FAST NEUTRON BEAMS FOR THERAPY: THE CURRENT STATUS AND ROOM FOR IMPROVEMENT?

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The current status of fast neutron production for therapy is discussed in the light of decreasing interest in the neutron therapy programme around the world. Some suggestions are made and problems highlighted where the nuclear physics and the accelerator communities can contribute significantly in order to examine whether the physical characteristics of the neutron beams can be further improved. It is pointed out that as enough is known about the radiological aspects of fast neutrons, only further improvement in their physical characteristics could possibly rejuvenate the flagging neutron therapy programme around the world.

1 Introduction

Looking at the radiotherapy community around the world and discussing the matter with leading medical/physical scientists, it is painfully obvious that the neutron therapy programme is for from being healthy. About 10–15 years ago there were more than a dozen centres around the world engaged in neutron therapy activities. More centres were being planned. However, now there are only less than half as many left in this field. Centre after centre unfortunately shut down and closed its doors for neutron therapy for good. Some notable examples are the Hammersmith Hospital in London, M.D. Anderson Hospital in Houston, the Royal Infirmary and the University of Edinburgh, the German Cancer Research centre in Heidelberg, and Clatterbridge Hospital in Liverpool. Some other, such as the University Klinikum in Essen and the Eppendorf Hospital in Hamburg, seem to be going down the same route if they have not already quit this field.

In almost all the cases, with the exception of Clatterbridge, the failure of the programme can probably be attributed to the inadequacy in the physical characteristics of the neutron beams produced by the available cyclotrons. However the closure of the Clatterbridge programme has also been due to less than satisfactory results (late reaction, complexities, skin reaction etc.) obtained with neutron treatment. After all, the Clatterbridge neutron beam was state-of-art and similar to the beams in use at the National Accelerator Centre (NAC) in South Africa, Louvain-la-Neuve, Fermilab and Nice which are still optimistic about the future and going ahead with neutron therapy. Similar negative vibes also came after the programme at M.D. Anderson Hospital ceased functioning.

The question now arises that whether it is the inadequacy in the physical characteristics of the neutron beam (broad spectrum rather than clean mono-energetic type similar to the D-T neutrons; poor penetrations with significant doses to skin and overlying tissues, etc.) which require further improvement or it is the inherent property of the neutron which makes it no better, or even worse that the photon for cancer treatment, irrespective of neutrons apparent advantages in the radiobiological effectiveness (RBE) and the oxygen enhancement ratio (OER). In an attempt to answer this question we are investigating whether or not it is possible to further improve the neutron beam, in this paper.

2 Neutron Production Methods

For the last few years it has become fairly customary to use the p(66 MeV)–p(40–45 MeV) proton beam on a Be-target to produce therapeutic neutron beams. This means that the Be-target is so thick as to reduce the energy of 66 MeV protons to 40–45 MeV. Of course, one has to have large enough cyclotrons to produce 66 MeV protons. Some notable examples of such institutions are NAC, Louvain-la-Neuve, Fermilab, Clatterbridge and Nice which has only recently started a neutron therapy programme. Some other institutions, such as Harper Hospital in Detroit and the University of Washington in Seattle use 30–5 MeV deuterons on Be-target to produce neutron beams for their rather active therapy programme. The neutron beam produced by p(66 MeV)–p(40–45 MeV) protons on Be-target has similar depth-dose characteristics as the 8 MeV Bremsstrahlung (X-rays) but less pronounced skin sparing properties.[1] The neutron spectrum is rather broad with a large number of low energy neutrons, although efforts have been made to harden the spectrum and minimise the low energy component by the use of different filters.[2] However, the resulting spectrum still remains rather broad (some tens of MeV), which means excessive radiation doses to healthy tissue overlying the tumour site. This, along with relative lack of skin sparing, could be one of the main reasons for late reactions and complications with neutrons.

