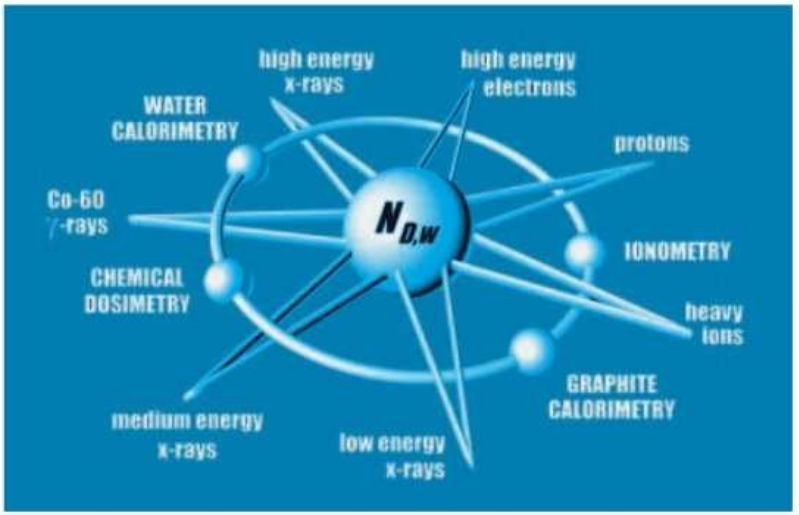
Determinazione della dose assoluta nella Radioterapia con fasci esterni

Marco Minella



TECHNICAL REPORTS SERIES No. **398**

Absorbed Dose Determination in External Beam Radiotherapy

An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water

Sponsored by the IAEA, WHO, PAHO and ESTRO

ESTRO

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2000

dalle 229 pagine
del Code of Practice ad
una semplice procedura
adatta alle attrezzature
disponibili

Index

A che serve?

- Erogare al paziente la dose prescritta dal medico entro i limiti di incertezza della metodica (farmacisti delle radiazioni)

- Gestire l'officina di produzione delle radiazioni
  - Allineamento dei rendimenti delle macchine
  - Istituzione di un sistema di QA congruente

Dose assorbita

$$D = \frac{\overline{dE_{ab}}}{dm} \qquad [\frac{energia}{massa}]$$

dE_{ab} = energia media impartita dalla radiazione ionizzante alla massa dm di materia

1 Gy (gray) = 1 J/kg

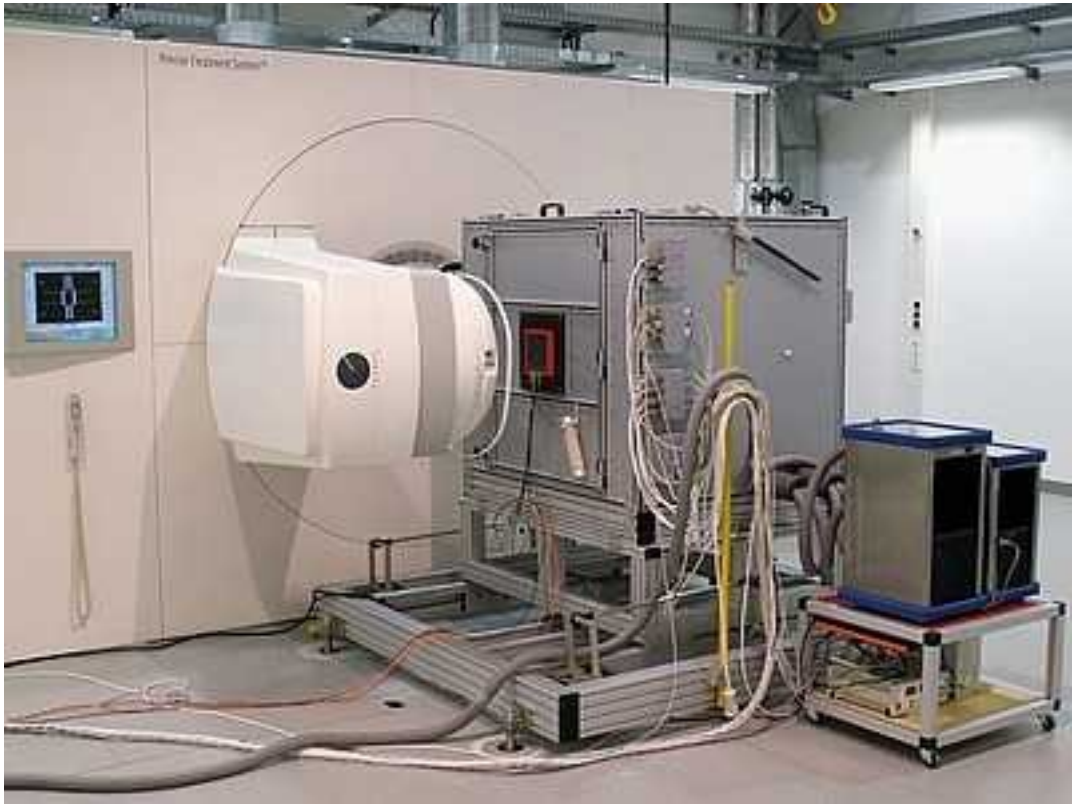
5 litri di acqua
da 20°C all'ebollizione ($\Delta T = 80°C$)

$Q = 80°C \times 5\ kg = 400\ kcal = 1.7\ MJ$

$D_w = E/m = 335\ kGy$

Calorimetro come standard primario

PTB
Messen ▪ Forschen ▪ Wissen



$1\ \mathrm{Gy} \rightarrow \Delta T = 0.24\ \mathrm{m°K}$

Metodo indiretto ionometrico e dose assorbita in un gas (aria)

W = 34 eV/coppia di ioni = 34 J/C

$$D_{aria} = Q/m \bullet W$$

Se l'aria assorbe **1 Gy**
(1 J/kg) / (34 J/C) = 0.029 C/kg

Camera di ionizzazione da **0.6 cm³** (≈ 0.7 mg di aria NTP)
0.029 C/kg x 0.7 mg = **20 nC**

