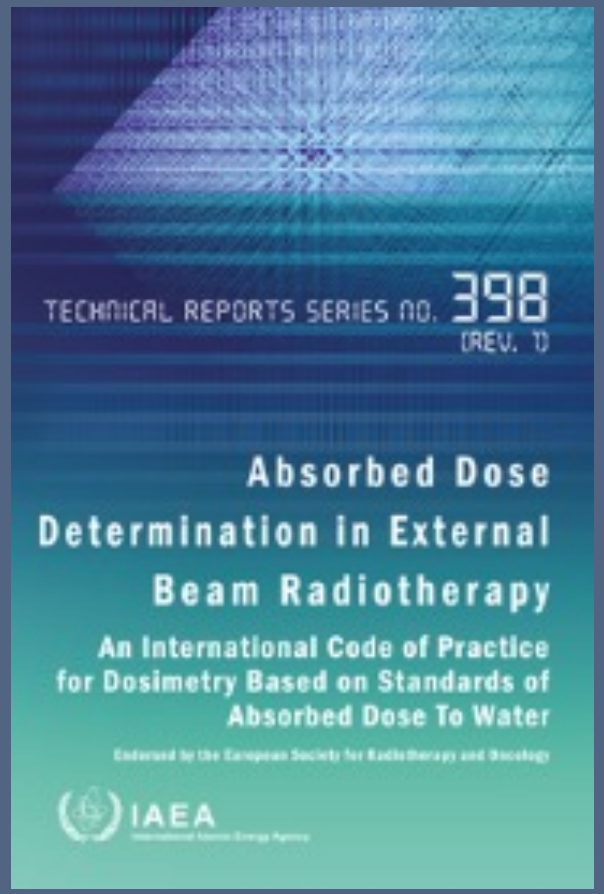
TRS 398 Revision 1 Code of Practice for high energy electron beams (3-25 MeV)



by

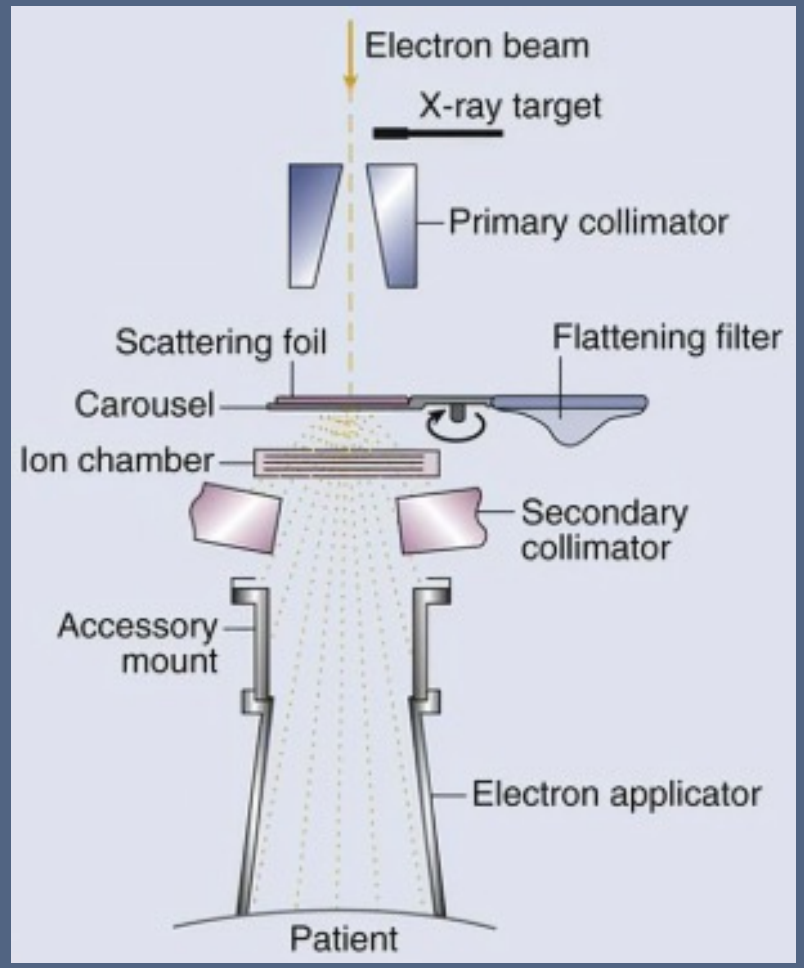
Karen Christaki

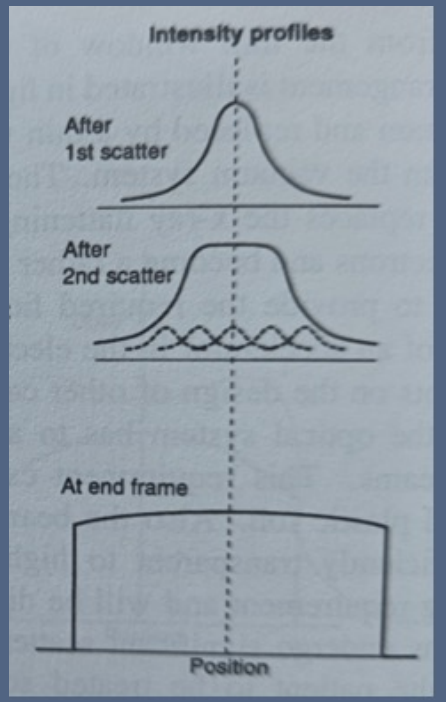
Acknowledgement: Malcolm McEwen

1. Background
2. Dosimetry equipment
3. Beam quality index
4. Reference conditions
5. Absorbed dose to water
6. Measurements under non reference conditions


