Dosimetry
Radiotherapy-Hadrontherapy
Radiobiology

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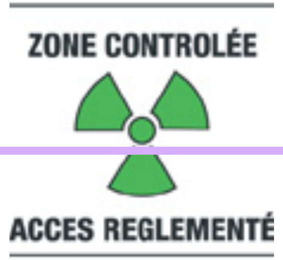
The Dose definition



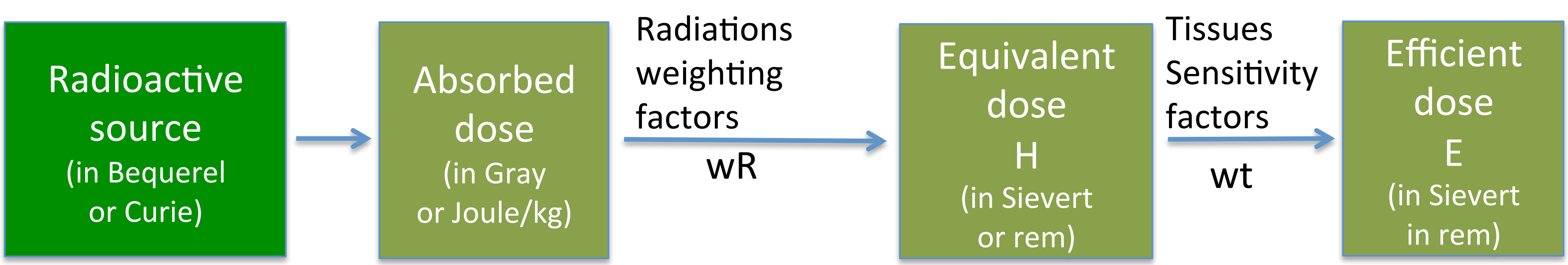
- The absorbed dose D by an organism is defined as the energy (Joules) deposited in a mass unit (Kg).

$$D = dE/dm$$

In the international system unit, the dose unit is the Gray (Gy):

$$1\ Gy = 1\ J/kg.$$

- The Gray is a unit that represents only the pure physical aspect of the dose. When the biological effect of a radiation has to be evaluated, we talk about the efficient dose and its unit is the Sievert (Sv).



Physics basis

Particle range (Distance after which the particle is stopped) : $R = \int_0^{E_0} \frac{dx}{dE} dE$

Bethe-Bloch Formula:

$$-\frac{dE}{dx} = \frac{z^2 e^4 n Z}{4\pi\epsilon_0^2 m_e v^2}\left[ln(\frac{2m_e v^2}{I}) - ln(1-\frac{v^2}{c^2}) - \frac{v^2}{c^2} \right]$$

where : z *is the particle charge*

e *is the electron charge*

n *is the number of atoms per volume unit*

Z *is the atomic number of the target media*

ϵ_0 *is the media permittivity*

m_e *is the electron mass*

v *is the particle velocity*

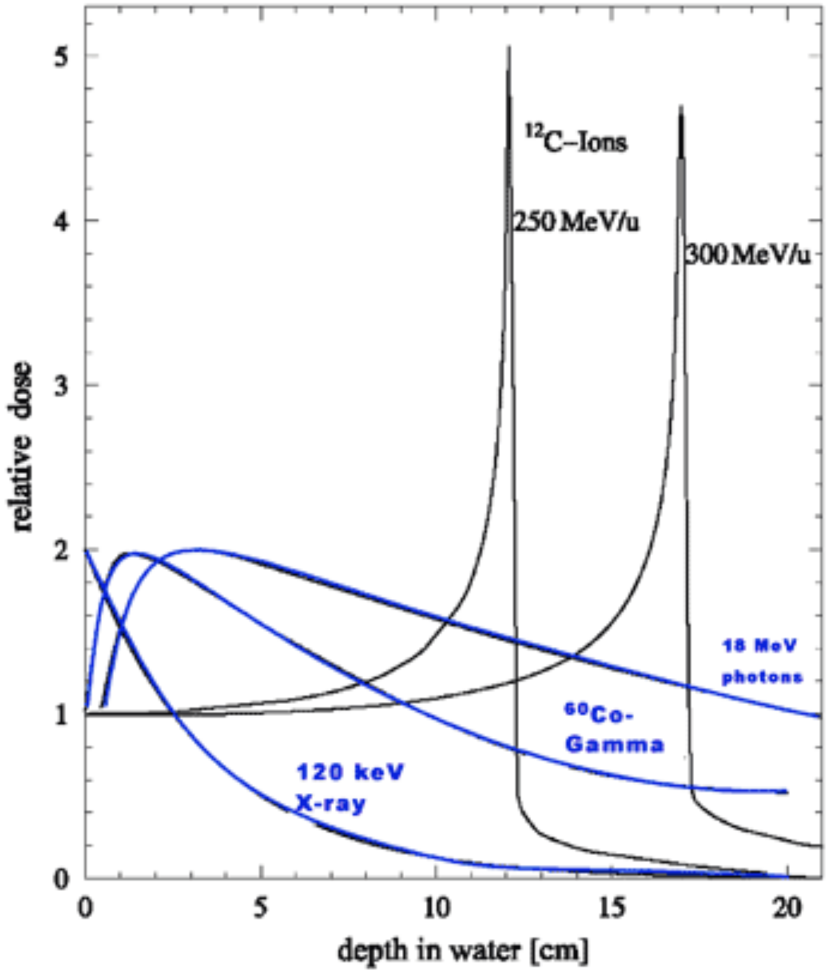
I *is the ionisation or excitation potential that depends of the media*

