The 52nd JAIF Annual Conference

Session 3: “Diversity and Possibilities for Nuclear Technology “

High-Precision Radiation Therapy for Cancer and Medical Physics

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Cancer in Japan

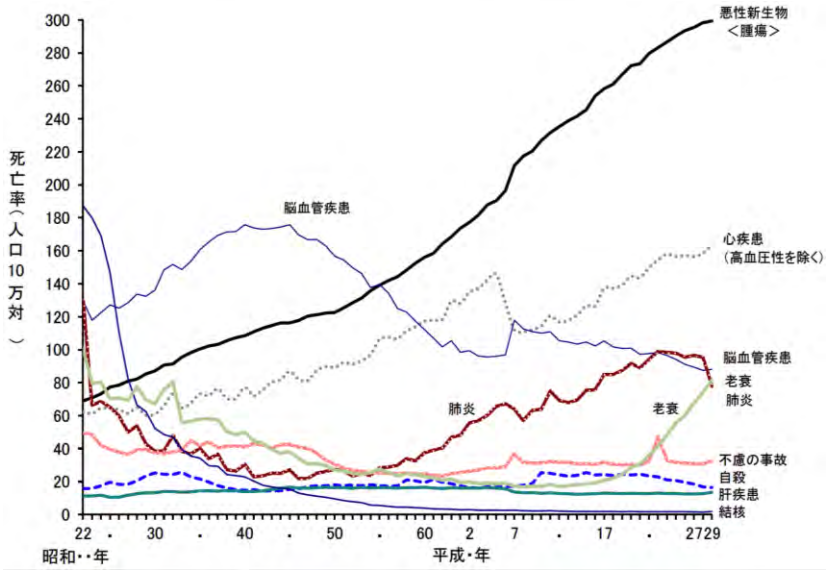
Novel, Challenge and Change

National Cancer Center

(Press Release on July 15, 2016)

Statistical Predictions for Cancer in 2016 Released

Cancer patients: Approximately 1,010,000
Deaths: Approximately 370,000

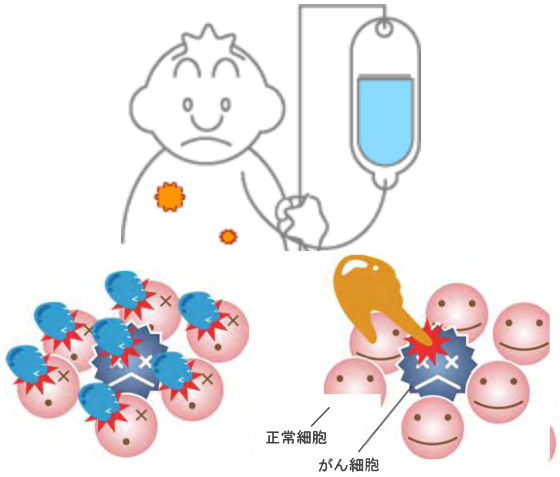


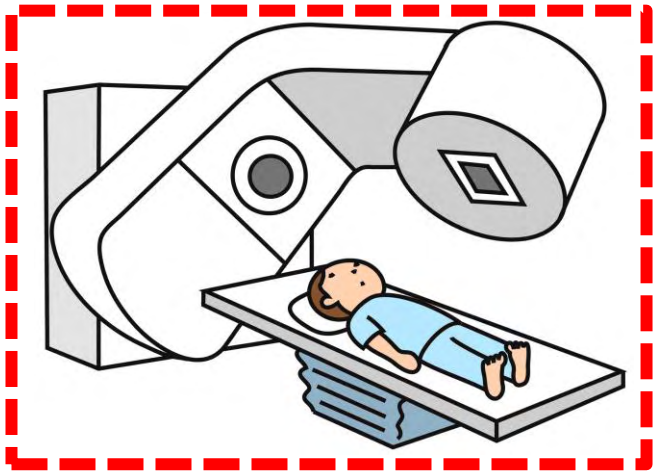
- As unprecedented aging of society continues in Japan, the number of cancer patients is increasing.
- Today, one in every three people dies of cancer.

What is Radiation Therapy for Cancer?

Three Major Cancer Treatments

- Surgery
- Chemotherapy (anticancer therapy)
- Radiation therapy



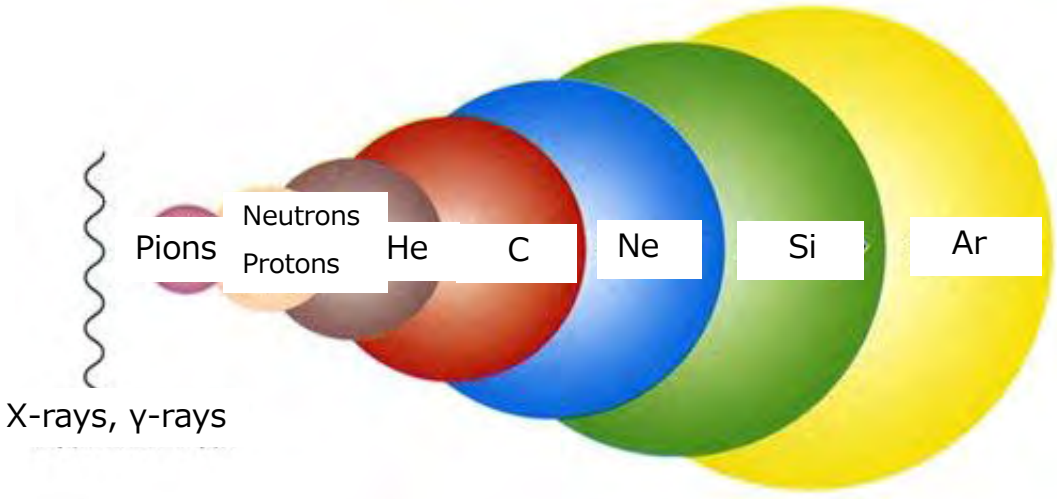


It is essential not only to treat, but to maintain a reasonable quality of life (QOL).

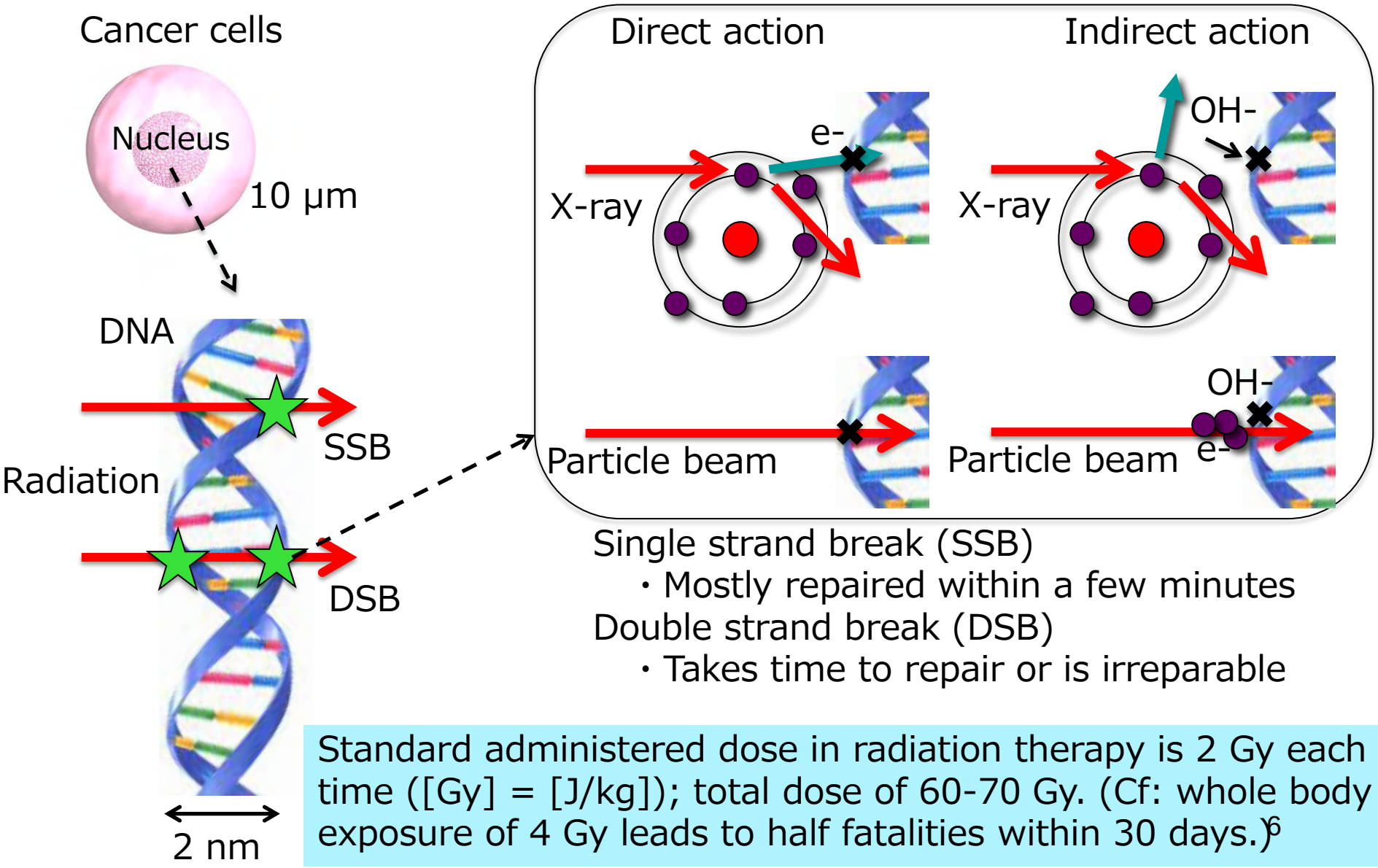
Implementation rate for radiation therapy:
30% in Japan
60-80% in the West

Radiation Used in Cancer Treatment

- Photons
  - X-rays
  - γ-rays
- Electrons
- Heavy particles (broadly defined)
  - Uncharged
    - Neutrons
    - Pions π0
  - Charged
    - Protons
    - Light ions He, C, Ne
    - Heavy ions Si, Ar
    - Pions π±



Action of Radiation on Cancer Cells



Single strand break (SSB)
- Mostly repaired within a few minutes

Double strand break (DSB)
- Takes time to repair or is irreparable

Standard administered dose in radiation therapy is 2 Gy each time ([Gy] = [J/kg]); total dose of 60-70 Gy. (Cf: whole body exposure of 4 Gy leads to half fatalities within 30 days.)[6]

Radiation (X-Ray/Electron) Therapy Equipment

TrueBeam/Varian

Synergy/Elekta

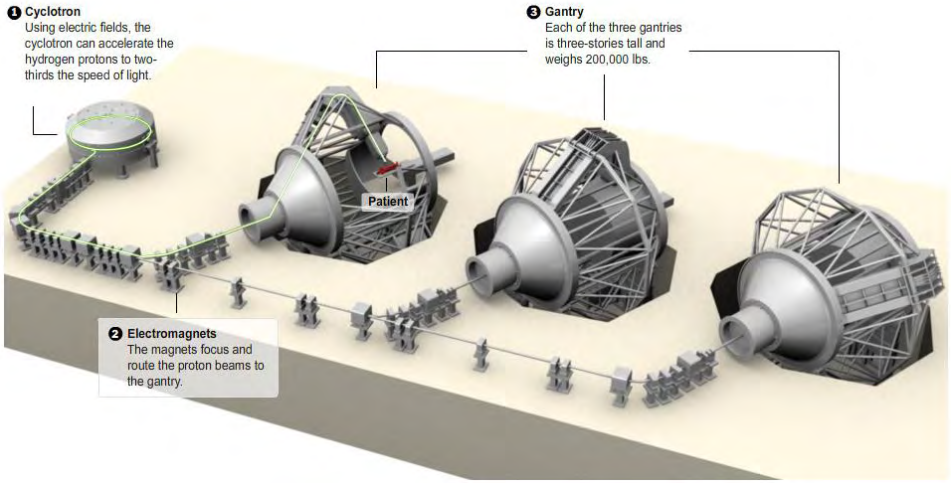
STx/Brainlab

CyberKnife/Accuray

TomoTherapy/Accuray

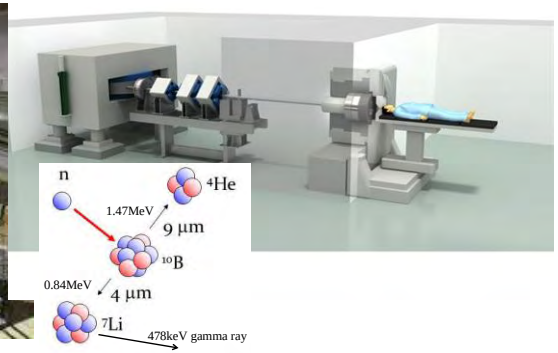
Vero/MHI

Radiation (Heavy Particle) Therapy Equipment



Proton/IBA

Carbon Ion Beam/Toshiba

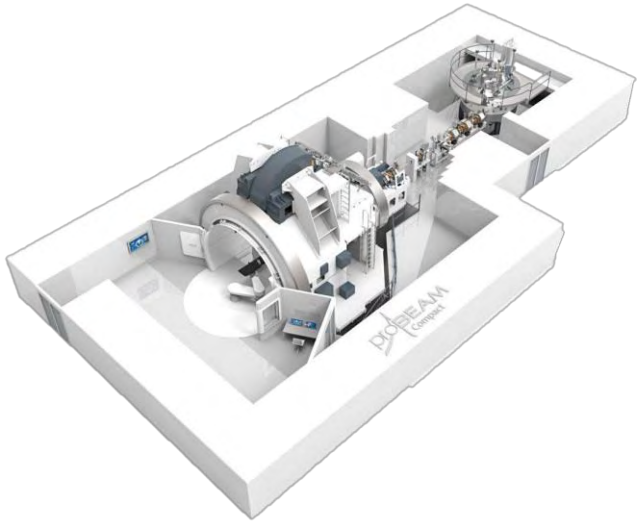


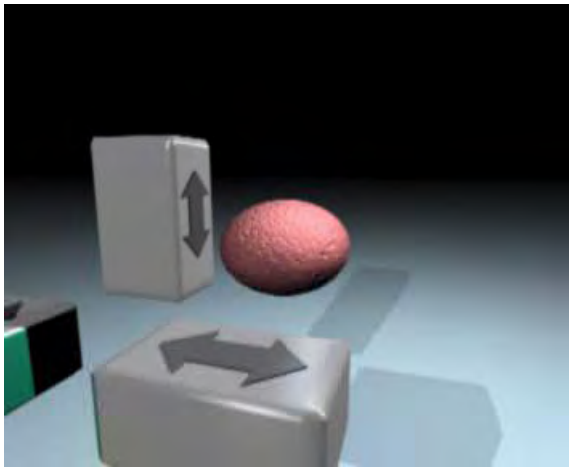
BNCT (Boron-Neutron Capture Therapy)
/Sumitomo Heavy Industries

High Technology in Radiation Cancer Therapy

High-Precision X-Ray Therapy

Proton Therapy

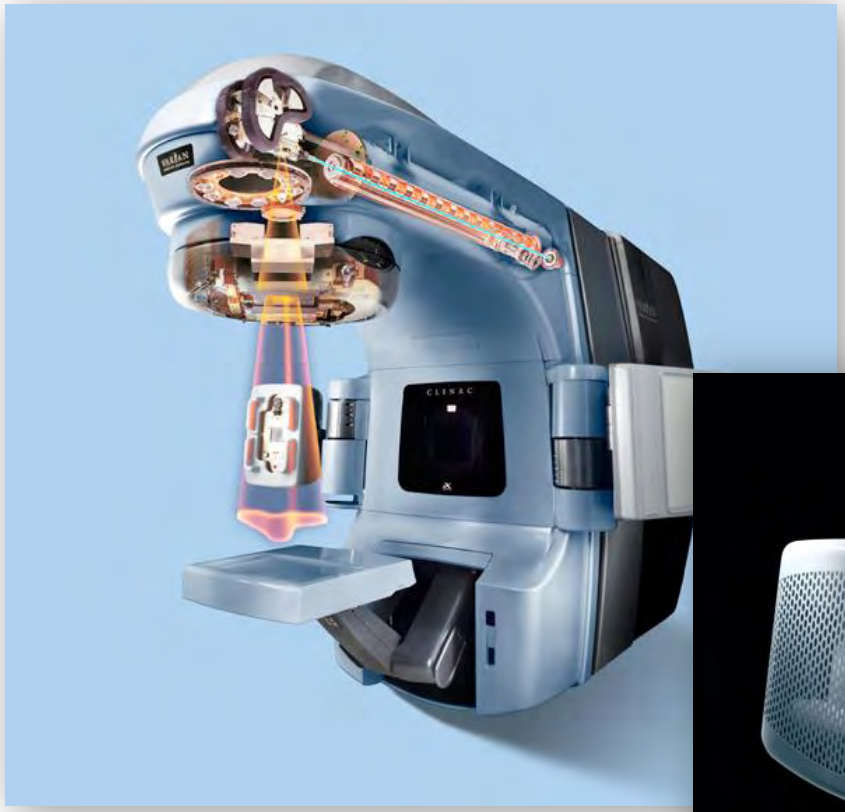




Cutting-Edge Radiation Therapy – Case 1 –

Intensity-Modulated Radiation Therapy (IMRT)