Background
INFORMATION

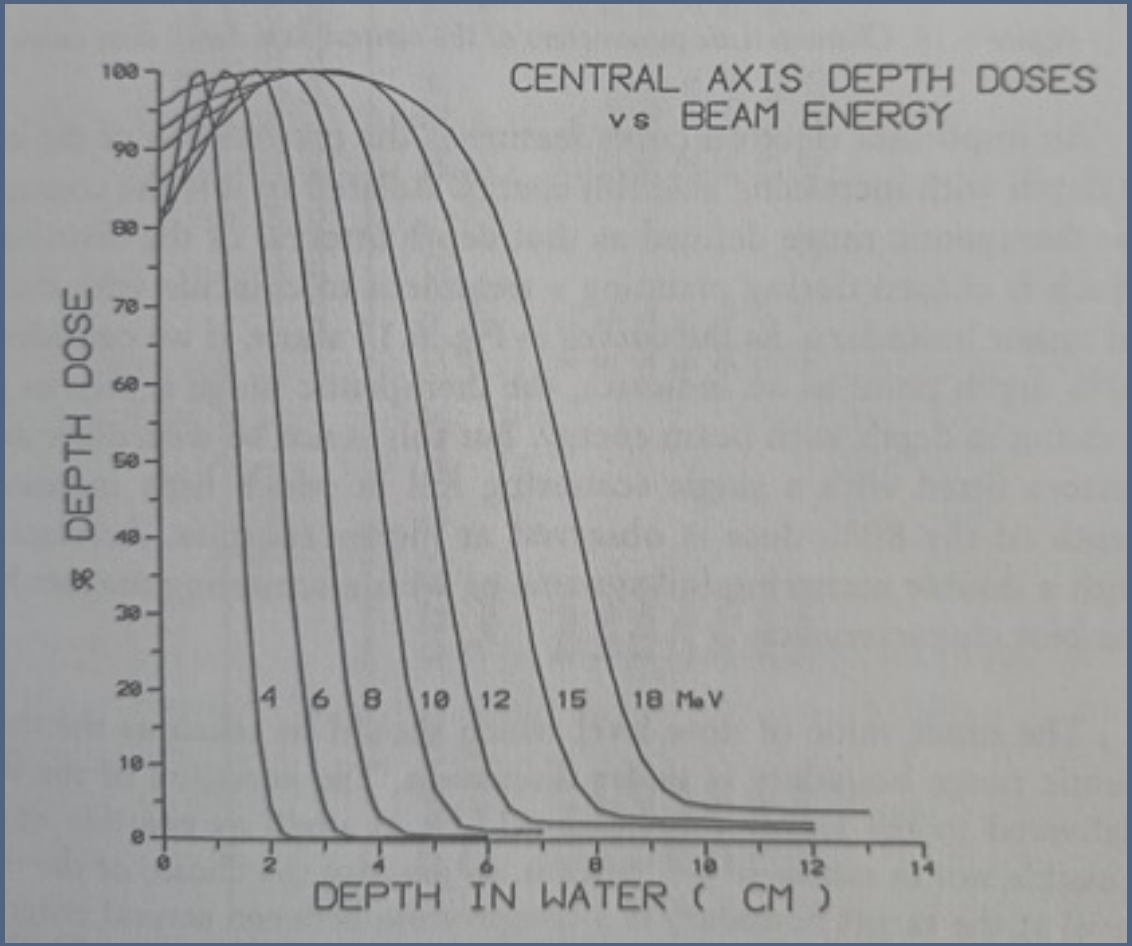
Electron Beam Production





Electrons are charged particles

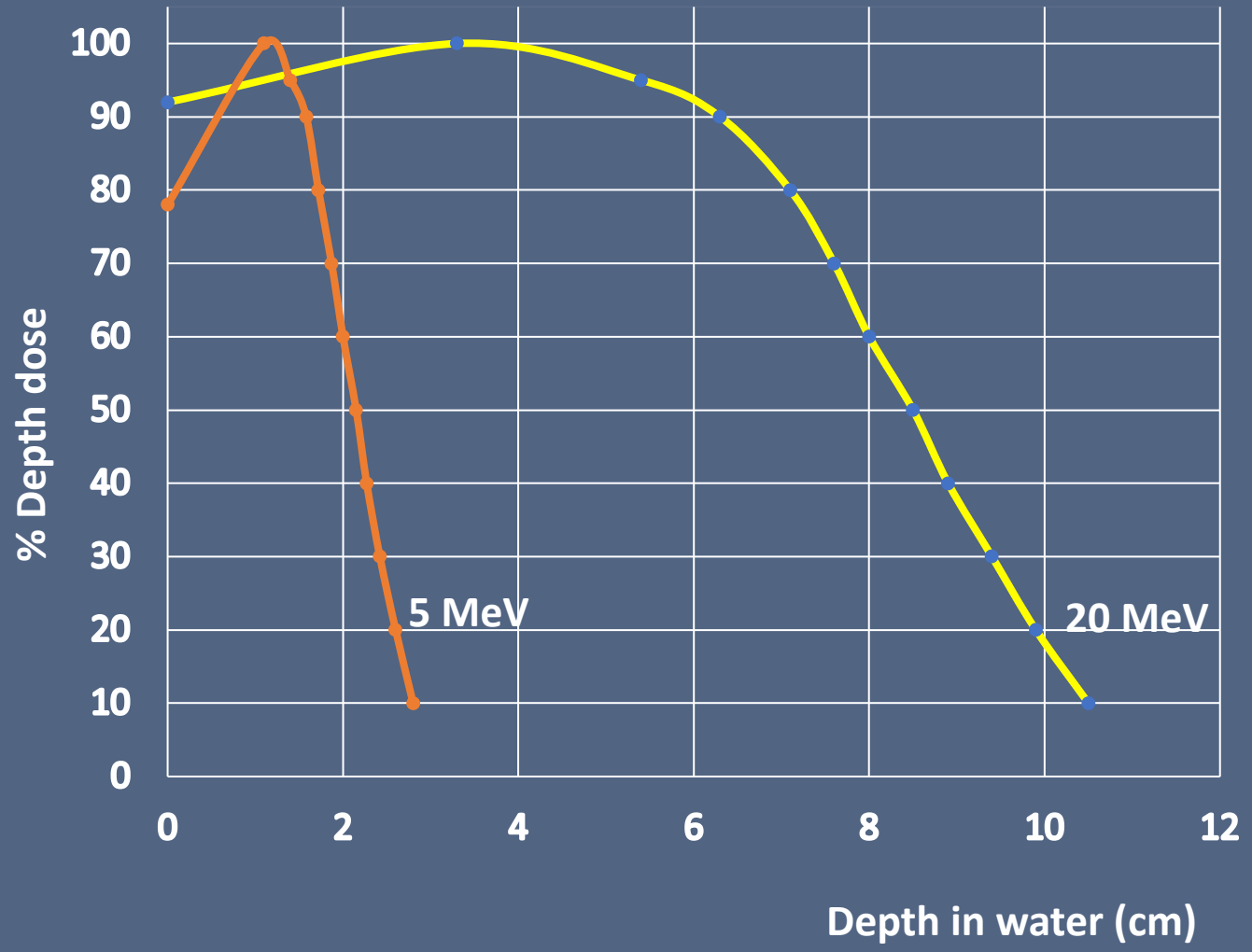
Typical central axis depth dose curves for a 10 cm x 10 cm field size.



Dosimetry equipment

- Ionization chamber
- Phantoms

What type of ionization chamber to use?

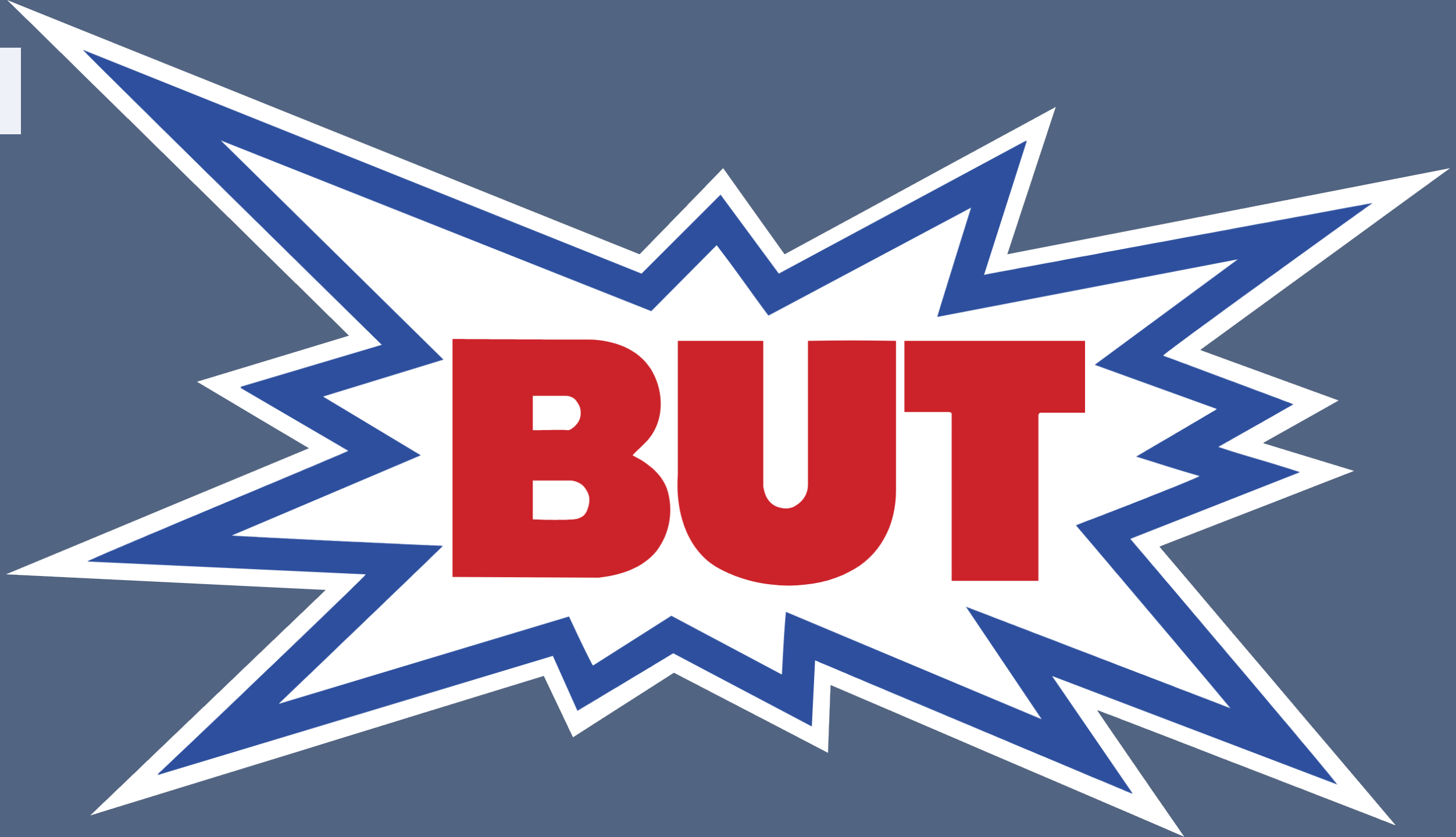

100
90
80
70
60
50
40
30
20
10
0
% Depth dose
0
2
4
6
8
10
12
Depth in water (cm)
5 MeV
20 MeV

Ionization chamber

Recommendation from TRS 398 (Rev 1)- Section 7.2.1

- **Plane parallel chambers are recommended type for all beam qualities.**
- **Plane parallel chamber have to be used for beam quality indexes of $R_{50} < 3$ g/cm^2 ($E_0 \leq 8$MeV).**
- **For beam qualities $R_{50} > 3$ g/cm^2 cylindrical chambers maybe used (chamber cavity volume should be between about 0.1 cm^3 to 1 cm^3).**

Note: recommended waterproof chambers used but if not possible a sleeve is used.


