NUCLEAR PHYSICS IN MEDICINE

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Our subject is nuclear physics in medicine. One branch of this field involves the use of radioactive substances in order to treat and diagnose certain diseases, tumors etc. Nuclide imaging is a part of nuclear medicine, it's a practice where radioactive substance are introduced into the human body. It records the radiation emitting from within the body rather than recording radiation that is emitted from external sources like X-rays.

Hadron therapy is a rather new therapy that is used to irradiate tumours.

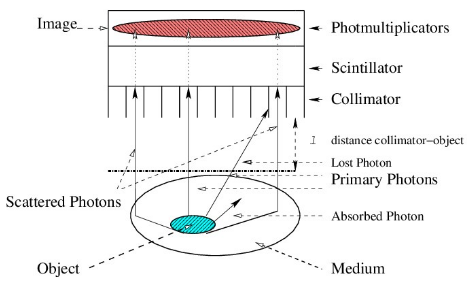
Single photon emission computed tomography (SPECT) and positron emission tomography (PET) scans are the two most common practices among nuclear imaging.

The following steps to do nuclide imaging are:
First inject radioactive isotopes into the body. Then these undergo radioactive decay and generate gammy rays, a camera detects gamma rays from the isotope after a certain amount of time.

Nuclear medicine detects regional variations of radioactivity as indication of presence or absence of specific physiologic functions. The gamma rays are detected by a gamma camera or another detection device which is called detector array.

The Gamma-Camera can be used to observe the effects of radioactive isotopes.

THE GAMMA CAMERA

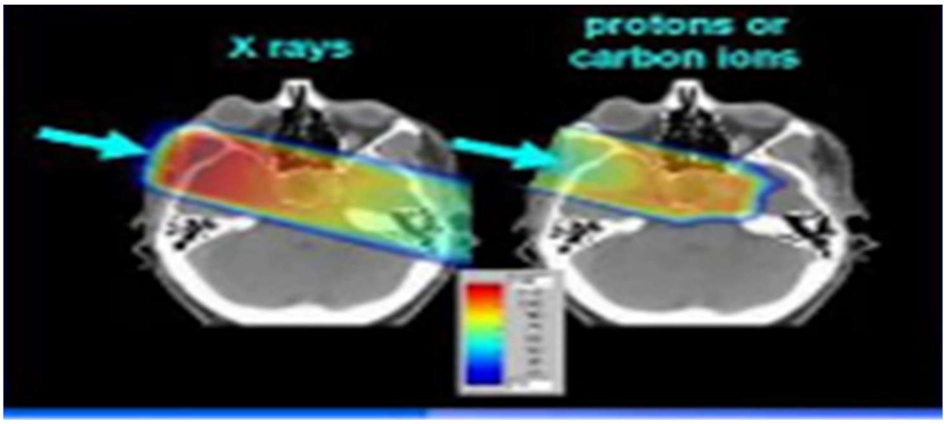


The gamma camera is used for the acquisition of static, dynamic and tomographic scintigraphic images. This is based on the detection of gamma rays emitted by radionuclides. Here the gamma rays that are emitted by the patient, after they have passed through the collimator, are converted into sparks of light in the camera crystal: a two-dimensional image is created inside the crystal, which shows the distribution of the patient's radioactivity.

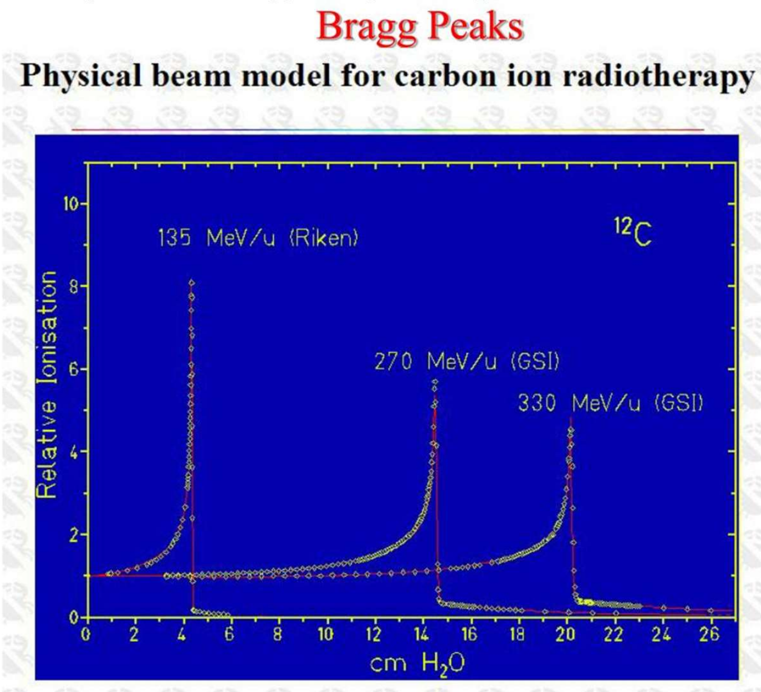
1. WHAT IS HADRON THERAPY?

