Prof François Bochud
Institut de radiophysique (IRA)
UNIL / CHUV

Chapter 1. Dosimetry

Kerma (Kinetic energy released per unit mass)

$$K = \frac{\Delta E_{tr}}{\Delta m}$$

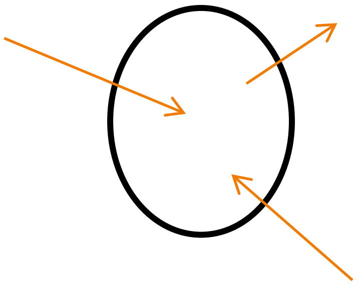
- Energy transferred (ΔE_{tr}) from the photons to the electrons within an element of mass (Δm)
- Units: Energy / mass = J/kg = Gy

- Defines a **photon field** in one point (not its effect)
- Has to be defined for a particular material
  - for instance: "**air kerma**"

Absorbed dose

- Energy deposited locally per unit mass

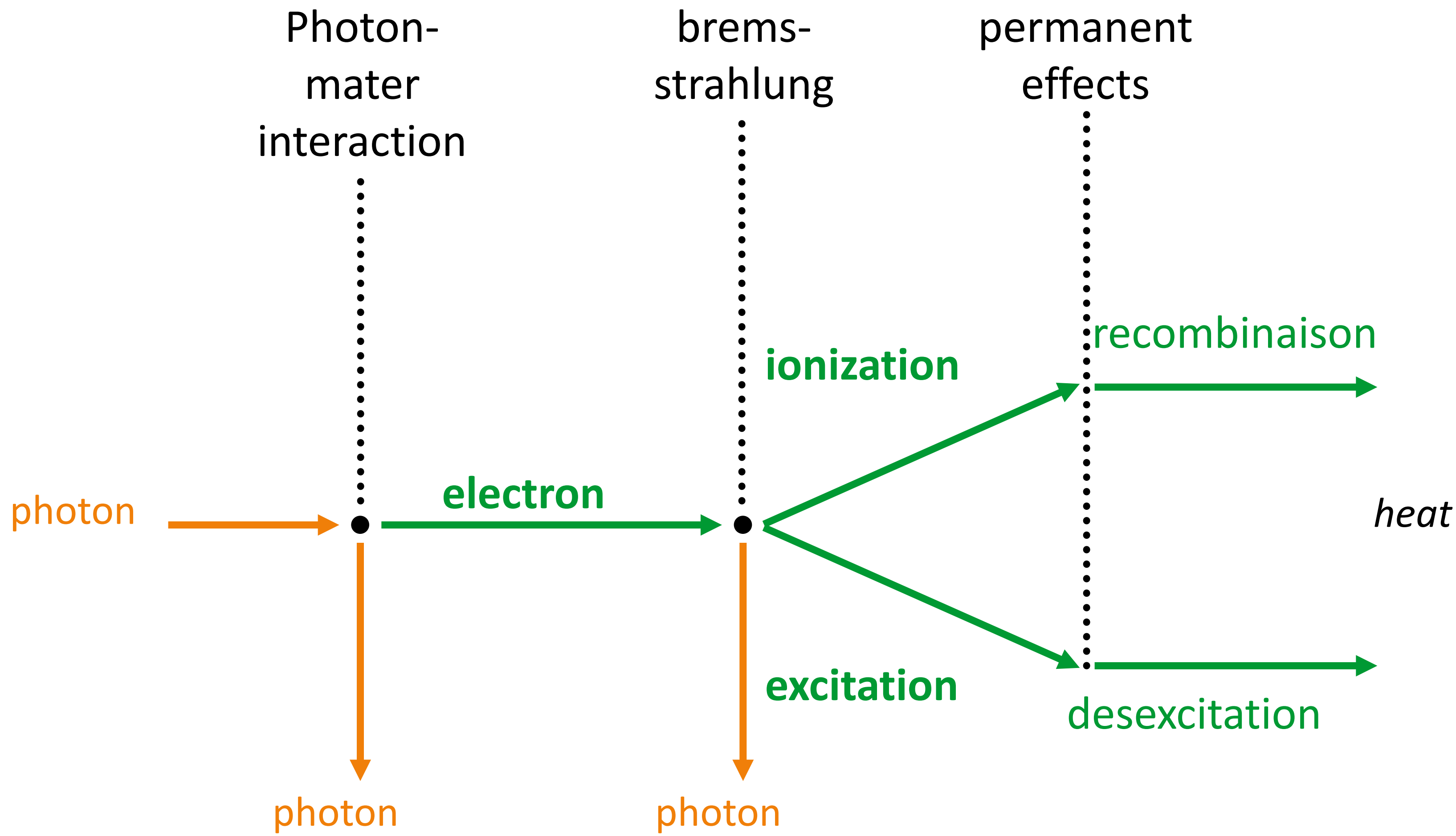
$$D = \frac{\Delta E}{\Delta m}$$



  - Units: Energy / mass = J/kg = Gy

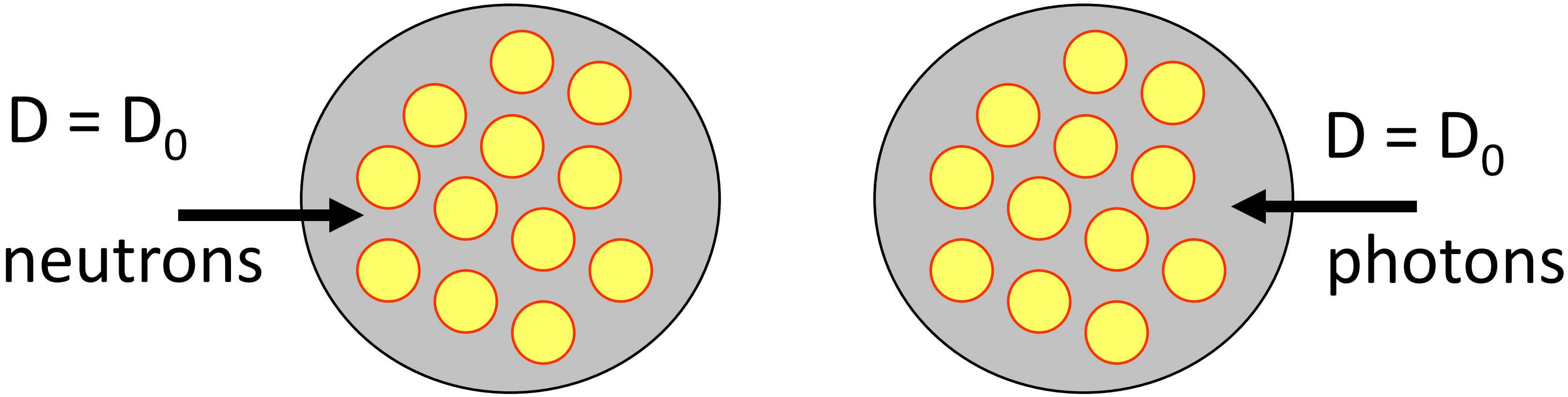
- Used for any kind of radiation
- Defines a **physical effect** of the beam in matter
- Has to be defined for a particular material
  - for instance "**absorbed dose to water**"

