Output Verification of Radiobiology Irradiators

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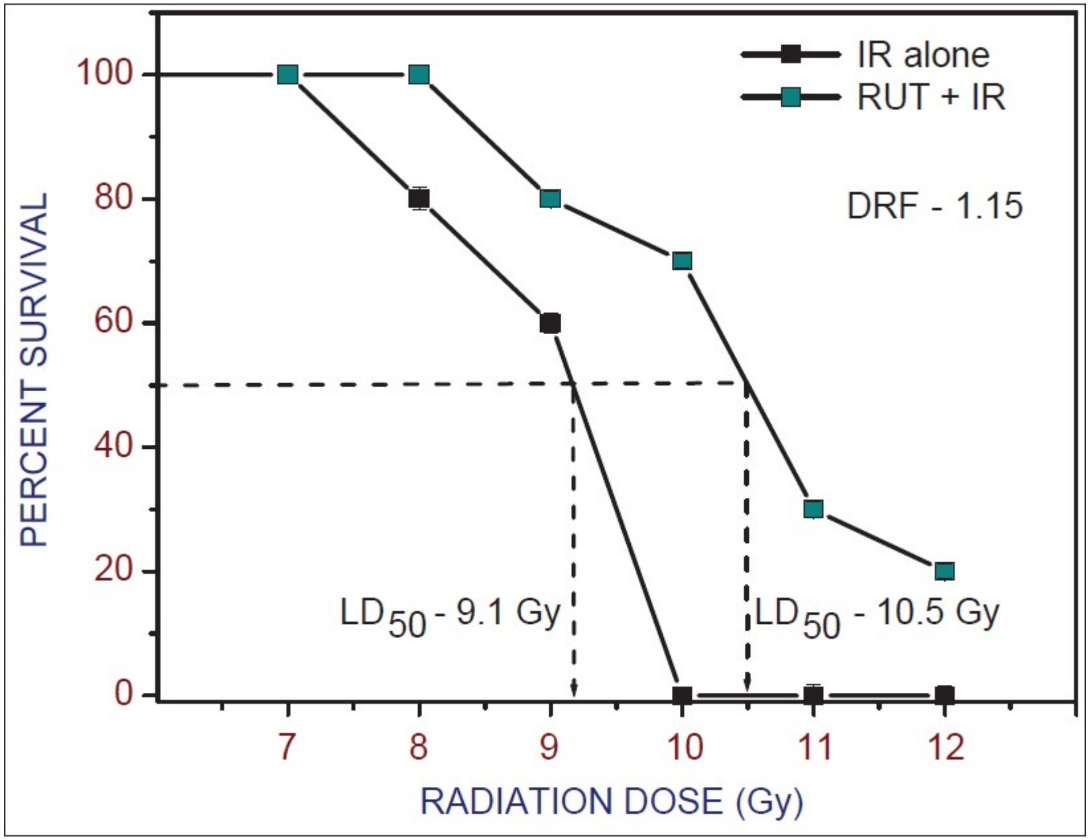
Motivation

- Radiobiology:
  - Dose vs. Effect
- Requires:
  - Accurate dose
  - Comprehensive dosimetry reporting
- There are concerns that requirements are not being met



Dose-survival curve for control and with administration of Rutin.[1]

[1]Patil SL, Somashekarappa H M, Rajashekhar K P. Radiomodulatory role of Rutin and Quercetin in Swiss Albino mice exposed to the whole body gamma radiation. Indian J Nucl Med 2012;27:237-42

Motivation

- 28 radiobiology papers were selected
  - 18 different journals
- Dosimetry reporting was reviewed
- Results compared with the recommendations from the 2011 NCI, NIAID, NIST workshop[2]

[2]Desrosier et al., (2013). "The importance of Dosimetry Standardization in Radiobiology," The Journal of Research of NIST 118:21

Motivation

Category	Information	%
Absolute Dosimetry/ Calibration	Published Standards Used	**6.9**
	Detector Type Used	**3.4**
Determination of Dose	Published Standards Used	**10.3**
	Specification of Medium	**6.9**
	Detector Type Used	**27.6**
Radiation Source Specification	Radioisotope	**86.2**
	kV, Filtration, HVL	**50.0**
Details of the Irradiation	Animal/Cell Type	**100**
	Dose Details	**100**
	Field Size and Shape	**0**
	Geometry of Fields	**24.1**
	Animal Containment	**100**