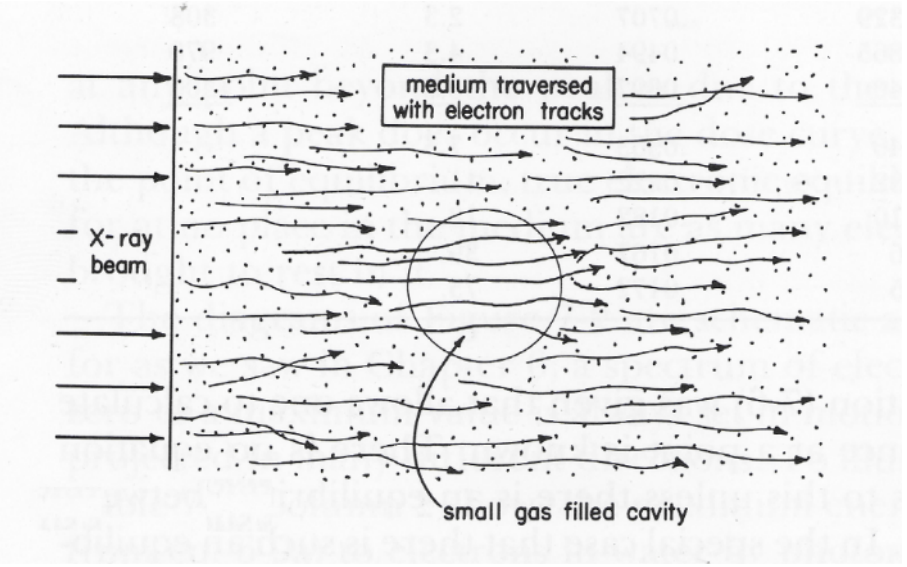
Fattore di taratura "a spanne" in aria
$N_{D,air}$ = 1 Gy / 20×10^{-9} C = 5×10^{-2} Gy/nC = **5×10^{7} Gy/C**

Dose assorbita in acqua (trascurando la parete della camera)

Relazione di Bragg-Gray

$D_{H2O} = D_{aria} \times s_{H2O/aria}$

$s_{H2O/aria}$ (^{60}Co) = 1.13



Fattore di taratura “a spanne” in acqua

$N_{D,w} = 5x10^{-2}$ Gy/nC x 1.13 = $5.7x10^{-2}$ Gy/nC = $5.7x10^{7}$ Gy/C

Dotazione strumentale (6.2)

Elettrometro e camera a ionizzazione

Fotoni:
cilindrica 0.1 - 1 cm^3
Farmer (0.6 cm^3)

Tab. 4.I e Tab. 6.III

Elettrometro

Elettroni: elettrodi piani e paralleli
Markus

Tab. 4.II e Tab. 7.III

Camere a ionizzazione:
- tarate in dose assorbita in acqua $N_{D,w}$ [Gy/C] al Co-60
- presenti nelle tabelle del Code of Practice

Certificato di taratura (pag. 1, 2)

Fattore di taratura “a spanne” in acqua

$N_{D,w} = 5.7 \times 10^7$ Gy/C

PTW
D-79115 Freiburg , Lörracherstr. 7
☎ (0761) 49055-0 FAX (0761) 49055-70

akkreditiert durch die / *accredited by the*

Deutsche Akkreditierungsstelle GmbH

als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst

Kalibrierschein
Calibration certificate

Kalibrierzeichen
Calibration mark

16D307
D-K-15059-01-00
2016-11

Gegenstand *Object*	**Strahlungs-Detektor** Radiation Detector
Hersteller *Manufacturer*	**PTW-Freiburg**
bestehend aus: *consisting of:*	
Gerät / *Instrument*	**Typ- Serien-Nr. / *Type - Serial No.***
Ionisationskammer *Ionization Chamber*	**[REF] TM30006 [SN] 000547**
Auftraggeber *Customer*	**Tema Sinergie S.p.A**
	Via Malpighi, 120
	I-48018 Faenza (RA)
Auftragsnummer / -datum *Order No. / Date*	**R162735 / 07.10.2016**
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	**4**
Datum der Kalibrierung *Date of calibration*	**23.11.2016**

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).

Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.

Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).

The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

The user is obliged to have the object recalibrated at appropriate intervals.

Ergebnis der Kalibrierung / *Calibration Results*

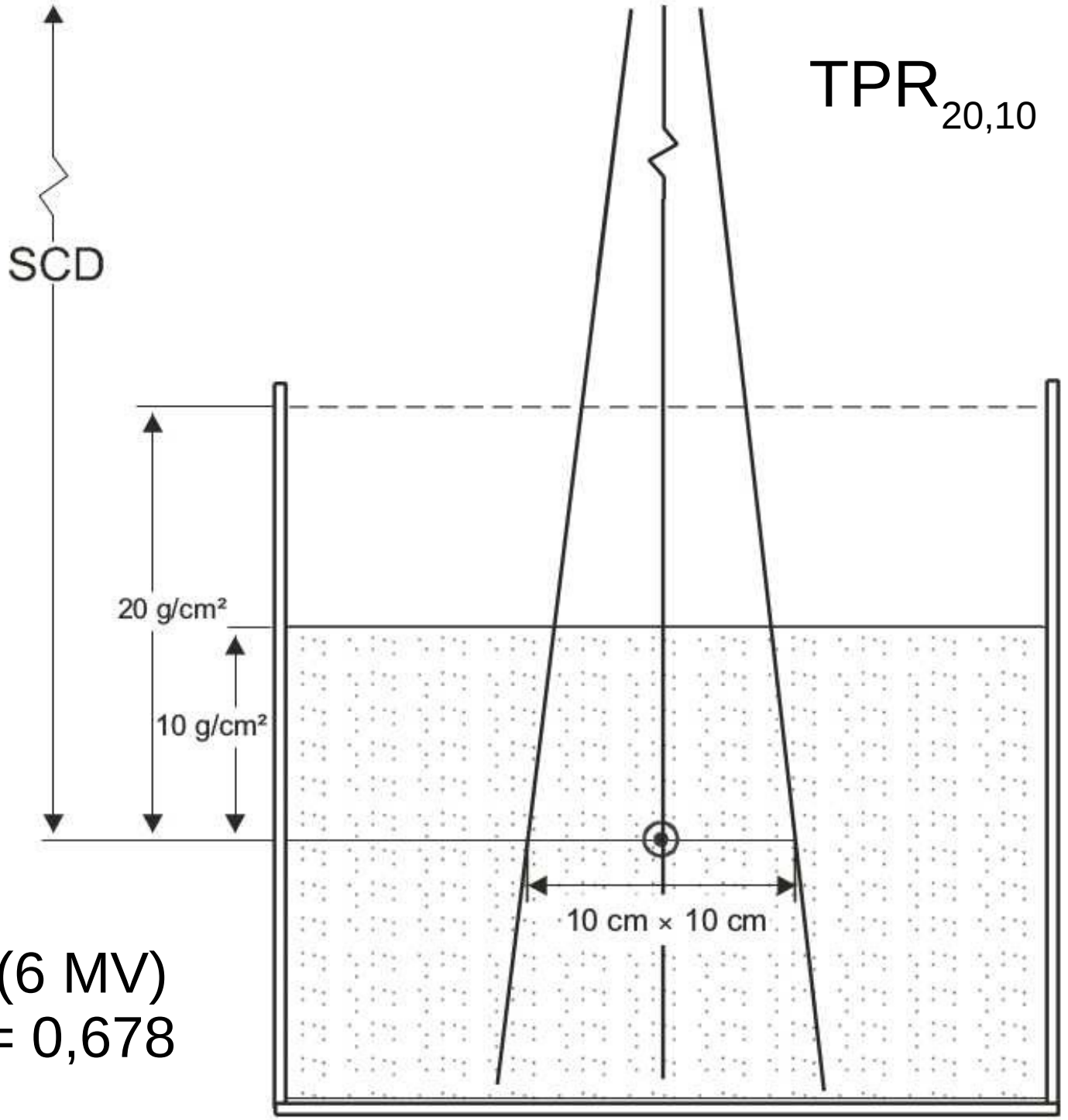
Messgröße *Measuring Quantity*	Wasserenergiedosis *Absorbed Dose To Water*
Detektor-Kalibrierfaktor *Detector Calibration Factor*	$N_{D,w} = 5{,}277 \cdot 10^7$ Gy / C