Energy deposit: **photons**



Dose equivalent

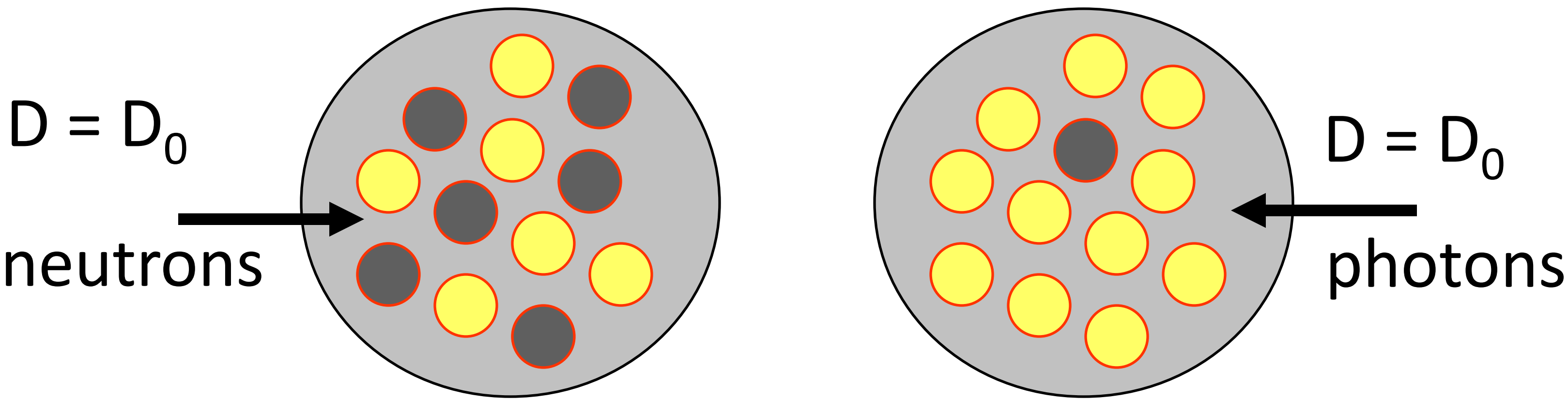
Same absorbed dose D_0



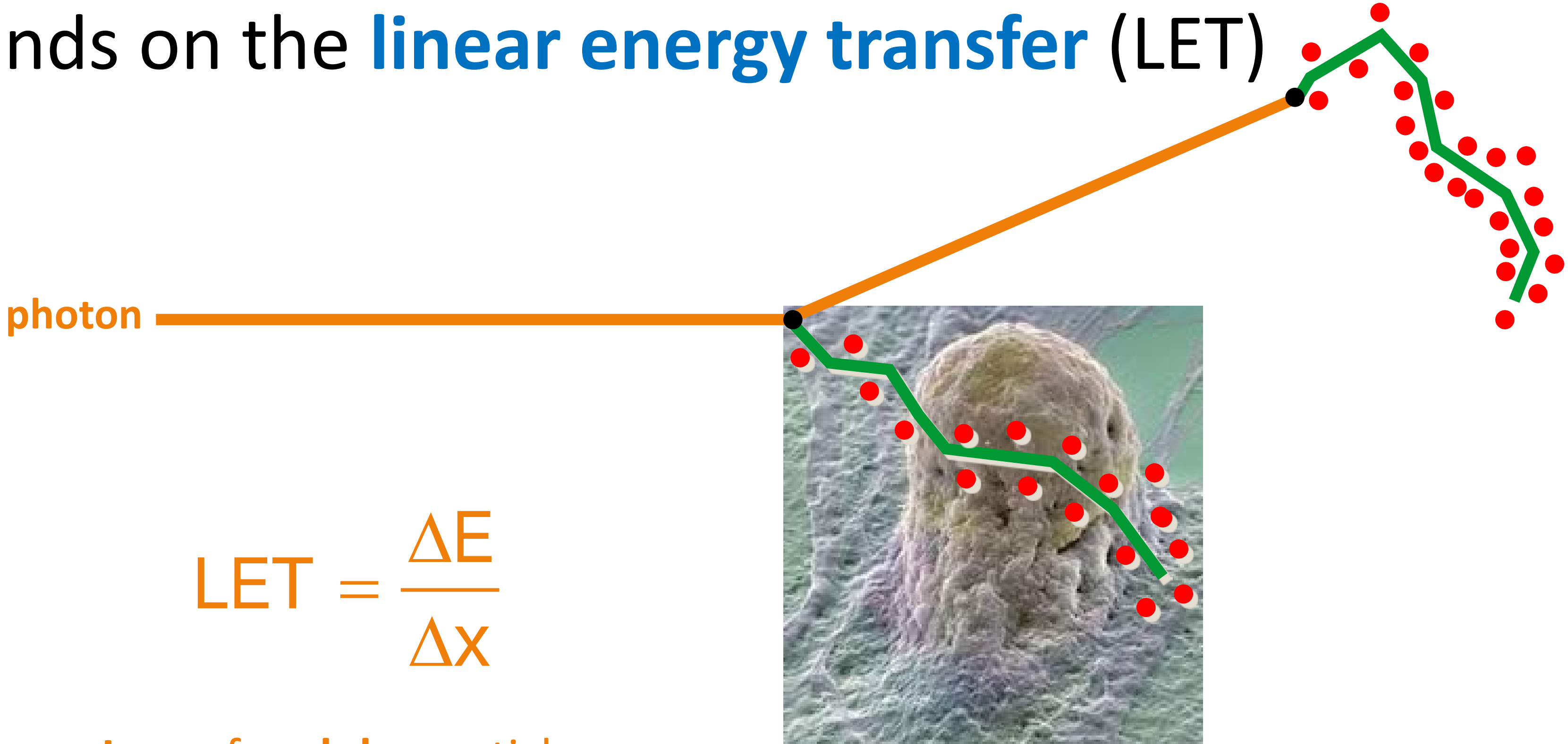
Dose equivalent

Same absorbed dose D_0

- Different effects



The **biological effect** is quantified by the relative biological effect (RBE), which depends on the **linear energy transfer** (LET)