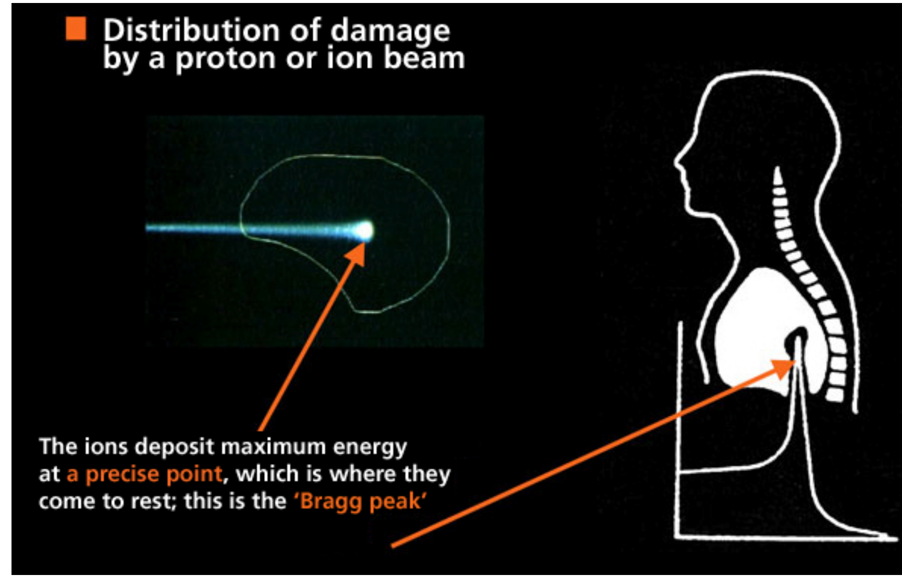
c *is the light velocity*

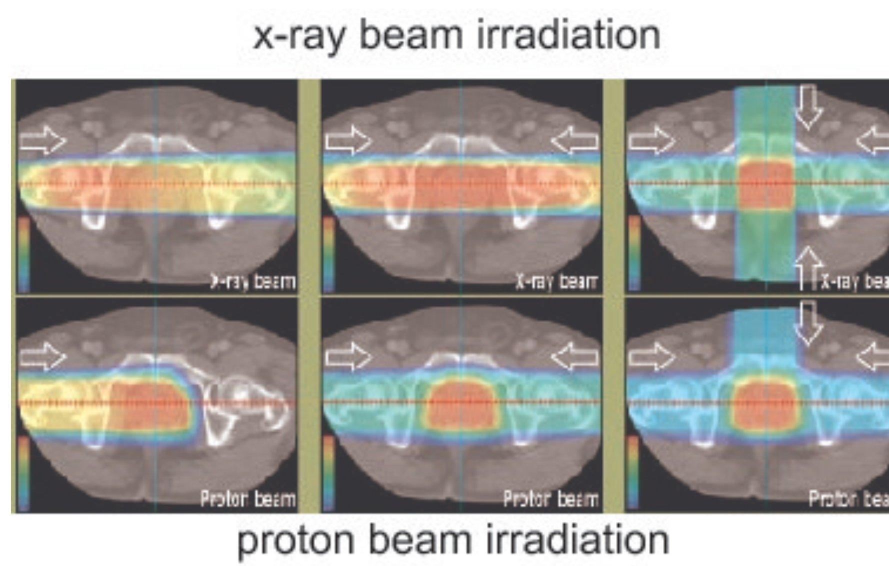
Hadrontherapy

- Radiotherapy technique that consists in using heavy ions (protons, carbon ions) beams to kill cancer cells.
- Advantage with respect to classical X-rays radiotherapy:
  1. High balistic precision: hadrons stop at the level of the tumor produce less damage to healthy tissues.
  2. High treatment efficiency for some tumors (radio-resistive celles, Radiobiological effect)

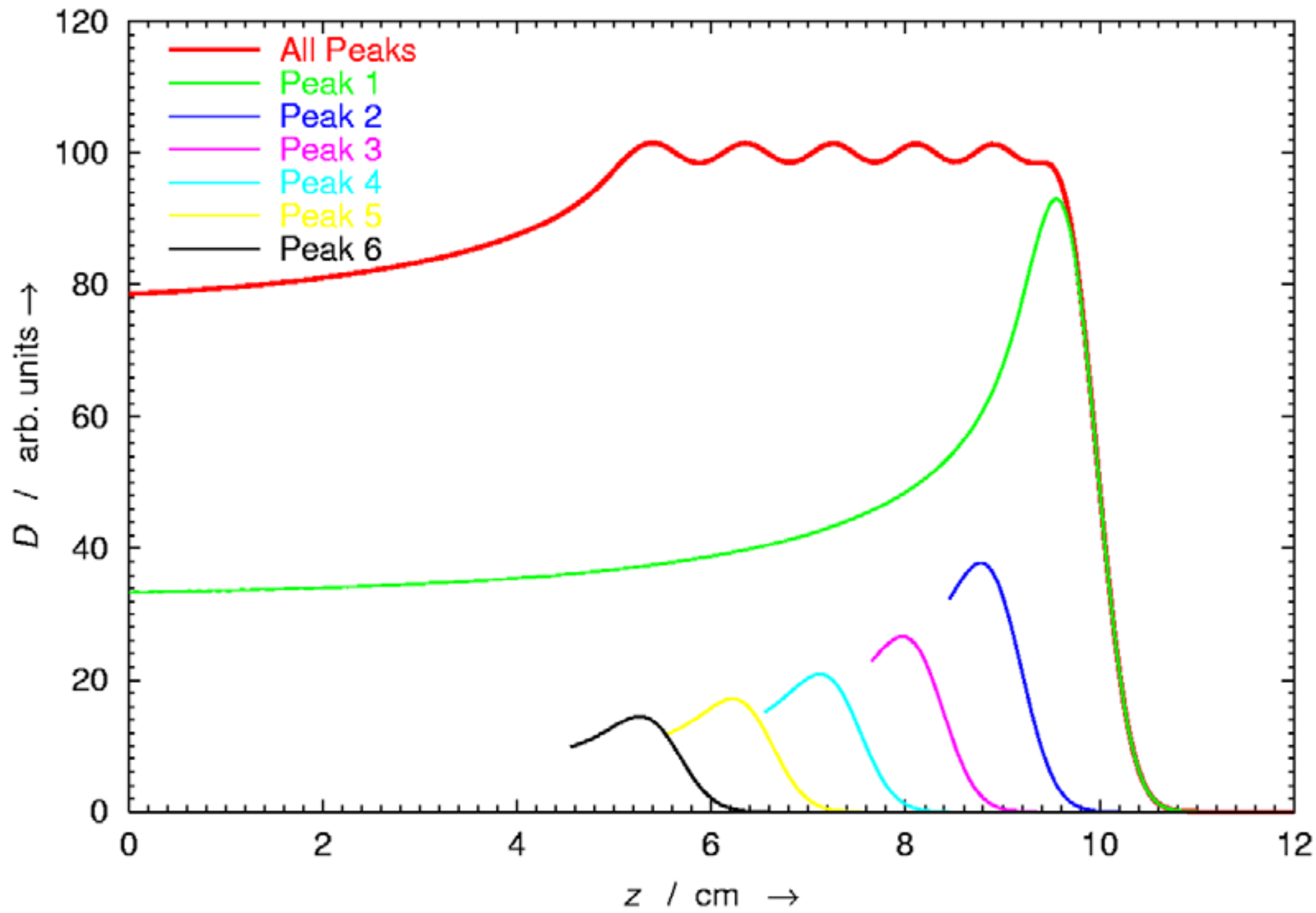
Bragg Peak


relative dose
depth in water [cm]
^{12}C–Ions
250 MeV/u
300 MeV/u
18 MeV photons
^{60}Co-Gamma
120 keV X-ray
0
5
10
15
20
1
2
3
4
5


