U.P.B. Sci. Bull., Series A, Vol. 72, Iss. 1, 2010 ISSN 1223-7027

MONTE CARLO INVESTIGATION OF LIGHT-IONS FRAGMENTATION IN WATER TARGETS

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Utilizarea fasciculelor de ioni grei pentru terapia cancerului necesita cunostinte precise despre procesele complexe care se produc la interactia ionilor cu substanta, asa cum este producerea de particule secundare. In timpul iradierii neutronii secundari, protonii si ionii grei contribuie la doza prompta si doza intarziata de radiatie in tesutul tumoral si in cel sanatos. In acest sens, producerea de fragmente usoare prezinta un interes special. Aceste particule sunt transportate in tesutul biologic, largind campul de iradiere si crescand riscul efectelor secundare. In lucrarea de fata s-au studiat intensitatile izotopilor produsi prin interactia fasciculelor de ^{12}C, ^{14}N si ^{16}O avand energia de 400MeV/u cu apa. Simularile numerice au aratat ca fragmentele cu intensitatile cele mai mari sunt particulele cu sarcina electrica mica generate in zona de intrare a tintei care se propaga ulterior dincolo de picul Bragg.

The use of ion beams in cancer therapy requires accurate understanding of the complex processes of ion interaction with matter, as it is the production of secondary particles. During irradiation therapy, secondary neutrons, protons and heavier ions contribute to the prompt and delayed dose delivered to tumor and healthy tissues. In this respect production of light fragments is of special interest. These particles are transported through the bio-tissues broadening the irradiation field and increasing the risk of secondary effects. Therefore in this work, isotope yield produced by ^{12}C, ^{14}N and ^{16}O at 400MeV/u in water was studied. The numerical simulations show that the highest yield fragments are the low-charged particles generated in the entrance area of target then propagating behind the Bragg peak.

Keywords: Heavy ions; Isotope yield, Fragmentation

1. Introduction

In the heavy ion therapy nuclear reactions cause a significant alteration of the radiation field. This shows mainly through a loss of primary beam particles

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and a build-up of secondary lower-charge fragments [1]. Consequently, the dose distribution along the beam path is altered as compared to the dose profile resulting from a simple stopping model considering only electronic stopping. In particular, the secondary lower-charge fragments, having longer ranges than the primary beam, give rise to the characteristic dose tail even beyond the Bragg peak. The importance of these effects generally increases with the beam energy and penetration depth.

Nuclear processes in heavy ion collisions are energy dependent. In the energy interval of therapeutic interest, interaction mechanisms go from pure fragmentation at highest energies to more complex ones at lower energies. The low energy reaction mechanisms range from Coulomb scattering to deep inelastic processes and complete/incomplete fusion [2]. The means to consider these processes in the present study are based on the Monte Carlo simulation.

FLUKA is a general purpose Monte Carlo code describing particle transport and interaction with matter. Currently it is applied to proton and electron accelerator shielding, target design, calorimetry, activation, dosimetry, detector design, accelerator driven systems, space radiation and cosmic ray showers, neutrino physics, radiotherapy [3]. About 60 different particles and heavy ions can be transported in the matter by this code. The energy range covered for hadron-hadron and hadron-nucleus interactions is from interaction threshold up to 10000 TeV, while electromagnetic interactions can be dealt with from 1 keV up to 10000 TeV. Nucleus-nucleus reactions relevant for therapeutic applications are treated with the Relativistic Quantum Molecular Dynamics (RQMD) code [4], [5] and the new Boltzmann Master Equation (BME) event generator [6].

In the present study the build up of fragments generated by hadronic beams in thick water targets has been investigated. As incident ion beams ^{12}C, ^{14}N and ^{16}O at 400 MeV/u have been used. In order to take into consideration all relevant processes for heavy ion interaction, Dual Parton Model JETs (DPMJET) event generator has been applied [6]. In Fig.1 the ratio of the Bragg peak dose versus dose in the entrance region for ^{12}C, ^{14}N and ^{16}O at 400 MeV/u are equal to 3.4, 4 and 4.5, respectively. The right hand side of the Bragg curves (shaded area) indicates the build of fragments.