$$\mathrm{LET} = \frac{\Delta E}{\Delta x}$$

Large for **alpha** particles

Smaller for **electrons**

electrons

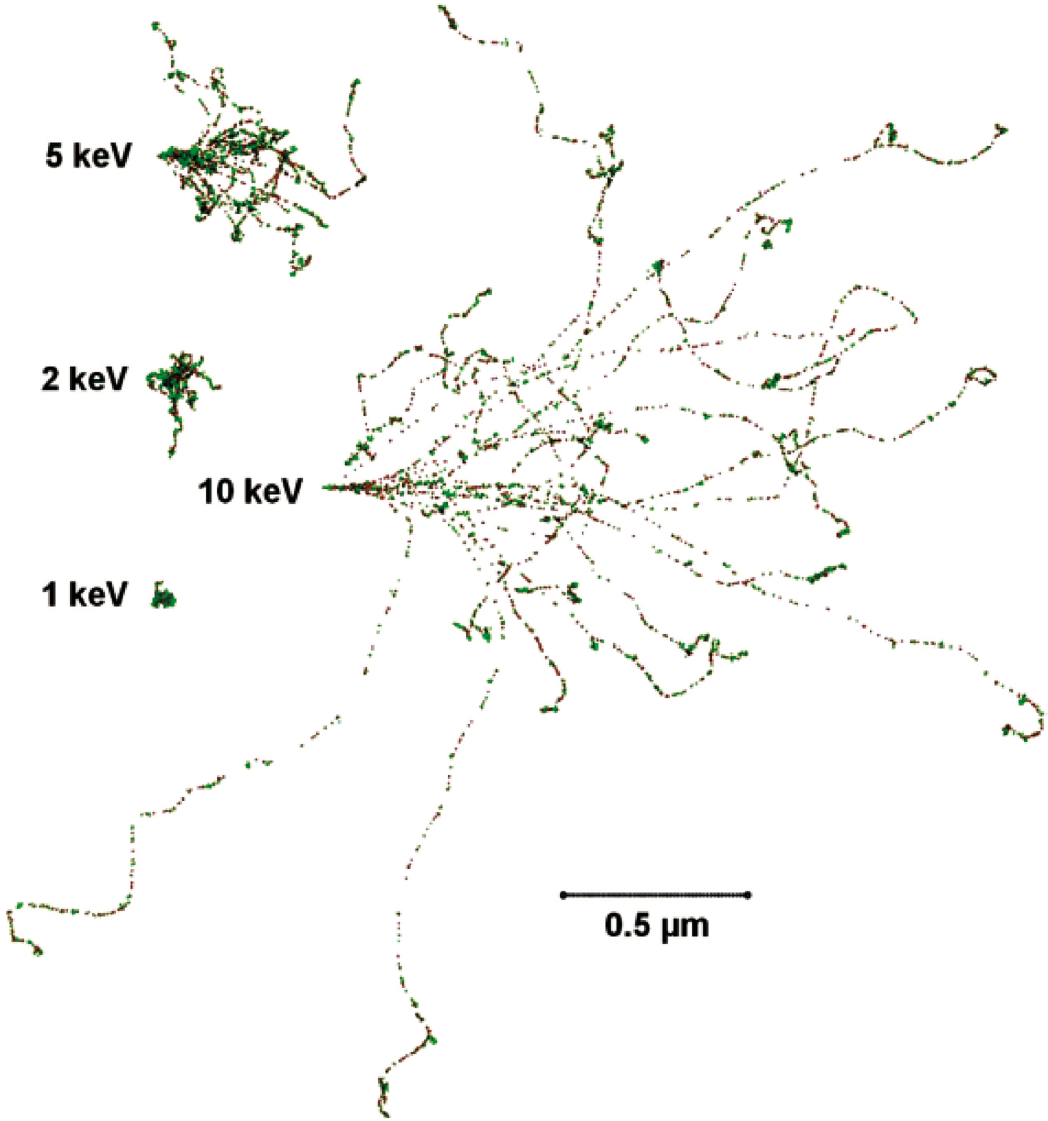


Figure 2.3. Twenty randomly generated electron tracks for initial kinetic energies of 1 keV, 2 keV, 5 keV, and 10 keV. Red points represent ionizations, and green points represent excitations. All tracks of the same energy start at the same point and initially proceed in the same direction (left to right in the figure).

