Mammographic Beam Quality Matching: Monte Carlo Simulations and Spectrometry

John Stasko[1] and Wesley Culberson[1]

[1]Department of Medical Physics, School of Medicine and Public Health, University of Wisconsin-Madison, Madison, WI, 53705

Purpose: Historically, mammographic x-ray tubes had molybdenum anodes, and the quality of images produced by the screen-film receptors was characterized by the image's contrast. The low average energy of spectra from molybdenum anodes provided the highest contrast with the lowest dose to the patient. With the advent of digital image receptors, image quality became characterized by signal-difference-to-noise ratio, instead of contrast. Now, tungsten anodes have been found to produce quality images with the least patient dose [1].

However, only molybdenum-anode beams are available for calibrating mammographic dosimeters in the US. NIST has many tungsten-anode mammography calibration beams in development. At the University of Wisconsin, we are striving to develop tungsten-anode mammography calibration beams that are matched in terms of half-value layer (HVL) with the beams at NIST. The work presented in this abstract focuses on initial HVL measurements, as well as validating a Monte Carlo (MC) model of the x-ray tube.

Methods: Filter materials of pure metals with thicknesses as close to the NIST filters as possible were procured. Filter and tube potential options are shown in Table 1. Using a tungsten anode x-ray tube, the HVL of each filter and tube potential combination was measured. The results of these measurements quantified the difference in beam quality between the x-ray tube at NIST and the x-ray tube at the University of Wisconsin – Madison. As our objective was to match the beams in terms of measured HVL, the next task was to determine filter thicknesses that would create beams with HVL equal to the measured HVL of the NIST beams. This required validated simulations of the beams.

Lawless's MC model of the COMET MXR-320/26 x-ray tube, with some changes made to reflect a new monitor chamber assembly, was then used to simulate the investigated beams [2, 3]. The simulated air kerma per starting particle after adding the measured HVLs to the simulations and before adding the measured HVLs to the simulations were calculated. The ratios of these values were used to benchmark the simulations.

As some ratios did not meet expectations, further experiments with the x-ray tube were performed. An Amptek (Bedford, MA) X-123 CdTe spectrometer was calibrated for use in the energy range below 50 keV. This spectrometer was then used to carry out endpoint kV measurements of the x-ray tube for the seven tube potential settings in this study. Discrepancies between nominal and measured tube potentials were observed, so the MC simulations were repeated using the measured tube potential values.

Table 1. Filter and tube potential options for tungsten-anode mammography calibration beams in development at UW – Madison and NIST.

Quantity	**Available Options**
Tube Potentials	20, 25, 28, 30, 35, 40, and 50 kV
Filters	0.05 mm Ag, AgX 0.06 mm Mo, MoX 0.05 mm Rh, RhX 0.5 mm Al, AlX (X indicates added 2 mm of Al)

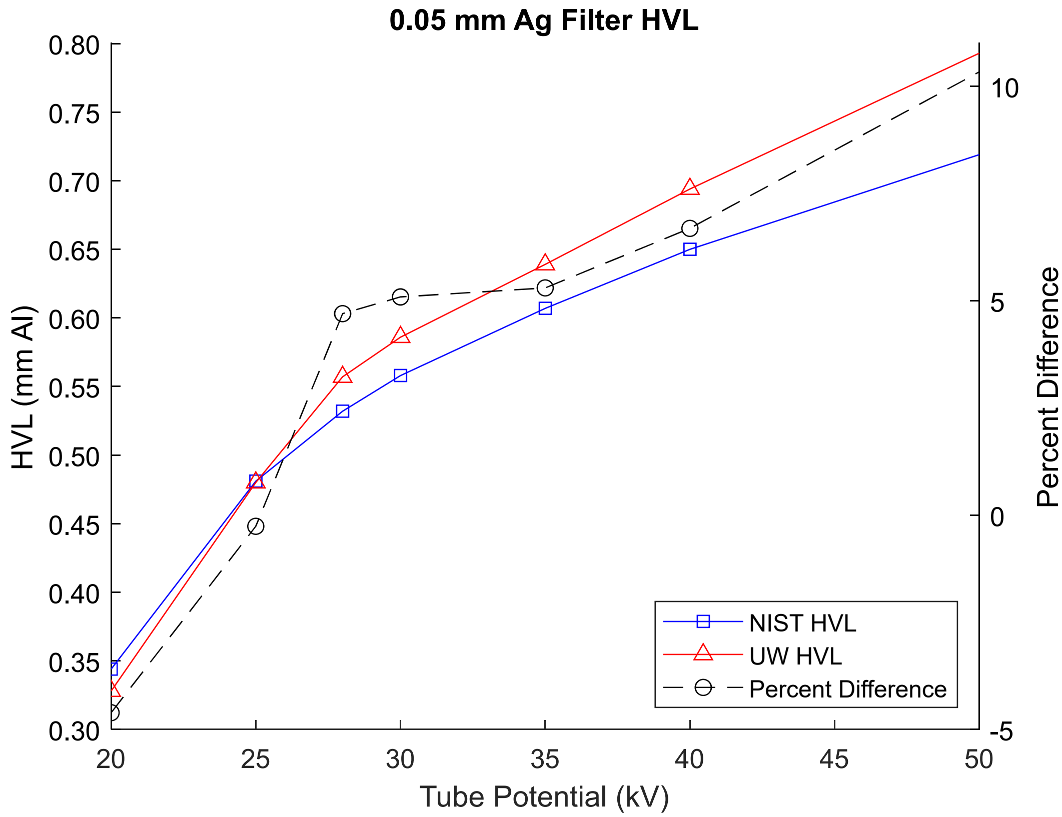

Figure 1. Measured HVLs vs. nominal tube potential. The right y-axis indicates the percent difference between the measured NIST and UW HVLs.

