Radiation dosimetry at cellular level

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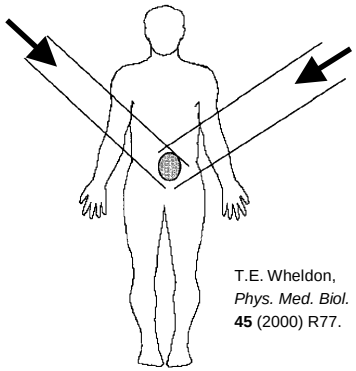
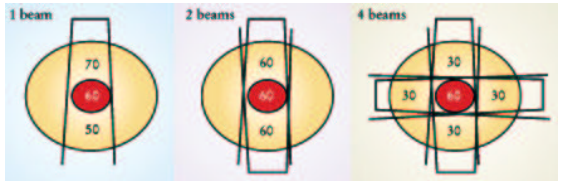
Introduction

- radiation therapy: kill cells selectively
- external radiation therapy



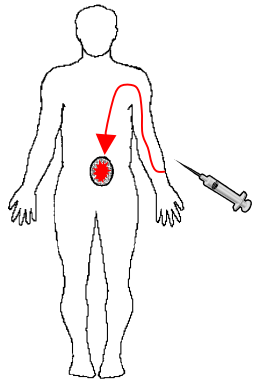
T.E. Wheldon, *Phys. Med. Biol.* **45** (2000) R77.

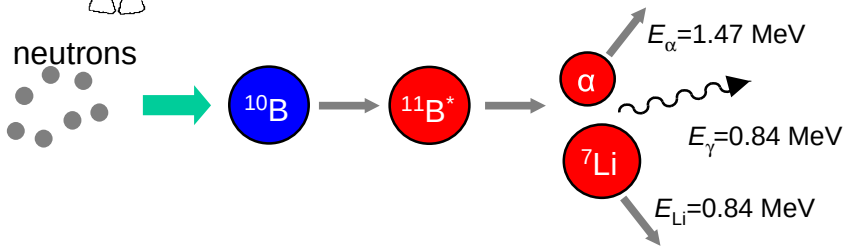


A.L. Boyer, *Physics Today* Sep. 2002 p. 34.

- ’internal’ radiation therapy
  - targeted radiation therapy
  - boron neutron capture therapy (BNCT)

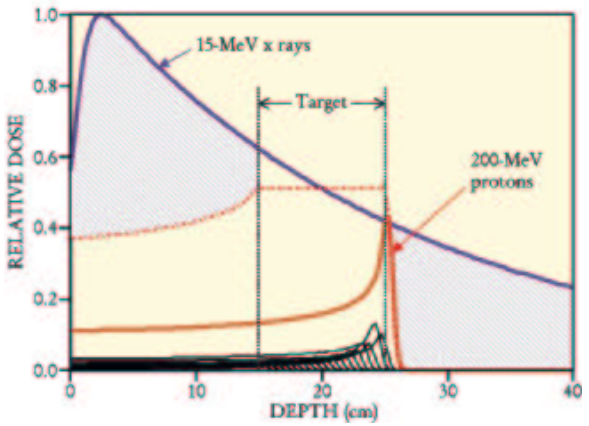
(LCE Friday seminar on BNCT in April)





Introduction

- energy depostion or dose D: energy/mass J/kg=Gy
  - external radiation therapy: broad, macroscopic
  - internal radiation therapy: inhomogeneous, microscopic
  - example: S-factors for a water sphere
    - activity inside a spherical volume
    - how much dose absorbed inside this volume