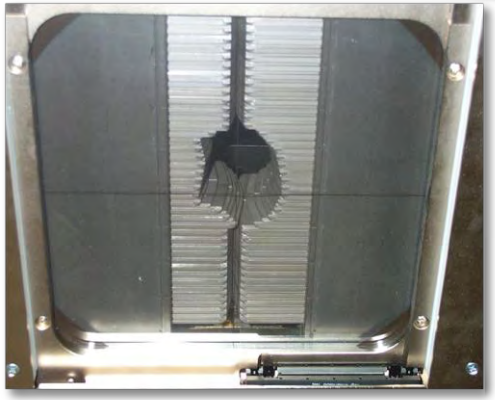
Radiation (X-Ray/Electron) Therapy Equipment

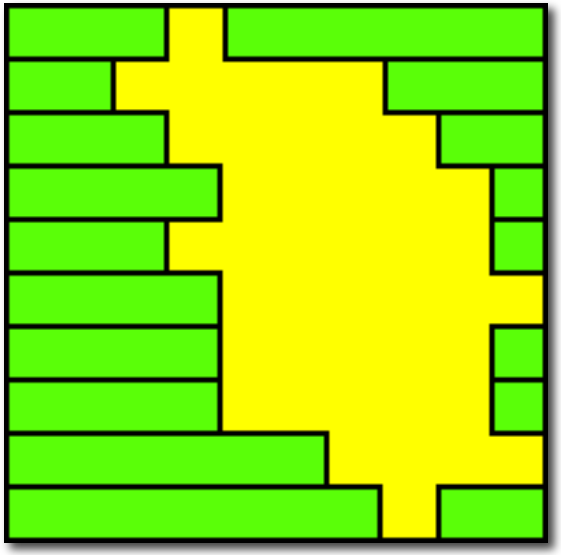


General Radiation Therapy

In conventional radiation therapy:

Shape of MLC (multi-leaf collimator)

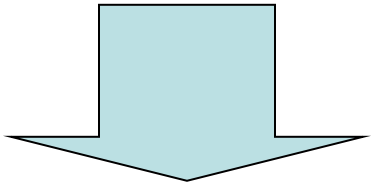




Radiation field in the shape of the tumor

Intensity-Modulated Radiation Therapy (IMRT)

Intensity of radiation (X-ray) is adjusted to each irradiation spot, concentrating dose on the tumor.

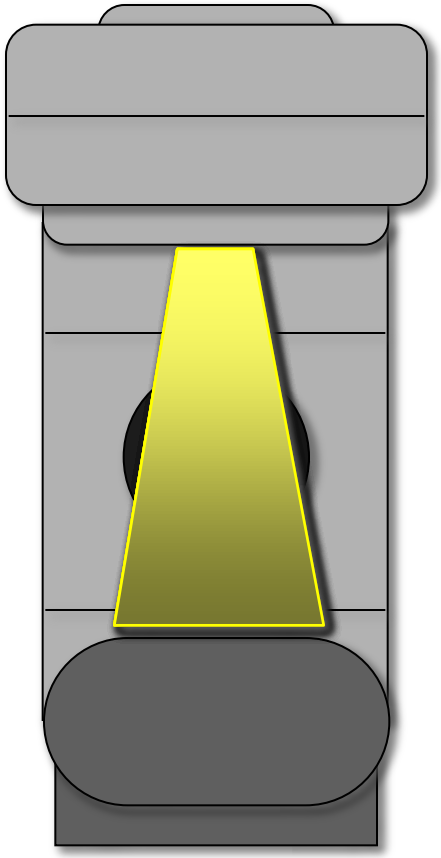


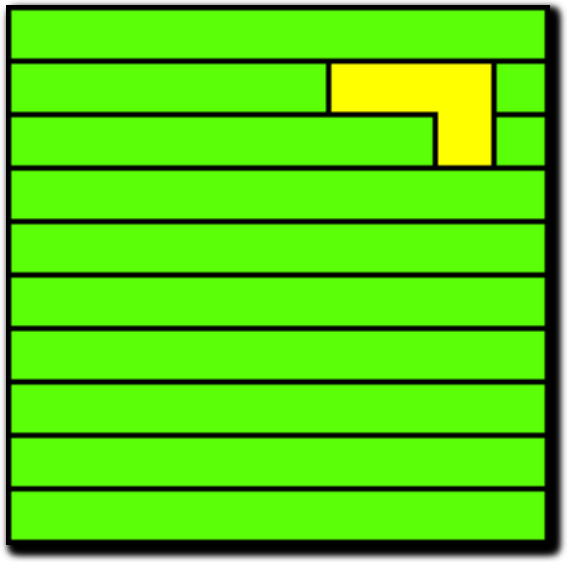
Making the best use of computer technology.

Inverse planning: Calculating optimum irradiation dose so as to deliver a uniform, high dose to the tumor and as little as possible to important organs.

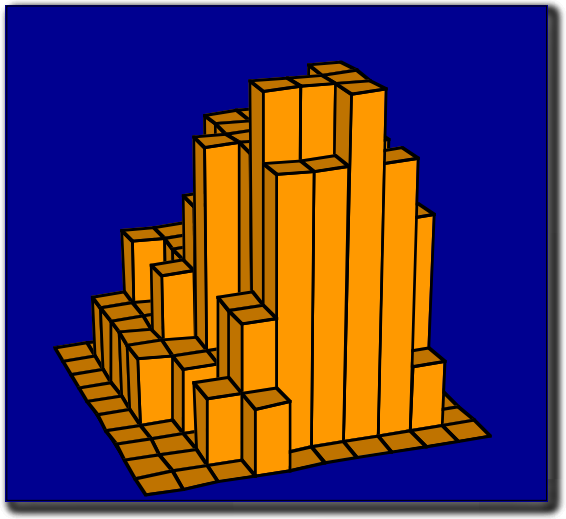
Intensity-Modulated Radiation Therapy (IMRT)

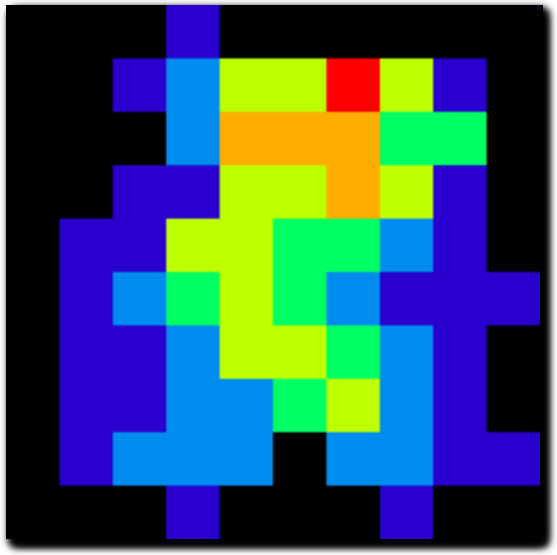
In IMRT:





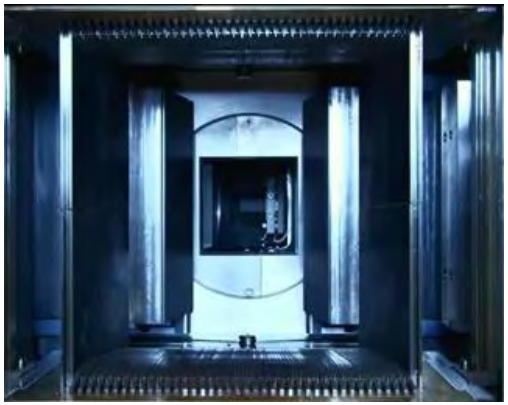
MLC shape

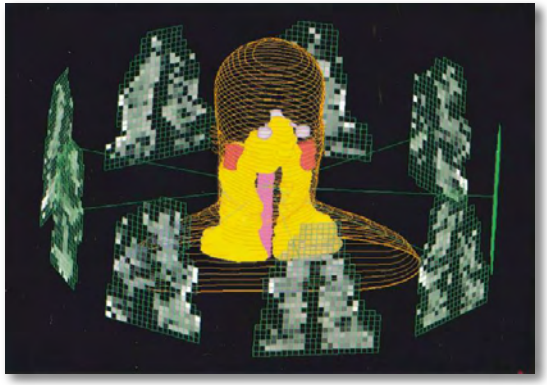


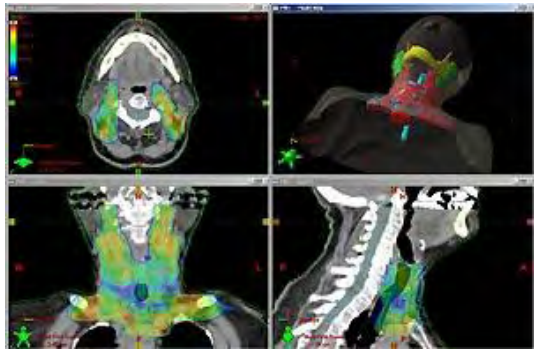


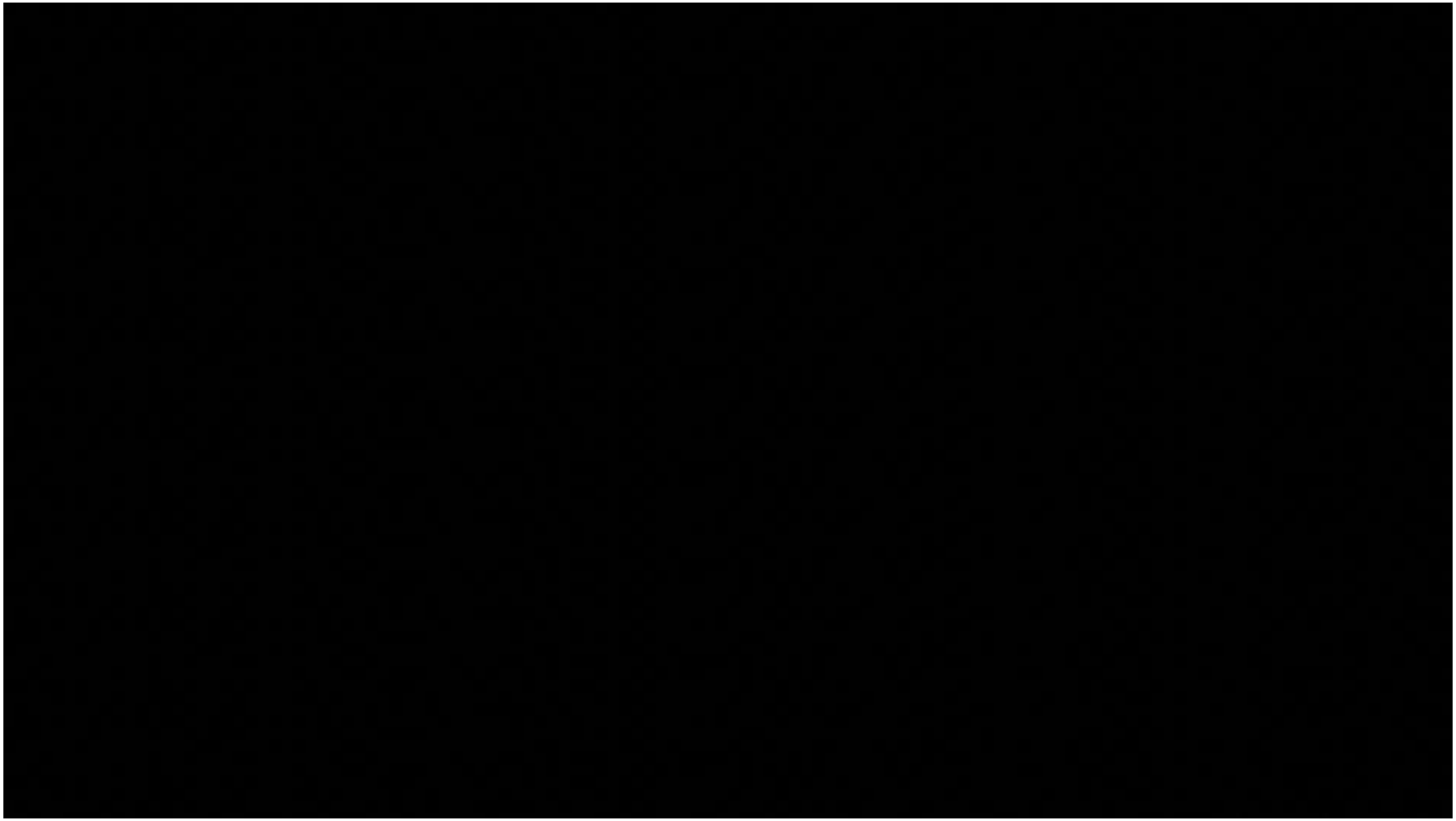
Intensity Map

Intensity-Modulated Radiation Therapy (IMRT)





