THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Knowledge that will change your world

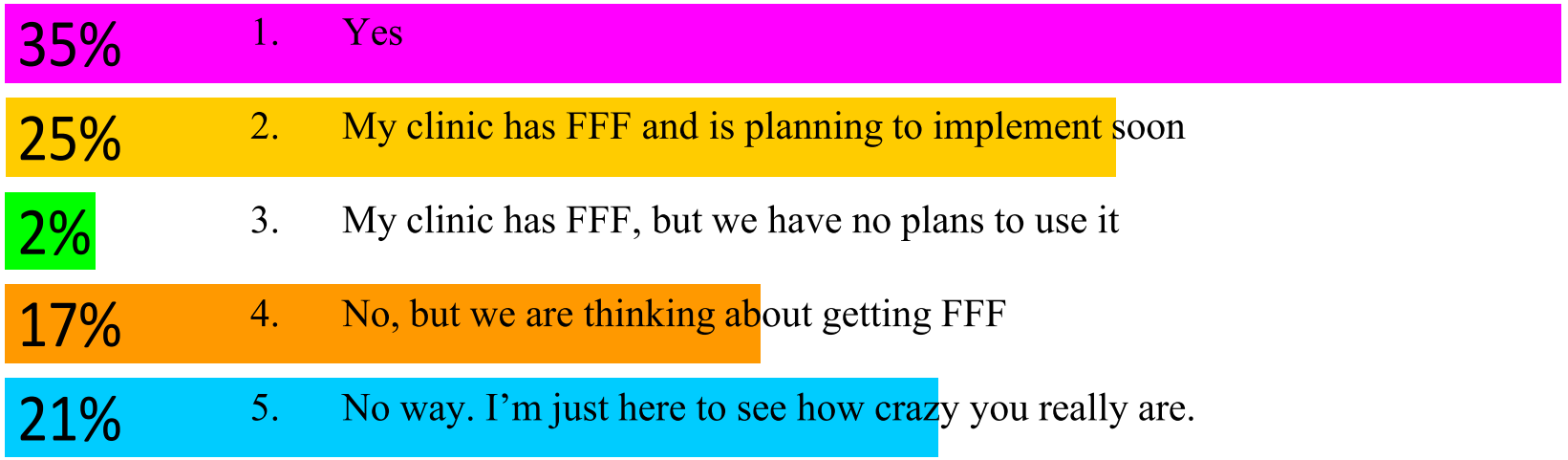
Flattening filter free beams for SRS and SBRT: It's all about speed

Richard Popple, Ph.D.

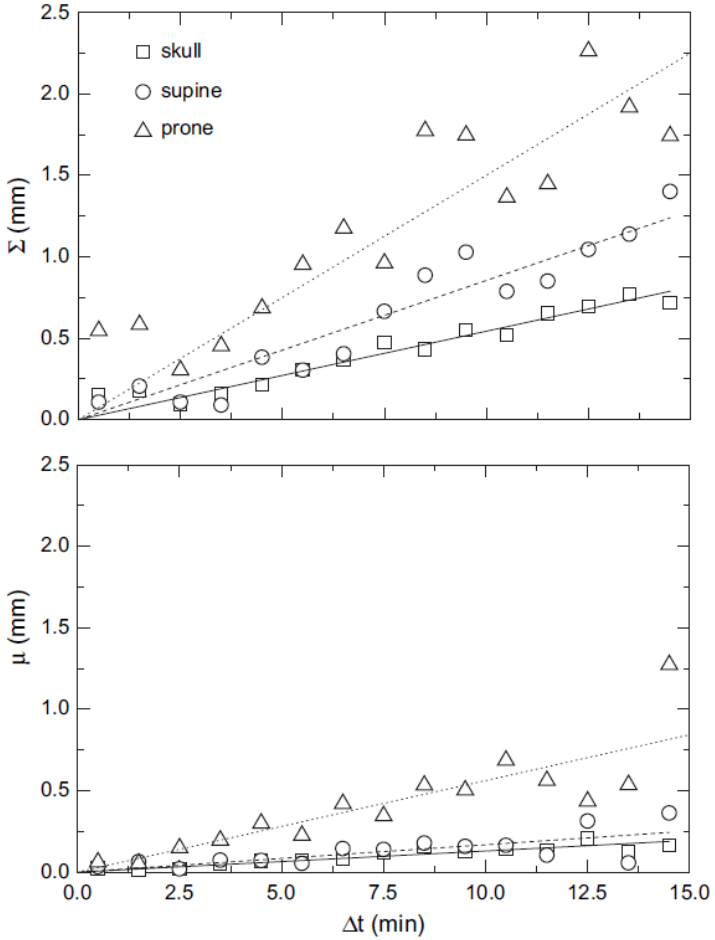
Disclosures

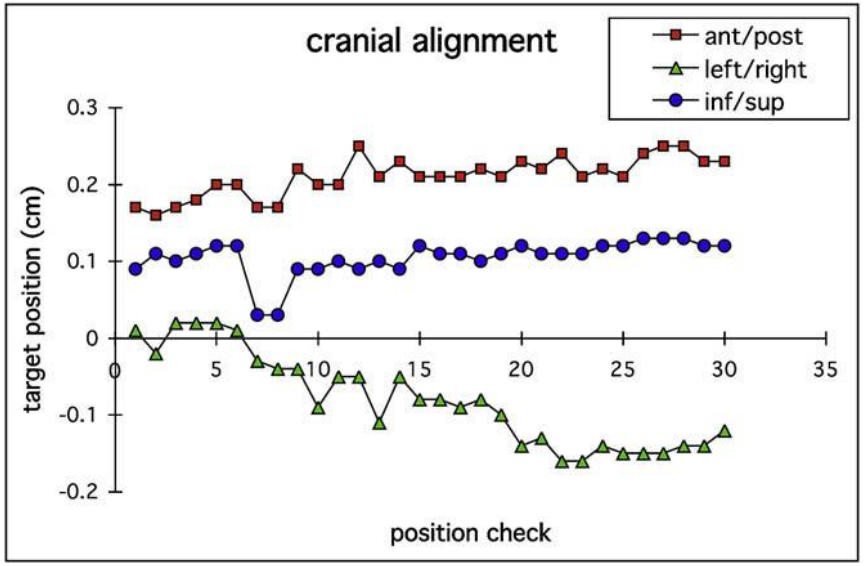
- UAB has research and development agreements with Varian Medical Systems

Are you using flattening filter free beams?



Why does speed matter?





	Fixed alignment			Dynamic alignment		
	σ	Σ	M	σ	Σ	M
Cranial	1.7	1.3	4.4 mm	1.0	0.2	1.2 mm
Cervical spine	1.8	1.3	4.5 mm	1.3	0.2	1.4 mm
Lumbar spine	1.5	1.0	3.6 mm	1.2	0.3	1.6 mm

Hoogeman MS, Nuyttens JJ, Levendag PC, Heijmen BJ. Time dependence of intrafraction patient motion assessed by repeat stereoscopic imaging. Int J Radiat Oncol Biol Phys. 2008 Feb 1;70(2):609-18.

Murphy MJ. Intrafraction geometric uncertainties in frameless image-guided radiosurgery. Int J Radiat Oncol Biol Phys. 2009 Apr 1;73(5):1364-8

First proposed in 1991!

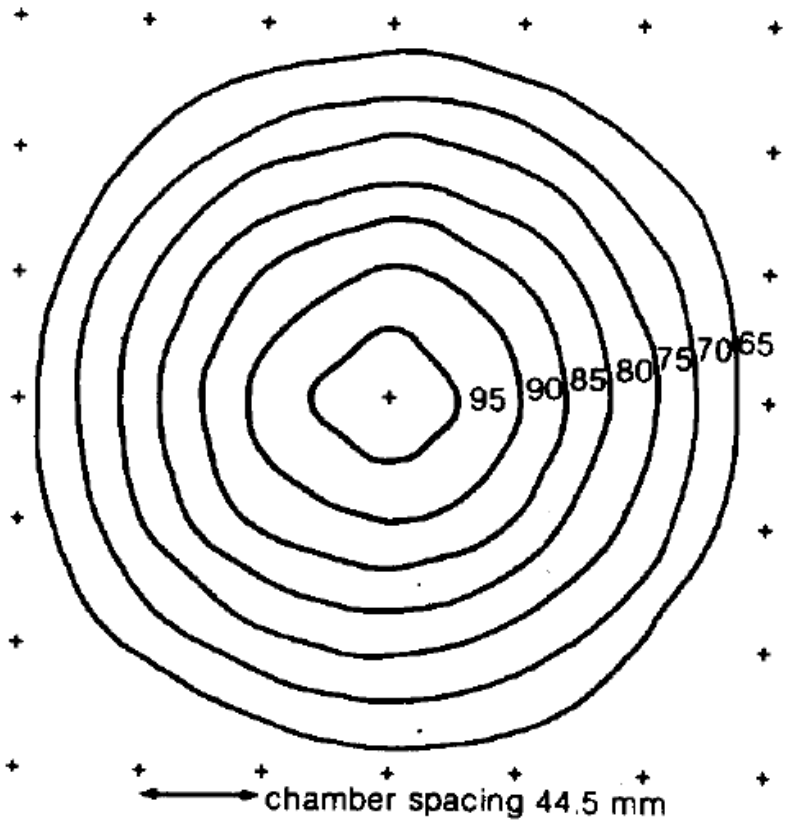


FIG. 2. Iso-ionization lines for the unflattened beam in a plane perpendicular to the central axis of the beam.

O'Brien PF, Gillies BA, Schwartz M, Young C, Davey P. Radiosurgery with unflattened 6-MV photon beams. Med Phys. 1991 May-Jun;18(3):519-21.