Strahlungsqualitäten
Radiation Qualities

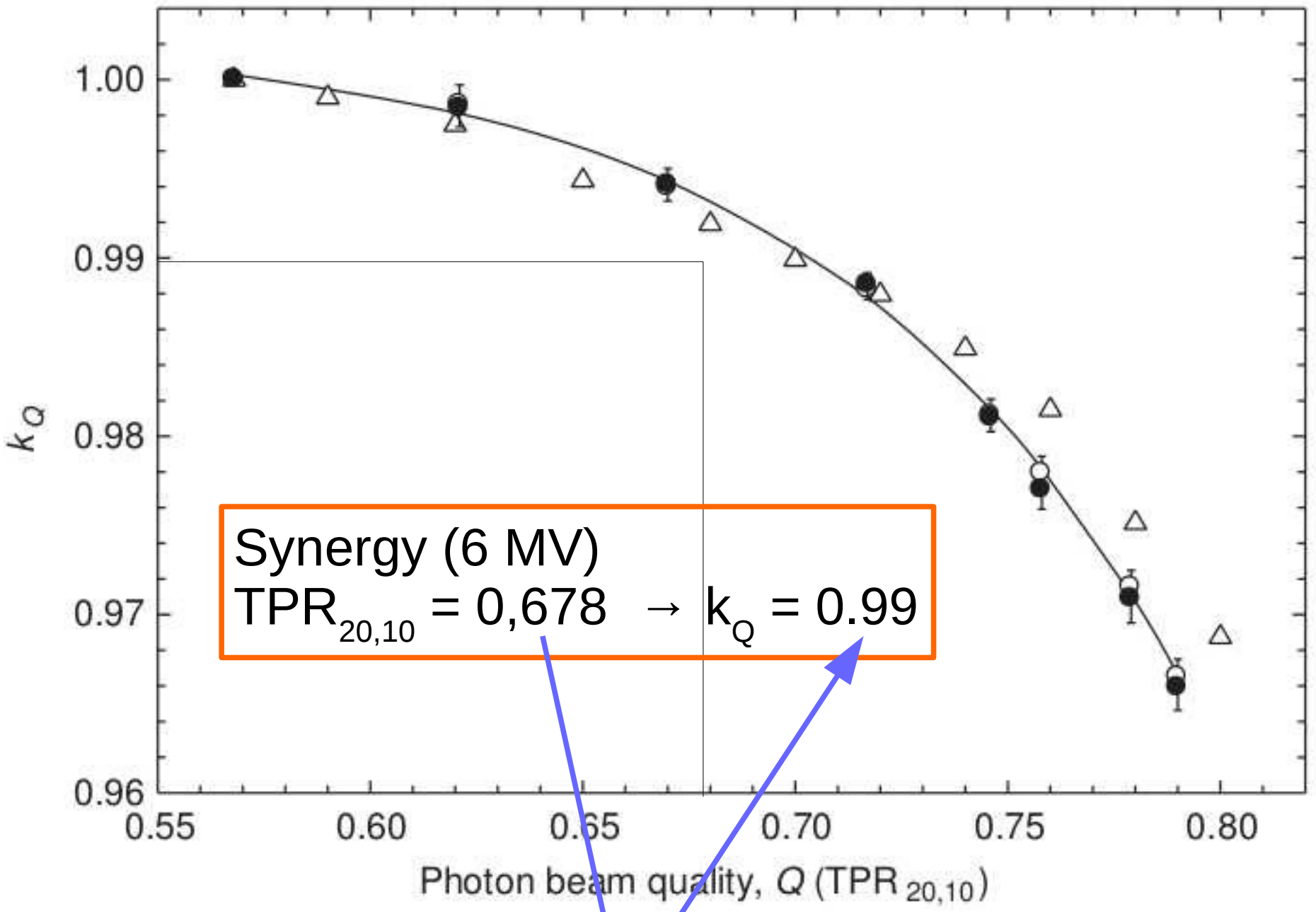
Strahlungsqualität *Radiation Quality*	Korrekturfaktor k_Q *Correction Factor* k_Q	Unsicherheit *Uncertainty*
^{60}Co	1,000	1,1 % (2σ)

Bezugsbedingungen *Reference Conditions*	Strahlungsqualität / *Radiation Quality*	^{60}Co
	Temperatur / *Temperature*	293,2 K (20°C)
	Luftdruck / *Air Pressure*	1013,25 hPa
	Relative Feuchtigkeit / *Relative Humidity*	50 % r. F.
	Kammerspannung / *Polarizing Voltage*	+ 400 V
Polaritätseffekt *Polarity Effect*	< 0,2 %	(im Detektor-Kalibrierfaktor nicht berücksichtigt / *not accounted for in the detector calibration factor*)
Korrekturfaktor für unvollständige Sättigung *Saturation Correction Factor*	k_S = 1,000	
Kontrollanzeige *Check Source Reading*	---	
Isotop - Halbwertszeit *Isotope - Half Life Time*	---	
Bezugsdatum *Reference Date*	---	

Qualità del fascio di radiazioni (6.3)



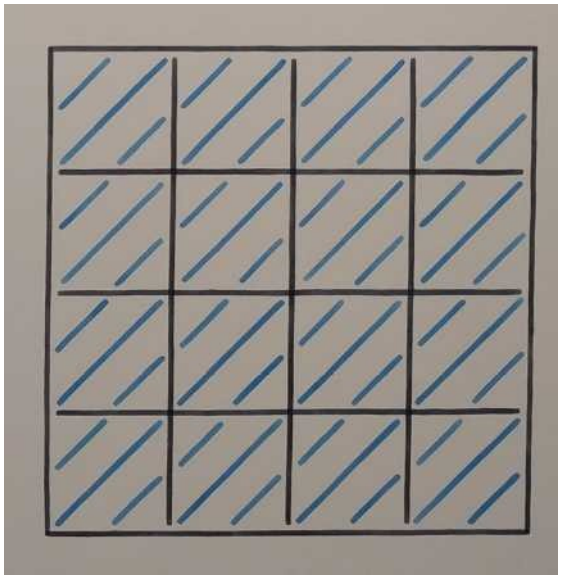
Synergy (6 MV)
$TPR_{20,10}$ = 0,678



IAEA TRS-398 Tab. 6.III per camera PTW 30006

$TPR_{20,10}$	0.50	0.53	0.56	0.59	0.62	0.65	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82	0.84
k_Q	1.002	1.002	1.000	0.999	0.997	0.994	0.990	0.988	0.984	0.980	0.975	0.968	0.960	0.952	0.940

