bennett of RMD, Inc.

- Data using filtered isotopic sources.



Algorithm

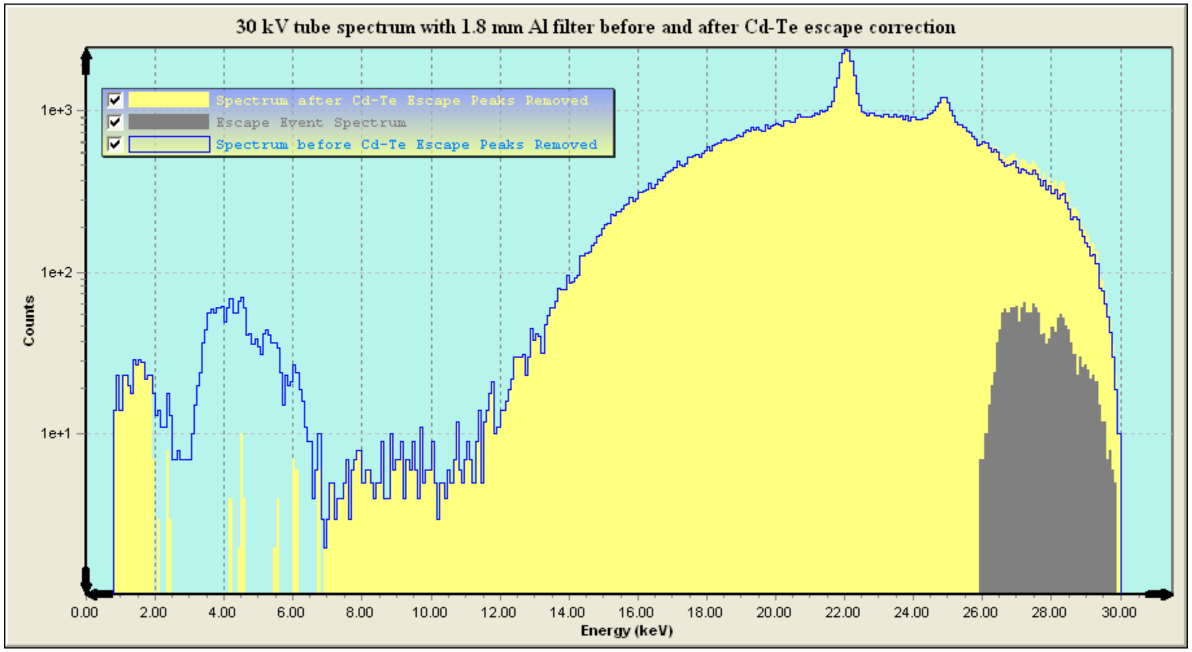
- 4 analytical equations, one for each of the weighted centroids for K_α and K_β of Cd and Te
- Subtraction starts at high energy, looking for all events above K edge

Equations of the general form:

$$Esc = a_0 + a_1 \cdot e + a_2 \cdot e^2 + a_3 \cdot e^3 + a_4 \cdot e^4 + a_5 \cdot e^5$$

where Esc=escape events, e=parent energy, and the a terms are coefficients.