ICRU-86

alpha

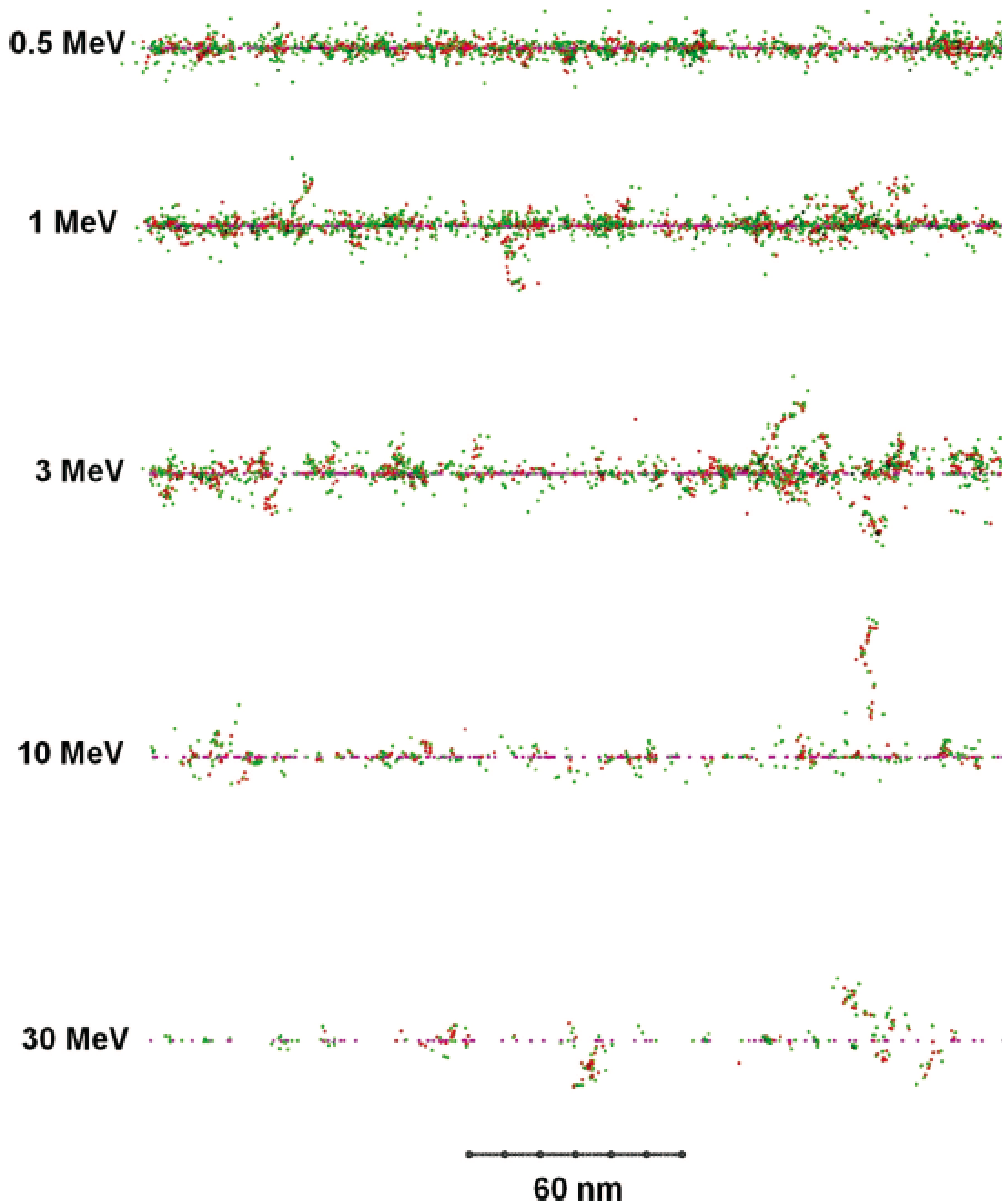


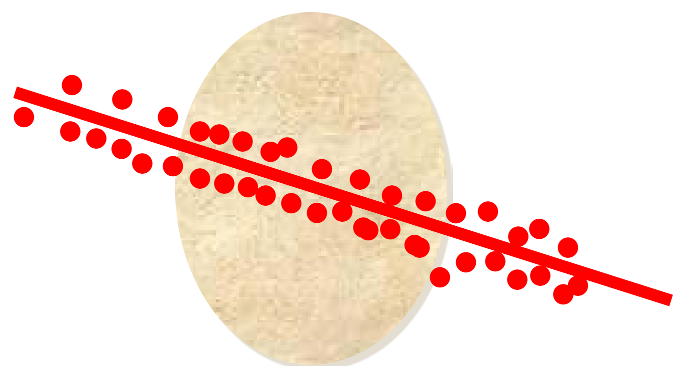
Figure 2.5. Calculated 230 nm track segments for 0.5 MeV, 1 MeV, 3 MeV, 10 MeV, and 30 MeV alpha particles in water. Red points represent ionizations, and green points represent excitations.

