GRAPHITE IONIZATION CHAMBER AS AN IONOMETRIC STANDARD OF ABSORBED DOSE TO WATER FOR THE DOSIMETRY OF THERAPEUTIC PHOTON BEAMS

PRELIMINARY STUDY

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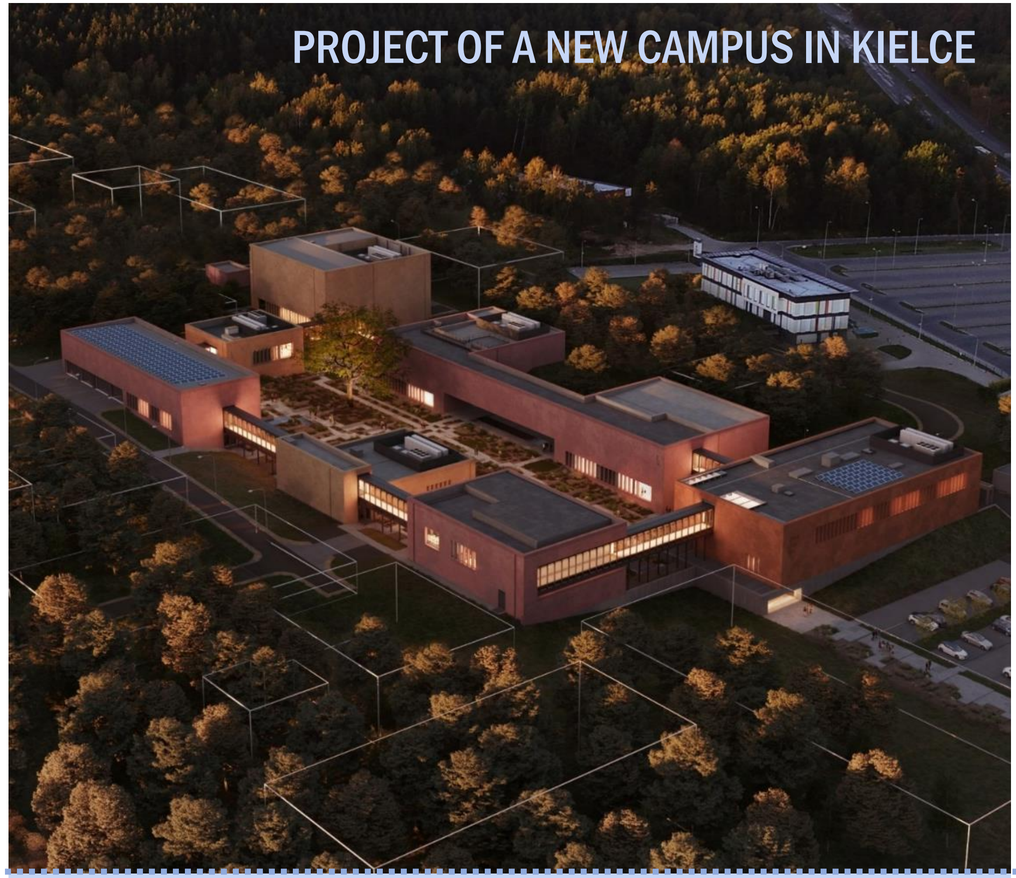

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HOW IMPORTANT IS PRECISON AND ACCURACY **IN RADIOTHERAPY**

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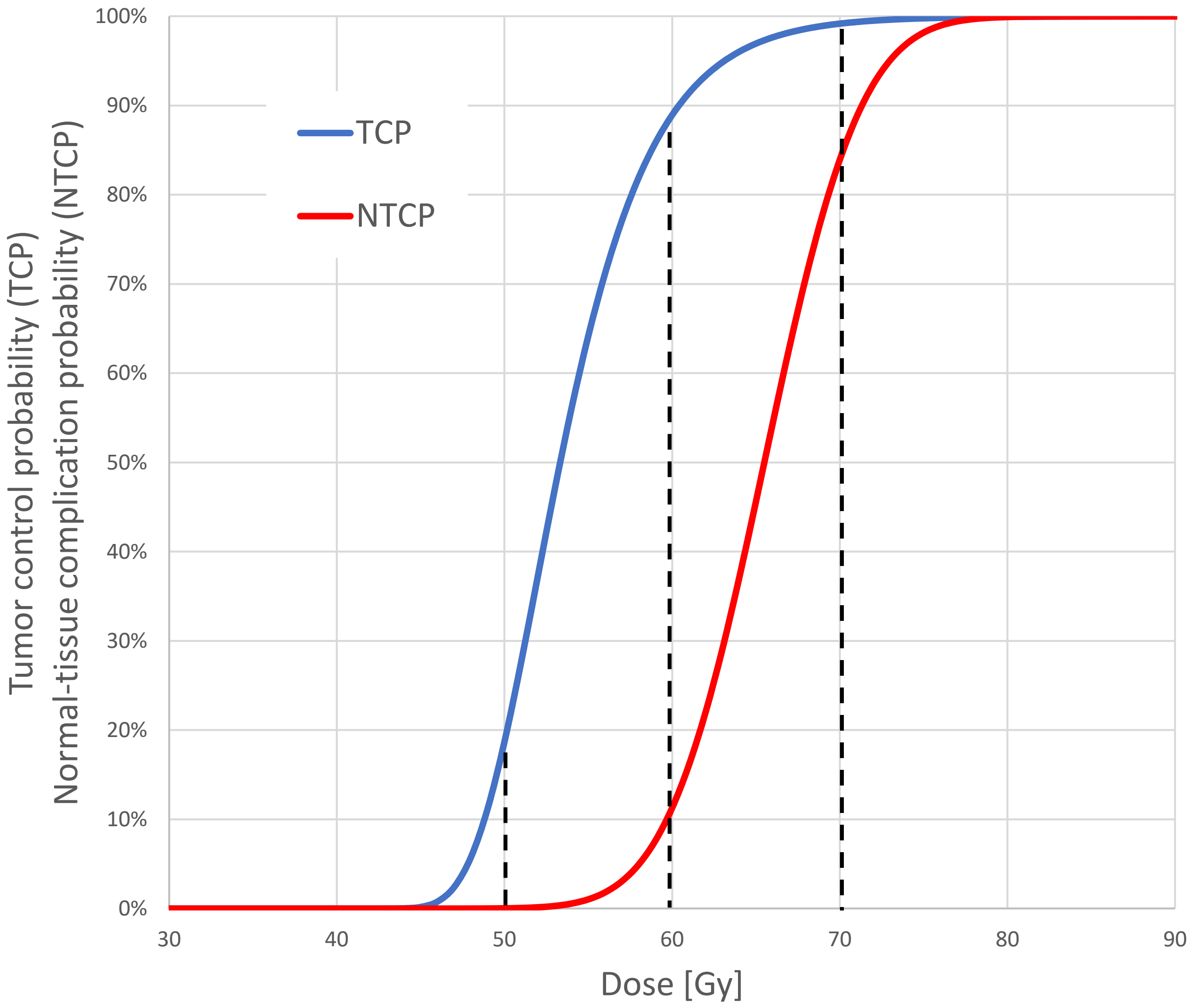
SERIOUS **CONSEQUENCES** OF AN OVERDOSE

