



End-to-end tests using alanine pellets read by EPR in a heterogeneous phantom for radiotherapy treatments

DE LA RECHERCHE À L'INDUSTRIE

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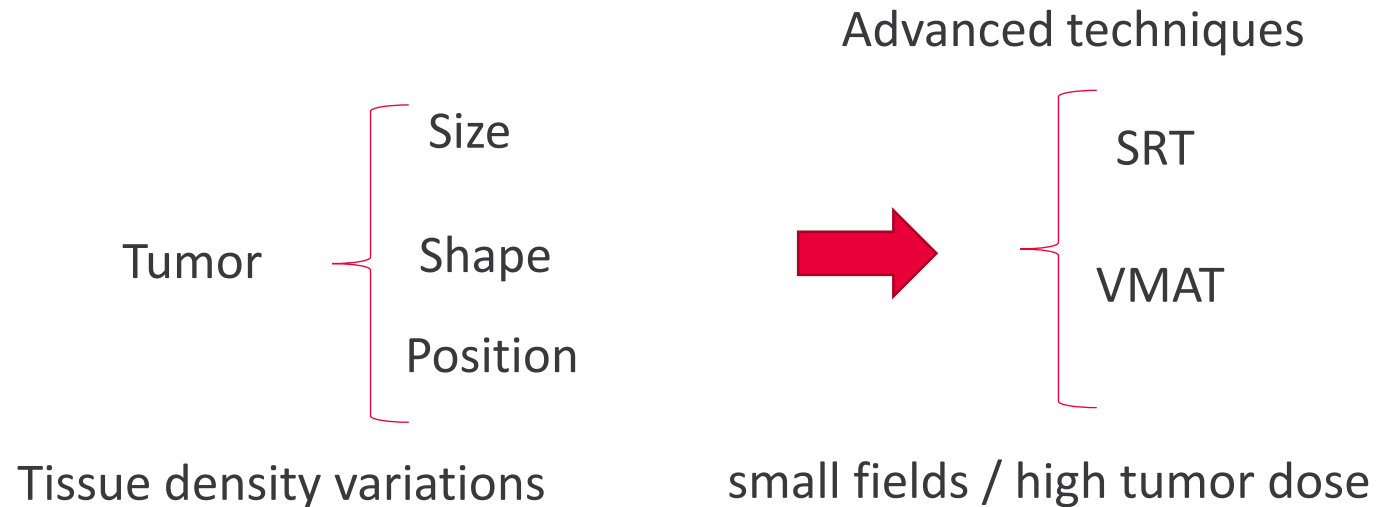
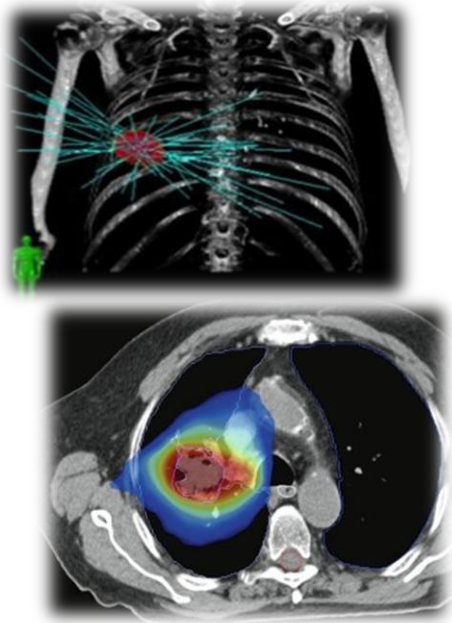


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The aim of Radiotherapy treatments is to deliver the dose to the tumor with an accuracy of absorbed dose $< 5\%$ and to spare healthy tissues.



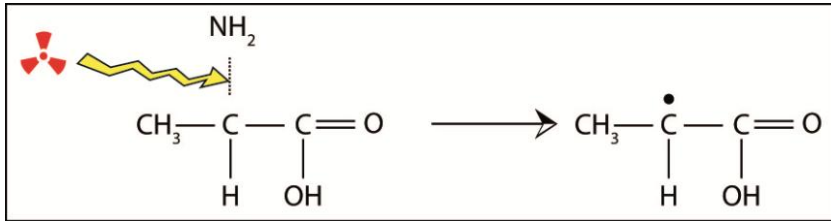
Dose calculation in low density medium and using small size photon beam is challenging for Treatment Planning System (TPS) algorithms

Present work consists in :

