Accelerator Based Neutron Beams for Radiation Therapy

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The main objective of any therapy is to destroy the tumour affected tissues without causing any harm to the surrounding healthy tissues. Among the methods employed, radiation therapy is believed to be least invasive and less likely to impair the Patient's Quality of Life (QOL) after the treatment. Various types of radiation therapies including electrons, X-rays, gamma rays, neutrons, light ions, heavy ions etc. are being termed as viable. But the techniques based on electrons, X rays and γ rays (Cobalt source) have so far acquired the status of acceptability and are commonly in use.

An extensive study carried out over a decade or two have brought out clearly the merits/demerits associated with different types of radiation therapies. It reveals that although electrons and photons (γ & X-rays) have acquired a status of acceptability but are not very useful in treating the deep-seated tumours. It is specially true in the case of electrons. Moreover, because of excessive scattering, these beams are not sufficiently controllable to conform to the treatment volumes. In addition, due to the exponential nature of dose distribution, the healthy tissues in front and behind the affected tumour, get severely damaged, a feature which is highly undesirable.

On the other hand, protons and heavy ions lose the greater part of their energy at the end of their trajectories, i.e. in the "Bragg-peak". The penetration is a function of energy and tissue density. The tissues behind the end of the trajectory remain largely unaffected and the ones in front of the tumour, receive very little dose. In addition, the high rigidity of the proton and heavy ions keep them in almost straight path, thus providing a good localization of the dose. This is in total contrast to the treatment with electron / x rays / γ rays

In case of neutrons, it is the recoils from elastic collisions and nuclear disintegration products, which contribute to the dose. These recoils are responsible for a high energy transfer to the biologically active molecules and destroy them in turn. High Relative Biological Effectiveness (RBE), Linear Energy Transfer (LET) characteristics and comparatively good Dose Distribution Advantage (DDA), are the main attractive feature of the neutron therapy.

A comparison of the overall effectiveness of radiation therapies is depicted in figure 1. As is evident, protons, X rays or γ rays are not as effective as the neutrons or heavy ions. Among the heavy ions too, Neon and ions, heavier than that are only able to compete with neutrons.

Although heavy ion therapy is excellent but requires beams with energies as high as 500 to 600 MeV per nucleon asking for big accelerators and consequently huge investments. Whereas for neutron therapy, low energy beams of proton or deuteron suffice, making it highly cost effective.

Neutron Therapy

The neutron therapy is presently realized in two versions: Neutron Capture Therapy (NCT) and the Fast Neutron Therapy (FNT). In Neutron Capture Therapy, the isotope with large absorption cross-section for thermal/epithermal neutrons, is introduced into the body mainly through the blood. The Boron Neutron Cap-

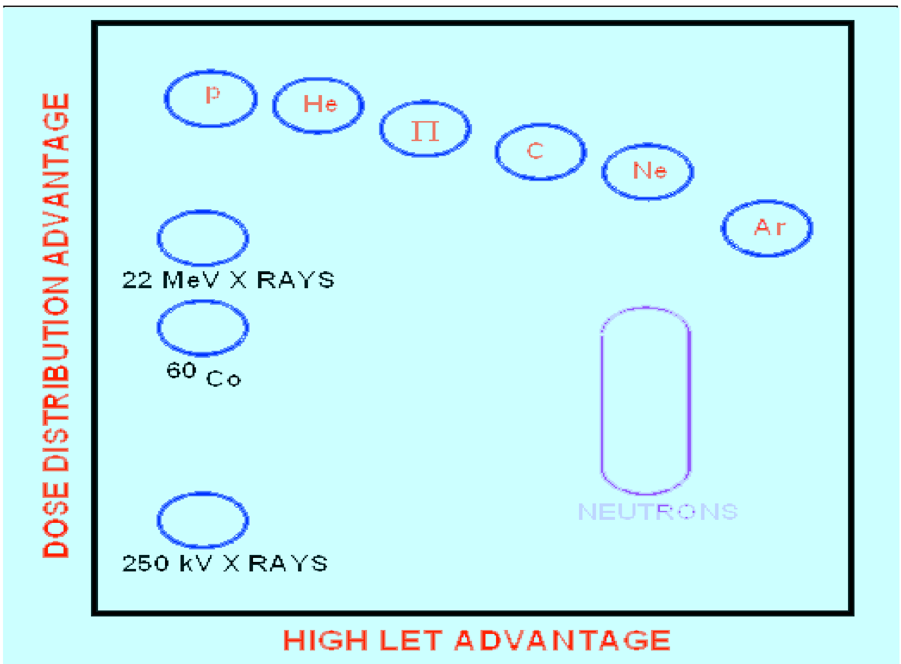


Fig.1:

ture Therapy (BNCT) belongs to this category. The boron-containing compounds enriched in isotope ^{10}B is introduced in the tumour cell with a concentration of ~ 30 mg/g. The surrounding normal tissue cells generally have the concentration as ~ 10 mg/g. The thermalised neutrons induce charge particles in the affected cell with a total kinetic energy of ~ 2.4 MeV. This has a range of ~ 10 mm, almost equal to the size of the tumour cell. As a result, the cell comprising ^{10}B gets effectively destroyed. Thus in BNCT, neutrons "find" out the tumour cells and destroy them. This therapy is being investigated for several types of cancers including malignant melanoma and glioblastoma multiforme, a highly malignant and therapeutically persistent type of tumour.