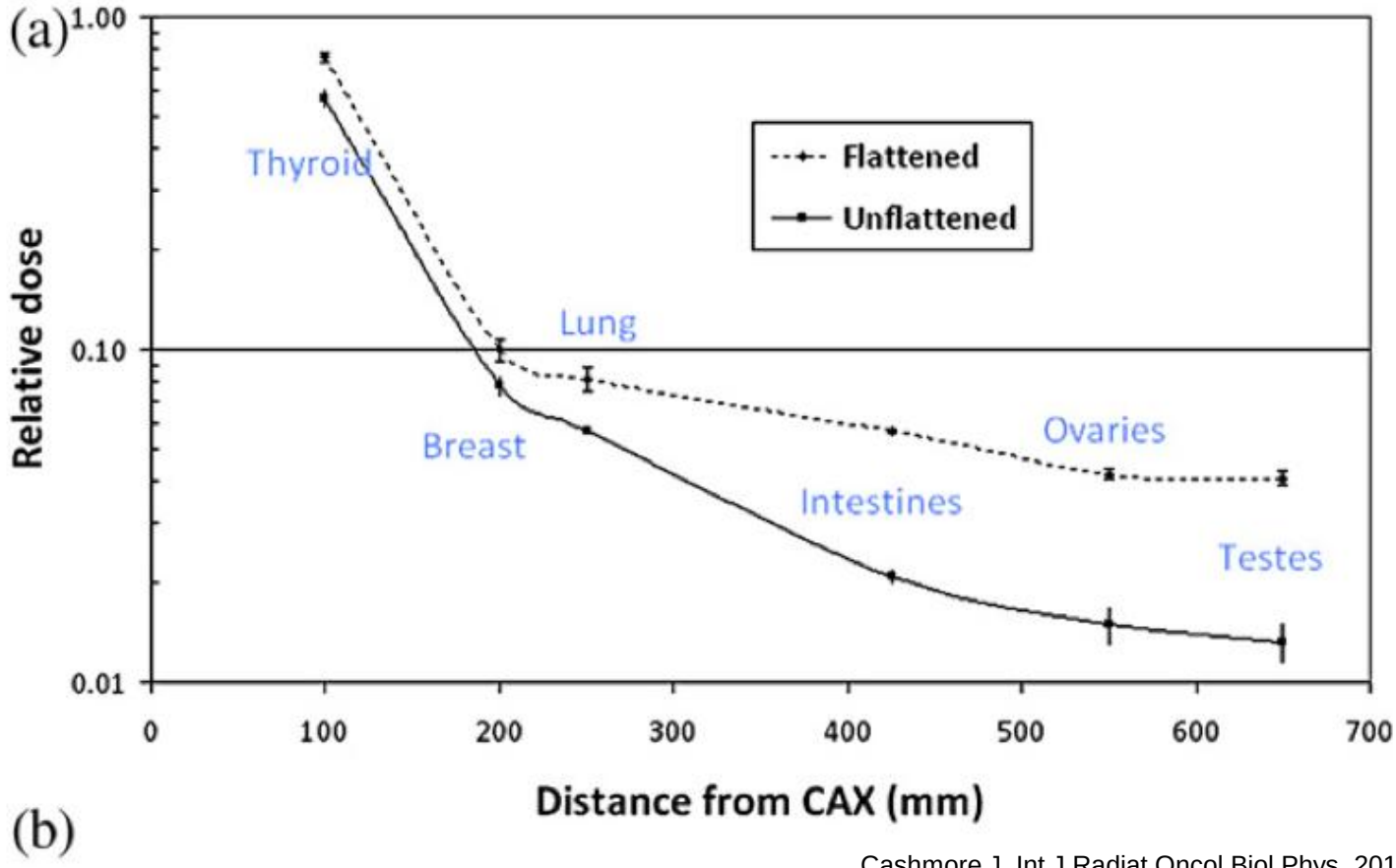
Possible Benefits of a FFF

- Efficiency
- More accurate beam modeling due to decreased head scatter
- Decreased leakage and dose outside field

The study showed that removing the filter increased the dose rate on the central axis by a factor of 2.31 (6 MV) and 5.45 (18 MV) at a given target current. Because the flattening filter is a major source of head scatter photons, its removal from the beam line could reduce the out-of-field dose.

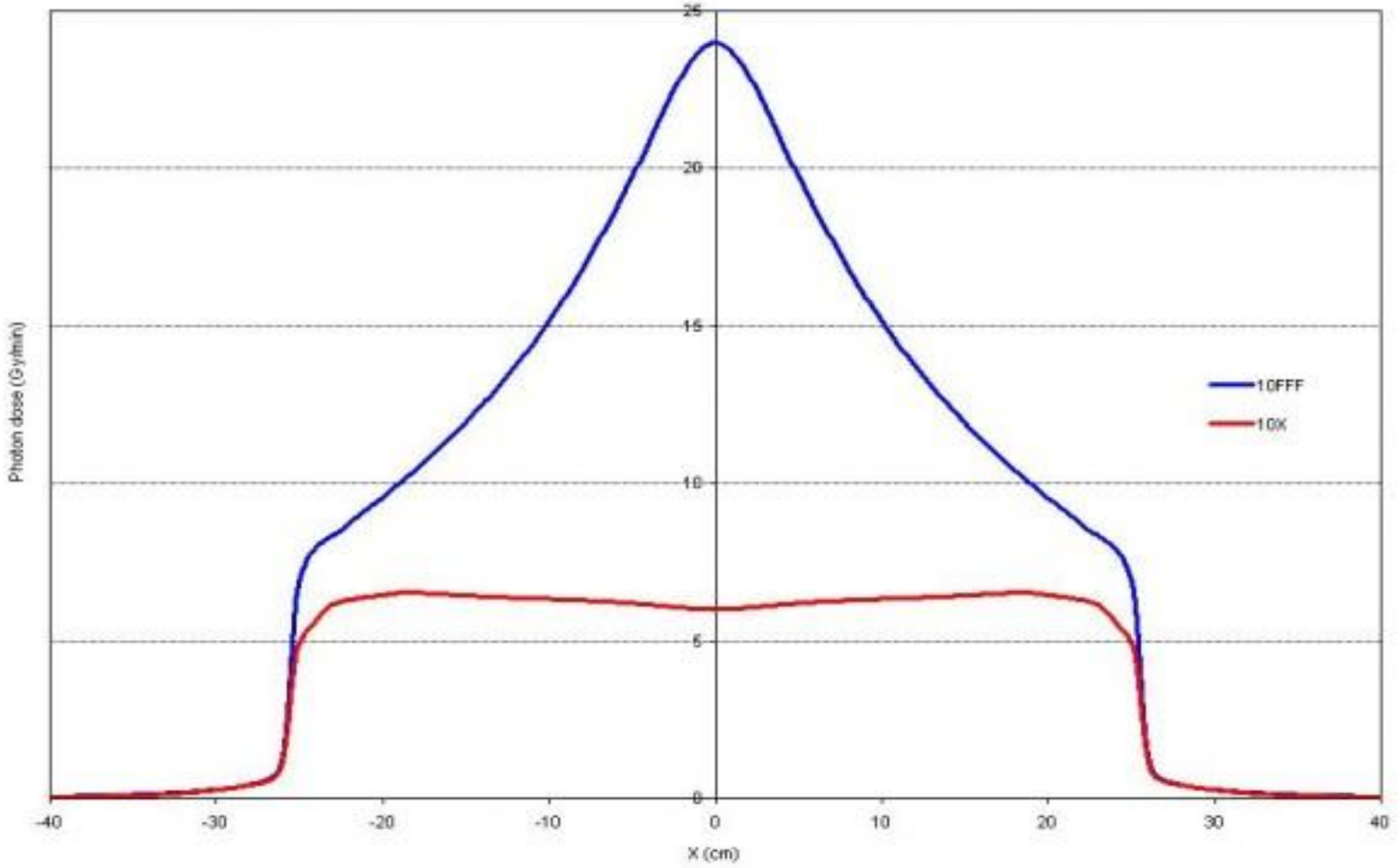
Vassiliev ON, Titt U, Kry SF, Pönisch F, Gillin MT, Mohan R Med Physics 2006 vol. 33 (4) pp. 820-7

Unflattened Beam Has a Lower Risk of Secondary Tumors



Cashmore J, Int J Radiat Oncol Biol Phys. 2011

Beam Profile – Flattening Filter



Depth Dose with Flattened Beam

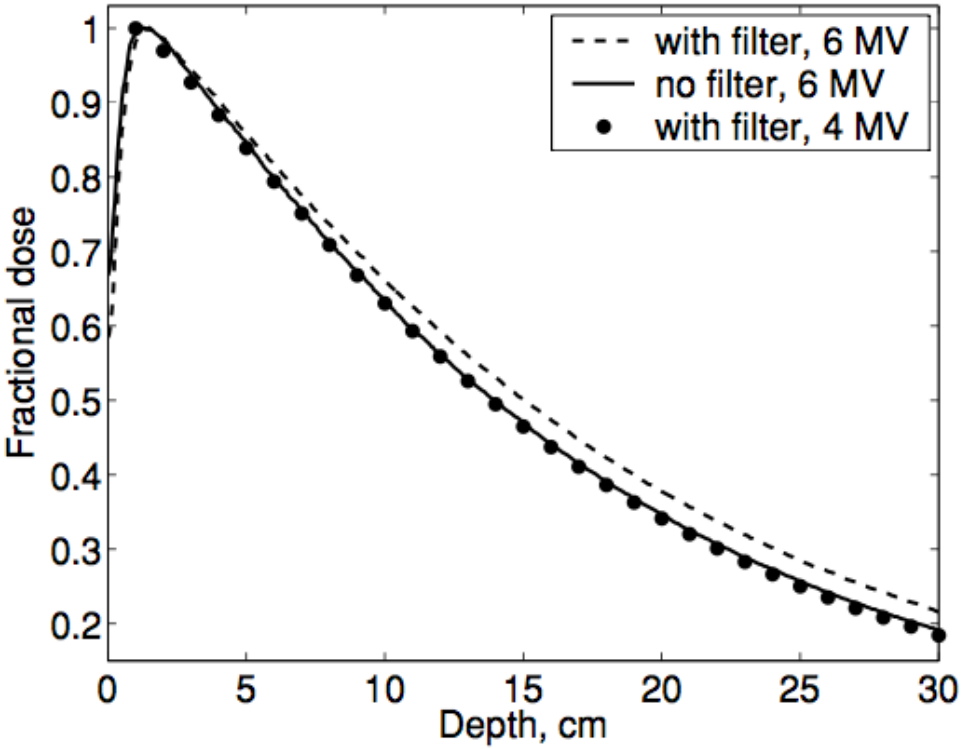


Figure 1. Depth dose dependence for a 10 × 10 cm^2 field. 6 MV with the flattening filter (dashed line), 6 MV without the filter (solid line), 4 MV with the filter (circles).

