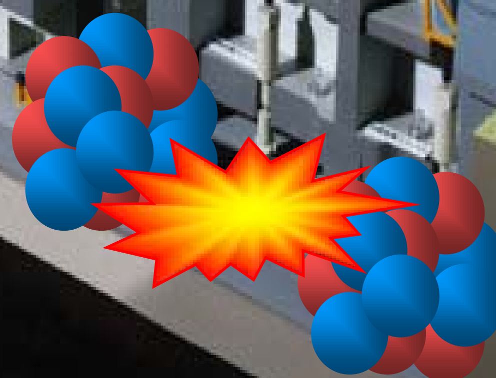
Symposium on Nuclear Data 2004
Nov. 12, 2004 @ JAERI, Tokai

Nuclear Data for Radiation Therapy

~from macroscopic to microscopic~



Naruhiro Matsufuji, Yuki Kase and Tatsuaki Kanai
National Institute of Radiological Sciences
Research Center for Charged Particle Therapy
NIRS

Résumé

- Introduction
  - radiations used for radiotherapy
  - what to estimate to carry out heavy ion therapy
- Macroscopic effect
  - nuclear reaction
    - dose
- Microscopic effect
  - beam quality
    - biological effect
  - spatial distribution
    - advanced irradiation
  - microdosimetry
    - nature of heavy ion radiotherapy
  - neutrons
- Summary

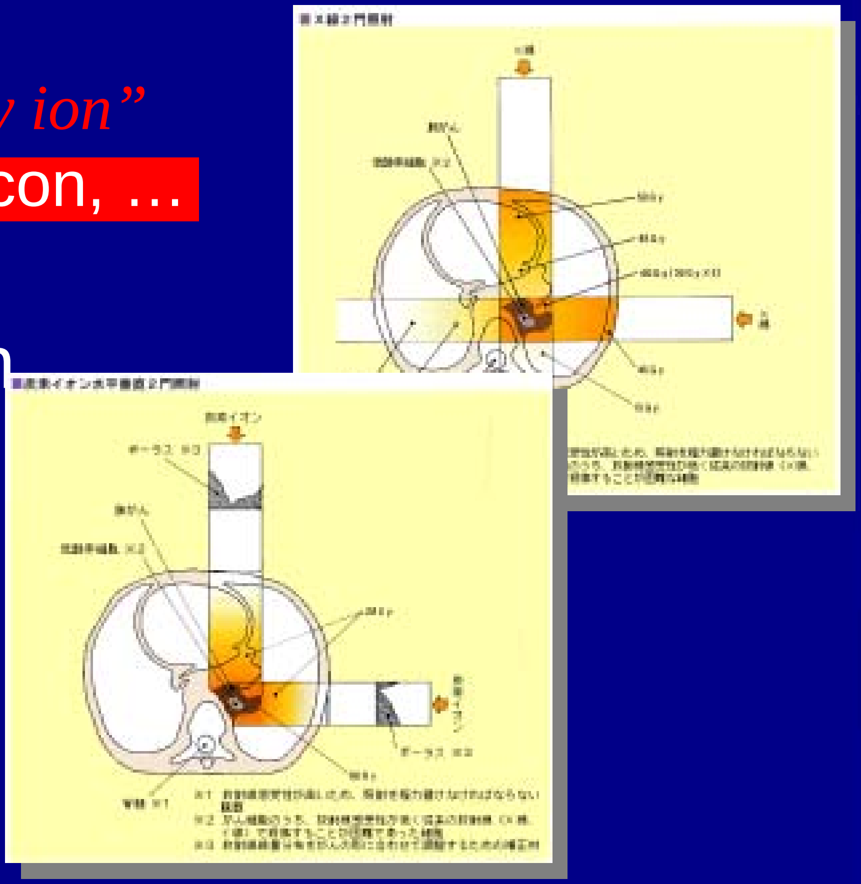
Radiations used for tumor therapy

- direct ionizing radiation
  - electron
  - proton
  - helium, carbon, neon, silicon, …

  "Heavy ion"

  :
- indirect ionizing radiation
  - photon
  - neutron

  :



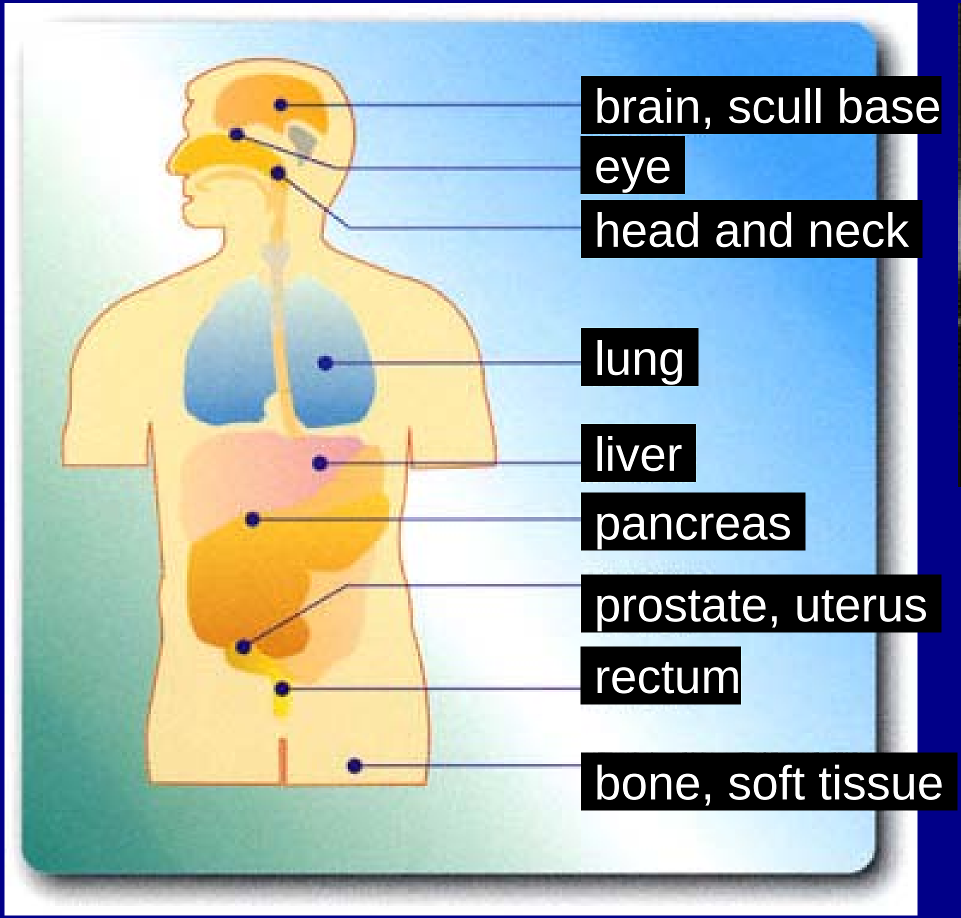
HIMAC (Heavy Ion Medical Accelerator in Chiba)

