Medical Applications of Particle Physics

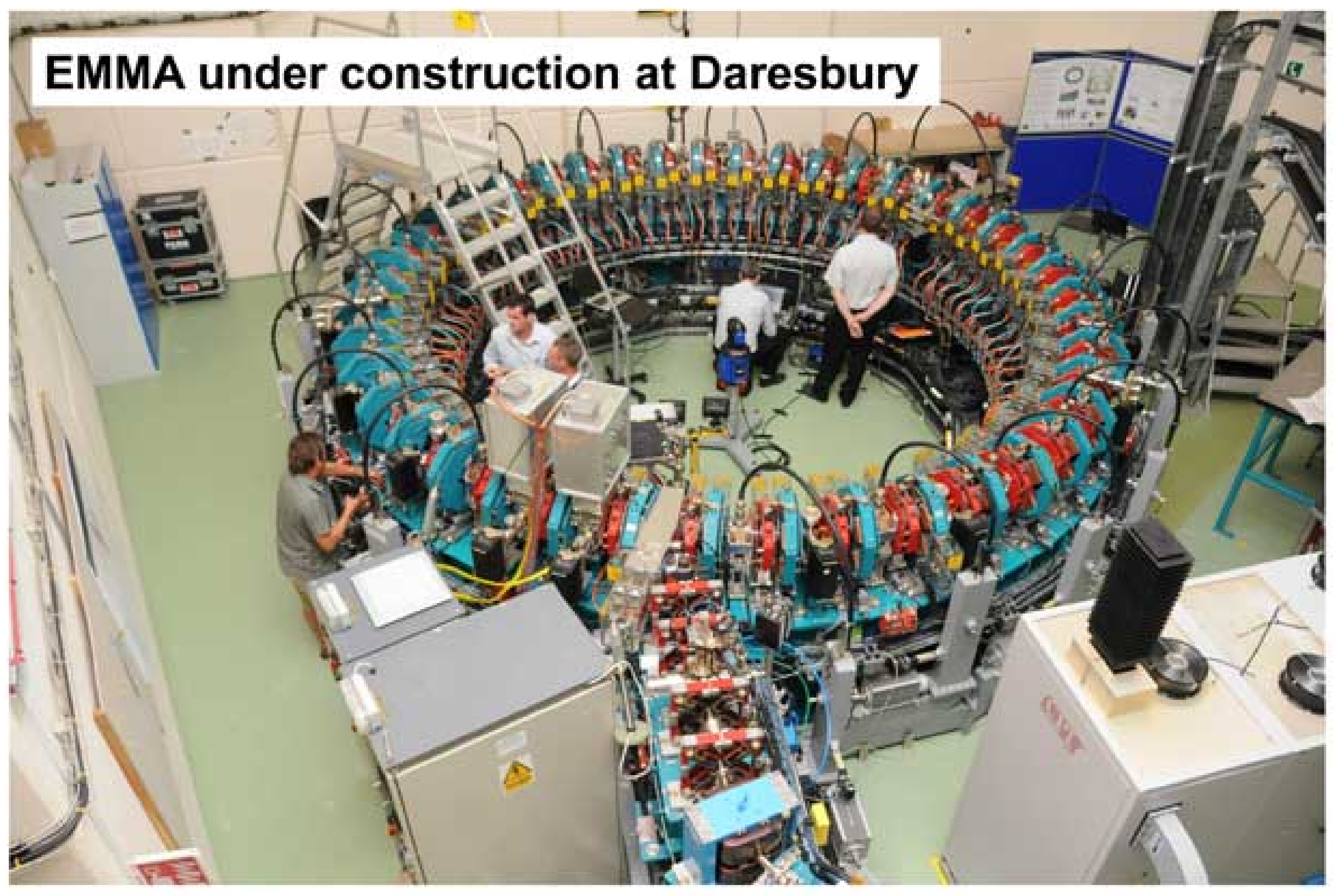
Novel forms of radiotherapy for cancer treatment

Radiotherapy is used as a treatment in around 50% of cancer cases in the UK. Predominantly, it uses beams of x-rays created by a device called a linear accelerator. With modern beam delivery techniques, this works very well. However, in many cases it is possible to do better by using other beams of particles, in particular protons, carbon ions and neutrons.