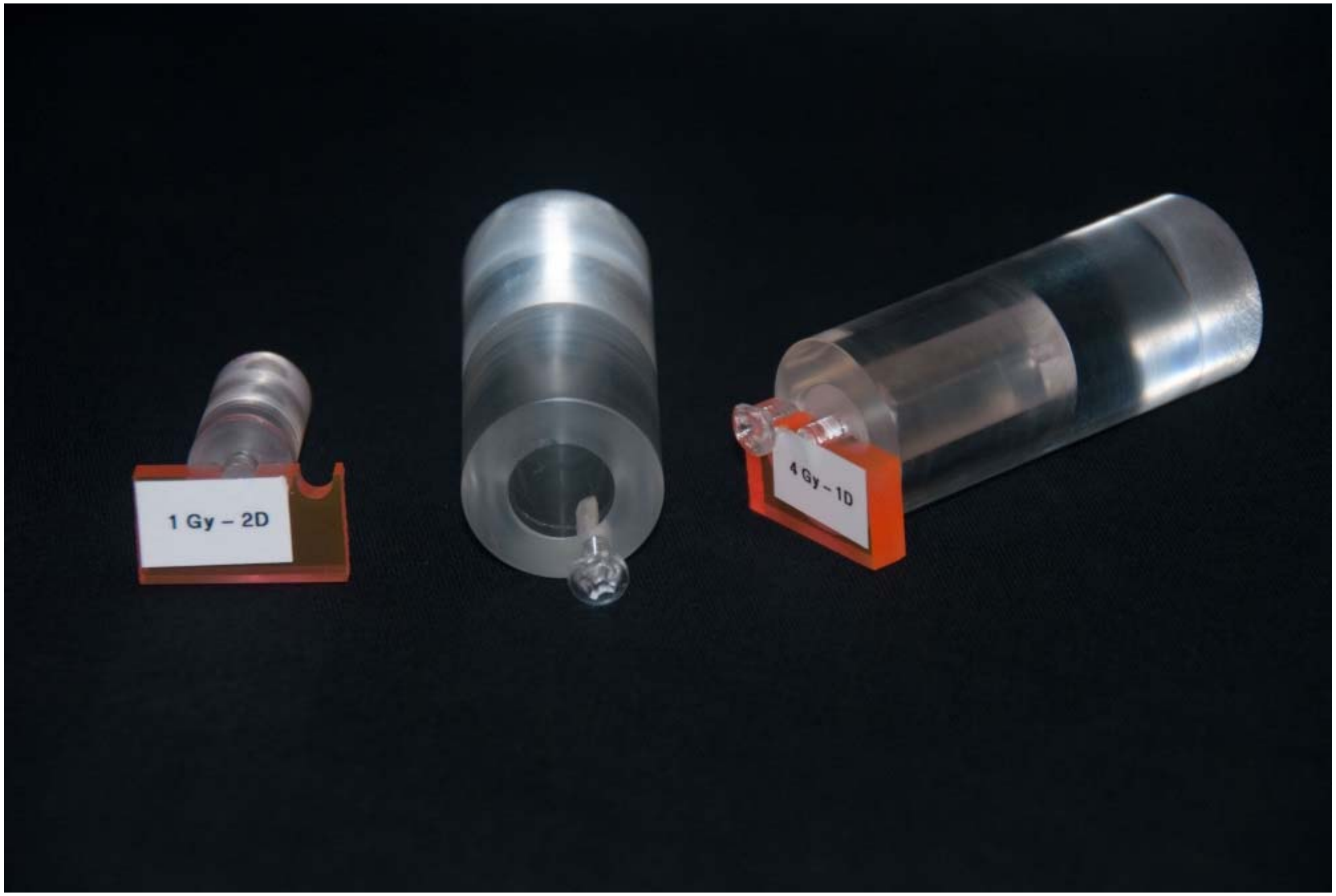
Table 1: Percentage of papers compliant with recommended standards for dosimetry reporting.

