18NRM02 PRISM-eBT

Primary standards and traceable measurement methods for

X-ray emitting electronic brachytherapy devices

WP2

Traceability for superficial (skin) external treatment

M30 – reporting (Dec 14, 2021)

WP2 - Objectives

To establish a dosimetric methodology for superficial (skin) treatment with eBT devices, in terms of **absorbed dose to water at the surface of a water phantom** (based on IAEA-TRS398, AAPM-TG61, DIN 6809-4 and NCS-10)**:**

$$D_w(d_{surface})$$

Dose to surface will be converted to dose to 1 cm depth via radiochromic film in a water phantom:

$$D_w(d_{1cm})$$

Target uncertainties (k = 1)

$$u[D_w(d_s)] = 3.5\ \%$$

$$u[D_w(d_{1cm})] = 5\ \%$$

Formalism based on NCS-10 and AAPM TG-61

$$D_{\mathrm{w,surface}} = K_{air} \cdot \left(\frac{\bar{\mu}_{\mathrm{en}}}{\rho}\right)_{\mathrm{air}}^{\mathrm{w}} \cdot B_{\mathrm{w}}$$

NOTE:

The actual D_w at the phantom surface is neither measurable nor clinically relevant.

However:

for low-energy photons TCPE is present at a specific (small) depth in the phantom

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D_w is therefore only defined at the minimum depth at
which TCPE is achieved (neglecting attenuation over this depth)

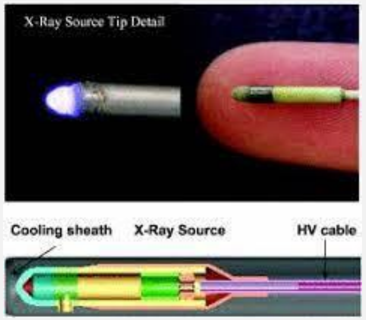
Thus:

TCPE is assumed at the ‘phantom surface’ starting at D_{max} (≥ 70 μm)

WP2 PRISM-eBT: Traceability for superficial treatment

Zeiss INTRABEAM

Xoft Axxent



Elekta Esteya

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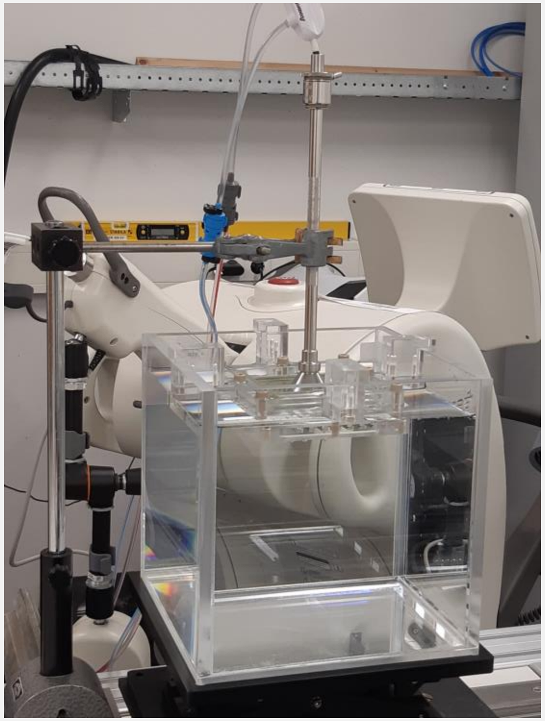