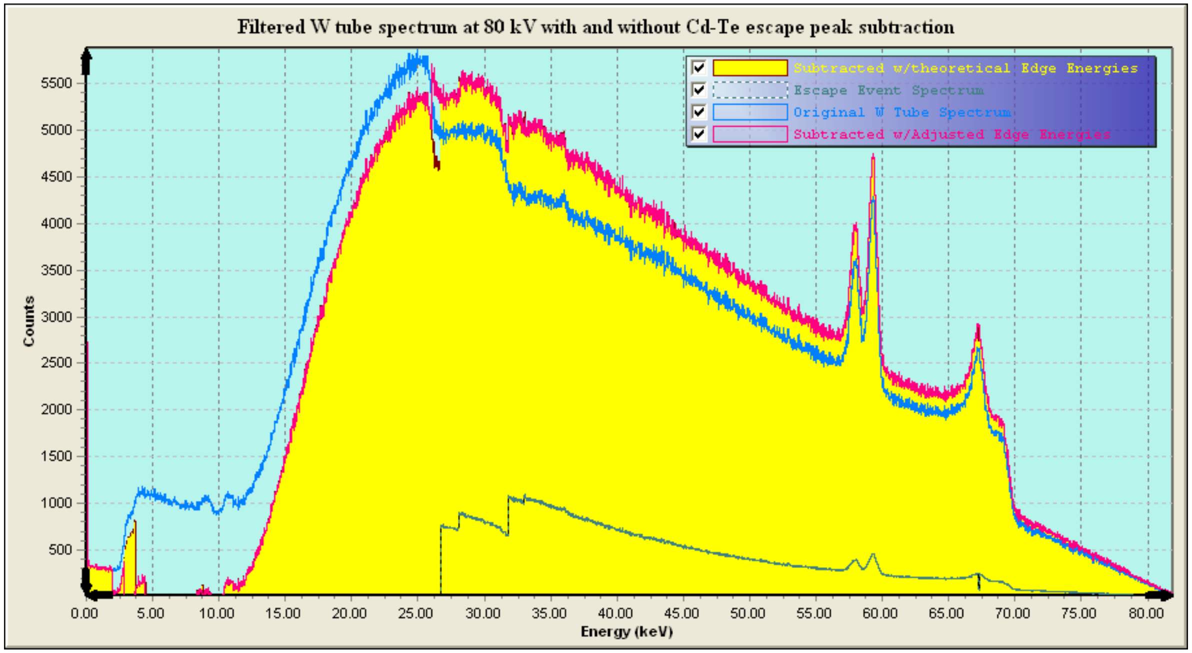
Escape Peaks: Correction



Results of Correction: Filtered Ag Tube Spectrum at 30 kVp

- Filter should remove everything below 14 keV.
- Raw spectrum (blue) shows broad peak around 5 keV, due to escapes
- Correction algorithm moves to the gray, removing almost entirely.
- Had to adjust Cd escape edge from 26.7 to 26.0 keV – not clear why.

