RELEVANCE OF MONTE CARLO SIMULATION VALIDATION ANALYSIS IN THE SCOPE OF THE DOSE-3D PROJECT*

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We present an analysis of the characteristics of a therapeutic photon beam simulated by the G4RT simulator which is based on the Monte Carlo method. Development of the G4RT is a part of the Dose-3D project. In order to verify the reliability of the implemented simulator, spatial dose distributions were compared with the real measurements and results from the PRIMO simulator. For the purpose of assessment, the primary photons analysis was performed. Results show the reliability of the G4RT. Therefore, the simulator can be used in further research.

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1. Introduction

The success of radiotherapy treatment depends on the precision with which the dose will be delivered to the tumor volume. The *Reconfigurable Detector for Measuring the Spatial Distribution of Radiation Dose for Applications in the Preparation of Individual Patient Treatment Plans* project

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(a.k.a. Dose-3D project [1]) aims to develop a new reusable tissue-like detection system that enables accurate and quick verification of advanced treatment plans in three-dimensional geometry corresponding to the patient's geometry.

A crucial part of the initiative is the development of high-quality software for dose simulation, configuration and control of the entire device, and data analysis. One of the research milestones is obtaining a high agreement between the simulated dose distributions and those measured during the detector tests. The critical issue was the implementation of a reliably functioning platform — G4RT.

2. Data flow and analysis scope

The Dose-3D module is being incorporated into the standard teleradiotherapy treatment data flow. Figure 1 presents the location of the Dose-3D system in the procedure and the overall approach to the validation analysis of the detector. The presented analysis results are based on the data from the Monte Carlo simulations (G4RT, PRIMO — Penelope engine-based MC simulator [2]) and from real measurements taken at the National Institute of Oncology in Kraków (NIO). Data sets consist of dosimetric outcomes for simple squared radiation fields deposited in a water phantom. The analysis was performed with the usage of in-house software packages which are being developed for data maintenance, pre-processing, and analysis. More information can be seen in the Hajduga contribution [3].

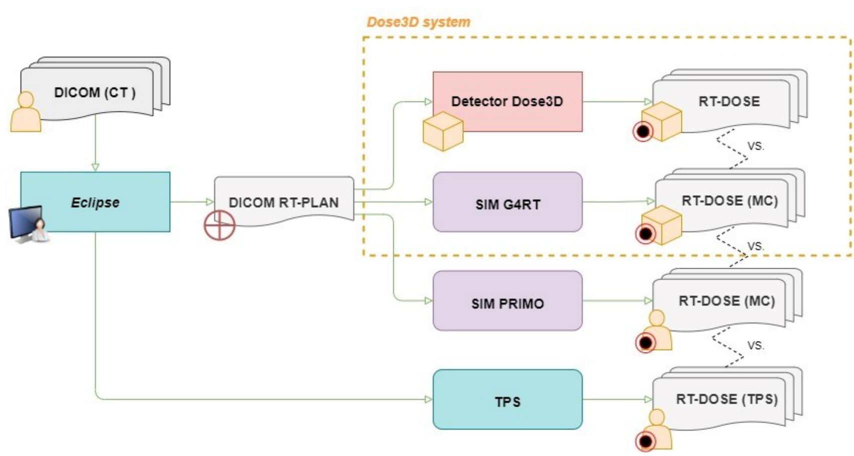

Fig. 1. Dose-3D system in the scope of the teleradiotherapy treatment procedure data flow.

3. G4RT validation

The G4RT simulation application is based on the Geant4 simulation toolkit and models the geometry of the Varian Clinac 2300C/D accelerator head geometry with a square water phantom and a photon beam with a nominal acceleration potential of 6 MV (Fig. 2). Due to the complexity of the beam formation process in the accelerator and the simulation time, the starting point for simulation was a phase-space file consisting of a beam of primary photons tally before secondary collimators. The input simulation data was calculated with the use of PRIMO. Once the geometry specification of linacs is not publicly available, we rely on the linac model defined in the PRIMO simulator. Extracting phase space for the given beam model from PRIMO, we continued simulation in the G4RT application including field modelling here. To verify the reliability of the modelled geometry and beam, the percentage depth dose distributions (PDD) and dose profiles were calculated and then correlated with the respective measurements. The comparisons were conducted using a variety of methods including the common and standard verification approaches used in clinical practice such as a dose difference analysis and gamma test. The examined parameters included the distance to agreement (DTA)/dose difference (DD) criteria. Examples of used dose distributions with analyses are presented in Figs. 3 and 4. Results of the assessment show that the implemented simulation is capable of reproducing the measured dose distributions.