[IAEA, 2004]



OUTCOME OF RADIOTHERAPY – DOSE-EFFECT CURVES

- TCP – Tumour Control Probability

$$TCP = \exp[-N_0 exp(-\alpha D - \beta d D)]$$

[Munro, 1961]

- NTCP – Normal Tissue Complication Probability

$$NTCP(D,V) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} exp\left(-\frac{1}{2}t^2\right) dt$$

[Lyman, 1985]

ACCURACY REQUIREMENTS FOR RADIATION THERAPY
– based on the steepness of dose-effect curves (NTCP)

Relative gradient of the dose-effect curve for normal tissue reaction after photon irradiation.

Normal tissue reaction	$\Delta_{50/25}$ (%)
Major chronic complications of the larynx [22]	2[a]
Peripheral neuropathy [44]	3[a]
Late skin damage [4]	4
Late intestinal damage [4]	4
Brachial plexus [46]	5[a]
Radiation pneumonitis [53]	6
Skin reaction [51]	7[a]
Major complications of the intestine and bladder [37]	9[a]
Skin and lip [45]	10[a]
Myelitis [39]	15
Major and non-major complications of the larynx [16]	17[a]

Increase in overall uncertainty of the absorbed dose of 7% can lead to unacceptable risk of complications ($\Delta_{50/25}$).

If 7% is considered as two standard deviations,
the combined acceptable uncertainty in the absorbed dose delivery is 3.5%.

[Mijnheer et al., 1987]

ACCURACY ACHIEVABLE IN ABSORBED DOSE DELIVERY

[Thwaites, 2013]

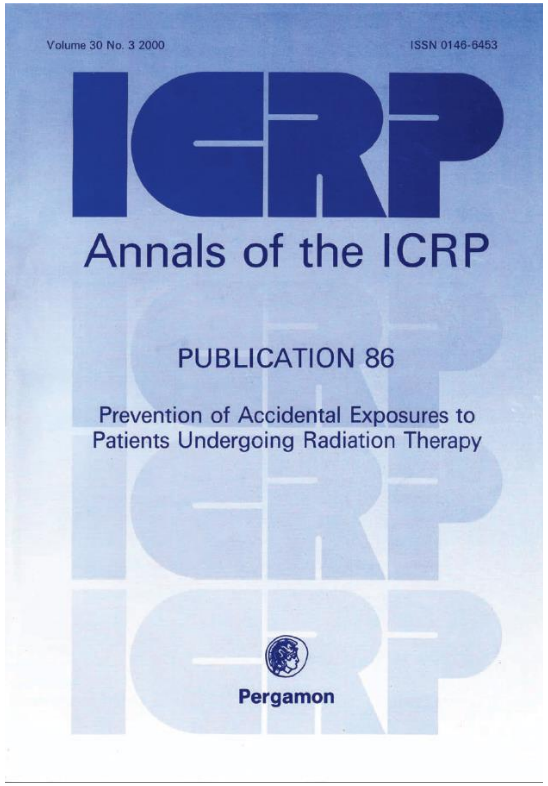
Source/step	*Single centre* (different beams/times)	*Multi-centre*
1. Dose at reference point in water phantom		
1.1. uncertainties quoted on calibration factors by the UK standards lab (NPL) are 0.7% (1 effective sd)	0.7%	0.7 %
1.2. variation in reference dose determination between beams and through time	0.5%	0.7-1%
1.3. combined	0.9%	1.0- 1.2%
2. Dose to phantoms representing various treatment sites (at a range of points within target volumes; given relative to reference dose)	0.8-1.8%	1.1-2.3%
3. Patient dose at specification point (based on estimates from *in vivo* dosimetry; for a wide range of treatment sites and techniques, given relative to reference dose)	1.5-3%	1.6 – 3.2 %
+ *where lung is significantly involved**	*(5%)**	*(5.1%)**
4. Estimated overall cumulative uncertainty on delivered patient dose at the specification point, including standards lab uncertainty	**1.7 – 3.1%**	**1.9 – 3.4%**
(+ where lung is significantly involved*	(5.1%)*	(5.2%)*

CLASSES AND FREQUENCIES OF ACCIDENTAL EXPOSURE IN RADIOTHERAPY

Table. 3

Accidental exposures in external beam therapy	No. of cases	Percentage of cases (rounded)
Equipment problems	3	6.5
Maintenance	3	6.5
Calibration of the beams	14	30
Treatment planning and dose calculation	13	28
Simulation	4	9
Treatment set-up and delivery	9	20 (**)
Total	46 (*)	100

[ICRP, 2000]



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HOW TO IMPROVE THE ACCURACY OF THE DELIVERED DOSE **IN RADIOTHERAPY**