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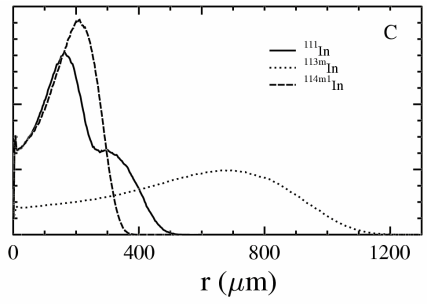
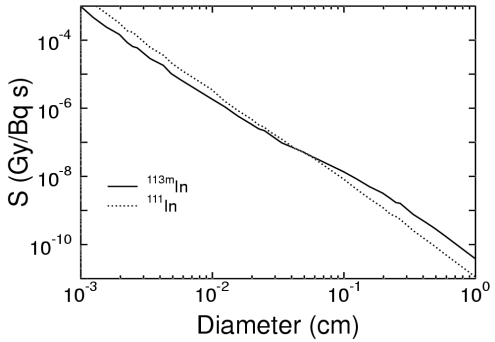
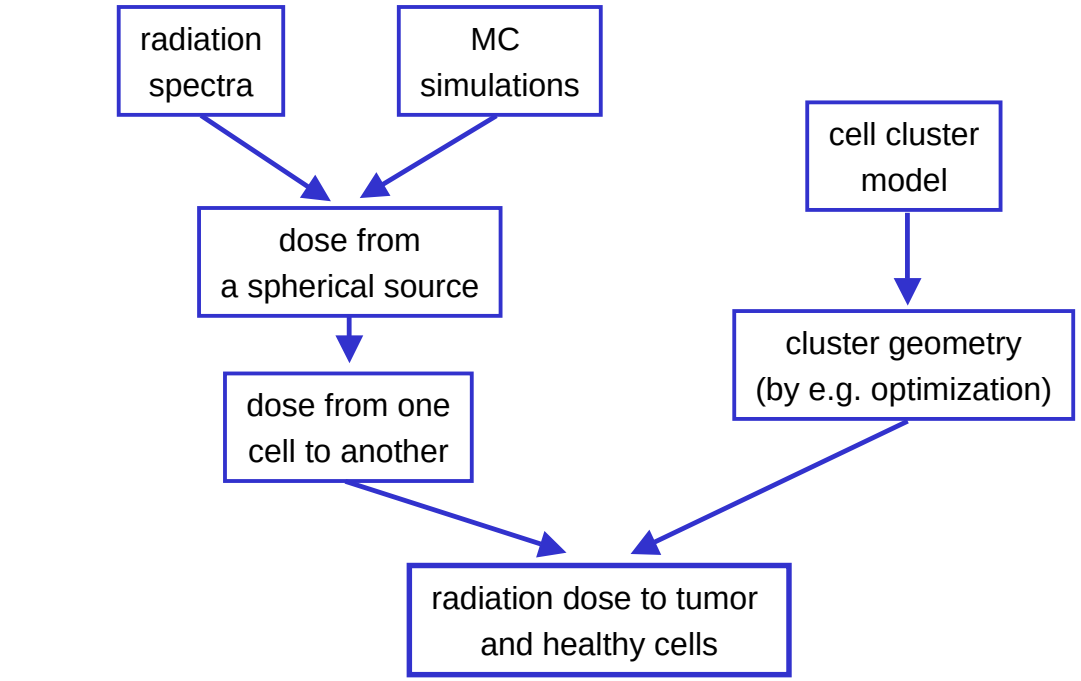




Introduction

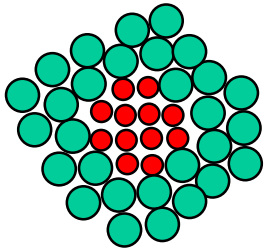
- this work
  - dosimetry of small metastases
  - activity entirely in the tumor cells
  - compare
    - three simple models to build cell cluster
    - three different isotopes: ^{111}In, ^{113m}In, ^{114m1}Inc



tumor cells d=12 µm

healthy cells d=30 µm

tumor diameter 30, 150 µm

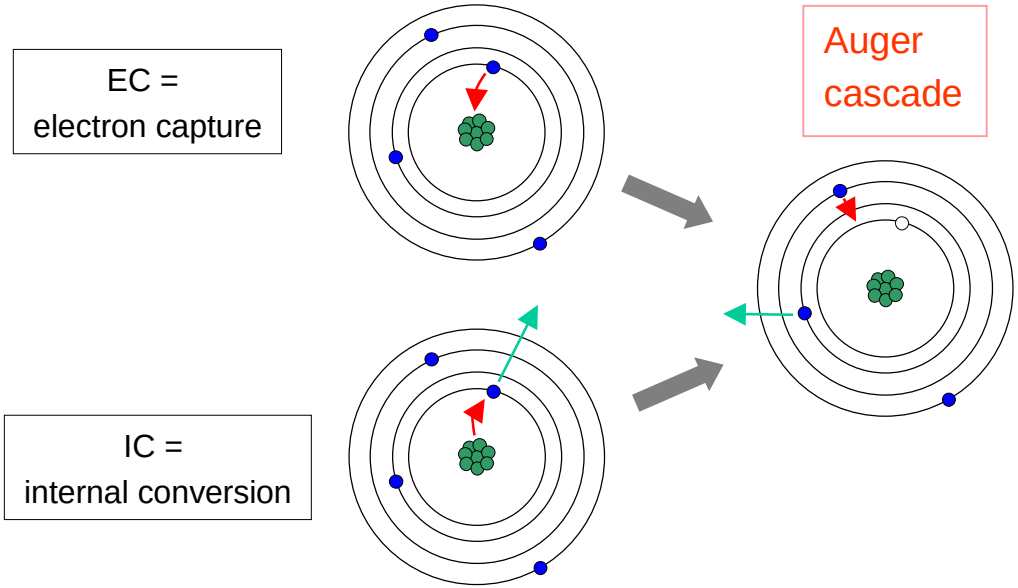


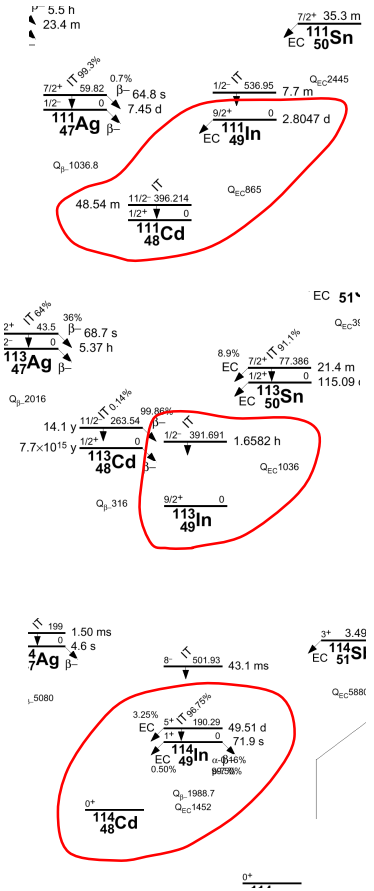
'water spheres in water'