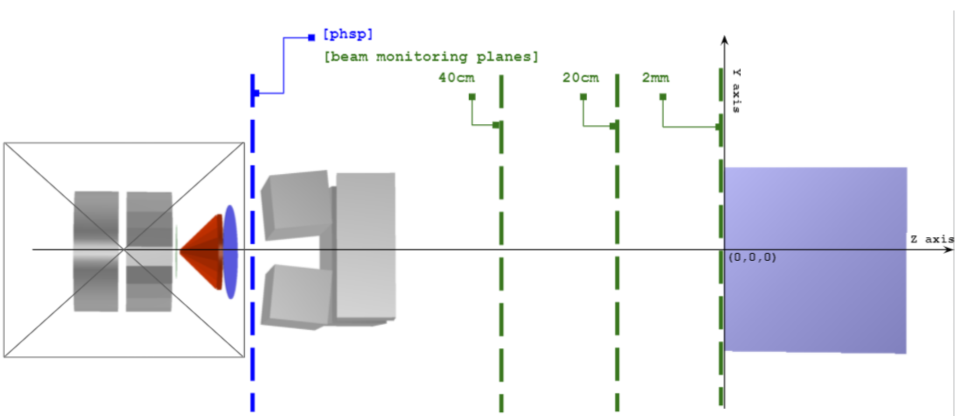

Fig. 2. Visualisation of geometry modelled in G4RT with water phantom.

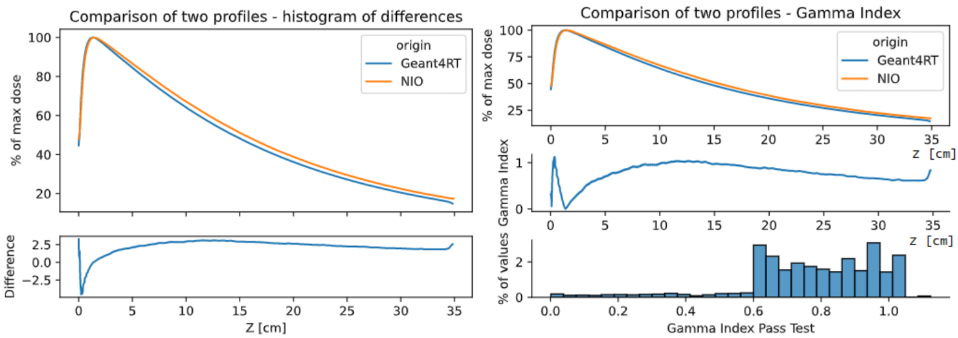

Fig. 3. PDDs obtained from G4RT the simulation and measurement (NIO) for 10 cm ×10 cm radiation fields with dose differences as a function of depth (left) and with gamma index values distribution and as a function of depth for DD/DTA: 3%/3 mm (right).

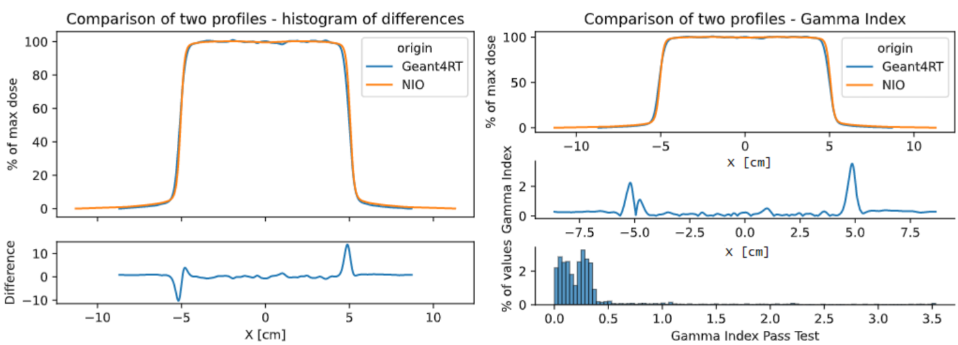

Fig. 4. Profiles obtained from the G4RT simulation and measurement with dose differences (left) as a function of depth and with gamma index values distribution and as a function of depth for DD/DTA: 3%/3 mm (right).

3.1. G4RT physics models comparison

The MC simulation allows for physics model specifications and tuning values correlated with it like production cut. We decided to make a comparison of the dose reproduction accuracy in dependency of the used Geant4 physics model for Low Energy Electromagnetic Physics which are: emstandard_opt3, emstandard_opt4, em_penelope. Based on the results (Fig. 5), the em_penelope was chosen to further simulations. The validation was extended by comparison with the results generated by Penelope engine-based MC simulator — PRIMO (Fig. 6). The results show that the selected model and tuning of the beam enable correspondence of simulation results with reference data to 3% and 3 mm of discrepancy.

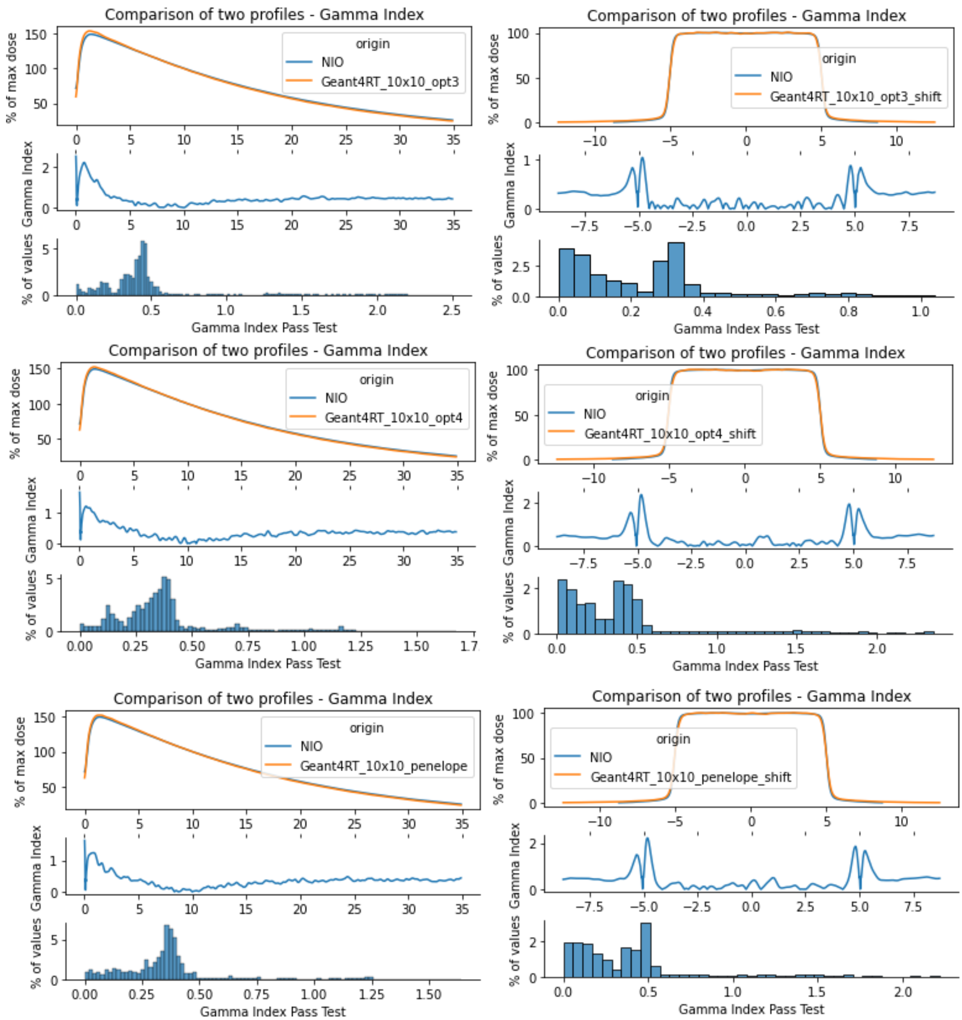

Fig. 5. Dose spatial distributions obtained from G4RT with the implementation of different physics models in comparison with real measurements (NIO).

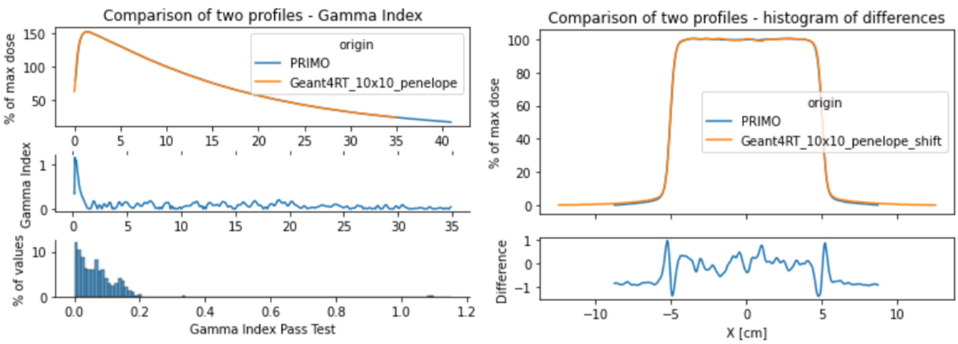

Fig. 6. Dose spatial distributions obtained from the G4RT with the em_penelope physics model in comparison with data obtained from PRIMO which also uses the Penelope model.

4. Primary photons analysis

The accuracy of MC simulation strongly depends on the accuracy of modelling physical interactions. Therefore, a key aspect in assessing the results of future simulations with the Dose-3D detector will be a good understanding of the physics taking place in the phantom medium according to the simulation. The advantage of using the MC simulator is that the output files contain information about each particle that has been recorded in the count volume. This allowed for a preliminary analysis of the beam attenuation. For this purpose, we select only primary photons which did not interact with matter on the basis of propagation angle. Only doses that did not exceed 1.72° were used for the analysis (Fig. 7). Preselection on the basis of the propagation angle turned out to be effective — their spectrum coincides with the spectrum of the photons before entering the phantom.

Next step was attenuation analysis the results of which presents Fig. 8. The presented outcomes show the assumed decrease in the number of photons with an increase in water volume and beam hardening. The number of low-energy photons diminishes faster with depth.

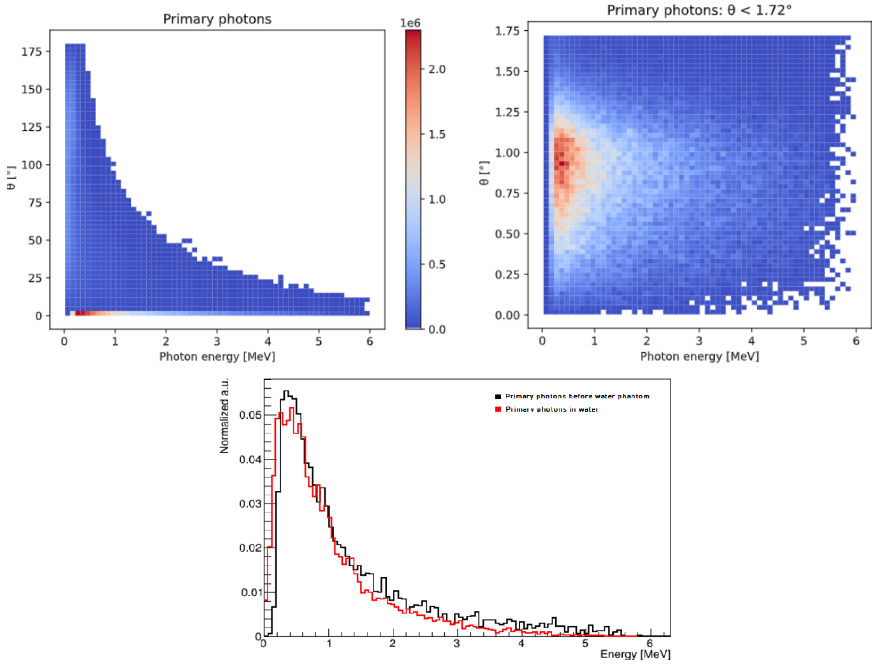

Fig. 7. Primary photons distribution in a function of energy and propagation angle in the water phantom (top figs). Energy spectra of primary photons before (black line) and after (red line) entering the water medium (bottom fig). The data within the phantom are filtered with the limit on the propagation angle value of 1.72°.

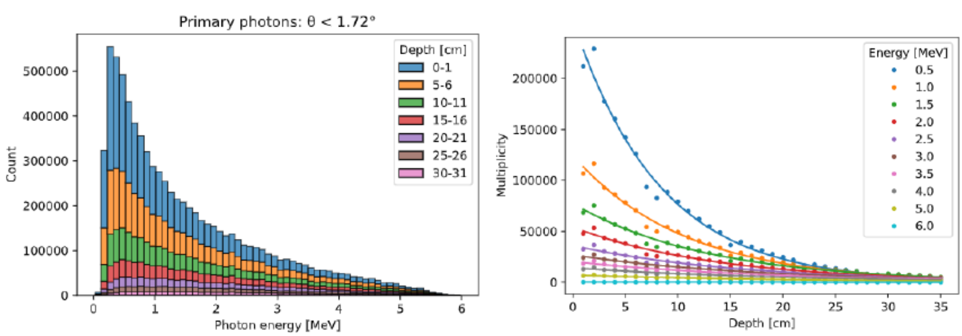

Fig. 8. Energy spectrum of primary photons on different depths in a water phantom (left). Number of monochromatic photons as a function of phantom depth (right).

5. Summary

The results of the G4RT assessment show that implemented simulation is capable of reproducing the measured dose distributions. The next step to be performed is the analysis of the MC and real data gathered with the Dose-3D detector.

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