Radiation biology, protection and applications

PHYS-450

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Radiation Protection Lectures

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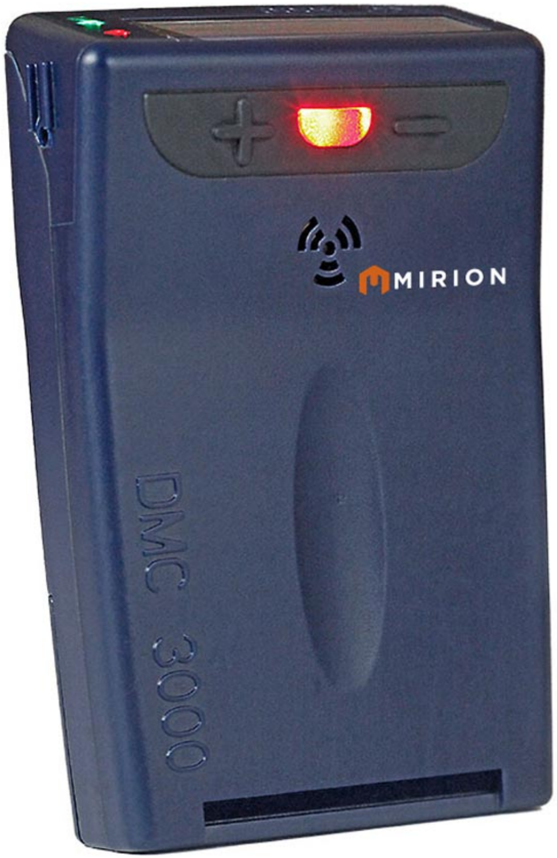
Objectives

- Become familiar with dosimetry and radiation measurements
- Understand the main concepts:
  - Definition of quantities
  - Interaction of radiation with biological systems
  - Radiation measurements (principles and use)

Objectives

- Differentiate between dosimetric quantities: absorbed dose, dose equivalent and effective dose.
- Explain the concept of effective dose.
- Apply measurement quantities to estimate the ambient dose equivalent near a radioactive source as well as the committed effective dose.

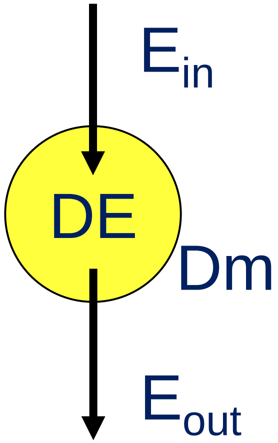
What's dosimetry?



Basic dosimetric quantities

Absorbed dose

- Basic **physical quantity:**
  - energy deposited per unit of mass
  - unit: gray (1 Gy = 1 J/kg)



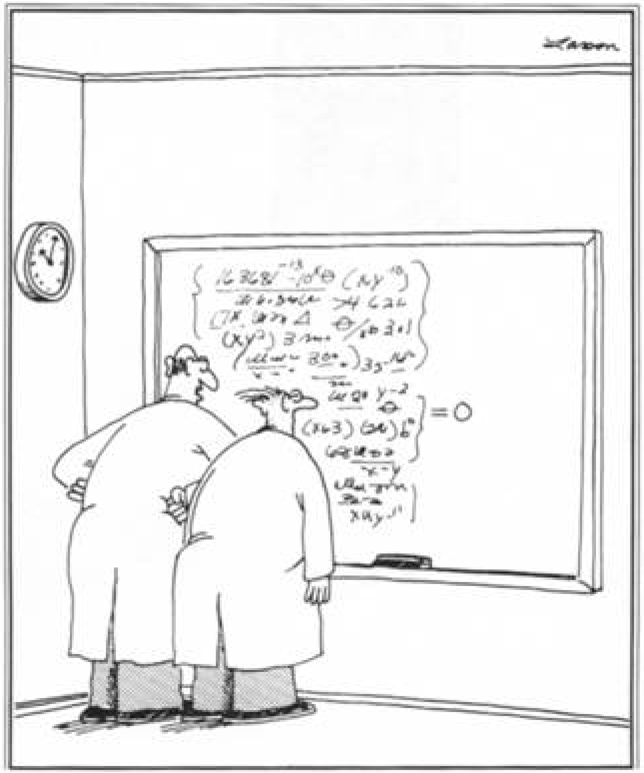
E_{in}

DE

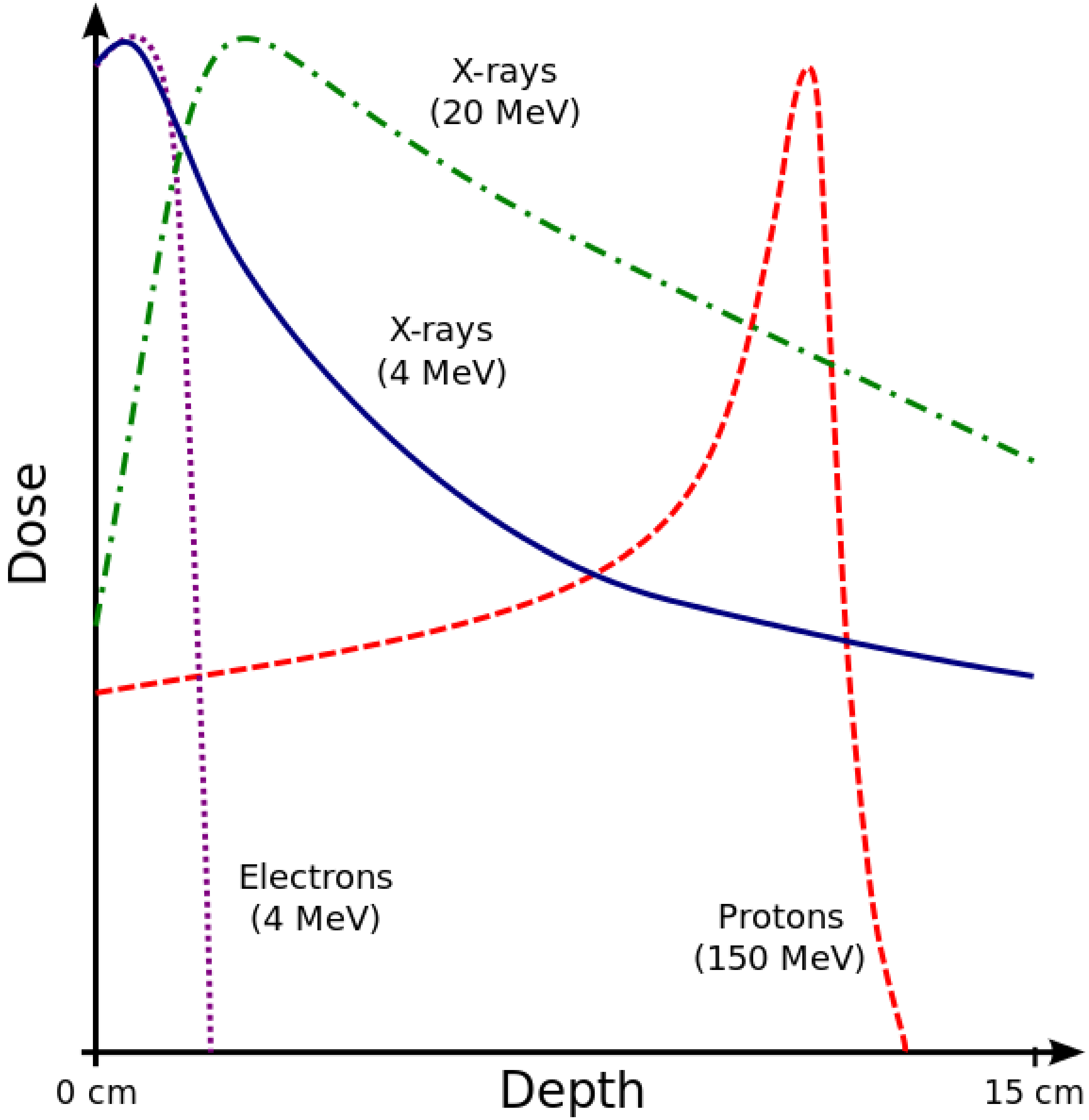
Dm

E_{out}

$$D = \lim_{\Delta m \to 0} \frac{\Delta E}{\Delta m}$$



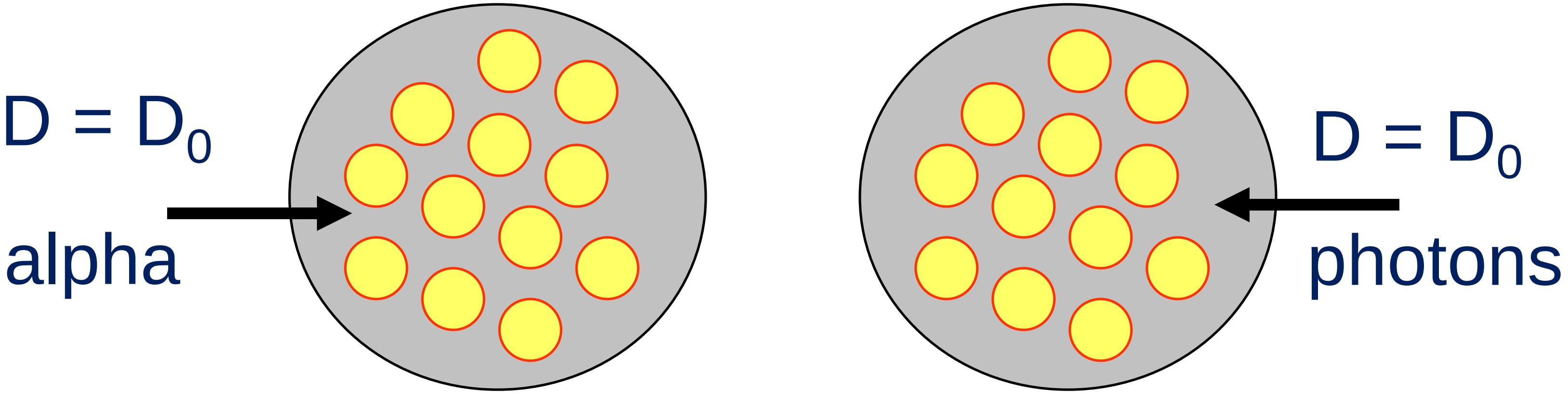
Absorbed dose



http://www.wikiwand.com/en/Particle_therapy

Question: dose and its biological effect

For a given absorbed dose, what kind of radiation is the most damaging?



$D = D_0$

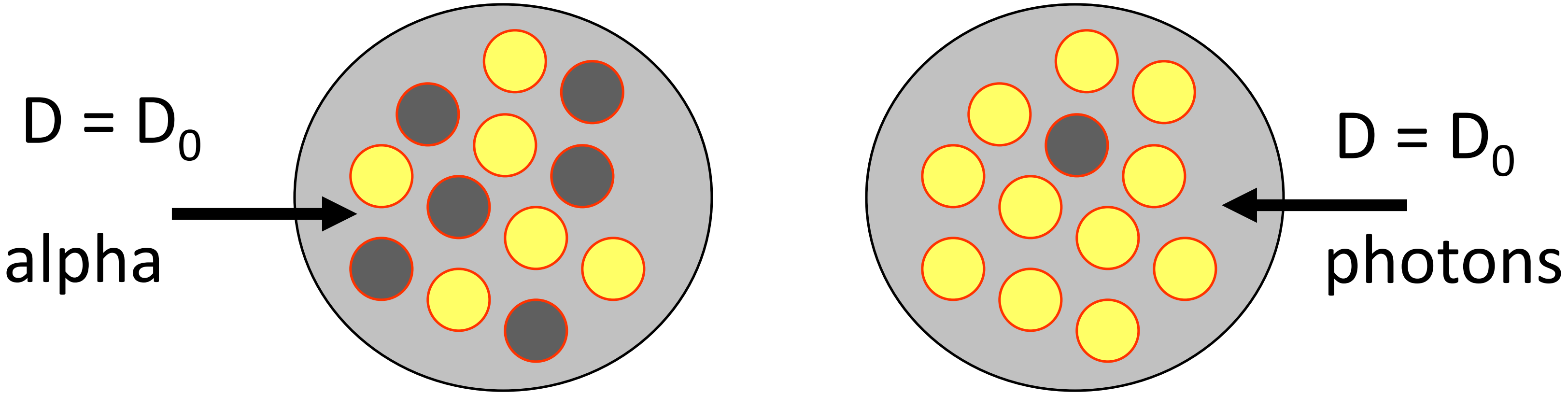
alpha

$D = D_0$

photons

For a given absorbed dose **alpha particles** are **more damaging** than **photons**

The absorbed dose is not always linked to the biological risk



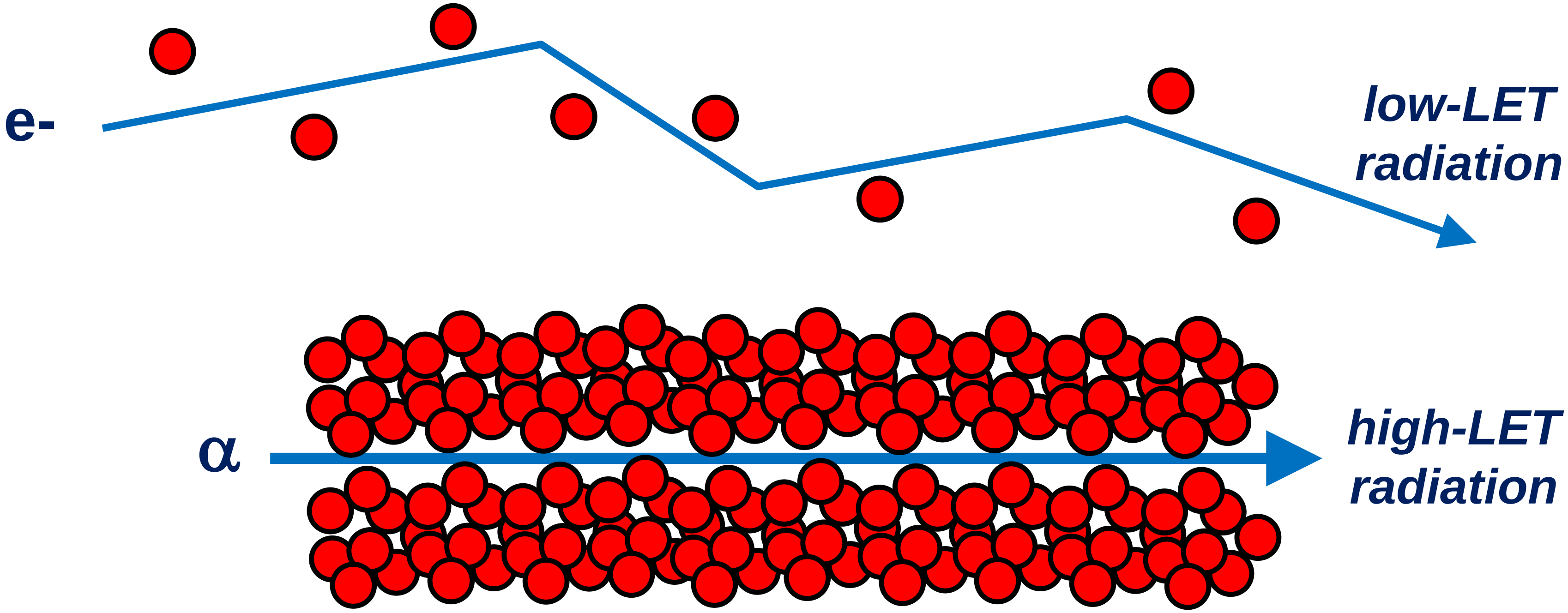
Linear energy transfer (LET)

- The microscopic distribution of energy along the path is characterized by a *linear energy transfer (LET).*
  - LET is a measure of the energy transferred to material as an ionizing particle travels through it. *(Can be seen as a force/friction)*

$$L_\Delta = \frac{dE_\Delta}{dx} \quad \left[J \cdot m^{-1}\right]$$

where dE_Δ refers to the energy loss due to electronic collisions minus the kinetic energies of all secondary electrons with energy larger than Δ.

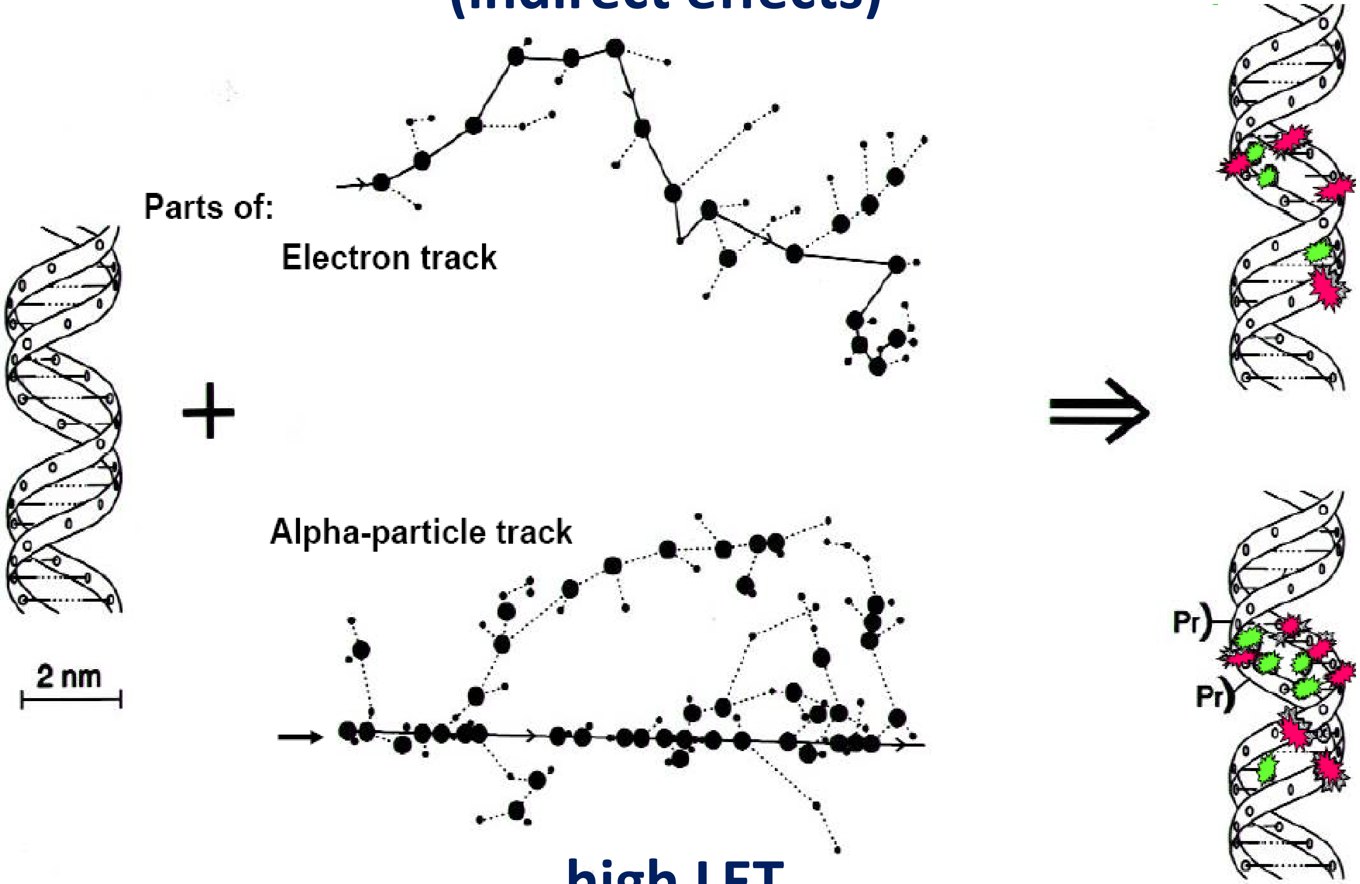
LET explains the difference of biological efficiency



LET: **linear energy transfer** (~dE_{coll}/dx)
(energy transferred through collision to the electrons of matter)

LET and biological effects

low LET
(indirect effects)



high LET
(direct effects)

RBE : Relative Biological Effectiveness

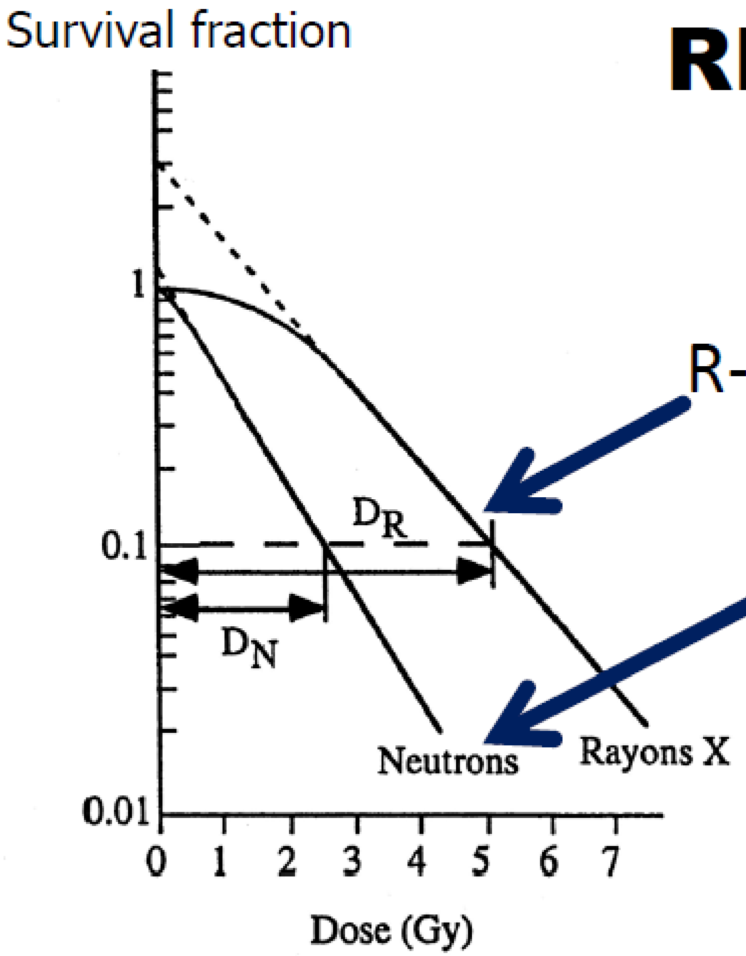
- To consider the variation of biological effects in terms of type of radiation, radiobiology defines the notion of relative biological effectiveness (RBE).

$$\mathbf{RBE} = \left.\frac{\mathbf{D_{ref.}}}{\mathbf{D}}\right|_{\textbf{same effect level}}$$

- ratio of the absorbed dose of a reference radiation (D_{ref}) over the absorbed dose of the radiation in question (D), which is necessary to obtain the same effect level.