Methods and Materials

- Output verification
  - Test of dose accuracy of irradiators
- 12 checks performed
  - Irradiators located in the US and Japan
  - Radionuclide and x-ray irradiators

Kimtron, Inc. cabinet x-ray irradiator at UWMRRC

Methods and Materials



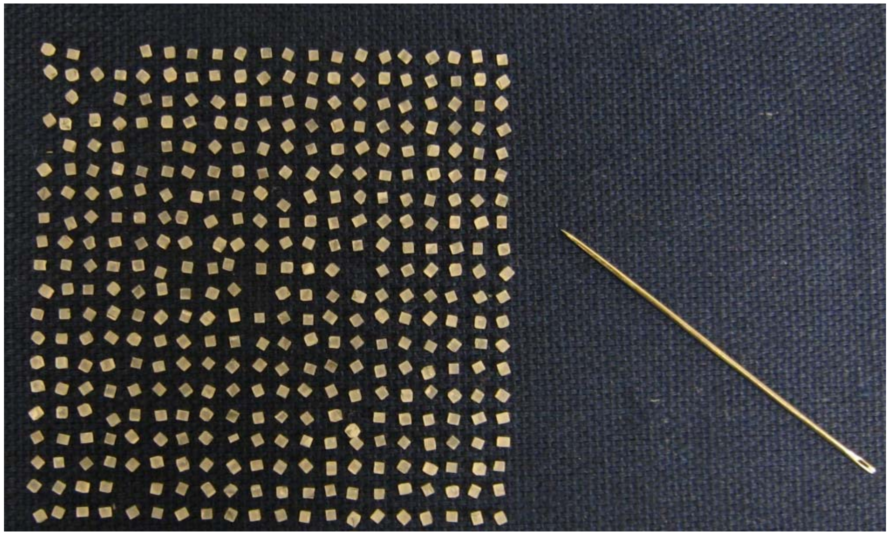
PMMA Mouse phantoms

Diameter=27mm

Length=65mm

Methods and Materials

- TLDs
  - Harshaw LiF:MgTi TLD-100 1mm^3 microcubes
  - TLDs were annealed based on the Cameron Method[3] and read using a Harshaw 5500 TLD reader
    - 400°C 1 hour anneal
    - 80°C 24 hour anneal
    - Stored 24 hours between irradiation and readout
  - Individual TLD sensitivity was taken into account

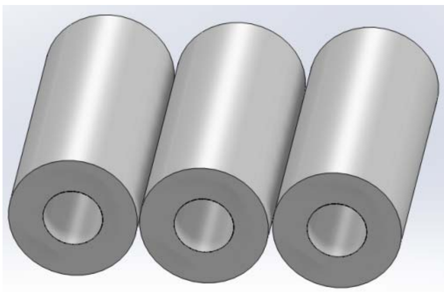


TLD microcubes
(courtesy of Samantha Simiele)

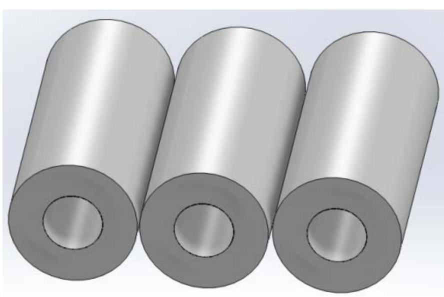
[3] J.R. Cameron, D. Zimmerman, G. Kenney, R. Buch, R. Bland, and R. Grant. "Thermoluminescent Radiation Dosimetry utilizing LiF." Health Phys. 10, 25-29 (1964).