Distribution of damage by a proton or ion beam
The ions deposit maximum energy at a precise point, which is where they come to rest; this is the 'Bragg peak'

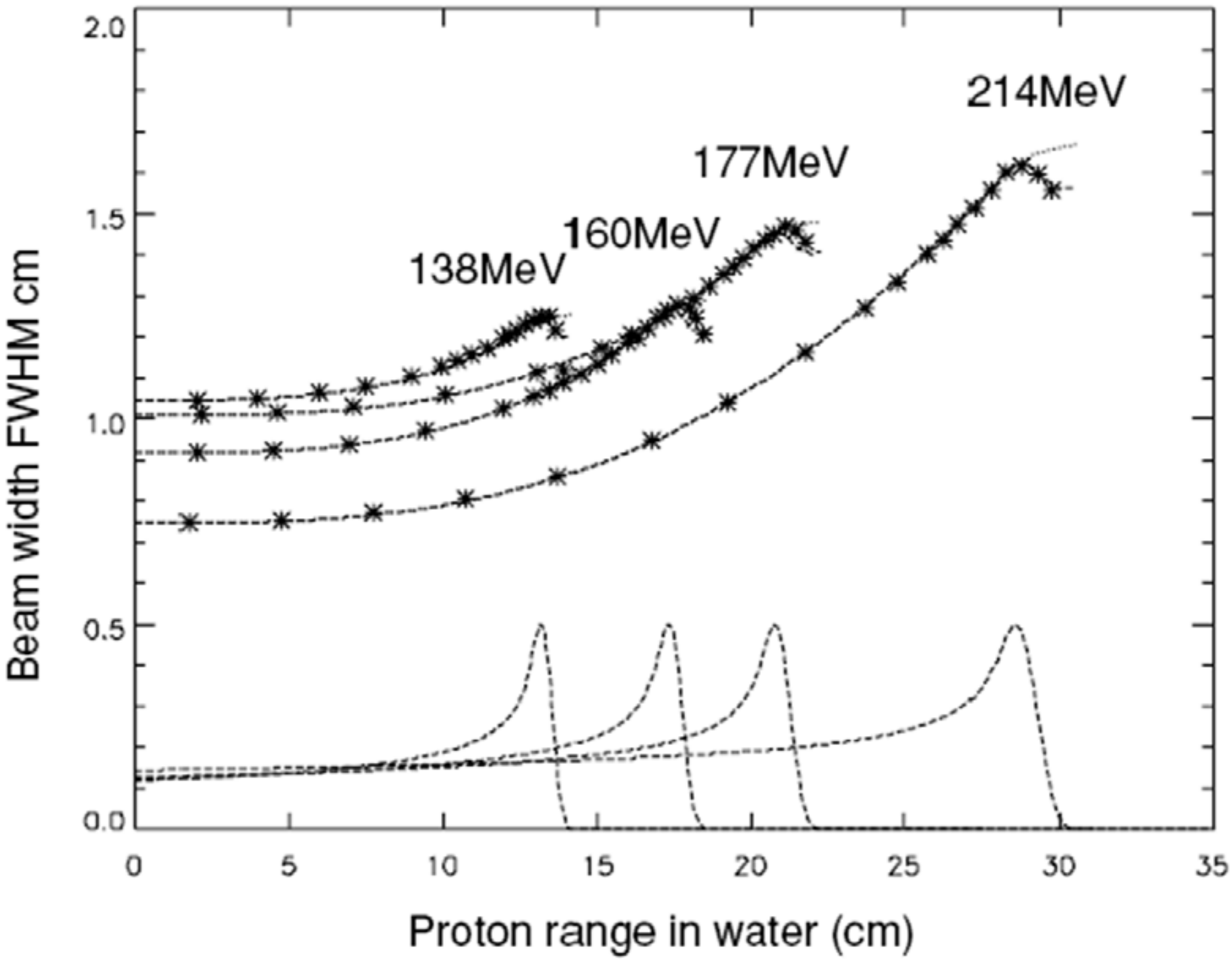

x-ray beam irradiation
X-ray beam
X-ray beam
X-ray beam
Proton beam
Proton beam
Proton beam
proton beam irradiation

Spread-out Bragg Peak (SOBP)



