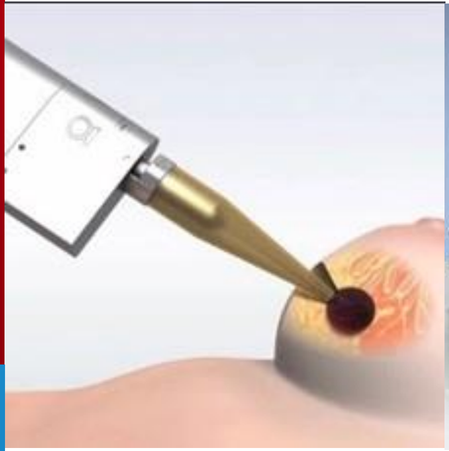
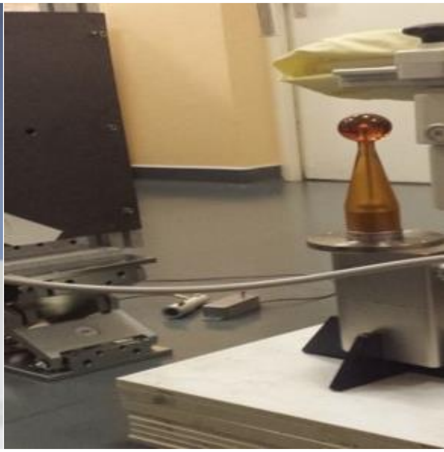
FROM RESEARCH TO INDUSTRY

DEVELOPMENT OF NEW DOSIMETRIC STANDARDS FOR LOW ENERGY X-RAYS (≤ 50 keV) USED IN RADIOTHERAPY

PHENIICS Days, 9-11 May 2016 | Abdullah ABUDRA'A





Laboratoire National Henri Becquerel

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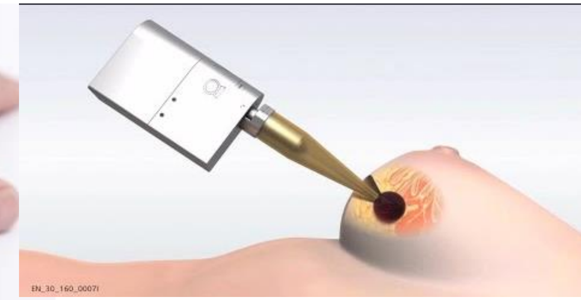

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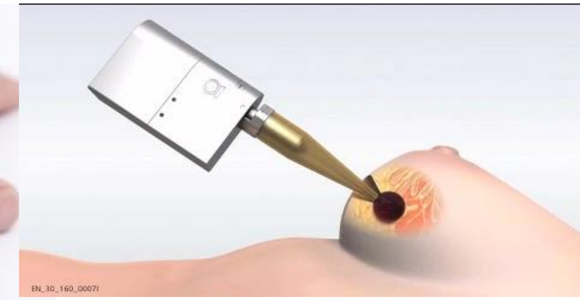
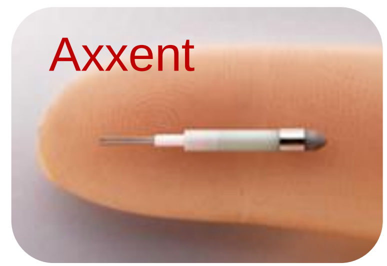
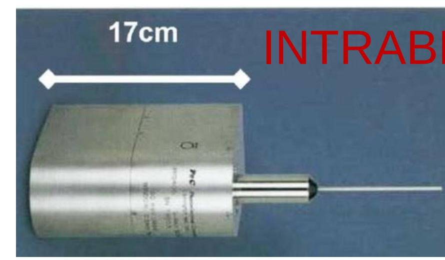




Axxent



INTRABEAM

CONTACT RADIOTHERAPY

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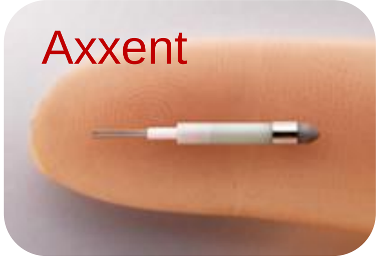

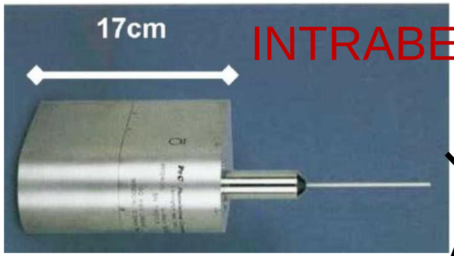

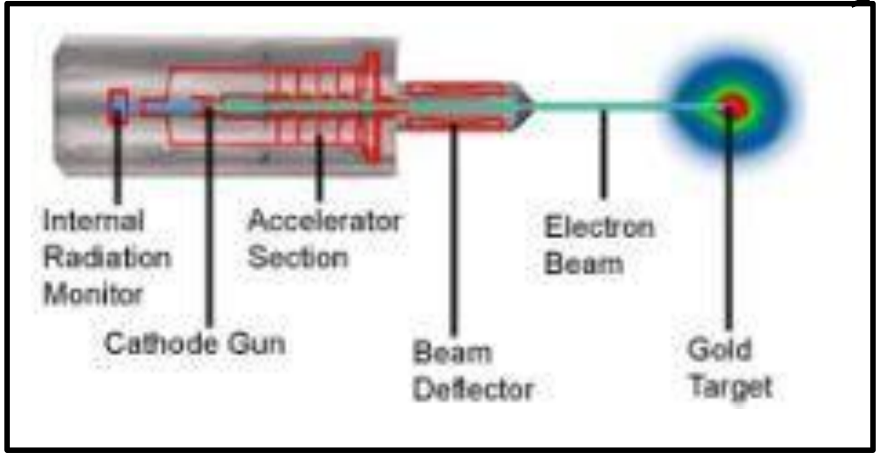

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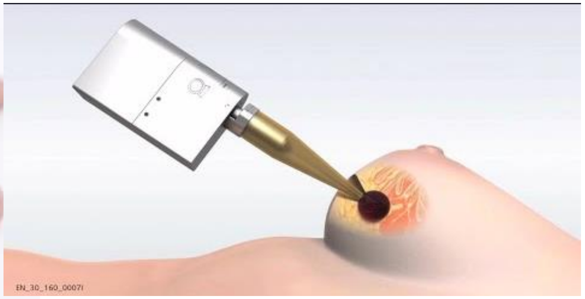
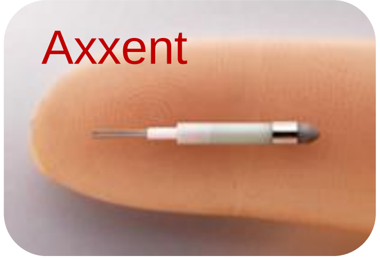
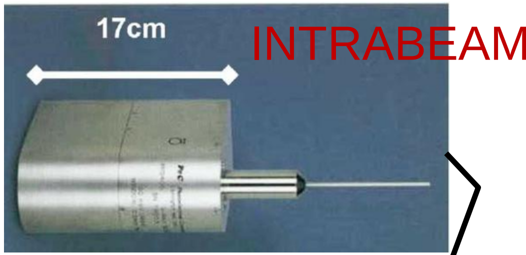
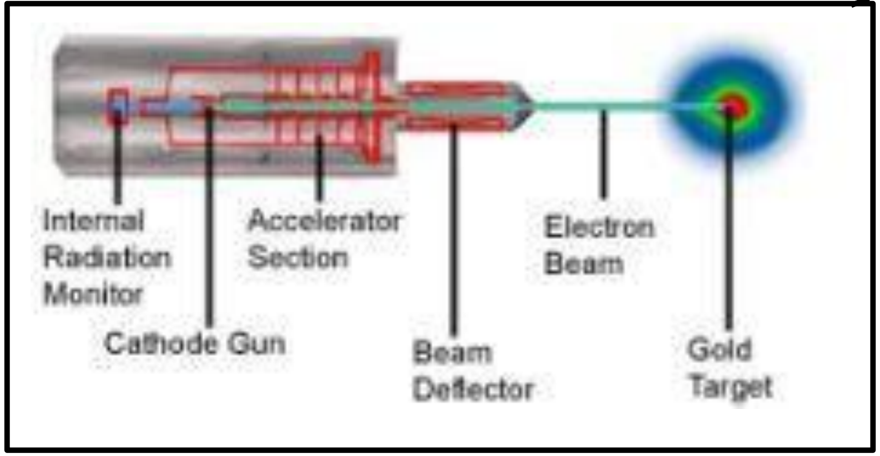


- **Radiation source is in contact with the tumor cells.**

- **Characteristics:**
  - Low penetration ➔ Low energy X-rays ≤ 50 keV
  - More preservation (protection) for healthy tissues
  - Higher dose can be delivered ➔ Lower treatment time (more comfort and lower cost)

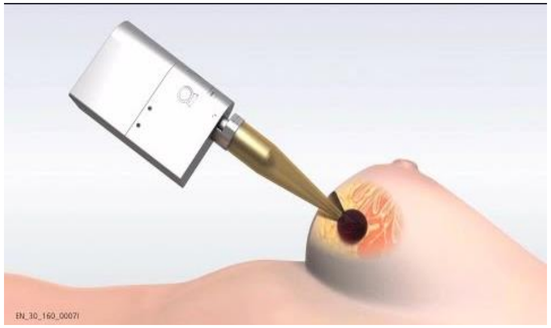






THE INTRABEAM SYSTEM

- Widely used in France for breast cancer.



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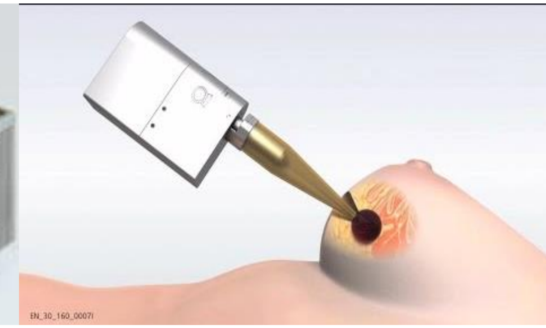

