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Assembling your detector toolkit – which types, how many, and why

Detectors for external beam reference dosimetry

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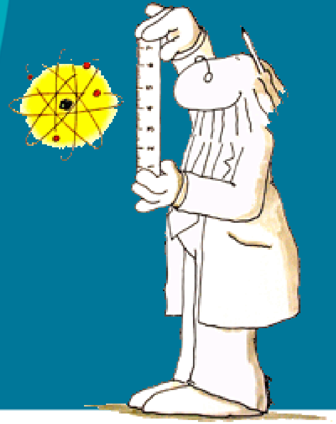
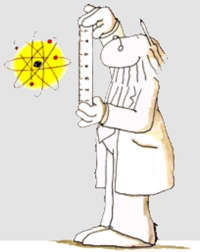




External beam reference dosimetry

Determination of ‘absolute’ dose

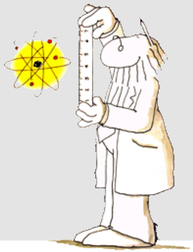
Chamber calibrated in cobalt-60 ($N_{D,w}^{^{60}Co}$)

$$D_w^Q = M N_{D,w}^Q = M k_Q N_{D,w}^{^{60}Co}$$

Only air-filled, reference-class ion chambers

Major efforts to update ongoing

Major efforts to modernize/update



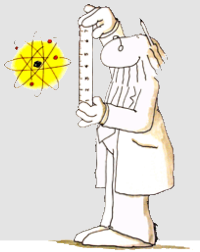
AAPM WGTG51 (Review and extension of the TG-51 protocol)

- Addendum for MV calibration published 2014
- Addendum for MeV calibration in progress

IAEA TRS-398 currently being revised

AAPM/IAEA TRS-483 CoP for reference and relative dosimetry (small static fields) published 2017

Equipment required



Ion chambers

Water phantoms

Measuring assembly (electrometer/cables)

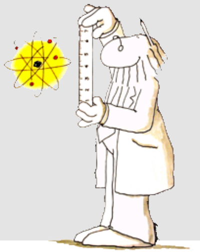
Environmental monitoring

Redundancy

It is the responsibility of the clinical physicist to ensure that there are adequate, independent, and redundant checks in place to ensure that any problems with the ion chamber will be detected prior to the routine calibration.[18] Checks are achieved by use of check sources, by regular measurements in a ^{60}Co beam, or by use of multiple independent dosimetry systems. With adequate and redundant checks in place, it is necessary to have the ion chamber calibrated when first purchased, when repaired, when the redundant checks suggest a need, or once every two years. The clinical physicist must perform at least two independent checks prior to sending a chamber for calibration and repeat the same checks when the chamber is returned to ensure that the chamber characteristics have not changed during transit and the calibration factor obtained applies to the chamber.

AAPM TG-51(1999)

What is a ‘reference-class’ ion chamber?



Addendum to TG-51 and TRS-483 give identical specifications

Measurand[a]	Specification
Chamber settling	Should be less than a 0.5% change in chamber reading per monitor unit from beam-on for a warmed up machine, to stabilization of the ionization chamber.
P_{leak}	$<$ 0.1 % of chamber reading ($0.999 < P_{leak} < 1.001$)
P_{pol}	$<$ 0.4 % correction ($0.996 < P_{pol} < 1.004$)
	$<$ 0.5 % maximum variation in P_{pol} with energy (total range)
$P_{ion} = 1 + C_{init} + C_{gen}D_{pp}$[b]	
General	P_{ion} should be linear with dose per pulse.
Initial	Initial recombination should be less than 0.2%, that is, $C_{init} < 0.002$, for the TG-51 reference conditions[c].
Polarity dependence	Difference in initial-recombination correction between opposite polarities should be less than 0.1%.
Chamber stability	Should exhibit less than a 0.3%[d] change in calibration coefficient over the typical recalibration period of 2 years.