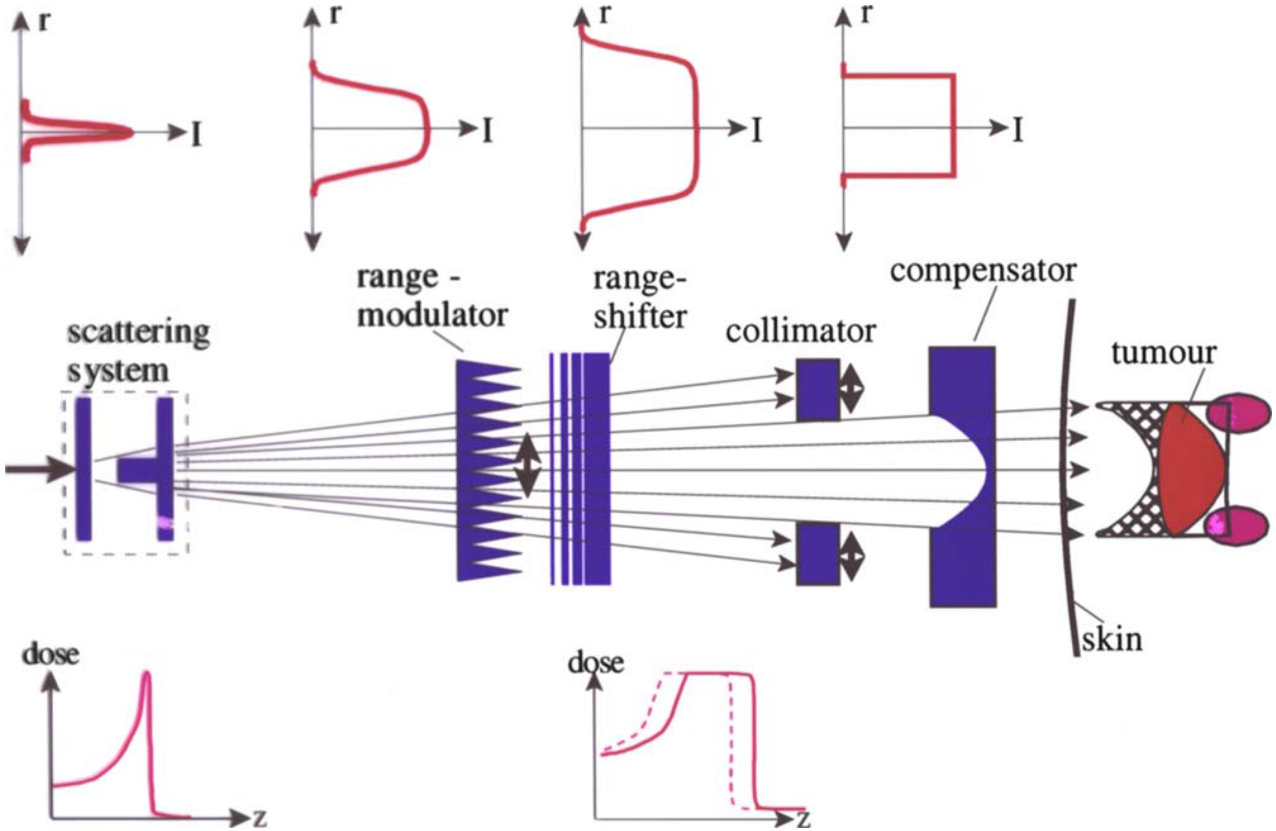
Newhauser and Zhang, Phys. Med. Biol. 60 (2015) R155

Straggling



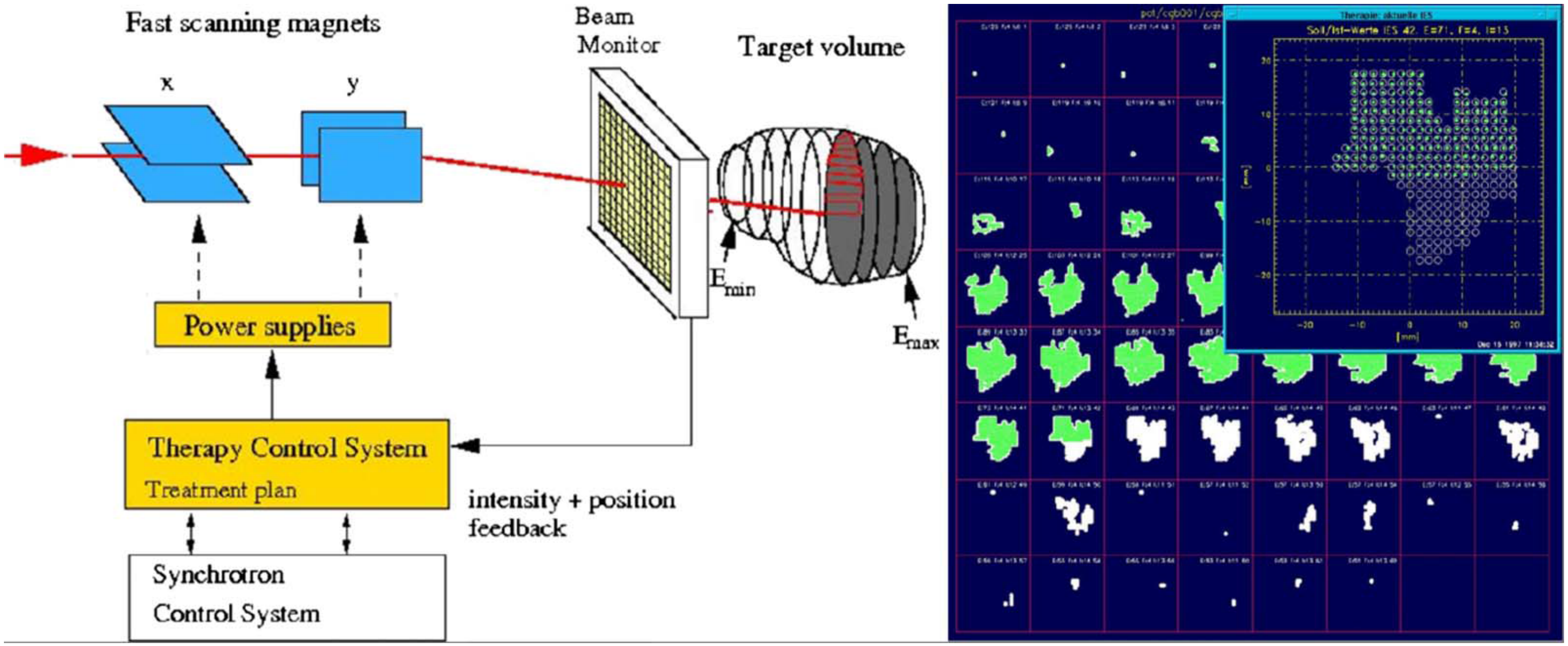
Newhauser and Zhang, Phys. Med. Biol. 60 (2015) R155