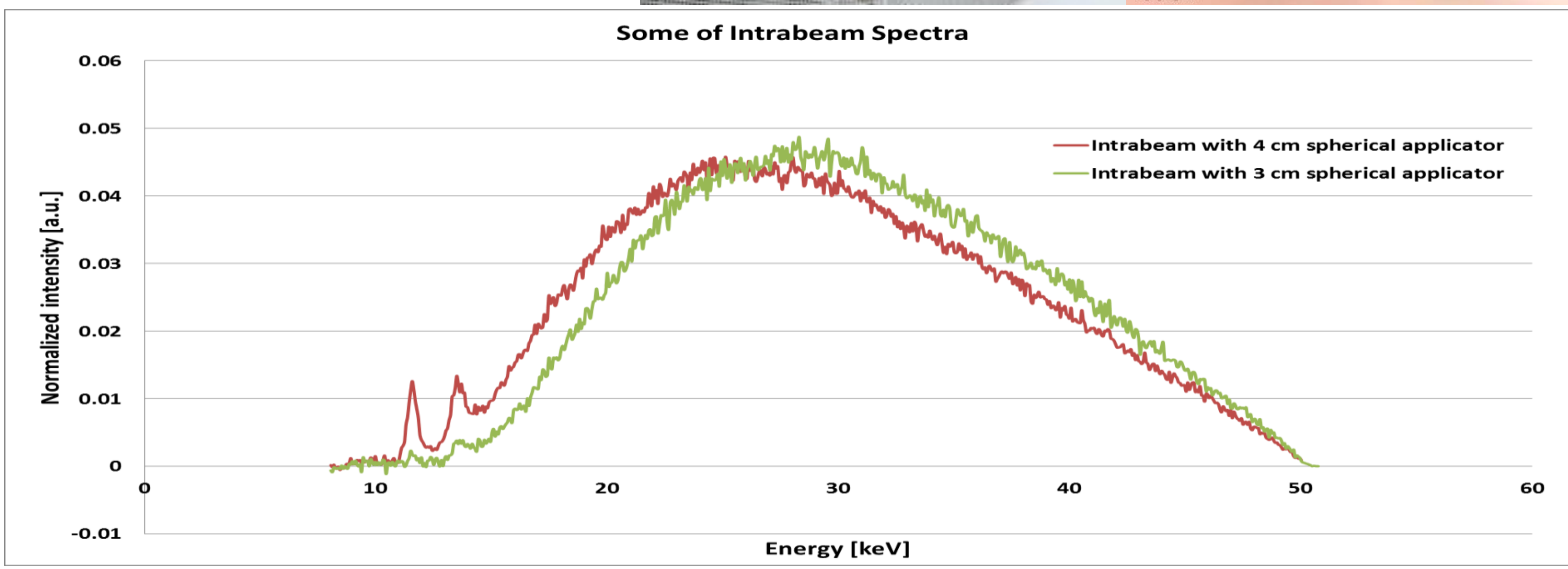

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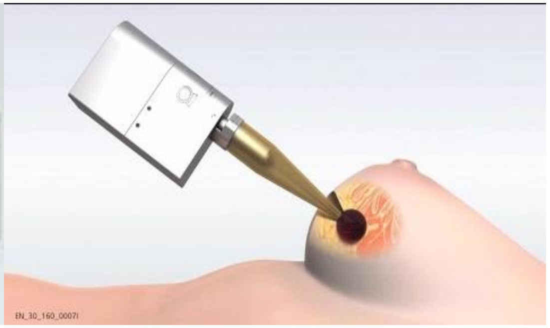
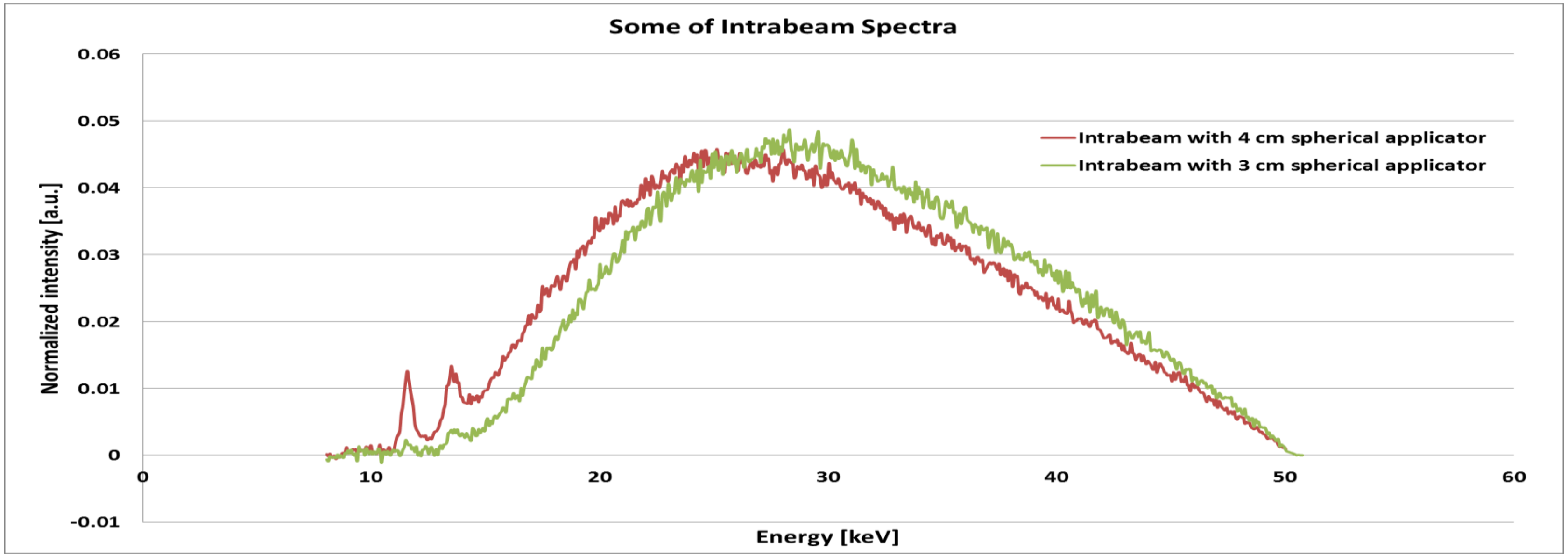
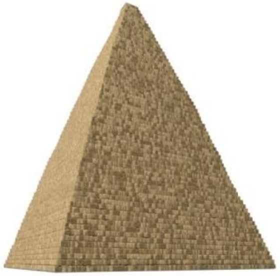




- Only dose distribution data of the manufacturer! ➔ Need for a dosimetric standard!

Dosimetric standard

Which is higher?



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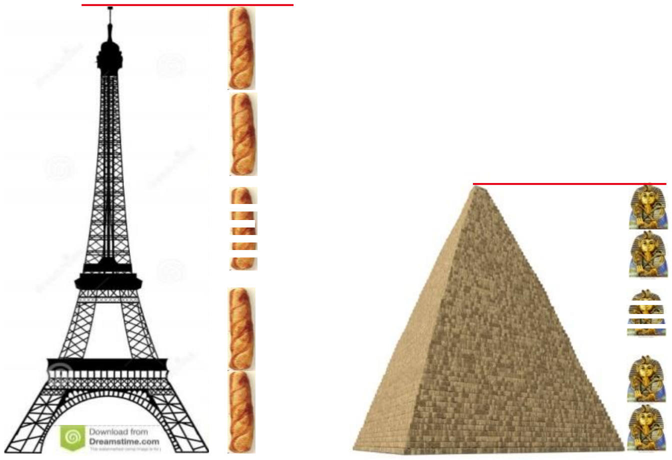

Dosimetric standard

Which is higher?

We need then:

- To agree on a unit, Quantity …
- A device, system, tool …→ Measure

A **Standard**

Dosimetric standard

Quantities defined for dose measurements (at a Point):

- **Absorbed dose to water, D_w**
- **Air kerma, K_{air}**

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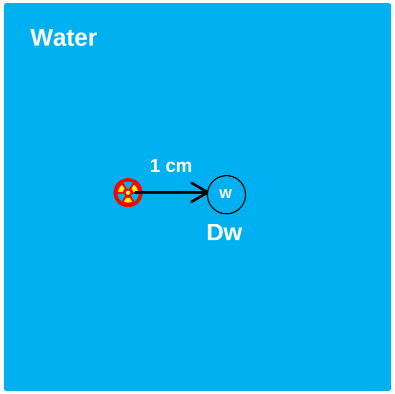
$$\frac{Energy}{Mass} \rightarrow J.\,Kg^{-1} = \mathbf{Gy}$$

Standard configurations:

D_w



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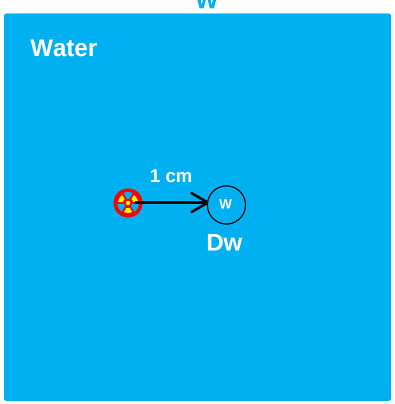
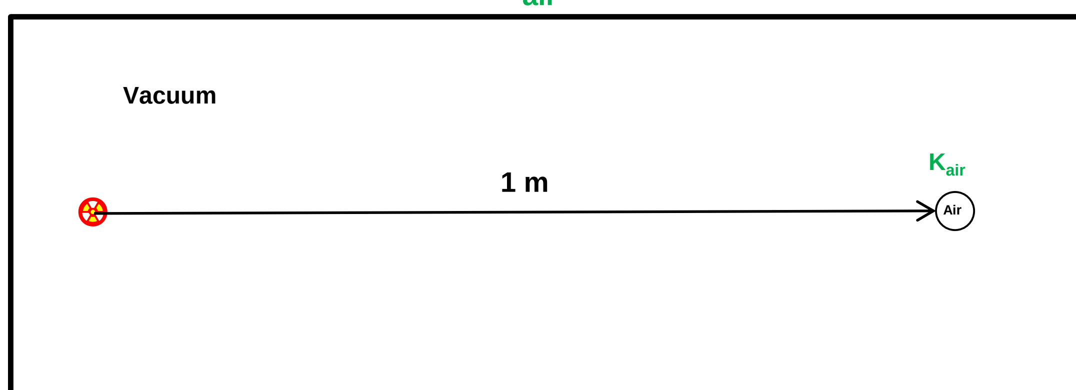


K_{air}



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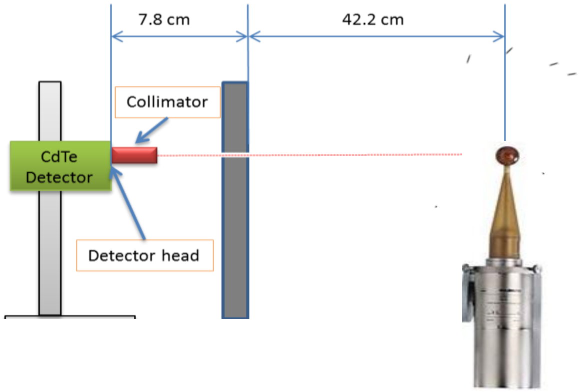
Using the K_{air} standard and the calibrated IC to measure the depth dose profile

REPRODUCTION OF INTRABEAM SPECTRA



Measurement of INTRABEAM spectra at Saint Louis Hospital in Paris

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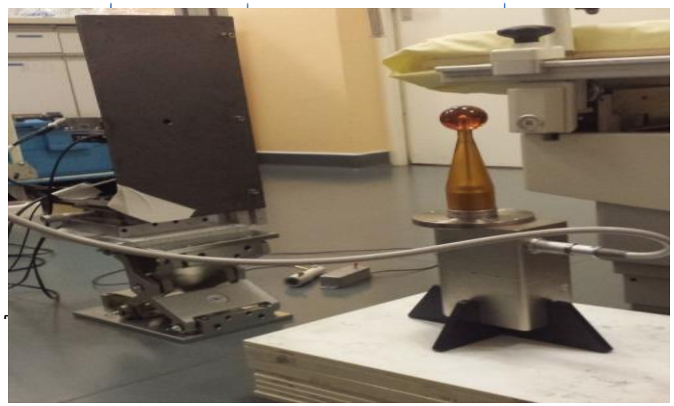

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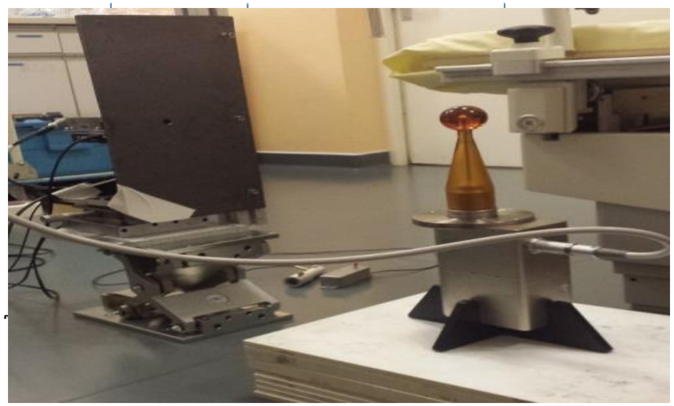

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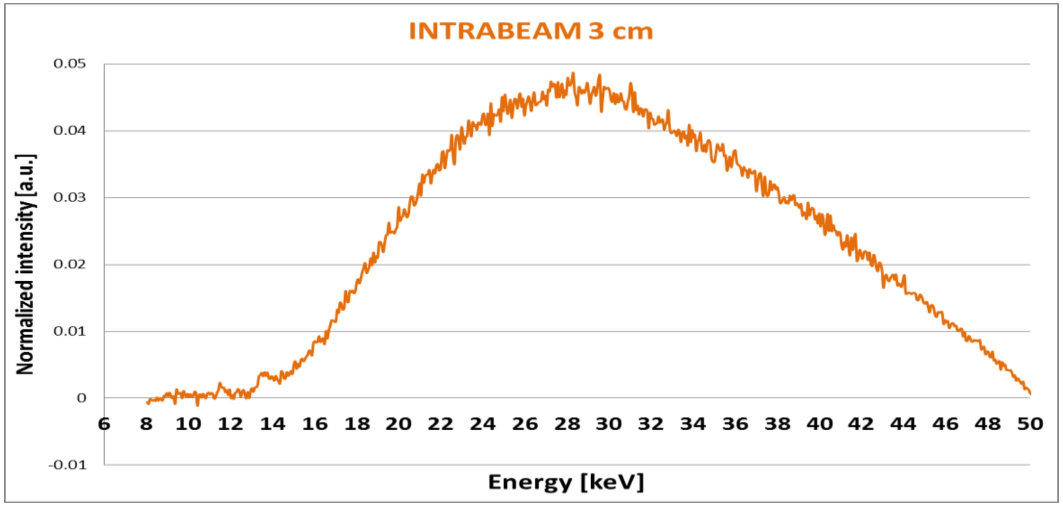

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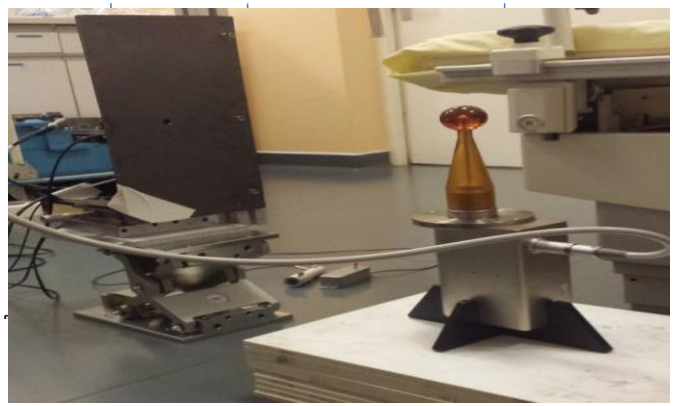