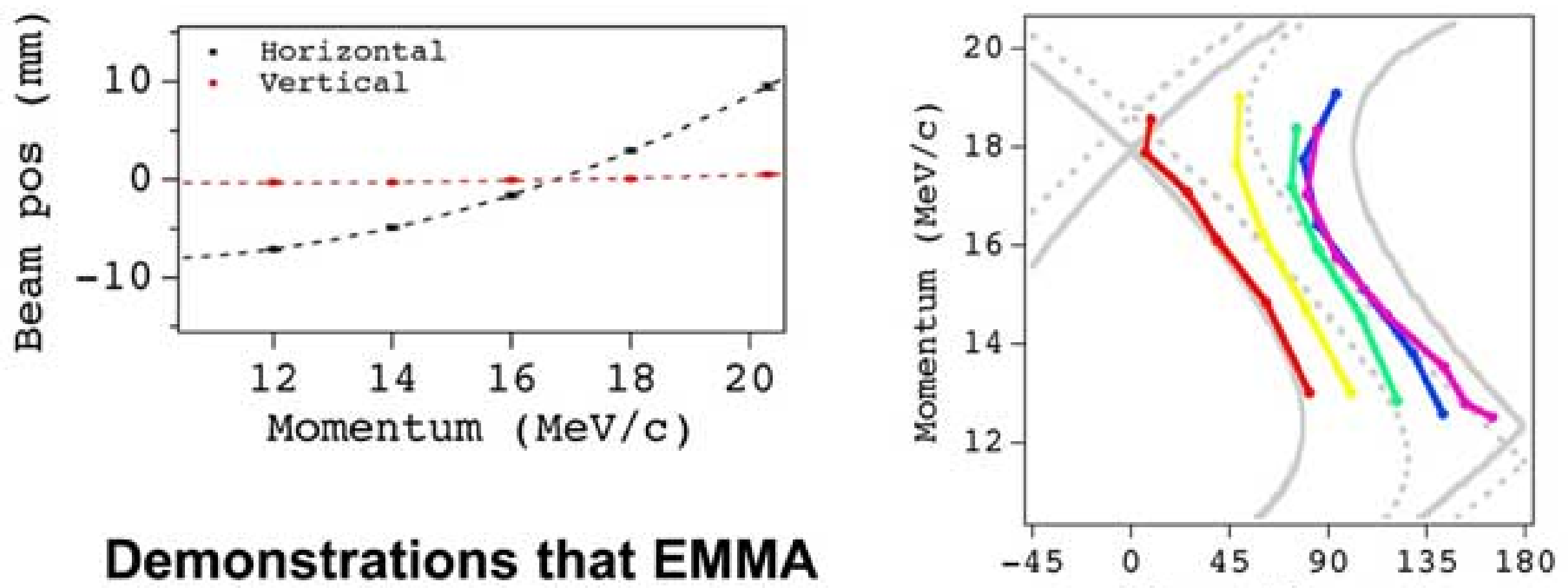
The facilities that deliver the proton beams are significantly larger than for the x-ray beams. Nevertheless, there are now around 40 World-wide, with 2 new facilities under development in the UK. The carbon facilities are much larger again and there are only 6 of these. Two of these are based on an accelerator design done at CERN.

Designs based on a new type of accelerator developed for Particle Physics have now been done. The first of these was called PAMELA, but has been superseded by a second which is less than half the size of the existing carbon accelerators. A prototype, called EMMA, has been built in STFC to demonstrate that this type of accelerator will really work.

