ESTABLISHMENT AND TRANFER OF A PRIMARY DOSIMETRIC STANDARD FOR BREAST CANCER INTRAOPERATIVE RADIOTHERAPY (IORT) USING THE INTRABEAM® SYSTEM

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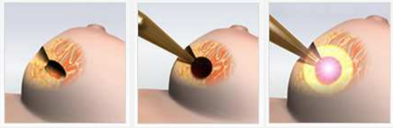
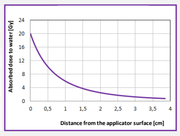
Purpose of the present study on intraoperative radiation therapy for breast cancer

IORT delivers a concentrated dose of low energy X-Rays (≤ 50 keV) by placing during surgery a miniaturized X-Ray tube in contact with the treated tumor bed. In France, the most used IORT treatment system is the INTRABEAM one, manufactured by the Zeiss Company and mainly used in case of breast cancer treatment.

INTRABEAM® IORT system: the X-ray tube is covered by a spherical applicator suited the surgery cavity.

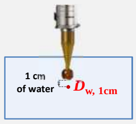
IORT then replaces all or part of the external radiation therapy sessions, currently delivered within the 6 weeks that follow the tumor excision to reduce the risk of recurrence. The tumor bed is irradiated for 20 to 50 minutes at the surgical block to receive ~ 20 Gy on its surface. Zeiss company delivers, along with the device, a database to assess the absolute dose distribution.





The absorbed dose decreases rapidly with the distance from the applicator surface.

This work aims at establishing a dosimetric traceability to a reference independent from the manufacturer, as required in the report published by the French Authority for Health (HAS, report 2016) on the evaluation of the IORT for breast cancer treatment. The HAS recommends a metrological traceability in terms of absorbed dose to water at a 1 cm distance from the applicator surface.



Standard conditions: at 1 cm in water from the bare source surface or from the applicator surface

Developed methodology to establish the $\dot{D}_W$ standard for the INTRABEAM® source

Since several types of IORT low-energy photon sources are available and that LNE-LNHB cannot afford to buy all of them, a **5-step methodology** was developed both to establish and transfer a dosimetric reference that may be applied to any X-ray-emitting IORT source without needing to bring together at the same place such source and the LNE-LNHB dedicated, but not transportable, primary instrument.

$$\dot{D}_{w,1\,cm} = \frac{I_{FAC}}{V.\rho_{air}} \cdot \frac{\overline{W}_{air}}{e} \cdot \frac{1}{(1-g_{air})} \cdot \prod_i k_i \cdot \frac{I_{tr,IB}}{I_{tr,XRG}} \cdot F_{K,D}$$

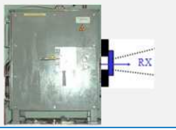
$$u(\dot{D}_{w,1\,cm})/\dot{D}_{w,1\,cm} = 2.5\,\%\ (k=1)$$

① **A beam presenting the same photon energy distribution as the photons emitted by the INTRABEAM source after crossing 1 cm of water is characterized to be reproduced at LNE-LNHB using a conventional X-ray generator.**

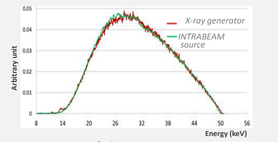
On site spectrometric characterization of the INTRABEAM source at St-Louis hospital and reproduction of its photon energy spectra at LNE-LNHB

Measurement of photons emitted by the INTRABEAM source associated with a spherical applicator (here Ø = 4 cm) after the crossing of 1 cm of water:
- collimated CdTe semi-conductor
- correction for detection artifacts [1]

Spectrometry of St-Louis hospital's INTRABEAM source, immerged in a vial of water

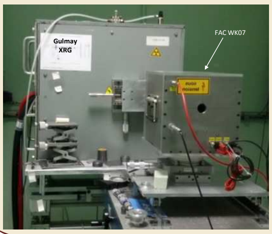


LNE-LNHB X-ray generator with appropriate filters



Comparison of the INTRABEAM spectrum with the reproduced one at LNE-LNHB

Measurement of the $\dot{K}_{air,XRG}$



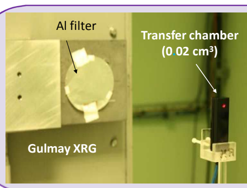
$$\dot{K}_{air,XRG} = \frac{I_{FAC}}{V.\rho_{air}} \cdot \frac{\overline{W}_{air}}{e} \cdot \frac{1}{(1-g_{air})} \cdot \prod_i k_i$$

$$u(\dot{K}_{air,XRG})/\dot{K}_{air,XRG} = 1.48\,\%\ (k=1)$$

With I_{FAC}: corrected current (noise, T, p, H)
ρ_{air}: air density   V: Interaction volume
$\overline{W}_{air}$: mean energy expended to produce an ion pair in air
g_{air}: fraction of energy lost through radiative processes
$\prod_i k_i$: correction factors (for attenuation, scattering, …)