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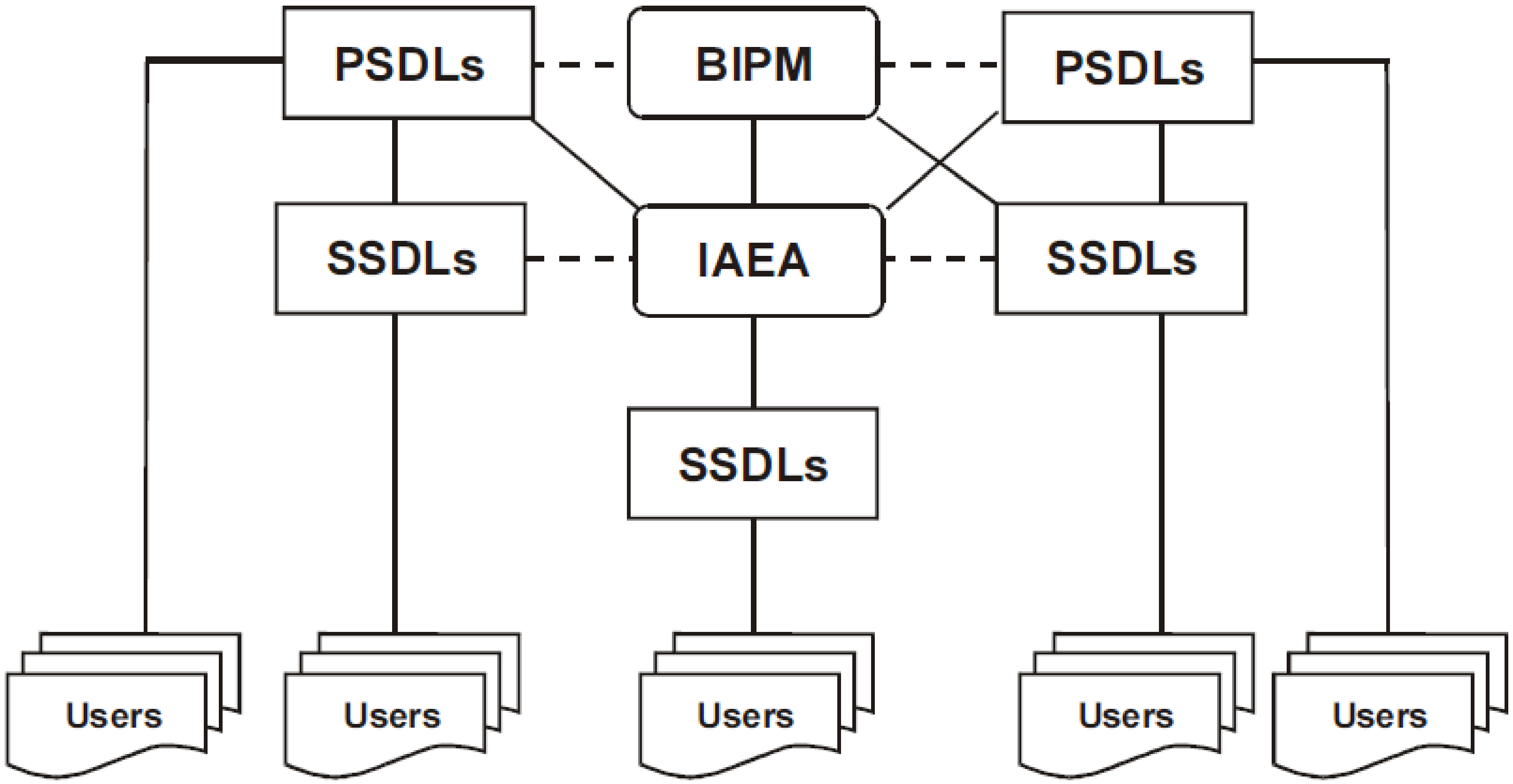
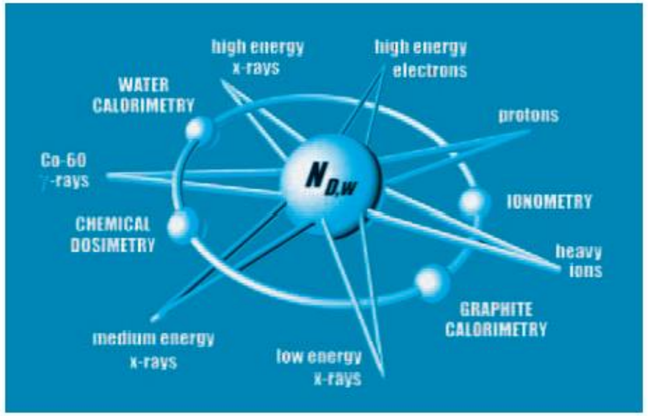
DOSIMETRY PROTOCOL
– THE INTERNATIONAL MEASUREMENT SYSTEM



[IAEA, 2000]

DOSIMETRY PROTOCOL – IAEA TRS NO. 398

CODE OF PRACTICE FOR HIGH ENERGY PHOTON BEAMS



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

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2000

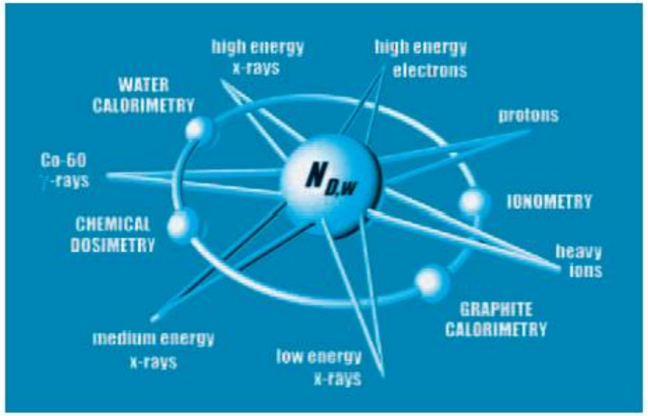
[IAEA, 2000]

$$D_{w,Q} = M_Q \cdot k_{TP} \cdot (k_h)_Q \cdot (k_{elec})_Q \cdot (k_{pol})_Q \cdot (k_S)_Q \cdot \frac{N_{D,w,Q_0}}{(k_{pol})_{Q_0} \cdot (k_S)_{Q_0}} \cdot k_{Q,Q_0}$$

