

Therapy

As life expectancy steadily improves, the incidence of cancer also increases as the population ages. Up to 50% of cancer patients undergo radiotherapy - a form of protracted biological surgery by selective sterilization of malignant cells.

X-ray radiotherapy

The most common form of radiotherapy is X-ray therapy, where a beam of photons or their parent electrons break down hydrogen bonds within the body's cells and remove certain DNA information necessary for cell multiplication. This process can eradicate malignant cells leading to complete recovery, to the remission of some cancers, or at least to a degree of pain relief.

The radiotherapy instrument is usually an electron linac, and the electrons are used either directly in 'electrotherapy' for some 10% of patients, or the electrons bombard a conversion target creating a broad beam of high energy photons or 'penetration X-rays'.

The simplest machine consists of several accelerating sections at around 3 GHz, accelerating electrons to 6 MeV; a cooled tungsten target is used to produce a 4 Gray/min X-ray field which can be collimated into a rectangular shape at the patient position. This tiny linac is mounted inside a rotating isocentric gantry above the patient who must remain perfectly still. Several convergent beams can also be used to increase the delivered dose.

More sophisticated accelerators operate at up to 18 MeV to increase

penetration depths and decrease skin exposure. Alternatively, electrotherapy can be used with different energies for lower and variable penetration depths - approximately 0.5 cm per MeV. In this way surface tissue may be treated without affecting deeper and more critical anatomical regions.

This type of linac, 1 to 2 metres long, is mounted parallel to the patient with a bending magnet to direct the beam to the radiotherapy system, which includes the target, thick movable collimator jaws, a beam field equalizer, dose rate and optical field simulation and energy controls.

There are over 2000 accelerator-based X-ray treatment units worldwide. Western countries have up to two units per million population, whereas in developing countries such as Bangladesh, the density is only one per 100 million.

Several major medical equipment companies manufacture X-ray therapy systems - General Electric, Mitsubishi, Philips, Siemens and Varian. In this crowded marketplace where the useful lifespan of machines exceeds 10 years, purchase prices are less than \$1 million per unit.

X-ray therapy remains the most common and cheapest form of accelerator therapy. Ongoing technical developments aim to achieve better matching of dose delivery to tumour volume; multileaf collimators shape the X-ray field to the biomedical target, and portal imaging from behind the patient can control positioning and dose delivery.

Combined compact X-ray sources are being developed with both treatment and realtime dosimetry control, incorporating CT scanning into one single device. Integrated diagnosis and therapy is the direction

for R&D investment, and this should lead to smaller hospital space requirements, lower operating costs, and elimination of external data handling, resulting in simpler and more cost effective clinical procedures.