② **The reproduced beam is characterized in terms of air kerma rate, $\dot{K}_{air,XRG}$, using a primary free-air ionization chamber (FAC, [2]) and assessing the appropriate correction factors.**

③ **The characterized reproduced beam is used to calibrate a secondary cavity ionization chamber in terms of $\dot{K}_{air}$ …**

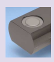


PTW-23342 secondary chamber calibration

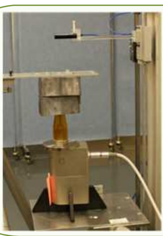
$$N_{\dot{K},tr} = \dot{K}_{air,XRG}/I_{tr,XRG}$$

$$u(N_{\dot{K},tr})/N_{\dot{K},tr} = 1.49\,\%\ (k=1)$$

$\dot{K}_{air,XRG}$: air kerma rate of the reproduced beam
$I_{tr,XRG}$: current collected by the transfer chamber



Calibration of the INTRABEAM system in terms of $\dot{K}_{air,IB}$



$$\dot{K}_{air,IB} = N_{\dot{K},tr} \cdot I_{tr,IB}$$

$$u(\dot{K}_{air,IB})/\dot{K}_{air,IB} = 1.52\,\%\ (k=1)$$ at a 13.5 cm from the source center

$\dot{K}_{air,IB}$: air kerma rate of the INTRABEAM source
$I_{tr,IB}$: current collected by the transfer chamber

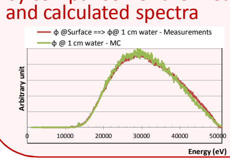
INTRABEAM measurement at St-Louis hospital:
- collimated beam to mimic the calibration conditions
- use of an Al filter equivalent to 1 cm of water (attenuation)

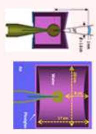
④ **… which as a transfer instrument is, in turn, used to calibrate the INTRABEAM system in terms of the $\dot{K}_{air,IB}$ delivered by the INTRABEAM photons after crossing 1 cm of water.**

PENELOPE Monte Carlo calculation of the $F_{K,D}$ conversion factor

Validation of the source model by comparison of the measured and calculated spectra

$$F_{K\to D} = \left(\frac{D_{eau,1cm}}{K_{air,IB}}\right)^{MC} \qquad \frac{u(F_{K\to D})}{F_{K\to D}} = 1.9\,\%\ (k=1)$$





$(K_{air,IB})^{MC}$ calculated in the measurement conditions

$(D_{eau,1cm})^{MC}$ calculated in the standard conditions

⑤ **A developed Monte Carlo model of the source is used to calculate a conversion factor, $F_{K\to D}$, from air kerma rate, $\dot{K}_{air}$, to absorbed dose to water, $\dot{D}_{w,1cm}$, in standard conditions**

Results and conclusion

This methodology was applied to the INTRABEAM® system of St-Louis hospital associated with a 4 cm spherical applicator [3]. The Zeiss Company recently changed its dosimetric procedure, going from the TARGIT method to the non- TARGIT one.

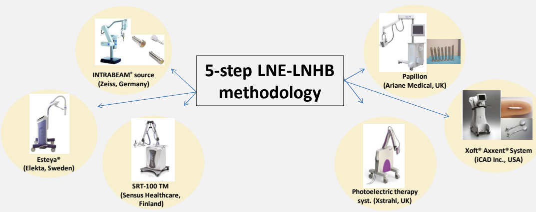
$\dot{D}_{w,1\,cm}$ defined from the applicator surface

LNE-LNHB $\dot{D}_{w,1\,cm}$ [mGy.s⁻¹] (Source Detector Distance: 13.5 cm)	Zeiss $\dot{D}_{w,1\,cm}$ [mGy.s⁻¹]		Ratio $\dot{D}_{w,1\,cm}$ (LNE-LNHB/Zeiss)	
	TARGIT	Non-TARGIT (V4.0)	TARGIT	Non-TARGIT (V4.0)
4.95	3.72	4.26	1.33	1.16

The LNE-LNHB dose value is respectively 33 % and 16 % higher than the TARGIT and non-TARGIT methods [3].

The German and Czech national metrology laboratories (PTB and CMI respectively) found, in a joint research study independent to the present one, similar results in another configuration (X-rays tube's naked needle, i.e. without any spherical applicator) [4]. The present study has to be continued, including international measurement comparisons, to strengthen the metrological traceability of end-user's IORT X-ray sources.

Since validated, the LNE-LNHB methodology could be transposed to other applicators and IORT sources.



LNE-LNHB methodology transposed to other applicators and IORT sources

References

[1] J. Plagnard, RFM n°43, 2016-3. [2] W. Ksouri, Thesis, 2008. [3] A. Abudraa', Thesis, 2017.
[4] https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_6/6.3/information/mfbt_vortrag05.pdf SEE ALSO: POSTER P209, C. STIEN, ECMP 2018.

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