In order to gain confidence in the numerical simulation, the results of FLUKA calculations were compared to PHITS code results and also to experimental data, where available. Particle and Heavy Ion Transport code System (PHITS) is a transport code for photons, particles and heavy ions [7]. The energy range of the transported heavy ions is 0 – 100 GeV. A simulation of the transport of ^{12}C, ^{14}N and ^{16}O ion beams at 400 MeV/u in a water target was carried out.

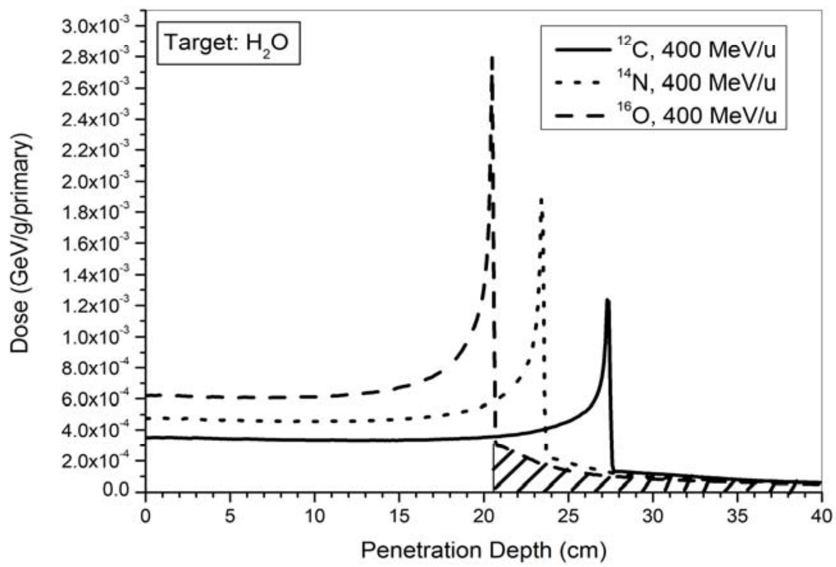

Fig. 1. Dose deposited in a thick water target by ^{12}C, ^{14}N and ^{16}O ions as a function of the penetration depth. The simulations have been performed with the computer code FLUKA.

Dose and charged fragments build-up as a function of penetration depth were obtained. The event generator which was used by PHITS to compute the energy deposition of the incident ions was ATIMA [8]. Also, the energy straggling option (Landau-Vavilov theory) was used together with an option for Coulomb diffusion (angle straggling, with Moliere First diffusion theory) [9].

The comparison of Bragg curves simulated by FLUKA and PHITS codes is presented in Fig. 2. The simulation results were also compared to experimental data points measured at GSI [2]. In the entrance region the experimental data are in agreement with FLUKA simulation while at Bragg peak position, the simulated data are lower than the experimental. This difference is due to the fact that FLUKA uses a default value of the water mean ionization potential which is 75eV, different from the value 76.75eV that gives the best fit of the experimental data as discussed in Ref. [10], [11].

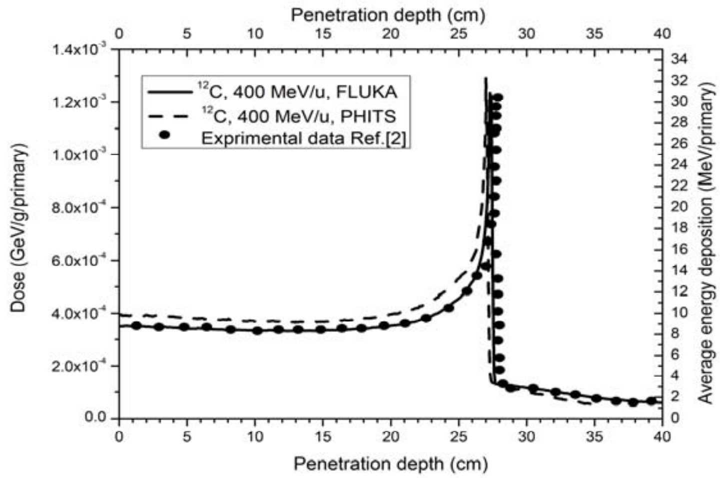

Fig. 2. Comparison of Bragg curves simulated by FLUKA and PHITS codes to experimental data for ^{12}C ion beam at 400MeV/u in thick water targets. Experimental data are from Ref.[2].

