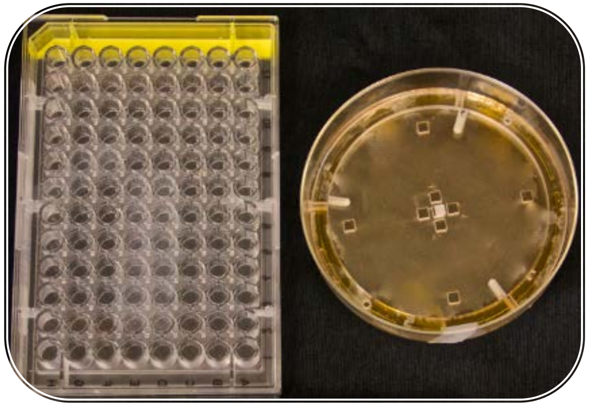
Dose measurements in radiobiology x-ray irradiators

Natalie Viscariello, MS
Under the supervision of Larry A. DeWerd, Ph.D

University of Wisconsin Medical Radiation Research Center

Council on Ionizing Radiation Measurements and Standards
April 16, 2018

Preclinical Studies



in vitro cell studies

in vivo animal studies [1]

Understanding of disease, human treatment

- Simplified goal: correlate delivered dose to biological endpoint

1 Xstrahl Inc, Suwanee, GA

Radiobiology Irradiators

- "Cabinet irradiators"
- High-throughput cell or animal studies
- Mounted X-ray tube
  - 160-360 kVp
  - Variable filtration
  - Stated dose rate 1-15 Gy/min
- This will focus on XRad 320

Precision X-Ray, Inc

Need for dosimetric accuracy

- Ability to intercompare results requires accuracy in the stated doses that is at least equal to the precision of the measurements[1]
- Reproducibility concerns
  - Drug-radiation combination studies not reproducible[2]
  - Spot-check in phantom average 10% dose discrepancy[3]
- Lack of reporting[1,3]

1. M. Derosiers et al, J Res Natl Inst Stand Technol, 118, 2013
2. H. Stone et al, Transl Oncol, 9, 2016
3. Pedersen et al, Rad Res, 185, 2016

NIST-matched X-Ray Beams-Comparison

- Requirement of increased irradiation detail reporting and NIST-traceable dosimetry
  - Enforce standards for reproducible, translational studies
- For clinical orthovoltage x-rays - AAPM TG-61 protocol
  - Limited distance, cabinet shielding, field size changes
- Requires characterization of the x-ray spectrum
  - However, these radbio irradiators are unlike any NIST or ISO beams

NIST-matched X-Ray Beams-Comparison

University of Wisconsin Accredited Dosimetry Calibration Lab (UWADCL)

Beam Code	Added Filter (mm Al or Cu)	HVL1 (mm Al)	HVL1 (mm Cu)	HC (percent)	Air Kerma Rate (mGy/sec)
UW120-M	3.0 Al + 0.10 Cu	6.77		75	2.365
UW150-M	2.83 Al + 0.28 Cu	10.1	0.657	87	2.173
UW200-M	1.00 Al + 1.01 Cu	14.8	1.63	95	1.930
UW250-M	1.96 Al + 2.36 Cu	18.3	3.01	98	1.633

XRad 320 :

- 320 kVp
- 1 or 4 mm Cu HVL ("F1" or "F2")

What beam is appropriate?

"...shall be calibrated at a beam quality sufficiently close to the user's beam quality in terms of both the tube potential and HVL"

Standard X-Ray Beams- Comparison

- Spectrum affects dosimeters
- TG-61

$$D_{w,z=0} = M \underline{N_K} \underline{B_w} P_{\mathrm{stem,air}} \underline{\left[\left(\frac{\overline{\mu}_{\mathrm{en}}}{\rho} \right)_{\mathrm{air}}^{w} \right]_{\mathrm{air}}}$$

