PRODUCTION AND POTENTIAL IMPLICATIONS OF SECONDARY NEUTRONS WITHIN PATIENTS UNDERGOING THERAPY WITH HADRONS

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Abstract

From experimental nuclear data, existing in the literature, it has been shown that a significant number of secondary neutrons are produced in patients undergoing radiotherapy with hadrons. These large numbers of neutrons, against which no part or organ of the patients can be shielded, have theoretical potential "to induce new primary cancers and/or cause other detrimental side effects, such as life shortening, malignant cell transformation, chromosome aberration and genetic effects or genome damage" [1]. It is therefore strongly suggested that this matter of secondary neutron production from tissue under irradiation with hadrons and its potential hazards be thoroughly investigated.

1 INTRODUCTION

Radiotherapy treatment of different types of cancers with hadrons (though mainly with protons)is being conducted at many centres around the world and till the end of 2000 more than 33000 patients had been treated with these particles [2] Furthermore, Chiba in Japan [3] , and Darmstadt-Heidelberg in Germany [4] have also been treating patients with carbon beams and as many as 745 (up to December 1999) and 72 (up to June, 2000) patients have been treated at these two sites respectively[2]. Further four facilities for carbon- ion therapy are being planned in Germany, France, Italy and Sweden [5], while four other groups in Slovakia, Japan, China and Austria are also seriously considering installation of heavy- ion therapy facilities[2]. However, it appears that so far, the matter of secondary neutron production from patients undergoing hadron therapy, and its potential implications, has not been considered thoroughly.

It has already been shown by Chadwick et al [6], that even very high energy neutrons (at least up to 150 MeV- the maximum energy considered in their calculations) would impart radiation doses to patients' tissues and organs and thus have the potential to cause damage. Furthermore, if these neutrons are taken into account, the observed radiobiological effectiveness (RBE) of carbon-ions may have to be modified. These neutrons could also widen the observed sharper "carbon-Bragg-Peak" and thus diminish its apparent advantage over protons in this respect, as claimed by the Darmstadt-Heidelberg Group[7].

2 METHOD OF ESTIMATION

Although there appears to be no measurements or calculations on neutron production from tissue under bombardment with hadrons in the literature, there are similar measurements available for thick targets (stopping the incident beam completely) of C and other heavier elements for incident energies of up to 400 MeV / nucleon [8,9], which covers the energy range being used in therapy. According to the authors the neutron yields include additional neutrons produced in the target by secondary reactions of neutrons and charged particles, and the effects of neutron scattering in the target. It is shown that the secondary neutrons produced have energies ranging from thermal to twice the incident carbon ion energy per nucleon.

Furthermore, it is pointed out by Kurosawa et al [8], that the dependence of the yield of neutrons with energies greater than 5 MeV (apparently the minimum neutron energy which they could measure), integrated for a hemisphere from 0 to 90°, on the target mass is very small compared with the difference of neutron numbers of the targets (Beyond 90° the neutron production cross section and hence the yields drop to insignificantly low values; at least a couple of orders of magnitude lesser than their values at 0°, and therefore the neutron yield for the 0 to 90° hemisphere can be treated as the total yield for all practical purposes). This means that the intensity of the secondary neutrons produced from thick targets of C, N and O would be very similar under bombardment with C-ions. In case of protons the dependence of neutron out put on the atomic number of target is slightly larger[9] but could still be assumed to be very similar for neighbouring nuclei.

Therefore, based on these observations, one is justified to use the secondary neutron production yields from a thick target of carbon in order to estimate the numbers of such neutrons produced within patients undergoing therapy with carbon ions and protons, where the incident carbon and proton beams are also completely stopped, as tissue can also be approximated by the formula $C_5 H_{40} O_{18} N$ [10].

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3 RESULTS AND DISCUSSION

The results of our estimation are shown in figures 1 and 2 for C-ions and protons respectively. It can be seen from the fig. 1 that as the carbon-ion energy increases from 100 to 400 MeV, the number of secondary neutrons of energies greater than 5 MeV generated per incident carbon ion increases from 0.3 to 4.2, that is by a factor of 14. However, in the case of proton irradiation, the number of secondary neutrons is much lower, being about 0.03, 0.25 and 0.5 n / protons at incident energies of 100, 200 and 300 MeV respectively.

