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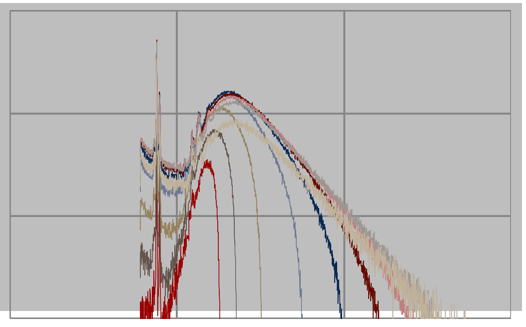

Characterization of the Beam Spectrum from an Industrial X-ray System

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Sandia National Laboratories

ASNT Digital Imaging XVI
July 22-24, 2013
Sandia National Laboratories

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Acknowledgments

- Dean Mitchel
- Lee Harding
- John Parmeter
- Burke Kernen
- Kevin Rolfe
- Edward Jimenez
- Lisa Theisen
- Gregory Thoreson

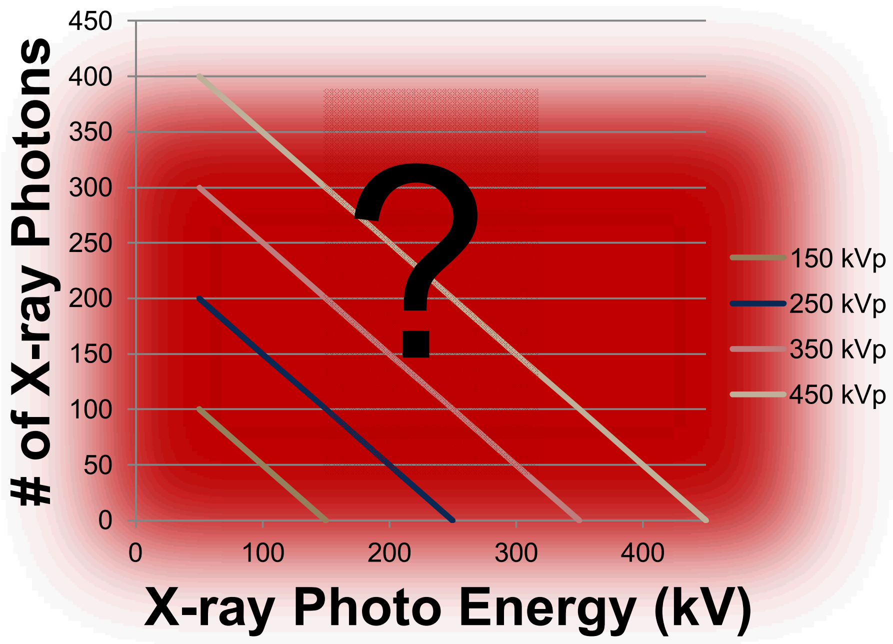
Presentation Outline

- What are we trying to characterize?
- Why do we want to characterize this system?
- Why simulate radiographic images?
- How the beam spectrum was characterized
- Results
- Lessons learned
- Future work

What are we trying to characterize?