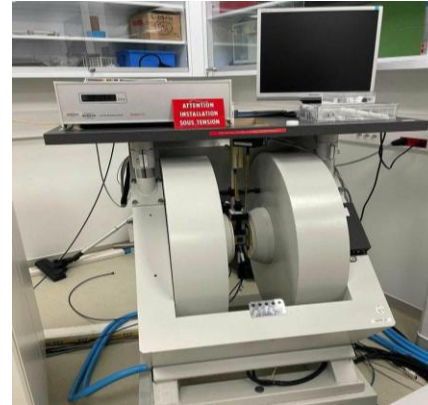
Evaluation of AAA and Accuros algorithm performances / E2E test using Alanine-EPR technique

Alanine is an amino acid (protein peptide chain)

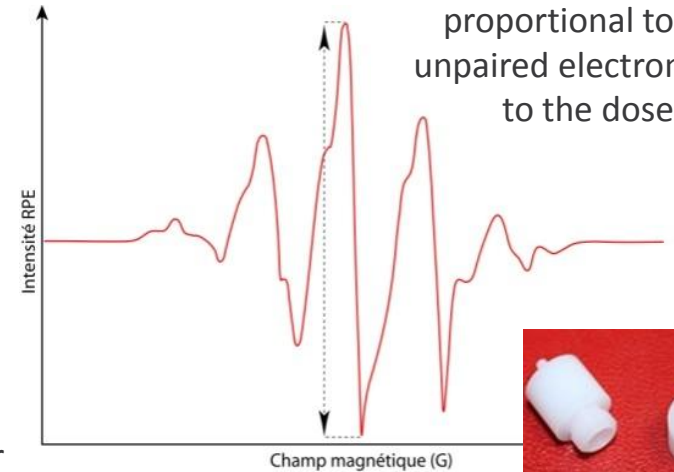
Radiolysis of alanine



Radical concentration proportional to the dose



X band Elexsys EPR spectrometer



central pic amplitude is proportional to the unpaired electron then to the dose



Alanine radicals are very stable the sample can be reread several times, it is tissue equivalent.

- Alanine pellets have a small size ($\varnothing = 5 \text{ mm}$, $h = 3 \text{ mm}$)
- The irradiated alanine EPR signal is linear with dose
- It is dose rate independent
- It has a negligible energy dependence for photon beams (1 MeV – 18 MeV)
- It has a wide dose range (1 \rightarrow 100 000 Gy)

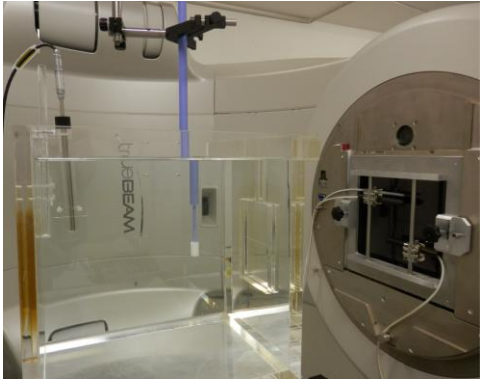
Drawbacks:

- It has to be stored in a dark and dry room
- The readout is delayed

Alanine dosimeters are used as secondary dosimeters

Calibration curve establishment

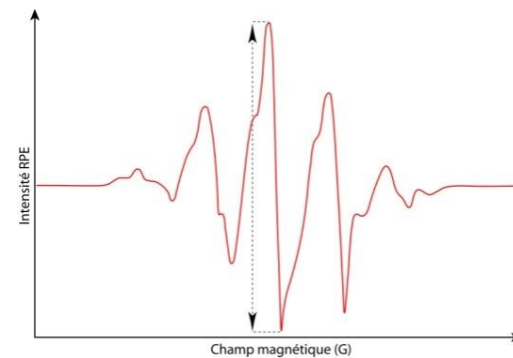
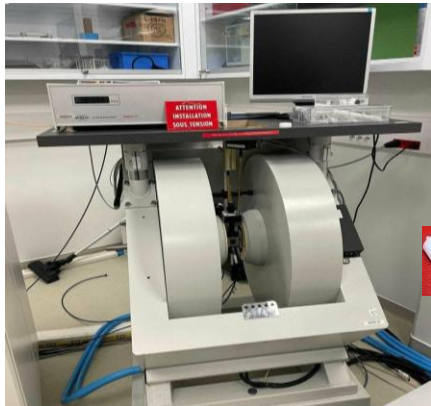
Alanine irradiation in in IAEA TRS 398 reference conditions using a medical accelerator facility