Determinazione della dose assorbita in acqua (6.4)



Condizioni di riferimento (set-up sperimentale)

TABLE 13. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN HIGH ENERGY PHOTON BEAMS

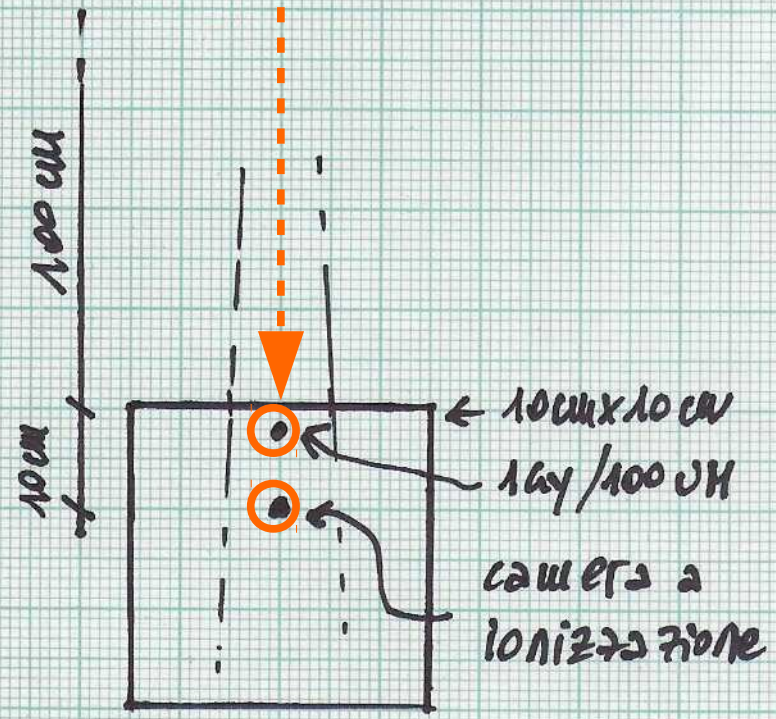
Influence quantity	Reference value or reference characteristics
Phantom material	Water
Chamber type	Cylindrical
Measurement depth z_{ref}	For $TPR_{20,10} < 0.7$, 10 g/cm^2 (or 5 g/cm^2)[a] For $TPR_{20,10} \geq 0.7$, 10 g/cm^2
Reference point of the chamber	On the central axis at the centre of the cavity volume
Position of the reference point of the chamber	At the measurement depth z_{ref}
SSD/SCD	100 cm[b]
Field size	10 cm × 10 cm[c]

10 cm

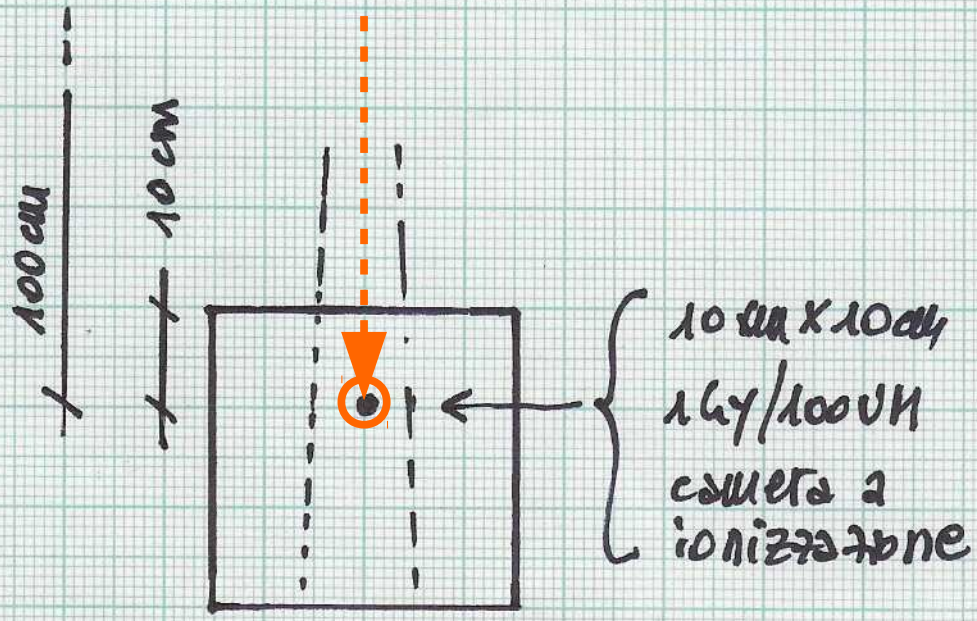
Set - Up

SCD (Source Chamber Distance)

SSD
Source - Surface - Distance



SAD
Source - Axis - Distance



Determinazione della dose assorbita in acqua nelle condizioni di riferimento

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

M_Q = lettura del dosimetro corretta per la densità dell'aria, taratura dell'elettrometro, effetti di polarità e ricombinazione ionica

$N_{D,w}$ = fattore di taratura della camera a ionizzazione in termini di dose assorbita in acqua all'energia di riferimento in taratura (normalmente ^{60}Co)

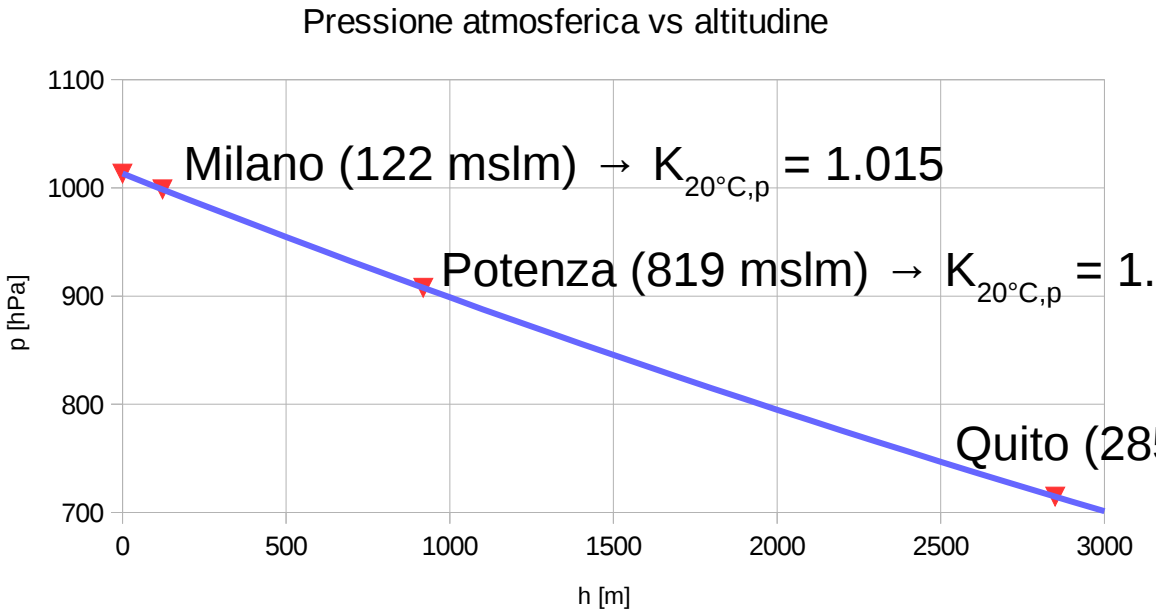
K_Q = fattore correttivo (specifico della camera) per la diversa **qualità del fascio** di radiazione rispetto a quello di taratura

