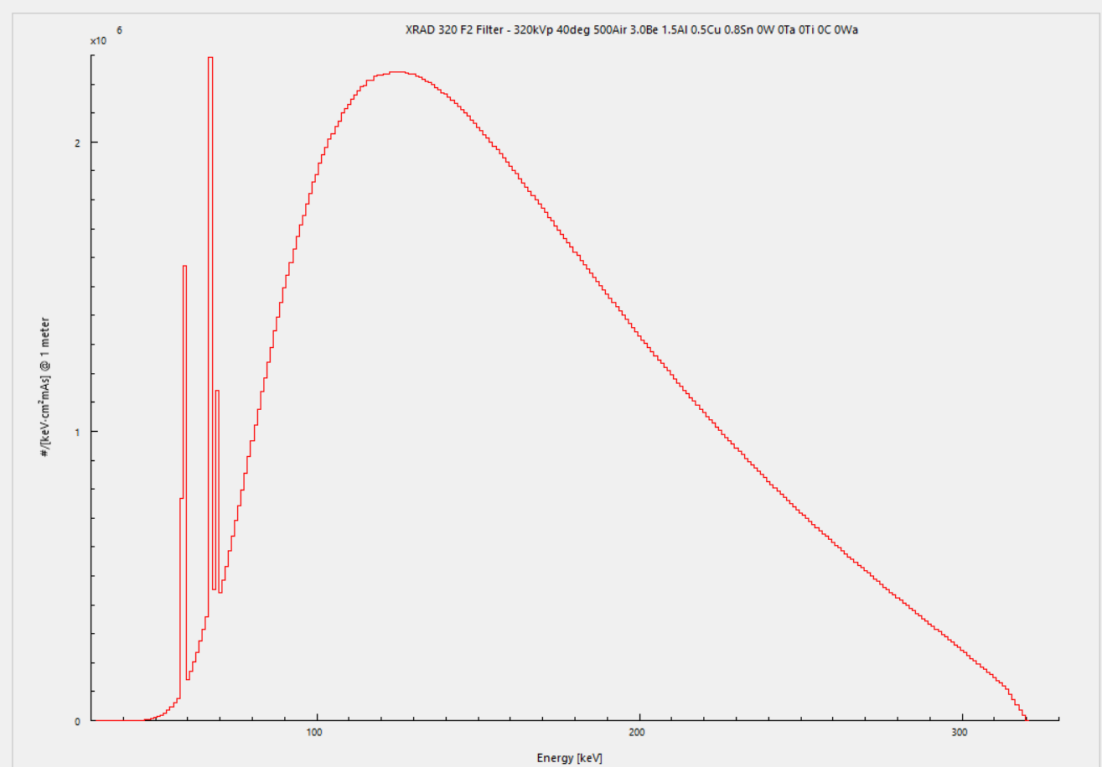
PRECISION X-RAY IRRADIATION

Technical Note

X-ray Energy Spectra and Filters

A key difference between gamma rays and X-rays is the energy of the beam. Typically, a gamma ray source will have just one energy: this is known as a **monoenergetic beam**. X-rays, on the other hand, are a large combination of many energies known as a **polyenergetic beam**. The combinations of these energies make up what's called the beam's **X-ray spectrum**. Scientists measure the energy of photons in the spectrum in **electron volts (eV)**; radiobiology studies typically employ photons in the kilo-electron volt (keV) range, while clinical treatments typically employ photons in the mega-electron (MeV) range. These energies refer to the potential applied to the electrons hitting the target in the X-ray tube – which is how the X-rays are produced. In contrast, gamma rays are produced from a radioactive material.

An example spectrum of a 320 kVp beam (meaning its peak voltage is 320kV, producing 320 keV photons), is shown below:



The X-ray spectrum of a beam is very important because of how X-rays are absorbed. Lower energy X-rays are absorbed very easily, even by the skin. High energy X-rays, on the other hand, can penetrate further into tissue. As a result, the higher the average energy of the beam, the better it penetrates tissue. A comparatively higher average energy beam is said to be a **harder** beam.

To set the X-ray spectrum, there are two parameters that can be adjusted:

1) The **maximum energy, or kVp** of the beam
2) The **added filtration** placed in front of the beam. This is typically thin pieces of metal such as aluminum, copper or tin.

Adding more filtration to a beam is known as **hardening** it. From this information, it is natural that different X-ray spectra are used for different applications. Below are some examples:

Small animal and cell radiation:

- A 320kVp beam with a Thoraeus filter (Al, Cu, Sn) used for bone marrow ablation.
- A 225 kVp beam with a Cu filter used for targeted irradiation.
- A 160 kVp beam with an Al filter used for irradiating cells.
- A 40 kVp beam with an Al filter used for soft-tissue imaging.

Human radiation:

- A 6 MV (megavolt) beam with a flattening filter used for treating humans.
- A 120 kVp beam with an aluminum filter used for imaging humans.

References:

1. Poludniowski, G., Landry, G., DeBlois, F., Evans, P. M. & Verhaegen, F. SpekCalc: a program to calculate photon spectra from tungsten anode X-ray tubes. *Phys Med Biol* **54**, N433-438 (2009).
2. American Cancer Society: What Are X-rays and Gamma Rays? https://www.cancer.org/cancer/risk-prevention/radiation-exposure/X-rays-gamma-rays/what-are-xrays-and-gamma-rays.html.
3. NIH Science Education: X-rays. https://www.nibib.nih.gov/science-education/science-topics/X-rays