Radiation Protection of Patients in External RT

Impact of New Treatment Technology on Patient Protection in Radiotherapy

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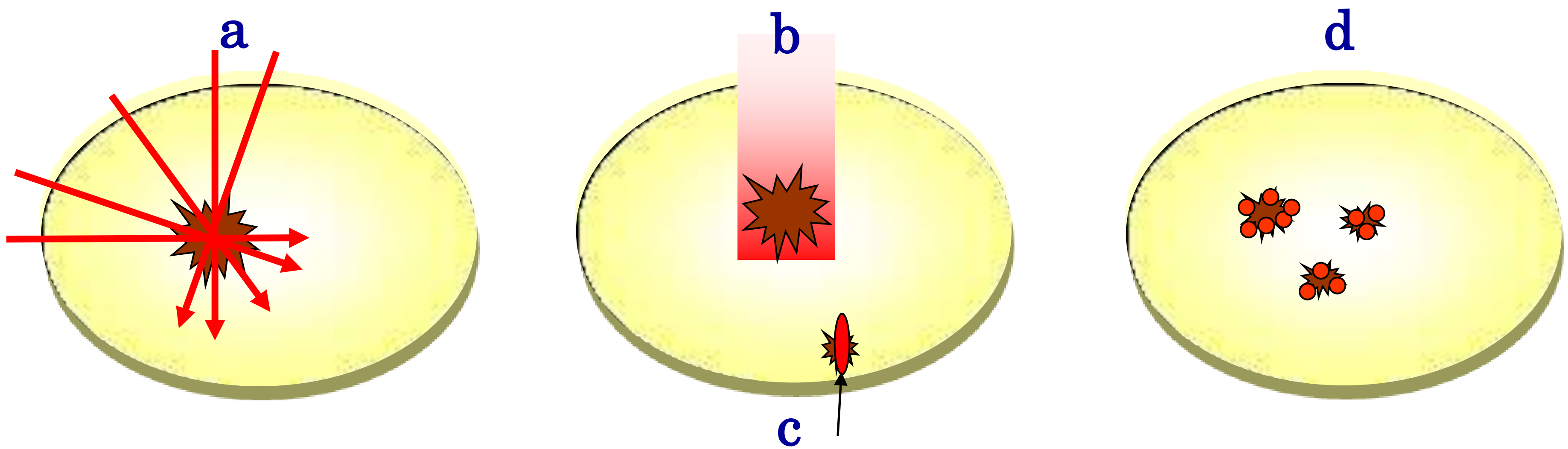
What did we learn from the past ?

- Biological effects of radiation
  - Threshold for high dose radiation (tissue reaction)
  - Different biological effects among the types of radiation
  - Different response in tumor and normal tissues (dose fractionation)
  - Radio-resistant tumor cells (hypoxia, cancer stem cell, etc.)
  - Individual variation of sensitivity in normal tissues

- Radiotherapy
  - Optimize dose fractionation
  - Maximize the target (tumor) to non-target (normal) ratio

Recent Progress in Radiotherapy

- Improve target /non-target ratio
  a. Irradiation from multiple directions (IMRT)
  b. Ion beam treatment (proton, carbon)
  c. Brachytherapy (sealed source)
  d. Molecular target radiotherapy (unsealed source)



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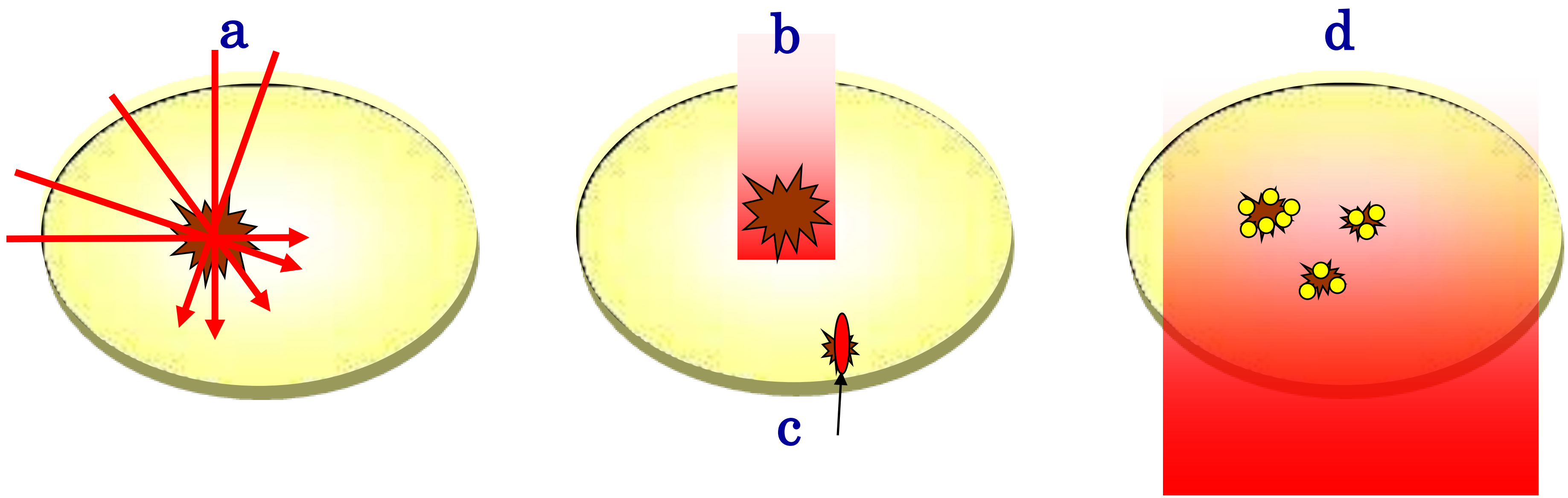