Besides these secondary neutrons, there will be a considerable number of slower neutrons of energies lesser than 5 MeV but which could not be measured by the authors [8,9]. Now, typically, the medium dose per treatment of skull base tumours is around 60 GyE in the Darmstadt-Heidelberg programme [4], which is equivalent to a physical dose of 20 Gy [11], in view of the RBE of carbon being 3 in their programme. The number of C-ions required to impart a dose of 1Gy in tissue is 6.2 x 10^6/cm^{2}and 18.7 x 10^6/cm^{2}at100 and 400 MeV / nucleon respectively. This means that, many millions and up to a billion of neutrons, with energy > 5 MeV, would be produced per C-ion treatment. These very large number of neutrons could potentially cause new primary cancers and could also have other side effects (as already mentioned) especially when the high RBE of neutrons is taken into consideration. The RBE of fission neutrons (energy 0.43-1 MeV) is considered to be in the range of 15-70 but for tumour induction it could be as high as 200, especially at low doses[12], while that of neutrons with energies varying from thermal up to hundreds of MeV (similar to the neutrons being produced from tissue under C-ion bombardment) it could vary from 7-177[13].

Currently it is not possible to accurately calculate the radiation dose to different parts / organs of the patients due to these secondary neutrons. Firstly, we have no knowledge about the flux of these neutrons with energies less than 5 MeV. Secondly, the kerma coefficients, which help convert the neutron flux data to radiation doses, are only known up tol 150 MeV neutron energy [6]

Keeping in view the safety of the patient undergoing hadron therapy, especially with carbon-ions, it is suggested that comprehensive measurements and calculations should be conducted as soon as possible in order (a) to determine accurately the yield and energy distribution of the secondary neutrons down to thermal region produced from the patient, (b) to estimate the radiation dose imparted to various organs and (c) thus to assess the risk of new primary cancers and other side effects. A knowledge of the intensity and energy distribution of the secondary neutrons is also needed in order to assess their contribution to the “observed” RBE of hadrons, especially of carbon ions.

This is essential in order to estimate the safety of therapy with hadrons especially with carbon-and other heavier ions.

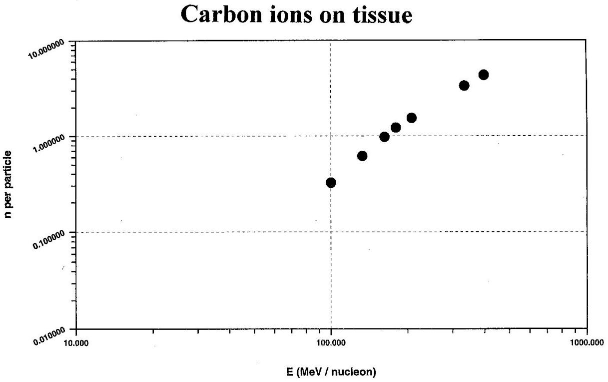

Figure 1. Estimated yield of secondary neutrons, of energies greater than 5 MeV, produced within patients undergoing therapy with carbon ions

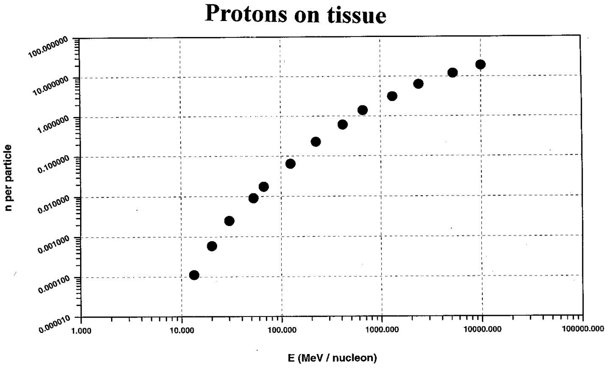

Figure 2. Estimated yield of secondary neutrons, of energies greater than 5 MeV, produced within patients undergoing therapy with protons

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