Passive beam shaping



REVIEWS OF MODERN PHYSICS, VOLUME 82, JANUARY–MARCH 2010

Dynamic beam shaping



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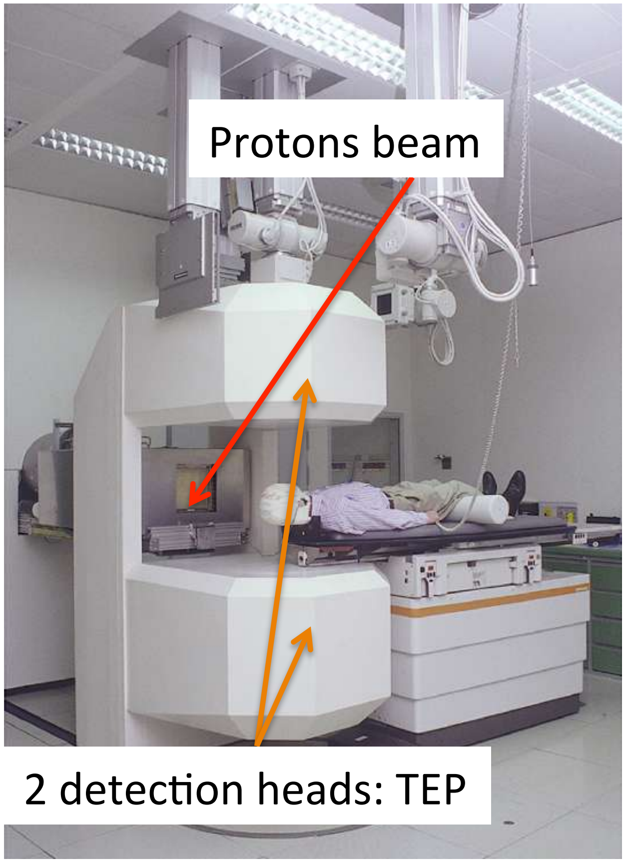
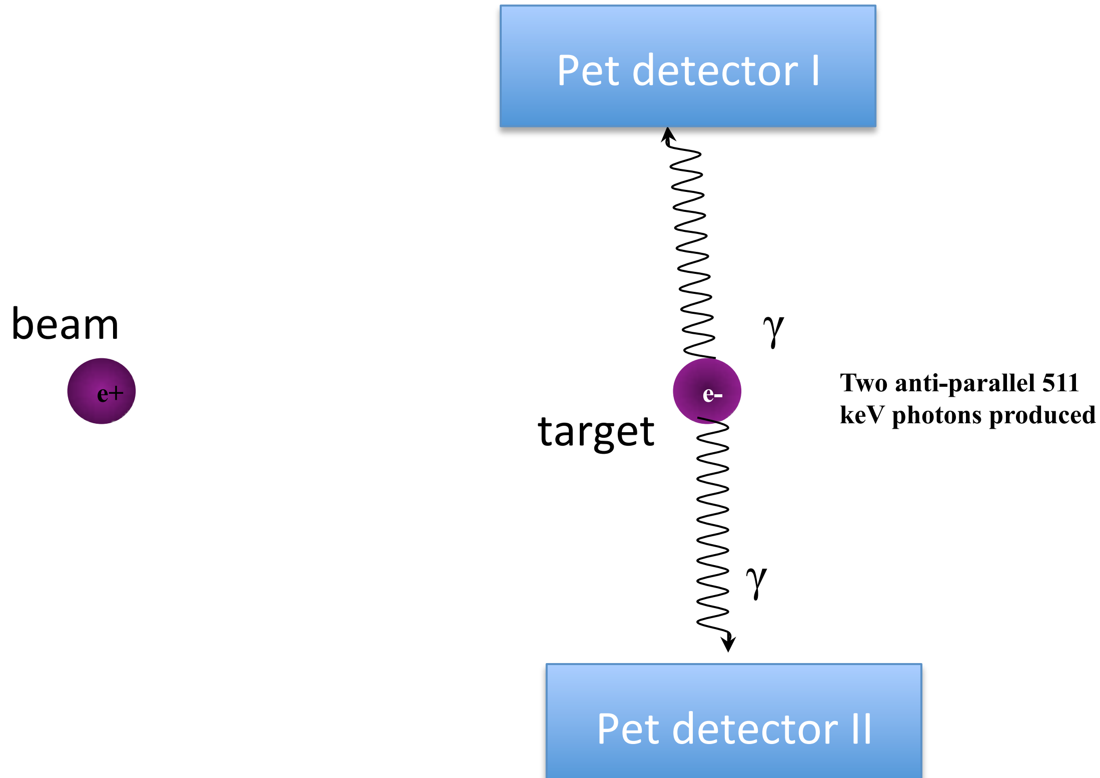
In situ dose control : inBeam PET



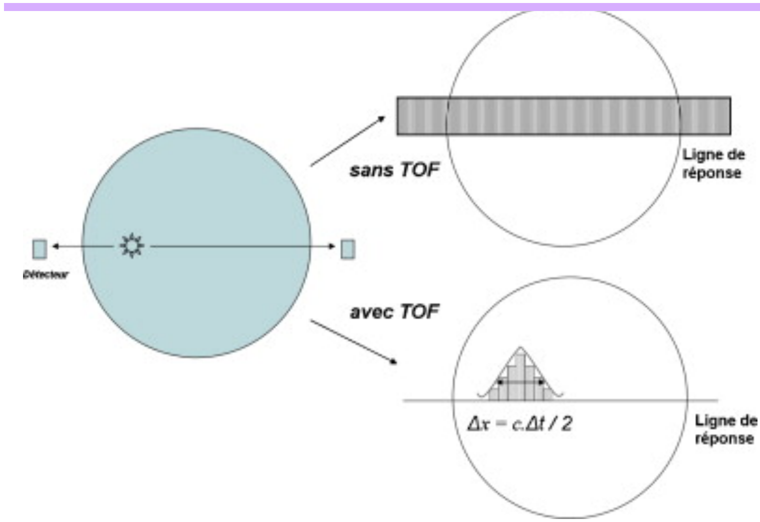


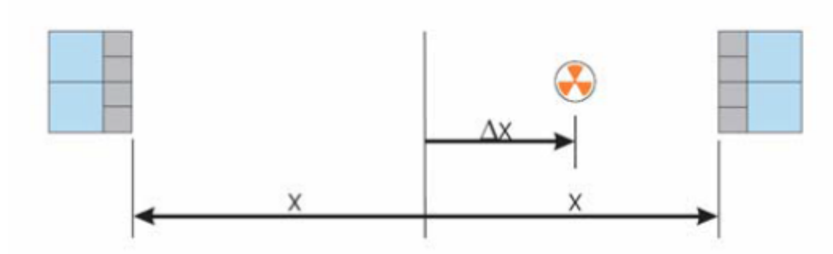
InBeam PET problem:

1. Short periods 11-C (20 min), 15-O (2min), 10-C (10s)
2. Low activities (~10 kBq), (Clinical PET ~250 MBq)
3. Static mode acquisition (3D ?)