RBE : Relative Biological Effectiveness

$$\mathbf{RBE} = \left.\frac{\mathbf{D}_{\mathbf{ref.}}}{\mathbf{D}}\right|_{\textbf{same effect level}}$$



R-reference

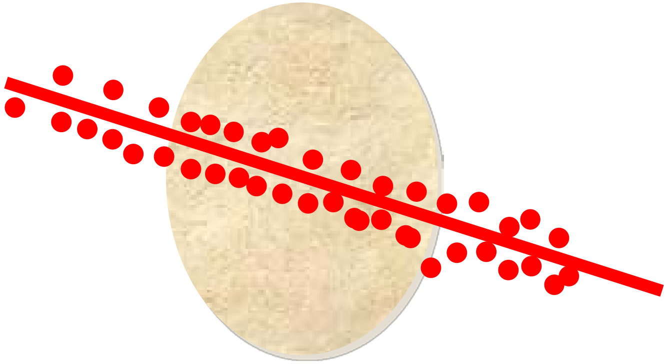
R-studied

- RBE = 2 - 50

LET and biological effects

- Low LET
  - Many cells lightly wounded
  - Possible recovery
  - Global effect little important for a given D

- High LET
  - Few cells highly injured
  - Less possibility to recover
  - Global effect important for a given D



Dose equivalent

- In radiation protection, strong need for a quantity measuring the average biological effects on the organ.

- Introduction by ICRP of the concept of dose equivalent, H, and weighting factors, w_R, determined using RBE studies.

  - Note also that the **dose equivalent** defined for radiation protection is only used to describe small values for which only **stochastic** effects may appear.
    The limit is fixed at 0.5 Sv. Beyond 0.5 Sv, **deterministic** effects appear, and the quantity of the radiation received by the organism is characterized by the **absorbed dose**.

Equivalent dose to an organ

- Radiation weighting (w_R) of the absorbed dose
  - Unit: **sievert** [Sv]

absorbed dose to the **organ T** delivered by the radiation of **quality R**

$$H_T = \sum_R w_R D_{R,T}$$

equivalent dose to organ T

radiation weighting factor

Radiation	w_R
X-rays, γ-rays, electrons	1
protons	5
neutrons	5-20
α-particles	20

Effective dose (for stochastic risk only)

https://www.zygote.com

Whole body dose

Effective dose (for stochastic risk only)

$$E = \sum_{T} w_T H_T$$

equivalent dose
to organ T

weighting factor
of organ T

sex and age averaged

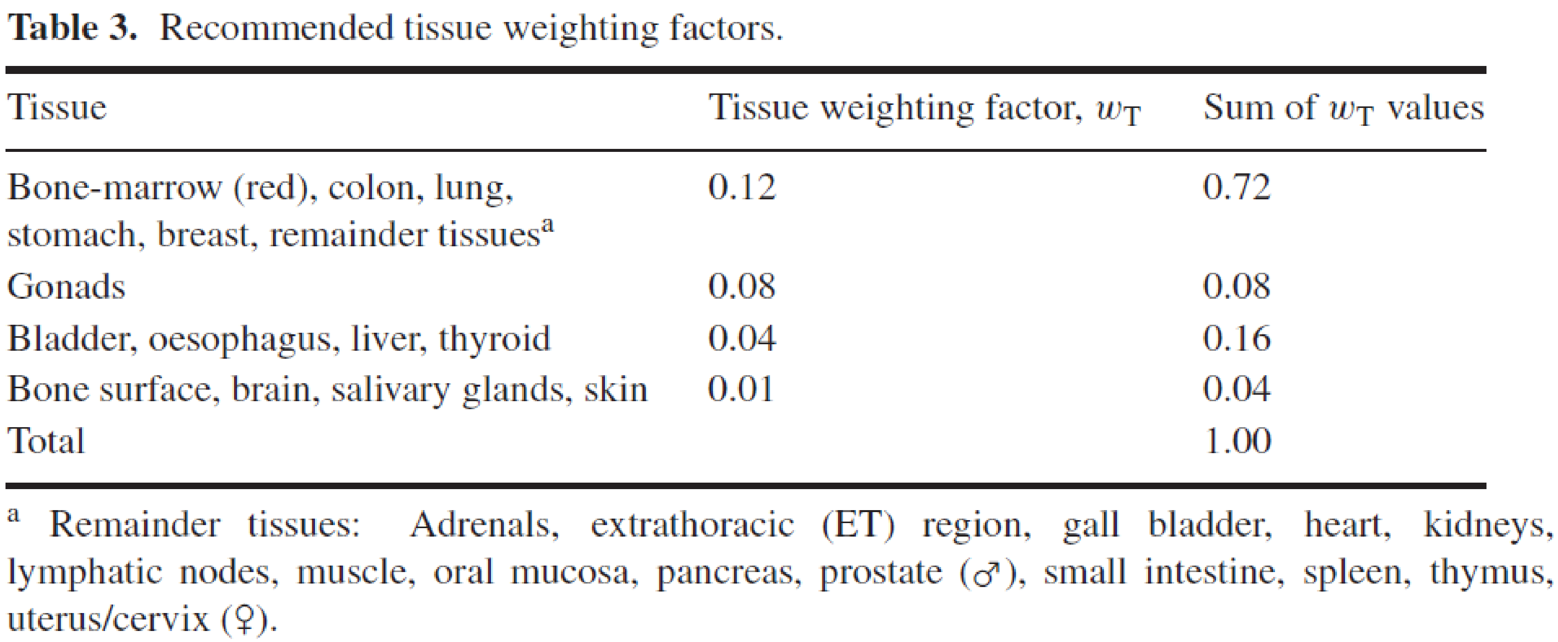
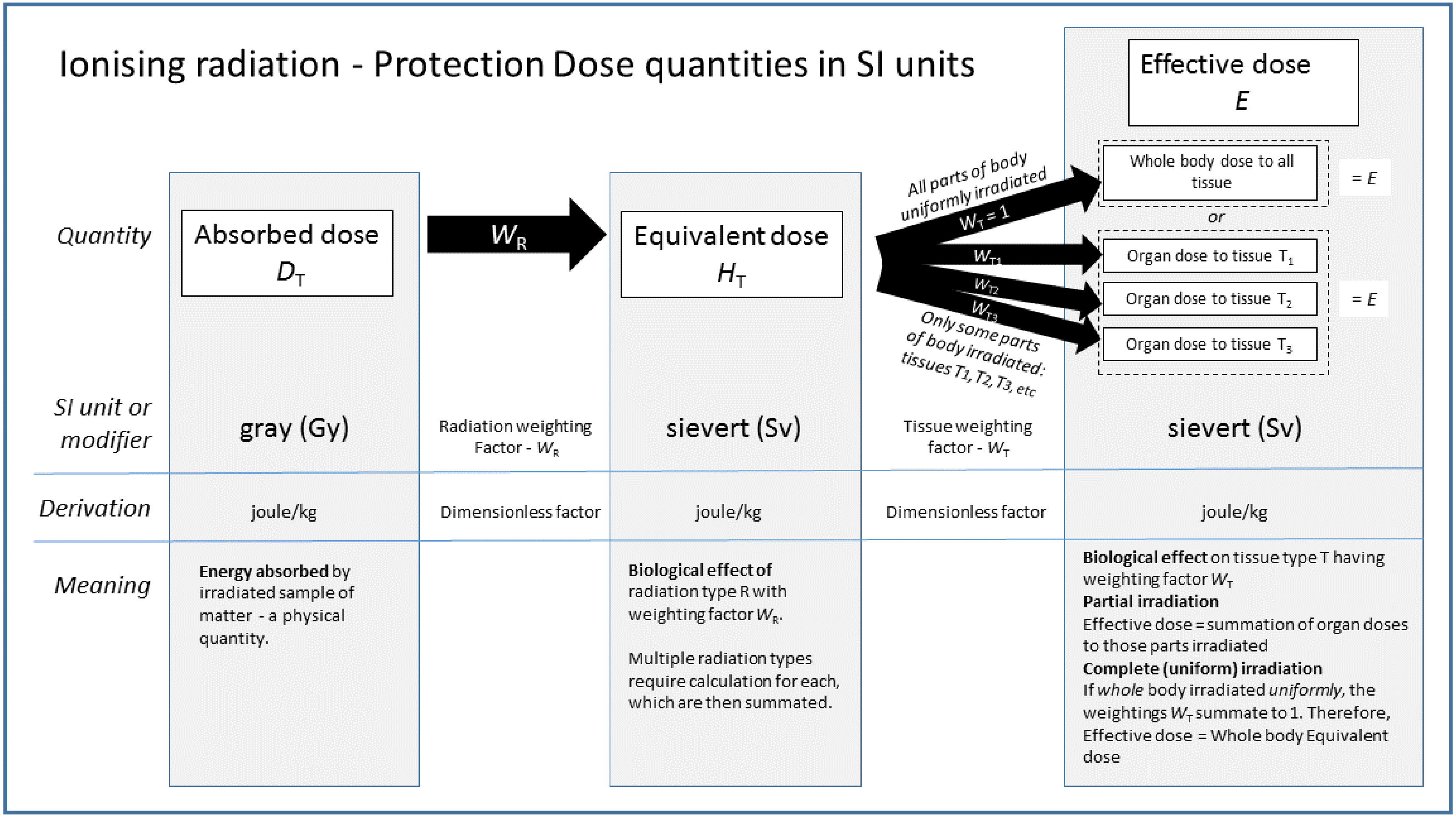


Table 3. Recommended tissue weighting factors.

Tissue	Tissue weighting factor, w_T	Sum of w_T values
Bone-marrow (red), colon, lung, stomach, breast, remainder tissues[a]	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
Total		1.00

[a] Remainder tissues: Adrenals, extrathoracic (ET) region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (♂), small intestine, spleen, thymus, uterus/cervix (♀).



Ionising radiation - Protection Dose quantities in SI units

Quantity	Absorbed dose D_T	W_R	Equivalent dose H_T	*All parts of body uniformly irradiated* $W_T = 1$ W_{T1} W_{T2} W_{T3} *Only some parts of body irradiated: tissues T1, T2, T3, etc*	Effective dose E Whole body dose to all tissue = E *or* Organ dose to tissue T_1 Organ dose to tissue T_2 Organ dose to tissue T_3 = E
SI unit or modifier	gray (Gy)	Radiation weighting Factor - W_R	sievert (Sv)	Tissue weighting factor - W_T	sievert (Sv)
Derivation	joule/kg	Dimensionless factor	joule/kg	Dimensionless factor	joule/kg
Meaning	**Energy absorbed** by irradiated sample of matter - a physical quantity.		**Biological effect of** radiation type R with weighting factor W_R. Multiple radiation types require calculation for each, which are then summated.		**Biological effect** on tissue type T having weighting factor W_T **Partial irradiation** Effective dose = summation of organ doses to those parts irradiated **Complete (uniform) irradiation** If *whole* body irradiated *uniformly*, the weightings W_T summate to 1. Therefore, Effective dose = Whole body Equivalent dose

W_R and W_T

How are they set?

Summary of dosimetric quantities

- KERMA **K**
  - – Photon kinetic energy released per unit of mass
    - unit: gray, 1 Gy = 1 J/kg
- Absorbed dose **D**
  - – Energy deposited per unit of mass
    - unit: gray, 1 Gy = 1 J/kg
- Equivalent dose **H**
  - – Mean absorbed dose weighted by radiation-specific factor (w_R)
    - unit: sievert, 1 Sv = 1 J/kg
- Effective dose **E**
  - – Sum of the organ equivalent doses weighted by organ-specific factors (w_T)
    - unit : sievert

Physics

Biology

A person has been irradiated by manipulating a bottle of radioactive solution

What do I need to know to evaluate the associated dose?

A person has been irradiated by manipulating a bottle of radioactive solution

By the way, what dose?

Absorbed dose?

Equivalent dose?

Effective dose?

....

A person has been irradiated by manipulating a bottle of radioactive solution

$$H = \sum_{R} w_R D_R$$

- The radionuclide → type of radiation (w_R)
- Absorbed dose (D_R)

A person has been irradiated by manipulating a bottle of radioactive solution

How do I measure the dose?

A person has been irradiated by manipulating a bottle of radioactive solution

- if I cannot measure anything, the liquid is non radioactive and I'm safe

Calculate the dose equivalent produced by irradiations at absorbed doses of 1 Gy (γ) and 0.2 Gy (alpha)

$$H = \sum_R W_R \cdot D_R$$

H = 1 x 1 [Gy] + 20 x 0.2 [Gy] = 5 Sv

Calculate the total effective dose for a person recieving10 mSv on the thyroid, 20 mSv on the marrow and 40 mSv on the lever.

$$E = \sum_T W_T \cdot H_T$$

E = 10 x 0.05 + 20 x 0.12 + 40 x 0.05 = 4.9 mSv

Operational parameters

- Radiation protection
  - About danger for human beings!

- Reality very complex
  - Simplifications

  - Human beings simplified
    - More or less equal to a sphere

  - Simple parameters
    - Personal deep dose equivalent
    - Personal surface dose equivalent
    - Effective dose to the entire body

Why should we measure dose at the working place?

- Evaluate the conditions on the working place
  - comparison can show differences of practices
  - unjustified doses can lead to accidents
  - protection improvements should be applied where they are most useful

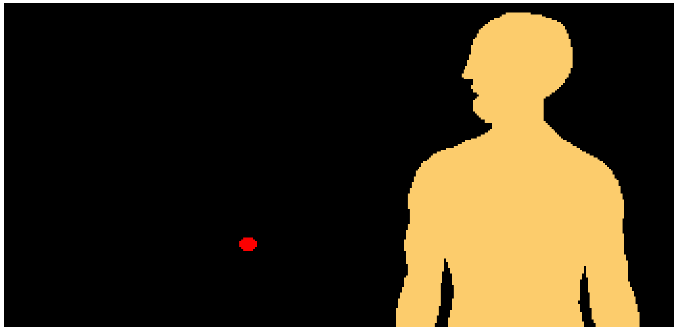
- Avoid the exposition of individuals
  - ALARA
    - As Low As Reasonably Achievable
  - doses should be below legal limits
  - if accumulated doses are close to the limits:
    - investigate working conditions

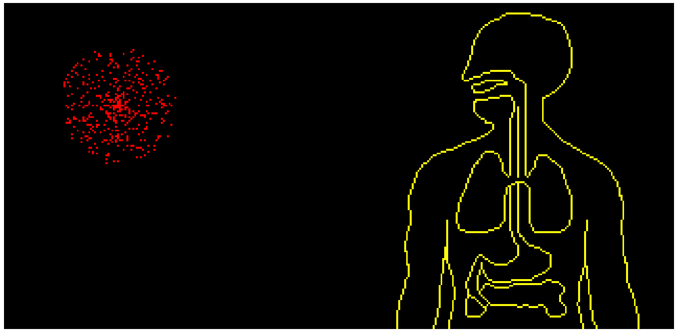
Individual dosimetry

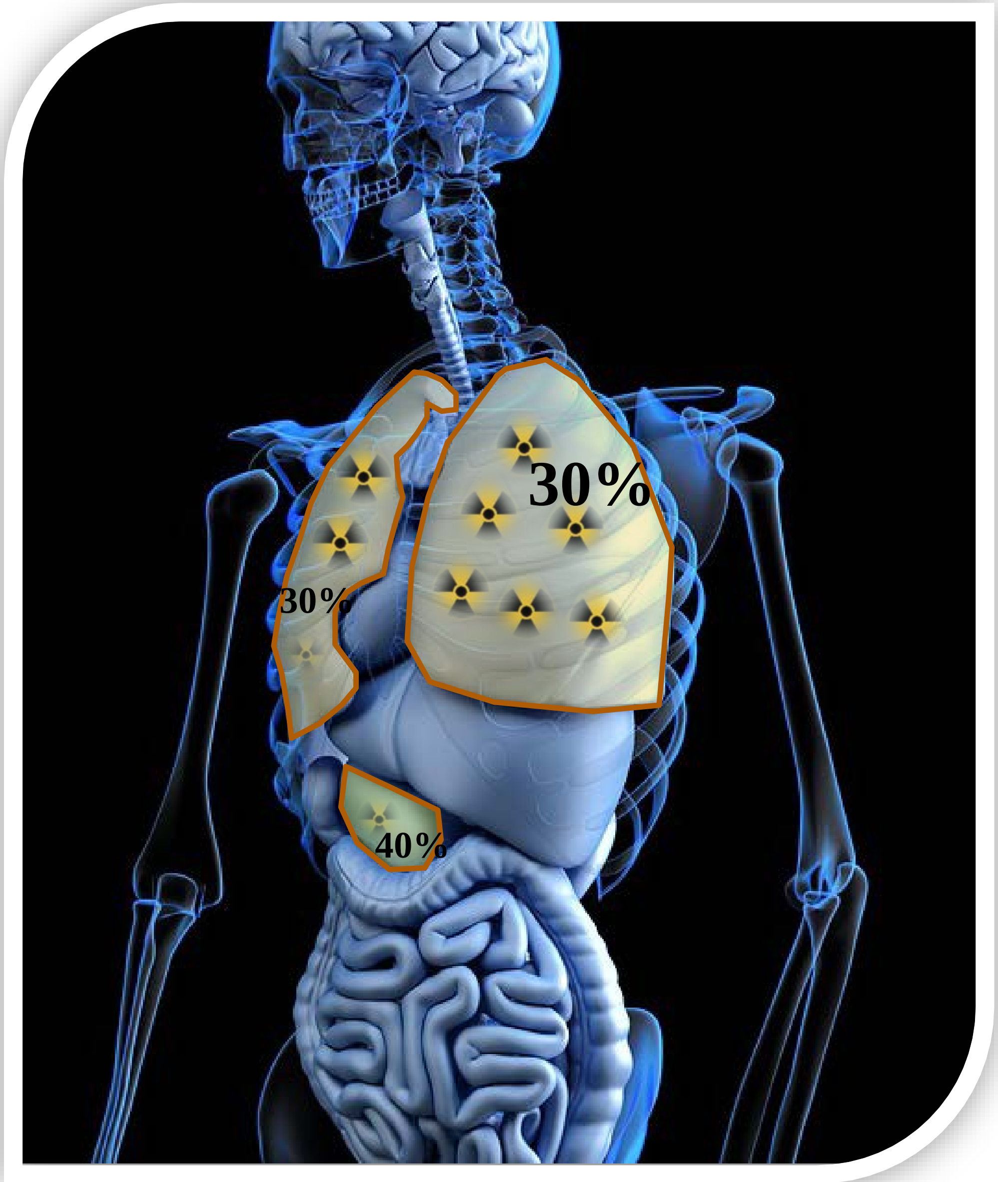
- **Measure the accumulated dose by an individual risks to the individual**
- **Make sure that the limits are respected**
- **Check that doses are as low as reasonably possible**
- **Know the radiation situation in the various sectors of activity**

- ✓ Risk incurred by the individual prof. exposed
- ✓ Risk related to a specific workstation
- ✓ Identify professional errors
- ✓ Risks to the population

The purpose of the medical examination is to verify the person's ability for work involving ionizing radiations and to monitor his state of health..