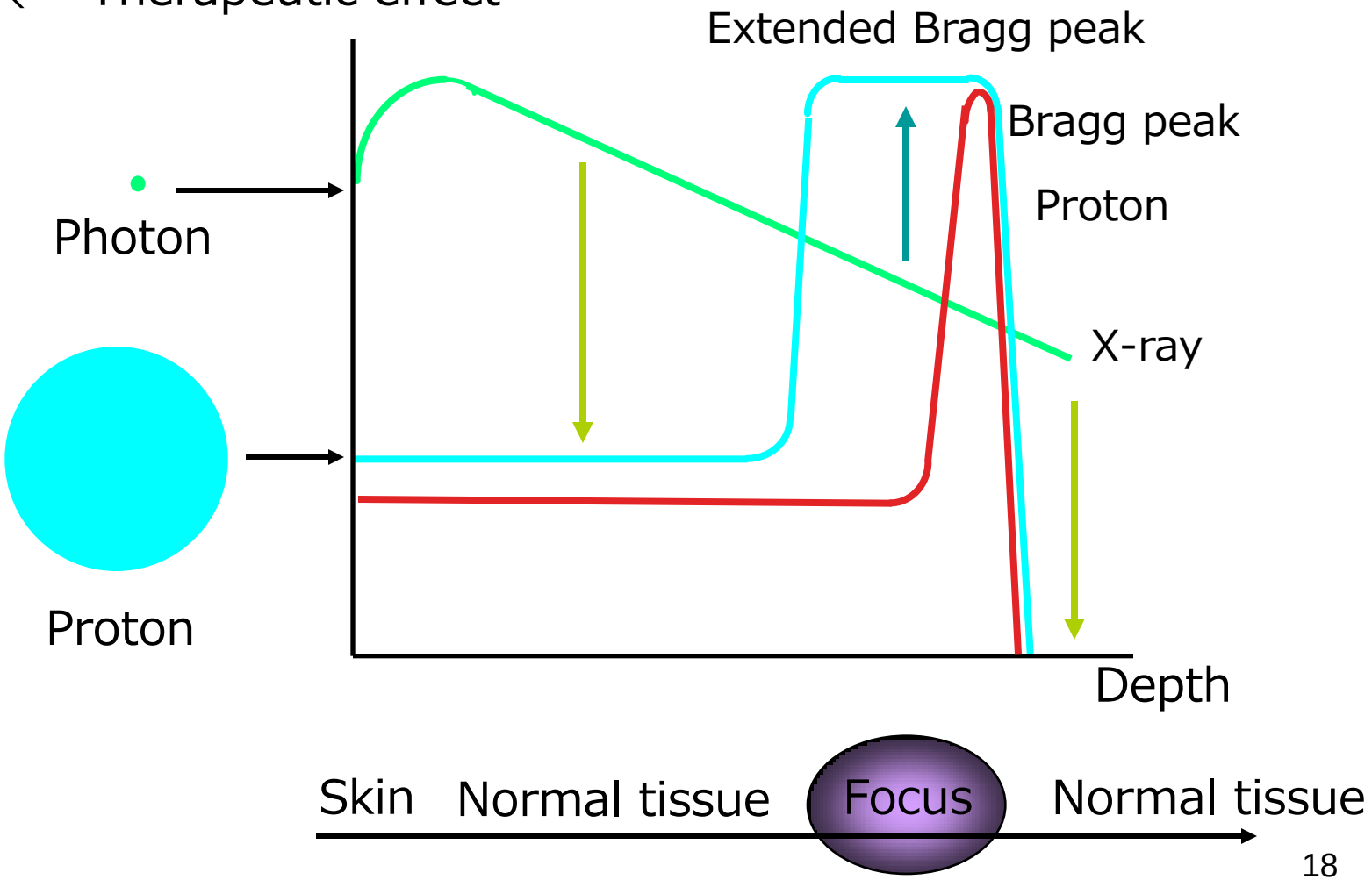




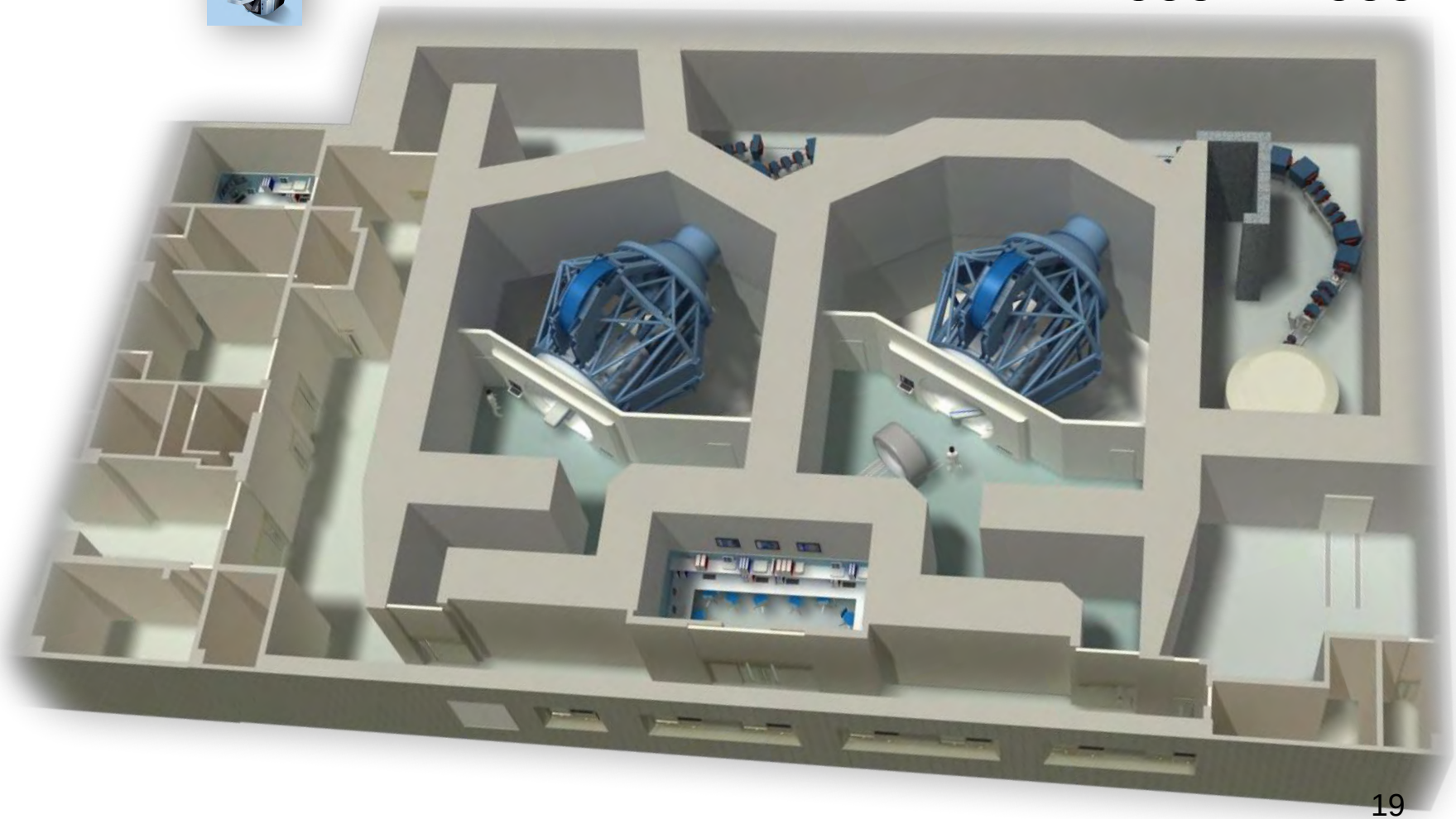
Cutting-Edge Radiation Therapy
– Case 2 –
Proton Therapy

Proton Characteristics

Dose ⇄ Damage to cell
⇄ Therapeutic effect

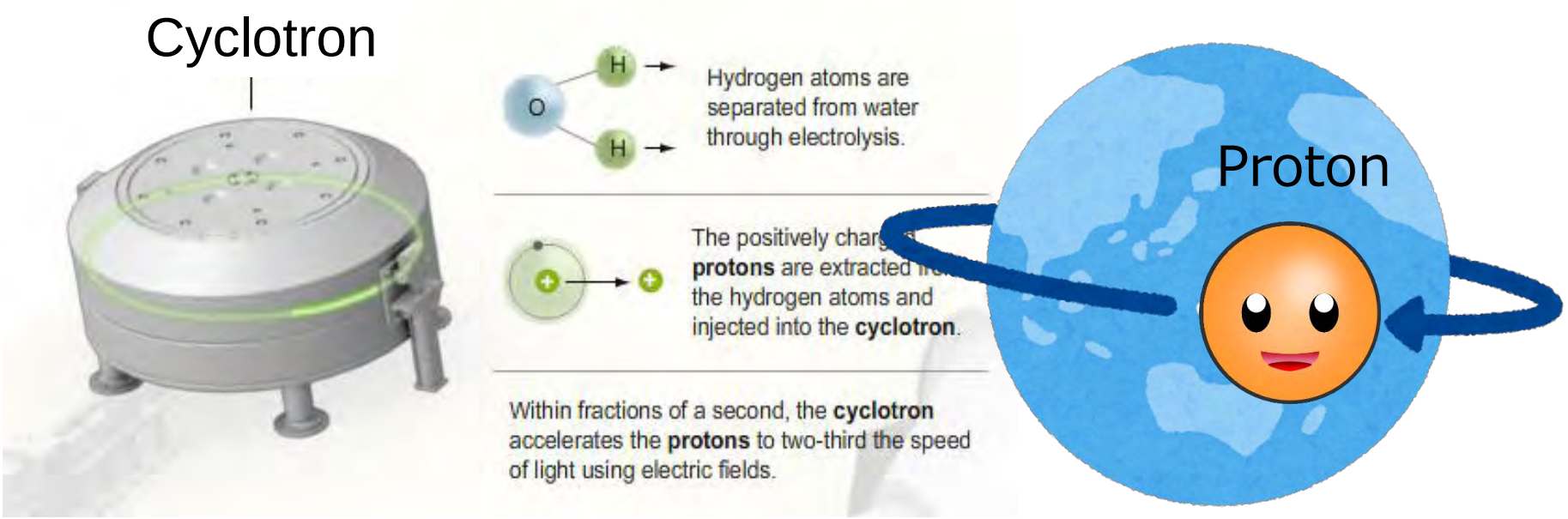


Proton Therapy System

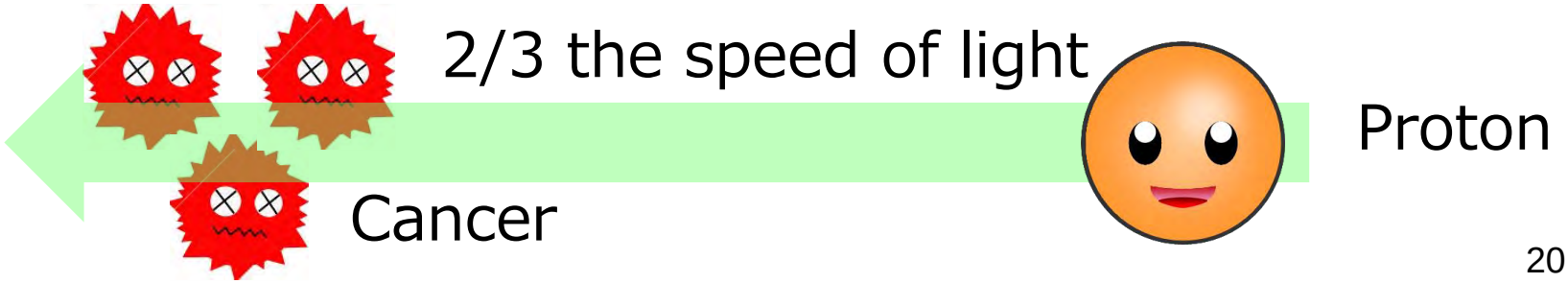


Proton Accelerator

Cyclotron

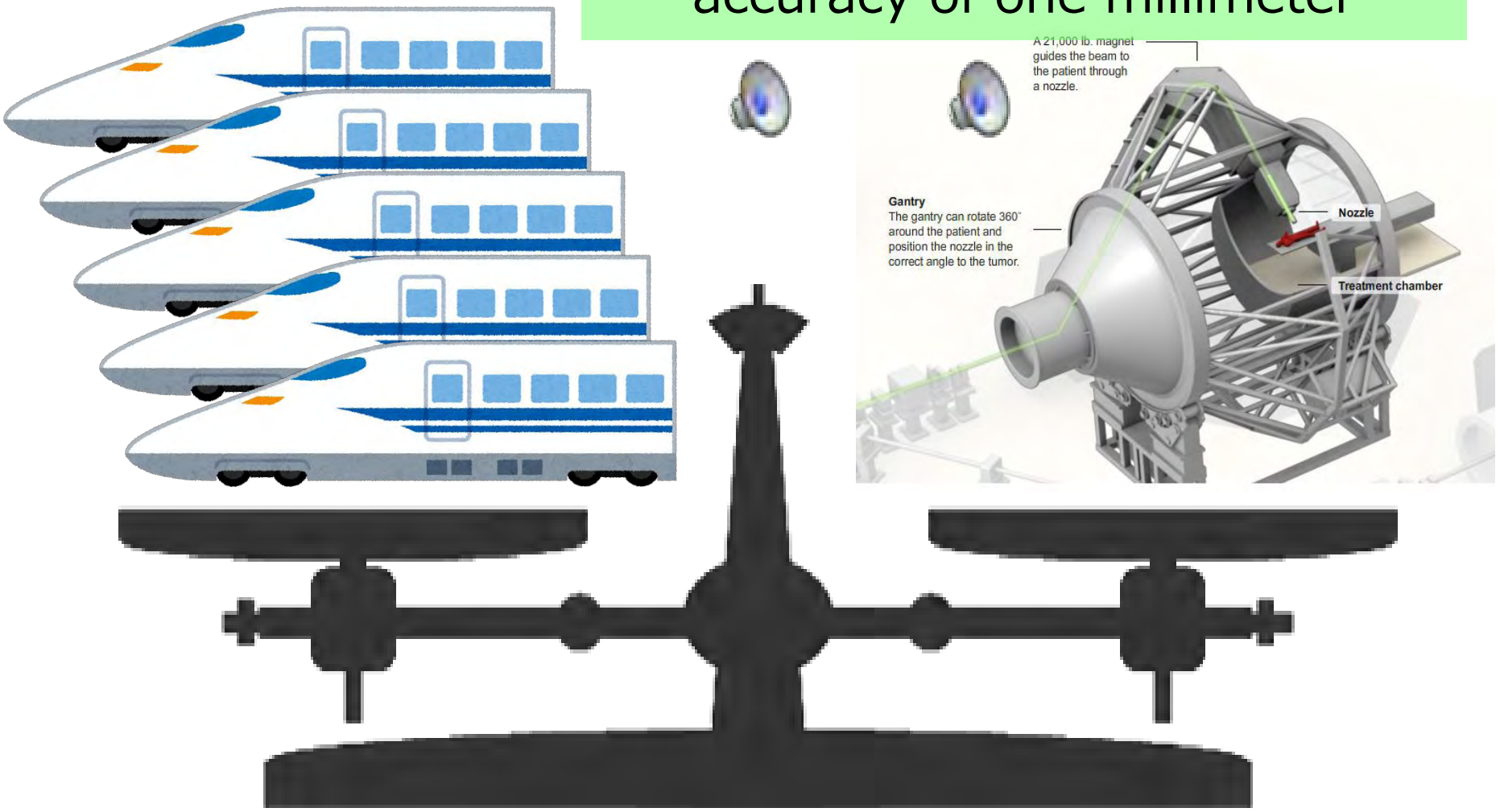


Accelerate protons to a speed equivalent to 4.5 orbits of the earth per second, and irradiate it to a cancer with an accuracy of one millimeter



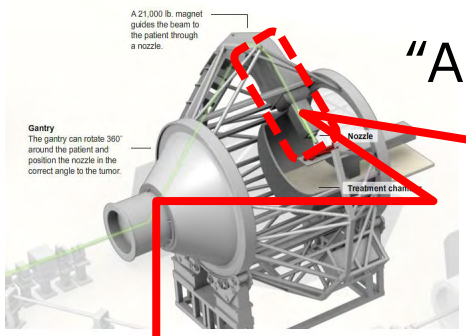
Rotating Gantry for Proton Therapy Equipment

