Contribution ID: **355** Type: **Oral**

Monte Carlo Simulation Techniques in Radiation Dosimetry: Advancements and Applications

Tuesday, 2 July 2024 19:05 (15 minutes)

Monte Carlo methods have revolutionized the field of radiation dosimetry by providing a robust framework for simulating the intricate interactions between ionizing radiation and matter. These methods, rooted in probabilistic sampling techniques, offer unparalleled accuracy and flexibility in modeling radiation transport, energy deposition, and dose distribution in diverse applications ranging from medical imaging to radiation therapy[1].
At the heart of Monte Carlo simulations lies the concept of random sampling, where individual interactions of photons, electrons, or other charged particles with tissues and materials are stochastically simulated. The trajectory of each particle is governed by the laws of classical or quantum mechanics, depending on the energy regime and particle type. The probability of interaction events, such as photoelectric absorption, Compton scattering, and pair production, is described by interaction cross-sections derived from fundamental physics principles.
The transport of particles through a medium can be described by the Boltzmann transport equation, which accounts for processes such as scattering, absorption, and production of secondary particles[2]. In a Monte Carlo simulation, the trajectory of a particle is tracked through successive interactions until it is either absorbed or exits the medium. The absorbed dose, defined as the energy deposited per unit mass, is calculated by tallying the energy deposited by all particles within a defined volume.
Validation and benchmarking of Monte Carlo codes are essential to ensure their accuracy and reliability in practical applications. This often involves comparing simulated results with experimental measurements and established dosimetric protocols[3]. By iteratively refining simulation parameters and adjusting models to better match experimental data, researchers can improve the fidelity of Monte Carlo simulations and enhance their predictive capabilities.
In summary, this review provides a comprehensive overview of Monte Carlo methods in radiation dosimetry, emphasizing their foundational principles, applications, validation techniques, recent advancements, and future prospects. By elucidating the role of Monte Carlo simulations in quantifying radiation dose distributions, this review aims to contribute to the ongoing dialogue surrounding radiation safety, treatment planning, and dosimetric accuracy in medical and industrial settings.

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Section

Applications of nuclear methods in science, technology, medicine and radioecology

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Session Classification: Applications of nuclear methods in science, technology, medicine and radioecology