- **Low LET**
  - Many cells,
    not much touched
  - Reparation possible
  - Global effect *not* important

  (at a given absorbed dose)

- **High LET**
  - Few cells,
    much touched
  - Reparation less easy
  - Global effect
    important

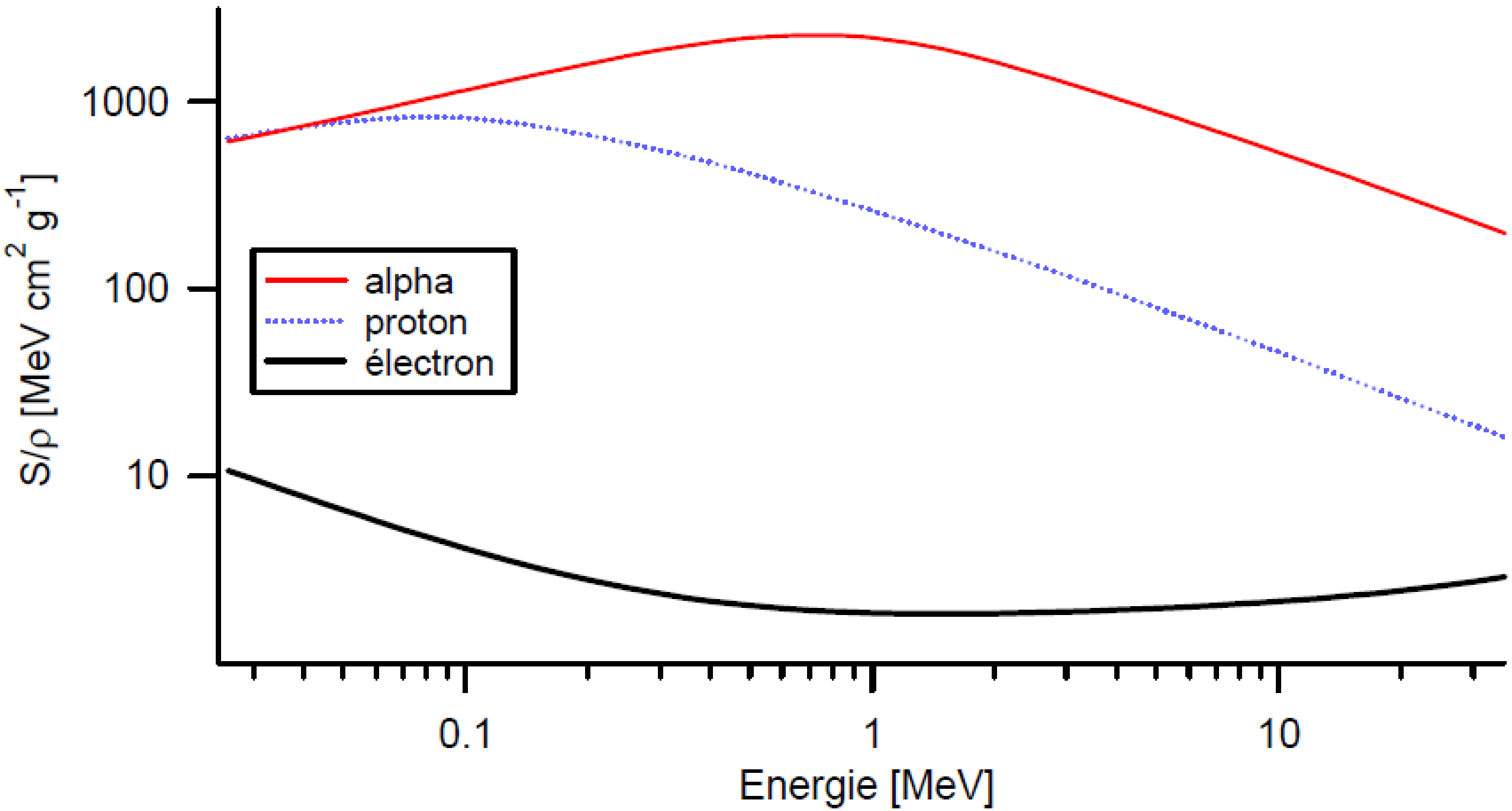
  (at a given absorbed dose)



Relative biological effect: RBE

- Exercise 2
  - Estimate the number of ionizations produced when a **1 MeV proton** passes through a cell?
    - Cell diameter: approximately 1 µm
    - We assume that an ionization requires 30 eV
  - Same question for an electron of 1 MeV