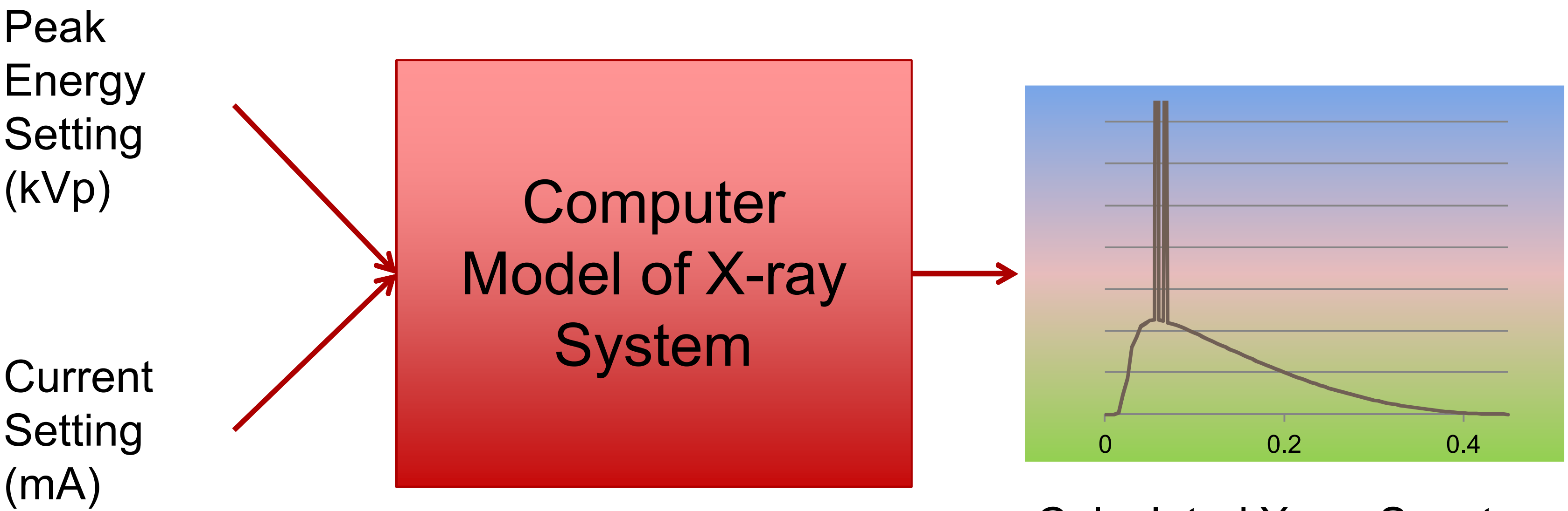
- Medical and industrial x-ray systems produce a polyenergetic beam of x-rays
- We want to know the spectrum (energy distribution) of the x-ray photons emitted from an industrial x-ray system

- 450 keV Kimtron x-ray system with a Comet model MXR451HP/11 tube
- Operated between 50 and 450 kVp



What are we trying to characterize?

- Need enough information about the spectrum to develop a high-fidelity mathematical model that can be used as the input for simulating digital x-ray images



Calculated X-ray Spectrum

Why do we want to characterize this x-ray system?

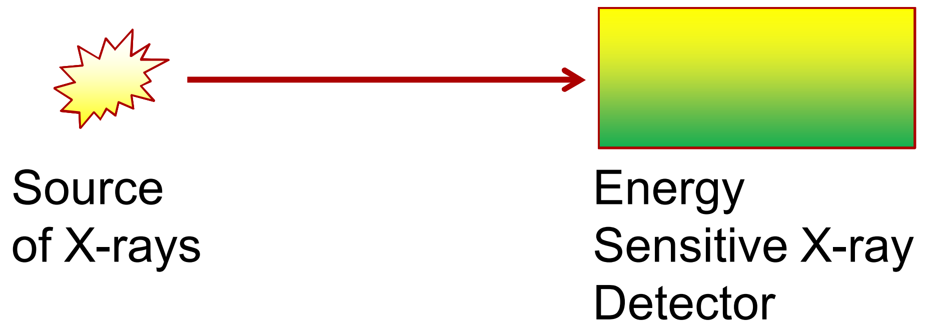
- We have software that can be used to simulate a digital radiographic image.
- To generate accurate images, this software requires digital representation of the x-ray beam spectrum.
- It is critical that this input spectrum be accurate to ensure a valid simulated image.
- The x-ray system manufacturers do not provide output beam spectrum information.
- Monte Carlo codes have been used to estimate beam profiles but haven’t been validated on most industrial x-ray systems.

Why simulate radiographic images?

- High-fidelity simulated radiographic images can be used to:
  - Determine detectability thresholds
  - Optimize x-ray technique parameters
  - Determine the feasibility of radiographing hazardous materials
  - Develop methods to distinguish between different materials/chemical compounds
  - Create simulated computed tomography data

How the beam spectrum was characterized

- In theory, it is a simple process to measure the x-ray beam spectrum.