Methods and Materials

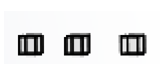
- Output

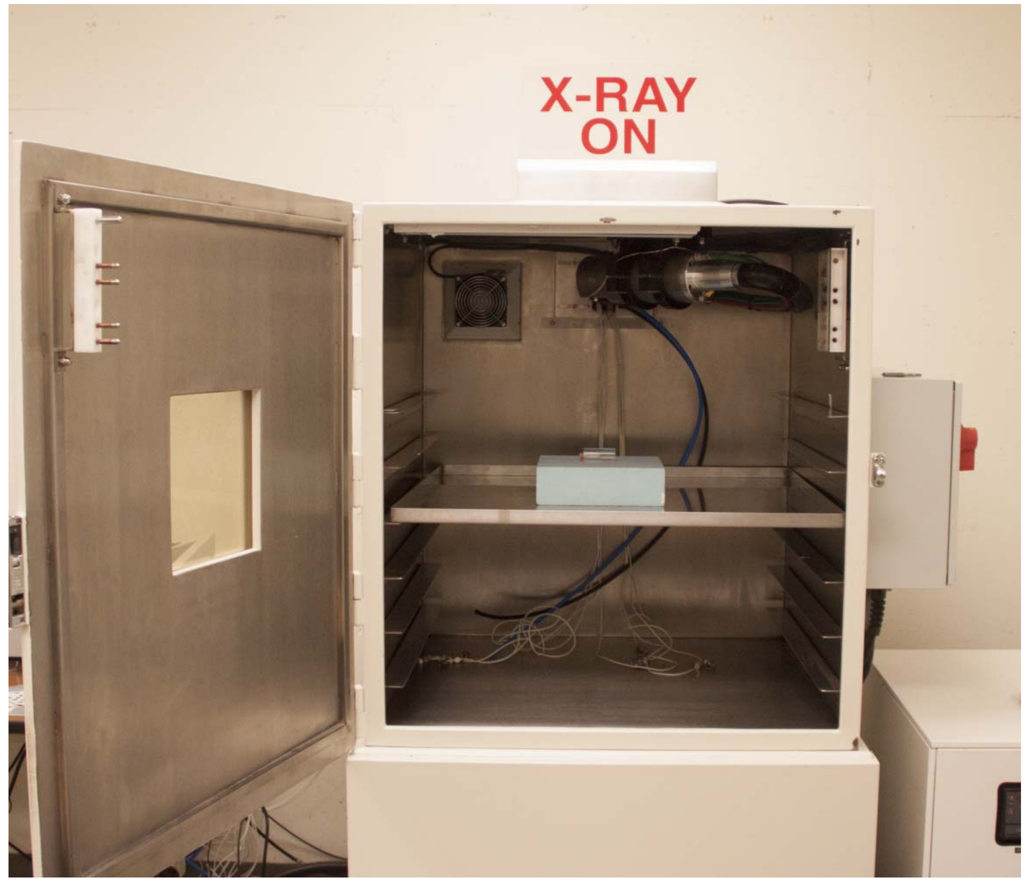


→
1GY
(ADW)



→
4GY
(ADW)





Example: Customer irradiation process

Methods and Materials

- Calibration irradiation
  - Two calibration mouse phantoms are irradiated
    - 1 Gy
    - 4 Gy
  - Irradiation is carried out with NIST-traceable air kerma beam qualities at UWADCL
    - 1 m from source
    - 10x10 field
    - TLDs center of field

Methods and Materials

- Air kerma to ADW conversion
  - Work by Tina Pike, PhD
  - Monte Carlo calculated conversion factor
    - Ratio of D_W/fluence and K_{air}/fluence
    - Each component of ratio determine in separate simulation
  - Calculated for each standard beam quality

$$t_{irrad} = \frac{D_W}{\left({K_{air}}/{t} \right)\left({D_W}/{K_{air}} \right)}$$

Methods and Materials

- Analysis of results
  - Read out all TLDs
  - Found average of the three mouse phantoms
    - Corrected for control
  - Calculated percent deviation, assuming calibration phantoms were correct within uncertainty

Methods and Materials

- Total combined relative uncertainty

TLD	1.7%
Air Kerma Rate	0.45%
ADW Calculation	1.7%
Combined k=1	2.4%
Combined k=2	4.8%

Methods and Materials

- TLD uncertainty

Component	Type A (%)	Type B (%)
Beam uniformity	n/a	0.1
TLD reader stability	n/a	0.2
TLD reader linearity	n/a	0.1
TLD sort criteria	n/a	1.7
Quadratic sum	n/a	1.7
A and B quadratic sum	1.7	

Methods and Materials

- Air-kerma rate calibration uncertainty (chamber)

Component	Type A (%)	Type B (%)
Charge	0.02	n/a
Timing	n/a	n/a
Air density	0.1	0.1
Ionic recombination	n/a	n/a
Distance from source	n/a	0.05
Beam uniformity	n/a	0.1
Air attenuation	0.1	n/a
Quadratic sum	0.14	0.15
A and B quadratic sum	0.21	
NIST chamber calibration	0.40	
Quadratic sum	0.45	