Time Of Flight technology (TOF) improves the signal to noise ratio

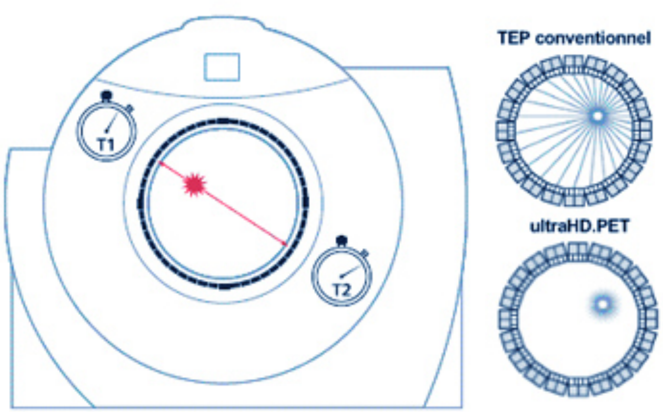
Improving spatial resolution using the Time Of Flight

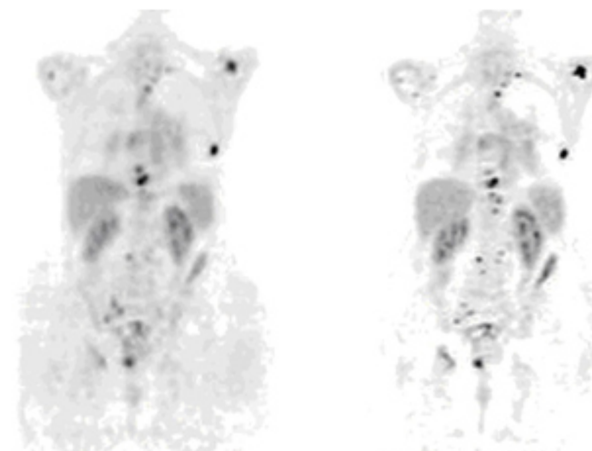




$$\Delta t = \frac{(x+\Delta x)}{c} - \frac{(x-\Delta x)}{c} = \frac{2\Delta x}{c}$$