Radiation spectra

- only electrons taken into account

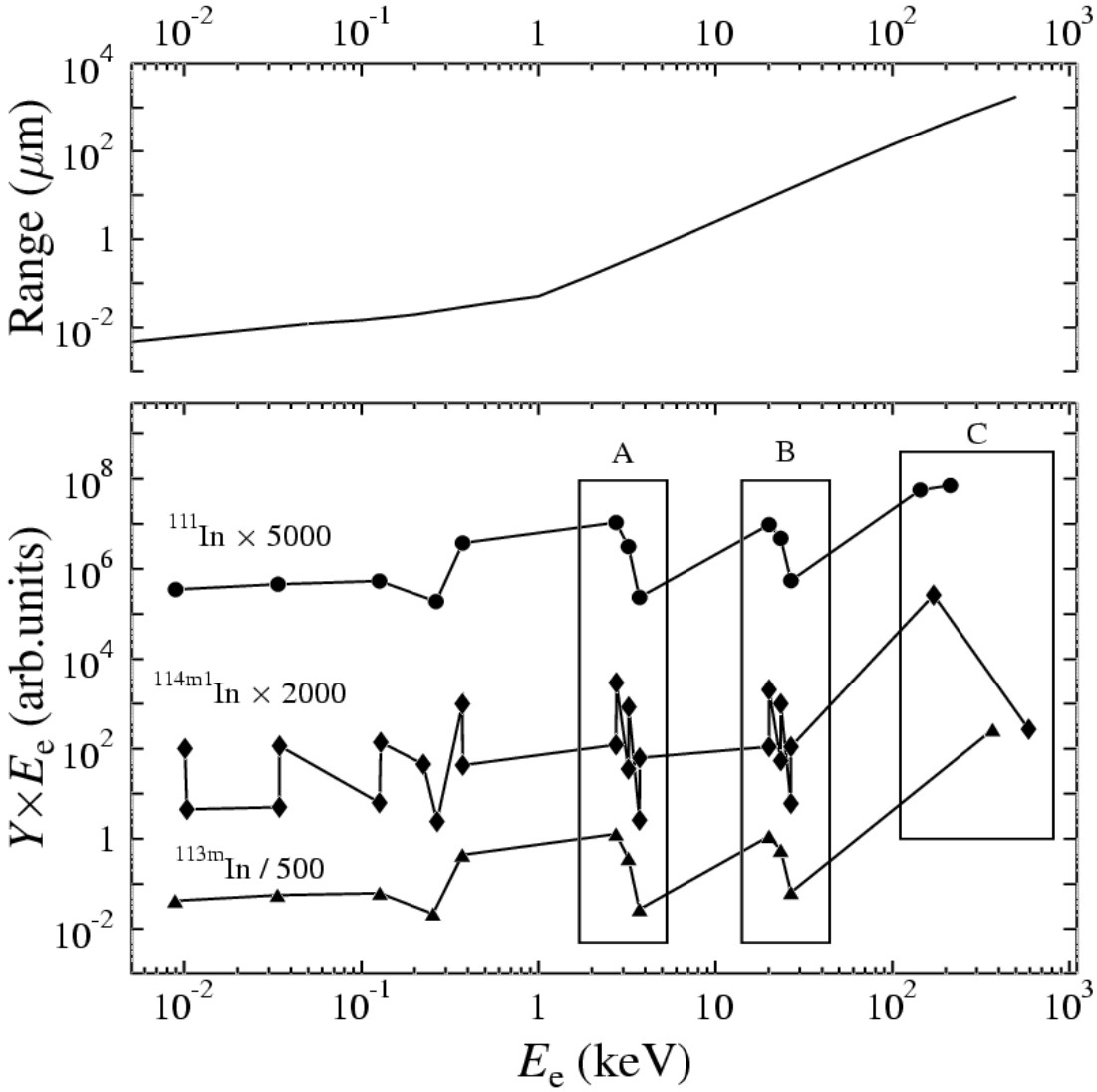
	$t_{1/2}$	decay mode
^{111}In	2.80 d	EC+IC
^{113m}In	1.66 h	IC
^{114m1}In	49.5 d	IC+EC





LBNL Isotopes Project Nuclear Data Dissemination Home Page. http://ie.lbl.gov/toi.html

Radiation spectra



Monte Carlo simulations

- EGS4 (**E**lectron-**G**amma **S**hower) simulation code
  http://www.slac.stanford.edu/egs/

  - EGS introduced in 1978
  - free for non-commercial use
  - applied in high-energy, nuclear and medical physics
    - electrons and photons from keV to 100 GeV
  - written in MORTRAN – a preprocessor for FORTRAN77 !!
    - conversion to C: EGSnova http://www.nemc.org/nova/