- In practice, there are several obstacles to overcome

How the beam spectrum was characterized

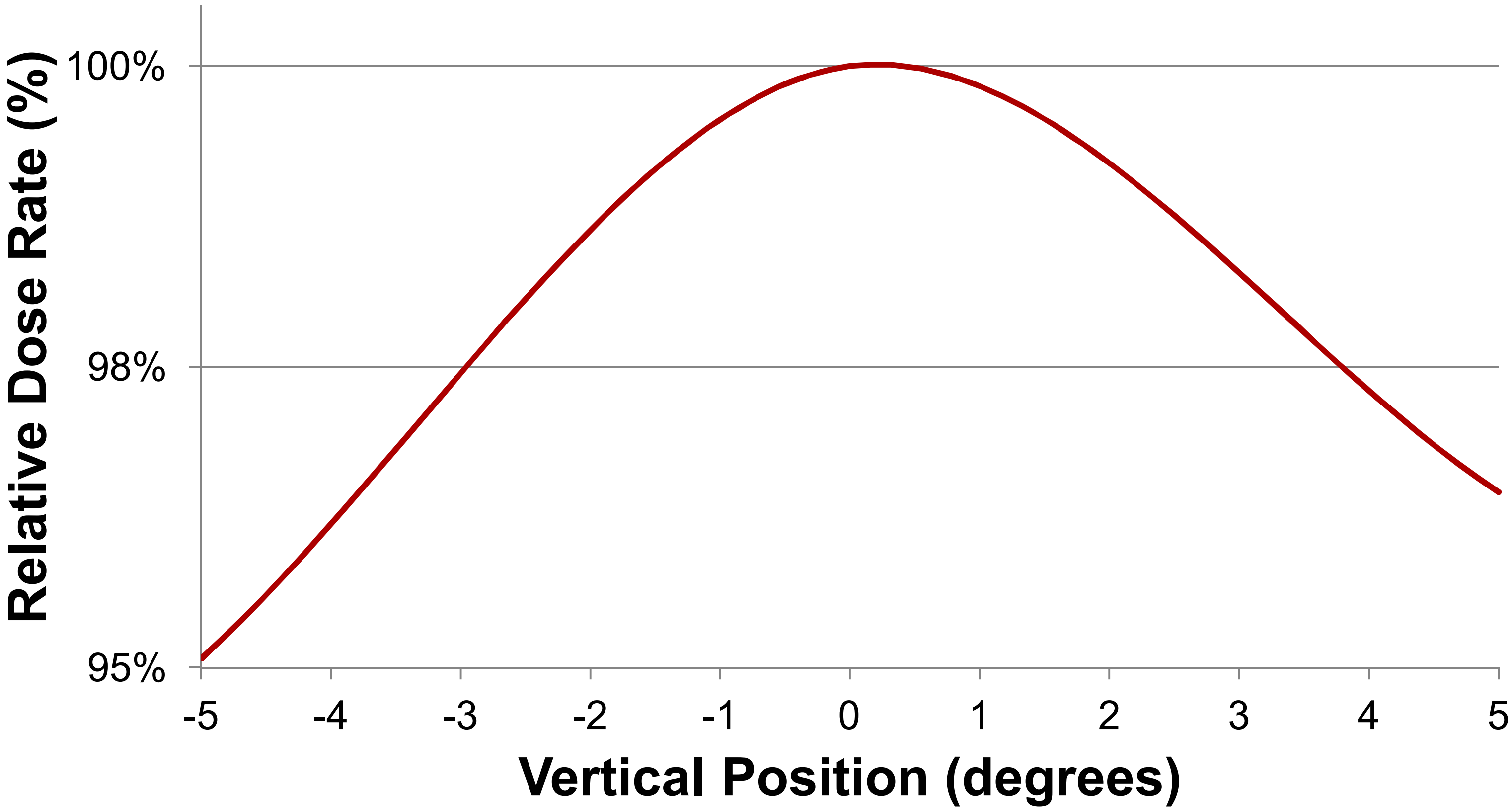
- Measured the variation of the dose output of x-ray system vs. position
- Measured dose output of x-ray system vs. current
- Determined detector response function for energy sensitive detector
- Measured x-ray system beam spectrum
- Corrected measured data and developed digital representation of beam spectrum