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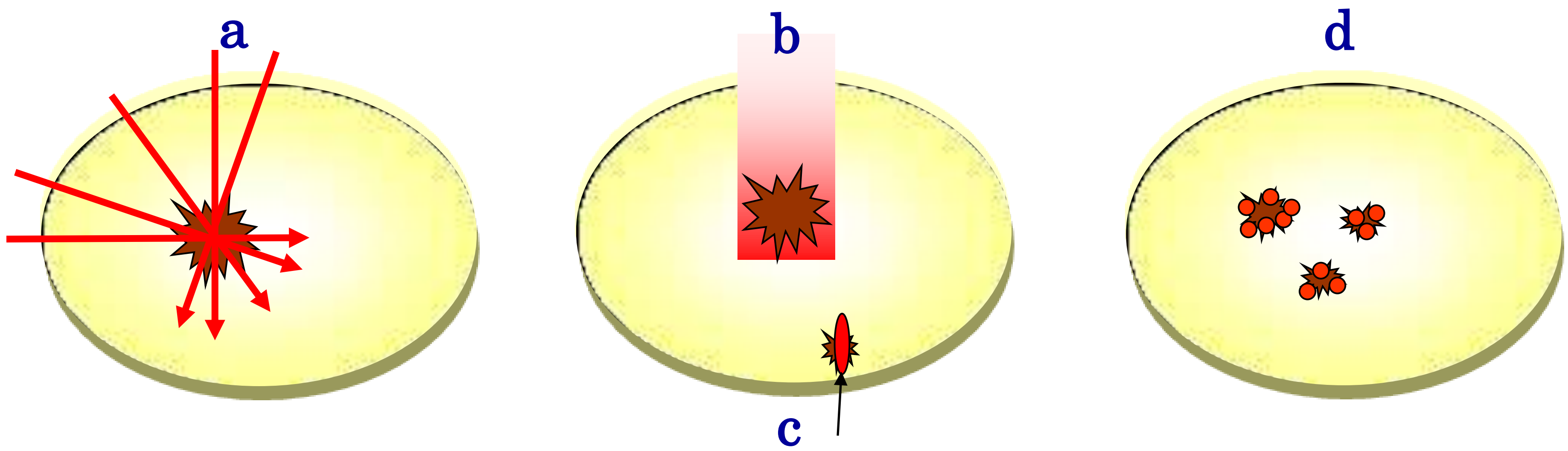