Radiation therapy is the medical use of ionizing radiation to treat cancer. In the conventional radiation therapy, beams of X rays (these are high energy photons) are produced by accelerated electrons. Those are delivered to the patient with the purpose to destroy the tumour cells. Using crossing beams from many angles, radiation oncologists irradiate the tumour target. They try their best to spare the surrounding normal and healthy tissues, but inevitably some radiation dose is always deposited in the healthy tissues.

When the irradiating beams are made of charged particles, this means protons and other ions such as carbon, the radiation therapy is called hadron therapy. This therapy's strength lies in its unique physical and radiobiological properties of these particles. They can penetrate tissues with little diffusion, and they deposit the maximum energy just before stopping. This allows a precise definition of the specific region which is going to be irradiated.



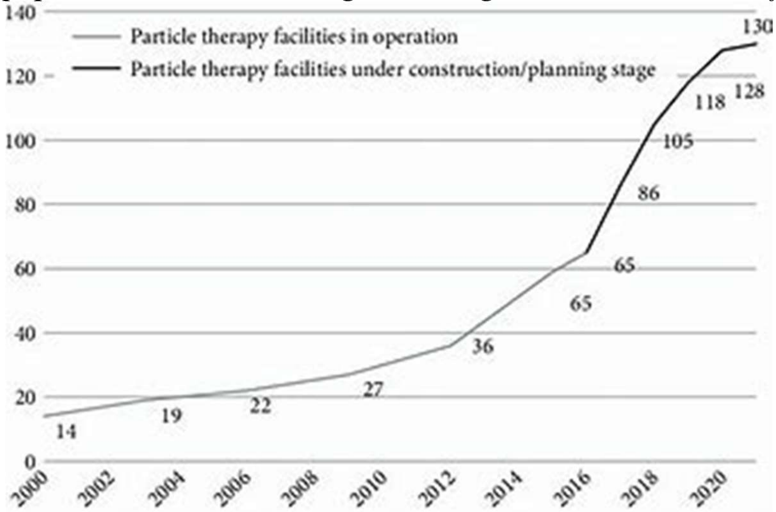
A feature of hadron therapy is its peaked shape of the hadron energy deposition. This is called the Bragg peak. The Bragg peak plots the energy loss of ionizing radiation during its travel through matter. The peak occurs immediately before the particles come to rest. Energy lost by charged particles is inversely proportional to the square of their velocity which explains the peak occurring just before the particles come to a complete stop



The use of hadrons to irradiate the tumour is significantly better then when you use X-rays because there is way less damage done to surrounding healthy tissues.

Although protons are used in several hospitals, the next step in radiation therapy is the use of carbon and other ions. This is because they have clear advantages even over protons in providing both local control of extremely aggressive tumours and a lower acute or toxicity. As result this gives the patients a better quality of life during and after the cancer treatment.

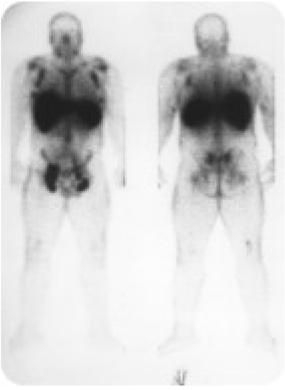
There are already 120,000 patients who have been treated with hadrons, including 20,000 with carbon ions. *As u can see in the graph below Hadron therapy has recently become very popular and it is something that will grow even more in the future*.



