CdTe Measurement of X-Ray Tube Spectra: Escape Events
Application Note ANCDTE1 Rev A1

R. Redus, February 4, 2008

CdTe detectors are often used to measure the spectrum emitted from an X-ray tube. A 1 mm thick CdTe detector has excellent sensitivity up to 100 keV, with a photopeak efficiency >90% to 65 keV. This is far superior to Si detectors, where the efficiency drops off by 20 keV. But the response function of the CdTe detector differs from that of Si or Ge detectors and these differences must be addressed to obtain quantitative results. Escape of the characteristic Cd and Te X-rays causes particularly noticeable effects.

Figure 1 shows a typical X-ray tube spectrum measured with an XR100T-CdTe detector. This was an 80 kVp tube with a tungsten anode and a 15 keV aluminum filter. Escape of the characteristic X-rays leads to two features which are clearly visible. First, there are discontinuities in the spectrum at 27 and 32 keV. Second, although the filter should stop essentially all X-rays incident on the detector below 15 keV, there is a clear edge at this point, many lower energy events are seen.

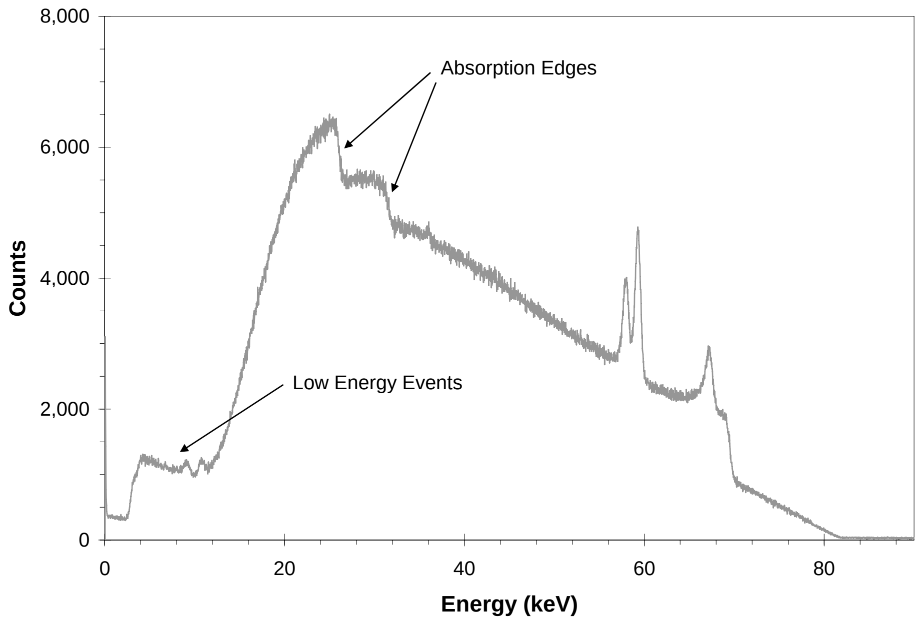

Figure 1. Plot showing the spectrum emitted from an 80 kVp X-ray tube with a tungsten (W) anode and a 15 keV filter, measured with a 1 mm thick CdTe detector.

Both of these features are due to escape events[i]. The Cd and Te K edges are 26.7 and 31.8 keV respectively. Photons with incident energy just above these edges undergo photoelectric interactions, leaving the Cd and Te atoms in an excited state. When the atoms transition to the ground level they often emit a characteristic X-ray at one of the energies shown in Table 1. Depending on the direction, this X-ray may leave the CdTe volume so only a small amount of the incident energy is deposited. Such events lead to fewer full energy events (causing the absorption edges) and more low energy events (below the filter value) than would otherwise occur. This process is responsible for the escape peaks which are well known in spectroscopy, but with a tube there is a continuum of escape events. Escape events are more important in CdTe than in Si or Ge due to the much higher energies of the characteristic X-rays. Fortunately, algorithms exist to “clean up” this artifact and are available in software sold by Amptek, Inc.

	K edge	$K_{\alpha1}$	$K_{\alpha2}$	$K_{\beta1}$	$K_{\beta2}$
Cd	26.704	22.982	23.172	26.093	26.641
Te	31.800	27.200	27.471	30.993	31.698

Table 1. Energies of the K edges and the characteristic X-rays in Cd and Te.

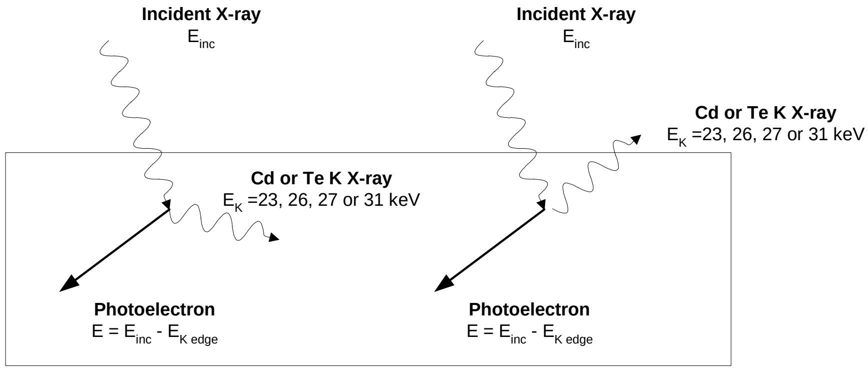

Figure 2. Sketch illustrating events in which the complete energy is deposited, on the left, and those in which a characteristic X-ray escapes, on the right. Photons incident at any one energy E_{inc}, if greater than the K edges, will lead to escape events at four lower energies. The fraction of events in each of these escape peaks depends on the probability of X-ray escape and so on the energy of the incident X-rays along with the geometry of the detector.