$$\Delta x = 1{,}5 \ cm \ \text{-->} \ \Delta t = 0{,}1 \ ns$$

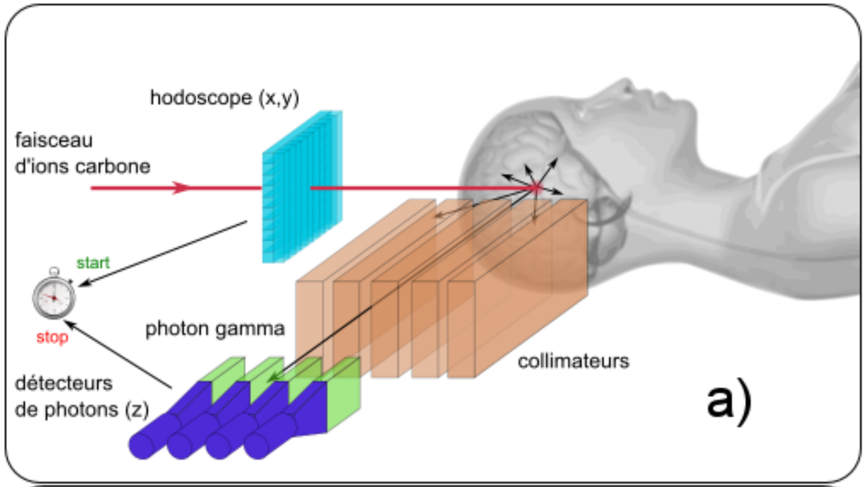




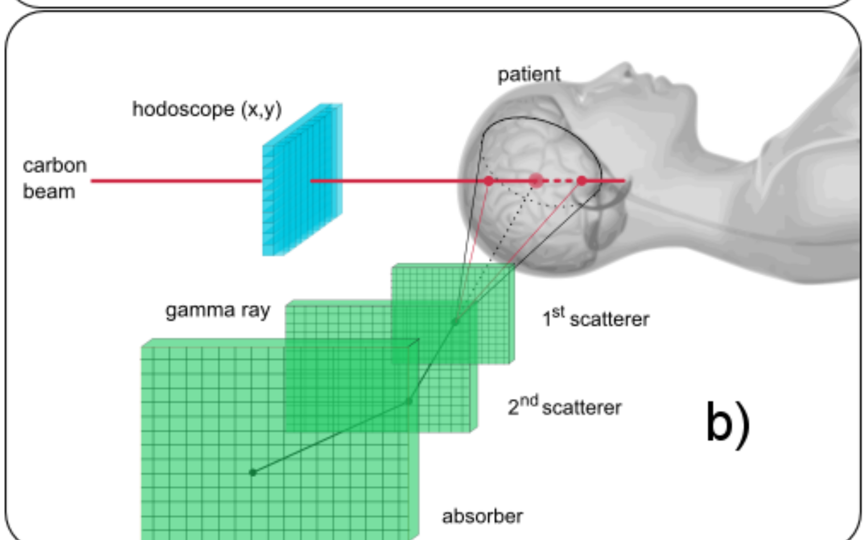
https://www.swe.siemens.com

In situ dose control: gamma prompts detection

Utilising gammas prompts produced by nuclear reactions

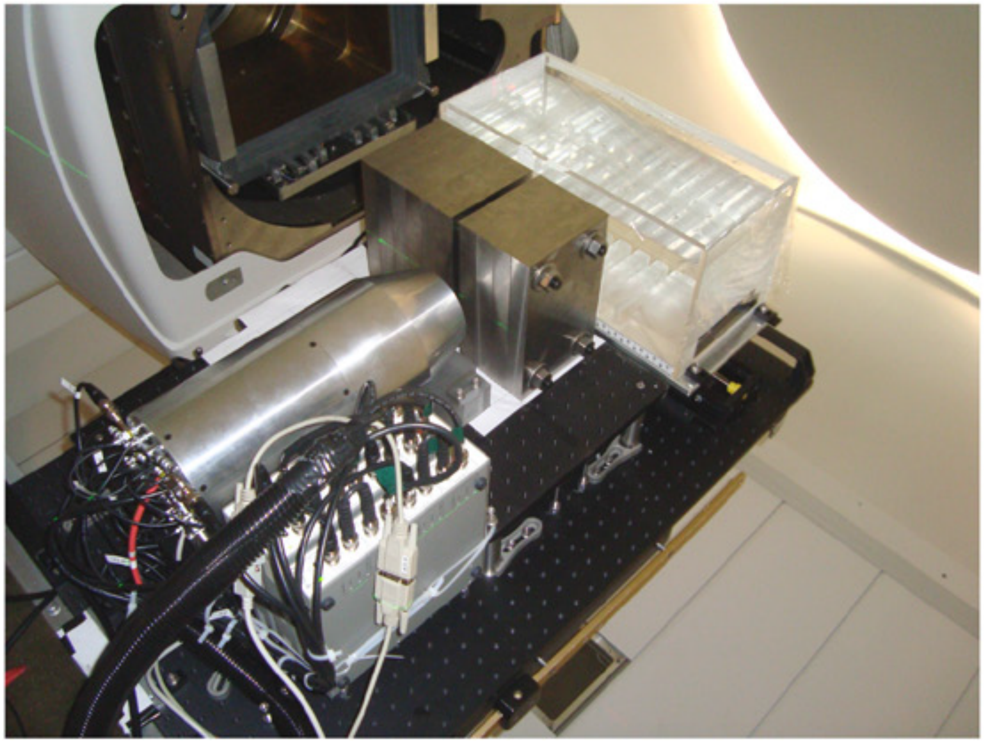


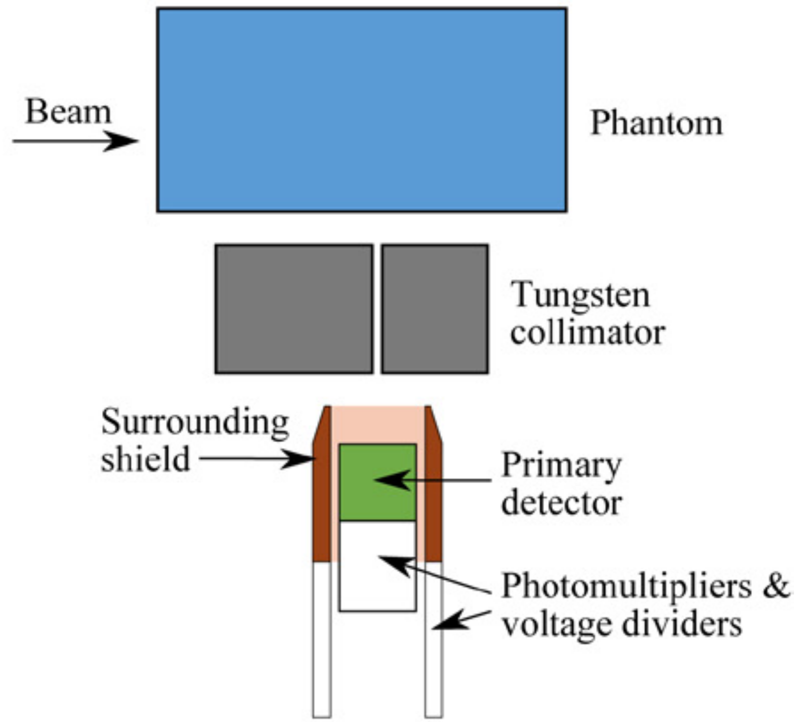
SPECT Technology



Compton Camera

In situ dose control: gamma prompts detection

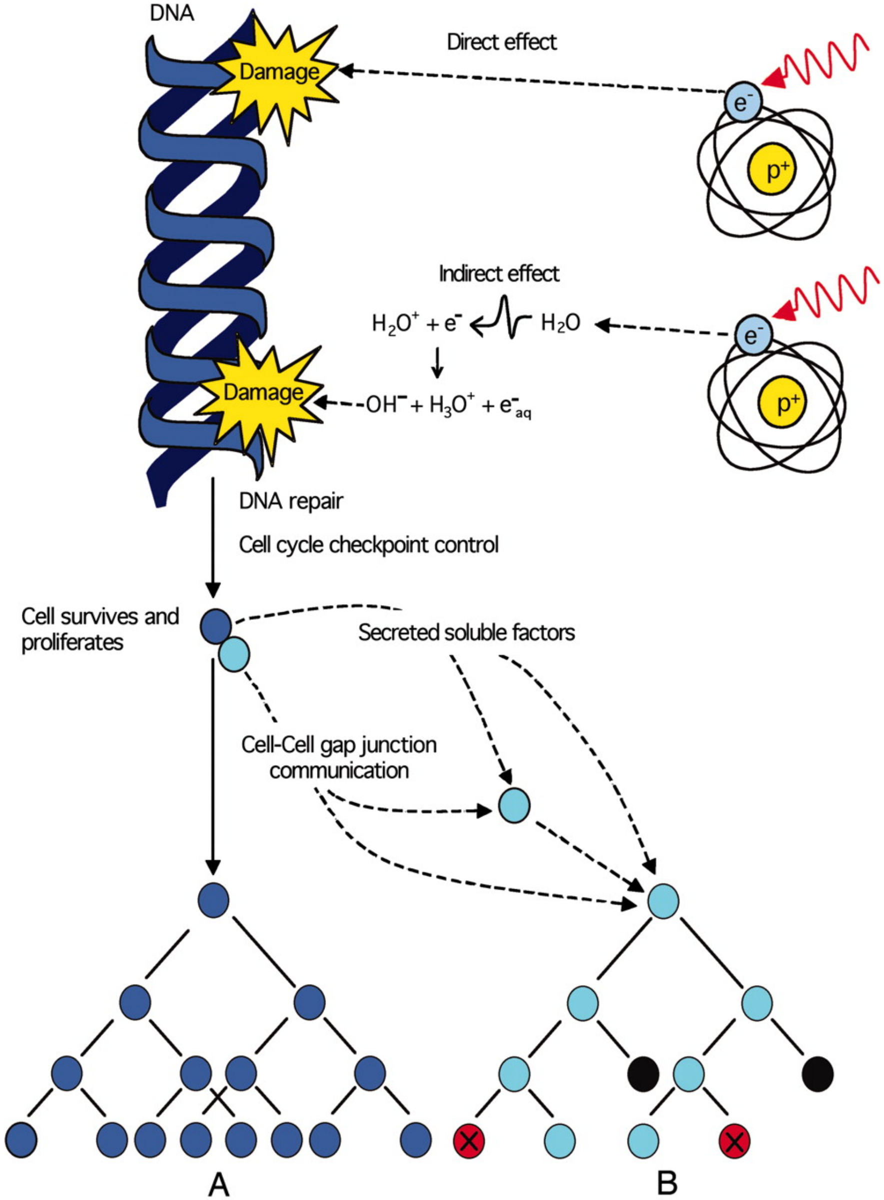




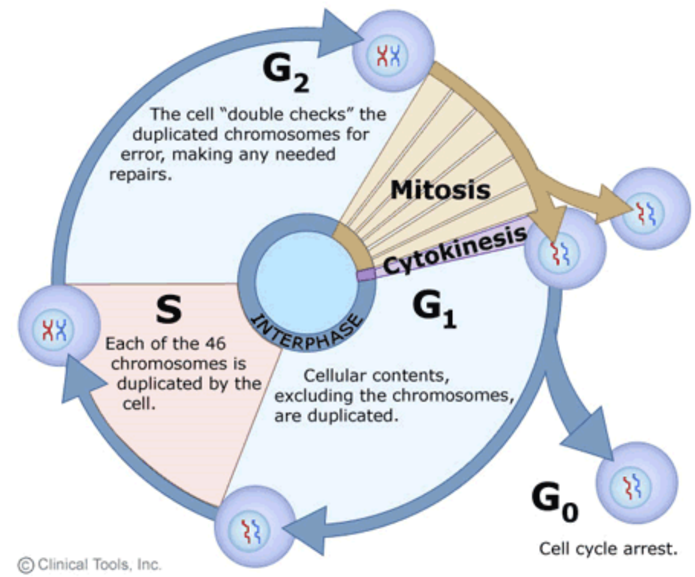
J M Verbung and J Seco. Phys. Med. Biol. **59** (2014) 7089-7106

Radiobiology

DNA induced damage by irradiation



http://www.pnas.org/content/102/40/14127



Cell Cycle

https://www2.le.ac.uk/projects/vgec/highereducation/topics/cellcycle-mitosis-meiosis

The Microdosimetric Kinetic Model

The Microdosimetric Kinetic model (MK model) is a biophysical model of cell survival after irradiations.
It assumes that the mean number of lethal lesions *L* in a domain can be described by a linear-quadratic function of specific energy *z*, as follows:

$$L = Az + Bz^2$$

N : is the total number of domains in a cell nucleus
