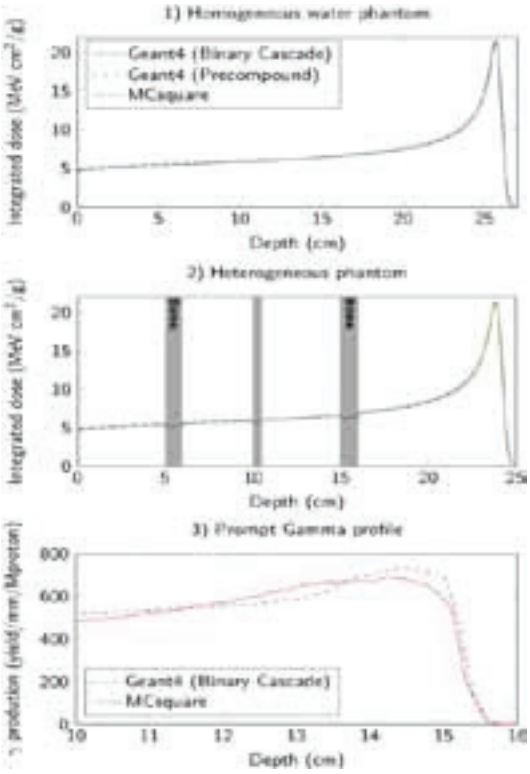
the two nuclear models of Geant4. MCsquare results are closer to Binary Cascade at high energy and closer to Precompound at lower energy. Good agreement was also achieved for PG production (see figure). In our speed benchmark, MCsquare is up to 90 times faster than Geant4 (see table).

Conclusions: A new, fast, and accurate Monte Carlo code has been developed and validated with Geant4 simulations for homogeneous and heterogeneous geometries. Due to optimized transport algorithms and the use of a Xeon Phi coprocessor, the computation time is short enough for clinical use.



	Geant4 (Binary Cascade)	Geant4 (Precompound)	MCsquare
Homogeneous phantom	37 min 29 s	14 min 11 s	25.6 s
Heterogeneous phantom	36 min 56 s	15 min 03 s	25.7 s

Table 1 – Comparison of the computation time spent to simulate 10^8 protons of 205 MeV.

PROFFERED PAPERS: PHYSICS 6: DOSE CALCULATION

OC-0274

Toward accurate tissue characterization using dual energy CT for particle therapy beam dose calculation

A. Bourque[1], J. Carrier[1], H. Bouchard[2]
[1]*Centre hospitalier de l'Universite de Montreal, Radio-oncologie, Montreal, Canada*
[2]*National Physical Laboratory, Acoustics and Radiation Dosimetry, Teddington, United Kingdom*

Purpose/Objective: The accuracy of radiotherapy dose calculation relies on the accuracy of patient composition data, e.g., electron density (ED) and effective atomic number (EAN). The goal of this work is to demonstrate that once improved, the stoichiometric method of Schneider *et al.* (1996) for conventional CT scanners can be extended to dual energy CT (DECT) and yield higher accuracy in determining tissue parameters and proton and light-ion beam ranges as compared to current methods found in literature.

Materials and Methods: A mathematical formalism is developed based on a parametrization of electronic cross sections using the expansion of Midgley (2011). Using a theoretical framework based on the XCOM photon cross section database and ICRP human tissue compositions (1975), the self-consistency of the model allows the expansion of Schneider et al.'s method to DECT. Measurements are performed with the Siemens DECT (Siemens SOMATOM Definition Flash) at using a Gammex 467 tissue characterization phantom. A mathematical relation between the ionization potential (I-value) and the effective atomic number (Changer pour EAN) is determined for ICRP compositions.

Results: Using the DECT stoichiometric calibration method,maps of ED and EAN of the Gammex phantom are determined with an average accuracy of (0.3 +/- 0.4)% and (1.6 +/- 2.0)%, respectively. I-values of the phantom are determined with an uncertainty of (4.1 +/- 2.7)% using the established mathematical relation, leading to expected clinical uncertainties in proton stopping power (216 MeV) of (0.5 +/-0.4)% over all human tissues. At therapeutic energies, the uncertainty in the range of protons and carbon ions, determined from the Bethe formula, is found below 1.3 mm and 0.6 mm respectively.

Conclusions: Results clearly demonstrate that the method presented in this work is more accurate in determining tissue parameters for dose calculation in proton and light-ion beams than that found in literature, which is currently known to be about 1-3 mm for protons (Paganetti (2012)). The use of this method to determine cross sections for Monte Carlo simulations is yet to be explored.

OC-0275

Hybrid Monte Carlo dose algorithm for low energy X-rays intra-operative radiation therapy

M. Vidal[1], P. Ibáñez[1], J. Cal González[1], P. Guerra[2], J.M. Udías[1]
[1]*Universidad Complutense de Madrid, Department of Atomic Molecular and Nuclear Physics, Madrid, Spain*
[2]*Universidad Politécnica de Madrid, Department of Electronic Engineering, Madrid, Spain*

Purpose/Objective: Low energy X-rays Intra-Operative Radiation Therapy (XIORT) treatment delivered during surgery (ex: INTRABEAM®, Carl Zeiss, and Axxent®, Xoft) can benefit from accurate and fast dose prediction in a patient 3D volume. Full Monte Carlo (MC) simulation may be time-consuming [1] and therefore a hybrid Monte Carlo tool which takes into account all the components of the XIORT X-rays up to 50 keV was developed. It computes in a fast and satisfactory way the dose delivered to the patient by a mobile accelerator of XIORT.

Materials and Methods: A few fast analytical algorithms to compute the dose given by X-rays have been previously described, generally dealing only with the primary X-ray beam [2]. A hybrid MC, combining a deterministic ray-tracing code which takes into account photoelectric interaction, with a first interaction Compton MC estimator for X-rays up to 50 keV, was developed to compute dose in 3D-CT volumes. Experimental dose distributions in water, for every spherical applicators (from 0.75 cm to 2.5 cm radius) as well as the needle applicator (0.22 cm radius) of the INTRABEAM® accelerator were employed to fit the energy spectra by means of a genetic algorithm [3]. The energy spectra were then implemented in the hybrid Monte Carlo algorithm. Absorbed dose distributions were then simulated in water phantom and voxelized geometries (validation phantoms, patient CT scan) both with penEasy [4] and our hybrid MC algorithm to validate our tool in homogeneous and heterogeneous conditions.

Results: Dose distributions computed by the fast hybrid MC tool are in good agreement (1%-1mm) with penEasy full simulations in water and heterogeneous media. The algorithm gives also a good prediction of the experimental dose distributions in water, and comparisons to measured data in heterogeneous phantoms are being carried out. The proposed algorithm makes it possible to simulate precise dose distributions in patient 3D-CT data with computation time below 5 seconds in a single core of a modern PC (2.5 GHz), compared to ten hours with penEasy. An example of 3D dose computation is shown in Figure 1, where the dose deliveredby the needle surrounded by its applicator in a vertebral treatment is represented on top of the CT image.

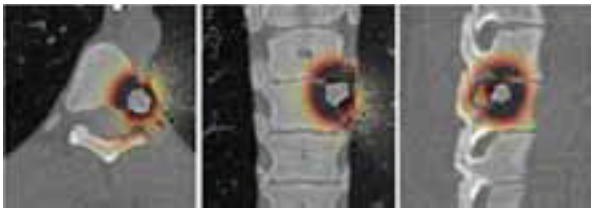


Figure 1. Dose distribution delivered by the needle, computed by the hybrid Monte Carlo algorithm in the transverse, coronal and sagittal plans of a patient spinal CT scan. Dose leaking can be appreciated into the lung area.

Conclusions: The hybrid Monte Carlo algorithm is a fast and robust tool to compute accurate dose distributions in patient voxelized geometries. The tool is being implemented in Radiance® (GMV SA, Spain), a powerful Treatment Planning System for intra-operative radiationtherapy [5], and can be used for any low energy X-rays intra-operative radiation therapy system.

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OC-0276

Development of 4D Monte Carlo dose calculation system for intensity modulated dynamic tumor-tracking radiotherapy

Y. Ishihara[1], A. Sawada[2], A. Nakamura[1], Y. Miyabe[1], T. Ono[1], M. Nakamura[1], S. Itasaka[1], T. Mizowaki[1], M. Kokubo[3], M. Hiraoka[1]
[1]*Kyoto University Graduate School of Medicine, Department of Radiation Oncology and Image-applied Therapy, Kyoto, Japan*
[2]*Kyoto College of Medical Science, Faculty of medical science, Sonobe, Japan*
[3]*Institute of Biomedical Research and Innovation, Division of Radiation Oncology, Kobe, Japan*

Purpose/Objective: Currently, few commercial treatment planning systems don't support intensity modulated dynamic tumor-tracking irradiation cases employing a gimbaled X-ray head. The purpose of this study was to develop a new 4D dose calculation system for intensity modulated dynamic tumor-tracking radiotherapy (IM-DTRT) by gimbals mechanism in Vero4DRT.

Materials and Methods: In the dose measurement, a QUASAR platform phantom with water-equivalent phantom was used. EDR2 film was inserted at 5 cm depth between water-equivalent phantoms. Then, the QUASAR platform phantom was driven at a frequency of 0.25Hz with amplitude of 15 mmin SI direction.The static IMRT and IM-DTRT were performed using a pyramid-shaped field with five segmental fields and a clinical field for a IMRT case, respectively. The phantom position measured by a laser displacement gauge, rotational angles by the x-ray head, MUs, and the time were recorded in a log file.
In the simulation, 6-MV photon beam delivered by the Vero4DRT was simulated using EGSnrc. Then, a phase-space data at any angles was created from both the log file and the particle data under the MLC. Finally, IM-DTRT as well as static IMRT was simulated by performing dose calculation under the target and the x-ray head position at each phase.
Next, dose calculation was performed using ten phase CT with the x-ray head rotated by the corresponding angle for pancreas IM-DTRT. Subsequently, deformable image registration between the CT at the intermediate phase and at other phases was performed using MIMvista to accumulate dose distribution. Isodose curves and DVHs of the IM-DTRT plan and the static IMRT plan were calculated.

Results: The averaged difference between the simulated and the measured doses was 2.4% using the pyramid field for IM-DTRT as well as static IMRT. The simulated and measured IM-DTRT profiles were represented in Fig. 1. Using the clinical IMRT field, the difference between the simulated and the measured doses for IM-DTRT was less than 3 % in the most areas except the high dose gradient. In the clinical simulation, target coverage was nearly equal for both plans. Then, the mean dose differences between the IM-DTRT and the static IMRT plans for stomach and duodenum were approximately 40% and 20%. The delivered dose to organ at risk could be decreased by IM-DTRT while the prescribed high dose could be delivered to the target.

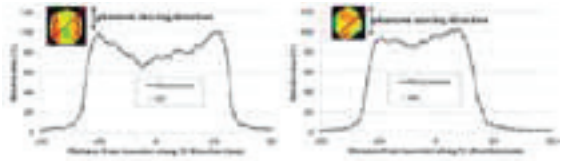

Fig. 1. The simulated and measured IM-DTRT profiles with a voxel resolution of 0.2 x 0.2 x 0.5 cm³. Figure 1(a) showed prostate IM-DTRT case and (b) showed pancreas IM-DTRT case (Line: Measured dose, Dot: Simulated dose).

Conclusions: This study has demonstrated our proposed system has acceptable accuracy for IM-DTRT using the Vero4DRT and capability to simulate a clinical IM-DTRT plan.

OC-0277

A Monte Carlo verification tool for dynamic trajectory radiotherapy

M.K. Fix[1], D. Frauchiger[1], L. Henrich[1], M. Sassowsky[1], D. Frei[1], D. Terribilini[1], P. Manser[1]
[1]*Division of Medical Radiation Physics and Department of Radiation Oncology Inselspital, Bern University Hospital and University of Bern, Bern, Switzerland*

Purpose/Objective: Within the last couple of years, volumetric modulated arc therapy (VMAT) is of increasing interest in radiation oncology. Using VMAT delivery technique gantry position, multi leaf collimator (MLC) as well as dose rate change dynamically during the application leading to efficient and conformal dose delivery to the patient. However, in principal additional components can be changed dynamically throughout the dose delivery such as the collimator or the couch. Thus, the degrees of freedom increase allowing almost arbitrary dynamic trajectories for the beam. While the dose delivery of such dynamic trajectories for linear accelerators is technically possible, there is currently no dose calculation and validation tool available. Thus, the aim of this work is to develop a dose calculation and verification tool for dynamic trajectories using Monte Carlo (MC) methods.

Materials and Methods: In a first step, the dose calculation for dynamic trajectories is implemented in the previously developed Swiss Monte Carlo Plan (SMCP) [1]. SMCP interfaces the treatment planning system Eclipse with a MC dose calculation algorithm and is already able to handle dynamic MLC or gantry rotations. Hence, the additional dynamic components, namely the collimator and the couch, are described similarly to the dynamic MLC by defining data pairs of positions of the dynamic component and the corresponding MU-fractions. In a second step the new tool is validated. For this purpose, measurements are performed with the Delta4 phantom using the developer mode on a TrueBeam linear accelerator. These measured dose distributions are then compared with the corresponding calculations using SMCP. First, simple cases applying one-dimensional movements are investigated and second, more complex dynamic trajectories with several simultaneously moving components are compared.

Results: The dose calculation for dynamic trajectories is successfully implemented into SMCP. The comparisons between the measured and calculated dose distributions for the simple as well as for the more complex situations show an agreement which is generally within 2% of the maximum dose or 2 mm. The required computation time for the dose calculation remains the same when the additional dynamic moving components are included.

Conclusions: The results obtained for the dose comparisons for simple and complex situations suggest that the extended SMCP is an accurate and efficient verification tool for dynamic trajectory radiotherapy. This work was supported by Varian Medical Systems.

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OC-0278

On the commissioning of Monte Carlo beam models and dose profile corrections on stereotactic photon beams.

P. Papaconstadopoulos[1], F. Tessier[2], A. Syme[1], J. Seuntjens[1]
[1]*McGill University, Medical Physics Unit, Montreal, Canada*
[2]*National Research Council Canada, Ionizing Radiation Standards, Ottawa, Canada*

Purpose/Objective: Several investigators have addressed concerns regarding large discrepancies observed on the output factors of small

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