Monte Carlo simulations

- event-driven MC simulation:
  - follow particles from one scattering event to another
  - distance between events: random variable, calculated from total scattering cross section: Σ_t

MFP $\lambda = \frac{1}{\Sigma_t}$ $P\{\text{interact. in d}x\} = \frac{\mathrm{d}x}{\lambda}$

$N_\lambda = \int_{x_0}^{x} \frac{\mathrm{d}x}{\lambda(x)}$ $P\{\hat{N}_\lambda < N_\lambda\} = 1 - \exp(-N_\lambda)$

number of MFP's sampled as $N_\lambda = -\ln \xi, \quad \xi \in [0,1[$

A: photoelectric

B: Compton

C: Rayleigh

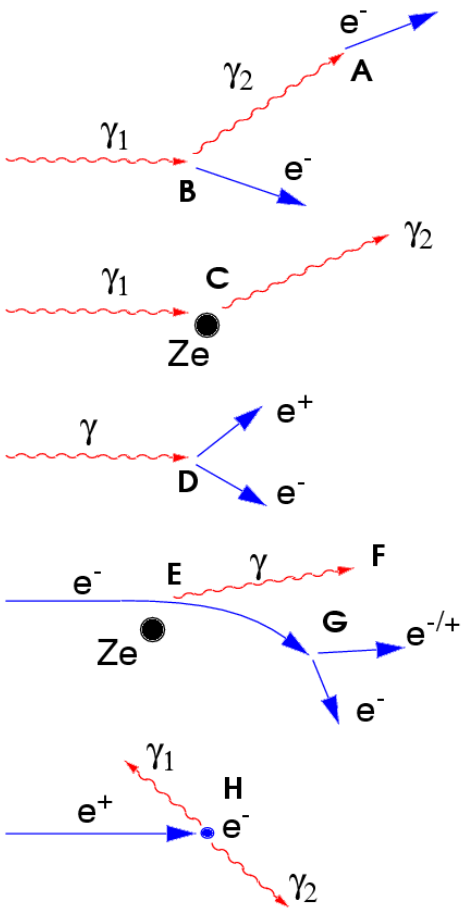
D: pair production

E: elastic

F: Bremsstrahlung

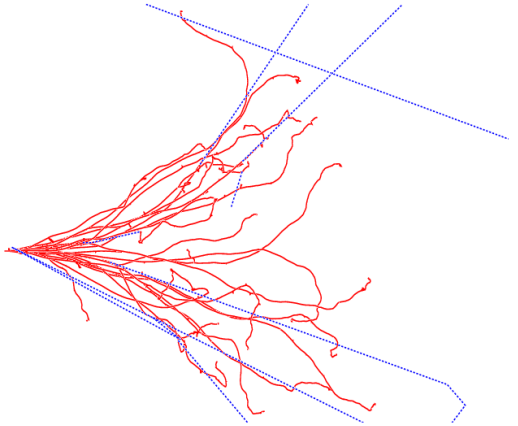
G: inelastic

H: annihilation



Monte Carlo simulations

- calculate many trajectories
  - spatial distribution of energy deposition



- dose kernel: fraction of the decay energy from a spherical source deposited at distance r from the center of the source

$$F(r) = \frac{1}{T_0}\frac{\delta E(r)}{\delta r}$$

- dose from a tumor cell to a healthy cell at a distance r

$$D_{\mathrm{th}}(r) = \frac{T_0}{m_j}\int_{r-r_j}^{r+r_j} F(r')A_j(r')\mathrm{d}r'$$

- average dose to healthy cells

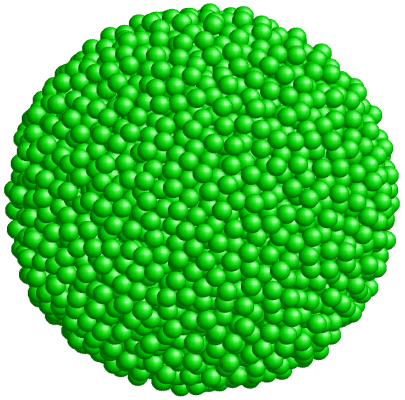
$$\overline{D}_{\mathrm{th}} = \frac{1}{N_{\mathrm{h}}}\sum_{\substack{i\in \text{ tumor}\\ j\in \text{ healthy}}} D_{\mathrm{th}}(|\mathbf{r}_i - \mathbf{r}_j|)$$

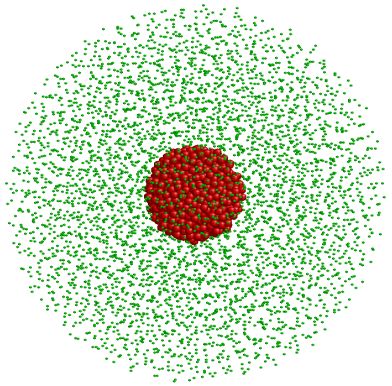
Cell cluster models

- close-packed cubic geometry (i.e. fcc)
  - both tumor and healthy cells in fcc lattices
  - avoid cell overlap → gap between tumor and healthy tissues
  - fast