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

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

$$k_{Q,Q_o}$$



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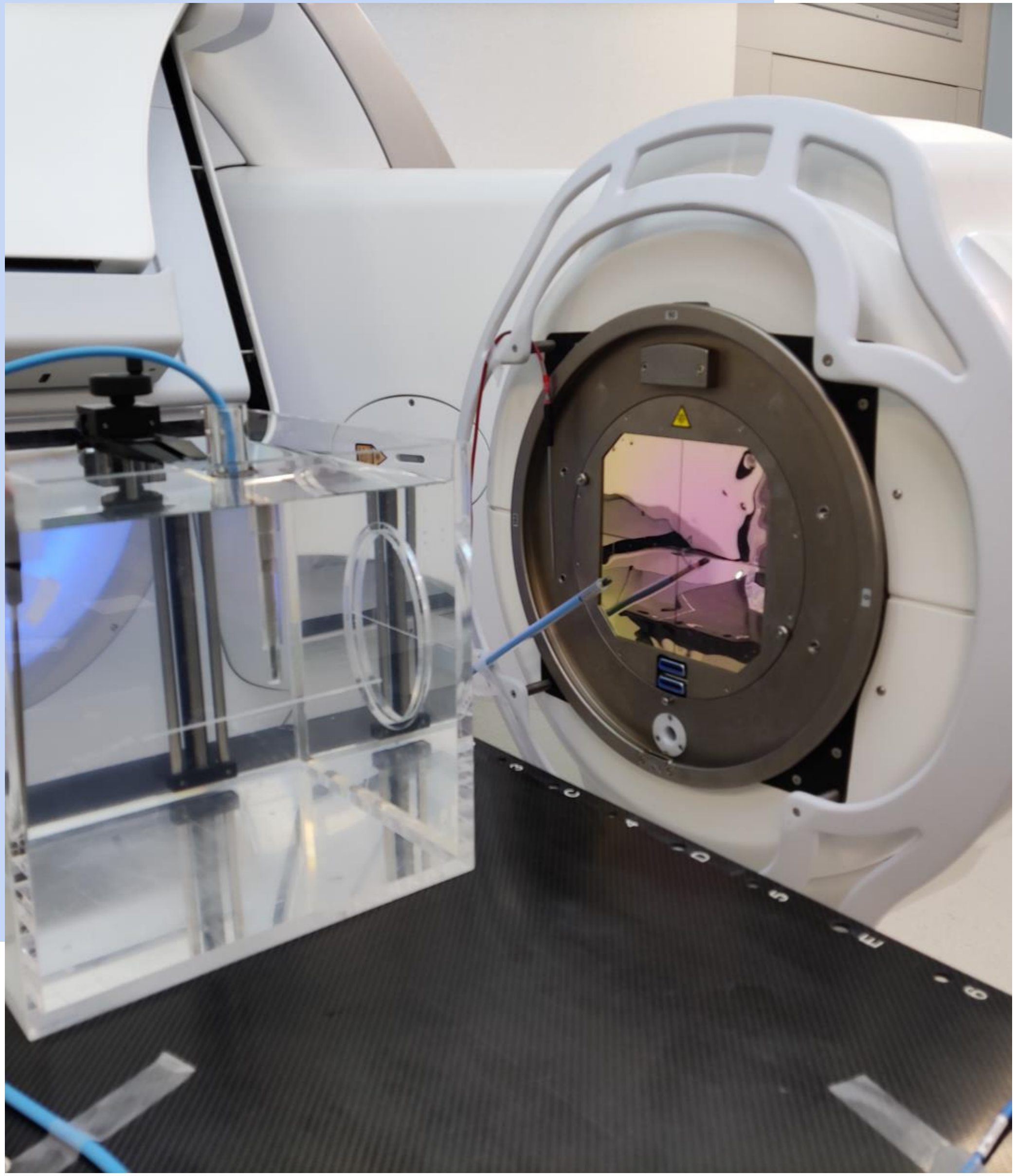
DOSIMETRY PROTOCOL – IAEA TRS NO. 398

CODE OF PRACTICE FOR HIGH ENERGY PHOTON BEAMS

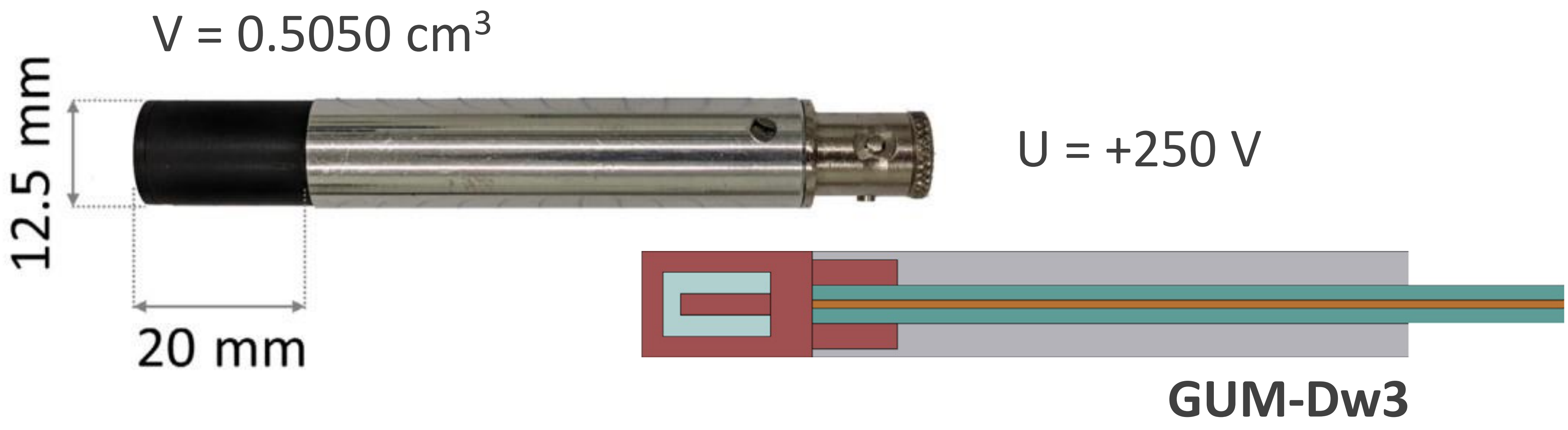
TABLE 15. ESTIMATED RELATIVE STANDARD UNCERTAINTY [a] OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR A HIGH ENERGY PHOTON BEAM, BASED ON A CHAMBER CALIBRATION IN ^{60}Co GAMMA RADIATION

Physical quantity or procedure	Relative standard uncertainty (%)
Step 1: Standards laboratory[b]	
$N_{D,w}$ calibration of secondary standard at PSDL	0.5
Long term stability of secondary standard	0.1
$N_{D,w}$ calibration of the user dosimeter at the standard laboratory	0.4
Combined uncertainty of step 1	*0.6*
Step 2: User high energy photon beam	
Long term stability of user dosimeter	0.3
Establishment of reference conditions	0.4
Dosimeter reading M_Q relative to beam monitor	0.6
Correction for influence quantities k_i	0.4
Beam quality correction k_Q (calculated values)	1.0[c]
Combined uncertainty of step 2	*1.4*
Combined standard uncertainty of $D_{w,Q}$ (steps 1 + 2)	**1.5**



DOSIMETRY PROTOCOL – CALIBRATION IN THE USER'S BEAM

$$D_{w,Q} = M_Q \cdot k_{Tp} \cdot k_h \cdot N_{D,w,Q}$$



EXPERIMENTAL GRAPHITE-WALLED CYLINDRICAL CAVITY IONIZATION CHAMBER AS A PRIMARY MOBILE IONOMETRIC STANDARD FOR ABSORBED DOSE TO WATER FOR 6 AND 10 MV HIGH-ENERGY PHOTON BEAMS