Methods and Materials

- Air-kerma rate calibration uncertainty (electrometer)

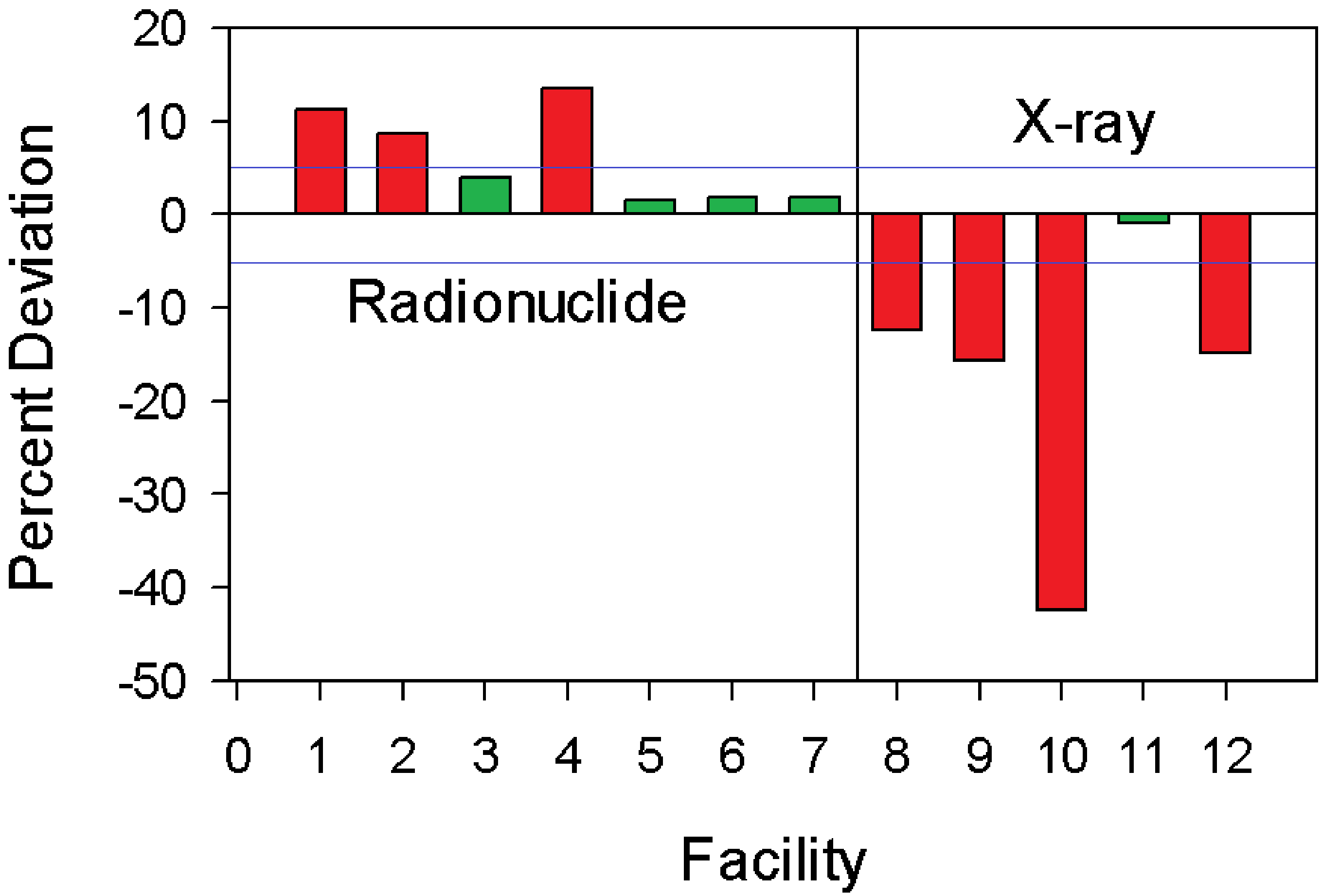
Component	Type A (%)	Type B (%)
Voltage	0.02	0.005
Charge Readout Error	0.05	0.017
Quadratic sum	0.054	0.018
A and B quadratic sum	0.057	
NIST capacitor calibration	0.005	
Quadratic sum	0.057	