Cell cluster models

- brute force packing
  - step spherical coordinates r, θ, φ
  - check for overlap (use cell method to calculate intercell distances)
  - no large gap between tumor and healthy tissues
  - non-optimum packing in bulk tissue
  - slow



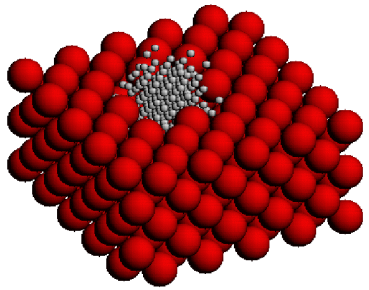


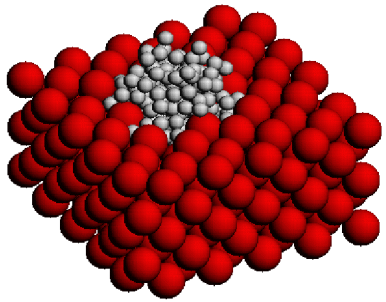
Cell cluster models

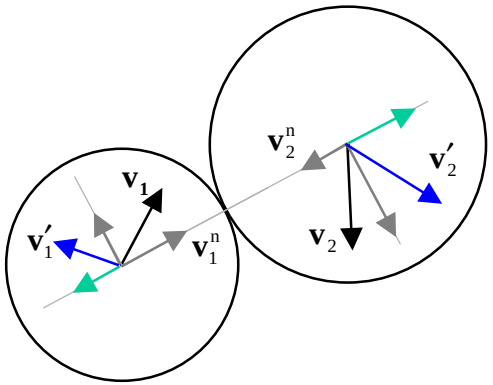
- optimization through hard sphere collisions
  - initial configuration: two fcc lattices, sphere radii 60% and 93% of the final values
  - during the simulation radii are slowly increased towards the final values
  - event-driven MD:
    - calculate time to next collision:

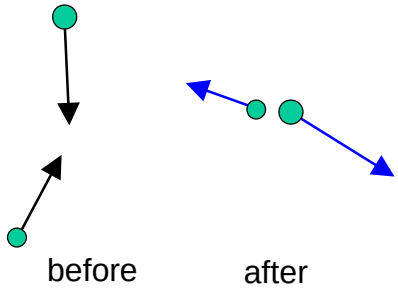
$$|\mathbf{r}_2 + \mathbf{v}_2 t_c - \mathbf{r}_1 - \mathbf{v}_1 t_c|^2 = (r_{10} + r_{c1} t_c + r_{20} + r_{c2} t_c)^2$$

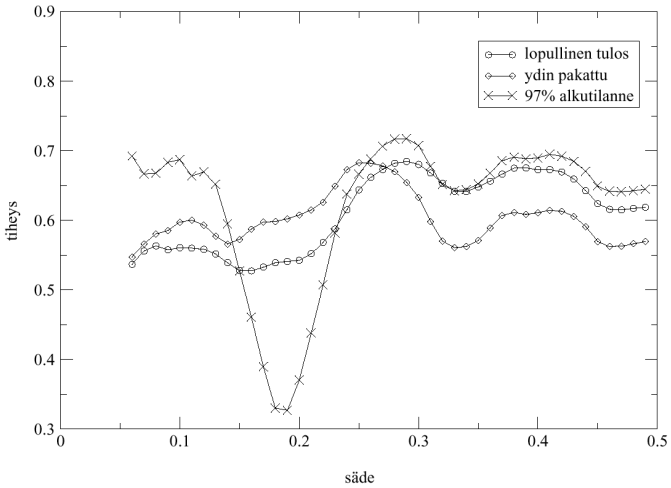
    - advance spheres to time t_c
    - collision: exchange normal components of the velocities