The Fast Neutron Therapy (FNT) uses fast neutron with high penetrability. Neutron beams of about 14 to 15 MeV serve the purpose. The main therapeutical effect is achieved due to the recoiling protons and heavier nuclei. Malignant tumours of the head, neck, dairy gland, osteogeneous sarcomas are treated with fast neutrons.

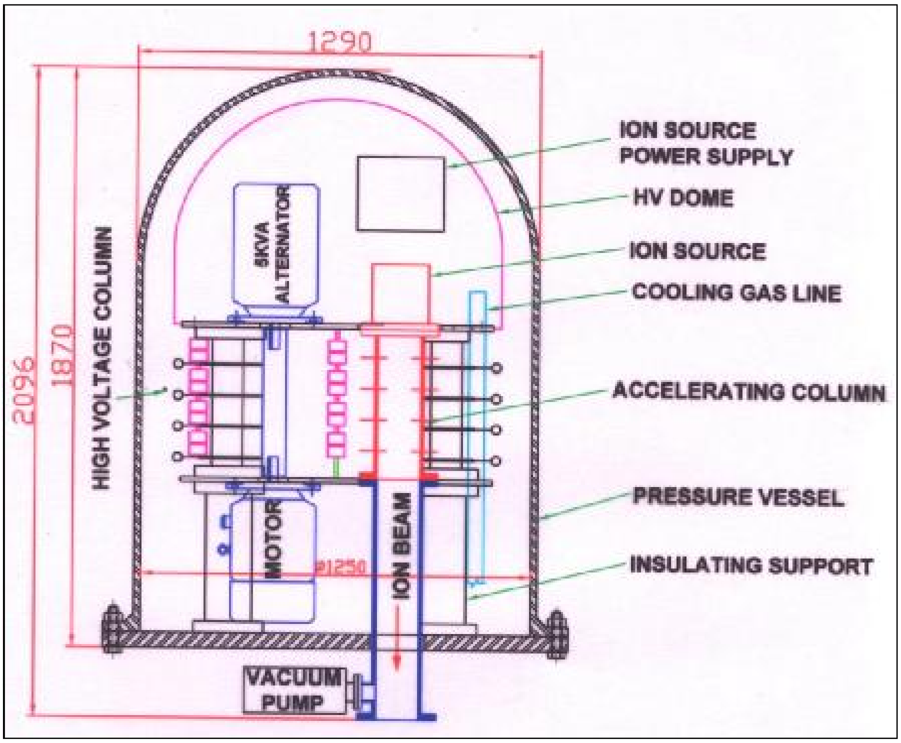
For BNCT or FNT, neutrons can be generated through any of the well known reactions: D(d,n) ^3He, T(d,n) ^4He, ^7Be(p, n) ^9B, ^7Li(p, n) ^7Be. For FNT, the rough estimates ask for a dose of about 20 rads/minute at the location of the tumour. Whereas, for BNCT, one requires epithermal neutrons ranging from 1 eV to a few tens of keV. For an absorbed dose of 20 Gy/min with a ^{10}B concentration of 30 mg/g in the cell, the neutron flux requirement is about 10^{10} cm^{-2} s^{-1}. Depending upon the time of irradiation and ^{10}B concentration, this value can go up or down. The accelerators having energy anywhere from 0.25 MeV deuteron to 50 MeV proton can be used for FNT and BCNT.

Accelerators for Neutron Therapy

Keeping the energy and hence the size of the accelerator in mind, one would like to go for as low in energy as possible. This in turn makes the system highly cost effective. The neutrons produced through the reaction, T(d, n) ^4He, are ideal. Firstly because the energy required is only about 0.25 MeV. At this energy, 10^8 neutrons / µA / sec. can be generated. Thus, with a deuteron beam of 10 mA, 10^{12} neutron / sec. will be easily realised. This is sufficient to produce the required dose. Secondly, the 14 MeV neutrons thus generated, can be used directly for FNT, after they are collimated. For BCNT also the same reaction can be employed. However in this case, the neutrons will have to be first degraded to the required epithermal energies and then collimated.

A scheme of the accelerator conceived on this basis is shown in figure 2.