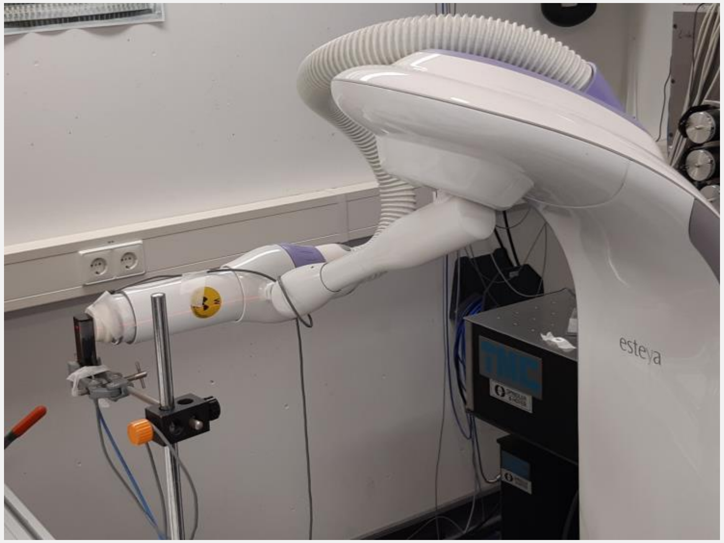

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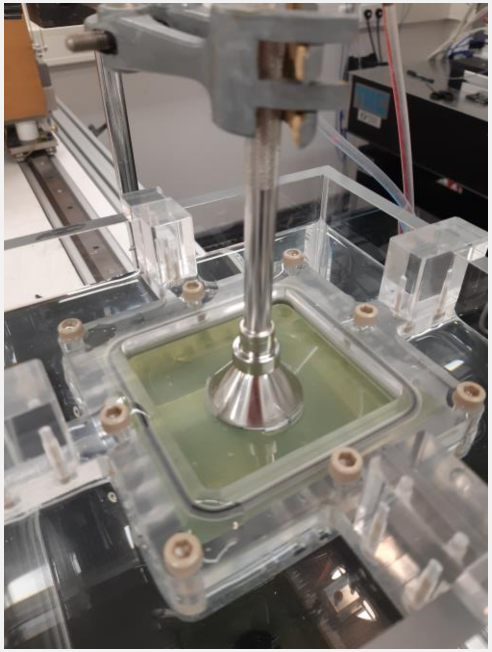
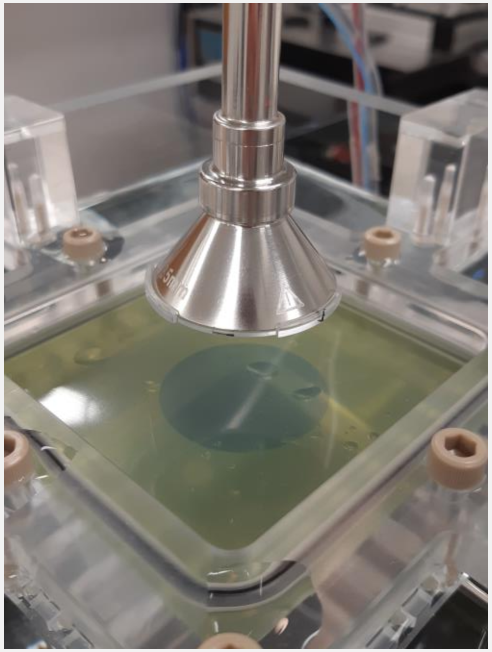
WP2 PRISM-eBT: Traceability for superficial treatment





Formalism based on NCS-10 and AAPM TG-61

apply from left to right

$$D_{\mathrm{w,surface}} = K_{air} \cdot \left(\frac{\bar{\mu}_{\mathrm{en}}}{\rho}\right)_{\mathrm{air}}^{\mathrm{w}} \cdot B_{\mathrm{w}}$$

VSL

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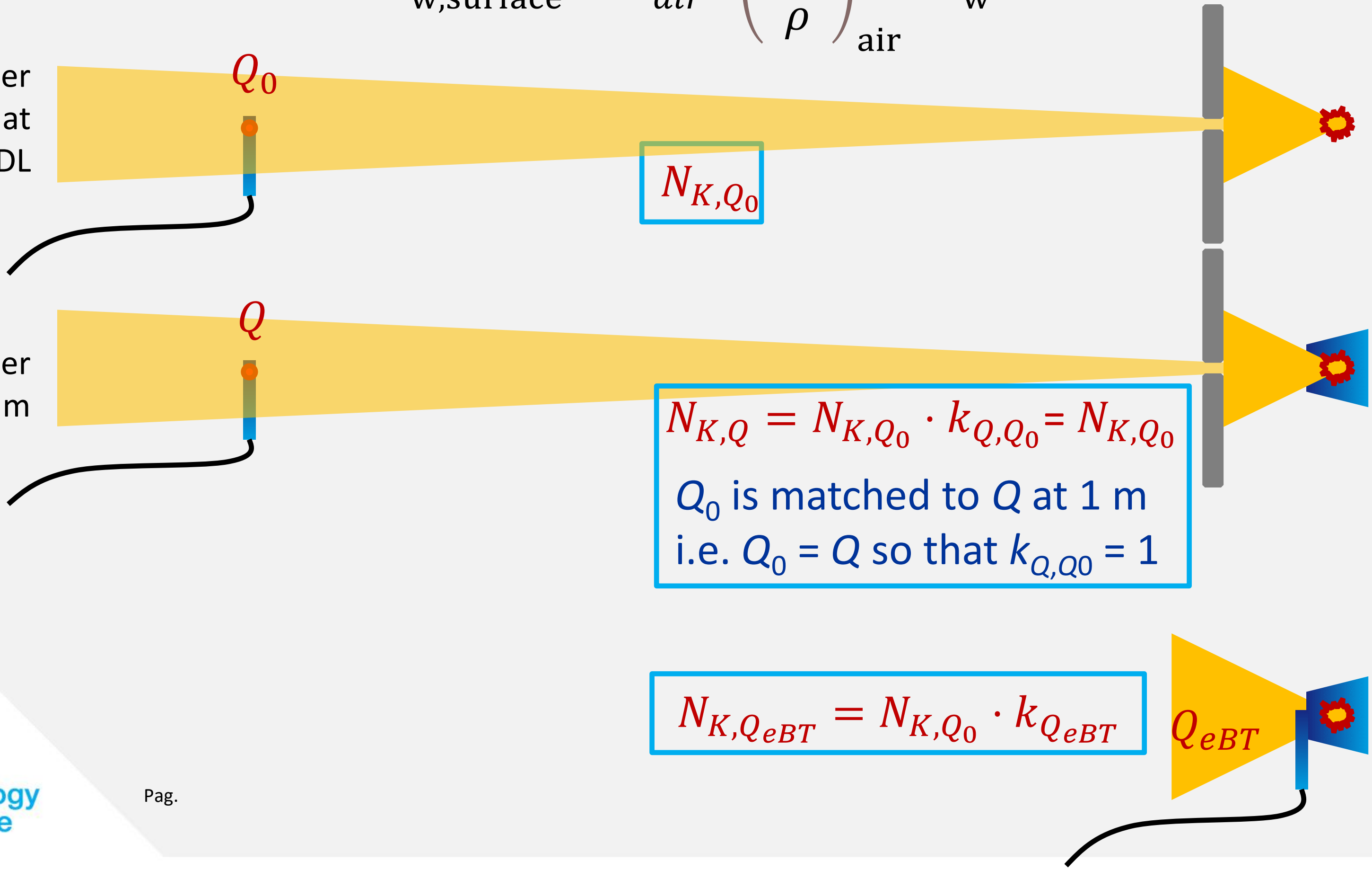
Modified formalism based on NCS-10 and AAPM TG-61