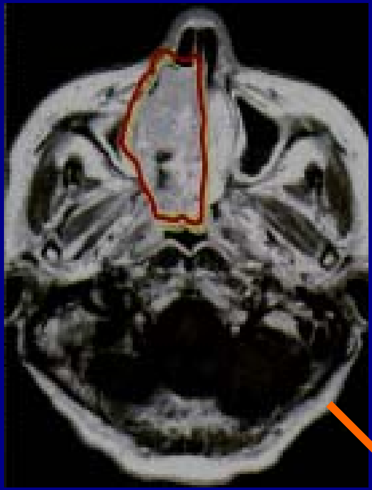
- Established in 1994.
- Aimed at finding optimal heavy ion therapy scheme.

ion species	H,He,C,Ne,Si,Ar,Fe,Kr,Xe
maximum energy	800 MeV/n (ε=Z/A=1/2)
beam intensity	$10^0 \sim 10^9$ particles/pulse
repetition cycle	0.3 / 0.5 Hz

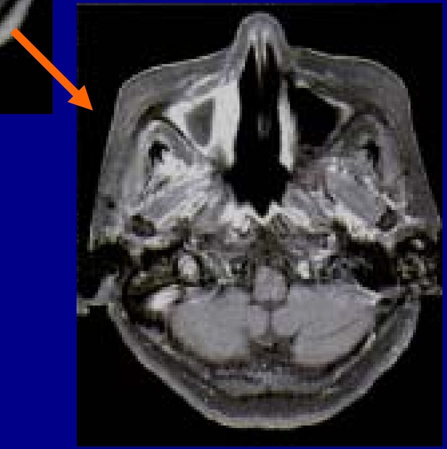
Clinical trials at HIMAC

- Targets of carbon therapy





nasal passage cancer

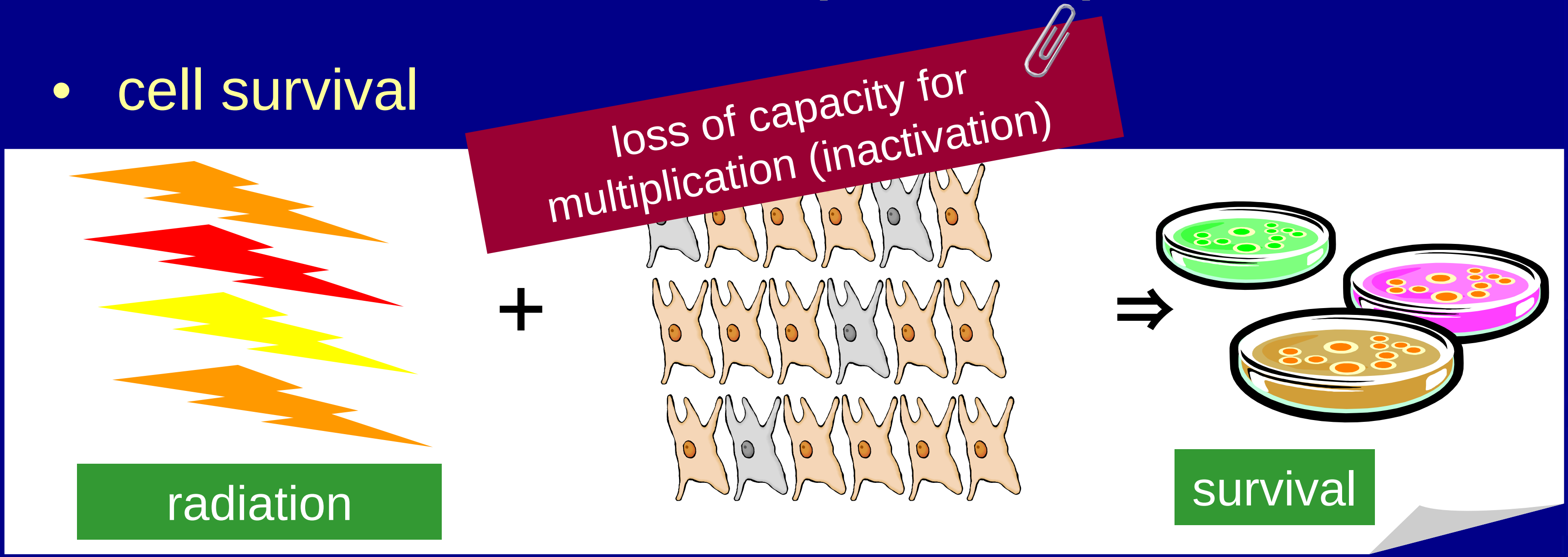


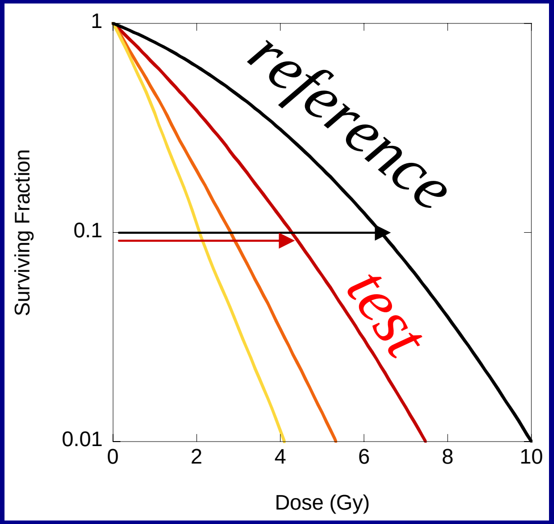
Nov. 1, 2003: approved as a Highly Advanced Medical Technology