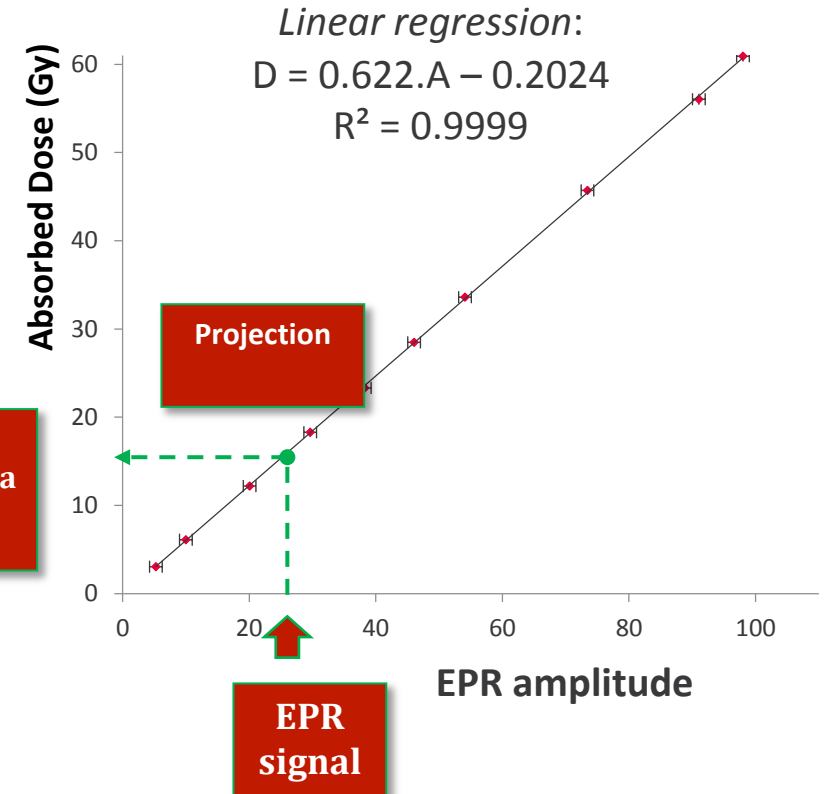
Alanine pellets are weighed



Dosimeters



EPR measurement



Typical uncertainty of a 40 Gy irradiated alanine pellet is equal to 1.2 % (k = 1)

The first step of the end to end process is to check the beam calibration

A calibration curve has been done in both sites at LNHB and at ICO Hospital in reference conditions (IAEA 398TRS)

Medical accelerators Varian Truebeam 6 MV

Alanine pellets are read at LNHB

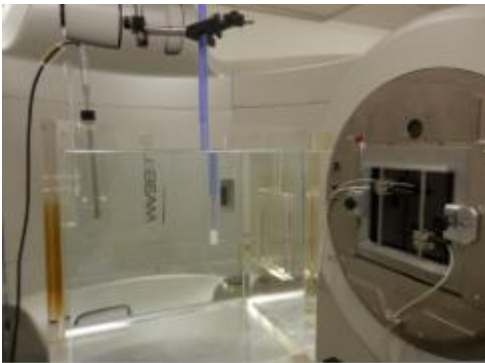
The two calibration curves are very linear and in excellent agreement

The deviation between the slope of the two calibration curves is below 1 %. There is a very good agreement with a coverage factor $k = 1$

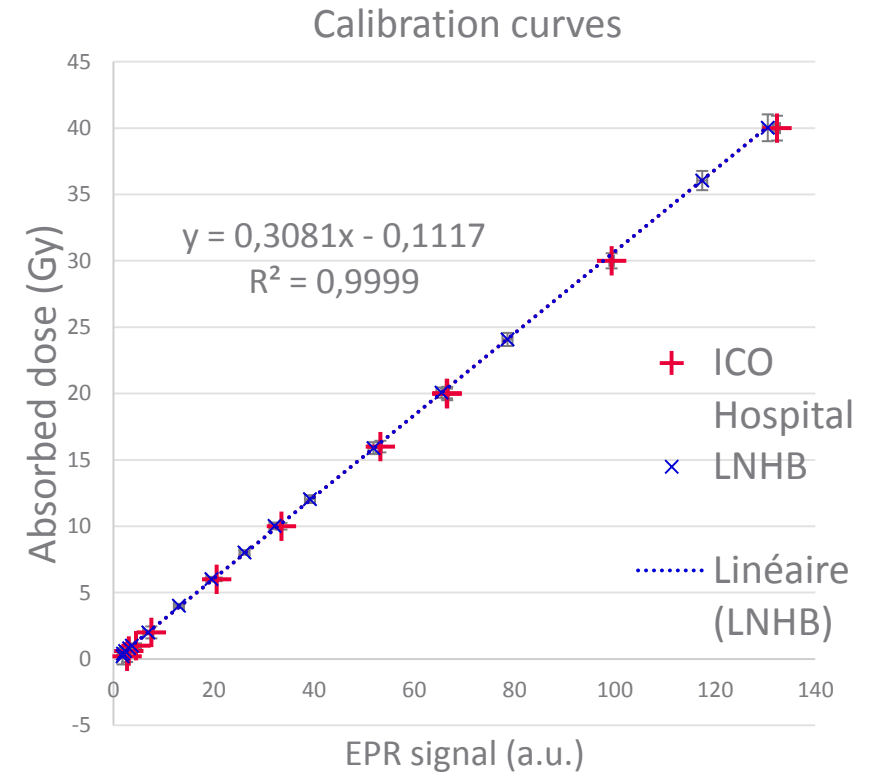
The ICO hospital beam calibration is validated