apply from left to right

$$D_{\mathrm{w,surface}} = K_{air} \cdot \left(\frac{\bar{\mu}_{\mathrm{en}}}{\rho}\right)_{\mathrm{air}}^{\mathrm{w}} \cdot B_{\mathrm{w}}$$



ion chamber calibration at P/SSDL

N_{K,Q_0}

collimated x-ray at P/SSDL

WP2
ion chamber in eBT at 1 m

$N_{K,Q} = N_{K,Q_0} \cdot k_{Q,Q_0} = N_{K,Q_0}$

Q_0 is matched to Q at 1 m
i.e. $Q_0 = Q$ so that $k_{Q,Q0} = 1$

collimated x-ray from eBT

$N_{K,Q_{eBT}} = N_{K,Q_0} \cdot k_{Q_{eBT}}$

x-ray from eBT at surface

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VSL

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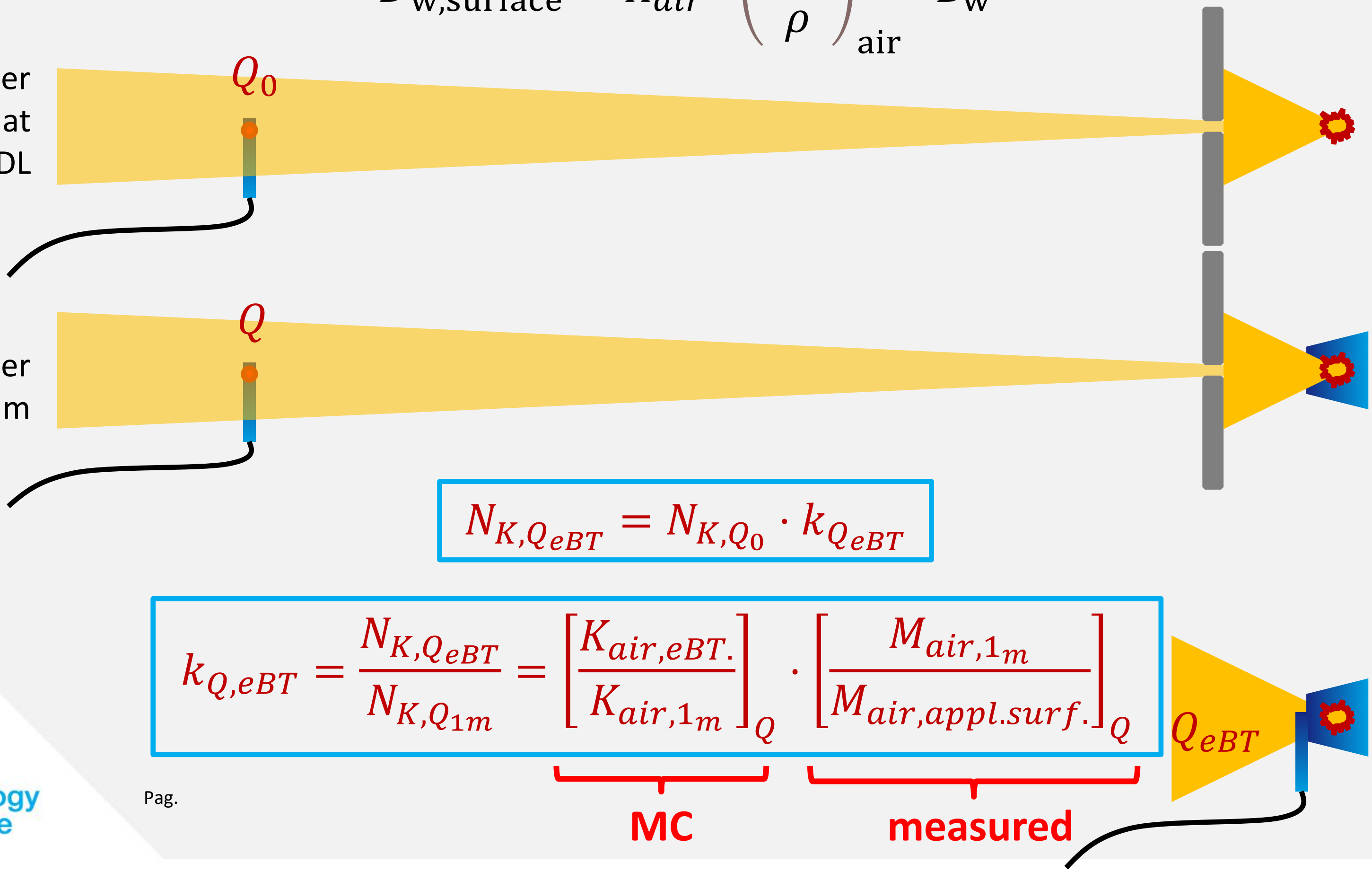
Modified formalism based on NCS-10 and AAPM TG-61

apply from left to right

$$D_{\mathrm{w,surface}} = K_{air} \cdot \left(\frac{\bar{\mu}_{\mathrm{en}}}{\rho}\right)_{\mathrm{air}}^{\mathrm{w}} \cdot B_{\mathrm{w}}$$



ion chamber calibration at P/SSDL

collimated x-ray at P/SSDL

WP2
ion chamber in eBT at 1 m

collimated x-ray from eBT

x-ray from eBT at surface

$$\boxed{N_{K,Q_{eBT}} = N_{K,Q_0} \cdot k_{Q_{eBT}}}$$

$$\boxed{k_{Q,eBT} = \frac{N_{K,Q_{eBT}}}{N_{K,Q_{1m}}} = \underbrace{\left[\frac{K_{air,eBT.}}{K_{air,1_m}}\right]_Q}_{\text{MC}} \cdot \underbrace{\left[\frac{M_{air,1_m}}{M_{air,appl.surf.}}\right]_Q}_{\text{measured}}}$$