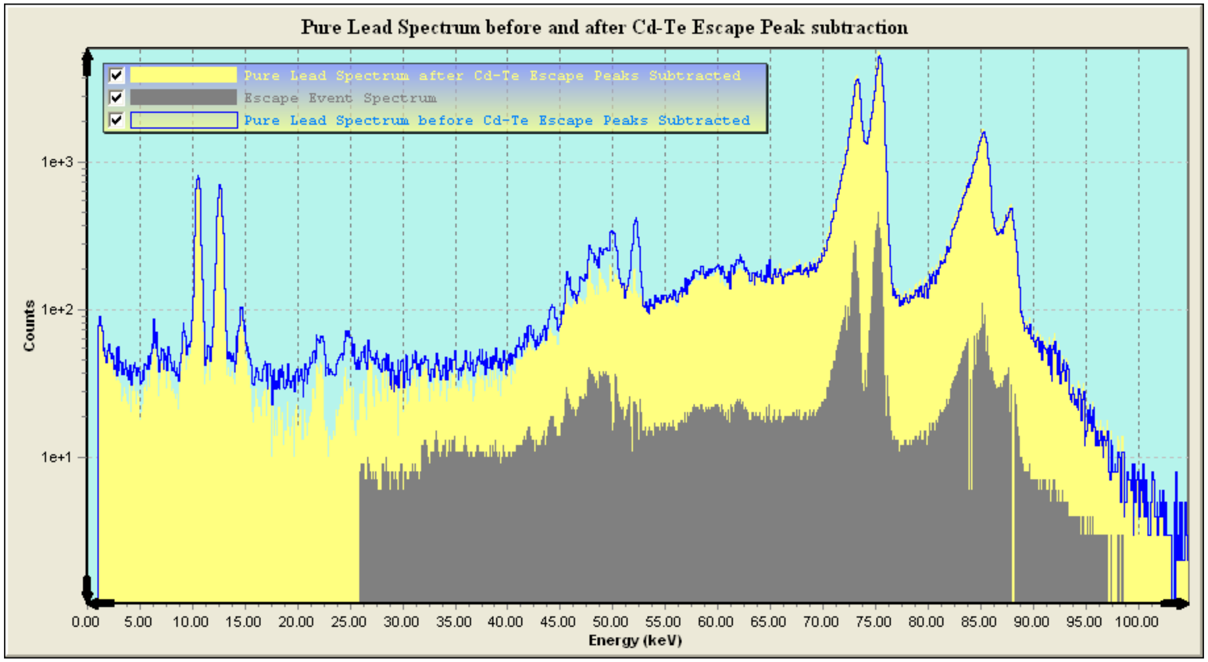
Escape Peaks: Correction



Results of Correction: W Tube Spectrum at 80 kVp

- Raw spectrum (blue) has large “steps” at K edges
- Theoretical correction (yellow) helped but left some structure at K edges
- Adjusting the Cd-K edge from 26.7 to 26.0 keV improves greatly, leaves a little structure at the K edges.

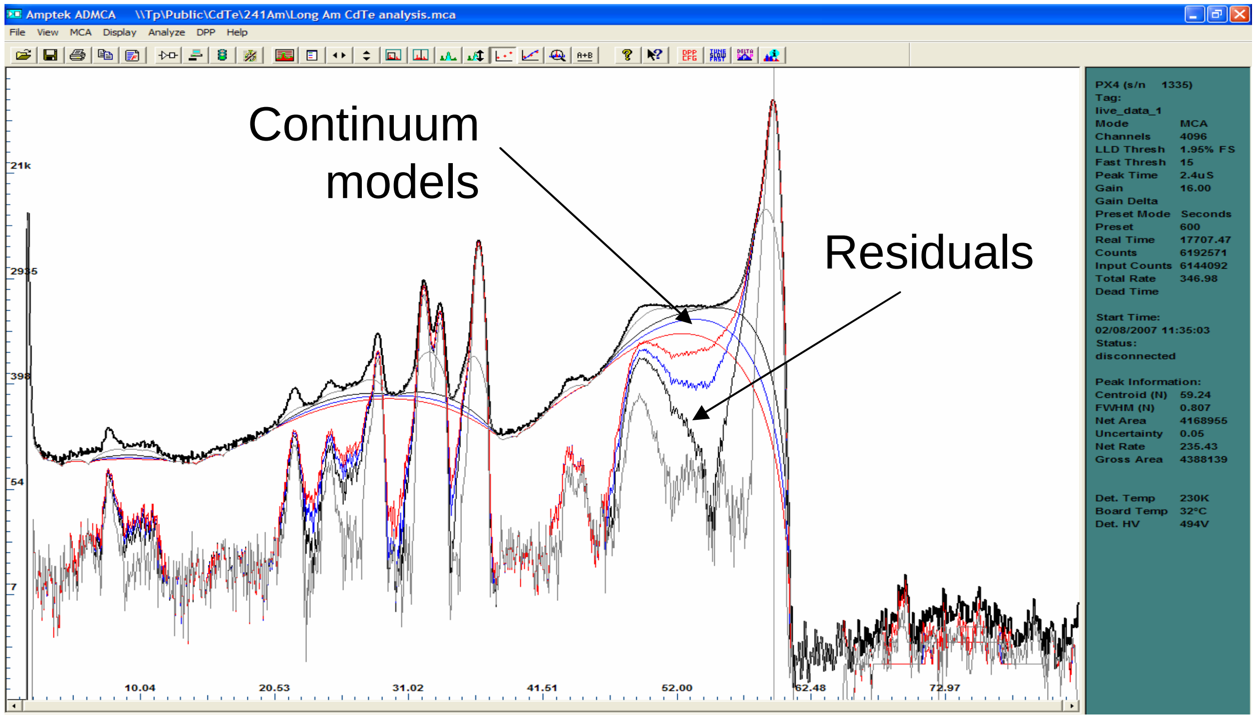
Escape Peaks: Correction



Result of Correction: Pure Lead

- Raw spectrum (blue) has clear escape peaks from 40 to 55 keV
- Four primary peaks, plus continuum, each with four escape peaks
- Gray represents the “reassigned” photons
- Yellow processed spectrum shows change to continuum and peaks