360 degree rotation with delivery accuracy of one millimeter

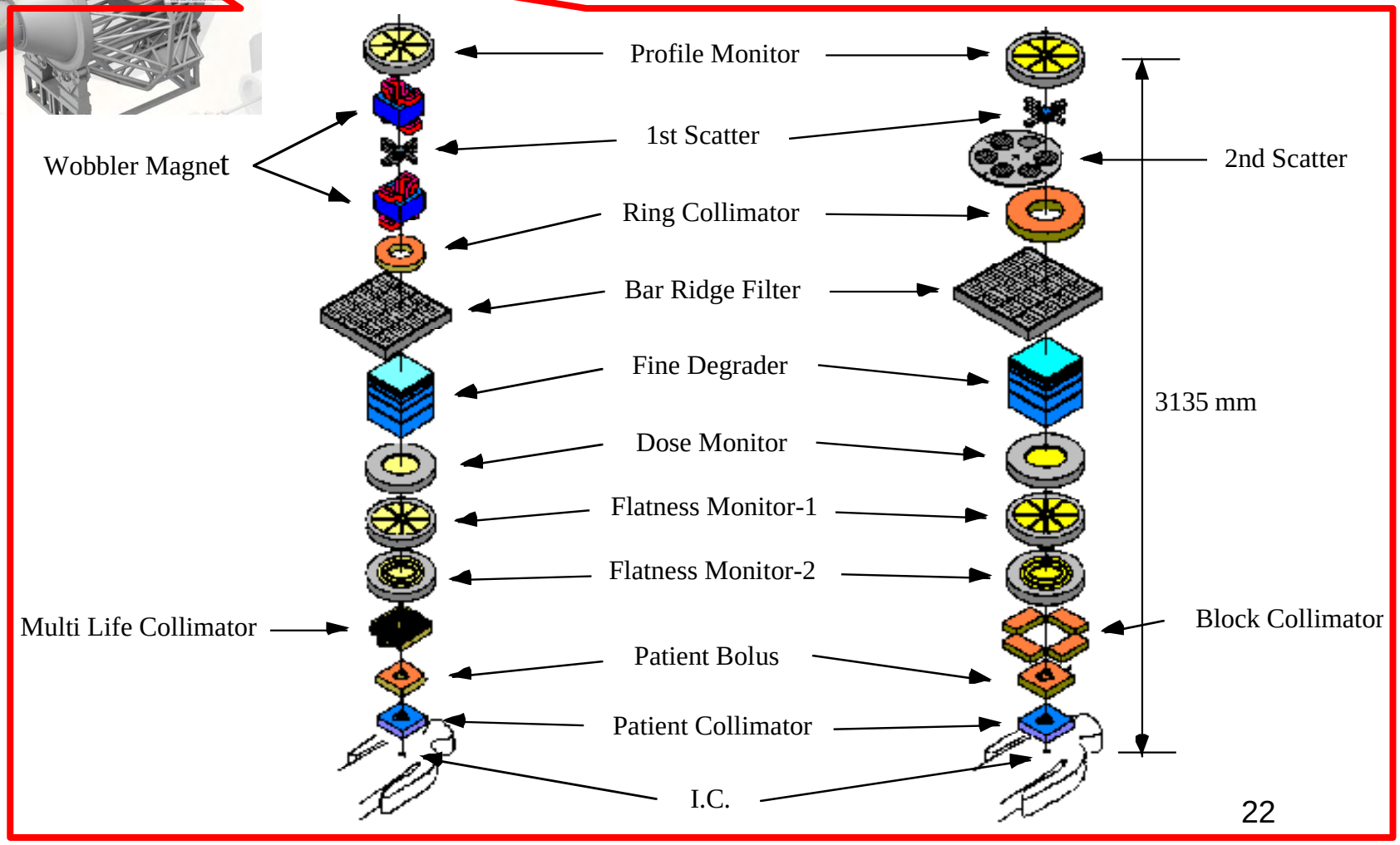


Weight of about 250 tons

Formation of the Irradiated Region

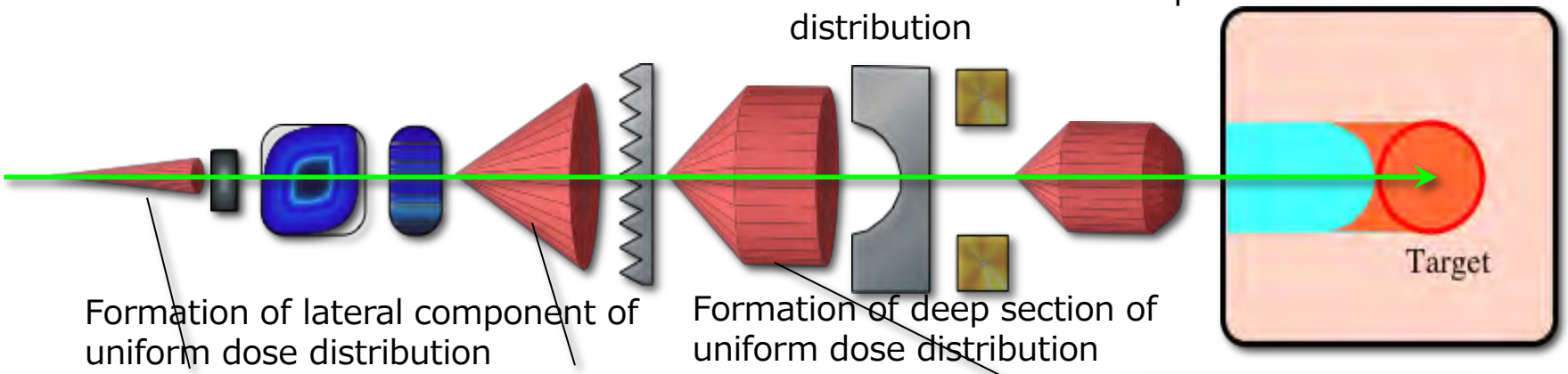


"A complex array of precision instruments is required."



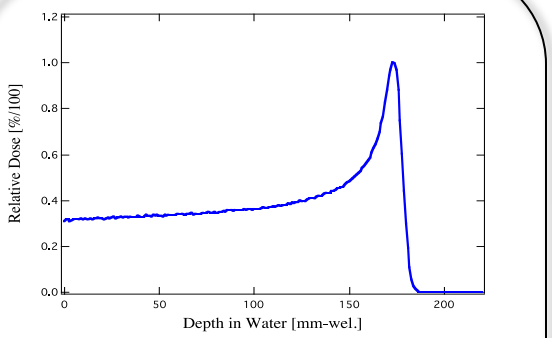
Formation of Uniform Dose Distribution

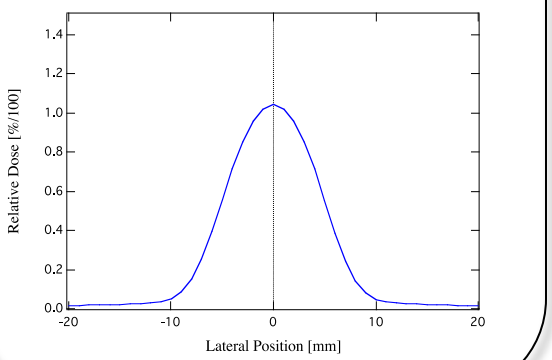
Formation of tumor shaped dose distribution

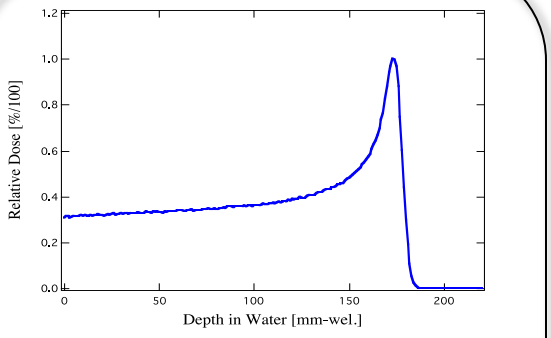


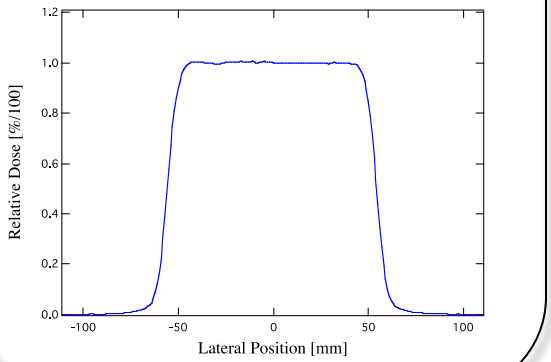
Formation of lateral component of uniform dose distribution

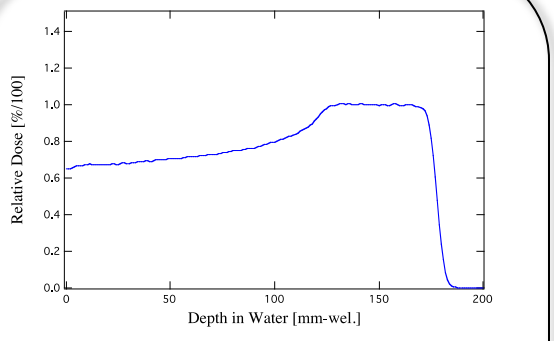
Formation of deep section of uniform dose distribution