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Formalism CIEMAT-VSL PRISM-eBT WP2

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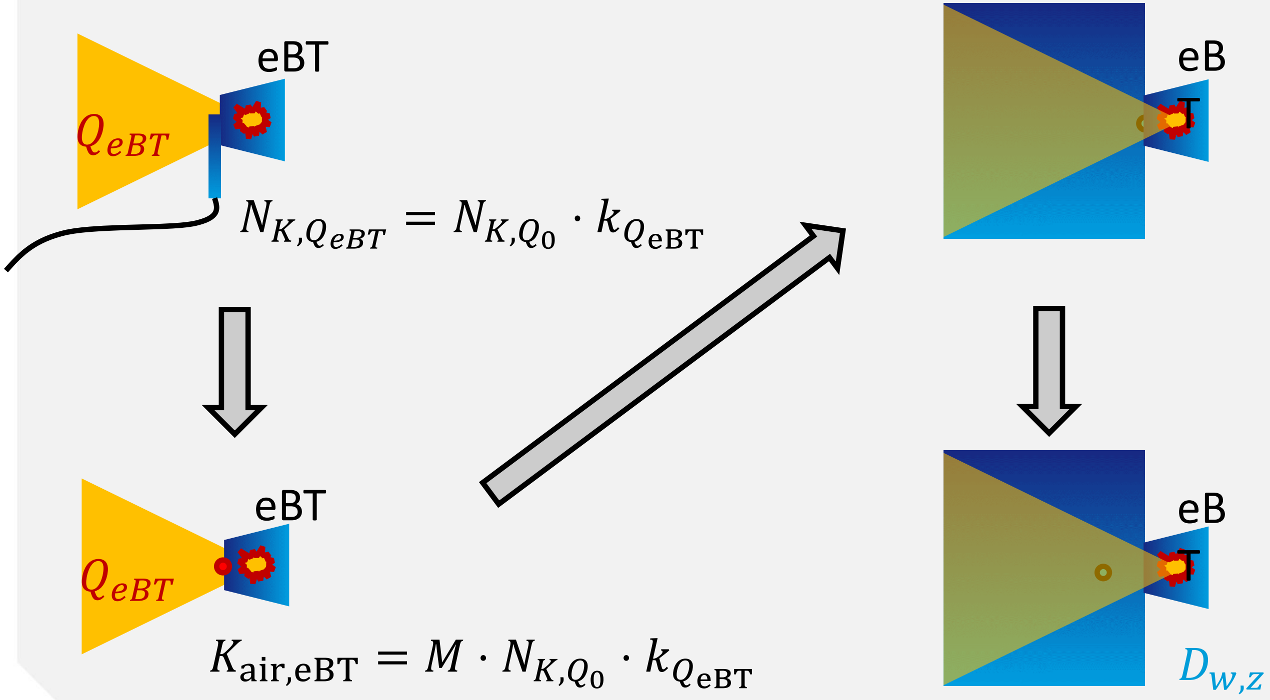


$$N_{K,Q_{eBT}} = N_{K,Q_0} \cdot k_{Q_{\mathrm{eBT}}}$$

$$K_{\mathrm{air,eBT}} = M \cdot N_{K,Q_0} \cdot k_{Q_{\mathrm{eBT}}}$$

$$D_{\mathrm{w,surf}} = \underbrace{K_{\mathrm{air,eBT}} \cdot B_{\mathrm{w,eBT}}}_{\textbf{MC}} \cdot \underbrace{\left(\frac{\bar{\mu}_{\mathrm{en}}}{\rho}\right)^{\mathrm{w}}_{\mathrm{air}}}_{\textbf{spc}}$$

$$D_{\mathrm{w,z}} = D_{\mathrm{w,sur}} \cdot \underbrace{k_{z,eBT}}_{\textbf{measured}}$$

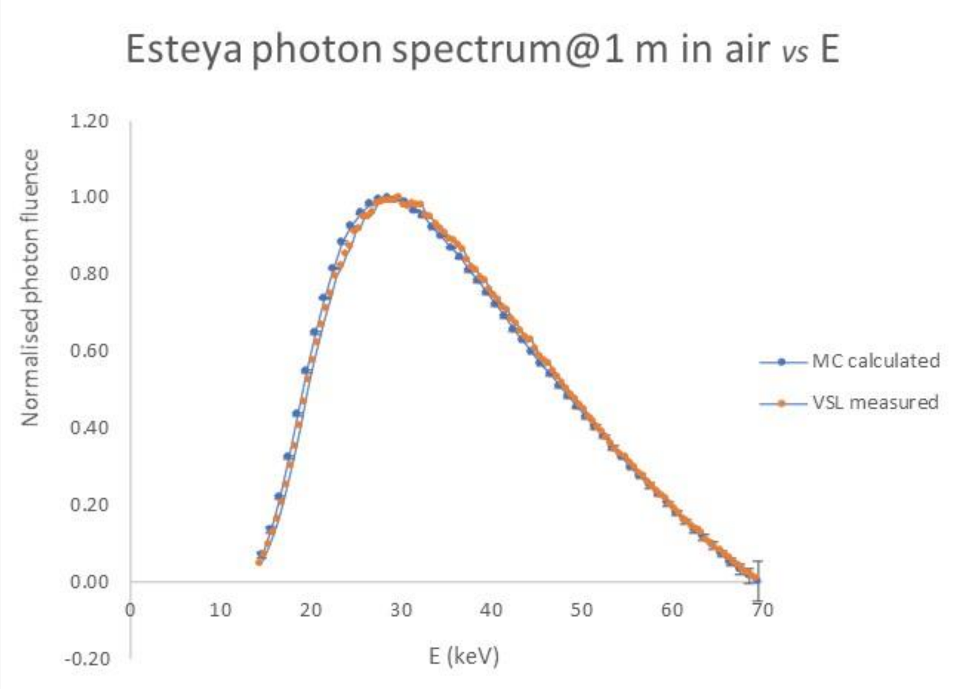
Valdes-Cortez et al. Med. Phys. 46 (1), January 2019