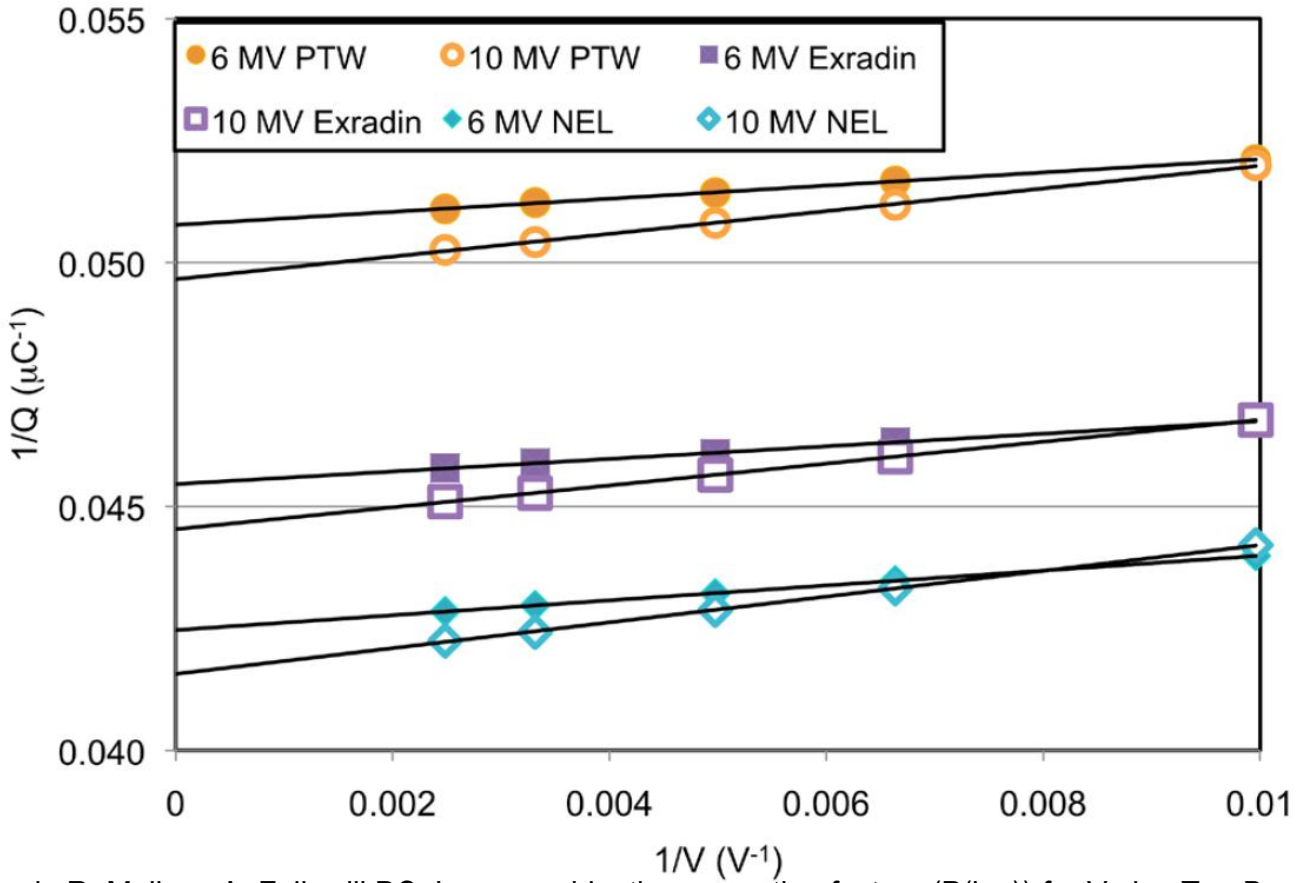
2004 Phys. Med. Biol. 49 1535

Calibration

- No difference for FFF
- Polarity and recombination corrections small

Energy	Dose rate	Ppol	Pion
6X	600	1.000	1.004
15X	600	1.000	1.005
6X FFF	1400	1.000	1.006
10X FFF	2400	1.000	1.013

Calibration



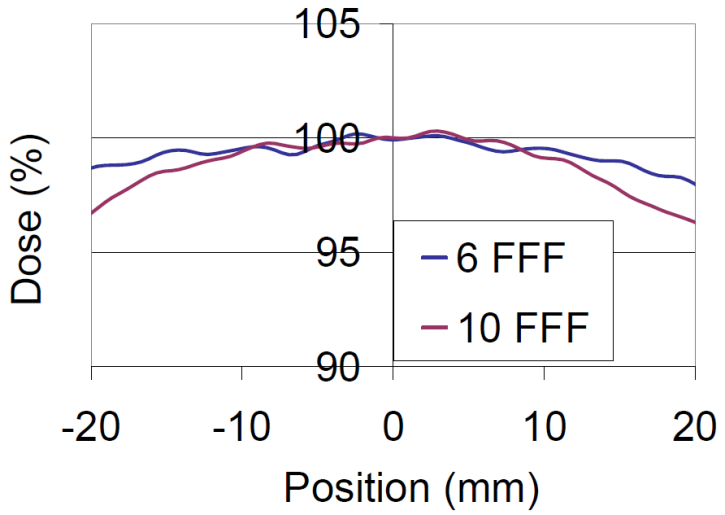
Kry SF, Popple R, Molineu A, Followill DS. Ion recombination correction factors (P(ion)) for Varian TrueBeam high-dose-rate therapy beams. J Appl Clin Med Phys. 2012 Nov 8;13(6):3803. doi: 10.1120/jacmp.v13i6.3803. PubMed PMID: 23149774.

Calibration

TABLE 5. Recombination factors at 300 V based on the two-voltage technique (P_{ion}), and based on a Jaffé-plot (1/V versus 1/Q curve).

	6 MV FFF		10 MV FFF	
Ion Chamber	P_{ion}	*Jaffé-plot*	P_{ion}	*Jaffé-plot*
Exradin A-12	1.009	1.009	1.014	1.017
PTW TN30013	1.008	1.008	1.013	1.015
NEL 2571	1.013	1.011	1.018	1.020

Kry SF, Popple R, Molineu A, Followill DS. Ion recombination correction factors (P(ion)) for Varian TrueBeam high-dose-rate therapy beams. J Appl Clin Med Phys. 2012 Nov 8;13(6):3803. doi: 10.1120/jacmp.v13i6.3803. PubMed PMID: 23149774.



Calibration – use Pb foil for all FFF beams

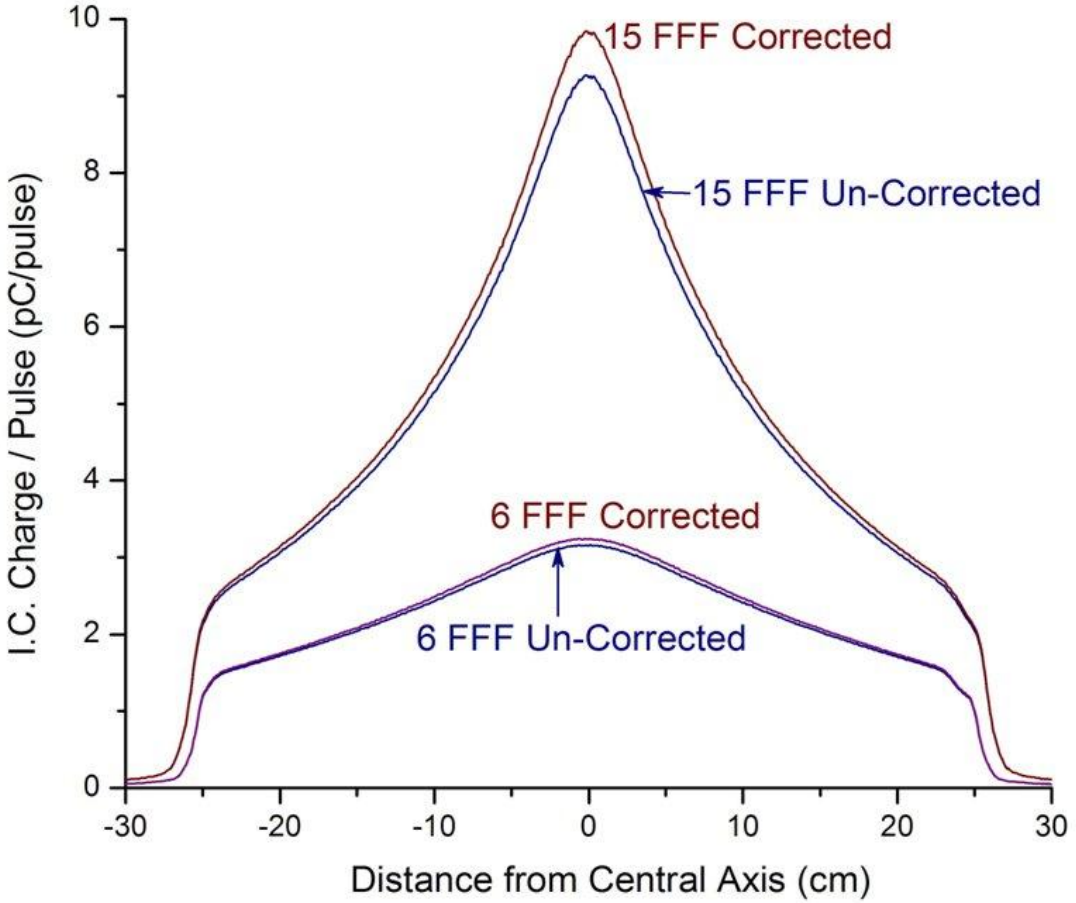
$$\%dd(10)_x = [0.8905 + 0.00150\%dd(10)_{Pb}]\%dd(10)_{Pb}$$
$$[\text{foil at } 50 \text{ cm}, \%dd(10)_{Pb} \geqslant 73\%], \qquad (13)$$