Therefore, the accelerator will consist of a high current deuteron ion source followed by a post- accelerator and a Tritium target. A Duoplasmatron or an ECR source can easily meet this requirement. Although a DC or an RF accelerator can be employed to accelerate deuterons to 250 keV but DC accelerator is preferred because it can meet the needed energy stability of 0.1 %.



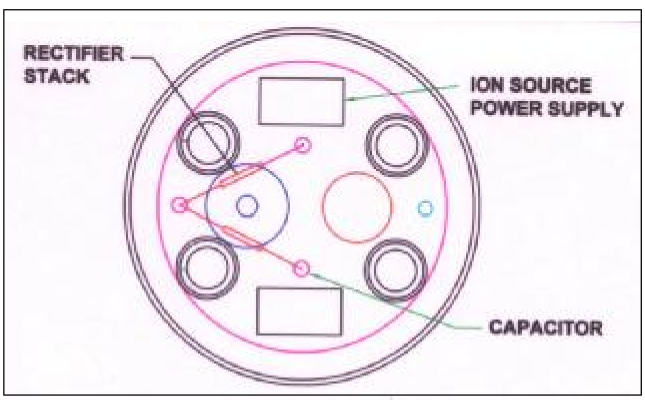


Fig. 2: A Schematic of the 0.250 MeV Accelerator for Neutron Therapy

Fig. 3: High Current Duoplasmatron Ion Source

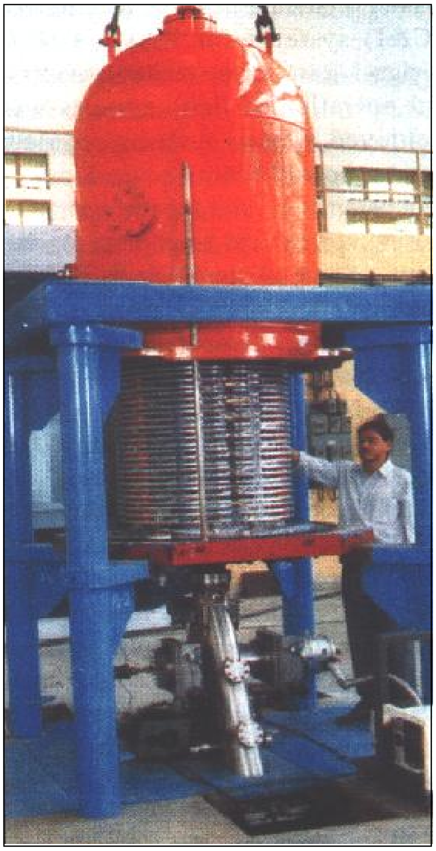


Fig 4: 500 kV DC Accelerator

Because of the low energy, the accelerator can be realised in a small space of about 2 m by 1.5 m only. However, the space needed for technical utilities, thermalisation, collimation and clinical facility, will be extra.

BARC has the required Expertise

The technologies needed for this accelerator for FNT/BCNT are available in BARC. The Centre has the expertise of designing and building high current ion sources. One such source, the duoplasmatron, was commissioned in 1992. It was tested up to a proton beam current of 12 mA. Duplicating this source or even using this itself for deuterons, will serve the purpose. At present this source is going through various types of beam quality tests. APPD/BARC has also designed & built indigenously, a 500 kV, DC accelerators (figure 4).

The accelerator is located at BRIT, Vashi, Navi Mumbai and is being used for various industrial applications. Designing and building a 250 kV terminal for neutron therapy will relatively be an easier task. The related technologies of thermalising and collimating the neutrons also exist in BARC.

Thus, realizing an indigenous Neutron Therapy Facility, at least on an experimental basis, is within the reach of BARC.

Conclusions

The international trends clearly indicate that in the coming decade radiation therapy will go through a revolutionary change. The therapies based on electrons, X rays or ã rays will slowly be replaced either by neutron or ion beams. Already Japan, Korea, Europe, Russia and quite a few places in USA have opted for neutron therapy. More and more countries are following suit.

Workshop on Hadron Physics

The Institute of Physics, Bhubaneswar, in collaboration with the Saha Institute of Nuclear Physics, Kolkata, is going to hold a workshop on Hadron Physics March 7-17th, 2005 during at Puri, Orissa. The workshop is being organized to provide a platform for physicists working in the area of strong interaction at GeV energies. Discussions on possible nuclear physics applications of the forthcoming electron accelerator facility (INDUS II) at Indore, India will also be initiated during the workshop.

Following topics will be covered:

a) Hadrons in nuclear medium

b) Photo and electro production of hadrons

c) Models of hadrons

d) Electron accelerators (INDUS II) for nuclear physics

e) Hadronic excitations

For further deatails website http://www.iopb.res.in may be visited.