PSF / Esteya characterisation of the Esteya x-ray tube from:

- 69.5 kVp and 3.0 cm diameter applicator
- source to surface distance (SSD) ≅ 6 cm

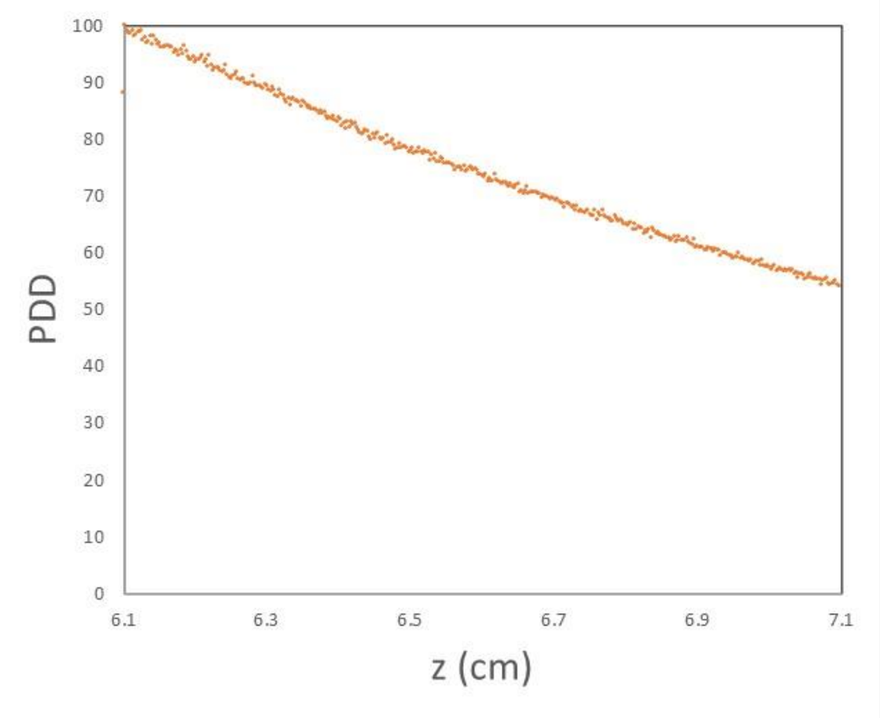
A.2.1.3 MC calculations with surface applicator to get x-ray spectra at three positions:

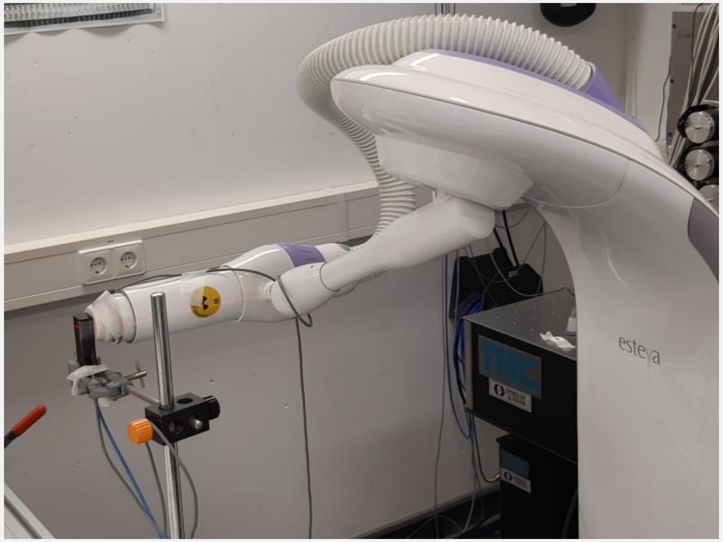
(a) 1 m free-in-air,
(b) the phantom surface at (near) applicator contact and
(c) 1 cm depth in water with phantom at (near) applicator contact



A.2.2.3 December 2021

- calculations of depth dose curves (@1 cm) for the eBT Esteya system:
    - ✓ in the water phantom, developed in A2.2.1, and
    - o in the solid phantom, developed in A2.2.2.





A.2.2.3 December 2021

- calculations of depth dose curves (@1 cm) for the eBT Esteya system:
    - ✓ in the water phantom, developed in A2.2.1, and
    - ○ in the solid phantom, developed in A2.2.2.