Alanine Irradiation at ICO Hospital

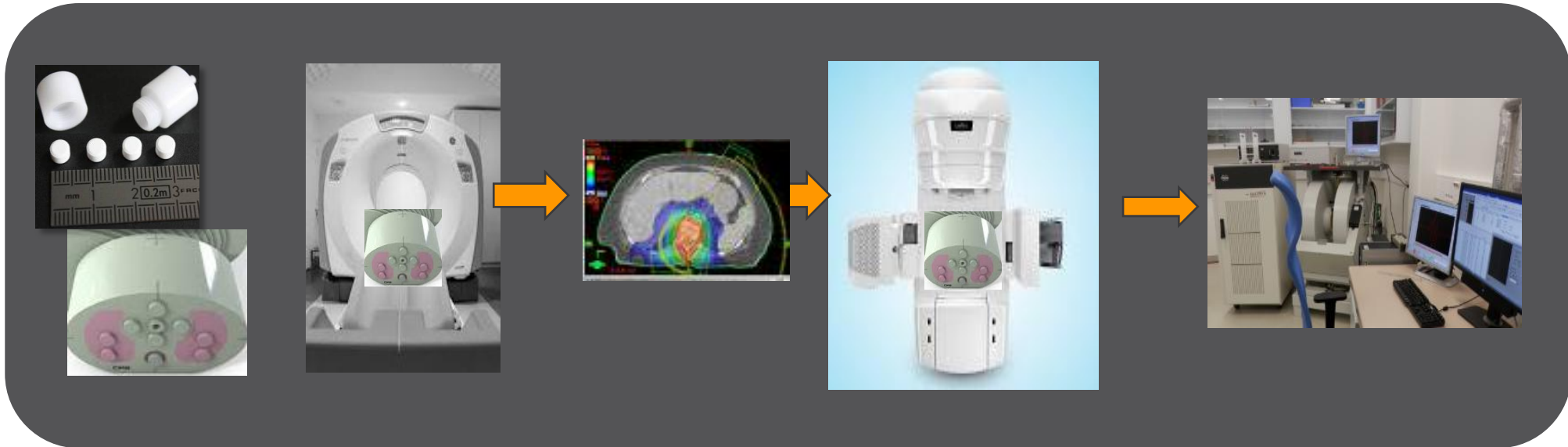


Alanine Irradiation at LNHB



	Calibration curve slope	Relative uncertainty
LNHB	0,308	0,54%
ICO Hospital	0,306	1,09%

End-to-end tests consist in the process validation of the patient whole treatment



The aim of these tests in the present work are to

- ❑ Check that the delivered dose corresponds to the prescribed dose within 5%
- ❑ Compare 2 TPS algorithm performances where a lack of electronic equilibrium is encountered for a small field size and an heterogeneous phantom

The IMRT Thorax Phantom CIRS 002LFC is recommended by IAEA for the clinical commissioning tests (TECDOC 1583)

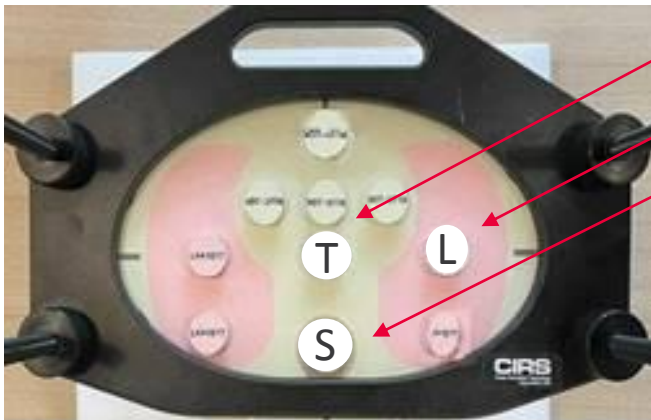


Special inserts for tissue, lung and spine adapted to our alanine pellet container were developed