- Dosimetry spot-checks require appropriate calibration beam

Goal

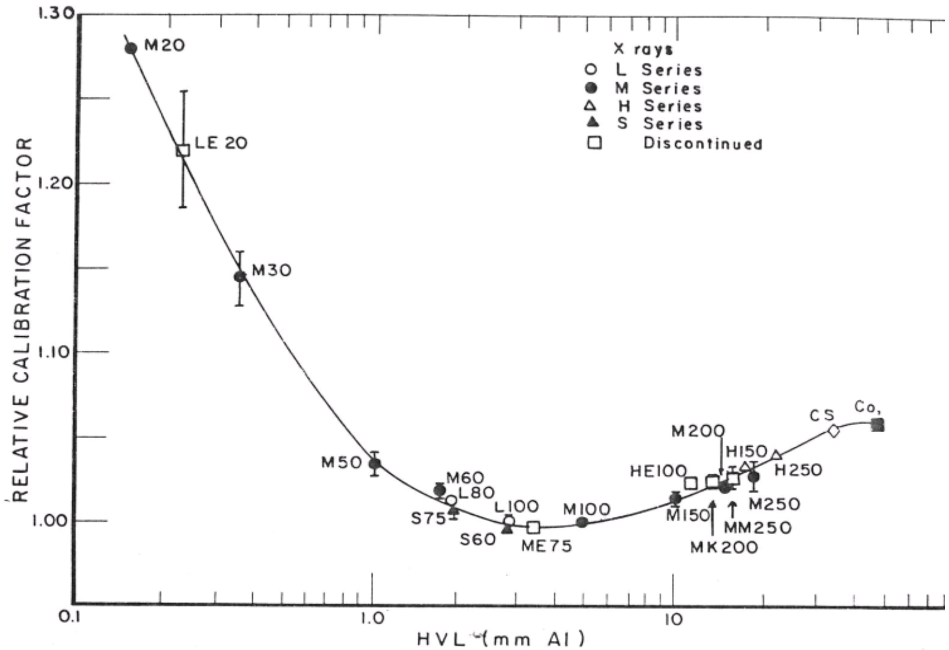
To characterize the XRad 320 and assess the effects of beam quality on detector response

Fabrication of RadBio Beams

- From nominal HVL alone: photon beams are different than reference

- Approximate XRad 320 spectra by matching HVL
  - Two filter packs generated

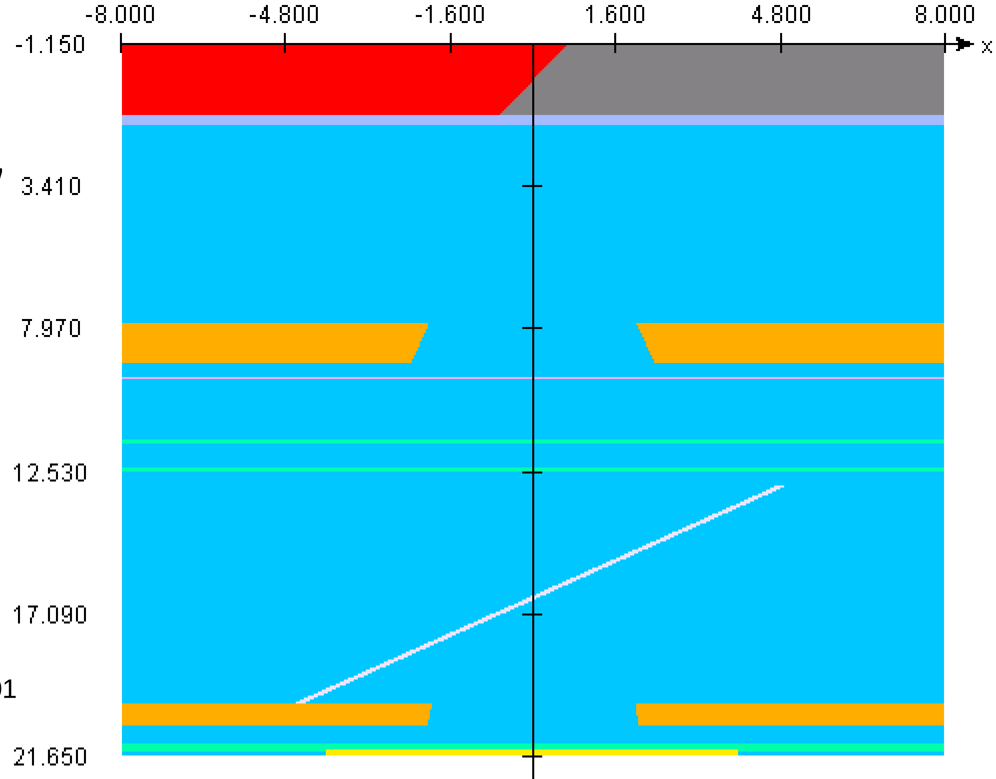
- Air kerma rate measured with A3 chamber
  - Allows for measurement in a known setup at UWMRRC