3 Improving the Neutron Beam: is it possible? Some Suggestions

Ever since Cohen et al.[3] suggested the use of p(66 MeV)–p(45 MeV) protons on a Be-target to produce fast neutron beams and demonstrated that their depth-dose characteristics were similar to that of 8 MeV Bremsstrahlung (X-rays), other institutions having access to similar proton energy machines adapted the same mode of neutron production. It seems that no major attempts were made to further improve the neutron beam and the neutron therapy community appeared satisfied with its properties. It would have been acceptable if all was well with the neutron therapy programme. However, due to late adverse reactions from neutrons, less than expected therapeutic gains, and discontinuation of neutron therapy programme at M.D. Anderson, Clatterbridge, Hammersmith Hospitals and other institutions, the future of this sort of treatment is far from rosy.

It is to be examined now if it is at all possible to improve upon the neutron beam produced by p(66 MeV)–p(40–45 MeV) protons and Be. Perhaps it might be possible to produce a much "cleaner" neutron spectrum by the interaction of protons and deuterons with nuclei other than Be. This, we believe, is an area where the nuclear physicists and accelerator scientists can really make substantial contributions. Our suggestions in this directions are:

i) To measure and/or calculate neutron spectra from nuclear reactions induced by protons (60–100 MeV) and deuterons (30–50 MeV) on different selected light nuclei, especially those which have not yet been thoroughly examined.

ii) To determine the neutron yields and spectra of (d,np) break-up neutrons on heavy nuclei when bombarded with deuterons from 30–50 MeV. It is to be examined whether the neutron yield from the deuteron break-up reaction (d,np) is large enough to mask the neutron from the (d,xn) reactions having much greater neutron energies. If it is so, one might be able to obtain a "cleaner" spectrum of the break-up neutrons and still have adequate average energy and thus the penetration.

iii) After selecting the most suitable nuclear reaction in (i) & (ii), to measure experimentally and/or by calculations (Monte Carlo), the effect of different target thicknesses and the backing materials on the yields and spectra of neutrons.

iv) To examine the effect of filters of light as well as heavy elements of different thicknesses, and their combinations, on the neutron spectra from the selected nuclear reactions (determined in (i) & (ii)). This is in order to study the beam hardening ("cleaner" neutron spectra with the maximum amount of low energy neutrons removed) properties of various filters and their combinations. We believe these calculations can easily be conducted with Monte Carlo methods and different transport codes. We demonstrated some years ago that the transport codes though originally developed for neutron transmission through heavy elements are also valid for lighter elements.[4]

If on the basis of these suggestions it is possible to produce a better ("cleaner" more skin-and-overlying tissue-sparing, etc.) neutron beam than the p(66 MeV)–p(40–45 MeV) on Be, it is quite possible that the flagging neutron therapy programme around the world could be rejuvenated. On the other hand, if it turns out that it is not possible to improve considerably upon the existing neutron beam, the future of neutron therapy looks bleak. Even fewer centre around the world would dare to go into this form of treatment or continue this type of work.

This is a real challenge for the nuclear physics and accelerator scientists to carry out the investigations (i)–(iv) as suggested, in order to provide a better neutron beam for therapy. Generally such sophisticated measurements and calculations are too complex and difficult for the majority of hospital/medical physicists who are normally responsible for the production and dosimetry of therapy neutron beams. Although there are centres, such as NAC, etc., where good nuclear physics support should be available.

It is apparent from the literature that, with few exceptions, most nuclear physicists capable of conducting such measurements and calculations do not find such activities exciting enough and therefore do not get involved. About 30 years ago when the neutron therapy was being revived the situation was similar. The only neutron producing method being used as bombardment of thick Be-target with 14–16 MeV deuterons.

The resultant neutron beam with an average energy of around 7 MeV, was obviously inadequate but nothing tangible was being done to improve it. We suggested in the late 60's the use of other light elements for neutron production and demonstrated by calculations and measurements that deuterium gas and even heavy water would produce more penetrant neutron beams than a Be-target when bombarded with deuterons.[5-8] Later on we were the first to suggests the use of protons, rather than deuterons, for producing therapy neutron from light elements.[9] Our suggestions were soon taken up by many laboratories around the world and by late 70's proton induced reactions in lighter elements, especially Be, had become the preferred neutron source.

The decline in the pure nuclear physics programme in the USA in the late 60's and 70's also saw many good nuclear physicists entering the field of medical/radiation physics, which was very beneficial for the neutron therapy programme.

Many neutron spectra, for thick and semi-thick target of light nuclei were accurately measured for the first time.

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