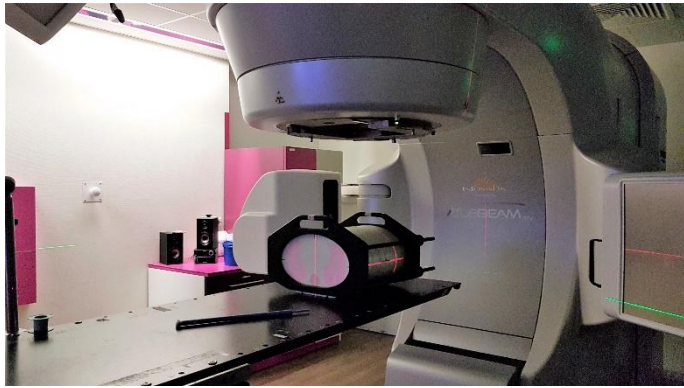
Each insert is inserted in its dedicated region

5 irradiations conditions were studied



Tissu : T
Lung : L and tissue insert in lung (RL)
Bone/Spine : S and tissue insert in spine (TS)

Additionally we made irradiations by using the tissue insert in the lung region (TL) and also in the bone region (TS) in order to check the algorithms calculation performances



5 irradiation configurations were studied

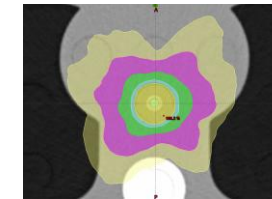


Tissu insert in tissu region (T)
Lung insert in lung region (L)
Tissu insert in lung region (TL)
Bone insert in spine region (S)
Tissu insert in bone region (TS)

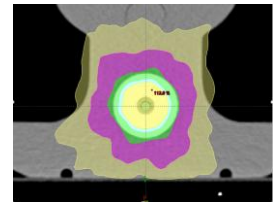
All irradiation configurations were irradiated using a 6 MV beam energy, 10 x 10 cm² beam size

Tissue and Bone Treatment plans

VMAT treatment using a Planning Target Volume (PTV) was the 4 alanine pellets



VMAT in Tissu

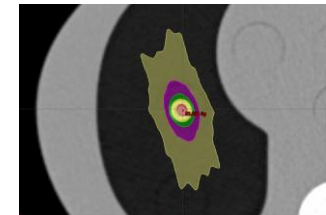
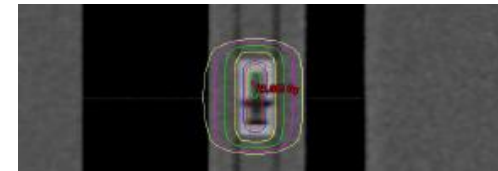


VMAT in Spine

Lung treatment plans

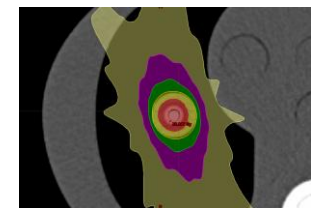
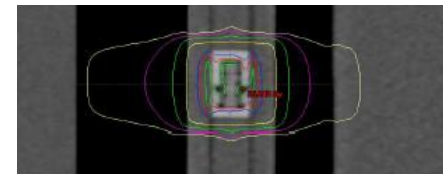
DCAI treatment plan

8 beam angles static irradiation
PTV was the Phantom insert
Leafs conformed close to the phantom insert



DCAT treatment plan

8 beam angles static irradiation
PTV was the 4 alanine
Leafs conformed close to the alanine container
Small field (2.5 cm x 1 cm)



Eclipse 15.8. Version TPS algorithms

(AAA), Analytical Anisotropic Algorithm

(Acuros XB), Advanced Dose Calculation algorithm

Deterministic solution of the linear Boltzmann transport equation (LTBE)

Absorbed dose to water

Dose calculation grid size : 1 mm³

For both algorithms, the alanine electronic density was entered in the TPS (HU determined using the electronic density and the scanner correspondence curve (HU = f(Ed)))

Alanine-EPR absorbed dose to water determination (EGS4 cavity)