Recent Progress in Radiotherapy

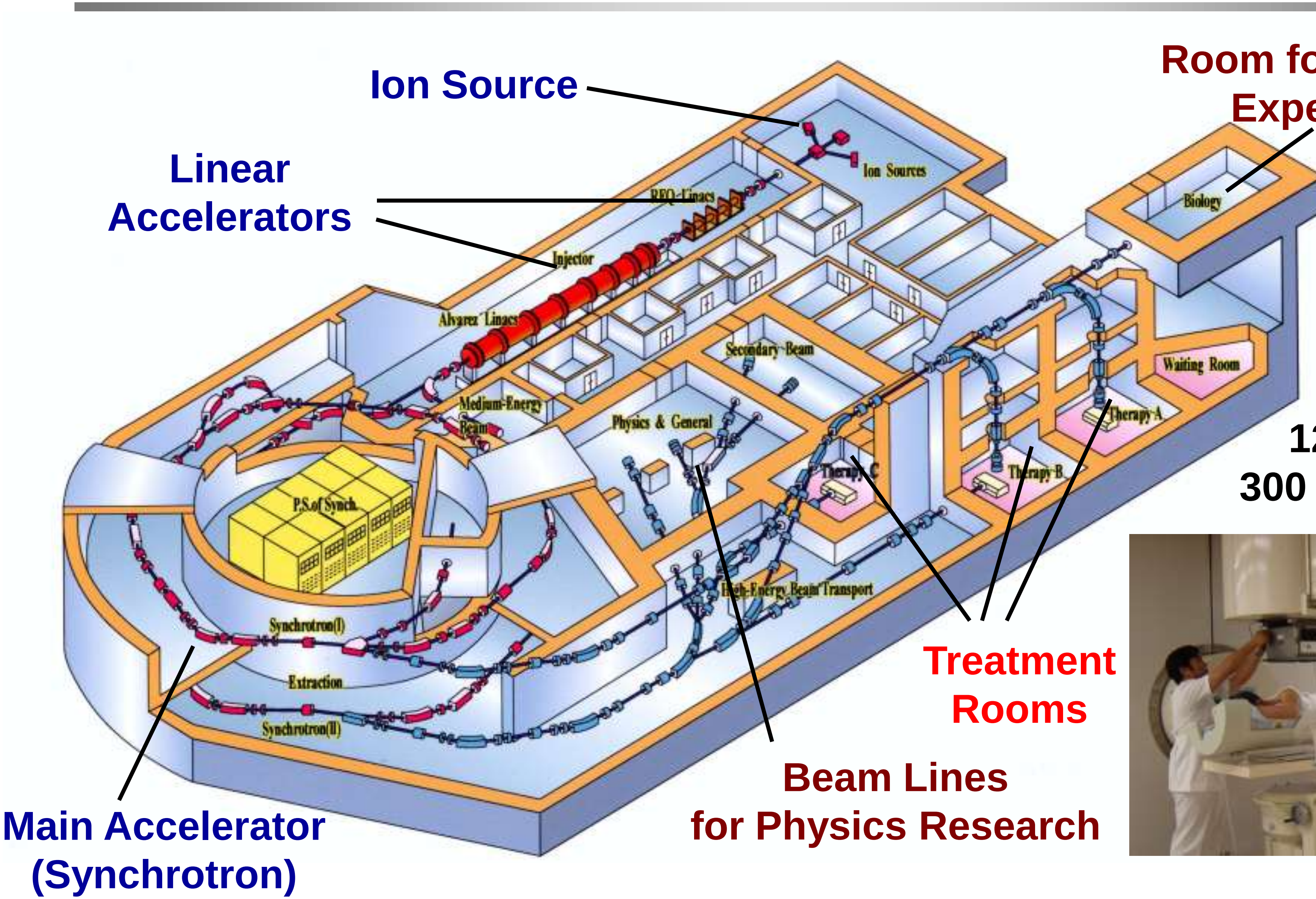
- Challenges in radiobiology

a. Radio-resistant tumor cell
   - Imaging of hypoxic tumor / cancer stem cell
   - Increase dose (dose painting)
   - High LET radiation (carbon-ion)

b. Variation in sensitivity
   - Effects of age / sex ; animal experiment
   - Hypersensitive genotype ; analysis of clinical sample

c. Integration of physics, chemistry and biology

HIMAC: *Heavy Ion Medical Accelerator in Chiba*



120 x 65 m
300 Million USD

Milestone of HIMAC Radiotherapy

1984 Carbon ion therapy project started under Comprehensive 10-year Strategic Project for Cancer.

1988 Construction of HIMAC started with vendor partners ; Mitsubishi, Hitachi, Sumitomo, Toshiba.

1993 Construction of HIMAC completed.

1994 Clinical trials of carbon ion radiotherapy started.

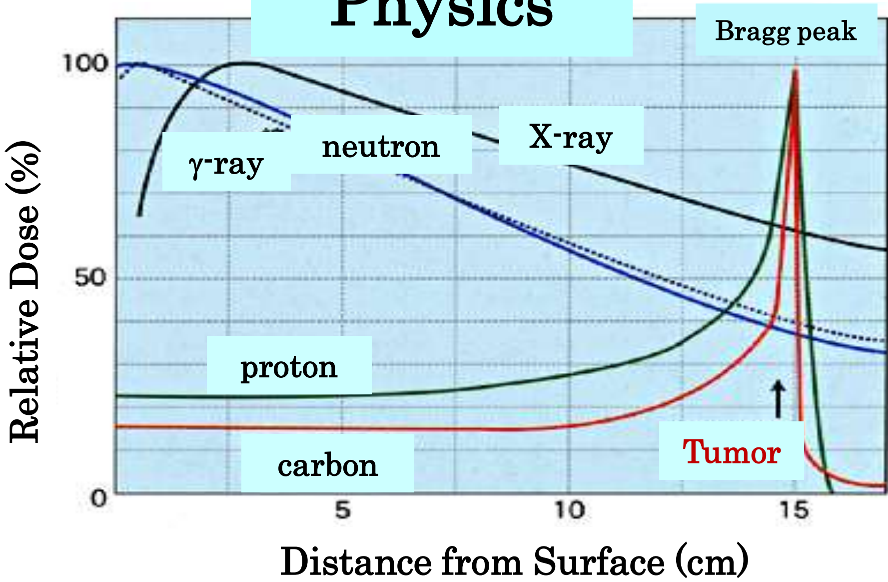
2003 Approved as advanced medical technology.

2010 Compact system (1/3 in size and cost) in Gunma Univ.

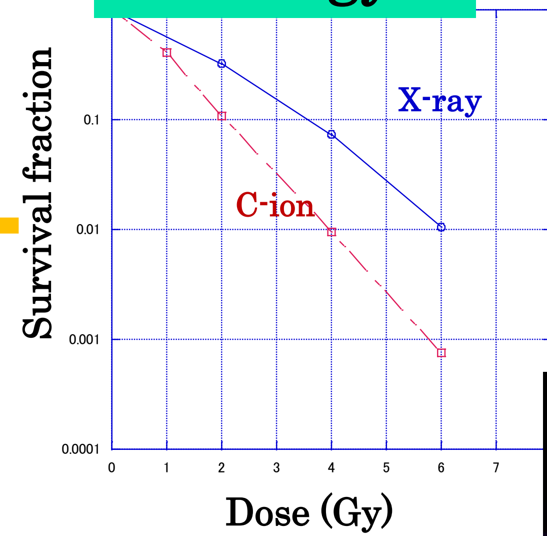
2012 Accept 700 new patients every year, reaching total 7,000 patients.

Need for Multidisciplinary Approach

Physics

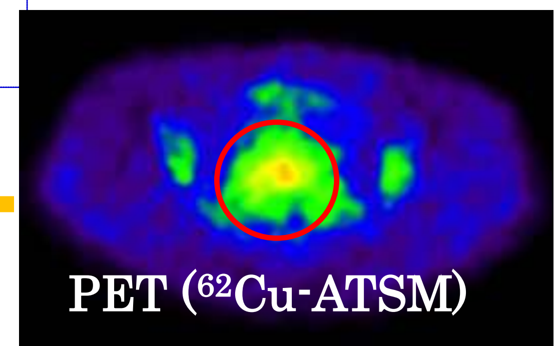


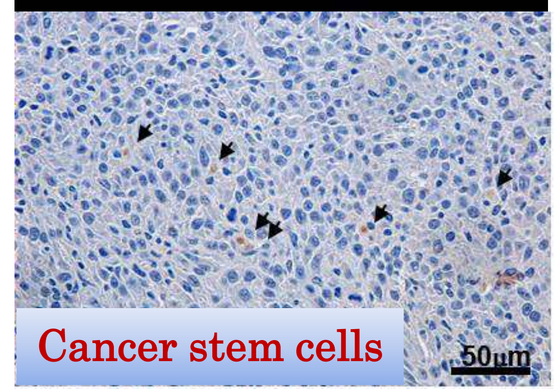
Biology



Imaging

Hypoxic tumor
(resistant to therapy)

