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A Ray-Tracing Accelerated Code System, RT^2, for General-Purpose Radiation Transport Monte Carlo in Intermediate Energy

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1. Introduction

Since 2018, ray-tracing (RT) hardware acceleration technology have been equipped in Nvidia's RTX graphic card series. Two algorithms, ray-triangle intersection and tree search that inefficient in arithmetic logical unit are processed by dedicated hardware known as RT cores. This technology has enabled real-time ray tracing rendering, which is now being utilized in the film and gaming industries [1].

There have been several attempts to apply this technology to scientific simulations in order to enhance performance. One of the codes using RT acceleration is the Opticks, The Geant4-based GPU accelerated optical photon simulation code developed by Simon et. al [2]. However, RT accelerated radiation transport Monte Carlo code was not reported in our knowledge. In this report, we will introduce newly developed ray-tracing accelerated Monte Carlo code, RT^2 for medical and engineering simulation.

2. Methods and Results

2.1 Radiation and Physics Scope

RT^2 supports multi-type particle transport. The energy range of photon is 1 keV-1 GeV. Rayleigh scattering, Compton scattering with Doppler broadening, photoelectric, and pair production are supported. The EGSnrc materials were utilized. Electron and positron are also having same energy range, from 1 keV to 1 GeV. EGSnrc's PRESTA-II condensed history algorithm was ported to GPU with optimizations [3]. Moller and Bhabha scattering with electron impact ionization, bremsstrahlung and electron-positron annihilation were implemented.

For neutron, group-wised scheme was implemented for the transport low energy up to 20 MeV. The ENDF-B/VII.0 library was utilized in this work. From 100 MeV to 1 GeV, Wilson abrasion-ablation model and Quantum Molecular Dynamics (QMD) model were implemented for inelastic neutron-nuclear reactions. Simplified Generalized Evaporation Model (GEM) and photon-evaporation model were also implemented for the nuclear de-excitation. From 20 MeV to 100 MeV, Boltzmann Master Equation (BME) model was planned but not implemented yet.

In charged hadronic transport, Geant4's Urban multiple scattering model was implemented for condensed history transport. Light hadronic projectiles up to ^{18}O was implemented for medical application such as heavy ion and proton therapy. As in case of neutrons, Wilson abrasion-ablation or QMD model were used o ion-nuclear reactions, followed by the GEM and photon-evaporation models. From 2 MeV/u to 100 MeV/u, ion-nuclear inelastic model was not supported yet since BME model was not implemented. The energy range of proton and heavy ion are 2 MeV/u – 1 GeV/u in this work.

2.2 Benchmarking I: Boron Neutron Capture Therapy

The boron neutron capture therapy (BNCT) scenario in ICRP reference phantom geometry was simulated in RT^2 and FLUKA respectively [4]. The dose component was divided into two group: gamma and ion. The calculation results of both codes are illustrated in **Figure 1**. The white region inside of the brain is an arbitrarily designated tumor. 45 ppm and 15 ppm Boron-10 was applied in tumor and normal tissue respectively. For FLUKA calculation, all 20 threads of Intel i-9 10900k was utilized [5]. And a single Nvidia RTX 4090 cards was used for RT^2 calculation. 7.5×10^{10} histories were simulated and total calculation time was 220 200 seconds in FLUKA and 1 559 seconds in RT^2. The processed history per second of RT^2 was 140 times higher than FLUKA.

2.3 Benchmarking II: Carbon Isotopes Beam in a Water Phantom

Since BME model was not implemented yet in RT^2, ion-inelastic model was turn off in both codes. The rectangular shape carbon ion beam with 10×10 cm^2 was applied in a water phantom. Three carbon isotopes, ^{11}C, ^{12}C, and ^{14}C were used. The delta-ray production cutoff was set to 700 keV in both codes. For FLUKA calculation, same device was utilized but single Nvidia RTX 4060ti cards was used for RT^2. The comparison results are depicted in **Figure 2**. The primary energy of

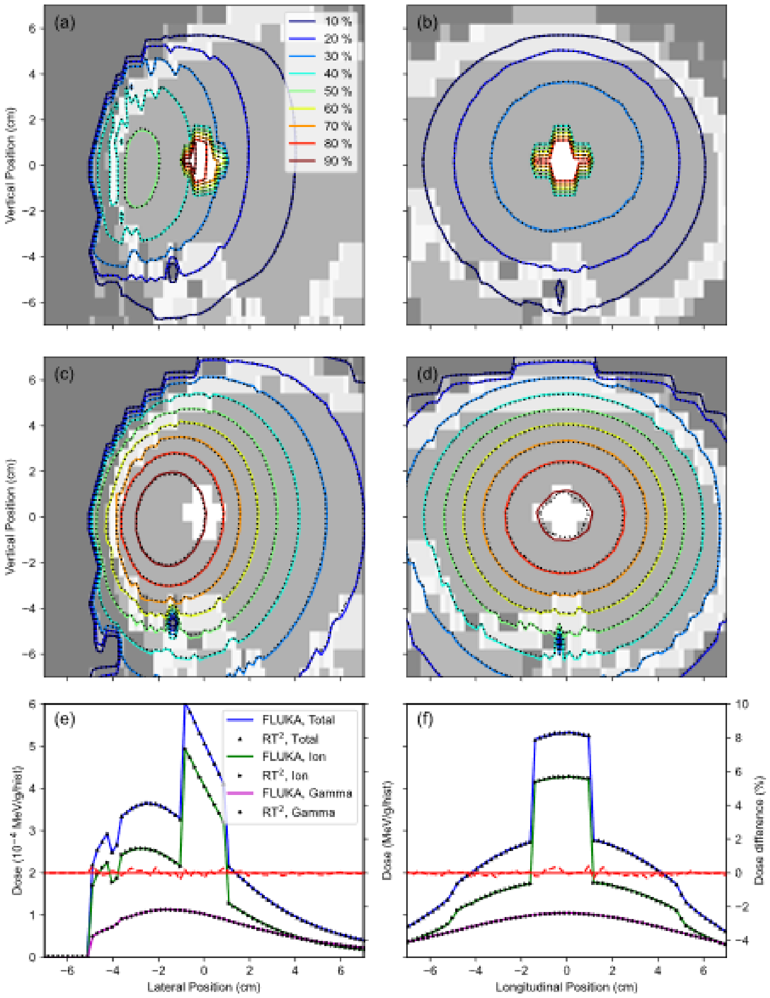

Figure 1. Dose calculation results in a scenario of head and neck BNCT. The isodose curve of FLUKA calculation results (colored solid lines) and this work (black symbols) are shown in 2-D image. Isodose curve of ion dose in frontal plane that contains the neutron beam axis (a), ion dose in sagittal plane (b), gamma-ray dose in frontal plane (c) and gamma-ray dose in sagittal plane (d). The depth- and lateral-dose profiles are shown in (e) and (f), respectively. The red-dotted lines present dose differences of RT^2 against to the FLUKA.

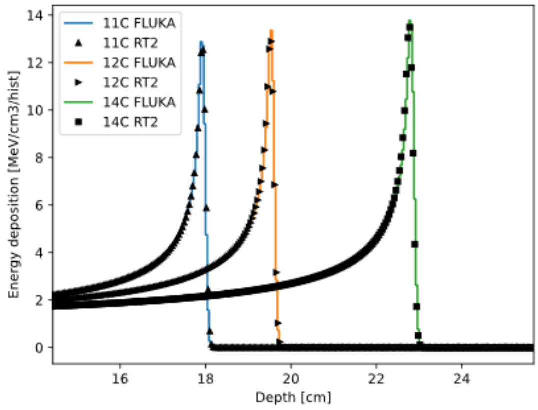

Figure 2. Dose calculation results of carbon isotopes beam irradiation in a water phantom. The depth-dose profiles were obtained from FLUKA and RT^2 respectively.

three isotopes beams were set to 325 MeV/u, which make CSDA range of ^{12}C to 20 cm. For FLUKA calculation, 2×10^6 histories were simulated for each case. For RT^2, 1×10^8 histories were simulated. The total computational time of ^{12}C primary was 98.32 seconds in FLUKA and 53 seconds in RT^2 respectively. The processed history per second of RT^2 was 92.8 times higher than FLUKA.

3. Conclusions

The Ray-Tracing technology was successfully integrated in Monte Carlo algorithm. Neutron and heavy ion transport were benchmarked against FLUKA. In both scenario, tens of times higher performance were achieved with comparable results. We expect the developed code can be improve efficiency of medical application and nuclear engineering simulation.

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