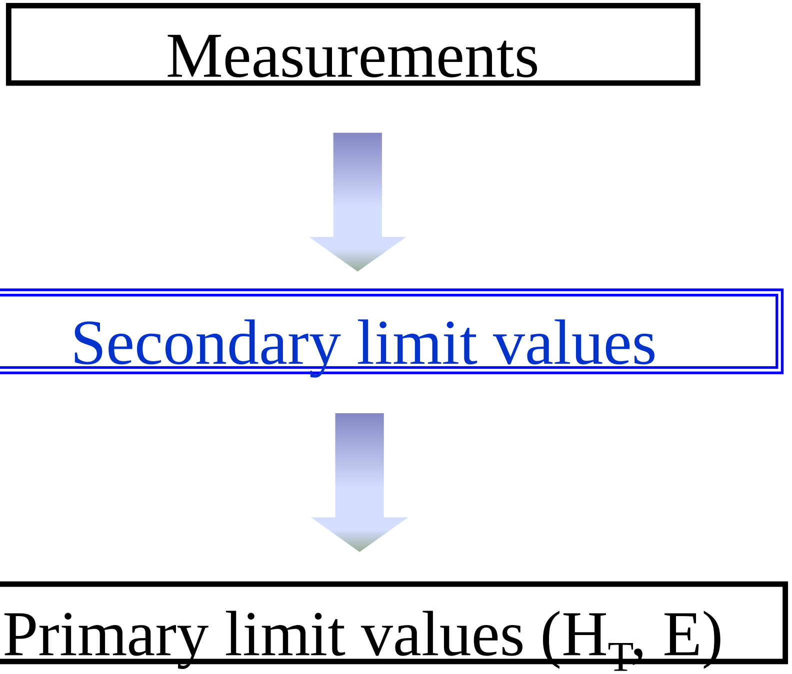





30%
30%
40%

Primary limit values (dose limit values): a fixed limit in the ordinance ⇒ dose equivalents to organs H_T, particularly to crystalline, the skin and the extremities, as well as effective dose E

it is not possible to directly measure dose equivalents to organs, nor the effective dose, we defined secondary limit values (operational values)



Measurements

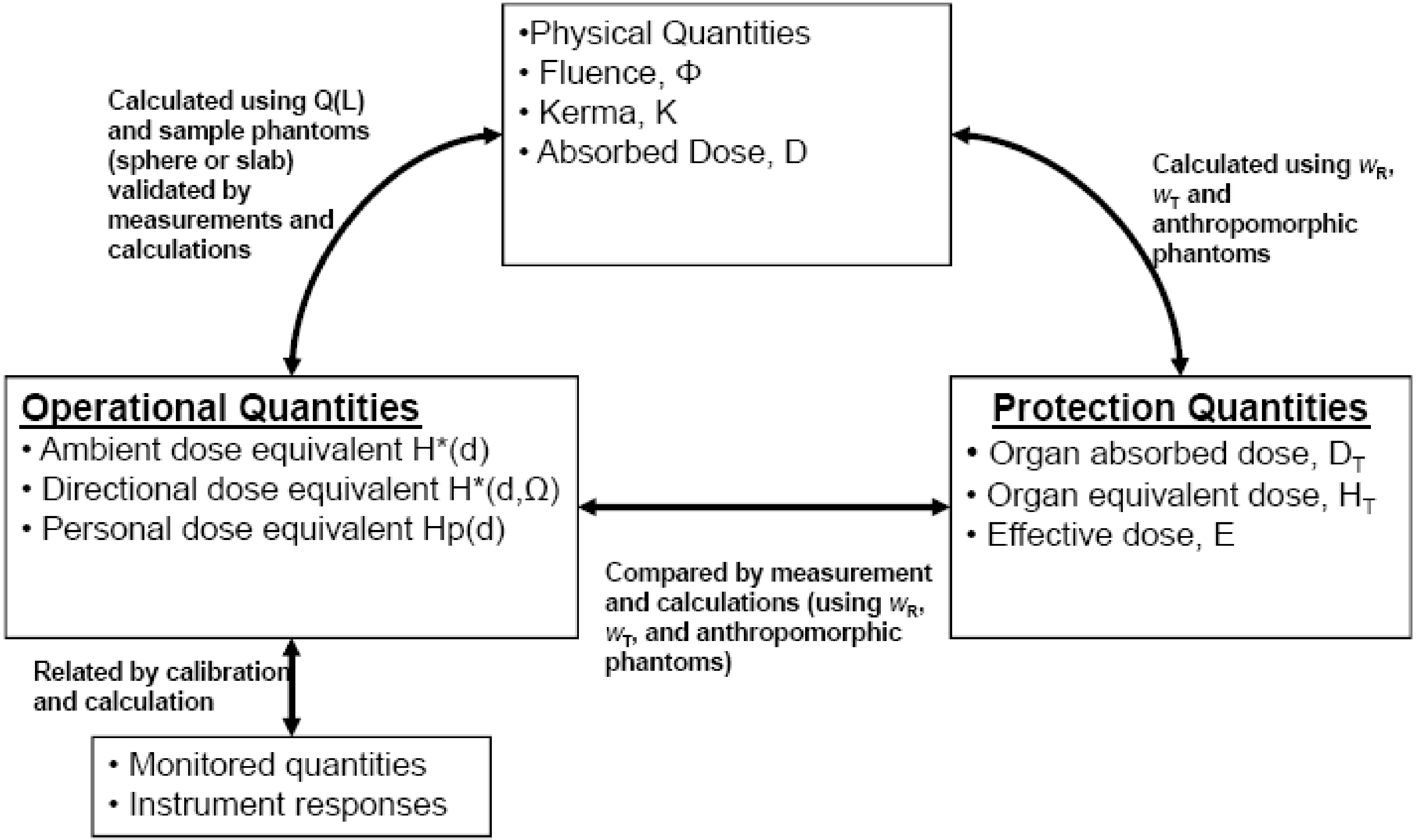
Secondary limit values

Primary limit values (H_T, E)

Equivalent dose to an organ

- The **equivalent dose H_T** is **not directly measurable**
  - – no laboratory standard for this quantity
  - – theoretical quantity (can be computed)

- Introduction of **operational quantities**
  - – can be used for practical measurements
  - – can be substituted to equivalent doses H_T



- Physical Quantities
- Fluence, Φ
- Kerma, K
- Absorbed Dose, D

Calculated using Q(L) and sample phantoms (sphere or slab) validated by measurements and calculations

Calculated using w_R, w_T and anthropomorphic phantoms

Operational Quantities

- Ambient dose equivalent H*(d)
- Directional dose equivalent H*(d,Ω)
- Personal dose equivalent Hp(d)

Protection Quantities

- Organ absorbed dose, D_T
- Organ equivalent dose, H_T
- Effective dose, E

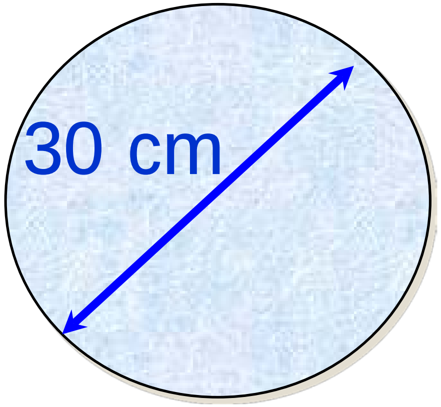
Compared by measurement and calculations (using w_R, w_T, and anthropomorphic phantoms)

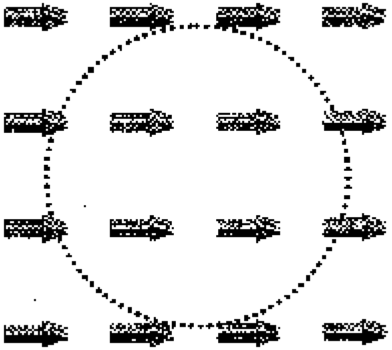
Related by calibration and calculation

- Monitored quantities
- Instrument responses

ICRU Sphere

- 76.2% O
- 11.1% C
- 10.1% H
- 2.6% N





The **ambient dose equivalent** *$H^*(d)$*, at a point, is the dose equivalent that would be produced by the corresponding expanded and aligned field *(An oriented and expanded radiation field is an idealized radiation field which is expanded and in which the radiation is additionally oriented in one , direction)* in the ICRU sphere at a depth *d* in millimetres on the radius opposing the direction of the aligned field. For measurement of strongly penetrating radiations the reference depth used is 10 mm and the quantity denoted *$H^*(10)$*.

The **directional dose equivalent** *$H'(d, \Omega)$*, at a point, is the dose equivalent that would be produced by the corresponding expanded field in the ICRU sphere at a depth *d* on a radius in a specified direction Ω. Directional dose equivalent is of particular use in the assessment of dose to the skin or eye lens.
H\`(d,0) is written as H\`(d) and is equal to H*(d)
α = 0° → AP (anteroposterior)
α = 90° → LAT
α = 180° → PA

The **personal dose equivalent** *$H_p(d)$*, is the dose equivalent in soft tissue, at an appropriate depth, *d*, below a specified point on the body. *$H_p(d)$* measured with a detector which is worn at the surface of the body and covered with an appropriate thickness of tissue-equivalent material.

→ $H_p(10)$, $H_p(0.07)$

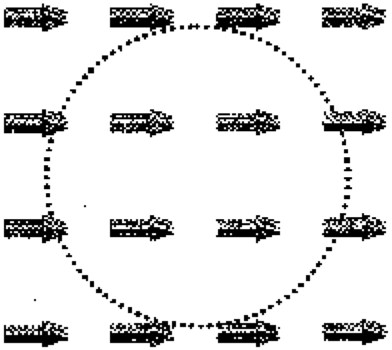
Operational quantities

- Operational quantities have the following characteristics:
  - Based on the equivalent dose at one point
    - in the human organism
    - or in a phantom
  - Linked to a type of radiation and its energy at this point
  - Can be calculated from the fluence at this point

- Two types of situation:
  - **Ambiance** dosimetry
    - independent of the person
  - **Personal** dosimetry
    - performed on the concerned person

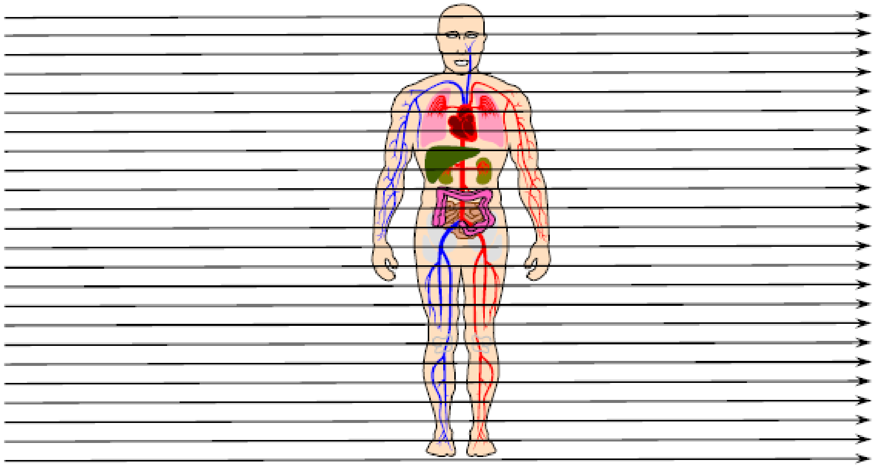
Operational quantities were defined by ICRU for evaluation of occupational radiation doses to workers and public in general. This is for external sources of radiation only.

Radiation field



$H^*(10)$

Ambient Dose Equivalent



$H_p(10)$

Personal Dose Equivalent

Individual dosimetry

Operational parameters for external exposure

What do we measure?

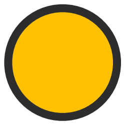
Parameter	Unit	Related primary parameter	type of dosimetry
$H^*(10)$ ambient dose equivalent	Sv	E effective dose	ambient
$H_p(10)$ personal deep dose	Sv	E effective dose	personal
$H'(0.07)$ directional dose equivalent	Sv	H_{skin}	ambient
$H_p(0.07)$ personal surface dose	Sv	H_{skin}	personal

$H_p(0.07)$ for extremities
$H_p(3)$ for eye lens

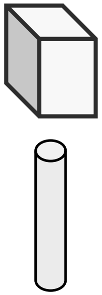
Summary of operational quantities

	Ambient monitoring	**Personal monitoring**
Low penetration	H*(0.07), H*(3) **H'(0.07, Ω)**, H'(3, Ω)	**H_p(0.07)**, H_p(3)
High penetration	**H*(10)** H'(10, Ω)	**H_p(10)**

skin (0.07)
eye (3)
internal organs (10)



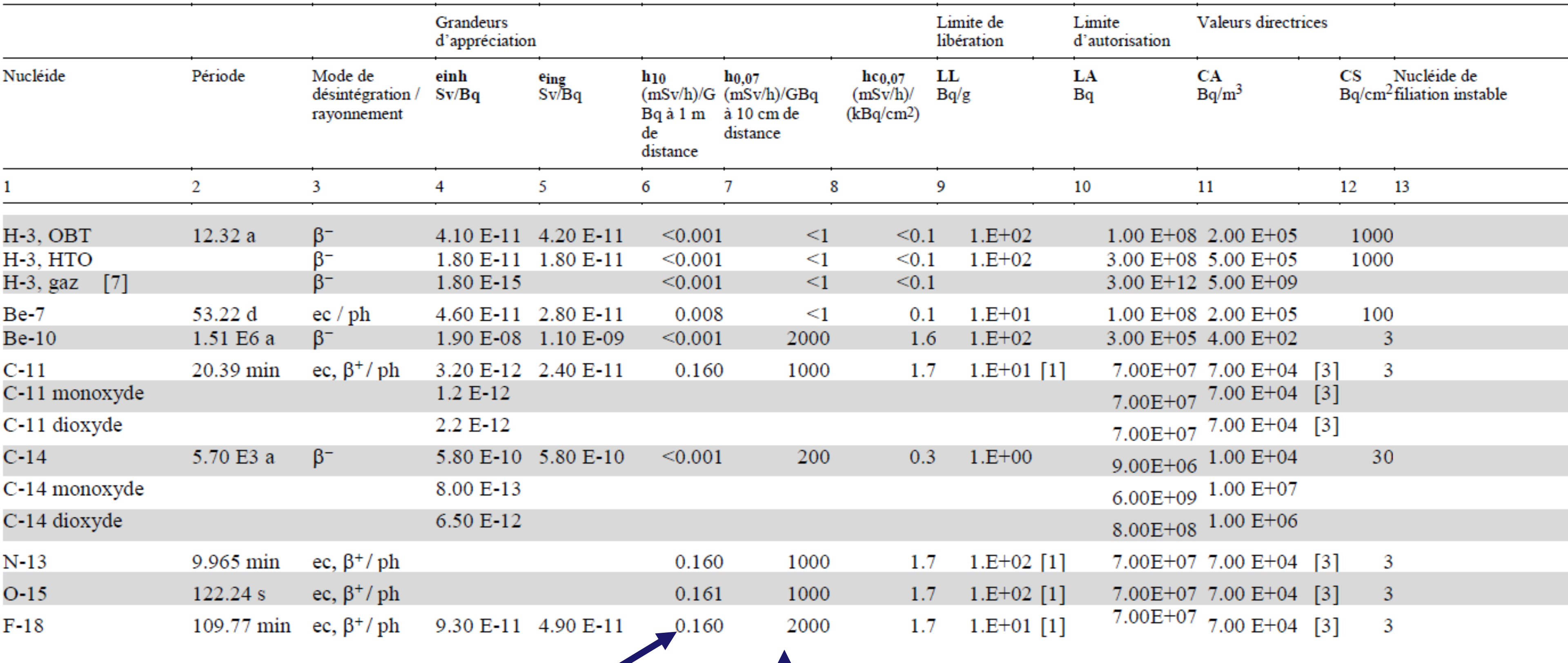
ICRU sphere
without dosimeter



chest
(whole body)

finger

ISO phantom
with dosimeter



			Grandeurs d'appréciation					Limite de libération	Limite d'autorisation	Valeurs directrices		
Nucléide	Période	Mode de désintégration / rayonnement	**e_{inh}** Sv/Bq	e_{ing} Sv/Bq	**h_{10}** (mSv/h)/GBq à 1 m de distance	**$h_{0,07}$** (mSv/h)/GBq à 10 cm de distance	**$h_{c0,07}$** (mSv/h)/(kBq/cm^2)	**LL** Bq/g	**LA** Bq	**CA** Bq/m^3	**CS** Bq/cm^2	Nucléide de filiation instable
1	2	3	4	5	6	7	8	9	10	11	12	13
H-3, OBT	12.32 a	β^-	4.10 E-11	4.20 E-11	<0.001	<1	<0.1	1.E+02	1.00 E+08	2.00 E+05	1000	
H-3, HTO		β^-	1.80 E-11	1.80 E-11	<0.001	<1	<0.1	1.E+02	3.00 E+08	5.00 E+05	1000	
H-3, gaz [7]		β^-	1.80 E-15		<0.001	<1	<0.1		3.00 E+12	5.00 E+09		
Be-7	53.22 d	ec / ph	4.60 E-11	2.80 E-11	0.008	<1	0.1	1.E+01	1.00 E+08	2.00 E+05	100	
Be-10	1.51 E6 a	β^-	1.90 E-08	1.10 E-09	<0.001	2000	1.6	1.E+02	3.00 E+05	4.00 E+02	3	
C-11	20.39 min	ec, β^+/ ph	3.20 E-12	2.40 E-11	0.160	1000	1.7	1.E+01 [1]	7.00E+07	7.00 E+04 [3]	3	
C-11 monoxyde			1.2 E-12						7.00E+07	7.00 E+04 [3]		
C-11 dioxyde			2.2 E-12						7.00E+07	7.00 E+04 [3]		
C-14	5.70 E3 a	β^-	5.80 E-10	5.80 E-10	<0.001	200	0.3	1.E+00	9.00E+06	1.00 E+04	30	
C-14 monoxyde			8.00 E-13						6.00E+09	1.00 E+07		
C-14 dioxyde			6.50 E-12						8.00E+08	1.00 E+06		
N-13	9.965 min	ec, β^+/ ph			0.160	1000	1.7	1.E+02 [1]	7.00E+07	7.00 E+04 [3]	3	
O-15	122.24 s	ec, β^+/ ph			0.161	1000	1.7	1.E+02 [1]	7.00E+07	7.00 E+04 [3]	3	
F-18	109.77 min	ec, β^+/ ph	9.30 E-11	4.90 E-11	0.160	2000	1.7	1.E+01 [1]	7.00E+07	7.00 E+04 [3]	3	

$$Hp(10) = \dot{h}p(10) \cdot \frac{A \cdot t}{r^2}$$

$$Hp(0.07) = \dot{h}p(0.07) \cdot \frac{A \cdot t}{(10 \times r)^2}$$

Calculate the total effective dose for a person who manipulates100MBq of Cs-137 during an estimated period of 30 minutes, working at 1m of the source

$$0.092\left[\mathrm{msV} \cdot \mathrm{h}^{-1} \cdot \mathrm{GBq}^{-1}\right]$$

$$E = H^*(10) = \dot{h}(10) \cdot \frac{A \cdot t}{r^2}$$

$$= 0.092\left[\mathrm{mSv} \cdot \mathrm{h}^{-1} \cdot \mathrm{GBq}^{-1}\right] \cdot \frac{0.1[\mathrm{GBq}] \cdot 0.5[\mathrm{h}]}{1^2}$$

$$= 4.6\ \mu\mathrm{Sv}$$

The calculation you just did, is that realistic?

What are the limitations?

How accurate or wrong would that be if you calculate the equivalent dose to the fingers when manipulating a tank filled with Co-60?

What's about I-131?

Measurements

Measuring radiation

1st question, what do I want to measure?

- Dose (mGy, mSv) – Internal exposure / external exposure
- Dose rate (mSv/h)
- Surface contamination (Bq/cm^2)
- Air contamiantion (Bq/cm^3)
- Activity (Bq)
- Source/radionuclide identification

…

2nd question, what else should we take into account ?

- parameter to measure: absorbed dose, activity, dose equivalent,…

- type of radiation: α, β, γ, neutrons, …
- radiation energy

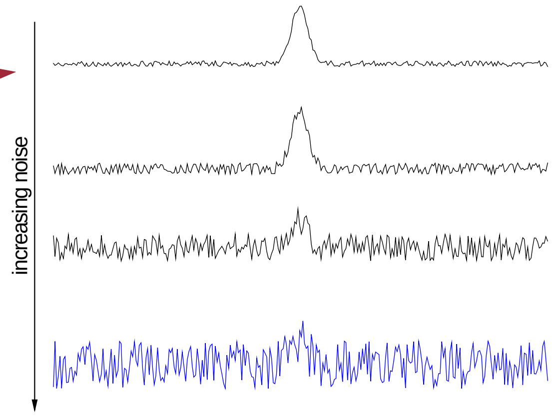
- type of measurement: geometry, instant data, individual measurement…

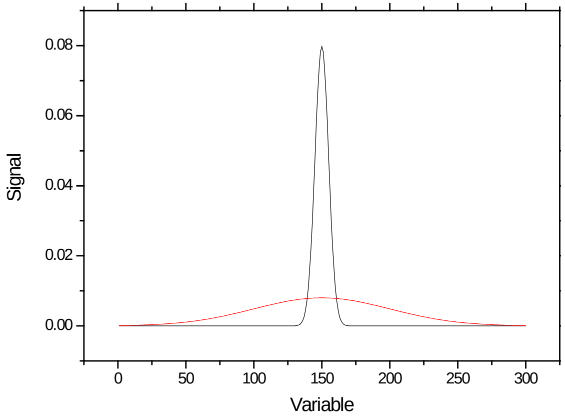
- other considerations: difficulties, duration of the measurement…

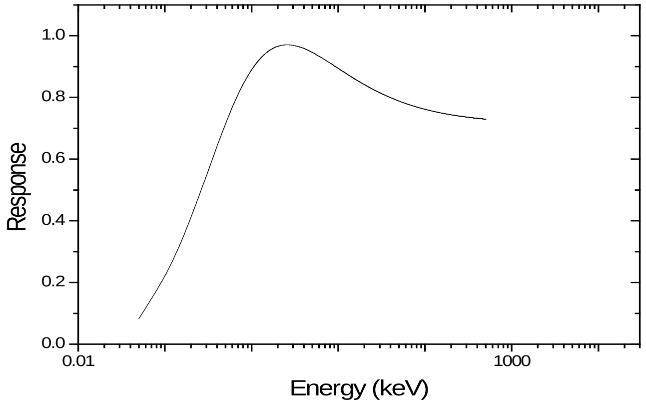
Properties of measuring instruments

Features depends on:

- the background
- the threshold (detection limits)
- the response in energy
- the angular response of the instrument
- the sensibility
- detection limits
- …etc







How would you measure the effective dose of a person working in a controlled area?

What detection technique do you know?