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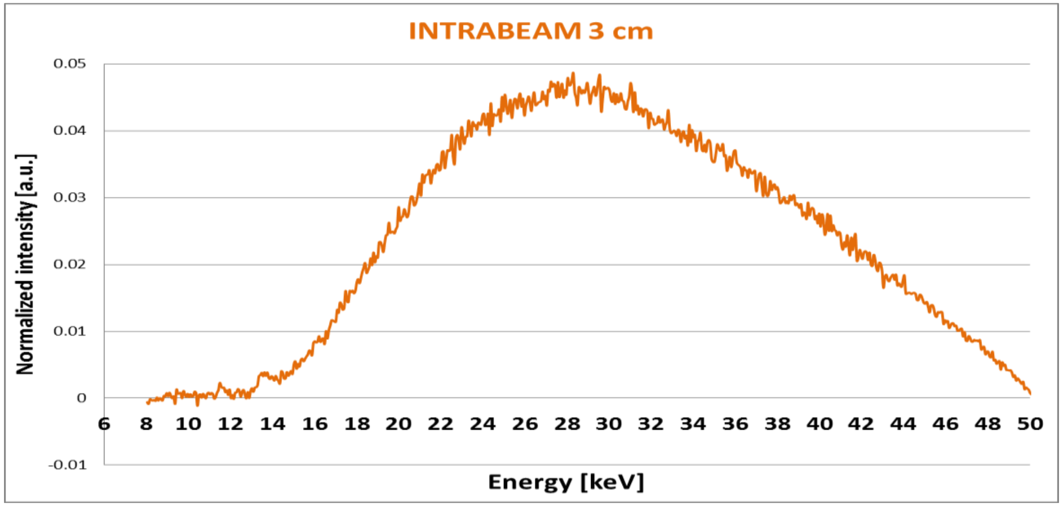

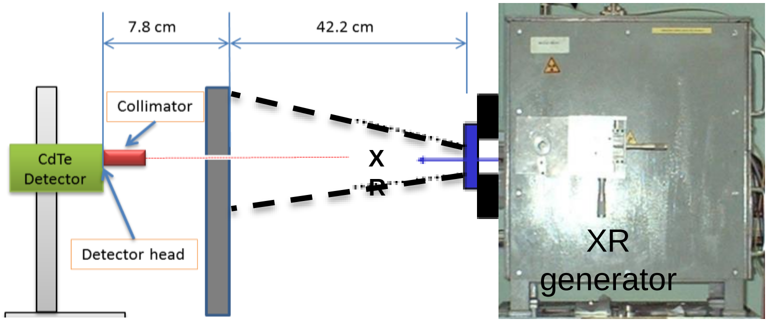

Reproduction of INTRABEAM spectra with the XR generator with 1.75 mm Al filter

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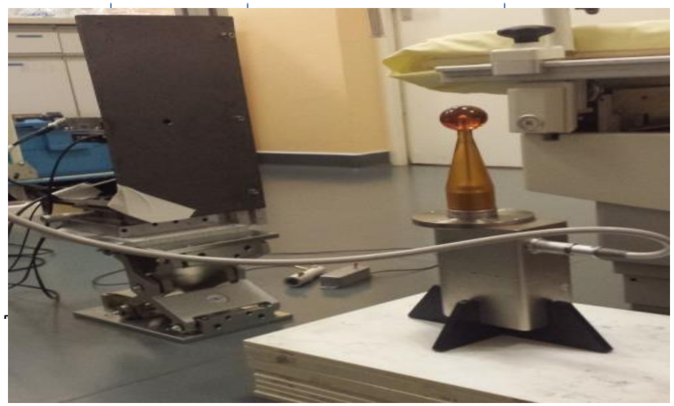

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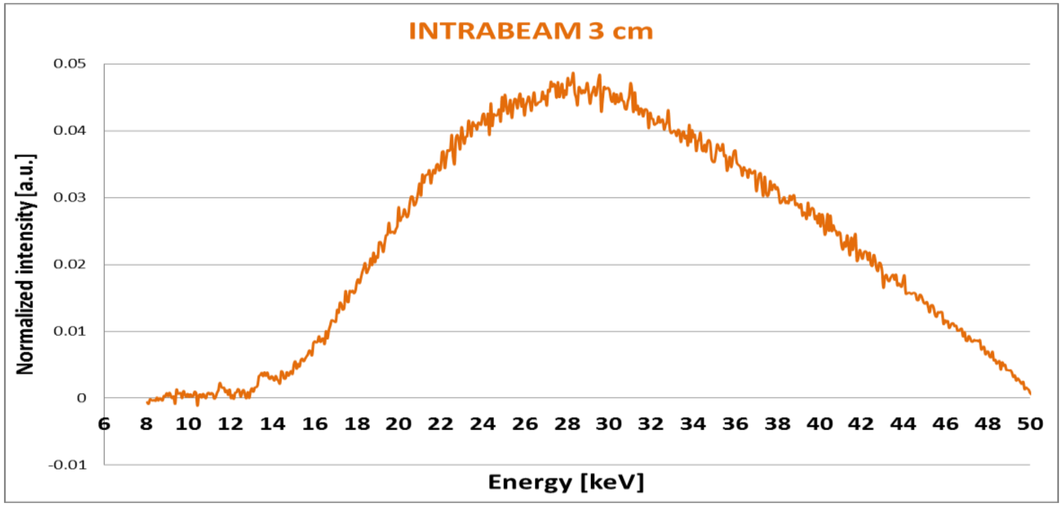
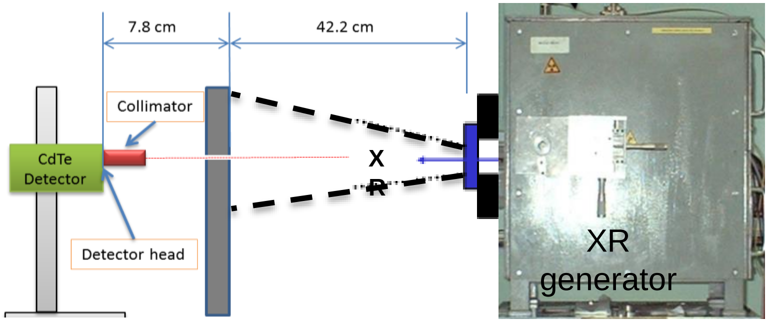
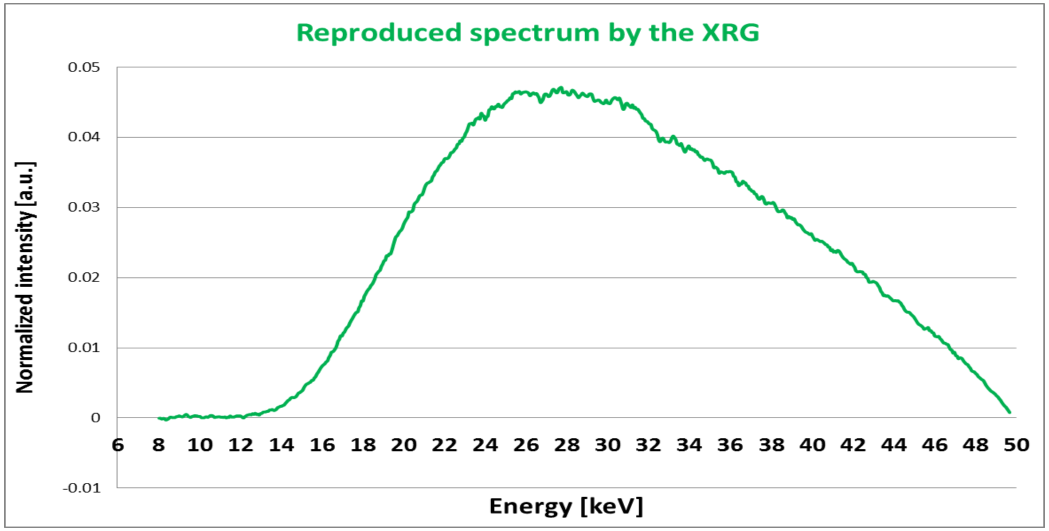




Reproduction of INTRABEAM spectra with the XR generator with 1.75 mm Al filter



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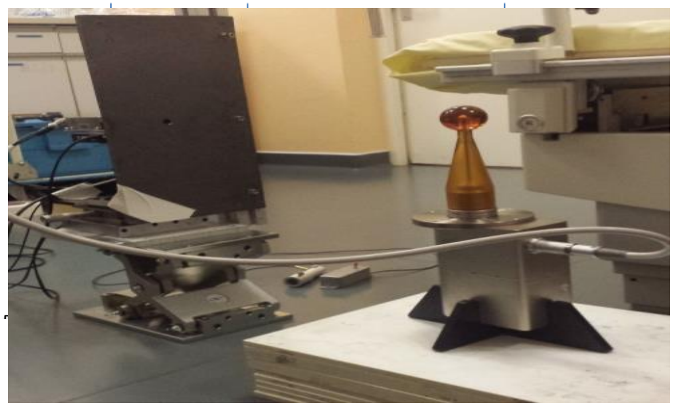

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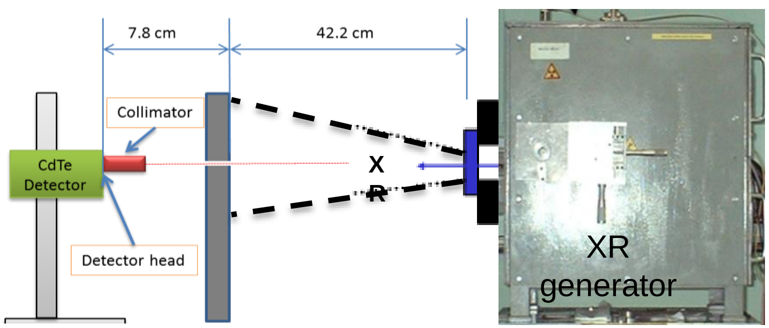

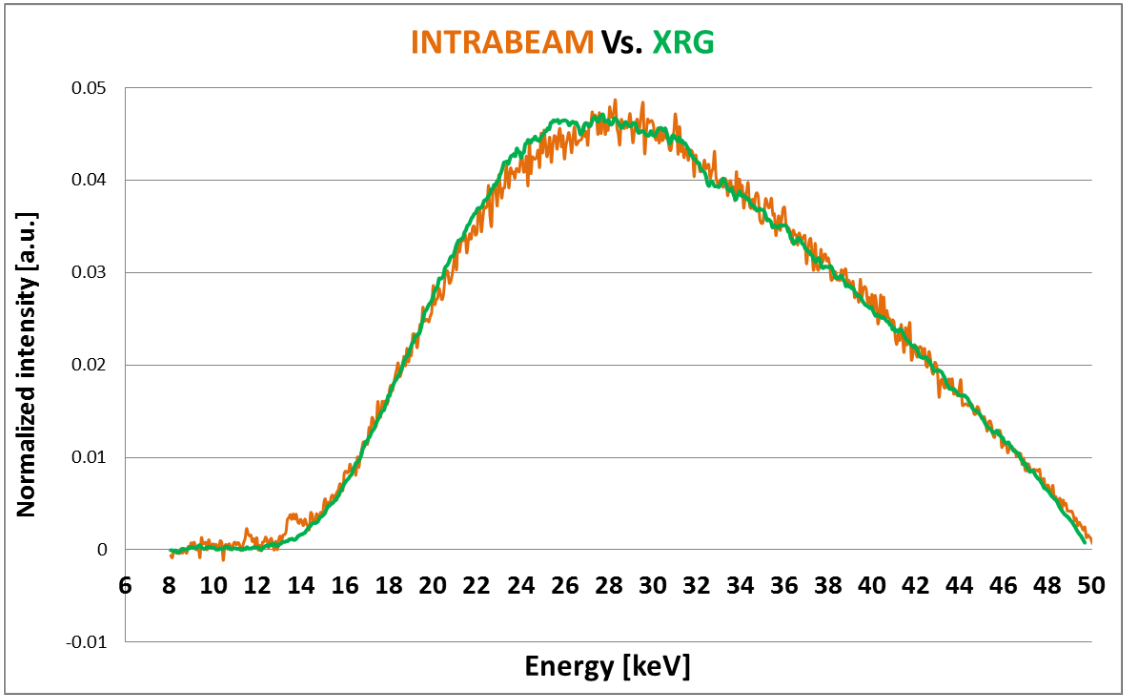

Reproduction of INTRABEAM spectra with the XR generator with 1.75 mm Al filter

VALIDATION OF REPRODUCED SPECTRA

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$$K_{air,norm} = \sum \left[\frac{\phi(E)}{[\sum \phi(E)\, \Delta E]} . \left(\frac{\mu_{tr}(E)}{\rho} \right)_{air} . E. \Delta E \right]$$

Normalized air kerma, $K_{air,norm}$ ➔ To validate the agreement between the two spectra by quantifying the total normalized air kerma of each spectrum.