BUT

Parallel plate chamber characteristics.

Plane parallel chamber dimensions:

- ❑ **Diameter of collecting electrode should not exceed 20 mm.**
- ❑ **Cavity height should not exceed 2 mm.**
- ❑ **Collecting electrode should be surrounded by a guard electrode with a width not smaller than 1.5 times the cavity height.**
- ❑ **The thickness of the front window is approximately 0.1 g/cm2 (1mm PMMA).**
- ❑ **Air cavity vented to the atmosphere.**

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

TABLE 3. SPECIFICATIONS FOR REFERENCE CLASS IONIZATION CHAMBERS FOR REFERENCE DOSIMETRY [12]

Parameter	Specification
Chamber settling	Monitoring chamber response with accumulated dose: equilibrium is reached in <5 min; the initial and equilibrium readings agree within 0.5%
Leakage	<0.1% of the chamber reading[a]
Polarity effect	Less than 0.4% of the chamber reading; the polarity energy dependence is <0.3% between the energies of the ^{60}Co beam and 10 MV photon beam
Recombination correction	1. The correction is linear with the 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 <0.2% at polarizing voltages of ~300 V 3. For pulsed beams, a plot of $1/M_Q$ (charge reading) versus $1/V$ is linear at least for practical values of V[b] 4. For continuous beams, the plot of $1/M_Q$ versus $1/V^2$ is 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 <0.1% 6. If the correction exceeds 1.05, other methods have to be used [102]
Chamber stability	Change in the calibration coefficient of <0.3% over a typical recalibration period of 2 years, as well as for long term (>5 years) stability
Chamber material	Wall material not exhibiting temperature and humidity effects

[a] In limited cases (e.g. small volume chambers in low dose rate beams) the leakage current may exceed this limit. In such circumstances, the leakage current has to be evaluated carefully and a correction needs to be applied to the raw ionization chamber reading.

[b] V: polarizing voltage.

Section 4.2.1

Polarity effect.

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

M_+ and M_- are the electrometer readings obtained at positive and negative polarity respectively and M is the reading obtained with the polarity used routinely.

Polarity effect.

k_{pol} – expect this to be larger than for photon beams because:

a) We now have net charge deposition

b) Parallel-plate chambers are not symmetric

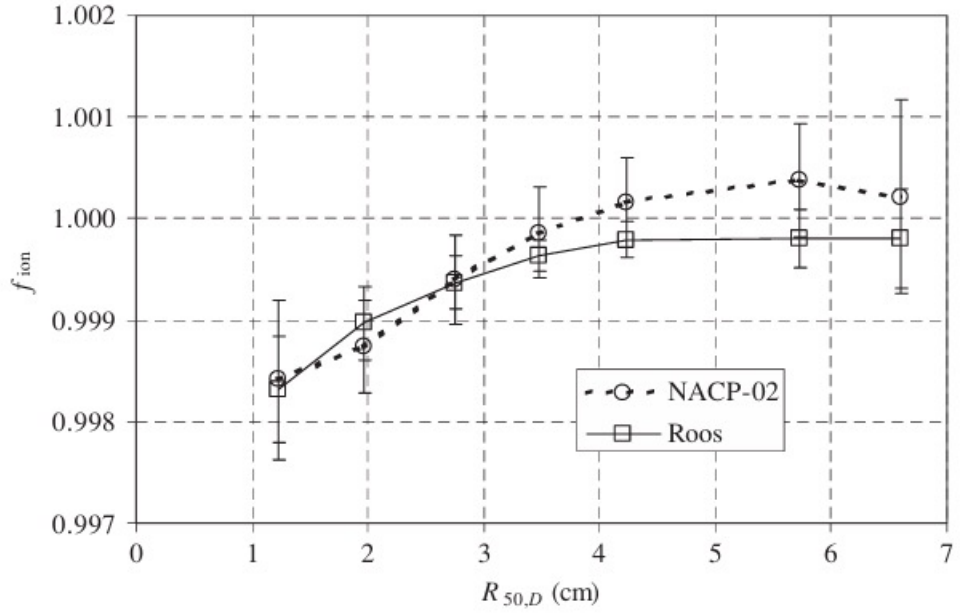


Figure 6. Mean polarity effect correction factors f_{pol} for type NACP-02 chambers and for type PTW Roos chambers as a function of beam quality $R_{50,D}$ (100 V applied). The error bars indicate one standard deviation. The results show the correction to be small (less than 0.2%) over the whole beam quality range for both chamber types but with a discernible quality dependence.

Bass et al, PMB (2009)

TABLE 3. SPECIFICATIONS FOR REFERENCE CLASS IONIZATION CHAMBERS FOR REFERENCE DOSIMETRY [12]

Parameter	Specification
Chamber settling	Monitoring chamber response with accumulated dose: equilibrium is reached in <5 min; the initial and equilibrium readings agree within 0.5%
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Chamber stability	Change in the calibration coefficient of <0.3% over a typical recalibration period of 2 years, as well as for long term (>5 years) stability
Chamber material	Wall material not exhibiting temperature and humidity effects

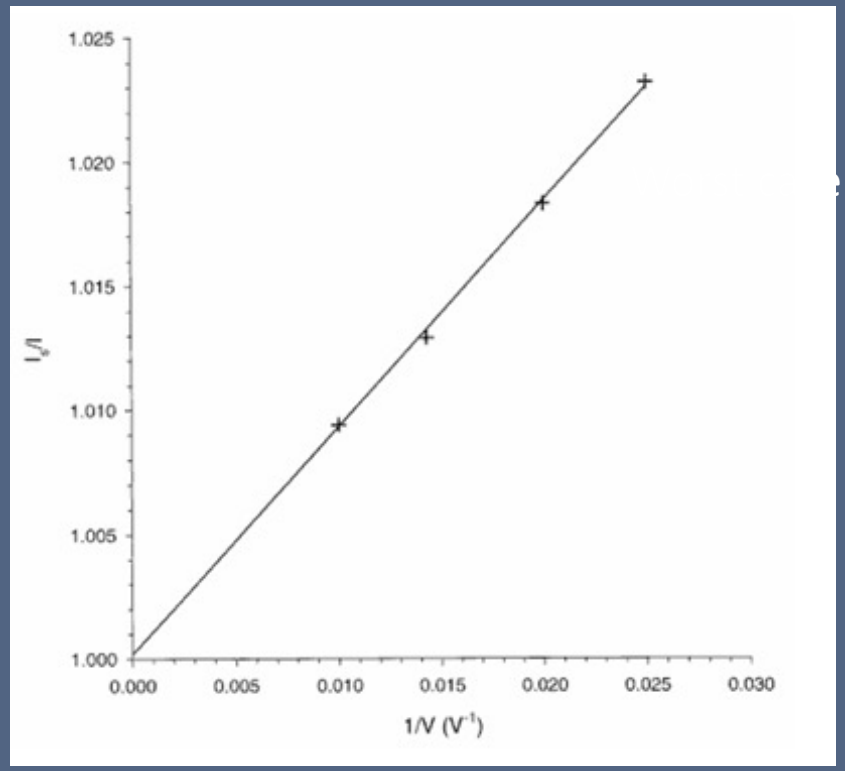
[a] In limited cases (e.g. small volume chambers in low dose rate beams) the leakage current may exceed this limit. In such circumstances, the leakage current has to be evaluated carefully and a correction needs to be applied to the raw ionization chamber reading.

