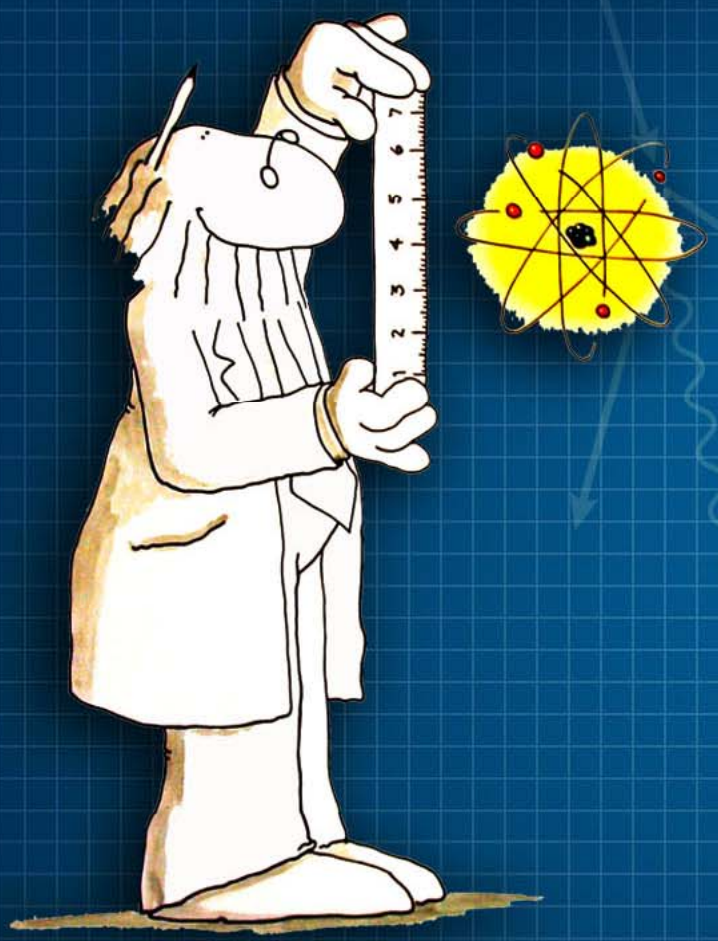


Calibrating the Output of a Linear Accelerator – TG-51 Updated

Malcolm McEwen

Ionizing Radiation Standards

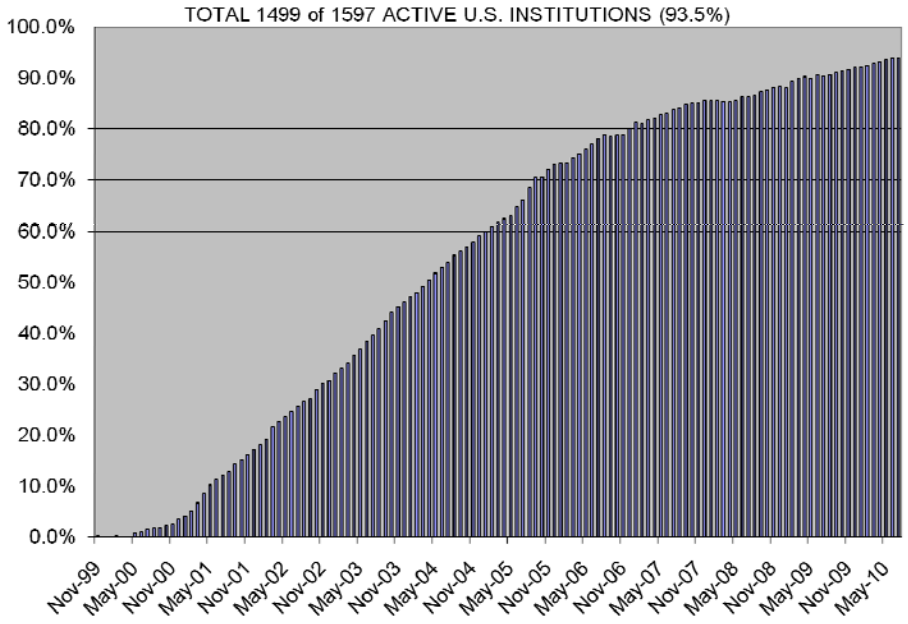
Institute for National Measurement Standards

National Research Council, Canada

COMP/AAPM Joint Meeting, Vancouver, 2011

Background

1. Reference dosimetry for linac beams based on a ^{60}Co calibration.
2. Simple step-by-step procedure.
3. Covers photon and electron beams.
4. Widely adopted in NA



AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams

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(Received 17 September 1998; accepted for publication 4 June 1999)

A protocol is prescribed for clinical reference dosimetry of external beam radiation therapy using photon beams with nominal energies between ^{60}Co and 50 MV and electron beams with nominal energies between 4 and 50 MeV. The protocol was written by Task Group 51 (TG-51) of the Radiation Therapy Committee of the American Association of Physicists in Medicine (AAPM) and has been formally approved by the AAPM for clinical use. The protocol uses ion chambers with absorbed-dose-to-water calibration factors, $N_{D,w}^{^{60}\mathrm{Co}}$, which are traceable to national primary standards, and the equation $D_w^Q = M k_Q N_{D,w}^{^{60}\mathrm{Co}}$, where Q is the beam quality of the clinical beam, D_w^Q is the absorbed dose to water at the point of measurement of the ion chamber placed under reference conditions, M is the fully corrected ion chamber reading, and k_Q is the quality conversion factor which converts the calibration factor for a ^{60}Co beam to that for a beam of quality Q. Values of k_Q are presented as a function of Q for many ion chambers. The value of M is given by $M = P_{\mathrm{ion}} P_{\mathrm{TP}} P_{\mathrm{elec}} P_{\mathrm{pol}} M_{\mathrm{raw}}$, where M_{raw} is the raw, uncorrected ion chamber reading and P_{ion} corrects for ion recombination, P_{TP} for temperature and pressure variations, P_{elec} for inaccuracy of the electrometer if calibrated separately, and P_{pol} for chamber polarity effects. Beam quality, Q, is specified (i) for photon beams, by $\%dd(10)_{\mathrm{x}}$, the photon component of the percentage depth dose at 10 cm depth for a field size of 10×10 cm^2 on the surface of a phantom at an SSD of 100 cm and (ii) for electron beams, by R_{50}, the depth at which the absorbed-dose falls to 50% of the maximum dose in a beam with field size $\geqslant 10\times10$ cm^2 on the surface of the phantom ($\geqslant 20\times20$ cm^2 for $R_{50} > 8.5$ cm) at an SSD of 100 cm. R_{50} is determined directly from the measured value of I_{50}, the depth at which the ionization falls to 50% of its maximum value. All clinical reference dosimetry is performed in a water phantom. The reference depth for calibration purposes is 10 cm for photon beams and $0.6R_{50} - 0.1$ cm for electron beams. For photon beams clinical reference dosimetry is performed in either an SSD or SAD setup with a 10×10 cm^2 field size defined on the phantom surface for an SSD setup or at the depth of the detector for an SAD setup. For electron beams clinical reference dosimetry is performed with a field size of $\geqslant 10\times10$ cm^2 ($\geqslant 20\times20$ cm^2 for $R_{50} > 8.5$ cm) at an SSD between 90 and 110 cm. This protocol represents a major simplification compared to the AAPM's TG-21 protocol in the sense that large tables of stopping-power ratios and mass-energy absorption coefficients are not needed and the user does not needed to calculate any theoretical dosimetry factors. Worksheets for various situations are presented along with a list of equipment required. © *1999 American Association of Physicists in Medicine.*

[S0094-2405(99)00209-6]

TG-51 reminder

- TG-51 is a procedure to give you a measurement of the absorbed dose to water at a point in a water phantom
- It's based on measurements with a calibrated ion chamber:

$$D_{w,Q} = N_{D,w}^{^{60}Co} \, k_Q \, M_{ion}$$

- $N_{D,w}$ is obtained from an ADCL or primary standards laboratory (e.g., NRCC in Canada)
- k_Q is the factor that converts from the calibration beam (^{60}Co) to the uses linac beam, defined by beam quality Q
- Q can represent a photon or electron beam

Why update?

Working Group review recommends:

- **Photons:**
  - i. An updated list of chambers
  - ii. Review of calculated k_Q factors
  - iii. Uncertainty analysis
  - iv. Implementation guidance notes (clarification)

- **Electrons:**

  More widespread revision required

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[S0094-2405(99)00209-6]

Part 1 - photon addendum

The report will cover the following:

A. k_Q factors for new chambers

B. Recommendations for implementation

C. Uncertainty analysis for implementation of TG-51

D. Comparison of measured and calculated k_Q factors

TG-51 photons – what stays?

