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Recent Improvements and Applications of the FLUKA Monte Carlo code in Hadrontherapy

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Purpose: Monte Carlo (MC) codes are widely used in the hadrontherapy community due to their detailed description of radiation transport and interaction with matter. In this work, we present the latest developments and applications of the FLUKA Monte Carlo code [1,2].
Material/methods: MC methods are being utilized at several institutions for a wide range of activities spanning from beam characterization to quality assurance and dosimetric/radiobiological studies. The suitability of a MC code for application to hadrontherapy demands accurate and reliable physical models for the description of the transport and the interaction of all components of the expected radiation field. This becomes extremely important to correctly perform not only physical but also biological dose calculations. In addition, accurate prediction of emerging secondary radiation is of utmost importance in emerging areas of research aiming at *in-vivo* treatment verification.
Results: Validations and applications at several experimental sites as well as proton/ion therapy facilities with active beam delivery systems will be presented:

- Physical database generation: laterally integrated depth-dose profiles, lateral-dose distributions at different depths, secondary fragment yields and fragment energy spectra at different depths.
- Forward MC re-calculations of physical/RBE-weighted dose distributions of proton and carbon ion treatment plans.
- MC-based treatment planning for proton and heavy ions beam therapy.
- Studies for introducing *new* ions (^{4}He and ^{16}O) in the clinical practice.

Conclusions: FLUKA's flexibility and the satisfactory agreements with several dosimetric data and nuclear fragment yields demonstrate that the code is a valuable and powerful support for the hadrontherapy community.

Keywords:
Particle therapy, Monte Carlo code, dosimetry

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Investigation of the use of inhomogeneous fractional dose distributions in IMPT to improve the therapeutic index

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Purpose: Conventionally, intensity modulated particle therapy (IMPT) fields are optimized independently of the fractionation scheme. Following some precursory works [1—3], this study aims at investigating whether the application of spatial and temporal modulations in fractionation patterns, which involve the delivery of daily inhomogeneous fractional dose (IFD) distributions, may increase the therapeutic gain.
Materials/Methods: We simulated the irradiation of different clinical cases with different ions (^{1}H, ^{4}He, ^{12}C) and we carried out a comparison between two types of treatment plans. These were: (1) a conventional plan with a standard fractionation scheme in which each beam irradiates the whole planning target volume (PTV) delivering a uniform dose of 2 Gy per fraction; (2) an alternative plan that implies IFD distributions, delivering homogeneous dose to distinct regions of the PTV in different fractions. Each field was weighted to minimize its contribution to the proximal region of the PTV, so to limit the dose excursion in the surrounding normal tissues and obtain different local fractionation schemes in the volumes of interest. The comparison was based on the evaluation of the tumor complication probability (TCP) and normal tissue complication probability (NTCP). We evaluated these quantities following the approach proposed by Kallman *et al.* [4], based on the Linear-Quadratic-Poisson model. We considered a variable relative biological effectiveness (RBE) and the impact of the variable linear energy transfer (LET) distributions on the sensitivity to the time structure of the irradiation.
Results: For the considered cases, the comparison showed that the IFD-based approach leads to an improvement of the therapeutic index with respect to the standard approach (+6-10%). The extent of the gain is dependent, among other factors, on the sensitivity of the tissues to the employed ion radiation. Some critical issues were identified related to the choice of weights and spatial configurations of the fields.
Conclusions: This work investigates the possibility to improve the therapeutic index by delivering temporally and spatially heterogeneous dose distributions in the PTV, following the IFD paradigm. A methodology has been found which has proven to be successful in the considered clinical cases.

Keywords: Inhomogeneous fractionation, intensity modulated particle therapy, therapeutic index

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MONDO: a neutron tracker for particle therapy secondary emission fluxes measurements

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In Particle Therapy, cancer treatments are performed using accelerated charged particles whose high irradiation precision and conformity allows the tumor destruction while sparing the surrounding healthy tissues. Dose release monitoring devices using photons and charged particles produced by the beam interaction with the patient body have already been proposed, but no attempt based on the detection of the abundant secondary radiation neutron component has been made yet. The reduced attenuation length of neutrons yields a secondary particle sample that is larger in number when compared to photons and charged particles. Furthermore, neutrons allow for a backtracking of the emission point that is not affected by multiple scattering. Since neutrons can release a significant dose far away from the tumor region, a precise measurement of their flux, production energy and angle distributions is eagerly needed