Mammographic Beam Quality Matching: Monte Carlo Simulations and Spectrometry

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INTRODUCTION

- Historically, molybdenum-anode x-ray tubes have been preferred for most mammograms. With the advent of digital image receptors, tungsten anodes have become the standard [1].
- No existing W-anode mammography calibration beams in the US.
  - Beams are in development at NIST.
- **Desire beams matched in terms of half-value layer (HVL) with the beams at NIST.**
- **The work highlighted in this poster focuses on initial HVL measurements, as well as validating a Monte Carlo (MC) model of the x-ray tube.**

MATERIALS AND METHODS

- Filter and tube potential options are shown in **Table 1**.
- The HVL of each filter and tube potential combination was measured.
- To determine the filters that produce matched HVLs with the beams at NIST, a validated MC model of the UW x-ray tube was required.
- Lawless's model of the COMET MXR-320/26 x-ray tube, with some changes made to reflect a new monitor chamber assembly, was used for this project [2].
- The air kerma per starting particle was computed for the following situations:
  - Before adding the measured HVL of Al to the simulation,
  - After adding the measured HVL of Al to the simulation.
- The ratios of these values were used to benchmark the simulations.
- To verify endpoint tube potentials of the beams, an Amptek (Bedford, MA) X-123 CdTe spectrometer was calibrated for use below 50 keV (see **Figure 1**).
- Simulations were repeated to reflect measured tube potentials.

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)

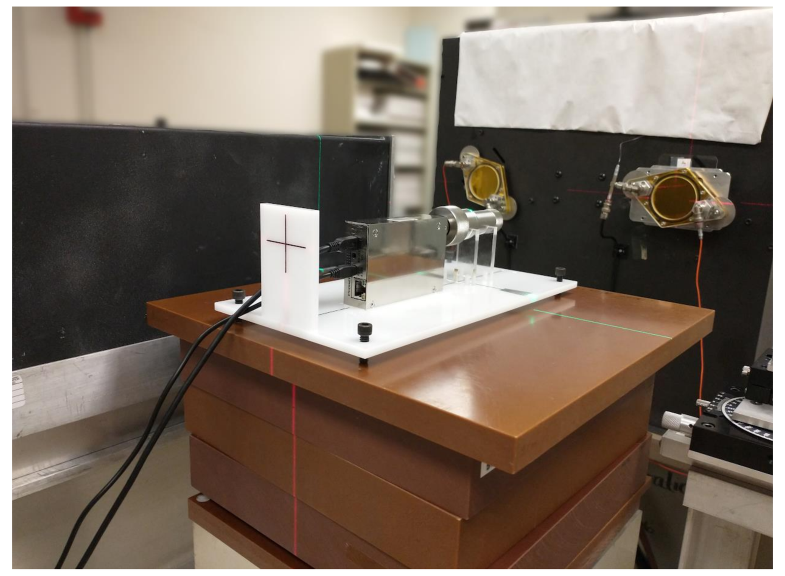

Figure 1. Spectrometer setup for measurements

RESULTS

- Example plot of measured HVLs in **Figure 2**. Plots for other filters show similar behavior:
  - UW HVL less than NIST HVL for low tube potentials,
  - UW HVL greater than NIST HVL for high tube potentials.
- Simulated spectra, with and without added HVL of Al, were tallied.
- Air kerma per starting particle was computed for all spectral pairs.
- Ratio of air kerma after to air kerma before adding HVL to simulation needs to be within 0.485 and 0.515 to meet TRS-457 criterion [3].
  - Criterion met for all tube potentials other than 20 kV (values listed in **Table 2**).
- Beam spectra were measured using X-123 spectrometer.
- Endpoint tube potential was computed for all tube potential settings [4]. Example fit provided in **Figure 3**. Results listed in **Table 3**.
- 20 kV tube potential simulations were repeated with accurate measured tube potential. All ratios now met the TRS-457 criterion.