1. Tom Heaton, Secondary-Level Laboratories: Methodology for a Calibration Program

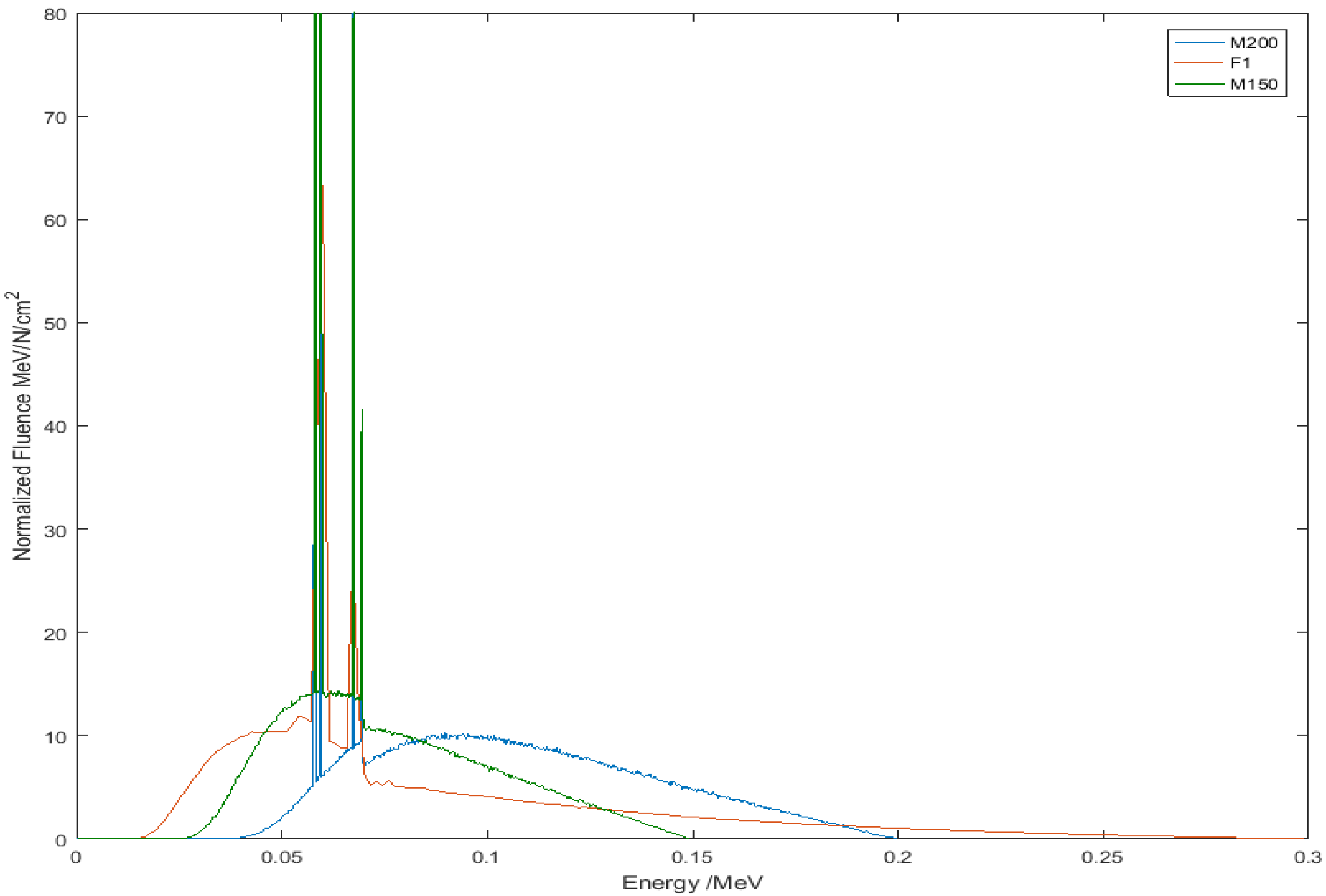
Simulation of RadBio Beams

- Simulate spectra from XRad 320
  - Use to simulate detectors in-phantom
- EGSnrc[1]
  - Previously validated M-series x-ray beams[2]
  - Benchmarked with thin-window water tank
- Phase space below filters



