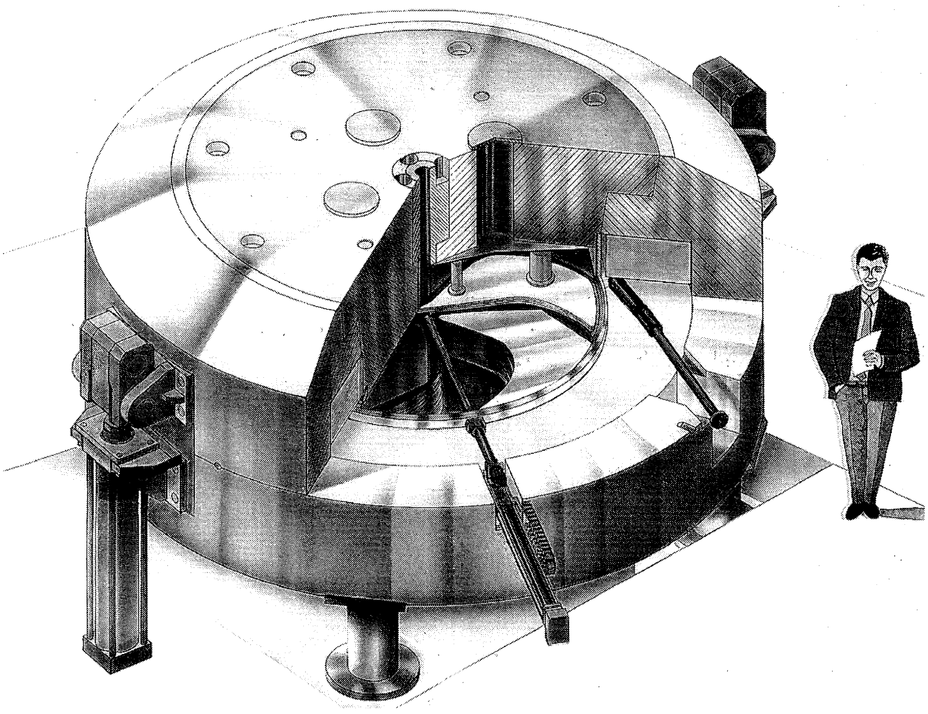
As with other therapy methods, the accelerator is only one component, and it is important that manufacturers are able to offer integrated medical service systems

From Rudi Riesler, University of Washington, Seattle, USA



To be clinically effective, energies of several hundred MeV are required for proton therapy. Pioneering projects had to work with complex, inadequate equipment originally intended for nuclear physics research, but recently a number of specialist organizations and commercial companies have been working on dedicated systems for proton therapy. This is an artist's view of a 235 MeV negative ion cyclotron for cancer therapy. This fixed energy isochronous cyclotron's magnet system is optimized for high magnetic field but is still small enough to be installed in a hospital; it can deliver beams of up to 1.5 microamps for treating certain categories of tumours.

(From IBA, Louvain-la-Neuve, Belgium)

Proton therapy

Ideal radiotherapy deposits a large amount of energy in the tumour volume, and none in the surrounding healthy tissues. Proton therapy comes closer to this goal because of a greater concentration of dose, well defined proton ranges and points of energy release which are precisely known - the 'Bragg peak'.

In the past, the development of clinical proton therapy has been hampered by complexity, size, and cost. To be clinically effective, energies of several hundred MeV are required; these were previously unavailable for hospital installations, and pioneering institutions had to work with complex, inadequate equipment originally intended for nuclear physics research.

Recently a number of specialist organizations and commercial companies have been working on dedicated systems for proton therapy. One, IBA of Belgium, has equipment for in-house hospital operation which encompasses a complete therapy centre, delivered as a turnkey package and incorporating a compact, automated, higher energy cyclotron with isocentric gantries. Their system will be installed at Massachusetts General Hospital, Boston.

The proton therapy system comprises:

- a 235 MeV isochronous cyclotron to deliver beams of up to 1.5 microamps, but with a hardware limitation to restrict the maximum possible dose;
- variable energy beam (235 to 70 MeV) with energy spread and emittance verification;
- a beam transport and switching system to connect the exit of the energy selection system to the entrances of a number of gantries and fixed beamlines. Along the beam transport system, the beam characteristics are monitored with non-interceptive multiwire ionization chambers for automatic tuning;
- gantries fitted with nozzles and beamline elements for beam control; both beam scattering and beam wobbling techniques are available for shaping the beam;
- a control system including an "accelerator control unit" with independent and networked "therapy control stations". Through this network, each of the therapy control systems can also take over the computer-based unit controlling the cyclotron, the beamline and the gantry optics;
- a safety management system, independent of the control system, using hardwired interlocks and independent programmable logic controllers;
- a robotic patient positioning system, with monitoring equipment completely surrounding the patient.