Equipment

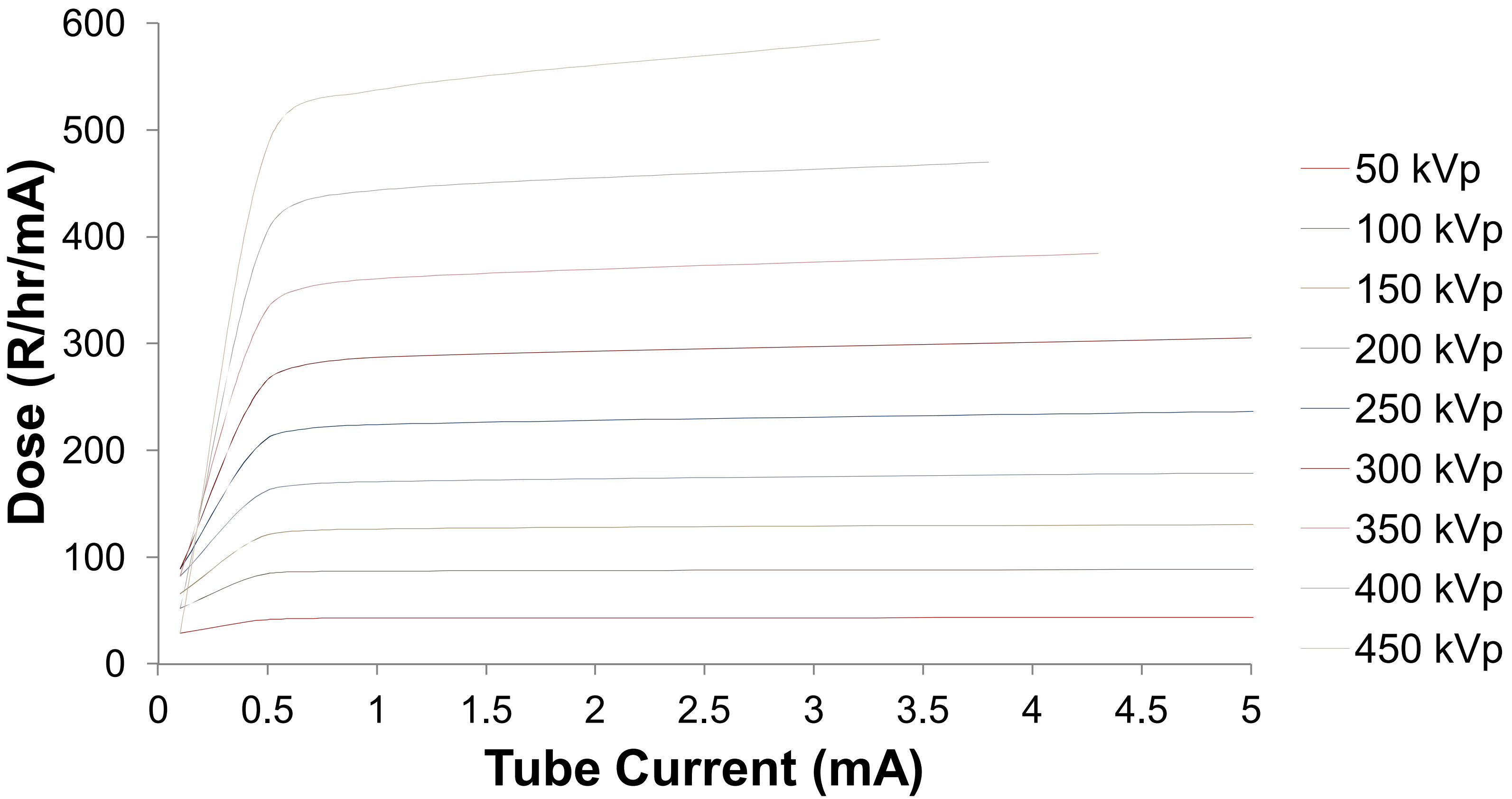
- Kimtron 450 kV industrial x-ray system with a Comet MXR-451HP/11 tube.
- X-ray spectrum detector: Amptek PX4 Digital Pulse Processor and a XR-100T CdTe (0.3x0.3x0.1 cm CdTe element)
- 0.2 cm copper filter
- 0.075 cm tin filter
- X-ray dose detector: Radcal 9010 with a 0.6 cc ion chamber