- Procedure remains unchanged
  - ✓ Continue to follow the procedure in the TG-51 document
- TG-51 remains based on a calibration coefficient obtained in Co-60
  - ✓ MV standards and calibration services are already available in certain countries but widespread dissemination in the US is not realistic at the present time.
- Calculated k_Q factors
  - ✓ Measured k_Q data are available for some chamber types
  - ✓ MV calibration services cannot meet demand in North America
- %dd(10)$_x$ remains the beam quality specifier
  - ✓ See discussion later

B. Recommendations

1. Implementation of TG-51 Addendum
2. k_Q data sets
3. Reference-class ionization chamber
4. Choice of polarizing voltage
5. Measurement of polarity correction, P_{pol}
6. Effective point of measurement
7. Use of small volume chambers in relative dosimetry
8. Non-water phantoms
9. Application to flattening-filter-free linacs

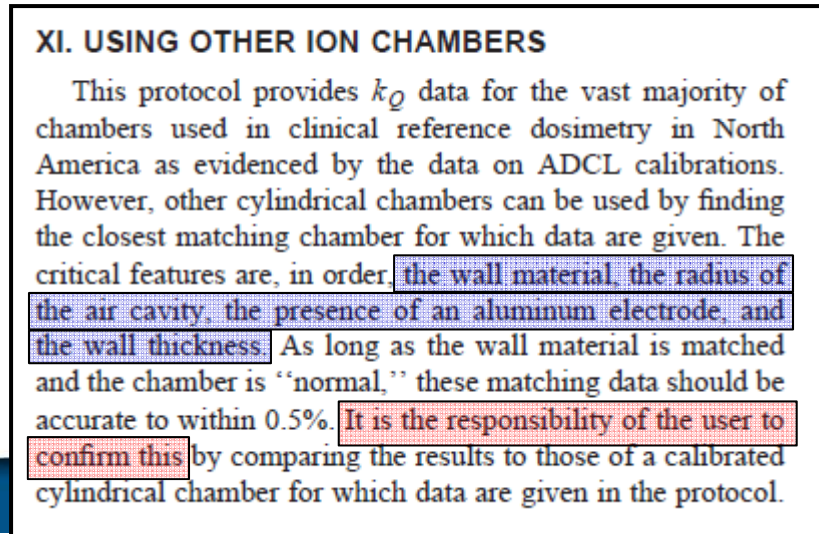
B.1 Implementation of Addendum

- **The addendum should be implemented!**
- **Minor changes in experimental procedure**
- **New equipment may be required**
- **Development of uncertainty budget may take some time**

B.2 k_Q data sets

1. **For chambers listed in both this addendum and the original TG-51 protocol, the k_Q factors listed in the addendum should be used.**

2. **For chambers that are not listed in either the original TG-51 protocol or in this addendum the recommendations of Section XI of TG-51 should be followed.**



XI. USING OTHER ION CHAMBERS

This protocol provides k_Q data for the vast majority of chambers used in clinical reference dosimetry in North America as evidenced by the data on ADCL calibrations. However, other cylindrical chambers can be used by finding the closest matching chamber for which data are given. The critical features are, in order, the wall material, the radius of the air cavity, the presence of an aluminum electrode, and the wall thickness. As long as the wall material is matched and the chamber is ''normal,'' these matching data should be accurate to within 0.5%. It is the responsibility of the user to confirm this by comparing the results to those of a calibrated cylindrical chamber for which data are given in the protocol.

B.3 Proposed Chamber spec

- Specification developed for cylindrical (thimble) chambers

- 3 sub-types (NOTE: WGTG51 definitions) –
  i. 0.6 cm^3 reference chambers (e.g., NE2571, PR-06C)
  ii. 0.125 cm^3 scanning chambers (e.g., PTW31010, IBA CC13)
  iii. 0.02 cm^3 micro chambers (e.g., Exradin A16, Pinpoint™)

Examples

PTW31010

IBA CC01

Exradin A12

NE2577

0.125 cm^3
Scanning chamber

0.01 cm^3
Micro chamber

0.6 cm^3
'Farmer' chamber

0.25 cm^3
'Short Farmer'

B.3 Proposed Chamber spec

Based on objective assessment of chamber performance

Measurand	Specification
Chamber settling	Must be less than a 0.5 % change in reading from beam-on to stabilization
P_{leak}	< 0.1 % of chamber reading
P_{pol}	< 0.4 % correction ($0.996 < P_{pol} < 1.004$) < 0.5 % maximum variation in P_{pol} with energy (total range)
$P_{ion} = P_{init} + P_{gen}$	
P_{gen}	Correction must be linear with dose per pulse
P_{init}	Initial recombination must be < 0.002 at 300 V Correction follows Boag theory for chamber dimensions. Difference in initial recombination correction between opposite polarities < 0.1 %
Chamber stability	Must exhibit less than a 0.3 % change in calibration coefficient over the typical recalibration period of 2 years

B.3 Chamber spec

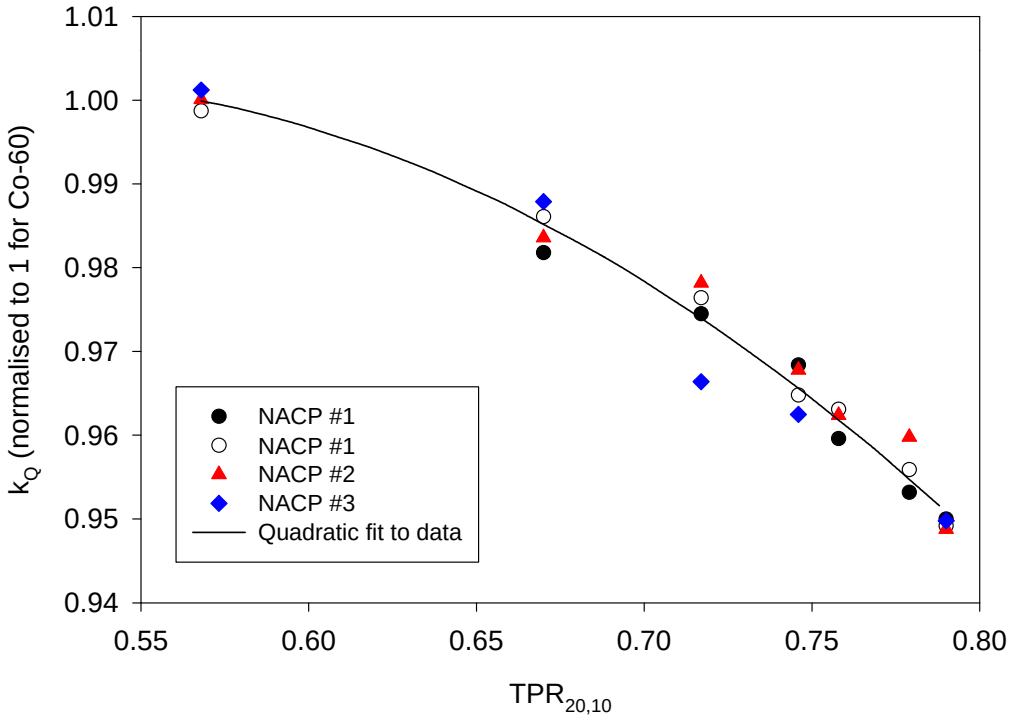
Based on results in the literature we can state that *at least* the following meet this specification:

- **NE2571 and NE2611**
- **PTW30010, PTW30012, PTW30013, PTW31013**
- **Exradin A12, A12S, A19, A18, A1SL**
- **IBA FC65-G, FC65-P, FC23-C, CC25, CC13**
- **Capintec PR-06C**

i) majority are 0.6 cm^3 'Farmer-type' chambers
ii) 5 scanning chambers, NO microchambers
iii) A-150 chambers explicitly excluded

B.3a Parallel-plate chambers?

- **TG-51 did not recommend any parallel-plate chambers for photon beam dosimetry**
- **Studies had indicated issues with the operation of such chambers in Co-60 beams but little info on MV performance**

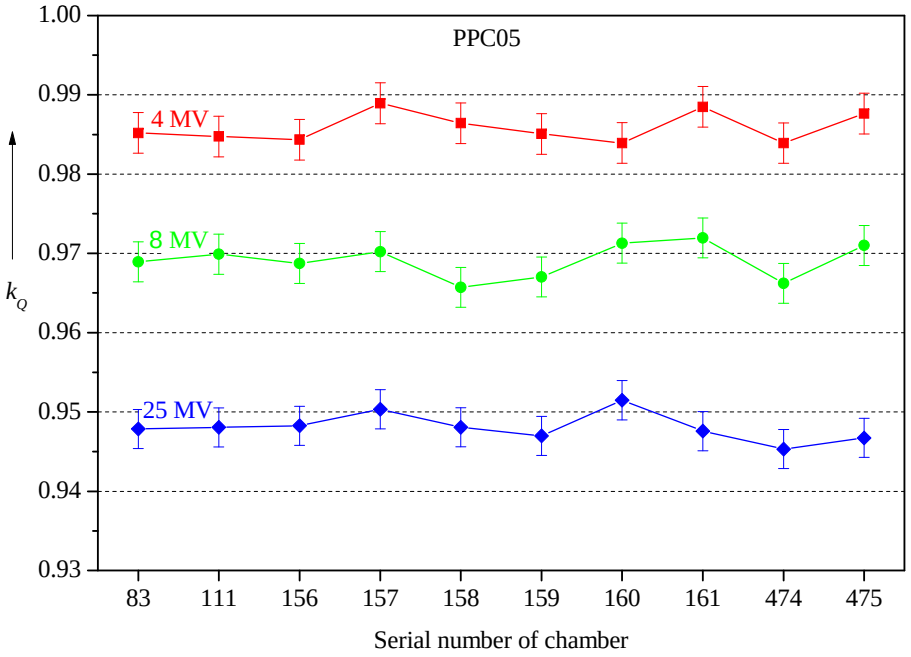


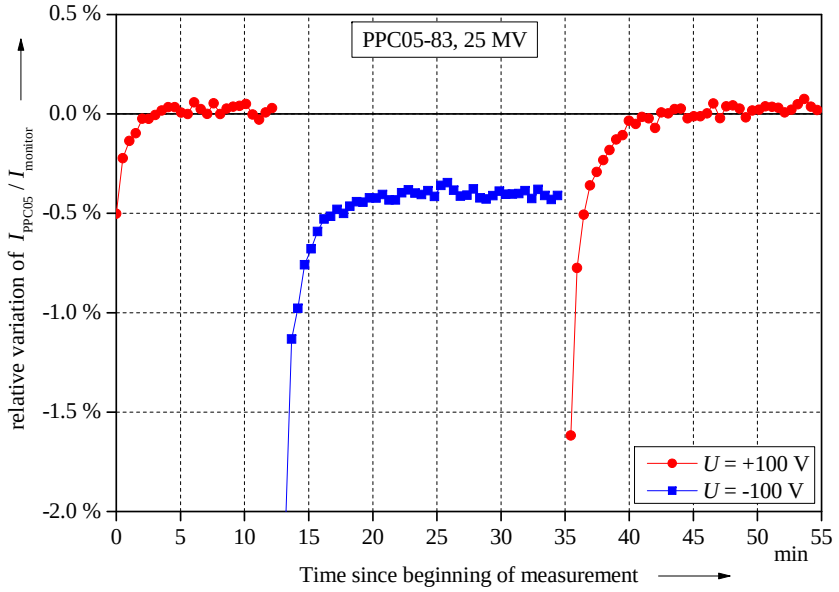
- Larger chamber-to-chamber variations than for cylindrical chambers
- Polarity correction larger than for cylindrical chambers and more variable