Correzione della lettura per la densità dell'aria

$K_{T,p} = ((273.2+T)/(273.2+20)) \times 1013/p$

T [°C]
p [hPa]

Valori attesi di $k_{T,p}$ a 20°C



Determinazione della dose assorbita in acqua nelle condizioni di riferimento

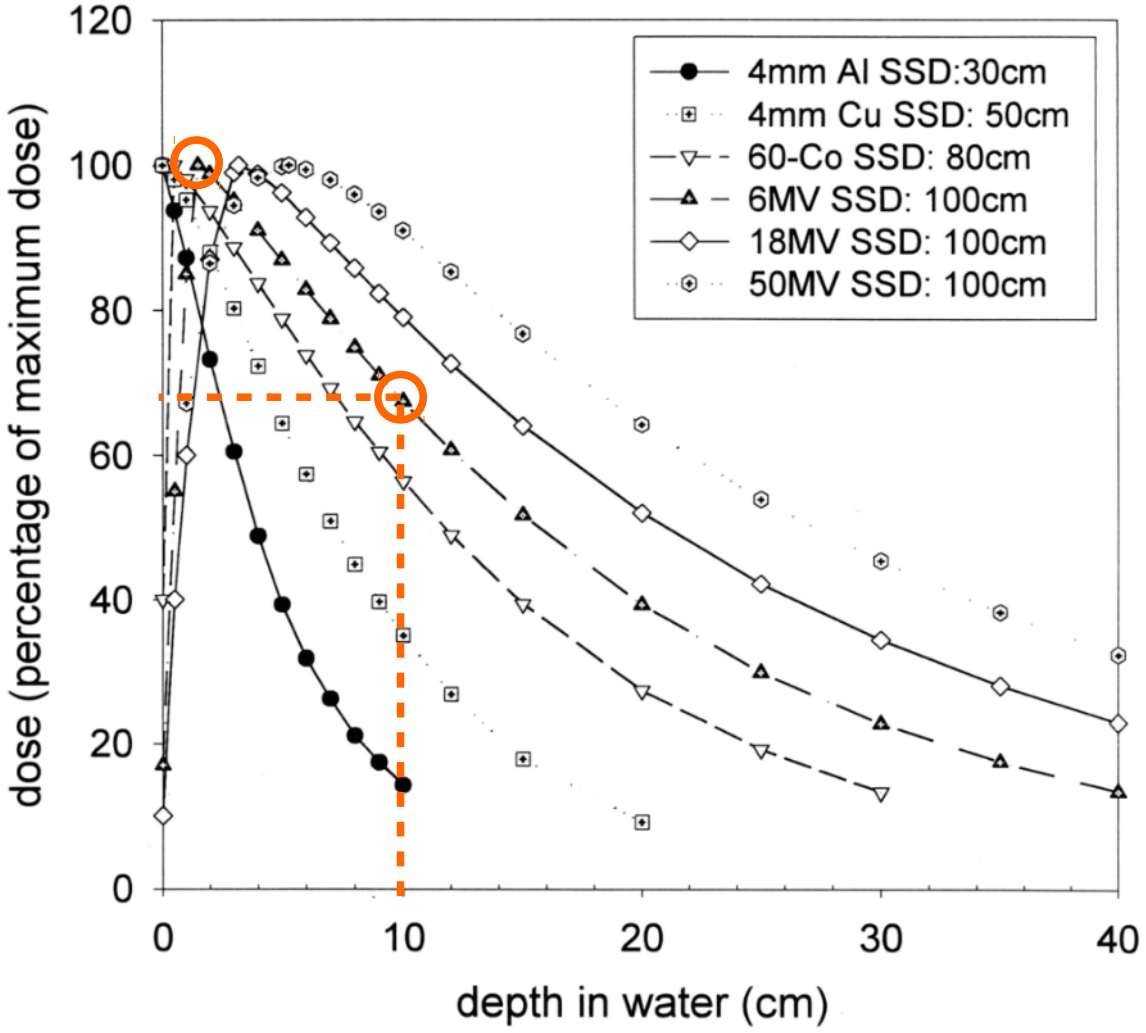
$$D_{w,Q} = M_Q \; N_{D,w} \; k_Q$$

M_Q = lettura del dosimetro corretta

$N_{D,w}$ = fattore di taratura della camera a ionizzazione

K_Q = fattore correttivo per l'energia del fascio

Determinazione della dose in z_{Dmax}



$D(z_{Dmax}) = D(z_{ref}) / PDD(z_{ref})$

Synergy (6 MV)
PDD (10 cm) = 67%

Tipica misura su Synergy a 6 MV

Dati da acquisire prima

- $TPR_{20,10}$ = 0.678 → k_Q = 0.99
- PDD (10 cm) = 67 %
- Fattore di taratura della camera PTW 30006-547 = 5.277×10^{-2} Gy/nC

(T = 22 °C; p = 998 hPa) → $K_{T,p}$ = 1.022

Misura in z = 10 cm erogando 200 UM

M_{6MV} = 25.54 nC

Dose in z_{ref} (10 cm)

$D_{w,6MV}$ (10 cm) = $k_{T,P}$ x M_{6MV} (nC) x 5.277×10^{-2} Gy/nC x 0.99

$D_{w,6MV}$ (10 cm) = 1.022 x 25.54 nC x 5.277×10^{-2} Gy/nC x 0.99 = **1.364 Gy**

Calcolo della dose al build-up = z_{Dmax}

$D_{w,6MV}$ (z_{Dmax}) = $D_{w,6MV}$ (10 cm) / PDD (10 cm)

$D_{w,6MV}$ (z_{Dmax}) = 1.364 Gy / 0.67 = **2.036 Gy**

6.9. WORKSHEET

Determination of the absorbed dose to water in a high energy photon beam

User: _____ Date: _____

1. Radiation treatment unit and reference conditions for $D_{w,Q}$ determination

Accelerator: _____ Nominal Acc. potential: _____ MV

Nominal dose rate: _____ MU/min Beam quality, Q ($TPR_{20,10}$): _____

Reference phantom: water Set-up: ❑ SSD ❑ SAD

Reference field size: 10 × 10 cm × cm Reference distance (cm): _____

Reference depth z_{ref}: _____ g/cm²

2. Ionization chamber and electrometer

Ionization chamber model: _____ Serial No.: _____

Chamber wall material: _____ thickness: _____ g/cm²

Waterproof sleeve material: _____ thickness: _____ g/cm²

Phantom window material: _____ thickness: _____ g/cm²

Absorbed dose to water calibration factor[a] N_{D,w,Q_o} = _____ ❑ Gy/nC ❑ Gy/rdg