Reminder: mass stopping power of charged particles



Equivalent dose: H

$$H = w_R D_R \quad \left[J \cdot kg^{-1}\right] = [Sv] = [sievert]$$

Weighting factor for radiation R ("RBE")

Absorbed dose from radiation R

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

Dose equivalent

- Exercise 4

20 mGy

4. An irradiation of P-32 occasions an absorbed dose of XXXX 2 Gy. What is the dose equivalent?

Dose equivalent

- Exercise 5

5. Calculate the dose equivalent produced by a simultaneous alpha and beta irradiation at the following absorbed doses: D_{α}=1.4 mGy and D_{β}=10.1 mGy.

Estimation of the equivalent dose

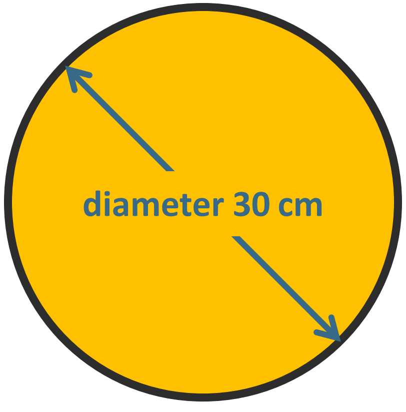
- The **equivalent dose** is **not directly measurable**
  - no laboratory reference standard for this quantity

- We need **operational quantities**
  - that can be used for practical measurements
  - used as substitutes to the equivalent dose H

Ambient dosimetry: ICRU sphere

- Everybody has a **different morphology**
- A radiation protection instrument should be based on quantities that are **simple** and **reproducible**

- Modelization with a sphere of tissue equivalent
  - **ICRU sphere** (density 1 g/cm^3)
  - composition
    - 76.2% oxygen
    - 11.1% carbon
    - 10.1% hydrogen
    - 2.6% nitrogen



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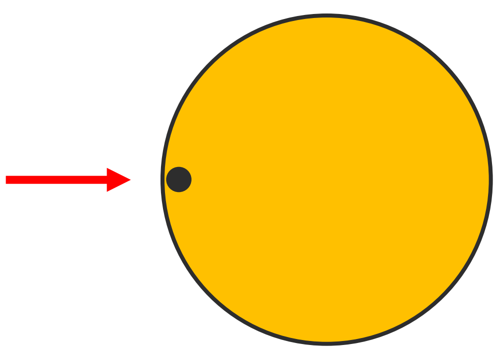
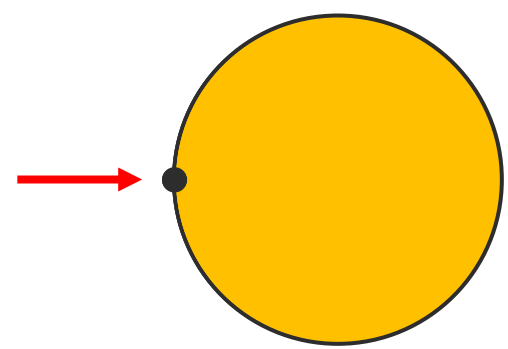
H*(10) & H'(0.07)

The instruments shows a value "as if the ICRU sphere were present"

- Ambient dose equivalent **H*(10)**
  - dose equivalent at 10 mm depth
    - in the ICRU sphere
  - good approximation of the equivalent dose received by an **organ** located **in depth**
  - not negligible for a penetrating radiation



- Directional dose equivalent **H'(0.07)**
  - dose equivalent at 0.07 mm de depth
    - in the ICRU sphere
  - good approximation of the equivalent dose received by the **basal cells of the skin**
  - essentially useful for **low-penetrating radiations**



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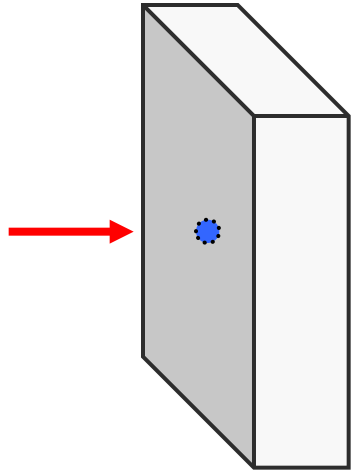
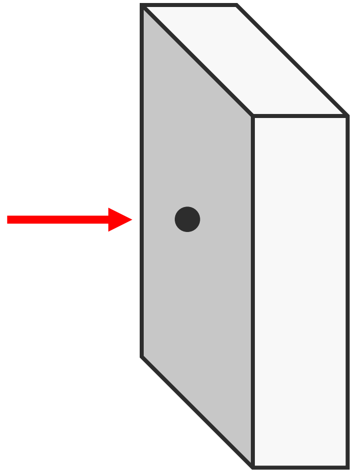
Hp(10) & Hp(0.07)