¥3.14M / treatment

Basis of clinical dose prescription

- cell survival



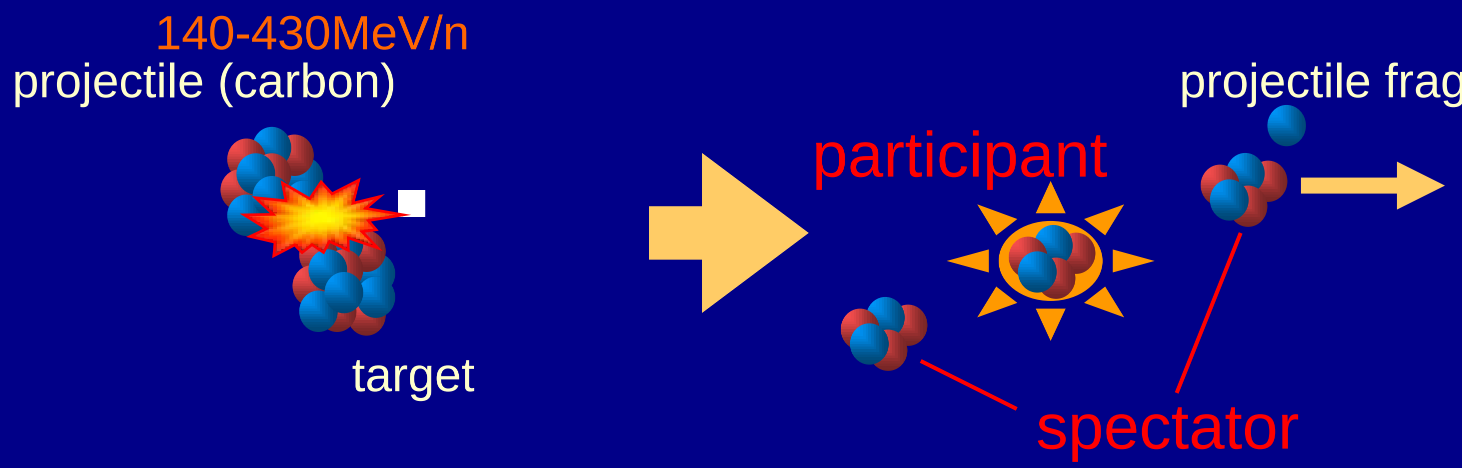


$$RBE = \frac{D_{reference\_radiation}}{D_{test\_radiation}}\Bigg|_{same\_effect}$$

carbon: 2~3

Characteristic of heavy-ion therapy

- Fragmentation of incident particles



Projectile fragments have almost

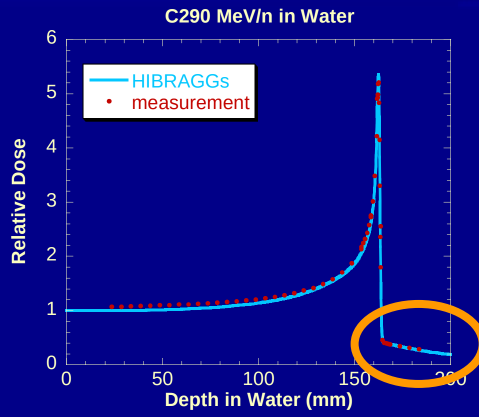
-…same velocity
-…same direction

with those of primaries.

Therapeutic beam is contaminated by fragments!

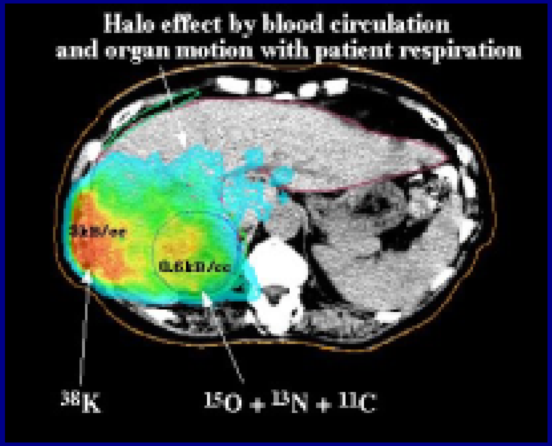
Why?

■Effect by fragmentation
from clinical point of view

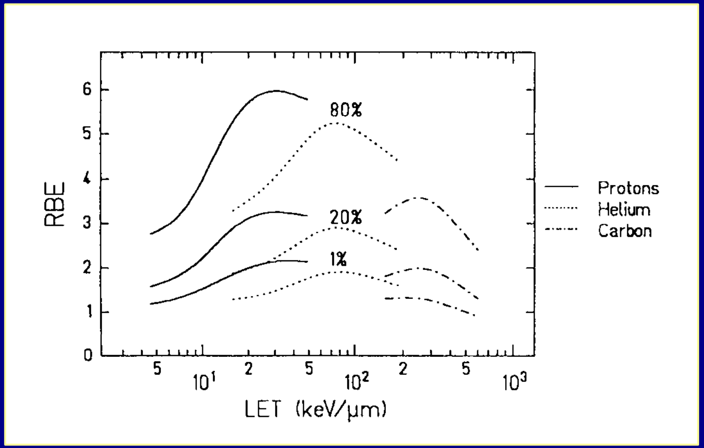


Production of fragment particles...

✓…causes unwanted dose beyond the range
✓…makes estimation of biological effect complex.
✓…makes it possible to monitor beam range.



T. Nishio (NCC-east), private comm.



M. Scholz et al., Radiat. Environ. Biophys., 36, 59 (1997).

▪ Macroscopic effect

Depth dose distribution

Depth-dose distribution

- Dose……”quantity of radiation”

$$Dose = J / kg[Gy]$$

the most fundamental factor to be controlled on radiotherapy

physical factors

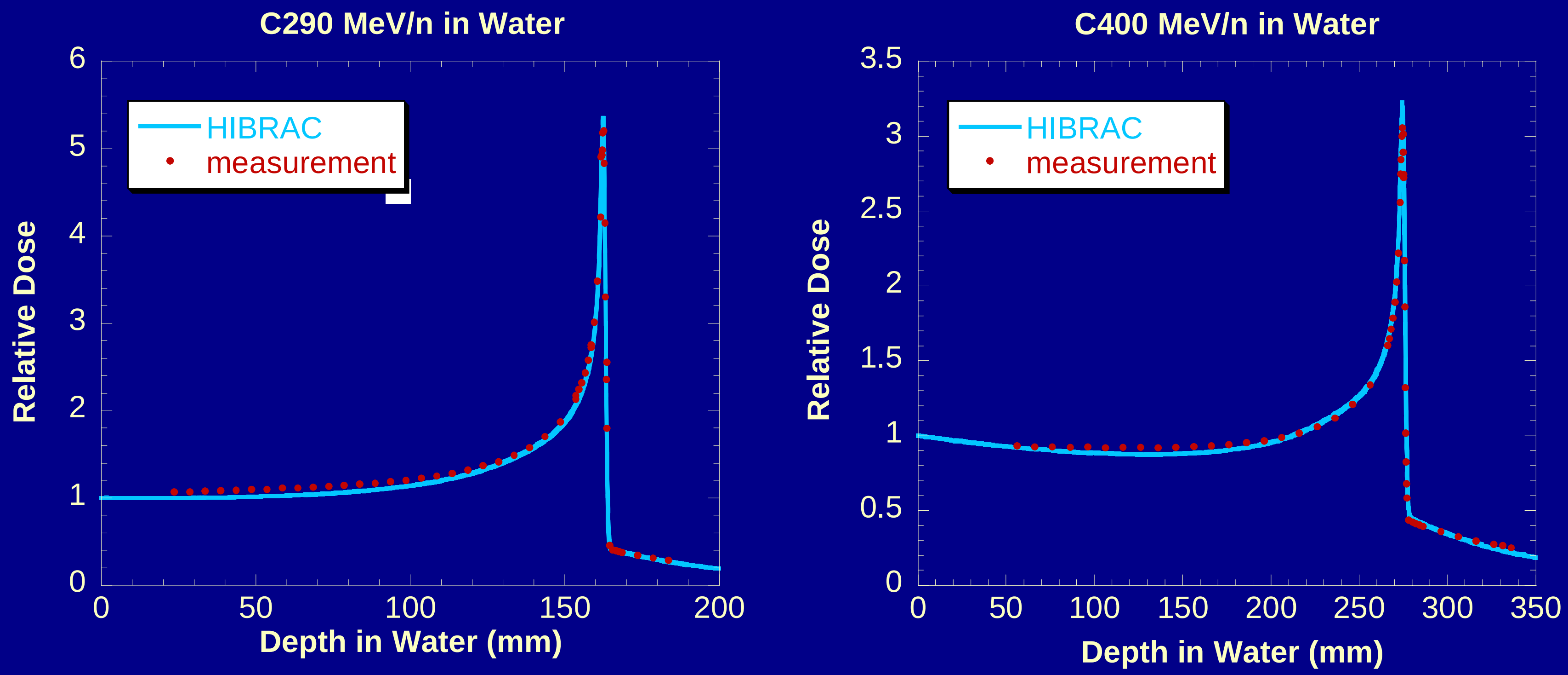
reaction cross section
stopping power
multiple scattering and straggling
:

✓Disintegration of primaries
☞loss of dominant dose carrier

✓Production of fragments
☞deliver dose but form ‘fragment tail’ beyond the range

Depth-dose distribution

- Depth-dose distribution in water measured at HIMAC



Dose can be controlled in clinically enough precision.

basis of ongoing carbon therapy

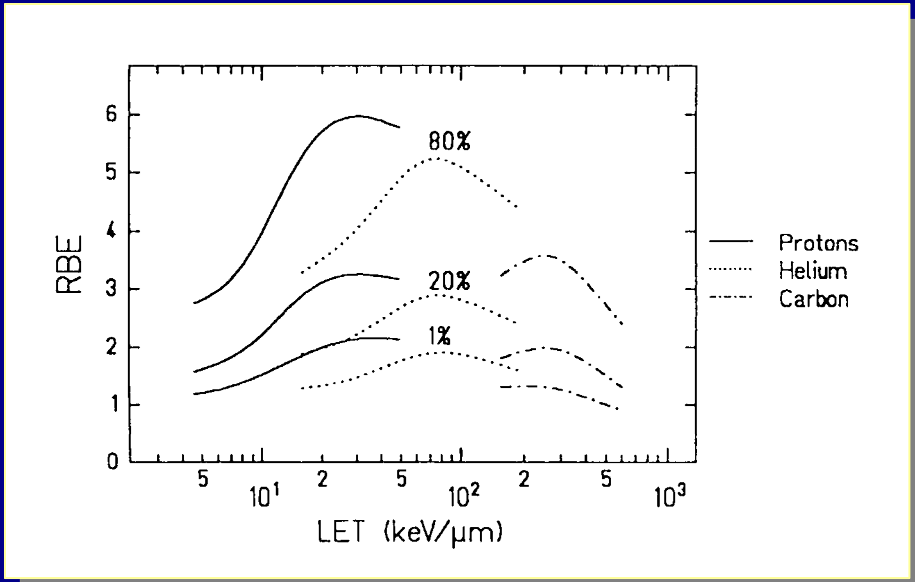
▪

Macroscopic to Microscopic

What? – particle identification

Importance of P. I.

- LET and particle species dependency of RBE (CHO cell)

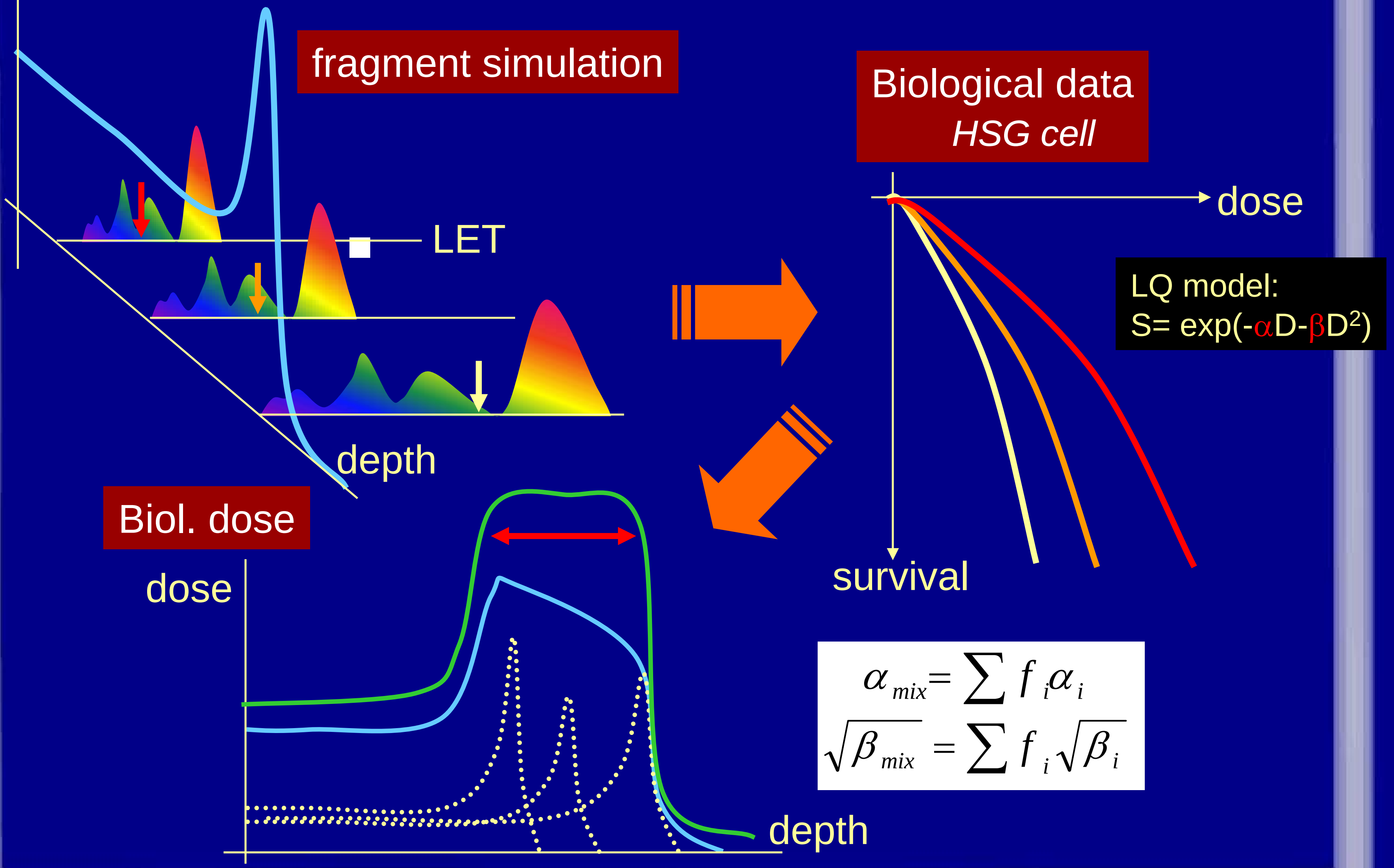


M. Scholz and G. Kraft, Rad. Prot. Dos., ***52****, 29 (1994)*

How should we take into account this complexity?

Radiation quality (fluence and energy)

How? - NIRS scheme



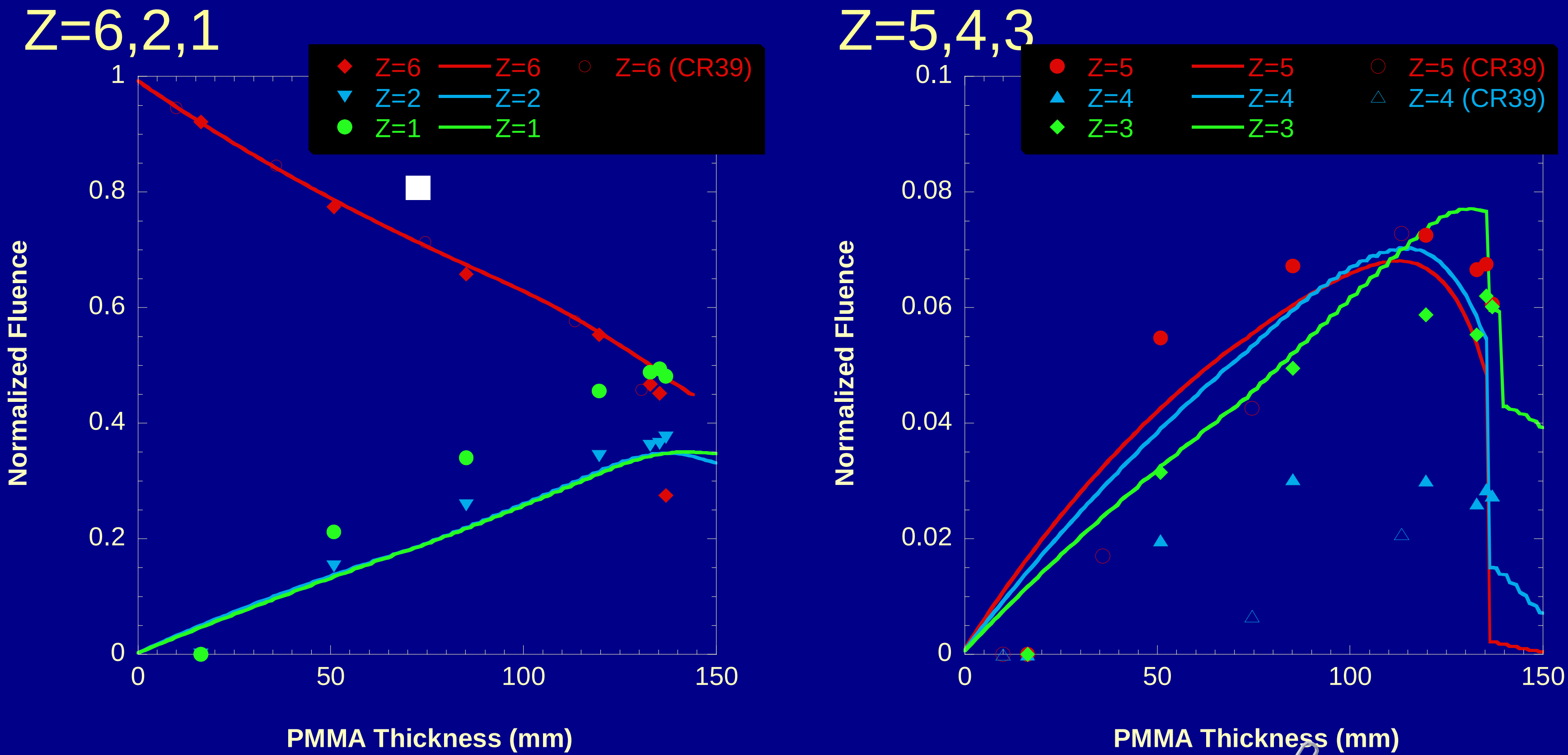
$$\alpha_{mix} = \sum f_i \alpha_i$$

$$\sqrt{\beta_{mix}} = \sum f_i \sqrt{\beta_i}$$

How many? - fluence

- ^{12}C-290MeV/n

Calculation: hibrac (old)



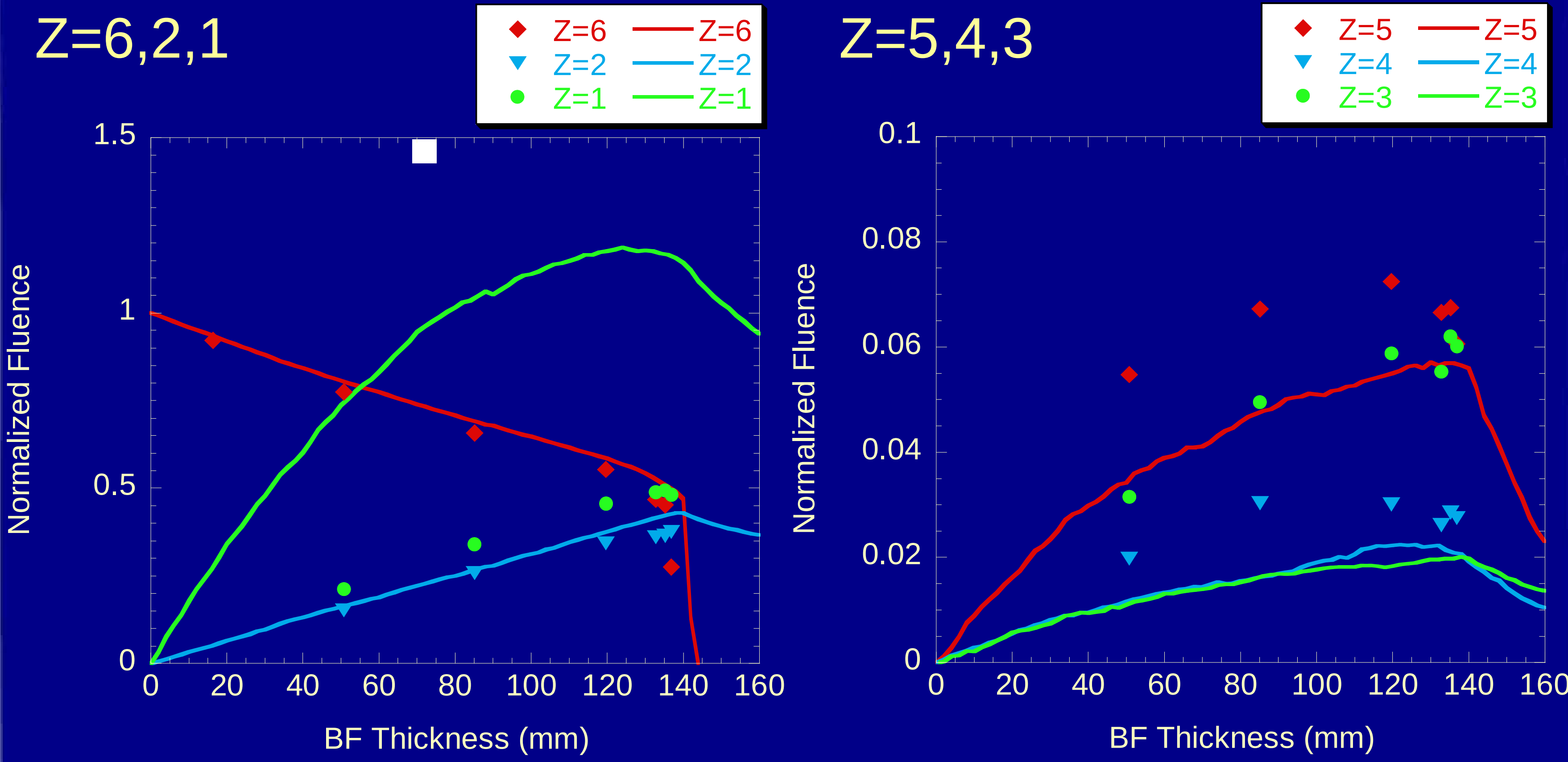
Need improvement on simulation model

N. Matsufuji *et al Phys. Med. Biol.*, **48**, 1605 (2003)

Comparison with PHITS

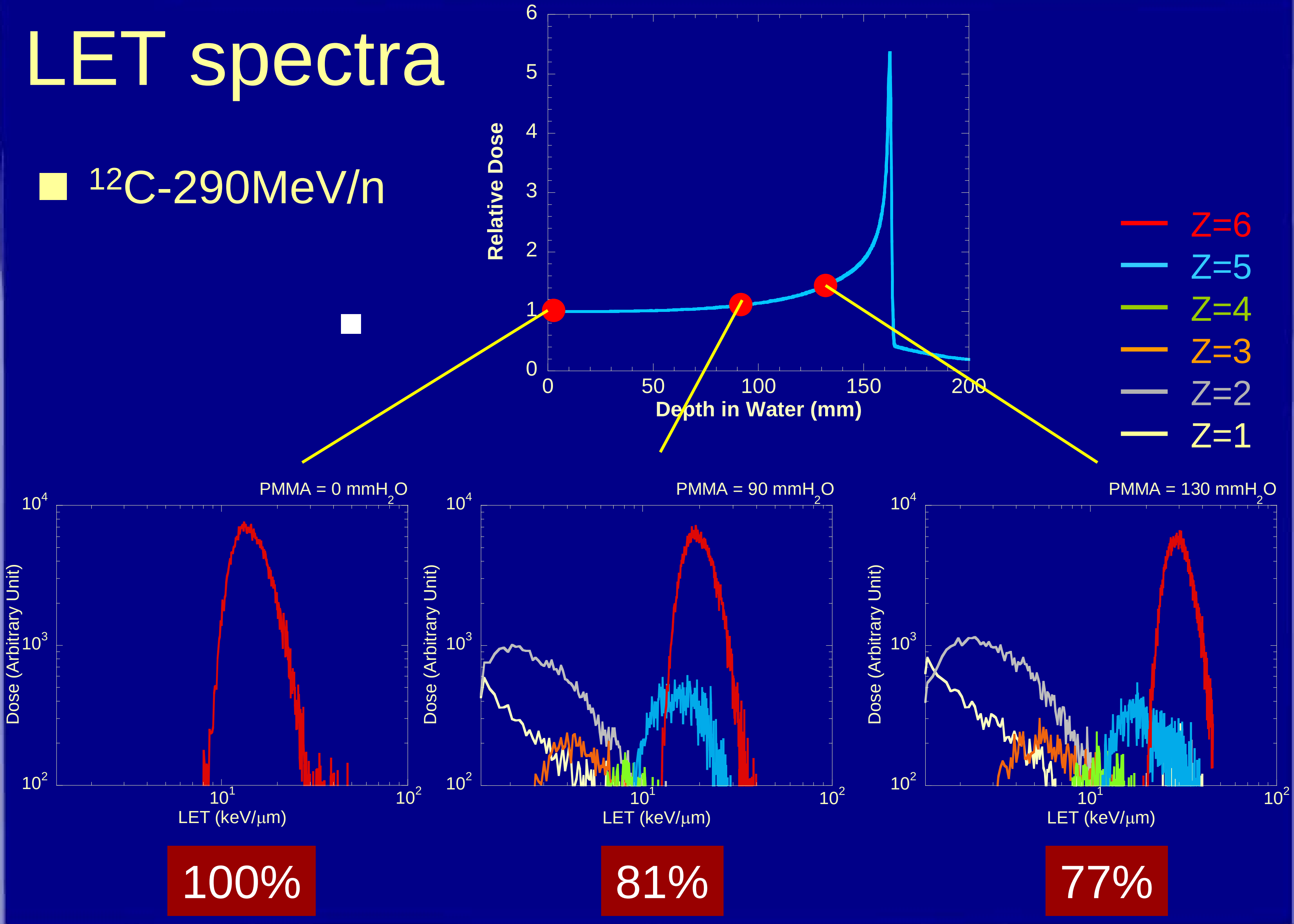
- ^{12}C-290MeV/n

Calculation: PHITS 1.80



LET spectra

- ^{12}C-290MeV/n



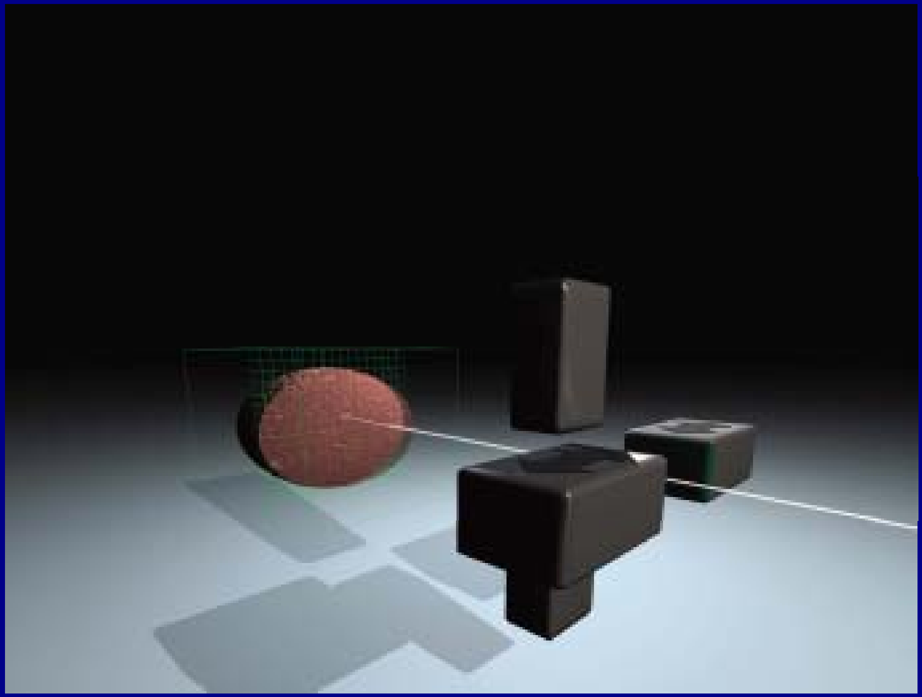
Heavy-ion therapy sites

- Where? – spatial distribution

Importance of the spatial distribution

- Scanning irradiation with pencil beam

stopping power
multiple scattering
production cross section
reaction cross section
momentum transfer
:



(picture from SIEMENS*)*

☞Not fully understood both experimentally / theoretically

More microscopic!

- microdosimetric approach

Microdosimetric problem

- Random energy deposition in cell nucleus

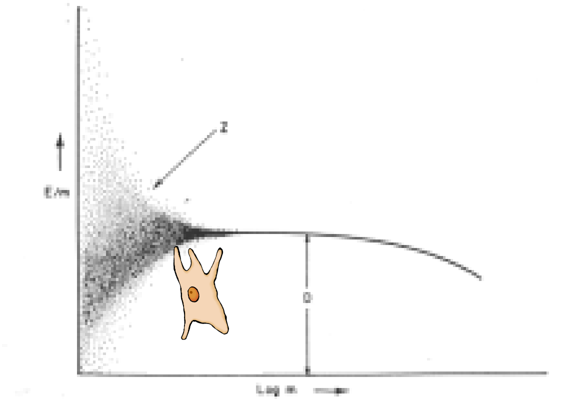
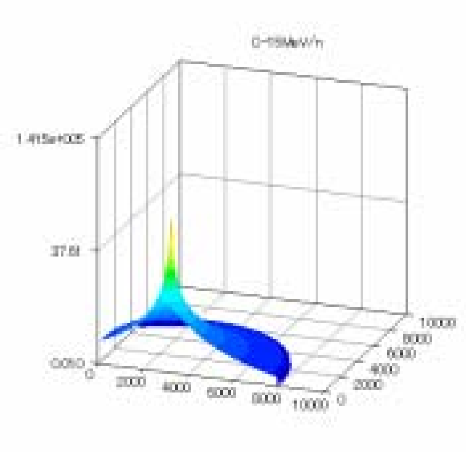
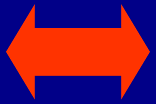


FIG. 1. Energy density as a function of the mass for which energy density is determined. The horizontal line covers the region in which the absorbed dose can be established in a single measurement. The shaded portion represents the range where statistical fluctuations are important.

- *amorphous (averaged) track*
- *actual (sparse) track*





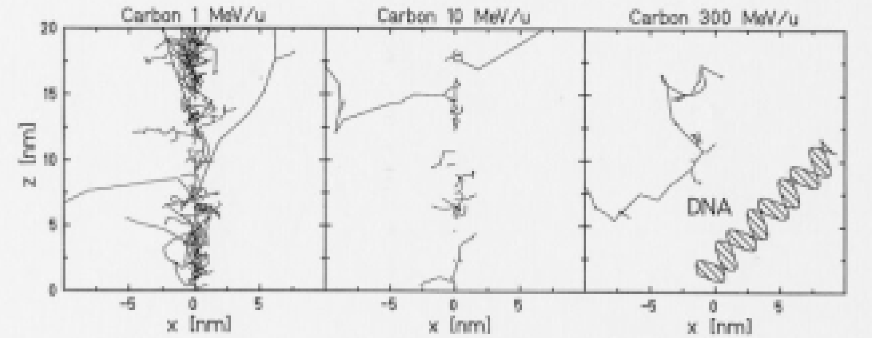
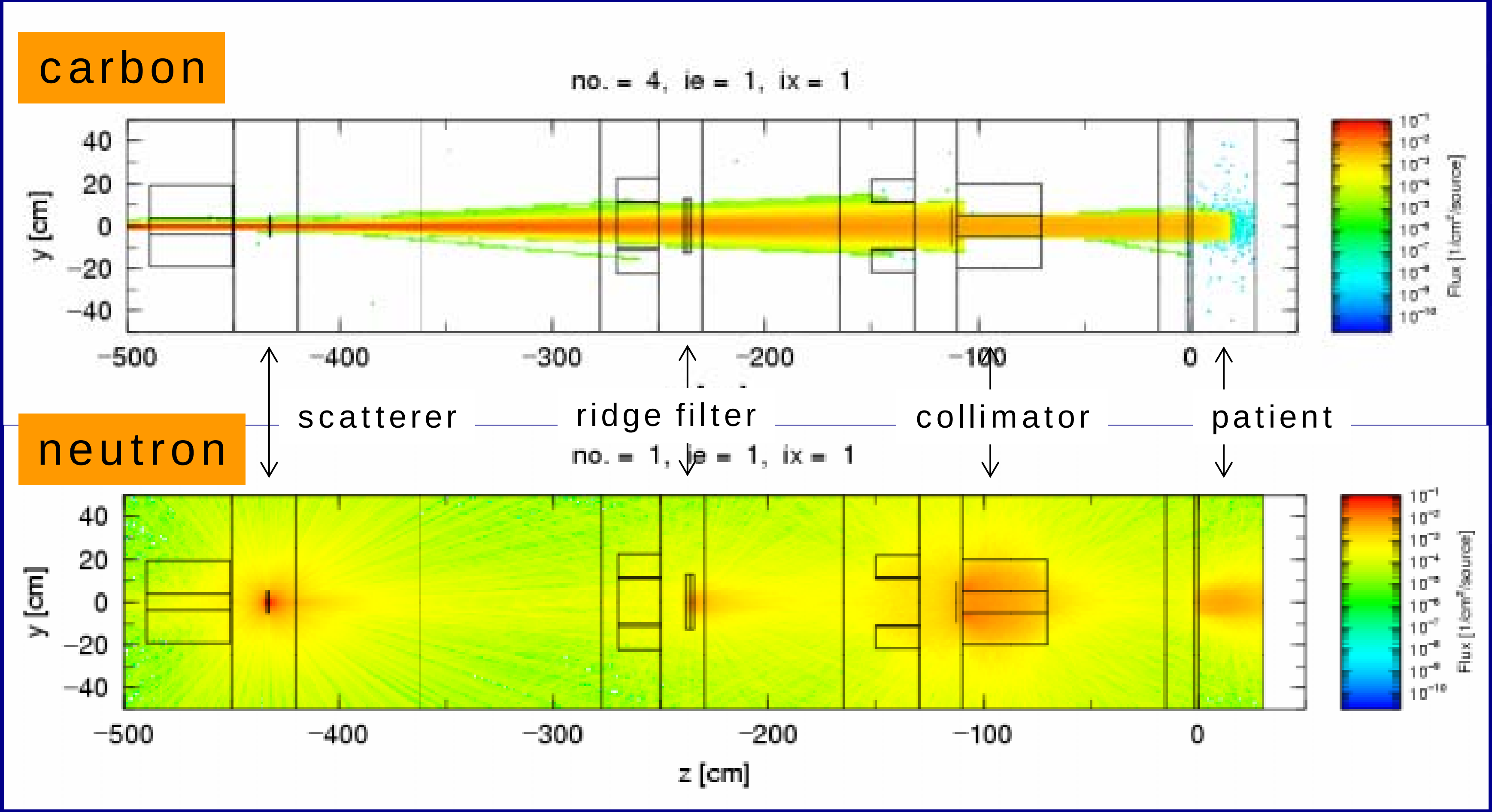


Fig. 5. Comparison of the microscopic structure of carbon tracks at different energies with a simplified depiction of a DNA molecule. Ionisation and consequently the damage to the DNA is low at high particle energies but increases significantly at lower particle energies yielding clustered damage that is difficult to repair.

- What? – neutrons

Neutrons in therapy room

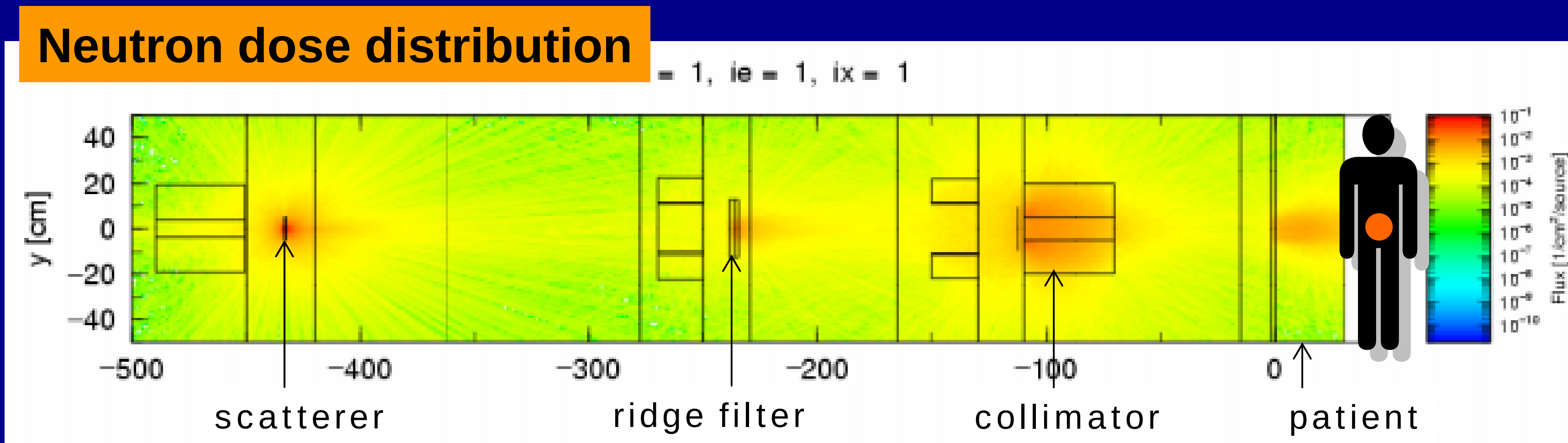
- ^{12}C-290MeV/n 10000 particles （simulation with PHITS）



Geometry: from Nose (IHI)

Neutrons in therapy room

- ^{12}C-290MeV/n 10000 particles （simulation with PHITS）



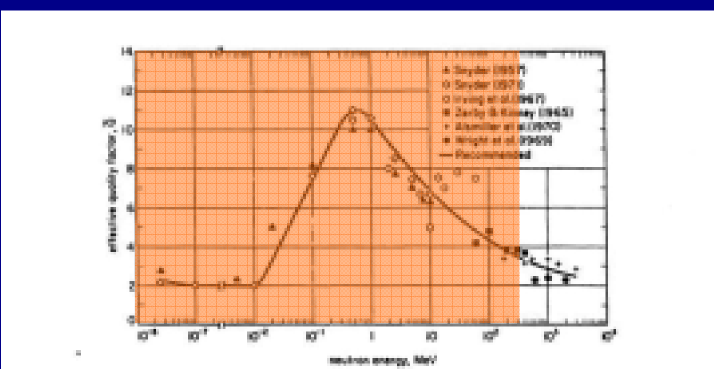


FIGURE 16.6. Quality factors for neutrons, that is, the maximum dose equivalent divided by the absorbed dose at the same depth in the body. The curve represents the recommendation of the ICRP. (ICRP, 1971. References in the figure are given in that report. Reproduced with permission from Pergamon Press, Ltd.)

•Risk estimation for the induction of the secondary cancer

•Dependency to irradiation scheme

•Optimal treatment method

Summary

- Macroscopic effect

✓<u>Charge-changing cross section</u>

☞Depth-dose distribution is given in good precision

Dose is delivered to tumor accurately

Need further investigation for heavier elements

Summary

- Microscopic effects

✓Fluence and LET distribution (broad beam)

☞Feedback to biology (ex. survival simulation)

✓Spatial distribution (pencil beam)

☞Input data for RTP of scanning irradiation

✓Angular distribution, double differential production cross section, momentum transfer, …

☞Development of simulation code including spatial information, advanced RTP (inhomogeneous structure)

✓Microdosimetric approach

☞Understanding of the nature of heavy ion therapy

Thank you for your attention.

Mt. Fuji from Chiba city

A part of this work was carried out as the Research Project with Heavy Ions at HIMAC.