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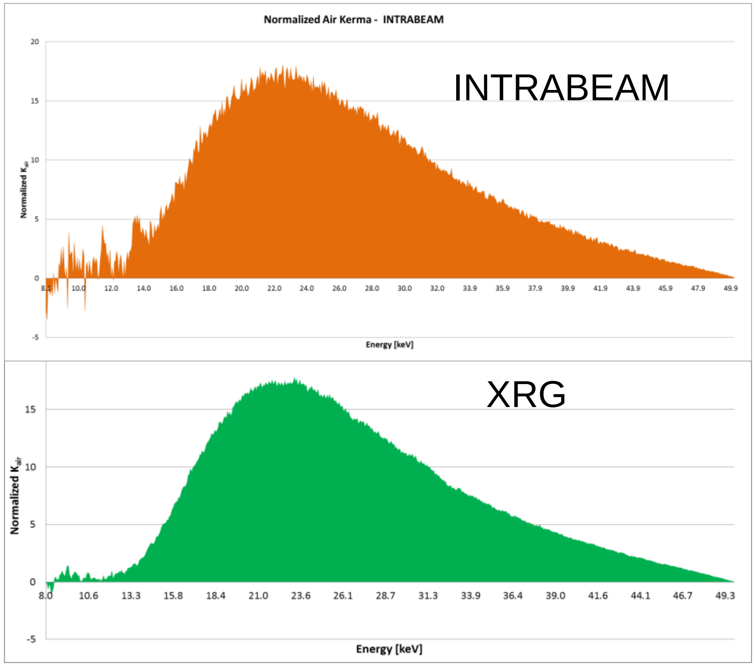

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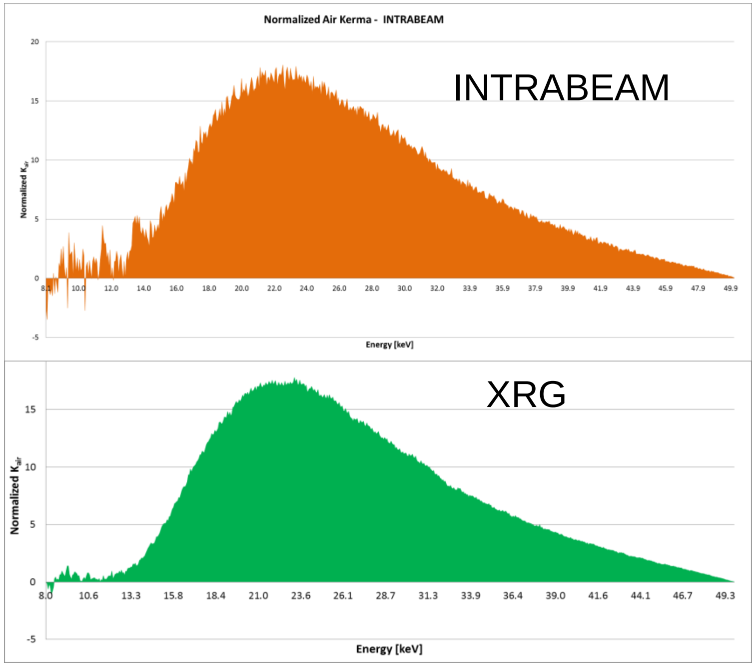

3 cm spherical applicator	
$\frac{K_{air,norm}(XRG)}{K_{air,norm}(INTRABEAM)}$	0.40 %

Establishment of the $\dot{K}_{air}$ standard

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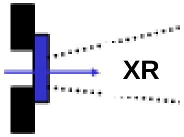

XR ≤ 50 keV
source

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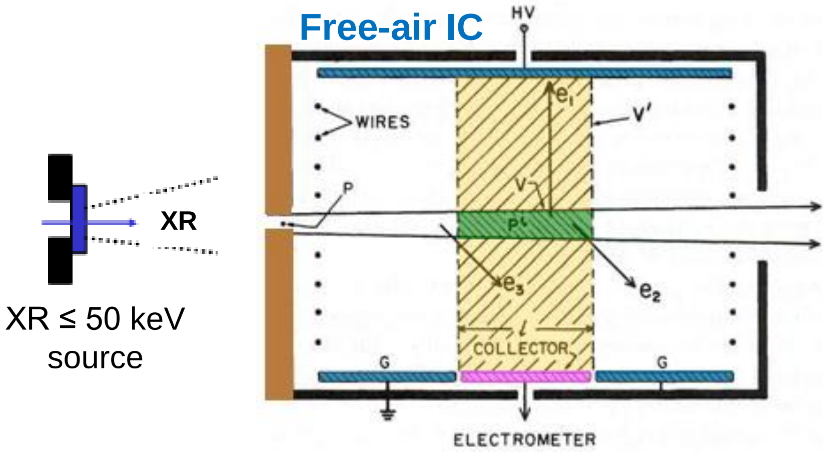

Establishment of the $\dot{K}_{air}$ standard

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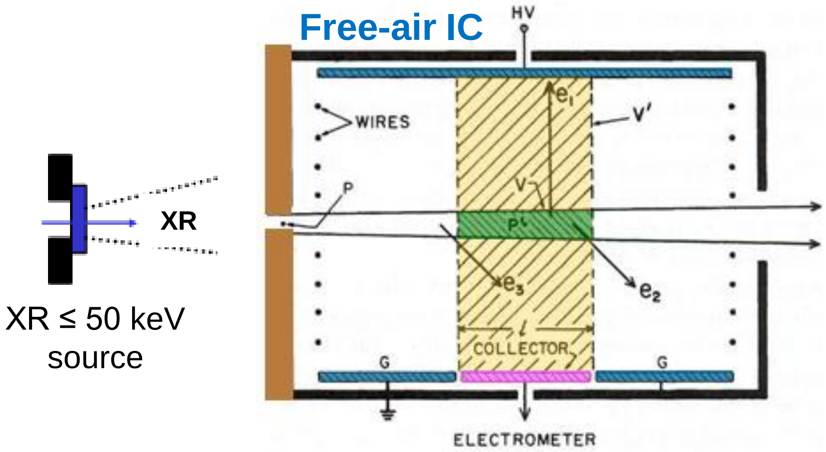

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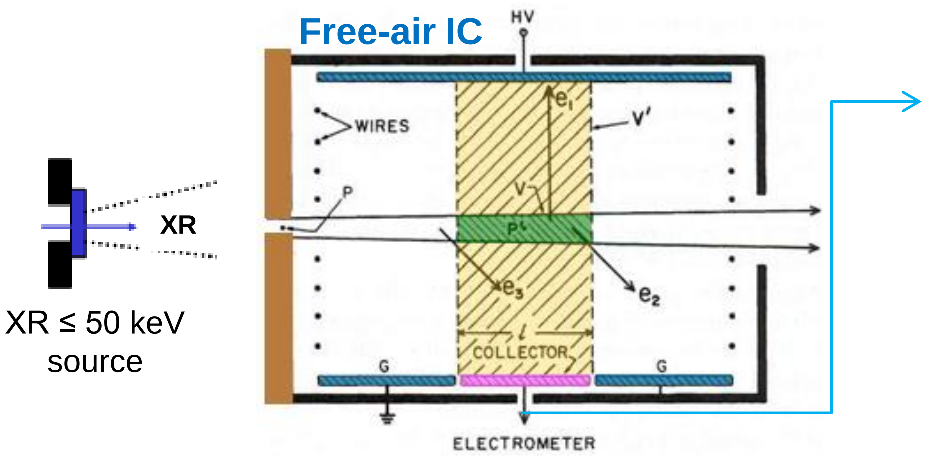

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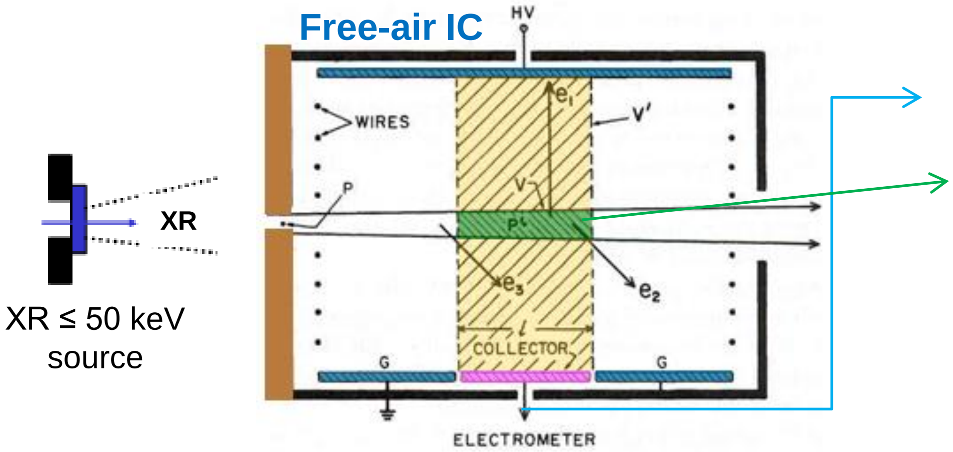

I: Measured current (A)

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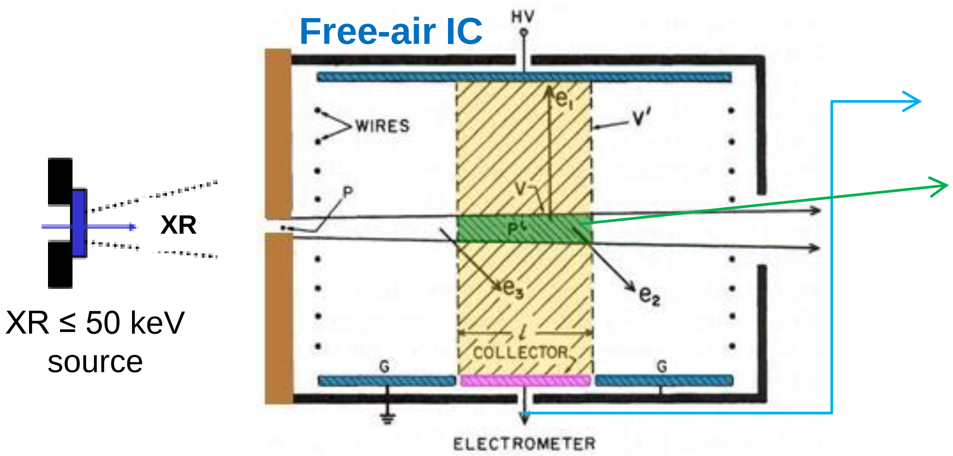

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Physical parameters:

ρ_0; Air density, $\frac{W_{air}}{e}$; Avg. Energ. Of ion-pair creation, …

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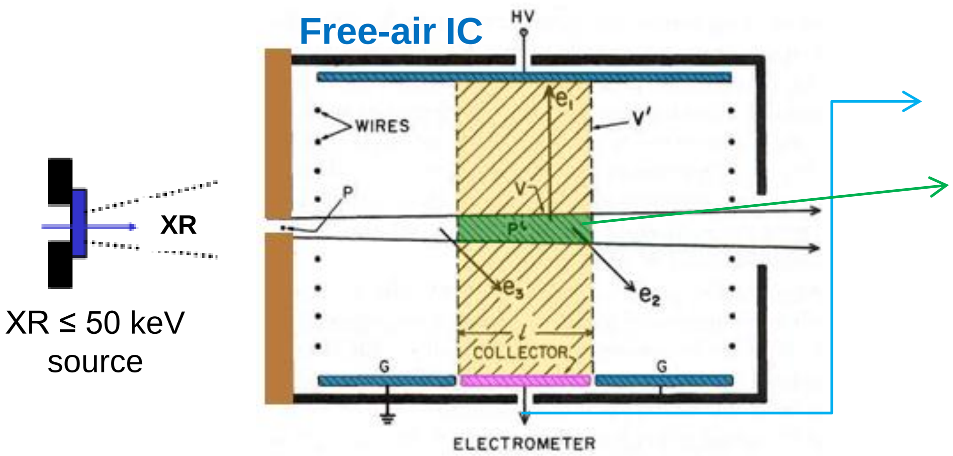

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Correction factors

$\prod_i k_i = \boldsymbol{k_{sc}}.\boldsymbol{k_a}.\boldsymbol{k_l}.k_{pol}.k_s$ ...

