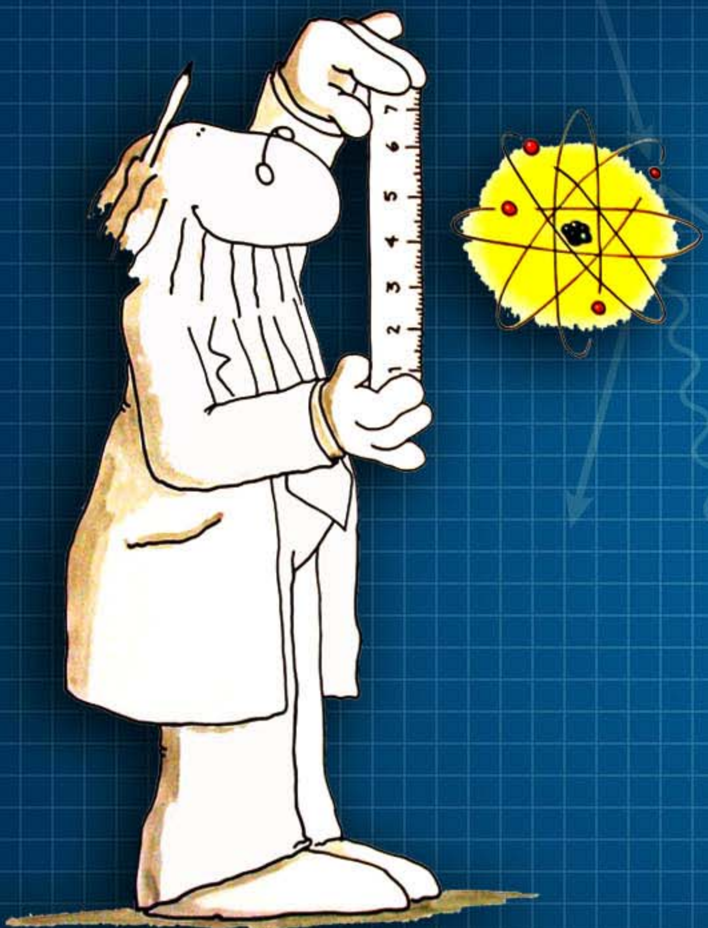


Linac dosimetry - are chamber-specific calibration coefficients really necessary?

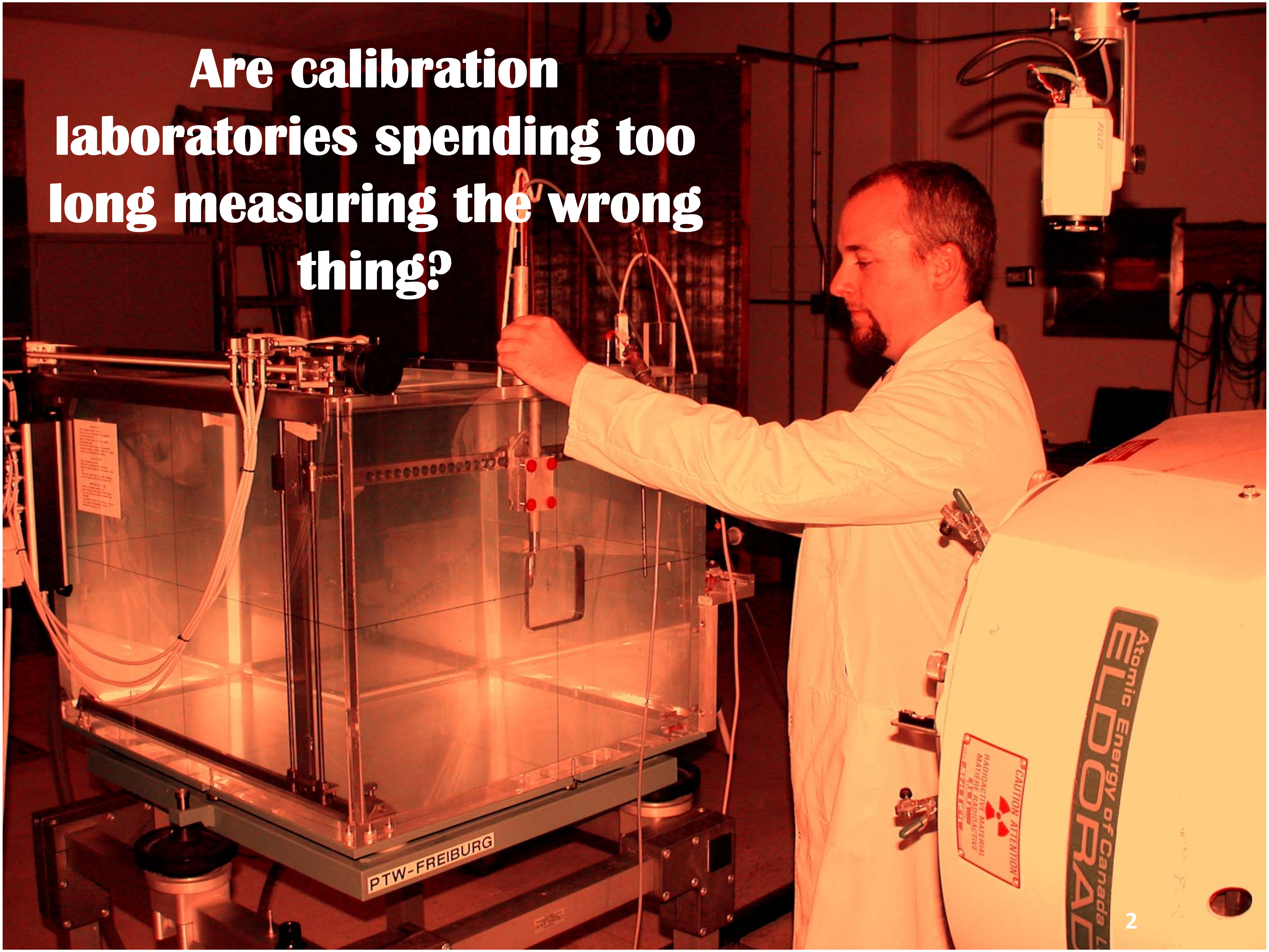
Malcolm McEwen

Ionizing Radiation Standards Group

National Research Council Canada, Ottawa

CIRMS Annual Meeting 2012, Gaithersburg, MD

Are calibration laboratories spending too long measuring the wrong thing?