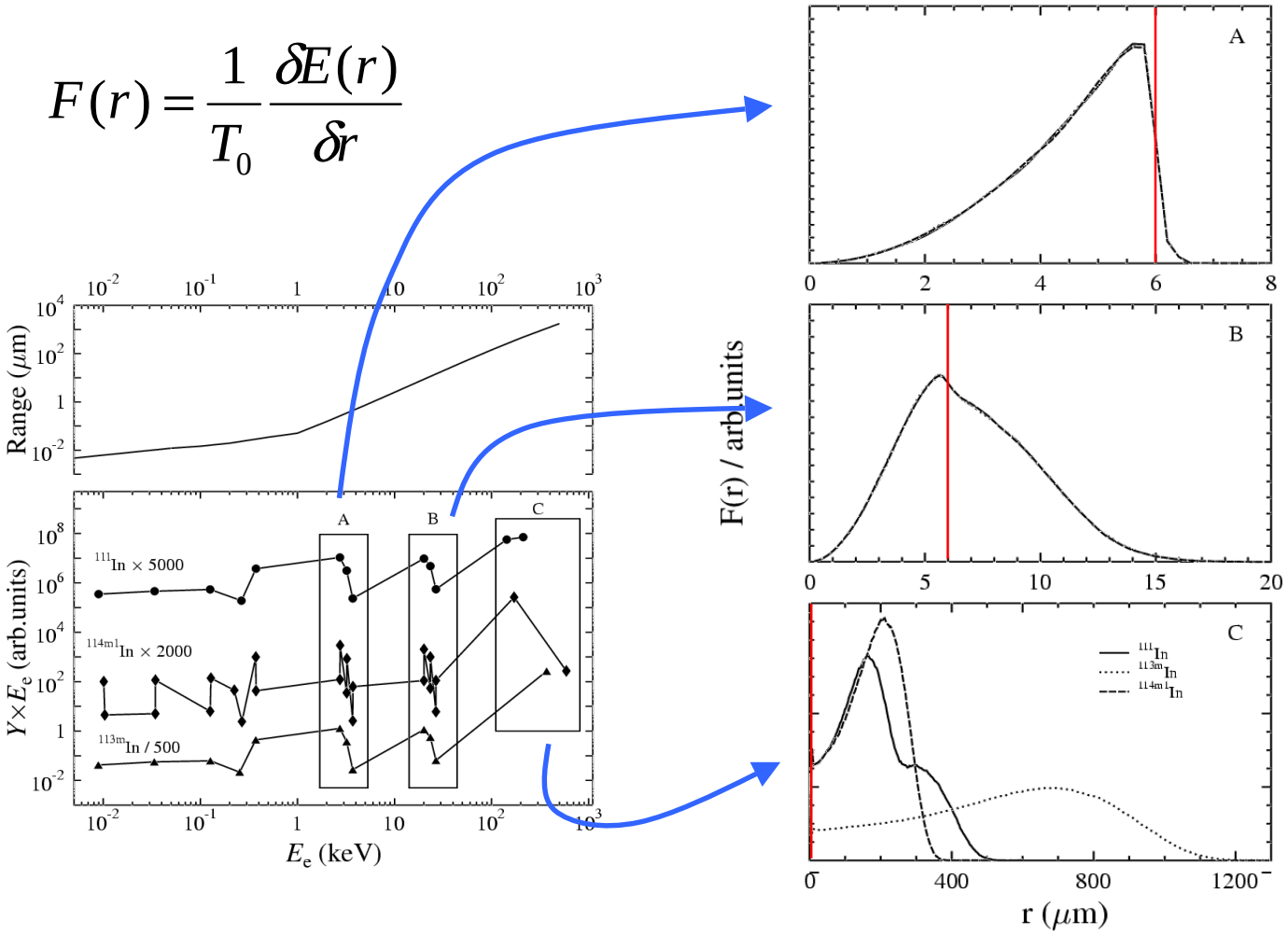




Results

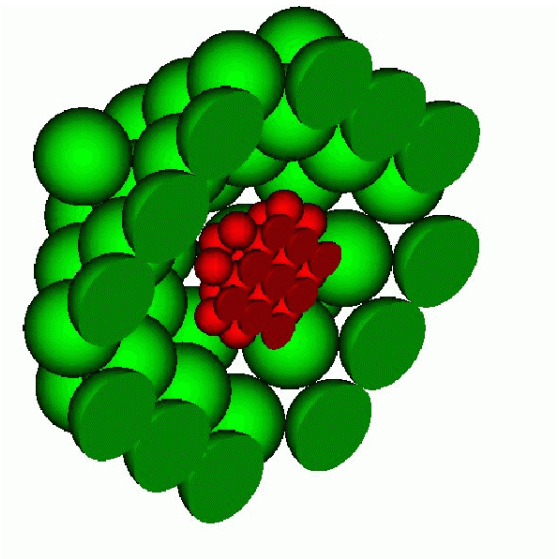
- dose kernels

$$F(r) = \frac{1}{T_0}\frac{\delta E(r)}{\delta r}$$

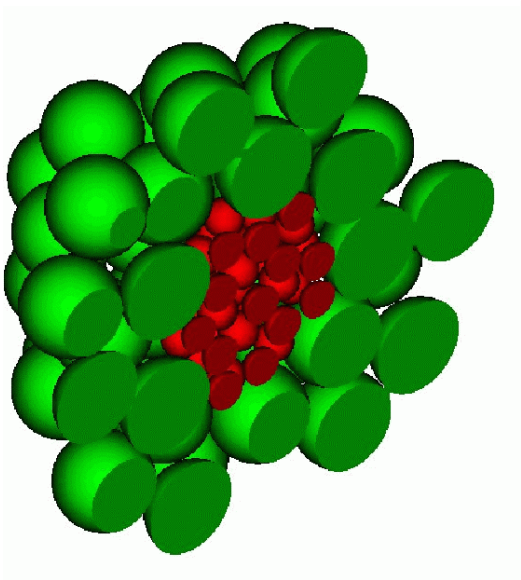


Results

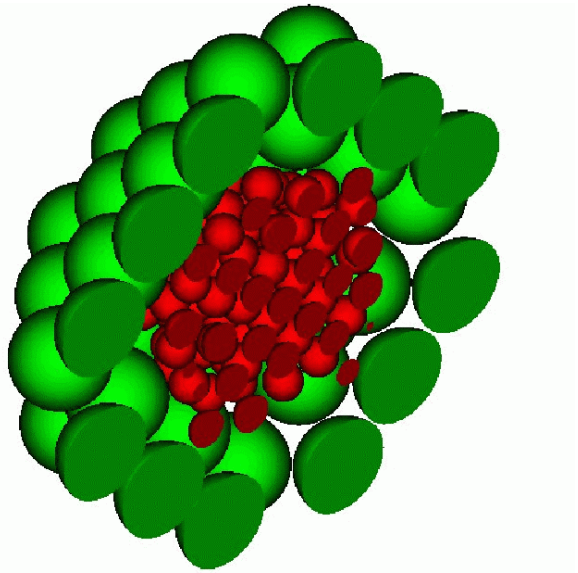
- cluster geometry



close-packed



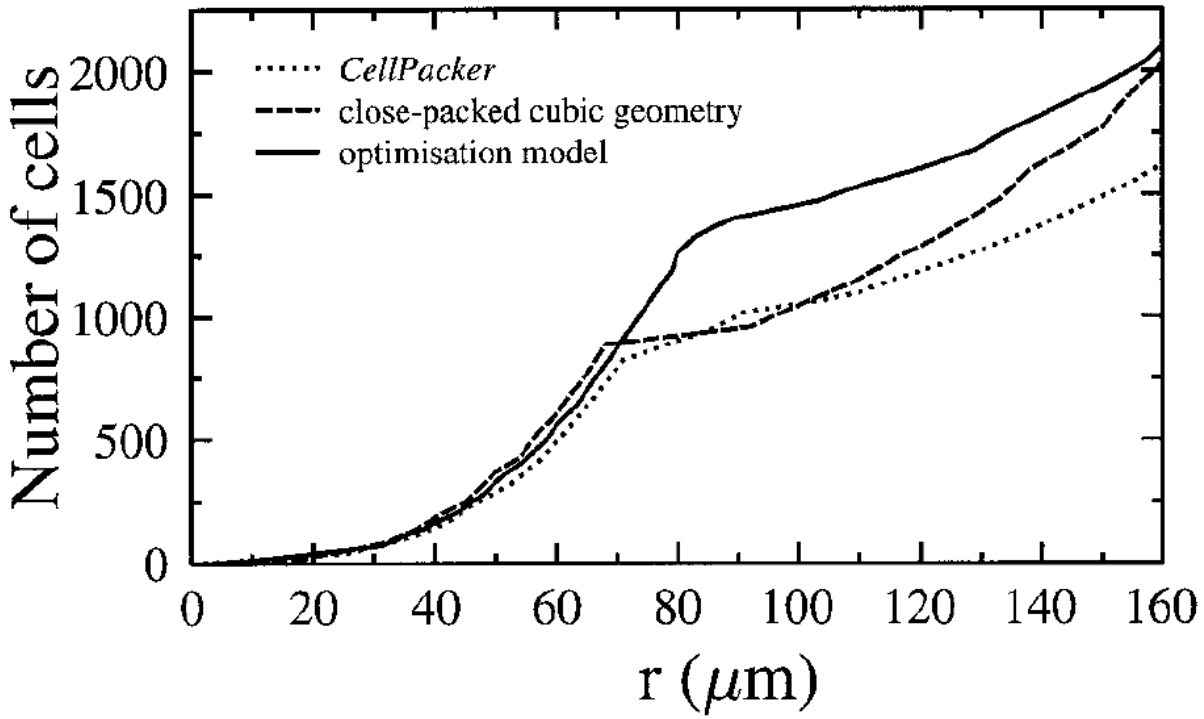
brute force



optimization

