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Energy deposition around swift proton and carbon ion tracks in biomaterials

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Synopsis Hadron therapy is a modern cancer treatment based on the interaction of proton or heavier ion beams with living tissue, whose purpose is the destruction of the malignant tumor cells producing minimal effects on the surrounding healthy tissue. To study the physical basis of the Relative Biological Effectiveness (RBE) of different projectiles, such as protons or carbon ions, we calculate the radial distribution of energy deposited by the secondary electrons generated in biomaterials by these ions at characteristic energies around the Bragg peak. This is done by means of the simulation code SEED, which follows in detail the motion and interactions of the secondary electrons as well as the subsequent electron cascade.

The interaction of energetic ions with biological targets lies in the basis of hadron therapy, which is a promising technique for oncological treatment due to its higher precision in energy delivery to the tumor cells, whereas sparing most of the healthy tissues surrounding the sensitive region [1].

The use of energetic ion beams for cancer treatment, suggested more than sixty years ago and being widely exploited nowadays, is based on the sharp and well-located dose maximum (the so-called Bragg peak) appearing at the end of their depth-dose curve. The advantages of ion beams as compared to other radiations lie mainly on their higher relative biological effectiveness (RBE), as well as in the precision with which the tumor can be irradiated, with minor side effects to the surrounding healthy regions.

A precise knowledge of the energy loss by swift ions in targets of biological interest (mainly liquid water, but also other constituents of living tissues, such as cell components…) is mandatory to suitably model the depth-dose profiles. This stage in the energy delivery by the ion beam to the target is successfully described by the SEICS code [2].

There are other important issues concerning the biodamage induced by ion bombardment. Among other questions, it is important to know the spatial distribution of the energy deposited around the ion's track by the secondary electrons generated by the projectile [3,4], as well as the subsequent electron cascade, which can propagate appreciable amounts of energy relatively far away from the ion's path.

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Given the importance of low energy electrons in producing biodamage [5], it is essential to know in detail the spatial and energy distribution of electrons around the tracks of different types of projectiles (proton or carbon ions), in relevant biological targets for representative energies around the Bragg peak.

For this purpose, we use the SEED code [6], which provides a detailed description of the elastic and inelastic processes in condensed phase materials. The whole cascade of secondary electrons is followed, because any truncation or cut off underestimates the secondary electron emission yield. Also, at very low electron energies, trapping phenomena due to electron-polaron interactions and electron-phonon interactions are considered.

By analyzing the radial distribution of energy deposited by the generated secondary electrons around the tracks of these projectiles in liquid water and other targets of biological interests, we hope to assess the physical basis of the higher RBE of carbon ion beams as compared to proton beams.

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