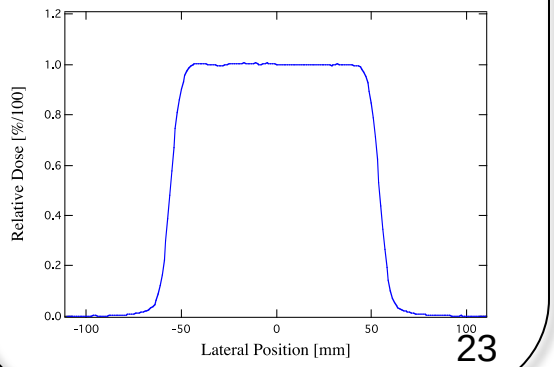




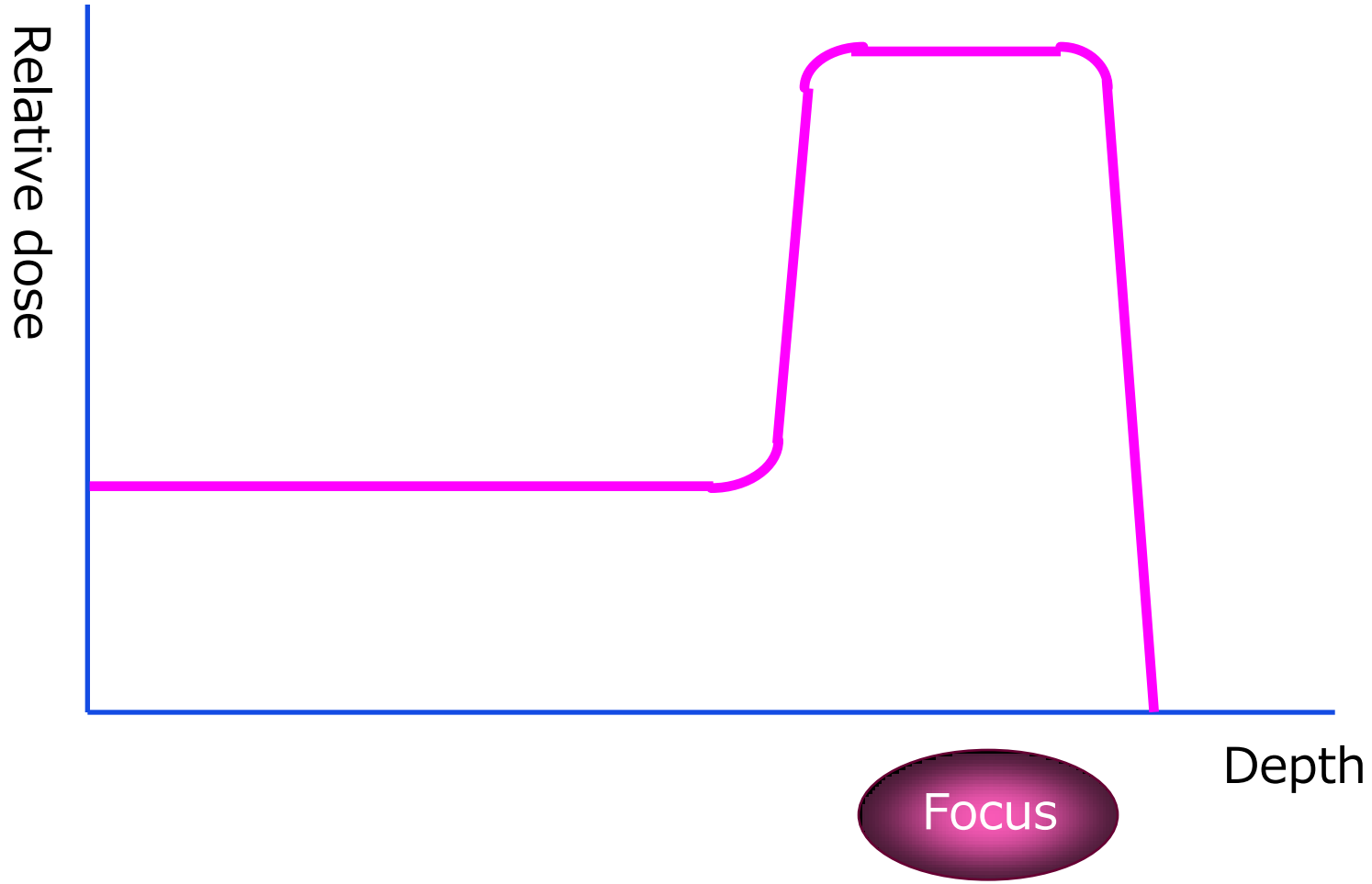




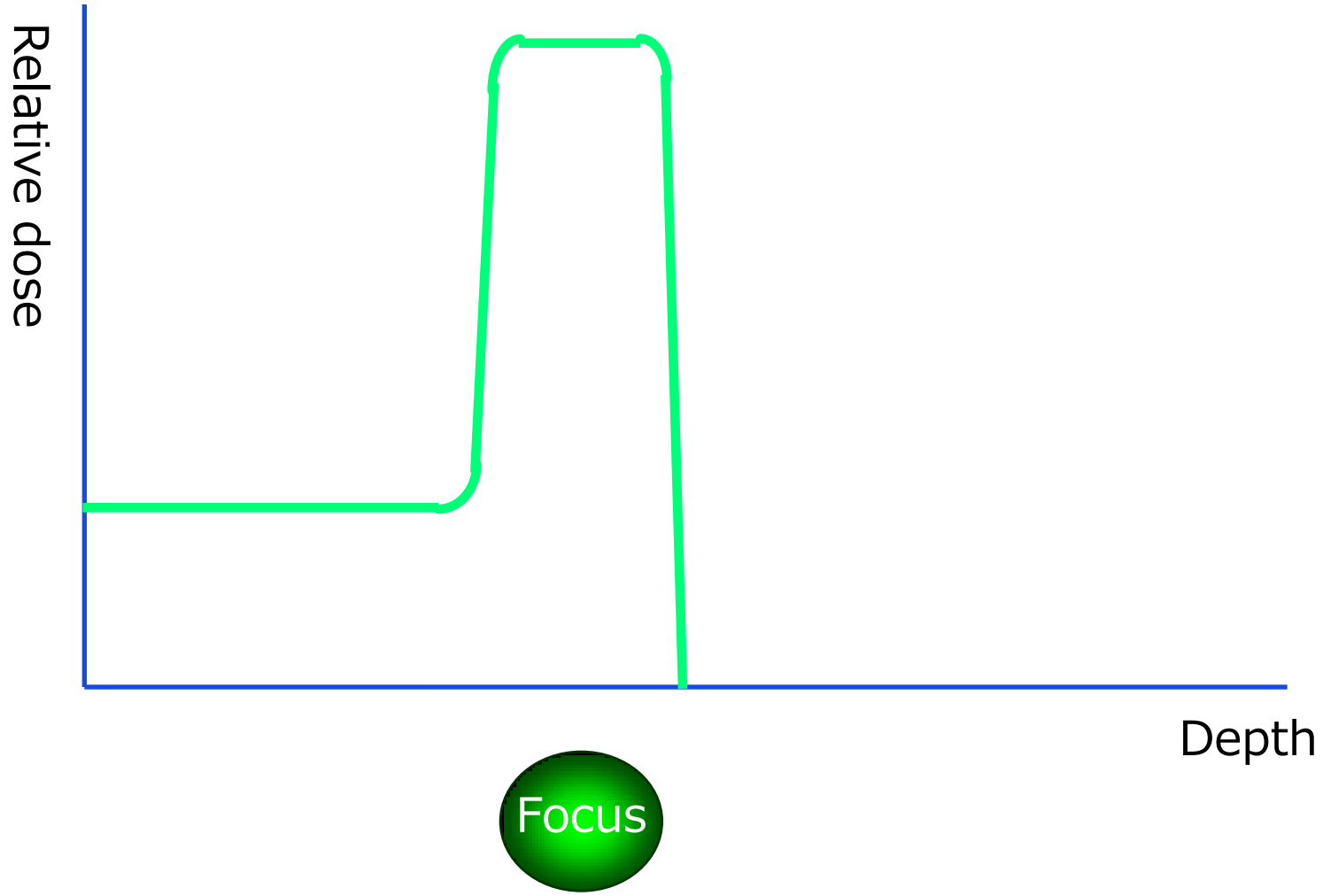




Irradiated Region Formation System



Irradiated Region Formation System



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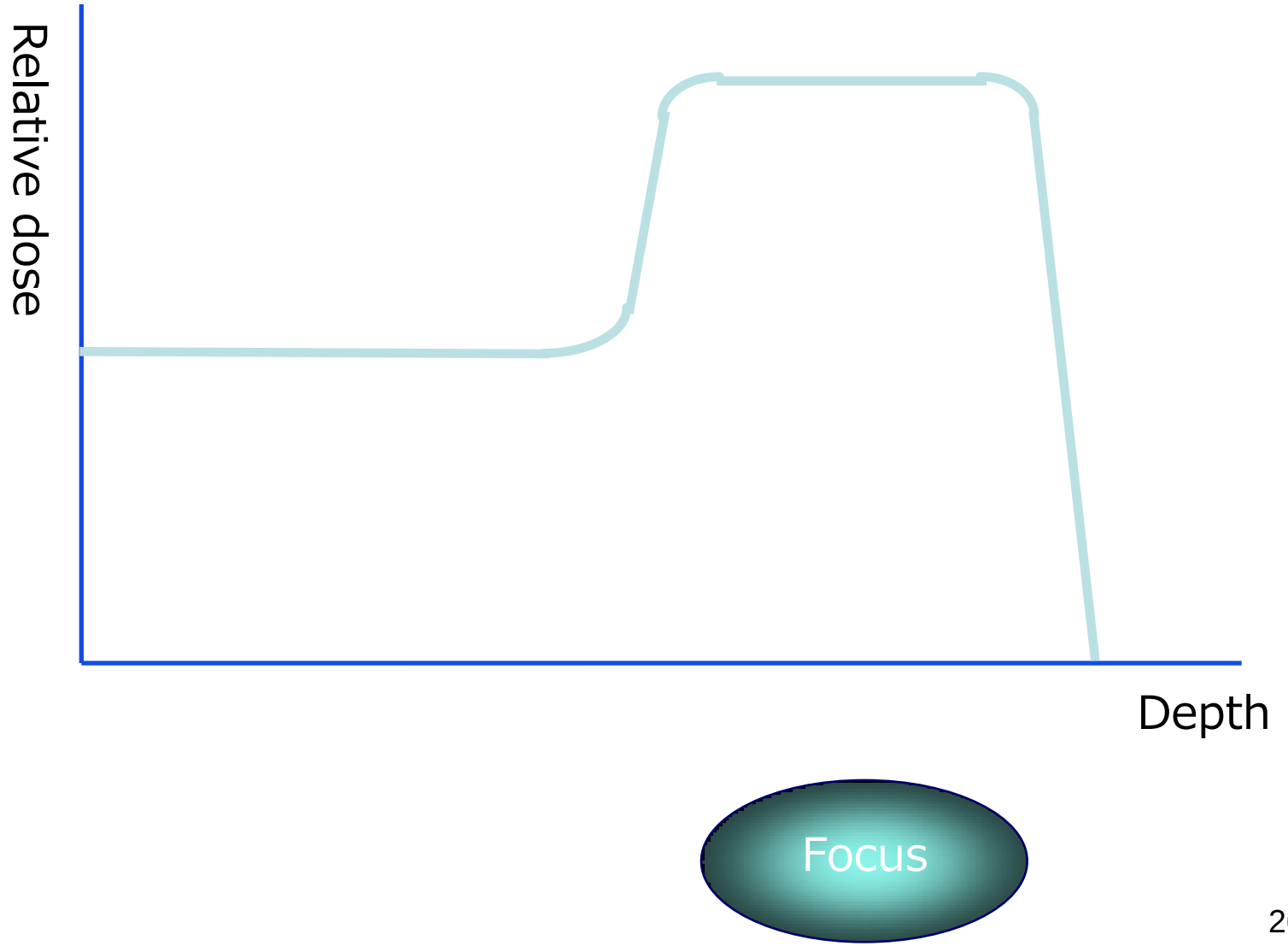
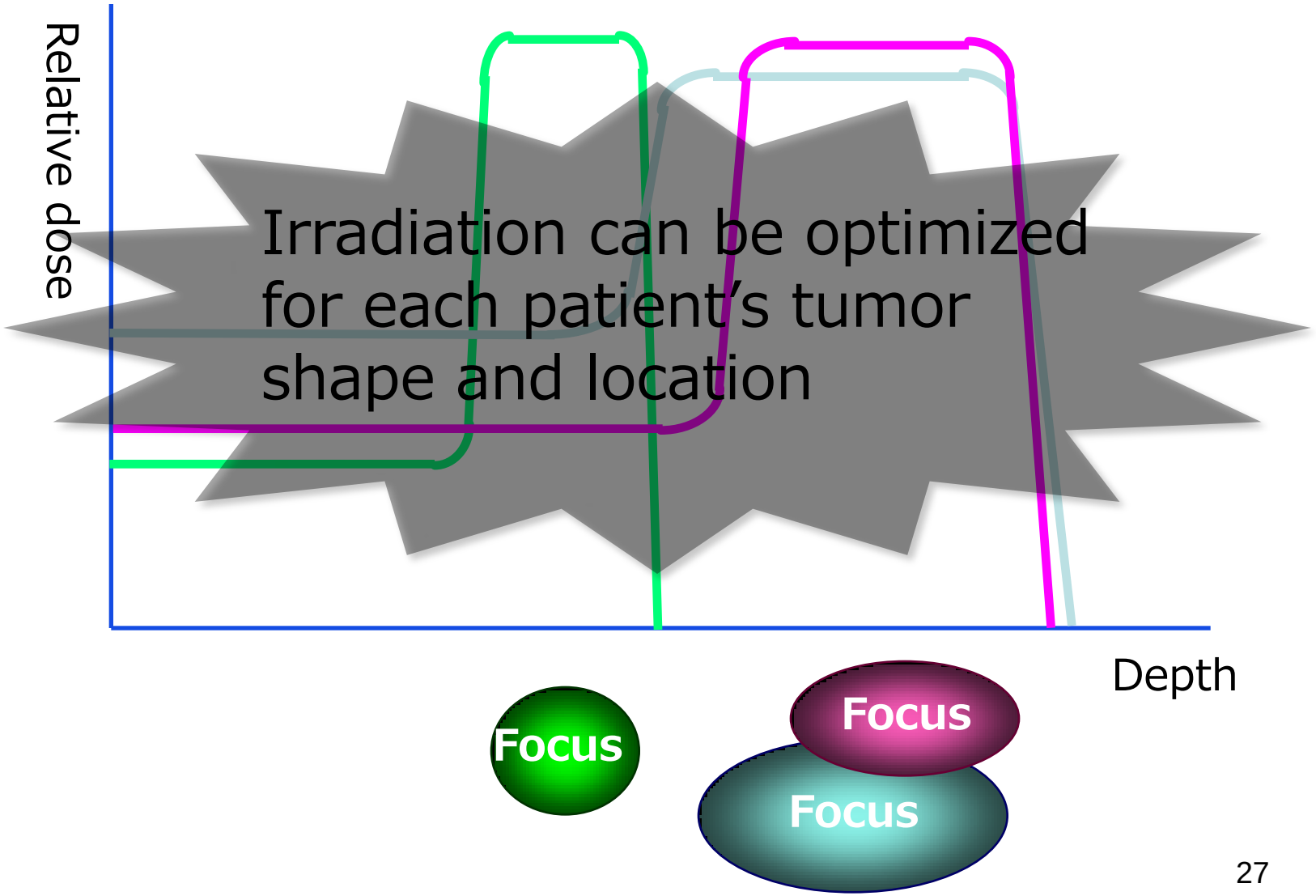
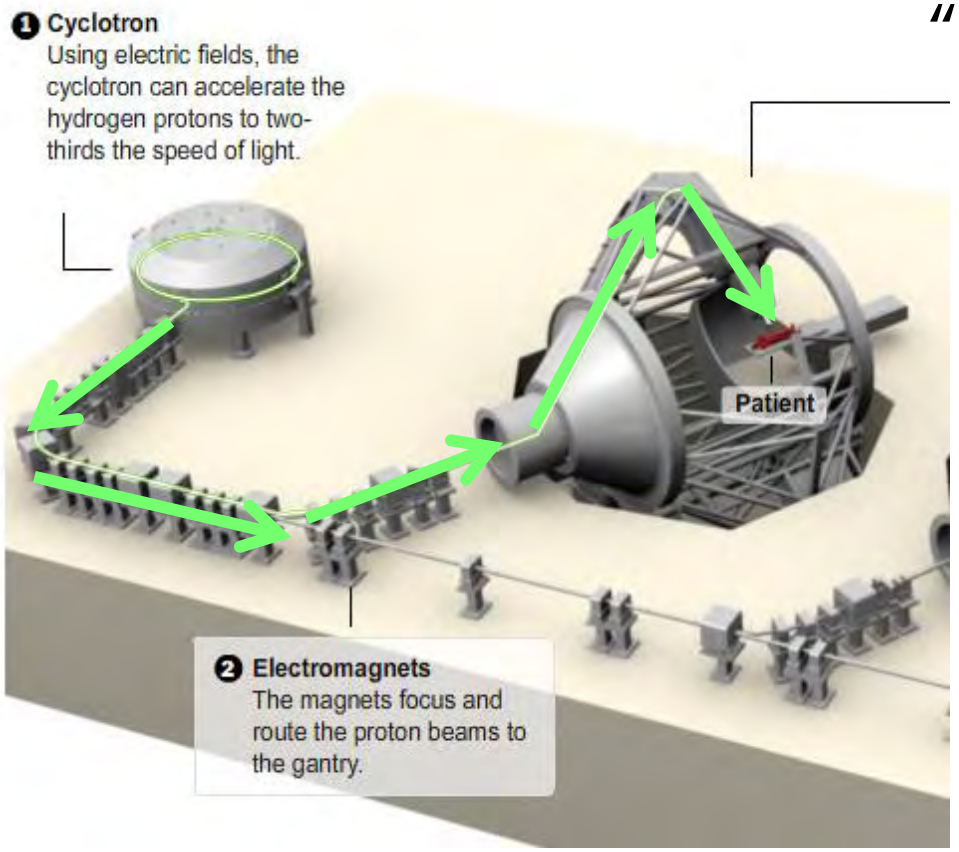


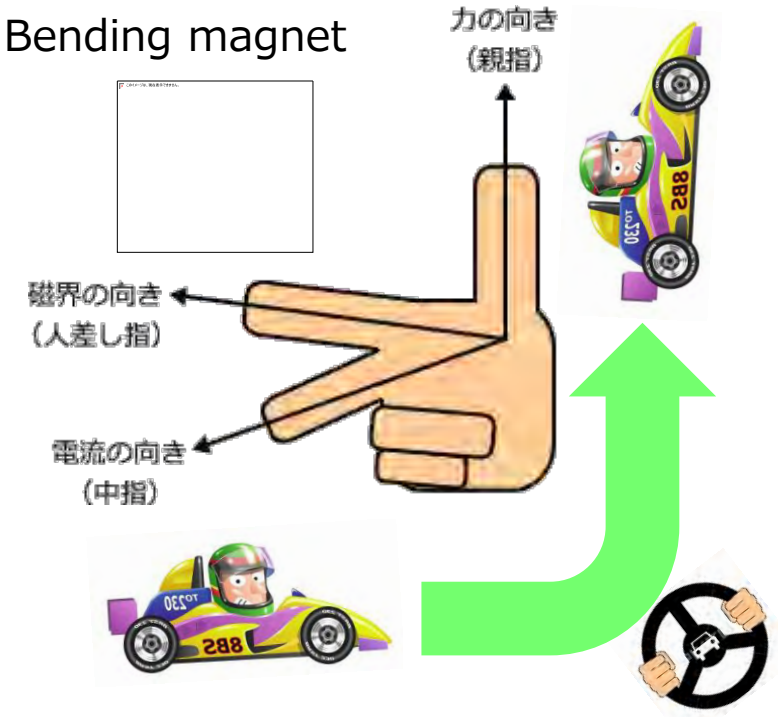
Irradiated Region Formation System



Proton Flight Times from Accelerator to Patient



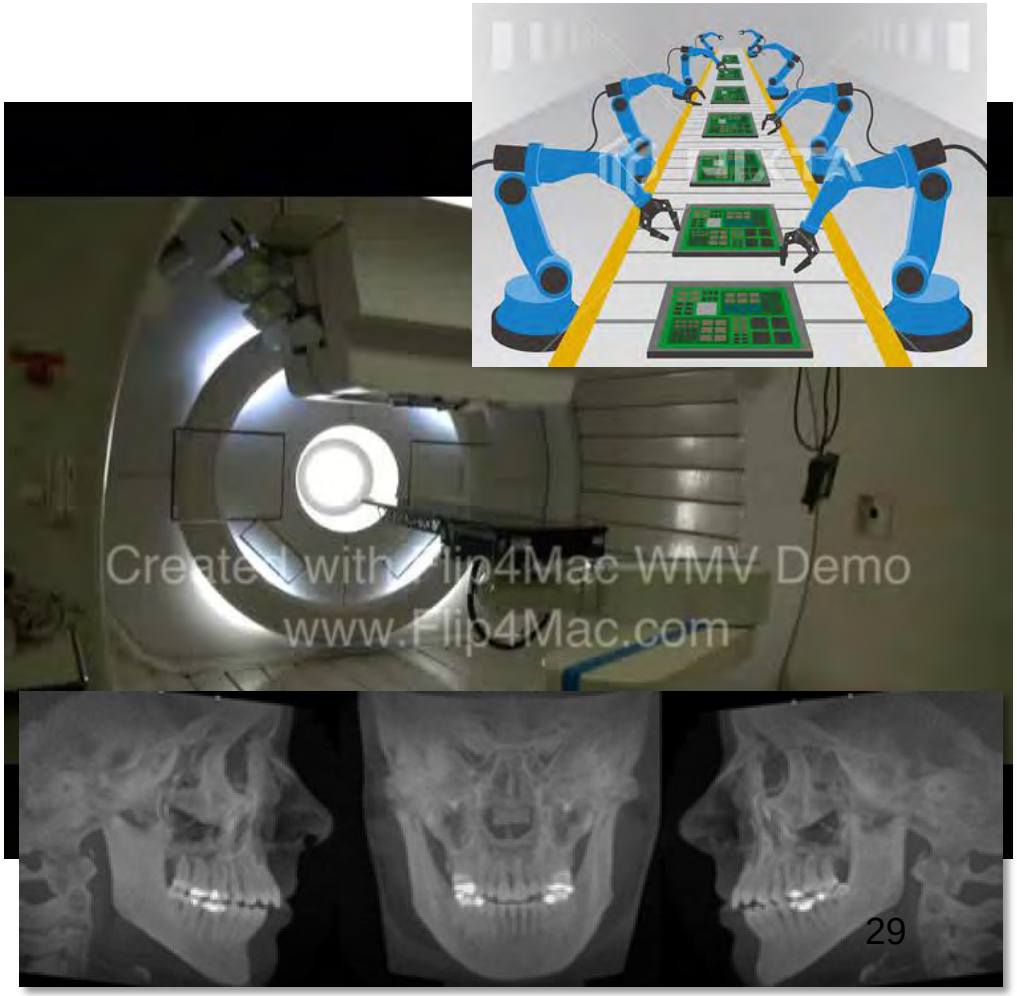
"Fleming's left-hand rule"



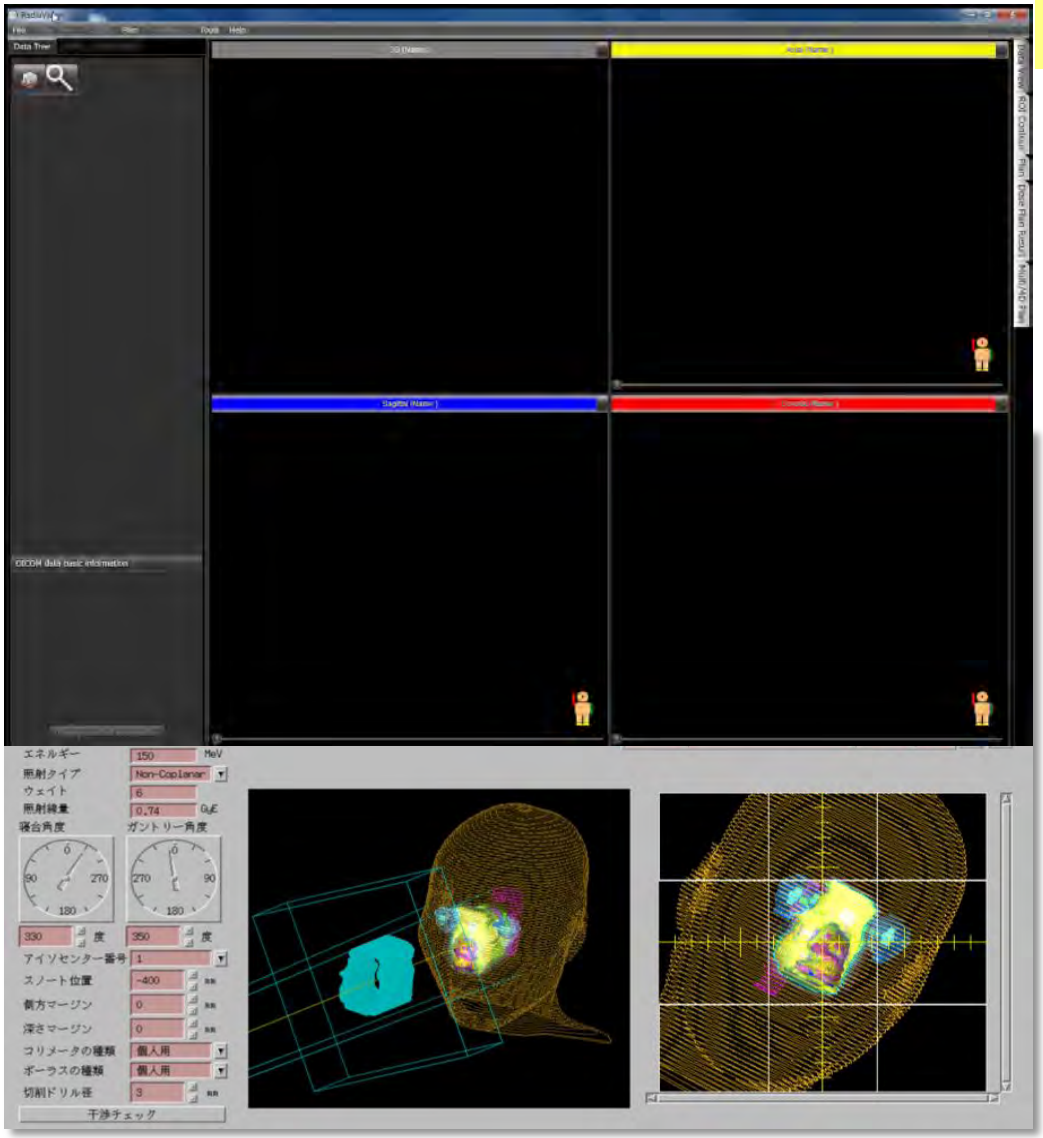
A proton travels the distance of 30 meters from the accelerator to the patient in only 0.00000015 seconds (150ns = 1.5 x 10^-7s).