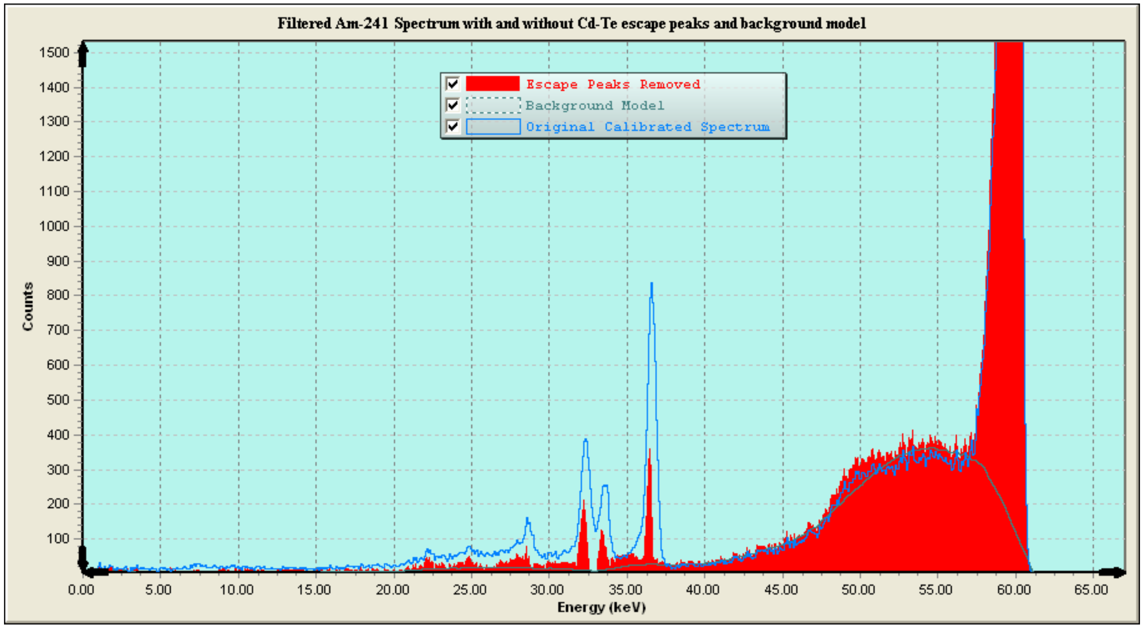
Compton Background



Continuum Removal

- CdTe spectra, at higher energy, have more scattering into detector
- Plot shows result of applying Si parameters to CdTe
- Yields residual false peaks

Compton Background



Continuum Removal

- Adjust parameters to give high curvature background continuum
  - First, Cd-Te escape peaks are removed (partially at least)
  - Second, automatic background function applied to spectrum
- Very little residual continuum