Alanine dose measurement using EPR is the dose in the alanine medium

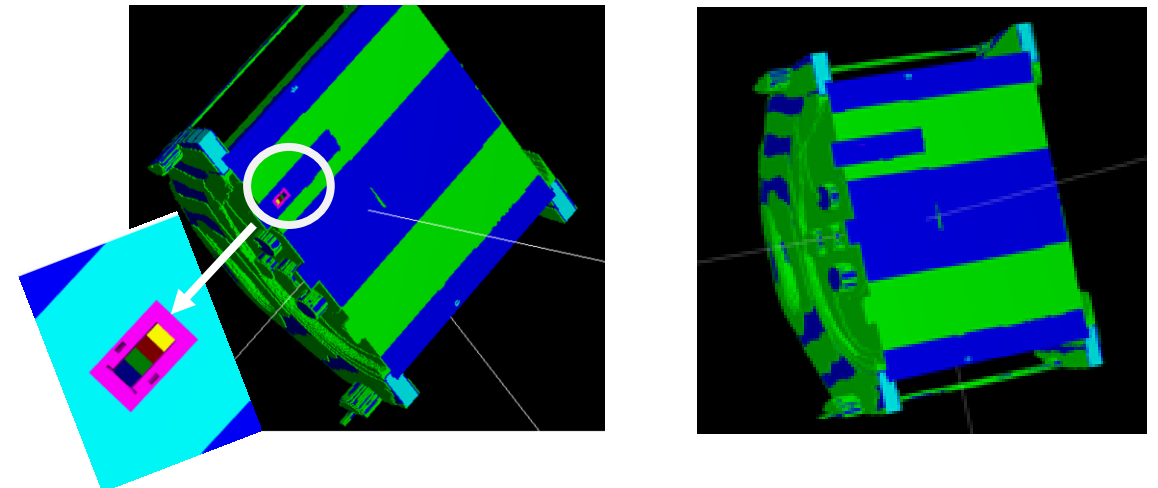
$$D_{al,Q_{clin}} = N_{D,al,Q_0}^{f_{ref}} M_{F,Q_{clin}}^{f_{clin}} k_{mass} k_{stab} k_T$$

$M_{F,Q_{clin}}^{f_{clin}}$ EPR measurement (3 angles)

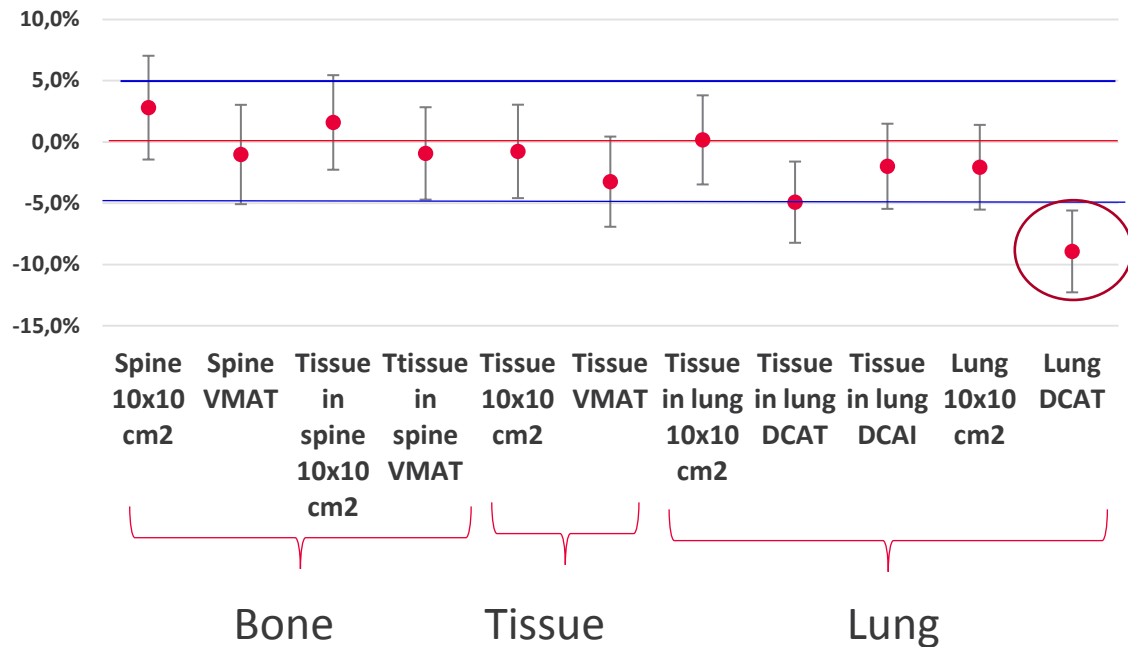
$N_{D,al,Q_0}^{f_{ref}}$ alanine calibration coefficient (TRS 398)

A transfer factor has been calculated (using EGS4 MC code) for the dose to water determination

$$D_{w,Q_{clin}} = \frac{(D_{w,Q_{clin}})^{MC}}{(D_{al,Q_{clin}})^{MC}} D_{al,Q_{clin}}$$