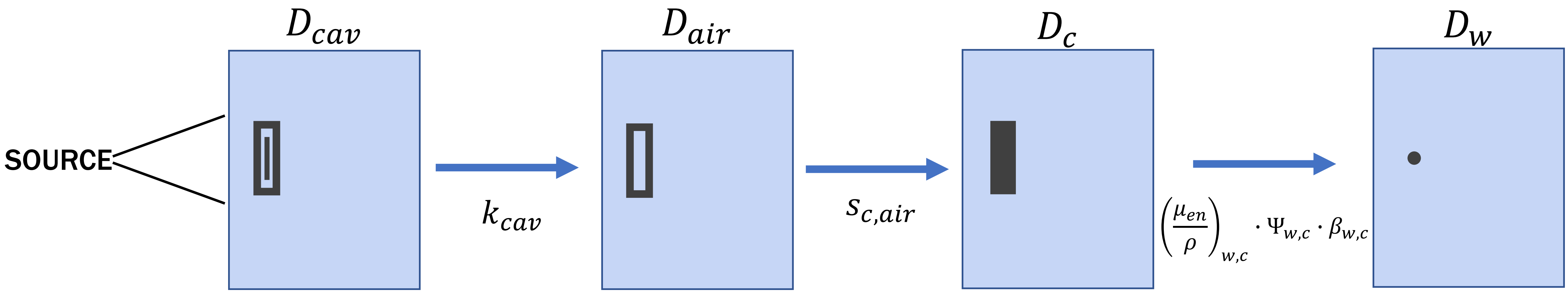
THE ABSORBED DOSE TO WATER FROM IONOMETRIC MEASUREMENTS

$$\dot{D}_w = \frac{I}{m_a}\frac{\overline{W}_a}{e} \cdot \bar{s}_{g,a} \cdot (\bar{\mu}_{en}/\rho)_{w,g} \cdot \Psi_{w,g} \cdot \beta_{w,g} \cdot k_{cav} \cdot k_{stem} \cdot k_{env} \cdot k_{win} \cdot k_{rn} \cdot k_{rec} \cdot k_{pol} \cdot k_h$$

I – measured ionization current, corrected for pressure and temperature conditions (k_{Tp}),
m_a – the mass of air in the cavity ($\rho_a \cdot V$),
W_a/e – the mean energy spent to produce an ion pair in dry air,
$s_{g,a}$ – the mean stopping power ratio of graphite and air,
$(\mu_{en}/\rho)_{w,g}$ – the ratio of the mean mass-energy absorption coefficient in water and graphite,
$\psi_{w,g}$ – the ratio of the photon energy fluence at a point in water to that in graphite,
$\beta_{w,g}$ – the ratio of absorbed dose at a given point and collision part of kerma,
k_{cav} – correction due to the finite size of the cavity,
k_{stem} – the stem scatter correction factor,
k_{env} and k_{win} – corrections for the presence of a chamber envelope and a phantom window,
k_{rec} – the correction factor for recombination losses,
k_{rec} – the correction factor for polarity effect,
k_{rn} – the correction factor for the radial non-uniformity of the beam,
k_h – the correction factor for humidity.

[Boutillon et al., 1993]

CONVERSION FROM THE IONIZATION MEASUREMENT IN THE GRAPHITE CAVITY CHAMBER TO ABSORBED DOSE IN HOMOGENEOUS WATER



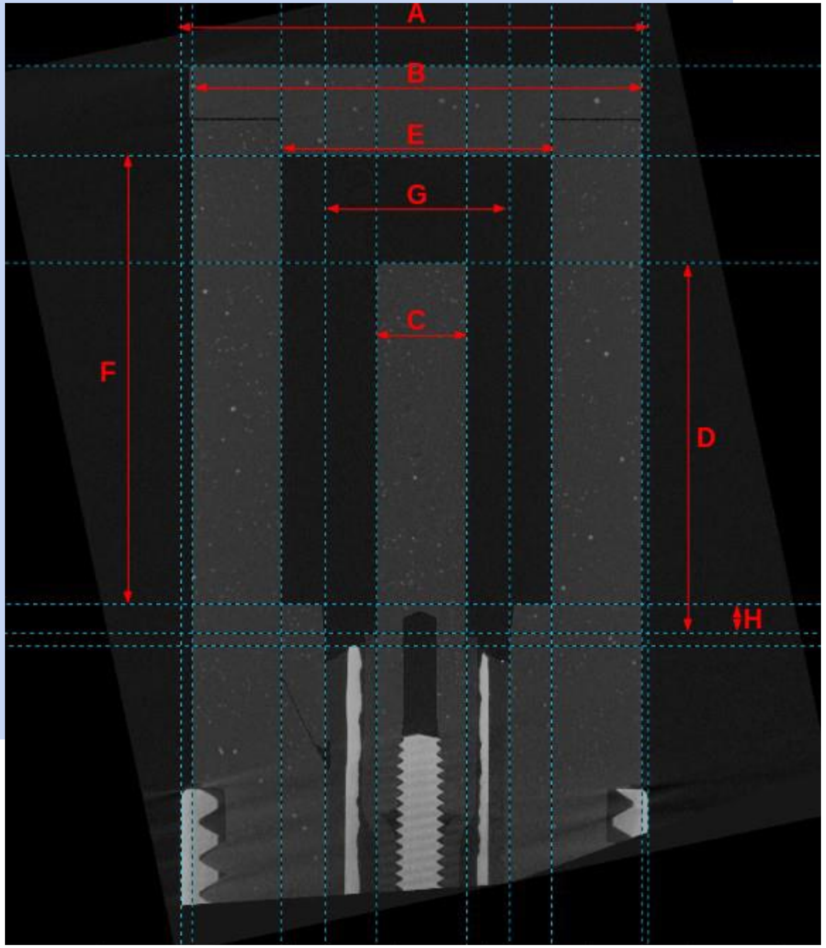
$$D_{cav} = \frac{W_{air}}{e} \cdot \frac{q}{m_{air}}$$

[Boutillon et al., 1993]