Apparatus for Determining Internal Tumor Position

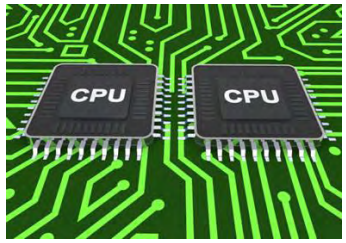
Fluoroscopes and beds are positioned by means of robotic arms.

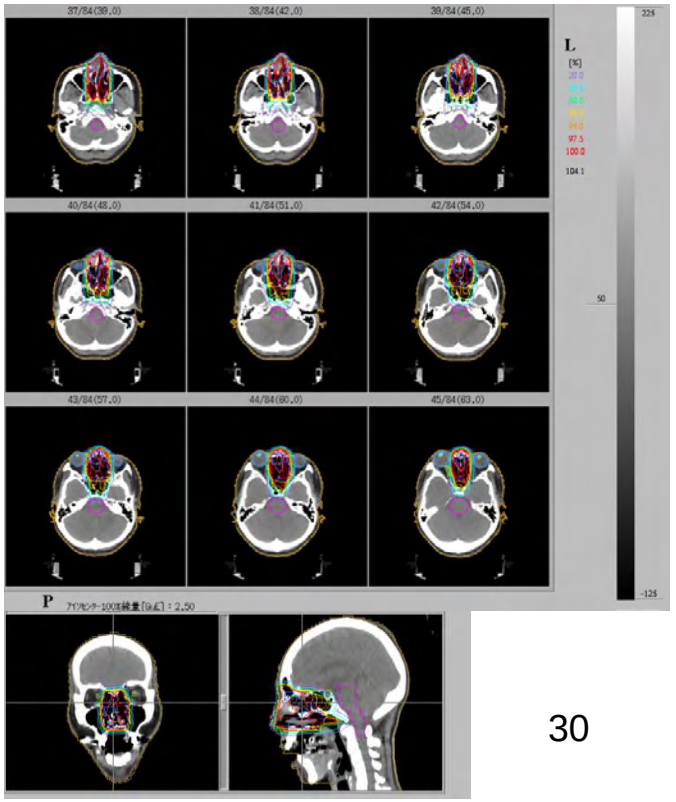


Proton Treatment Planning Device



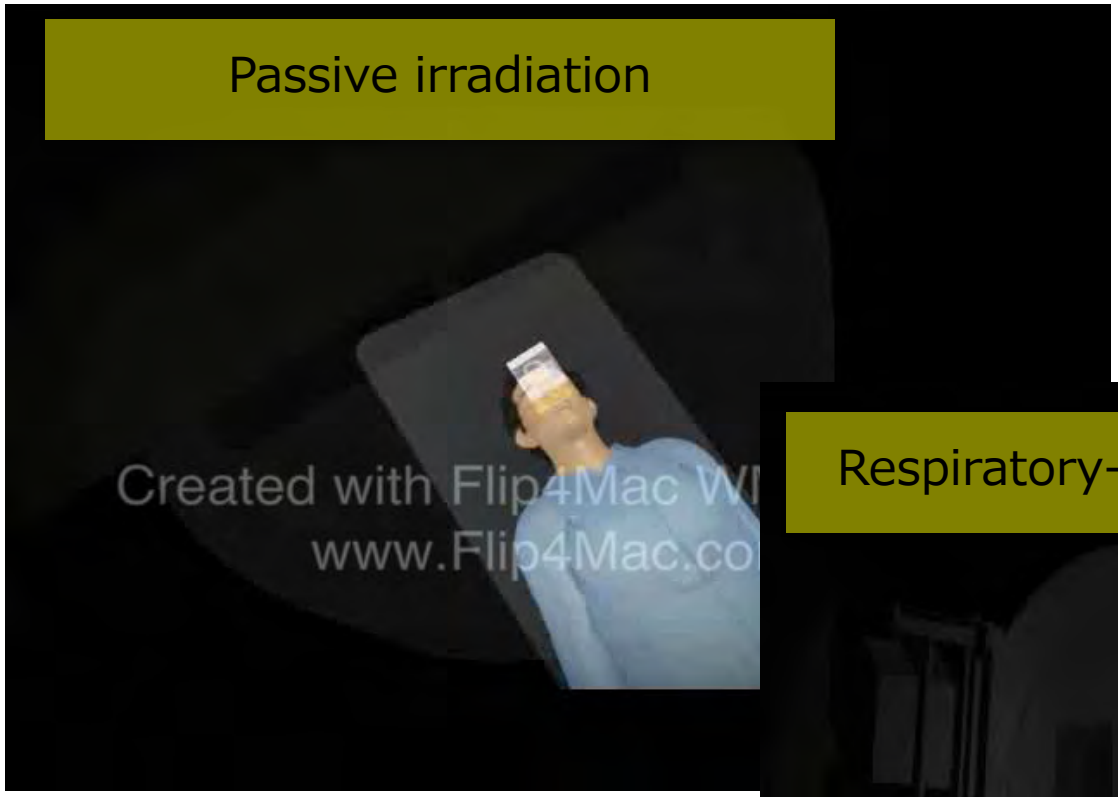
Minute calculations by computer



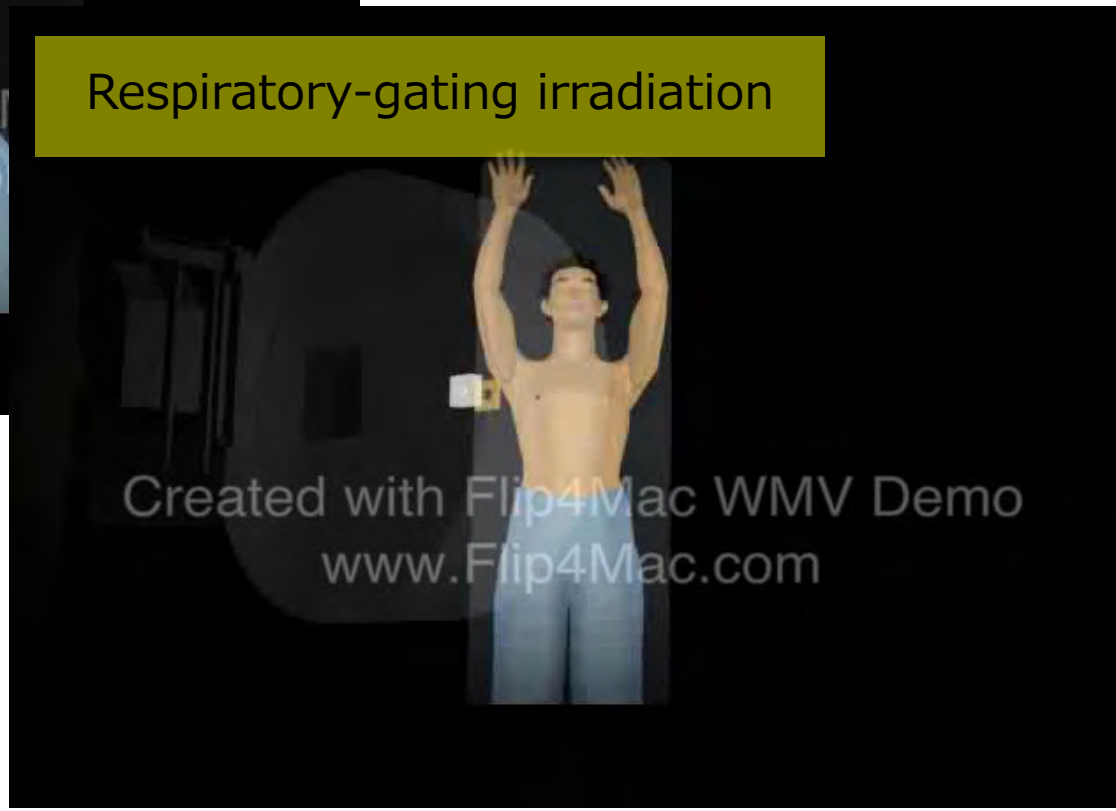


Method of Formation for Tumor Shape Dose Distribution

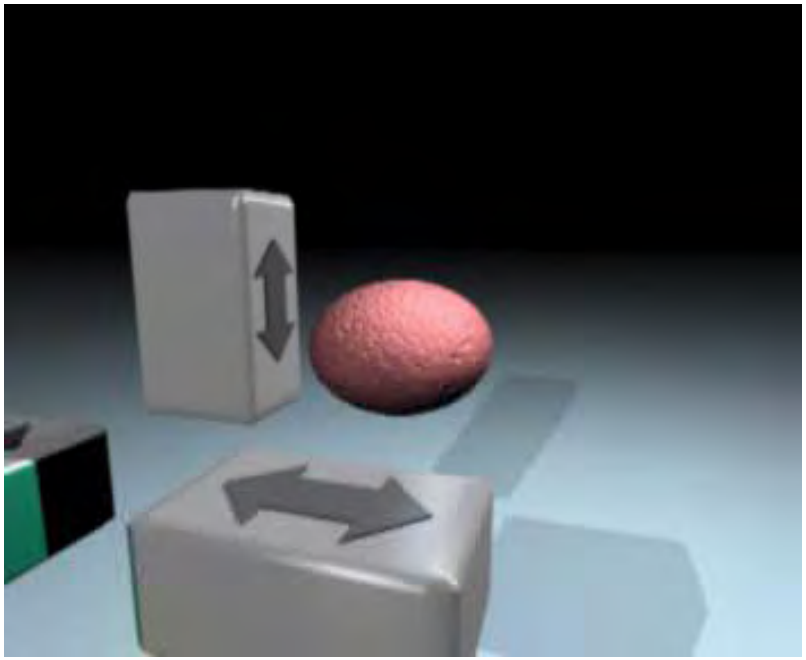
Passive irradiation



Respiratory-gating irradiation



Intensity-Modulated Radiation Therapy: IMRT

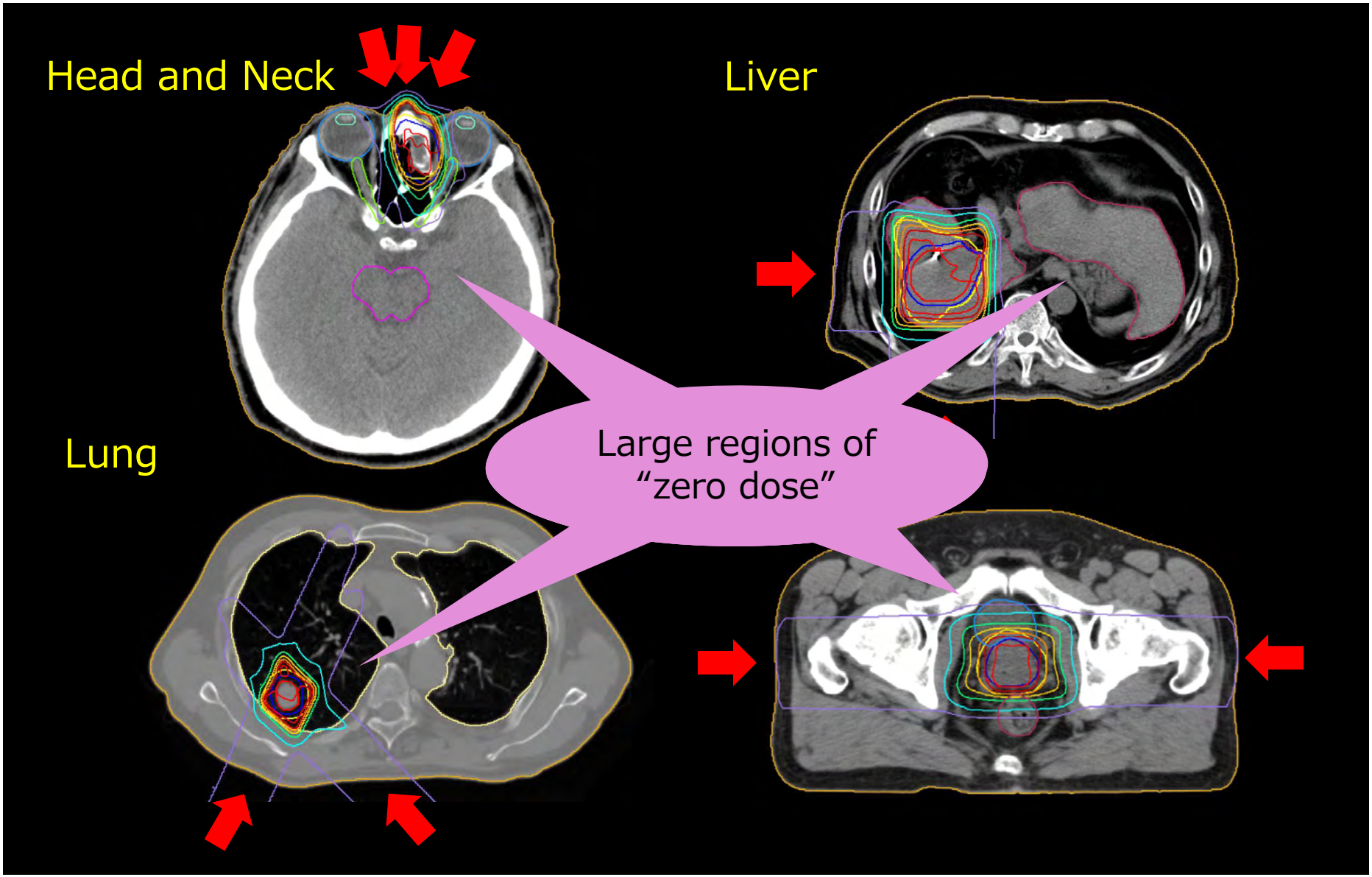


270 deg. : “N” “KA”

315 deg. : “C” “SHI”

0 deg. : “C” “WA”