Results

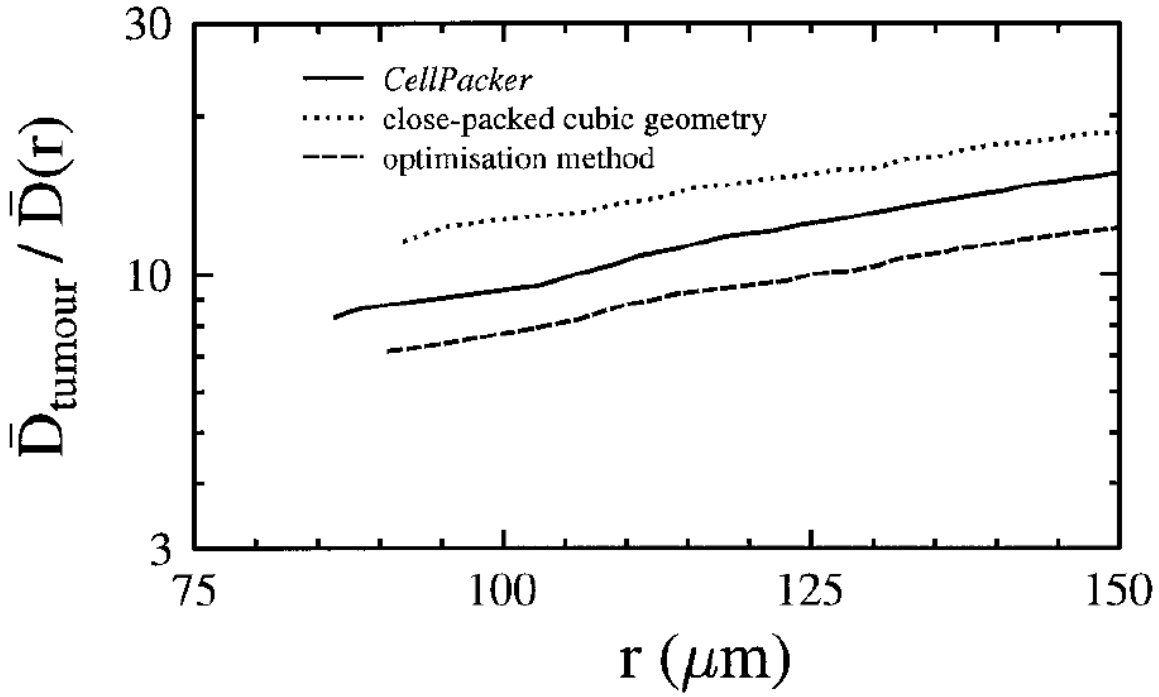
- cluster geometry



Results

- dose distributions:

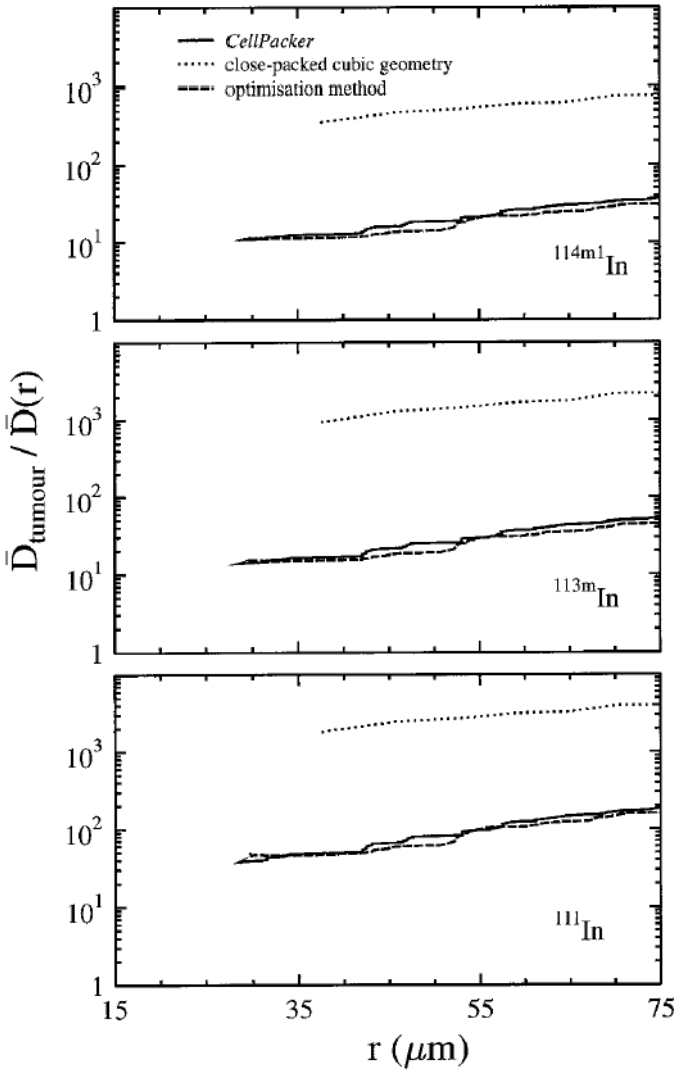
therapeutic effect $\frac{\overline{D}_{\text{tumor}}}{\overline{D}(r)} =$ ratio of the mean absorbed dose in tumor cells to the mean absorbed dose of the healthy cells inside radius r



tumor radius
75 µm

Results