IROC Calibration check

- RPC OSLD measurement / Institution
  - 6X FFF = 0.99
  - 10X FFF = 0.99

Profile and depth dose correction for recombination

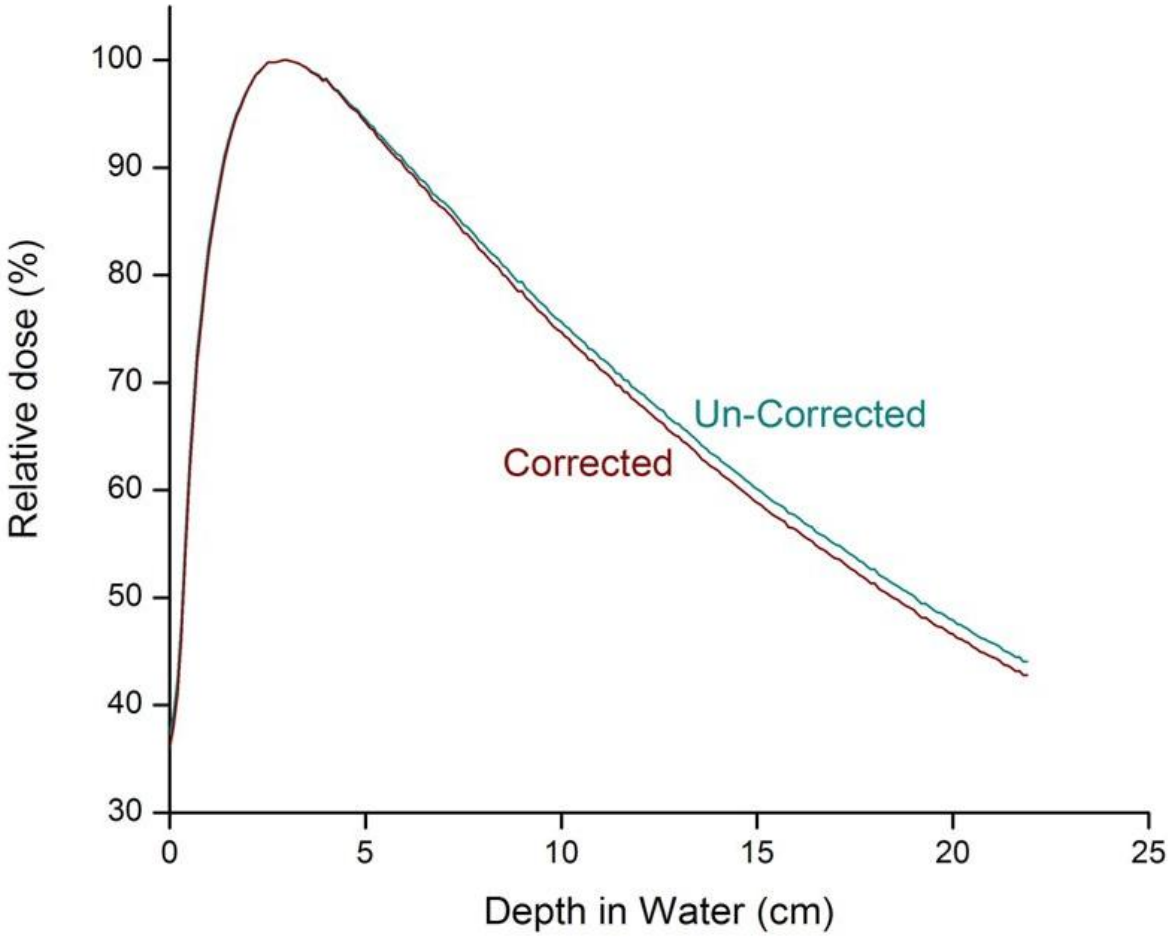
Measured x-ray distributions of 6FFF and 15FFF beams plotted against charged collected per beam pulse. Also plotted are the results from applying corrections for the ion chamber collection efficiency. The distributions were measured at 100 cm SSD with the 0.1 cm^3 chamber at D_{max} and biased with 300 V.



S Johnsen "Ion Chamber Collection Efficiency Considerations for Un-Flattened X-Ray Beams," Med. Phys. 35, 2770 (2008)

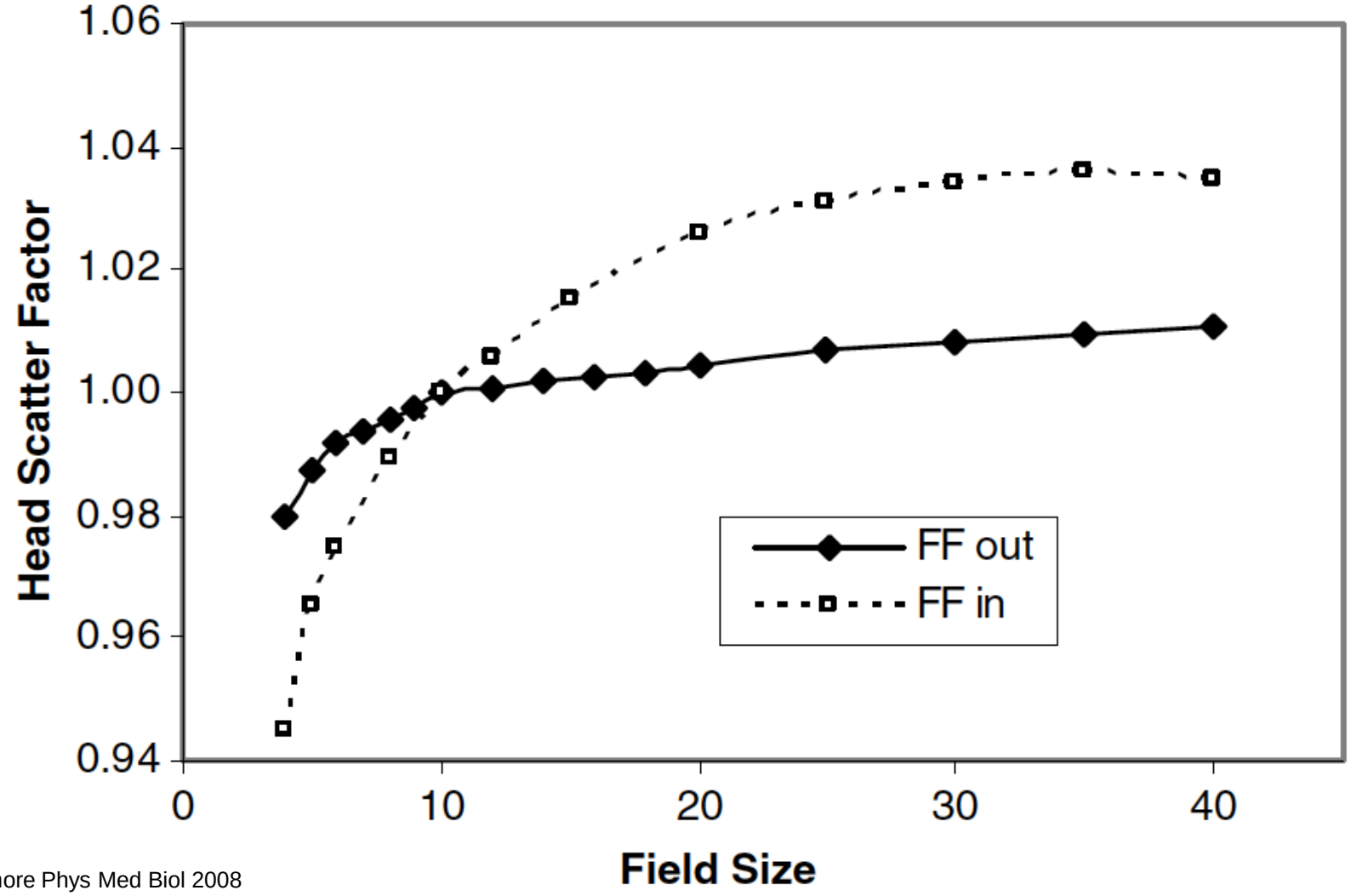
Profile and depth dose correction for recombination

Measured 15 FFF x-ray depth-dose distribution and distribution resulting from corrections for ion chamber collection efficiency. Each curve is normalized to 100% at D_{max}. Data is for a 0.1 cm^3 chamber biased to 300 V; 10x10 cm^2 field at 100 cm SSD.