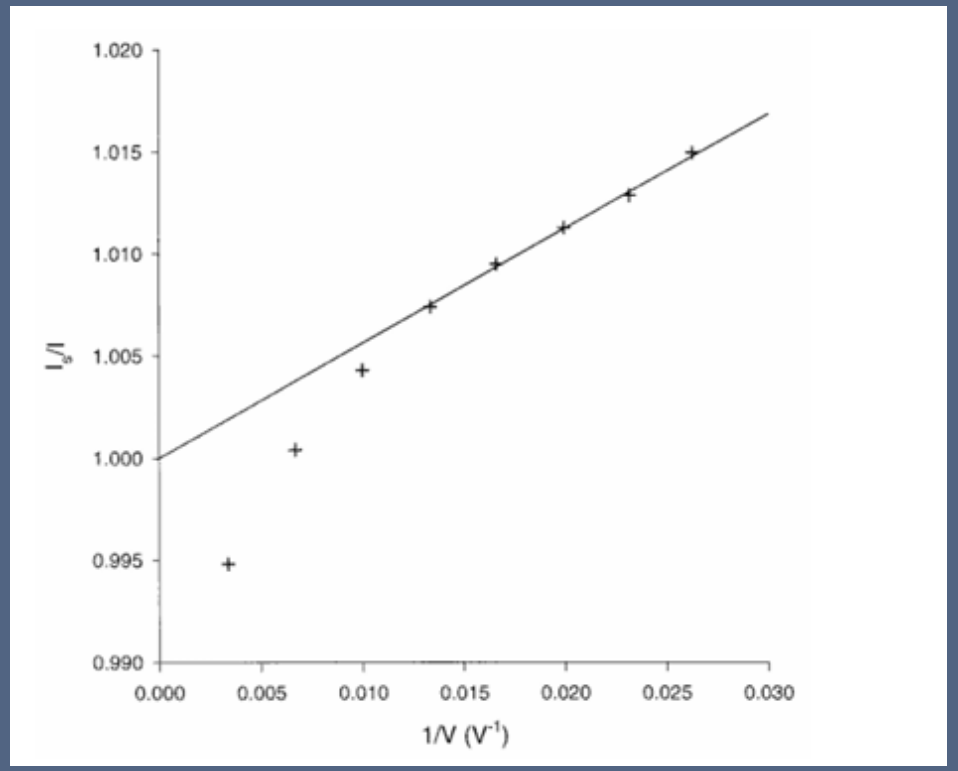
[b] V: polarizing voltage.

Section 4.2.1

Ion recombination for NACP chamber

Pulsed beam: A plot of $1/M_Q$ (charge reading) versus is linear at least for practical values of V (Table 3)





Worst case!

Burns and McEwen, PMB (1998)

Ion recombination

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

TABLE 10. QUADRATIC FIT COEFFICIENTS FOR THE CALCULATION OF k_s BY THE TWO VOLTAGE TECHNIQUE IN PULSED AND PULSED–SCANNED RADIATION AS A FUNCTION OF THE VOLTAGE RATIO V_1/V_2 [117]

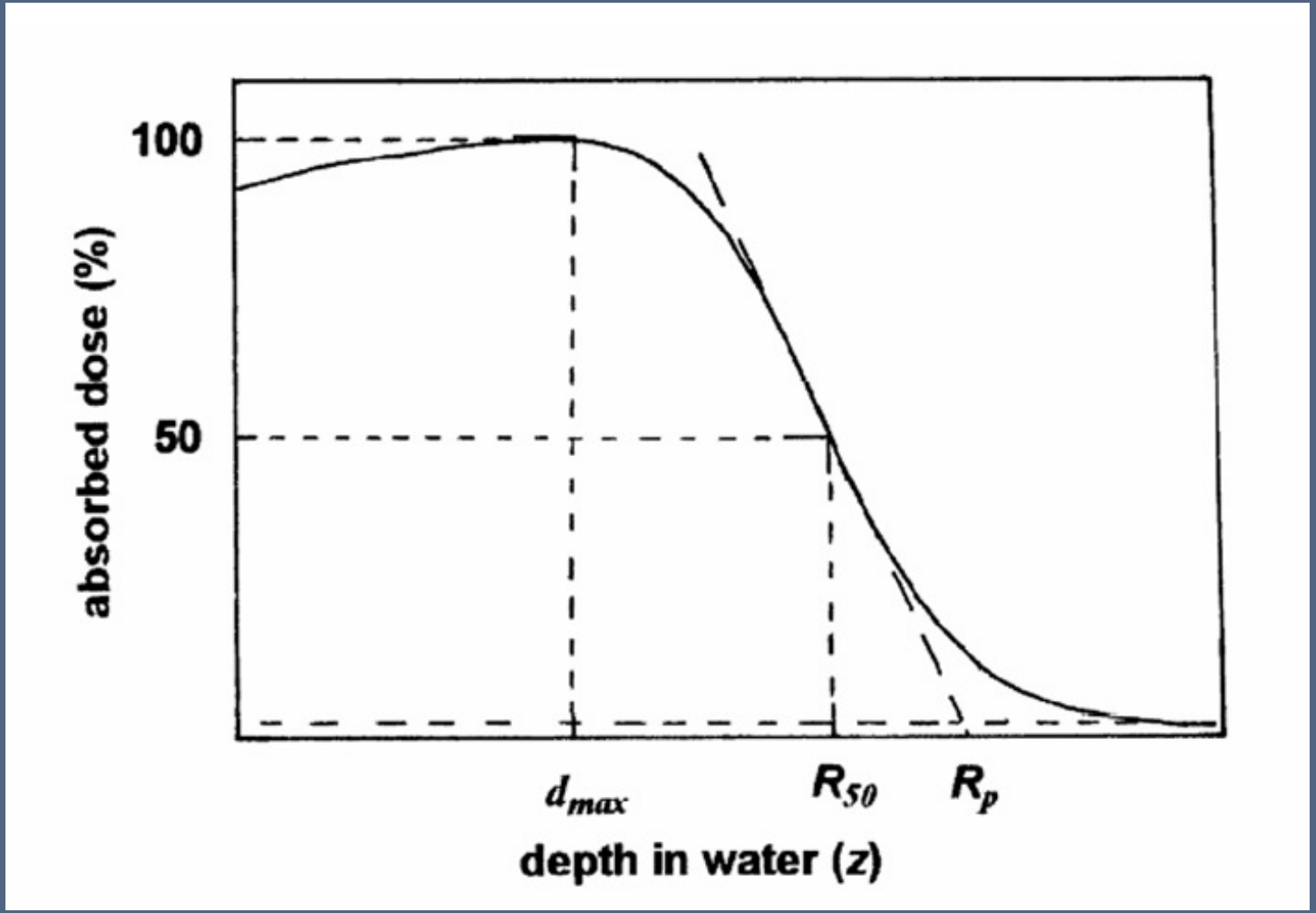
V_1/V_2	Pulsed			Pulsed–scanned		
	a_0	a_1	a_2	a_0	a_1	a_2
2.0	2.337	−3.636	2.299	4.711	−8.242	4.533
2.5	1.474	−1.587	1.114	2.719	−3.977	2.261
3.0	1.198	−0.875	0.677	2.001	−2.402	1.404
3.5	1.080	−0.542	0.463	1.665	−1.647	0.984
4.0	1.022	−0.363	0.341	1.468	−1.200	0.734
5.0	0.975	−0.188	0.214	1.279	−0.750	0.474

V_1/V_2 should ideally be equal or larger than 3.

Phantom

Beam quality index

Beam Quality Index



R_{50}:
The depth in water (g/cm^2) at which the absorbed dose is 50% of its value at the maximum.

Nominal Linac energy (MeV)	d_{max} (cm)	R_{50} (cm)
6	1.2	2.3
9	2.0	3.5
12	2.8	5.0
15	3.2	6.3
20	3.5	8.5

Measurement of beam quality index

TABLE 18. REFERENCE CONDITIONS FOR THE DETERMINATION OF THE ELECTRON BEAM QUALITY INDEX (R_{50})

Influence quantity	Reference value or reference characteristic
Phantom material	Water
Chamber type	For $R_{50} > 3$ g/cm^2, plane parallel or cylindrical For $R_{50} < 3$ g/cm^2, plane parallel
Reference point of chamber	For plane parallel chambers, on the inner surface of the window at its centre[a] For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	For plane parallel chambers, at the point of interest[b] For cylindrical chambers, $0.5r_{cyl}$ deeper than the point of interest[c]
Source–surface distance	100 cm
Field size at phantom surface	At least 10 cm × 10 cm

[a] The entrance window should be scaled to the water equivalent thickness.

