Simulation of Radiation Therapy

Leo Szilárd, after whom the competition was named, was born 125 years ago. In the second part of his life, he turned to biology. He cured himself of bladder cancer with radiation treatment designed by himself. We remember him with this simulation.

Right at the start we emphasize that there are several important differences between a real radiation therapy and the current simulation model (see a drawing of a real radiation therapy device).

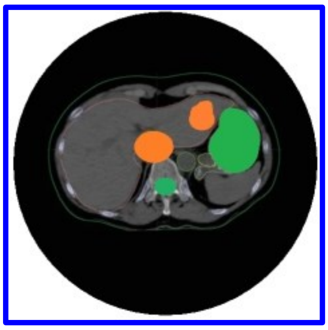
- A real radiation therapy irradiates a selected volume of the body in three dimensions (3D), the current simulation, in contrast, is only two-dimensional.
- In a real radiation therapy device, the "isocenter" - the center of irradiation and rotation - is usually fixed, and the patient is moved with the treatment table on which he lies, so that the volume to be irradiated moves to the right place. Contrary, in this simulation, the isocenter moves relative to the patient, and the two-dimensional "patient" does not move.
- In a real radiation therapy center, the X-ray (or gamma) irradiation equipment is in a different room from the proton therapy (if this latter exists at all). In our simulation, the beam can be "switched" with one click between X-ray and proton.
- In the case of real radiation therapy, the necessary dose is usually delivered in several parts (fractions), and some time must elapse between the fractions (e.g. a day or even a few days). There are biological/medical reasons for this. In our simulation, we "treat" the patient in a single fraction. Carrying out several steps of irradiation (e.g. from different angles) does not count as separate fractions, since even in real radiation therapy the device (gantry) rotates around the patient during one irradiation session (one fraction).

The goal of radiation therapy

The goal of radiation therapy is to destroy tumor cells in such a way that healthy tissues and cells are only minimally damaged. With ionizing radiation we can destroy practically all types of cells, the question is, at what cost we can achieve this at the tissue and organ level. The study of the effects of ionizing radiation at the cellular level is dealt with by the science of radiation biology.

The task

Previous diagnostic tests revealed two cancerous tumors in the patient's liver. These tumors should be destroyed by radiotherapy. However, care should be taken to ensure that the dose received by the "organs at risk" (OAR) in the vicinity does not exceed the limits given below. In the simulation, we monitor the dose of five types of tissue:



- 2 „liver tumors” (orange areas),
- 2 „organs at risk”, (stomach and spinal cord, green areas),
- „other” organs/tissues (grey).
- „body cavities” (black, they cannot get radiation dose)

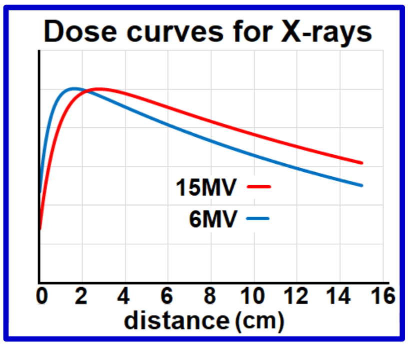
Target dose values for the following tissue types	dose	organ fraction %
Tumors	min. 25 Gy	100%
Organ at Risk (stomach)	max. 6 Gy	90%
Organ at Risk (spinal chord)	max. 6 Gy	100%
Other tissues	max.12 Gy	75%

The interpretation of the values in the table e.g. in the case of the organs at risk: 90% of the stomach cannot receive more than 6 Gy. The remaining 10% can receive more. 100% of the spinal cord cannot receive more than 6 Gy. (For real radiation treatments, the system of dose limits is much more detailed and complicated, we have only highlighted a few aspects in the simulation).

In our simulated radiation therapy center, we have at our disposal X-ray beams of two energy (6 MV and 15 MV) and a proton beam with energy variable between 50 MeV - 240 MeV. Some important properties of these beams are summarized below.