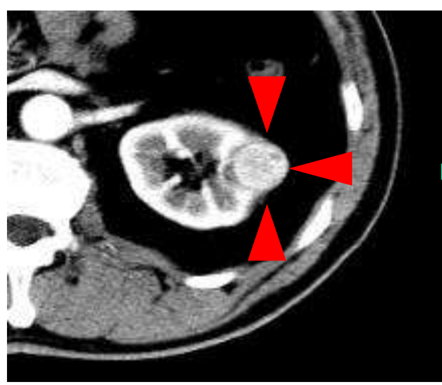




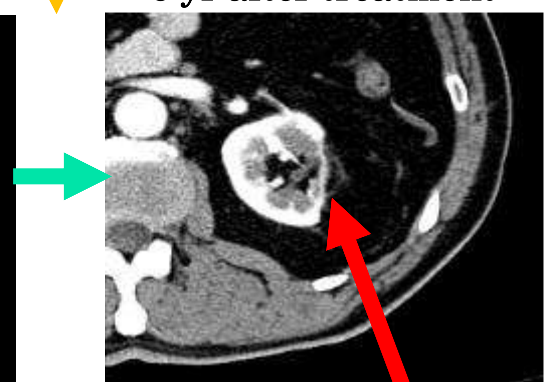
Therapy

Carbon ion radiotherapy

before treatment



6 yr after treatment



like surgical resection

Characteristics of C-ion Radiotherapy

- Clinical advantages

  a. Effective for intractable tumors which are difficult to be resected, and resistant to radiotherapy or chemotherapy.

     Sarcoma, Head & neck (skull-base) tumor,
     Spinal chordoma, Pancreatic cancer

  b. Short term treatment is possible with less fractionation.

     Lung cancer; 1 day
     Liver cancer; 2 day
     Prostate cancer; 12 fractions / 3 weeks

Characteristics of C-ion Radiotherapy

- **Sophisticated procedures**
  a. Maintenance of high energy accelerator
  b. High precision beam delivery
  c. Variable RBE
  d. Treatment planning
  e. Immobilization of patient / respiratory gating

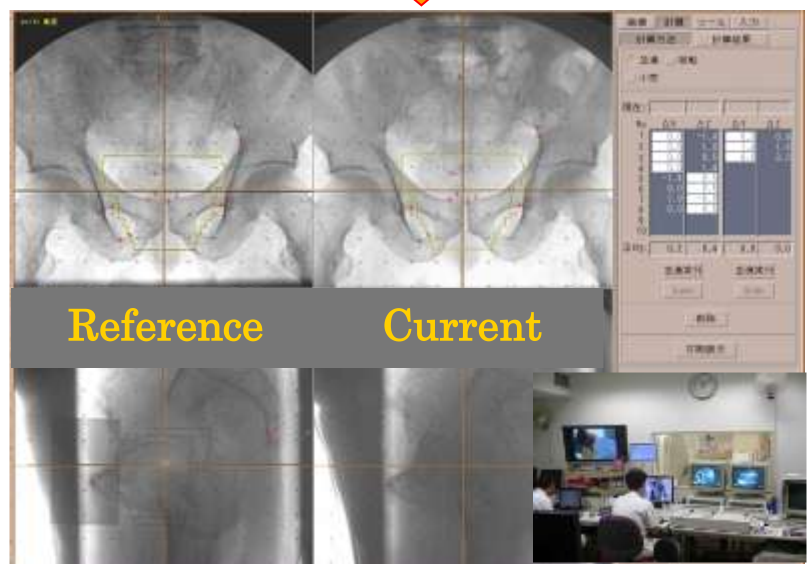
- **New problems**
  a. Activation of equipment, air, patient (protection)
  b. Verification of irradiation (dose)
  c. Change of tumor size / shape during treatment (dose)