Measuring radiation

- Ionisation

  gaz (Ionisation chambers, proportional counter, Geiger-Müller), **solid** (semiconductor)

- Luminescence

  liquids (scintillator), **solids** (TLD, NaI)

- Heat

  Calorimetry

- Chemistry

  Gel (polymers), **liquids** (Fricke), **solids** (emulsion sheets)

- Phase changes

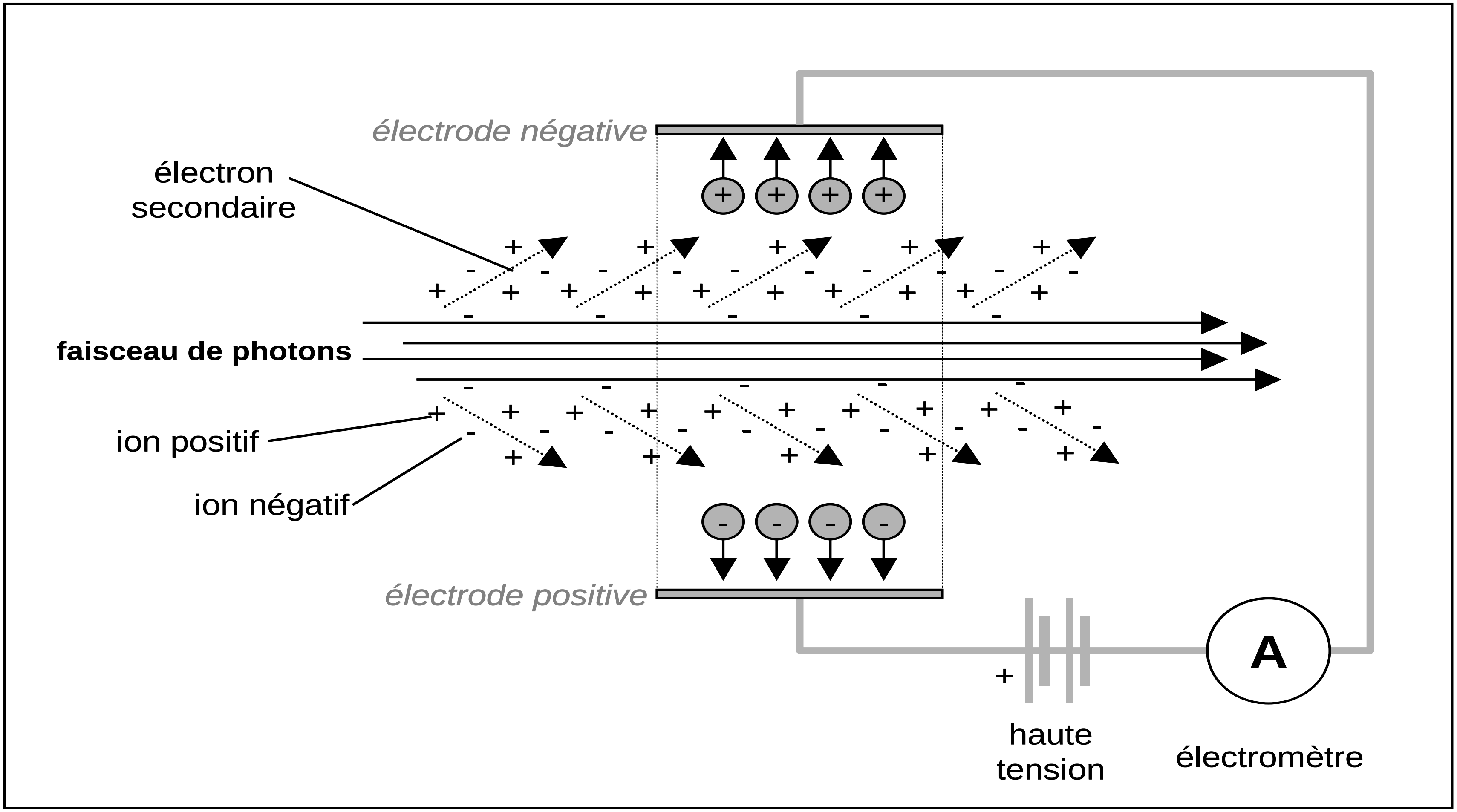
  Bubble chambers, cloud chambers

- Activation

  for neutrons

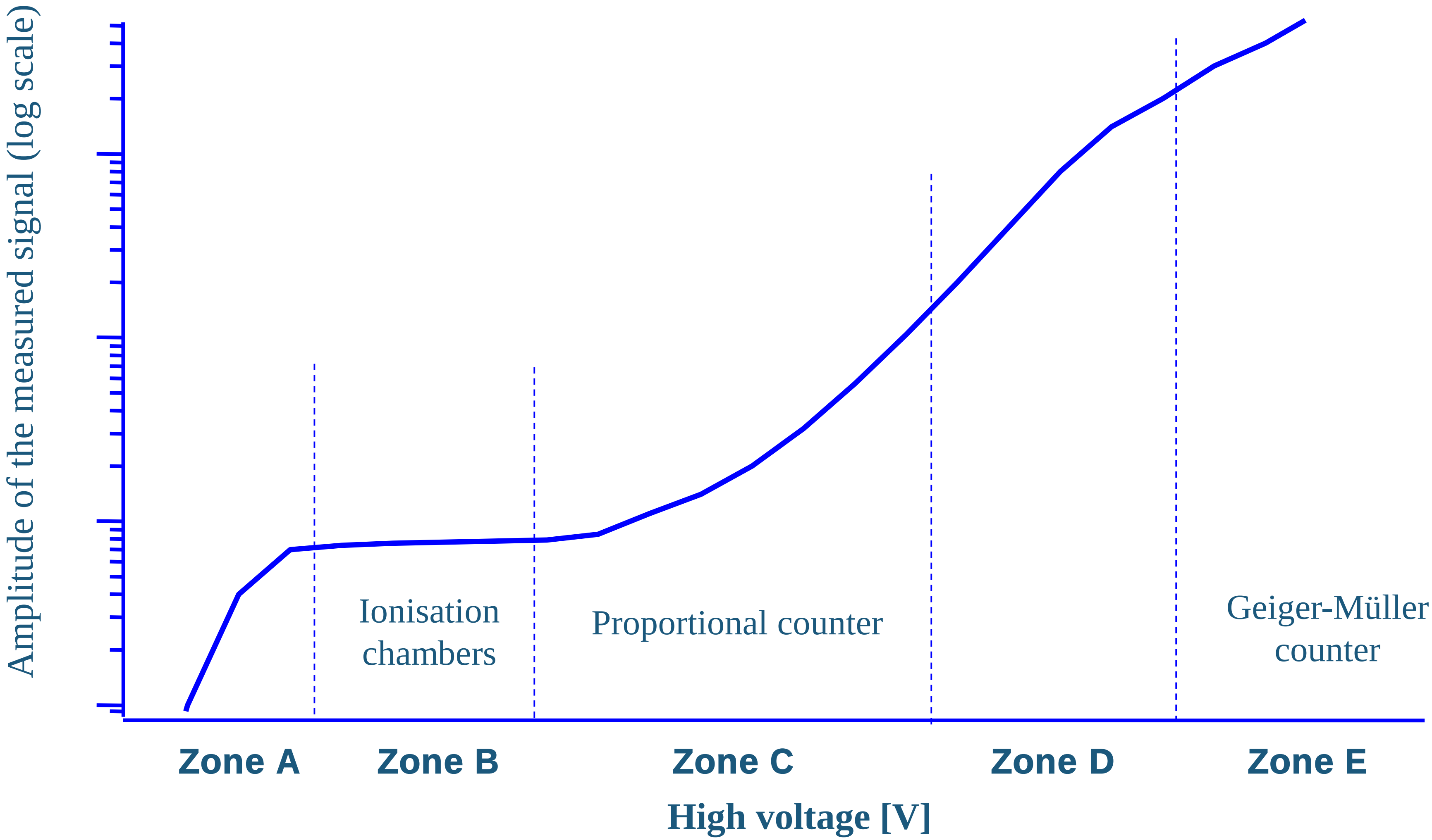
Ionisation-based detectors

Working principle of a radiation detector based on gaz ionisation



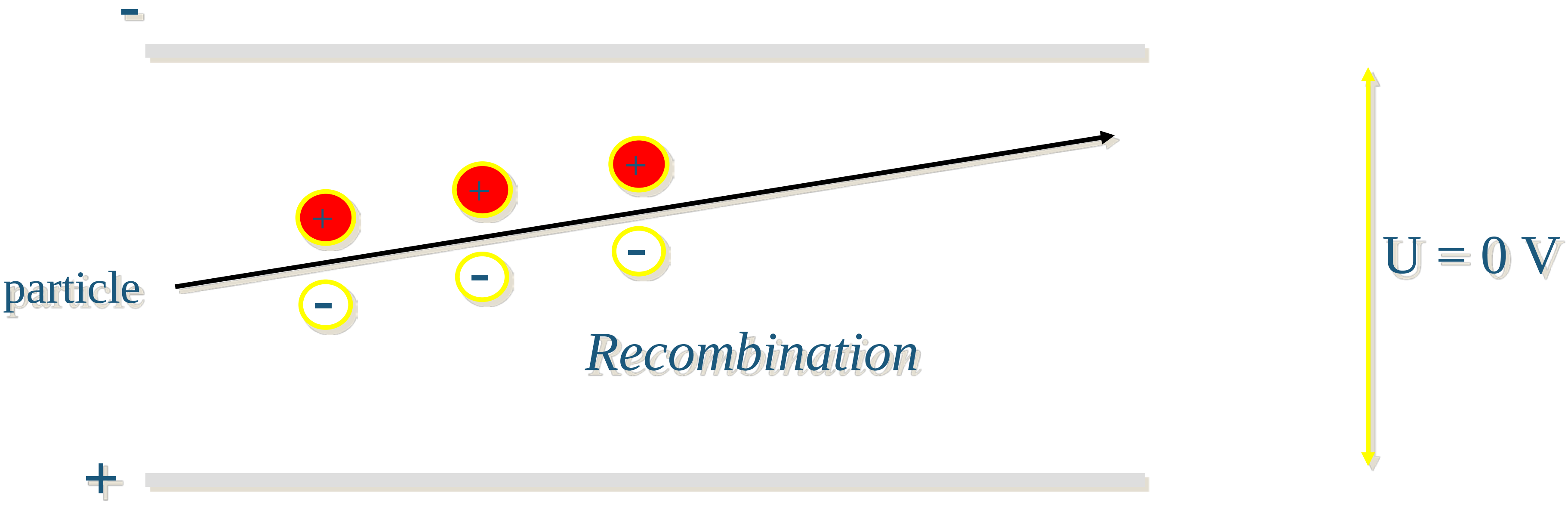
Ionisation-based detectors

Variation of the signal as a function of high voltage



Ionisation-based detectors

Ionisation chamber



-

particle

Recombination

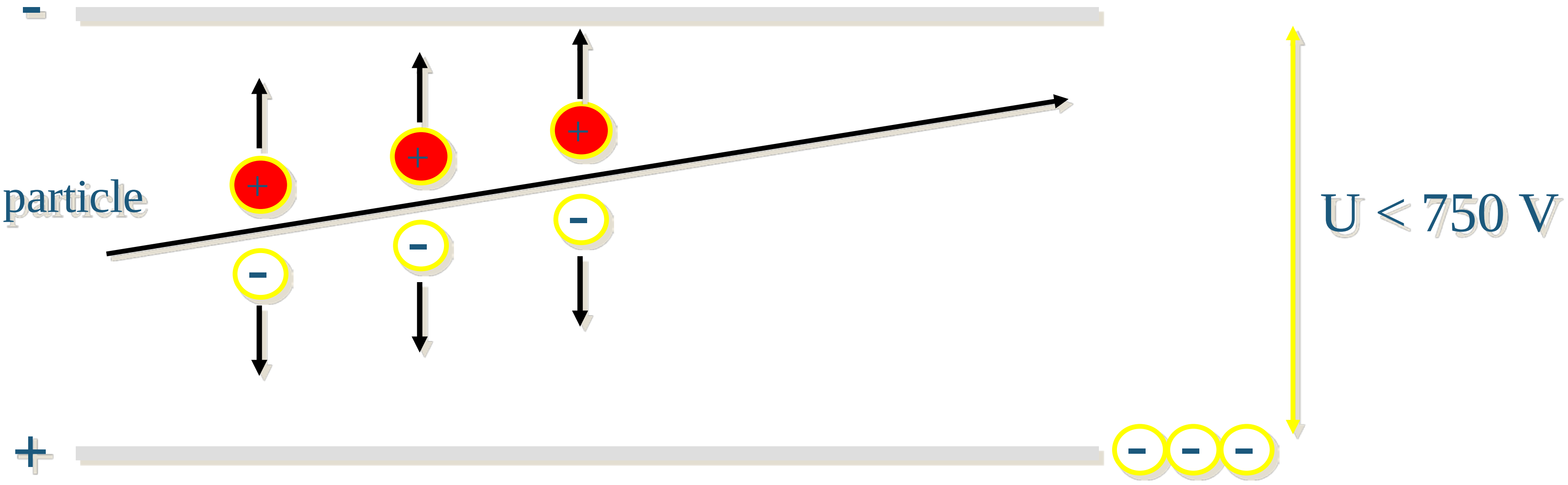
U = 0 V

+

ionisation of the gaz

Ionisation-based detectors

Ionisation chamber



ionisation of the gaz

Ionisation-based detectors

Ionisation chamber

Main features:

- Recombination of ions with low voltage
- Low sensibility
- Mostly independent of the type and energy of the radiation

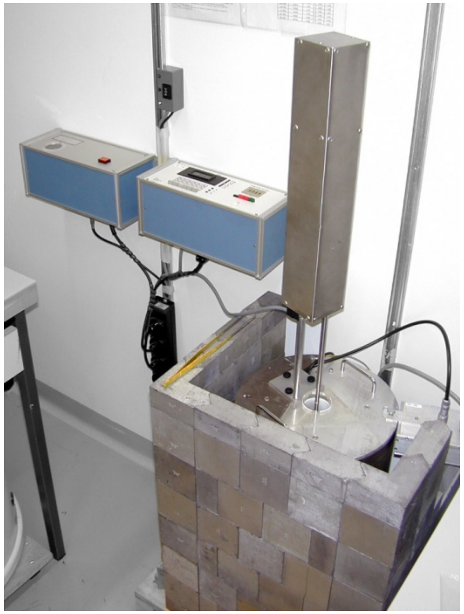
Used as:

- Activimeter
- Clinical dosimetry
- In-situ measurements (large area to be controlled)

Figure 2.5: Example of an ionization chamber used in radiodiagnostics (Radcal chamber with a volume equal to 6 cm^3).

Ionisation-based detectors

Ionisation chamber



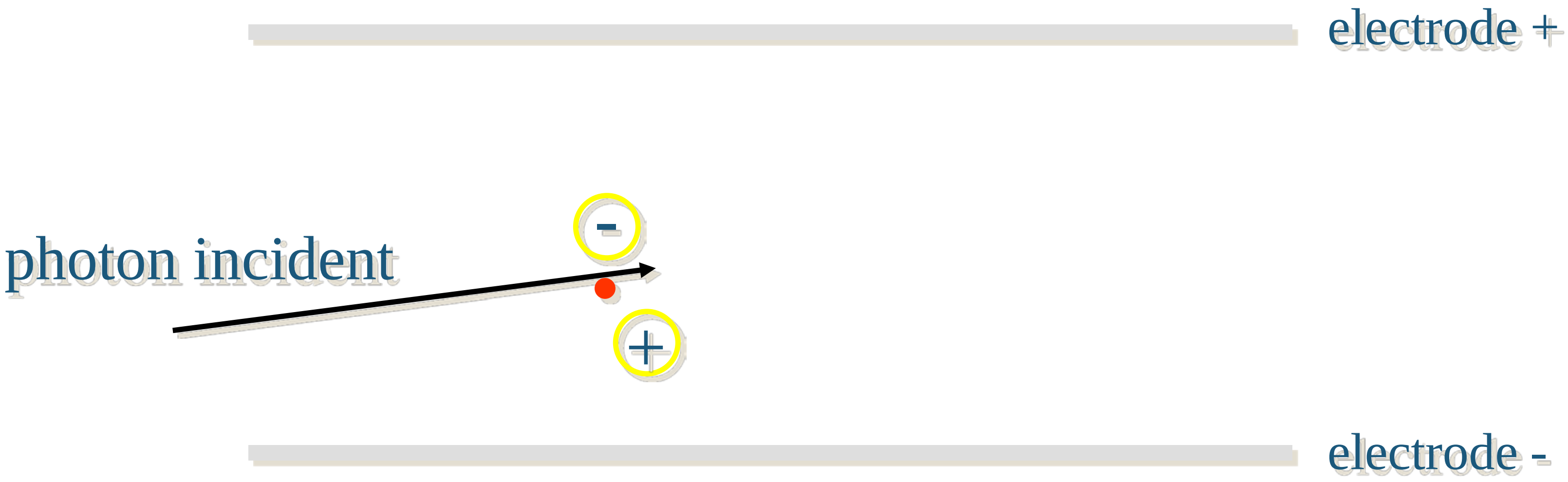
Activitmeter (IRA)

Dosimeters → kerma/dose

Ionisation-based detectors

Proportional counter

Measurements of secondary ionisations produced by accelerated primary charges



electrode +

photon incident

-

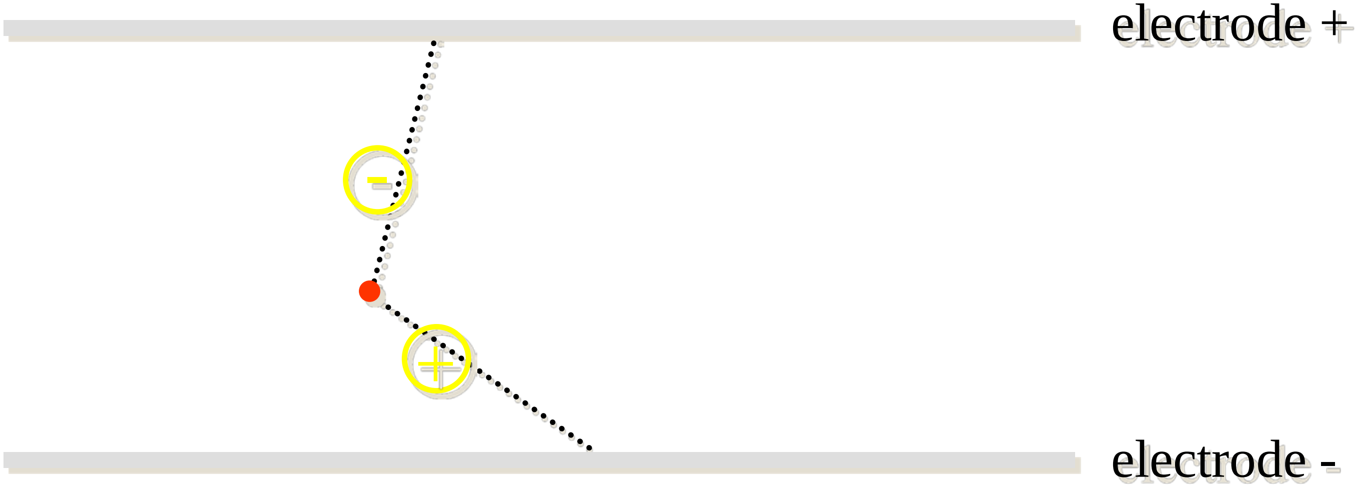
+

electrode -

Ionisation-based detectors

Proportional counter

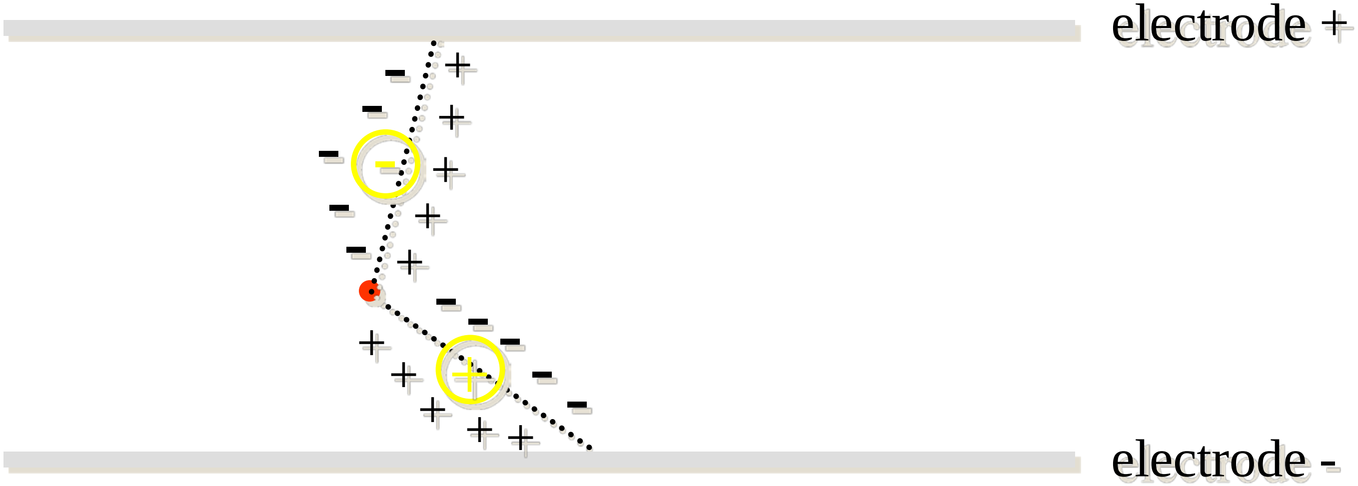
Measurements of secondary ionisations produced by accelerated primary charges