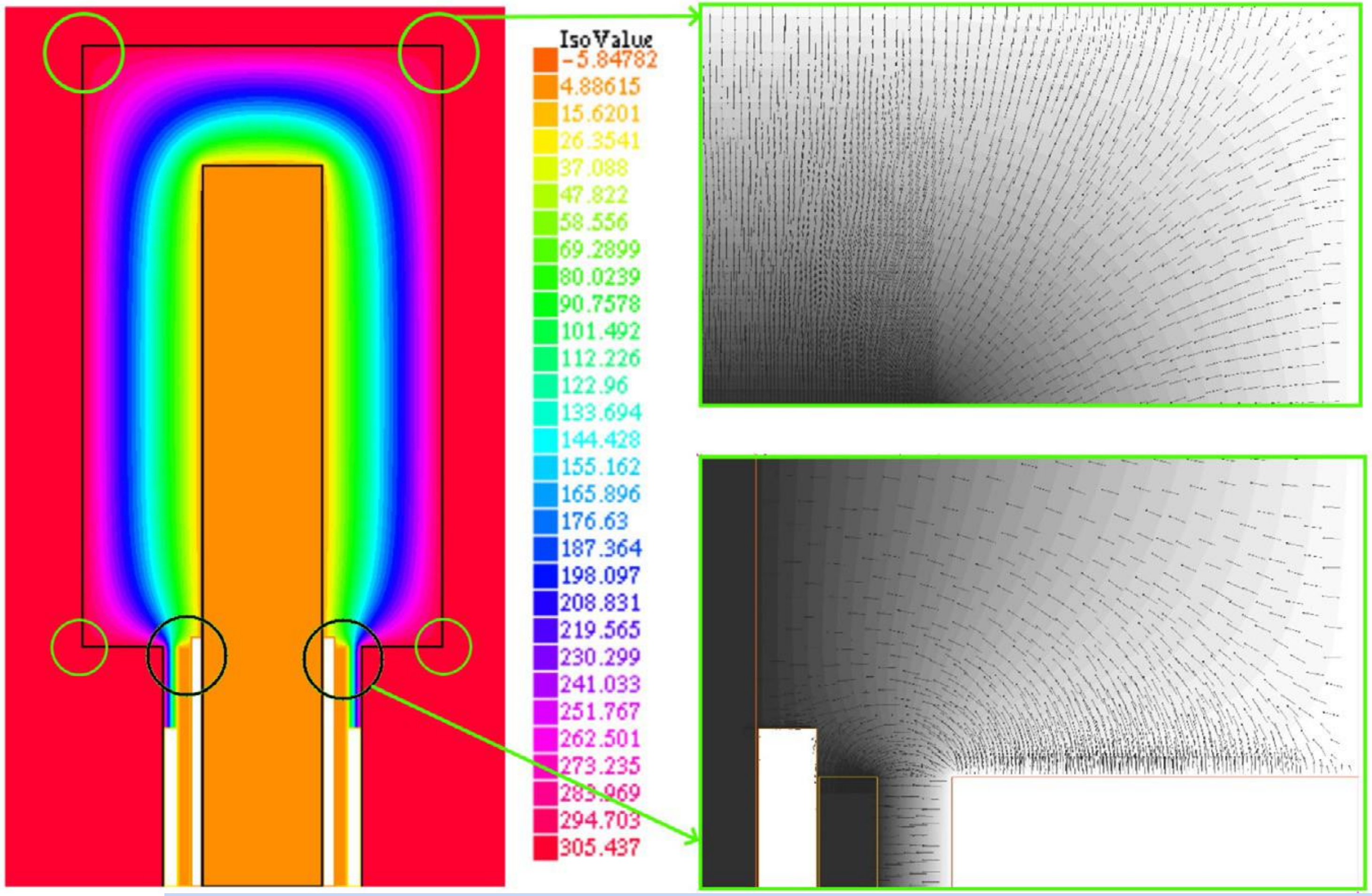
[Andreo et al., 2017]

DETERMINATION OF THE CAVITY VOLUME

[Szymko et al., 2022]



0.5050 cm^3



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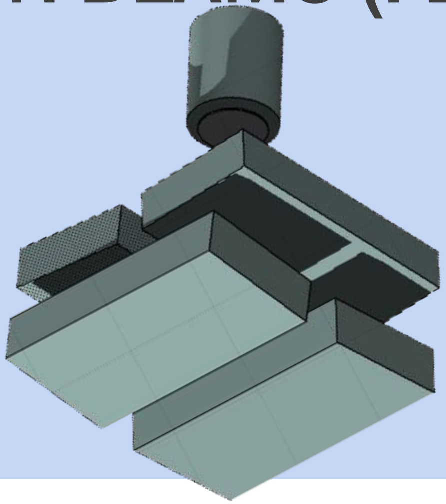
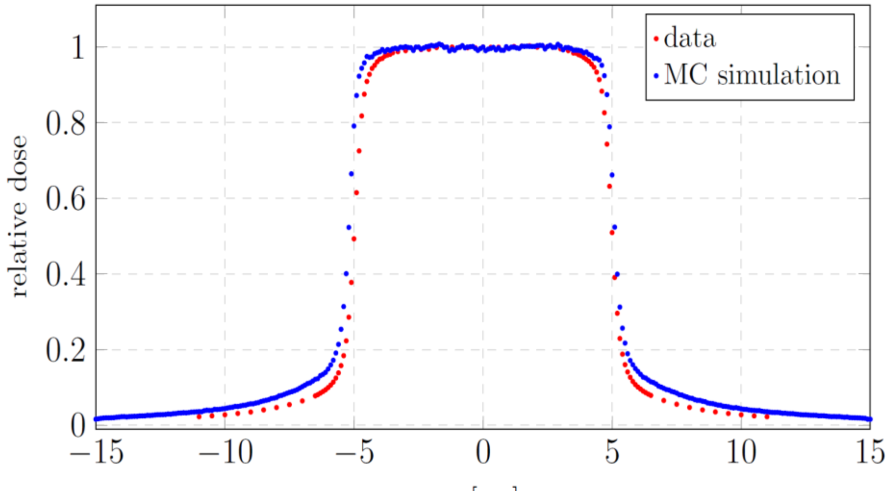
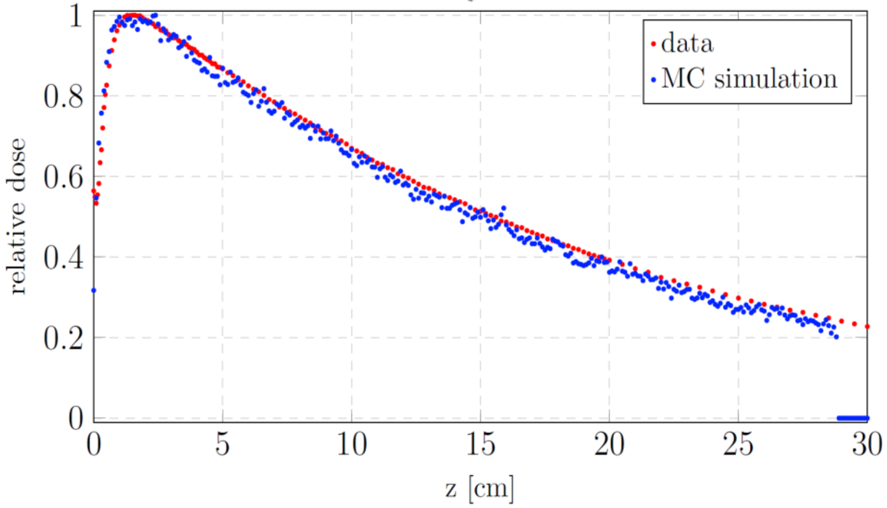
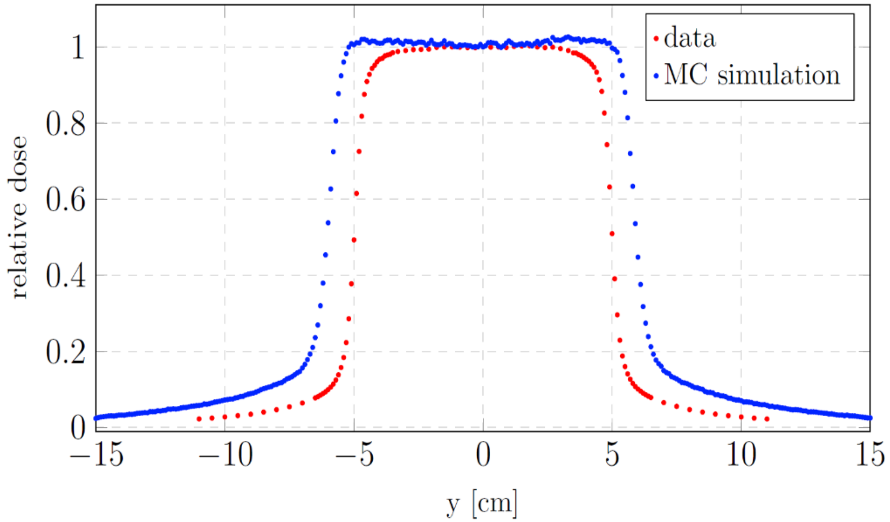
MONTE CARLO MODEL OF THE ELEKTA VERSA HD ACCELERATOR HEAD FOR SIMULATION OF 6 AND 10 MV PHOTON BEAMS (FLUKA CODE)