2. Build-up of charged fragments

The build-up curve describes the particle yield as a function of atomic mass and Z number. This build-up represents the number of generated fragments per cm^3 of target volume per primary incident ion. As can be observed from Fig. 3, the isotope yield of light ion fragments such as H and He are relatively high in comparison to heavier ions. The maximum atomic mass number of fragments for all above mentioned incident ion beams is 16, which represents the yield isotopes of ^{16}O and ^{16}N in nuclear interactions.

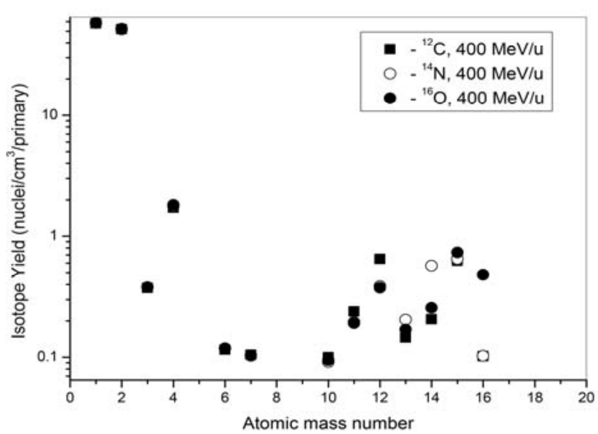

Fig. 3. Build-up of charged particles fragments in a thick target of water as a function of the atomic mass number by ^{12}C, ^{14}N and ^{16}O ions beam. The simulations have been performed with the computer code FLUKA.

Fig. 4 represents the distribution of fragments produced by the incident ^{12}C ion beam in a thick water target as a function of penetration depth. In this simulation the highest yield was the isotope of He which is produced in the entire trajectory of the carbon ion. Like all the other fragments, this yield reaches a maximum a few centimeters before Bragg Peak position. Its subsequent decrease - due to the lack of carbon ions - is however less steep than the fall of high charged fragments, like nitrogen and oxygen isotopes. Low charged fragments like He are produced behind the Bragg peak by the high charged fragments in nuclear interactions. Notice that the PHITS simulation results match well the experimental results obtained from reference [2].

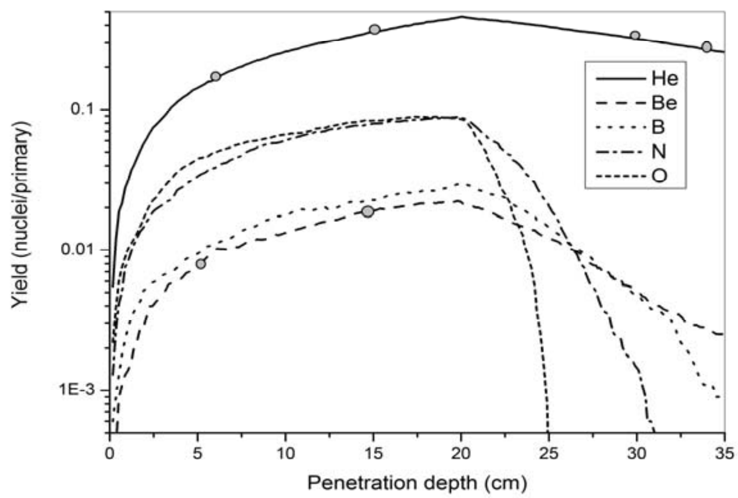

Fig. 4. Build up of charged particles fragments in a thick target of water as a function of penetration depth for ^{12}C ion beams. The simulations have been performed with the PHITS computer code. Experimental data points (solid circle) are from Ref.[2].

3. Conclusion

Light ion beams are used in irradiation therapy and good knowledge of the fragments produced in the interaction of these beams with bio-tissue is a basic requirement. Nuclear fragmentation reactions may cause a significant alteration of the radiation field. In this paper we studied the fragments produced by ^{12}C, ^{14}N and ^{16}O in water targets. The simulated dose delivered by ^{12}C ion beam to the water target was different from measured data at GSI, especially at Bragg peak position. This is due to a lower <I>-value for water used by the transport codes FLUKA and PHITS as compared to the best fit value for the experimental data, a situation which we investigate elsewhere [12].

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