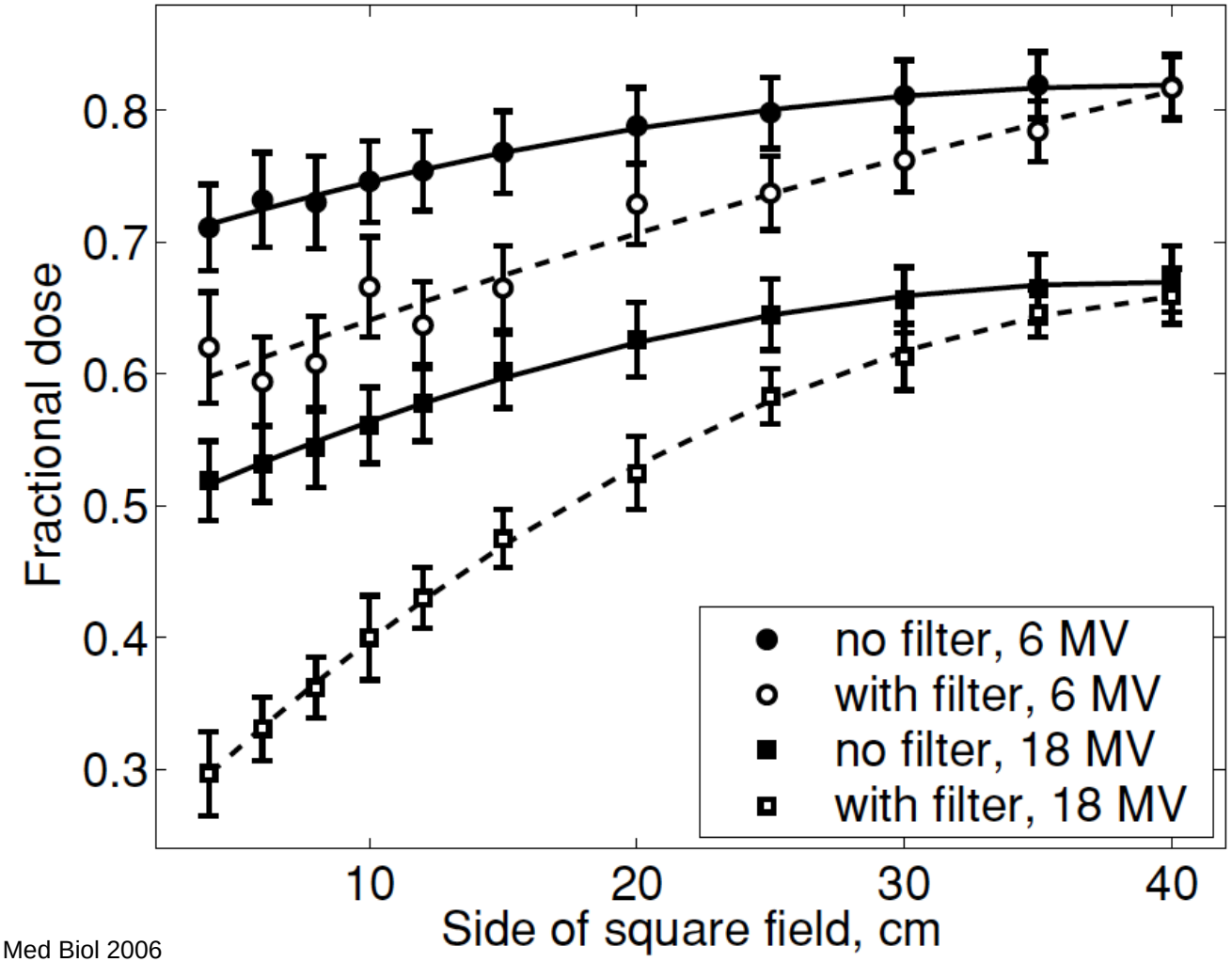
S Johnsen "Ion Chamber Collection Efficiency Considerations for Un-Flattened X-Ray Beams," Med. Phys. 35, 2770 (2008)