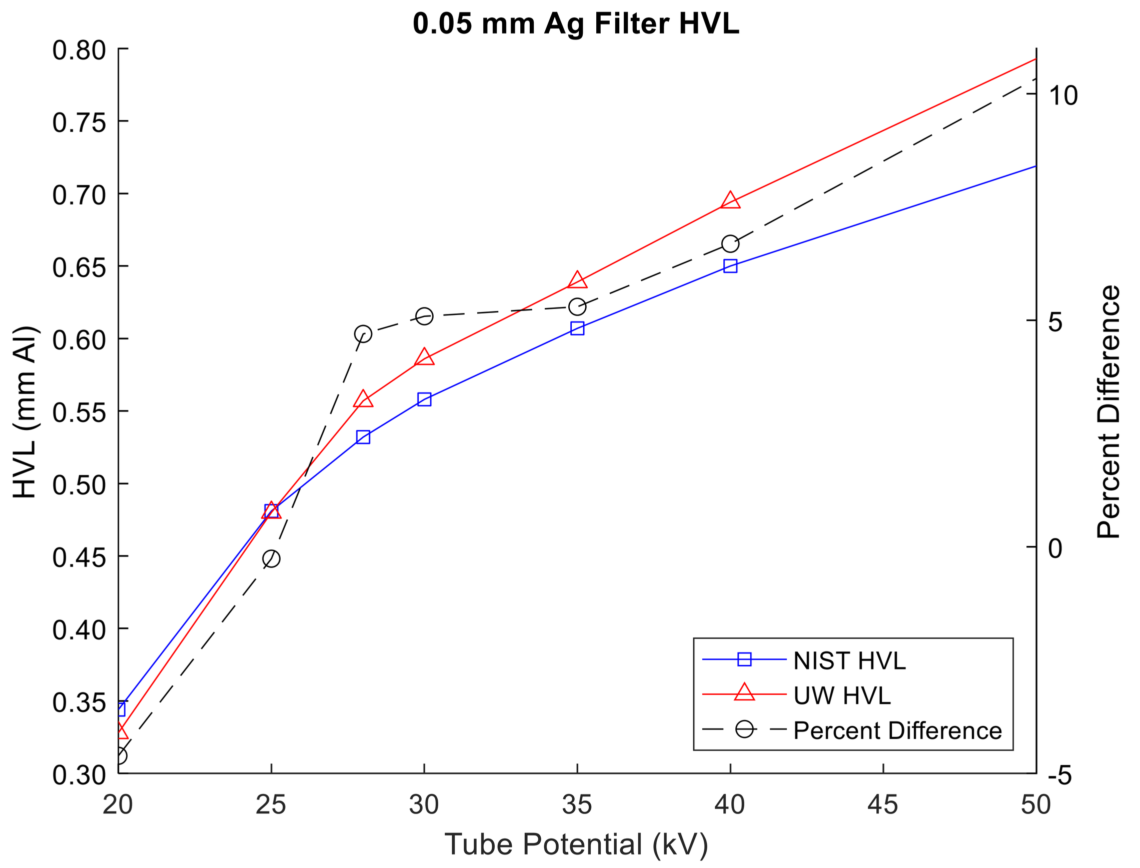

Figure 2. Measured HVLs vs. nominal tube potential. The right y-axis indicates the percent difference between the measured NIST and UW HVLs. The differences shown in this plot are representative of the differences observed for other filters.

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

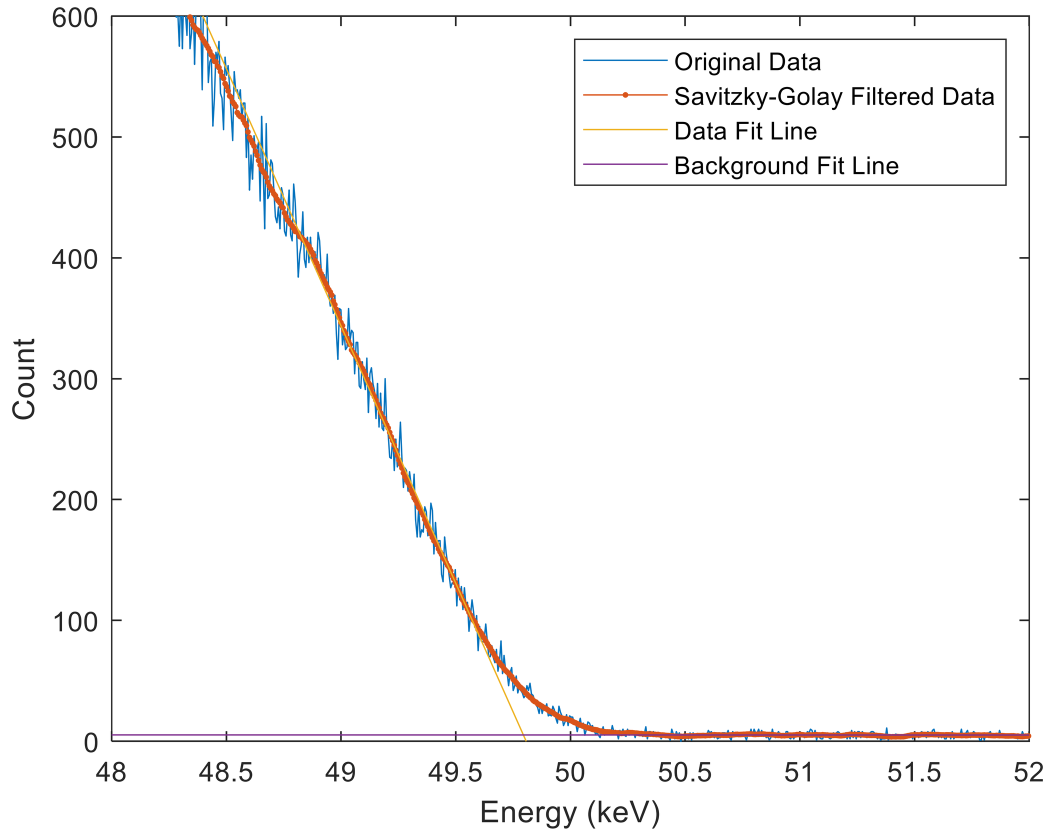

Figure 3. Measured counts vs. energy for the AlX filter with a nominal tube potential of 50 kV.

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

CONCLUSION

- **MC model of the COMET MXR-320/26 x-ray tube was validated for use in predicting the HVL of beams with various filter materials and thicknesses.**
- MC model will be used in the future to determine the filters necessary to produce matched beams.
- X-123 spectrometer was calibrated for the energy range below 50 keV.
- **Spectral measurements with this device will help determine corrections necessary for future air kerma measurements.**
- 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.

REFERENCES

[1] Bernhardt P, Mertelmeier T, Hoheisel M. X-ray spectrum optimization of full-field digital mammography: Simulation and phantom study. Med Phys. 2006;33(11):4337-4349.

[2] Lawless MJ, Dimaso L, Palmer B, Micka J, Culberson WS, DeWerd LA. Monte Carlo and 60Co-based kilovoltage x-ray dosimetry methods. Med Phys. 2018;45(12):5564-5576.

[3] Dosimetry in Diagnostic Radiology: An International Code of Practice, no. 457. International Atomic Energy Agency. 2007.

[4] Silva MC, Herdade SB, Lammoglia P, Costa PR, Terini RA. Determination of the voltage applied to x-ray tubes from the bremsstrahlung spectrum obtained with a silicon PIN photodiode. Med Phys. 2000;27(11):2617-23.

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