Methods and Materials

- ADW calculation uncertainty

Component	Type A (%)	Type B (%)
Zero/Anneal	0.1	0.2
Air kerma to absorbed ADW conversion	n/a	1.7
Quadratic Sum	0.100	1.7
A and B quadratic sum	1.7	

Spot Check Results



Conclusions

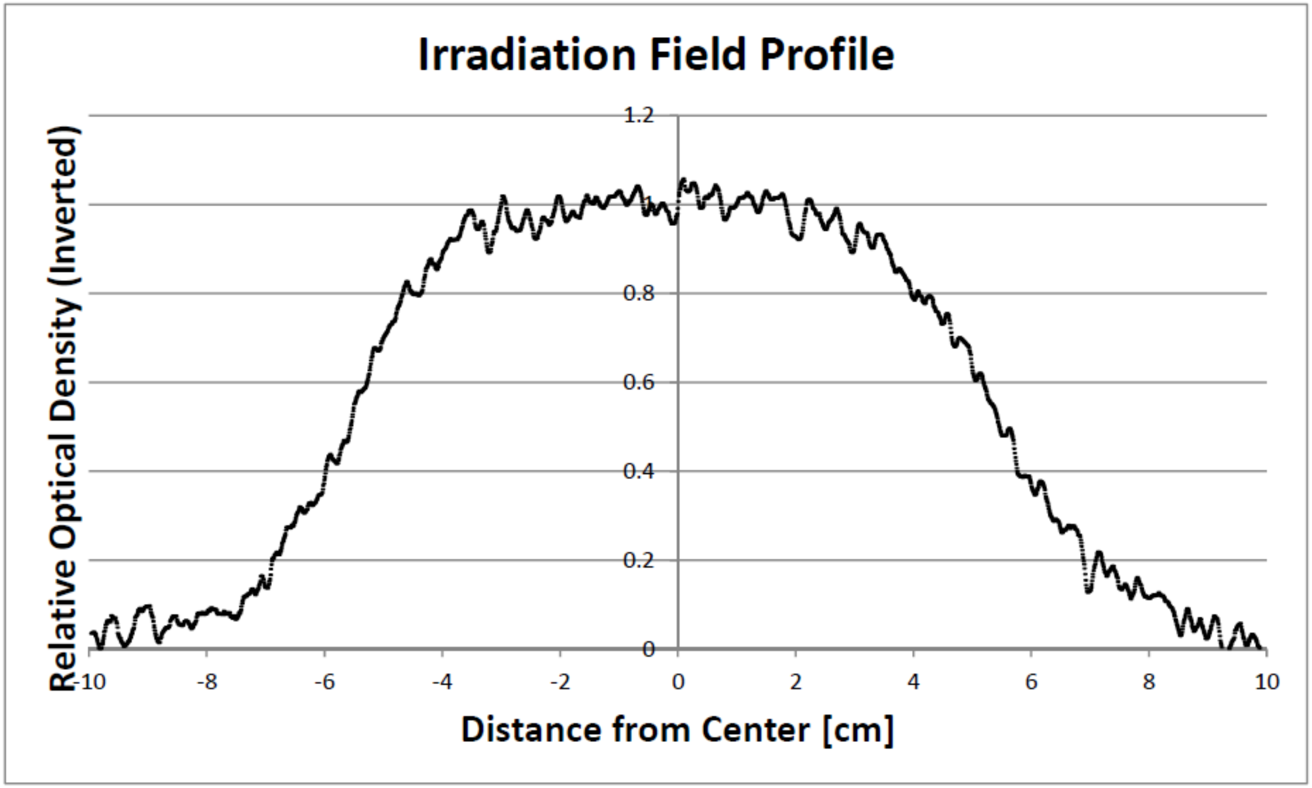
- Dosimetry reporting in radiobiology articles does not meet the recommended standards
- Many facilities failed to deliver an accurate dose
- Dose accuracy more of a concern with x-ray irradiators
  - X-ray irradiator use expanding
  - Radionuclide irradiators being phased out
- Independent output verification