Reference: McEwen, Duane and Thomas, IAEA Symposium, Nov 2002

B.3a Parallel-plate chambers

- There is nothing inherently wrong with the parallel-plate configuration
- More recent measurements indicate better performance – but still not as good as cylindrical chambers





Reference: Kapsch And Gomola, IAEA Symposium, Nov 2010

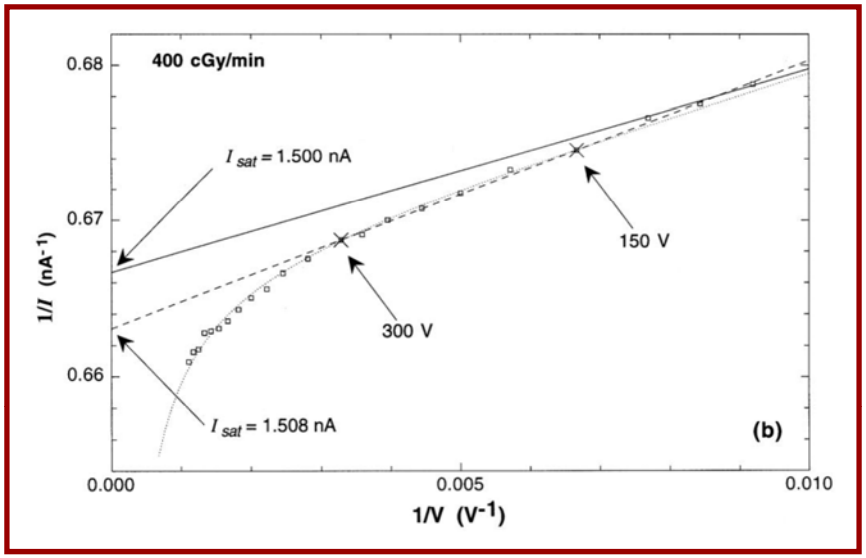
See also Poster SU-E-T-103

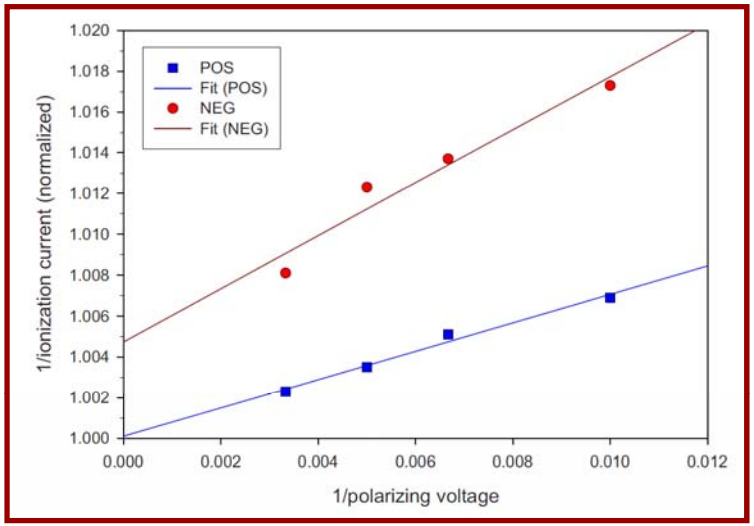
B.4 Polarizing voltage

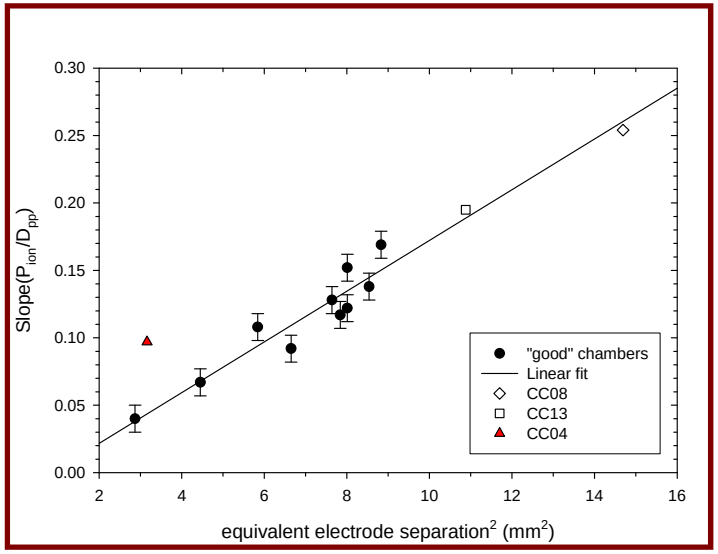
$$M_{corr,w} = M_{raw} P_{TP} P_{ion} P_{pol} P_{elec}$$

- **Recombination correction directly affects measurement of absorbed dose**
- **Recombination correction well established <u>but</u> not always straightforward**
- **2-voltage technique as set out in TG-51 applicable only to chambers exhibiting ideal behaviour**
- **Many examples in literature of anomalous behaviour**

B.4 Polarizing voltage







References: DeBlois et al (Med. Phys., 2000), McEwen (Med. Phys., 2010)

B.4 Polarizing voltage

Based on results in the literature we can state the following:

- Not all chambers follow standard ‘Boag’ theory
- Manufacturers’ statements on voltage limits need verifying (at least for chamber types, if not individual chambers)
- Going to a higher polarizing voltage can lead to a larger uncertainty in the measurement
- Recombination can be a function of the sign of the charge collected
- Addendum recommends a maximum value of 300 V (lower values may be required for small-volume chambers)

B.5 Measurement of P_{pol}

The polarity effect has many potential sources:

1) *guard ring distortion,*
2) *secondary electron emission produces negative current independent of polarity of the electrode,*
3) *low energy electron ejection from chamber wall which is not compensated by electrode,*
4) *uneven distribution of the space charge,*
5) *virtual variation of active volume due to space charge distortion,*
6) *stopping of the fast electrons in the collecting electrode not balanced by the ejection of the recoil electrons,*
7) *collection of current outside the chamber volume due to leakage in solid insulator.*

B.5 Measurement of P_{pol}

Bottom line:

- **the polarity effect is associated with a net deposition of charge in the chamber**
- **in the situation of transient charged particle equilibrium there is no net charge deposited.**
- **the polarity correction in photon beams should therefore be small.**

But it's not zero. P_{pol} values between 0.997 and 1.003 should be expected.

Type	Mean
NE2571	0.9994
PTW Farmers	1.0003
Exradin Farmers	0.9996
IBA Farmers	0.9994
PTW scanning	1.0013
Exradin scanning	0.9990
IBA scanning	0.9993
PTW micro	1.0046
Exradin micro	1.0049
IBA micro	0.9965

Type	Mean
NACP	0.9980
IBA PPC-05	0.9992
IBA PPC-40	0.9998
PTW Roos	0.9996
PTW Markus	0.9991
Exradin A10	1.0027
Exradin A11	1.0012

Note large P_{pol} values for micro chambers

B.5 Measurement of P_{pol}

The polarity correction should be measured for any new chamber and beam combination. It doesn't take very long.

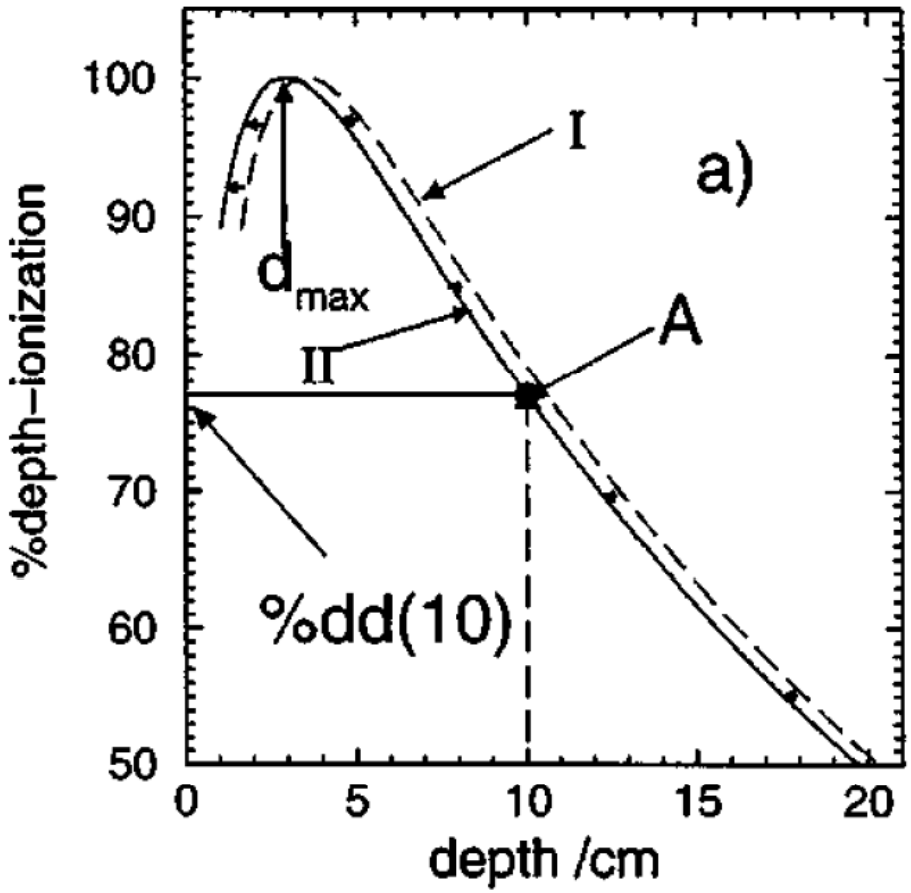
The measurement of P_{pol} is a very simple QA check of the chamber/electrometer system:

i) it confirms that the polarizing voltage is applied correctly between the chamber's electrodes,

ii) chamber-to-variations in P_{pol} tend to smaller than differences in chamber volume ($N_{D,w}$) – any deviation from published values may indicate non-standard behaviour