General Treatment Process

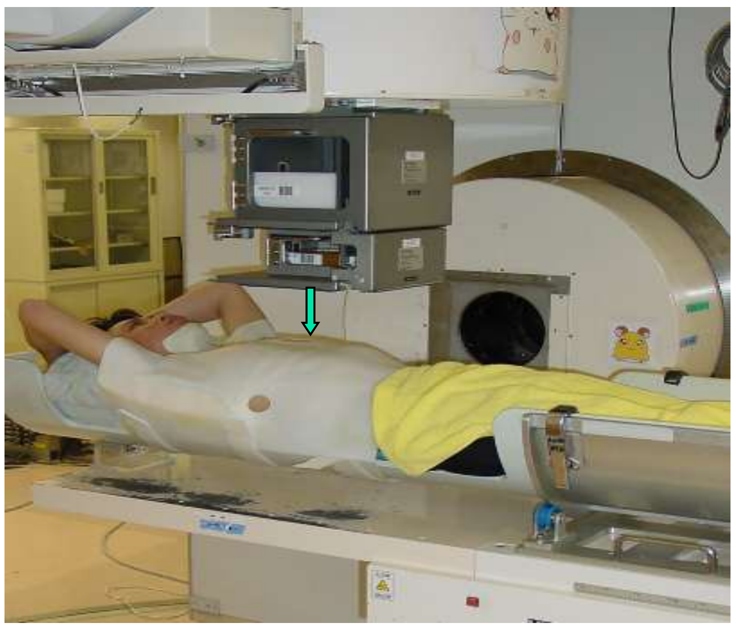

Immobilization


Planning CT

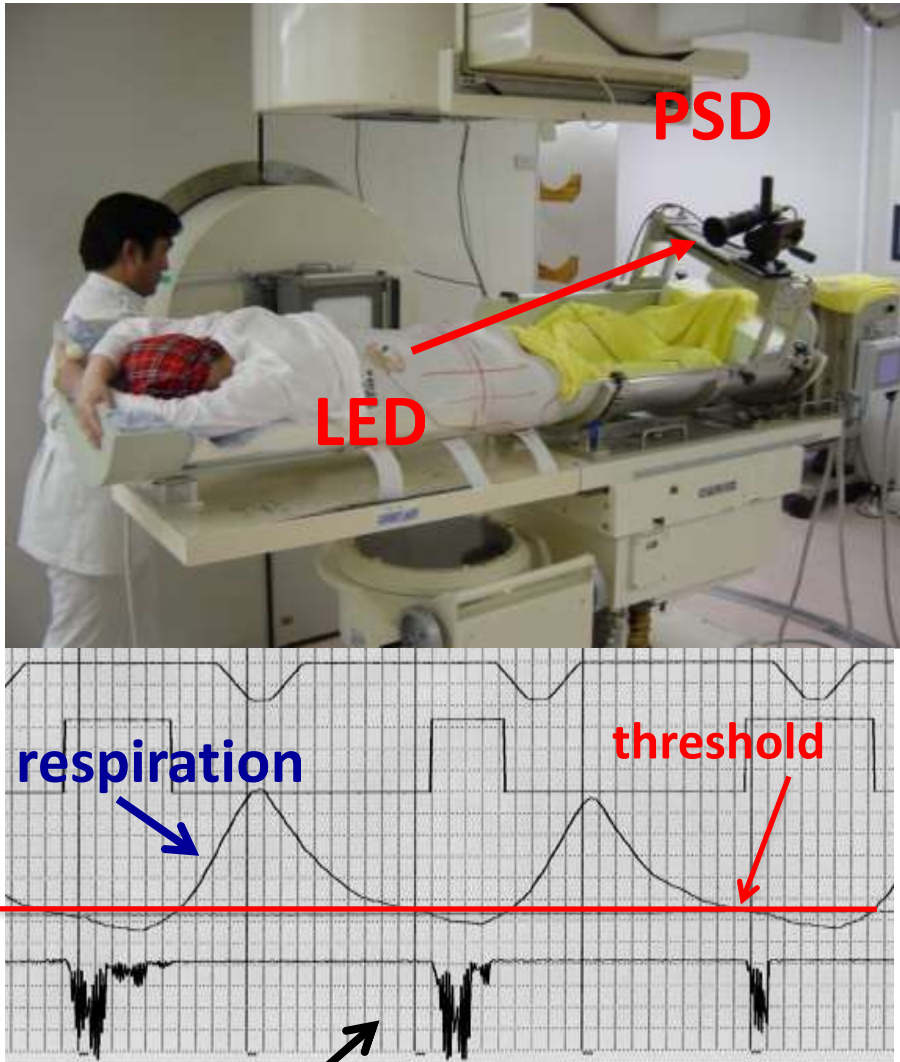

Treatment planning



Patient positioning

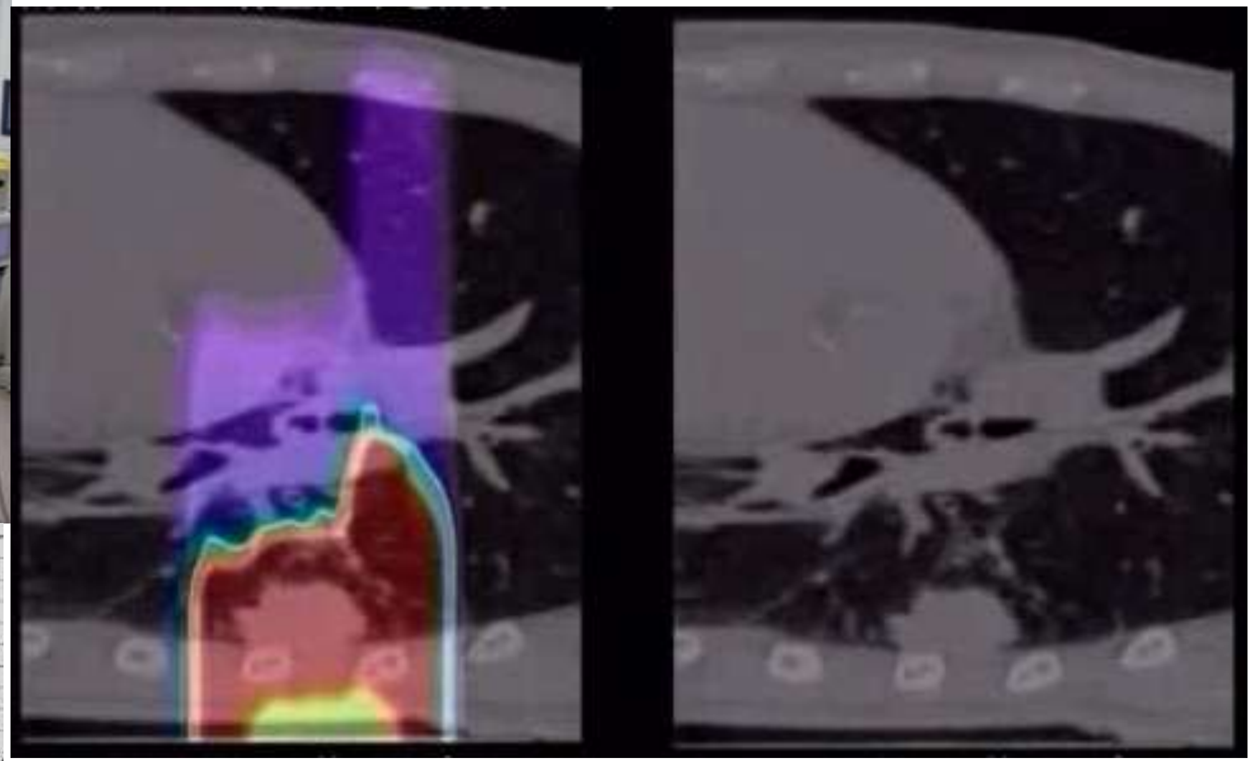

Beam delivery

Respiratory Gating Treatment



Beam signal

Lung cancer



Non-gating

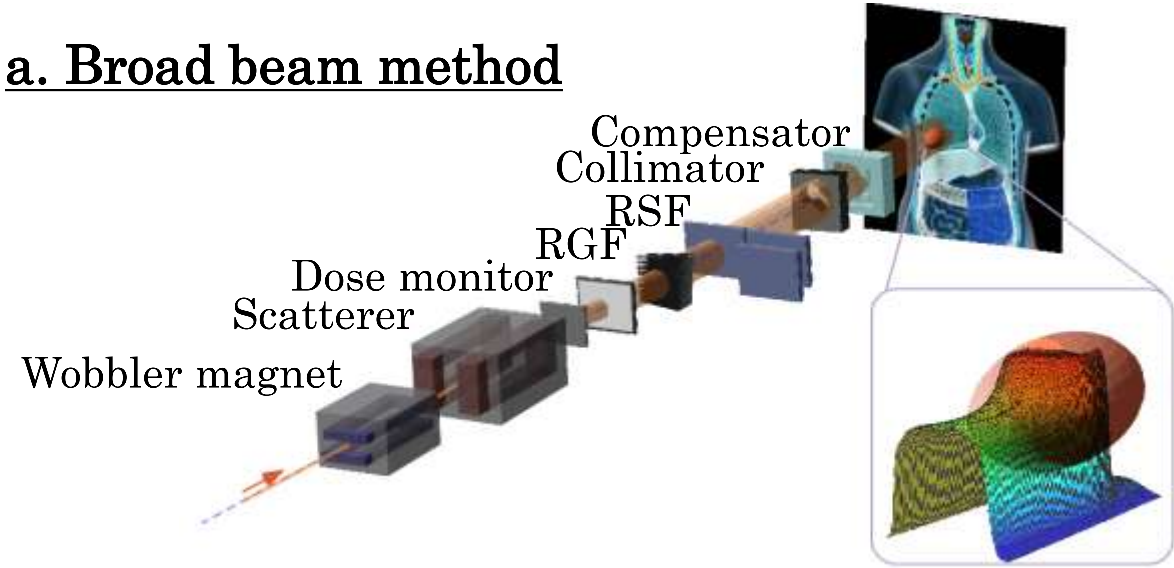
Gating

Strategy for Radiological Protection

- Optimize the treatment
  - Provide sufficient dose to the target tumor.
  - Minimize the effects in surrounding normal tissues.
- Safety culture to avoid accidental exposure
  - New methods are associated with complicated procedures.
  - Biological effects appear in the later period.
- Need for long term follow up of the late effects
  - Longer survival of the patients increases the risk of second malignancy.
  - "Low dose" exposure in large area of normal tissues
- Protection of personnel
  - Activation of equipment, air, and patient.