From D Tronc, General Electric Medical Systems, Paris

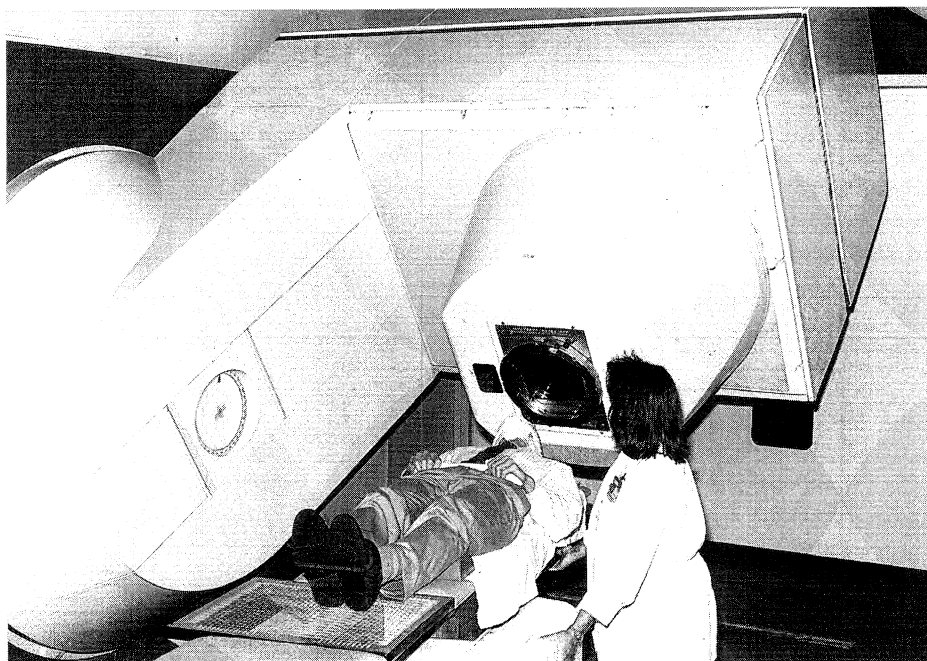
Neutron therapy

Standard radiotherapy uses X-rays or electrons which have low LET (linear energy transfer); in contrast, particles such as neutrons with high LET have different radiobiological responses. In the late 1960s, clinical trials by Mary Catterall at the Hammersmith Hospital in London indicated that fast neutron radiation had clinical advantages for certain malignant tumours.

Following these early clinical trials, several cyclotron facilities were built in the 1980s for fast neutron therapy, for example at the University of Washington, Seattle, and at UCLA. Most of these newer machines use extracted cyclotron proton beams in the range 42 to 66 MeV with beam intensities of 15 to 60 microamps. The proton beams are transported to dedicated therapy rooms, where neutrons are produced from beryllium targets.

Second-generation clinical trials showed that accurate neutron beam delivery to the tumour site is more critical than for photon therapy. In order to achieve precise beam geometries, the extracted proton beams have to be transported through a gantry which can rotate around the patient and deliver beams from any angle; also the neutron beam outline ("field shape") must be

In the late 1960s, clinical trials showed that fast neutron radiation had clinical advantages for the treatment of certain cancers. In modern neutron therapy centres, protons from a cyclotron bombard a beryllium target to generate a collimated beam of neutrons. (Photo University of Washington, Seattle)



adjusted to extremely irregular shapes using a flexible collimation system.

A therapy procedure has to be appropriately organized, with physicians, radiotherapists, nurses, medical physicists and other staff in attendance; other specialized equipment, such as CT or MRI

scanners and radiation simulators must be made available. Neutron therapy is usually performed only in radiation oncology departments of major medical centres.

However neutron therapy is much more expensive than conventional photon or electron therapy. Often the cyclotron operation has to be shared

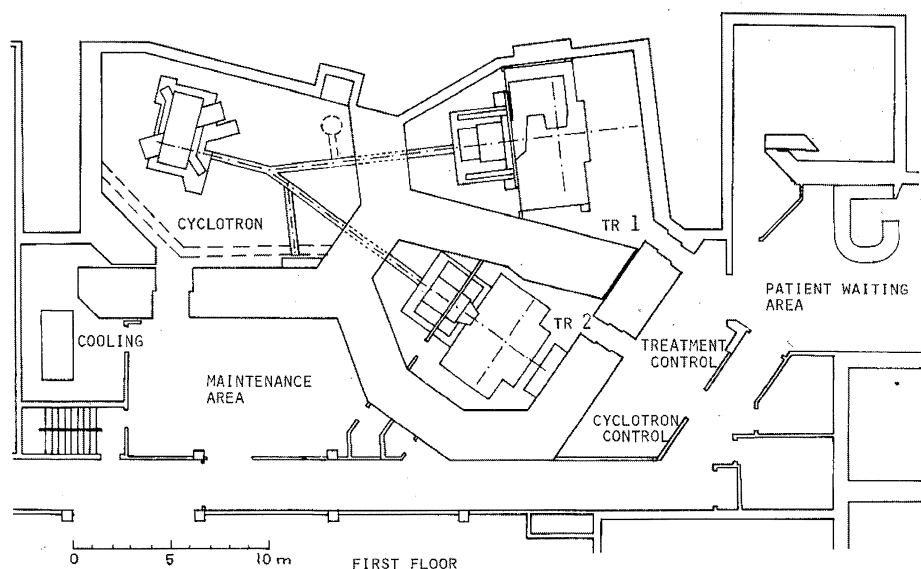
with other users, particularly since beam-time for an actual therapy run is only a few minutes but involves considerable set-up periods between runs; radioisotope or PET production may be performed concurrently with neutron therapy. At present there are about a dozen neutron therapy facilities worldwide, but due to limitations of fixed beams, low energies or low intensities, only a few of these can deliver the precision beams required.