To correct the spectrum analysis software must first determine how many low energy events arise from higher incident energies. These must be subtracted from the original spectrum, their energy must be corrected (by adding the energy which escapes), and then these counts are added back. Figure 3 illustrates this using the same spectrum as Figure 1. The green trace shows approximately where these escape events are found in the original spectrum (gray). The dark blue trace shows the escape events after they have been shifted in energy to account for the energy lost by the characteristic X-rays. The dark black trace shows the corrected spectrum after processing. Counts were subtracted at low energies, below the filter cut-off, and added back in above the absorption edges. There is still a "glitch" at the Cd K edge due to second order effects, but the absorption edges are removed and the effectiveness of the filter is seen.

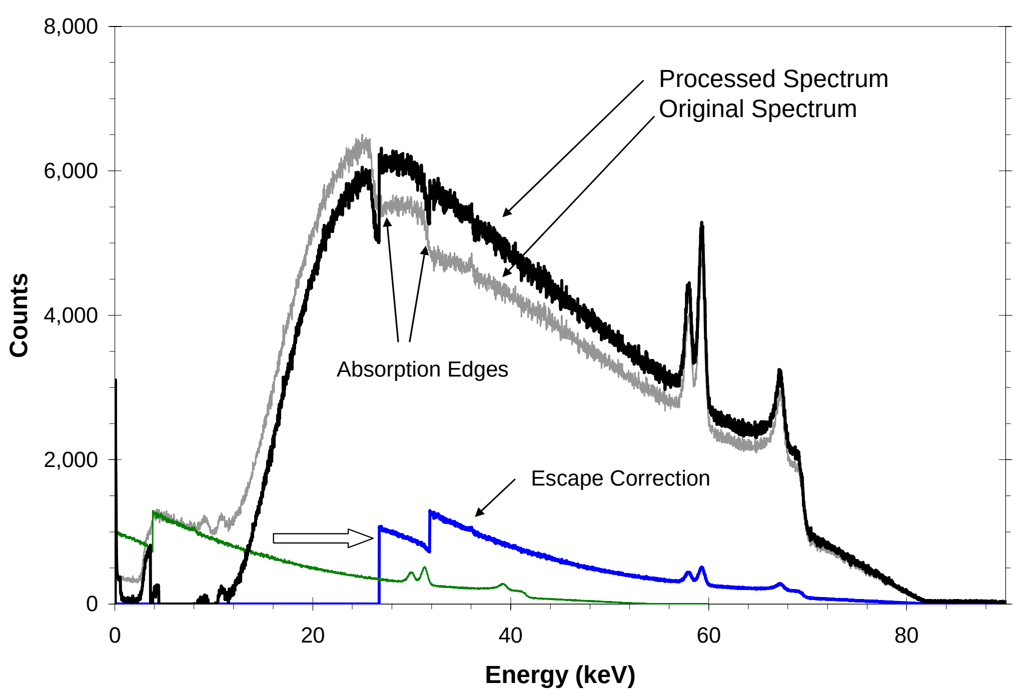

Figure 3. Plot showing the same spectrum as Figure 1 after processing to remove escape events. The gray trace shows the original spectrum. The green trace illustrates the escape events in the original spectrum. These are subtracted from this original spectrum, then the correct energies are computed (by adding in the energy which escaped). The blue trace shows the corrected escape events, which are then summed with the gray trace. The dark black trace shows the final result of the processing with the events in their correct channels.

This processing was carried out using the XRS-FP software sold by Amptek Inc. and described at http://www.amptek.com/fp.html. The technique used in XRS-FP has been described in a paper presented at the 2007 Denver X-ray Conference and submitted to the IEEE Trans. Nucl. Sci.[ii] The technique is based on work done originally by Paul Bennet of RMD Inc. To summarize from this paper:

> Simulation software was used to determine the fraction of events escaping the CdTe volume as a function of energy and this is fit to a polynomial function. The maximum was 15% for the Cd K_α and 3% for the Cd K_β, for photons incident just above the 26.7 keV Cd K edge. At energies above 100 keV the yield asymptotically approaches 5% for Cd K_α, 1.5% for Cd K_β and Te K_α, and 0.4% for the Te K_β. We measured the escape fraction using isotopic sources and found good agreement with the simulation results.
>
> The correction software begins with the highest energy channel, treating it as a 1 channel photopeak. The four channels for the corresponding escape peaks are calculated. The ratio of escape to photopeak counts is calculated from the polynomials for each escape peak. These counts are subtracted from the escape channels and added to the photopeak channel. The process is repeated with the next lower energy channel, using the processed spectrum, and continuing down to the Cd escape edge, channel by channel.

The XRS-FP software includes considerable functionality beyond the escape peak correction, as it was designed for full, quantitative analysis using X-ray fluorescence. Other users have written their own correction algorithms[iii]. In any case, understanding and correcting for these escape events are important to obtaining accurate results with the CdTe detectors.

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[i] See R. Jenkins, R.W. Gould, D. Gedcke, *The Interaction of X-rays with Matter*, Chapter 1 in **Quantitative X-Ray Spectrometry**, 2nd Edition, Marcel Dekker, Inc., 1995.

[ii] R. Redus, J. Pantazis, T. Pantazis, A. Huber, B. Cross, *Characterization of CdTe detectors for quantitative X-ray spectroscopy*, presented at the 2007 Denver X-ray Conference and submitted to IEEE Trans. Nucl. Sci, 2008.

[iii] S. Miyajima, *Thin CdTe detector in diagnostic x-ray spectroscopy*, Med. Phys 30 (5), p 771, 2003.