X-ray Tube Output vs. Horizontal Position

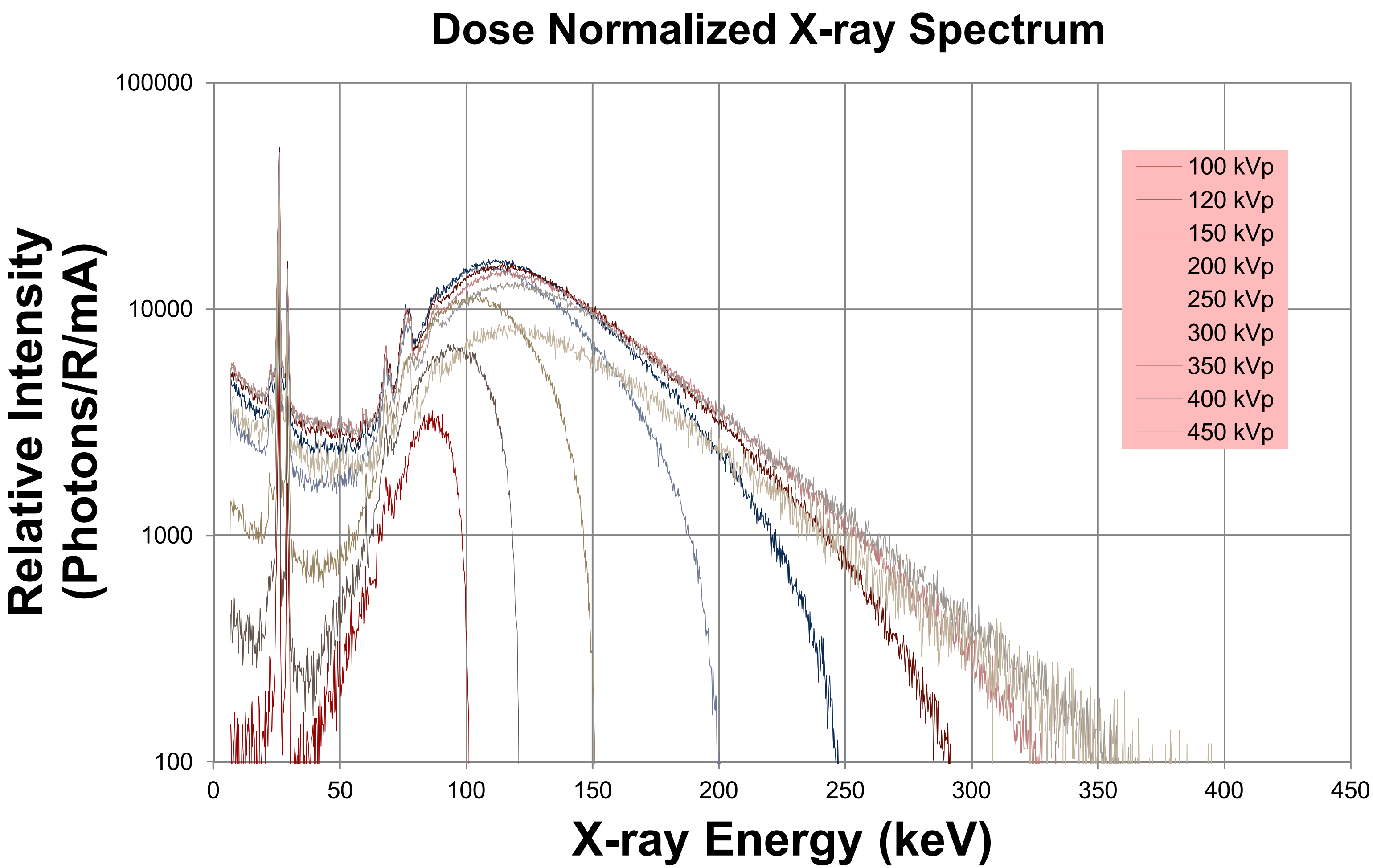
X-ray Tube Output vs. Vertical Position



X-ray Tube Output vs. Current



Measured X-ray Spectrum



Analytical representation of beam spectrum

$$F_\gamma = s\left[1-\left(\frac{E_\gamma}{E_e}\right)\right]^p$$

- E_γ is the photon energy
- E_e is the peak electron energy (kVp)
- F_γ is the photon flux (photons/electron/cm2/MeV) at 1 meter
- *s* and *p* are the two adjustable parameters

