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Comprehensive validation of a Monte Carlo kV-CBCT model using OSL and spectral measurements

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I. Purpose and Objective

The use of Cone-Beam computed Tomography (CBCT) is progressively increasing in radiotherapy treatments and there is a need from the medical physics community to develop tools to estimate, report and drive strategies to reduce CBCT doses. Hence, we developed a Monte Carlo (MC) model for the XVI kV-CBCT system, and the aim of this work is to validate our simulator in pre-clinical conditions against :

- Experimental spectra measured with a CdTe semi-conductor.
- Organ dose measurements with OSL nanoDot (Landauer) in CIRS ATOM anthropomorphic phantoms.

II. Material and Methods

1. Spectral measurements

Measurements were performed in air with the CdTe detector, on the central beam axis, and were corrected for detection artifacts [1].

2. Dosimetric protocol for OSL measurements

a. In air calibration

Cross calibrations in air with a FARMER type ionization chamber were performed for 6 beam qualities: 120, 100 and 80 kVp, filtered with F1 bowtie and unfiltered. Thus, we obtained calibration factors $N_{K_{air},Q_{ref}}$ linking air Kerma values to OSL signals S_{OSL} :

$$K_{air,Q_{ref}} = N_{K_{air},Q_{ref}} \cdot S_{OSL}$$

b. Irradiation in CIRS phantoms

OSL were inserted in heterogeneities of the CIRS phantoms, and irradiated with usual CBCT acquisition protocols. They were read three times and corrected for the background.

c. Energy correction

Because of spectral variations between calibration and

measurement, and of the important energy dependence of OSL, an energy correction had to be applied. To this end, the evolution of calibration factors $N_{K_{air},Q_{ref}}$ with spectrum mean energy \bar{E} was fitted with a linear function (Fig. 1). This curve allows the determination of the $N_{K_{air},Q}$ for the beam quality Q at the location of the OSL in the phantom:

$$K_{air,Q} = (a\bar{E} + b) \cdot S_{OSL}$$

Variations of beam qualities in CIRS phantom were estimated by MC simulation with spectra validated by CdTe measurements.

d. Medium correction

The correction was made under the hypothesis of electronic equilibrium to convert air Kerma values to tissue doses :

$$D_{tissue,Q} = K_{air,Q} \cdot \left[\frac{\left(\frac{\mu_{en}}{\rho}\right)_{tissue}}{\left(\frac{\mu_{en}}{\rho}\right)_{air}} \right]_Q$$