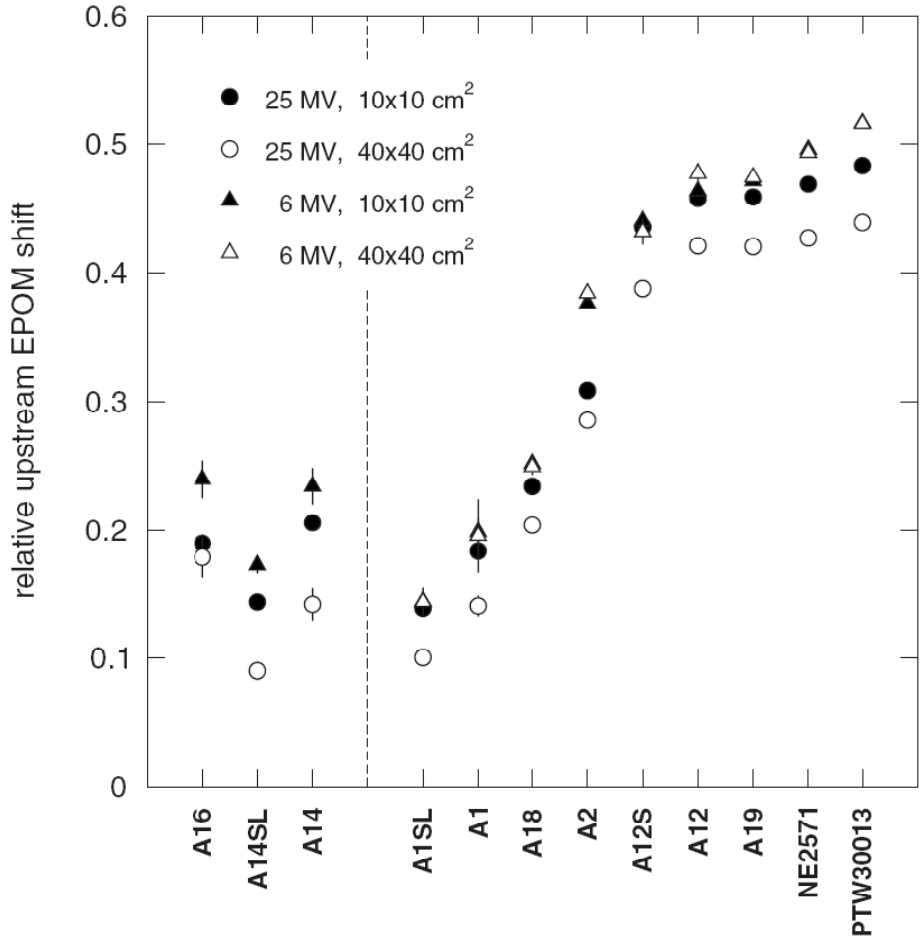
iii) any change in P_{pol} with time indicates a possible change in chamber response.

B.6 Effective point of measurement



- Measurement of depth-dose curves requires taking account of the effective point of measurement.
- For thimble chambers TG-51 recommends $0.6 r_{cav}$ upstream from centre.
- Recent theoretical and experimental investigations have shown that this is not correct.

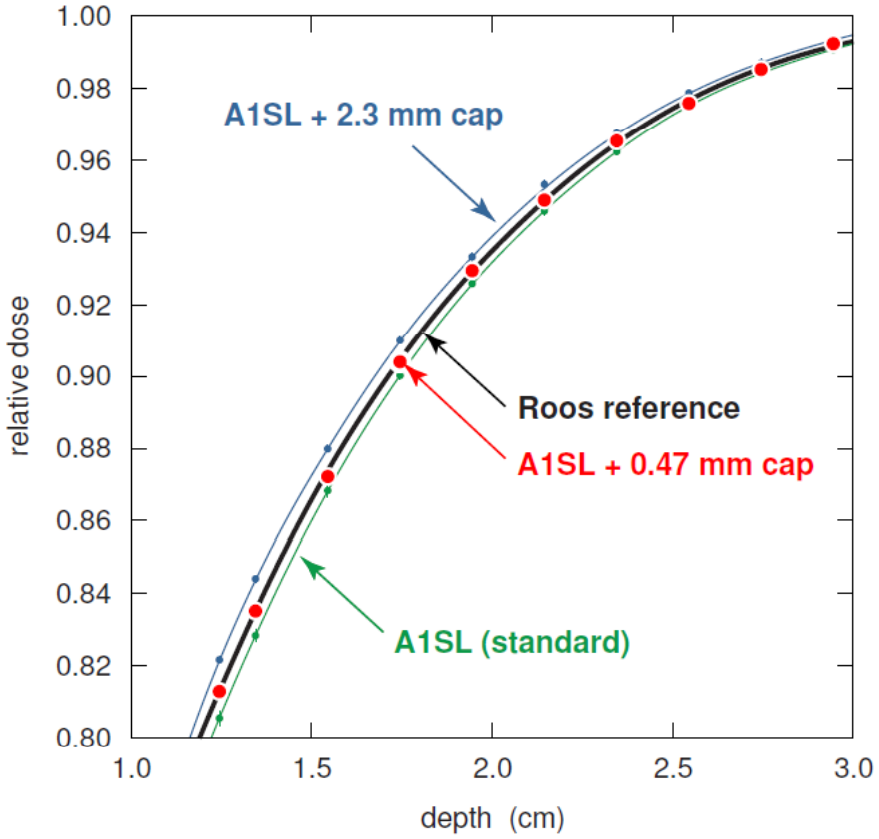
B.6 Effective point of measurement



- **EPOM varies with chamber design and beam specification – shift is <u>not</u> universal.**
- **<u>No chamber</u> has the TG-51 recommended shift of $0.6 r_{cav}$**
- **Effect is generally small but easily measurable with modern water phantoms in the build-up region.**

Reference: Tessier and Kawrakow (Med. Phys., 2010)

B.6 Effective point of measurement



- **Experimental demonstration of effect of wall thickness on EPOM**
- **Indicates that one could design a chamber with a zero EPOM (i.e., no shift from centre of chamber)**

Reference: Tessier et al (Med. Phys., 2010)

B.6 Effective point of measurement

Literature	Examined detector	Reference detector	Beam quality, literature	Δz value from literature	Beam quality, present study	Δz value from this study
Kawrakow (2006)[c]	PTW 31010 ($r = 2.75$ mm)	MC	25 MV (10 cm × 10 cm)	$-0.41\ r$	15 MV	$-0.47\ r$
Kawrakow (2006)[c]	PTW 31010 ($r = 2.75$ mm)	MC	25 MV (30 cm × 30 cm)	$-0.35\ r$		
Kawrakow (2006)[c]	PTW 31010 (r = 2.75 mm)	MC	6 MV (10 cm × 10 cm)	$-0.49\ r$	6 MV	$-0.47\ r$
Kawrakow (2006)[c]	PTW 31010 ($r = 2.75$ mm)	MC	6 MV (30 cm × 30 cm)	$-0.43\ r$		
Huang *et al* (2010)	PTW 30006 ($r = 3.05$ mm)	Roos[d]	6, 15 MV	$-0.5\ r$ to $-0.65\ r$		
Huang *et al* (2010)	PTW 31002 ($r = 2.75$ mm)	Roos[d]	6, 15 MV	$-0.5\ r$ to $-0.6\ r$	6, 15 MV	$-0.47\ r$
Huang *et al* (2010)	PTW 31003 ($r = 2.75$ mm)	Roos[d]	6, 15 MV	$-0.5\ r$ to $-0.6\ r$	6,15 MV	$-0.47\ r$
Tessier (2010)	27 cylindrical chambers of various design	MC	6, 25 MV	$-0.15\ r$ to $-0.5\ r$	6, 15 MV	$-0.30\ r$ to $-0.58\ r$ $r = 1.0$ to 3.95 mm

Reference: Looe et al (PMB, 2011)

Good agreement between measurement and MC

NOTE - no significant effect on measurement of dose at z_{ref}

B.7 Use of small-volume chambers

- **Very small chambers (volumes < 0.05 cm^3) are not recommended for reference dosimetry.** ***They do not meet the specification for a reference dosimeter.***
- **Issues include: anomalous recombination behaviour, large polarity effect, long settling times, leakage, cable currents.**
- **These can also impact relative dosimetry measurements (such as measurement of depth-dose curves or beam profiles)**
- **Careful characterization of such chambers is recommended before use in <u>any situation</u>.**

B.8 Solid phantoms

Advantages:

1. No water to spill!
2. Easy to move from one linac to another.
3. Robust setup of SSD and chamber position.
4. Improved formulations with 'reference' grade material now available

Disadvantages:

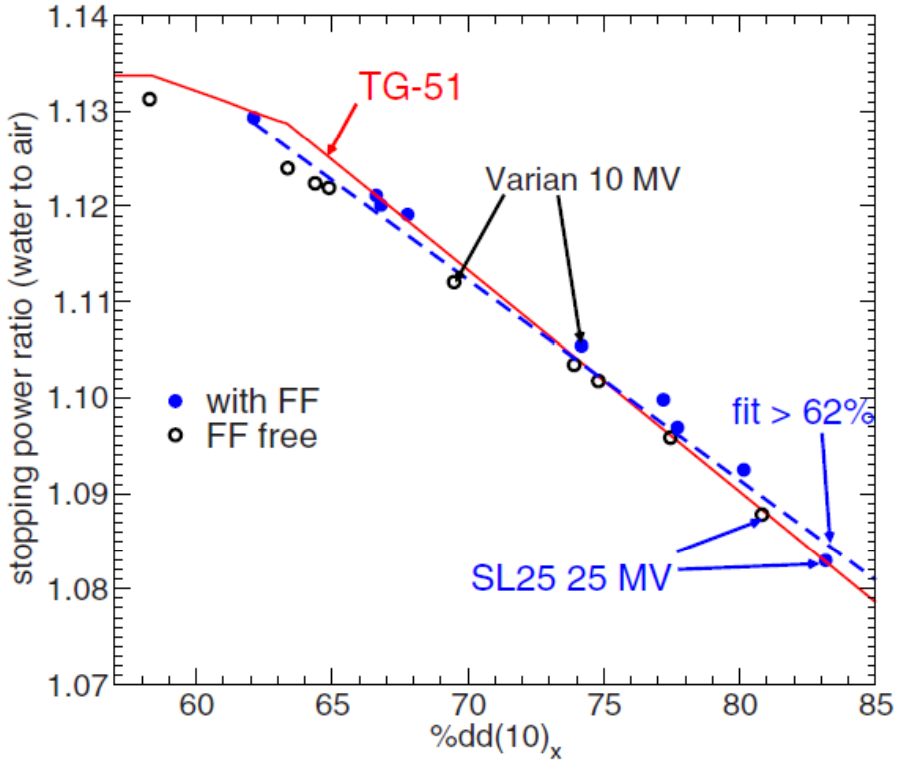
1. Not truly water equivalent for all beams.
2. Not easy to distinguish different formulations.
3. Homogeniety not guaranteed.
4. Characterization in the clinic is time consuming.

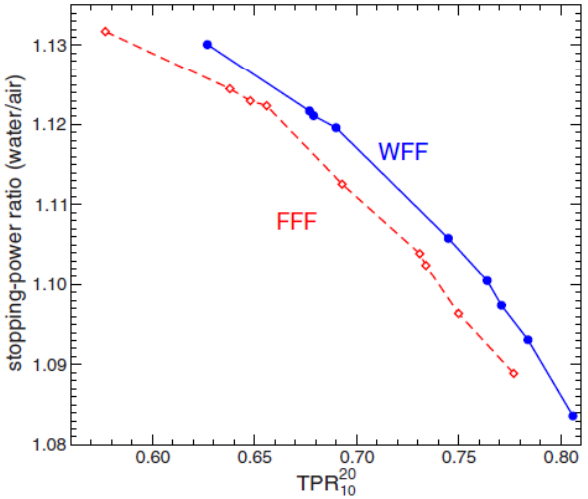
Conclusion - reference dose-to-water measurements should be based on the dose measured in a water phantom – solid phantoms not recommended for reference dosimetry.

B.9 Flattening-filter-free linacs

A. Beam quality specification

$TPR_{20,10}$ and $\%dd(10)_x$ are both valid in heavily filtered beams
but $\%dd(10)_x$ provides greater consistency in assignment of k_Q factors across varied MV beams (low-Z targets, flattening free linacs, etc).





Consistent with k_Q measurements from lightly filtered linacs

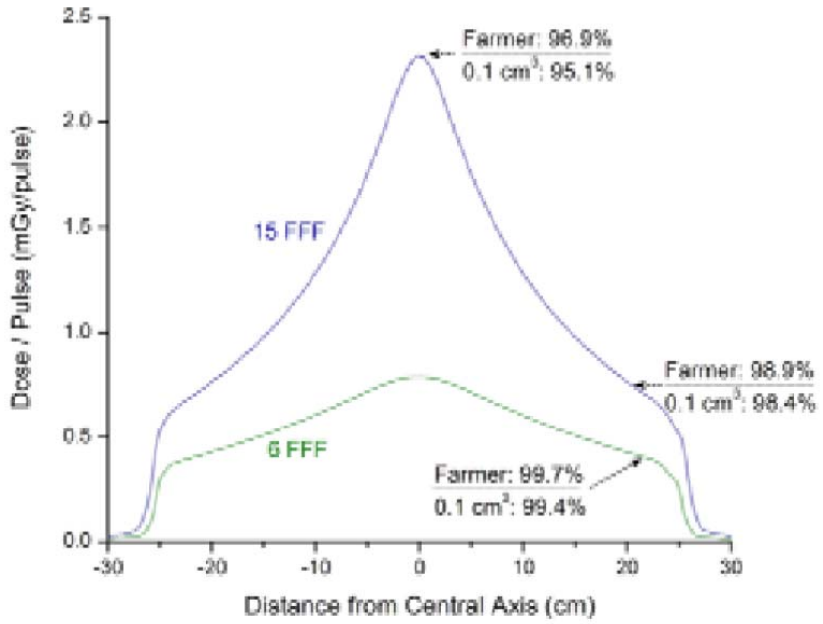
Reference: Xiong & Rogers (Med. Phys., 2008)

B.9 Flattening-filter-free linacs

B. Measurement issues

Dose averaging – dose profile is significantly peaked, therefore averaging of a large volume ion chamber can be significant

Ion recombination - dose per pulse is large, P_{ion} can reach 5%



Make sure you know how your linac operates

Reference: Johnsen, AAPM Annual Meeting, 2008

B10. Lead foil for beam quality

Measurement of $\%dd(10)_x$

- Having to insert the 1 mm Pb sheet is a complaint heard frequently
- TG-51 includes an "interim measure" to relate $\%dd(10)_x$ to the simple quantity %dd(10)
- Could this become the default?
- RPC data looks convincing:

Table 1: Error in k_Q if lead sheet is not used.

	Nominal MV	$\%dd(10)_{Pb}$ @ 30	$\%dd(10)\big\|_0^{Pb@30}$	$\%dd(10)_x\big\|_0^{Pb@30}$	$k_Q\big\|_0^{Pb}$
Varian Machines	23	80.0	1.010	1.018	1.002
	18	79.7	1.008	1.015	1.002
	10	73.4	1.004	1.009	1.001

Reference: Tailor et al, JACMP, 2003

B.11 Best practice

This addendum is **not intended** to be a comprehensive best practice guide.

Over the last decade the RPC has collated a large amount of information on implementing TG-51 correctly in the clinic, and common mistakes to be avoided.

B.11 Best practice

TG-51: Experience from 150 institutions, common errors, and helpful hints

JACMP, 2003

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Abstract: The Radiological Physics Center (RPC) is a resource to the medical physics community for assistance regarding dosimetry procedures. Since the publication of the AAPM TG-51 calibration protocol, the RPC has responded to numerous phone calls raising questions and describing areas in the protocol where physicists have had problems. At the beginning of the year 2000, the RPC requested that institutions participating in national clinical trials provide the change in measured beam output resulting from the conversion from the TG-21 protocol to TG-51. So far, the RPC has received the requested data from ~150 of the ~1300 institutions in the RPC program. The RPC also undertook a comparison of TG-21 and TG-51 and determined the expected change in beam calibration for ion chambers in common use, and for the range of photon and electron beam energies used clinically. Analysis of these data revealed two significant outcomes: (i) a large number (~1/2) of the reported calibration changes for photon and electron beams were outside the RPC's expected values, and (ii) the discrepancies in the reported versus the expected dose changes were as large as 8%. Numerous factors were determined to have contributed to these deviations. The most significant factors involved the use of plane-parallel chambers, the mixing of phantom materials and chambers between the two protocols, and the inconsistent use of depth-dose factors for transfer of dose from the measurement depth to the depth of dose maximum. In response to these observations, the RPC has identified a number of circumstances in which physicists might have difficulty with the protocol, including concerns related to electron calibration at low energies (R_{50} < 2 cm), and the use of a cylindrical chamber at 6 MeV electrons. In addition, helpful quantitative hints are presented, including the effect of the prescribed lead filter for photon energy measurements, the impact of shifting the chamber depth for photon depth-dose measurements, and the impact of updated stopping-power data used in TG-51versus that used in TG-21 particularly for electron calibrations.

Key words: TG-51, calibration protocol, dosimetry, plane-parallel chamber

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Chapter 8

Clinical Implementation of the TG-51 Calibration Protocol

AAPM Summer School 2009

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1. Introduction

In 1999 when the AAPM's TG-51 protocol (Almond et al. 1999) for clinical reference dosimetry of high-energy photon and electron beams was published, many radiotherapy clinics across the United States and Canada began preparations for converting over from the TG-21 protocol (AAPM TG-21 1983) to this new protocol. This process of preparation included reading and understanding the requirements of the protocol, acquiring the necessary calibration equipment, and understanding the magnitude of the change in the reference calibration dose between the old and new protocols. To this end, the Radiological Physics Center (RPC), which had already implemented the TG-51 protocol by January 2000, was offering assistance and advice to the community on how to best clinically implement this new protocol. Although the TG-51 protocol was thought to have been written in a very clear prescriptive manner outlining each step of the calibration process, many in the medical physics community found parts of it to be confusing since it was quite different from the TG-21 protocol. Figure 8-1 shows the rate at

C. Uncertainties

1. TG-51 made the deliberate decision not to include uncertainties.
2. Other protocols have included uncertainty budgets and/or detailed reviews of uncertainty components.
3. It's time to give some guidance on:
   i. How to develop an uncertainty budget
   ii. Typical values for individual components.
4. The ISO GUM is the starting point

Uncertainties – what's the GUM?

1. ISO Guide to the Expression of Uncertainty in Measurement
2. Short answer – procedure to estimate the total uncertainty in your measurement
3. Long answer – more than you ever wanted to know about probability distributions, uncertainty budgets, degrees of freedom, coverage factors and how to turn a guess into a number.
4. BUT, the best way to ensure that you take all uncertainty components into account properly.

✓ NIST has produced an explanatory document (a guide to the Guide) - NIST Technical Note 1297

✓ BUT, a document specific to external beam radiation dosimetry is also necessary (TG-138 deals with brachytherapy)

C. Uncertainties: contents

- Discussion of Type A and B uncertainties (distinct from 'random' and 'systematic')
- Uncertainty budget broken down into:
  - Measurement
  - Calibration data
  - Influence quantities
- Typical values discussed but emphasis on individual users constructing site-specific uncertainty budgets for their calibration situations
- Improved, uniform uncertainty reporting in radiotherapy dosimetry will lead to improved QA of treatment delivery and allow better comparisons between cancer centres.

C. Uncertainty types

- "Type A" uncertainties are those that are calculated by statistical methods, and "Type B" uncertainties are evaluated by other means. **There are only 2 types.**
- The **Type A** component of uncertainty can be calculated as the standard deviation of the mean of a series of measurements.
- A **Type B** component of uncertainty is typically evaluated based on an instrument manufacturer's specifications, observed variations in previously acquired data, or the investigator's own knowledge **(scientific judgment)**.
- Type A and Type B uncertainties are not the same as "random" and "systematic" uncertainties.
- **Random uncertainties** vary for each measurement, yielding an observable "spread" in the data that will average to the conventional true value.
- **Systematic uncertainties** are constant for each measurement, equal to the bias of the measurement technique, and are not observable in the data since the true value of the quantity being measured is unknown.
- **Type A and Type B uncertainties involve analysis by the scientist.**

Chapter 22

Treatment of Uncertainties in Radiation Dosimetry

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Uncertainty analysis

TG-51 is pretty straightforward:

$$D_{w,Q} = N_{D,w}^{^{60}Co} k_Q M_{ion}$$

$$M_{ion} = M_{raw} P_{TP} P_{ion} P_{pol} P_{elec}$$

linear equations, independent variables

$$M_{ion} = M_{raw} P_{TP} P_{ion} P_{pol} P_{elec} P_{leak} P_{rp} P_{hum}$$

Uncertainty components – examples

1. Setup

$$M_{raw} = M(x, y, z, SSD, FS)$$

- Wherever the chamber actually is positioned and whatever the actual geometry, M will be assigned to:
  - x = y = 0 cm (on axis)
  - z = 10 cm (d_{ref})
  - SSD = 100 cm (assuming SSD setup)
  - Field size = 10 cm x 10 cm
- By writing the equation out this way we identify the influence quantities, and therefore uncertainty components
- **Uncertainty analysis is also a procedural review**

Uncertainty components – examples

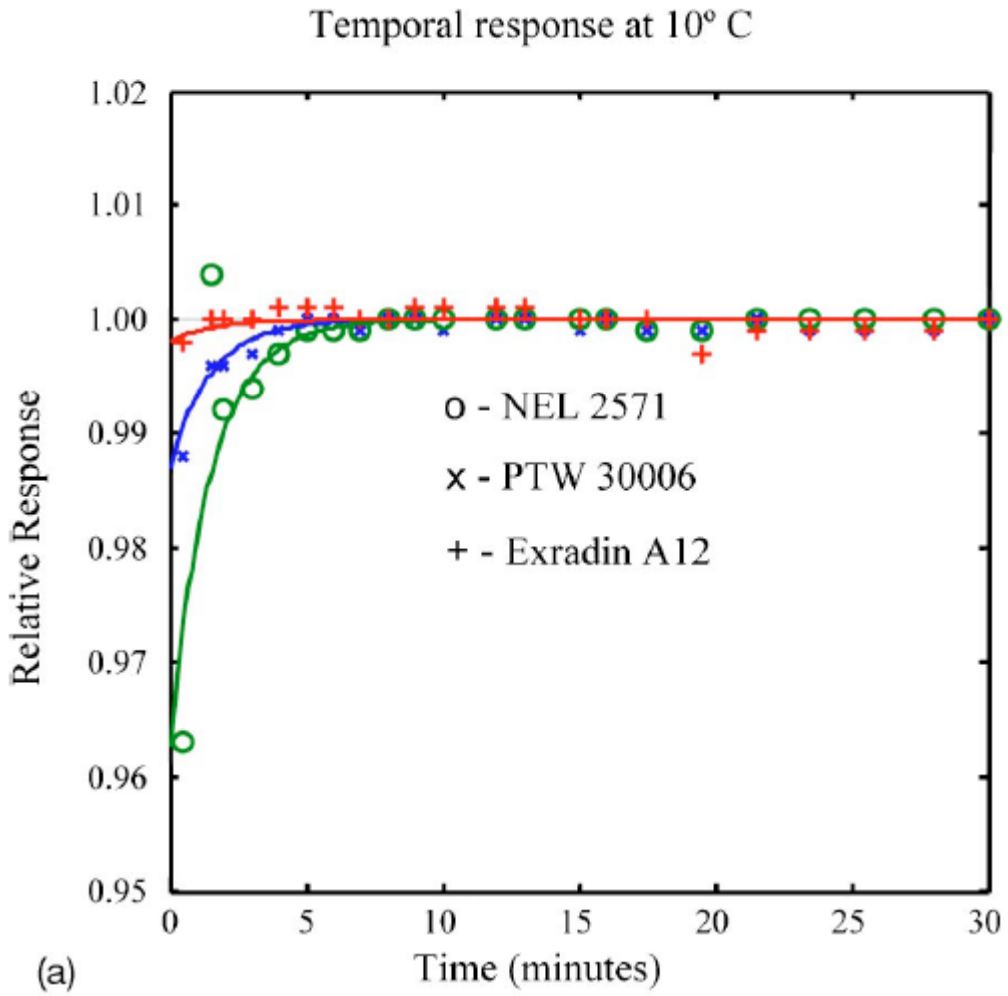
2. Temperature-Pressure correction

$$P_{TP} = \frac{273.15 + T_w}{295.15} \frac{101.325}{P_{air}}$$

For T in °C, P in kPa

- Calibrated meters with sufficient resolution are required
- Need water temperature at ion chamber:
  - Water should be in equilibrium with room
  - Ion chamber should be in equilibrium with water
  - P_{TP} does not take account of thermal expansion of thimble
- Need air pressure in air volume:
  - Only realistic to measure room air pressure
  - Need to confirm air communication of ion chamber (ADCL)

Thermal equilibration



Chamber at 22°C placed in water at 10°C

Equilibration is pretty quick, but not instantaneous

Reference: Das and Zhu (Med. Phys., 2004)

Uncertainty components – examples

3. Ion chamber stability

$$D_{w,Q} = N_{D,w}^{^{60}Co}\, k_Q\, M_{ion}$$

There is really a time dependence:

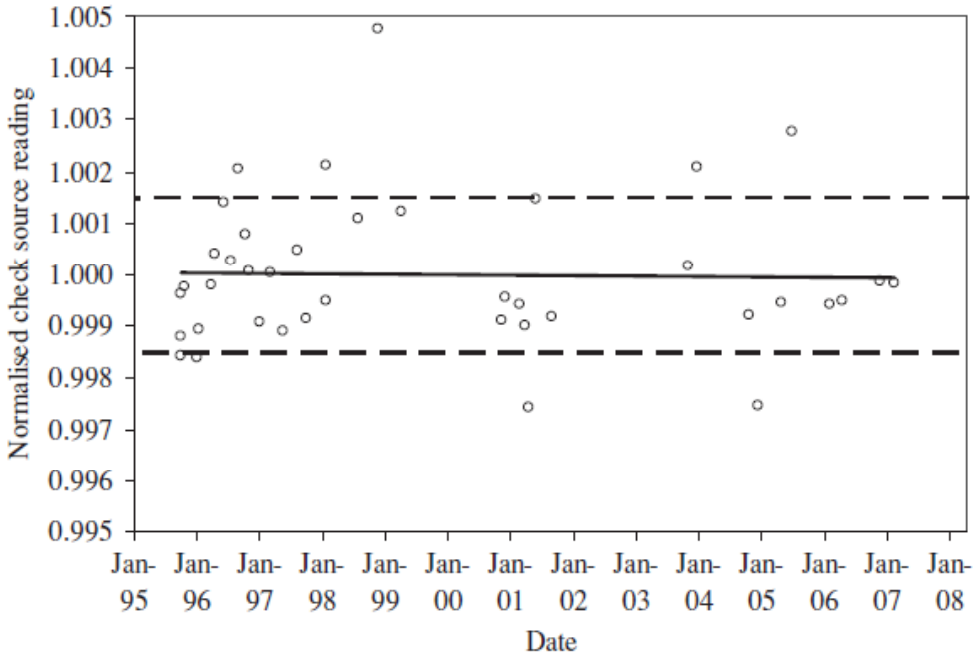
$$D_{w,Q}(t_{meas}) = N_{D,w}^{^{60}Co}(t_{cal})\, k_Q\, M_{ion}(t_{meas})$$

- Underlying assumption is that the calibration coefficient on the certificate applies at the time of measurement
- Need to estimate the uncertainty in this assumption

Monitoring ion chamber stability

1. Monitoring in a ^{60}Co beam with the reference conditions as defined in TG-51.
2. Regular comparison with other reference-class ionization chambers in a linac beam. At least three chambers are required to make such a comparison method robust.
3. Use a ^{90}Sr check source

- A calibration certificate without intermediate monitoring is worthless
- Do not assume a reference-class ion chamber will be stable!



Reference: Bass et al (Phys. Med. Biol., 2009)

C. Uncertainty budget

Addendum provides two scenarios:

1. All components of the dose determination are evaluated, reference-class equipment is used.
2. Uncertainty components of the dose determination are evaluated using 'typical' assumptions, and the performance of the equipment could be questionable.

Table shows values for scenario (1)

Component of Uncertainty	Type A	Type B
Measurement		
SSD setting	0.10%	
Depth setting	0.25%	
Charge measurement	0.10%	
P_{TP} correction	0.10%	
Calibration data		
Co-60 $N_{D,w}$		0.70%
k_Q factor		0.33%
Assignment of k_Q factor	0.10%	
Influence quantities		
P_{pol}	0.05%	
P_{ion}	0.10%	
Pre-irradiation history	0.10%	
P_{leak}	0.05%	
Calibration coefficient	0.20%	
Linac stability	0.10%	
OVERALL	**0.9%**	
User-dependent part	**0.3%**	

C. What's possible?

MV calibrations now available in Canada!

1. No k_Q factors required
2. $D_w = M N_{D,w}$

Note – no change in component that user influences

Component of Uncertainty	Type A	Type B
Measurement		
SSD setting	0.10%	
Depth setting	0.10%	
Charge measurement	0.10%	
P_{TP} correction	0.10%	
Calibration data		
MV $N_{D,w}$		0.38%
k_Q factor		0.0%
Assignment of k_Q factor	0.10%	
Influence quantities		
P_{pol}	0.05%	
P_{ion}	0.10%	
Pre-irradiation history	0.10%	
P_{leak}	0.05%	
Calibration coefficient	0.05%	
Linac stability	0.10%	
OVERALL	**0.5%**	
User-dependent part	**0.3%**	

Part 2 – electron dosimetry

- Same basic equation is used for electrons as for photons:

$$D_{w,Q} = N_{D,w}^{^{60}Co} k_Q M_{ion}$$

- k_Q is split into 3 components:

$$k_Q = P_{gr} k_{ecal} k'_{R_{50}}$$

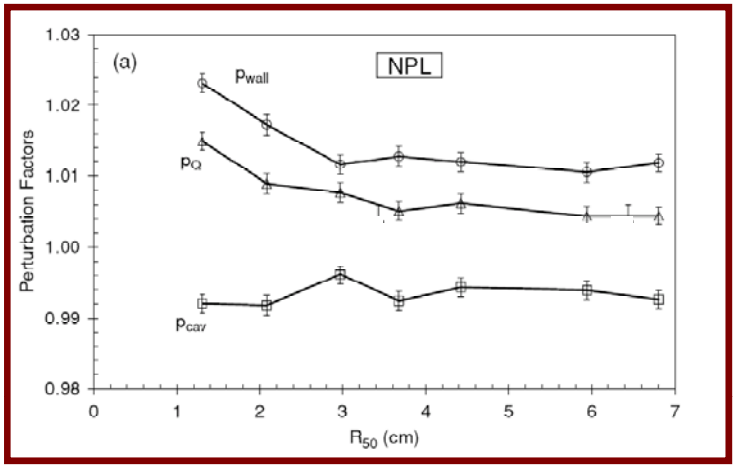
- P_{gr} corrects for gradient effects (thimble chambers only)
- k_{ecal} converts from Co-60 to a high-energy electron beam
- k'_{R50} gives relative energy dependence in electron beams

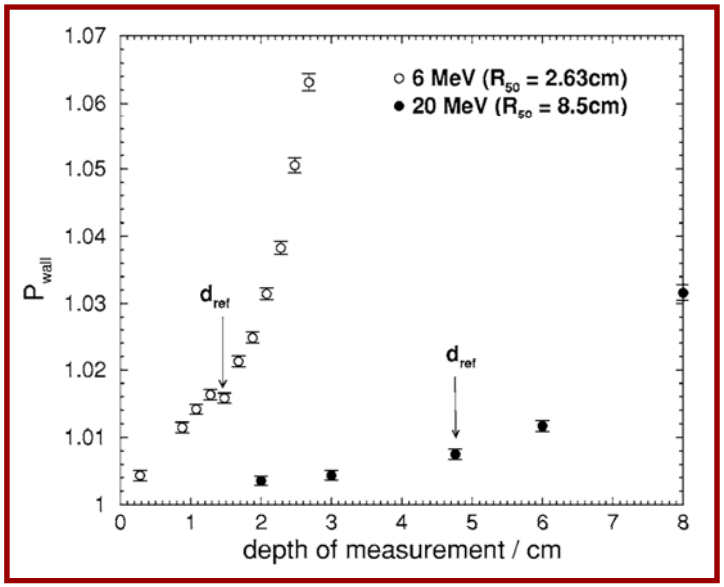
Part 2 – electron revision

$$k_Q = P_{gr} k_{ecal} k'_{R_{50}}$$

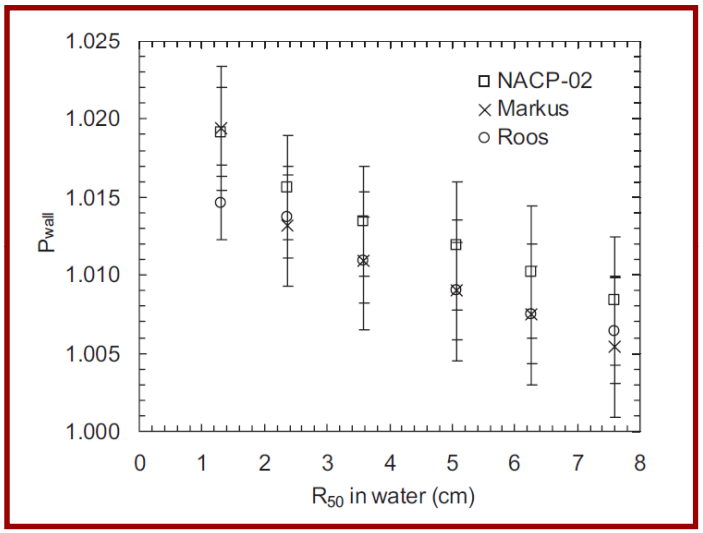
- P_{gr} - need to revisit in light of new effective point of measurement data for photon beams.
- k_{ecal} – improved value available in literature for NACP-02 chamber, new values required for new chamber types (Exradin A10, IBA PPC-05, PTW34045).
- $k'_{R_{50}}$ – TG-51 assumes that well-guarded parallel-plate chambers have a unity perturbation correction. Multiple publications now show this is not the case – new data required.

1. Ion-chamber perturbation corrections





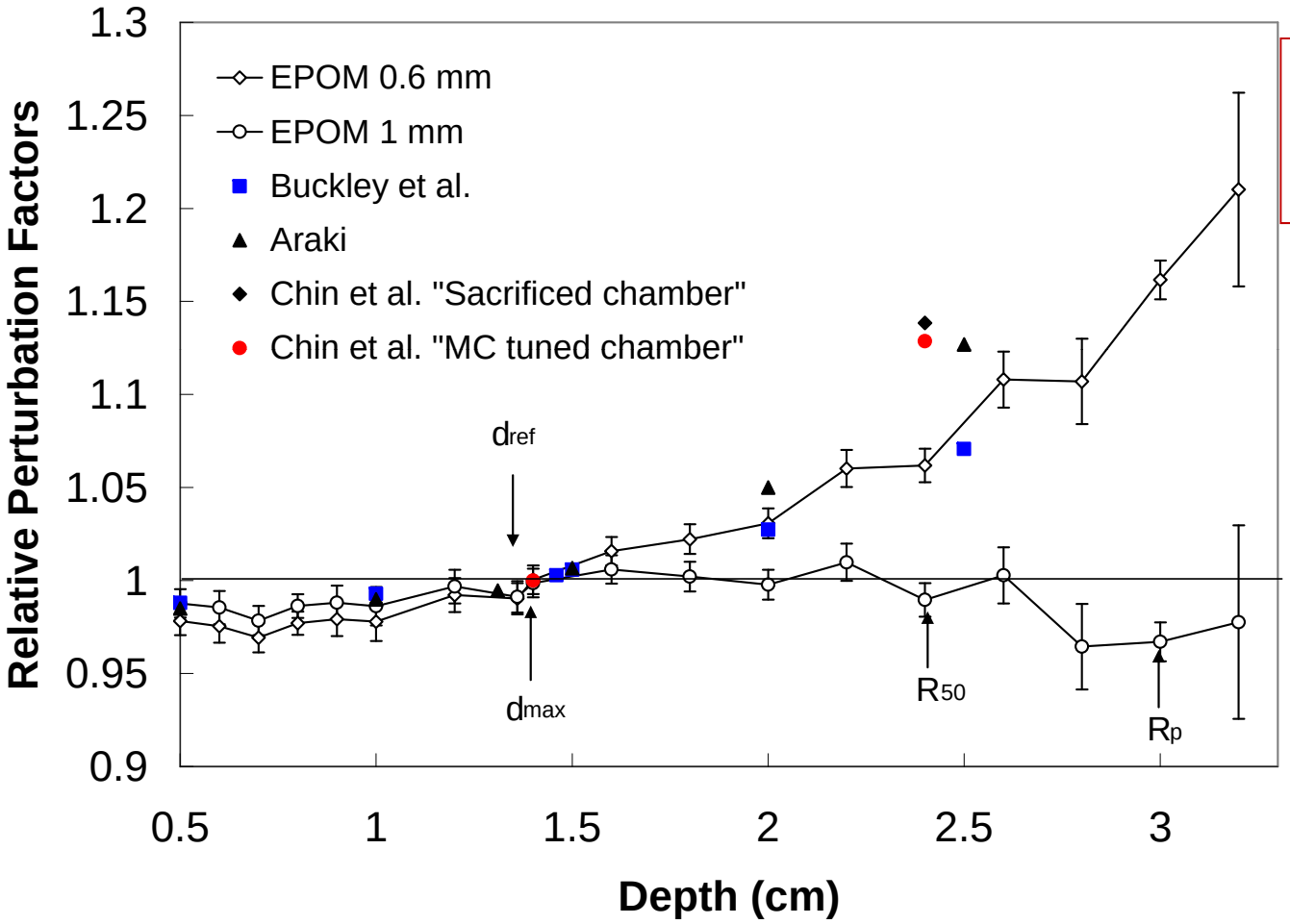
Monte Carlo investigations

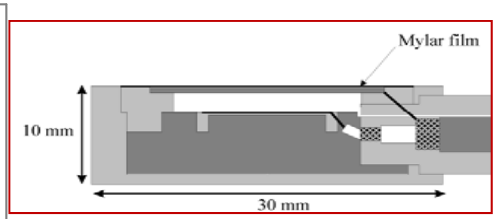


References: Verhaegen et al (PMB, 2006), Buckley and Rogers (Med. Phys., 2006), Araki (Med. Phys., 2008)

Ion-chamber perturbation corrections

Experimental investigation using scintillating fibre dosimeter

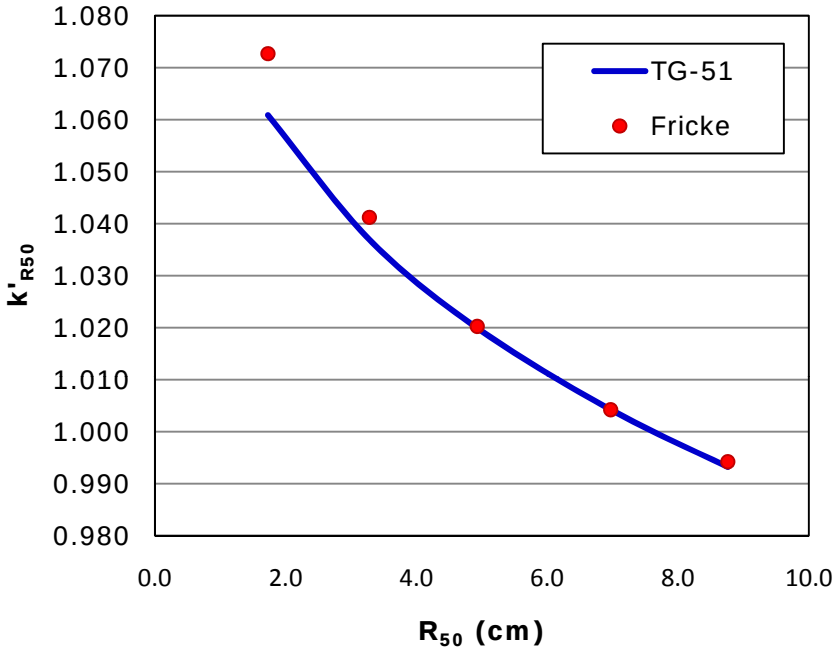




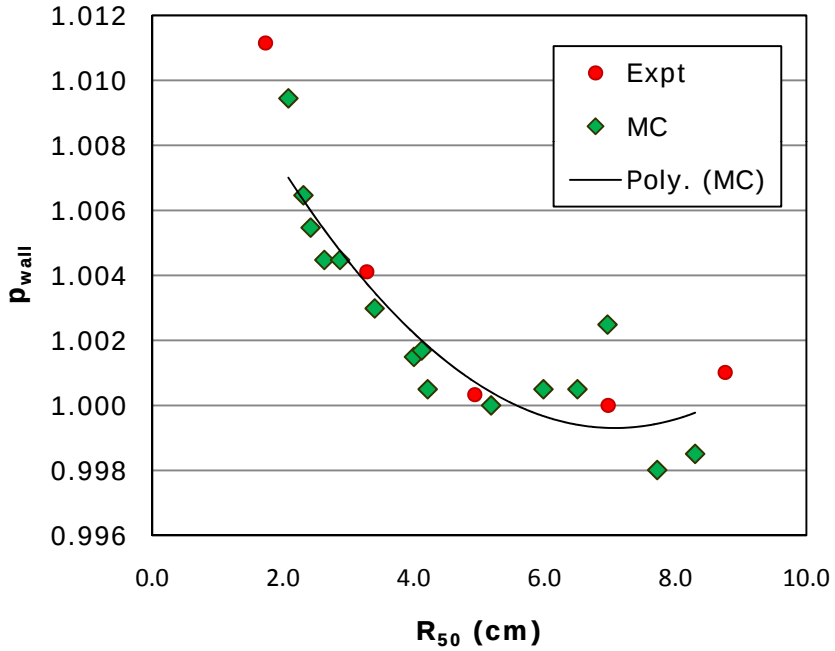
"Sacrificed" and "tuned" refers to different front wall thicknesses used in MC calculations

Reference: Lacroix et al (Medical Physics, 2010)

Measurement of k'_{R50}



Reference: Cojocaru et al, (IAEA Symposium, 2010)



MC data from: Zink and Wulff (PMB, 2010)

Early days – more work required to develop electron bean primary standards

2. Choice of chamber type needs addressing

Chamber type – what should be the recommendation regarding ion-chamber types and low energy beams?

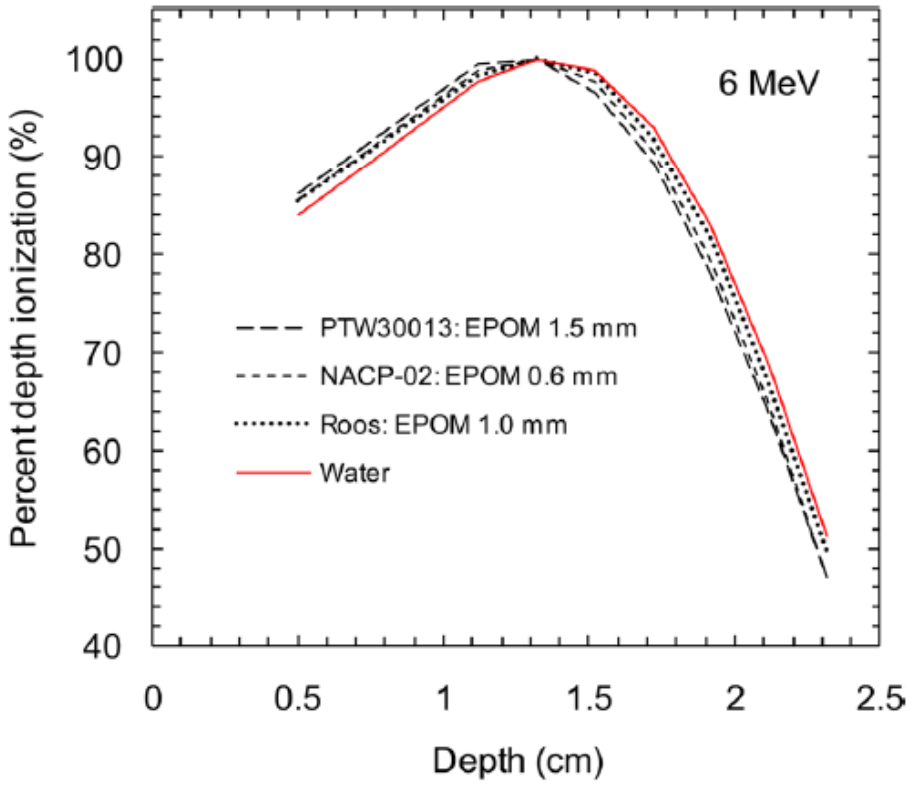
i) Most commonly used beams are 6 & 9 MeV

ii) Some protocols insist on using parallel-plate chambers, TG-51 allows cylindrical down to R_{50} = 2 cm

iii) Objectively, which is better?

iv) Requires accurate experimental data comparing different detectors together with experimental values of k_{ecal} and k'_{R50}

Choice of chamber type

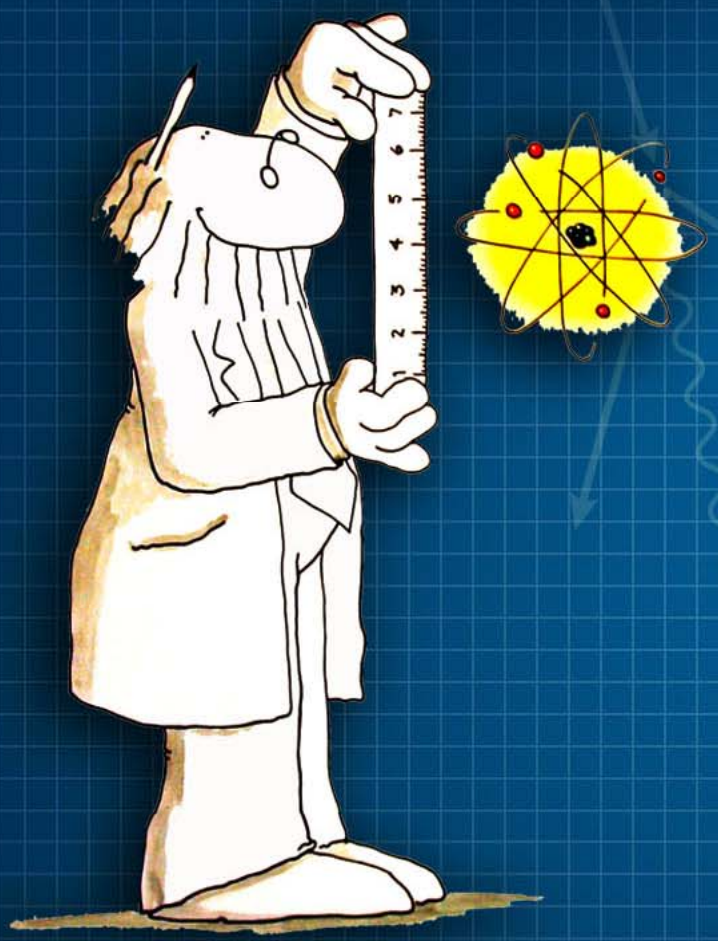


Reference: Ono et al, Med Phys 2011

- Suggests Farmer chambers not significantly worse than parallel-plate chambers
- MC only – needs experimental validation.

Conclusions

- **There is still interesting work to be done in the field of reference dosimetry**
- **TG-51 is looking (pretty) good as it moves into a second decade**
- **Some changes are required – both photons and electrons**
- **Keep an eye out for published Addenda**



Thank you