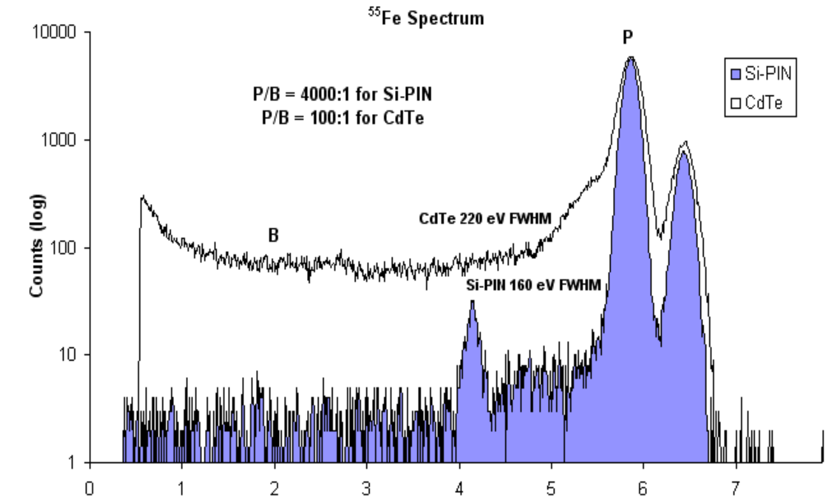
Low Energy Background

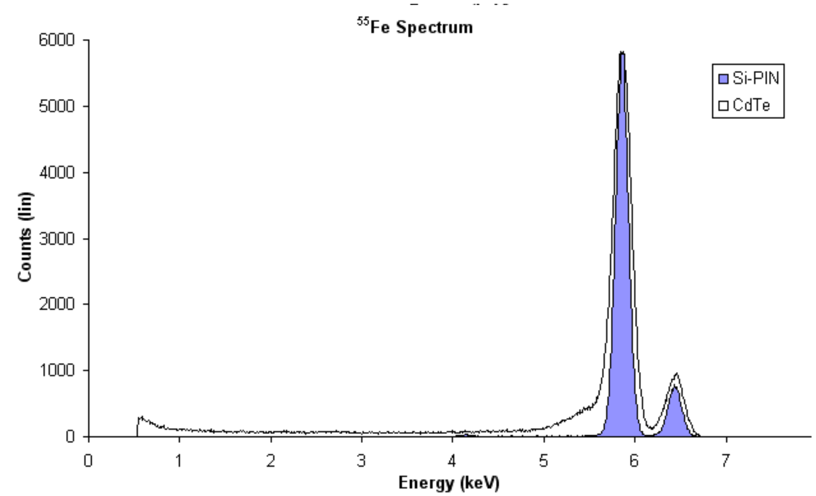
Dead Layer Effects

- CdTe dead layer much more significant than Si
  - Metal contact (200nm Pt)
  - CdTe higher Z and density