Ionisation-based detectors

Proportional counter

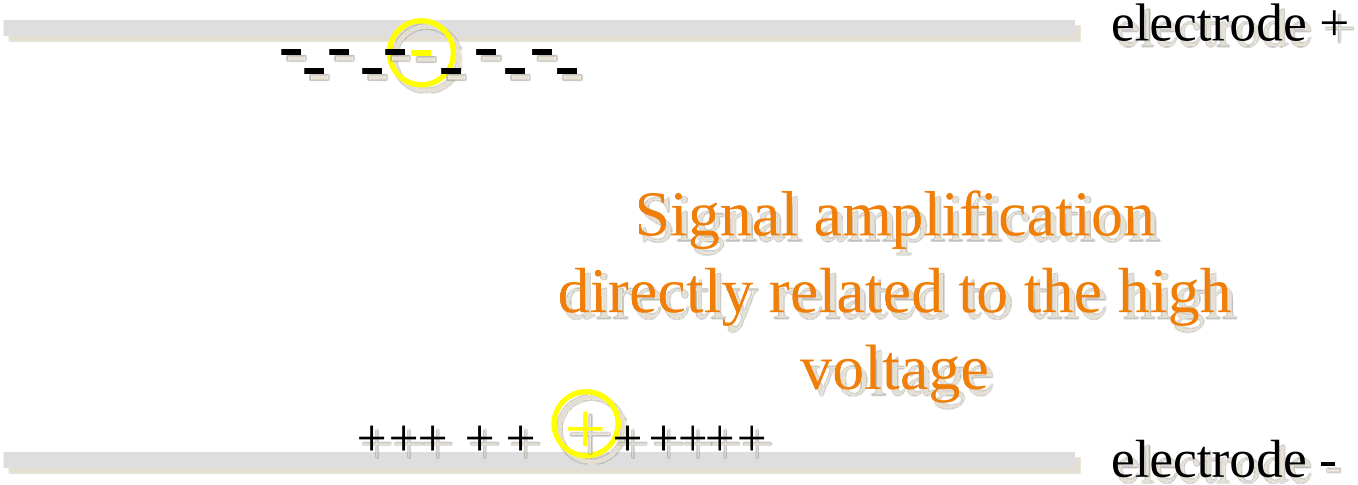
Measurements of secondary ionisations produced by accelerated primary charges



Ionisation-based detectors

Proportional counter

Measurements of secondary ionisations produced by accelerated primary charges



Signal amplification directly related to the high voltage

Ionisation-based detectors

Proportional counter

Features:

- Rather high voltage
- Output signal directly proportional to the primary charge
- Measurement by pulse
- High sensibility
- Possibility to discrimate α/β

Used as:

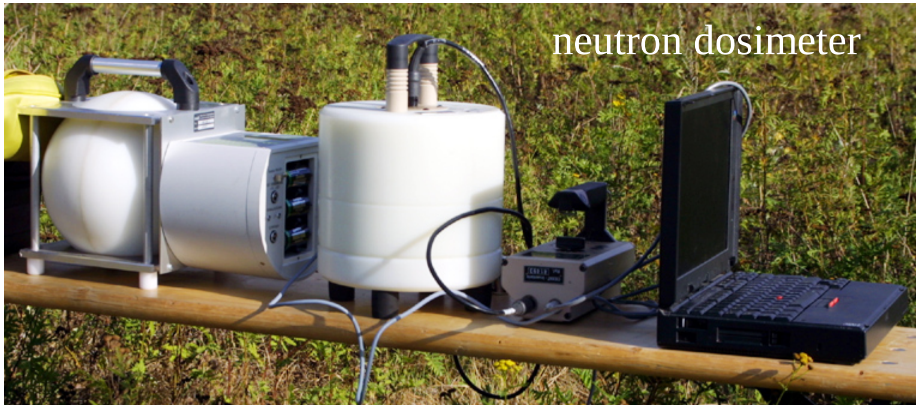
- In-situ measurements
- Contamination monitor
- γ and low energy X-ray : detection / spectrometry

Ionisation-based detectors

Proportional counter

Contamination monitor
(Berthold LB1210)
pulse $s^{-1} \rightarrow$ activity cm^{-2}

$${}^{3}_{2}He + n \rightarrow {}^{3}_{1}H + p$$



neutron dosimeter

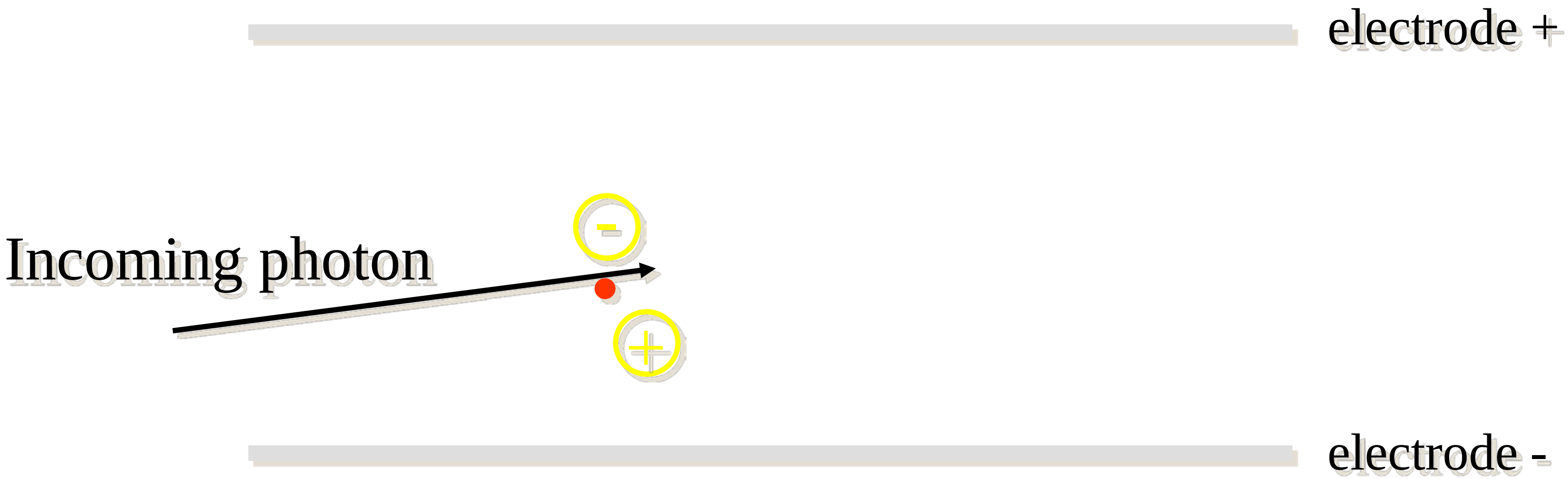
Ionisation-based detectors

Example proportional counter used to monitor foot and hand contamination (Berthold LB 1041 counter).

Ionisation-based detectors

Geiger-Müller counter

Maximum amplification of the output signal (avalanche)



electrode +

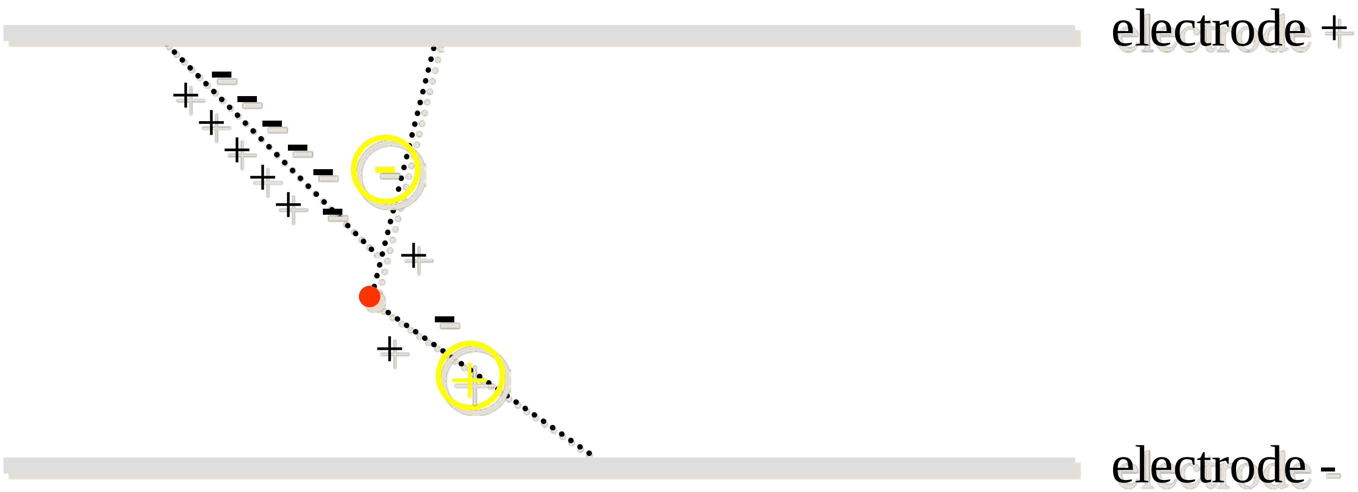
Incoming photon

electrode -

Ionisation-based detectors

Geiger-Müller counter

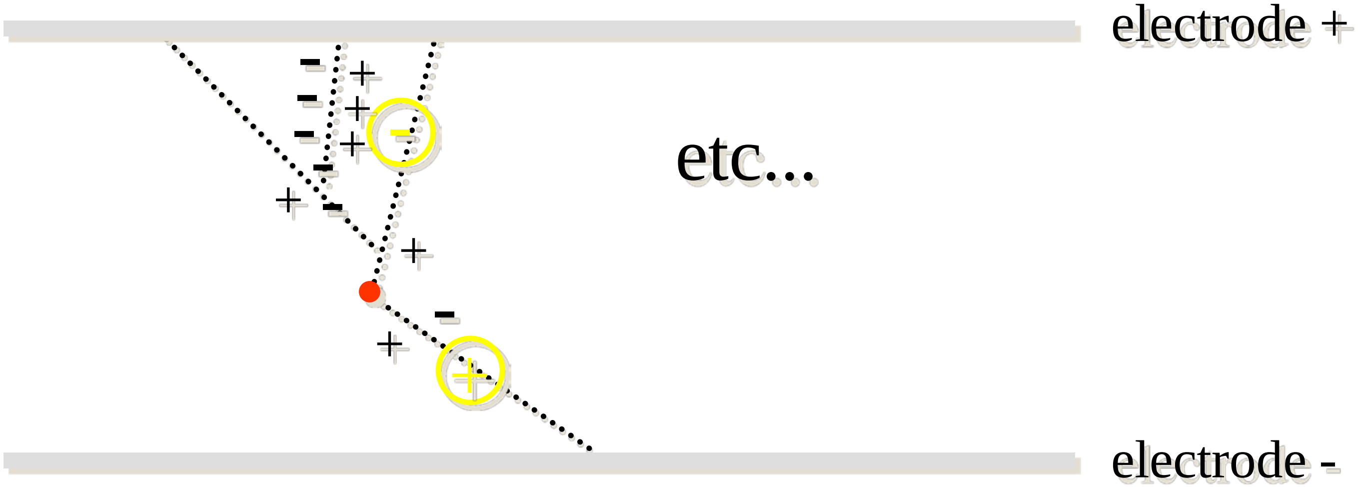
Maximum amplification of the output signal (avalanche)



Ionisation-based detectors

Geiger-Müller counter

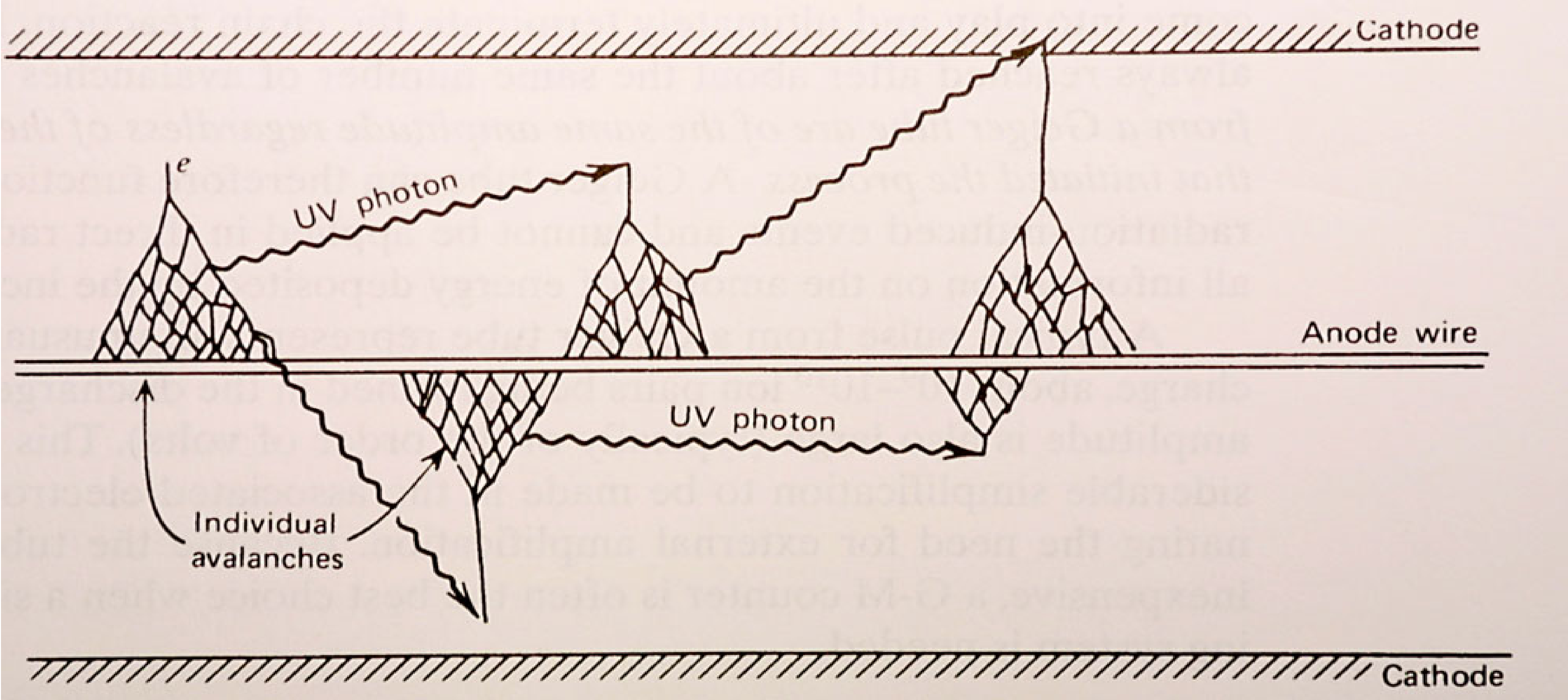
Maximum amplification of the output signal (avalanche)



Ionisation-based detectors

Geiger-Müller counter

Maximum amplification of the output signal (avalanche)



Ionisation-based detectors

Geiger-Müller counter

Features:

- High voltage required
- Output signal not related to the primary charge
- Measurement by pulse
- Spectrometry cannot be performed with this kind of instrument

Used as:

- In-situ measurements
- Robust and cheap

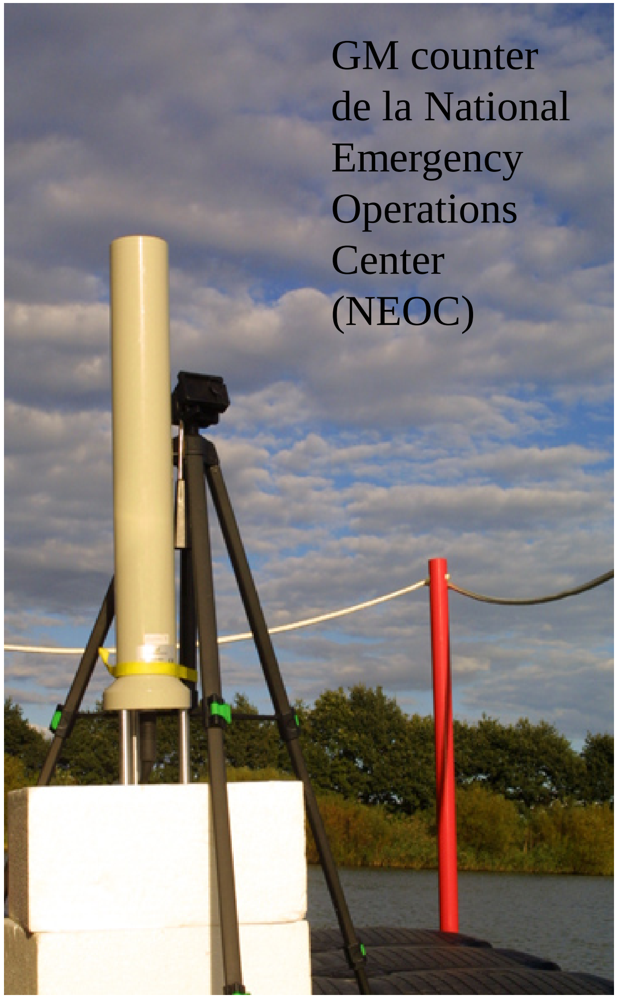
Ionisation-based detectors

Geiger-Müller counter

impulsion $s^{-1} \rightarrow$ dose s^{-1}

Dose rate probes
Berthold LB1236 / LB123

Automess



GM counter
de la National
Emergency
Operations
Center
(NEOC)

Properties of gas detectors

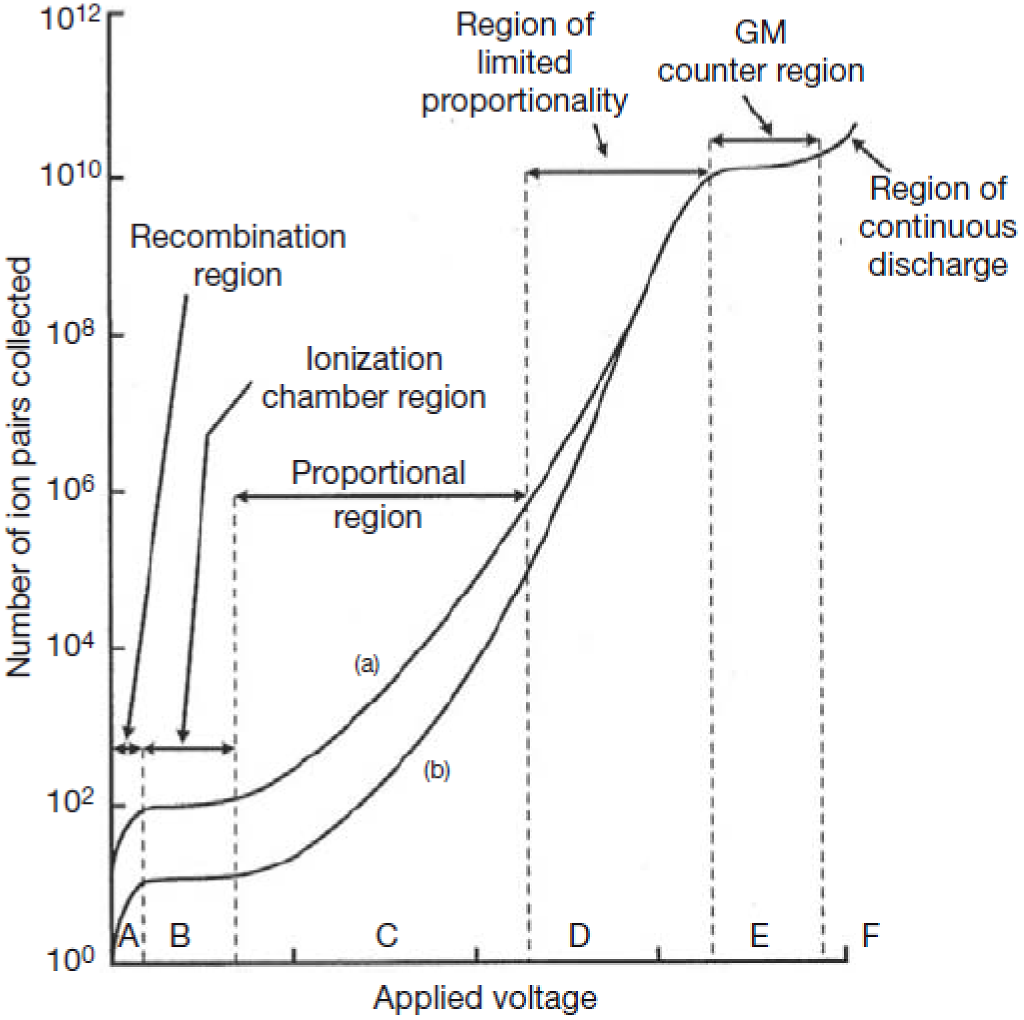


FIG. 4.1. Various regions of operation of a gas filled detector. Region A represents the recombination region, region B the ionization region, region C the proportionality region, region D the region of limited proportionality and region E the GM region. Curve (a) is for 1 MeV β particles, curve (b) for 100 keV β particles.