- calculations of dose ratios surface-to-depth ($D_{70\mu m}/D_{1cm}$) will be calculated:

    - ✓ ($D_{70\mu m}/D_{1cm}$) in the water phantom:

    - ○ ($D_{70\mu m}/D_{1cm}$) in the solid phantom:

The **target uncertainty** for the conversion of **dose at the surface (i.e. 70 µm) to dose at 1 cm depth is 5%**

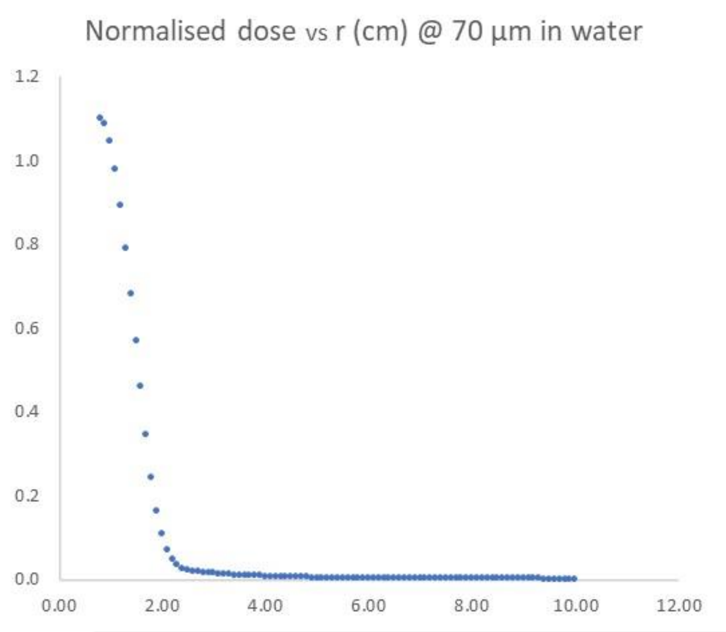
The outcomes of this activity will be used in A2.2.5

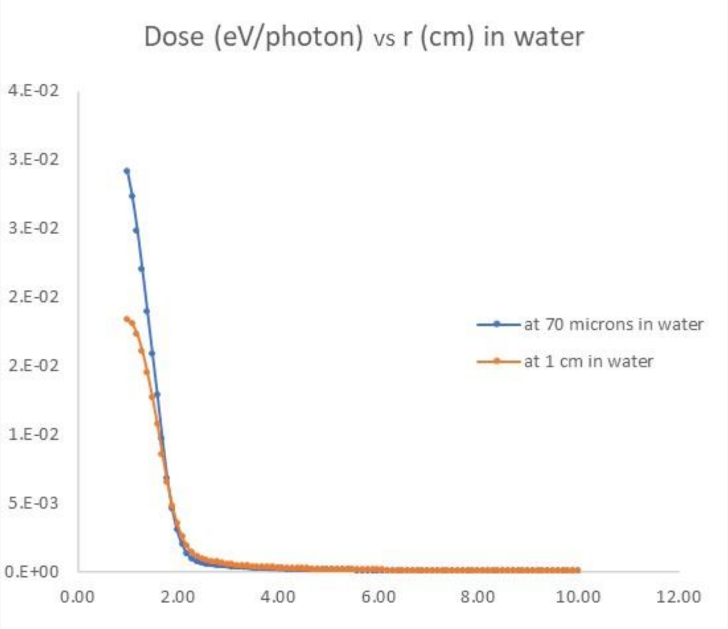
A.2.2.3 December 2021

- calculations of depth dose curves (@1 cm) for the eBT Esteya system:
  - ✓ in the water phantom, developed in A2.2.1, and
  - ○ in the solid phantom, developed in A2.2.2.
- calculations of dose ratios surface-to-depth ($D_{70µm}/D_{1cm}$) will be calculated:
  - ✓ ($D_{70µm}/D_{1cm}$) in the water phantom: 1.8 ± 0.7%
  - ○ ($D_{70µm}/D_{1cm}$) in the solid phantom
- calculations of the beam profile:
  - ✓ at the surface (70 µm) in the water phantom
  - ○ at the surface (70 µm) in the solid phantom
  - ✓ at a depth of 1 cm in the water phantom
  - ○ at a depth of 1 cm in the solid phantom

A.2.2.3 CIEMAT - December 2021

- Beam profile:
  - ✓ at the surface (70 µm) in the water phantom
  - ○ at the surface (70 µm) in the solid phantom
  - ✓ at a depth of 1 cm in the water phantom
  - ○ at a depth of 1 cm in the solid phantom





A.2.1.5, A.2.1.6 and A.2.1.9 - k_{QeBT}

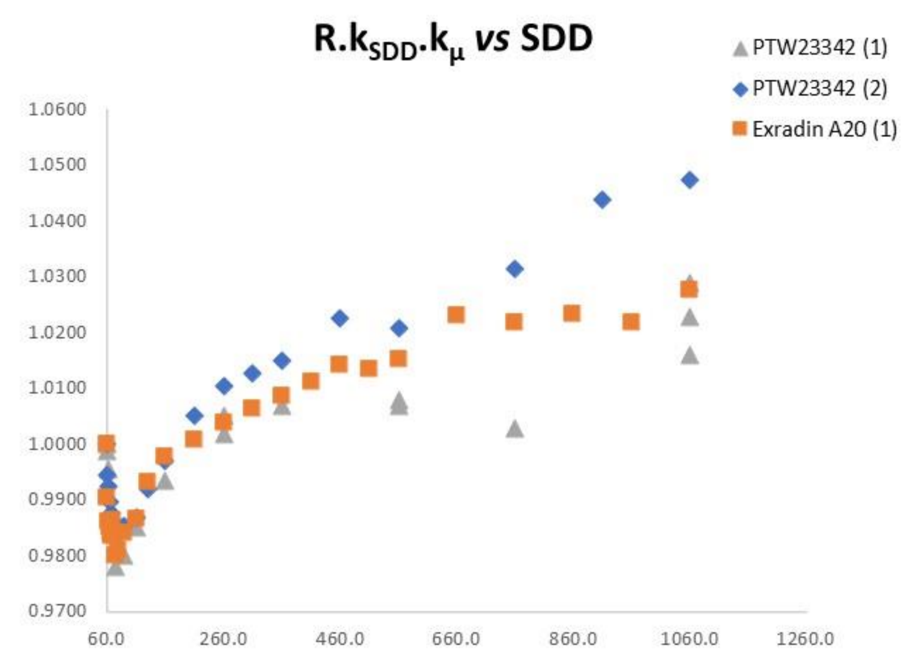
$$k_{QeBT} = \boxed{\frac{M(r_0)}{M(r_m)}} \cdot \boxed{\frac{K(r_m)}{K(r_0)}}$$