- Secondary electrons deposit more energy while escaping

- At low energies, peak to background ratio lower for CdTe

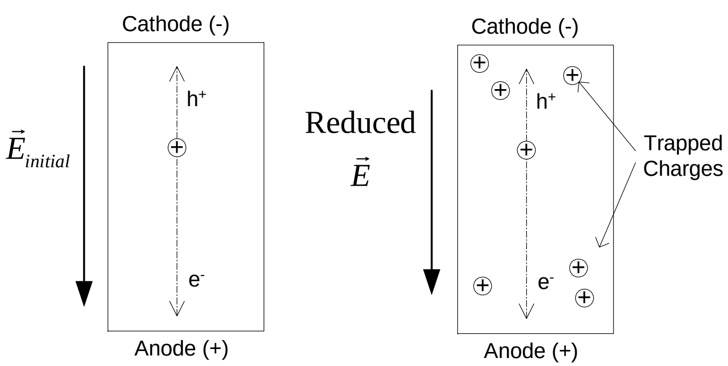


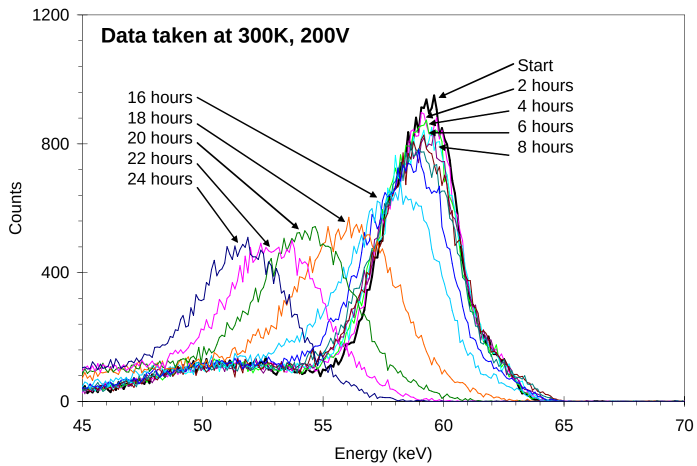


Stability

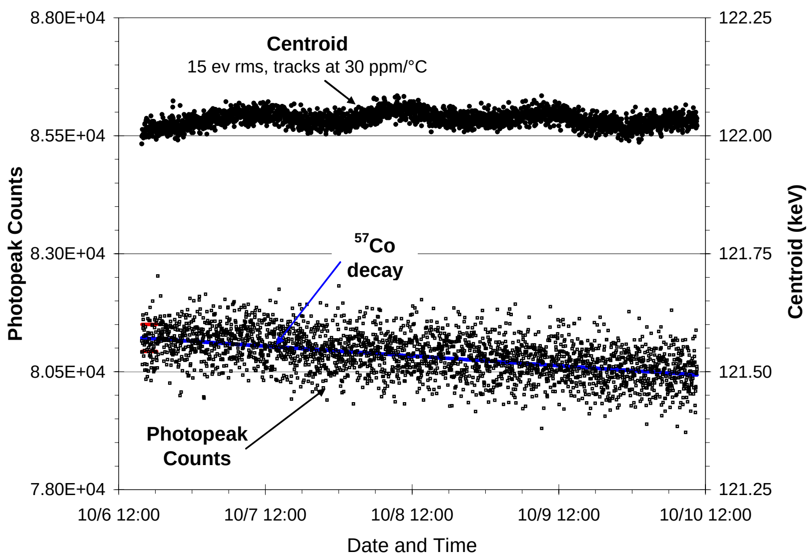
Does CdTe polarize?

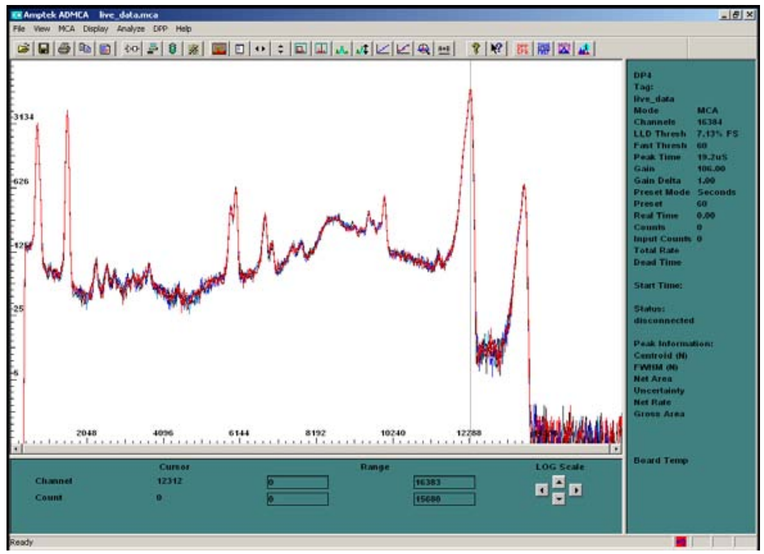
- At room temperature and low electric field strength, CdTe Schottky diodes polarize
- Polarization slows rapidly with cooling and high bias voltage
- As operated in XR100-CdTe, negligible on time scale of days
- Recovers within minutes at zero bias





Stability





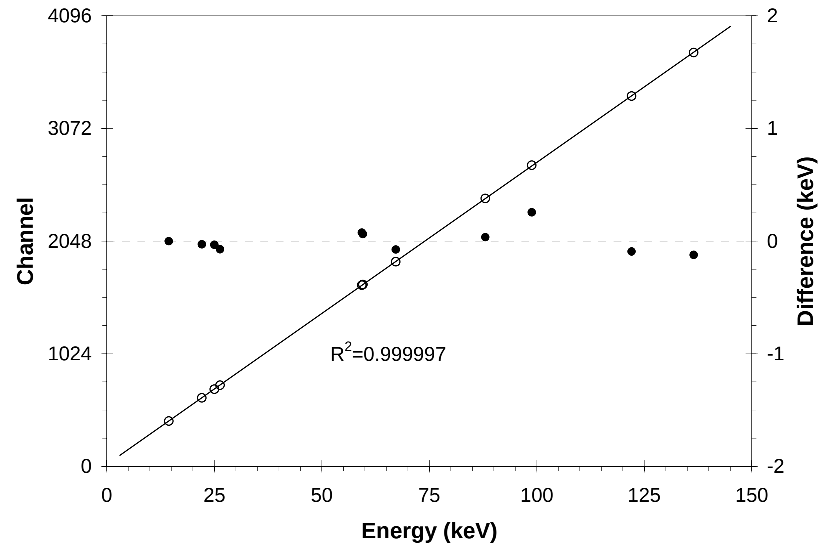
- Left: photopeak centroid and counts over 5 days
  - Gain fluctuations consistent with 30 ppm/˚C temperature coefficient
  - Count rate follows radioactive decay of ^{57}Co
- Right: Spectra measured 60 hours apart
- Stable over period of days. Expect drift at some longer time scale

