National Calibration Needs: X-Ray Multimeters and Mammography

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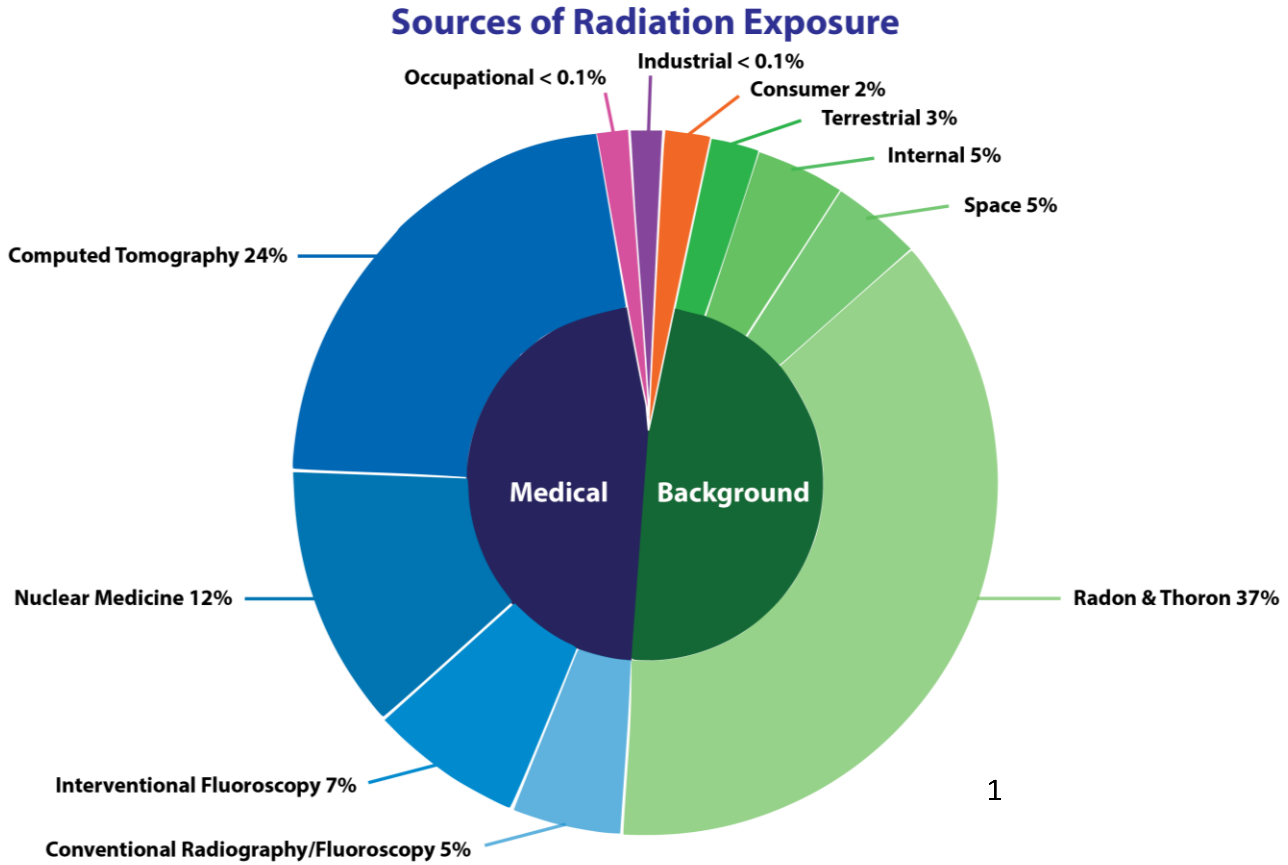
Radiation Exposure

- 48% of the average annual radiation dose per person in the US is the result of medical x-ray procedures (2006)[1]
- 3.6 billion diagnostic x-ray examinations worldwide (2016)[2]



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[1] National Council on Radiation Protection & Measurements, Report No. 160, 2009
[2] World Health Organization, 2016

Benefit vs. Risk and Calibrations

- Image quality vs. absorbed dose

Radiologists constantly face the dilemma of trying to minimize patient exposure whenever possible, while still using exposures that are high enough to produce images of good enough quality as to be able to provide a proper diagnosis. Quality assurance provides a framework for achieving this goal.[1]

- Quality control tests require calibrated dosimeters
- Calibrations should be traceable to a primary standard dosimetry laboratory (National Institute of Standards and Technology (NIST))
- Accredited Dosimetry Calibration Labs (ADCLs) help fulfill demand for calibrations while maintaining NIST traceability

[1] International Atomic Energy Agency, TRS 457, 2007

QA Devices

- Ion Chambers
- X-Ray Multimeters

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[1] Exradin A11TW Ion Chamber, Standard Imaging
[2] RTI Piranha, RTI Group

X-Ray Multimeters (XMMs)

- "An integrated, solid-state instrument (one that automatically measures kVp, half-value layer [HVL], and dose) …"[1]
- Several commercially available options including the RTI (Mölndal, Sweden) Piranha and Radcal (Monrovia, CA) Accu-Gold+ with AGMS-DM+ sensor
- Makes quality control measurements simple with near-instantaneous readout

2

[1] Berns et al., American College of Radiology, 2018
[2] RaySafe X2, Unfors RaySafe

XMM Performance

- Calibration and measurement uncertainties provided by manufacturer
- Existing research is limited
- **Calibrations should be traceable to a primary standards lab**
- **XMM performance needs more evaluation**

Evaluated HVL for radiography and fluoroscopy systems[1]

Evaluated air kerma and HVL for mammography systems[2]

Evaluated HVL, kV, and air kerma rates, but over limited anode/filter and tube potential combinations[3,4]

[1] Lin and Goode, *J Appl Clin Med Phys*, 2021
[2] Bemelmans et al., *Physica Medica*, 2021
[3] Brateman and Heintz, *Med Phys*, 2015
[4] Salomon et al., *Med Phys*, 2020

International Interest in XMMs

- Update to IAEA TRS-457[1]

  To assess the accuracy of measurements performed using semiconductor-based dosimeters (in standard radiation qualities (RQR), radiation qualities for mammography applications (RQM), radiation qualities for CT applications (RQT)), e.g. practical peak voltage (kVp), air kerma, air kerma rate, total filtration, half value layer (HVL), etc.

- Traceability in Medical X-Ray Imaging Dosimetry (TraMeXI)[2]
  - Review existing and suggest updated radiation qualities for IEC 61267[3] and IAEA TRS-457[4]
  - Investigate x-ray dosimeters in calibration and clinical conditions
  - Define calibration procedures for XMMs

[1] International Atomic Energy Agency, CRP E24024, 2021
[2] Toroi et al., European Partnership on Metrology, 2022
[3] International Electrotechnical Commission, Medical Diagnostic X-Ray Equipment, 2005
[4] International Atomic Energy Agency, TRS 457, 2007