TPS AAA/EPR dose to water discrepancies

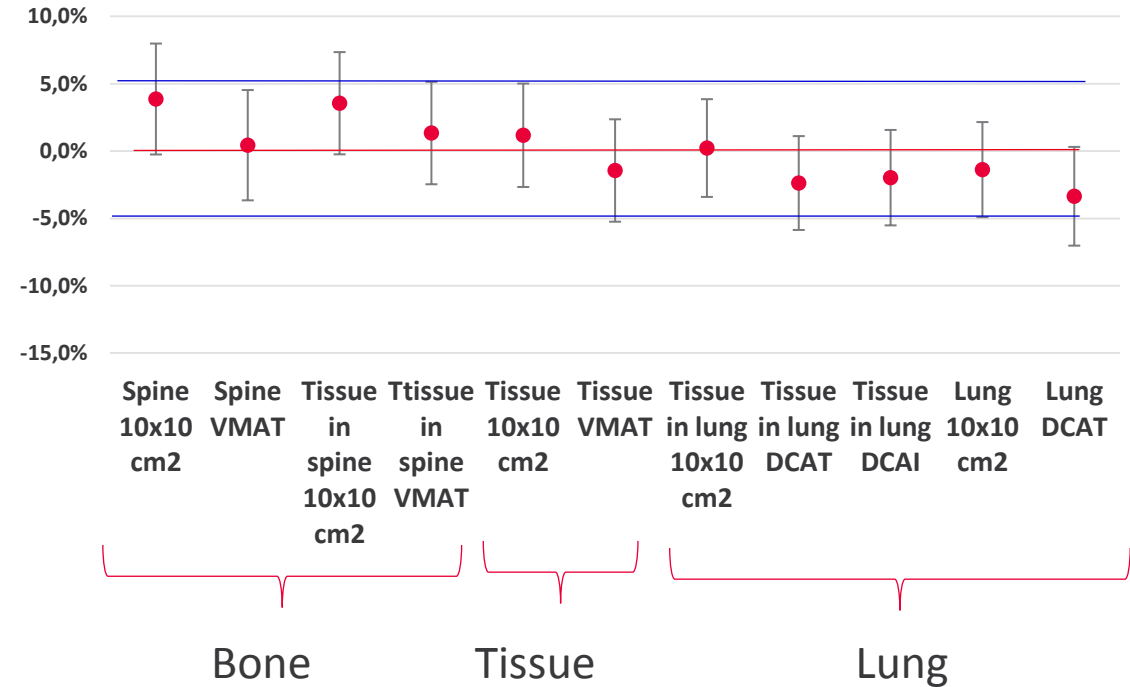


All discrepancies between AAA calculation and the alanine EPR measurement do not exceed 5 % except for lung DCAT clinical TPS

DCAT irradiation was also done in lung but using the tissue insert in lung and it does agree with alanine measurements

This result reveals a difficulty for the AAA algorithm to manage a calculation in a light material as the lung in a small static field

TPS AXB/EPR dose to water discrepancies



All discrepancies between AXB calculation and the alanine EPR measurement do not exceed 5 %

AXB TPS dose to water calculations agree with alanine-EPR measurements within their uncertainties ($k = 2$).

Uncertainties are calculated with a coverage factor $k = 2$

Measurements were done at the hospital in the same phantom irradiation configurations using a IBA ionisation chamber

Ionization chamber: CC04 (IBA)

- Cavity volume: 0.4cc
- Cavity length: 3.6 mm
- Cavity diameter: 4 mm

Inserted in specifically designed inserts (lung, tissue, bone)