$$s = (0.80 - 1.63 \times E_e) \times 10^{-6}$$

$$p = 1.0204 + 0.7738 \times E_e$$

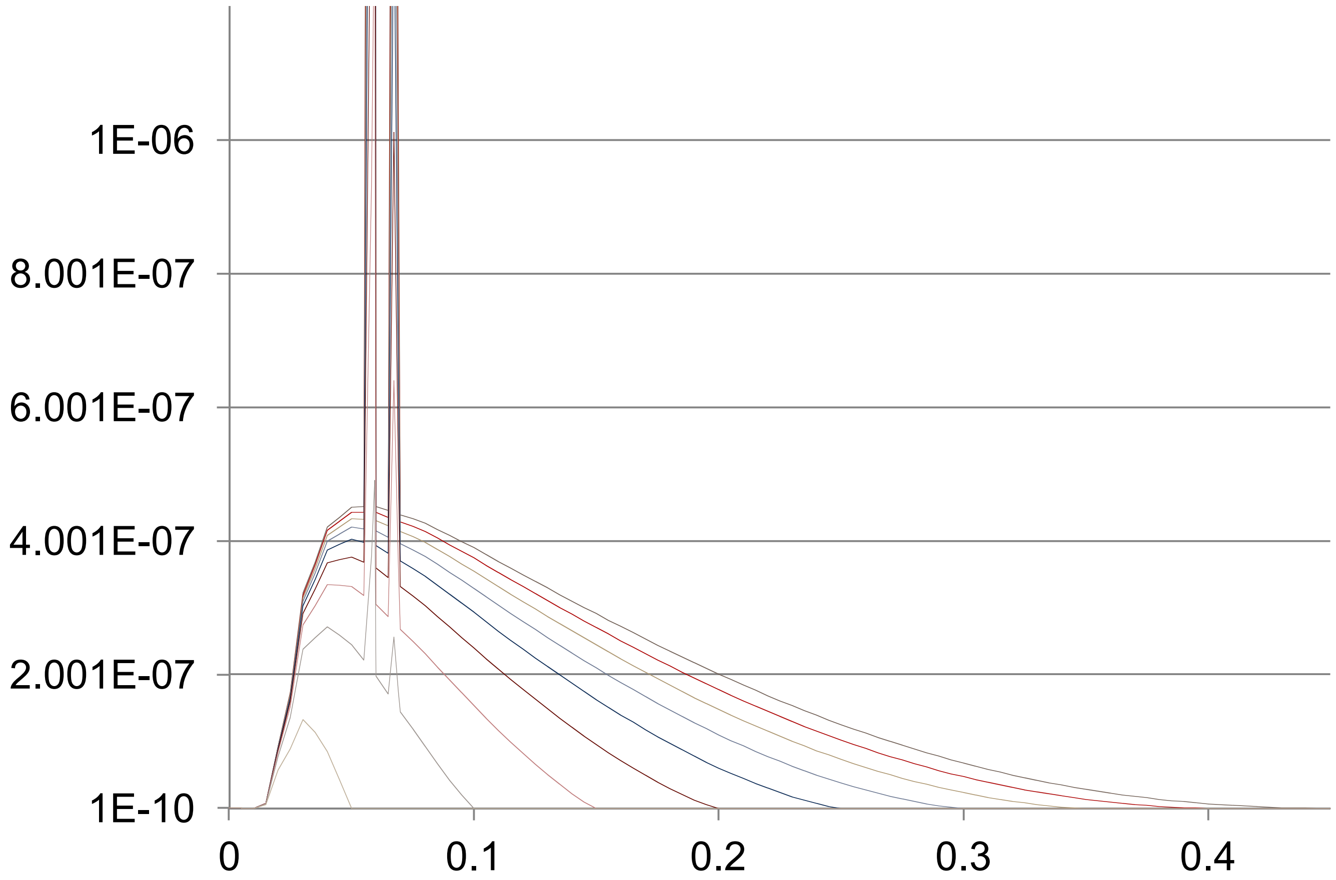
Characteristic tungsten x-ray peaks

$$F_{x_i} = F_\gamma\Big|_{70\ keV} Y_{x_i}[80 \times (E_e - 0.05)]$$

- $F_\gamma\big|_{70\ keV}$ is the continuum photon flux at 70 keV
- Y_{x_i} is the relative x-ray yield
- F_{x_i} is the photon flux @ the characteristic energy

X-ray Energy (keV)	Relative Yield
57.98	0.288
59.32	0.500
67.20	0.169
69.10	0.043

Computed Spectrums 50-450 kVp



Lessons Learned

- It is difficult to get a low enough regulated output from the x-ray machine that does not saturate the energy sensitive detector
- Collimators, filters and other beam-limiting devices distort the measured spectrum
- If collimators are used, alignment is critical
- It always takes longer than you anticipate

Future Work

- Measure x-ray beam spectrums without filters
- Use non-tungsten collimators (Bismuth)
- Measure x-ray beam spectrums from other x-ray tubes
- Combine models for x-ray beam spectrums with x-ray imaging detector (DR flat panels) response functions
- Compare simulated x-ray radiographs with experimentally acquired images

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Characterization of X-Ray Generator Beam Profiles, SAND2013-5247