Reference dosimetry

- In North America 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 <u>calibrated ion chamber</u>:

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

- $N_{D,w}$ 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

TG-51 and k_Q factors

k_Q is derived from calculations, based on simplified chamber designs

TABLE I. Values of k_Q for accelerator photon beams as a function of $\%dd(10)_x$ for cylindrical ion chambers commonly used for clinical reference dosimetry. Values calculated as described in Refs. 45 and 51. The tabulated values can be interpolated linearly in $\%dd(10)_x$. The ion chamber specifications used in these calculations are found in Table III. Figure 4 presents the same data within 0.1%. For ^{60}Co beams, k_Q=1.000 by definition.

Ion chamber	k_Q $\%dd(10)_x$ 58.0	63.0	66.0	71.0	81.0	93.0
Capintec PR-05/PR-05P	0.999	0.997	0.995	0.990	0.972	0.948
Capintec PR-06C/G 0.6cc Farmer	1.000	0.998	0.994	0.987	0.968	0.944
Exradin A1 Shonka[a]	0.999	0.998	0.996	0.990	0.972	0.948
Exradin A12 Farmer	1.000	0.999	0.996	0.990	0.972	0.948
NE2505/3,3A 0.6cc Farmer	1.000	0.998	0.995	0.988	0.972	0.951
NE2561 0.3cc NPL Sec. Std[b]	1.000	0.998	0.995	0.989	0.974	0.953
NE2571 0.6cc Farmer	1.000	0.998	0.995	0.988	0.972	0.951
NE2577 0.2cc	1.000	0.998	0.995	0.988	0.972	0.951
NE2581 0.6cc robust Farmer	1.000	0.994	0.988	0.979	0.960	0.937
PTW N30001 0.6cc Farmer[c]	1.000	0.996	0.992	0.984	0.967	0.945
PTW N30002 0.6cc all Graphite	1.000	0.997	0.994	0.987	0.970	0.948
PTW N30004 0.6cc Graphite	1.000	0.998	0.995	0.988	0.973	0.952
PTW 31003 0.3cc waterproof[d]	1.000	0.996	0.992	0.984	0.967	0.946
Wellhofer IC-10/IC-5	1.000	0.999	0.996	0.989	0.971	0.946

[a]The cavity radius of the A1 here is 2 mm although in the past Exradin has designated chambers with another radius as A1.
[b]The NE2611 has replaced the equivalent NE2561.
[c]PTW N30001 is equivalent to the PTW N23333 it replaced.
[d]PTW N31003 is equivalent to the PTW N233641 it replaced.

Medical Physics, Vol. 26, No. 9, September 1999

Are those calculations correct?

TABLE VII. Determination of experimental k_Q factors for thimble ionization chambers and comparison with TG-51 calculated values. Chambers are grouped according to the category (Farmer-type, scanning, and micro) and the number of each chamber type involved in the investigation is given. The effect of the 1 mm PMMA waterproofing sleeve (where required) on the comparison is also shown (sleeve correction applied to calculated k_Q values).

Chamber type	Number of chambers characterized	6 MV $\%dd(10)_x=67.2$ $\mathrm{TPR}_{20,10}=0.681$	10 MV $\%dd(10)_x=72.6$ $\mathrm{TPR}_{20,10}=0.731$	25 MV $\%dd(10)_x=84.4$ $\mathrm{TPR}_{20,10}=0.800$	Maximum difference $\lvert k_{Q,\mathrm{exp}}-k_{Q,TG51}\rvert/k_{Q,\mathrm{exp}}$ (%)	Maximum difference Accounting for 1 mm PMMA sleeve[a] (%)
NE2571	9	0.9930	0.9852	0.9655	0.0	0.3
NE2581	1	0.9876	0.9765	0.9543	0.2	0.2
NE2611	4	0.9956	0.9865	0.9700	0.3	0.1
PTW30001	1	0.9916	0.9823	0.9604	0.2	0.3
PTW30010	1	0.9901	0.9820	0.9613	0.0	0.3
PTW30012	1	0.9923	0.9835	0.9637	0.3	0.6
PTW30013	3	0.9890	0.9788	0.9575	0.4	
Exradin A12	2	0.9938	0.9865	0.9675	0.3	
Exradin A12S	1	0.9939	0.9846	0.9662	0.3	
Exradin A19	2	0.9921	0.9845	0.9656	0.3	
IBA FC-65G	1	0.9914	0.9844	0.9620	0.4	
IBA FC-65P	1	0.9899	0.9834	0.9601	0.1	
IBA FC-23C	1	0.9910	0.9838	0.9625	0.3	
Capintec PR-06C	1	0.9948	0.9885	0.9680	0.7	0.5
PTW233642	2	0.9873	0.9796	0.9541	0.7	
PTW31010	3	0.9872	0.9741	0.9568	0.8	
PTW31013	1	0.9912	0.9797	0.9577	0.4	

≈ 0.3 %

Are k_Q factors really generic?

Duane & Simon, WC2003

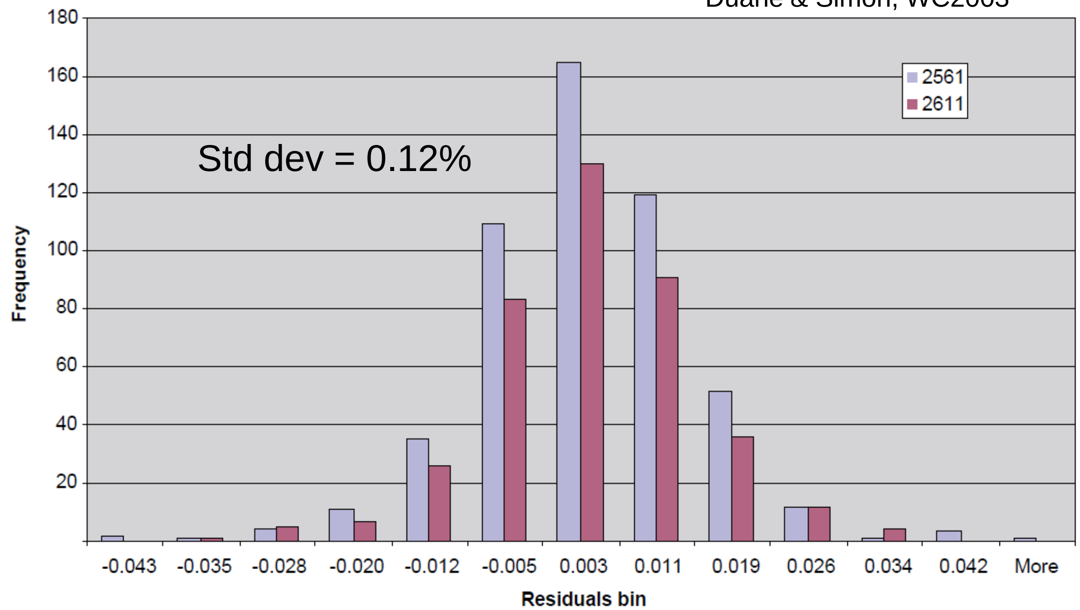
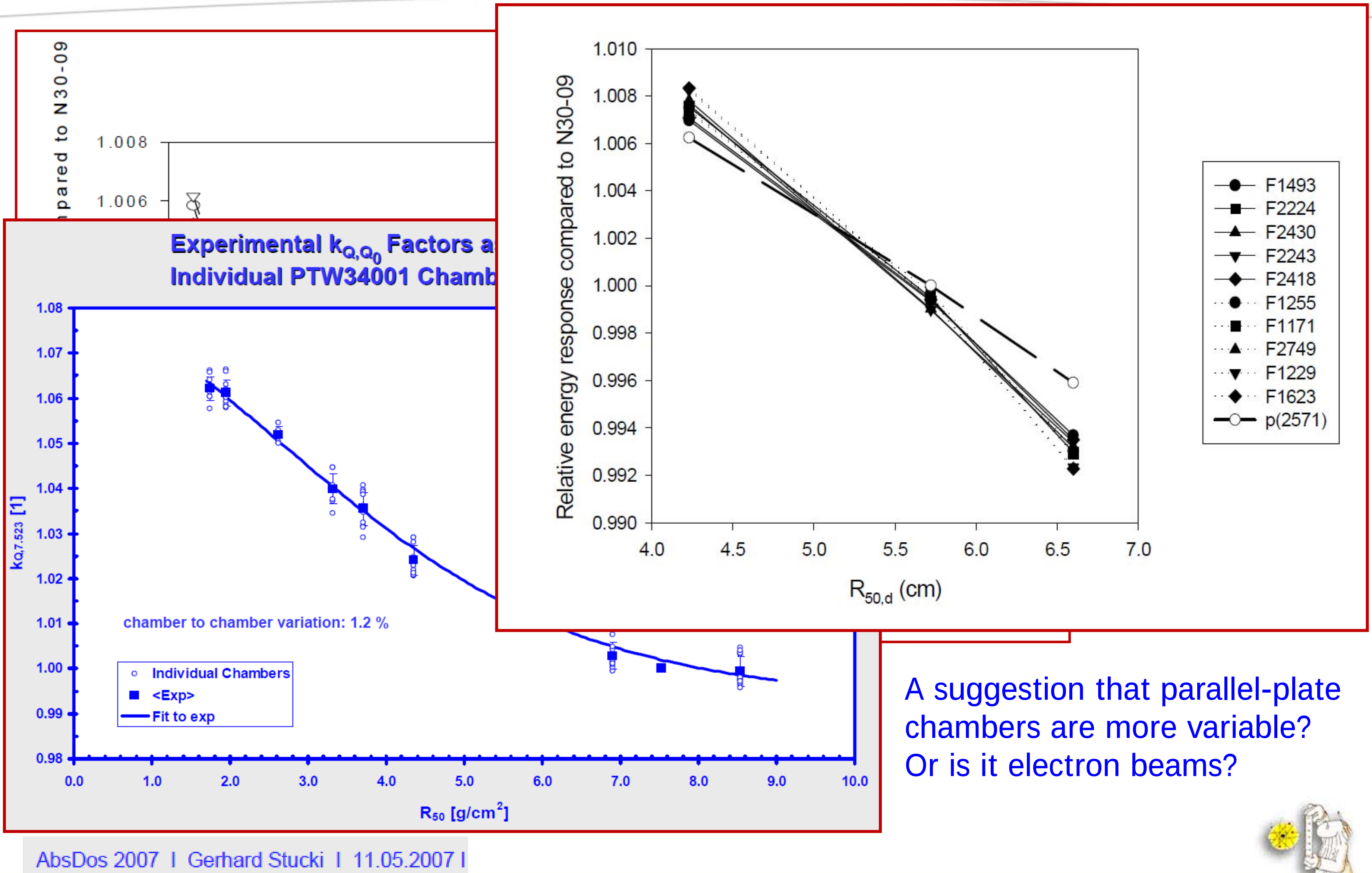


Figure 1. Distributions

Chamber type	Standard deviation ^{60}Co $N_{D,w}$	6 MV	10 MV	25 MV
NE2571		0.06%	0.11%	0.08%
PTW30013		0.10%	0.08%	0.06%
IBA FC-65G		0.14%	0.14%	0.14%

NRC data, 2012

How about electron beams?



A suggestion that parallel-plate chambers are more variable? Or is it electron beams?

Back to reference dosimetry

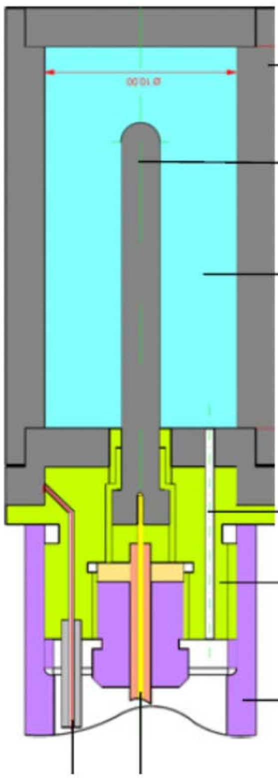
- It's based on measurements with a calibrated ion chamber:

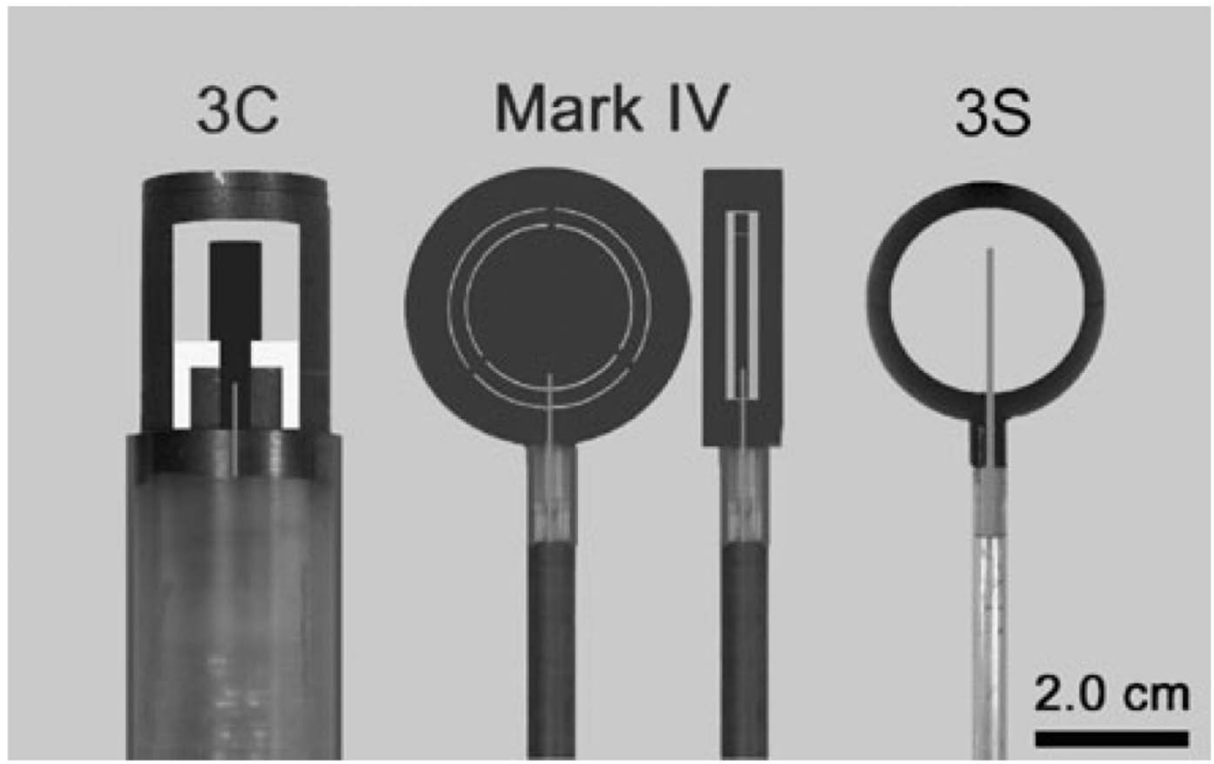
$$D_{w,Q} = N_{D,w}^{^{60}Co} \, k_Q \, M_{ion}$$

- $N_{D,w}$ is obtained from an ADCL or primary standards laboratory (e.g., NRCC in Canada)

- **Irrespective of how k_Q is determined (calculation, generic measurement, individual measurement) we have to calibrate every chamber in ^{60}Co**

Back to air kerma - the primary standard for ^{137}Cs & ^{60}Co gamma rays is the Cavity Chamber





What is required for a cavity standard?

$$K_{air} = \frac{Q_{air}}{\rho_{air} \cdot V} \cdot \left(\frac{W}{e}\right)_{air} \cdot \frac{1}{1-g} \cdot \left(\frac{L}{\rho}\right)_{g,air} \cdot \left(\frac{\mu_{en}}{\rho}\right)_{air,g} \cdot \prod K_i \cdot P_{pol} \cdot P_{ion}$$

- ***A chamber with a very well defined volume***
- ***W/e & $L_{g/air}$***
- ***Monte Carlo***

For chambers of the same design this is the only one that will change from chamber to chamber

^{60}Co calibration is really just a relative volume measurement

^{60}Co - what does the data say?

Chamber type	Standard deviation			
	^{60}Co $N_{D,w}$	6 MV	10 MV	25 MV
NE2571	1.01%	0.06%	0.11%	0.08%
PTW30013	0.54%	0.10%	0.08%	0.06%
IBA FC-65G	0.42%	0.14%	0.14%	0.14%

NRC data, 2012

Not inconsistent with uncertainty in ND,w

More calibration laboratory data - ^{60}Co

Cylindrical	$stdev_{Lab\,1}$	$stdev_{Lab\,2}$
2505/3	1.7%	0.8%
2571	1.4%	0.7%
2581	2.3%	0.8%
A1	4.5%	
A12	1.5%	1.6%
A12S	1.2%	
A14	15.2%	
A14SL	39.9%	
A16	7.2%	1.8%
A18	1.1%	
A1SL	2.3%	1.8%
CC13	1.2%	
FC65-G	0.4%	
FC65-P	1.0%	
N23333	1.9%	1.8%
N233641	5.3%	4.4%
N30001	1.4%	1.4%
N30002	1.8%	0.3%
N30004	1.9%	
N30006	1.0%	1.3%
N30010	0.8%	0.7%
N30013	1.1%	1.1%
N31002	2.9%	2.1%
N31003	2.5%	2.9%
N31006	5.0%	2.4%
N31010	4.3%	4.1%
N31013	1.1%	0.7%
N31014	1.0%	
PR-05P	4.3%	1.2%
PR-06C	1.8%	1.0%
PR-06G	2.5%	2.0%

Cylindrical	$stdev_{Lab\,1}$	$stdev_{Lab\,2}$	Lab 1/Lab 2
2505/3	1.7%	0.8%	1.0098
2571	1.4%	0.7%	1.0050
A1	4.5%		
A12	1.5%	1.6%	0.9929
A12S	1.2%		
A18	1.1%		
A1SL	2.3%	1.8%	1.0226
CC13	1.2%		
FC65-G	0.4%		
FC65-P	1.0%		
N23333	1.9%	1.8%	1.0022
N233641	5.3%	4.4%	1.0084
N30001	1.4%	1.4%	1.0035
N30002	1.8%	0.3%	0.9925
N30004	1.9%		
N30006	1.0%	1.3%	1.0041
N30010	0.8%	0.7%	1.0011
N30013	1.1%	1.1%	1.0038
N31003	2.5%	2.9%	1.0253
N31006	5.0%	2.4%	0.9962
N31013	1.1%	0.7%	1.0070
PR-05P	4.3%	1.2%	0.9988
PR-06C	1.8%	1.0%	0.9997
PR-06G	2.5%	2.0%	0.9865

What about parallel-plate chambers?

	$stdev_{Lab\ 1}$	$stdev_{Lab\ 2}$	Lab 1/Lab 2
Parallel-plate			
A10	5.5%	2.3%	0.9329
A11	6.5%	2.8%	1.0096
P11	6.5%	2.7%	0.9199
N23343	2.1%	2.5%	1.0026
N34001	1.8%	1.6%	1.0051
N34045	2.6%	1.6%	1.0143
PPC05	3.2%		
PPC40	5.1%		

Same two calibration labs

Standard deviations generally larger than for cylindrical chambers of the same volume

Muir, McEwen, and Rogers: k_Q for plane-parallel chambers Med. Phys. 39 (3), March 2012

Results: Chamber behavior was variable in MV photon beams, especially with regard to chamber leakage and ion recombination. The plane-parallel chambers did not perform as well as cylindrical chambers. Significant differences up to 1.5% were observed in calibration coefficients after a period of eight months although k_Q factors were consistent on average within 0.17%. Chamber-to-chamber variations in k_Q factors for chambers of the same type were at the 0.2% level. Systematic uncertainties in Monte Carlo calculated k_Q factors ranged between 0.34% and 0.50% depending on the chamber type. Average percent differences between measured and calculated k_Q factors were −0.02%, 0.18%, and −0.16% for 6, 10, and 25 MV beams, respectively.

Electron beams

Table 3 Mean $N_{D,w}$ factors for PTW Roos chambers

E_{nom} MeV	4	6	8	10	12	16	19
$R_{50,D}$ cm	1.23	1.97	2.75	3.48	4.23	5.72	6.60
$N_{D,w}$ Gy/C x10^7	7.97	7.95	7.88	7.83	7.77	7.65	7.60
σ	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%

NPL REPORT IR 5

A review of the calibration of parallel-plate electron ionisation chambers at NPL for use with the IPEM 2003 Code of Practice

G A BASS, R A S THOMAS and J A D PEARCE

Smaller variation than in ^{60}Co – may be confirmation of P_{wall} problems
(Both TG-51 and TRS-398 do not favour calibration in ^{60}Co for pp chambers)

Table 2 Mean $N_{D,w}$ factors for NACP-02 chambers

E_{nom} MeV	4	6	8	10	12	16	19
$R_{50,D}$ cm	1.23	1.97	2.75	3.48	4.23	5.72	6.60
$N_{D,w}$ Gy/C x10^7	14.67	14.62	14.47	14.38	14.26	14.07	13.96
σ	6.2%	6.0%	6.0%	5.9%	6.0%	5.9%	6.0%

A closer look at the NACP chamber type

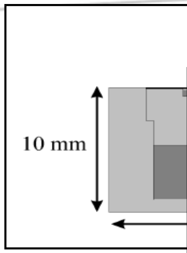
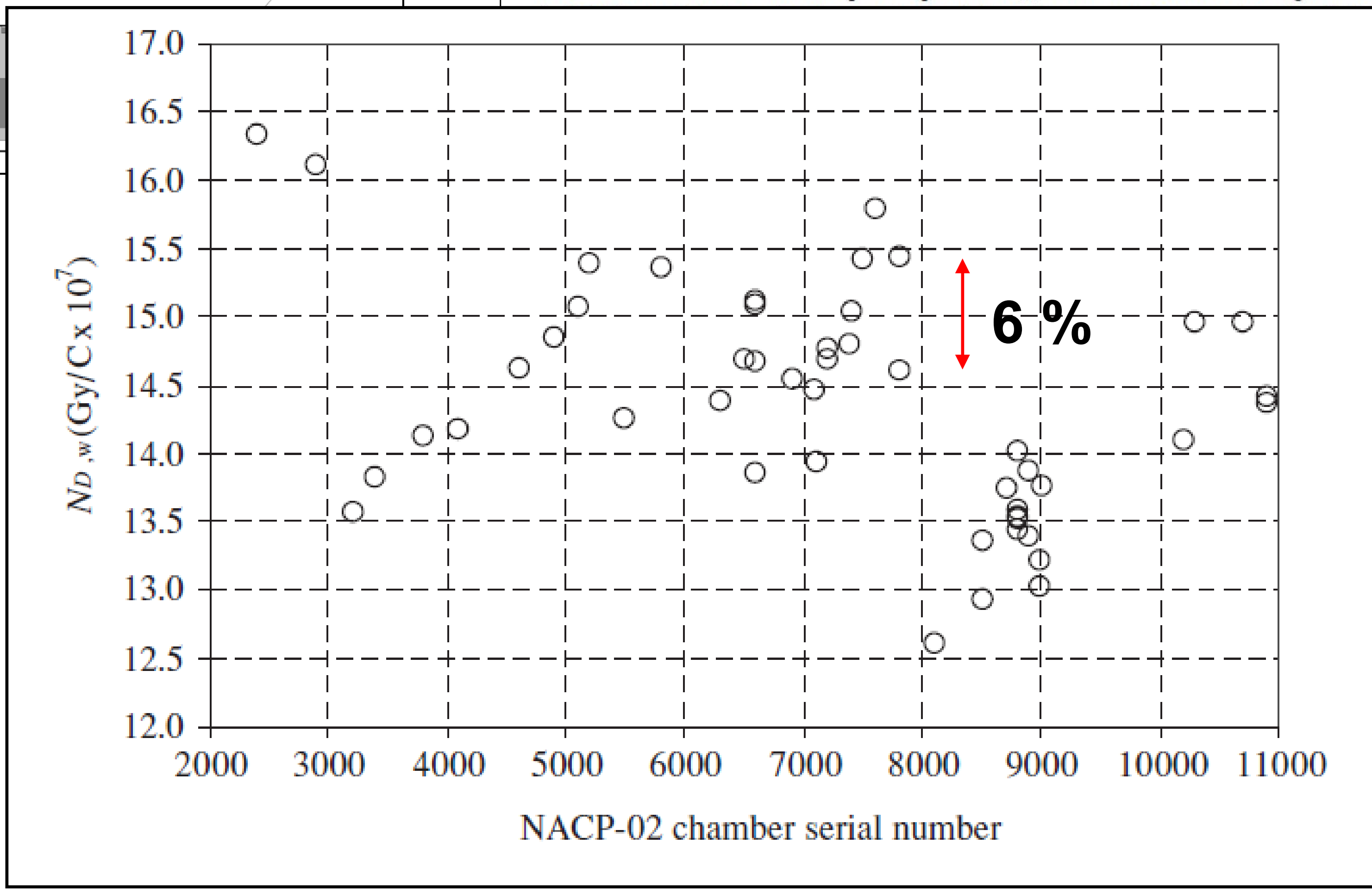


Table 3. Values for the effective plate separation d_{eff} and the effective collecting radius r_{eff} for ...) and

–2045.



No data for most recent 'version' from IBA

Phys. Med. Biol. **54** (2009) N115–N124

Conclusion (part 1)

- **For the vast majority of reference-class <u>cylindrical chambers</u> the standard deviation on $N_{D,w}$ is < 2 %**

- **This variation includes all possible reasons for chamber-to-chamber variation – there is the indication that volume differences are at the 0.5 % to 1 % level**

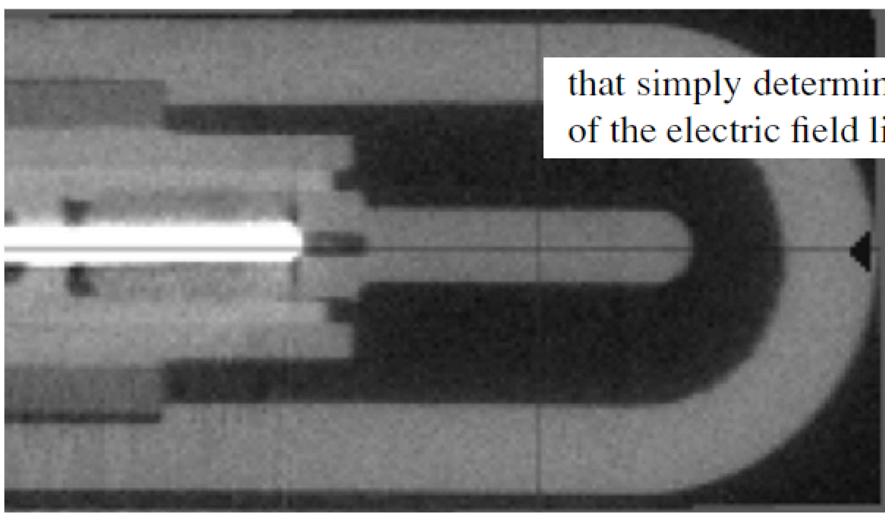
- **For parallel-plate chambers the variation tend to be much larger – likely due to manufacturing method**

- ***With a 2 % uncertainty one can assign a generic calibration coefficient for any MV beam for a limited range of chamber types***

Can we independently get the volume?

The previous conclusion really means s that we cannot rely on the manufacturer’s production QC at the level of uncertainty that we need (better than 1 %)

Is there a simple measurement that can easily give the *effective* chamber volume?

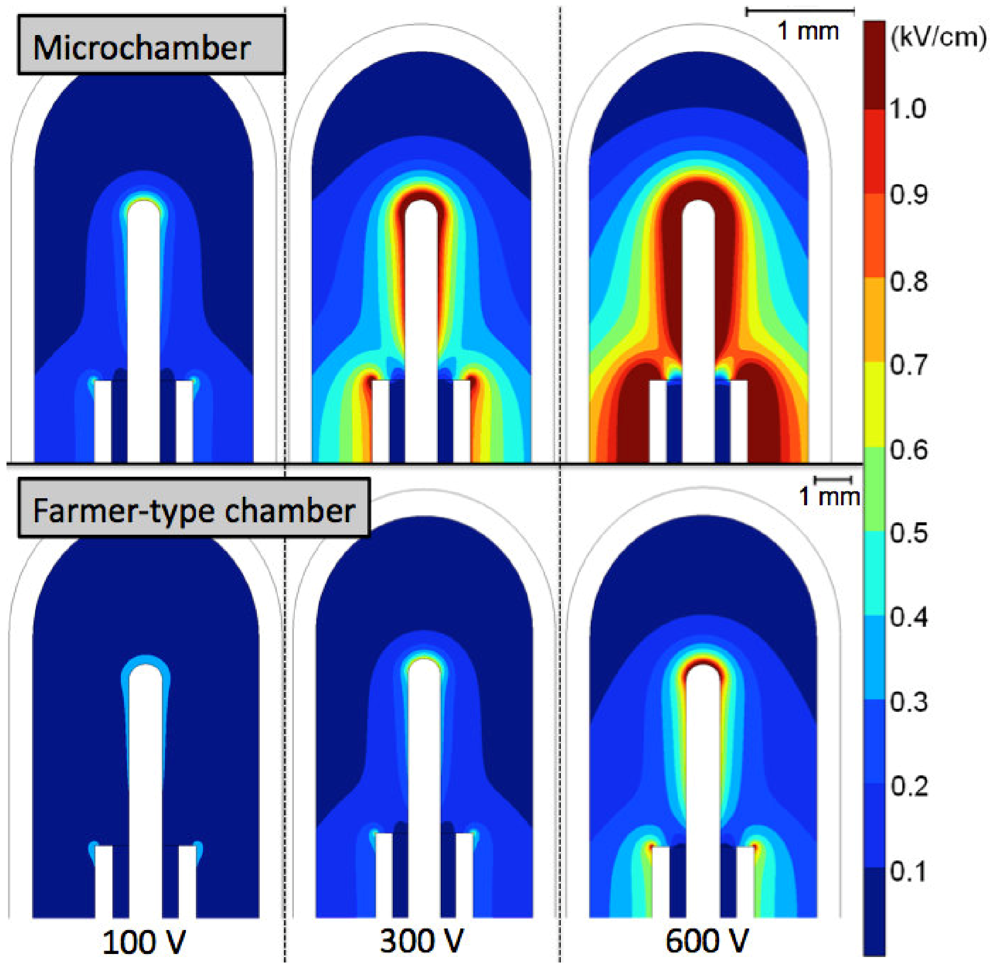


that simply determining the mechanical volume without careful consideration of the electric field lines within the cavity is not a useful dosimetric technique.

2009 Phys. Med. Biol. 54 L23

Phys. Med. Biol. **53** (2008) 5029–5043

Modelling what is going on in the chamber cavity



Snow and DeWerd, *Med. Phys.* **39** (2012)

Can we independently get the volume?

Traceable micro-CT scaling accuracy phantom for applications requiring exact measurement of distances or volumes

Purpose: Volumetric x-ray microcomputed tomography (CT) can be employed in a variety of quantitative research applications such as image-guided interventions or characterization of medical devices. To ensure the highest geometric fidelity of images for these applications, a phantom and image processing algorithm have been developed to calibrate the scaling accuracy of micro-CT scanners to a traceable standard and provide corrections to image voxel sizing.
Methods: The calibration phantom contains six borosilicate beads whose separations have been measured to a traceable standard. An image processing algorithm compares the known separations of the beads to their separations in micro-CT images. A least-squares solution is used to determine linear scaling correction factors along each of the three scanner axes to minimize errors in the bead separations within the images by correcting the image voxel size. The correction factors were applied to images of a similar phantom with beads at different positions to evaluate the ability of the correction factors to reduce errors at points independent of the fiducial locations in the calibration phantom. The calibration phantom was used to evaluate the scaling accuracy of five different micro-CT scanners representing four different scanner models.
Results: In two of the five scanners evaluated, the correction factors significantly reduced the mean error in bead separations in the images from 0.17% to 0.05% and from 0.37% to 0.07% of the actual bead separations, respectively. Scanners yielding similar voxel sizes possessed comparable geometric errors after correction using the phantom.
Conclusions: Although the magnitude of the corrections is small, such corrections can be important for demanding micro-CT applications. Even if no voxel size correction is required, the phantom provides an easily implemented method to verify the geometric fidelity of micro-CT scanners to a traceable standard of measurement. © *2012 American Association of Physicists in Medicine.* [http://dx.doi.org/10.1118/1.4752083]

6022 Med. Phys. 39 (10), October 2012

Micro-CT + electric field modelling could give us the effective volume with the required accuracy

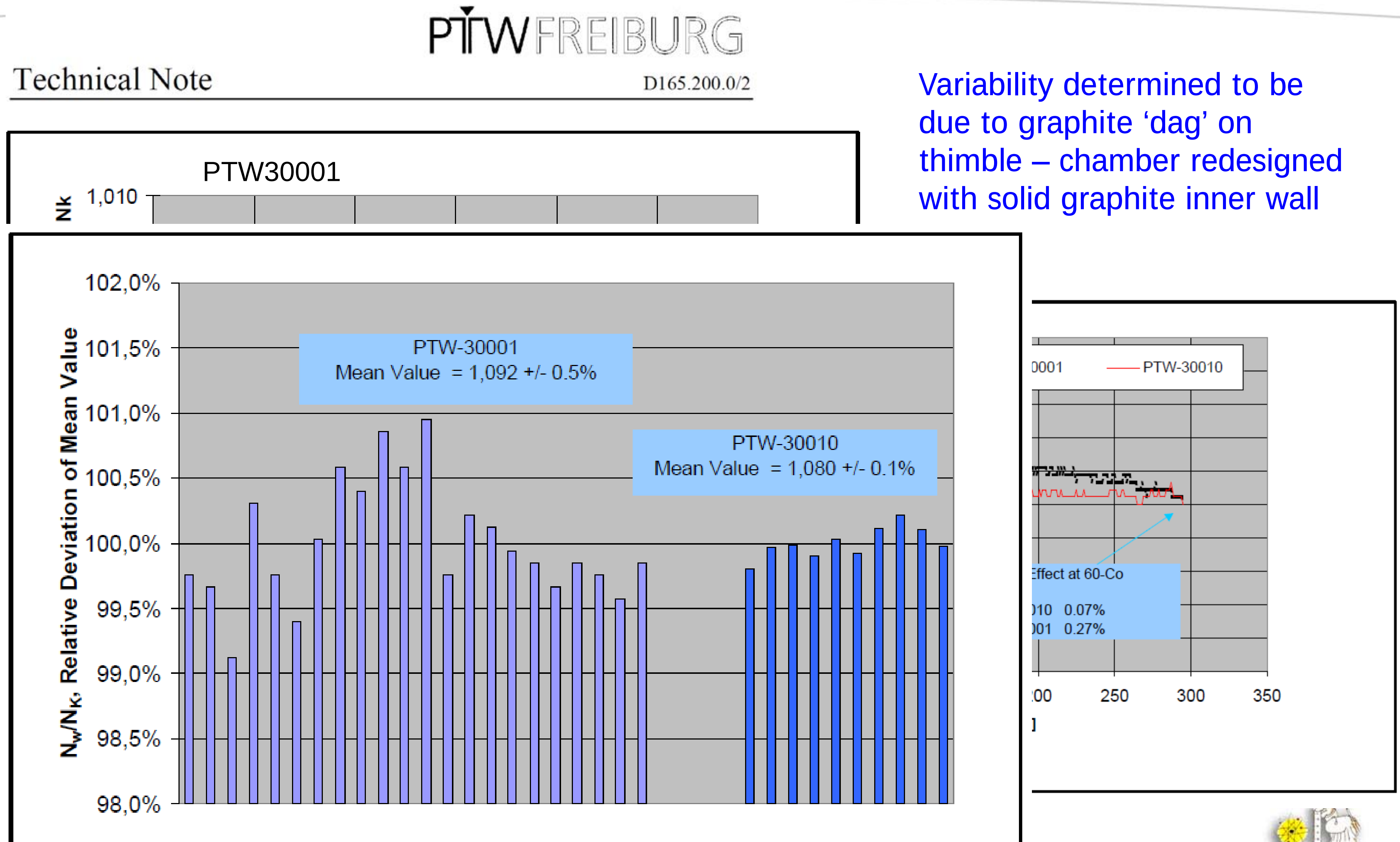
But does it pass a reality test?

Is there any other value in an $N_{D,w}$ calibration?

- **An ion chamber is much more than an air volume**
- **Radiation measurements tell us about operation as well as sensitivity**
- **Only by making radiation measurements can you:**

  i. **Determine that the electrical connections are correct (polarity)**
  ii. **Confirm that components are not failing (leakage)**
  iii. **Compare response with theoretical models (recombination)**
  iv. **Really know how the device will work in its intended environment**

Here's an example



Variability determined to be due to graphite 'dag' on thimble – chamber redesigned with solid graphite inner wall

Conclusion

- Modern ion chamber designs and manufacturing processes result in small chamber-to-chamber variations in the volume of the air cavity
- Alternative techniques potentially offer a non-radiation route to determining the chamber volume, allowing the possibility of generic $N_{D,w}$ and k_Q values
- BUT - radiation measurements remain the only way to verify that ion chambers are "fit for purpose"

Conclusion

- **Ionizing Radiation Calibration Laboratories are not obsolete!**

BUT:

- **Quantitative imaging has a potential role to play in the calibration lab as well as in the clinic**

- **We need to regularly review our procedures to make sure that the right measurements are being made**

THANK YOU