Addendum to TG-51(2014)

Stabilization – response could be "user-dependent"

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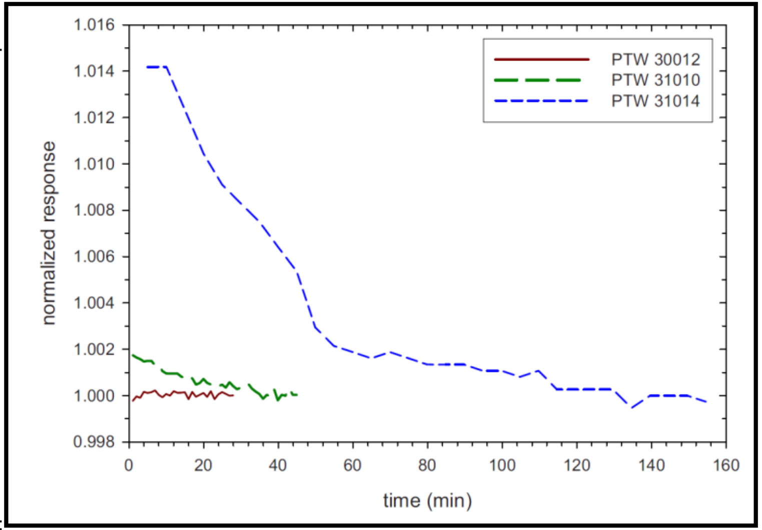

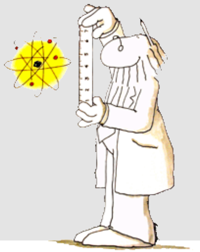

Behavior according to theory

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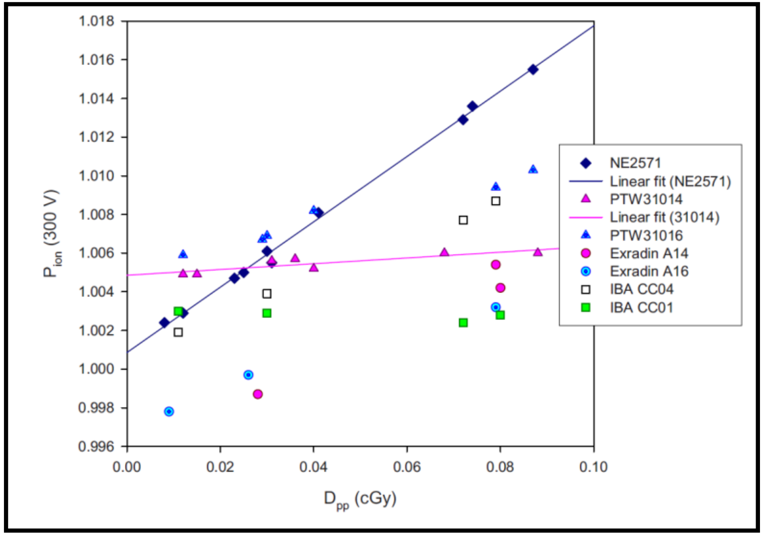
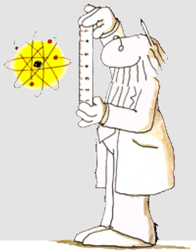


Assumptions could lead to errors

Applicability of calibration coefficient



$$D_{w,Q}(t_{meas}) = N_{D,w}^{60Co}(t_{cal})\, k_Q\, M_{ion}(t_{meas})$$

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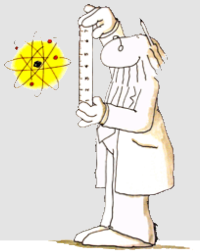
Change implies $N_{D,w}$ not applicable at time of linac calibration

Suitability of chambers for reference dosimetry



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Meet specs (in general)?

-Most Farmer-type
-Some scanning-type
-No micro-type (<0.02 cm^3)

Must evaluate particular chamber in use!

Reference conditions (photon beams)

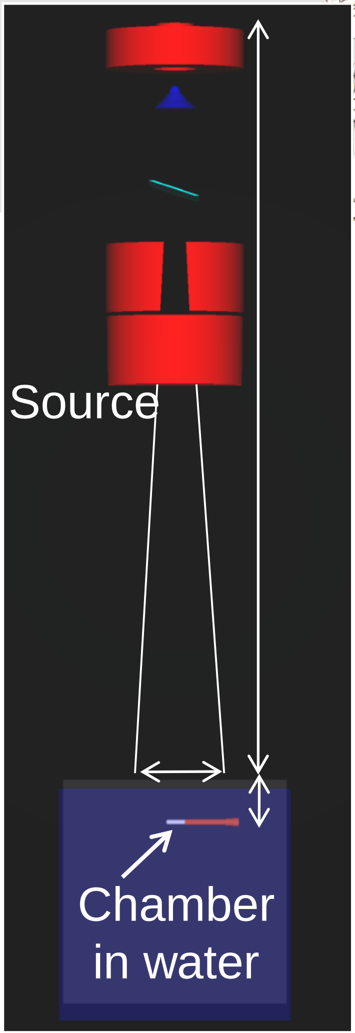
10x10 cm^2 field

100 cm SSD (normally)

