Estimating photon flux from ion chamber currents

During the EXAFS experiment, it is useful to know the number of photons you are actually detecting. This lets you estimate your signal to noise ratio (if you are limited by photon counting statistics, the usual case for dilute enzyme solutions), and how long it will take you to obtain your desired signal to noise ratio. It can help you diagnose some experimental problems. For example, it is not difficult to calculate the expected number of fluorescence photons from a given sample in a given geometry if you know the incident flux. If the actual numbers are much different from the calculation, your sample alignment may be off, or there may be some other problem.

When an x-ray photon is absorbed by a gas, it results in ejection of one or more photoelectrons from the gas atom (or molecule). These high energy photoelectrons collide with other gas atoms, which may eject more photoelectrons at a yet lower energy. Ejection of electrons leaves vacancies in inner quantum levels of the atoms, which are unstable: electrons from higher energy states “fall into” the “hole”, and give up their energy by emitting a fluorescence photon (which may be absorbed by other gas atoms, causing ejection of more photoelectrons) or by directly ejecting electrons by the Auger effect.

For our purposes, the consequence of these complicated processes is that each x-ray photon produces a number of charge carriers (free electrons and positive charged gas atoms or molecules), and the number is proportional to the energy of the x-ray photon. For a wide variety of gases, it takes about 32 ev to produce an electron–ion pair, so an x-ray photon of energy 9600 ev (which corresponds to the Zn K edge) produces about 300 electrons. The high electric field across the plates of the ion chamber that is applied by the high voltage power supply causes the electrons and the positively charged ions to migrate toward opposite plates. The electrons are collected at the anode plate, and the resulting current is converted to a voltage output (with an adjustable gain: volts output / amps input) using a low noise amplifier.

Fluorescence ion chambers are normally filled with a sufficiently heavy gas that essentially all of the photons incident upon it are absorbed. I_0 ion chambers, on the other hand, usually absorb between 1–20% of the incident photons, depending on the length, the photon energy, and the gas or gas mixture used. The fraction of the photons of energy E that are transmitted between ion chamber plates of length x is $\exp(-\mu(E)x)$, where $\mu(E)$ is the absorption coefficient of the gas. The fraction of the photons that contribute to the photocurrent therefore is $1-\exp(-\mu(E)x)$. Thus if N photons per second are incident on the ion chamber, they give rise to a current $N(1-e^{-\mu(E)x})\,(E/32\text{ev})$. As an example, suppose the ion chamber absorbs 10% of the incident photons, and there are 10^{10} of 6.4 KeV photons incident per second. The resulting current is $.1 \times 10^{10}$ photons/sec $\times\ 6.4 \times 10^3$ ev/photon

$\times$ 1.6 $\times$ 10^{-19} Coulombs/electron $\times$ 1 electron/32 ev $\approx$ .32 μA. At an amplifier gain of 10^7 volt/amp (a gain setting of 7 on a Keithley 427) this would give a output signal of 3.2 volts.

Exactly the same type of calculation can be done to determine the number of photons you are collecting in a fluorescence ion chamber. A useful number to memorize is that *one volt output at 10^{10} gain corresponds to 3 $\times$ 10^6 photons/sec for iron Kα fluorescence (6400 ev).* The number can be scaled for the situation at hand. For example, if you measure 3.0 volts output at 10^9 gain at an energy of 9600 ev, the number of photons absorbed is about 3.0 $\times$ ($10^{10}/10^9$) $\times$ (6400/9600) $\times$ 3 $\times$ 10^6 photons/sec = 6 $\times$ 10^7 photons/sec.