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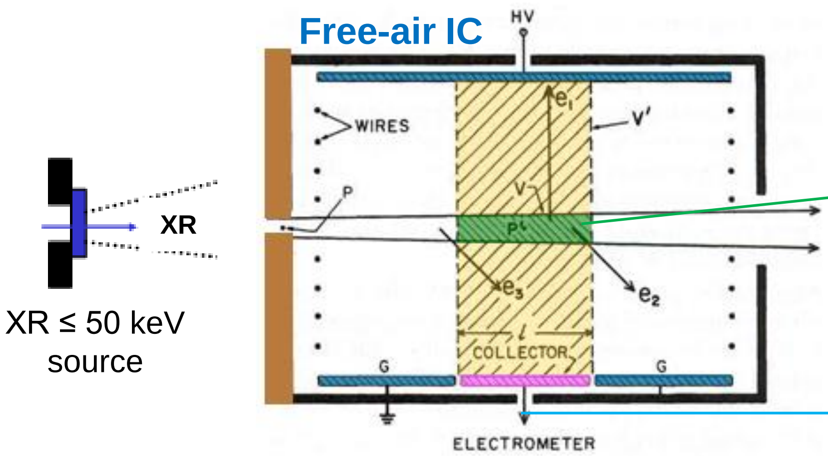

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$$\prod_i k_i = \boldsymbol{k_{sc}}.\boldsymbol{k_a}.\boldsymbol{k_l}.k_{pol}.k_s \ldots$$

$\boldsymbol{k_{sc}}$: Scattered radiation

$\boldsymbol{k_a}$: Air attenuation

$\boldsymbol{k_l}$: Aperture transmission

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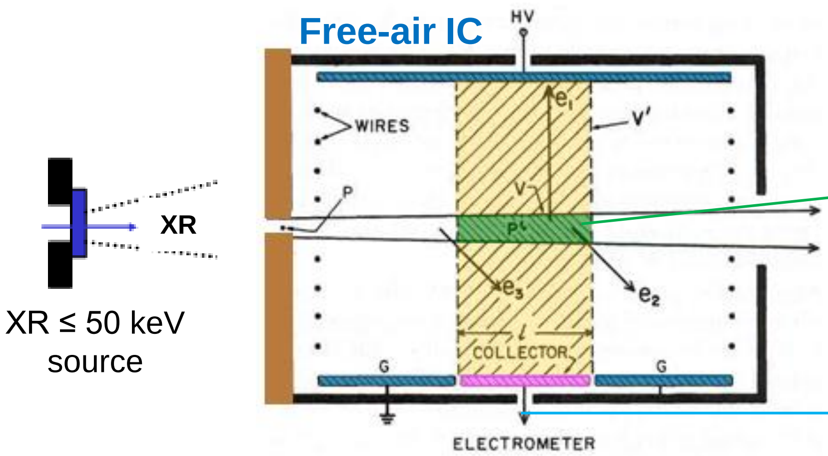

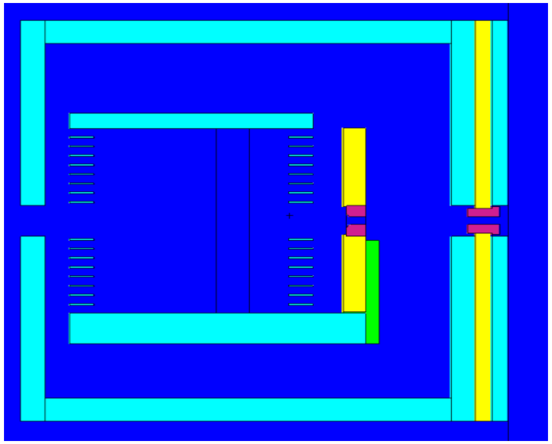

Monte carlo simulation

I: Measured current (A)

V: Interaction Volume

Physical parameters:

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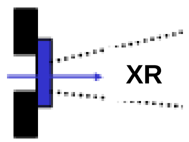
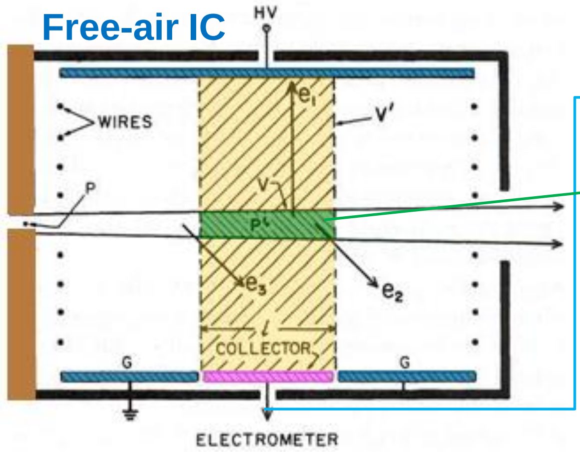
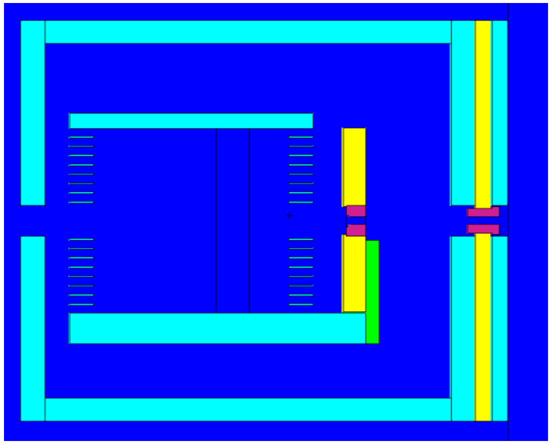
Establishment of the $\dot{K}_{air}$ standard

$$\dot{K}_{air} = \frac{I}{V.\rho_0}.\frac{W_{air}}{e}.\frac{1}{(1-g_{air})}.\prod_i k_i$$







Monte carlo simulation

I: Measured current (A)

V: Interaction Volume

Physical parameters:

ρ_0; Air density, $\frac{W_{air}}{e}$; Avg. Energ. Of ion-pair creation, …

Correction factors

$\prod_i k_i = \boldsymbol{k_{sc}}.\boldsymbol{k_a}.\boldsymbol{k_l}.k_{pol}.k_s$ ...

$\boldsymbol{k_{sc}}$: Scattered radiation

$\boldsymbol{k_a}$: Air attenuation

$\boldsymbol{k_l}$: Aperture transmission

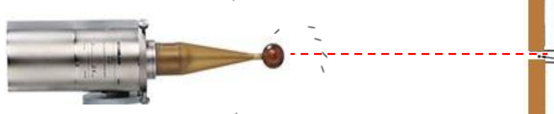
CALIBRATION OF HOSPITALS/INSTITUTES READING CHAMBERS

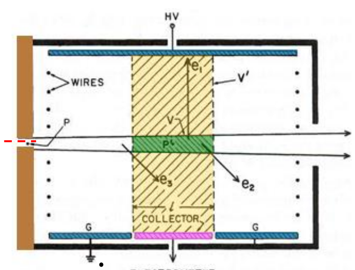
CALIBRATION OF HOSPITALS/INSTITUTES READING CHAMBERS

In Hospitals

CALIBRATION OF HOSPITALS/INSTITUTES READING CHAMBERS

In Hospitals

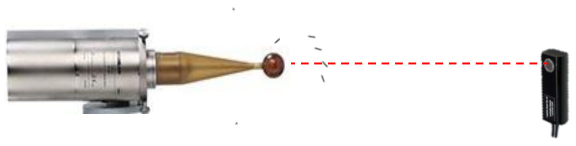




$\dot{K}_{air,hosp}$

CALIBRATION OF HOSPITALS/INSTITUTES READING CHAMBERS

In Hospitals

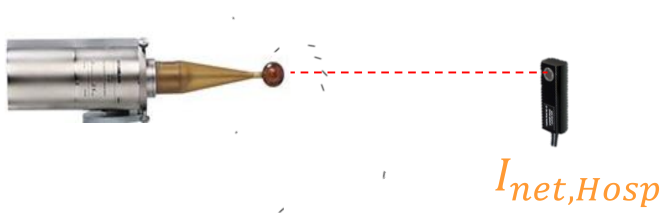


$I_{net,Hosp}$

CALIBRATION OF HOSPITALS/INSTITUTES READING CHAMBERS

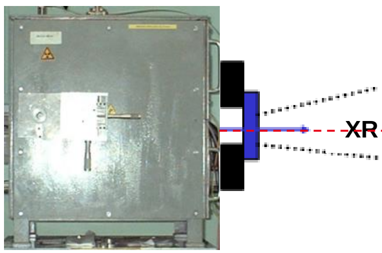
In LNHB Laboratory

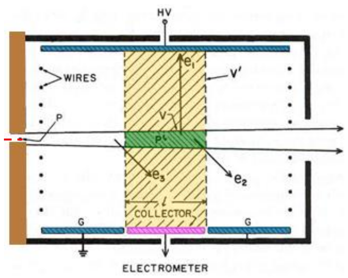
In Hospitals



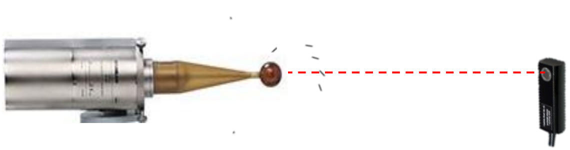
CALIBRATION OF HOSPITALS/INSTITUTES READING CHAMBERS

In LNHB Laboratory





In Hospitals



$I_{net,Hosp}$

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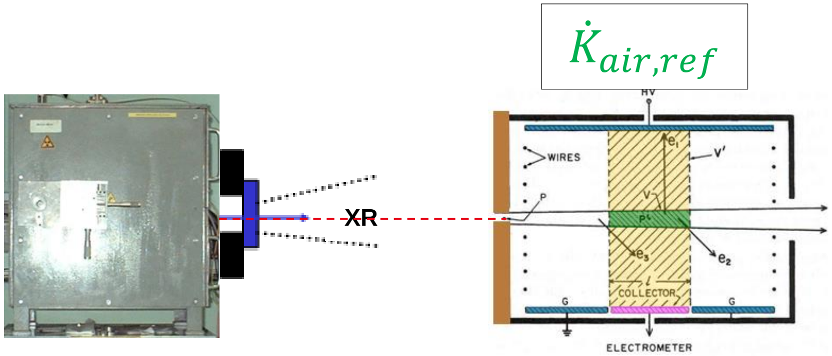
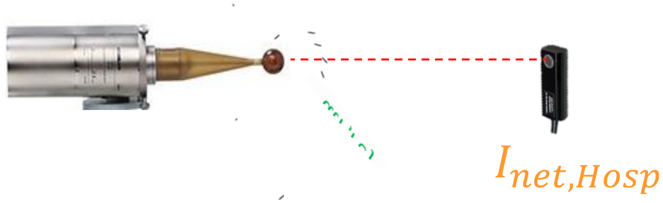


In Hospitals



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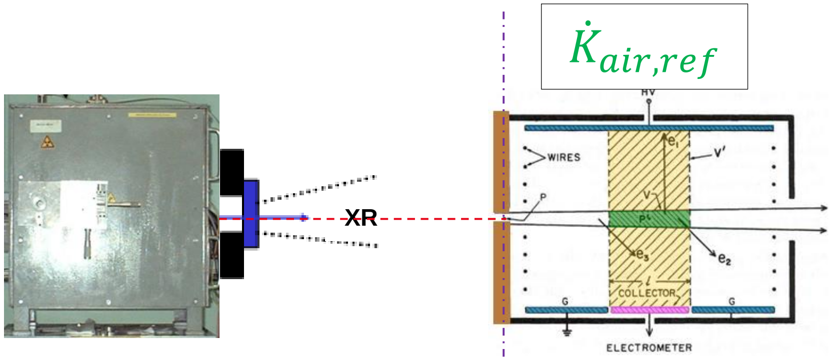
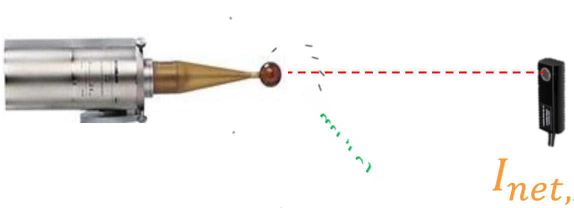


