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Physical and biological property comparisons of 4He and 3He ion beams for applicability in radiation therapy

Background and aims
The importance and clinical significance of ion beam therapy for cancer treatment is sharply increasing due to the favorable physical and biological characteristics compared to conventional radiotherapy. With the established clinical use of proton and carbon ion beams, lately there is a growing interest for use of helium ion beams for cancer treatment due to improved physical and biological properties compared to protons, while having less demanding accelerator design compared to carbon ions. While the main focus from clinical perspective has been on He-4 ion beams, possible use of He-3 ions has been considered from accelerator physics perspective –with charge-to-mass ratio of He-3 ions, reduced beam contamination would be achieved at injection and smaller synchrotron ring could be used due to the lower beam rigidity.
The aim of this study is therefore to compare clinically relevant physical properties and associated biological effects for He-3 and He-4 ion beams.

Methods
Work has been done under collaboration of Riga Technical University, CERN Next Ion Medical Machine Study (NIMMS) group and German Cancer Research center (DKFZ).
Datasets of initial beam energies corresponding to 100 to 150 mm treatment range for He-3 and He-4 pencil beams impinging on water and muscle tissue have been acquired with Monte Carlo simulations in GEANT4 environment. Initial energies have been calculated according to Bethe-Bloch formalism, no initial energy spread was applied for the beam.
Integrated depth doses, lateral dose distribution profiles, primary particle and fragment fluences, kinetic energy distributions and linear energy transfer maps have been calculated and evaluated. Pristine peak weights have been calculated to deliver a single field uniform spread-out Bragg peak. Correspondingly, relative biological effectiveness (RBE) values have been calculated with Microdosimetric Kinetic Model. Moreover, neutron production and kinetic energy distributions have been calculated for neutron biological effect estimations.
For estimation of He-3 and He-4 ion beam feasibility for *in-vivo* range monitoring, two detection methods have been considered - positron emission tomography and prompt gamma imaging. For positron emission tomography (PET) based verification production yields of positron-emitting isotope fragments have been calculated, corresponding activity distributions have been calculated and positron range effects have been considered. For prompt gamma imaging information of photon emission vertices has been registered - photon energy, spatial coordinates and corresponding nuclear reaction process.

Results
A throughout simulation data comparison has been made for He-3 and He-4 ion beams, regarding their physical dose distributions, associated radiobiological effects and neutron dose, while also investigating feasibility for positron emitter and prompt gamma based in-vivo range monitoring methods.
Based on the acquired data He-3 ion beams stand as a viable option and clinical alternative to He-4 ion beams for use in radiation therapy, due to their comparable physical dose deposition characteristics and associated biological effects. Differences have been observed in the theoretically achievable signal for the considered in-vivo range monitoring methods which should be further benchmarked and confirmed with experimental measurements due to complexity of Monte-Carlo modelling for nuclear processes.

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