Linearity

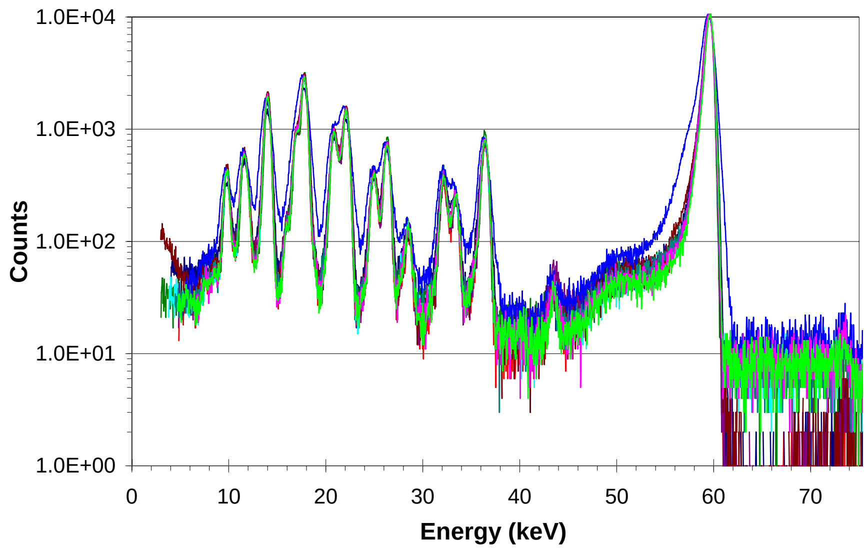
Highly Linear at X-ray Energies

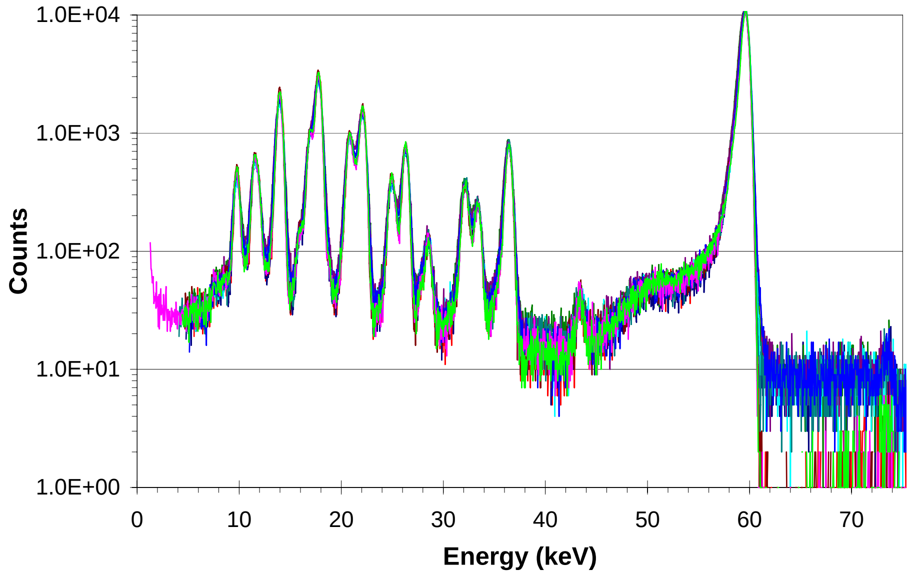
- 14 to 136 keV
- R^2 = 0.0.999997

- Use peak channel, not centroid
- At higher energies, use Q_{max} from photopeak fit