Calibration quality Q_o ❑ ^{60}Co ❑ photon beam Calibration depth: _____ g/cm²

If Q_o is photon beam, give $TPR_{20,10}$: _____

Reference conditions for calibration P_o: _____ kPa T_o: _____ °C Rel. humidity: ___ %

Polarizing potential V_1: _____ V Calibration polarity: ❑ +ve ❑ –ve ❑ corrected for polarity effect

User polarity: ❑ +ve ❑ –ve

Calibration laboratory: _____ Date: _____

Electrometer model: _____ Serial No.: _____

Calibrated separately from chamber: ❑ yes ❑ no Range setting: _____

If yes, calibration laboratory: _____ Date: _____

3. Dosimeter reading[b] and correction for influence quantities

Uncorrected dosimeter reading at V_1 and user polarity: _____ ❑ nC ❑ rdg

Corresponding accelerator monitor units: _____ MU

Ratio of dosimeter reading and monitor units: M_1 = _____ ❑ nC/MU ❑ rdg/MU

(i) Pressure P: _____ kPa Temperature T: _____ °C Rel. humidity (if known): _____ %

$$k_{TP} = \frac{(273.2+T)}{(273.2+T_o)}\frac{P_o}{P} = \_\_\_\_\_$$

(ii) Electrometer calibration factor[c] k_{elec}: ❑ nC/rdg ❑ dimensionless k_{elec} = _____

(iii) Polarity correction[d] rdg at + V_1: M_+ = _____ rdg at –V_1: M_- = _____

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

(iv) Recombination correction (two voltage method)

Polarizing voltages: V_1 (normal) = _____ V V_2 (reduced) = _____ V

Readings[e] at each V: M_1 = _____ M_2 = _____

Voltage ratio V_1/V_2 = _____ Ratio of readings M_1/M_2 = _____

Use Table 9 for a beam of type: ❑ pulsed ❑ pulsed–scanned

a_0 = _____ a_1 = _____ a_2 = _____

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

Corrected dosimeter reading at the voltage V_1:

$M_Q = M_1\, k_{TP}\, k_{elec}\, k_{pol} k_s$ = _____ ❑ nC/MU ❑ rdg/MU

4. Absorbed dose to water at the reference depth z_{ref}

Beam quality correction factor for the user quality Q: k_{Q,Q_o} = _____

taken from ❑ Table 14 ❑ Other, specify: _____

$D_{w,Q}(z_{ref}) = M_Q\, N_{D,w,Q_o} k_{Q,Q_o}$ = _____ Gy/MU

5. Absorbed dose to water at the depth of dose maximum z_{max}

Depth of dose maximum: z_{max} = _____ g/cm²

(i) SSD set-up

Percentage depth dose at z_{ref} for a 10 cm × 10 cm field size: PDD (z_{ref} = _____ g/cm²) = _____ %

Absorbed dose calibration of monitor at z_{max}:

$D_{w,Q}(z_{max}) = 100\, D_{w,Q}(z_{ref})$/PDD ($z_{ref}$) = _____ Gy/MU

(ii) SAD set-up

TMR at z_{ref} for a 10 cm × 10 cm field size: TMR (z_{ref} = _____ g/cm²) = _____

Absorbed dose calibration of monitor at z_{max}:

$D_{w,Q}(z_{max}) = D_{w,Q}(z_{ref})$/TMR($z_{ref}$) = _____ Gy/MU

---

[a] Note that if Q_o is ^{60}Co, N_{D,w,Q_o} is denoted by $N_{D,w}$.

[b] All readings should be checked for leakage and corrected if necessary.

[c] If the electrometer is not calibrated separately, set $k_{elec} = 1$.

[d] M in the denominator of k_{pol} denotes reading at the user polarity. Preferably, each reading in the equation should be the average of the ratios of M (or M_+ or M_-) to the reading of an external monitor, M_{em}.
It is assumed that the calibration laboratory has performed a polarity correction. Otherwise k_{pol} is determined according to:
rdg at $+V_1$ for quality Q_o: M_+ = _____ rdg at $-V_1$ for quality Q_o: M_- = _____

$$k_{pol} = \frac{\left[(|M_+|+|M_-|)/|M|\right]_Q}{\left[(|M_+|+|M_-|)/|M|\right]_{Q_o}} = \_\_\_\_\_$$

[e] Strictly, readings should be corrected for polarity effect (average with both polarities). Preferably, each reading in the equation should be the average of the ratios of M_1 or M_2 to the reading of an external monitor, M_{em}.

Protocollo di Niguarda (foglio di lavoro)

4.6.6. Misure del 6/11/2006 sui fasci di fotoni del Synergy

Esecutore delle misure	MGB & MM	Data	6/11/2006

Acceleratore lineare	Elekta Synergy

MISURE IN FANTOCCIO AD ACQUA

PDD

V [MV]	z_{max} [mm]	$D_{10\,cm}$ [%]
6	14	67
10	21	72.7
15	26	75.5

Misure per $TPR_{20,10}$

	z = 20 cm (DSP 80 cm)			z = 10 cm (DSP 90 cm)		
	6 MV	10 MV	15 MV	6 MV	10 MV	15 MV
M1 [nC]	21.05	25.00	27.14	31.03	34.05	35.70
M2 [nC]	21.07	24.99	27.11	31.04	34.10	35.75
M3 [nC]	21.07	25.00	27.12	31.05	34.07	35.72
Media	21.06	25.00	27.12	31.04	34.07	35.72

TPR e k_Q

IAEA TRS-398 Tab. 6.III per camera PTW 30006

$TPR_{20,10}$	0.50	0.53	0.56	0.59	0.62	0.65	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82	0.84
k_Q	1.002	1.002	1.000	0.999	0.997	0.994	0.990	0.988	0.984	0.980	0.975	0.968	0.960	0.952	0.940

V [MV]	$TPR_{20,10}$	k_Q
6	0.678	0.990
10	0.734	0.981
15	0.759	0.975

K_{TP} in acqua

$M_{barometro}$ [kPa]	$T_{barometro}$ [°C]	p [kPa]	$T_{dosimetro}$ [°C]	$K_{TP,\,acqua}$
101.3	23	100.9	21.0	1.007

Misure con camera di Farmer

Ionizzazione	6 MV	10 MV	15 MV
Ion1 [nC]	25.84	28.22	29.57
Ion2 [nC]	25.81	28.24	29.56
Ion3 [nC]	25.86	28.28	29.58
Media	25.84	28.25	29.57

Determinazione della dose alla profondità di dose massima

D_W [Gy]	=	$K_{TP,\,acqua}$	x	N_W [Gy/nC]	x	k_Q	x	Ion [nC]	/	Rel. DD_{10cm}		
$D_{W,\,6MV}$						0.99		25.84		0.67		2.010
$D_{W,\,10MV}$	=	1.007	x	5.229×10^{-2}	x	0.981	x	28.25	/	0.727	=	2.007
$D_{W,\,15MV}$						0.975		29.57		0.755		2.011