In Hospitals

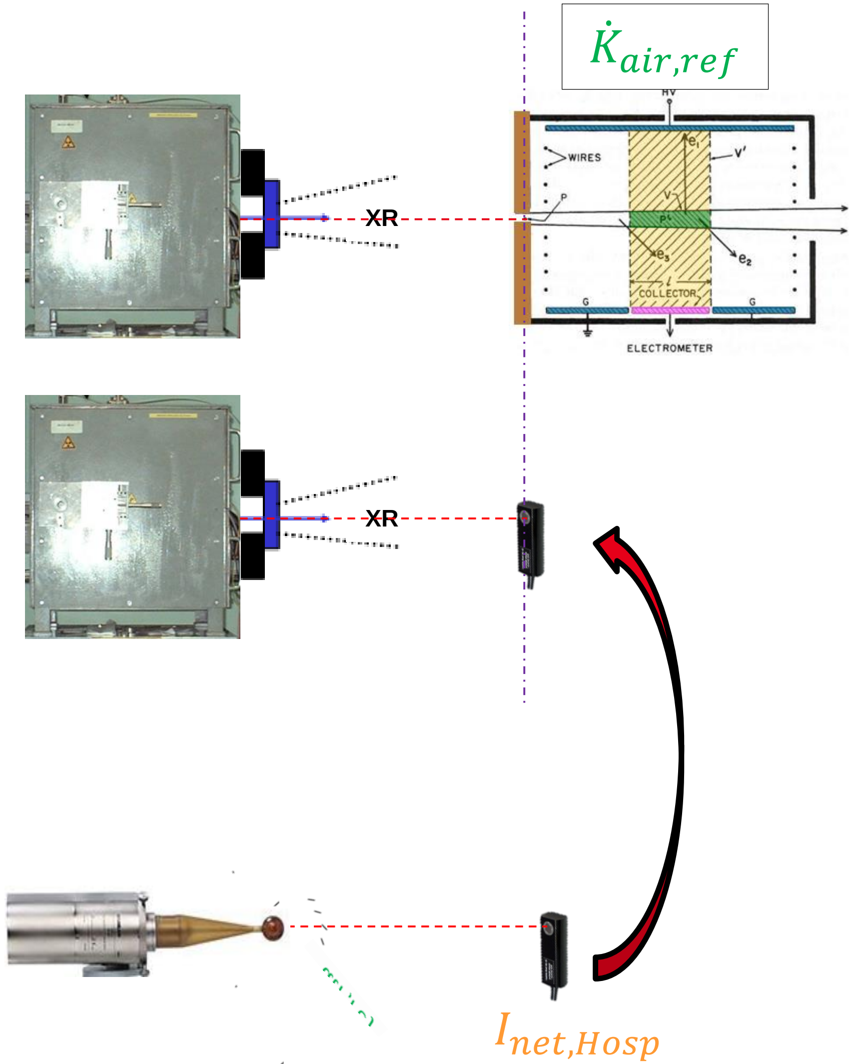


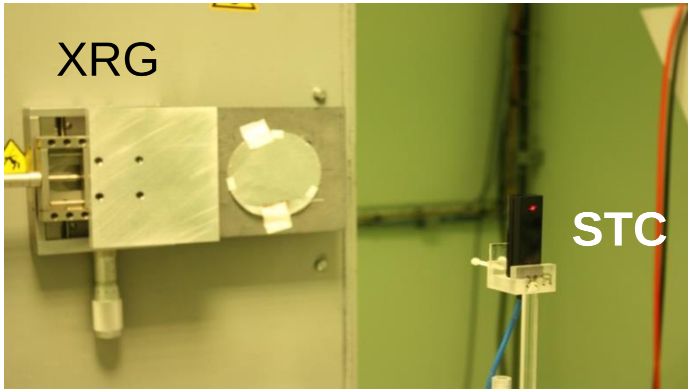
$I_{net,Hosp}$

CALIBRATION OF HOSPITALS/INSTITUTES READING CHAMBERS

In LNHB Laboratory

In Hospitals





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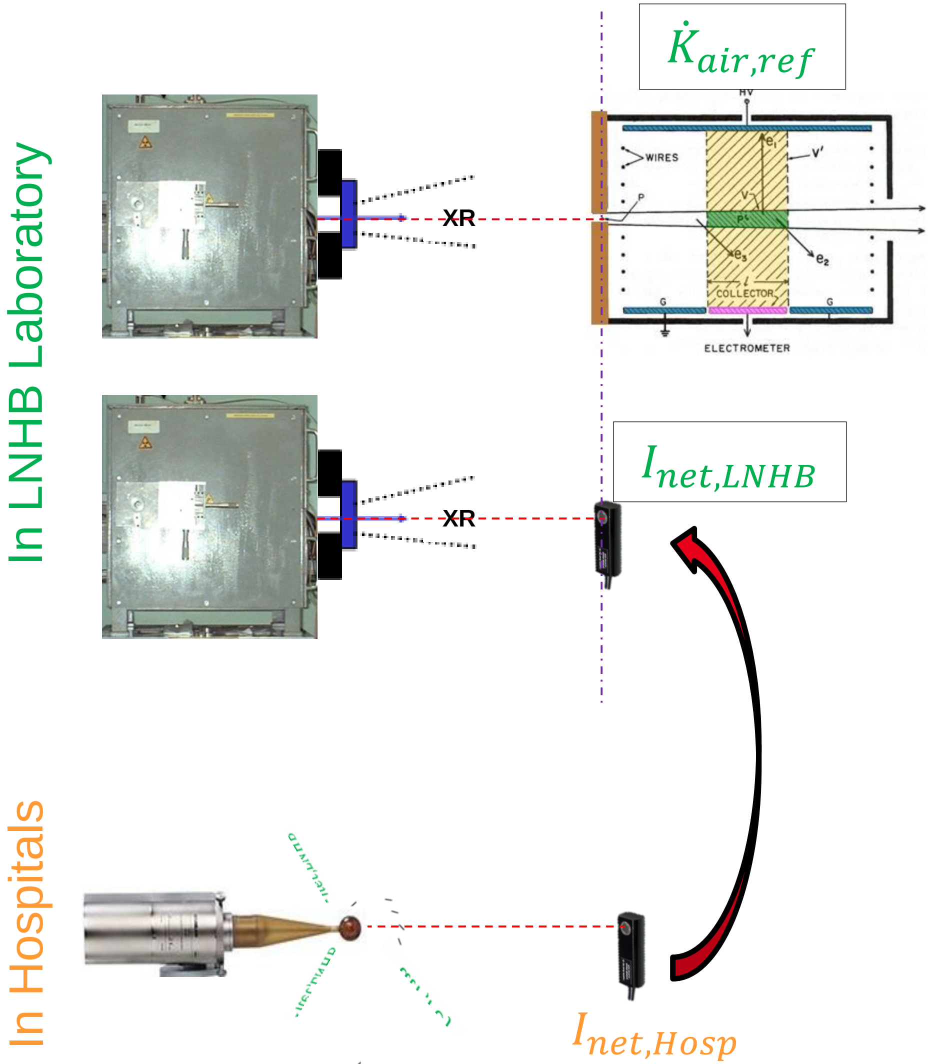
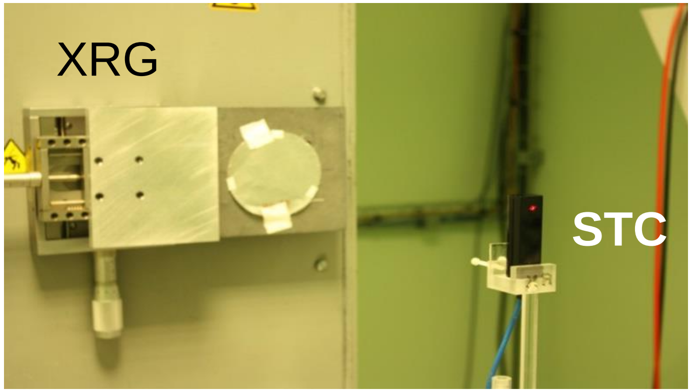
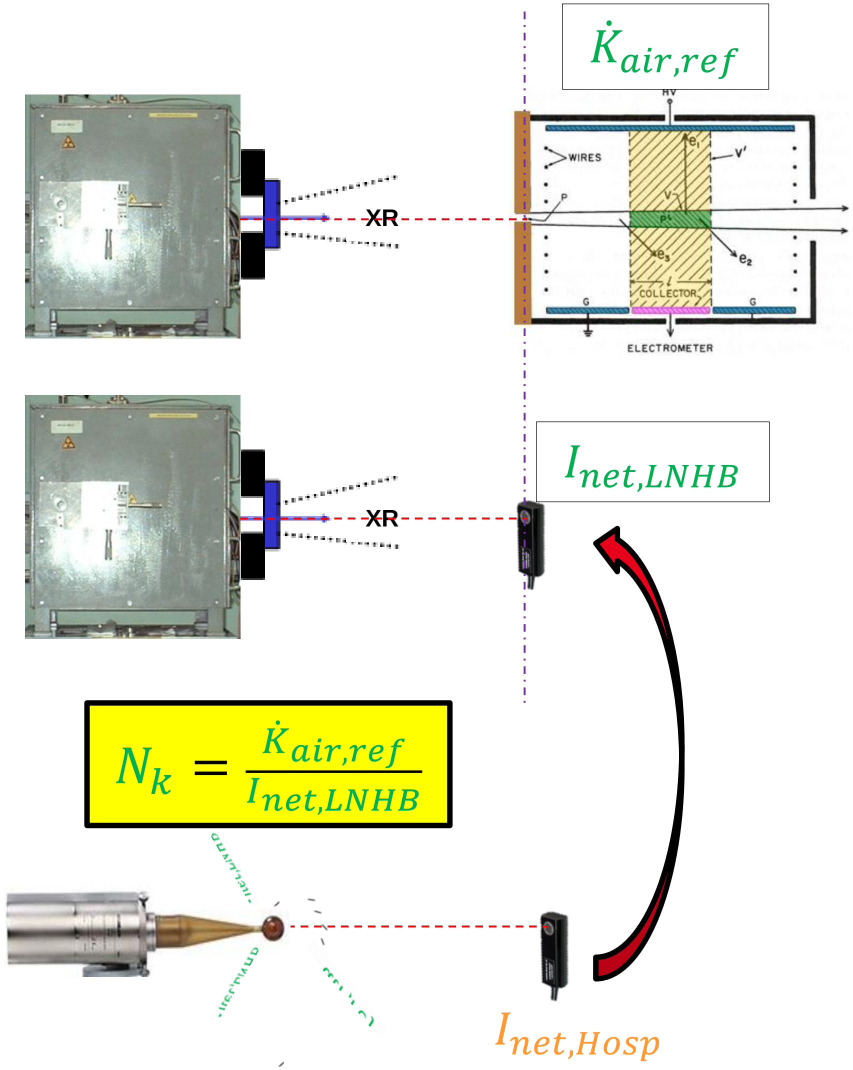




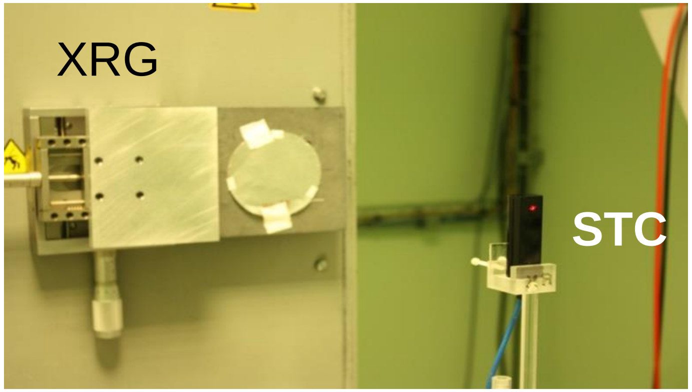
CALIBRATION OF HOSPITALS/INSTITUTES READING CHAMBERS

In LNHB Laboratory

In Hospitals



$$N_k = \frac{\dot{K}_{air,ref}}{I_{net,LNHB}}$$



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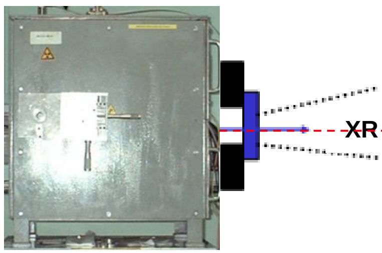
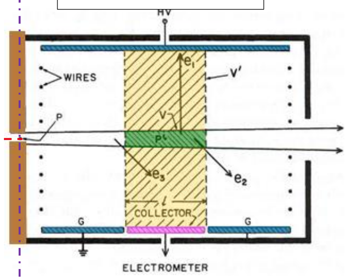
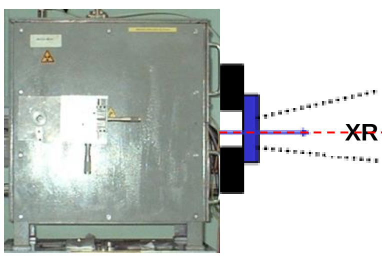
In LNHB Laboratory



