

BACKGROUND CONTAMINATION IN AMPTEK'S SI-PIN AND SDD DETECTORS

Figure 1 (left) shows X-ray spectra measured from a piece of Lucite in a typical laboratory configuration at Amptek, Inc. Lucite is polymethyl methacrylate, composed entirely of carbon, hydrogen, and oxygen. These elements emit very low energy characteristic X-rays, which are stopped by the Be window or the air between the sample and the detector. If the Lucite were pure and the spectrometer ideal, there would be no characteristic X-ray lines in the spectrum. The spectrum would be a smooth continuum. In reality, there are several characteristic lines visible. These could be due to impurities in the Lucite or to materials in the vicinity of the detector and tube, e.g. the package containing the detector, the sample fixture, radiation shielding, etc. These lines are called *environmental interferences*, *background*, or *contaminants*.

Figure 1 (right) indicates the importance of the contaminants in a typical measurements. This plot compares a spectrum taken from stainless steel (alloy 316 in this case) to the Lucite spectrum. The major constituents of steel (Fe, Cr, Ni, and Mo) yield X-rays at least a thousand times as intense as the contaminants in Lucite. Put another way, the counts due to these contaminant peaks contribute errors of tens to a hundred ppm. The contaminants have a small effect on the measurement of major constituents but can quite be important when detecting trace elements.

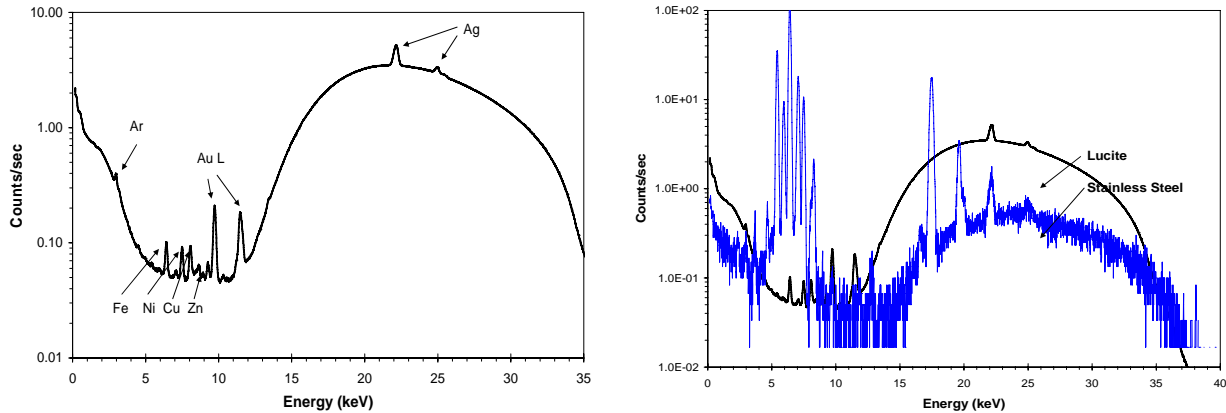


Figure 1. Left: Plot showing spectra measured from Lucite. Lucite is a hydrocarbon, so any characteristic lines result either from impurities in the Lucite or materials in the spectrometer. Right: Plot comparing the Lucite spectrum with a spectrum measured from stainless steel.

What contaminants are present and at what intensity?

The spectrum in Figure 1 (left) was measured using Amptek's XR100SDD, Mini-X X-ray tube, and MP1 baseplate. It was processed with Amptek's XRS-FP spectral analysis software to find the intensity of the lines, shown in Table 1. The background rate of the Fe was less than 1 ct/sec, while the Fe peak in steel was 1000 cts/sec. A Cr peak is visible but at 0.05 cts/sec.

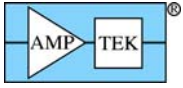
These lines do not necessarily originate in the detector or the detector package. Some users take a "null" spectrum and then assume that all contaminating counts arise in the detector module. In fact, 50 ppm impurities in the "null" sample may be responsible. The shielding, filtering, collimation, etc supplied by the user may also be responsible.

	Energy	Cts/sec	Origin
Ti	4.51	0.09	
Cr	5.41	0.05	
Mn	5.90	0.05	
Fe	6.40	0.77	Kovar
Ni	7.48	0.71	Kovar
Cu	6.93	0.68	Brass
Zn	8.64	0.17	Brass
W	8.4	0.00	
Au	9.71	3.56	

Table 1. Intensity of the lines in Figure 1 (left).

Should I expect to reproduce Figure 1 with my spectrometer?

Not necessarily. Only if you reproduce exactly the geometry, the shielding, the collimation, the filtering, etc. It is very difficult to know the origin of the different lines and hence whether they will be present in your particular setup.



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What causes these contaminants?

Figure 2 is a sketch of the sensor geometry used here. The key components are the X-ray tube, the sample, and the detector. In the ideal picture, the primary X-rays from the tube reach the sample (thick red arrow), interact in the sample, and the secondary X-rays from the sample reach the detector (thick blue arrow). The real world picture is considerably more complex.