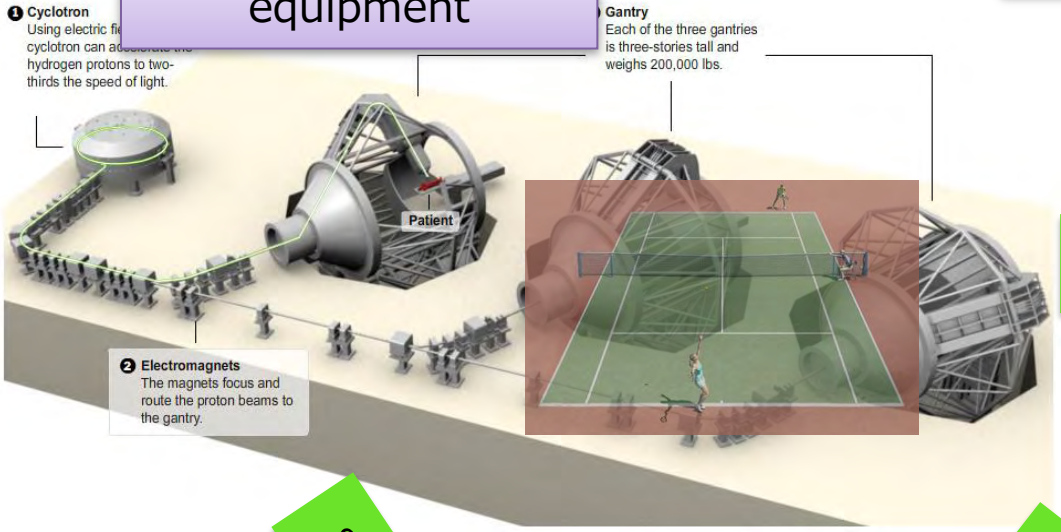
Proton Therapy Dose Distribution



Smaller Proton Therapy Equipment

Conventional equipment

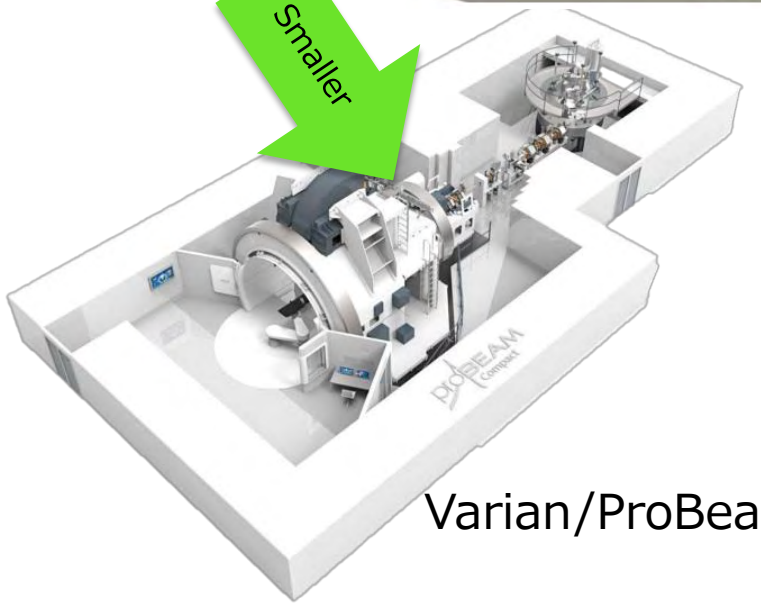
Smaller equipment



Smaller

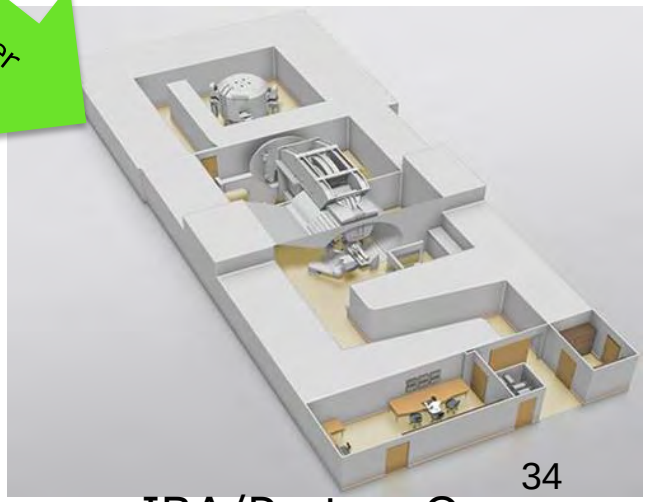
Sumitomo Heavy Industries

Smaller



Varian/ProBeam

Smaller

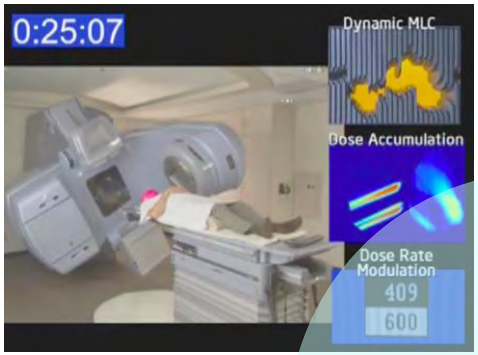


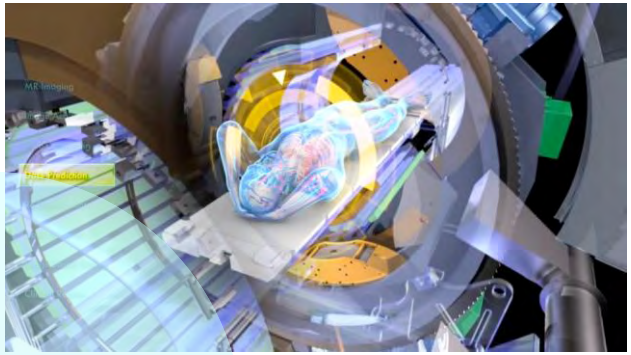
IBA/ProteusOne

Recent Improvements in Precision

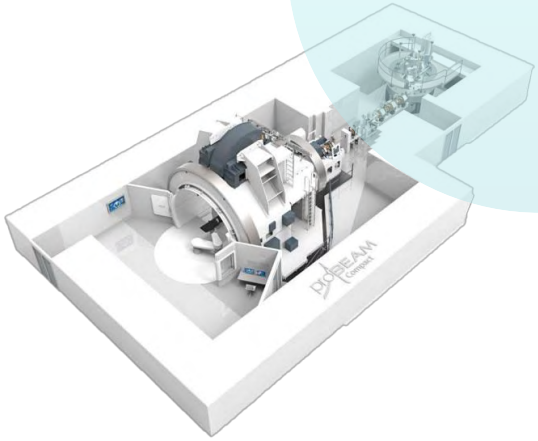
Various technological developments have rapidly brought to increased precision therapy.

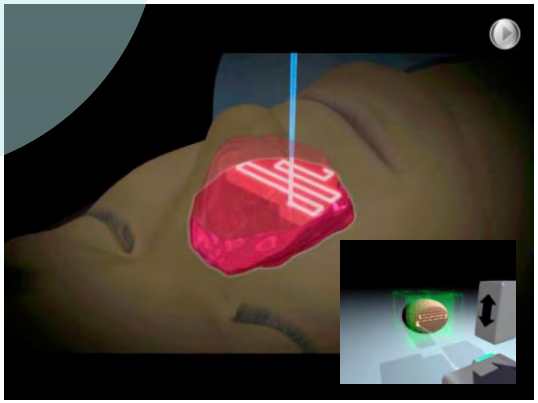
→ Highly-precision radiation therapy: From preventive and palliative treatments to definitive treatments





IMRT/IGRT
Proton therapy





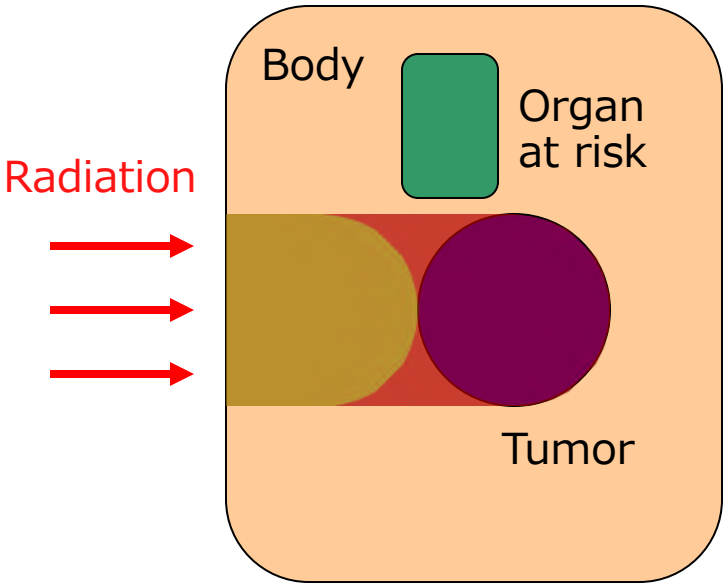
Highly accurate radiation therapy is an aggregate of physics and engineering

- Radiation physics
- Radiometry
- Electro magnetics
- Accelerator physical engineering
- Statistical physics
- Nuclear physics

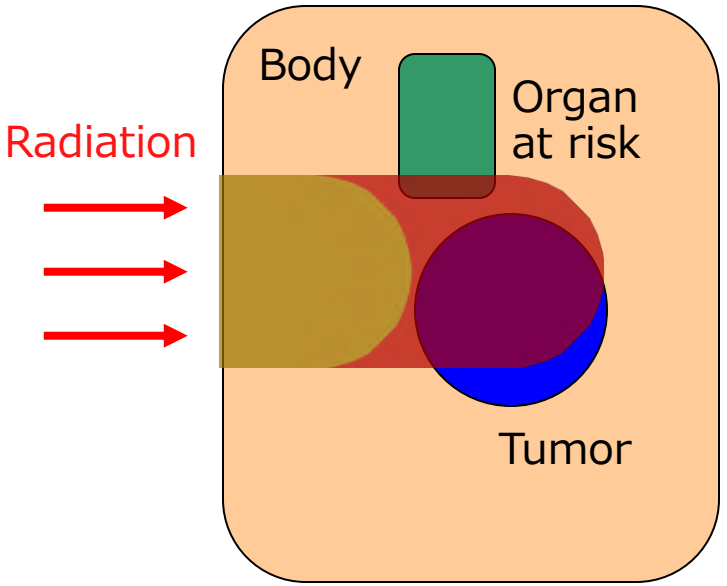
Convergence of High Intensity and High Precision

Dose is high. In turn, unless careful planning and accurate delivery are achieved, administration of the dose to the target will be insufficient and/or high doses will be provided to important organs.

Tumor may remain or recur, and other problems may arise.



Radiation delivered with high accuracy



Radiation delivered inaccurately

Directing High Dosage to the Tumor

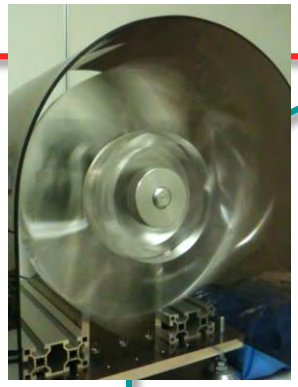
Tumor

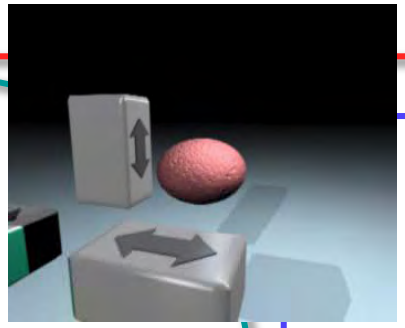
- **Simulate accurately !**
- **Aim accurately !**
- **Irradiate accurately !**

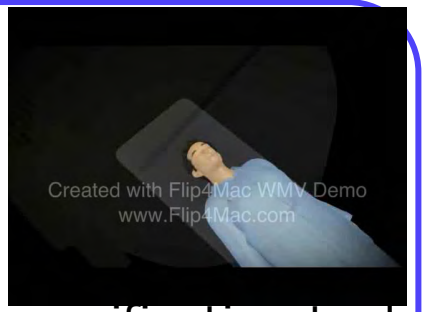
These are essential

Research & Development of Four Advanced Technologies

High-Precision Radiation Therapy

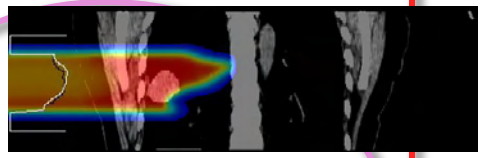






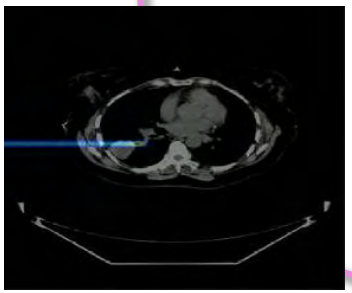
Irradiation system

Dose verification tool



Imaging system

Simulation system



Medical Physicists to Carry the Future of Radiation Therapy

Medical Physicists

"Medical physicists" work in hospitals, schools and research institutes, contributing to medicine and medical care in aspects of physical engineering, and have passed examinations as medical physicists.
(There are now about 1,200 in Japan.)

仕事人 医学物理士

放射線治療 より精度高く

医師と技師の すき間埋める

がんの放射線治療はテクノロジーの進歩が著しい分野。最近ではコンピューターを使い、腫瘍（しゅよう）にピンポイントで放射線を当てる治療も可能になった。

体内の見えない腫瘍の位置や形、大きさを正確につかみ、放射線の当て方をミリ単位で調整するには物理の専門知識が必要になる。医学物理士は高度化する放射線治療を支える医療スタッフだ。

「医師と放射線技師の守備範囲にできたすき間を埋める仕事」。国立がんセンター東病院（千葉県柏市）の医学物理士、西尾禎治さん（40）は自らの職務をこう表現する。キャリアは約十年。陽子線治療施設を使った治療計画作りや精度管理などにあたっている。

西尾さんがコンピューターの画面を開くと、人体の一部が再現されたCG（コンピューターグラフィックス）画像が浮かび上がった。患者のコンピューター断層撮影装置（CT）写真や医師の診断結果から作り上げたものだ。この画像を基に陽子線が効果的に腫瘍に当たるよう計算し、治療計画を仕上げる。

放射線治療は切らずにがんをたたく効果がある。治療の精度を高めることは患者の生活の質（QOL）の維持に直結する。

西尾さんによると、欧米では医師一人に医学物理士一人が対し日本は人材不足が深刻だ。放射線治療施設はつくのが普通。これに全国に約七百カ所ある。医学物理士は現在三百八十二人で、単純計算しても一カ所に一人程度。この数字ですら実態を反映していない。

日本で認定制度ができたのは一九七七年。数がなかなか増えず、要件を緩和したところ、放射線技師が多数合格した。「本来の仕事で手いっぱいで、医学物理士としての仕事をしている人は多くない」と西尾さん。

元の専門は天体核物理学。全く異なる分野のようだが、「放射線が星の中でどんな反応を引き起こすかという研究だったので、人体の中で起こす反応を計算する今の仕事とは概念的に近い」。

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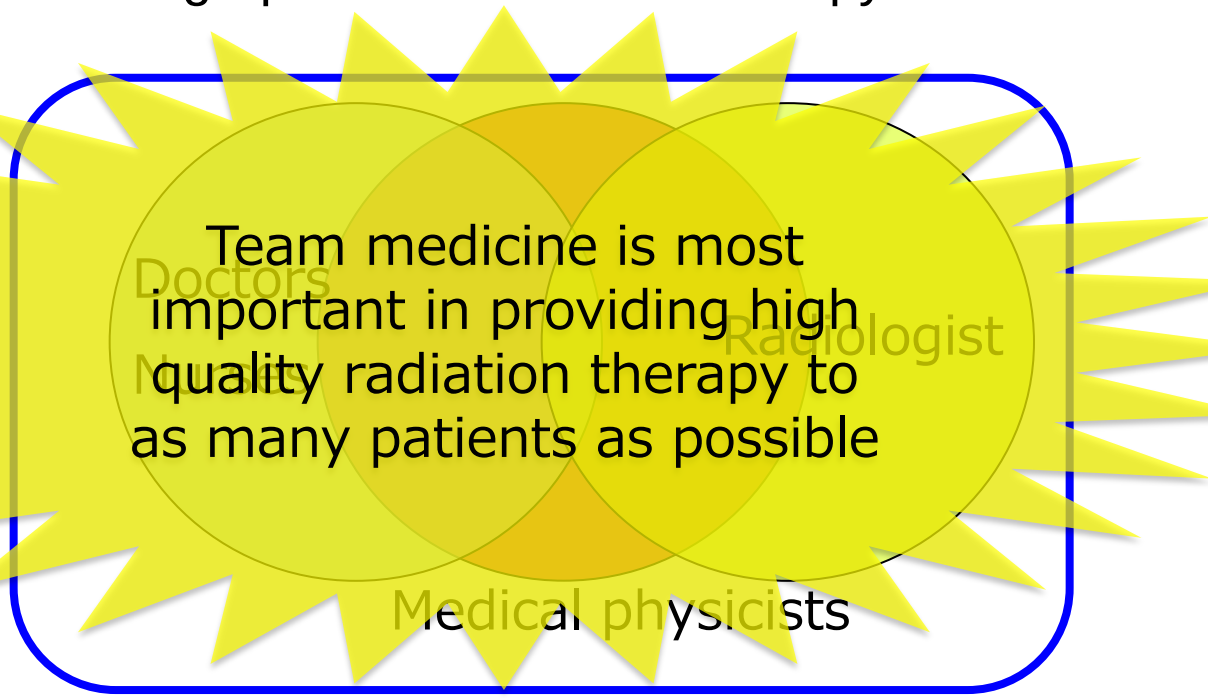
（社会部　吉田直子）

業務内容	放射線治療の計画作りや精度管理。新たな治療法の研究・開発も
資格・条件	日本医学放射線学会による認定試験に合格後、臨床経験を経て認定申請が必要。受験資格は理系の学位を持つ経験者や放射線技術・医学物理系の修士以上
業界事情	学会の認定を受けた382人の多くは医師や放射線技師。がん医療の専門家育成を目指した文部科学省の「がんプロフェッショナル養成プラン」で約30大学が養成コースを設置した

High-precision radiation therapy



High-precision radiation therapy requires more than improved devices and technology.

Medical Physicists

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ザ 仕事人

医学物理士

放射線治療 より精度高く

医師と技師の すき間埋める

陽子線治療の計画をたてる西尾さん

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などにあたっている。

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放射線治療は切らずにがんをたたく効果があるが、必要のない場所に当たると正常な細胞を傷つけてしまう。例えば鼻やあごのがんに照射した放射線が周囲に当たると、視力低下や手足のまひが起きることがある。治療の精度を高めることは患者の生活の質（QOL）の維持に直結する。

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（社会部　吉田直子）

- Implement treatment plans for each patient and management of dose precision.
- At clinical sites, contribute to maintenance and management of precision, the performance of therapeutic devices and their improvement.
- Contribute to growth/development of medical physics in research and development aspects.
- Contribute to human resource development and further education in medical physics.