<L> : is the average number of lethal lesions in a domain
y_D : is the single-event dose-mean lineal energy
ρ : is the domain density
r_d : is the domain radius
S : *is the survival fraction*

Expectation:

$$L_n = N\langle L\rangle = N(A\langle z\rangle + B\langle z^2\rangle)$$
$$= \left(\alpha_0 + \frac{\beta y_D}{\rho \pi r_d^2}\right) D + \beta D^2$$
$$= \alpha D + \beta D^2 = -\ln S$$

Lineal dose:

$$y = \frac{\varepsilon}{l}$$

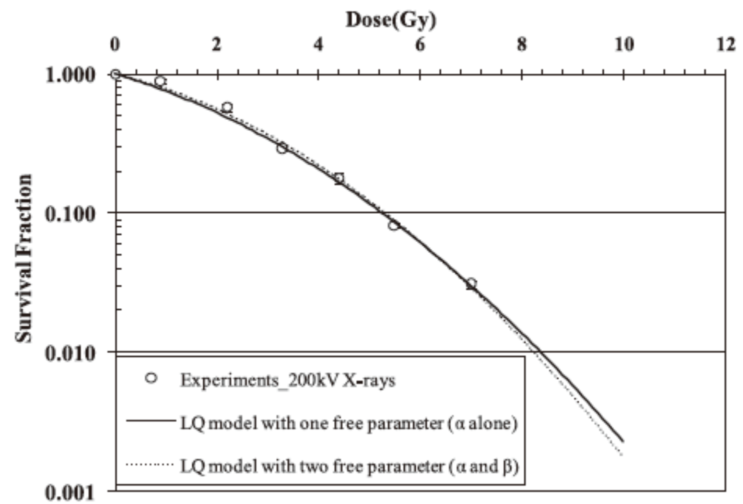


Fig. 6. Comparison between the two methods of the fitting to survival fraction of the HSG tumor cells for 200 kV X-rays.

OKAMOTO et al, J. Radiat. Res., 52, 75- 81 (2011)

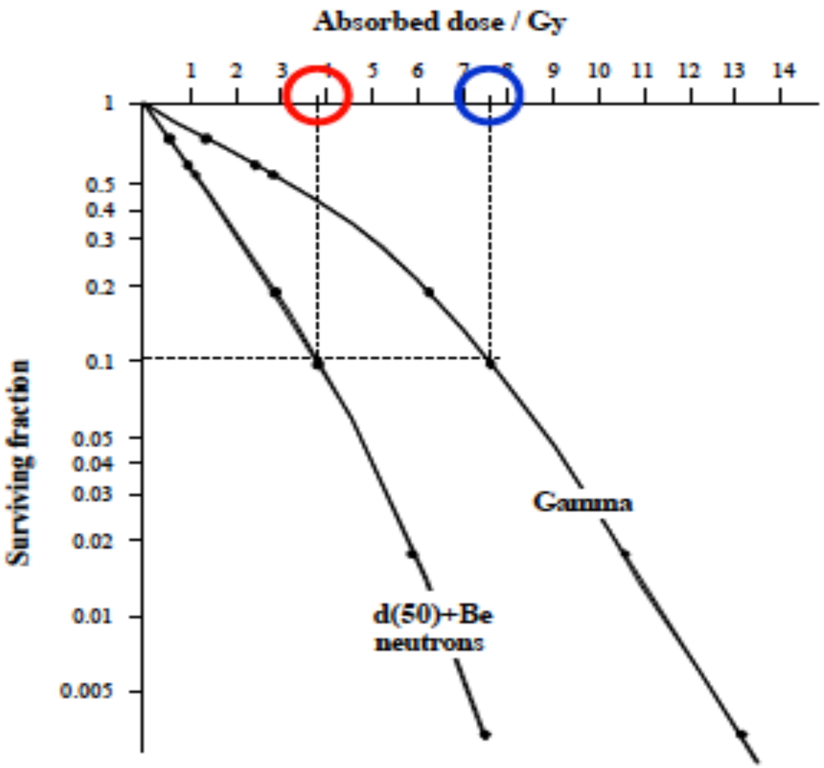
Cell survival (dose, radiation type, tissues)

The cell surviving fraction rate is expressed as :

$$S(D) = \exp(-(\alpha D + \beta D^2))$$

α/β is high for radio-sensitive celles

α/β is low for radio-resistive celles



Iso-dose

Gamma = 7.5 Gy
Neutrons = 3.8 Gy

RBE = 7.5 / 3.8 = **2**

Relative Biological Effectiveness :
Ratio between a reference radiation and the considered radiation that produces the same effect