Available online at www.sciencedirect.com
ScienceDirect
Journal of Taibah University for Science 10 (2016) 187–194
Journal of Taibah University for Science
www.elsevier.com/locate/jtusci

Biophysical and radiobiological aspects of heavy charged particles

Omar Desouky [a,*], Guangming Zhou [b]

[a] *Radiation Physics Department, National Center for Radiation Research and Technology, Egyptian Atomic Energy Authority, Nasr City, Cairo, Egypt*

[b] *Department of Space Radiobiology, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China*

Available online 6 April 2015

Abstract

Heavy-ion beams have unique biophysical and radiobiological properties, such as the inverted depth dose profile compared to photon beams, relative biological effectiveness and oxygen enhancement ratio. These physical and biological properties are much more favourable than those of photon radiotherapy and can be used to treat tumours efficiently. During a long-term stay in space, astronauts will be constantly exposed to low-dose space radiation. Thus, space radiation is one of the major health-related concerns for space exploration. This review summarizes the biophysical and biological properties of charged particles and their advantage in radiotherapy. In addition, we briefly reviewed the importance of the heavy ion during space flight and how to suppress its deleterious effects.

Keywords: Heavy charged particles; Biophysics; Radiobiology radiotherapy and space mission

1. Introduction

The principle aim of radiation biophysics is to relate physical properties to observed biological responses to radiations of different qualities and their implications in radiation therapy and radiation protection [1]. The use of proton and heavy ion irradiation in cancer therapy was proposed due to their biophysical and biological superiority compared with photon beams [2]. R. Wilson, from Berkeley, analyzed the depth dose profile of protons and proposed their use in 1946. In 1954, Tobias, Lawrence and Larson began to treat patients with protons and, later on, with He (helium) ions [3]. Now, interest in the biological effects of heavy ions is rapidly growing in the scientific community. Heavy charged particles represent the best tool for an external radiotherapy due to their favourable depth dose distribution, i.e., where the dose increases with penetration depth, allowing irradiation of deep-seated target volumes with optimum precision. Recent results of heavy-ion cancer therapy in Japan and Germany [4] have stimulated the construction of several accelerator facilities for particle therapy.

On the other hand, the greater RBE (relative biological effectiveness) of heavy ion particles is the concern of space-radioprotection because the radiation spectrum of the galactic cosmic radiation (GCR) consists of heavy charged particles, from protons to iron ions. Astronauts and cosmonauts aboard Low Earth Orbit (LEO) spacecraft, such as the NASA Space Shuttle and the International Space Station (ISS), or aboard spacecraft

* Corresponding author. Tel.: +202 22747413.
E-mail address: omardesouky@yahoo.com (O. Desouky).
Peer review under responsibility of Taibah University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jtusci.2015.02.014

travelling outside the Earth's magnetosphere on missions to and from the Moon or Mars are exposed to levels of ionizing radiation far in excess of those encountered on the ground [5]. The levels of ionizing radiation in deep space are far in excess to levels on the ground, and crew members could be exposed to GCRs at a dose rate of ≈1 mSv/day, compared to an average ≈10 μSv/day on Earth. Moreover, SPEs ranging from less than an hour to several weeks can cause lethal dose rates 100 times higher than those of GCRs. Therefore, space radiation is one of the major health-related concerns for manned space exploration [6].

The radiation environment in space is a complex mixture of particles of solar and galactic origin with a broad range of energies. For radiological protection, the relevant radiation fields are galactic cosmic radiation (GCR), particles ejected from the Sun during solar particle events (SPE) and secondary radiation produced through interaction with the planet's atmospheric nuclei [7].

The distribution of GCRs is believed to be isotropic throughout interstellar space and consists mainly of protons and ions with energies up to several hundred GeV, with their peaks ranging from several hundred MeV to approximately 1 GeV. The GCRs consist of approximately 98% hadrons and approximately 2% leptons (e+ and e−), and the hadron component consists of approximately 87% protons, 12% α particles and 1% heavy ions [8]. In the case of ISS, the GCRs contribute approximately 50% of the total dose equivalent rate received by astronauts/cosmonauts. SPE are predominantly composed of protons, electrons and an even smaller part of heavy ions. Geomagnetically trapped particles consist of protons and electrons, which are trapped in the geomagnetic field layer [9].

2. LET (linear energy transfer) and stopping power

HZE (High charge and energy) particles create ionization immediately and continuously as they penetrate matter. Because of their large mass, they travel in straight trajectories with a relatively well defined stopping point or range. The pattern of HZE energy deposition is characterized by a dense core of ionization that is localized along the trajectory of the particle [10]. LET reflects the rate at which ionization is produced along the track of charged particles and has dimensions of energy per unit length (e.g., keV/μm).

X-ray and γ-ray photons deposit energy in tissue in a highly dispersed manner, characterized as low LET. Linear energy transfer (LET) is the major parameter that characterizes radiation in this field. Also referred to as stopping power, LET represents the mean amount of energy an incident particle transfers to the target medium per unit path length. IR (ionizing radiation) can either be low LET (sparsely ionizing) or high LET (densely ionizing). Photons are low LET radiation, displaying a very broad energy distribution in tissue, and the peak dose is located relatively close to the surface [10] (Fig. 1).

Electrons have sparse ionizations along the track (0.2 keV/μm) and are classified as low LET radiation. This classification also applies to photons that produce sparsely ionizing electrons, whereas HZE particles can have a LET > 100 keV/μm and are classified as high LET radiations [11].

3. Depth dose distribution (Bragg peak)

In Fig. 1, the depth dose profile of electromagnetic radiation is compared to that of carbon ions. For low-energy X-rays, the stochastic absorption by photoelectric and Compton scattering yield an exponential decay of absorbed dose with penetration. For greater photon energies, the produced Compton electrons are strongly forwardly scattered and transport some of the transferred energy from the surface to greater depths, yielding an increase in dose in the first few centimetres. For photon beams produced as electron Bremsstrahlung in clinical linacs, there is an increase of the dose distribution within the first few centimetres ('build up'), and after the maximum, the dose drops essentially according to an exponential law. Thus, for deep seated tumours, the dose delivered to the tumour using a single beam is generally lower than the dose to the normal tissue in front of the tumour [12].

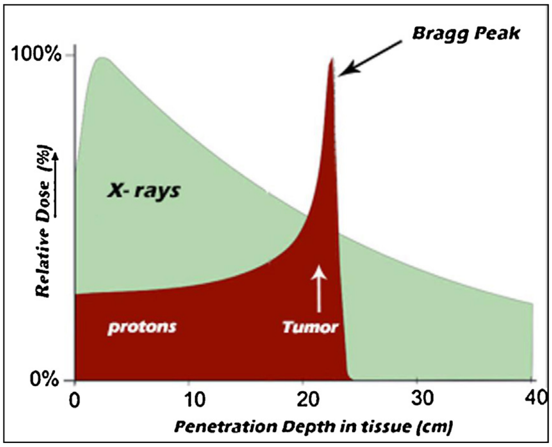

Fig. 1. Comparison of the depth dose profiles of high energetic photons and protons. Protons show the characteristic inverse depth dose profile (Bragg peak).
Modified from Ref. [10].