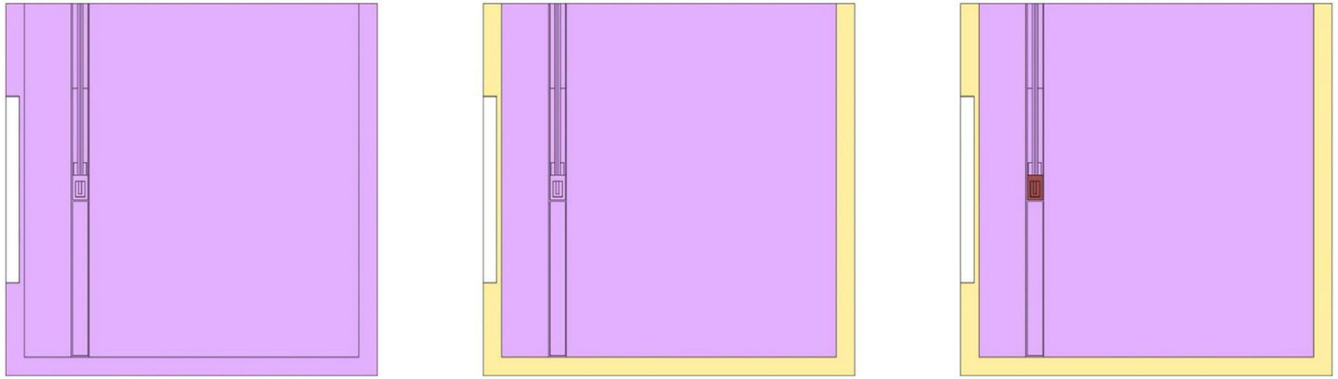








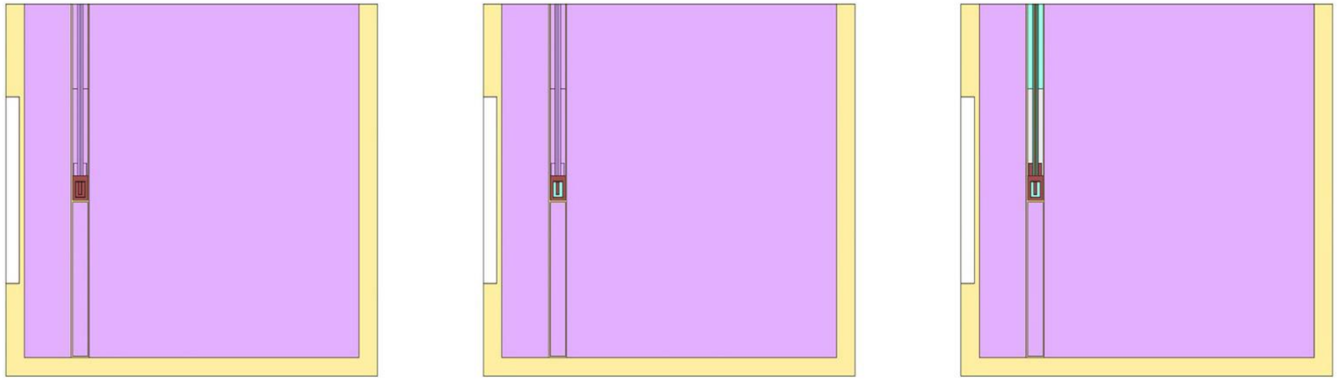
DETERMINATION OF PERTURBATION CORRECTIONS – MONTE CARLO



(a) Step 1 - phantom with ‘water‘ wall.

(b) Step 2 - realistic PMMA-walled phantom fulfil with water.

(c) Step 3 - realistic phantom with graphite ‘chamber‘.



(d) Step 4 - added PMMA envelope.