XMM Performance

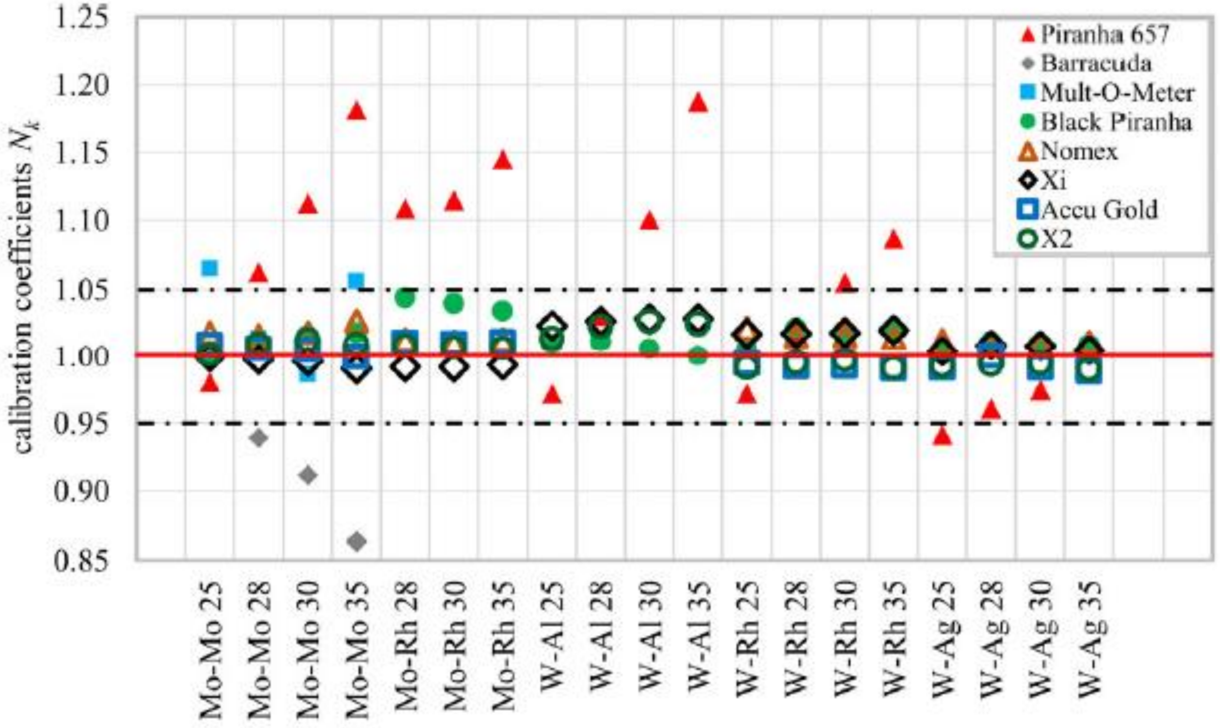


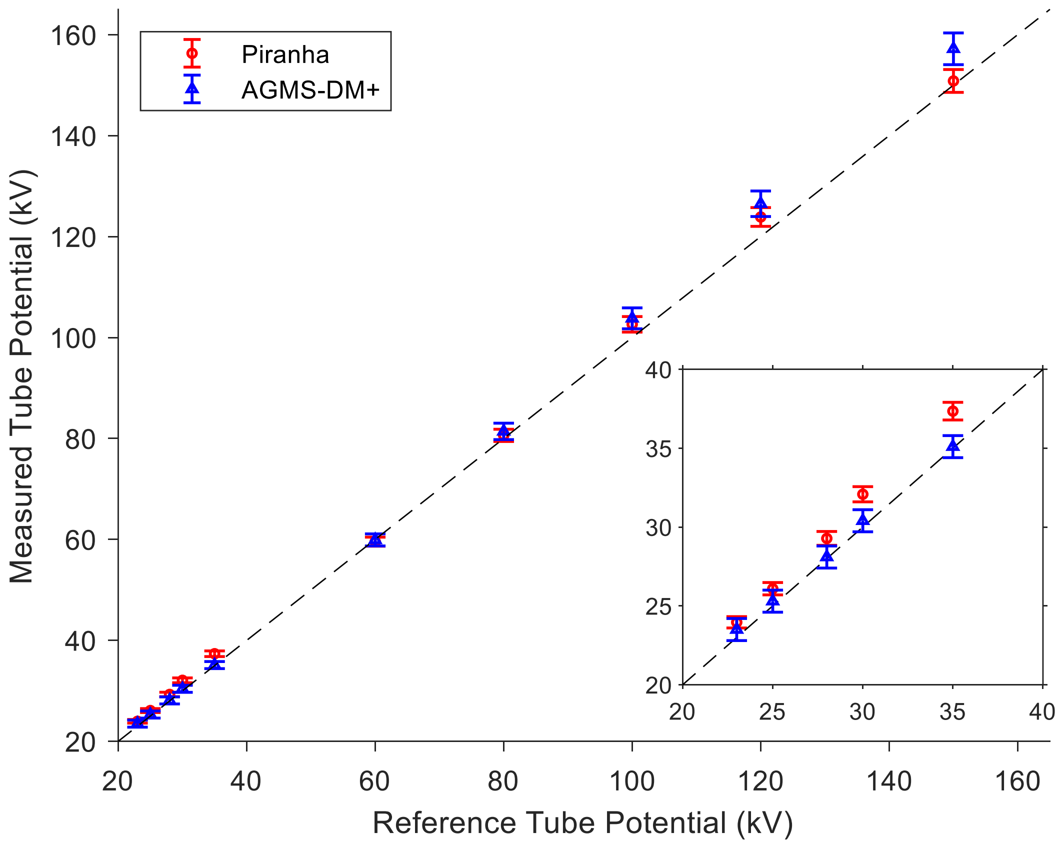
TABLE VII. Deviation in air kerma rate (error) in case no calibration or one single point calibration coefficient applied.

	Maximum deviation	
Measuring assembly	No calibration	Single point calibration with Mo-Mo 28
Piranha 657	−16%	−12%
Barracuda	16%	8.1%
Mult-O-Meter	−6.1%	−5.1%
Black Piranha	−4.2%	−3.2%
Nomex	−2.6%	−1.1%
Xi	−2.8%	−3.1%
Accu Gold	1.1%	1.7%
X2	−2.5%	1.9%

[1] Salomon et al., *Med Phys*, 2020

Ongoing Research

- Measurements with RTI Piranha and Radcal Accu-Gold+ with AGMS-DM+ sensor in UW M- and MO-series beams
- Typical calibration geometry used
- Results relative to reference values shown to the right