Determinazione del rapporto rispetto alla dose nominale

D_{mis} / D_{nom}	=	D_W misurata [Gy]	/	D_W nominale [Gy]		
D_{mis} / $D_{nom\,6MV}$		2.010		2		1.005
D_{mis} / $D_{nom\,10MV}$	=	2.007	/	2	=	1.004
D_{mis} / $D_{nom\,15MV}$		2.011		2		1.006

Incertezza e cifre significative

- Il CoP stima che l'**incertezza standard** (1 σ) associata alle determinazioni di dose alla profondità di riferimento sia dell'ordine dell'**1.5%**

- **In metrologia**, per apprezzare il centesimo di gray, uso 4 cifre significative, quindi **tre decimali del gray** (2.036 Gy)
- Per **attestazioni di dose** e comunicazioni con i medici, esprimo le dosi (associate ad un'incertezza del %) al centesimo di gray (rad), cioè con **solo due decimali del gray** (2.04 Gy)

Valutazione della misura

$D_{w,6MV}\ (z_{Dmax}) = 1.364\ Gy / 0.67 =$ **2.036 Gy**

- **Intervallo di accettabilità ±2%**
  - valore misurato / valore atteso = 2.036 / 2 = 1.018 = +1.8%
- Stabilire un **livello di azione più restrittivo** dell'intervallo di accettabilità per tenere conto della propagazione dell'errore alle misure di CQ più semplici e frequenti (daily-check e fantoccio solido)

Azioni conseguenti alle misure

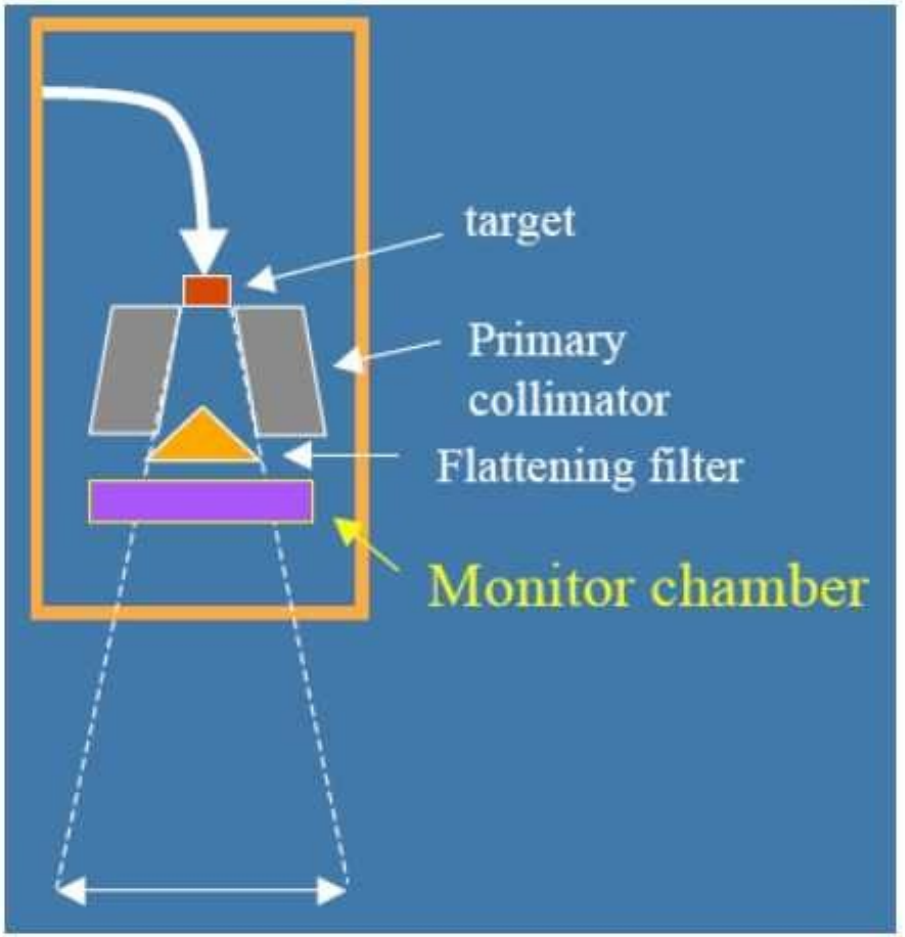
- Eventuale **regolazione del rendimento** del LINAC per riportarlo al rendimento nominale di 1 Gy / 100 UM nelle condizioni di riferimento in uso nel reparto
- Allineare le misure in fantoccio solido e la strumentazione di controllo quotidiano del rendimento (daily check) alla determinazione della dose assoluta

Monitor chamber

Dual transmission ionization chamber:

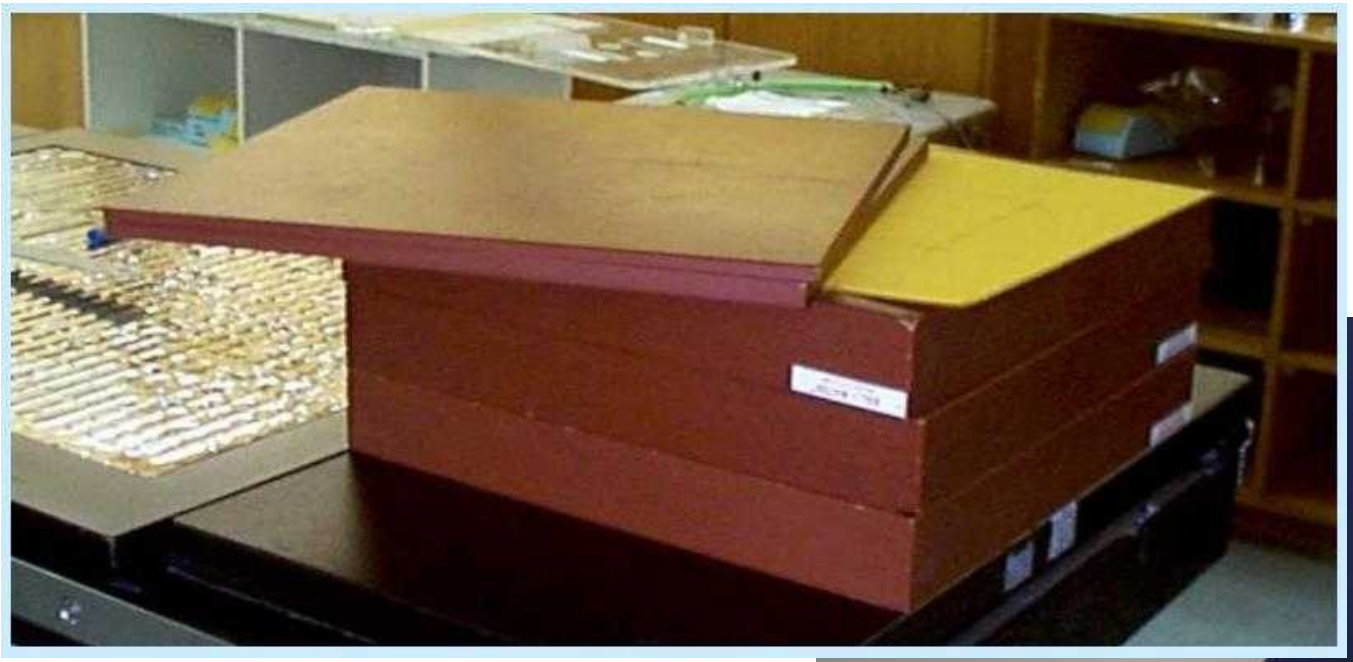
- Determination of treatment beam dose
- Two chambers: Redundant dose determination