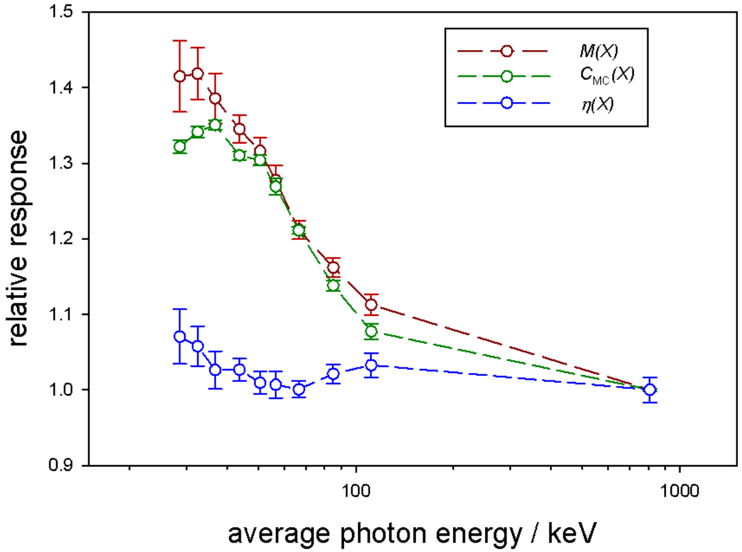
1. I. Kawrakow and D. W. O. Rogers, “The EGSnrc Code System: Monte Carlo simulation of electron and photon transport”, NRC Report PIRS–701 (2003)
2. M. Lawless, PhD Thesis, 2016

Simulations of RadBio Beams- Spectra



Detector Response in Mouse Phantom

- TLD energy response
  - Air vs water difference[2]
- Determine how beam quality affects TLD response in phantom
  - Energy corrections for spot-check measurements



1

- 3D-printed murinemorphic phantoms
  - CT image sets of 25 g lab mouse
  - TLD-100 microcubes in kapton
  - Resin composition measured and accounted for in simulation

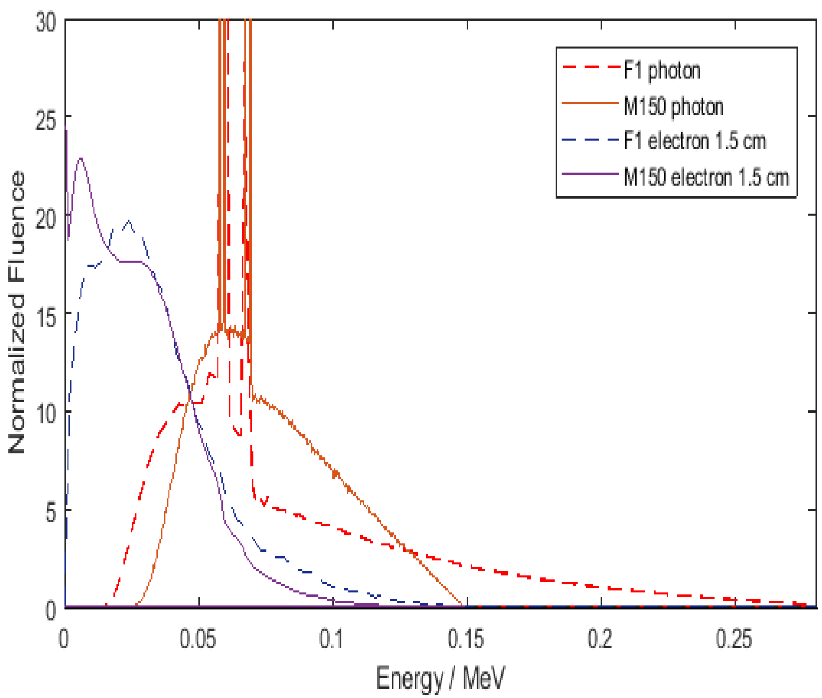
1. Nunn et al. Medical Physics, Vol.35 (5) 2008
2. Lawless, PhD Thesis, 2016