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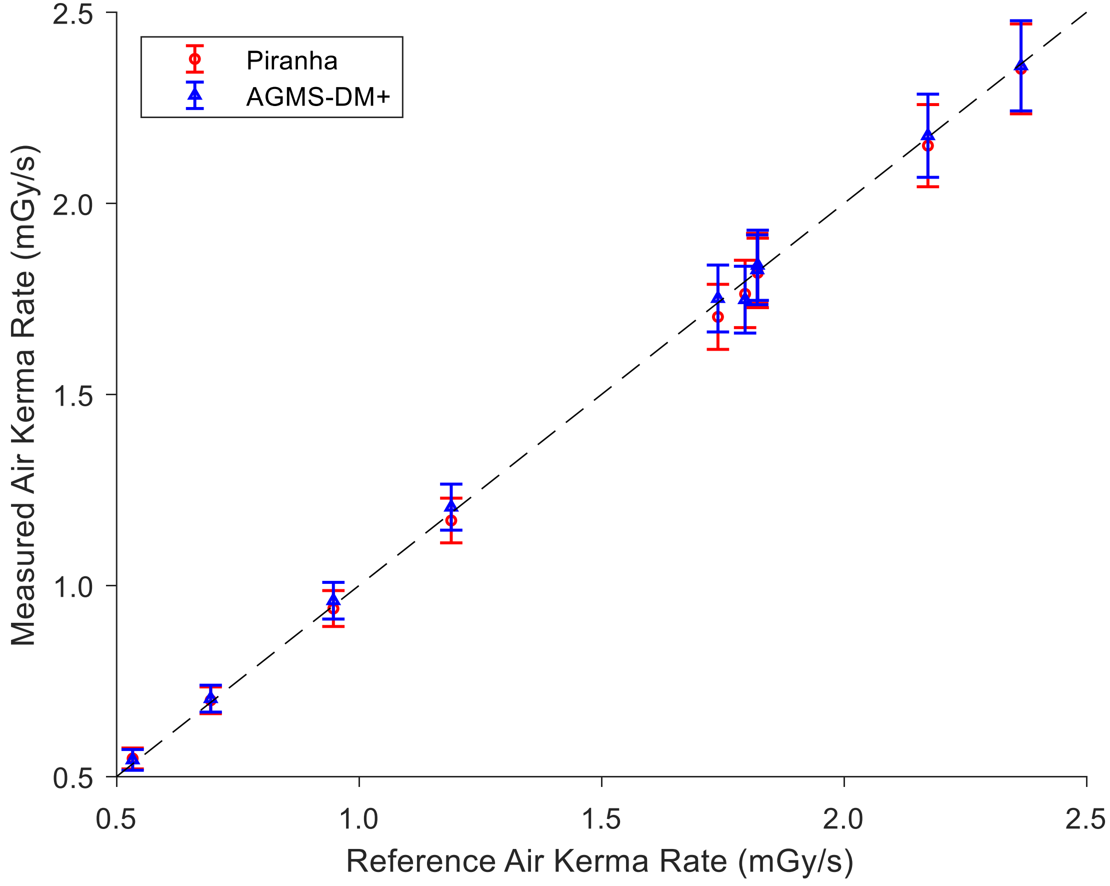