Applicability of TG-61

- TG-61 calls for:
  - $30x30x30cm^3$ water phantom
  - Setup precision
  - Scatter-free environment
  - 100cm SSD
  - Attenuating material halfway between source and detector for HVL measurements
  - $10x10cm^2$ field
  - Requires chamber specific correction
- Calibration of the UWMRRC Kimtron, Inc. cabinet irradiator
  - Will apply an adapted TG-61 protocol
  - Will perform output verification

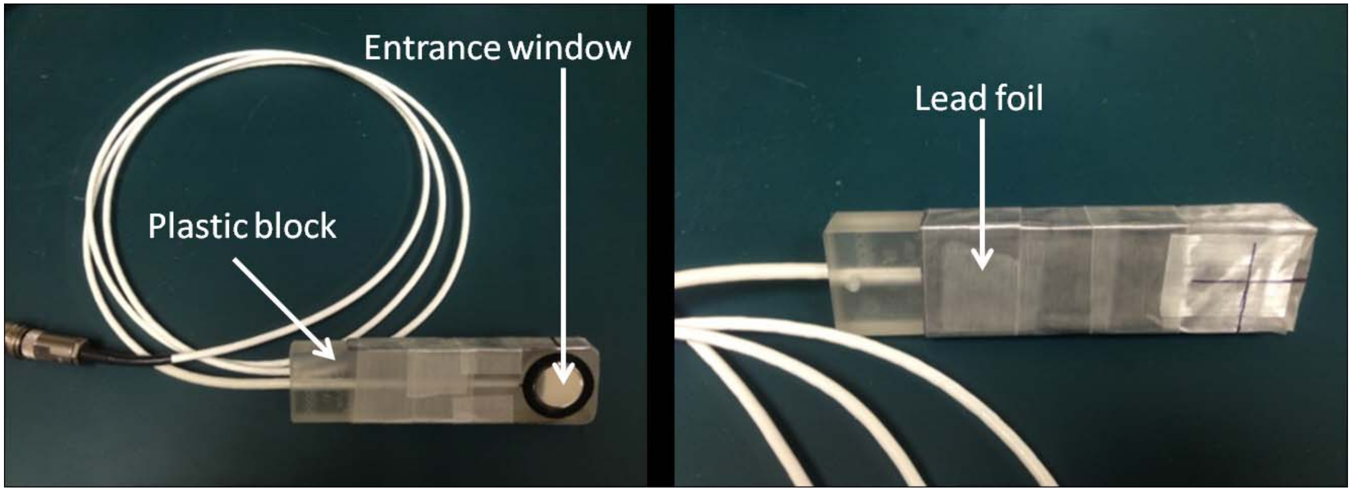
Applicability of TG-61

- Collimation and filtration
  - 0.4mmAl, 0.1mmCu



Applicability of TG-61

- HVL measurement
  - Scattered radiation a concern
  - Place irradiation target away from bottom wall
  - Lead shielded parallel plate chamber for HVL measurement
  - Attenuating material proximal to source
  - SSD is a concern
    - Max SSD in our Kimtron, Inc. irradiator <100cm



Lead shielded custom Capintec PS-033 parallel plate chamber

Applicability of TG-61

- Calibration
  - Adapt TG-61 in-phantom protocol

$$D_w = MN_K P_{Q,cham} P_{sheath} \left[\left(\frac{\overline{\mu}_{en}}{\rho} \right)_{air}^{w} \right]_{water}$$

  - Use Virtual Water^{TM} phantom
    - 10x10cm^2 phantom
    - No P_{sheath} correction needed
  - PDD and ADW calibration
    - PDD with 0.5cm resolution
    - ADW calibration using protocol at 2cm

Applicability of TG-61

- Mouse phantom dose calculation
  - Mouse phantom at same SSD as calibration phantom
  - Adjust for PDD
  - Use Monte Carlo to correct for phantom scatter

Future Work

- Complete calibration and output check
- Publish mouse phantom results
- Develop a HVL phantom to remotely measure irradiator beam quality

Acknowledgements

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- Tina Pike, PhD
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- UWADCL customers

References

- Patil SL, Somashekarappa H M, Rajashekhar K P. Radiomodulatory role of Rutin and Quercetin in Swiss Albino mice exposed to the whole body gamma radiation. Indian J Nucl Med 2012;27:237-42
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