EDITORIAL
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Editorial: Challenges for Radiation Transport Modelling: Monte Carlo and Beyond

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Editorial on the Research Topic

Challenges for Radiation Transport Modelling: Monte Carlo and Beyond

Radiation transport codes have become a key tool in many fields of research, from high energy physics to medical applications, passing through detector design optimization, radiation protection on Earth and in space, and other fields of applications. Over the last decades, many codes with different approaches and specific purposes have been developed. Also, general-purpose Monte Carlo codes are being continuously developed in order to expand their domains of applicability and/or improve their computational efficiency.

A total of twelve (12) papers have been published in this research topic, of which nine (9) present original research works. Approximately two thirds of the papers included correspond to the application of Monte Carlo codes in medical physics, especially in dosimetry and microdosimetry, whereas the others present latest developments and/or adaptations of general-purpose radiation transport codes, such as FLUKA, Penelope/PENH or Geant4.

As for the papers with general-purpose perspective, the work by Asai et al. presents a translation to C++ of the Penelope physics subroutines originally written in FORTRAN, so that transport of electrons and positrons with the class-II algorithm implemented in Penelope is now possible with the Geant4 toolkit. The mean features of the resulting code, named PenG4, are also described and verified using as benchmark calculations obtained with Penelope. The paper by Ahdida et al. describes the physics processes currently implemented in the code distributed by the FLUKA.CERN Collaboration. The code has reached a high level of maturity, as shown by its applications in research fields such as transport of high energy hadron beams in crystal devices, evaluation of radiobiological effects, and description of effects induced by ionizing radiation in microelectronic devices. Future development plans under object-oriented programming paradigm are also described. In another general-purpose work, Salvat and Quesada have calculated databases of proton-impact elastic collisions and ionizations for neutral atoms, from hydrogen (Z = 1) to einsteinium (Z = 99), using the relativistic plane-wave Born approximation including binding and Coulomb-deflection corrections. These databases were incorporated into PENH code with the aim of incorporating the transport of neutrons and include their effect on simulated dose distributions of interest in proton therapy. García-Pareja et al. present a review of the variance-reduction techniques available for radiation transport Monte Carlo codes, including combinations of several ones, as it occurs with the ant-colony method; they concluded that the ant-colony method is proved to be effective in focusing the radiation flux towards small volumes of interest, whereas interaction forcing was useful in simulations involving small probabilities for key processes in the volume of interest. Finally, Sarrut

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et al. presented a perspective work on the use of artificial intelligence methods for Monte Carlo simulation in medical physics and their main associated challenges; they covered the use of neural networks in various situations, such as dose estimation, dose denoising from low statistic calculations, detector modelling, and source and phase-space modeling, among others. Further, they discuss the current challenges still open in this promising field.

Microdosimetry and track-structure simulations of charged particles is the main topic of various papers, given its relevance in the radiation quality assessment in radiation therapy and radiation protection. In this context, Kyriakou et al. present the latest advances in their theoretical work on the dielectric models included in Geant4-DNA for application to electron transport, improving its capabilities from 10 eV to 1 MeV, with work in progress to extend the validity range up to 10 MeV. In another work, Baratto-Roldán et al. show the main capabilities of a code developed to calculate with Geant4-DNA various microdosimetry quantities for track segment of protons in liquid water, including the energy imparted to the site per electronic collision of the proton, a quantity needed to relate dose-average linear energy transfer (LET) with dose-mean lineal energy; due to the effect of secondary electrons, the analysis suggested the possibility of using an effective mean chord length for the relation mentioned above. The work by Kundrát et al. addresses the incorporation of track-structure calculations in macroscopic simulations, a key issue in multi-scale simulation. In this work, the authors produced with PARTRAC a database of DNA damage induced by protons and light ions up to neon below 500 MeV/u, and discussed the capabilities of the analytical formulas derived in terms of energy and LET to incorporate the biological effect into macroscopic simulations. Finally, Bianchi et al. verified the repeatability and reproducibility of a miniaturized tissue-equivalent proportional counter (mini-TEPC) by simulating the experimental conditions at the CATANA facility (Catania, Italy) with the *hadrontherapy* example of the Geant4 toolkit.

Finally, in other works Monte Carlo simulations were the cornerstone in the development of dose calculation systems in radiation therapy with protons and light ions. Grevillot et al. developed an independent dose calculation system called IDEAL, based on GATE-RTion, with the purpose of improving quality assurance of light ion beam therapy in MedAustron Ion Therapy Center (Wiener Neustadt, Austria); the benchmark against treatment planning system (TPS) calculations showed limitations arising from the pencil beam algorithm implemented in the TPS in presence of air cavities. Another Monte Carlo dose calculation engine, MonteRay, has been developed by Lysakovski et al. aiming at supporting clinical activity in proton therapy and MRI-guided therapy at the Heidelberg Ion Beam Therapy Center (HIT, Heidelberg, Germany); the engine was benchmarked against calculations with FLUKA with a remarkable agreement in various case scenarios. At the same institution, Besuglow et al. compared calculations "carried out with FLUKA" with various lateral beam profiles measured for helium ion beams with a 2D-array of liquid-filled ionization chambers with the aim of building a database for the first clinical TPS supporting raster-scanned helium ion therapy.

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