A few companies have proposed other systems, which may differ in concept designs for the gantries, nozzles, patient positioners or safety and control systems. The proton therapy system at the Loma Linda University Medical Centre, California, is based on a proton synchrotron and was built by the Fermi National Accelerator Laboratory, the Loma Linda University, the Lawrence Berkeley Laboratory and Science Applications International Corporation (SAIC) of San Diego.

From Y. Jongen, IBA S.A., Louvain, Belgium

Industrial applications

As well as providing proton beams for cancer treatment, accelerators have also been used with particles with higher linear energy transfer (LET). Pioneer work with pions has been carried out at the accelerators at TRIUMF (Vancouver), the Swiss Paul Scherrer Institute and at Los Alamos. Therapy using ion beams is considered promising. The first clinical trials were at Berkeley, and an active programme has started at the GSI heavy ion Laboratory, Darmstadt, using ions up to 300 MeV per nucleon.

Confidence in ion therapy is so high that a $326 million dedicated synchrotron facility - HIMAC, the Heavy Ion Medical Accelerator in Chiba - has recently been completed near Tokyo. Ions from helium to argon can be accelerated up to 800 MeV per nucleon for difficult cancers, such as those in the head or neck, and preliminary work with carbon ions has shrunk tumours.

High capital and operating costs will inevitably restrict the availability of this therapy.

Interest in proton therapy is particularly high in the treatment of ocular melanoma where there is no alternative treatment, and success rates of up to 90% have been reported.

In manufacturing industry, beams from particle accelerators can be used for a variety of purposes:

- to improve the quality or finish of a product, as in the sterilization of medical equipment;
- to alter the material composition, as in ion implantation;
- to manufacture components, as in silicon wafer production;
- to provide information about manufacturing processes, such as wear studies of materials.

These industrial applications frequently require small but well engineered accelerator systems giving reliable performance.

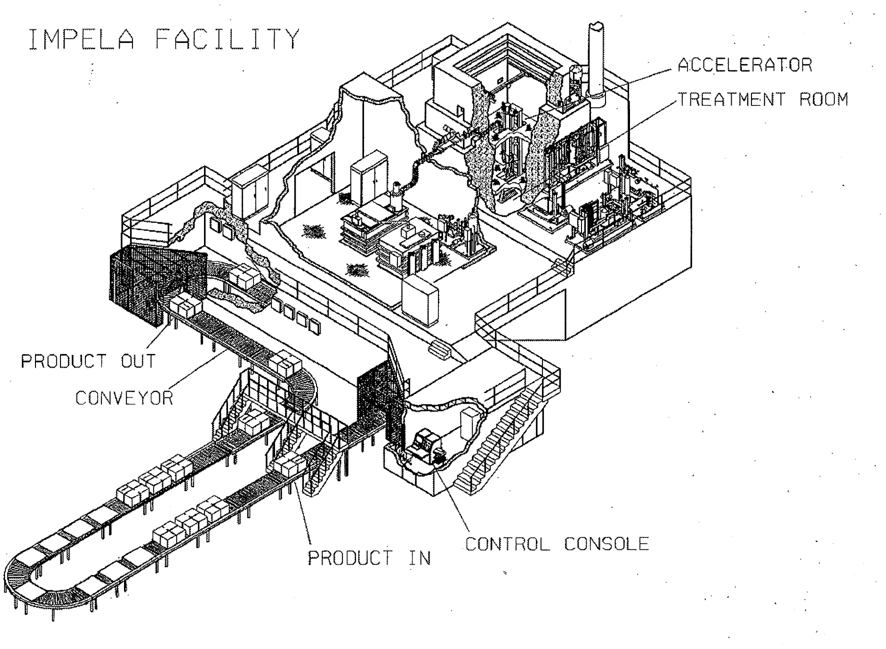
Industrial irradiation

Production lines for rubber gloves would not appear to have much in common with particle physics laboratories, but they both use accelerators. Electron beam irradiation is often used in industry to improve the quality of manufactured goods or to reduce production cost. Products range from computer disks, shrink packaging, tyres, cables, and plastics to hot water pipes. Some products, such as medical goods, cosmetics and certain foodstuffs, are sterilized in this way.

In electron beam irradiation, electrons penetrate materials creating showers of low energy electrons. After many collisions these electrons have the correct energy to create chemically active sites. They may either break molecular bonds or activate a site which promotes a new chemical linkage.

This industrial irradiation can be exploited in three ways: breaking down a biological molecule usually renders it useless and kills the organism; breaking an organic molecule can change its toxicity or function; and crosslinking a polymer can strengthen it.

In addition to traditional gamma



In this schematic of an industrial irradiation plant, a conveyor mechanism moves large containers through the radiation from an electron beam accelerator, The container contents are processed or sterilized.
(Photos AEC Accelerators, Kanata, Canada)