The X-ray tube consists of a W anode, so the primary X-rays include both a brehmstrahlung continuum and W characteristic lines. The X-ray collimator is made of brass (Cu and Zn), lined with an Al sleeve to attenuate the Cu and Zn from the brass. The tube filter is made of Al. The sample is supported by a fixture of aluminum (an alloy, containing small amount of Cu and Ni). The sample, tube, and detector are surrounded by radiation shielding. The shielding is made of brass (Cu and Zn), covered with an aluminum alloy. The detector itself is made of silicon. It is mounted behind a Be window, inside a package made of Kovar, an alloy consisting mostly of Fe and Ni. In some of the spectra shown here, an Ag shield was placed over the cover to attenuate the flux reaching the Kovar. In front of the detector is a collimator, made of several materials but ultimately coated with Al (to attenuate the lines from the other materials). Also inside package are a substrate to hold the detector, electronic components (such as the JFET, a temperature diode, etc), a thermoelectric cooler, bond wires, etc.

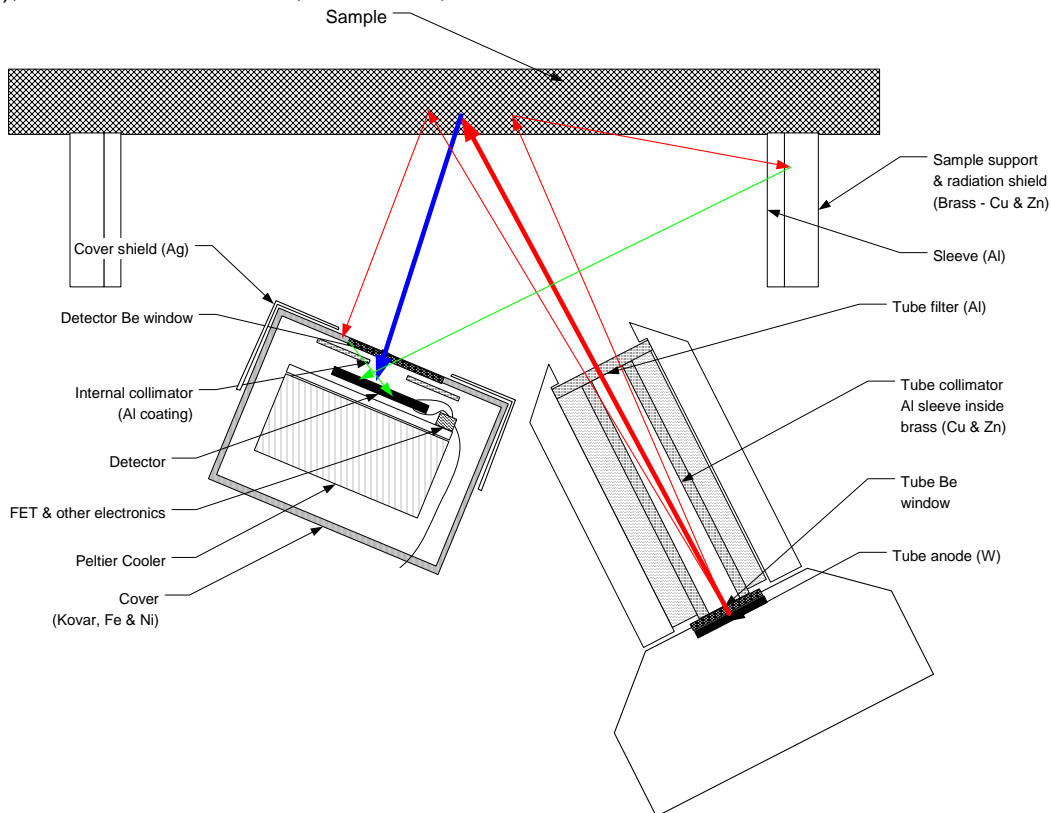
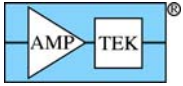


Figure 2. Sketch illustrating the sensor geometry used for the measurements reported here.

X-rays from the tube will reach each of these materials, if not directly then by scattering. Each of these materials will produce characteristic X-rays. The system has been designed to minimize the number of these contaminating X-rays reaching the detector but there always be some. Materials inside the detector package are particularly insidious. Simple dirt or debris on the Be window or on the sample can also make a significant contribution.

In Table 1, note that the intensity of the W lines from the X-ray tube is zero. The tube filter successfully eliminated this contribution. The Fe and Ni lines most likely originate in the Kovar cover. The Au lines most likely originate from interconnects in the package. The Ag lines (not listed in the table but clearly visible in the spectrum) originate from the Ag cover on the package. The Cu and Zn are presumed to originate in the



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brass, which is used extensively around the detector. The Ti, Cr, and Mn, along Fe, Cr, Zn, and Ni, could be in the aluminum or Kovar, or impurities in the Lucite, or even in a dirt/debris layer on the Lucite.

How can I reduce the contaminants?