2. <u>THE INJECTION OF RADIOACTIVE ISOTOPES FOR DIAGNOSTIC (finding tumours)</u>

<u>How does it work?</u>

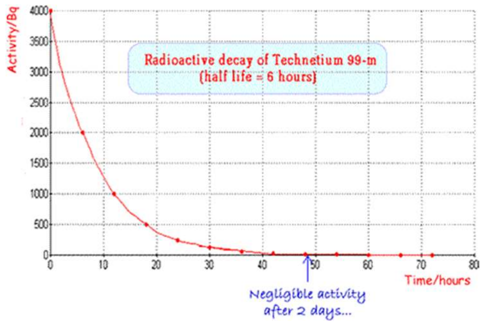
Radioisotopes are used to diagnose disease and as effective treatment tools. For diagnosis, the isotope is administered and then located in the body using a scanner. The decay product (often gamma emission) can be located and the intensity measured. The amount of isotope taken up by the body can then give information as to the extent of the medical problem.



Radioisotope scans can be used to detect tumours, as in the figure. The dark spots in the body represent areas where tumour cells exist.

Technetium-99m:

Technetium-99 is produced during nuclear reactor operation, and is a by-product of nuclear weapons explosions.
Technetium-99m is a short-lived form of Tc-99 that is used as a medical diagnostic tool; it is also an excited state of Tc-99 which decays by gamma emission (emission of a photon). Thus, there is no change in nuclear composition in this case.
Technetium-99m is perhaps the most widely used radioisotope in diagnosis and treatment. This isotope decays to Tc-99 and a gamma emission of low intensity, making the radiation damage fairly negligible.
It has a short half-life (6 hours) and does not remain in the body or the environment for long. Half-life is the time required for half of the radioactive atoms present to decay, that is the spontaneous change in nucleus composition with associated emission of energy to reach a more stable state.



SPECT:

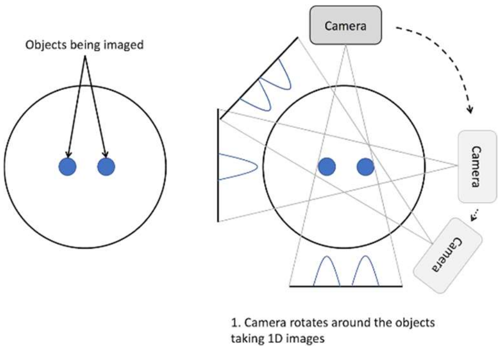
Single photon emission computerised tomography (SPECT) is the current major scanning technology to diagnose and monitor a wide range of medical conditions.

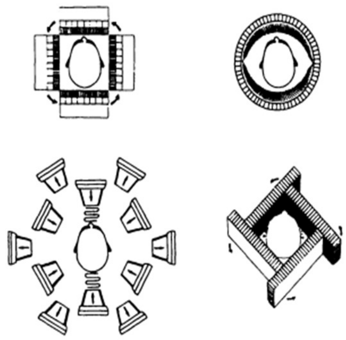
Positioning of the radiation source within, rather than external to the body is the fundamental difference between nuclear medicine imaging and other imaging techniques such as X-rays. Gamma imaging by either method described provides a view of the position and concentration of the radioisotope within the body. Organ malfunction can be indicated if the isotope is either only partially taken up in the organ: cold spot, or taken up in excess: hot spot.

A distinct advantage of nuclear imaging over X-ray techniques is that both bone and soft tissue can be imaged very successfully.

The patient is in a circular array of detectors that may be stationary or rotated, with detector output used by a computer to construct a detailed image. This technique is called single-photon-emission computed tomography (SPECT). The spatial resolution of this technique is poor, about 1 cm, but the contrast, that makes an object distinguishable from other objects and the background, is good.

Figure SPECT uses a geometry similar to a CT scanner to form an image of the concentration of a radiopharmaceutical compound.