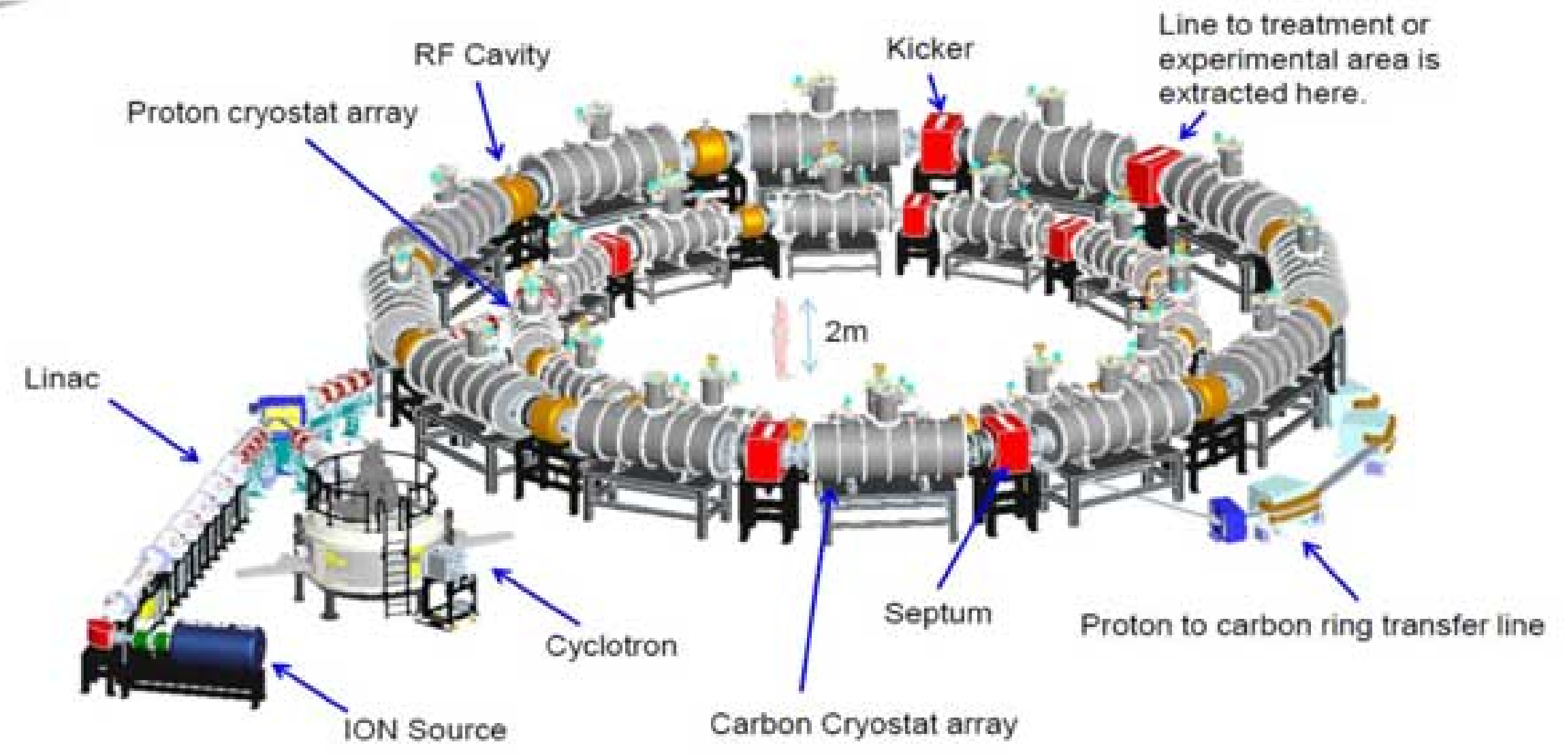
Neutrons are used in a very different way in a process called Boron Neutron Capture Therapy. In this, the cancerous cells are loaded with boron-10. This has a very large probability of absorbing low energy neutrons, thereby destroying the cancer. We are developing a method of making enough neutrons using an accelerator to treat certain cancers.