Most importantly, examine closely the geometry of the components sketched in Figure 2. Make certain that the detector is not directly viewing the tube collimator, the sample support or shields, or any other material. As far as possible, cover all the high Z elements (which will emit detectable characteristic X-rays) with a low Z material, such as aluminum. Consider materials “behind” the sample.

There are additional steps one can take. Figure 3 (left) shows the Lucite spectrum with and without the Ag cover. The black spectrum, with the Ag cover, has the clear Ag K_{α} and K_{β} peaks around 25 keV. To first glance, the contamination might appear worse since these peaks appear, but the Fe and Ni peaks due to the Kovar are significantly lower. The Ag cover reduces contamination from Fe and Ni while adding Ag counts. If one is trying to measure Fe and Ni, then the cover helps, even though it adds additional lines.

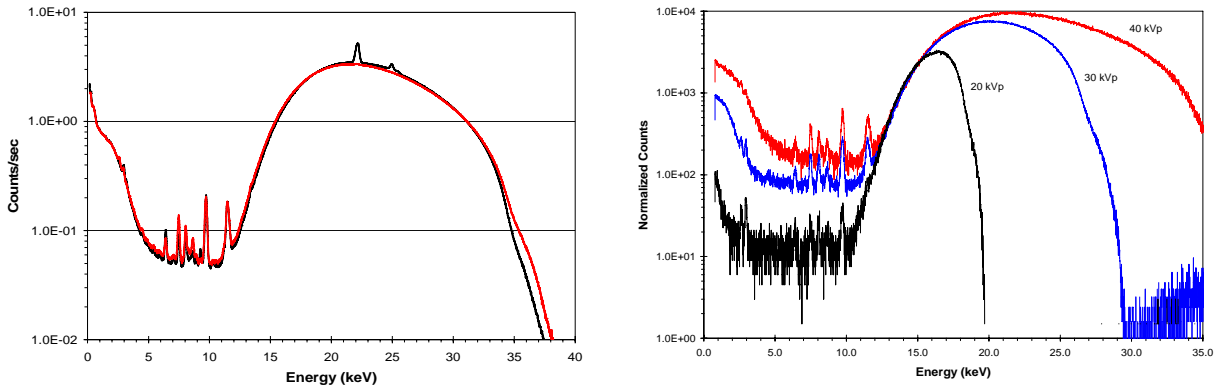


Figure 3. Left: Lucite spectra taken with the Ag cover (black) and without (red). Right: Lucite spectra taken at 20, 30, and 40 kVp.

Figure 3 (right) shows the variation with X-ray tube energy. As the energy of the X-ray tube is increased, the X-rays penetrate more deeply into the Kovar cover, into the brass shielding, etc. The count rates for the contaminants increase significantly with energy. It is best to use an energy sufficient to excite well all of the characteristic X-rays to be analyzed, and to penetrate the sample well, but greater energies are counterproductive. Figure 4 (left) compares Lucite spectra taken with two different Amptek detectors, of essentially the same active volume. The details of the fabrication of the detector are obviously quite important.

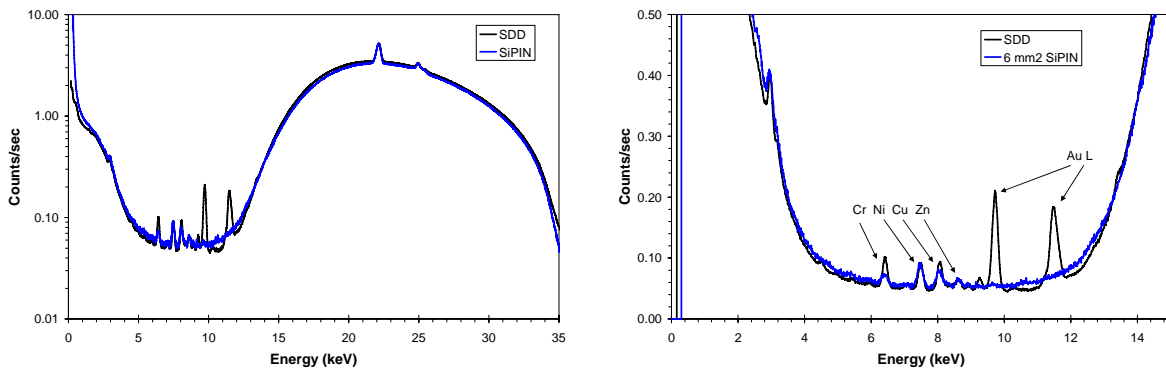


Figure 4. Lucite spectra taken with an SDD (left) and a 6 mm² SiPIN (right), both at 40 kVp and the same geometry.

Figure 1 (right) compares the Lucite and stainless steel spectra. Note that the Lucite sample has a much higher continuum response. This is because the low X materials in the Lucite have a high scattering cross-section while the higher Z materials in the steel have a higher photoabsorption cross-section. The Lucite scatters more high energy X-rays into the detector, thereby stimulating emission of more X-rays within the detector assembly. This plots makes the very important point that the spectrum and count rate of the contaminants depends on the sample. One cannot measure the contaminants with one samples and expect this to be the same with all materials.