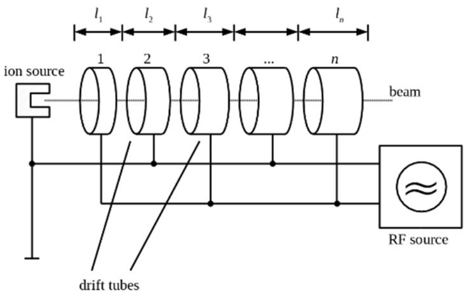


3. THE INJECTION OF RADIOACTIVE ISOTOPES (FOR KILLING TUMOURS)

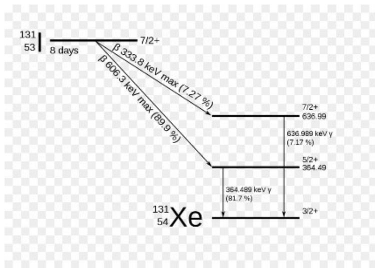
When we talk about injections of radioactive isotopes, we must, first of all, talk about radiotherapy. Radiation therapy is a therapy that is localized, non-invasive and painless in the patient. This treatment allows cancer cells to die through high-energy radiation, called ionizing radiation. Generally, X-rays are used, whose doses and methods of administration are different depending on the uses. These rays have the function of directly targeting and destroying cancer cells, while still trying to save healthy ones. In these cases, the radiation is produced by a linear accelerator, called LINAC. But in radiotherapy, gamma rays are also used, which are emitted by radioactive isotopes. Radiotherapy is now essential in one out of two cases of cancer. Radiotherapy today is more and more personalized, powerful and precise, and less toxic and therefore less dangerous for the patient's health. From this we can understand the importance of such therapy, as it has a success rate and represents a real hope for the fight against cancer

THE LINAC

A medical linear accelerator (LINAC) modifies X-rays or high-energy electrons to destroy cancer cells while sparing the healthy tissue around them. LINAC uses microwave technology to accelerate electrons in a part of the accelerator, which is called the "wave guide". In this way the electrons that are accelerated collide with a heavy metal target and produce high-energy X-rays. These high-energy X-rays are customized and shaped as they come out of the machine to match the shape of the cancer cells and these rays are so directed to tumors.



<u>IODINE – 131 – A PERFECT EXAMPLE OF RADIOACTIVE ISOTOPE</u>



Let's look at iodine-131, which is an important radioisotope of iodine, which is usually used with thyroid cancers. In therapy, we want to exploit the radiation emitted due to the decay of the isotope to hit the target cells to damage them or reduce their spread. Also, in this case, radiopharmaceuticals are used, specifically designed to accumulate as close as possible to the cells to be treated. The therapy consists in the oral intake of one or two capsules containing iodine 131, which is captured by the residual thyroid cells and through the emission of radiation causes its destruction. The radiation acts within a few millimeters, not affecting other organs.

Decay of Iodine 131: Iodine-131 decays with a half-life, that is the time that must pass for half of the nuclei of a given radionuclide to undergo decay, of about 8 days with the emission of beta particles and gamma rays. With decay it turns into xenon-131.

The Gamma-Camera can be used to observe the effects of radioactive isotopes.

4. POSITRON EMISSION TOMOGRAPHY

Positron emission tomography (PET) is an imaging technique that uses radioactive substances, also known as radiotracers, to visualize and measure changes in metabolic processes, blood flow, absorption, regional chemical compositions as well as other physiological activities. Different tracers are used for different purposes. Some detect cancers, some detect the bone formation.

PET scans are most commonly used to detect:

- Cancers
- Heart problems
- Brain disorders
- Problems with the central nervous system

I. Oncology

- PET scanning with a certain radiotracer also known as 18F-FDG is used in clinical oncology. These scans are for detecting cancer metastasis, the spread of cancer cells in the human body, and are the most used in standard medical care. This 18F-FDG tracer may also be used to diagnose several types of dementia.

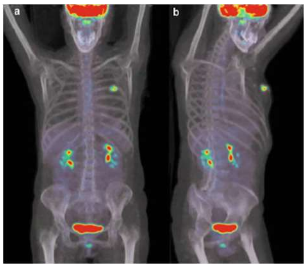
II. Cardiology

- A heart PET scan can detect whether areas of your heart are receiving a decreased blood flow. The scan can also identify dead tissue and injured tissue within the heart.
- The scan gives a doctor or a surgeon more insight if the patient may benefit from a surgical procedure.

III. Neurology

- A brain positron emission tomography scan is an imaging test that allows medical practitioners to see how the brain is functioning through images that show the activity of the brain and its tissues. Diseases and injuries can be detected by applying this method.

- PET scanning the brain happens with oygen-15. The method also measures the blood flow to the brain. The increased radioactivity indicates the flow. Oxygen-15 only has a 2-minute half-life.



The image to the left shows us a PET scan of a woman with breast cancer.

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