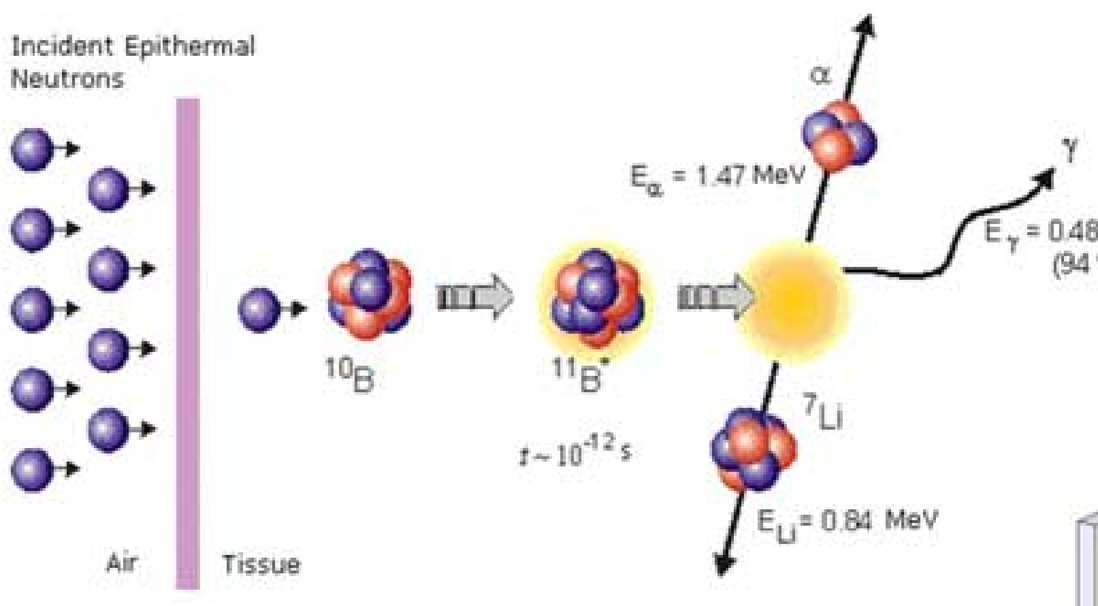
EMMA under construction at Daresbury



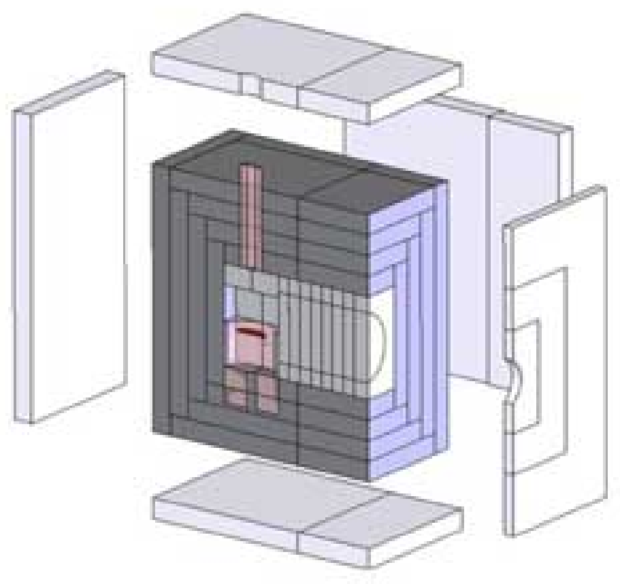
Demonstrations that EMMA works as expected



PAMELA: First attempt at an FFAG Carbon Therapy Facility



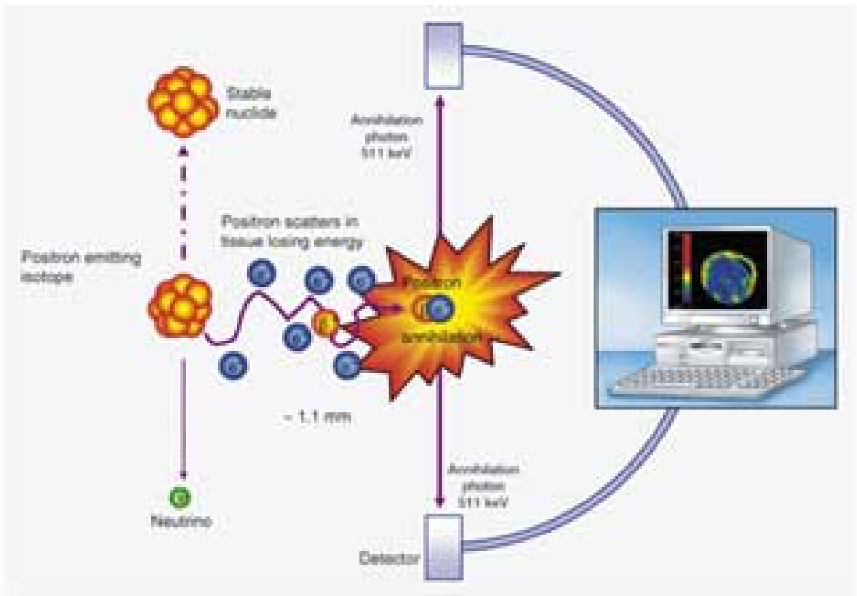
Principle of BNCT



Neutron production for BNCT

Medical imaging and radioisotope production

A PET scanner used by the NHS



The principle of PET

A 30 MeV radioisotope production cyclotron manufactured by IBA of Belgium

A SPECT scanner and a combined SPECT and CT image

Medical imaging is extensively used to seek, diagnose and examine disease within the human body. A number of different techniques are used, including Computed Tomography (CT) scans, Magnetic Resonance Imaging (MRI) and molecular imaging.

In molecular imaging, a radioisotope is used to tag a specific molecule that will accumulate in certain parts of the patient based on their physiology. The location of the molecule can be determined by detecting the products from the decay of the radioisotope. Two basic types of radioisotope are used: those which decay by emitting a single photon and those which decay by emitting a positron. The single photons are detected directly, outside of the body, using a gamma camera or a more sophisticated device called a Single Photon Emission Computed Tomography (SPECT) scanner. In the case of positron decay, the positron immediately annihilates with a nearby electron to produce two photons. These can then be detected in a Positron Emission Tomography (PET) scanner.