[b] 'Point of interest' refers to any point in the water phantom where data are to be obtained. In this case, it is at the inner surface of the entrance window.

[c] The shift Xr_{cyl}, where $X = 0.5$, is an approximation; the actual values depend on the chamber geometry. To achieve the highest accuracy, the actual shift should be taken into account for beam quality measurements [166, 167].

Preferred choice of detector is plan parallel

$$R_{50} = \begin{cases} 1.029R_{50,\text{ion}} - 0.06\ \text{g/cm}^2 & \text{for } R_{50,\text{ion}} \le 10\ \text{g/cm}^2 \\ 1.059R_{50,\text{ion}} - 0.37\ \text{g/cm}^2 & \text{for } R_{50,\text{ion}} > 10\ \text{g/cm}^2 \end{cases} \quad (37)$$

Few clinical beam have $R_{50,ion} >$ 10 g/cm^2

Reference conditions

TABLE 19. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE IN ELECTRON BEAMS

Influence quantity	Reference value or reference characteristic
Phantom material	Water
Chamber type	For $R_{50} \geq 3$ g/cm^2, plane parallel or cylindrical[a] For $R_{50} < 3$ g/cm^2, plane parallel
Measurement depth, z_{ref}	$0.6R_{50} - 0.1$ g/cm^2
Reference point of chamber	For plane parallel chambers, on the inner surface of the window at its centre[b] For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	For plane parallel chambers, at z_{ref} For cylindrical chambers, $0.5r_{cyl}$ deeper than z_{ref}[c]
Source–surface distance	100 cm
Field size at phantom surface	10 cm × 10 cm

[a] This is a reduction from the previous recommendation, based on an analysis of clinical data.

[b] The entrance window of the chamber should be scaled to a water equivalent depth to determine the reference point.

[c] As noted in the previous text, the factor 0.5 is an approximation. Actual values depend on the chamber geometry but for reference positioning, the assumption of a shift of $0.5r_{cyl}$ does not introduce a significant error.

Measurement depth

Burns et al, Med Phys 1996

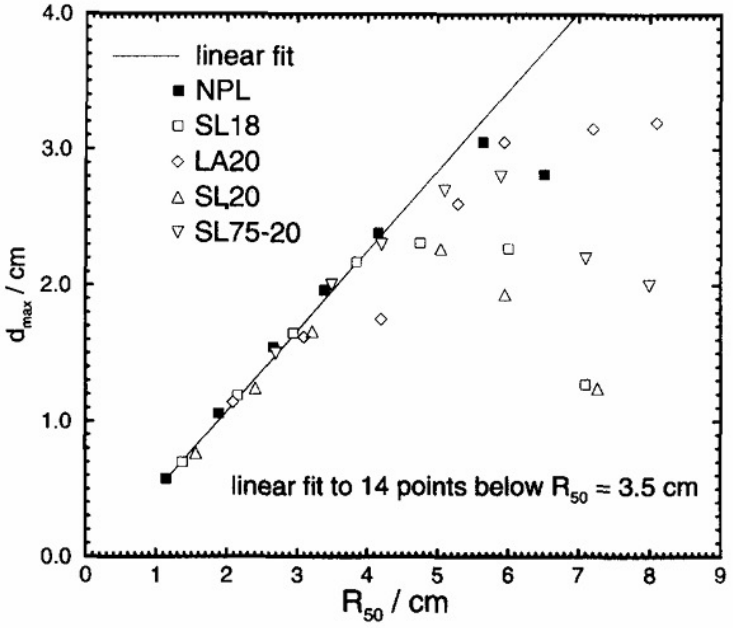
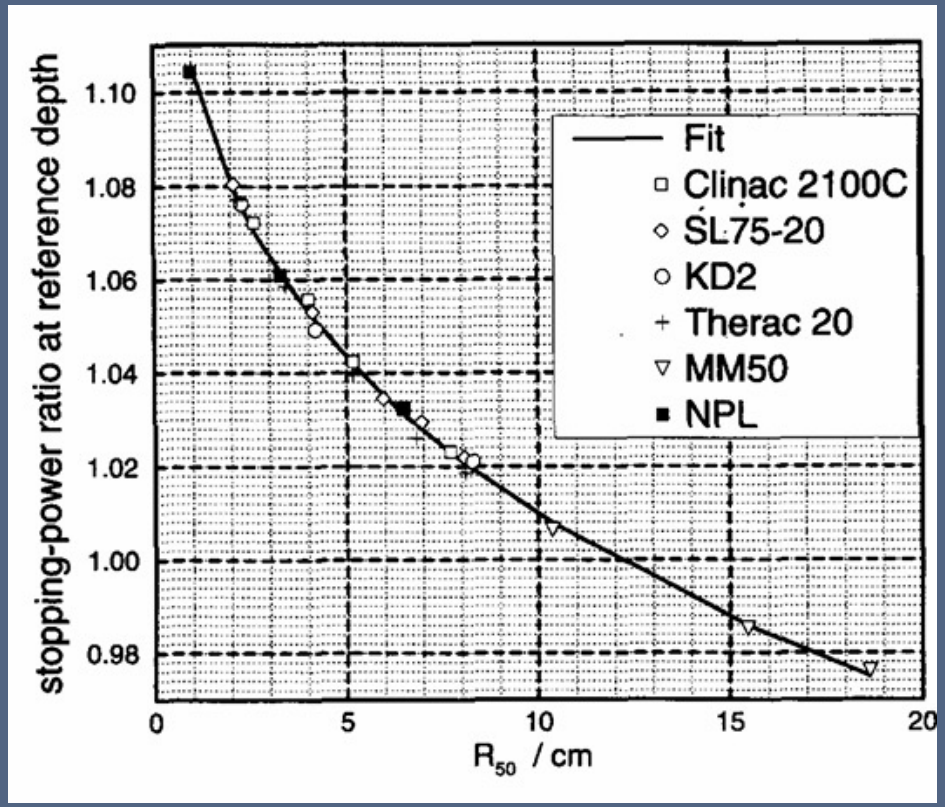
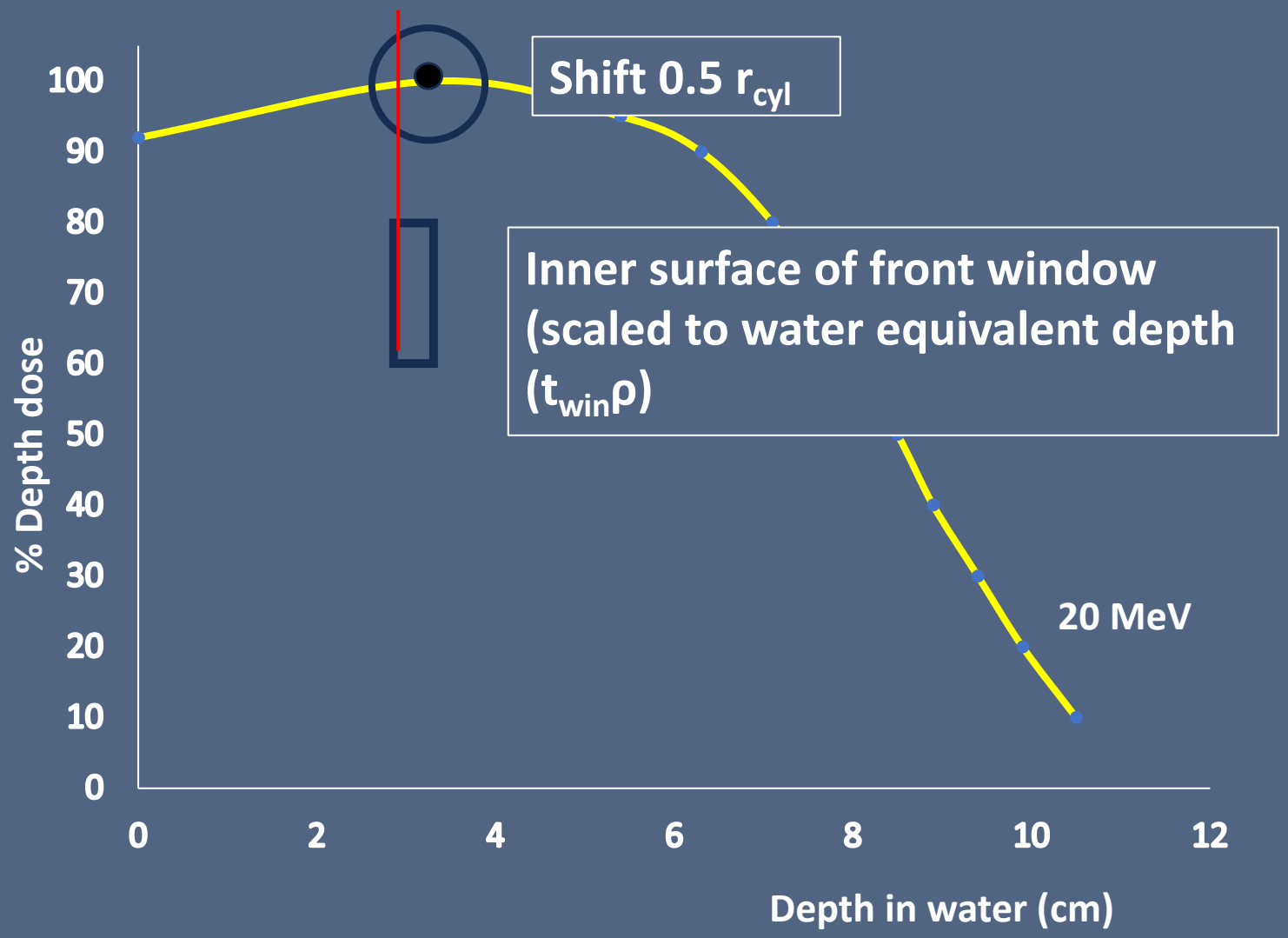