- Personal deep dose equivalent Hp(10)
  - dose equivalent in **soft tissue** beneath a thickness of **10 mm at the chest**



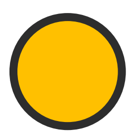
- Personal surface dose equivalent Hp(0.07)
  - dose equivalent in **soft tissue** beneath a thickness of **0.07 mm at the chest**



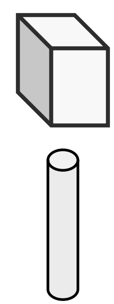
Summary of operational quantities

	Ambient monitoring	Personal monitoring
Low penetrating radiations	$H^*(0.07)$, $H^*(3)$ **$H'(0.07, \Omega)$**, $H'(3, \Omega)$	**$H_p(0.07)$**, $H_p(3)$
Penetrating radiations	**$H^*(10)$** $H'(10, \Omega)$	**$H_p(10)$**

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



ICRU sphere
without dosimeter



chest
(whole body)

finger

ISO phantoms
with dosimeter

H*(10) & H'(0.07)

- Values of ORaP / StSV

					Grandeurs d'appréciation			Limite d'exemp-tion	Limite d'auto-risation	Valeurs directrices		
Nucléide	Période	Type de désintégra-tion/ de 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)	LE Bq/kg ou LE_{abs} Bq	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
Tc-99	2.13 E5 a	β^-	3.2 E-09	7.8 E-10	<0.001	1000	1.1	1 E+04	2 E+06	3 E+03	3	
Tc-99m	6.02 h	γ	2.9 E-11	2.2 E-11	0.022	300	0.2	5 E+05	2 E+08	3 E+05	30	-> Tc-99
Tc-101	14.2 m	β^-, γ	2.1 E-11	1.9 E-11	0.055	1000	1.6	5 E+05	2 E+08	4 E+05	3	
Tc-104	18.2 m	β^-, γ	4.8 E-11	8.1 E-11	1.219	1000	1.8	1 E+05	1 E+08	2 E+05	3	

Effective dose

- Weighted sum of equivalent dose H_T to the irradiated organs and tissues T

$$E = \sum_T w_T \cdot H_T$$

Organ or tissue	w_T	$\sum_T w_T$
Surface of the bone, skin	0.01	0.02
Bladder, breast, liver, esophagus, thyroid, remainder[1]	0.05	0.30
Bone marrow, colon, lung, stomach	0.12	0.48
Gonads	0.20	0.20
Total		1.00

Intake

- Committed effective dose

$$E_{50} = \int_{t_o}^{t_o + 50\text{ years}} E(t)\,dt$$

- depends on
  - physical half-life of the radionuclide
  - physiological mechanisms (biological half-life)
  - spatial distribution of the activity

$$E_{50} = e_{inh} \cdot A_{inh}$$

$$E_{50} = e_{ing} \cdot A_{ing}$$

ORap/StSV values

Intake: E_{50}

- Values of ORaP / StSV

					Grandeurs d'appréciation			Limite d'exemp-tion	Limite d'auto-risation	Valeurs directrices		
Nucléide	Période	Type de désintégra-tion/ de 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)	LE Bq/kg ou LE_{abs} Bq	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
Tc-99	2.13 E5 a	β^-	3.2 E-09	7.8 E-10	<0.001	1000	1.1	1 E+04	2 E+06	3 E+03	3	
Tc-99m	6.02 h	γ	2.9 E-11	2.2 E-11	0.022	300	0.2	5 E+05	2 E+08	3 E+05	30	-> Tc-99
Tc-101	14.2 m	β^-, γ	2.1 E-11	1.9 E-11	0.055	1000	1.6	5 E+05	2 E+08	4 E+05	3	
Tc-104	18.2 m	β^-, γ	4.8 E-11	8.1 E-11	1.219	1000	1.8	1 E+05	1 E+08	2 E+05	3	

Operational quantities & effective dose

- External irradiation

$$E_{ext} = H_p(10) \quad \text{or} \quad H^*(10)$$

$$H_{skin} = H_p(0.07) \quad \text{or} \quad H'(0.07)$$

- Intake

$$E_{inc} = E_{50}$$

- Total

$$E = E_{ext} + E_{inc}$$