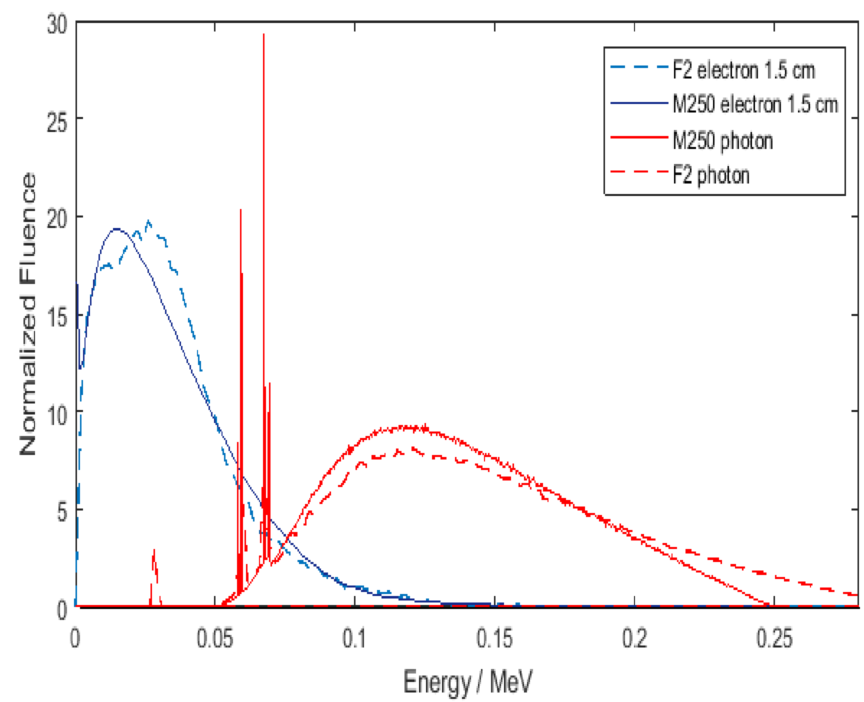
Simulations of RadBio Beams- In Phantom

- TLDs simulated in phantom
- Electron spectra at 1.5 cm depth simulated
  - Compare M-series beams to RB beams

Simulations of RadBio Beams- In Phantom

- Electron spectra at 1.5 cm depth simulated
  - Compare M-series beams to RadBio beams
- Electron spectra for RadBio beams similar to M-series