FFF head scatter



Cashmore Phys Med Biol 2008

FFF surface dose

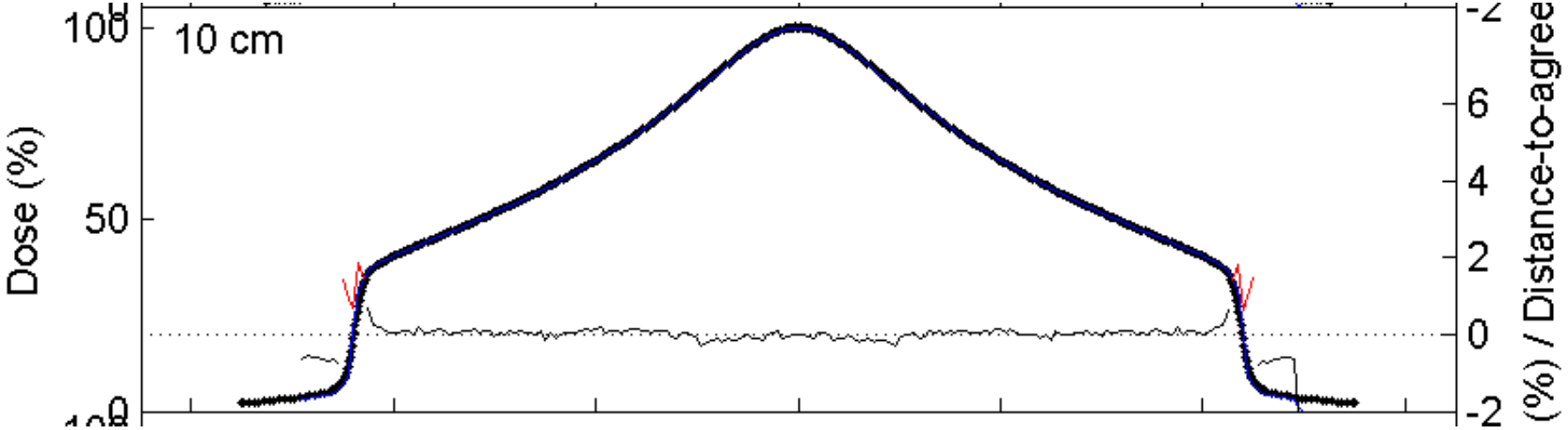


Vassiliev et al. Phys Med Biol 2006

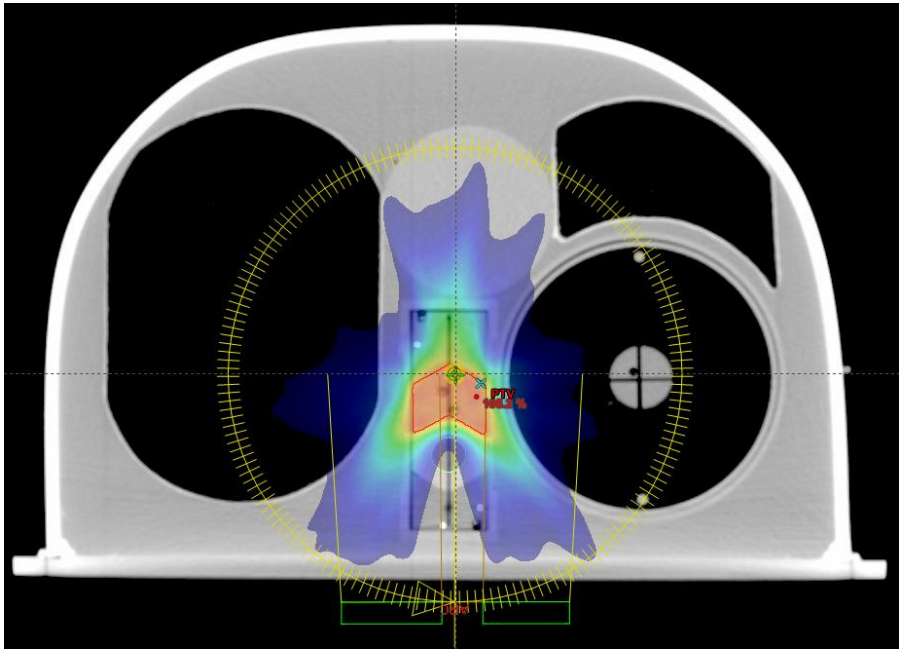
Photon commissioning

- AAA Data requirements are the same
- No additional data required for FFF

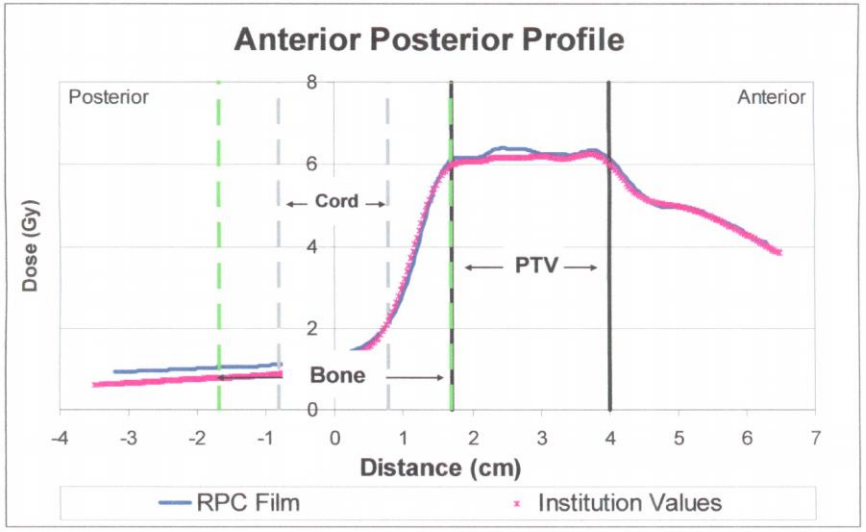
10X FFF profile

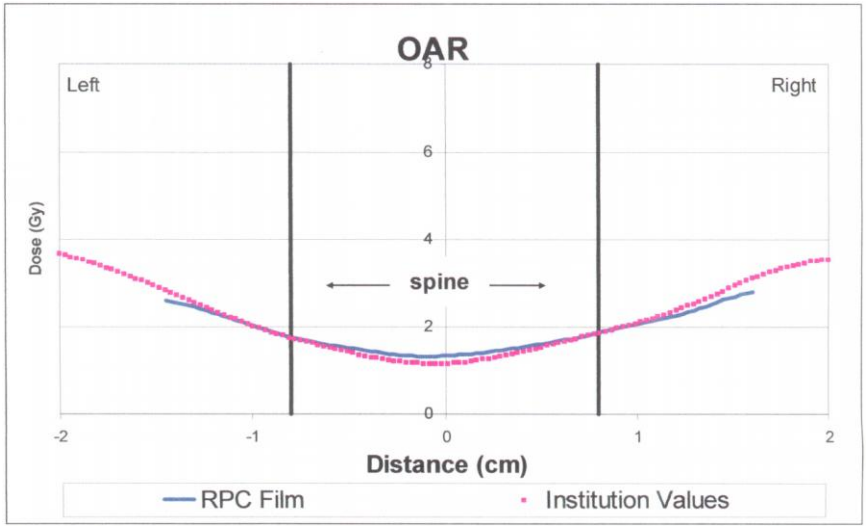


IROC VMAT Spine

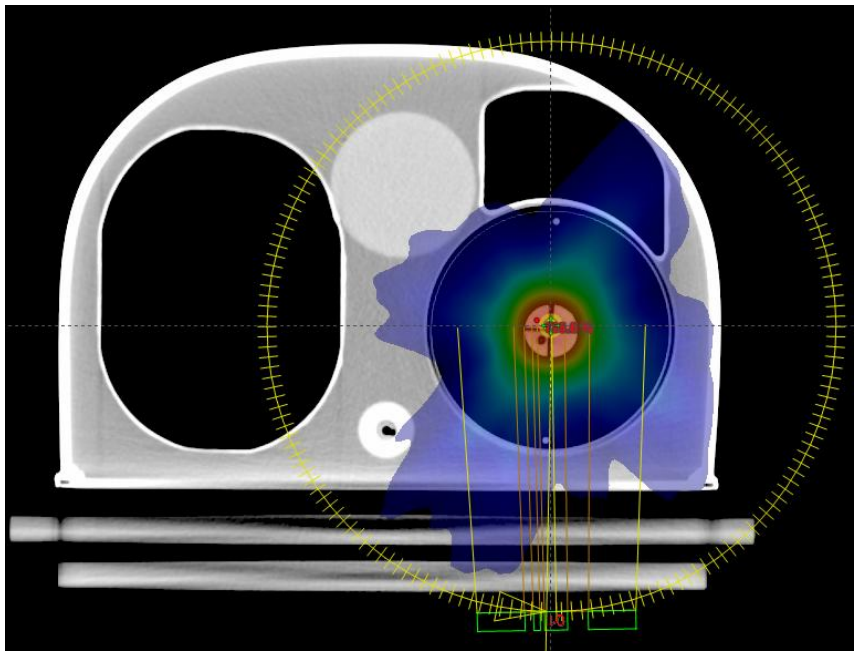


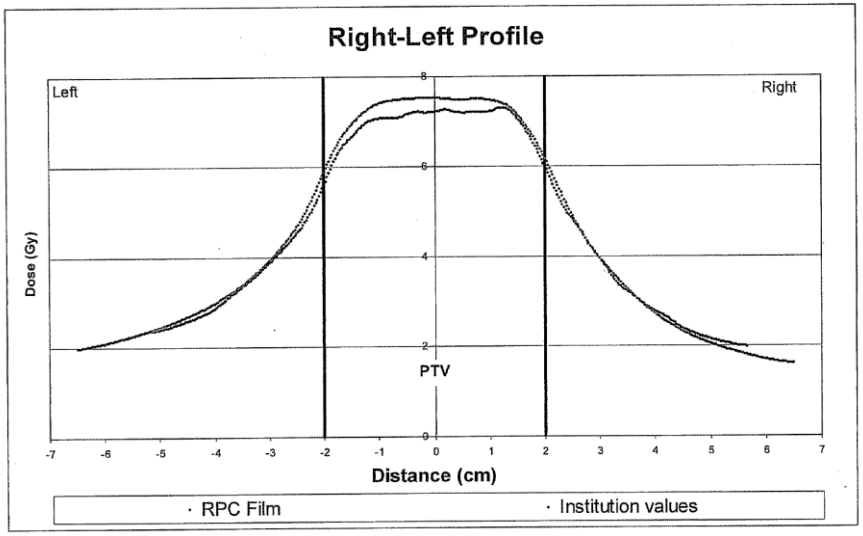
Location	Institution Reported Doses (cGy)	TLD Dose (cGy)	Measured/Institution
PTV_TLD_sup_ant	612	618	1.01
PTV_TLD_inf_ant	614	619	1.01
PTV_TLD_sup_post	616	619	1.00
PTV_TLD_inf_post	620	627	1.01
HEART_TLD	134	135	1.01

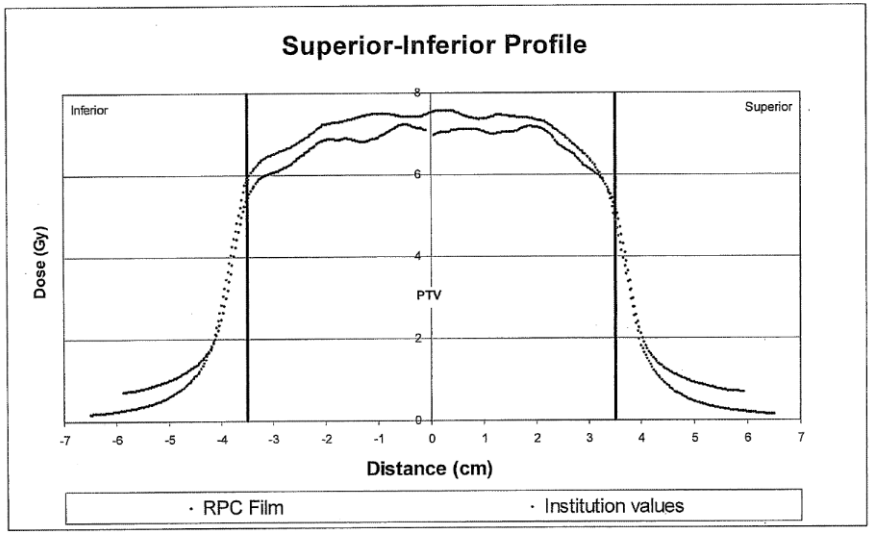




IROC Gated VMAT Lung







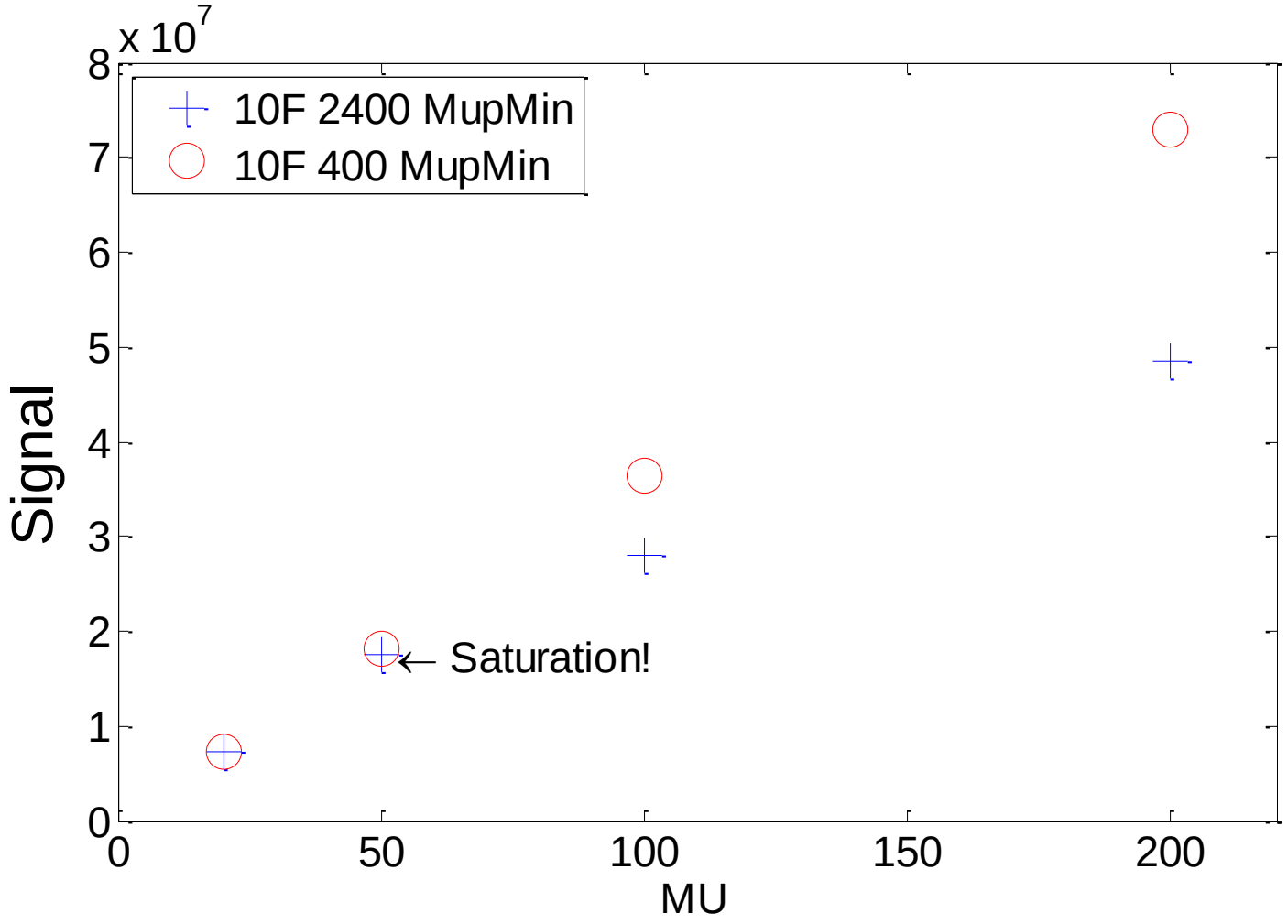
Summary of TLD and film results:

Location	RPC vs. Inst.	Criteria	Acceptable
PTV_TLD_sup	0.96	0.92 – 1.02	Yes
PTV_TLD_inf	0.96	0.92 – 1.02	Yes