FIG. 1. Location of the depth of dose maximum, d_{max}, vs R_{50}. The values shown are from experimental measurements on four clinical accelerators and the NPL's research accelerator. The fit is to all beams with R_{50}<3.5 cm.



$$z_{ref} = 0.6R_{50} - 0.1 \ g/cm^2$$ (R_{50} in g/cm^2)

Position of reference point of chamber.



Determination of absorbed dose to water under reference conditions

- Chamber calibrated at a series of electron beams.
- Chamber calibrated at ^{60}Co

Chamber calibrated at a series of electron beams

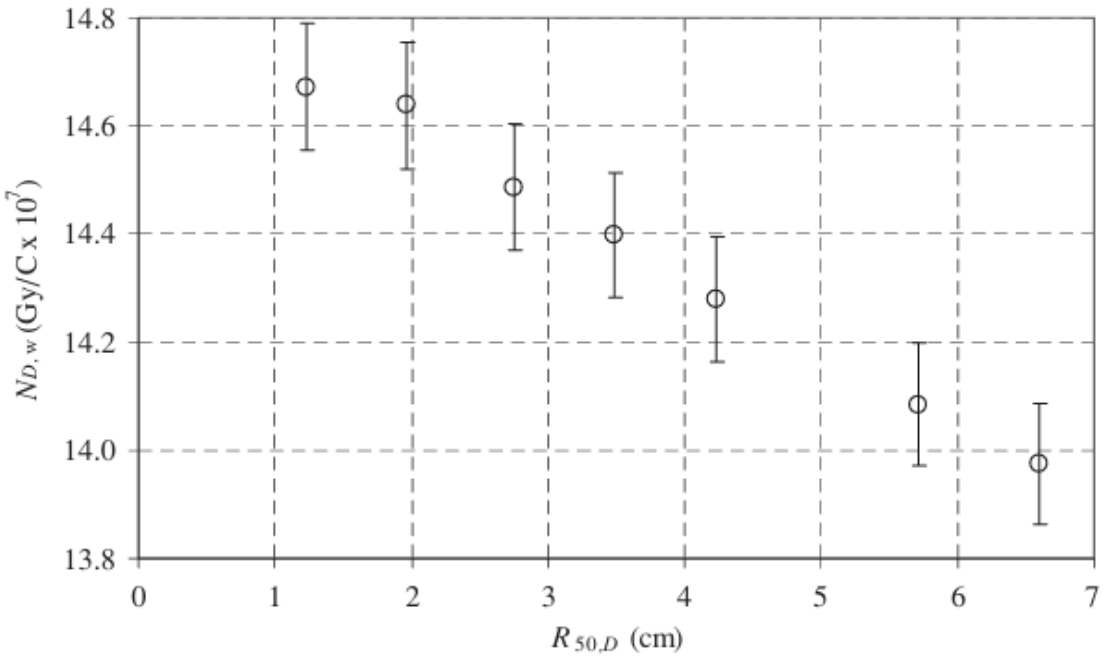


Figure 1. Mean absorbed dose to water calibration factors $N_{D,w}$ for NACP-02 chambers as a function of the beam quality $R_{50,D}$. The error bars indicate one standard deviation of the mean, which is approximately 0.8% for this chamber type. For comparison, the standard deviation of the mean calibration factor of an NPL-owned NACP-02 chamber calibrated several times over many years is approximately 0.6%.

Bass et al, PMB (2009)

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

$$M_Q = M_{raw} k_{elec} k_{leak} k_{TP} k_{pol} k_s$$

TABLE 25. ESTIMATED RELATIVE STANDARD UNCERTAINTY[a] OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER FOR AN ELECTRON BEAM, BASED ON A CHAMBER CALIBRATION IN A HIGH ENERGY ELECTRON BEAM

Physical quantity or procedure	Relative standard uncertainty (%)	
	Cylindrical $R_{50} \geq 3$ g/cm^2	Plane parallel $R_{50} \geq 2$ g/cm^2
Step 1: PSDL		
$N_{D,w}$ calibration of user dosimeter at PSDL	0.5	0.5
Combined uncertainty of step 1	0.5	0.5
Step 2: user electron beam		
Long term stability of user dosimeter	0.2	0.4
Establishment of reference conditions	0.3	0.3
Dosimeter reading M_Q relative to beam monitor	0.3	0.3
Correction for influence quantities k_i	0.3	0.3
Beam quality correction, k_{Q,Q_o} (calculated values)[b]	0.2	0.2 [c]
Applicability of k_Q to beam–chamber combination[d]	0.1	0.1
Combined uncertainty of step 2	0.6	0.7
Combined standard uncertainty of $D_{w,Q}$ (steps 1 and 2)	0.8	0.9

Chamber calibrated at ^{60}Co

$$D_{w,Q} = M_Q N_{D,w} k_Q$$

$$M_Q = M_{raw} k_{elec} k_{leak} k_{TP} k_{pol} k_s$$

k_Q

II.4. ELECTRON BEAMS

In contrast to the situation for photons, limited data are available for electron beams from which consensus values for k_Q can be selected. This is the case for both experimental values determined from comparison with primary standards of absorbed dose to water and Monte Carlo simulations that follow the same formalism as for other beam modalities. This lack of data reflects: (a) the smaller number of PSDLs that have developed primary standards and of currently active academic research groups and (b) the relatively low usage of megaelectronvolt electron beams in clinical radiotherapy. The expectation at the start of the project to revise the first edition of this international code of practice was that significant new data would be forthcoming and some kind of average (weighted or otherwise) could be determined for each chamber type from multiple determinations. However, for some chamber types there is no more than one dataset of each type — experimental and simulated — and the resolution and uncertainty are often significantly different for the two types.

