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Development of the nuclear reaction and fragmentation models for heavy ion collisions in the therapeutic energy range

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Background:
Ionizing radiation is exploited in radiotherapy to damage malignant cells' DNA and therefore to cause tumor death. Proton and carbon ion beams are already used since decades in many institutes worldwide, while helium ions are planned to be used in the next future at the Heidelberg Ion-Beam Therapy center in Germany [1, 2].
With increasing mass and charge of the primary beam particles, a more conformed dose to the tumor, less lateral scattering and a higher biological effects can be achieved. However, ions heavier than protons may undergo fragmentation in the patient tissues. The resulting fragments have broader lateral distributions and longer paths than the primary particles, and therefore they can reach and damage healthy tissues surrounding the tumor. For this reason, nuclear reaction and fragmentation processes need to be carefully considered for accurate treatment plannings and dose calculations.

Aim:
The FLUKA [3, 4] Monte Carlo code is used for medical purposes at HIT (Heidelberg), MIT (Marburg) and CNAO (Pavia). It provides all the basic inputs to the treatment planning systems (TPS), and it is also used to validate the TPS dose calculations, especially in complex scenarios [5]. Our work aims to improve the precision of the physics models embedded in FLUKA, in order to predict more accurately the dose delivered during radiotherapy treatments.

Method and Results:
For different primary particles (He, C and heavier ions) and various target materials (e.g. C, O, Al, Ti, water), we investigated the nuclear reaction cross sections as well as the angular and energy distributions of the secondary radiation produced by fragmentation of the primary ions. By comparison with experimental data available in literature, we identified the factors which need to be refined in the FLUKA physics models. Significant improvements were achieved, especially concerning i) the nuclear reaction cross sections of helium ions and ii) the angular and energy distributions of secondary protons originated from carbon ion beams in graphite.

Conclusions and Outlook:
Analysis of the nuclear reaction cross sections for helium ions is required prior to the clinical use of FLUKA for helium ion therapy. Initial studies have been carried out and new measurements, planned for February 2018, will provide the information required in order to finalize this study.
Improvements in the FLUKA ion fragmentation modeling for C-C collisions (symmetric system) have been obtained. The results achieved will improve the FLUKA-based-TPSs used in the clinics.
Asymmetric systems with heavy primary particles (e.g. O, Ne, Ar) and high-Z target materials (e.g. Al, Ti, Au) are currently under investigation. This work is of interest for radiotherapy and also for astrophysics and heavy ion research in general.

References:
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