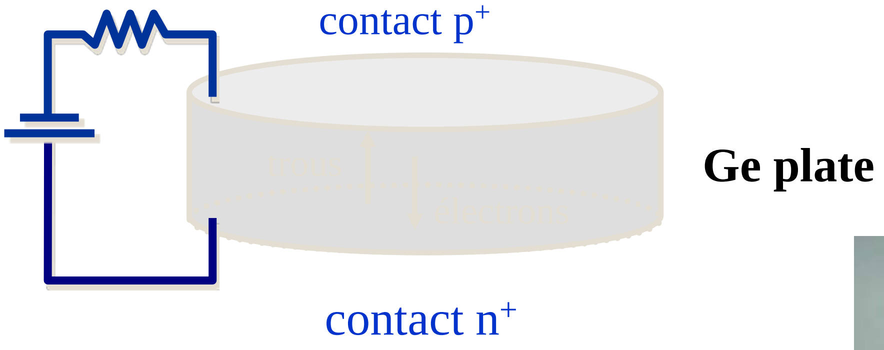
Ionisation-based detectors

Features:

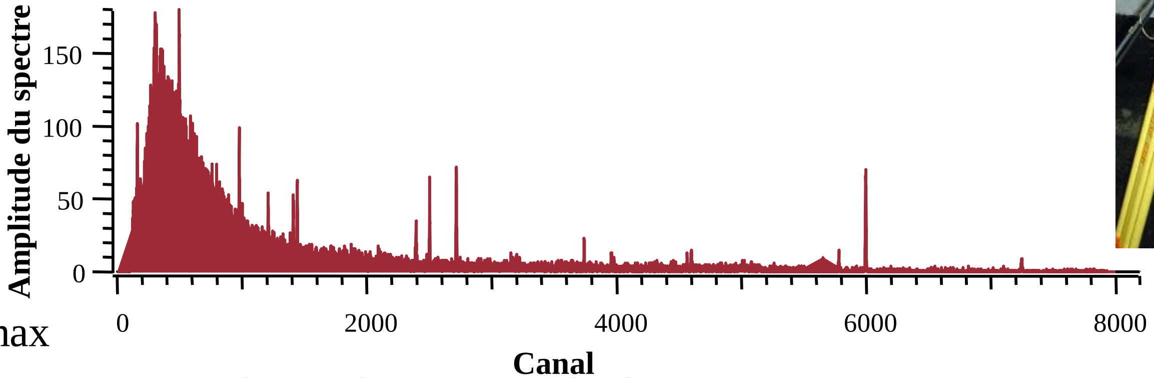
- Similar to detectors based on gaz ionisation

Used for:

- Dosimetry
- Spectrometry

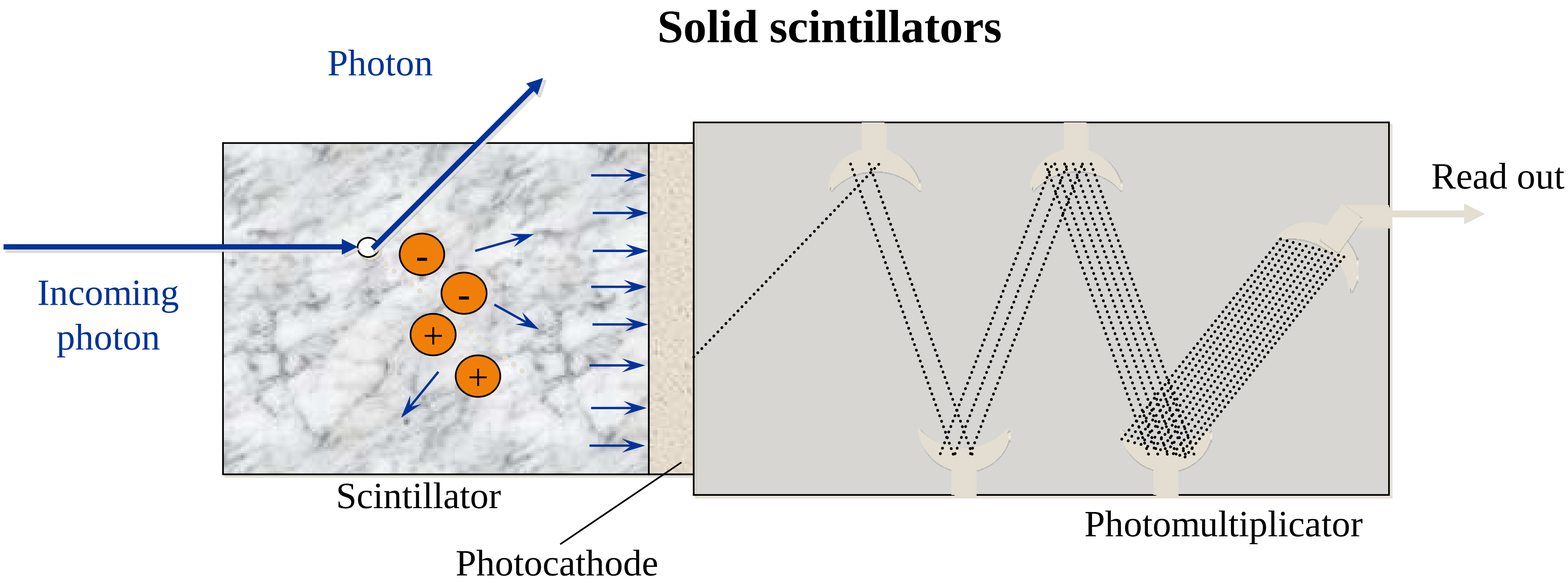


Dosimetry
Wellhöfer Dosimax



Background spectrum with a low activity Eu-250 source

Scintillation-based detectors



Scintillation-based detectors

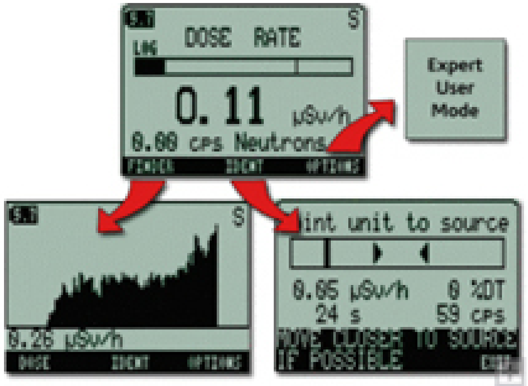
Falcon 5000® Portable
HPGe-Based Radionuclide

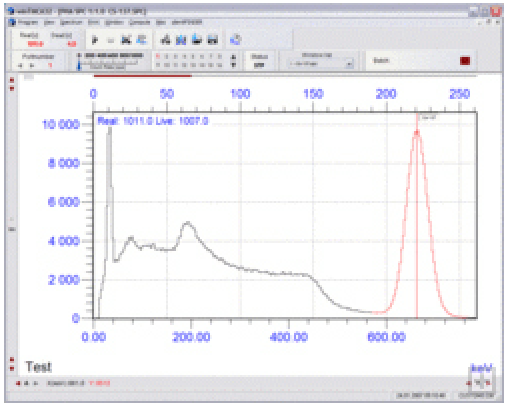
Geiger-Mueller detector
(γ)
Crystal scintillation
detector (γ)

Scintillation-based detectors

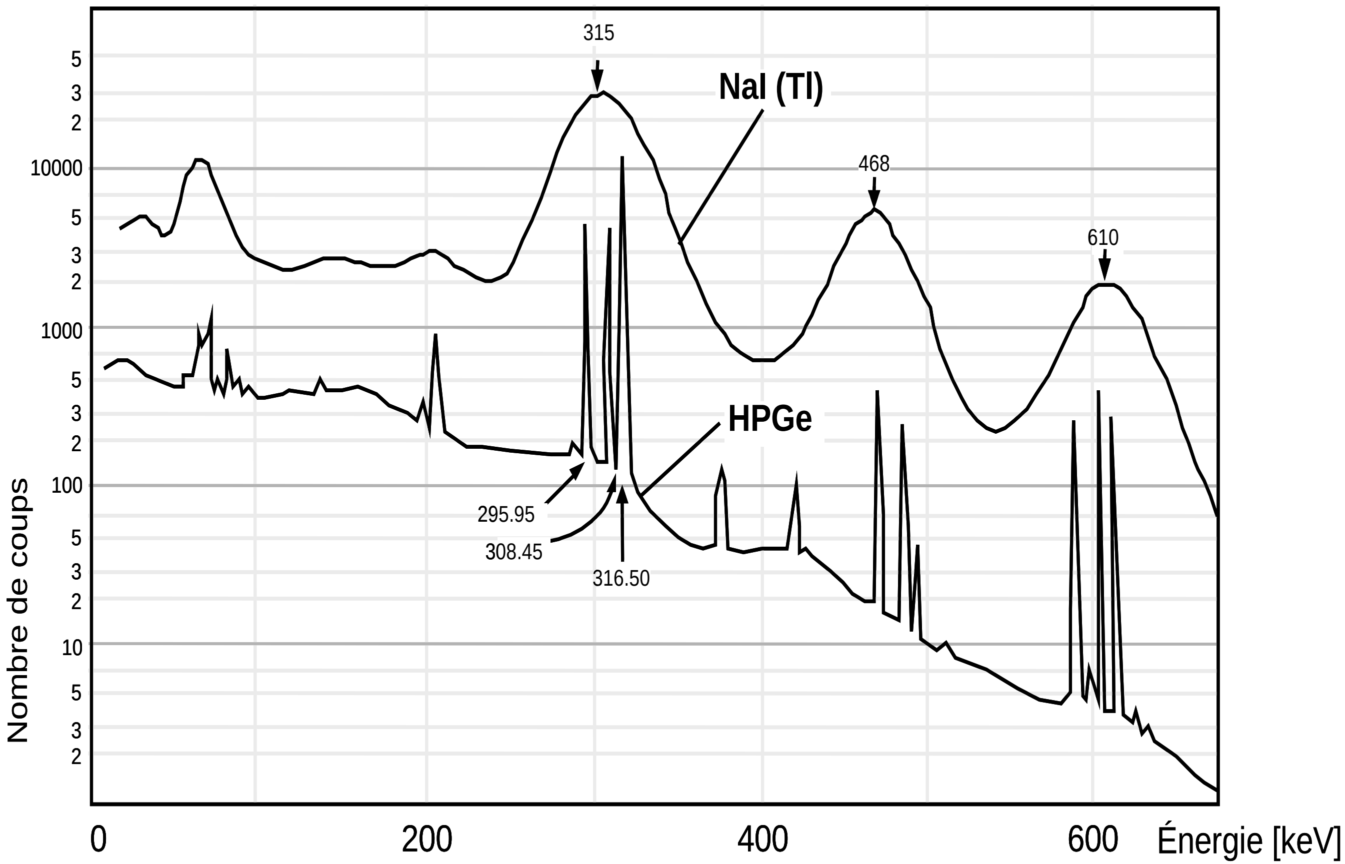
Fieldspec / identifinder

Geiger-Mueller detector(γ)
NaI(Tl) scintillation detector (γ)



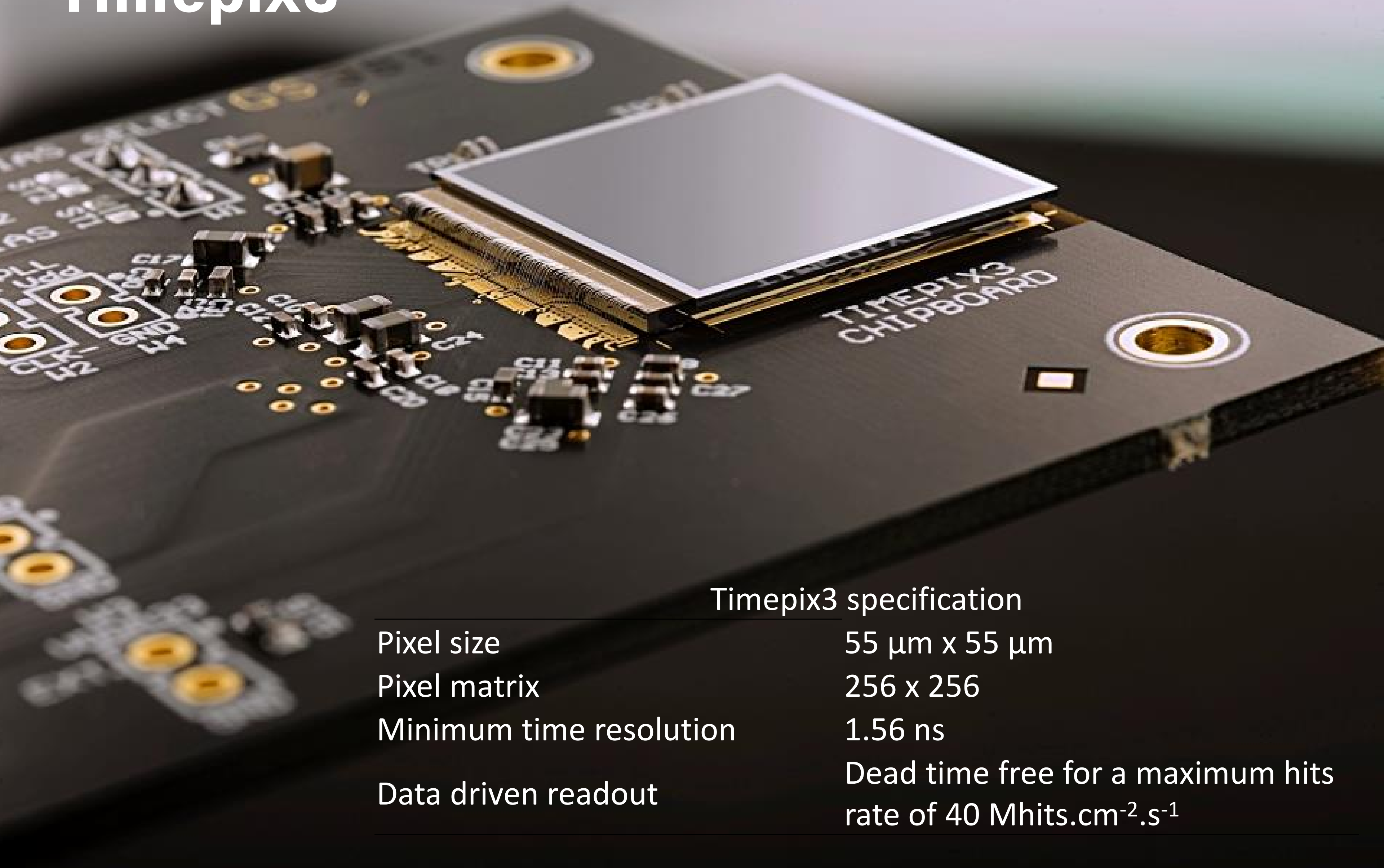


Detectors for γ spectrometry



Comparison of Iridium-192 spectrum measured with
a crystal scintillator (NaI) vs. a semi-conductor detector (HPGe).

Timepix3

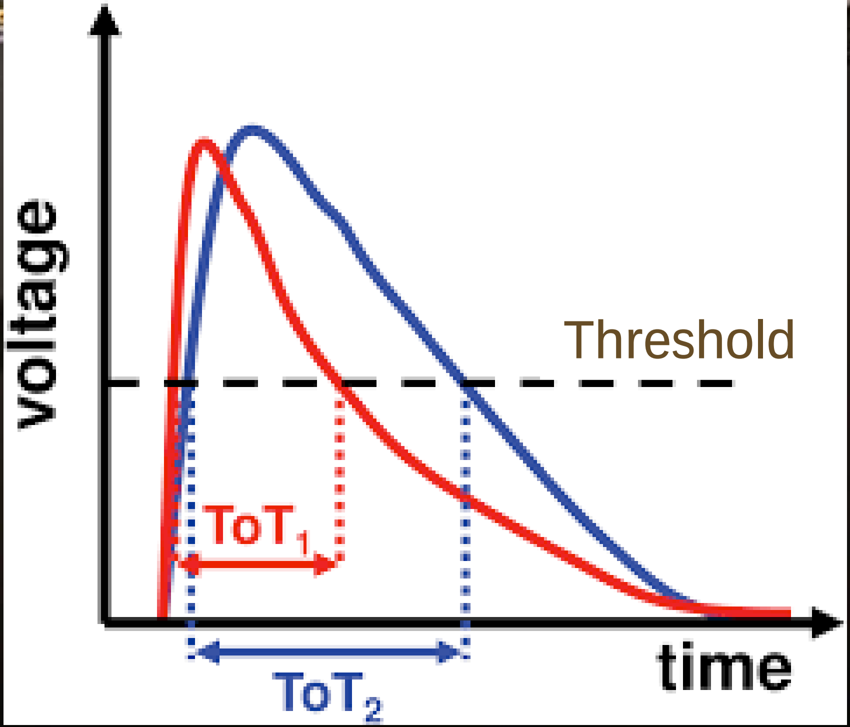


Timepix3 specification	
Pixel size	55 µm x 55 µm
Pixel matrix	256 x 256
Minimum time resolution	1.56 ns
Data driven readout	Dead time free for a maximum hits rate of 40 $\text{Mhits.cm}^{-2}.\text{s}^{-1}$

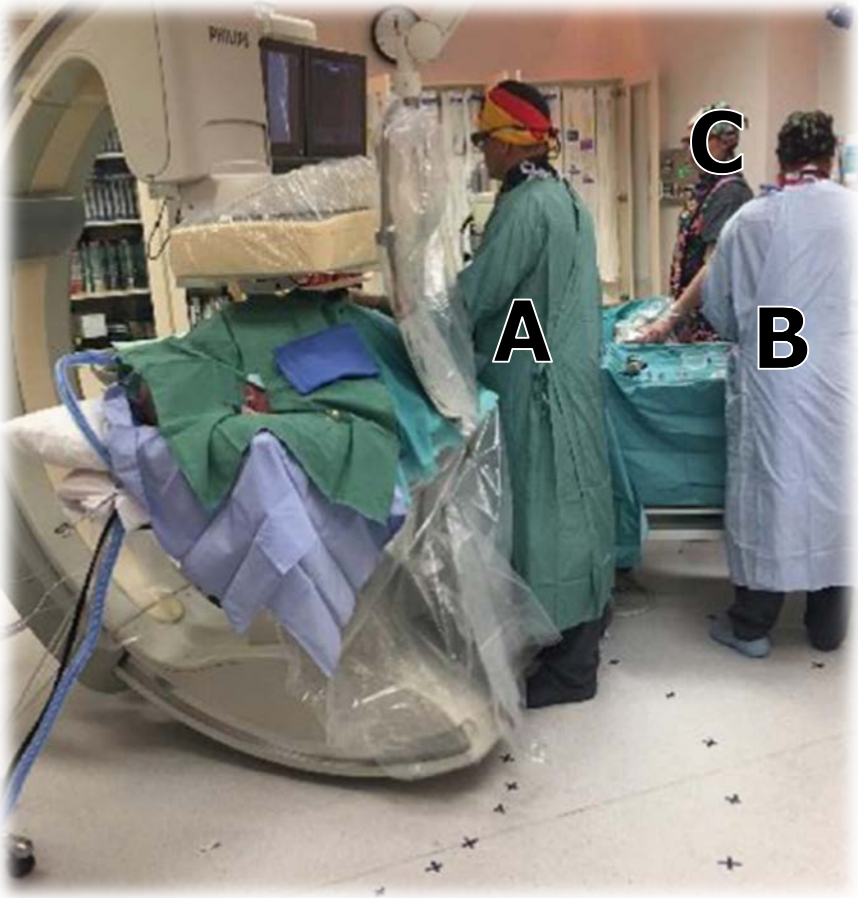
Timepix3

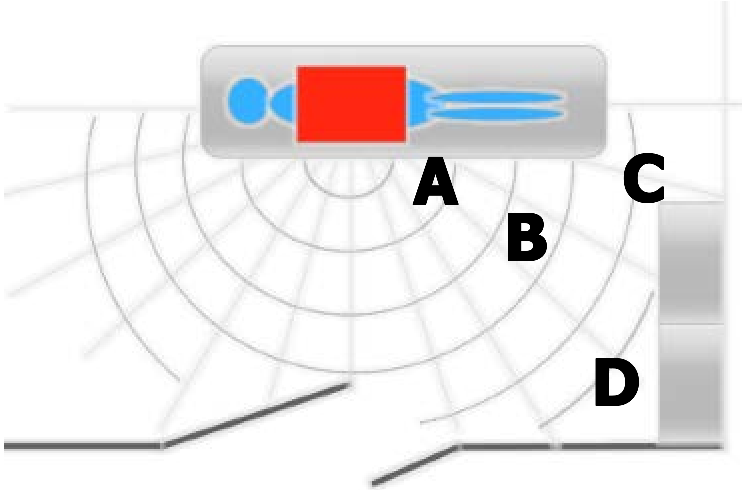
For each incoming photon:

- Spatial information
- Temporal information
- Time over Threshold = ToT



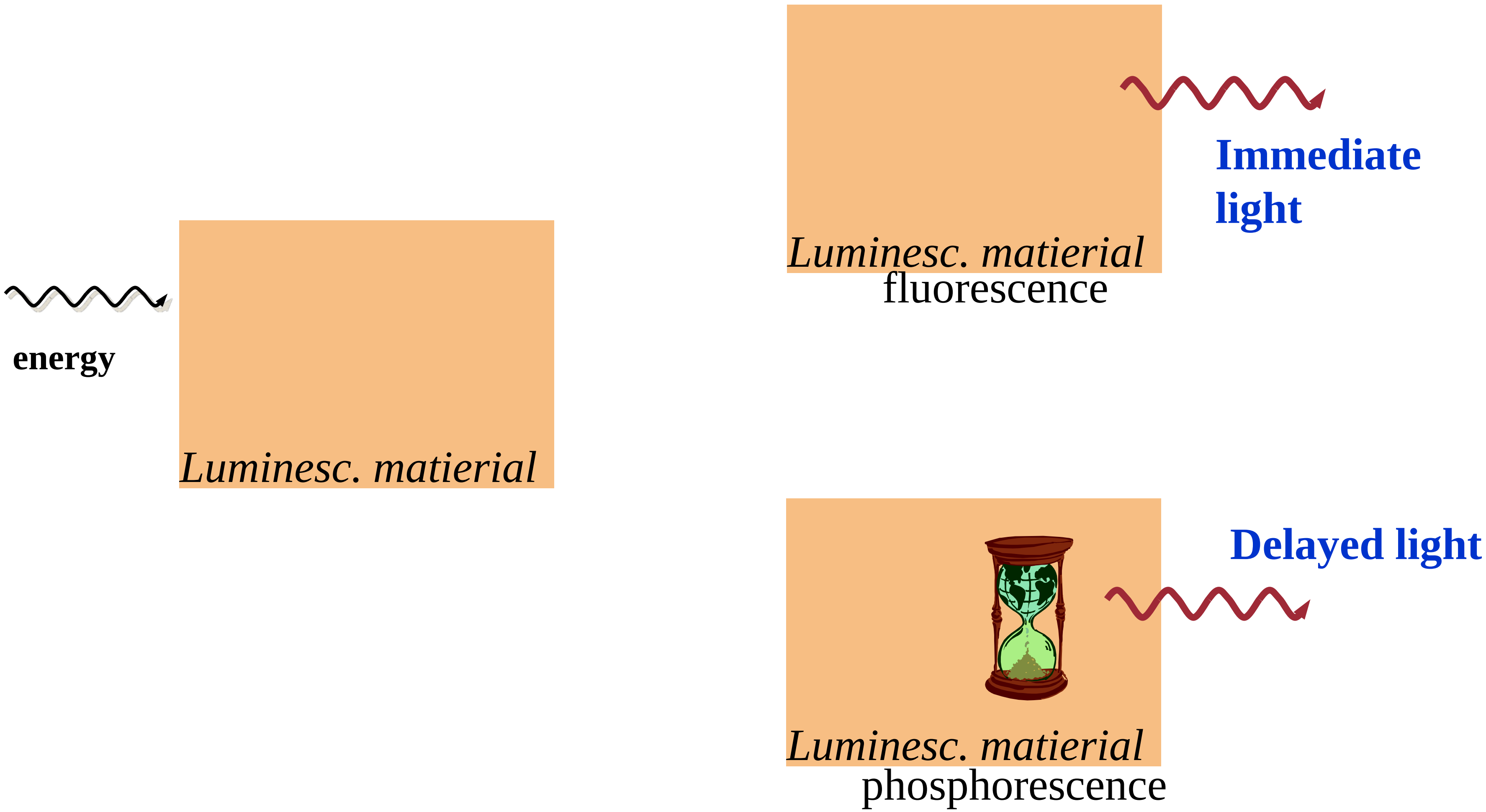
X-ray Spectra measurements





Luminescence-based detectors

Luminescence-based detectors



energy

Luminesc. matierial

Luminesc. matierial

fluorescence

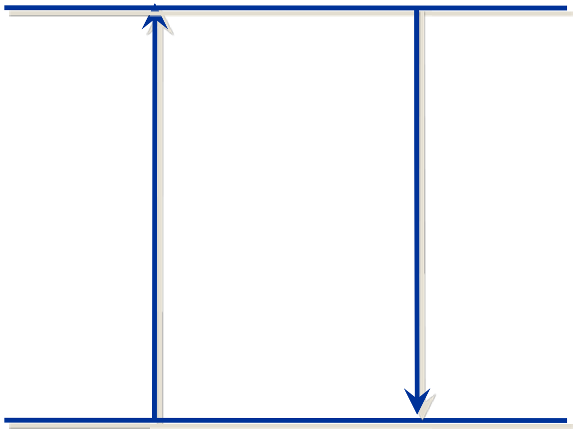
Immediate light

Luminesc. matierial

phosphorescence

Delayed light

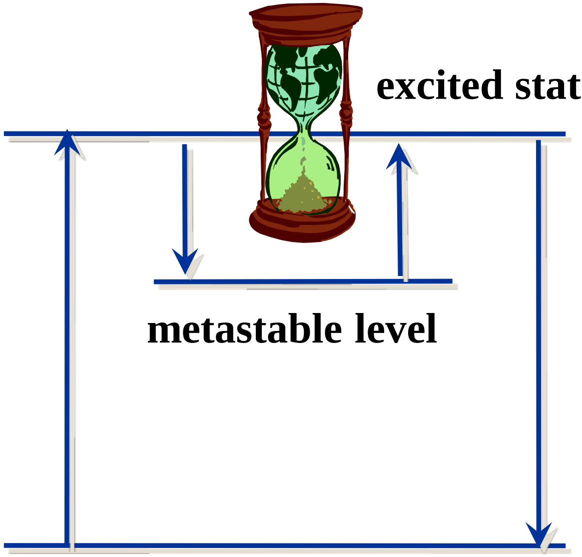
Luminescence-based detectors



excited state (e)

fundamental state (f)

Fluorescence



excited state (e)

metastable level

fundamental state (f)

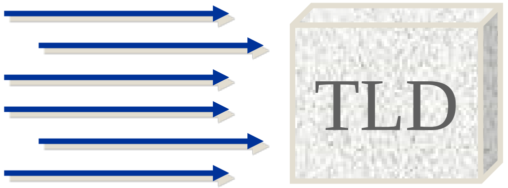
Phosphorescence

Luminescence-based detectors

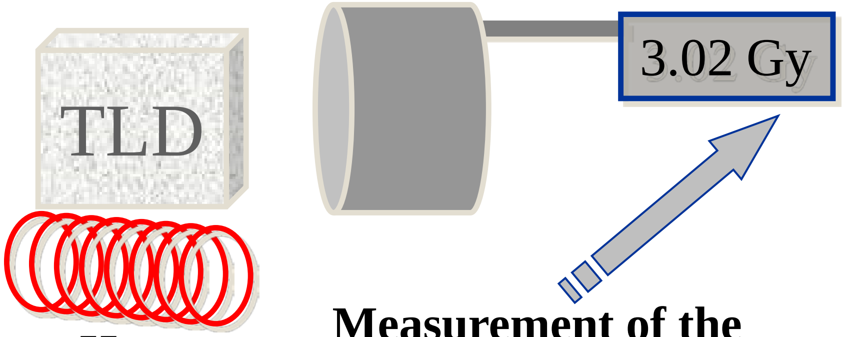
- Used for:

  Dosimetry

Irradiation



Read out



Heat

Measurement of the light

Luminescence-based detectors

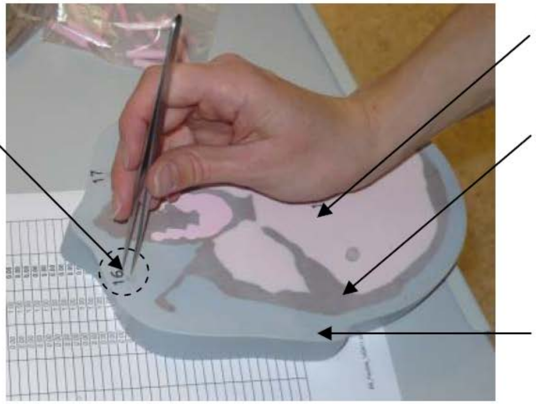
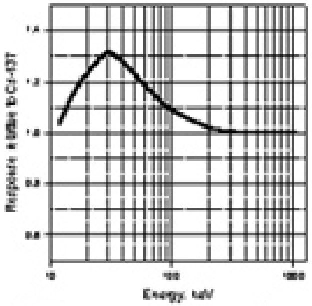


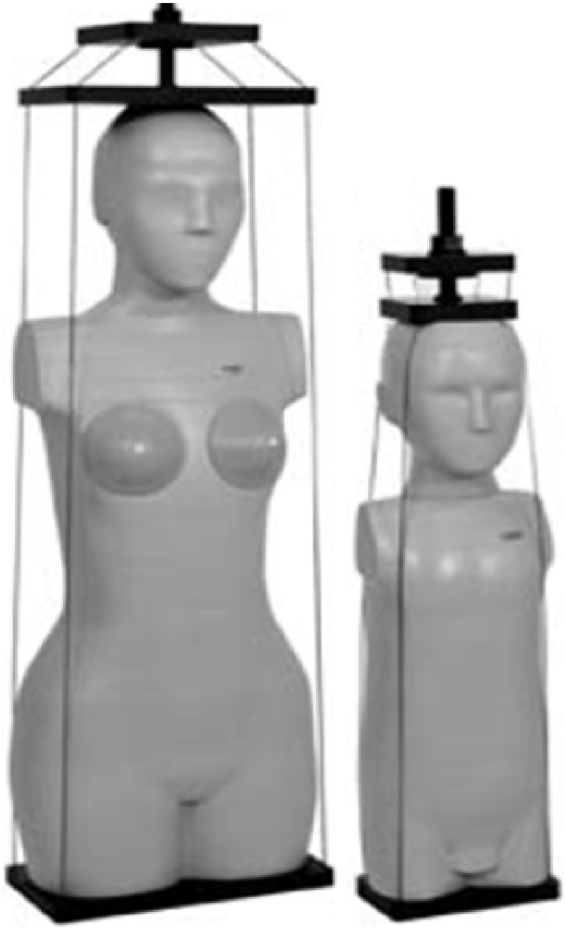
Figure 12: Example of a section of the phantom with the different organ densities and the TLDs' positions



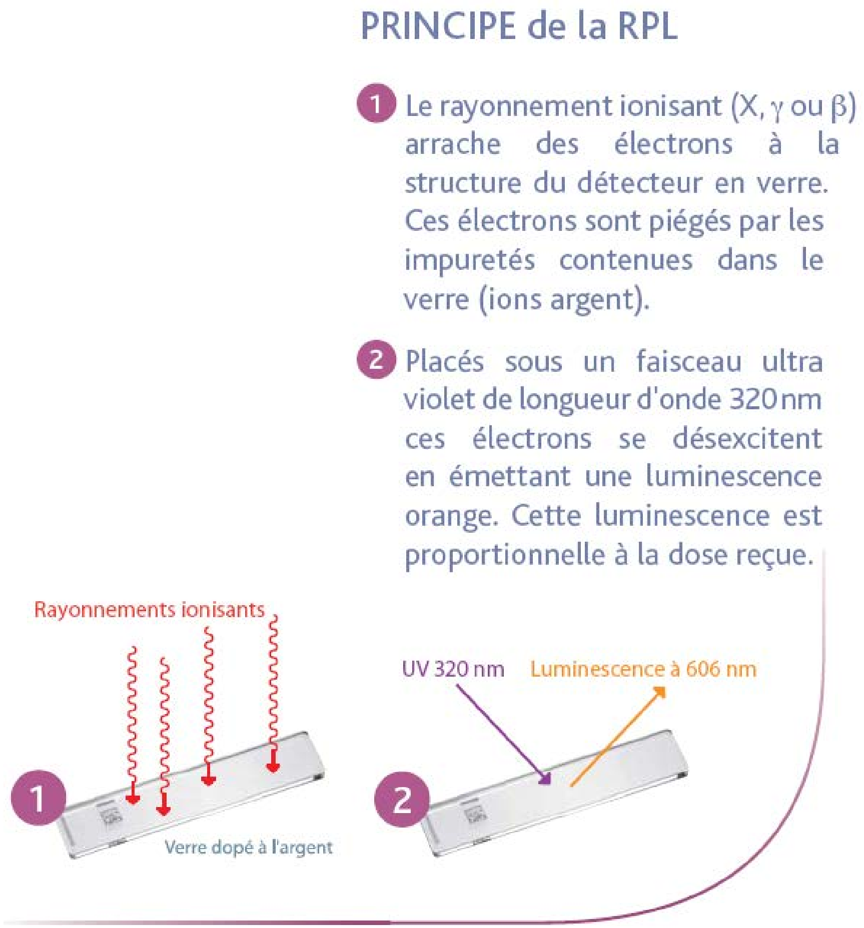
Photon energy dependence

Absorbed dose → Organ dose → calculation of the Effective dose

Anthropomorphic phantoms.



Luminescence-based detectors



PRINCIPE de la RPL

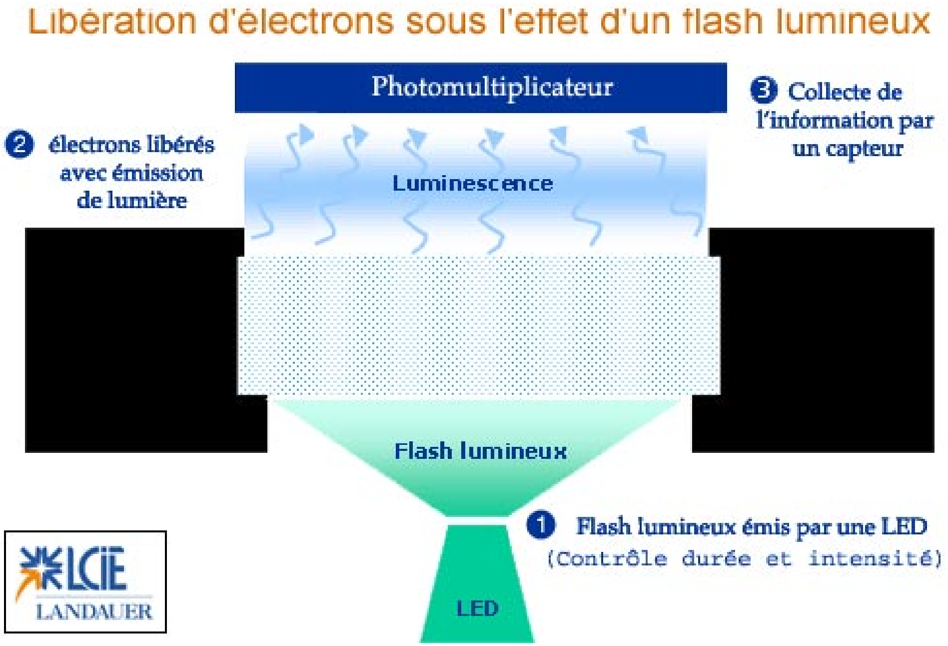
1. Le rayonnement ionisant (X, γ ou β) arrache des électrons à la structure du détecteur en verre. Ces électrons sont piégés par les impuretés contenues dans le verre (ions argent).

2. Placés sous un faisceau ultra violet de longueur d'onde 320 nm ces électrons se désexcitent en émettant une luminescence orange. Cette luminescence est proportionnelle à la dose reçue.

Luminescence-based detectors

OSL Optically Stimulated Luminescence

On illumine brièvement le cristal par une diode électroluminescente (LED). Ce flash lumineux (dont on contrôle l'intensité et la durée) libère une fraction des électrons piégés par les impuretés de carbone. Ces électrons restituent leur supplément d'énergie sous forme de lumière. Cette émission de lumière qui est proportionnelle au nombre d'électrons piégés, donc à la dose, est mesurée par un photomultiplicateur.

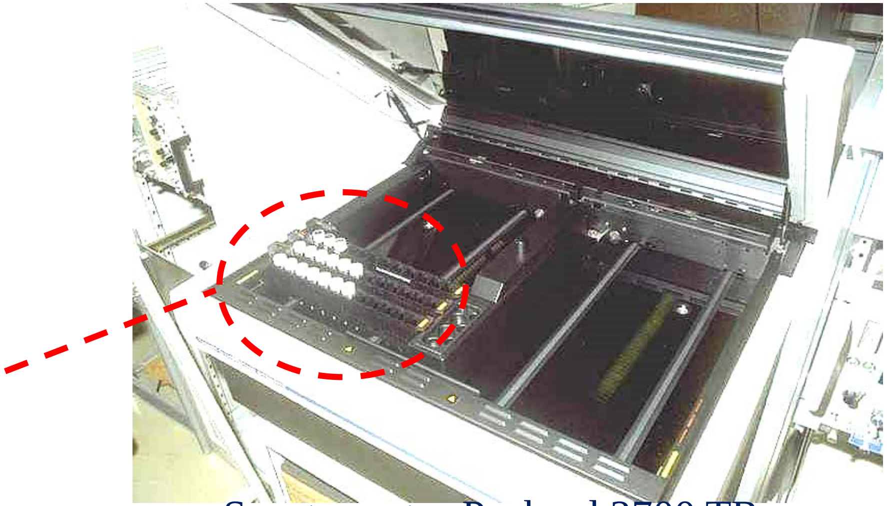


Scintillation-based detectors

Liquid scintillators

<u>Features</u>:

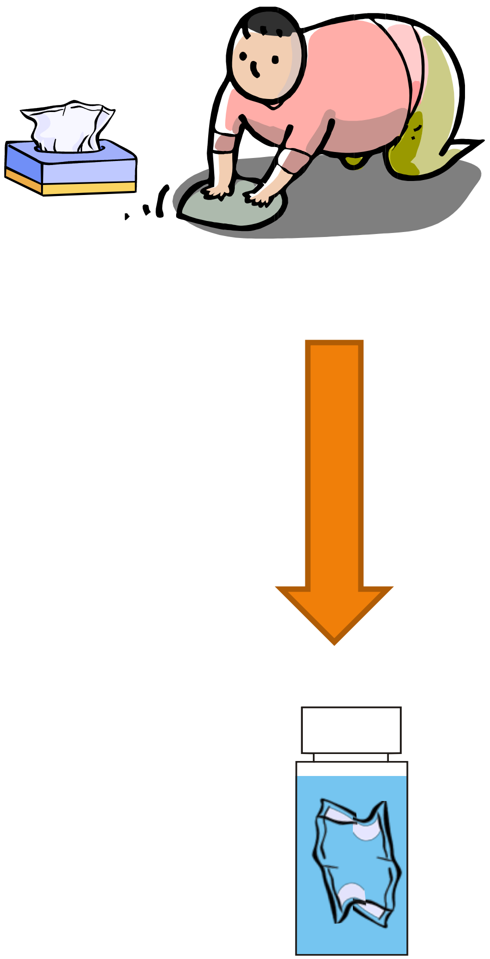
- fluorescent liquid is added to the source
- the amount of emitted light is proportional to the dose
- light is measured with a photomultiplicator (PM tube)
- spectrometry

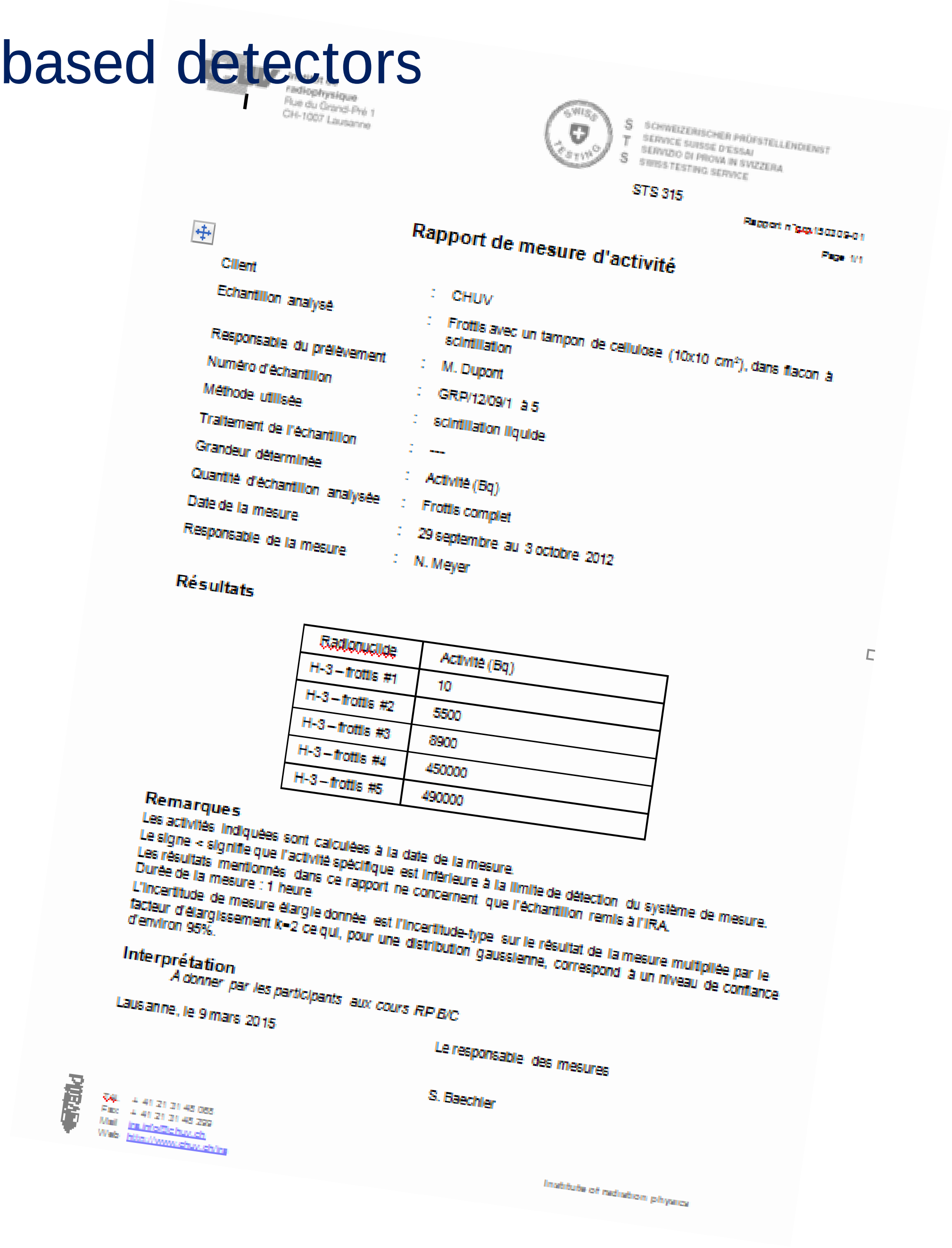


samples

Spectrometer Packard 2700 TR

Scintillation-based detectors





Institut de radiophysique
Rue du Grand-Pré 1
CH-1007 Lausanne

SCHWEIZERISCHER PRÜFSTELLENDIENST
SERVICE SUISSE D'ESSAI
SERVIZIO DI PROVA IN SVIZZERA
SWISS TESTING SERVICE

STS 315

Rapport n° [illegible]

Page 1/1

Rapport de mesure d'activité

Client : CHUV
Echantillon analysé : Frottis avec un tampon de cellulose (10x10 cm^2), dans flacon à scintillation
Responsable du prélèvement : M. Dupont
Numéro d'échantillon : GRP/12/09/1 à 5
Méthode utilisée : scintillation liquide
Traitement de l'échantillon : ---
Grandeur déterminée : Activité (Bq)
Quantité d'échantillon analysée : Frottis complet
Date de la mesure : 29 septembre au 3 octobre 2012
Responsable de la mesure : N. Meyer

Résultats

Radionuclide	Activité (Bq)
H-3 – frottis #1	10
H-3 – frottis #2	5500
H-3 – frottis #3	8900
H-3 – frottis #4	450000
H-3 – frottis #5	490000

Remarques

Les activités indiquées sont calculées à la date de la mesure.
Le signe < signifie que l'activité spécifique est inférieure à la limite de détection du système de mesure.
Les résultats mentionnés dans ce rapport ne concernent que l'échantillon remis à l'IRA.
Durée de la mesure : 1 heure
L'incertitude de mesure élargie donnée est l'incertitude-type sur le résultat de la mesure multipliée par le facteur d'élargissement k=2 ce qui, pour une distribution gaussienne, correspond à un niveau de confiance d'environ 95%.

