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 far 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 deuteron 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. The neutron spectrum is rather broad with a large number of low energy neutrons, although
efforts have been made to harden the spectrum and mini-
mise the low energy component by the use of different 
filters.3 However, the resulting spectrum still remains 
rather broad (some tens of MeV), which means exces-
sive radiation doses to healthy tissue overlying the tu-
mour 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 ac-
cess to similar proton energy machines adapted the same 
mode of neutron production. It seems that no major 

ttempts 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. How-
ever, due to late adverse reactions from neutrons, less 
than expected therapeutic gains, and discontinuation of 
neutron therapy programme at M.D. Anderson, Clatter-
bridge, 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 sugges-
tions 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 
bombed 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 be-
lieve 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 flag-
ning 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 meas-
urements 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 conduct-
ing such measurements and calculations do not find such 
activities exciting enough and therefore do not get in-
volved. 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.\(^5\) Later on we were the first to suggest 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.

References