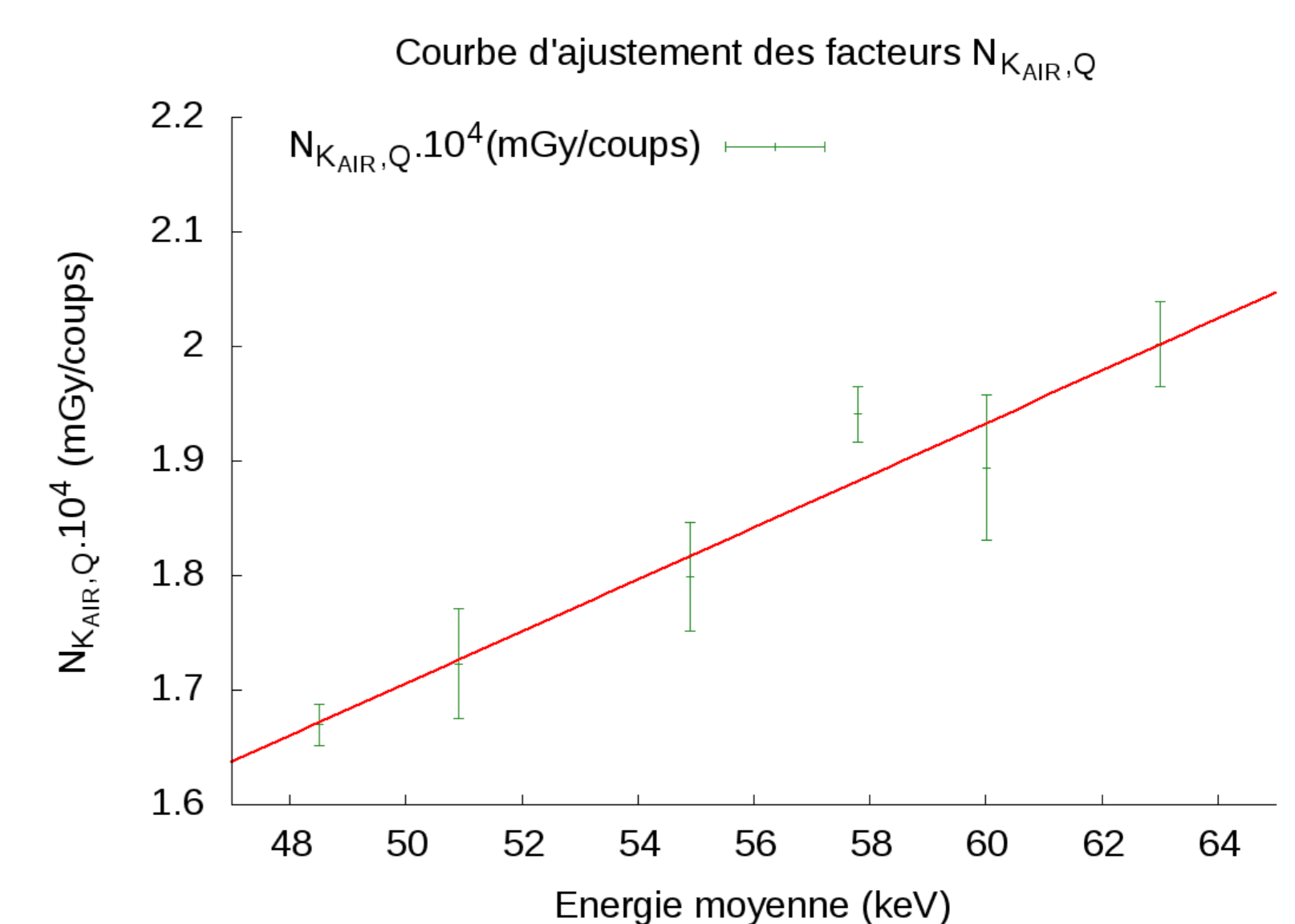


Figure 1

II. Results

1. Spectral measurements

Comparisons of experimental and MC spectra for various CBCT beam qualities showed very good agreement (Fig 2 and Tab 1).