$\dot{K}_{air,ref}$



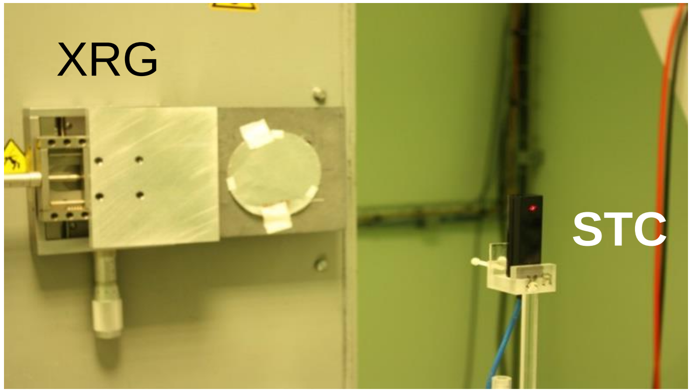


$I_{net,LNHB}$

$$N_k = \frac{\dot{K}_{air,ref}}{I_{net,LNHB}}$$

In Hospitals

$I_{net,Hosp}$

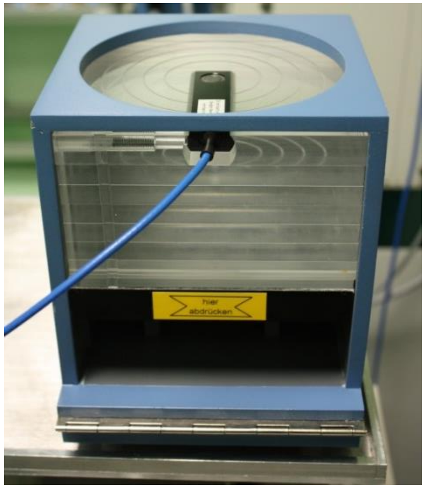


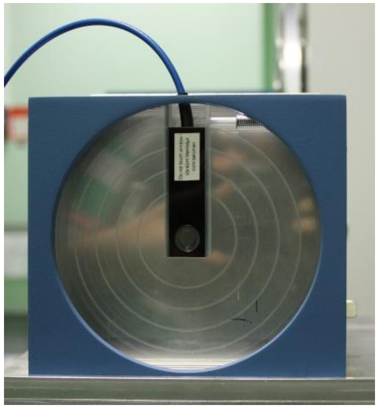
$$\dot{K}_{air,hosp} = I_{net,Hosp} \times N_k$$

DEPTH DOSE PROFILE DETERMINATION:

DEPTH DOSE PROFILE DETERMINATION:

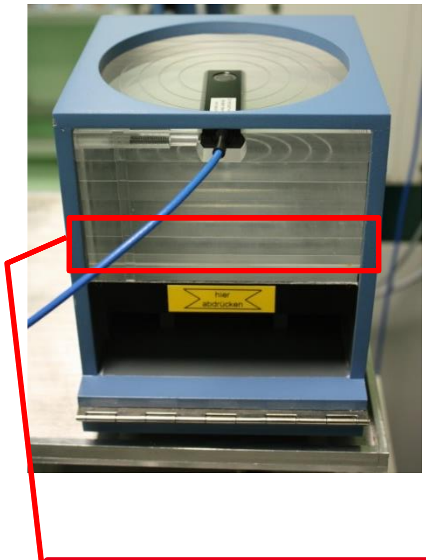
First approach to the D_w

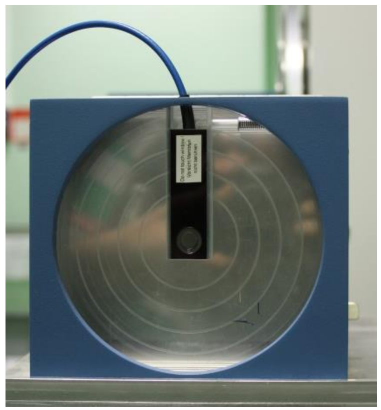




DEPTH DOSE PROFILE DETERMINATION:

First approach to the D_w





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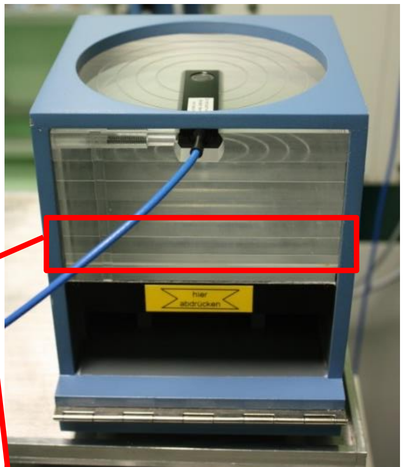
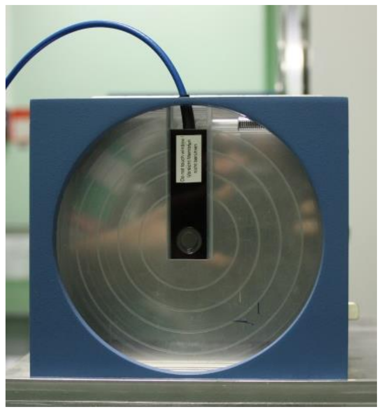
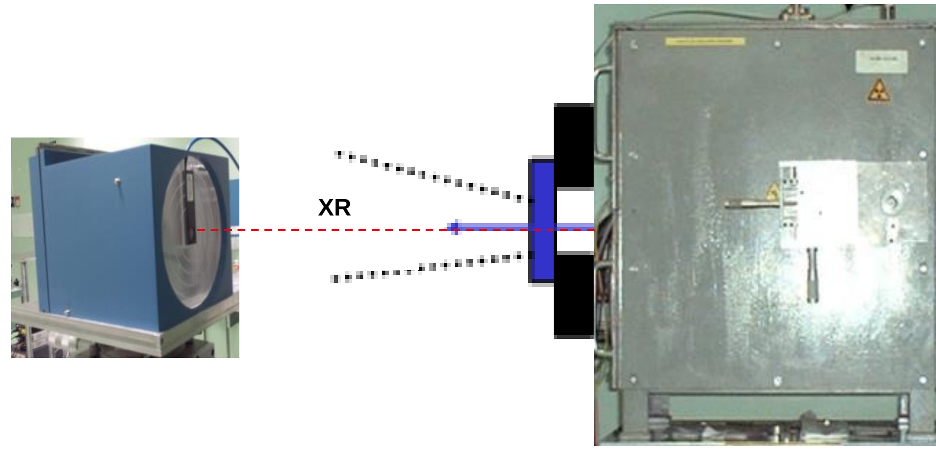
First approach to the D_w

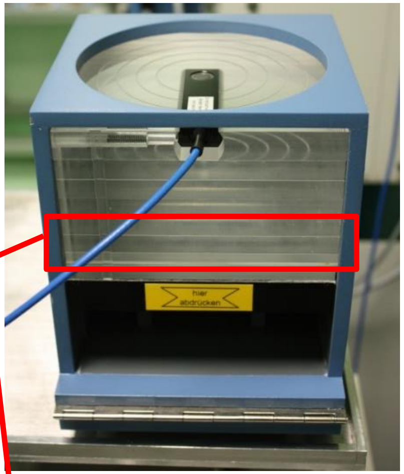


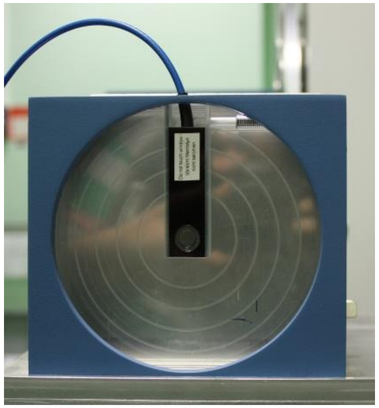


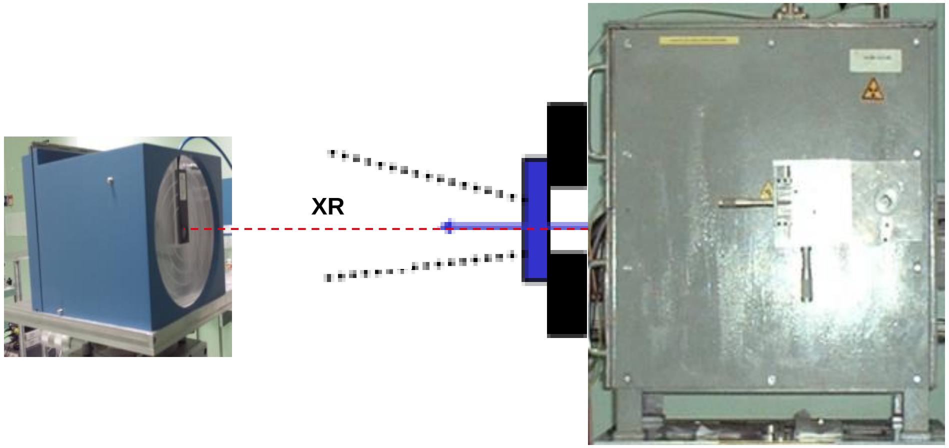


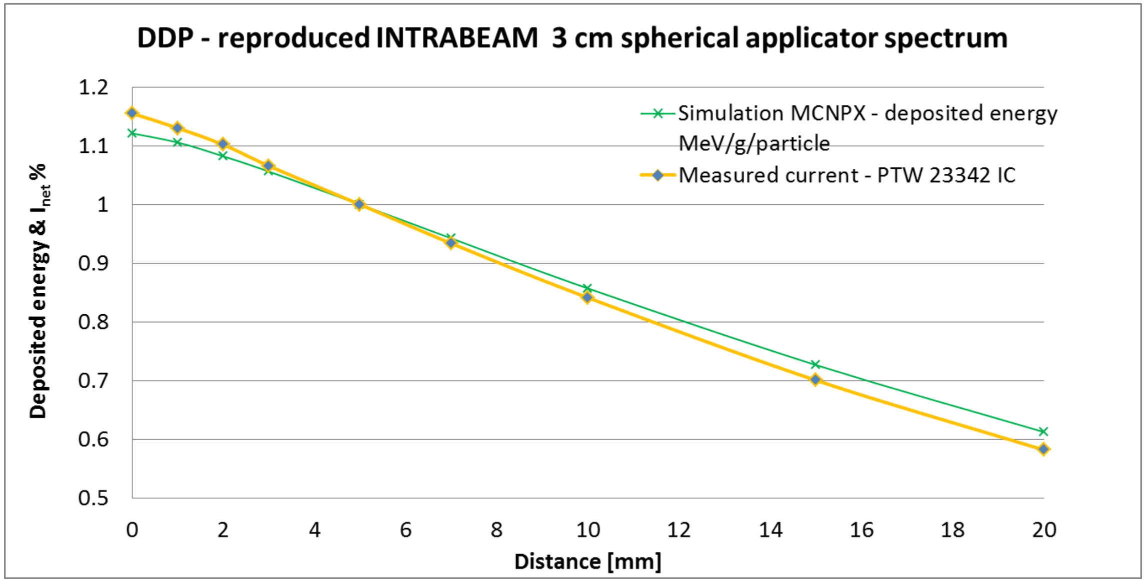
DEPTH DOSE PROFILE DETERMINATION:

First approach to the D_w





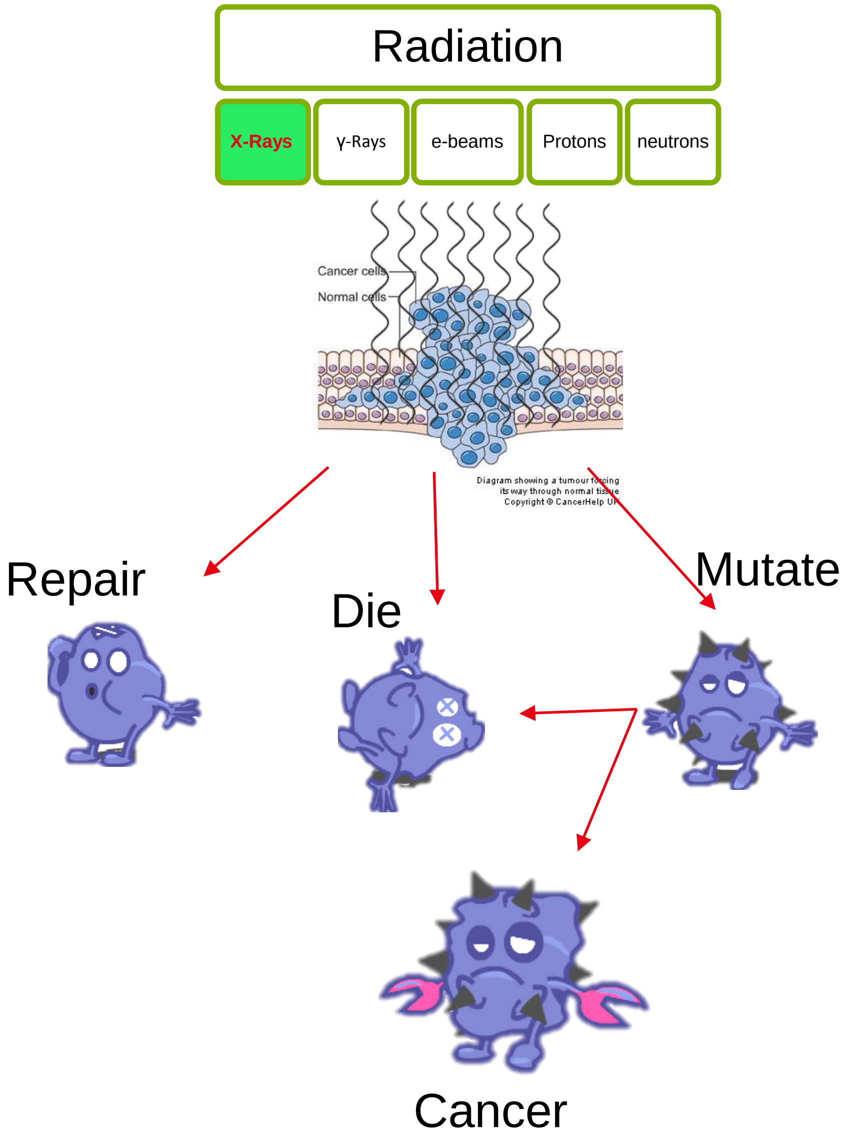




CONCLUSIONS AND PERSPECTIVES

- **Two INTRABEAM spectra were reproduced at LNHB by standard x-ray generator.**
- **The air kerma standard was established.**
- **A transfer ionization chamber was calibrated in terms of $\dot{K}_{air}$.**
- **The calibrated transfer ionization chamber was used to determine the depth dose profiles → Further analysis of the depth dose profile should be done due to an important difference between measurements and MC simulations.**
- **The rest of INTRABEAM applicators are to be studied in the same way.**


Thank
You


Radiation
X-Rays
γ-Rays
e-beams
Protons
neutrons
Cancer cells
Normal cells
Diagram showing a tumour forcing its way through normal tissue
Copyright © CancerHelp UK
Repair
Die
Mutate
Cancer

- A **calibration**, by contrast and as defined by ISO10012 is, “The set of operations which establish under specified conditions the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure or reference material, and the corresponding value of a quantity realized by a reference standard.”
- A **reference standard**, according to ISO/BIPM/OIML, is, “A standard, generally of the highest metrological quality at a given location, from which measurements made at that location are derived.”
- A **primary standard** is operationally defined by ISO10012 as, “A standard which provides a magnitude or value of the highest accuracy (lowest) uncertainty in a given metrology discipline, for a given parameter or quantity.”
- a **measurement standard** and ISO10012 defines that as, “A material measure, measuring instrument, reference standard, material or system intended to define, realize, conserve or reproduce a unit or one or more values of quantity in order to transmit them to other measuring instruments by comparison.”