Results: Figure 1 is a plot of measured HVLs at UW – Madison and NIST vs. tube potential for the Ag filter. Other plots for the various filters showed similar behavior: the measured HVL for the beam at UW – Madison was less than the measured HVL of the beam at NIST for low tube potentials and greater than the NIST measured HVL for high tube potentials. These results were used for the MC simulations.

The simulated beam spectra at one meter from the source, before and after adding the measured HVL of Al to the simulation, were tallied. Figure 2 is an example of one pair of spectra. The ratio of the air kerma before and after adding the Al to the simulation was computed using the collected spectra. The criterion from the International Atomic Energy Agency's Technical Report Series no. 457 is that if the ratio falls between 0.485 and 0.515, then the simulations can be considered an adequate representation of reality [4]. This requirement was met for all beams other than those with nominal 20 kV tube potential, with values listed in Table 2.

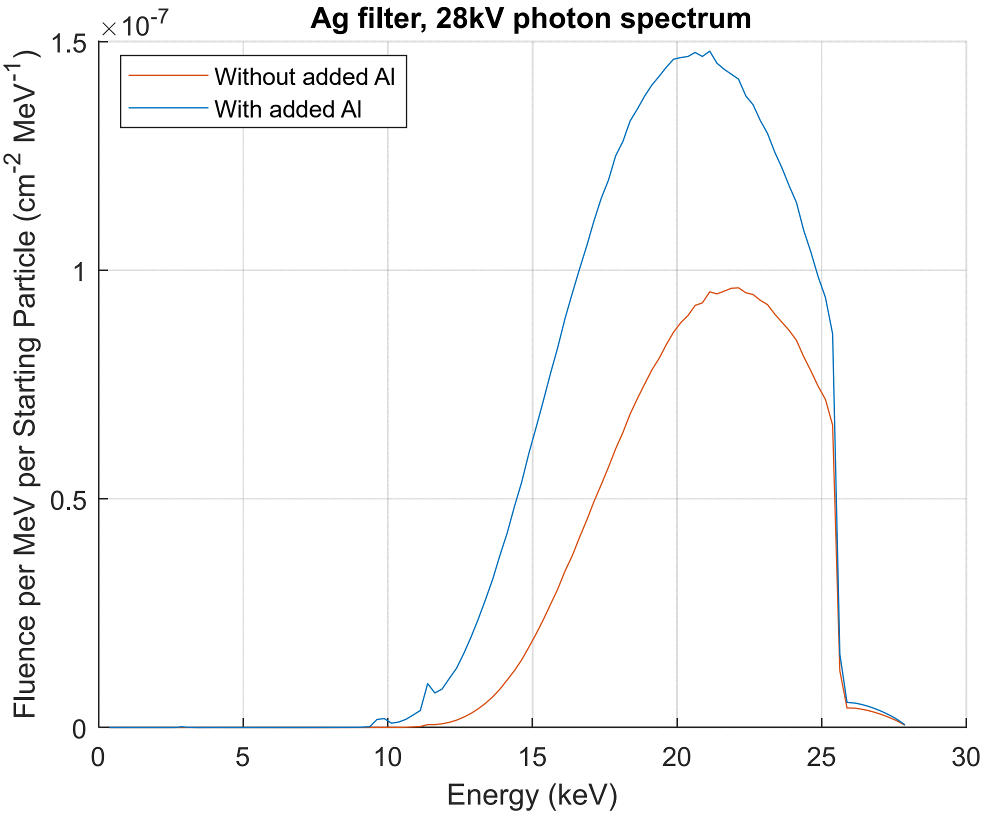

Figure 2. Simulated spectra with and without the added HVL of Al for the 28 kV, Ag filter beam.

Table 2. Air kerma ratios for nominal 20 kV tube potential beams.

Filter	Before Correcting Tube Potential (20 kV)	After Correcting Tube Potential (19.05 kV)
Ag	0.5185	0.4897
AgX	0.5293	0.4914
Al	0.5129	0.4916
AlX	0.5288	0.4946
Mo	0.5171	0.4927
MoX	0.5330	0.4979
Rh	0.5164	0.4883
RhX	0.5312	0.4957

Beam spectra for each tube potential were measured using the calibrated X-123 spectrometer, in order to determine if the endpoint tube potential of the x-ray tube matched the potential on the console. The spectra were smoothed using a Savitzky-Golay filter, and linear fits were applied to the end of the spectra and the background. The energy of the intersection of the two lines corresponded to the endpoint tube potential of the x-ray tube [5]. Figure 3 is an example fit, and Table 3 lists the determined endpoint tube potentials.