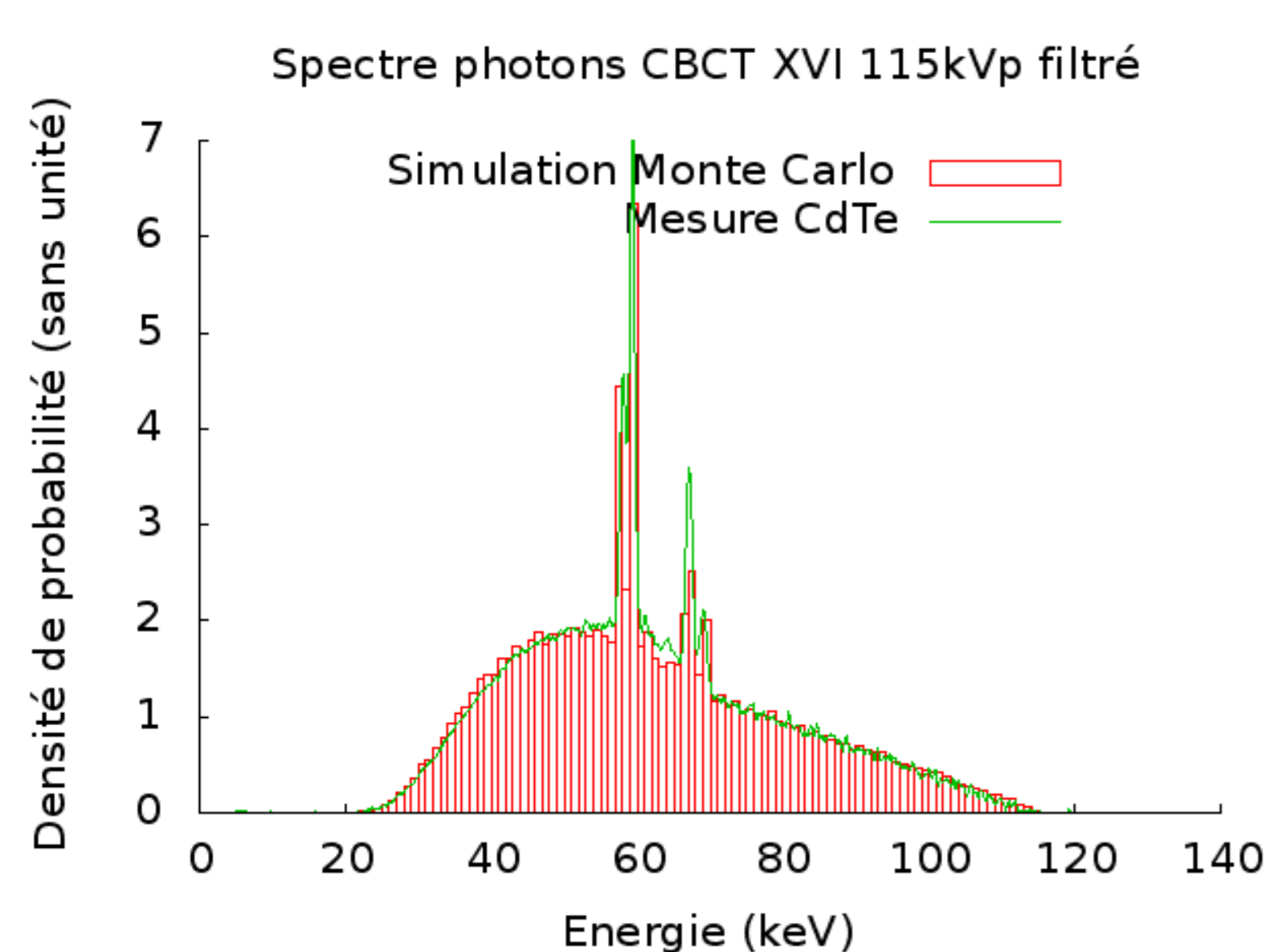


Figure 2

Tab. 1: Spectra mean energies

Beam qualities	$\bar{E}_{meas.}$	\bar{E}_{MC}
120 kV F0	59.7 keV	60.0 keV
120 kV F1	61.7 keV	63.1 keV
100 kV F0	54.3 keV	55.0 keV
100 kV F1	56.1 keV	57.7 keV
80 kV F0	47.8 keV	48.5 keV
80 kV F1	49.4 keV	51.0 keV

2. Comparisons of OSL measurements and MC dose values

A total of 84 OSL were irradiated in CIRS phantoms and a mean difference between measured and MC dose values of 8,6% was obtained. Tables 2 and 3 present examples of comparisons.

Tab. 2: 5 years old - Lung 80 kV F0

Location	$D_{meas.}$ (mGy)	D_{MC} (mGy)
Lung Left	3.07 ± 0.05	3.08 ± 0.14
Lung Right	2.76 ± 0.05	2.94 ± 0.13
Heart	2.53 ± 0.04	2.76 ± 0.12
Liver	2.29 ± 0.04	2.38 ± 0.11
Medisatinium	2.37 ± 0.04	2.50 ± 0.11
Rachis	7.36 ± 0.13	5.77 ± 0.26

Tab. 3: Female adult - H&N 100kV F0

Location	$D_{meas.}$ (mGy)	D_{MC} (mGy)
Lung	0.72 ± 0.03	0.67 ± 0.08
Thyroid	0.88 ± 0.03	0.93 ± 0.08
Brain	0.27 ± 0.01	0.31 ± 0.03
Jawbone	2.48 ± 0.10	2.26 ± 0.19
Eye	0.64 ± 0.03	0.60 ± 0.05
Rachis	1.88 ± 0.08	1.61 ± 0.14

II. Conclusion and Perspectives

The MC simulator of the XVI CBCT was validated against an extensive set of experimental measurements, and enables the organ dose calculation with accuracy. It can now be used to compute and report doses to organs for clinical cases.

[1] Plagnard, J. (2014). Comparison of measured and calculated spectra emitted by the X-ray tube used at the Gustave Roussy radiobiological service. (W. O. Library, Éd.) *X-Ray Spectrometry*, 43(5), pp. 298-304.