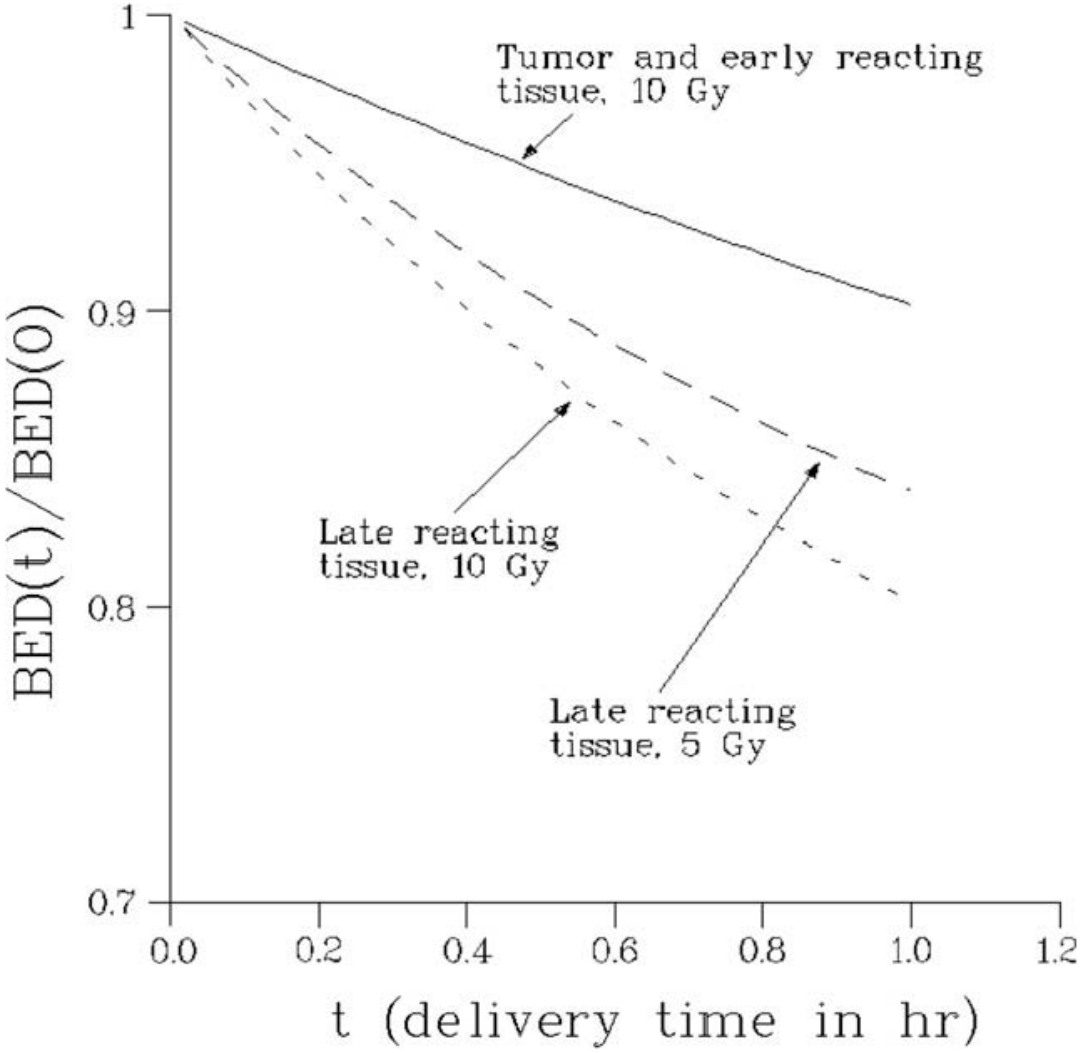
Film Plane	Gamma Index*	Criteria	Acceptable
Axial	100	≥ 80%	Yes
Coronal	99	≥ 80%	Yes
Sagittal	98	≥ 80%	Yes
Average over 3 planes	99	≥ 85%	Yes

*Percentage of points meeting gamma-index criteria of 5% and 5 mm

Daily QA device

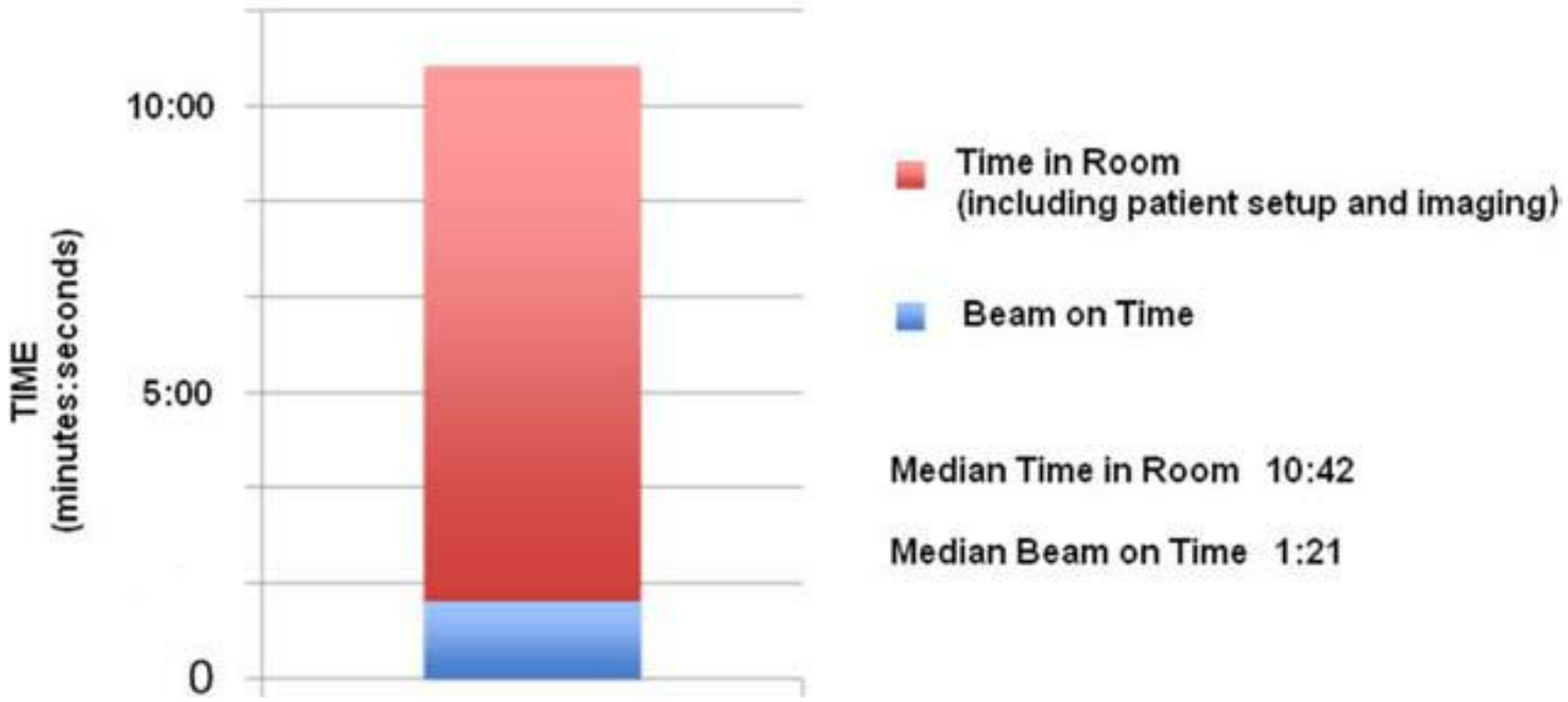


Dose rate bioeffect



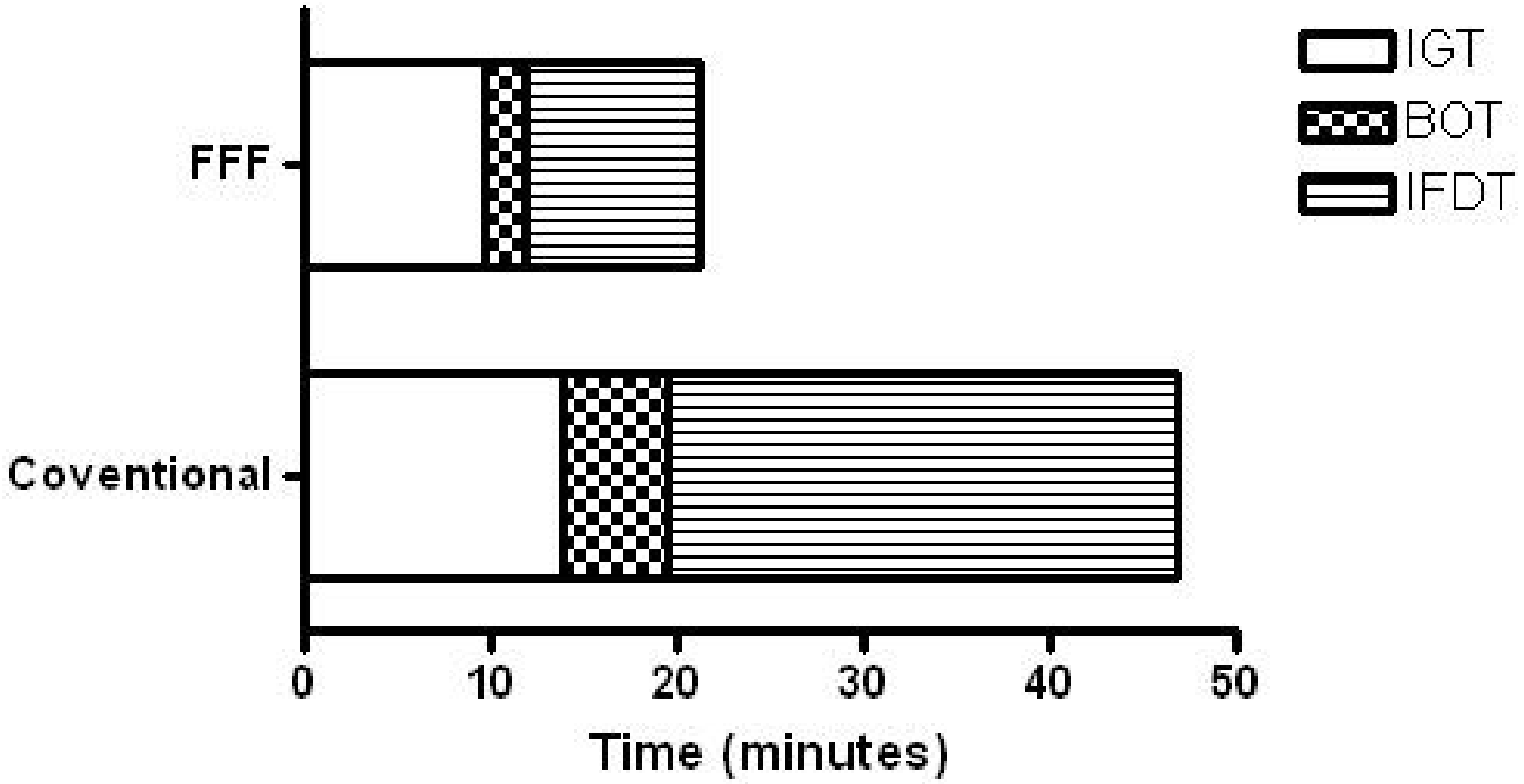
Ling CC, Gerweck LE, Zaider M, Yorke E. Dose-rate effects in external beam radiotherapy redux. Radiother Oncol. 2010 Jun;95(3):261-8.