CC04

$$D_{w,Q_{clin}} = M_{Q_{clin},corr}^{f_{clin}} N_{D,w,Q_0}^{f_{ref}} k_{DO}$$

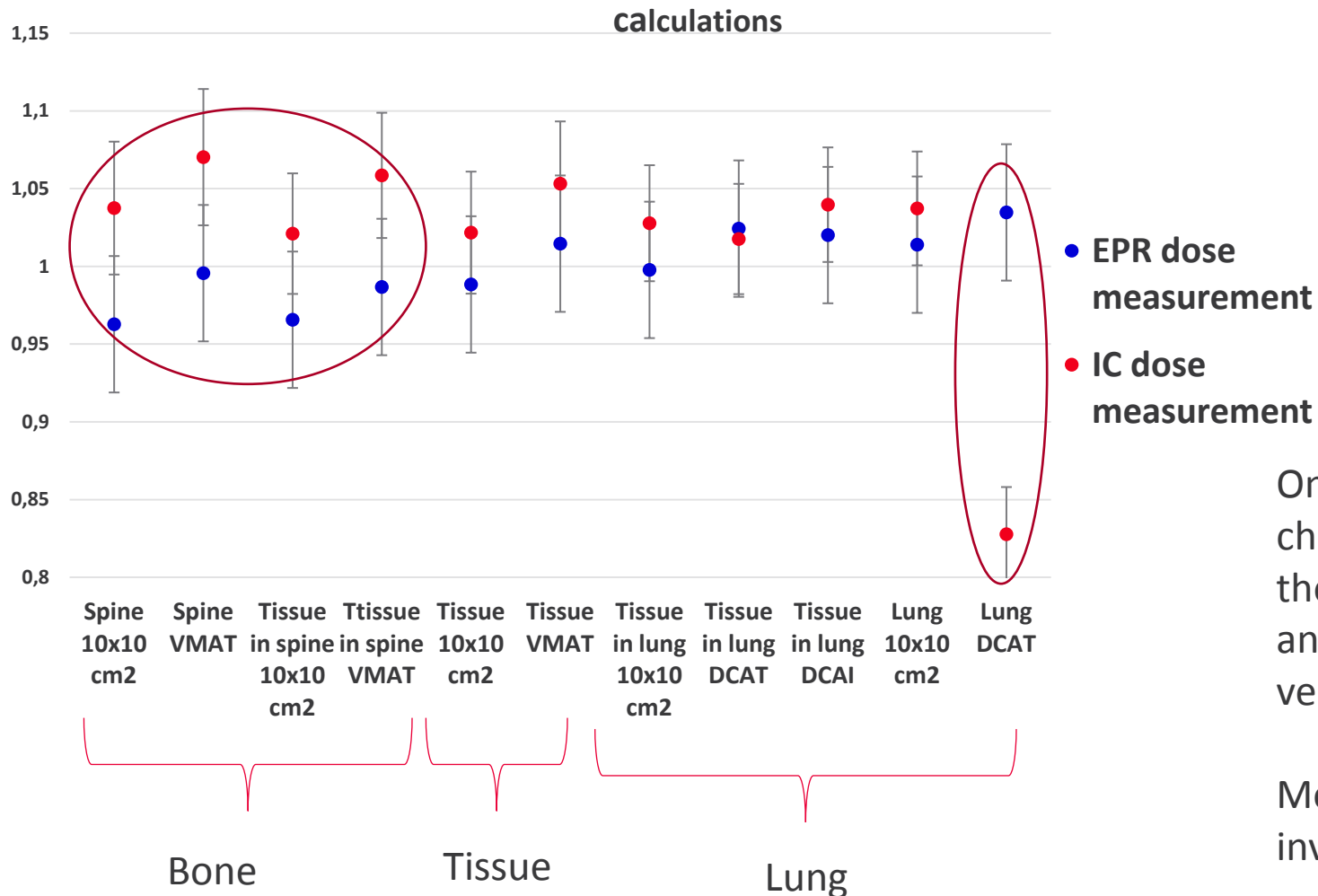
$M_{Q_{clin},corr}^{f_{clin}}$ reading of the ionization chamber corrected from background, temperature, pressure, polarity effect and ion recombination

$N_{D,w,Q_0}^{f_{ref}}$ cross-calibration coefficient from a reference chamber directly calibrated at LNE-LNHB
(no k_{Q,Q_0} because the reference chamber is directly calibrated for the $TPR_{20,10}$ of the linac)

k_{DO} daily output of the linac

But clinical measurements are far from reference measurements (Field size and heterogeneous phantom)

Discrepancies of EPR and IC dose measurements to TPS AXB



Discrepancies between EPR and IC measurements in spine region equal to around 7 %

Discrepancy in lung region with the lung insert for small field equal to 20 % for DCAT treatment plan

On the contrary to alanine, IC calibration coefficient changes when the beam size changes (mainly due to the dosimeter density which not water equivalent and to the fact that the phantom density which is very different to the reference conditions).



Monte Carlo simulations are needed in order to investigate these discrepancies

End to end tests were undertaken at an hospital using EPR alanine dosimeters in an heterogeneous phantom

Beam calibration in reference conditions verification

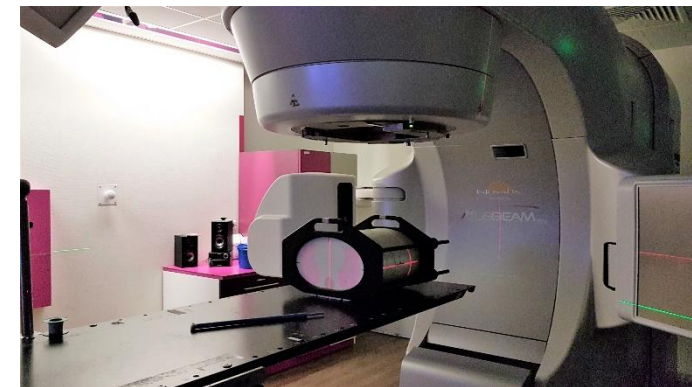
The calibration of the hospital facility has been validated by establishing a calibration curve, that was in full agreement with the LNHB reference calibration curve.

« End-to-end » tests were carried out using a Thorax phantom

- Difficulties of the AAA algorithm to deal with the calculation of the dose in the presence of a light material like lung and a small field has been identified.
- The E2E test was validated for all configurations using the Acuros AXB algorithm of the Eclipse TPS

Next step

Implement end-to-end quality assurance for stereotactic radiotherapy using alanine dosimeters





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Thank you for your attention

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