Therefore, the approach taken in this publication was to base the consensus k_Q and $k_{Q,Q_{\text{int}}}$ values for electron beams on the Monte Carlo simulations of Muir and Rogers [167], the most extensive single dataset available, and use other determinations for validation and to provide an estimation of the uncertainty.

k_Q

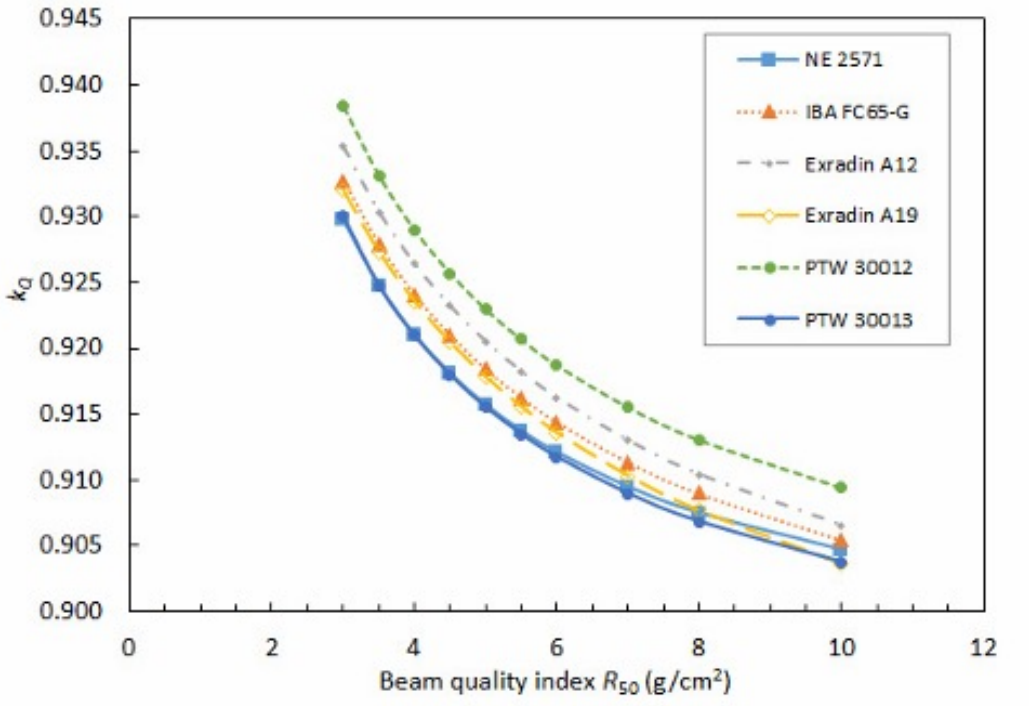


FIG. 9. Calculated k_Q values for electron beams for various cylindrical chamber types calibrated in ^{60}Co gamma radiation.

$$k_{Q,Q_o} \approx \frac{\left(s_{w,air}\right)_Q}{\left(s_{w,air}\right)_{Q_o}} \frac{p_{ch,Q}}{p_{ch,Q_o}}$$

Shapes are very similar, since stopping power ratio is the dominant energy dependence.

k_Q factors are MC based (limited experimental data)

TABLE 20. CALCULATED k_Q VALUES[a] FOR ELECTRON BEAMS, FOR VARIOUS CHAMBER TYPES CALIBRATED IN ^{60}Co GAMMA RADIATION, AS A FUNCTION OF BEAM QUALITY INDEX R_{50}

Ionization chamber type[b]	Beam quality index, R_{50} (g/cm^2)													
	1.0[c]	1.4	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10.0
PTW 34001 Roos	0.9743	0.9645	0.9518	0.9428	0.9349	0.9281	0.9222	0.9171	0.9127	0.9088	0.9055	0.9001	0.8960	0.8907
IBA NACP-02	0.9679	0.9580	0.9451	0.9360	0.9281	0.9214	0.9155	0.9104	0.9061	0.9023	0.8990	0.8938	0.8899	0.8848
NE 2571					0.9297	0.9248	0.9210	0.9181	0.9157	0.9137	0.9121	0.9095	0.9075	0.9047
IBA FC65-G					0.9328	0.9279	0.9241	0.9210	0.9184	0.9163	0.9144	0.9114	0.9090	0.9055
Exradin A12					0.9353	0.9304	0.9264	0.9232	0.9205	0.9182	0.9163	0.9130	0.9104	0.9066
Exradin A19					0.9320	0.9273	0.9236	0.9205	0.9178	0.9156	0.9136	0.9103	0.9077	0.9036
PTW 30013					0.9300	0.9247	0.9210	0.9180	0.9155	0.9135	0.9118	0.9090	0.9068	0.9037
PTW 30012					0.9384	0.9331	0.9290	0.9257	0.9230	0.9207	0.9187	0.9156	0.9131	0.9094

It is now possible to use a parallel plate chamber calibrated at Co-60. One of the main reasons for updating TRS 398.

TABLE 24. ESTIMATED RELATIVE STANDARD UNCERTAINTY[a] OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR AN ELECTRON BEAM, BASED ON A CHAMBER CALIBRATION IN ^{60}Co GAMMA RADIATION

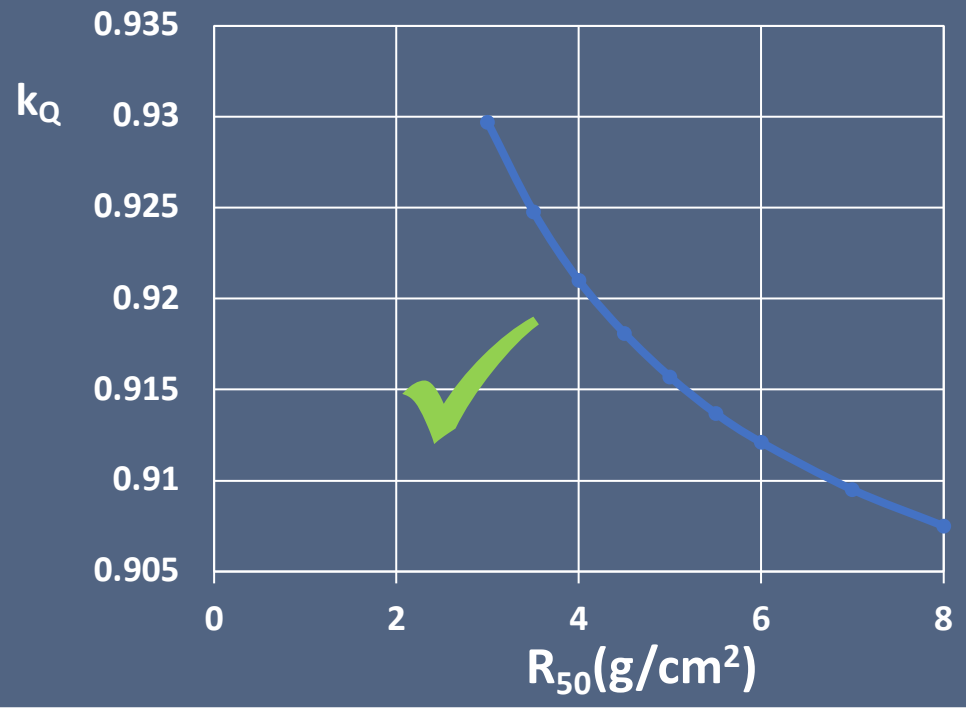
Physical quantity or procedure	Relative standard uncertainty (%)	
	Cylindrical $R_{50} \geq 3$ g/cm^2	Plane parallel $R_{50} \geq 2$ g/cm^2
Step 1: standards laboratory		
$N_{D,w}$ calibration of secondary standard at PSDL	0.5	0.5
Long term stability of secondary standard	0.1	0.1
$N_{D,w}$ calibration of user dosimeter at SSDL	0.4	0.4
Combined uncertainty of step 1[b]	0.6	0.6
Step 2: user electron beam		
Long term stability of user dosimeter	0.2	0.4
Establishment of reference conditions	0.3	0.3
Dosimeter reading M_Q relative to beam monitor	0.3	0.3
Correction for influence quantities k_i	0.3	0.3
Beam quality correction k_Q (see Appendix II)	0.7	0.7[c]
Applicability of k_Q to beam–chamber combination[d]	0.2	0.2
Combined uncertainty of step 2	0.9	1.0
Combined standard uncertainty of $D_{w,Q}$ (steps 1 and 2)	1.1	1.2