Interprétation

A donner par les participants aux cours RP B/C

Lausanne, le 9 mars 2015

Le responsable des mesures

S. Baechler

Tél. + 41 21 31 48 088
Fax + 41 21 31 48 299
Mail ira.info@chuv.ch
Web http://www.chuv.ch/ira

Institute of radiation physics

Calorimetry-based detectors

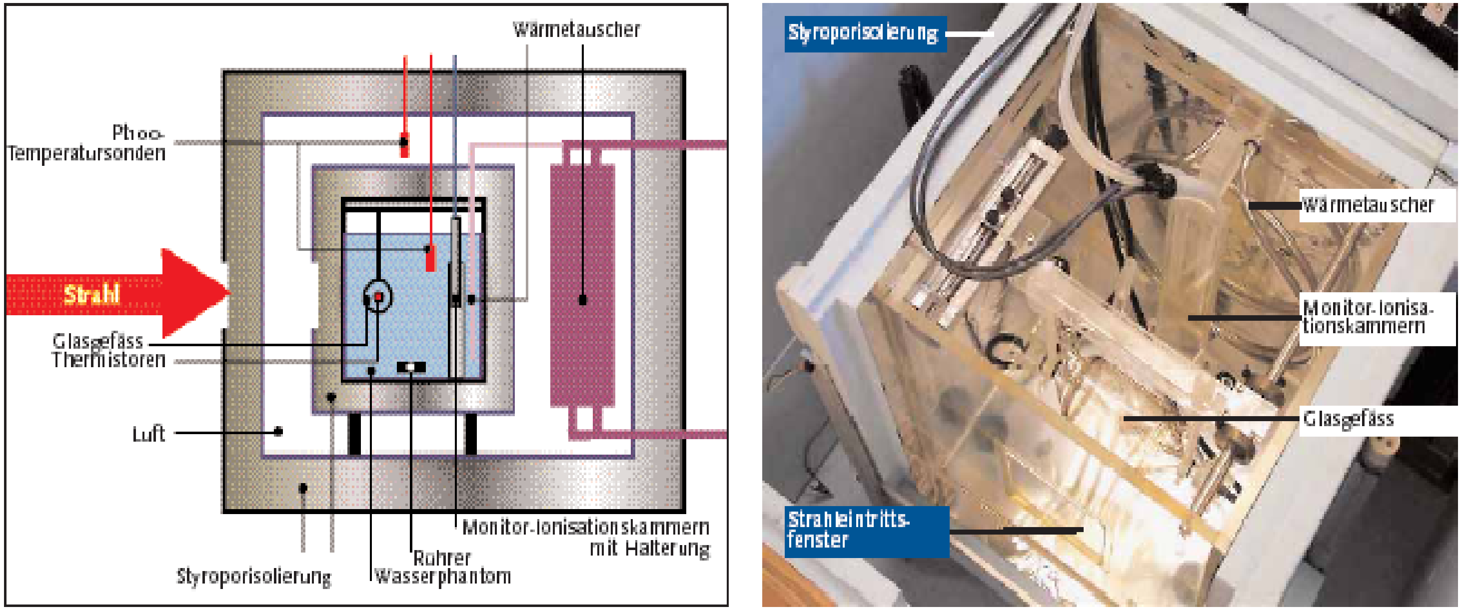


Diagram of calorimetry in water performed at the Swiss Primary Lab: METAS

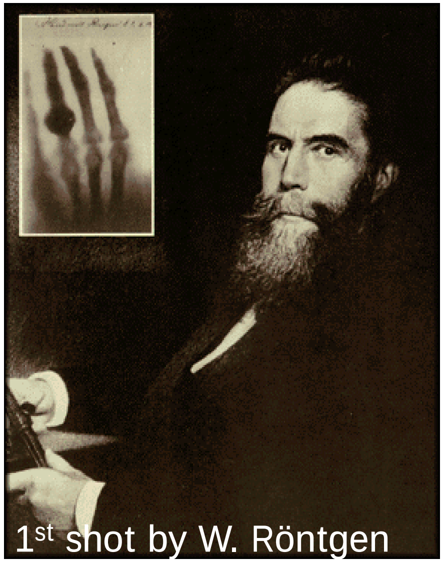
the temperature increase corresponding to an absorbed dose of 1 Gy is approximately 10^{-3} °C in graphite. This measurement technique, which allows for an absolute determination of absorbed dose, is mainly used in national metrology labs to calibrate other measuring instruments

Chemical detectors

Emulsion sheets

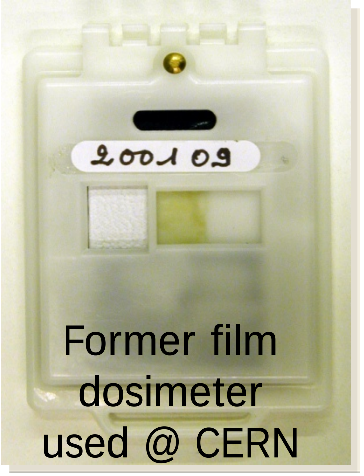
<u>Features</u>:

- Particles ionise silver bromide crystals
- Silver grains (after developement) are opaque to light
- the blackness is directly related to the dose


1st shot by W. Röntgen

<u>Used for</u>:

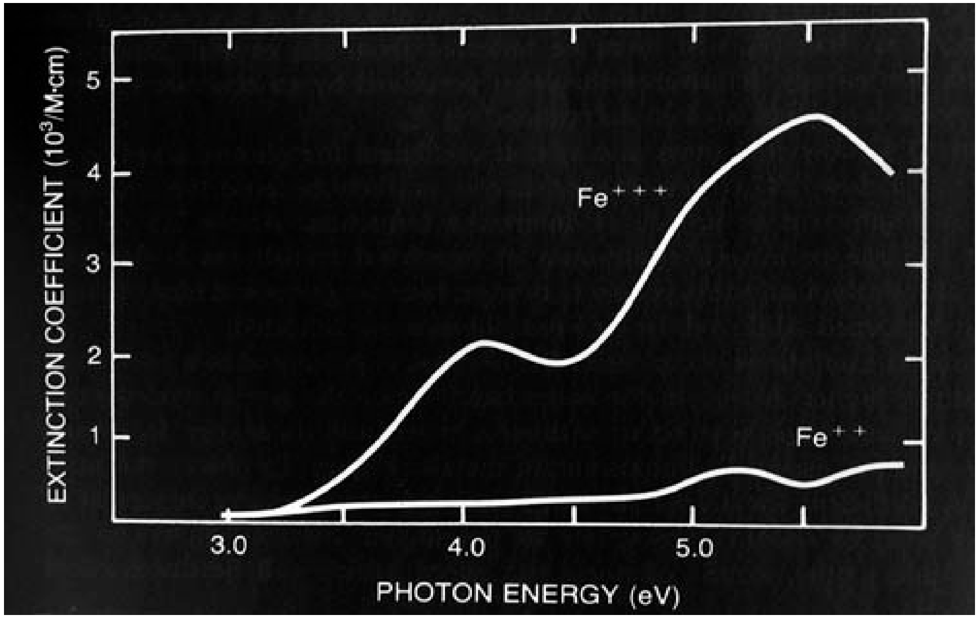
- radiography
- personal dosimetry
- 2D dosimetry for radiotherapy beam



Former film dosimeter used @ CERN

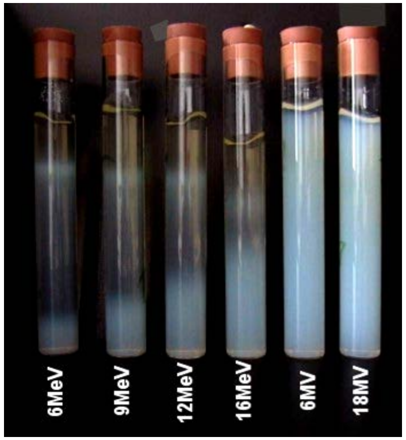
Other detectors

Frick



Irradiating a ferrous solution (Fe^{2+}) leads to the appearance of ferric ions (Fe^{3+}) whose relationship is directly linked to absorbed dose. This property is used as the basis of a system called Fricke dosimetry and is used as a primary measurement of absorbed dose.

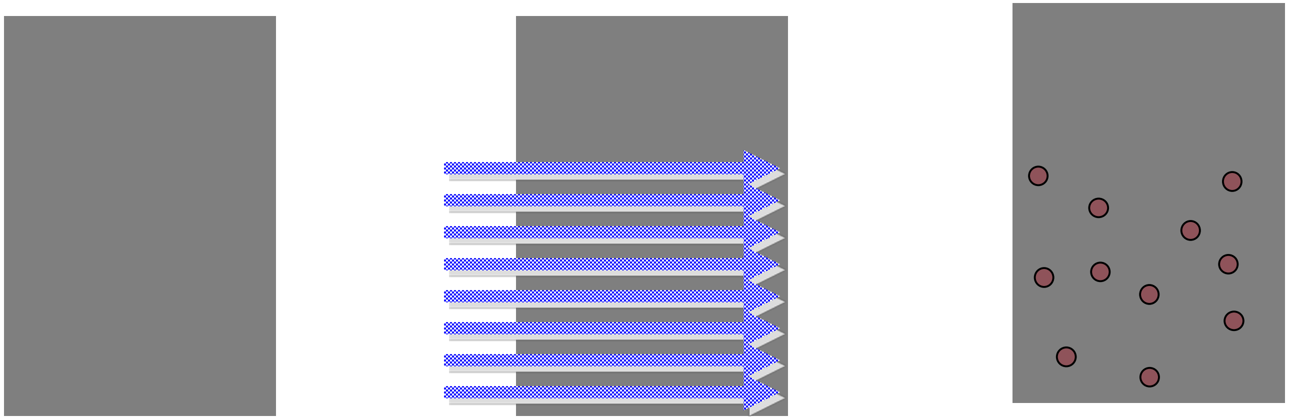
Gel-based dosimetry



Example of polymer gels irradiated by photon beams at increasing energy

Other detectors

Bubble dosimetry is a technique which uses a tube filled with a transparent gel. This gel contains very fine drops of a superheated liquid. When any neutronic radiation touches one of the drops, the liquid turns into a vapor and forms a bubble which remains trapped inside the gel. This type of dosimetry measures neutrons in real time and is not sensitive to photons.



Gel + liquide en suspension

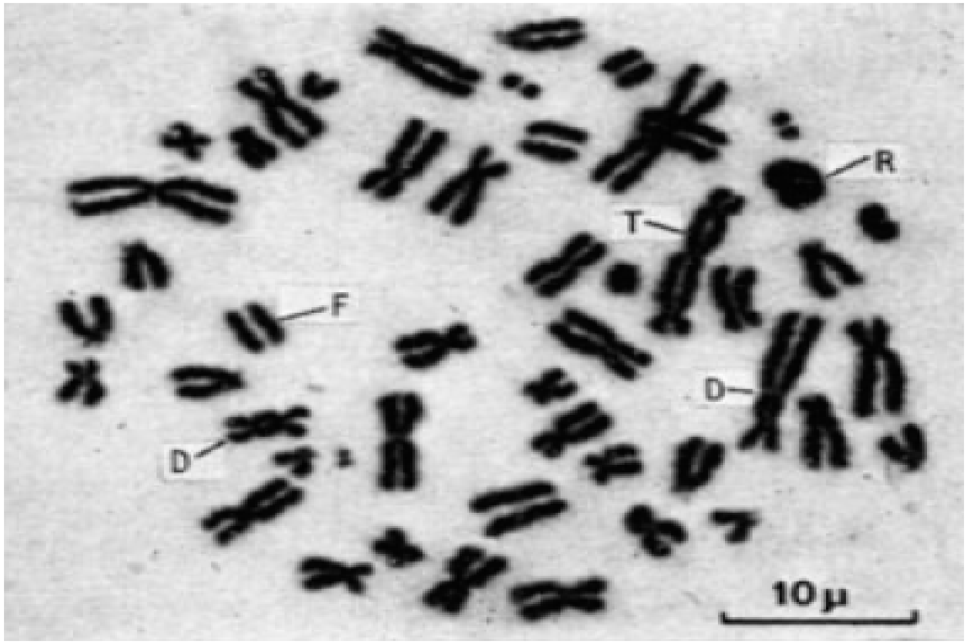
Irradiation

Formation de bulles

Other detectors

Ionizing radiation can modify the chromosomal structure of an irradiated individual.

In a situation of strong irradiation, it is possible to estimate the received dose by calculating the number of chromosomal abnormalities in the entire cell structure



Measurements in radiation protection

Measuring ambient radiation

The goal of measuring ambient radiation is to determine individual irradiation in a relatively wide radiation field.

This concerns penetrating radiation, meaning γ (X-ray or neutrons).

It can also be used to determine the exposure linked to a specific task, or determine the efficiency of shielding protection (measure *without* shielding, then *with*).

There are also stationary instruments which can be used for continuous monitoring of the level of ambient radiation in certain laboratories; these generally carry alarms and a data recording function.

→ Dose rate meter

→ Ambient dose rate equivalent in μSv/h or mSv/h

Measurements in radiation protection

Example:

The irradiation of nuclear medicine personnel when manipulating Tc-99m for a radiodiagnostic exam can be evaluated using a dosimeter.

A radioactive package sent through the post must not present a dose rate higher than 5 μSv/h on the surface of the package. To ensure the shielding of a radioactive source is sufficient and that the limit is not exceeded, we use a dose rate meter when preparing the package for shipping.

Measurements in radiation protection

Measurements in radiation protection

Measuring surface contamination

→ Surface contamination monitor

→ Contamination in counts per second or pulses per second → Bq.cm^{-2}

Measurements in radiation protection

Measuring activity intake – screening measurements

Handling radioactive substances in liquid or powder form can involve a risk of activity intake (through inhalation or ingestion).

For individuals exposed to this risk, regular monitoring is recommended.

Monitoring consists in a rough measurement, called a screening measurement, whose goal is to detect any internal contamination. If necessary, a more precise measurement is then conducted with a dosimetry department for intake

→ the instrument depends on the incorporated nuclide

→ the measured parameter depends on the instrument → Bq

AD6 + Probe ADb

AD6 + probe AD17

AD6 + probe ADK

RadEye

Application	Contamination $\alpha\beta\gamma$	Contamination $\beta\gamma$	Dose Rate H*(10)	Dose Rate H'07
Autodetection Filter	No Filter	Alpha Blocker 425068581	H*(10)Filter 425068582	H'07 Filter 425068583
RadEye B20 / B20-ER				
Filter Code displayed at the LCD	No Code	(α Blocker)	(H*(10))	(H'07)
Related Units	cps cpm Bq/cm² Bq dpm dps	cps cpm Bq/cm² Bq dpm dps	Sv/h rem/h	Sv/h rem/h

Automatic recognition of the filter by the RadEye's processor

Automatic recognition of the filter by the RadEye's processor

Measurements in radiation protection

< 500 Gauss (0.05 T)

Issu du transfert de technologie du CERN

Personal dosemeters

- What are the objectives and goals of the individual dosimetry?
- Who is concerned?
- What do you measure ?
- How is dosimetry monitored?

Personal dosemeters

- body-worn
- calibrated on phantom
- measure depth and skin dose ($H_p(10)$ and $H_p(0.07)$ …)

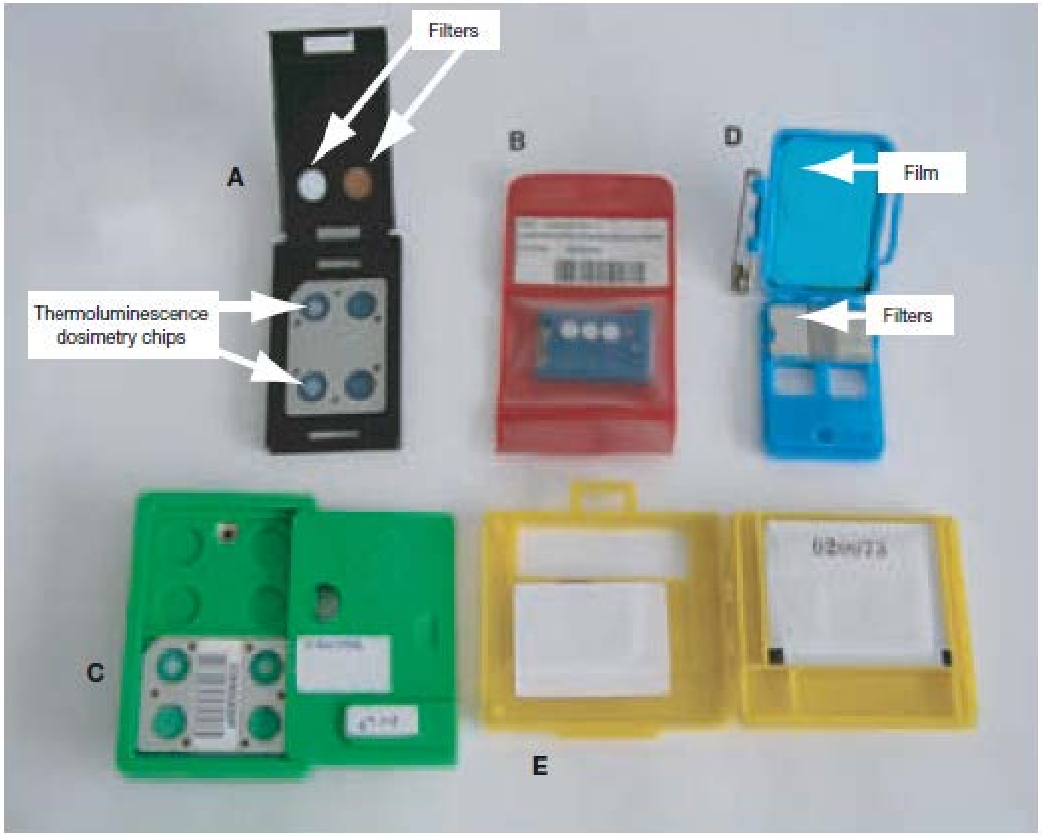


FIG. 4.5. Personal dosimeters: examples of thermoluminescence dosimetry badges (A, B, C) and film badges (D, E).

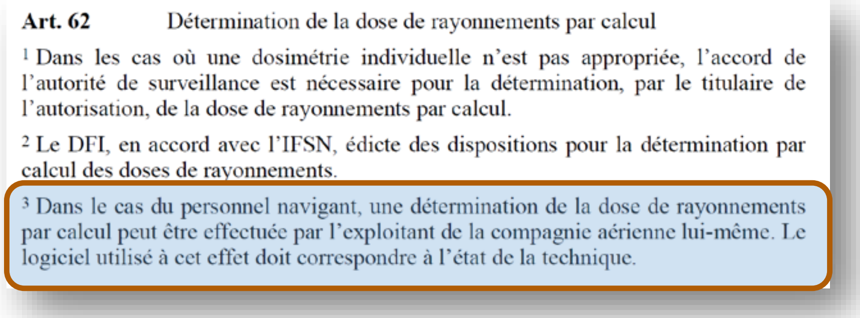
Personal dosemeters

whole body personal TL dosemeters

electronic personal dosemeters (Si diode)

TL dosemeters for extremities

Personal dosimetry

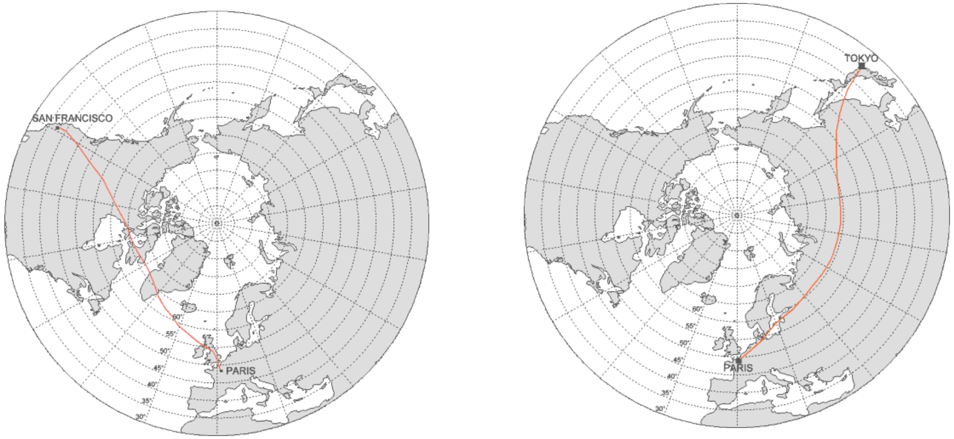


Art. 62 Détermination de la dose de rayonnements par calcul

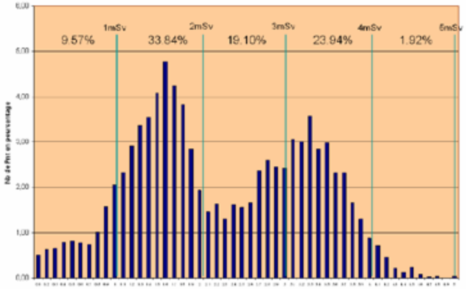
[1] Dans les cas où une dosimétrie individuelle n'est pas appropriée, l'accord de l'autorité de surveillance est nécessaire pour la détermination, par le titulaire de l'autorisation, de la dose de rayonnements par calcul.

[2] Le DFI, en accord avec l'IFSN, édicte des dispositions pour la détermination par calcul des doses de rayonnements.

[3] Dans le cas du personnel navigant, une détermination de la dose de rayonnements par calcul peut être effectuée par l'exploitant de la compagnie aérienne lui-même. Le logiciel utilisé à cet effet doit correspondre à l'état de la technique.



74 µSv



4204 **flight deck crew** (2007)

AIR FRANCE

58 µSv

11h38

Objectives

- Become familiar with dosimetry and radiation measurements

- Understand the main concepts:
  - Definition of quantities
  - Interaction of radiation with biological systems
  - Radiation measurements (principles and use)