10 cm depth

30x30x30 cm^3 water phantom

Conditions for temperature, pressure, humidity



Some machines can’t realize these conditions

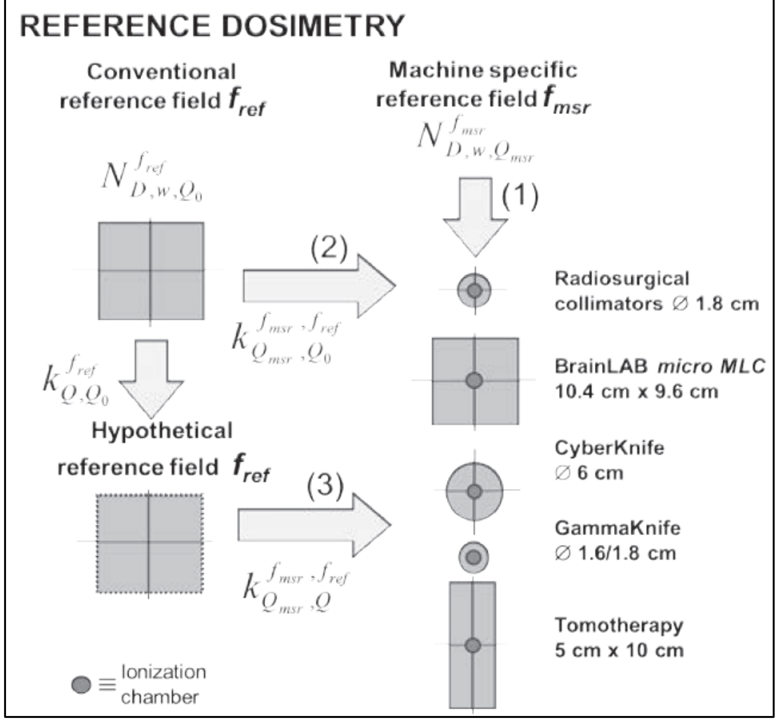
Concept of machine specific reference field

Might be hypothetical – tabulated or derived

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w,Q_{msr}}^{f_{msr}} \quad (1)$$

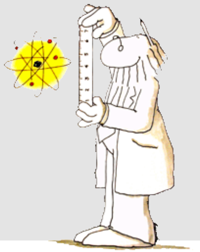
$$= M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w,Q_0}^{f_{ref}} \cdot k_{Q_{msr},Q_0}^{f_{msr},f_{ref}} \quad (2)$$

$$= M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w,Q_0}^{f_{ref}} \cdot k_{Q,Q_0}^{f_{ref}} \cdot k_{Q_{msr},Q}^{f_{msr},f_{ref}} \quad (3)$$



TRS-483 (2017)

TRS-483 gives recommendations



Concept of machine specific reference field

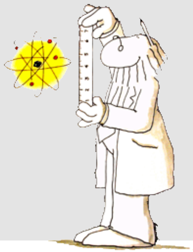
Might be hypothetical – tabulated or derived

Still based on air-filled ion chambers

Sometimes restricted to smaller chamber types

TABLE 2. msr FIELDS FOR COMMON RADIOTHERAPY MACHINES

Machine type	msr field
CyberKnife	6 cm diameter fixed collimator
TomoTherapy	5 cm × 10 cm field
Gamma Knife	1.6 cm or 1.8 cm diameter collimator helmet, all sources simultaneously out
Brainlab micro MLC add-on	For example 9.8 cm × 9.8 cm or 9.6 cm × 10.4 cm
SRS cone add-ons	The closest to a 10 cm × 10 cm equivalent square msr field achievable