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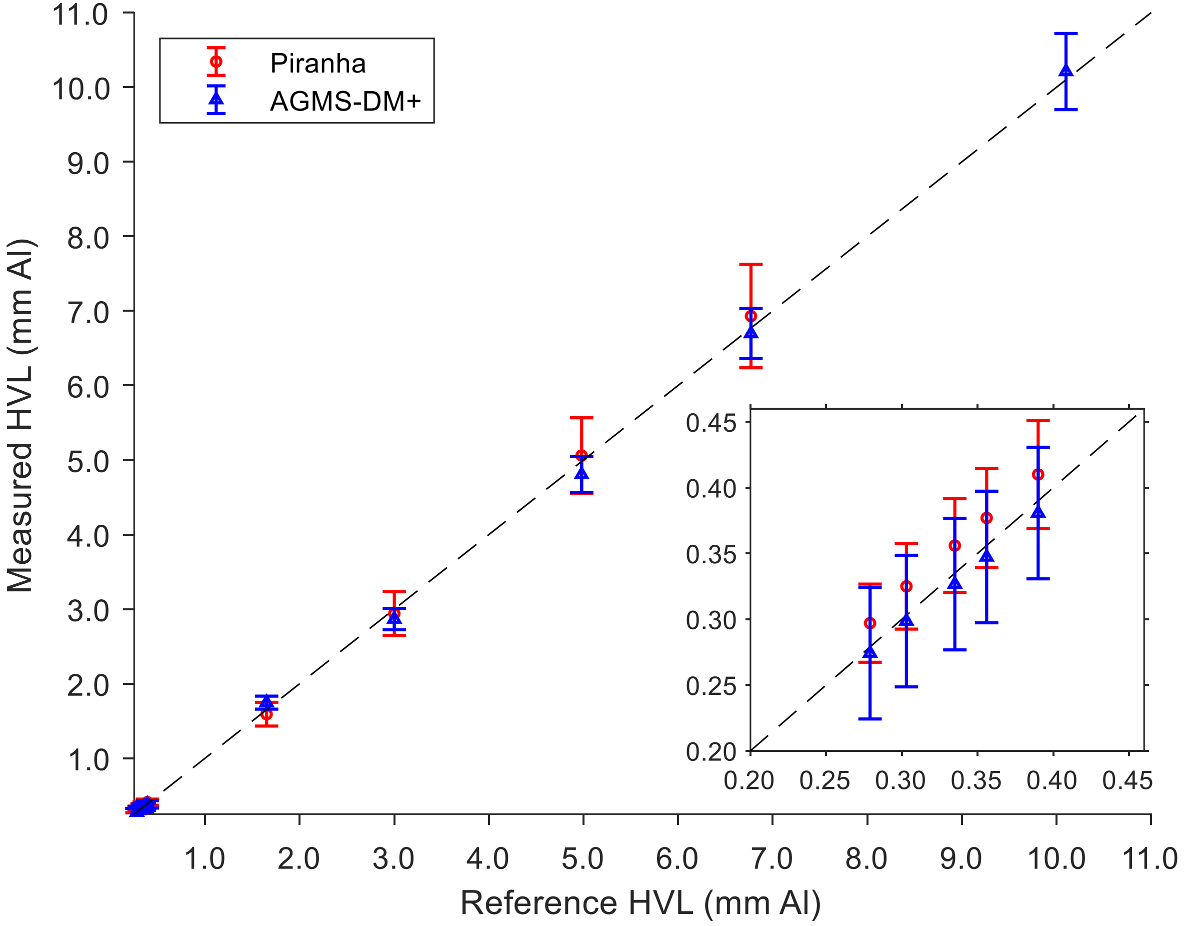


Ongoing Research

- Investigation of long-term performance of XMMs is in progress
- Following table lists the maximum percent change between measurements made three months apart

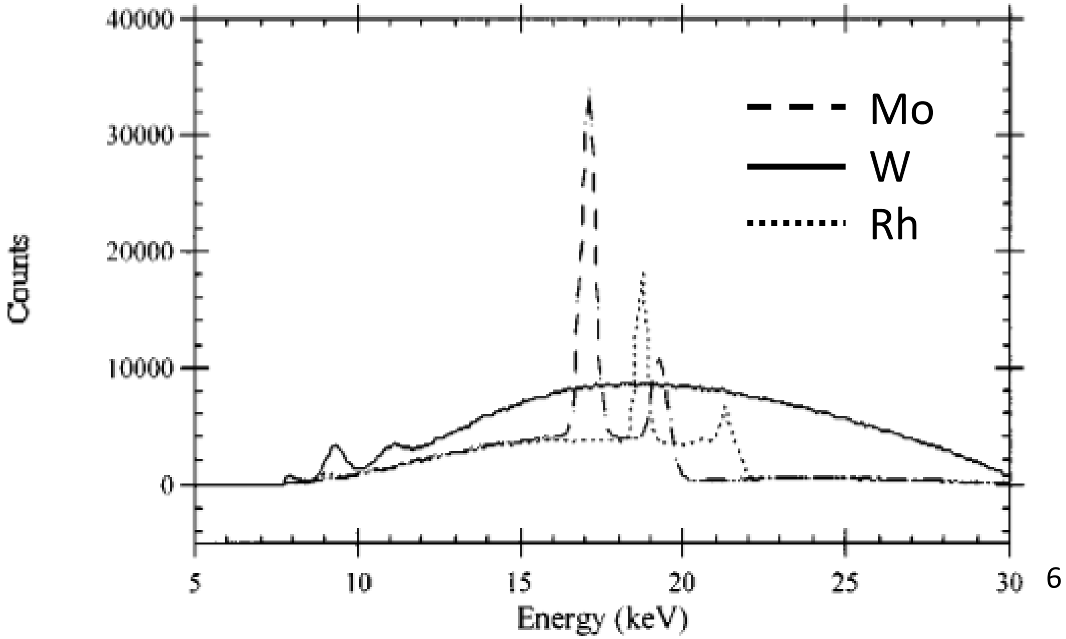
XMM	Tube Potential	Air Kerma Rate	HVL
Piranha (UW M-Series)	0.50%	0.28%	0.14%
Piranha (UW MO-Series)	0.06%	0.87%	0%
AGMS-DM+ (UW M-Series)	0.08%	0.09%	0.04%
AGMS-DM+ (UW MO-Series)	0.33%	1.08%	0.36%