CNS– how much faster?



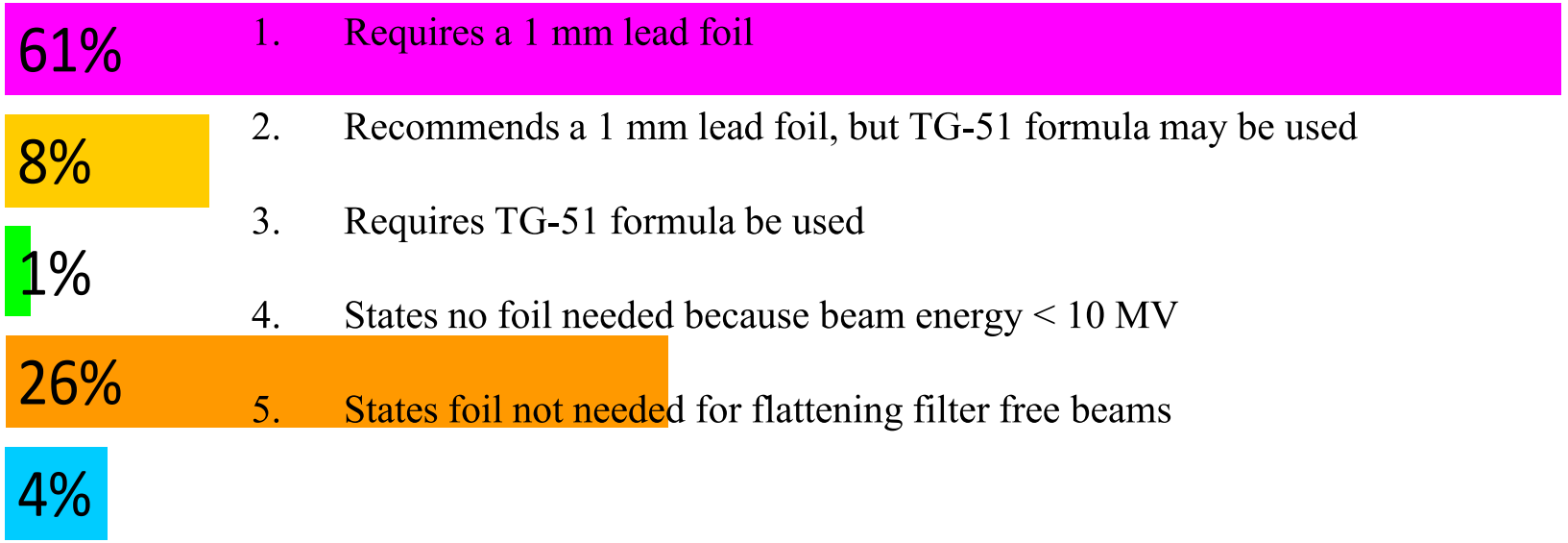
Prendergast BM et al., Jour. of Radiosurgery and BRT, Vol. 1, pp. 117–122 .

Lung & liver – how much faster?



Prendergast BM, Fiveash JB, Popple RA, Clark GM, Thomas EM, Minnich DJ, Jacob R, Spencer SA, Bonner JA, Dobelbower MC. Flattening filter-free linac improves treatment delivery efficiency in stereotactic body radiation therapy. J Appl Clin Med Phys. 2013 May 6;14(3):4126.

When calculating the beam quality specifier %dd(10)$_X$ for a 6 MV flattening filter free beam, TG-51

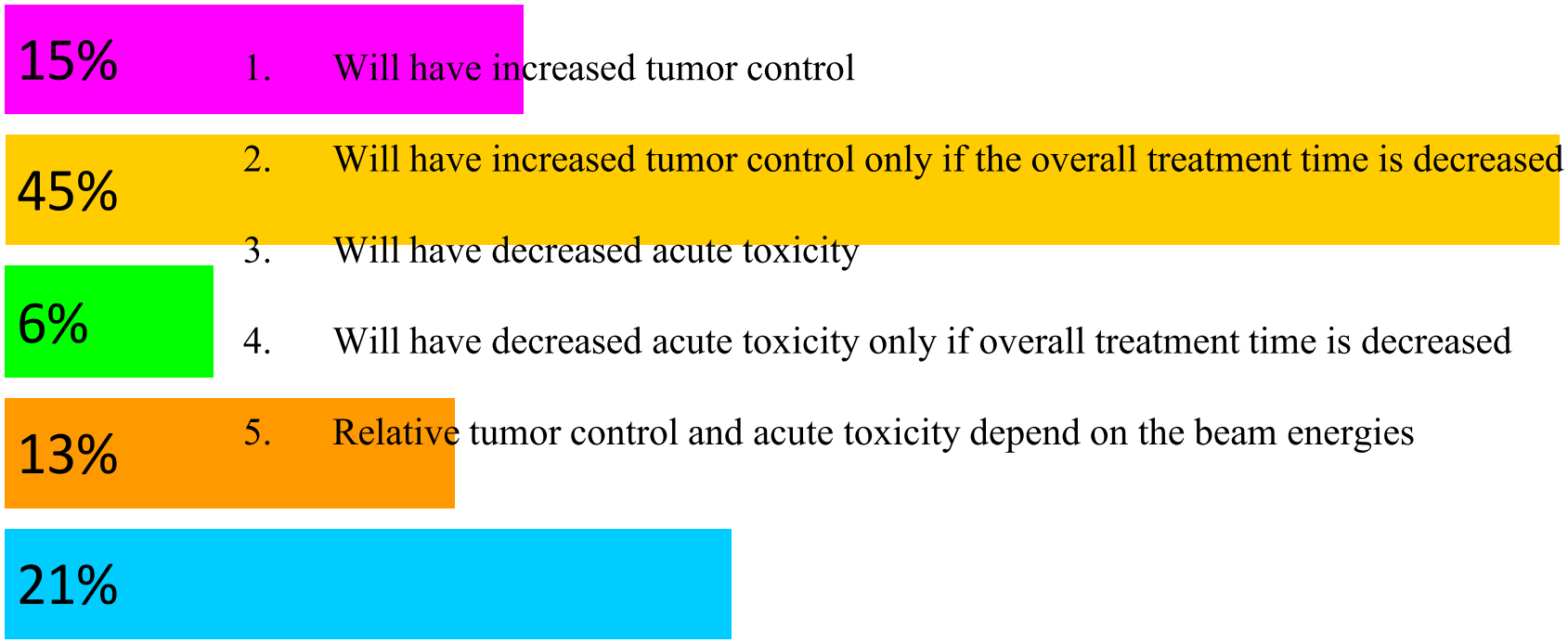


When calculating the beam quality specifier $\%dd(10)_X$ for a 6 MV flattening filter free beam, TG-51

1. Requires a 1 mm lead foil

Reference: McEwen M, DeWerd L, Ibbott G, Followill D, Rogers DW, Seltzer S, Seuntjens J. Addendum to the AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon beams. Med Phys. 2014 Apr;41(4):041501.

Compared to a flattened beam with dose rate 600 MU per minute, calculations based on the linear-quadratic model predict that a 2400 MU per minute flattening filter free beam



Compared to a flattened beam with dose rate 600 MU per minute, calculations based on the linear-quadratic model predict that a 2400 MU per minute flattening filter free beam

2. Will have increased tumor control only if the overall treatment time is decreased

Reference: Ling CC, Gerweck LE, Zaider M, Yorke E. Dose-rate effects in external beam radiotherapy redux. Radiother Oncol. 2010 Jun;95(3):261-8.

Relative to a flattened beam of the same energy, the surface dose for a flattening filter free beam is

4%	1.	Lower for all field sizes
9%	2.	Lower for small field sizes and comparable at 40x40 cm^2
3%	3.	Equivalent for all field sizes
56%	4.	Higher for small field sizes and comparable at 40x40 cm^2
29%	5.	Higher for all field sizes

Relative to a flattened beam of the same energy, the surface dose for a flattening filter free beam is

4. Higher for small field sizes and comparable at 40x40 cm^2

Reference: Vassiliev ON, Titt U, Pönisch F, Kry SF, Mohan R, Gillin MT. Dosimetric properties of photon beams from a flattening filter free clinical accelerator. Phys Med Biol. 2006 Apr 7;51(7):1907-17.