(Activities A.2.1.5, A.2.1.6 and A.2.1.9) the air kerma free in air was calculated for the eBT Esteya system at distances ranging from (near) contact to 1 m

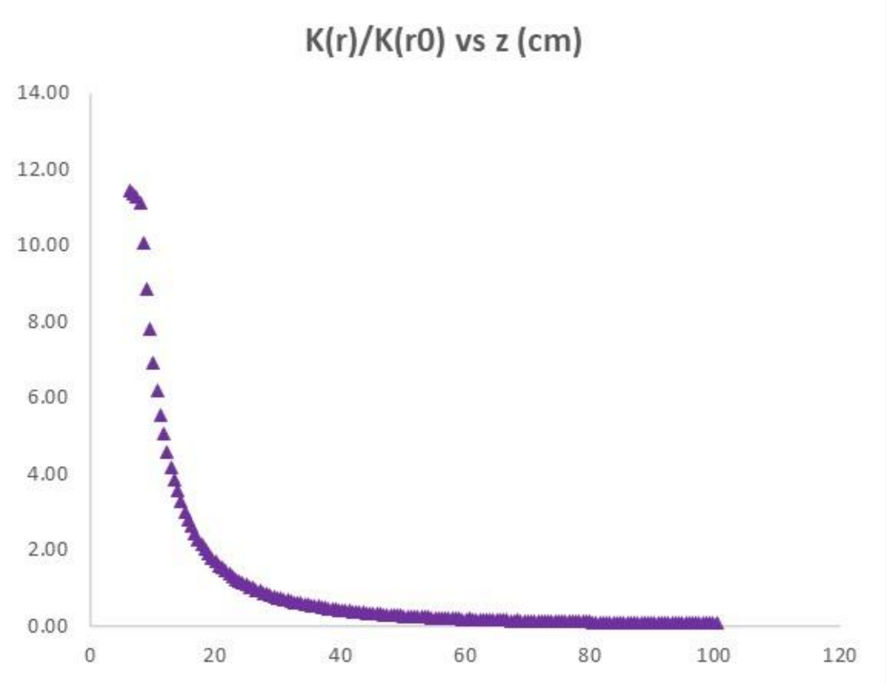
(Activities A.2.1.6 and A.2.1.9) the signal has been measured with the two ion chambers selected directly in eBT Esteya system at distances ranging from (near) contact to 1 m

A.2.1.5, A.2.1.6 and A.2.1.9 - k_{QeBT}

$$k_{QeBT} = \frac{M(r_0)}{M(r_m)} \cdot \frac{K(r_m)}{K(r_0)}$$



$R.k_{SDD}.k_{\mu}$ *vs* SDD



K(r)/K(r0) vs z (cm)

WP2 – Activities A2.1 $D_{\text{w,surface}}$ calibration (t/m M30)

eBT device output calibration, D_{w} at the phantom surface

A2.1.1 (M8) VSL – To modify x-ray calibration set-up for characterisation of eBT-devices: Esteya, Axxent

A2.1.2 (M8) VSL, MAASTRO, UHasselt, PTB – To select of 2 ion chambers, build-up material and distances:

PTW 23342 with 50 µm PE BU-foil (NCS report 10); Exradin A20 without additional BU-foil

0 cm; 5 cm; 10 cm; 15 cm; 20 cm; 25 cm and closest achievable to 1 m (+ more distances measured)

A2.1.3 (M8) MAASTRO, Uhasselt, CIEMAT – To obtain phsf for Esteya, Axxent and INTRABEAM w. applicators

phsf or photon fluence spectra were obtained either by MC (Axxent) or from (newly) available literature

validation of spc with measurements is only possible at 1 m free in air (+ spc made available in 1.1.2)

A2.1.4 (M18) VSL, CIEMAT – To match x-ray calibration beams at their calibration facilities (1 m in air)

Esteya beam quality was theoretically matched and physically verified (1.5 m FAC distance; 1 m to be repeated)

Axxent and INTRABEAM qualities were theoretically matched (1.5 m FAC distance; 1 m to be repeated)

A2.1.5 (M18) MAASTRO, UHasselt, CIEMAT – To obtain $\left(\overline{\mu/\rho}\right)_{\text{w/air}}$ and B_{w}-factors for eBT devices

$\left(\overline{\mu/\rho}\right)_{\text{w/air}}$ calculated at CIEMAT and uploaded in May, and B_{w}-factors calculated at (Esteya: CIEMAT) at Hasselt: INTRABEAM done, Axxent running almost finished (uploaded?)

This activity will contain additional calculation of K_a-ratios at distances form the applicators to determine $k_{\text{Q,eBT}}$ (see formalism) this includes effects of photon beam divergence and resulting photon beam non-uniformity.

A2.1.6 (M24) VSL – To calibrate 2 ion chambers (A2.1.2) in terms of N_K in VSL-matched beams. Calibrate ion chambers directly in front of the Esteya and calibrate an Esteya beam output.