Future Research

- Continue long-term performance study
- Investigate XMM performance in other beam qualities
  - Clinical mammography units
  - Tungsten-anode mammography calibration beams
- Analyze potential calibration options
  - Optimal calibration points
  - Effect of additional calibration on measurement

Digital Mammography

- Mo anodes preferred for screen-film mammography[1]
  - Contrast at fixed dose
- Advent of digital image receptors for mammography
  - Signal-difference-to-noise ratio at varied doses
- W anodes are most efficient for digital mammography[1-5]



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$$\mathrm{FOM} = \frac{\mathrm{SDNR}^2}{\mathrm{MGD}}$$ [1,2]

[1] Bernhardt, Mertelmeier, and Hoheisel, Med Phys, 2006
[2] Toroi et al., Eur Radiol, 2007
[3] Borg, Badr, and Royle, Radiat Prot Dosimetry, 2012
[4] Fahrig and Yaffe, Med Phys, 1994
[5] Flynn et al., Med Imaging 2003 Phys Med Imaging
[6] DeWerd et al., *Med Phys*, 2002

Tungsten-Anode Calibration Beams

Mo Anode

UW Beam Code	Added Filter (mm)	1^{st} HVL (mm Al)
UW23-MO	0.032 Mo	0.279
UW25-MO	0.032 Mo	0.303
UW28-MO	0.032 Mo	0.335
UW30-MO	0.032 Mo	0.356
UW35-MO	0.032 Mo	0.390
UW28-MR	0.03 Rh	0.407
UW32-MR	0.03 Rh	0.441

W Anode

UW Beam Code	Added Filter (mm)	1^{st} HVL (mm Al)
UW20-M	0.15 Al	0.146
UW30-M	0.40 Al	0.351
UW40-M	0.79 Al	0.742

[1]

[1] NIST-Traceable Beam Qualities, UW Accredited Dosimetry Calibration Laboratory

Tungsten-Anode Calibration Beams

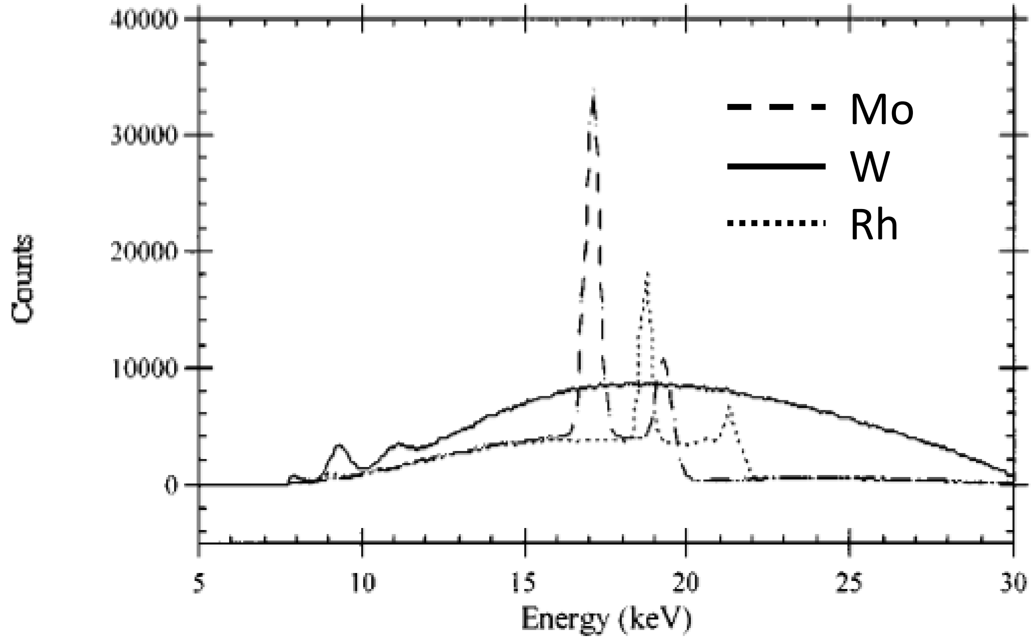
- Available tungsten-anode mammography calibration beams in the US are limited
  - NIST has tungsten-anode mammography beams with various filter options in development
  - PTB in Germany does have several of these beams available[2]

- **Gap in calibration radiation qualities for mammography**

[1] Physikalisch – Technische Bundesanstalt, Dosimetry for Diagnostic Radiation Qualities

Current Practice

- Is calibrating in Mo-anode beams good enough?
  - Ion chamber response does not significantly change for beams with HVL in mammography range[1]
  - "… good mammography dosimeters … can be calibrated with almost any of the beams studied with an HVL in the mammography range"[2]



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[1] DeWerd et al., *Med Phys*, 2002
[2] International Atomic Energy Agency, TRS 457, 2007

Current Practice

- Issues
  - Higher energies
    - Contrast-enhanced mammography
    - Different scan protocols for varying anatomy[1]
  - W-anode beams with certain filters
    - W/Ag, W/Rh
    - Higher HVLs even at "typical" kVs
  - Solid-state dosimeters are not equivalent to reference-class chambers

"And if higher-energy beams become more commonly used, such as for contrast subtraction mammography, even the reference IC might not be sufficiently accurate because of its thin window."[2]

Potential (kV)	Measured HVL (mm Al)
20	0.328
25	0.480
28	0.557
30	0.586
35	0.639
40	0.694
50	0.793

[1] Young and Oduko, *Br J Radiol*, 2016
[2] Brateman and Heintz, *Med Phys*, 2015