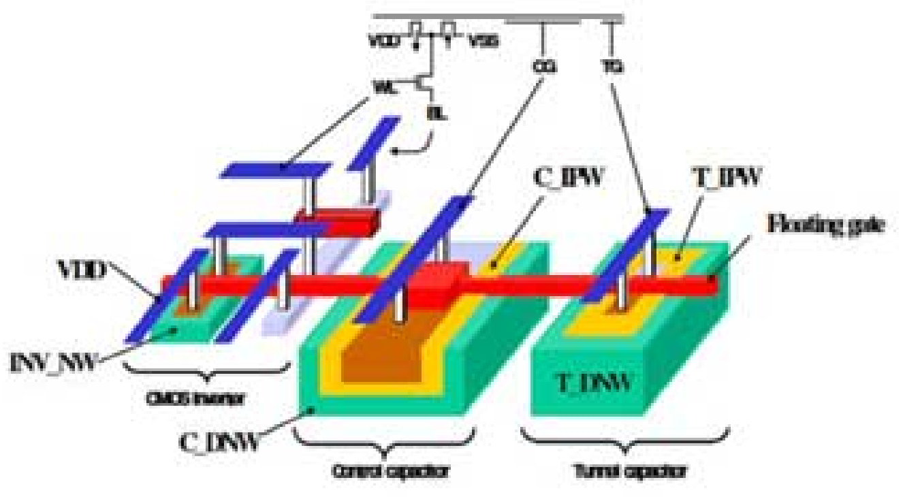
The radioisotopes used have lifetimes from a few minutes up to around a day and they must be manufactured just before use. The main isotopes are ^{99m}Tc and ^{18}F. The first is made from the decay of ^{99}Mo produced in a limited number of nuclear reactors around the World. ^{18}F is made directly by particle accelerators.

There is a strong desire to create a more stable supply of ^{99m}Tc using accelerators and to reduce the size and cost and improve the performance of the existing accelerators to increase the availability of other new radioisotopes. The accelerator technology we are working on looks likely to bring these improvements.

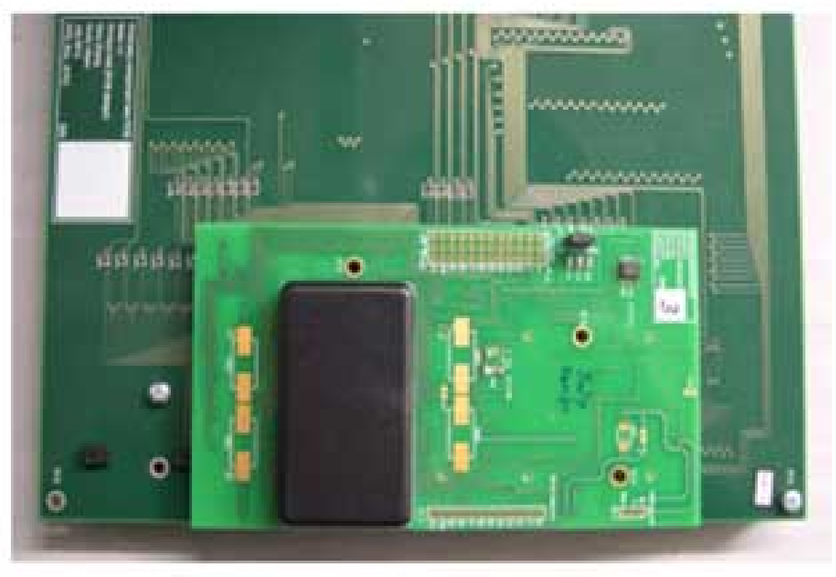
Dosimetry for radiotherapy

Advances in cancer therapy are primarily focused upon treating the tumour while minimising damage to healthy cells, as it is this that leads to the side-effects from the treatment. In radiotherapy, modern techniques in principle allow the accurate delivery of high doses to more targeted areas. However, they suffer from a number of uncertainties. To help get around these, precise measurements of the dose delivered to the patient are required.

The current state of the art uses devices attached to the skin or inserted into cavities. These require the extrapolation of the measured dose to the tumour, which still introduces uncertainties. We are developing miniature devices that can be used internally, close to the tumour, and powered and readout wirelessly to provide the most accurate measurement of the dose actually delivered.