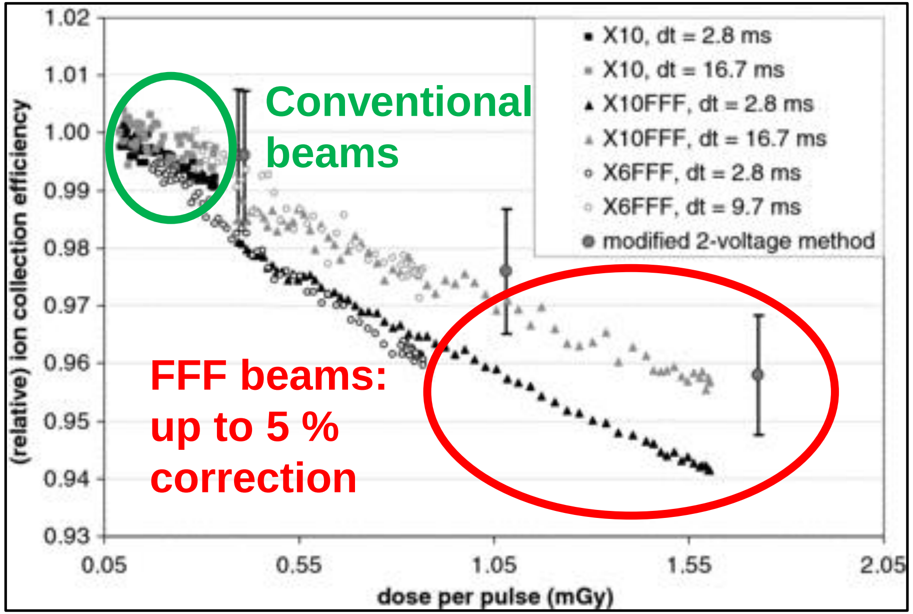
Example specialty technique: FFF linacs

Removal of flattening filter (replaced with light filtration)

- Increased dose rate
- ‘Softer’ photon energy spectrum
- Non-uniform profile

Application to FFF linacs: ion recombination

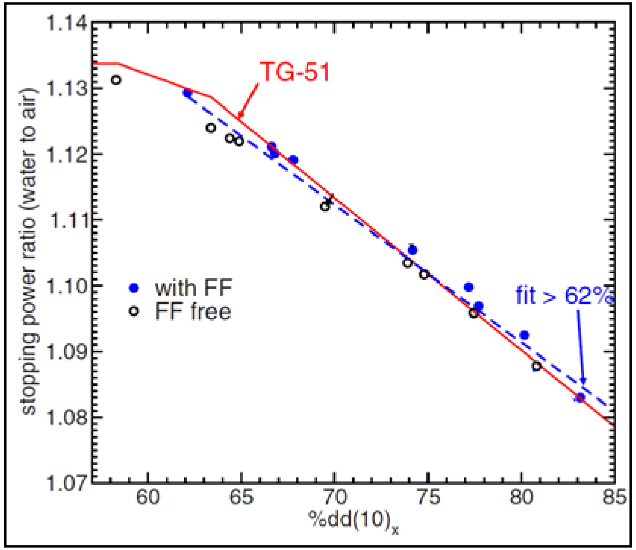
Large P_{ion} due to very high dose-per-pulse

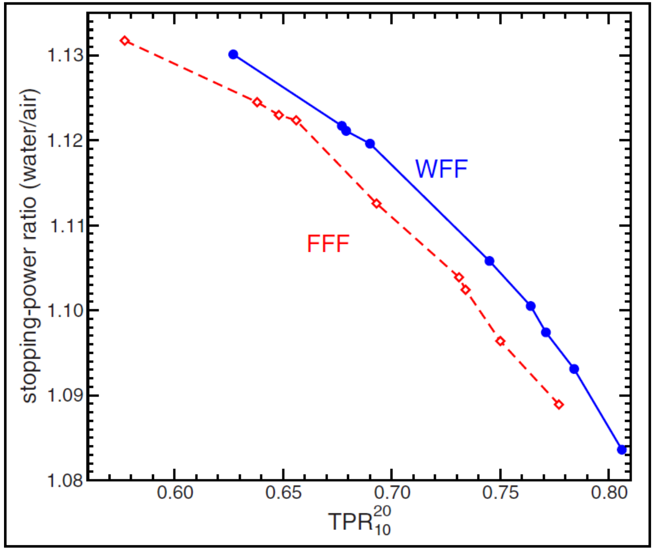


Lang et al., PMB (2010).

Application to FFF linacs: light filtration

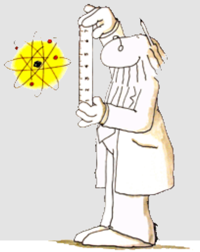
Consistent beam quality specification using %dd(10)$_x$