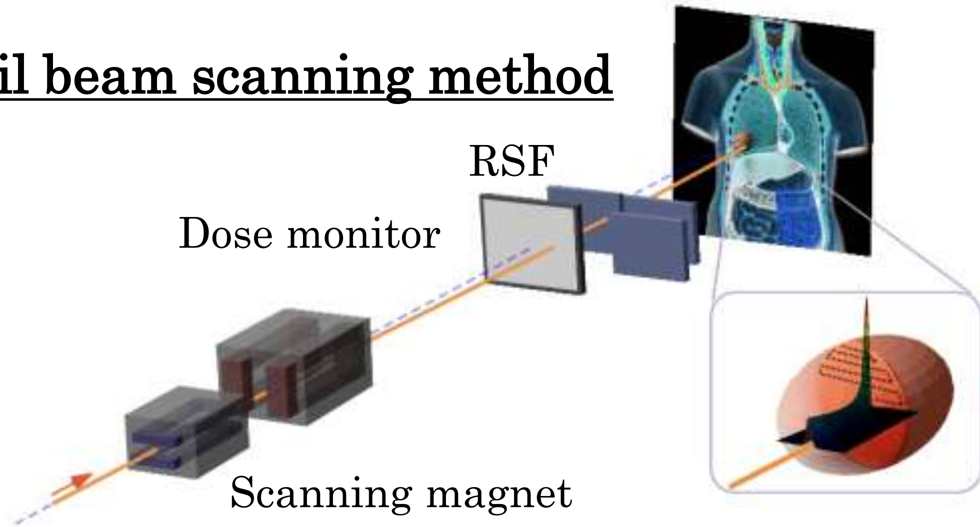
Beam Delivery and Irradiation

a. Broad beam method



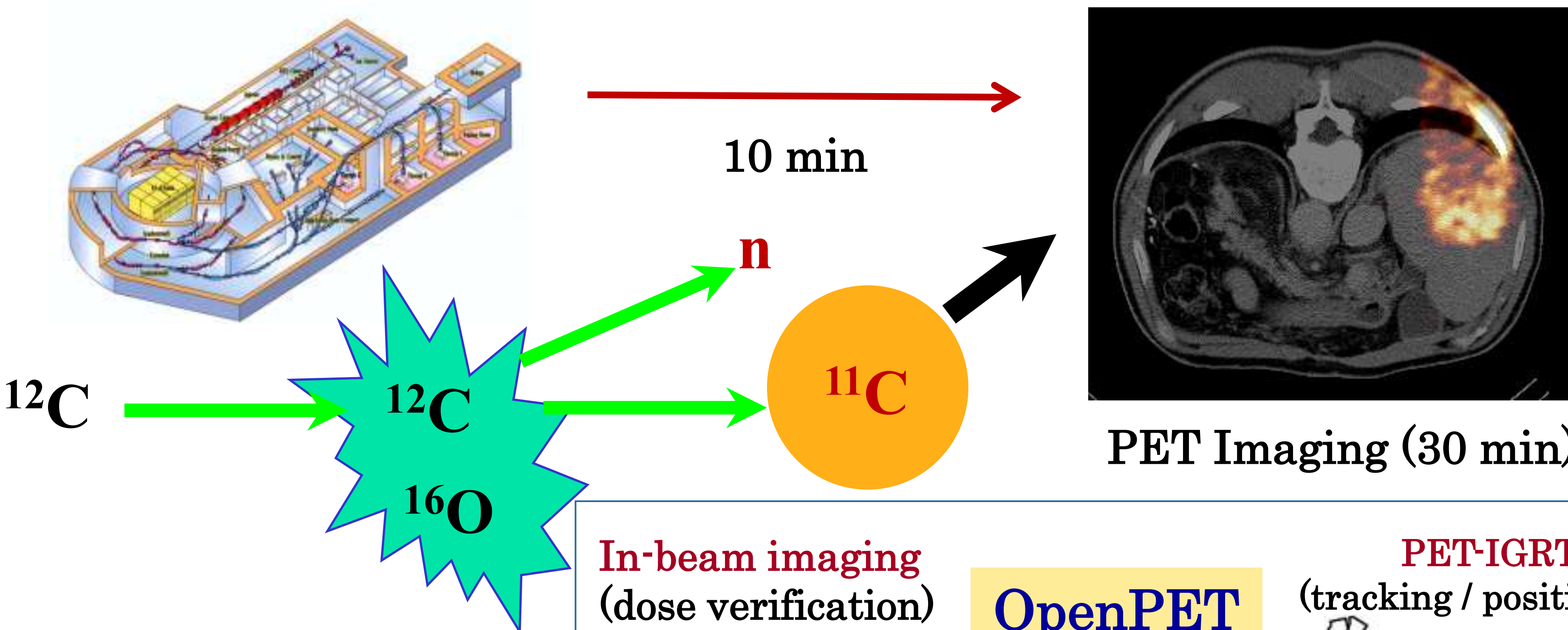
The beam efficiency is low, about 30%, for the broad beam method. There is a beam loss at every device used to modulate and shape the beam, and those points can be production sources of undesirable radiation such as neutrons.

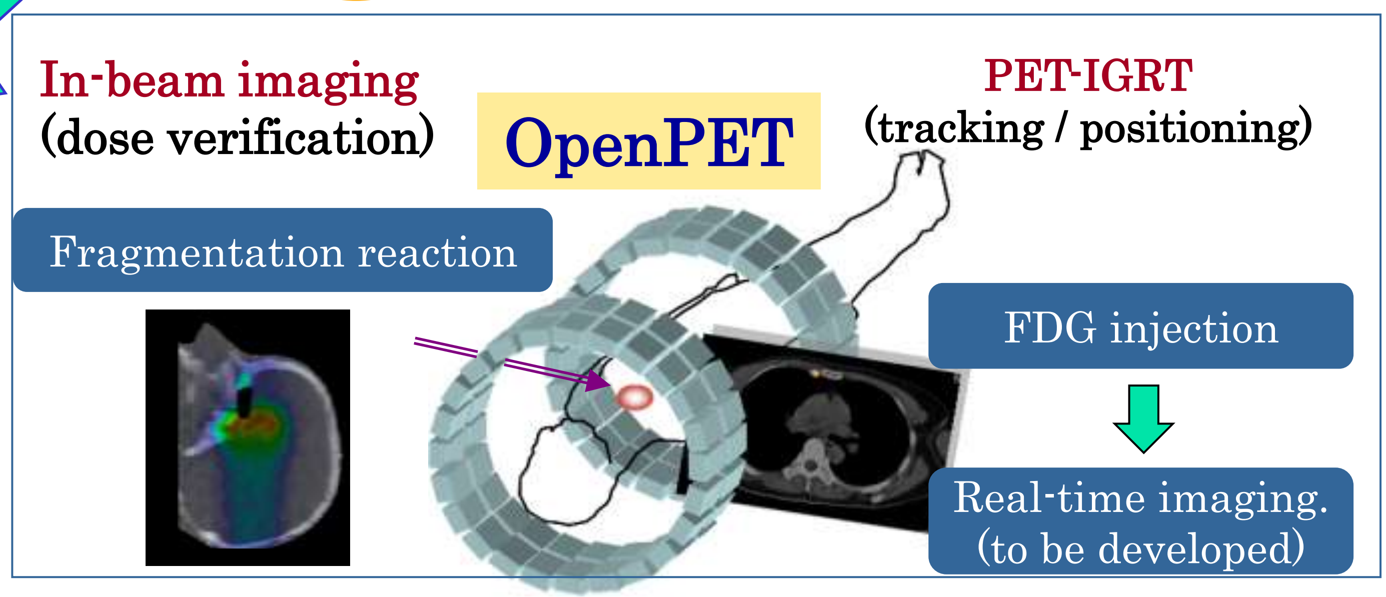
b. Pencil beam scanning method



The pencil beam scanning method is characterized by high beam use efficiency, almost 100%, and therefore is low production of neutrons.

Auto-activation PET for Dose Verification

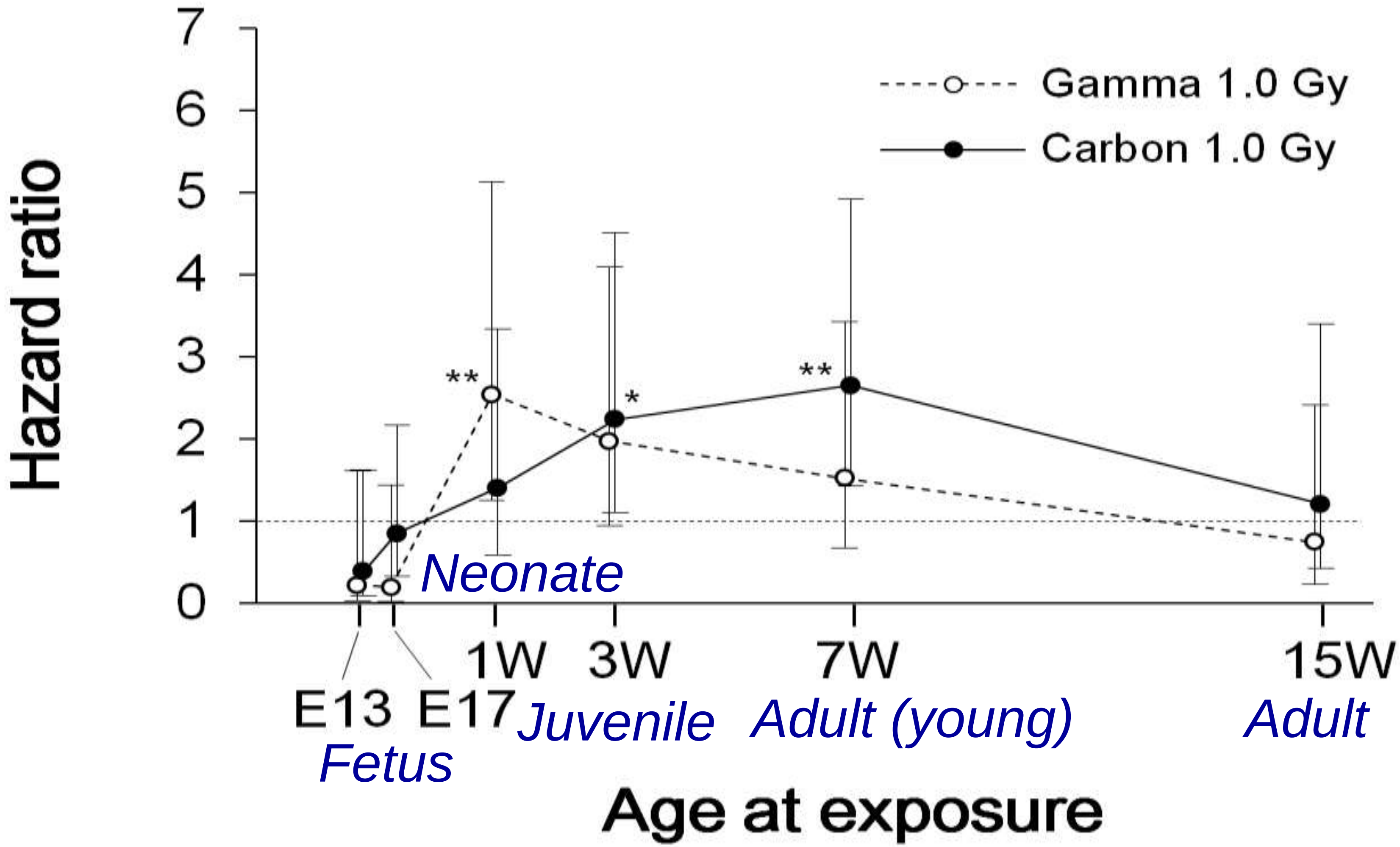




The OpenPET geometry: original idea to visualize physically open field-of-view

[Yamaya et al, PMB 2008].

Carbon-ion RBE of carcinogenesis



Imaoka et al., Int J Radiat Oncol Biol Phys (in press)

How to Apply New Technology for Practice?

- Clinical effectiveness of advanced technology
  - Optimize clinical protocols for diagnosis and treatment
  - Clinical research to establish the evidence
  - Select the most appropriate method for clinical practice

- Safety of new technology
  - Careful and rational design of clinical protocol
  - Based on the basic research in physics and biology
  - Monitoring the process of clinical research
  - Regulation and management of new technology
  - Education / Training for wide clinical use