Clinical results with neutron therapy are very encouraging for certain specific tumour sites; for salivary gland tumours neutron therapy is considered the treatment of choice. Other promising areas of clinical research are advanced adenocarcinoma of the prostate, some head and neck tumours, some lung cancers and sarcomas of bone and soft tissue.

For future neutron therapy systems there is a choice between two basic designs:

- a small cyclotron with internal target, mounted directly on the therapy gantry in a very compact machine dedicated to neutron therapy (such as that developed for Harper Hospital in Detroit using a superconducting deuteron cyclotron at 48.5 MeV); or
- a cyclotron in a separate vault with a beamline feeding one or more therapy rooms with rotating isocentric gantries. This type of facility has been built commercially, e.g. a 60 MeV system by Scanditronix.

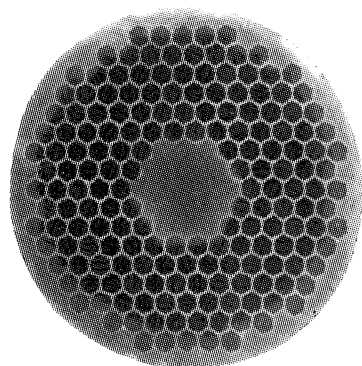
Like X-ray therapy, future developments in this field depend on reducing the cost of therapy systems and providing total systems suitable for hospital environments with limited technical and engineering resources.



Layout of a neutron therapy centre

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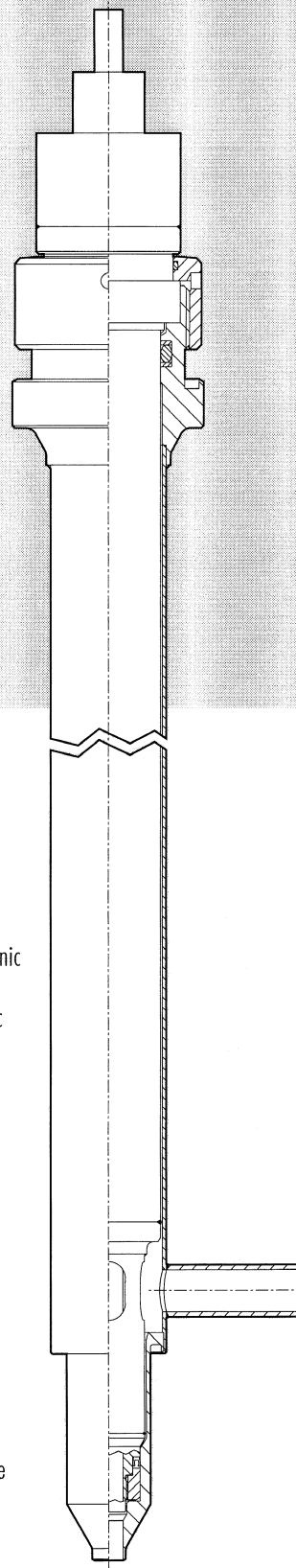
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To be clinically effective, energies of several hundred MeV are required for proton therapy. Pioneering projects had to work with complex, inadequate equipment originally intended for nuclear physics research, but recently a number of specialist organizations 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)

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

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