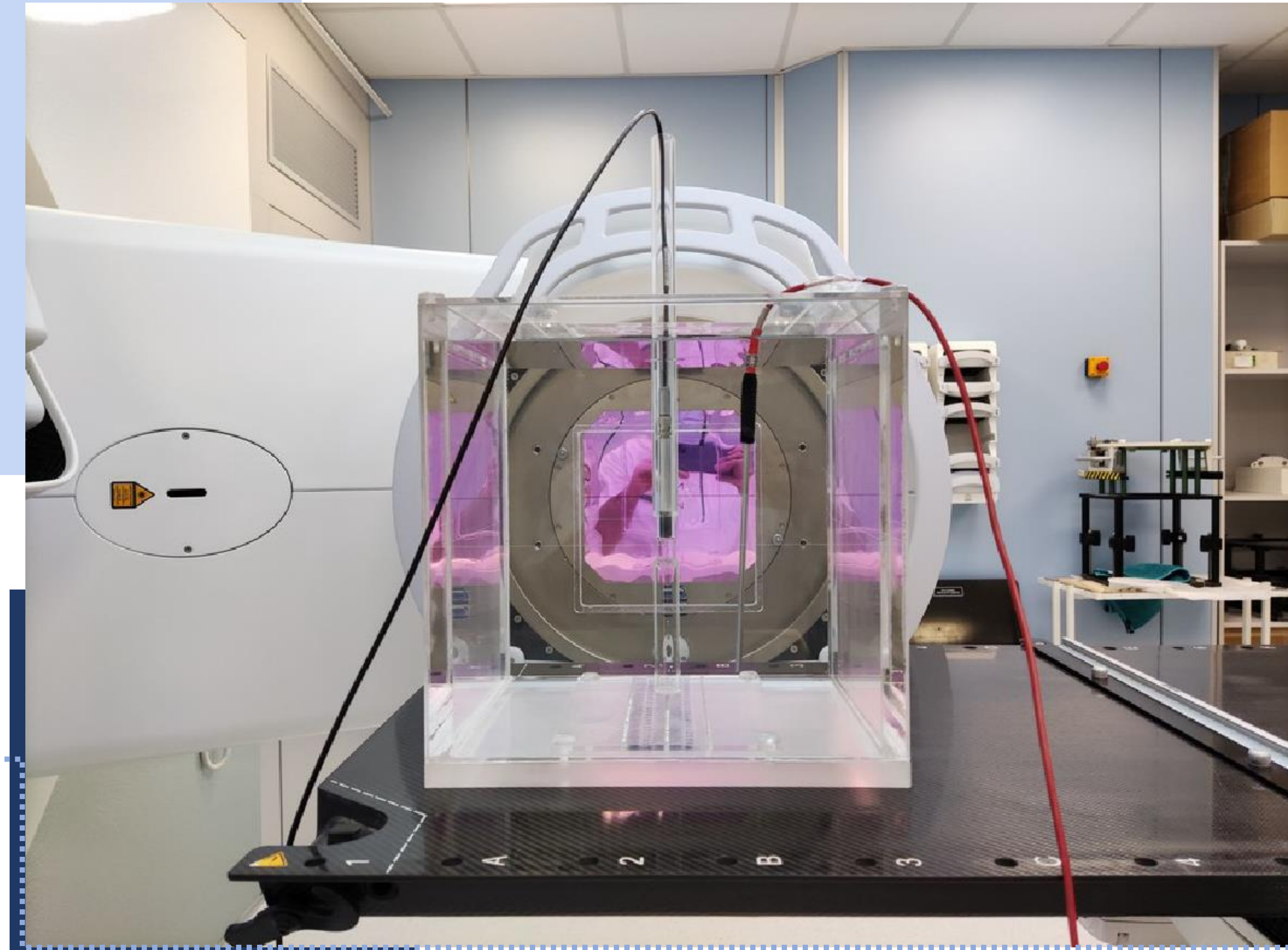
(e) Step 5 - added air cavity and graphite electrode.

(f) Step 6 - real chamber in water phantom.

[Szymko et al., 2022]

$$f = \bar{s}_{g,a} \cdot (\bar{\mu}_{en}/\rho)_{w,g} \cdot \Psi_{w,g} \cdot \beta_{w,g} \cdot k_{cav} \cdot k_{stem} \cdot k_{env} \cdot k_{win} \cdot k_{rn}$$

DETERMINATION OF CORRECTION FACTORS – WATER PHANTOM MEASUREMENTS



6 and 10 MV
10×10 cm^2
SDD = 100 cm
d = 10 g/cm^2

$k_{rec}, k_{pol}, k_{Tp}, k_h$

VALUES AND RELATIVE STANDARD UNCERTAINTIES OF ALL FACTORS INCLUDED IN THE ABSORBED DOSE TO WATER MEASURED WITH GUM-DW3 IONIZATION CHAMBER

Physical quantity	**6 MV**	**Rel. std. uncertainty (6 MV)**	**10 MV**	**Rel. std. uncertainty (10 MV)**
$V [cm^3]$	0.5050	0.09 %	0.5050	0.09 %
Q_{corr} [nC]	16.2600	0.15 %	16.3000	0.10 %
k_{rec}	1.0015	0.08 %	1.0017	0.08 %
k_{pol}	0.9985	0.06 %	0.9986	0.06 %
f	1.1031	0.20 %	1.1002	0.20 %
k_h	0.9970	0.03 %	0.9970	0.03 %
k_{Tp}	1.0334	0.03 %	1.0225	0.03 %
$\mathbf{D_w}$	**99.81**	**0.29 %**	**99.95**	**0.26 %**

[Kacker et al., 2010]

$$\zeta(D_{GUM-Dw3} - D_{Farmer}) = \frac{|D_{GUM-Dw3} - D_{Farmer}|}{\sqrt{U^2(D_{GUM-Dw3}) + U^2(D_{Farmer})}} \leq 1$$

Beam Energy [MV]	$D_{GUM-Dw3}$ [cGy]	$U(D_{GUM-Dw3})$	D_{Farmer} [cGy]	$U(D_{Farmer})$	$D_{GUM-Dw3}/D_{Farmer}$	ζ
6	99.81	0.57%	99.87	2.92%	**-0.06%**	-0.04
10	99.95	0.53%	99.75	2.92%	**0.20%**	0.14

COMPARISON OF THE GUM-DW3 EXPERIMENTAL IONIZATION CHAMBER AND A COMMERCIALLY AVAILABLE FARMER TYPE IONIZATION CHAMBER

CONCLUSIONS

THE GUM-DW3 EXPERIMENTAL CHAMBER CAN BE USED AS A PRIMARY STANDARD:

- FOR THE DOSIMETRY OF THERAPEUTIC PHOTON BEAMS
- FOR CALIBRATION OF REFERENCE DOSIMETERS IN HOSPITAL CONDITIONS

CONCLUSIONS

„Podstawy metrologiczne terapii z wykorzystaniem promieniowania jonizującego”

POLSKA METROLOGIA

„Metrological basis of ionizing radiation therapy”

WHAT'S NEXT?

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