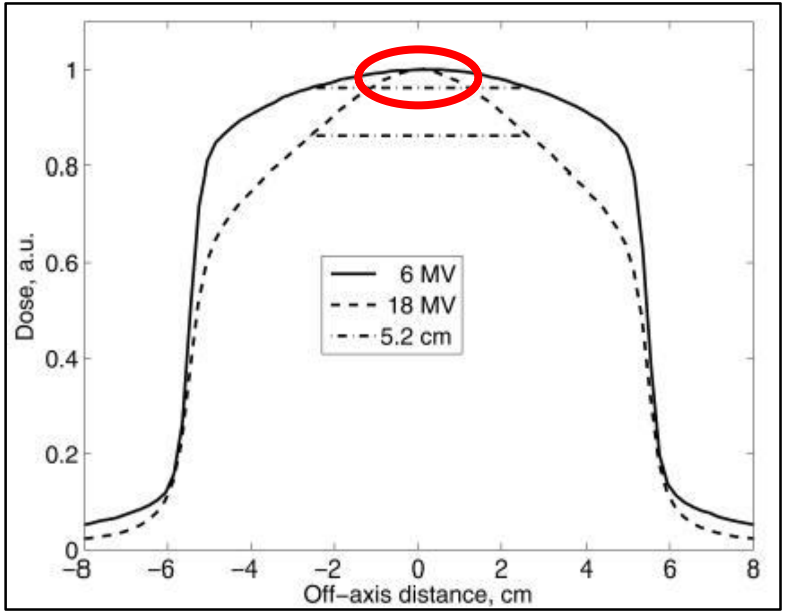


Xiong and Rogers, Med. Phys. (2008).

Application to FFF linacs: peaked dose profile



Dose averaging over chamber volume

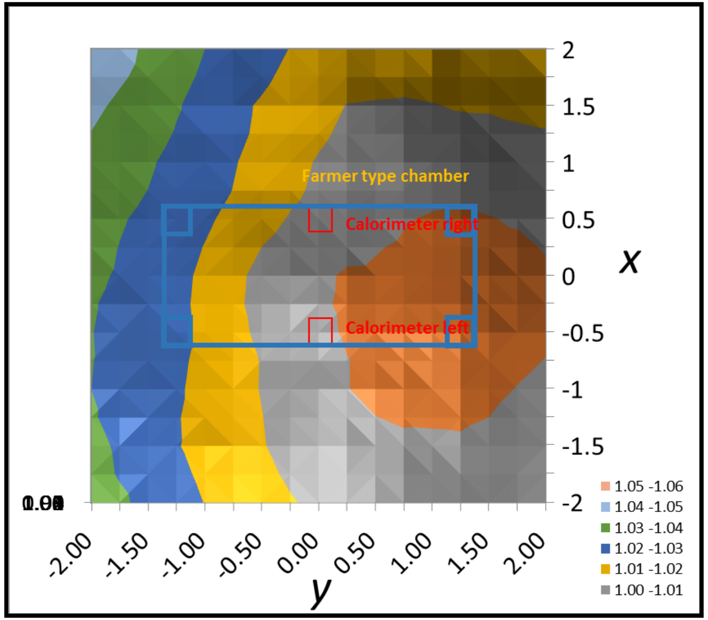


Vassiliev et al., JACMP (2009).

Correction for variations in radial profile

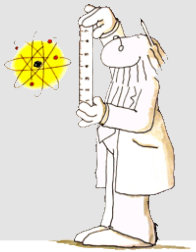
P_{rp} or k_{vol}: $$k_{\text{vol}} = \frac{\iint_A w(x,y)\,\mathrm{d}x\,\mathrm{d}y}{\iint_A w(x,y)\,\mathrm{OAR}(x,y)\,\mathrm{d}x\,\mathrm{d}y}$$

Corrects for non-uniformity over chamber volume



Addendum to TG-51 (2014)
TRS-483 (2017)

What about electrons? Addendum to TG-51 in progress



For electron beams
$$D_w^Q = MN_{D,w}^Q = Mk_Q N_{D,w}^{^{60}Co} = MP_{gr}^Q k'_{R_{50}} k_{ecal} N_{D,w}^{^{60}Co}$$

Choice of chamber type:

- cylindrical chambers for high-energy
- parallel-plate against cylindrical in high-energy
- parallel-plate chambers recommended $E_0 < 10$ MeV

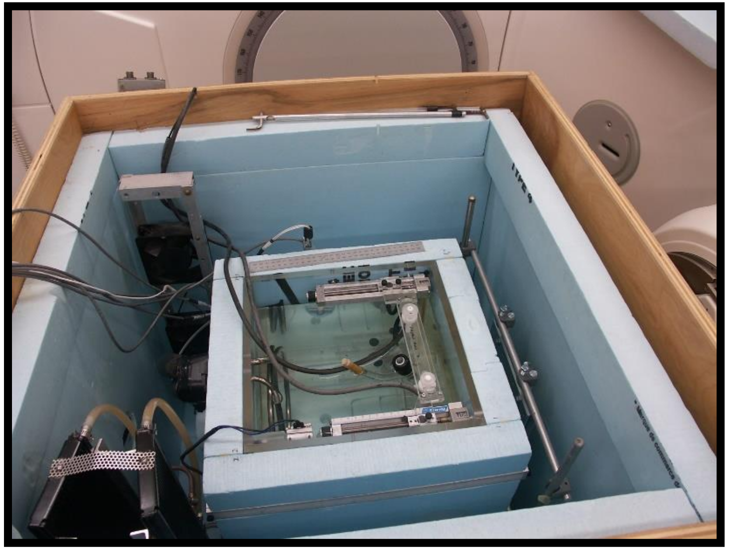
$$(k_{ecal} N_{D,w}^{^{60}Co})^{pp} = \frac{(D_w)^{cyl}}{(Mk'_{R_{50}})^{pp}} = \frac{(MP_{gr}^Q k'_{R_{50}} k_{ecal} N_{D,w}^{^{60}Co})^{cyl}}{(Mk'_{R_{50}})^{pp}} \ (\text{Gy/C})$$

Complicated procedures can lead to misinterpretation or errors

State-of-the-art determination of k_Q

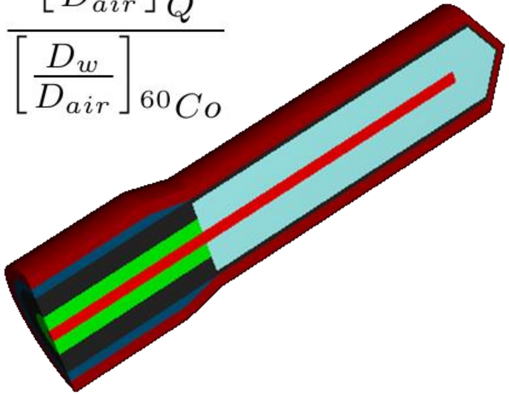
Measured

$$k_Q = \frac{N_{D,w}^{Q}}{N_{D,w}^{Co}}$$



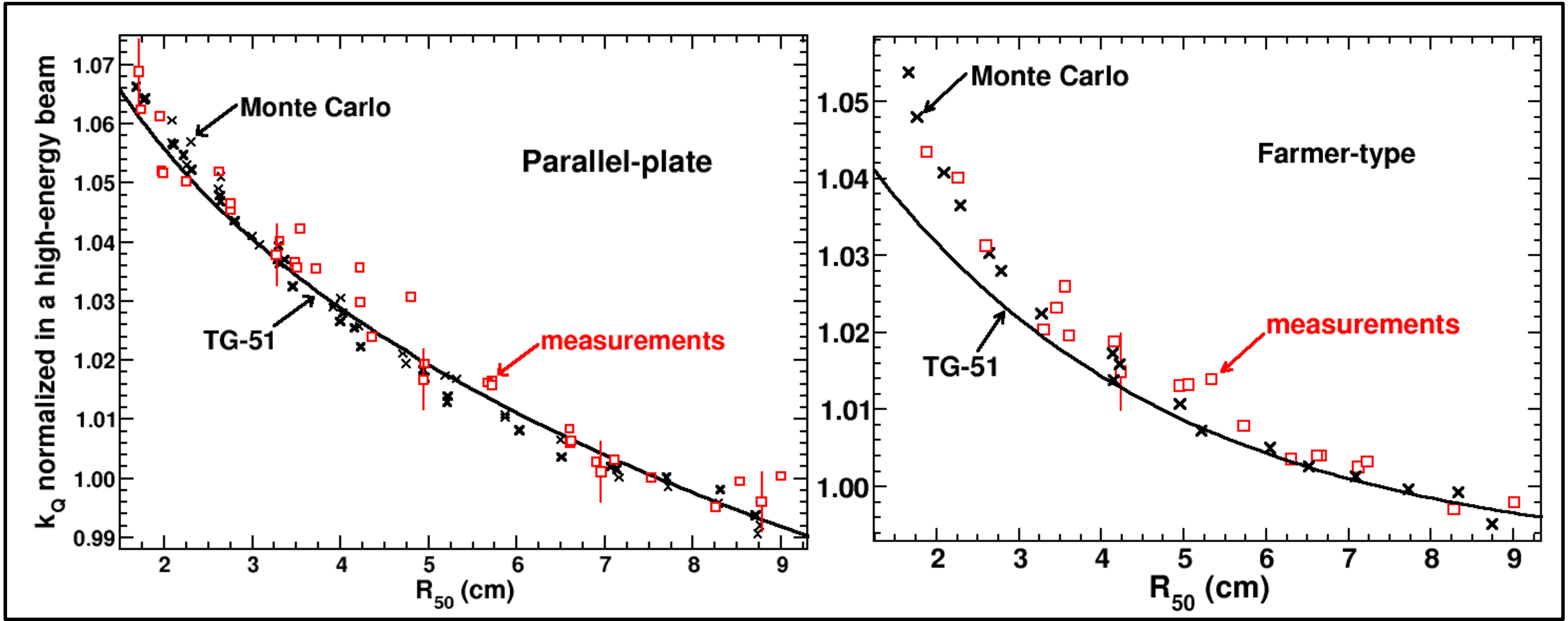
Monte Carlo

$$k_Q = \frac{\left[\frac{D_w}{D_{air}}\right]_Q}{\left[\frac{D_w}{D_{air}}\right]_{^{60}Co}}$$

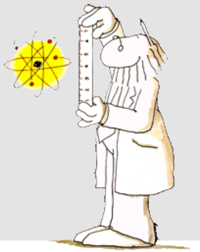


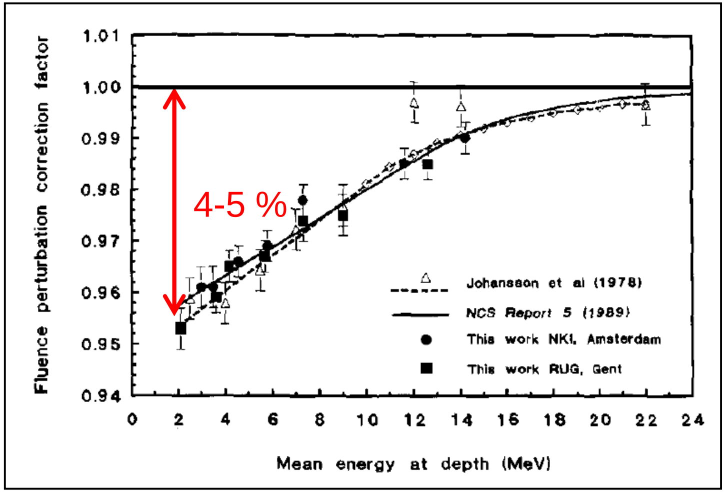
Both approaches include all corrections by definition

Now have more accurate, updated data



Why not use cylindrical chambers for all beams?



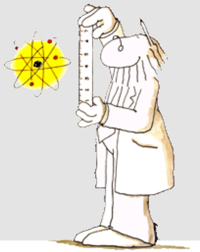


We know they are well-behaved and stable.

So, are corrections really more variable for cylindrical chambers?

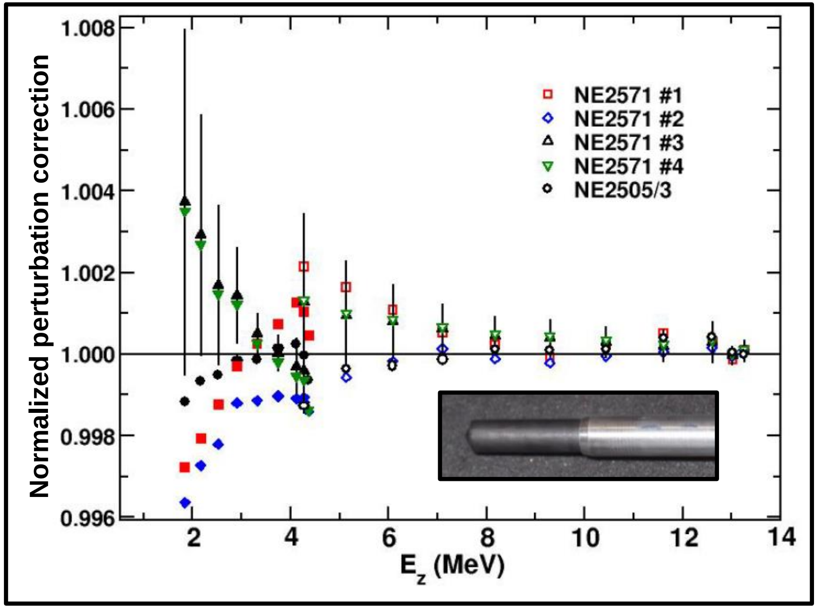
Revisit older experiments with focus on variability

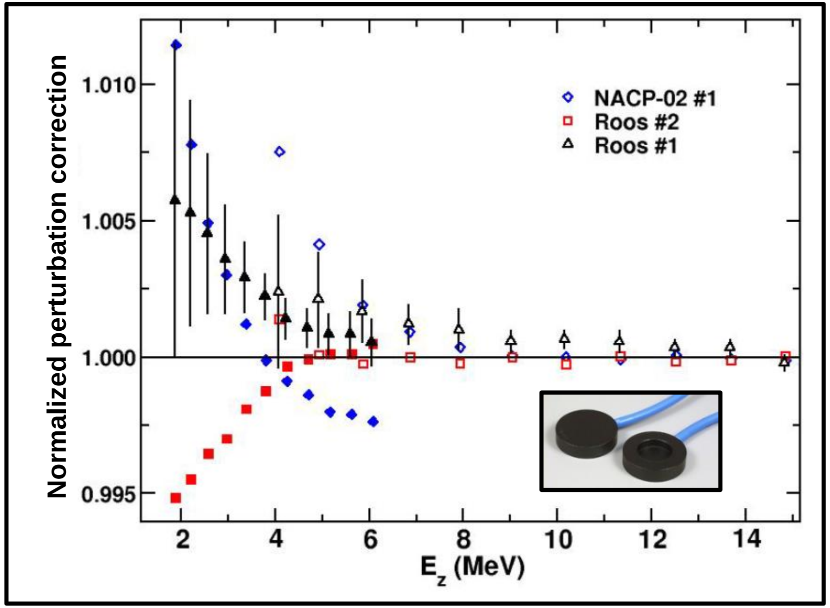
Wittkamper et al., PMB 36 1639 (1991).



Corrections are not more variable using cylindrical chambers

Variability at +/- 0.4 %, no worse than plane-parallel chambers



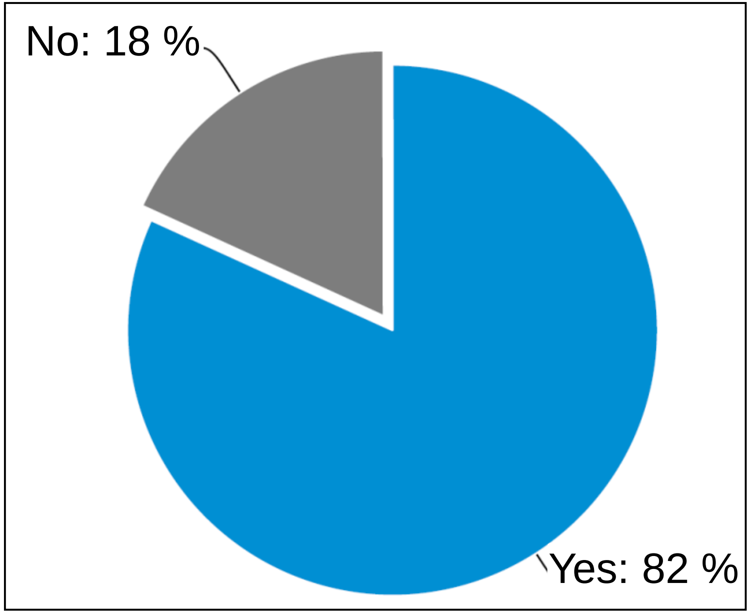


Simplify using cylindrical chambers in all beams with generic k_Q

Muir and McEwen, Med. Phys. (2017).

Preference in North America for use of cylindrical chambers

"Do you use the same chamber for electron beam calibration as for photon beams?"



Muir et al., JACMP 182 (2017).

Choice of chamber type for MeV beams

Updated state-of-the-art k_Q factors from the literature

Simplified procedure:

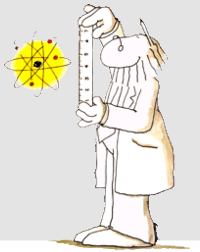
$$D_w^Q = M N_{D,w}^Q = M k_Q N_{D,w}^{^{60}\mathrm{Co}}$$

- Use of cylindrical reference-class chambers (all beams)

- Acceptable results using k_Q

$$P_{gr}^Q \; k'_{R_{50}} \; k_{ecal}$$

Take-home message



All reference dosimetry based on air-filled reference-class ion chambers

But… Clinical physicists MUST evaluate chamber to ensure fit for purpose

THANK YOU

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