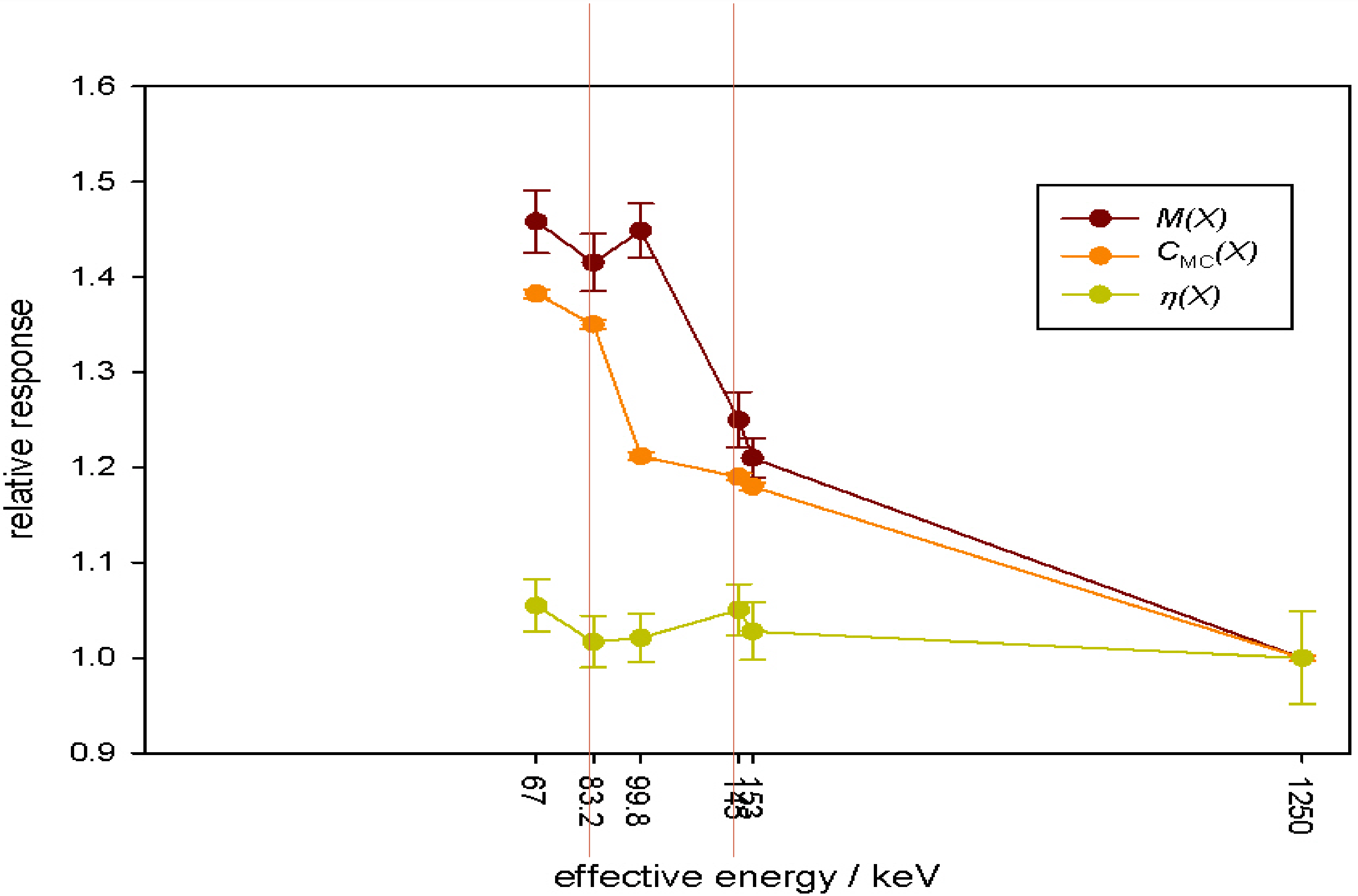
Energy Response

- Dose to water, dose to TLD, air kerma simulated
  - Detailed simulation of irradiation geometry and NIST-matched air-kerma rates
  - M150-M250, ^{60}Co, RB Beams

- TLDs irradiated to the same dose in phantom at each energy
  - Detector output per dose to water $$M(X) = \frac{(R/D_{\mathrm{w}})_X}{(R/D_{\mathrm{w}})_{\mathrm{ref}}}$$
  - Monte Carlo-predicted response $$C_{\mathrm{MC}}(X) = \frac{(D_{\mathrm{det}}/D_{\mathrm{w}})_X}{(D_{\mathrm{det}}/D_{\mathrm{w}})_{\mathrm{ref}}}$$
  - Detector output/dose to TLD $$\eta(X) = \frac{M(X)}{C_{\mathrm{MC}}(X)} = \frac{(R/D_{\mathrm{det}})_X}{(R/D_{\mathrm{det}})_{\mathrm{ref}}}$$

Pedersen et al 2015

Energy Response



Conclusions

- RadBio spectra compared to NIST-matched beams
  - Photon in-air and electron spectra at plane of TLDs
  - TLDs sensitive to spectrum at depth of measurement
- Measured and intrinsic detector responses of RadBio beams agreed with the reference beams within uncertainty
- With selection of appropriate reference beam, TLD microcube measurements in-phantom require minimal energy response corrections

Acknowledgements

- Cliff Hammer
- Dr. Mike Lawless
- UWMRRC students and staff
- Customers of the UWADCL, whose calibrations help to fund student research

Thank you for your attention