Cross calibration

Cross-calibration example

Reference chamber

N_{D,W,Q_0}^{ref} ✓



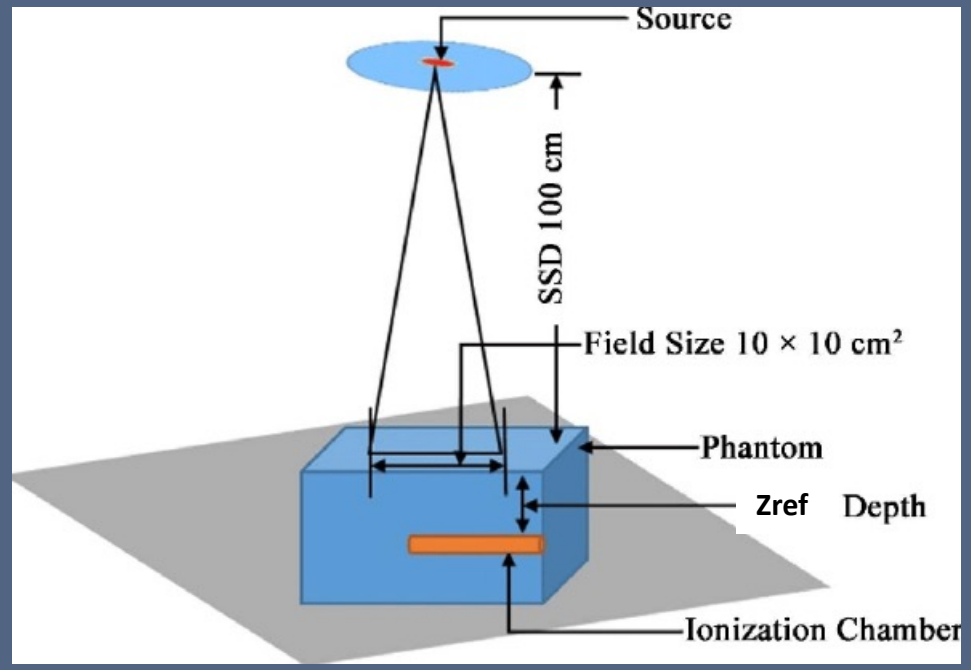
$D_{w,Q}$ ✓ ☺

Clinical equipment

Field chamber

✗ ? ✗

Cross-calibration example



Notes:

1. Energy: highest possible stable energy available R_{50} >> 7 g/cm² (≈18 MeV).

2. Standard reference conditions.

3. Correct M_{raw} for influence quantities such as temperature, pressure, k_{ion}, k_{pol}.

Cross-calibration example.

$$D_{w,Q} = M_Q^{ref} N_{D,w,Q_0}^{ref} k_{Q,Q_0}^{ref}$$

$$N_{D,W,Q_0}^{field} = \frac{D_{w,Q_{cross}}}{M_{Q_{cross}}^{field}} = \frac{M_{Q_{cross}}^{ref}}{M_{Q_{cross}}^{field}} N_{D,W,Q_0}^{ref} k_{Q_{cross}Q_0}^{ref}$$

Field chamber can be used to determine absorbed dose to water at any beam quality

$$D_{w,Q} = M_Q^{field} N_{D,w,Q_{cross}}^{field} k_{Q,Q_{cross}}^{field}$$

Cross-calibration example.

Field chamber can be used to determine absorbed dose to water at any beam quality

$$D_{w,Q} = M_Q^{field} N_{D,w,Q_{cross}}^{field} k_{Q,Q_{cross}}^{field}$$

$$k_{Q,Q_{cross}} = \frac{N_{D,W,Q}}{N_{D,W,Q_{cross}}} = \frac{N_{D,W,Q}}{N_{D,W,Q_{int}}} \frac{N_{D,W,Q_{int}}}{N_{D,W,Q_{cross}}}$$

$$k_{Q,Q_{cross}}^{field} = \frac{k_{Q,Q_{int}}^{field}}{k_{Q_{cross},Q_{int}}^{field}}$$

Q_{int}=7.5 g/cm^2
(intermediate beam quality)

Note: No measurements or calculations are made by the user at Q_{int}. It is just a tool to “simplify the data”

Fit of k_Q and $k_{Q,Qint}$ data

Chapter 7

TABLE 21. CALCULATED $k_{Q,Q_{int}}$ VALUES[a] FOR VARIOUS CHAMBER TYPES CALIBRATED IN ELECTRON BEAMS, AS A FUNCTION OF BEAM QUALITY INDEX R_{50} (Q_{int} = 7.5 g/cm^2)

Ionization chamber type[b]	Beam quality index, R_{50} (g/cm^2)													
	1.0[c]	1.4	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10.0
PTW 34001 Roos	1.0851	1.0742	1.0600	1.0500	1.0412	1.0337	1.0271	1.0214	1.0164	1.0122	1.0084	1.0024	0.9979	0.9919
IBA NACP-02	1.0855	1.0743	1.0599	1.0497	1.0409	1.0332	1.0267	1.0210	1.0161	1.0119	1.0082	1.0023	0.9980	0.9923
PTW 34045 Advanced Markus	1.0861	1.0747	1.0601	1.0498	1.0409	1.0332	1.0266	1.0209	1.0160	1.0118	1.0082	1.0023	0.9980	0.9924
PTW 23343 Markus	1.0705	1.0620	1.0507	1.0425	1.0354	1.0291	1.0236	1.0188	1.0146	1.0108	1.0076	1.0022	0.9981	0.9924
IBA PPC40	1.0826	1.0721	1.0583	1.0485	1.0401	1.0327	1.0263	1.0208	1.0160	1.0118	1.0082	1.0024	0.9980	0.9922
IBA PPC05	1.0647	1.0572	1.0474	1.0401	1.0337	1.0279	1.0229	1.0183	1.0143	1.0107	1.0076	1.0022	0.9980	0.9921
Exradin A10	1.0714	1.0611	1.0482	1.0393	1.0317	1.0254	1.0200	1.0155	1.0117	1.0085	1.0058	1.0016	0.9986	0.9950
Exradin A11	1.0720	1.0615	1.0483	1.0393	1.0316	1.0252	1.0199	1.0154	1.0116	1.0084	1.0057	1.0016	0.9987	0.9952
Exradin P11	1.1113	1.0944	1.0733	1.0590	1.0472	1.0373	1.0291	1.0223	1.0167	1.0120	1.0081	1.0022	0.9982	0.9934
Sun Nuclear SNC350p	1.0851	1.0742	1.0600	1.0500	1.0412	1.0337	1.0271	1.0214	1.0164	1.0122	1.0084	1.0024	0.9979	0.9919

Appendix II

$$k_{Q,\mathrm{pp}} = a + be^{-\frac{R_{50,D}}{c}} \quad (98)$$

$$k_{Q,\mathrm{cyl}} = a + bR_{50,D}^{-c} \quad (99)$$

TABLE 47. FITTING PARAMETERS FOR k_Q FOR ELECTRON BEAMS FOR VARIOUS CHAMBER TYPES CALIBRATED IN ^{60}Co GAMMA RADIATION

Ionization chamber type[a]	*a*	*b*	*c*
Plane parallel chambers			
PTW 34001 Roos	0.884	0.120	3.511
IBA NACP-02	0.879	0.120	3.398
Cylindrical chambers			
NE 2571	0.892	0.103	0.920
IBA FC65-G	0.884	0.103	0.680
Exradin A12	0.880	0.108	0.607

Measurements under non reference conditions

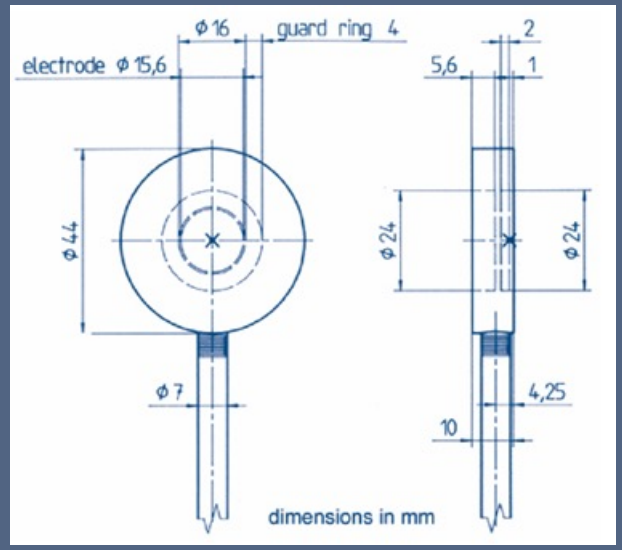
Field output factors

Field output factor

$$\Omega = \frac{D_{w,Q_{clin}}^{f_{clin}}}{D_{w,Q_{ref}}^{f_{ref}}}$$

Notes:

- For non-reference conditions measured at field sizes and SSDs used for treatment or according to TPS.
- Reference and non-reference conditions measured at Zref
- If ionization chamber used, charge should be corrected for variation of stopping power ratio with depth (Table 22).
- For example, external dimensions of Roos chamber is 4.4 cm so (guard ring width) be careful!



1. Background
2. Dosimetry equipment
3. Beam quality index
4. Reference conditions
5. Absorbed dose to water
6. Measurements under non reference conditions

Thank you


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS