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Book of abstracts

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Conference Tracks

1 - Updates on MC codes physics

2 - MC physics and geometric input

3 - MC models for radiation sources and beams

4 - MC approaches in brachytherapy

5 - GPU/parallel implementations and deterministic methods

6 - MC applications in imaging and nuclear medicine

7 - MC in particle therapy

8 - MC treatment planning and evaluation

9 - MC applications in micro-dosimetry

10 - MC applications in IGRT and dosimetry

11 - MC in radiobiology

1 - Elastic scattering in FLUKA code for MONDO experiment: characterisation of the secondary fast and ultrafast neutrons emitted in Particle Therapy

Presenter: Dr. MARAFINI, Michela (Centro Fermi)

The particle therapy (PT) is a modern technique of non-invasive radiotherapy mainly devoted to the treatment of tumours untreatable with surgery or conventional radiotherapy, because localised closely to organ at risk. The beam interactions with the patient produce a large component of secondary particles: the largest fraction of the dose is released to the tumour volume, but a non-negligible amount is deposed in other body regions, mainly due to the scattering and nuclear interactions of the neutrons within the patient body. The risk of developing a radiogenic second malignant neoplasm, years or decades after undergoing a PT treatment is one of the main concerns in PT administration and planning. Since neutrons can release a significant dose far away from the tumour region, precise measurements of their flux, production energy and angular distributions is eagerly needed in order to improve the analytical models and the MonteCarlo simulation underlying the Treatment Planning Systems codes, so to predict the normal tissue toxicity in the target region and the risk of late complications in the whole body.
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The MONDO (MOnitor for Neutron Dose in hadrOntherapy) project is devoted to the construction of a secondary fast and ultrafast neutron tracker and to the characterisation of that secondary neutron component in the range of [10-400] MeV. The detector, based on the tracking of the recoil protons produced produced in two consecutive (n,p) elastic scattering interactions, is a matrix of thin scintillating fibres, arranged in layer x-y oriented (10x10x20 cm3, with fibers of square cross sections 250μm thick). The detector is under development the construction is expected to be completed by the end of the year so to start the experimental tests in Proton and Carbon Ion Therapy Centres. A Monte Carlo FLUKA code has been developed to study the detection efficiency with double scattering events and to study the possible background due to inelastic scattering. Simulation details and the results obtained in the design study will be presented. One of the most important goal to be achieved in the simulation study is the estimation of the achievable energy resolution of the incoming neutrons.

2 - MONTE CARLO SIMULATION OF 18 MV MEDICAL LINEAR ACCELERATOR AND PERFORMING NEUTRONIC ANALYSES

Presenter: Mr. YAZGAN, CAGRI (ISPARTA STATE HOSPITAL)

In order to simulate radiation transport, various algorithms and various codes and softwares have been developed which use these algorithms. The need for devices and physical conditions has been reduced through the creation, operation and testing of models and systems in a computer environment. Thus, benefits have been achieved in terms of cost and time.
In this study, the 18 MV medical electron linear accelerator was simulated with the MCNP code, which is calculated by the Monte Carlo method. Dosimetric quality controls were made by comparing simulation results with experimental and theoretical values.
Unwanted neutron exposure is due to neutrons, which are generated by photonuclear reactions. The linear accelerator is a device that produces electrons and photons, as well as a source of neutrons resulting from interactions of high atomic numbered nuclei with high-energy photons. Photoneutrons are produced by components of device such as targets, collimators and filters.
For quality control, PDD (percent depth dose) and dose profile were obtained by measuring the dose at the water phantom modelled at a distance of 100 cm from the source. By controlling specific factors, simulated values are compared with experimental and theoretical values.
Linear accelerator model and simulations can also be used for research, development, design, shielding. The device can be operated at any energy level other than the specific energy levels allowed by medical linear accelerator software.
In this study detailed photon and neutron analyses obtained.

3 - Inter-Comparision of the Flux to Dose Conversion Factors Recommended in ICRP-74 and ICRP-116 to Evaluate Radiation Dose Rates

Presenter: Dr. HOANG, SY MINH TUAN (KOREA ATOMIC ENERGY RESEARCH INSTITUTE)

The analysis of radiation dose rates for beam radiotherapy is evaluated by applying dose conversion factors to radiation flux. The conversion of flux to dose mainly used in nuclear and radiation fields, particularly in radiation therapy, has been made with the dose coefficients presented in ICRP Publication 74 (ICRP-74) [1], which are produced based on ICRP Publication 60. On the other hand, ICRP Publication 116 (ICRP-116) [2], which adopts the protection system of ICRP Publication 103, has recently been published and provides the dose conversion coefficients calculated with a variety of Monte Carlo codes. The coefficients have more than an update of those in ICRP-74, including new particle types and a greatly expanded energy range. In this study, a shielding evaluation of a specific container for neutron and gamma sources was performed with the MCNP6 code [3]. The flux to dose conversion factors produced based on ICRP-74 and ICRP-116 were applied, and the resultant radiation dose rates were quantitatively analyzed from a series of calculations. As a result, the dose rates evaluated with ICRP-74 were shown higher than those with ICRP-116. For neutrons, the difference is mainly occurred by the decrease of radiation weighting factors in a part of the energy ranges in the ICRP-116 recommendations. For gamma-rays, the ICRP-74 recommendation applied with the kerma approximation leads to overestimated results than the other assessment.

Keywords: ICRP, Monte Carlo, Dose rate, Radiotherapy.

[1] ICRP, Conversion Coefficients for Use in Radiological Protection against External Radiation, International Commission on Radiological Protection (ICRP) Publication 74, Pergamon Press, 1996.
[2] ICRP, Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures, International Commission on Radiological Protection (ICRP) Publication 116, Elsevier, 2010.
[3] Pelowitz D. B., MCNP6 User’s Manual Version 1.0, LA- CP-13-00634, Los Alamos National Laboratory, 2013.

4 - MONTE CARLO SIMULATION of MEDICAL LINEAR ACCELERATOR for FILTERED and FFF SYSTEMS

Presenter: Mr. YAZGAN, CAGRI (ISPARTA STATE HOSPITAL)

Monte Carlo is a method that can be used to solve mathematical and physical problems by using simulation technique. A stochastic process can be simulated with random events with regular random numbers. Many centers have developed many computer based Monte Carlo codes.
In this study MCNP (Monte Carlo N-Particle) code is used to simulate Philips SLI-25 medical linear accelerator. Detailed geometry of LINAC head and water phantom are modelled and simulated for calculations. Analyses are made for 10x10 cm2, 20x20 cm2 and 40x40 cm2 irradiation fields for filtered and FFF (Flattening Filter Free) systems. Flux and spectrum analyses were performed for filtered and FFF systems separately.
Dosimetric quality controls were made by comparing the simulated results with the experimental results. For this purpose PDD and dose profile measurements for filtered and FFF systems in 18 MV photon energy were examined and compared with experimental data. After ensuring the quality control of the device, other measurements were investigated.
In the simulation, the electrons generated in the electron source were accelerated to the target by moving in the vacuum tube and X-rays were produced. The X-rays are shaped in the primary and secondary collimators, flattened in a flattening filter and measured in the water phantom through the ion chamber.
As a result, the data obtained in this study using the Monte Carlo method provided a detailed analysis of the working principles of the linear accelerator and of the generated radiation types.
The model may be used for the development of a linear accelerator in future studies, the development of a Monte Carlo-based treatment planning system, and the testing of different radiotherapy methods such as BNCT (Boron neutron capture therapy) virtually before experiments.

5 - Monte Carlo simulation studies on a beam monitor based on MPGD detectors for hadron therapy

Presenter: Dr. ALTIERI, Palma Rita (Istituto Nazionale di Fisica Nucleare - Università degli Studi di Bari)

Remarkable scientific and technological progress during the last years has led to the construction of accelerator based facilities dedicated to hadron therapy. This kind of technology requires precise and continuous control of position, intensity and shape of the ions or protons used to irradiate cancers. Patient safety, accelerator operation and dose delivery should be optimized by a real time monitoring of beam intensity and profile before and during the treatment, by using non-destructive, high spatial resolution detectors. The authors have studied, developed and initially tested a beam monitor based on Micro Pattern Gaseous Detectors (MPDGs) called TPC-GEM (TPG) detector, characterized by high spatial resolution and rate capability. Due to the low amount of material in the active volume, it is “not invasive”, therefore the beam characteristics are preserved, so minimizing the uncertainties on beam position, intensity, energy and stability.

Computer simulation could be done as a preliminary step for analyzing the basic characteristics of a detector, and Monte Carlo simulation is one approach that can be established. For better understanding of the first TPG prototype design, and its further improvements, several Monte Carlo simulations were performed.

The aim of this talk is to give an overview of the full and specific Monte Carlo simulation framework, including different tools (GEANT4, FLUKA/FLAIR, Garfield++, ANSYS and ROOT), developed in order to study in detail the interaction of a proton beam with the detector sensitive volume in a typical hadron therapy environment and the performance of the chamber, especially for the calculation of the primary ionization, charge transport through the amplification stages and signal creation. The results obtained will be presented, as well as the future perspectives.

6 - Determination of X-ray Contamination and Dosimetric Characteristics of Electron Beams produced by LIAC Intraoperative Radiation Therapy Accelerator Using Monte Carlo Simulation

Presenter: Mr. TANHA, Kaveh (The Persian Gulf Nuclear Medicine Research Center, Bushehr University of Medical Sciences, Bushehr, Iran)

Purpose: Determination of the dosimetric characteristics of the electron beams is one of the main concerns in IORT accelerators. The aim of this study is to determine these characteristics using Monte Carlo simulation of the accelerator’s head and also produced electron beam to the improvement of the beam dosimetry accuracy.
Materials and Methods: EGSnrc-based BEAMnrc code was used to simulation. Phase-space files were generated at the bottom of the applicators and were used as an input source in DOSXYZnrc and BEAMDP codes for dose calculation and analysis of the characteristic of the electron beams in all applicators and energies.
Results: Our results showed that the peak of the initial spectrum decreases when electrons move from the end of accelerator waveguide to the end of the applicator. By decrement of the applicator diameter, the mean energy of electron beam and also the X-ray contamination decreased.
Conclusions: The results of this study showed that special design of LIAC head accompanying by PMMA collimator system cause to produce an electron beam with an individual dosimetric characteristic making it a useful tool for intraoperative radiotherapy purposes.
Keywords: Monte Carlo Simulation, IORT, Photon Contamination, Dosimetry, LIAC

7 - Monte Carlo Simulation of Radiation Treatment Planning for Pituitary Adenoma; A Comparison Between the Model-Based and Correction-Based Dose Calculation Algorithms

Presenter: Mr. TANHA, Kaveh (The Persian Gulf Nuclear Medicine Research Center, Bushehr University of Medical Sciences,Busehr, Iran)

Purpose: The aim of this study was to compared the results of the Monte Carlo simulation, collapsed cone convolution (CCC) and Equivalent tissue-air ratio (ETAR) dose calculation algorithms in pituitary adenoma radiation treatment planning.
Materials and Methods: The Linac head validation in water phantom simulated by EGSnrcMP-based BEAMnrc and DOSXYZnrc codes. A conventional three small non-coplanar field technique were used for irradiation of the pituitary gland in Rando phantom. The results of MC simulation, CCC and ETAR dose calculation algorithms were compared to the results of EDR2 radiographic and EBT2 gafchromic film dosimetry.
Results: Our results showed that in comparison to Monte Carlo simulation was more accurate than CCC and ETAR. The mean difference between the algorithms and film dosimetry were 4.93 ± 0.87 % for MC, 4.98 ± 0.47 % for CCC and 6.52 ± 1.23 % for ETAR. There was about 1.2% difference between EDR2 and EBT2 results.
Conclusions: Difference between calculation and true dose value affects radiation treatment outcome and normal tissue complication probability. It is of prime concern to select appropriate treatment planning system according to our clinical use and technique. It is further emphasized that MC is a method choice for comparison of clinical dose calculation algorithms.
Keywords: Radiation Treatment planning, Dose calculation algorithm, Monte Carlo simulation, ETAR, CCC, Film Dosimetry

10 - Monte Carlo based validation of Compton scattering for 5 MV and 10 MV photon beams using Aluminium and Tungsten targets

Presenter: Mr. JAGTAP, AMOL (STUDENT)

Purpose: To validate scattered photon energy spectrum from Tungsten and Aluminium target of energies 5 MV and 10 MV at angle 0, 45, 90 degree and in target region by using EGSnrc Monte Carlo code.
Materials and Methods: EGSnrc based FLURZnrc user code is used for the calculation of energy spectra at different positions. Parallel monoenergetic photon beam of radius 0.1 cm was made incident on target of thickness 1cm and radius 1 cm. All the spectrums are scored in 1x1 cm2 area at 10 cm distance in vacuum.
Results: Verification and validation of EGSnrc Monte Carlo code with the Compton scattering formula is done for Cs-137 and Co-60 and results are found in good agreement. It is observed that presence of energy spread of scattered photon of energy 0.4 MV and 1.4 MV for 5MV and 10 MV photon beams respectively at an angle of 0 degree for both the target materials.
Conclusion: The calculated energy of scattered photon at angles 0 and 45 degree are consistent with Compton scattering formula. It is observed that Compton scattering formula does not give correct value for energy of scattered photon for both photon energies of 5 MV and 10 MV at an angle of 90 degree when compared with the Monte Carlo results. Calculation of total fluence in all region of interest involves photons of energy 0.511 MV which are created in annihilation process.

13 - Monte Carlo simulations for the beam quality factor of a parallel-plate ion-chamber in the presence of magnetic field

Presenter: Prof. YE, Sung-Joon (Seoul National University)

Magnetic resonance image-guided radiotherapy provides real-time imaging with a superior soft-tissue contrast without additional exposure. Recently, several groups have been developing such a new technology. Strong magnetic fields can influence trajectories of the secondary electrons by the Lorentz force. The reference dosimetry using an ion-chamber in magnetic fields needs additional correction factors [1, 2]. In this study, we calculated magnetic field correction factors by the Monte Carlo method for the reference dosimetry using a parallel-plate ion-chamber.
The EGSnrc user code, egs_chamber was used to simulate an ion-chamber. A full head of Varian therapeutic linear accelerator of 6 MV, 10 MV, and 15 MV photon beam has been simulated by BEAMnrc. A parallel-plate ion-chamber (NACP-02) was positioned in the water phantom at a depth of 10 cm. The additional correction factor for the magnetic field is defined as the effect of the magnetic field on the dose response of the ion-chamber. The absorbed dose of parallel-plate ion-chamber was scored with and without a 1.5 T of magnetic field.
The beam quality factors of 6, 10, and 15 MV were 0.992, 0.980, and 0.973, respectively. These values were compatible to the previous published data [3]. In a 1.5 T of magnetic field, the additional correction factors for the magnetic field of 6, 10, and 15 MV were 0.922, 0.972, and 0.983, respectively. All of simulation uncertainties were within 0.2%.
The magnetic field correction factors of a parallel-plate ion-chamber were successfully calculated by the Monte Carlo method. The parallel-plate ionization chambers need several percent of correction factors when measuring doses in the presence of a magnetic field.

[1] M. Reynolds, B. G. Fallone, and S. Rathee. Dose response of selected ion chambers in applied homogeneous transverse and longitudinal magnetic fields. Medical Physics 2013;40:042102
[2] D. J. O'Brien, D. A. Roberts, G. S. Ibbott, and G. O. Sawakuchi. Reference dosimetry in magnetic fields: formalism and ion-chamber correction factors. Medical Physics 2016;43:4915-4927
[3] B. R. Muir, M. R. McEwen, and D. W. O. Rogers. Beam quality conversion factors for parallel-plate ionization chambers in MV photon beams. Medical Physics 2012;39:1618-1631

14 - Montecarlo calculation of reaction cross sections for the production of innovative radionuclides

Presenter: FONTANA, Andrea (PV)

The production of innovative radionuclides in the context of theranostics is currently a topic of great interest. Various INFN projects are underway in search of new data and new techniques for radionuclides production. Among the possible channels under study, recent developments indicate 67Cu and 47Sc as good candidates competitive with more traditional nuclides, thanks to their application both for diagnostic and for therapy. INFN recently started two projects for the measurement of proton-induced reactions, considering the forthcoming use of the high-performance cyclotron installed atINFN-LNL (70 MeV maximum energy): COME in CSN3 (2016) and PASTA in CSN5 (Young Researchers grants 2016).

The knowledge of reaction cross sections at low-intermediate energies is crucial in this context and, in parallel to the need of new measurements, it is important also to review the current situation in the reaction-model simulation of the production yields, by using the existing and available nuclear reaction codes. In particular the FLUKA code, based on the PEANUT (Pre-Equilibrium Approach to Nuclear Thermalisation) model, was used to calculate the production of residual nuclei in di■erent experiments and is already validated with data.

In this study we use FLUKA to calculate the reaction cross sections for the production of copper and scandium isotopes at the energy of interest for the LARAMED project (10-100 MeV). A comparison of the results obtained with dedicated codes (Talys and Empire) and with available experimental data is also given.

15 - Experimental verification of 4D Monte Carlo calculations of dose delivered to a deforming anatomy

Presenter: Dr. CYGLER, Joanna (Medical Physics Department, The Ottawa Hospital Cancer Centre)

Joanna E. Cygler(1, 2,*), Sara Gholampourkashi (2), Emily Heath (2)
(1) Department of Medical Physics, The Ottawa Hospital Cancer Centre, 501 Smyth Road, Box 927, Ottawa, Ontario K1H 8L6, Canada
(2) Carleton University, 1125 Colonel By Drive, Ottawa, Ontario K1S 5B6, Canada

The aim of this work is to validate 4D Monte Carlo (MC) simulation method [1] for reconstructing dose delivered to a breathing patient. Static and VMAT plans were delivered to a deformable lung phantom by an Elekta Agility linear accelerator and measured doses were compared with simulations.
Measurements were performed in a deformable lung phantom containing a 2.6 cm diameter tumour with the phantom in stationary and moving (sinusoidal) states. Dose within the tumor was measured using EBT3 film and a RADPOS detector connected to the RADPOS 4D dosimetry system [2]. Dose inside the lung was measured by another RADPOS detector mounted outside the tumor at 1.5 cm from the tumor center.
A single 6 MV 3x3 cm2 square field and a VMAT plan, both covering the tumour, were created on the end-of-inhale CT scans using Monaco V.5.10.02. A validated BEAMnrc model of our Elekta linac was used for all MC simulations. For 4D simulations, deformation vectors were generated by deformable registration of end-of-exhale to end-of-inhale 4DCT images using Velocity AI 3.2.0 as input to the 4DdefDOSXYZnrc code along with the phantom motion trace recorded with RADPOS.
Dose values from MC simulations and measurements were found to be within 4% of each other. The passing rate for a gamma comparison of 3%/2 mm between Monte Carlo simulations and film measurements were found to be better than 98%.
In conclusion, our 4D Monte Carlo simulations using the defDOSXYZnrc code accurately calculates dose delivered to a deforming anatomy. Future work will focus on irregular respiratory motion patterns.

[1] S. Gholampourkashi et al., “Experimental verification of 4D Monte Carlo simulations of dose delivery to a moving anatomy”, 2017; Med.Phys. 44(1):299-310.
[2] A. Cherpak et al., “Evaluation of a novel 4D in vivo dosimetry system”, 2009; Med.Phys. 36(5):1672-8.

16 - An automated Monte Carlo QA system for volumetric modulated arc therapy: possibilities and challenges

Presenter: Dr. CHAKAROVA, Roumiana (Department of Medical Physics and Biomedical Engineering, Sahlgrenska University Hospital, Gothenburg, Sweden)

Objectives
To develop and implement an automated MC system for patient specific VMAT QA generating treatment planning system (TPS) compliant DICOM objects and including a stand-alone module for 3D analysis of dose deviations based on the normalized dose difference (NDD) method.
Material and methods
The MC system developed is based on the EGSnrc code package with modifications [1]. The workflow consists of a number of modules connected to the TPS by means of DICOM exports and imports which are executed sequentially without user interaction. DVH comparison is performed in the TPS. In addition, MC- and TPS dose distributions are imported to the stand-alone analysis module based on the NDD formalism [2]. NDD failure maps and a pass rate for a certain threshold are obtained. 70 clinical plans are selected for analysis; 21 thorax plans, 26 prostate plans, 13 H plans and 10 gynecological plans.
Results/conclusion
Agreement within 1.5% has been found between clinical- and MC data for the mean dose to the target volumes. The agreement is within 3% for parameters more sensitive to the shape of the DVH, e.g. D95% PTV or minimum dose to CTV. Tolerance criteria of 2%/3mm are recommended for NDD analysis of prostate plans and 3%/3mm for rest of the cases. Evaluation procedure is suggested where NDD analysis is the first step. For pass rate lower than 95% the evaluation continues with comparison of DVH parameters. For deviations larger than 2%, a visual inspection of the clinical- and MC dose distributions is performed. A fully automated evaluation is hindered by artefacts in the CT images, presence of contrast in the bladder, dose to air included in the target volume, interpretation of HU in rectum etc.
[1] J. Lobo and I. A. Popescu, Two new DOSXYZnrc sources for 4D Monte Carlo simulations of continuously variable beam configurations, with applications to RapidArc, VMAT, TomoTherapy and CyberKnife, Phys Med Biol 2010; 55:4431-4443
[2] S. B. Jiang, G. C. Sharp, T. Neicu, R. I. Berbeco, S. Flampouri, T. Bortfeld, On dose distribution comparison. Phys Med Biol 2006; 51: 759-776

17 - Optimum Parameter for Photon Radiotherapy Monte Carlo Dose Calculation Method in GPU and Cluster MPI Computation Environment

Presenter: Mr. BAYHAQI, Yakub Aqib (University of Indonesia)

Currently, some developed countries have started to leave the methods of conventional radiation therapy planning. Adaptive radiation therapy has become a new trend currently being developed. However, this method requires a radiation dose distribution computing method which fast and accurate. As one of the most accurate method, fast Monte Carlo is needed to shorten the time of radiation therapy planning. So that the accumulation of patients, especially in Indonesia can be reduced. The use of parallel computing in the Monte Carlo method has been carried out in two models. DPM code-MPI which is an implementation of DPM codes in MPI and gDPM environment that optimizes DPM Monte Carlo code to run on a single GPU device.
This study aimed to test the accuracy and performance of both the Monte Carlo code in parallel. Accuracy and optimal performance by varying the parameters of computation of each code. In the DPM-MPI code, the number of processors used very influential in computing time. While on gDPM code, the number of threads per Grid and threads per block affect the acceleration of computing Monte Carlo. In this study was also carried out optimization of code gDPM by using streaming.

18 - FLUKA validation of MONET code for dose calculation in Hadrontherapy

Presenter: EMBRIACO, Alessia (PV)

The accurate evaluation of the dose distribution is an open issue in Hadrontherapy. MONET (MOdel of ioN dosE for Therapy) is a code for the computation of the 3D dose distribution for protons in water. The model accounts for all the interactions and is benchmarked with the FLUKA code, that is already validated for protons and Helium beams in water, as testified by its use in different facilities. In the FLUKA simulation, the physical process can be easily switched on or off: therefore the MC code is an important tools for the verification of our formulas, implemented in MONET.
In particular, FLUKA has been used for the study of nuclear interactions in the lateral and longitudinal profiles. For the lateral profile, MONET is based on the Molière theory of multiple Coulomb scattering with an addictional Cauchy-Lorentz function for the nuclear interactions, with two parameters obtained by a fit to FLUKA (Bellinzona et al., PMB 2016). For the longitudinal profile, we have implemented a new calculation of the average energy loss, the straggling based on the convolution with a Gaussian function and a linear parametrization for the nuclear contributions, with two free parameters obtained by a fit to simulation.
After the implementation, MONET has been validated with FLUKA in two cases: a single Gaussian beam and a lateral scan as a sum of many beams. In both cases, we have obtained a good agreement for different energy of protons in water.
Recently, we are investigating the possibility to extend MONET code to the case of He beam. For the implementation of Helium beam in the MONET code, we study the effect of nuclear interactions again with FLUKA. For the lateral profile, the nuclear interaction is parametrized with a Cauchy-Lorentz distribution, as in case of protons. With the lateral profile of FLUKA, we have estimated the decrease of primary particles as a function of depth, in good agreement with experimental data. For the last step, the implementation of MONET for Helium beams in water, we are studying the depth-dose distribution and the contributions of straggling and the nuclear interactions.

19 - Validation of the Monte Carlo GATE platform for the dosimetry of ocular protontherapy

Presenter: Dr. LAOUES, Mostafa (University of sciences and the technology Houari Boumediene); Mr. AHMED, Sidi Moussa (1 Laboratory of Nuclear Science and Radiation -Matter Interactions (LSNIRM) USTHB, Bab Ezzouar 16111, Algiers, Algeria 2 Laboratory of Theoretical Physics and Radiation -Matter Interactions (LPTHIRM) USDB, Soumaa 09000, Blida, Algeria)

Purpose:
The aim of this work consisted to validate the Monte Carlo GATE platform in dose distributions of a proton beam on a mathematical model of the human eye.
Methods and materials:
As a first step, a recommended 62 MeV proton beam for the treatment of ocular melanoma was simulated with GATE to check its aptitude to reproduce experimental measurements. In the second step, this beam was applied to a mathematical model of the human eye was defined precisely with real dimensions and densities. Depth-dose profile, lateral profile, dosimetric parameters according to international recommendations, and absolute dose in tumor and each organ were calculated and compared to other therapeutic techniques and Monte Carlo codes. A total of 106 incident protons were simulated in 20 min on a single i5 3.2 GHz CPU.
Results:
Relative comparisons of percentage depth-dose and lateral profiles, performed between measured beam data and the simulated, show an agreement of the order of 2% in dose and 0.1 mm in range accuracy. These comparisons carried out with and without beam-modifying device, yield results compatible to the required precision in ocular melanoma treatments. Doses distributions issued from calculations and measurements were also compared. GATE platform show better results compared to other Monte Carlo codes. Results obtained from this study show that protontherapy is the most suitable treatment for ocular melanoma due to the unique property of its beam (Bragg peak).
Conclusions:
The ease of use, reproducibility and speed of GATE allows it to be used as an integrated tool for modeling imaging, dosimetry and processing in the same simulation platform. Ocular protontherapy offers excellent levels of eye retention, even in unfavorable cases such as large tumors.
Keywords: Uveal melanoma; Protontherapy; Dosimetry; GATE 6.1.

21 - Simulation of Synchrotron-based Microbeam Radiation Therapy using Geant4

Presenter: Dr. GUATELLI, Susanna (Centre For Medical Radiation Physics, University of Wollongong)

At the Centre For Medical Radiation Physics, University of Wollongong we modelled the Microbeam Radiation Therapy beamline of the Australian Synchrotron. The development, optimisation, and validation of this Geant4-based software tool for MRT Quality Assurance will be presented.

22 - Validation of Geant4 Fragmentation for Heavy Ion Therapy

Presenter: Dr. GUATELLI, Susanna (Centre For Medical Radiation Physics, University of Wollongong)

C-12 ion therapy has had growing interest in recent years for its excellent dose conformity. However at therapeutic energies, which can be as high as 400 MeV/u, carbon ions produce secondary fragments. For an incident 400 MeV/u C-12 ion beam, ~70% of the beam will undergo fragmentation before the Bragg Peak. The dosimetric and radiobiological impact of these fragments must be accurately characterised, as it can result in increasing the risk of secondary cancer for the patient as well as altering the relative biological effectiveness. This work investigates the accuracy of three different nuclear fragmentation models available in the Monte Carlo Toolkit Geant4, the Binary Intranuclear Cascade (BIC), the Quantum Molecular Dynamics (QMD) and the Liege Intranuclear Cascade (INCL++).

23 - Design Simulation of a Low Radiation Dose-Producing Device

Presenter: Dr. ATAK, Haluk (Hacettepe University)

There are combined treatment techniques that very low doses of radiation can have inhibitory effect on cancers. Researches show that exposure to some phytonutrient compounds that exhibit anti-cancer activities at certain levels after increasing the sensitivity in tumor cells by very low doses of radiation increases effectiveness of therapeutic effect by avoiding toxicity to normal cells [1, 2]. Application of combined treatment techniques with low doses have the potential to reduce the cost of treatment by the use of a compact radiation equipment [3]. In relation to those findings, we aimed to study the electron-photon spectrum and distribution characteristics of a device that generates x-rays pyroelectrically using Monte Carlo (MC) simulation. Main purpose of the simulation is to design a compact battery powered portable electron source that can be used to achieve low dose delivery of x-rays. Devices that generates x-ray pyroelectrically are used to produce electron beams when they are either heated or cooled [4]. By introducing an electric field between the pyroelectric material and the target foil, it is possible to accelerate electrons from about 40 keV up to the energies of 140-170 keV [5]. Our MC computations on target parameters of Cu, W and Ag foils showed that when 10e6 electrons with the endpoint energy of 80 keV impinge on 10 μm-thick targets under the system pressure of 5.5 mTorr, production of photons on the order of 10e5 is achievable. For the purpose of the simulation, we made appropriate level of approximation on device geometry but the resulting model captures the basic features of the device. The main computations are focused on the determination of dimensional as well as geometric configuration of components, vacuum level, and determination of the type of materials to be used.

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26 - Development and validation of the Monte Carlo model of a widely diffused activity meter

Presenter: Dr. ZAGNI, Federico (Medical Physics Department, University Hospital “S.Orsola – Malpighi”, Bologna, ITALY)

Introduction. Accurate calibration of radionuclide activity meters (“dose calibrators”) is critical in Nuclear Medicine as it affects the amount of radiopharmaceutical injected to patients and secondary calibration procedures. It is preferably performed with traceable reference sources, anyway in many cases this is not feasible, for which MC modeling is a powerful alternative. To this aim, in this work we developed and validated the models of several of the world's most diffused radionuclide activity meters, belonging to the Capintec CRC family, using FLUKA.
Materials and Methods. The main geometrical elements and materials of the ionizing chambers were modeled. Thickness and position of internal components was evaluated through both direct measurements of external dimensions and CT/X-ray imaging. For validation, a set of reference sources was used: 137Cs (22.7±1.5% MBq), 133Ba (1.3±1.5%), 131I (100±1.5%), 177Lu (196±1.0%), 68Ge “mock 18F” (7.5±1.65%), 60Co (1.9±1.5%), 99mTc (80±5.0%). For each source, container and filling were suitably modeled as well as the nuclides full decay schemes. The cuts for transport and for secondary particles production was set to 10 keV. Calibration factors could be evaluated based on the energy deposited in the Argon gas. Simulations results were normalized to the response of the modeled 137Cs source. For each run 10^7 decay events were simulated, giving a final statistical error <1%. The sensitivity–source position dependence was also assessed in a range of 15 cm.
Results. An high accuracy energy–response curve could be evaluated, as well as the sensitivity-position curve (maximum discrepancy < 4%). For the CRC-15beta, the ratio between simulated and measured relative response was: 133Ba 1.00±0.03, 68Ge 1.01±0.03, 131I 0.98±0.03, 177Lu 1.03±0.03, 60Co 1.01±0.03, 60Co 0.97±0.04.
Conclusion. Accurate models of these widely diffuse activity meters have been validated for a variety of gamma-emitting nuclides, covering a wide range of energies and source positions, showing discrepancies below 3% for all cases. Monte Carlo simulations proved to be a powerful tool for assessment of activity meter’s calibration factors for radionuclides used in radiopharmacy, in particular for very short lived or non-conventional, research radionuclides, and for the easy assessment of geometrical correction factors.

27 - Implementation of very high energy electron grid therapy: Monte Carlo study of source definition

Presenter: Dr. DELORME, Rachel (IMNC Laboratory, UMR 8165-CNRS/IN2P3, Paris-Saclay university, 91405 Orsay, France)

The use of very high-energy (70-300 MeV) electron (VHEE) beams for radiation therapy has recently started to be explored [1]. Among their main advantages over photons, the fact that small diameter VHEE beams can be scanned, thereby producing finer resolution intensity modulated treatment than photon beams and a reduced sensitivity to tissue heterogeneity can be highlighted. Along this line, the combination of VHEE with the benefits of Spatially Fractionated Radiotherapy (a significant increase in normal tissue tolerance) has been proposed [2]. This novel approach, called VHEE grid therapy, is planed to be implemented at the future French Platform for Research and Applications with Electrons (PRAE). This facility [3] will deliver 70 MeV electron beams in a first phase, reaching 140 MeV in the second one. The purpose of this work was to define the most adequate source and beamline parameters in order to have the optimum conditions to perform pre-clinical studies. Monte Carlo simulations (GATE version 7.1) were used to assess the dose distributions resulting from various possible configurations. The influence of technically feasible beam parameters (beam size, divergence and energy achievable at PRAE facility) were characterized. Depth-dose curves and beam width were used as figures of merit. Our results show the feasibility of implementing our strategy at PRAE. Our main targets are neurological, i.e., targets that can be immobilized against cardio-respiratory cycles. If sub-millimetric beams would be requested at all depths in the rat head in order to exploit dose-volume effects, high energies (>= 140 MeV) would be needed. However, energies around 70 MeV could be used to treat tumors up to 1 cm depth (center of rat head, approximately). Experimental dosimetry measurements are foreseen to validate our calculations before proceeding to radiobiological experiments. The results presented here showed that potential high tissue protection can be achieved and support the interest of performing such experiments to evaluate the therapeutic benefit of the VHEE Grid Therapy technique to treat brain cancer.

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28 - Evaluation of silicon and diamond based microdosimetry for boron neutron capture therapy Quality Assurance

Presenter: Dr. GUATELLI, Susanna (Centre For Medical Radiation Physics, University of Wollongong)

We will present the characterisation of silicon and diamond based microdosimeters developed at the Centre For Medical Radiation Physics (CMRP), University of Wollongong, for Quality Assurance of Boron Neutron Capture Therapy. The study is performed by means of Geant4 simulations.

29 - Assessment of Neutron Dose Equivalent during Line Scanning Proton Therapy using Dynamic Multi-Leaf Collimator

Presenter: Mr. KIM, Dae-Hyun (Department of Radiation Oncology, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea)

The purpose of this study was to evaluate the neutron dose equivalent from proton nuclear interactions with the multi-leaf collimator (MLC) during line scanning proton therapy. We generated a wobbling mode plan and scanning mode plan, and a dynamic MLC with scanning mode plan with a field size of 7 cm and 12 cm, a maximum proton energy of 150 MeV. A Monte Carlo study was performed using the GEANT4 code (version 10.01.p01) [1] for our virtual machine based on the multi-purpose proton nozzle. In the wobbling mode, scanning mode, and scanning mode with dynamic MLC, the neutron dose equivalent generated through the nozzle was compared using the 12 cm diameter receptor. The receptors were located at the distance of r = 0, 25, 50, 100, 150, and 200 cm from the isocenter. In both field size conditions, the neutron doses equivalent in the scanning mode were 3.4%, 1.3%, 1.3%, 1.6%, 1.8%, and 2.1% lower than the wobbling mode in each receptor position, respectively. However, the neutron doses equivalent using line scanning with dynamic MLC to reduce the lateral penumbral width were 47.0%, 8.2%, 10.0%, 9.8%, 8.0%, and 8.4%, respectively, compared to the wobbling mode. The use of dynamic MLC in the scanning increases the neutron dose equivalent, but the use of dynamic MLC can reduce the dose to the organ at risk around the target and avoid disadvantages of the conventional scanning proton therapy [2]. However, according to the results of this study, secondary cancer caused by the effect of neutron dose increased when scanning with dynamic MLC is not negligible [3].

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30 - Facility shielding evaluation using Monte Carlo simulation for proton therapy

Presenter: Prof. CHO, Sungkoo (Samsung Medical Center)

The secondary neutrons generated as a result of interaction with protons and material in the beam path introduces a significant radiological hazard. The radiation shielding must be designed to protect workers in close proximity to the therapy equipment and the general public in aspect of radiation protection. Therefore, this study evaluated the shielding wall design using Monte Carlo code in proton facility.

In this study, several terms are assumed for the conservative calculation and simplification of calculation. First, the direction of proton beam loss is fixed in the accelerator room and the gantry room. Second, the neutron spectrum has been generated by using Monte Carlo method at the specific condition of reference target composition (80% of Fe and 20% of C) with 235 MeV incident proton beam and the simple geometry. Also, we assumed that every evaluation point is full occupancy and the workload safety factor is 1.5 for the conservative result. The dose evaluation places for the effective dose were selected as places at where the dose is considered highly among various places that can be accessible to people when the proton facility is operated. In this study, the radiation transport was simulated with the Monte-Carlo code such as ANISN, MCNPX and FLUKA. And then, the neutron dose at evaluation point is got by the calculated value using the simulation value and the neutron dose coefficient (ICRT-74). In all evaluation points, annual dose calculated with Monte Carlo method is under a factor of 10 than the annual dose limit of 20 mSv/yr in the Korea regulation based on ICRP 60. And, the most of result of MCNPX and FLUKA showed a smaller value than result of ANISN in Monte Carlo simulation using the complicated geometry.

Based on this calculation result, we assigned areas that cannot be allowed during the proton facility operation time, routinely occupied by workers involved directly for operation, and accessible to members of the general public.

31 - MONTE CARLO SIMULATIONS OF INTENSITY MODULATED RADIOTHERAPY USING PRIMO SOFTWARE

Presenter: Dr. ESPOSITO, Alessandro (Azienda Ospedaliera Santa Maria - Terni)

Introduction.
Intensity Modulated Radiation Therapy (IMRT) allows creating complex dose distributions. The dose distribution is calculated using different algorithms, but Monte Carlo (MC) is the gold standard for dose calculations for its complete description of radiation-matter interaction [1]. Several MC codes are in use for medical applications. Recently, new MC software named PRIMO was developed [2] with a user-friendly interface. Nevertheless, IMRT is not introduced yet.

Materials and methods.
Two Radiotherapy units mounting Varian 2300CD LINAC head were considered. While one unit uses Millennium120, the other has 120HD as Multi Leaf Collimator (MLC). Static simulations were performed to validate the primary beam and both the MLCs. Dedicated software was developed to allow automatic configuration of PRIMO in order to simulate MLC motion. A general dynamic MLC delivery was split into static segments and simulated on solid water phantom. Gafchromic films in solid water phantom measured the actual dose. Comparisons with experimental was performed by creating simulated dose images at specific planes through automatic software manipulation of the PRIMO output files. Assessments were performed using the 2D Gamma analysis (2%, 2mm).

Results.
In static simulations of both units, more than 95% of Gamma points were < 1. Simulation of dynamic procedures resulted in around 99% of Gamma points < 1 on both the MLC units. A higher modulation MLC motion simulation showed 99.1% of Gamma points < 1 with respect to the experimental using the 120HD. Both the agreement and the calculation time show increment with the number of the static configurations to reproduce the MLC motion.

Conclusion. A workflow was found to drive PRIMO to simulate IMRT procedures. While the total calculation time increment with the number of static fields was unexpected, the results of simulations agree with the experimental measurements, indicating PRIMO software as a potential tool for clinical implementation of MC simulations of IMRT technique.

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32 - Considering Bragg curve degradation in particle therapy due to lung-equivalent materials in Monte Carlo codes by applying a density modulation

Presenter: Mr. BAUMANN, Kilian (Department of Radiotherapy and Radiooncology, University Medical Center Giessen-Marburg)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

Considering Bragg curve degradation in particle therapy due to lung-equivalent materials in Monte Carlo codes by applying a density modulation

Kilian-Simon Baumann (1,2,*), Matthias Witt (3), Uli Weber (4), Rita Engenhart-Cabillic (1), Klemens Zink (1,2,5)

(1) University Medical Center Giessen-Marburg, Department of Radiotherapy and Radiooncology, Marburg, Germany
(2) University of Applied Sciences, Institute of Medical Physics and Radiation Protection, Giessen, Germany
(3) Marburg Ion-Beam Therapy Center (MIT), Marburg, Germany
(4) GSI Helmholtzzentrum für Schwerionenforschung, Biophysics Division, Darmstadt, Germany
(5) Frankfurt Institute for Advanced Studies (FIAS), Frankfurt, Germany
(* presenting author)

Introduction

Sub-millimetre-sized heterogeneities like lung tissue cause Bragg peak degradation. If not considered in treatment planning this can significantly influence the dose distribution in lung cancer patients [1,2].
We are capable of considering Bragg Peak degradation in Monte Carlos codes and hence MC-based treatment-planning systems by applying a density modulation within the voxels associated with the lung.

Material & Methods

In a first simulation a voxelised geometry consisting of sub-millimetre-sized voxels filled with either lung tissue or air was used to demonstrate Bragg peak degradation due to lung-equivalent materials. A new material characteristic ‘modulation power’ was introduced to quantify the magnitude of the degradation.
Using the modulation power, a density distribution was derived applicable to 2 mm thick voxels. This is the resolution of typically used treatment-planning CTs for lung cancer. The previously used voxelised geometry was replaced by 2 mm thick voxels. Hence, the transition from realistic lung-equivalent materials to clinically relevant data was performed. Each voxel was filled with lung tissue and the lung tissue’s density in each voxel was individually randomised for each simulated particle in order to reproduce the Bragg peak degradation.

Results

Using the voxelised geometry representing lung tissue we were able to demonstrate Bragg peak degradation due to lung-equivalent materials. A greater modulation power correlated with a greater degradation.
By modulating the density of the lung tissue in each of the 2 mm thick voxels we were able to almost perfectly reproduce the Bragg peak degradation from the previously used voxelised geometry representing lung tissue.

Conclusion

We are capable of describing and reproducing Bragg peak degradation due to lung-equivalent materials in Monte Carlos codes by applying a density distribution. We can hence consider and analyse the effects of this degradation in treatment planning.

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33 - Monte Carlo Evaluation of Glandular Dose Estimates in X-ray Breast Computed Tomography

Presenter: Dr. SARNO, Antonio (Università di Napoli Federico II, Dipartimento di Fisica “Ettore Pancini” and INFN Sezione di Napoli)

A few groups have developed cone-beam breast computed tomography scanners dedicated to the breast (BCT) [1], for breast cancer diagnosis. BCT is a 3D X-ray imaging technique, which aims at reducing the presence of the anatomical noise in X-ray breast images, due to the superposition of breast structures and tissues.
The common metric for breast radiation dosimetry in BCT is the Mean Glandular Dose (MGD), i.e. the average absorbed dose in the glandular component of the breast tissue. The MGD is estimated on the basis of air kerma measurements, and normalized glandular dose coefficients (DgN) evaluated via Monte Carlo (MC) simulations [2]. In such a context, the breast is modeled as a homogenous mixture of glandular and adipose tissue embodied in a skin layer.
We evaluated the DgN in BCT by modeling the breast as a heterogeneous mixture of adipose and glandular tissues. We realized an MC code based on GEANT4 toolkit simulating the acquisition setup and considering the interactions included in the standard electro-magnetic libraries. The MC code was previously validated vs. data from the AAPM Task Group 195, as well as vs. measured data. The dose was scored in locations inside a grid of cubic voxels designed using patient BCT scans provided by University of California Davis. The voxels were classified in adipose tissue, glandular tissue, skin tissue or air via an opportune segmentation algorithm. Such a voxellized phantom, with a real glandular distribution, was input in the MC code for estimating the MGD. This post-exam estimate was compared with the corresponding estimate evaluated before the exam using a homogeneous tissue mixture approximation.
This project received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 692097 for the MaXIMA project: Three dimensional breast cancer models for X-ray imaging research.

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34 - Comparison of two Monte Carlo calculation engines for proton pencil beam scanning

Presenter: Ms. WINTERHALTER, Carla (Center for Proton Therapy, Paul Scherrer Institute, Villigen PSI, Switzerland)

Two independently configured Monte Carlo simulation engines for pencil beam scanned proton therapy have been compared in both geometric setups and real patient data. Both are based on Geant4.10.02.p01 and have been tuned with the same commissioning data. One however uses Gate7.2, the other TOPAS3.0.p1. In addition, different physics lists were chosen; the QGSP_BIC reference physics list (Gate) versus the Topas default physics list. The source planes also differed, being placed at the MU chamber in Gate, and at the nozzle exit in Topas. Finally, the preabsorber was included as a physical component in Topas, while in Gate, it was modeled by modifying the beam input parameters.
To compare the two systems, single spots (70-230 MeV with and without preabsorber), simulated in homogeneous volumes of air, water, bone and brain (defined using elemental compositions), were first calculated in both systems. Then 7 clinical fields were compared to verification measurements taken in water using a PTW-2D-ARRAY-XDR (T10031). Finally, the same 7 fields were recalculated in the relevant CT’s.
Initially, differing default ionization potentials in Gate and Topas led to range differences for single spots of 1.5-2.1% and absolute differences in CT simulations of 1.8-2.4%. Matching ionization potentials, and retuning the models, resolved these range differences however. Using gamma-analysis to compare clinical fields simulated in water, 99.9% of points agreed between the two simulations at 2%/2mm, and 100% and 79% agreed relatively with QA measurements for 3%/3mm and 2%/2mm respectively. Simulated absolute doses were however 1.0-2.7% lower than measurements. For simulations in CT geometries, 95% of points agreed between both calculations @2%/2mm relatively, and to within 1% for absolute dose. With the different preabsorber implementations, relative dose distributions in water agreed to better than >98% (2%/2mm) between the simulations, but since proton loss in the preabsorber is not taken into account in the Gate simulations, absolute doses differed by 7-8%.
With this work, the importance of correctly defining ionization potentials and modeling beam modifying devices as physical devices has been highlighted. Excellent agreements between the dose distributions resulting from the two setups and between Monte Carlo and measurements have been shown.

35 - Monte Carlo dosimetric study for preclinical small animal hadrontherapy using Geant4 toolkit.

Presenter: Mr. PISCIOTTA, Pietro (University of Catania, Department of Astronomy and Physics, Catania, Italy; National Institute of Nuclear Physics, South National Laboratory (LNS-INFN), Catania, Italy; Institute of Bio-imaging and Molecular Physiology, National Council of Research (IBFM-CNR), Cefalù (PA), Italy)

Preclinical studies represent an important step to study molecular mechanism induced inside cells in response to ionizing radiations.
The scope was the study of the preliminary steps to perform particle treatment of cancer cells inoculated in small animals and to realize a preclinical hadrontherapy facility.
At this scope, a well-defined dosimetric protocol was developed to perform the steps needed in order to perform a precise proton irradiation in small animals and achieve highly conformal dose. Homemade positioning system for small animals was developed at INFN-LNS(Italy) and an accurate Monte Carlo simulation was developed. The application, developed using Geant4.10.03 version, includes in the current version of the advanced example “Hadrontherapy”[1] the main functionalities of the “DICOM” extended example[2]. In this way, this application simulates the CATANA beam line geometry and includes the capability to implement DICOM-TC images as target. The application will be used to carry out dosimetric and LET studies[3] using the real target composition.
This application was validated comparing its results with experimental measurements.
A validation test, using solid water slabs phantom, and a treatment simulation, irradiating a PMMA phantom that simulate subcutaneous tumours, were executed at CATANA facility using in both cases EBT3-Gafchromic films as dose detector. The dosimetric results were compared with the simulation ones using Kolmogorov and gamma index test. Experimental data are in good agreement with the simulation ones. The phantom targets were included in the simulation environment using DICOM-TC images.
Dosimetric measurements were useful to determine the efficiency of the developed Geant4 application and to demonstrate that it is a valid instrument to study the dose distribution in different types of phantoms with different kinds of geometry. This work has been carried-out in the perspective of realization of a preclinical hadrontherapy facility at INFN-LNS in order to implement interesting future in vivo studies using small animals.

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36 - Geant4 Modeling of Targeted Radionuclide Therapy for Brain Metastasis

Presenter: Prof. ACKERMAN, Nicole (Agnes Scott College)

Many patients with breast cancer develop brain metastases, which are typically treated through whole-brain irradiation. As a potential alternative treatment, targeted radionuclide therapy (TRT) could be delivered early, targeting the areas of the vasculature where tumor cells are penetrating into the brain. We have developed a Monte Carlo model representing brain vasculature to evaluate and understand a variety of potential therapeutic nuclides: (alpha emitters) Pb212, At211, Ac225, Bi213, and Tb149; (beta/Auger electron emitters) Lu177, Tb161, I124, In111, Y90, Zr89, and Ga67. The micron-scale dose distributions from all radioactive decay products were modeled in Geant4, as well as eV-scale interactions through the G4DNA models [1]. These interactions were then superimposed on an atomic-scale DNA model [2] to estimate strand break yields. Some of the alpha emitters have decay chains with multiple daughter nuclei; we investigate the change in dose profiles and biological effectiveness as a function of time. Alpha emitters have higher doses per decay, and the depth-dose profiles fall off less quickly. The general qualities of the depth-dose profiles are maintained through biologically-relevant variations in vasculature geometry.

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37 - The BIANCA biophysical model/MC code: calculations of radiation-induced cell damage in view of hadrontherapy treatments

Presenter: BALLARINI, Francesca (University of Pavia and INFN-Pavia)

A biophysical model and Monte Carlo code simulating cell death and chromosome damage by different ionizing radiations, including those used in hadrontherapy, will be presented. The model, called BIANCA (BIophysical ANalysis of Cell death and chromosome Aberrations [1,2]), assumes that DNA “Cluster Lesions” (CLs) can produce chromosome aberrations (i.e., distance-dependent incorrect rearrangements of chromosome fragments), some of which can lead to cell death. The mean number of CLs per Gy and per cell is the first adjustable parameter; the second parameter is either the probability that a chromosome fragment remains unrejoined, or the characteristic distance governing chromosome-fragment rejoining, depending on which model version is used.
Comparisons with experimental dose-response curves for cell survival and/or chromosome aberrations allowed tuning the model parameters for a radioresistant cell line (representative of tumour cell response) and a normal one (representative of the response of healthy tissues), thus producing a database of CL yields for different particle types and LET values. Since the CL yield for a given particle type showed a linear-quadratic increase with LET, a fit of such database allows performing full predictions of cell death and chromosome aberrations in principle for any LET value within the range covered by the experiments.

Recently, the model was applied to calculate the dependence of cell death and chromosome damage on depth in tissue for SOBP profiles used in different centres, including the CATANA facility for eye melanoma treatment at INFN-LNS and the CNAO hadrontherapy centre in Pavia. In particular for protons, the biological effectiveness was found to increase in the distal region, and significant levels of damage beyond the distal dose fall-off were observed. In line with other studies, these results suggest that assuming a constant biological effectiveness along a proton SOBP may be sub-optimal.

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38 - Investigating energy deposition in cellular targets using multiscale tissue models

Presenter: Ms. OLIVER, Patricia (Carleton University, Department of Physics, Ottawa, Canada)

PURPOSE:
To investigate energy deposition in subcellular targets, quantify the microdosimetric spread in a population of cells, and determine how these results depend on details of multiscale Monte Carlo tissue models.

METHODS:
Multiscale tissue models are developed involving microscopically-detailed regions of interest (ROIs) embedded in bulk tissue phantoms irradiated by photons (20 keV to 1.25 MeV). Each ROI includes >1500 explicitly-modelled cells; specific energy (energy imparted per unit mass) is scored in nuclei and cytoplasm compartments using the EGSnrc user-code egs_chamber. Different cell arrangement methods and cell/nucleus size distributions are investigated. These microscopic tissue structure models are developed using published data on cell elemental compositions, sizes and number densities. Five cancerous/normal human soft tissues and water are considered. Use of egs_chamber at low doses (~mGy), considering subcellular (~micron) targets, is validated by comparison with results from the published literature.

RESULTS:
Populations of 1000 cells generate (normalized) specific energy distributions f(z) indistinguishable from those of a larger population, which suggests that 1000 is an adequate population size for statistical analysis. Validation test results are in good agreement with published experimental and computational data. For ~mGy doses, there is considerable variation in energy deposition (microdosimetric spread) throughout a cell population: considering muscle with 7.5 microns (3 microns) cell (nucleus) radius and a dose of 4 mGy, the standard deviation of specific energy (relative to the mean) for nuclear targets is 177% for 50 keV photons, and 114% for a Cobalt-60 spectrum. If the nuclear radius increases to 6 microns, then the relative standard deviation decreases to 74% and 47% for 50 keV and Cobalt-60, respectively. The mean specific energy for nuclei differs from bulk tissue dose by up to 30%, depending on cellular elemental compositions.

CONCLUSIONS:
At low doses, there is considerable variation in energy deposition within a population of cells. Mean nucleus specific energy generally differs from corresponding bulk tissue dose. Results highlight the importance of model validation and microdosimetric considerations at low doses, and indicate that energy deposition within subcellular targets is sensitive to cell morphology and composition, phantom medium, source energy, and dose.

39 - A Geant4-based simulation tool for irradiation of biological samples

Presenter: Mr. ŠEFL, Martin (Nuclear Physics Institute, Czech Academy of Sciences)

DNA is assumed to be the most critical target considering the biological effects of ionising radiation. Many radiobiological studies are lacking a detailed description of the irradiation set-up, which is particularly essential for experiments with heavy charged particles at the end of the Bragg peak when the LET varies considerably along the track.
Using Geant4, several configurations of radiobiological experiments with liquid plasmid DNA have been simulated. The calculations revealed that even a slight variation in the setup can affect the distribution of dose and LET substantially, and therefore modify the yield of radiation damage.
Ambiguous descriptions of the irradiation experiments led us to develop a Geant4-based application for biologists offering an easy way to model their radiobiology experiments, and provide them a tool to analyse the LET within their sample. It contains a library of widely used test tubes and selected other laboratory equipment to simplify the modelling for the user.

40 - Microdosimetry calculations for monoenergetic electrons using Geant4-DNA combined with a weighted track sampling algorithm

Presenter: Mr. FAMULARI, Gabriel (McGill University)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

Microdosimetry calculations for monoenergetic electrons using Geant4-DNA combined with a weighted track sampling algorithm

Gabriel Famulari (1,*), Piotr Pater (2), Shirin A Enger (1,3,4)
(1) McGill University, Medical Physics Unit, Montreal, Canada
(2) Centre hospitalier de l'Université de Montreal - Hôpital Notre Dame, Montreal, Canada
(3) McGill University, Department of Oncology, Montreal, Canada
(4) Research Institute of the McGill University Health Centre, Montreal, Canada
*presenting author

Purpose: The aim of this study was to calculate microdosimetric distributions for low energy electrons simulated using the Monte Carlo track structure code Geant4-DNA.

Materials and Methods: Tracks for monoenergetic electrons with kinetic energies ranging from 100 eV to 1 MeV were simulated in an infinite spherical water phantom using the Geant4-DNA extension included in Geant4 toolkit version 10.2 (patch 02). The microdosimetric distributions were obtained through random sampling of transfer points and overlaying scoring volumes within the associated volume of the tracks. Relative frequency distributions of energy deposition f(>E)/f(>0) and dose mean lineal energy (yD) values were calculated in nanometer-sized spherical and cylindrical targets. The effects of scoring volume and scoring techniques were examined. The results were compared with published data generated using MOCA8B and KURBUC.

Results: Geant4-DNA produces a lower frequency of higher energy deposits than MOCA8B. The yD values calculated with Geant4-DNA are smaller than those calculated using MOCA8B and KURBUC. The differences are mainly due to the lower ionization and excitation cross sections of Geant4-DNA for low energy electrons. To a lesser extent, discrepancies can also be attributed to the implementation in this study of a new and fast scoring technique that differs from that used in previous studies. For the same mean chord length, the yD calculated in cylindrical volumes are larger than those calculated in spherical volumes. The discrepancies due to cross sections and scoring geometries increase with decreasing scoring site dimensions.

Conclusion: A new set of yD values has been presented for monoenergetic electrons using a fast track sampling algorithm and the most recent physics models implemented in Geant4-DNA. This dataset can be combined with primary electron spectra to predict the radiation quality of photon and electron beams.

41 - Consequences of patient heterogeneities for intermediate-energy sources in post-implant assessment of prostate brachytherapy treatment plans.

Presenter: Mr. FAMULARI, Gabriel (McGill University)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

Consequences of patient heterogeneities for intermediate-energy sources in post-implant assessment of prostate brachytherapy treatment plans.

Gabriel Famulari (1,*), Marc-André Renaud (1), Emilie Soisson (1), Marie Duclos (2), Shirin A Enger (1,2,3)
(1) McGill University, Medical Physics Unit, Montreal, Canada
(2) McGill University, Department of Oncology, Montreal, Canada
(3) Research Institute of the McGill University Health Centre, Montreal, Canada
*presenting author

Purpose: Recent studies have identified and proposed gamma emitting radionuclides (75Se, 169Yb, 153Gd) with intermediate energy (50 keV < E < 200 keV) as an alternative to 192Ir for HDR brachytherapy. The impact of tissue composition and density on the treatment plan quality was studied in a retrospective evaluation for a prostate cancer patient using a range of high- and intermediate-energy brachytherapy sources: 60Co, 192Ir, 75Se, 169Yb, and 153Gd.
Material and Methods: Post implant treatment plans were simulated with a Geant4-based Monte Carlo dose calculation engine, BrachySource, coupled to a column-generation based optimizer, for a prostate brachytherapy case. The patient was treated with a brachytherapy boost with a dose of 15 Gy in a single fraction. Simulations were performed using 60Co, 192Ir, 75Se, 169Yb, and 153Gd as the active cores of the source. The plans were independently approved by two radiation oncologists. Two MC calculation protocols were performed for each radionuclide: (1) dose calculations for which patient anatomy is modelled as unit density water and (2) dose calculations for which patient anatomy is modelled with accurate chemical composition of tissues and densities are obtained using the HU values from CT scan.
Results: The inclusion of tissue composition and density corrections resulted in a reduction of the PTV D90 (urethral D10) by 0.0 % (0.0 %), 0.8 % (0.7 %), 1.8 % (1.6 %), 3.0 % (4.7 %) and 4.5 % (4.1 %) for 60Co, 192Ir, 75Se, 169Yb, and 153Gd, respectively. In general, dose homogeneity within the PTV increased with decreasing average photon energy. With 90 % of the planning target volume (PTV) receiving over 15 Gy, plans can reduce the PTV V150 to 19.8 %, 18.0 %, 18.5 %, 13.7 % and 11.6 % for 60Co, 192Ir, 75Se, 169Yb, and 153Gd, respectively, without sacrificing the urethral D10, the bladder V75 and the rectum V75.
Conclusion: This work shows the importance of using accurate model-based treatment planning, which can account for tissue composition and heterogeneities, for the dosimetry of intermediate-energy sources. Intermediate-energy sources have the potential to increase dose homogeneity within the PTV while reducing hot spots in the urethra, bladder, and rectum.

42 - Three-Dimensional Dose Evaluation of the Blood Irradiator using Monte Carlo Simulation

Presenter: Prof. WU, Jay (Department of Biomedical Imaging and Radiological Sciences, National Yang-Ming University); Mr. LIU, Yan-Lin (Institute of Nuclear Engineering and Science, National Tsing Hua University, Hsinchu, Taiwan)

Blood irradiators are frequently used to irradiate blood products to decrease the occurrence of the graft versus host disease and inhibit the proliferation of lymphocytes. The dose distribution within the irradiation volume is affected by the source and sample geometry. Understanding the three-dimensional dose distribution is therefore necessary. In this study, MCNPX was used to construct the geometry of the blood irradiator, and simulate the Cs-137 exposure to the sample. Absorbed doses were tallied in different distances from the central axis, and compared with the results obtained by the Gafchromic EBT film. In addition, the mesh tally was used to evaluate the three-dimensional dose distribution. Simulated results showed that the dose at the distances of 0.0, 0.8, 1.8, and 2.8 cm from the axis was 29.7, 25.8, 22.4, and 21.3 Gy, respectively. The percent differences between Monte Carlo simulation and film measurement were 8.7%, 3.0%, -0.5%, and -5.1%. The dose was a function of distance from axis in the XY plane with a fitting formula of y = 29.233e-0.128x (R2=0.99). Cold spots can be observed in the top and bottom of the axis.

43 - Database of neutron shielding for a 250-MeV proton accelerator

Presenter: Prof. WU, Jay (Department of Biomedical Imaging and Radiological Sciences, National Yang-Ming University); Mr. LIU, Yan-Lin (Institute of Nuclear Engineering and Science, National Tsing Hua University, Hsinchu, Taiwan)

Semi-empirical formulas and analytical solutions are frequently used for shielding design of a proton accelerator in the preliminary planning phase. However, comprehensive distribution information about medium and low energy neutrons are still lacking. In this study, the FLUKA Monte Carlo code was used to simulate the collision of 250-MeV protons with copper, iron, and soft tissue, respectively. The angular distribution of neutrons and the depth dose in concrete caused by neutrons were evaluated. The results showed that the neutron yield of proton collision with the high Z material was higher than that with the low Z material. The mean energy of neutrons in the small emission angle was higher than that in the large emission angle. For the depth dose simulation, the proportion of low energy neutrons increased as the emission angle increased. The source terms and the attenuation lengths were fitted and can be further applied to the neutron dose evaluation.

44 - Evaluation of Skin Doses during Manipulation of Radioactive Sources in Nuclear Medicine: a Comparison between Varskin Code and Geant4 Simulations

Presenter: Dr. AMATO, Ernesto (University of Messina)

Ernesto Amato (1,*), Antonio Italiano (2), Sergio Baldari (1)

(1) University of Messina, Department of Biomedical and Dental Sciences and of Morphofunctional Imaging, Messina, Italy
(2) Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Messina, Italy
* presenting author

The assessment of dose equivalents, Hp(0.07), to the skin of the hands during manipulation of radioactive sources for radiopharmaceutical preparations is a critical task in radiation protection.
During these preparations, alpha-, beta- and gamma-emitting radionuclides in liquid solutions are contained in vials, syringes or other small receptacles, eventually inside plastic or metal shields, and hands are protected against contamination with gloves. Accidentally, some contamination of gloves or even of the naked skin can happen.
Estimation of skin doses to fingertips can be carried out exploiting pre-calculated tables of dose rates in standardized geometries [1], or using softwares based on analytical calculations such as Varskin [2].
We compared systematically, for 20 radionuclides commonly emlpoyed in nuclear medicine, Hp(0.07) in mSv/MBq for point-like and extended sources, either in contact or in presence of different thicknesses of interposed material (glass, plastic), as resulted from severeal releases of Varskin (mod2, 4, 5.3) with the output of Monte Carlo simulations in Geant4.
Results indicate that the most recent version of Varskin gives the best agreement with Monte Carlo simulation, having implemented a more accurate treatment of both photons and electrons.
A good agreement was found for all nuclides for a point source in contact with skin. When a material is interposed, however, the disagreement between analytical and Monte Carlo results increases with material thickness for some nuclides, particularly for pure beta emitters and low-energy electron emitters.
These results can be explained by the deterministic approach in which electron energy deposition is treated in the analytical code and its influence in proximity of electron range, and to the neglection of bremsstrahlung emission.
Another source of discrepancy, for some nuclides, is the difference in radionuclide emission spectra.
When the accuracy of estimation of skin doses is critical, as after an anomalous exposition event with high activities in extended sources or with a thin layer of interposed material, