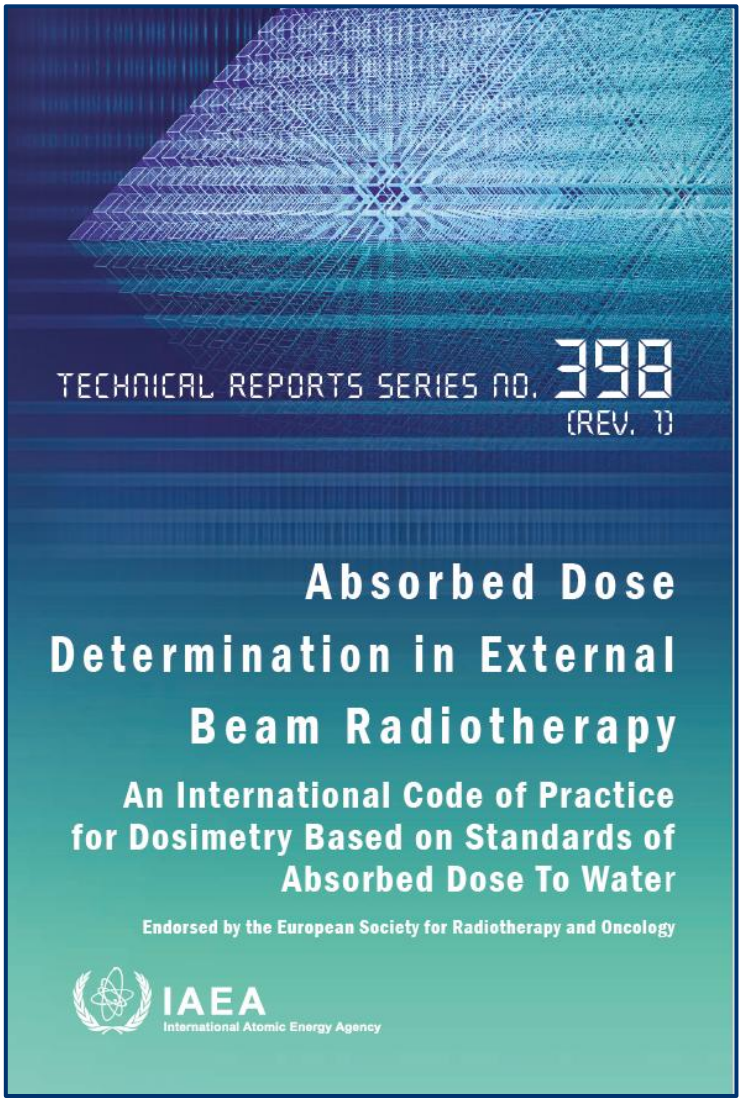


IAEA TRS-398 Rev. 1 Chapter 4 Implementation

Hugo Palmans

National Physical Laboratory, Teddington, UK and
MedAustron, Wiener Neustadt, Austria

Chapter 4…

…is the first 'technical' chapter of TRS-398 Rev.1 and is essential reading before implementing reference dosimetry for **any** modality.

It provides general guidance, with beam-specific details then provided in the subsequent chapters.

With 40 pages it is the most substantial chapter

IAEA TRS-398 (2000 and 2024) simple absorbed dose formalism

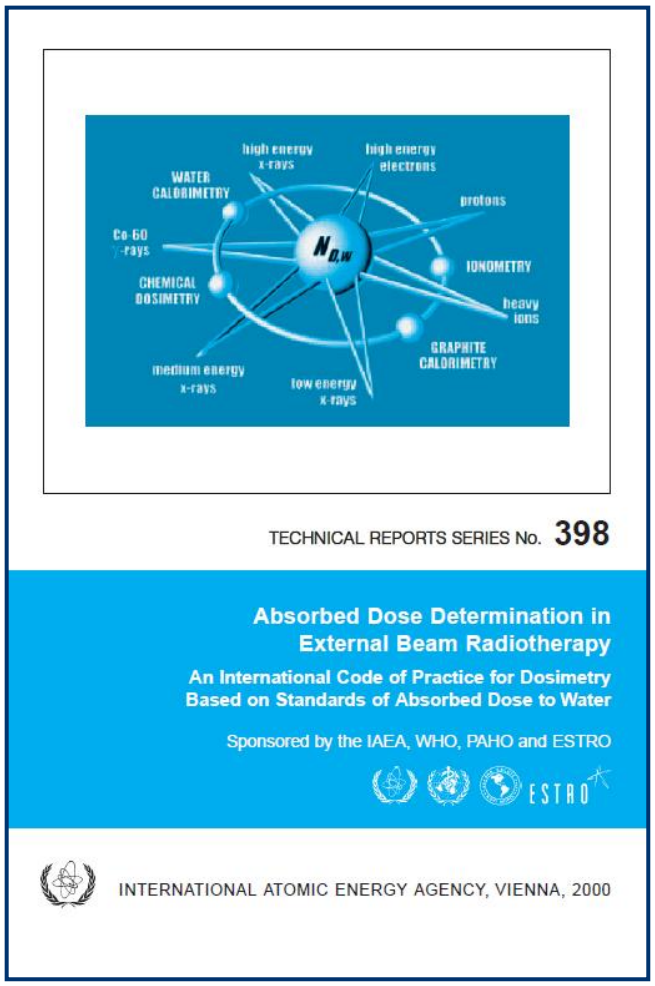
$$D_{\mathrm{w},Q} = M_Q N_{D,\mathrm{w},Q}$$

But we have N_{D,w,Q_0} with $Q_0 \neq Q$

$$\rightarrow \quad D_{\mathrm{w},Q} = M_Q N_{D,\mathrm{w},Q_0} k_{Q,Q_0}$$

If Q_0 = ^{60}Co

$$\rightarrow \quad D_{\mathrm{w},Q} = M_Q N_{D,\mathrm{w}} k_Q$$



e.g., UK calibration

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OF AN IONISATION CHAMBER IN TERMS OF ABSORBED DOSE

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Absorbed dose to water, $D_{w,Q}$, at the position of the centre of the chamber when the chamber and sheath are replaced by water can be expressed as:

$$D_{w,Q} = M_Q N_{D,w,Q} \qquad (1)$$

where

M_Q is the instrument response in coulombs (C), corrected to a chamber air temperature of 20 °C, an ambient air pressure of 1013.25 mbar, a relative humidity of 50% and for losses due to ion recombination

$N_{D,w,Q}$ is the calibration coefficient for the radiation quality Q to convert the corrected instrument reading to absorbed dose to water, given in Table 1 and Figure 1.

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Absorbed dose to wate

the chamber and sheat

where

M_Q is t

cha

of

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$N_{D,w,Q}$ is t

cor

to

Quality index ($TPR_{20,10}$)	Beam energy (MV)	Depth in water (g/cm^2)	Calibration coefficient, $N_{D,w,Q}$ (Gy/C)
0.568	(^{60}Co)	5	10.27×10^7
0.633	4	5	10.24×10^7
0.682	6	5	10.20×10^7
0.713	8	5	10.15×10^7
0.733	10	5	10.11×10^7
0.758	15	7	10.04×10^7
0.775	18	7	9.99×10^7
0.800	25	7	9.89×10^7

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OF AN IONISATION CHAMBER

Absorbed dose to wate

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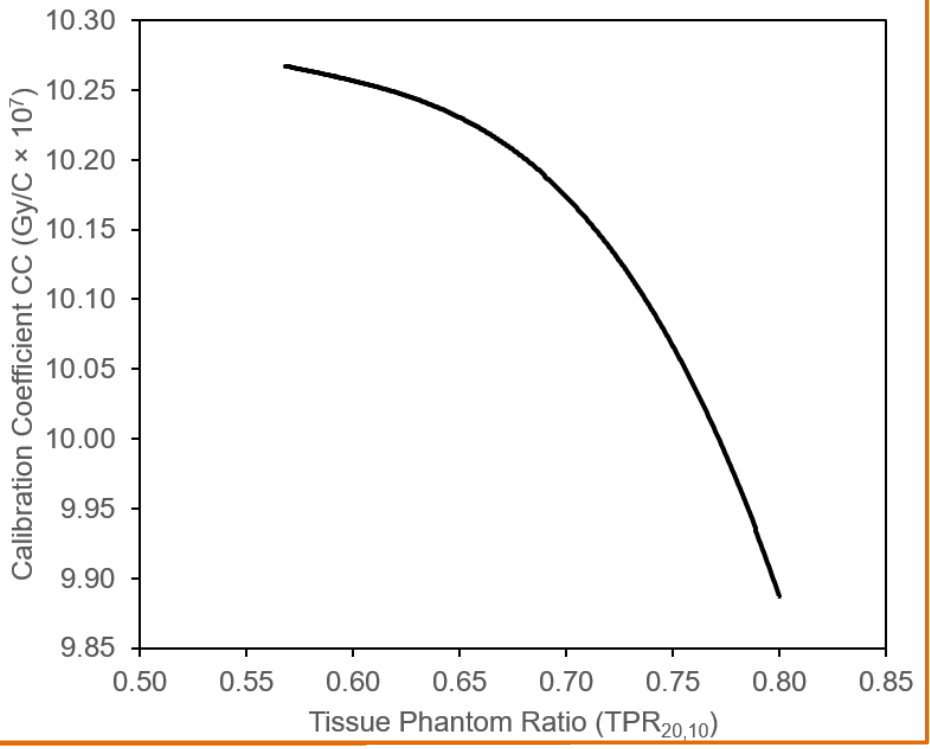
0.800	25



4.1.1. Calibrations in standards laboratories made at multiple beam qualities

(a) Users are provided with a series of $N_{D,w,Q}$ calibrations of the user ionization chamber at beam qualities Q. One of the beam qualities is selected by the user as the reference quality Q_o at the clinical site, with its calibration coefficient being denoted by N_{D,w,Q_o}. Values of k_{Q,Q_o} are derived by normalizing all calibration coefficients to N_{D,w,Q_o}, as defined in Eq. (3), which corresponds to directly measured values of k_{Q,Q_o}. The advantage of this approach is that, once directly measured values of k_{Q,Q_o} for a particular chamber have been obtained, it may not be necessary to recalibrate the

(b) Users are provided with a calibration coefficient N_{D,w,Q_o} at a laboratory selected reference quality Q_o, together with a series of k_{Q,Q_o} factors directly measured for the user chamber at beam qualities Q. The criteria for the type and frequency of calibrations are as above.

But… these are considered equivalent since $k_{Q,Q_0} = \frac{N_{D,w,Q}}{N_{D,w,Q_0}}$

4.1.2. Calibrations in standards laboratories made at a single reference quality Qo

(a) Generic experimental values obtained from measurements at standards laboratories for a sample of ionization chambers of a given type. This approach is an alternative option to option (b) in Section 4.1.1 only when k_Q or k_{Q,Q_o} values have been obtained by a standards laboratory from a large sample

(b) Generic calculated values using the following:

(i) The Bragg–Gray based analytical expression given in Eqs (91) and (92) in Appendix II. This procedure was used in the first edition of this

(ii) Detailed Monte Carlo simulations of a given chamber type. This technique was used in Ref. [99]

(c) Generic compound values, derived statistically from the combination of the following:

(i) Detailed Monte Carlo simulations of specific chamber types and PSDL based experimental values for a sample of chambers of that type, such as the 'consensus' k_Q data for megavoltage photon beams

(ii) Chamber specific Monte Carlo calculated values and analytical calculations using Eq. (92) in Appendix II, as for proton beams.

4.2. Equipment

An ionometric dosimeter system for radiotherapy contains the following components:

(a) One or more ionization chamber assemblies, including the permanently attached cable and connector. It is advised that these ionization chambers be specifically designed for the intended purpose (e.g. modality, radiation quality).

(b) A measuring assembly (electrometer). This can be considered to form a system with the ionization chamber, and that system is calibrated as a unit, or the electrometer can be calibrated separately in terms of charge or current per scale division.

(c) One or more phantoms with waterproof sleeves (if required). A special holder might be required to position the chamber correctly within the phantom.

(d) Calibrated devices to measure the phantom temperature and air pressure, to correct the ionization chamber reading to reference conditions.

(e) One or more stability check devices. It is recognized, however, that in many facilities the use of radioactive check sources is actively discouraged. In such circumstances, and without access to a ^{60}Co beam, stability monitoring can be carried out through the regular comparison of duplicate dosimeters. Such an approach is also recommended from a quality assurance perspective to ensure that a robust dosimetry system is maintained.

4.2.1. Ionization chambers - definition of a reference class ionization chamber (since AAPM TG-51 Addendum)

Parameter	Specification
Chamber settling	Monitoring chamber response with accumulated dose, equilibrium is reached in less than 5 minutes; the initial and equilibrium reading agree within 0.5 %.
Leakage	Smaller than 0.1 % of the chamber reading
Polarity effect	Smaller than 0.4% of the chamber reading. The polarity energy dependence is less than 0.3% between ^{60}Co and 10 MV photons.
Recombination correction	1. The correction is linear with dose per pulse 2. Initial recombination (the part of the total charge recombination that is independent of the dose rate or the dose per pulse) is below 0.2% at polarizing voltages around 300 V. 3. For pulsed beams, a plot of $1/M_Q$ (charge reading) vs 1/V (polarizing voltage) is linear at least for practical values of V. 4. For continuous beams, a plot of $1/M_Q$ vs $1/V^2$ should be linear, describing the effect of general recombination. The presence of initial recombination disturbs the linearity but this is normally a small effect, which may be neglected. 5. The difference in the initial recombination correction obtained with opposite polarities is less than 0.1%.
Chamber stability	Change in calibration coefficient over a typical recalibration period of 2 years below 0.3 %. Same figure for long term (>5 y) stability
Chamber material	Wall material does not exhibiting temperature and humidity effects

4.2.1. Cylindrical ionization chambers

TABLE 4. CHARACTERISTICS OF CYLINDRICAL CHAMBER TYPES *(as stated by manufacturers)*

Ionization chamber type	Cavity volume (cm^3)	Cavity length (mm)	Cavity radius (mm)	Wall material	Wall thickness (g/cm^2)	Central electrode material	Waterproof
NE 2571	0.69	24.1	3.2	Graphite	0.065	Aluminium	No
PTW 30010	0.6	23.0	3.1	PMMA/graphite	0.057	Aluminium	No
PTW 30012	0.6	23.0	3.1	Graphite	0.079	Aluminium	No
PTW 30013	0.6	23.0	3.1	PMMA/graphite	0.057	Aluminium	Yes
PTW 31010[a]	0.13	6.5	2.8	PMMA/graphite	0.078	Aluminium	Yes
PTW 31013	0.3	16.3	2.8	PMMA/graphite	0.078	Aluminium	Yes
PTW31021	0.07	4.8	2.4	PMMA/graphite	0.084	Aluminium	Yes
IBA CC13	0.13	5.8	3.0	C552	0.070	C552	Yes
IBA FC65-G	0.65	23.0	3.1	Graphite	0.073	Aluminium	Yes
IBA FC65-P	0.65	23.0	3.1	POM	0.057	Aluminium	Yes
Exradin A12	0.64	n.a.[b]	3.1	C-552	0.088	C-552	Yes
Exradin A19	0.62	n.a.[b]	3.1	C-552	0.088	C-552	Yes

[a] Although PTW 31010 does not meet the reference class specification, as demonstrated in Ref. [98], it is included here as an option for flattening filter free beams, where a shorter thimble is potentially advantageous. Use of this chamber type requires additional characterization and may result in a larger overall uncertainty in the determination of absorbed dose to water.

[b] n.a.: not applicable. Manufacturer data state 21.6 mm for the electrode length, and 26.5 mm (A12) and 26.2 mm (A19) for a so called 'spot size', defined as the smallest circle that inscribes the collecting volume and shell.

4.2.1. Plane-parallel ionization chambers

TABLE 5. CHARACTERISTICS OF PLANE PARALLEL CHAMBER TYPES FOR MEGAVOLTAGE PHOTON AND ELECTRON BEAMS *(adapted from Ref. [10])*

Ionization chamber type	Materials	Window thickness	Electrode spacing	Collecting electrode diameter	Guard ring width
Exradin A10 Markus type chamber	Kapton window C-552 body	3.86 mg/cm^2 0.05 mm	2 mm	5.4 mm	4.3 mm
Exradin 11[a] Roos type chamber	Wall and electrode in model P11: polystyrene equiv. model A11: C-552	1 mm polystyrene (P11) C-552 (A11)	2 mm	20 mm	4.4 mm
IBA PPC05	C-552 window and body Graphited (PEEK[b]) electrode	176 mg/cm^2 1 mm	0.5 mm	10 mm	3.5 mm
IBA PPC40 Roos type chamber	PMMA and graphite window Graphited electrode	118 mg/cm^2 1 mm	2 mm	16 mm	4 mm
IBA NACP	Mylar foil and graphite window, PMMA body Graphited electrode	104 mg/cm^2 0.6 mm	2 mm	10 mm	3 mm
PTW 34001 Roos type chamber	PMMA and graphite window Graphited electrode	132 mg/cm^2 1.13 mm	2 mm	16 mm	4 mm
PTW 34045 Advanced Markus type chamber	Polyethylene foil window PMMA cap, PMMA body	106 mg/cm^2 1.3 mm (incl. cap)	1 mm	5 mm	2 mm
PTW 23343[c] Markus type chamber	Polyethylene foil window PMMA cap, PMMA body	106 mg/cm^2 1.3 mm (incl. cap)	2 mm	5.3 mm	0.2 mm
Sun Nuclear SNC350p Roos type chamber	PMMA and graphite window Graphited electrode	n.a.[d]	2 mm	15.6 mm	4.1 mm

[a] Exradin T11 is no longer recommended because of the hygroscopic nature of A-150 plastic.

[b] Polyetheretherketone ($C_{19}H_{18}O_3$) 1.265 g/cm^3.

[c] The PTW 23343 (Markus) chamber is included here, despite having a narrower guard ring than specified in Section 4.2.1, as it is still commonly used for a range of beam modalities and applications.

[d] n.a.: not applicable

4.2.1. Other plane-parallel ionization chambers

TABLE 6. CHARACTERISTICS OF PLANE PARALLEL IONIZATION CHAMBERS USED FOR PROTONS AND HEAVIER ION BEAMS

Ionization chamber type	Cavity volume (cm^3)	Collecting electrode diameter (mm)	Window material	Window thickness (mm)
PTW 34070	10.5	81.6	PMMA	3.47
PTW 34080	10.5	81.6	PMMA	0.62
PTW 34073	2.5	39.6	PMMA	1.13

Note: For proton dosimetry, cylindrical chambers (Table 4) can also be used.

TABLE 7. CHARACTERISTICS OF PLANE PARALLEL IONIZATION CHAMBERS USED FOR X RAY DOSIMETRY AT LOW ENERGY

Ionization chamber type	Cavity volume (cm^3)	Collecting electrode diameter (mm)	Window material	Window thickness (mg/cm^2)
PTW 23342	0.02	5.1	Polyethylene	2.76
PTW 23344	0.20	15.9	Polyethylene	2.76

4.2.2. Measuring assembly

The measuring assembly for the measurement of charge (or current) includes an electrometer and a power supply for the polarizing voltage of the ionization chamber. The electrometer should have a digital display and should be capable of four digit resolution (i.e. 0.1% resolution on the reading). The variation in the response should not exceed ±0.2% over one year (long term stability).

The electrometer and the ionization chamber may be calibrated together as a complete system or separately. The latter option can be useful in centres that have several electrometers and/or chambers.

It should be possible to reverse the polarity of the polarizing voltage, so that the polarity effect of the ionization chamber can be determined, and to vary the voltage in order to determine the collection efficiency, as described in Section 4.4.3.4. The available range of polarizing voltages should be 50–400 V for ionization chambers used for radiotherapy dosimetry.

4.2.2. Measuring assembly

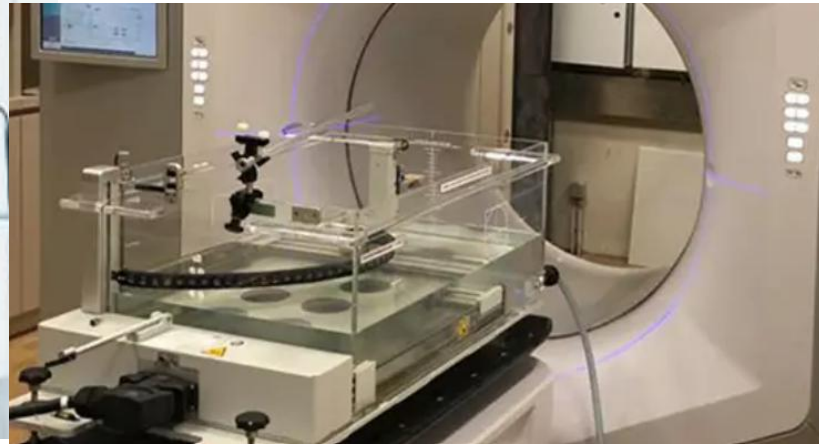
4.2.3. Phantoms

Water is the reference medium for measurements of absorbed dose for medium energy X rays and photon, electron, proton and heavier ion beams. The phantom should extend to at least 5 cm beyond all four sides of the largest field size employed at the depth of measurement. There should also be a margin of at least 5 g/cm^2 beyond the maximum depth of measurement, except for medium energy X rays, in which case it should extend to at least 10 g/cm^2. In practice, these requirements can be met with a standard 30 cm × 30 cm × 30 cm acrylic walled phantom available from many suppliers.

Solid phantoms in slab form, such as polystyrene, PMMA, and certain water equivalent plastics such as Solid Water, Plastic Water and Virtual Water (see Refs [103, 104]) may **not** be used for reference dosimetry, except in the case of low energy X rays, where a PMMA phantom is permitted. However, Ref. [12] mentions the possibility of using solid phantoms for some treatment machines where the use of water phantoms is impractical. In these situations, only a water equivalent solid phantom material may be used for reference dosimetry and for the measurement of beam quality indices.

Plastic (slab) phantoms can be used for routine quality assurance measurements, provided that they have been suitably commissioned. This

Water phantoms



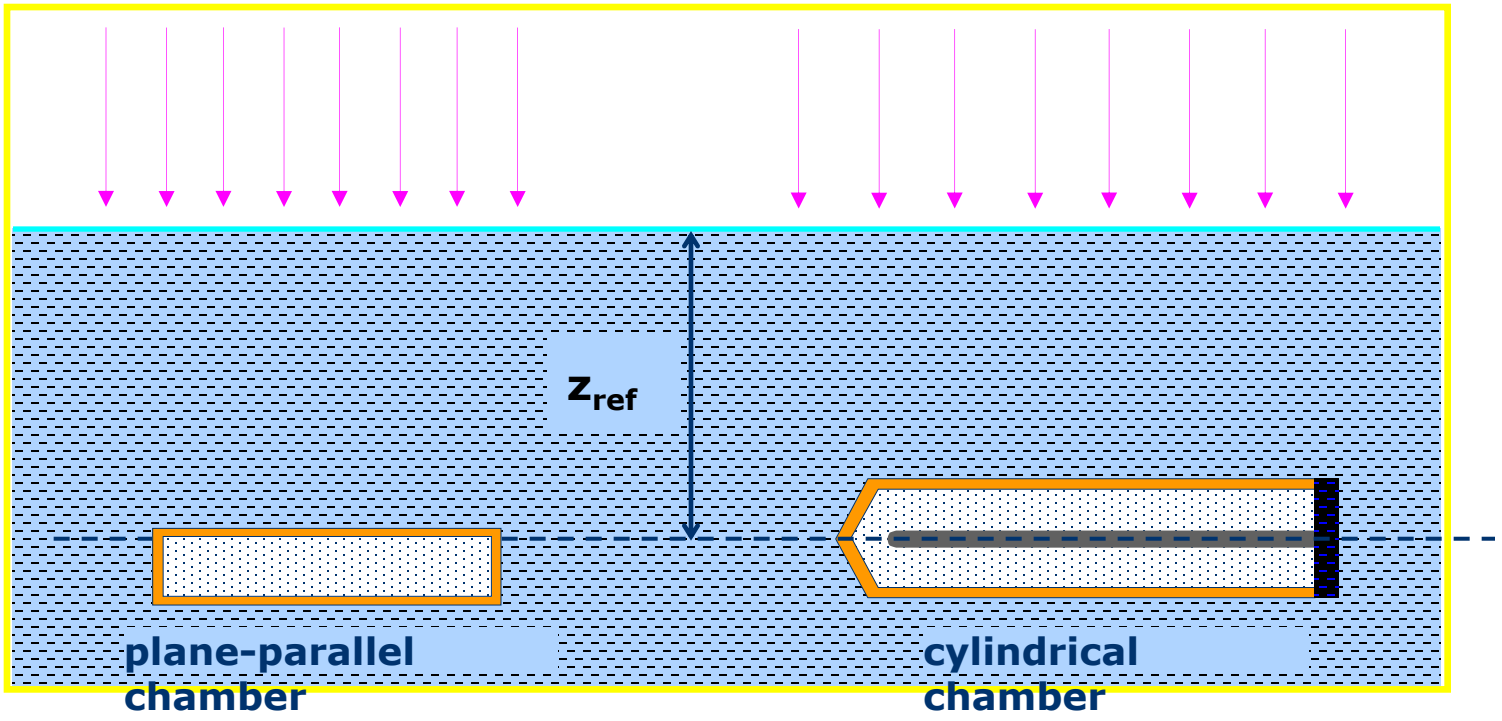
Dosimetry is done in a phantom

Because it's a good model for the human body

4.2.4. Waterproof sleeve

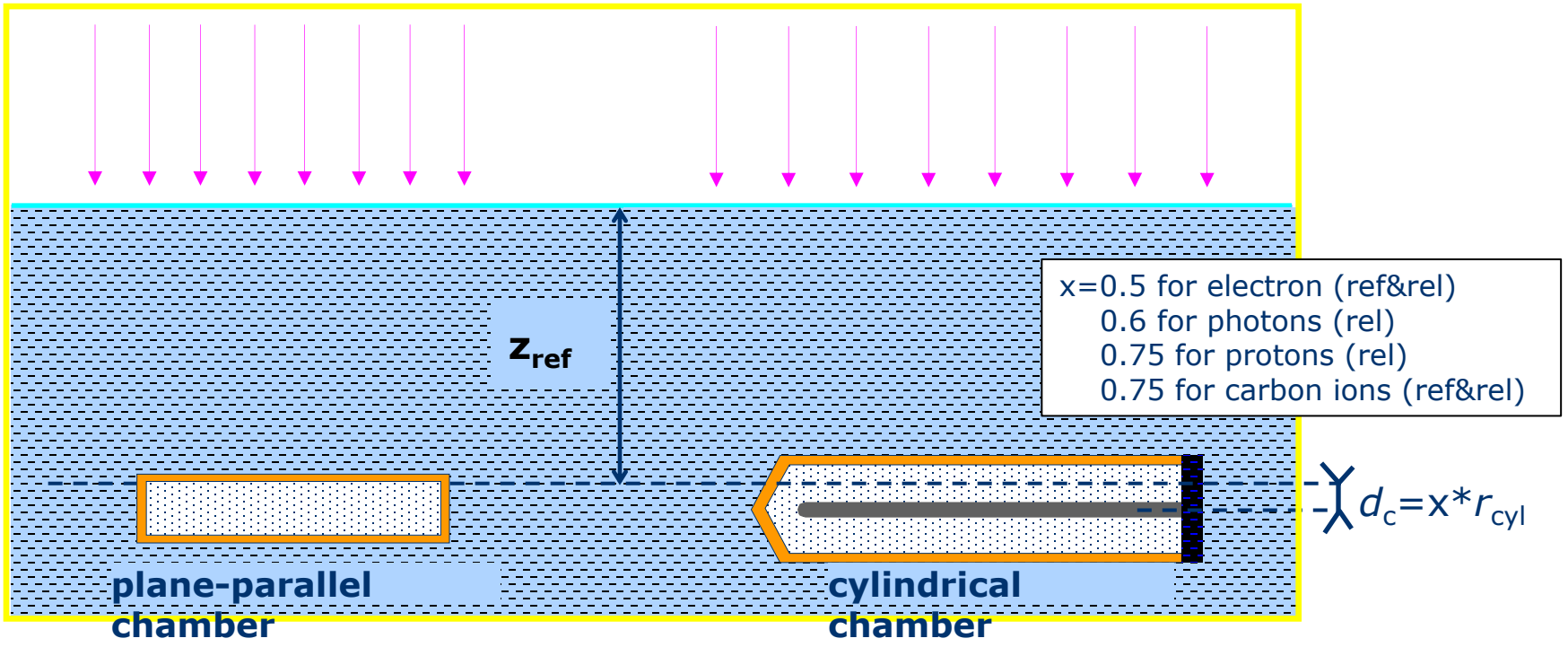
Unless the ionization chamber is designed so that it can be inserted directly into water, it has to be used with a waterproof sleeve. The sleeve should be made of PMMA, with a wall that is sufficiently thin (preferably not greater than 1.0 mm in thickness) to allow the chamber to achieve thermal equilibrium with the water in less than 10 min. The sleeve should be designed to allow the air pressure in the chamber to reach ambient air pressure quickly; an air gap of 0.1–0.3 mm between the chamber and the sleeve is adequate. This specification

4.2.5. Positioning at the reference depth



The reference points is always on the inner surface of the window at its centre for plane-parallel chambers and on the central axis at the centre of the cavity volume for cylindrical chambers. Sometimes this is positioned at the reference depth, sometimes shifted according to the effective point of measurement P_{eff}

4.2.5. Positioning at the reference depth



The reference points is always on the inner surface of the window at its centre for plane-parallel chambers and on the central axis at the centre of the cavity volume for cylindrical chambers. Sometimes this is positioned at the reference depth, sometimes shifted according to the effective point of measurement P_{eff}

Some subtlety in positioning of plane-parallel chambers – TRS-398 (2000)

4.2.5.2. Chamber wall effects

The factor p_{wall} included in calculated k_{Q,Q_o} factors corrects for the different radiation response of the chamber wall material from that of the phantom material. However, p_{wall} does not include the effect of the different attenuation of the primary fluence by the chamber wall compared with the same thickness of phantom material. When the calibration quality Q_o and the user quality Q are the same, this attenuation is accounted for in the calibration of the chamber. Even when Q_o is not the same as Q, the wall attenuation in photon beams is sufficiently small that cancellation may be assumed. On the other hand, in charged particle beams, the attenuation due to the chamber wall can be significantly different from that due to the same thickness of phantom material, and strictly, the water-equivalent thickness of the chamber wall should be taken into account when calculating where to position the chamber. In practice, for the wall thicknesses normally encountered the required adjustment is small and may be neglected.

Positioning of plane-parallel chambers

4.2.5.2. Chamber wall effects

The factor p_{wall} included in calculated k_{Q,Q_0} factors in the previous TRS-398 data corrects for the different radiation response of the chamber wall material from that of the phantom material. However, p_{wall} does not include the effect of the different attenuation of the primary fluence by the chamber wall compared with the same thickness of phantom material. When the calibration quality Q_0 and the user quality Q are the same, this attenuation is accounted for in the calibration of the chamber. Even when Q_0 is not the same as Q, the wall attenuation in photon beams is sufficiently small that cancellation may be assumed. On the other hand, in charged particle beams, the energy loss due to the chamber wall can be significantly different from that due to the same thickness of phantom material, and the water-equivalent thickness of the chamber wall should be taken into account when calculating where to position the chamber. For the chambers listed in Tables 4 and 5 the difference between physical and water-equivalent thicknesses is generally small (< 1 mm water).

4.3. Calibration of ionization chambers

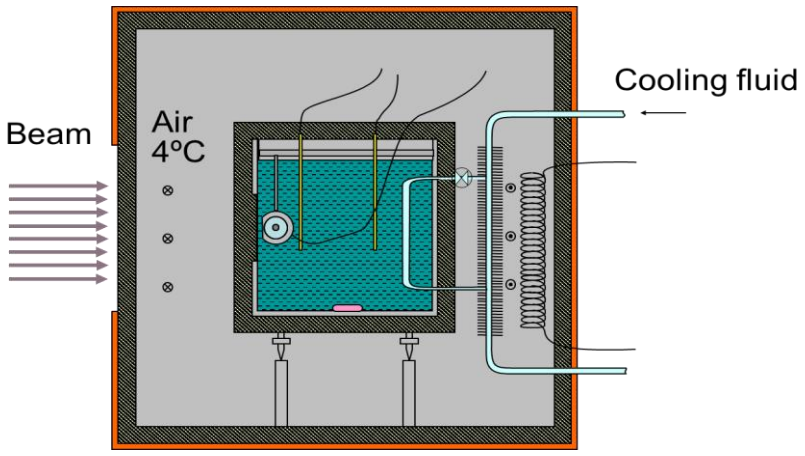
4.3.1. Calibration in a ^{60}Co beam

4.3.2. Calibration in kilovoltage X rays

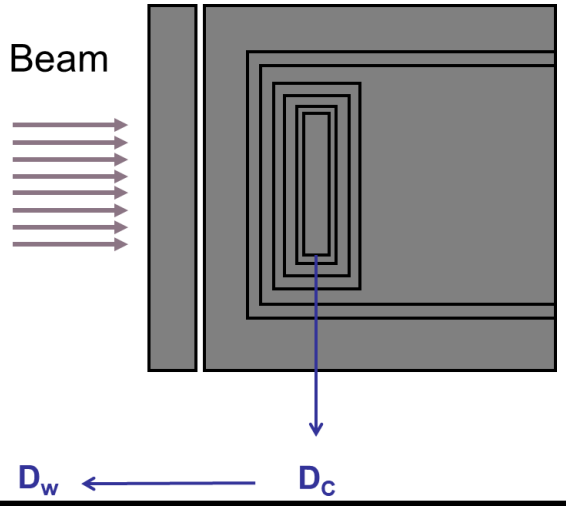
4.3.3. Calibration at other qualities

A robust system of D_w standards

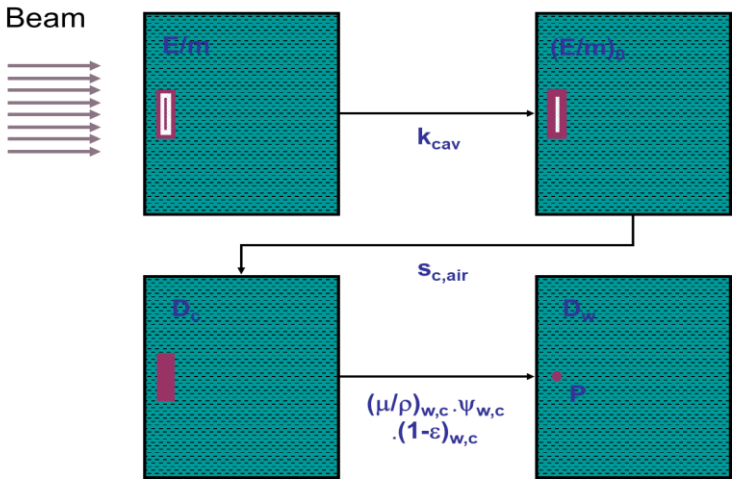
Water calorimetry



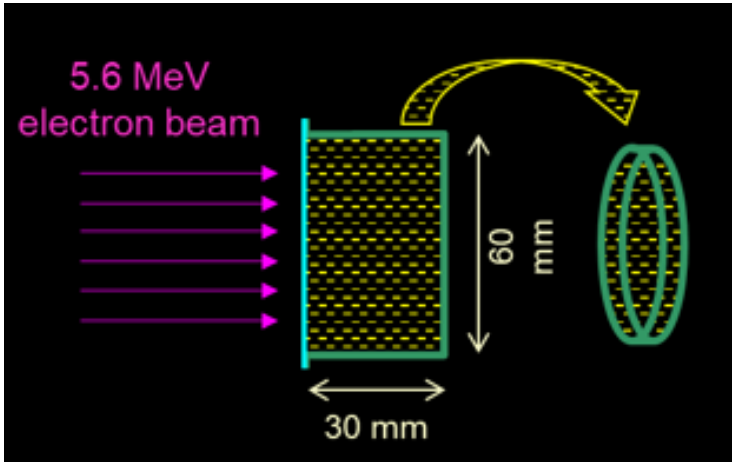
Graphite calorimetry



Ionometry

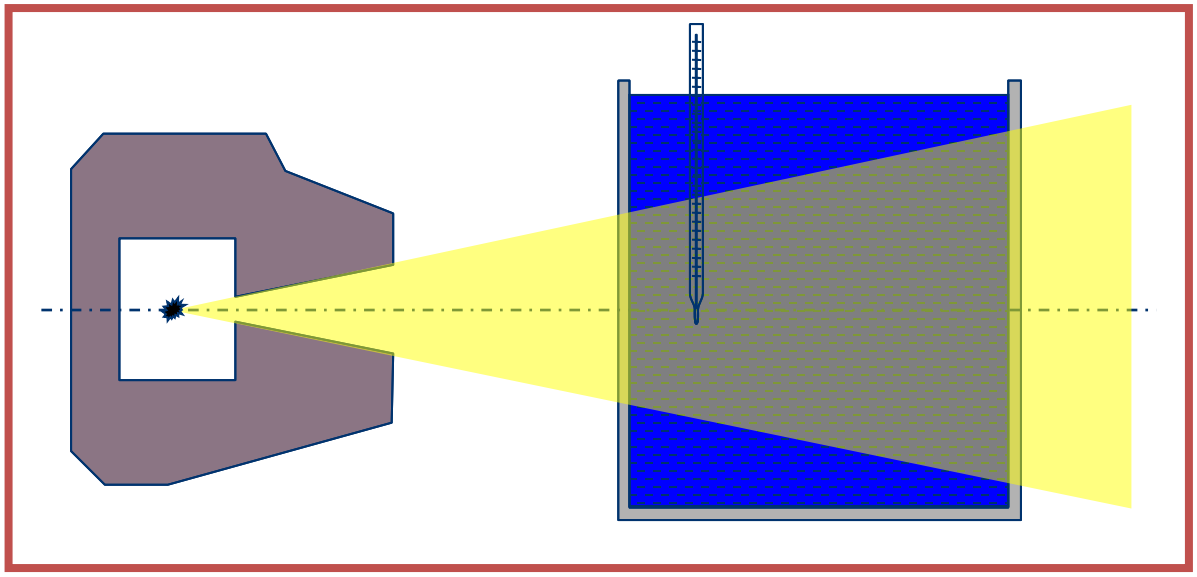


Fricke



Calorimetry

Radiation energy turns into heat



heat is tiny, but measurable

Calorimetry - principle

$$D = c\ \Delta T$$

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + \frac{1}{c}\frac{\partial D}{\partial t}$$

	c ($J \cdot kg^{-1} \cdot K^{-1}$)	$\Delta T/D$ ($mK \cdot Gy^{-1}$)	α ($m^2 \cdot s^{-1}$)
water	4180	0.24	1.44×10^{-7}
graphite	710	1.41	0.80×10^{-4}

Calorimetry: principle

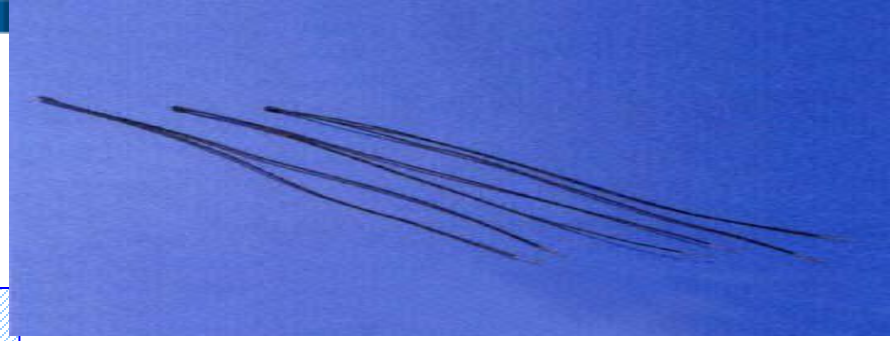
Mind: hold glass of water for 10 s

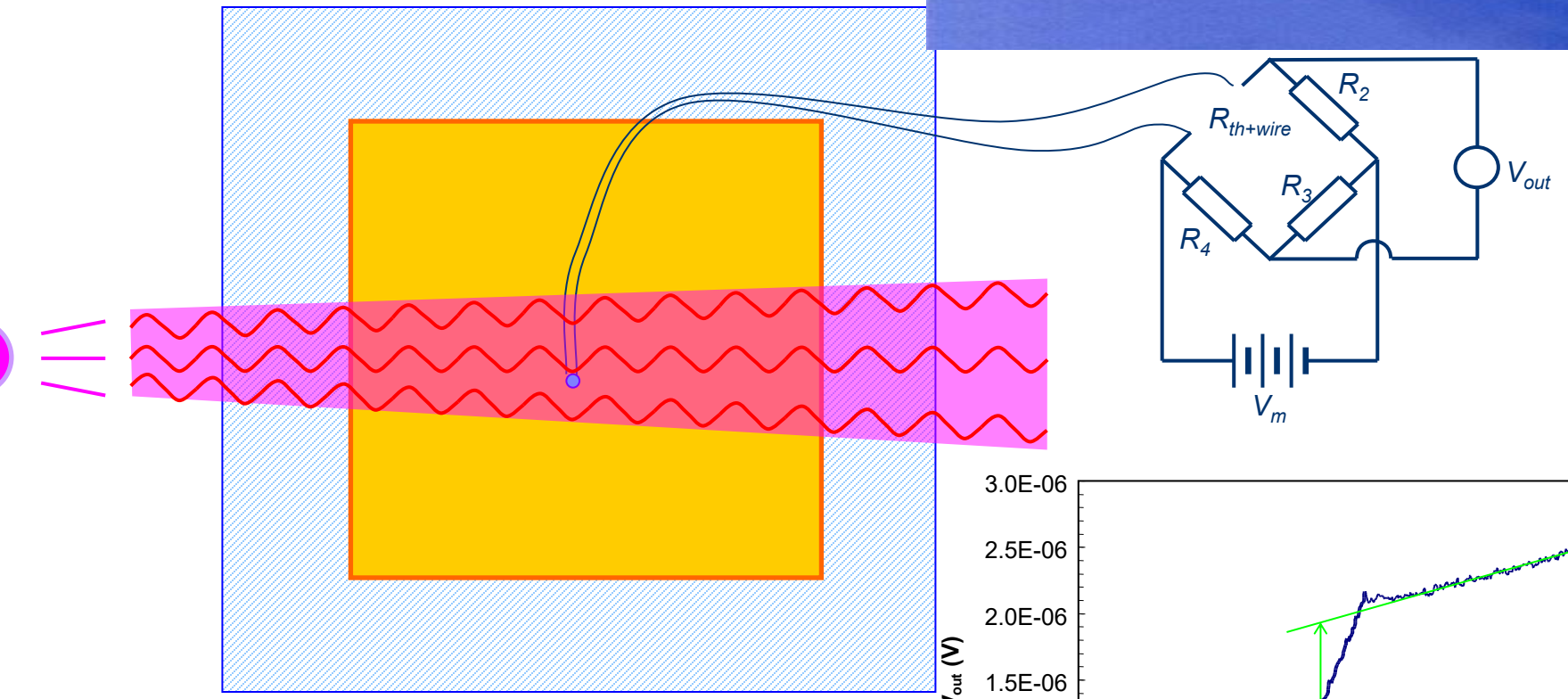
→ the amount of energy put in corresponds to the energy needed to kill a tumour! (but it is non-ionizing so it doesn't do anything)

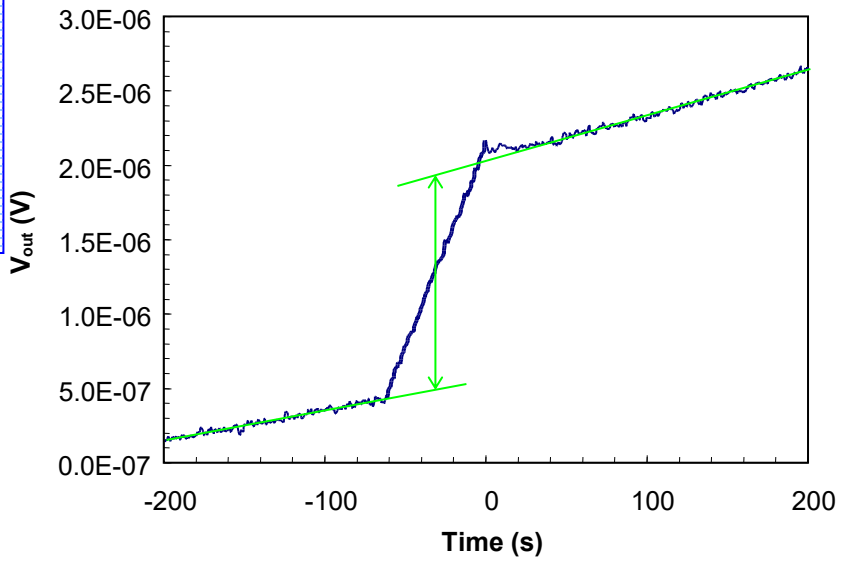
→ temperature rises of level mK

→ influence of environment is huge

Calorimetry

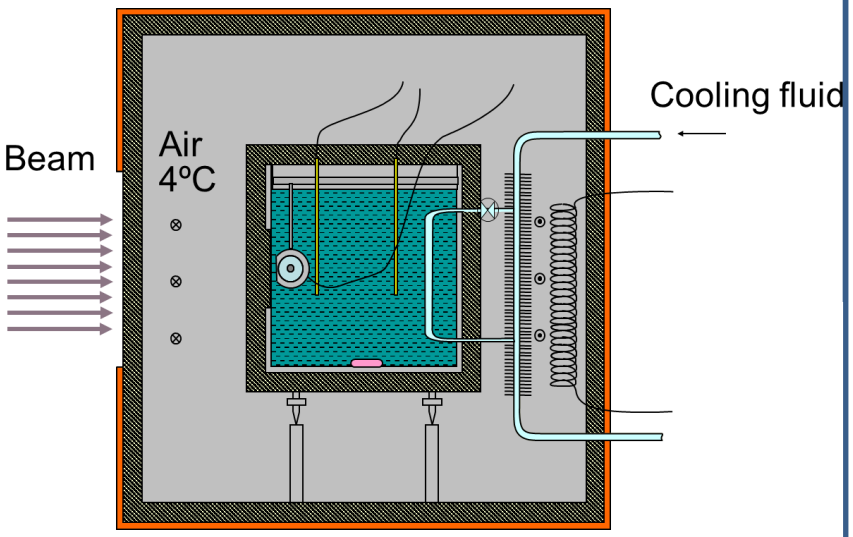




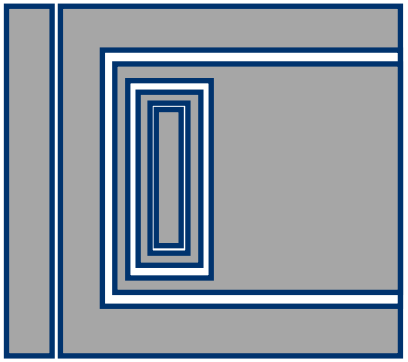


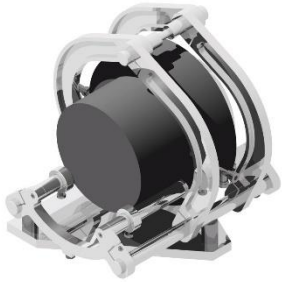
Calorimeters: examples

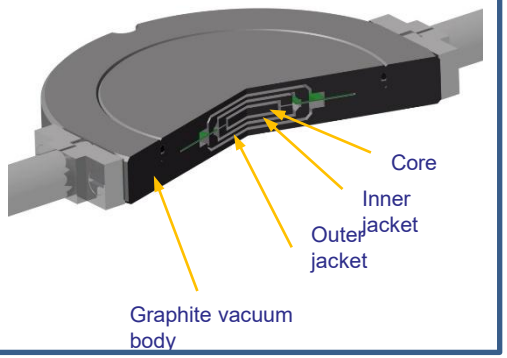
Water calorimeter



graphite calorimeter







Dose determination with gas-filled ionization chamber

$$D_{\text{med}} = D_{\text{gas}}\ s_{\text{med,gas}}\ p$$

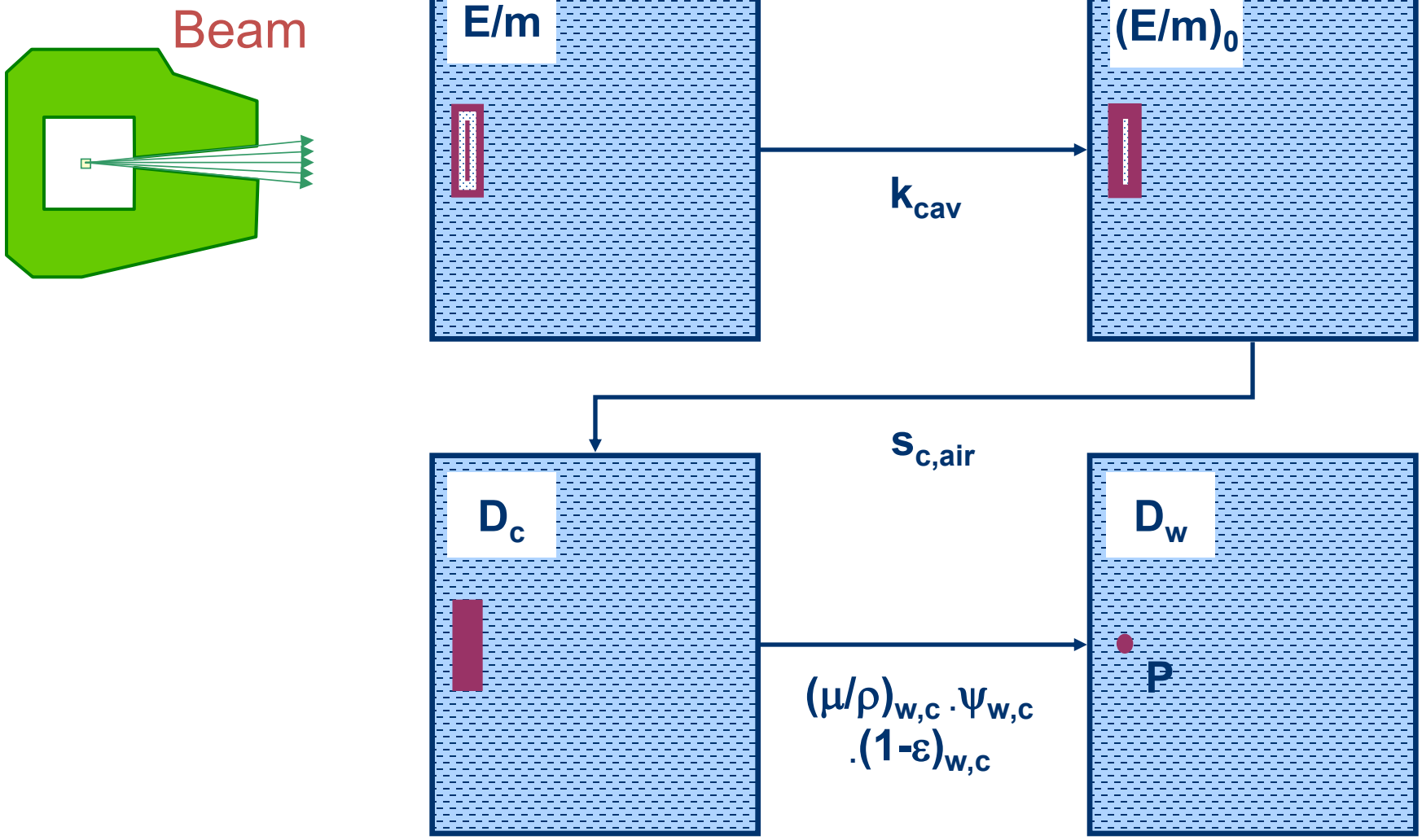
$$D_{\text{med}} = \frac{Q\ (W_{\text{gas}}/e)}{m_{\text{gas}}}\ s_{\text{med,gas}}\ p = \frac{Q\ (W_{\text{gas}}/e)}{\rho_{\text{gas}}\ V_{\text{cav}}}\ s_{\text{med,gas}}\ p$$

Q : charge produced in the gas of the chamber

W_{gas}: mean energy required to produce an ion-pair in gas

D_w from ionization chamber dosimetry

(Boutillon and Peroche 1993 Phys Med Biol 38 439-454)



Dose to water determination with air-filled ionization chamber

$$D_{\mathrm{w}} = \frac{Q\ (W_{\mathrm{air}}/e)}{\rho_{\mathrm{air}}\ V_{\mathrm{cav}}} s_{\mathrm{w,air}}\ p$$

Q : charge produced in the air of the chamber

W_{air}: mean energy required to produce an ion-pair in air

For commercially available chambers, the volume V_{cav} is not known with the necessary accuracy

We have to rely on methods other than "first principles", which involve the use of ion chamber calibration factors

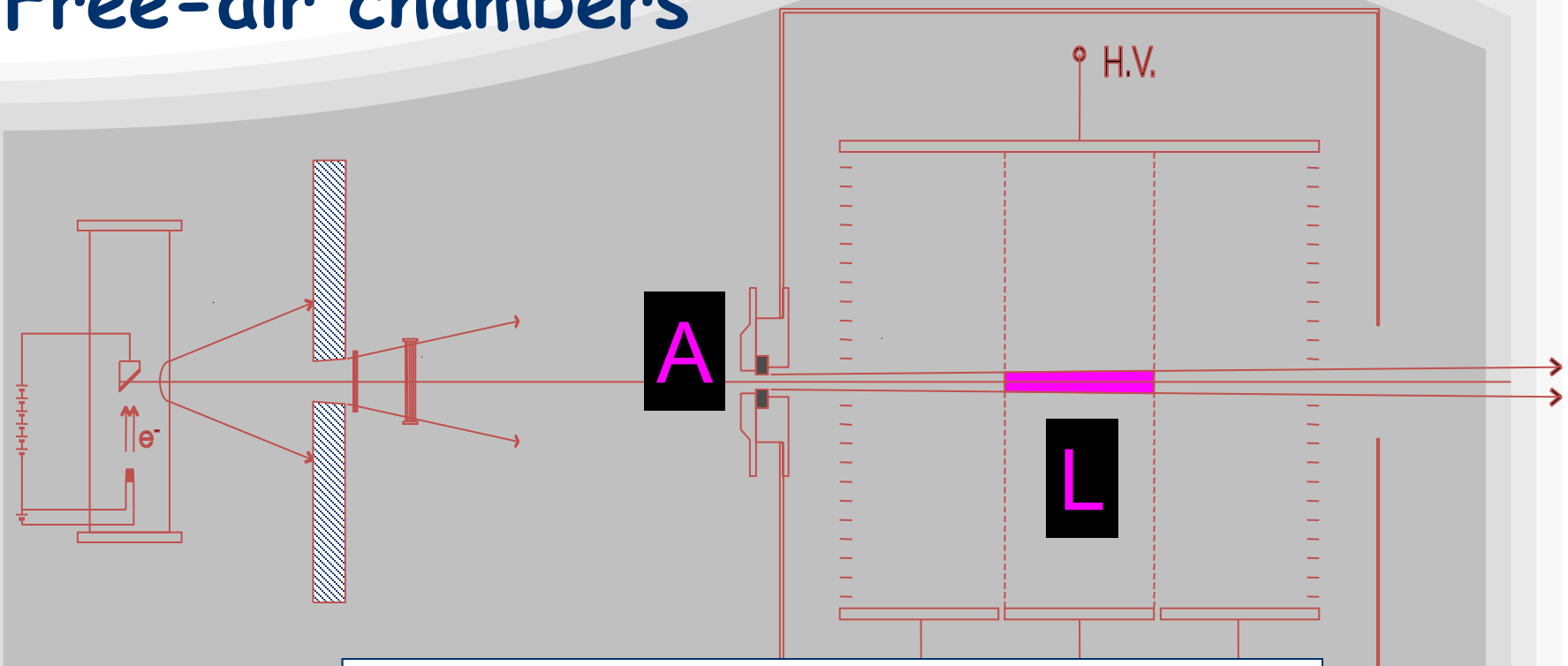
Free-air chambers

primary standard of exposure (we measure the ionisation per mass of air), rather than of air kerma (we don't measure the energy released)

every electron track producing ionisation which will be collected should originate when a primary photon scatters (or is absorbed) in air.

no electron track can reach the collecting electrodes.

Free-air chambers



$$K_{air} = \frac{M}{V.\rho_{air}} . (W_{air}/e).k_s.k_h.k_a.k_{sc}.k_e$$

A.L

Calibration in a ^{60}Co beam

P_0 -> $D_{w,^{60}Co}$

$$\rightarrow N_{D,\mathrm{w},^{60}Co} = \frac{D_{\mathrm{w},^{60}Co}}{M_{\mathrm{corr},^{60}Co}}$$

Reference conditions for calibration in a ^{60}Co beam

TABLE 8. REFERENCE CONDITIONS RECOMMENDED FOR THE CALIBRATION OF IONIZATION CHAMBERS IN ^{60}Co GAMMA RADIATION IN STANDARDS LABORATORIES

Influence quantity	Reference value or reference characteristic
Phantom material	Water
Phantom size	30 cm × 30 cm × 30 cm (approximately)
Source–chamber distance[a]	100 cm
Air temperature[b]	20.0°C [c]
Air pressure	101.33 kPa
Reference point of the ionization chamber	For cylindrical chambers, on the chamber axis at the centre of the cavity volume For plane parallel chambers, on the inner surface of the entrance window, at the centre of the window

TABLE 8. REFERENCE CONDITIONS RECOMMENDED FOR THE CALIBRATION OF IONIZATION CHAMBERS IN ^{60}Co GAMMA RADIATION IN STANDARDS LABORATORIES (cont.)

Influence quantity	Reference value or reference characteristic
Depth in phantom of the reference point of the chamber[a]	5 g/cm^2
Field size at the position of the reference point of the chamber	10 cm × 10 cm [d]
Relative humidity	50% [e]
Polarizing voltage and polarity	No reference values are recommended, but the values used should be stated in the calibration certificate
Dose rate	No reference values are recommended, but the dose rate used should always be stated in the calibration certificate. The certificate should also state whether a recombination correction has been applied and, if so, the value of the correction

[a] After a water phantom with a plastic window has been filled, its dimensions may slowly change with time. Evaporation may also be non-negligible. It may therefore be necessary to check the source–surface distance and the chamber depth every few hours.

[b] The temperature of the air in a chamber cavity should be taken to be that of the phantom, which should be measured; this is not necessarily the same as the temperature of the surrounding air.

[c] In some countries the reference air temperature is 22°C.

[d] Some laboratories use a set-up with a source–surface distance of 100 cm; in that case, the field size is defined at the phantom surface.

[e] For relative humidity values in the range 20%–80%, no correction for humidity is required (see Section 4.4.3.1).

Reference conditions for calibration in a low- or medium-energy x-ray beam

TABLE 9. REFERENCE CONDITIONS RECOMMENDED FOR THE CALIBRATION OF IONIZATION CHAMBERS IN TERMS OF ABSORBED DOSE TO WATER IN LOW AND MEDIUM ENERGY X RAY BEAMS IN STANDARDS LABORATORIES

Influence quantity	Reference value or reference characteristic	
	Low energy X rays	Medium energy X rays
Phantom material	PMMA or water equivalent plastic designed for use in kilovoltage X rays	Water
Phantom size (approximate)	12 cm × 12 cm × 6 cm	30 cm × 30 cm × 30 cm
	The phantom has to extend in the beam direction beyond the ionization chamber by at least 5 g/cm^2 for low energy X rays and 10 g/cm^2 for medium energy X rays, and in the lateral direction far enough beyond the reference field size used to ensure that the entire primary beam exits through the rear face of the phantom	
Source–surface distance	Treatment distance as specified by the user[a]	
Air temperature[b]	20°C [c]	
Air pressure	101.3 kPa	
Reference point of the ionization chamber	For plane parallel chambers, at the centre of the outside surface of the chamber window (or of the buildup foil, if used)	For cylindrical chambers, on the central axis at the centre of the cavity volume
Depth in phantom of the reference point of the chamber	Surface of the phantom	2 g/cm^2

TABLE 9. REFERENCE CONDITIONS RECOMMENDED FOR THE CALIBRATION OF IONIZATION CHAMBERS IN TERMS OF ABSORBED DOSE TO WATER IN LOW AND MEDIUM ENERGY X RAY BEAMS IN STANDARDS LABORATORIES (cont.)

Influence quantity	Reference value or reference characteristic	
	Low energy X rays	Medium energy X rays
Field size at the position of the reference point of the chamber[d]	Dependent on standards laboratory; a minimum of 3 cm in diameter or 3 cm × 3 cm	10 cm × 10 cm or 10 cm diameter
Relative humidity[e]	50%	
Polarizing voltage and polarity	No reference values are recommended, but the values used should be stated in the calibration certificate	
Dose rate	No reference values are recommended, but the dose rate used should always be stated in the calibration certificate. The certificate should also state whether a recombination correction has been applied and, if so, the value of the correction	

[a] If more than one source–surface distance is used, the greatest should be chosen for calibration.
[b] The temperature of the air in a chamber cavity should be taken to be that of the phantom, which should be measured; this is not necessarily the same as the temperature of the surrounding air.
[c] In some countries the reference air temperature is 22°C.
[d] If these field sizes do not correspond to any of the user's clinical beams, then the closest field size to that of the beams used clinically should be used.
[e] For relative humidity values in the range 20%–80% no correction for humidity is required (see Section 4.4.3.1).

Calibration in other qualities

P_0 -> $D_{w,Qo}$

$$\rightarrow \; N_{D,\mathrm{w},Q_0} = \frac{D_{\mathrm{w},Q_0}}{M_{\mathrm{corr},Q_0}}$$

4.4. Reference dosimetry in the user beam

$$D_{\mathrm{w},Q} = M_Q \, N_{D,\mathrm{w},Q_0} \, k_{Q,Q_0}$$

where

M_Q is the reading of the dosimeter incorporating the product $\prod k_i$ of the correction factors for influence quantities

k_{Q,Q_0} is the correction factor that corrects for the difference between the reference beam quality Q_0 and the actual quality Q being used.

4.4.2. Practical considerations

Stability checks (e.g., check source)

Thermal equilibration

Electrometer warm up

Pre-irradiation

Leakage

Repeatability (number of readings)

Radioactive check source

Warm up

Temperature and pressure correction

Correction for decay

4.4.2. Practical considerations, cont'd.

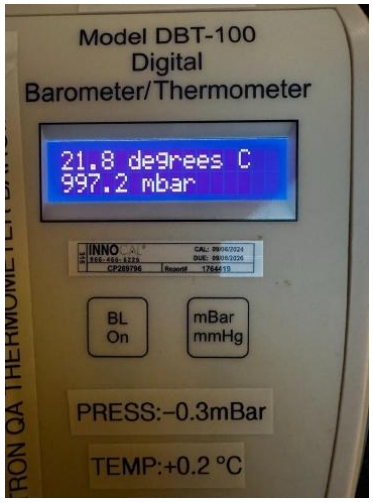
For relative dosimetry

(a) A transmission type monitor chamber intercepting the beam prior to the phantom;
(b) A detector positioned in air between the radiation source and the phantom, a few centimetres from the central axis;
(c) A detector positioned within the phantom, a few centimetres from the central axis.

4.4.3. Corrections for influence quantities

$$M_Q = M_{\text{raw}}\, k_{\text{elec}}\, k_{\text{TP}}\, k_{\text{pol}}\, k_{\text{s}}\, k_{vol}$$

Pressure and Temperature



$$k_{Tp} = \frac{(273.15 + T)}{(273.15 + T_0)} \frac{p_0}{p}$$

Polarity effect

$$k_{pol} = \frac{|M_+| + |M_-|}{2M}$$

Ion recombination (generic)

Method 1 (2V): $k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2$

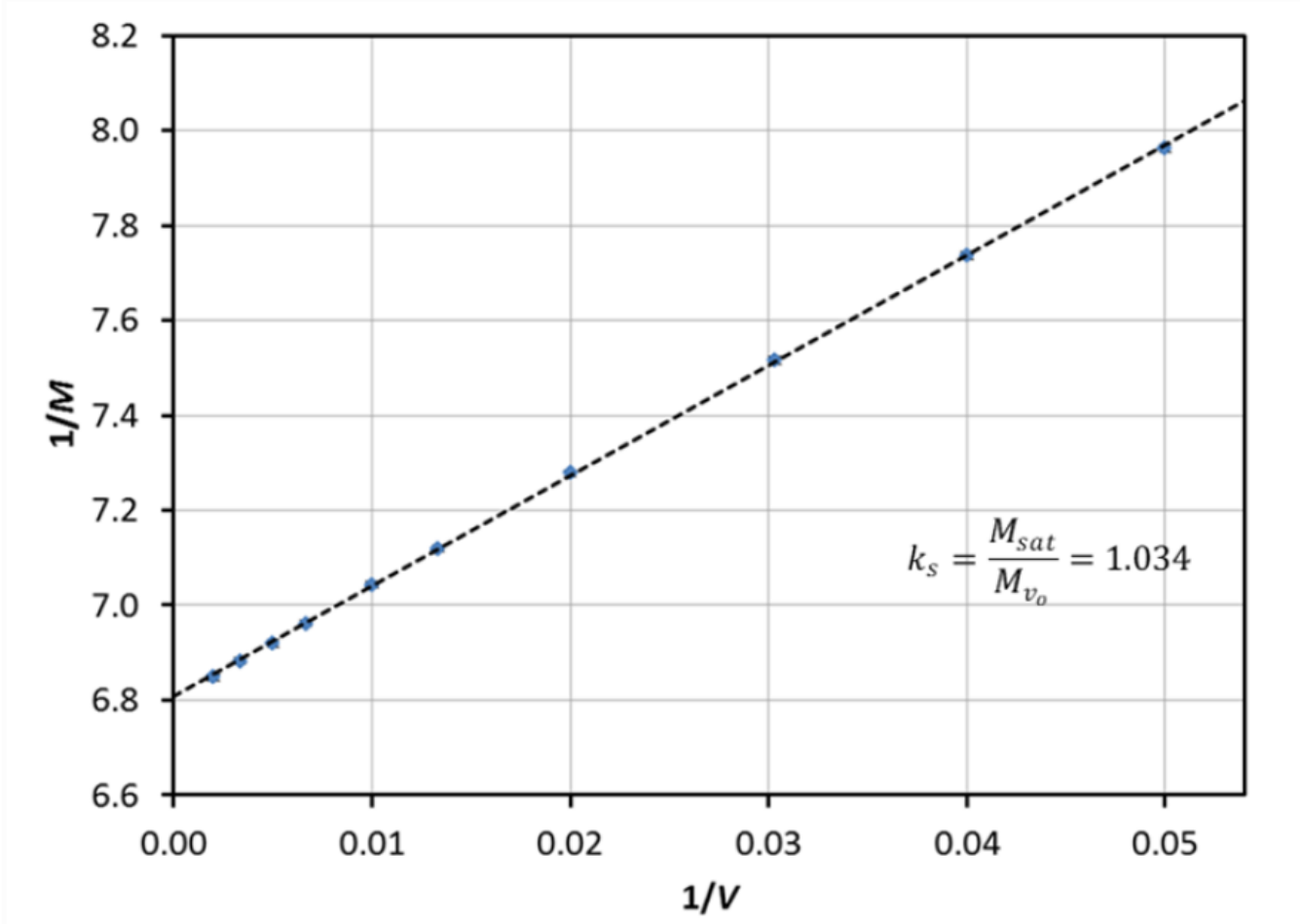
Method 2 (2V): $k_s = \frac{n-1}{n-M_1/M_2}$ or $k_s = \frac{n^2-1}{n^2-M_1/M_2}$

Method 3 (Niatel):

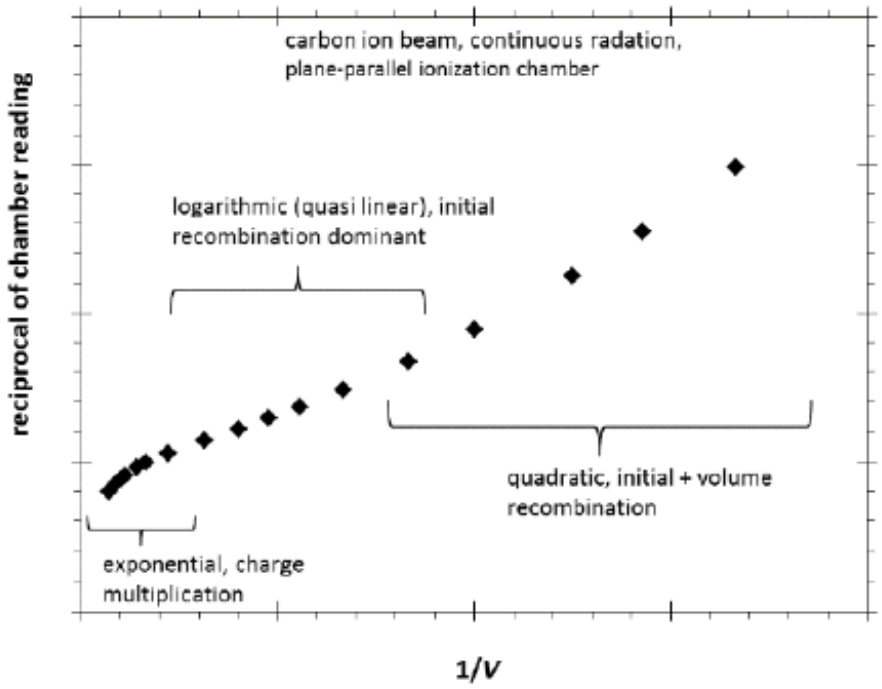
$k_s = 1 + \frac{b_0}{(n-1)} + \frac{b_1}{(n-1)}M_1$ or $k_s = 1 + \frac{b_0}{(n-1)} + \frac{b_1}{(n^2-1)}M_1$

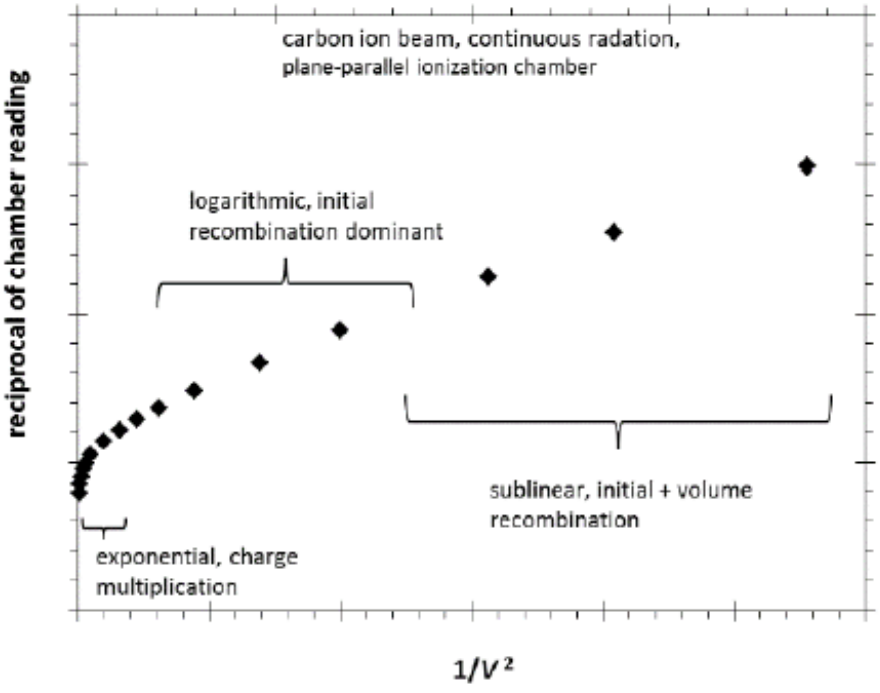
where $1+b_0$ and b_1 are the intercept and slope in a M_1/M_2 versus M_1 plot for different instantaneous dose rates or dose-per-pulse

Jaffé plot


8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
1/M
0.00
0.01
0.02
0.03
0.04
0.05
1/V
$k_s = \frac{M_{sat}}{M_{v_o}} = 1.034$

Jaffé plot

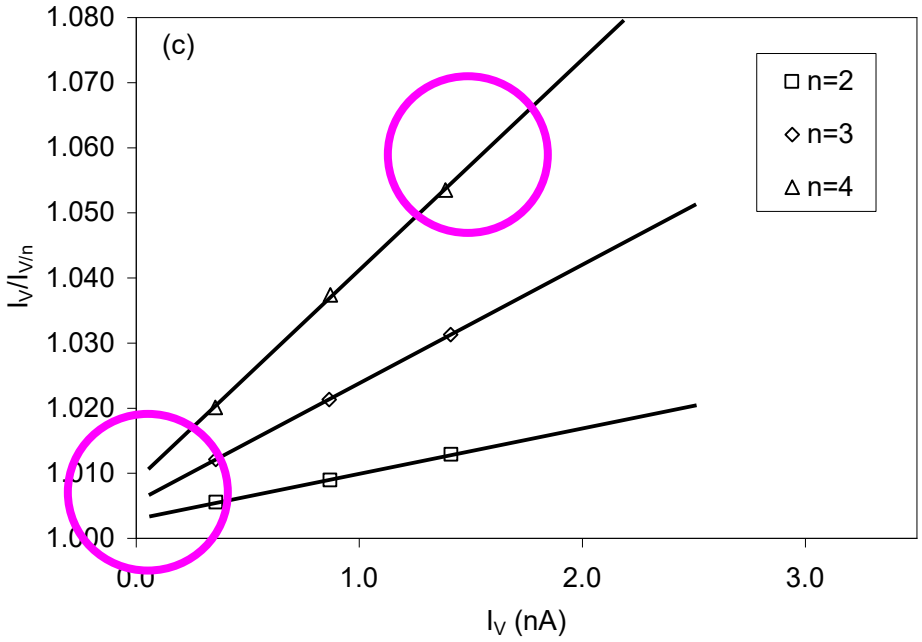

carbon ion beam, continuous radation,
plane-parallel ionization chamber
logarithmic (quasi linear), initial
recombination dominant
quadratic, initial + volume
recombination
exponential, charge
multiplication
reciprocal of chamber reading
1/V


carbon ion beam, continuous radation,
plane-parallel ionization chamber
logarithmic, initial
recombination dominant
sublinear, initial + volume
recombination
exponential, charge
multiplication
reciprocal of chamber reading
1/V²

Niatel method, e.g., continuous beam

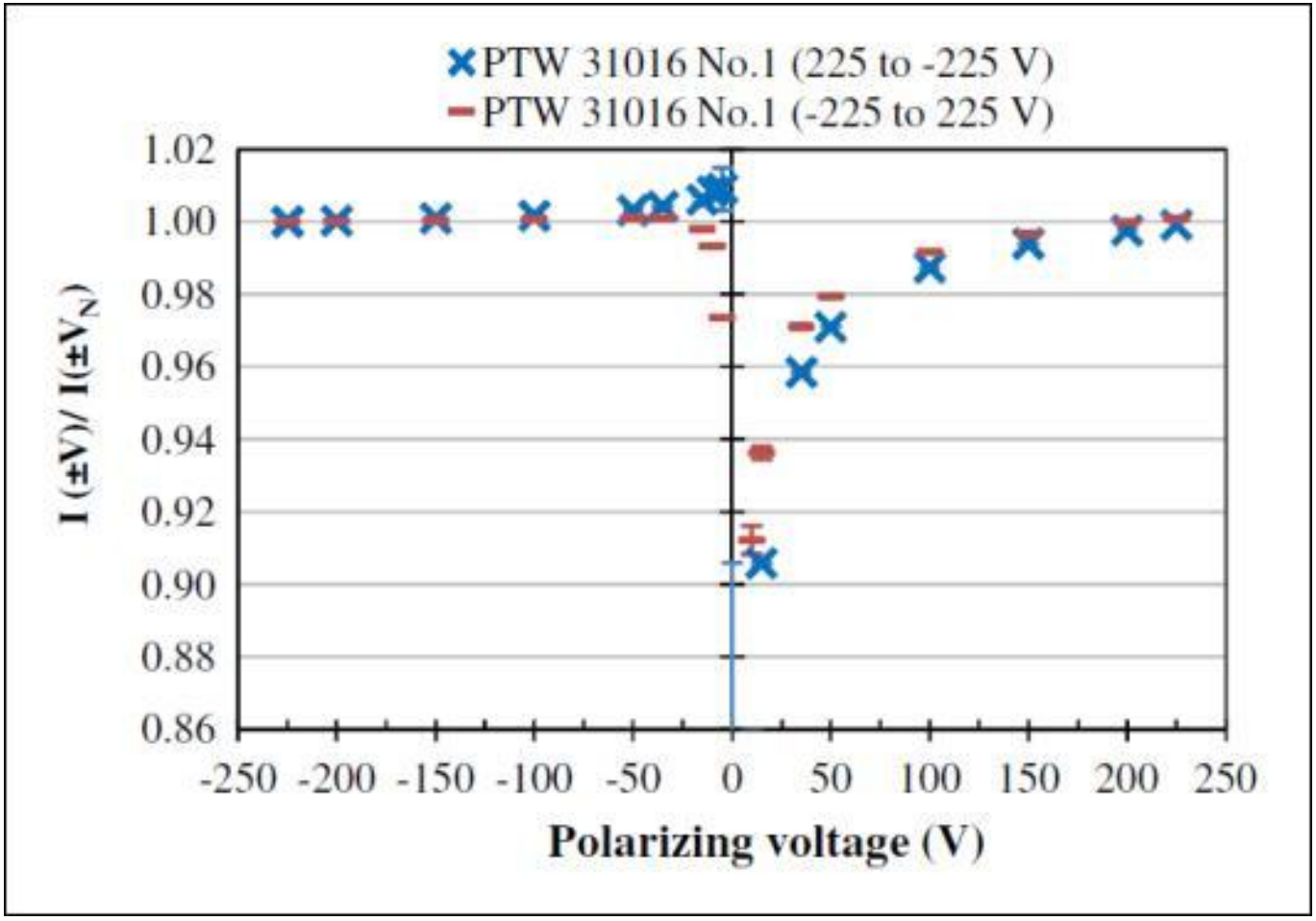
$$k_s = 1 + \frac{b_0}{(n-1)} + \frac{b_1}{(n^2-1)} M_1$$

Slope = b_1



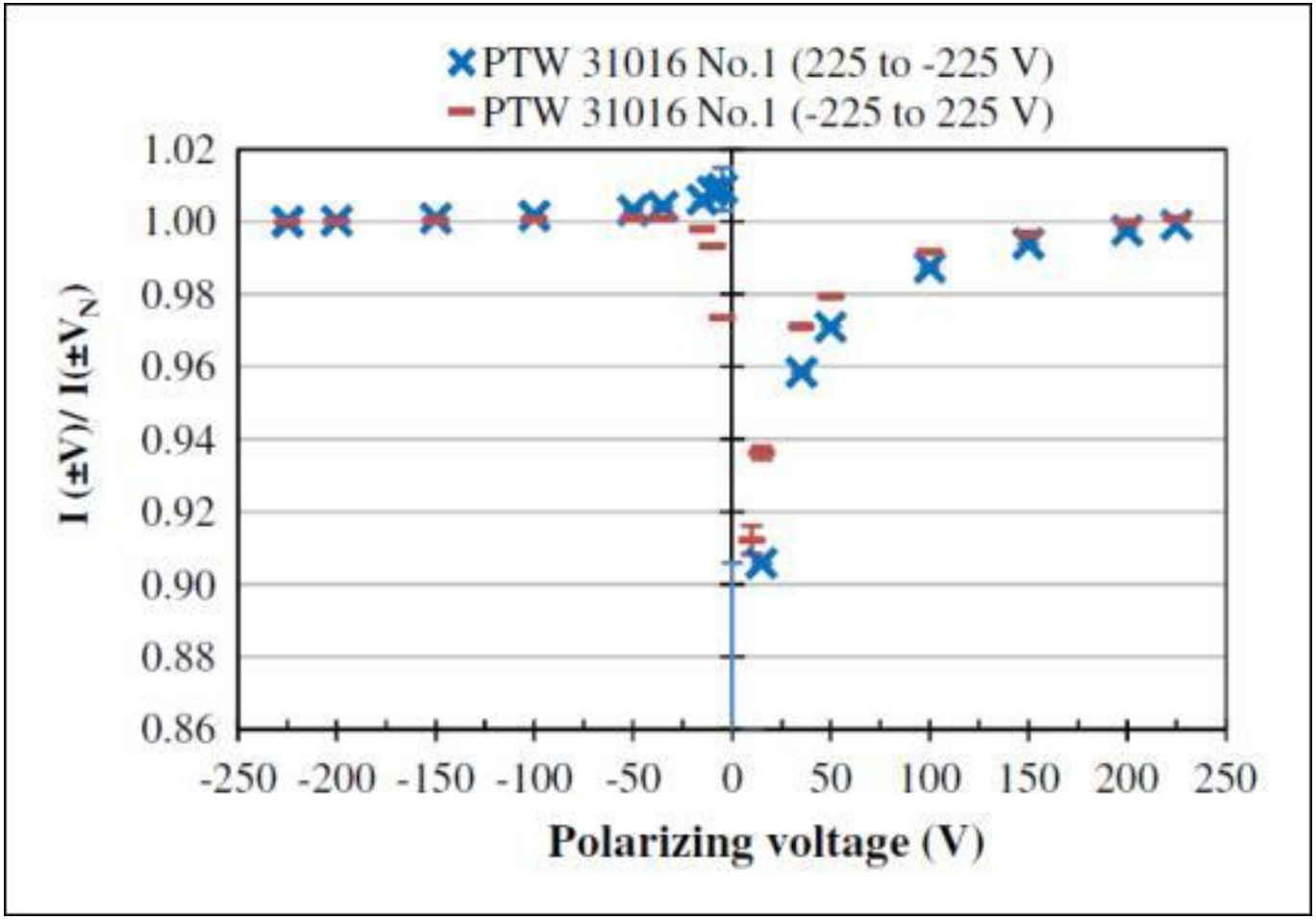
Intercept = $1+b_0$

Ion chambers, recombination



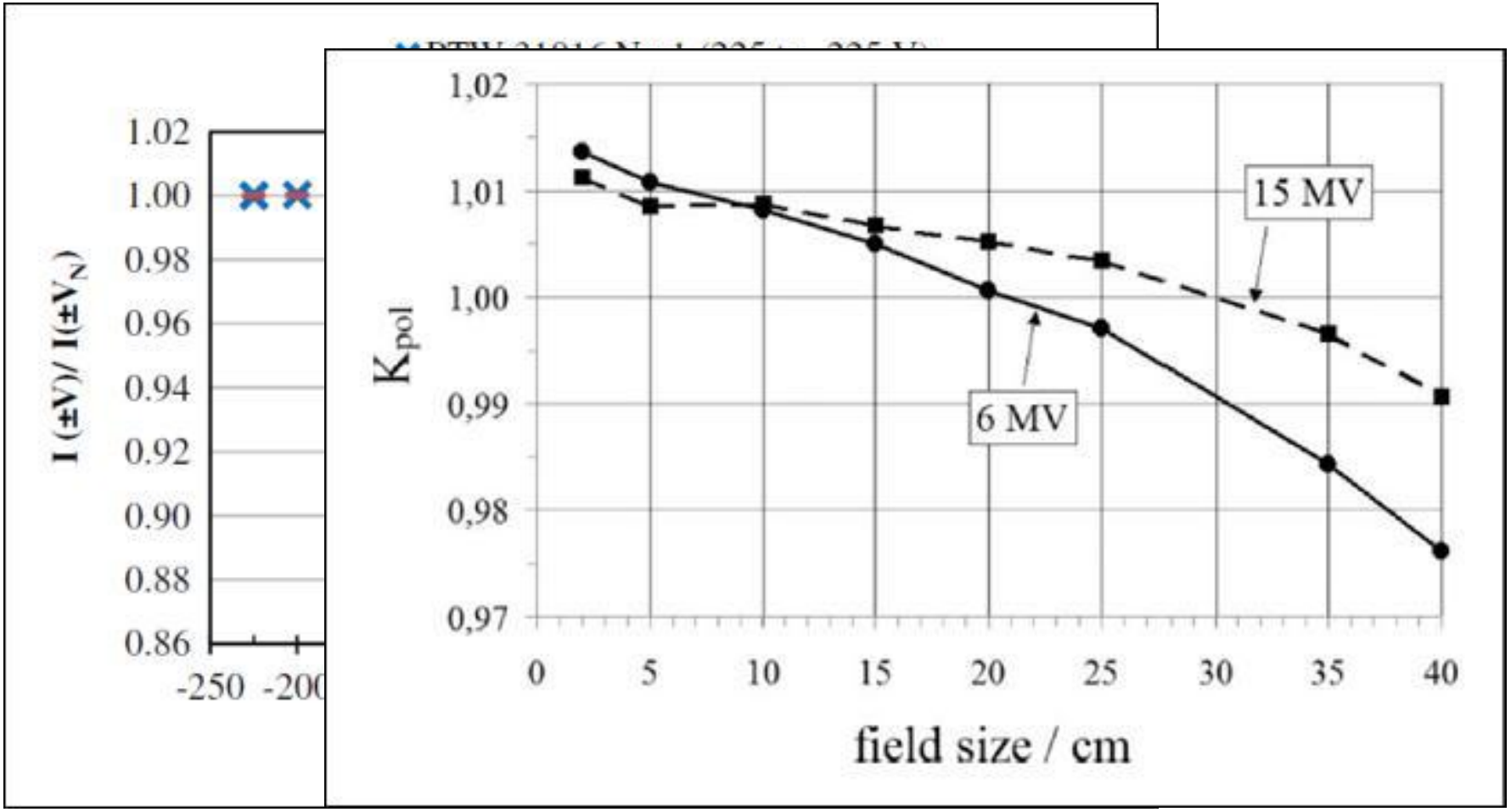
LeRoy et al., PMB 56:5637-51 (2011)

Ion chambers, recombination



LeRoy et al., PMB 56:5637-51 (2011)

Ion chambers, recombination , polarity

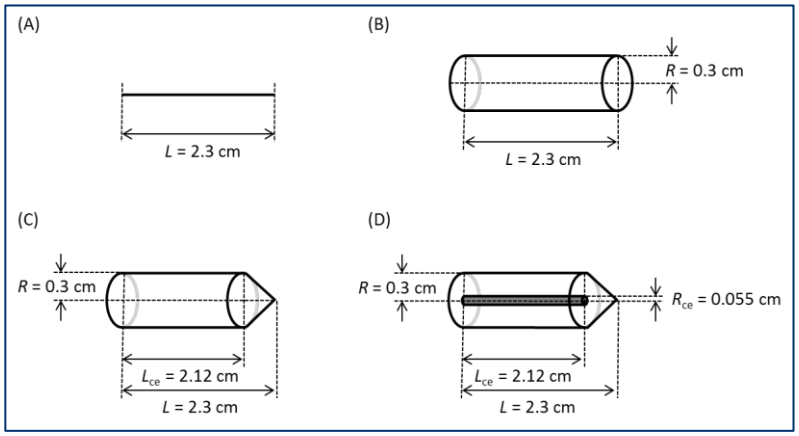


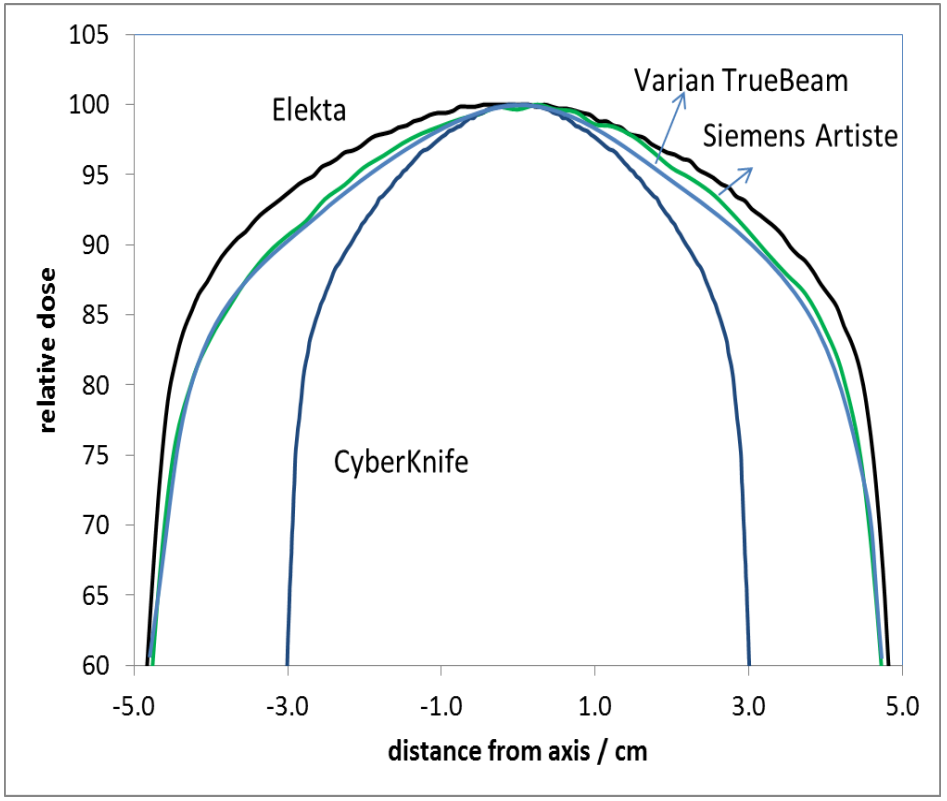
LeRoy et al., PMB 56:5637-51 (2011)