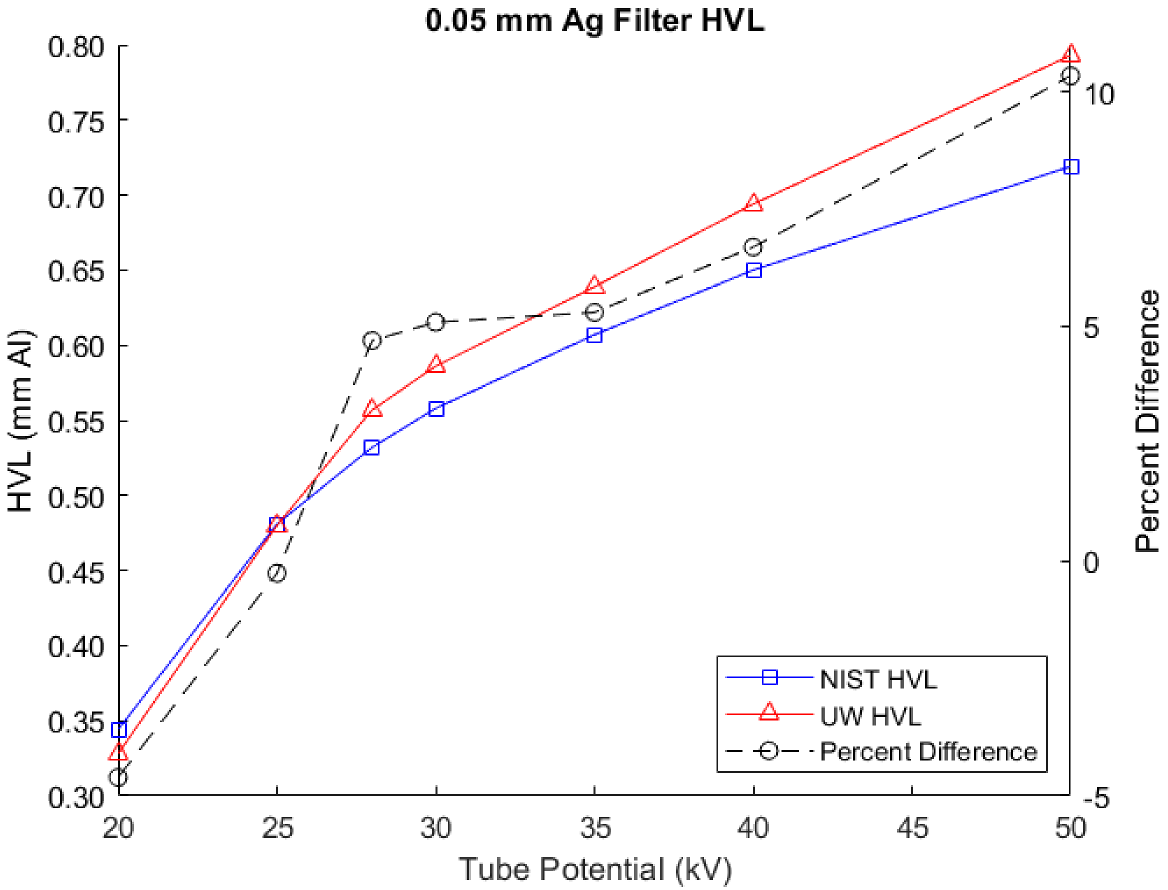
Planned Beams

- Filter Options (PTB equivalent[1]) [X indicates added 2 mm Al]
  - Ag, AgX
  - Al, AlX (WAV, WAH)
  - Mo, MoX (WMV, WMH)
  - Rh, RhX (WRV, WRH)
- Tube Potentials: 20-50 kV
- Want beams to have similar HVLs to beams in development at NIST

[1] Physikalisch – Technische Bundesanstalt, Dosimetry for Diagnostic Radiation Qualities

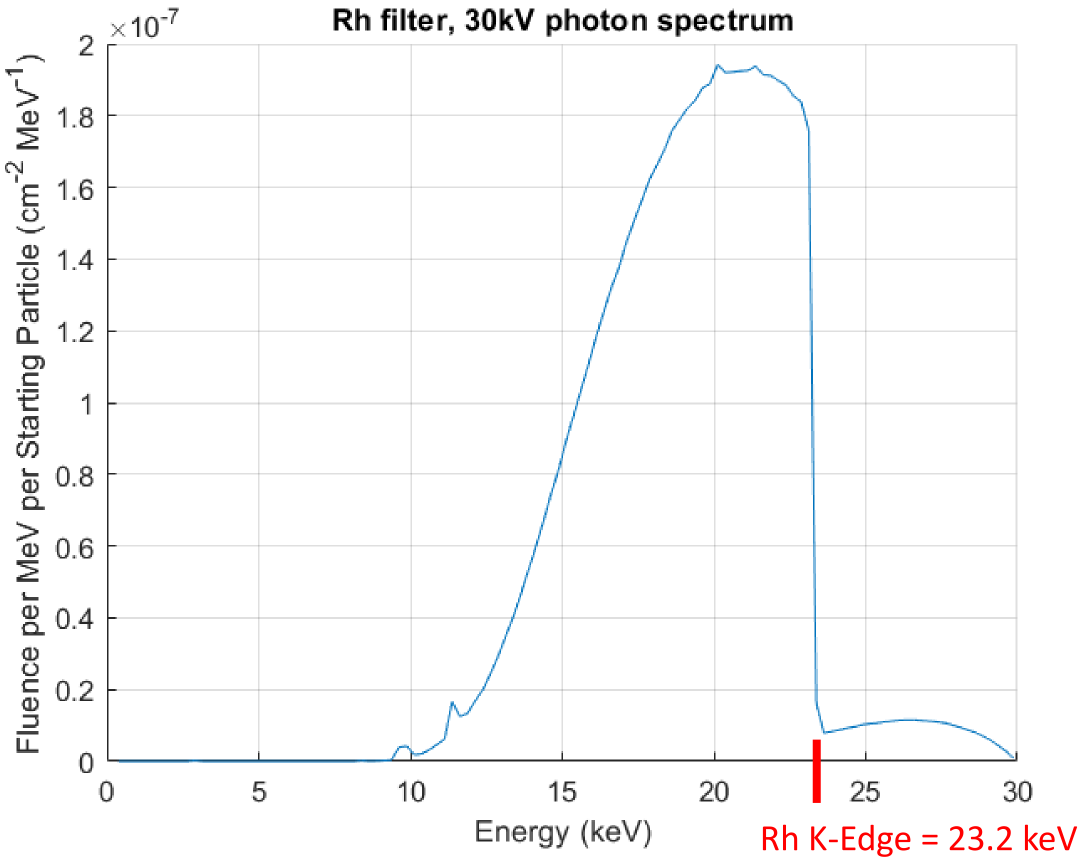
Matching Beams

- Measure HVL, determine difference from NIST
- HVLs measured using Attix FAC
  - Higher signal than ion chamber
  - No attenuating window or wall



Matching Beams

- Use measured HVLs and spectra to validate Monte Carlo simulation
- Use simulation to determine optimal filter thicknesses
- Perform final HVL measurements with optimal filters
- Take air kerma measurements using Attix FAC and calculated correction factors



Summary

- Needs
  - National procedure for calibrating XMMs
  - More XMM performance data
  - Tungsten-anode mammography calibration beams
- Improve dosimetry in diagnostic radiology and mammography
- Who are we helping?
  - Researchers
  - Patients

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