RADIOTHERAPY

- Radiotherapy uses radiation, such as x-rays, gamma rays, electron beams or protons, to kill or damage cancer cells and stop them from growing and multiplying. It is a localized treatment, which means it generally only affects the part of the body where the radiation is directed
- Radiotherapy damages cancer cells in the region being treated. Although the radiation can also damage normal cells, they can usually repair themselves. During this repair process, you may experience some side effects, depending on the part of your body being treated.
- Depending on the type and size of the cancer, and where it is in your body, you may have one or both types of radiotherapy.
- Radiotherapy uses radiation to kill or damage cancer cells and stop them from growing and multiplying.
- Treatment also affects normal cells, but they are better able to repair themselves.
- Radiotherapy is used to treat cancer, slow its growth or relieve symptoms.
- You may have treatment in hospital or at a clinic. Most people have outpatient treatment – this means they come to each treatment session without staying in hospital.
- Radiotherapy can be given by a variety of machines and devices, depending on which part of the body is affected, and the type and stage of the tumor. The two main types are external and internal (brachytherapy or radioisotope) radiotherapy.

Contexte

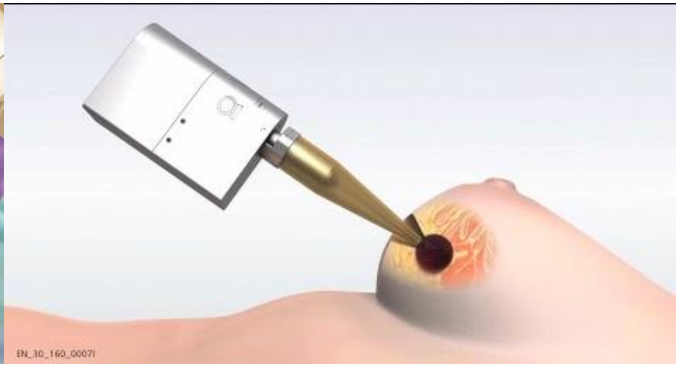
NUCLEAR SAFETY AUTHORITY (ASN) REPORT 2012

- In France, a dozen of INTRABEAM® systems were installed since 2011.
- A call for project by the French national cancer institute (INCa) ➔ Installation of intraoperative radiotherapy systems ➔ breast cancer.
- One of the main objects is to reduce the treatment time

NEED : NUCLEAR PHYSICISTS REQUEST

- The medical physicists have just the dose distributions data provided by the INTRABEAM's manufacturer.
- This data should be validated by an independent party; it calibtrate the beams and determine the dose distribution.

THE INTRABEAM SYSTEM



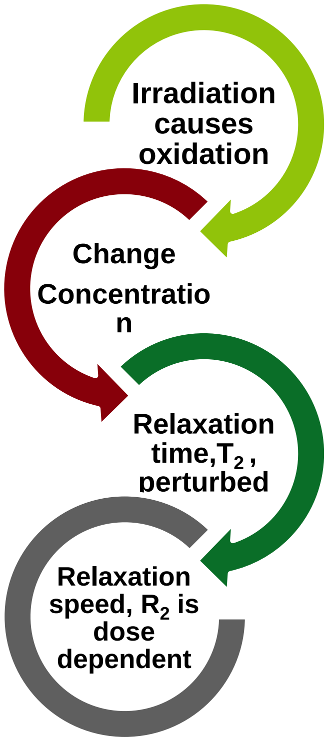
Skin	Vertebral column Brain
	 

DOSIMETRIC GEL

It is a system to capture the dose information in 3D.

It has many advantages:

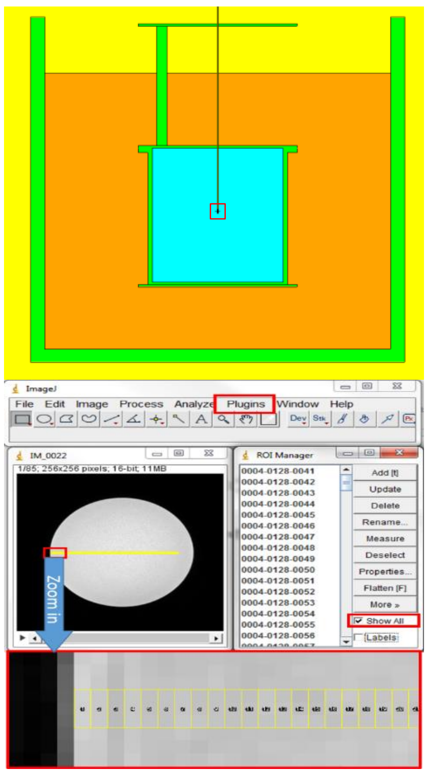
- Tissue equivalent (mostly water)
- Stabilize the dose information regarding the space and time aspects (no diffusion within the 5 hours following the irradiation).
- Could be shaped in different forms.

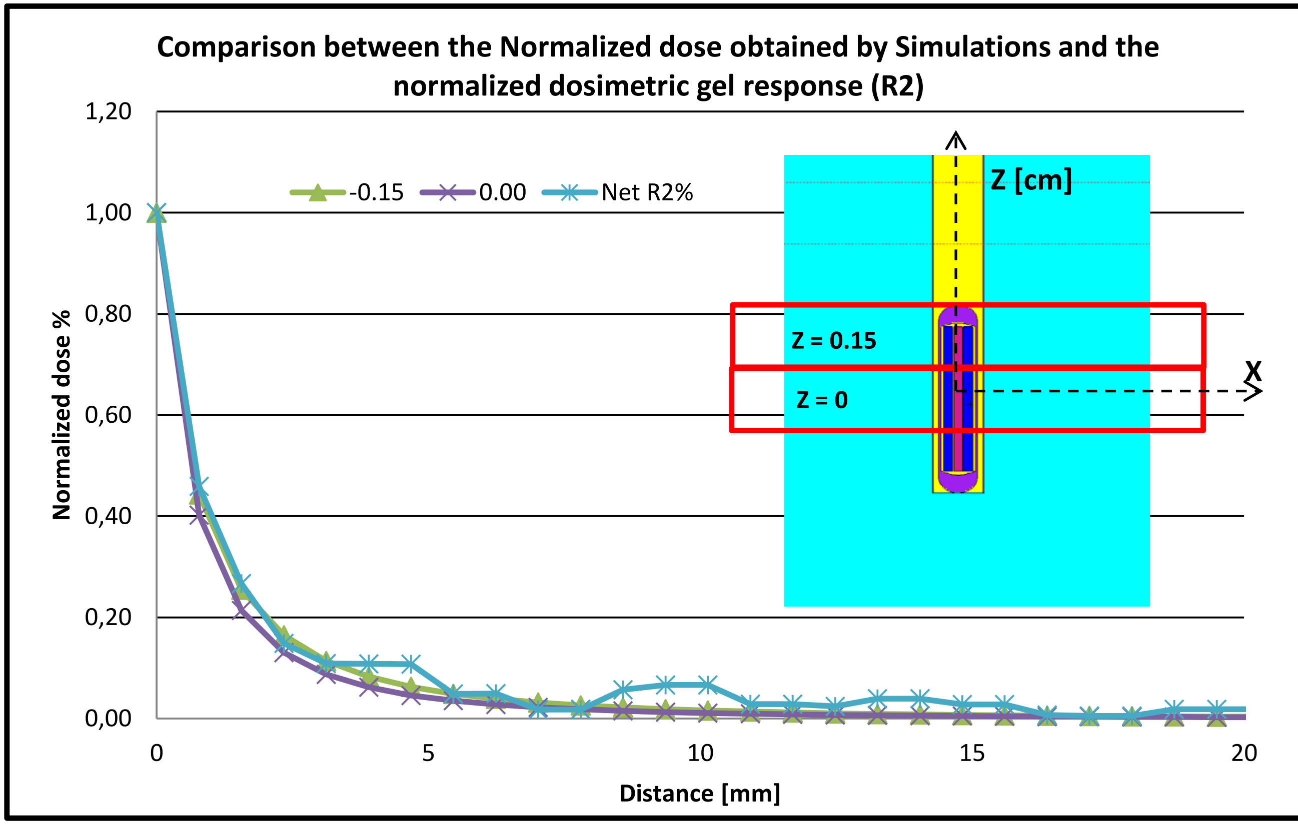


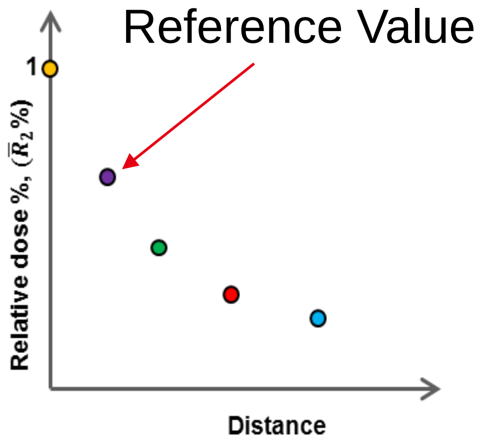
Reading by MRI

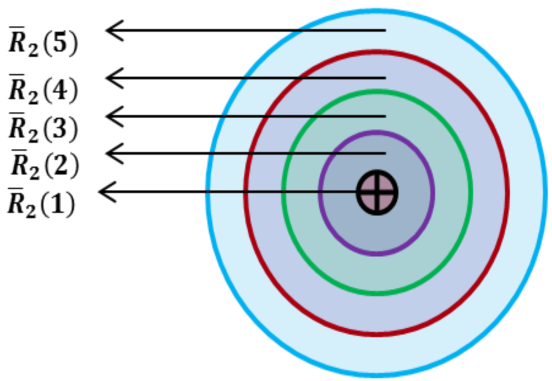
Determination of relative dose

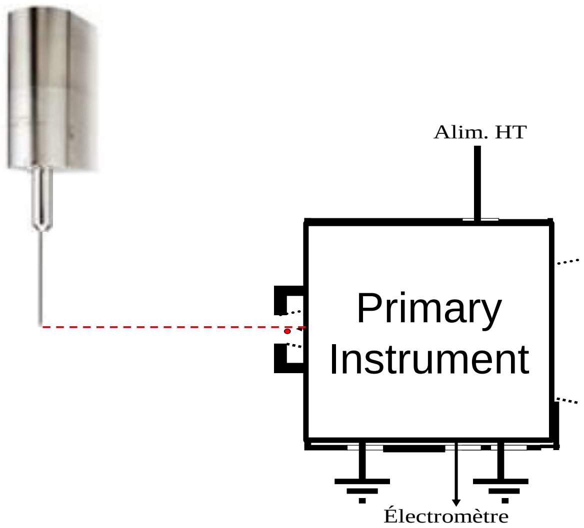
COMPARAISON MC SIMULATIONS VS. MEASUREMENTS






Reference Value
1
Relative dose %, $(\bar{R}_2\%)$
Distance


$\bar{R}_2(5)$
$\bar{R}_2(4)$
$\bar{R}_2(3)$
$\bar{R}_2(2)$
$\bar{R}_2(1)$


Alim. HT
Primary Instrument
Électromètre