Chambers have been calibrated in all matched beam qualities for Esteya, Axxent and INTRABEAM.

Chamber signal ratios measured end-of-2021 / Spectra beginning 2022

WP2 – Activities

A2.1 $D_{\text{w,surface}}$ calibration

eBT device output calibration, D_{w} at the phantom surface

A2.1.7 (M25) MAASTRO, Uhasselt, CIEMAT – To calibrate $D_{\text{w,surface}}$ of an Axxent with the 2 ion chambers

With respect to the updated protocol, this has to be postponed until VSL measurements are finished.

This an always be done at a later stage to validate the practical application. Beginning 2022 at VSL.

A2.1.8 (M26) PTB – To calibrate an INTRABEAM with the 2 ion chambers in terms of $D_{\text{w,surface}}$

With respect to the updated protocol, this has to be postponed until VSL measurements are finished.

This an always be done at a later stage to validate the practical application. Beginning 2022 at PTB.

A2.1.9 (M30) VSL – To calibrate 2 ion chambers directly in (Esteya), Axxent and INTRABEAM, N_K at 1 m

To calibrate (Esteya), Axxent and INTRABEAM directly in terms of $K_{\text{air}}/I_{\text{tube}}$ in Gy/mA

Calibration of any of the eBT devices only makes sense at applicator surface (0 cm). Based on the k_{QeBT}, $\left(\overline{\mu/\rho}\right)_{\text{w/air}}$ and B_{w}-factors determined earlier, this will be done during the measurements beginning 2022.

A2.1.10 (M30) VSL, MAASTRO, UHasselt, PTB, CIEMAT – To compare measured and chamber and output calibrations with **calculated conversion factors** between the participants.

The formalism is robust, but does not allow for an internal consistency check as proposed here. Only the final comparison with primary standards will provide the necessary information to validate the method.

A2.1.11 (M32) VSL, MAASTRO, Uhasselt, PTB – To write a summary report on the results obtained in A2.1

To be done when measurements and necessary calculations AND MEAUREMENTS are finished

WP2 – Activities
A2.2 $D_{w,1cm}$ calibration

Conversion from $D_{w,surface}$ to $D_{w,1cm}$ in water

A2.2.1 (M30) VSL – To build a water phantom for measurement of ratio $D_{w,s}$/$D_{w,1}$cm with radiochromic film

To measure $D_{w,surface}$/$D_{w,1cm}$ for Esteya, Axxent, INTRABEAM (at VSL during 2.1.9 M24/30 or on-site)

To measure profiles at surface & 1 cm for Esteya, Axxent, INTRABEAM (at VSL or on-site)

The water phantom is finished. Film is available for measurement. The measurements are planned to take place when the eBT equipment is at VSL beginning of 2022.

A2.2.2 (M30) MAASTRO, UHasselt – To build a solid phantom for measurement of ratio $D_{w,s}$/$D_{w,1}$cm with alanine

To measure profiles at surface & 1 cm for Esteya, Axxent, INTRABEAM (at VSL during 2.1.9 M24/30 or on-site)

Uhasselt built an solid phantom. The measurements are planned to take place at VSL beginning of 2022.

A2.2.3 (M30) MAATRO, Uhasselt, CIEMAT – To calculate for Esteya, Axxent, INTRABEAM:

- *PDD* in water phantom (incl. ratio $D_{w,surface}/D_{w,1cm}$) + D_w profile at surface and 1 cm
- *PDD* in solid phantom (incl. ratio $D_{s,surface}/D_{s,1cm}$) + D_s profile at surface and 1 cm

Uhasselt calculated and measured Axxent PDDs (available on SharePoint). CIEMAT is finished with the Esteya PDDs. INTRABEAM has not calculate yet by Uhasselt, but the present model can be used as soon a person is available.

A2.2.4 (M36) VSL, MAASTRO, Uhasselt , CIEMAT – To compare measured and calculated results incl. validation of uncertainties

Later in the project

A2.2.5 (M38) VSL, PTB, MAASTRO, Uhasselt , CIEMAT – To draft of a protocol for calibration of superficial eBT-devices

Later in the project

A2.2.6 (M40) VSL, PTB, MAASTRO, Uhasselt – To submit a manuscript with A2.2 results in a peer-reviewed journal

Later in the project

WP2 – Activities

A2.3 $D_{w,1cm}$ calibration

Verificaiton of A2.1 and A2.2 with primary standards developed in A1.1

A2.3.1 (M30) PTB – To modify the primary standard developed in A1.1 to establish $D_{w,1cm}$ with Esteya, Axxent, INTRABEAM equipped with a surface applicator

A2.3.2 (M34) PTB – To calibrate an Esteya, Axxent and INTRABEAM equipped with surface applicator in terms of Dw at 1 cm depth in a water phantom: $D_{w,1cm}$

A2.3.3 (M36) VSL, MAASTRO, Uhasselt – To transfer the $D_{w,surface}$ to $D_{w,1cm}$ for the available Esteya, Axxent, INTRABEAM systems calibrated by PTB in A2.3.2

A2.3.4 (M40) PTW, VSL, MAASTRO, Uhasselt – To submit a manuscript with A2.3 results in a peer-reviewed journal

Coming period

- Continue the measurements at VSL
- Continue at VSL measurements with Elekta Esteya
- Start at VSL measurements with Xoft Axxent
- Plan a visit at PTB and their measurements with Zeiss Intrabeam
- To execute the rest of the measurements according to (revided plan):
  - Spectra
  - Calibration of the systems
  - Calibration of the chambers in eBT beams with VSL FAC

Thank you!

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