Agostinelli et al., Med Phys 35:3293-301 (2008)

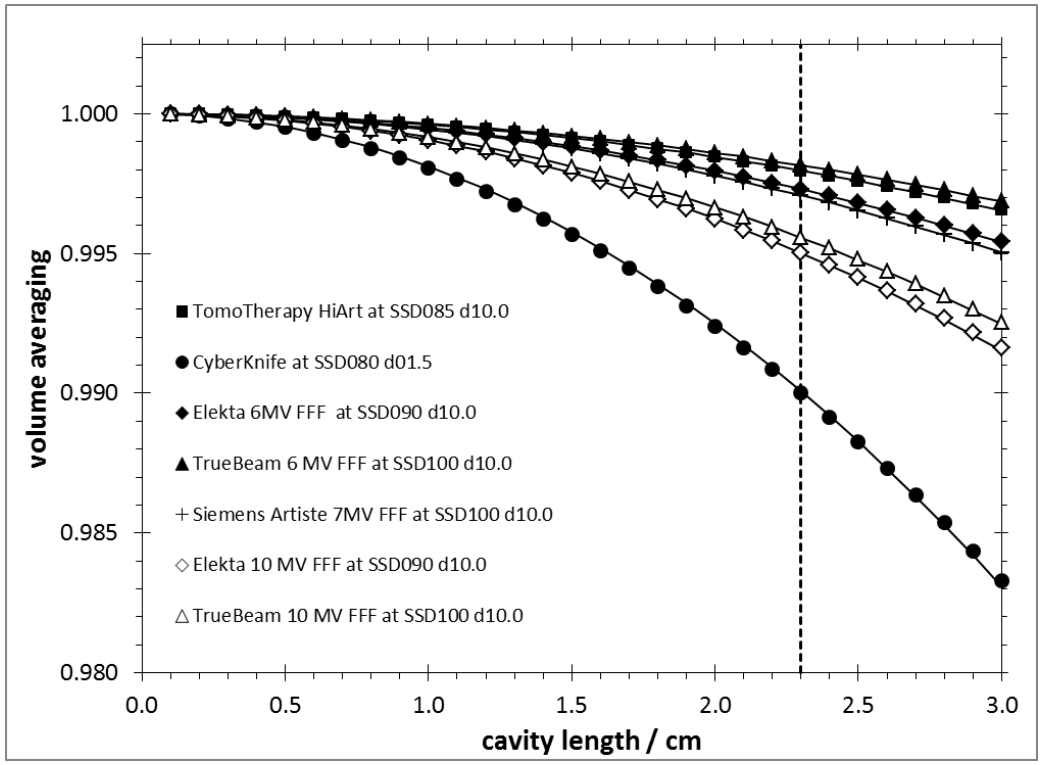
Volume averaging

$$k_{vol} = \frac{\iint_A w(x,y)dxdy}{\iint_A w(x,y)\mathrm{OAr}(x,y)dxdy}$$



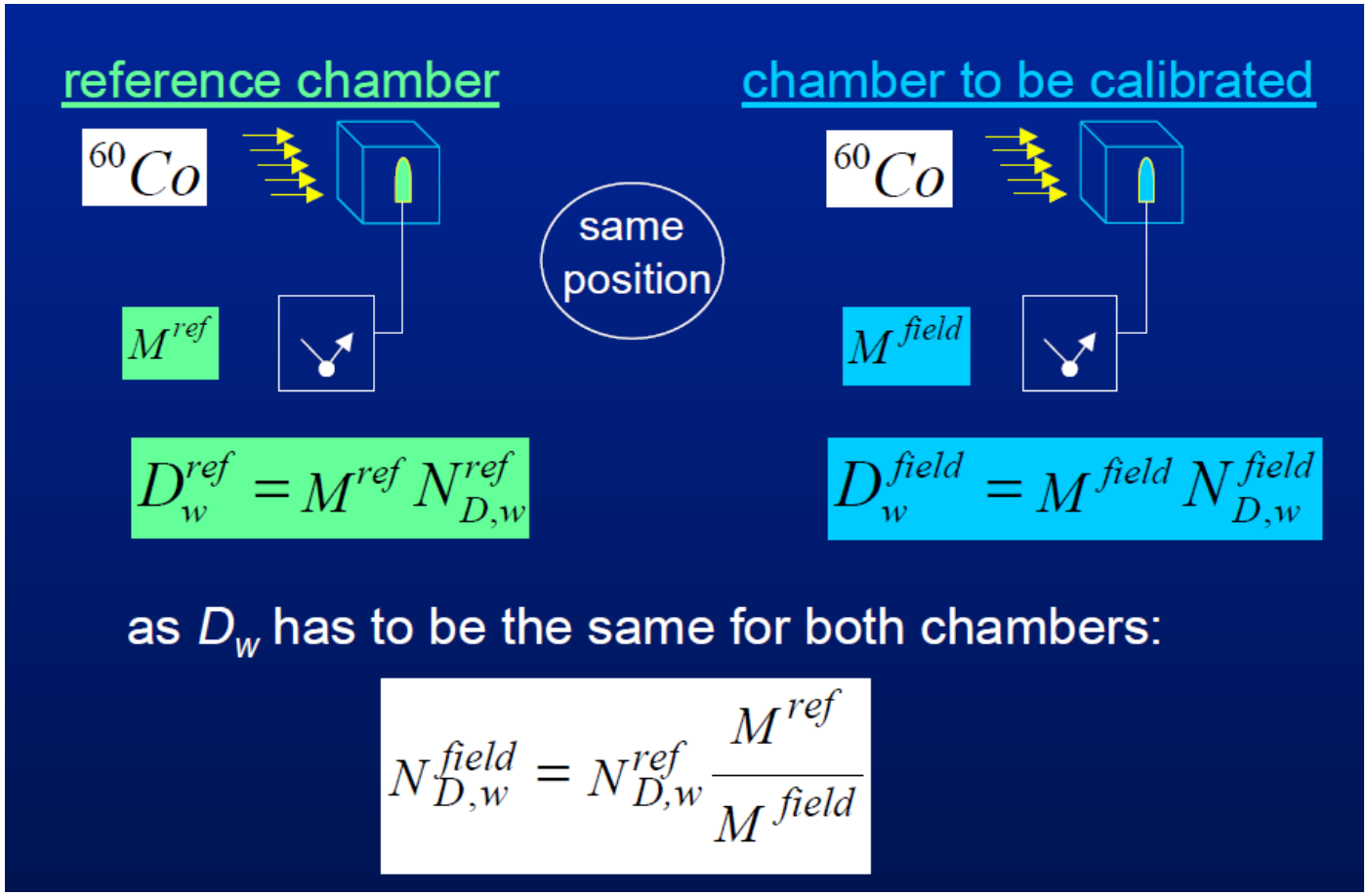


Volume averaging FFF beams (TRS-483)

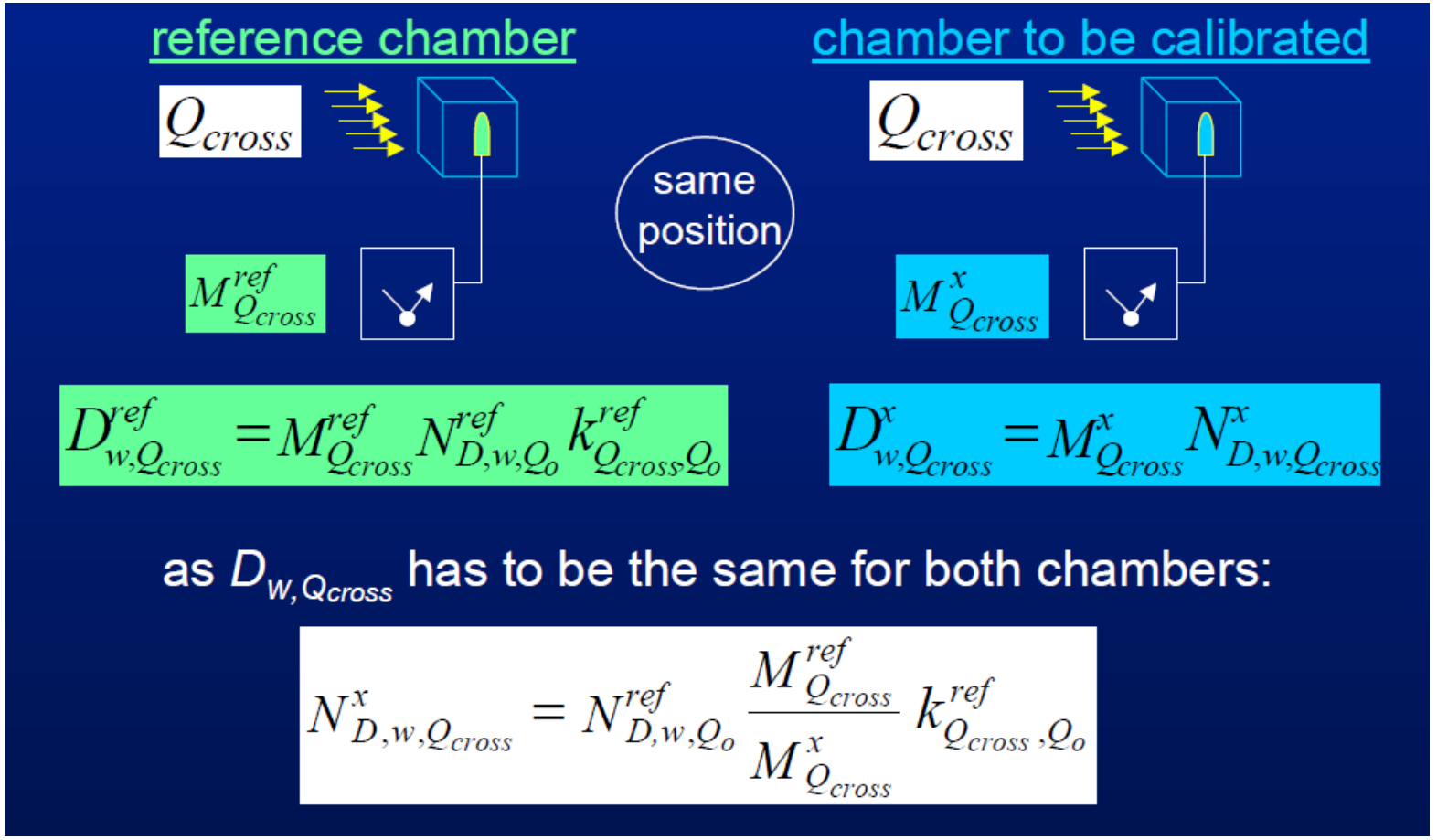


$$k_{\text{vol}} = 1 + \left(0.0062\,\text{TPR}_{20,10} - 0.0036\right) \times \left(\frac{100}{\text{SDD}}\right)^2 \times L^2 \qquad (22)$$

4.5. Cross calibration of ionization chamber / calibration beam



4.5. Cross calibration of ionization chamber / non-calibration beam



Use of a cross-calibrated ionization chamber

$$D_{\mathrm{w},Q} = M_Q \, N_{D,\mathrm{w},Q_{\mathrm{cross}}} \, k_{Q,Q_{\mathrm{cross}}}$$

where

M_Q is the reading of the dosimeter incorporating the product $\prod k_i$ of the correction factors for influence quantities

$k_{Q,Q_{\mathrm{cross}}}$ is the correction factor that corrects for the difference between the cross-calibration beam quality Q_{cross} and the actual quality Q being used

$$k_{Q,Q_{\mathrm{cross}}} = \frac{k_{Q,Q_0}}{k_{Q_{\mathrm{cross}},Q_0}} = \frac{k_Q}{k_{Q_{\mathrm{cross}}}}$$

CODE OF PRACTICE FOR xxxx BEAMS

1. General
2. Dosimetry equipment
   - Ionization chambers
   - Phantoms and chamber sleeves
3. Beam quality specification
   - Choice of beam quality index
   - Measurement of beam quality
4. Determination of absorbed dose to water
   - Reference conditions
   - Determination of D_w under reference conditions
5. Values for k_{Q,Q_0}
6. Cross calibration of field ionization chambers
7. Measurements under non-reference conditions
   - Central-axis depth-dose distributions
   - Output factors
8. Estimated uncertainty in D_w under reference conditions
9. Worksheet