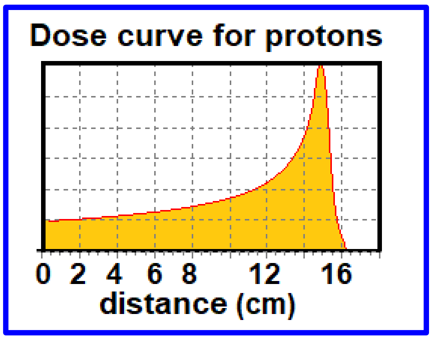
X-ray or gamma-beam radiation

Most of the machines in most radiation therapy centers use X-rays or gamma rays to perform radiation therapy. Gamma radiation is produced by the decay of atomic nuclei (e.g. ^{60}Co), and X-rays are produced by colliding the beam of a high-energy electron accelerator with a heavy metal target (e.g. tungsten). While the energy of the quanta of gamma radiation is a well-defined value, the energy distribution of the X-ray photons produced by the accelerator is continuous in a given energy range ("Bremsstrahlung"). Therefore, the latter radiation field is not characterized by the energy of the photons (MeV), but by the accelerating voltage with which the electrons were accelerated. That's why we can talk about 6 MV or 15 MV X-rays for example.



The radiation beam of X-ray and gamma photons behaves similarly: as it reaches the body, after a very short "dose build-up" phase, it reaches a maximum, and from there the dose delivered decreases exponentially depending on the distance travelled by the beam in the body. This is shown in the figure. (On the horizontal axis is the distance travelled by the radiation in the body, on the vertical axis is the dose intensity at the given distance, in relative units).
In our simulation, we do not distinguish between individual tissues (of course, this is handled in professional software).
In this simulation, the dose curve is calculated as if the radiation travelled all the way through water (the energy absorption of human tissue from radiation is very similar to that of water).

Dose curve of proton beam



The protons come from an accelerator, and therefore the energy of the protons in the beam is a well-defined value. The energy spread of the proton beam used in practice is approx. 1-2%. (Of course, a beam with a better energy resolution can also be achieved, but these values are adequate for radiation therapy purposes.) Protons – being electrically charged particles – ionize along their path, and therefore slow down and lose their initial energy. The energy transferred to the medium per unit path length (the so-called linear energy transfer, or LET) is inversely proportional to the square of the particle's speed (Bethe-Bloch formula).

It follows that the protons transfer the most energy to the cells towards the end of their path - before they stop. Therefore, the dose curve of protons is fundamentally different from the dose curve of X-rays or gamma radiation. This is shown in the figure.

Of course, how deep the maximum of the dose curve – the so-called Bragg peak – is inside the body depends on the initial energy of the proton beam and also on the medium in which the protons travel. In the simulation, the medium – as in the case of X-ray or gamma radiation – is considered to be water, but the energy of the proton accelerator can be changed. The figure shows the dose curve for protons with an energy of approximately 150 MeV.

Tasks

1) **Task** (0 points)
   – Get to know the program! (See the user's guide to the program separately!)
2) **Task** (4 points)
   – Irradiate one of the tumors with **6 MV** X-rays from one direction. Adjust the slit and the irradiation time so that the whole tumor receives the prescribed dose!
   – Use the **Evaluation** button to check the maximum dose received by the organs at risk (OAR) and other tissues! (What proportion is above the dose limit of 12 or 6 Gy?)
   – Note the irradiation configuration!
3) **Task** (4 points)
   – New patient (clear the previous dose values).
   – Irradiate the other tumor from 3 directions with the **15 MV** X-ray by setting up an **irradiation program**! Assure that the minimum dose requirement for the tumor is reached!
   – What is the maximum dose to the organs and risk and to the other tissues? (What proportion is above the dose limit of 12 or 6 Gy?)
   – Note the irradiation configuration!
4) **Task** (4 points)
   – New patient (clear the previous dose values).
   – Irradiate one of the tumors using the **proton-beam** by setting up an **irradiation program**! Assure that the minimum dose requirement for the tumor is reached!
   – What is the maximum dose to the organs and risk and to the other tissues? (What proportion is above the dose limit of 12 or 6 Gy?)
   – Note the irradiation configuration!
5) **Task** (10 points)
   – New patient (clear the previous dose values).
   – **Optimize**! Based on the previous experiences, put together an irradiation program that reaches the minimum requirement for tumors and puts as little radiation load on healthy tissues as possible! (Several programs can be created and saved during optimization, but your documentation must indicate which program you considered optimal!
6) **Task** (3 points)
   – **Document** your work, describe your thought process and the results!