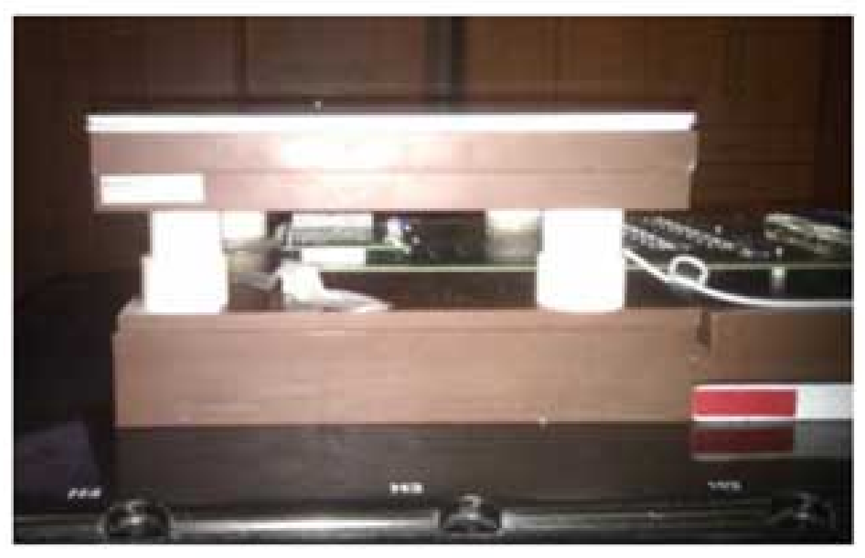


Design of the dosimeter

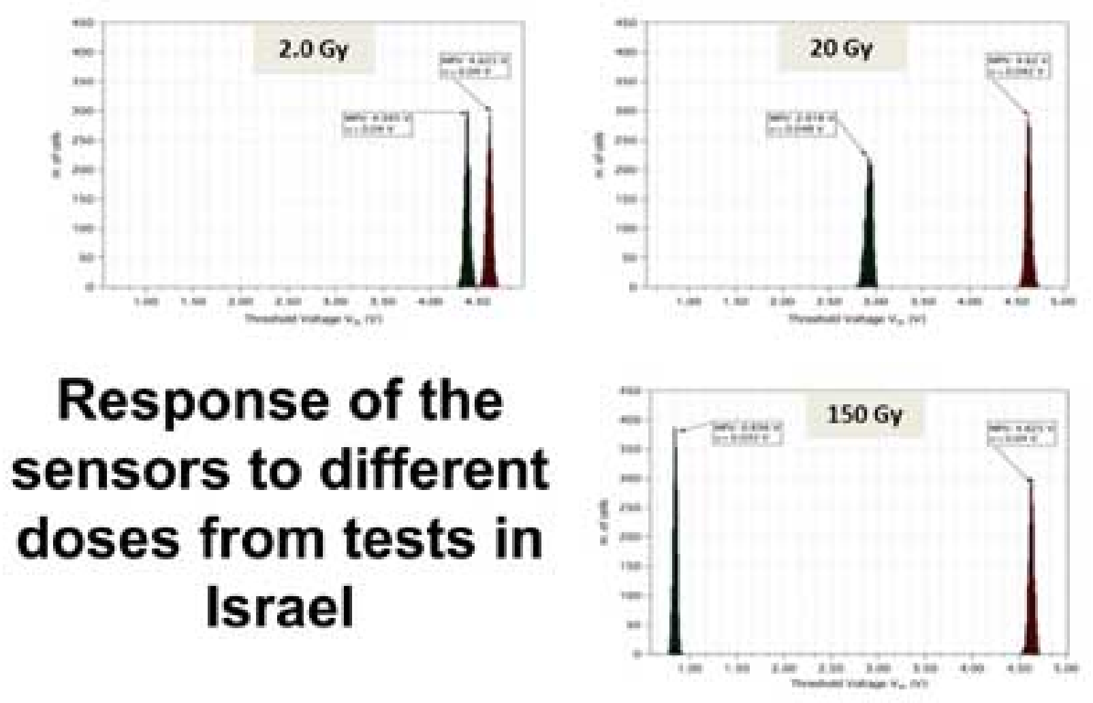


Prototype dosimetry device

Radiotherapy linear accelerator at the Churchill hospital used for the tests



Prototype device ready for testing



Response of the sensors to different doses from tests in Israel