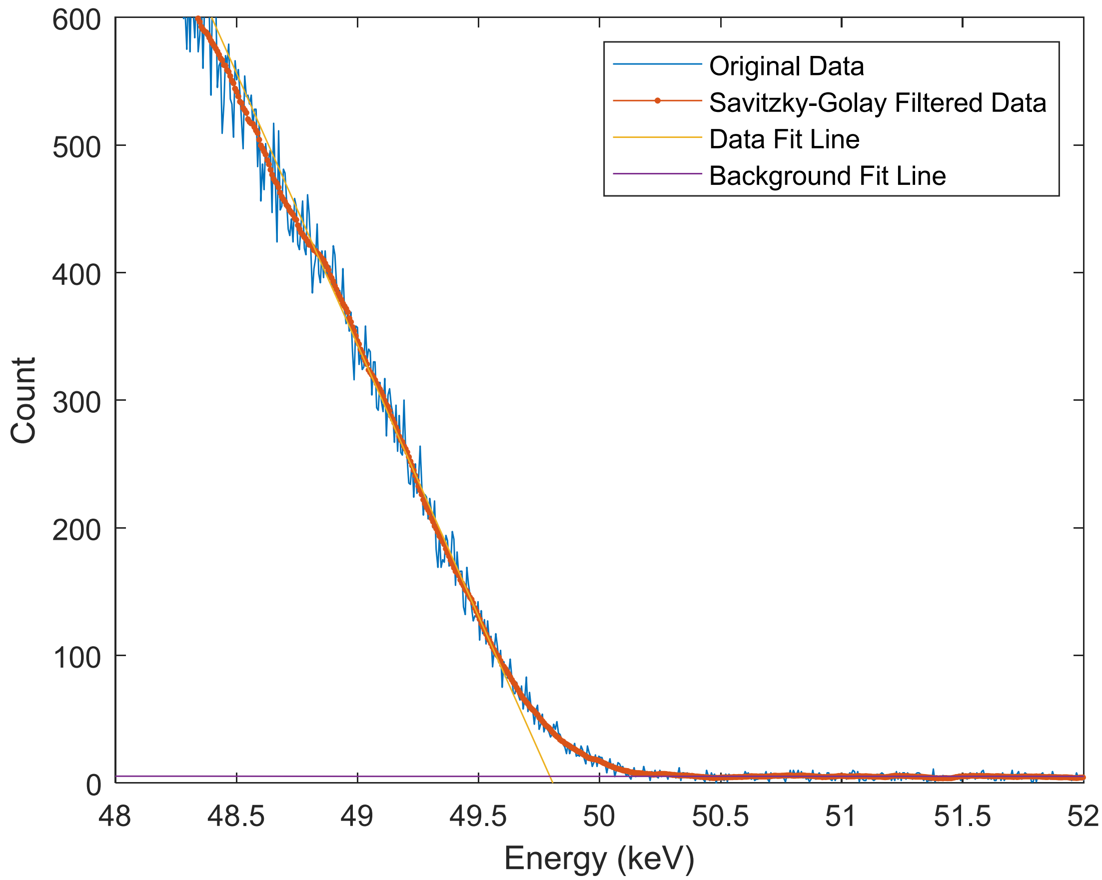

Figure 3. Measured counts vs. energy for the AlX filter with a nominal tube potential of 50 kV. The intersection of the data fit and background fit lines occurs at 49.79 keV. Therefore, the endpoint tube potential is 49.79 kV.

Table 3. Nominal tube potentials and corresponding endpoint tube potentials.

Nominal Tube Potential (kV)	Endpoint Tube Potential (kV)
20	19.05
25	24.18
28	27.16
30	29.30
35	34.45
40	39.58
50	49.79

As can be seen in the above table, the actual tube potential is nearly one kV lower when the console is set to 20 kV. Once the 20 kV HVL simulations were repeated with the accurate tube potential, all air kerma ratios met the TRS-457 criterion (see Table 2).

Conclusions: In this study, a MC model of the COMET MXR-320/26 x-ray tube was validated for use in predicting the HVL of various filter materials and thicknesses. The MC model will be utilized in the future to determine optimal filters to produce beams that match the measured HVL of the beams in development at NIST. Additionally, the X-123 spectrometer was calibrated for the energy range between 0 and 50 keV. Spectral measurements with this device will help determine corrections necessary for air kerma measurements of the beams.

Relevance to CIRMS: This work is relevant to CIRMS, as updated calibration options for the mammographic energy range are long overdue in the US medical physics community. By matching beam qualities with the beams in development at NIST, this project ensures that dosimeter performance will be evaluated similarly, whether that dosimeter be calibrated at NIST or the UW Accredited Dosimetry Calibration Laboratory. This research is part of the doctoral work of the first author which focuses on solid-state dosimetry in mammographic x-ray beams. The first author is a student of the University of Wisconsin Medical Radiation Research Center, investigating radiation metrology, and he is working towards becoming a clinical medical physicist.

References:

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