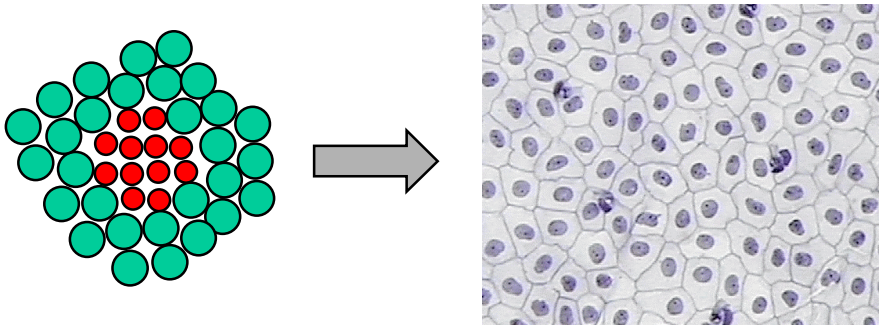
- dose distributions



tumor radius
15 µm

Conclusions

- cell model important
- future studies: model based on microscopy data of real tissue



- experimental data?

- BNCT: energy deposition also by ions (α, ^{7}Li)
  - MD? (overkill)
  - binary collision approximation (BCA) codes (e.g. SRIM http://www.srim.org/)