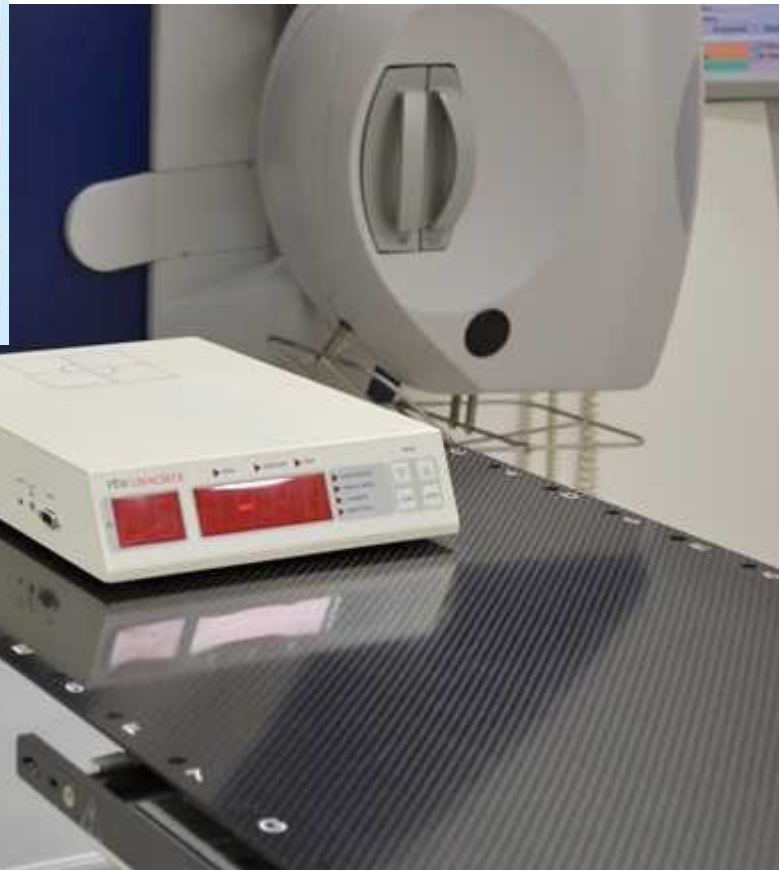
TrueBeam dual transmission monitor chamber



Regolazione del rendimento (guadagno delle camere monitor)

Allineare la risposta della strumentazione di QC alle determinazioni in acqua





Elettroni 3-50 MeV

- Camera a ionizzazione con elettrodi piani e paralleli
- La dose non è proporzionale alla ionizzazione
- Qualità del fascio in R_{50} [cm]
- $z_{ref} = 0.6\ R_{50} - 0.1 \quad (z_{ref} > z_{max})$
- $D_{w,Q}\ (z_{ref}) = M_Q\ N_{D,w}\ k_Q$
- $D_{w,Q}\ (z_{max}) = D_{w,Q}\ (z_{ref}) / PDD\ (z_{ref})$

ESTRO QUALity Assurance Network (EQUAL)
Reduction of Radiation Morbidity Through Q.A. of Dosimetry and Evaluation of Morbidity
MORQA project (Task 1), supported by the EUROPE AGAINST CANCER programme of the E.U.
European Society for Therapeutic Radiology and Oncology

Dr. Stefano De Crescenzo
Medical Physics Department
Ospedale Niguarda Ca'Granda
P. zza Ospedale Maggiore 3
20162 Milan
Italy

IF-AB-JC/am
Milan 85[99]

Villejuif, March-09, 2000

Dear Dr. De Crescenzo,

Please find, enclosed, the results concerning the postal dosimetric checks performed in the frame of the ESTRO QUALity Assurance Network (EQUAL) [MORQA project (Task 1)] for the following X-ray beams : **6 MV, 15 MV and 25 MV of the Saturne 43.**

These results are divided into two parts, each of them including the user stated values, the measured values, and the ratio of these two data [1].
The first part presents the results obtained for points located on the beam axis.
The second part deals with additional dosimetric data checks, and provides ratios calculated from the measurements.

Results of TLD measurements for on axis points

For the **6 MV X-ray beam**, the results are within the optimal level (deviations on D_m/D_s $\leq \pm 3$ %) except for the points 1 and 6 which are outside the optimal level and within the tolerance level (deviations $> \pm 3$ % and $\leq \pm 5$ %).

For the **15 MV X-ray beam**, the results are within the optimal level (deviations on D_m/D_s $\leq \pm 3$ %) except for the points 4b and 8 which are outside the optimal level and within the tolerance level (deviations $> \pm 3$ % and $\leq \pm 5$ %).

For the **25 MV X-ray beam**, the results are within the optimal level (deviations on D_m/D_s $\leq \pm 3$ %) except for the points 4a, 4b, 6 and 8 which are outside the optimal level and within the tolerance level (deviations $> \pm 3$ % and $\leq \pm 5$ %).

For any question, please do not hesitate to contact us.

Milan 85[99]

Thank you for your participation in the ESTRO-EQUAL Programme.

Sincerely yours,

Dr. I.H. FERREIRA Dr. A. BRIDIER Prof. J. CHAVAUDRA

Enclosures : 6 pages
Copy to : Prof. H. SVENSSON, Prof. A. DUTREIX

[1] Protocol : Strict confidentiality of the results is maintained by the EQUAL Network. The levels of deviation between measured and stated quantities (Dm/Ds) and the corresponding EQUAL actions are specified as follows :
- optimal level when the deviation Dm/Ds is $\leq \pm 3\%$;
- outside optimal and within tolerance level when the deviation is $> \pm 3\%$ and $\leq \pm 5\%$,
- outside tolerance level when the deviation is $> \pm 5\%$ and $\leq \pm 10\%$; and
- emergency level when the deviation is $> \pm 10\%$.

Ottimo: $D_m/D_s \leq \pm 3\%$

In tolleranza: $D_m/D_s \leq \pm 5\%$

Take-home points

Dal protocollo IAEA alla procedura interna

Istituire controlli periodici di rendimento frequenti e semplici

Partecipare ad interconfronti

Evidenza documentale di Quality Assurance