Attraction of Medical Physics

- Has a very clear purpose: to treat cancer patients.
- Includes the "consciousness and responsibility" of a medical professional.
- Enables fostering a "broad personal perspective" though interactions with people in a wide range of jobs
- "There are almost limitless research subjects," some offering results in a short period and others requiring extended time.
- Because it is a field not yet well established in Japan, it affords the opportunity to become a "pioneer in the area of medical physics," subject to your effort.

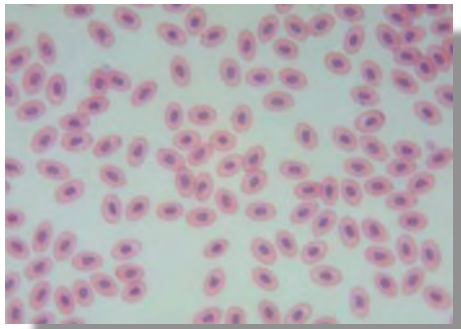
Attraction of Medical Physics

Cosmos



From the macro to the microscopic world

Human body



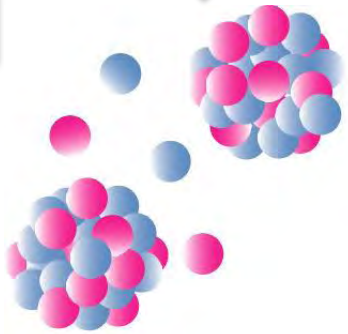
Observed object is unexpectedly the same scale.

Attraction of Medical Physics

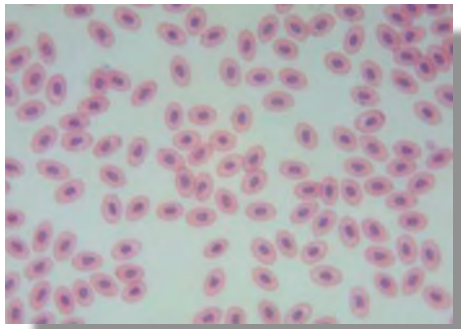
Cosmos



From the macro to the microscopic world

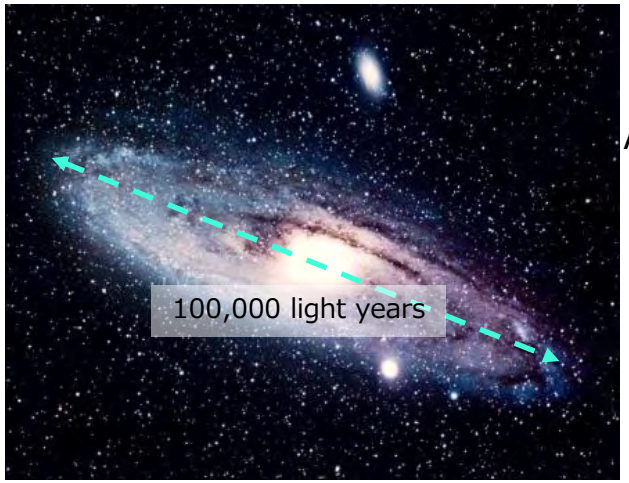


Human body

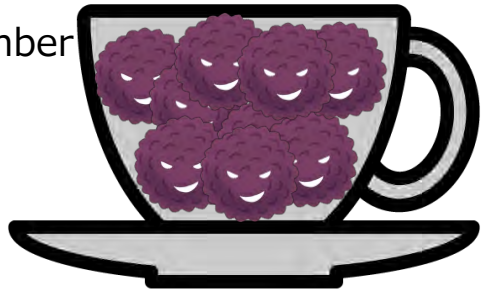



Wide range of possible studies from basic science to technological applications to clinical practice

Attraction of Medical Physics



Almost the same number

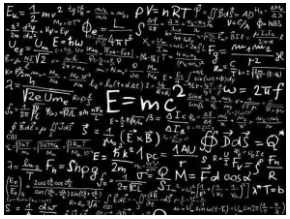


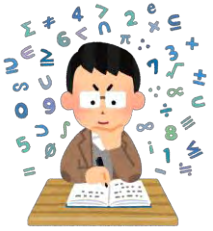
Number of cancer cells in a cup: 200 billion
(Number of cells in the human body: 37 trillion)

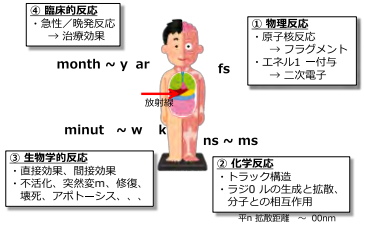
Number of stars in our galaxy: 200 billion
(Number of stars in the universe: 10^22)

Distance between stars is great:
4 light years on average
(Sun to Earth: 8 light minutes)

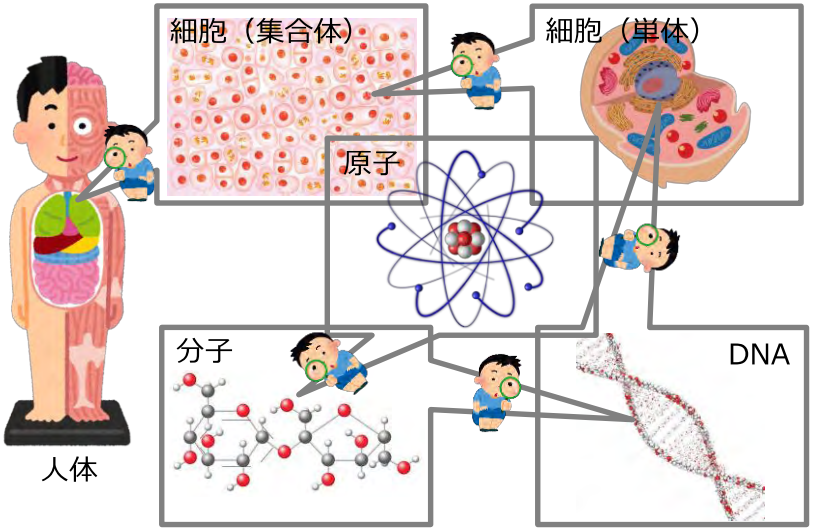
“Reciprocal actions between stars can be ignored.”







Mechanisms of the human body are more complex and difficult than star structures in the cosmos



Human cells and molecules interact electromagnetically.

Medical Physics

Medical physics, as the name implies, combines medicine and physics.

Medicine

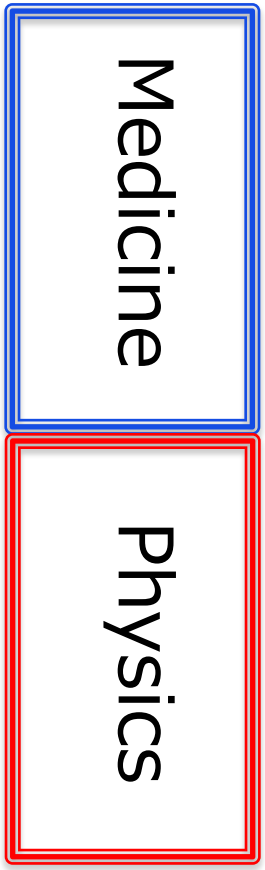
It is quite possible to learn adequately at a medical site after graduating from college.

Physics

Ideally, basics of physics are learned adequately at undergraduate/graduate school.

Medical Physics

Medical physics, as the name implies, combines medicine and physics.



Medical Physics

Medical physics, as the name implies, combines medicine and physics.

The field of study called medicine is broad.

Medicine

Physics

Medical Physics is …

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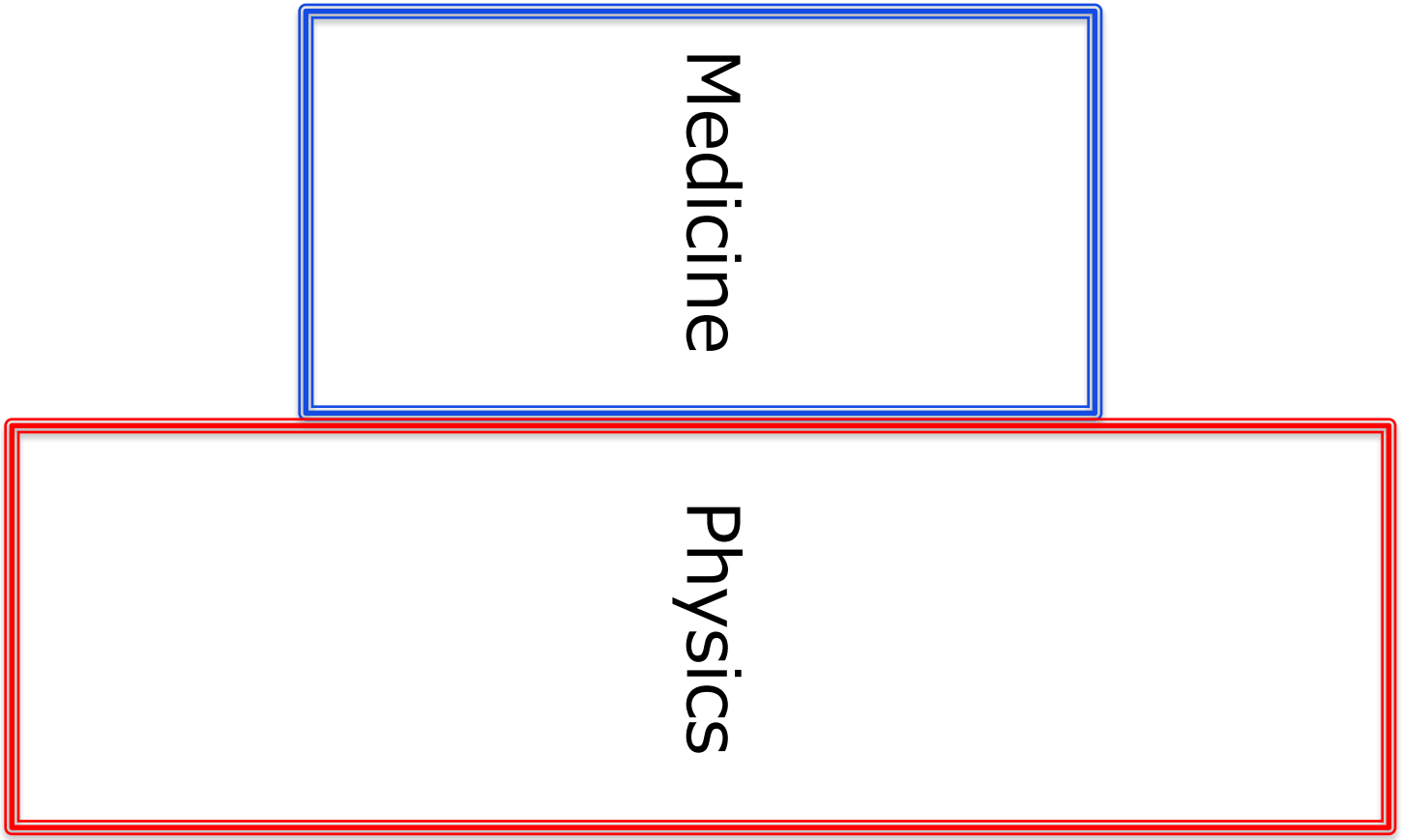
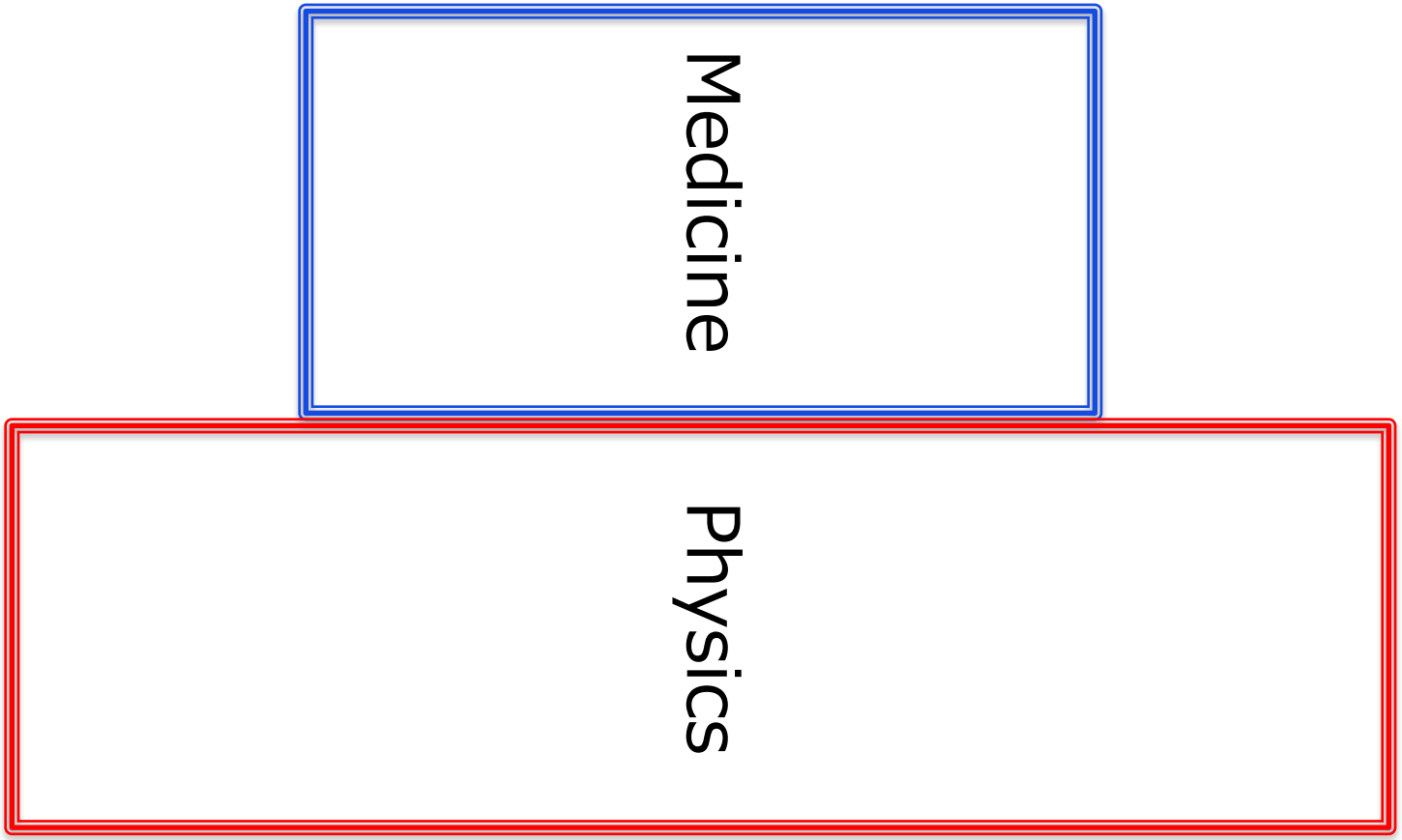
The field of study called medicine is broad.



A broad foundation in physics is the base.

Medical Physics is …

In medical physics,
medical-engineering collaboration
→ medical, science, engineering, health science
→ medical-science-engineering-health science collaboration



A broad foundation in physics is the base.

Study and Education in Medical Physics through Industry-Academia-Government Collaboration

Rikkyo Univ.

Univ. of Tokyo

Medical Physics Studies

Tokyo Women's Medical College
Waseda University

St. Luke's International Hospital

National Cancer Center Japan

Kitasato Univ.

Hiroshima Univ.

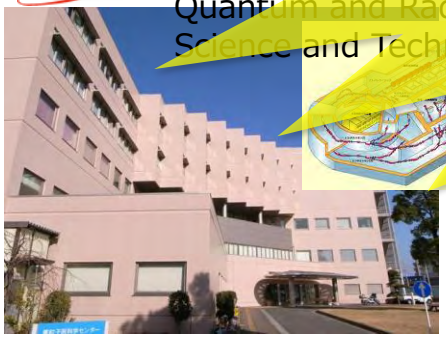
Kyoto Univ.

Tokai Univ.

Through strong collaboration with other organizations, research and education in medical physics are established.

We hope to establish close cooperation in research and human resource development with the nuclear field.

NIRS National Institute for Quantum and Radiological Science and Technology



Wakasa Wan Energy Research Center

RIKEN, Japan

RIKEN NISHINA CENTER 独立行政法人 理化学研究所 仁科加速器研究センター

Thank you for your kind attention.

Tokyo Women's Medical University, Graduate School of Medicine,
Department of Medical Physics
– Graduate School Specialized in Research and Education in Advanced Medical Physics –

4 Teachers in Medical Physics

（左から、松原、西尾、寅松、恒田）

First Focus on Medical Physics in Japan

If you are interested in this, please contact

nishio.teiji@twmu.ac.jp