Reproducibility

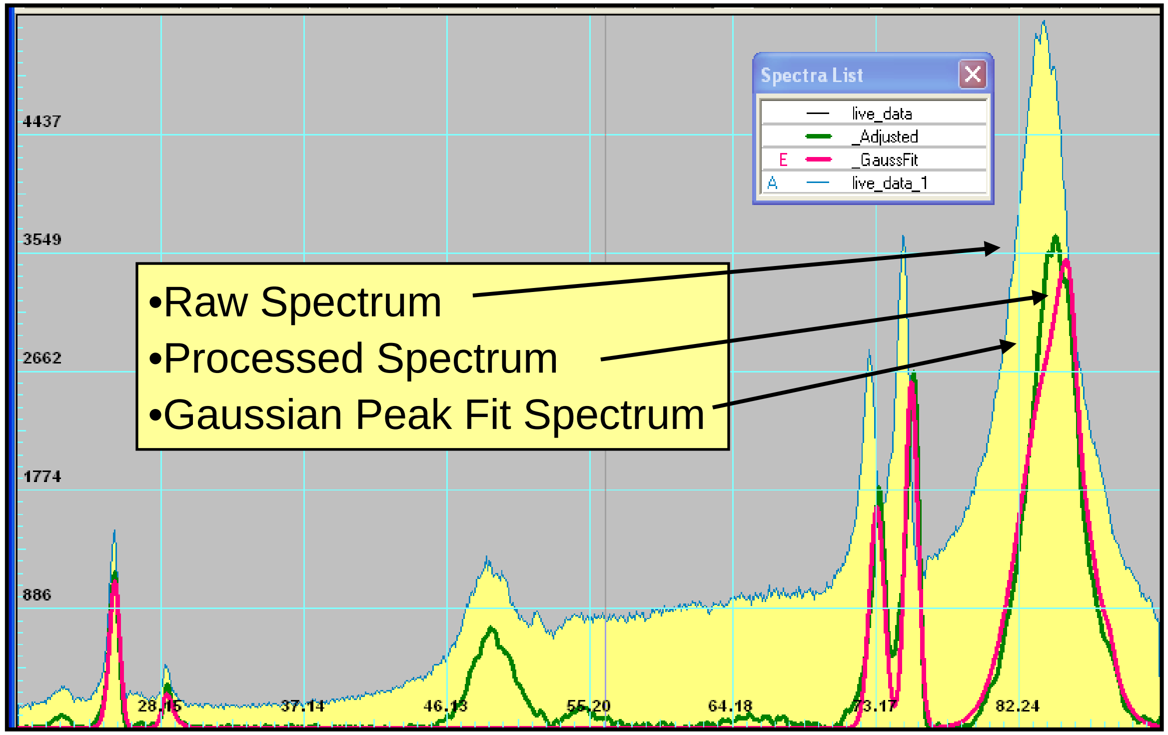




– Plots show data from production lot of 20 detectors
– One detector exhibited higher noise and worse tailing
– Other nineteen consistent

Conclusion

- Sample analysis of Pb-Sn Solders
- Spectrum Processing
  - Cd-Te escape
  - Background
  - Gaussian peak fits
- FP Calibration
  - Pure Sn & Pb stds.
- FP Analysis
  - 68% Sn for Sn-Pb thickness = 1 mm
  - 63% Sn for Sn-Pb thickness = 0.5 mm
  - (Nominal Sn = 63%)



Even though Pb-K_{α} peaks have significant low-energy tails, quantitative analysis is possible.

Conclusions

– CdTe is a powerful tool for measuring metals via XRF
  - It has high sensitivity for K lines, with fewer interferences
  - One can carry out quantitative analysis

– Spectral characteristics require changes to algorithms
  - Hole tailing shape is different
  - Escape peaks more significant
  - Continuum more significant and shape different
  - Amptek's XRS-FP will implement these corrections

– For more information, go to www.amptek.com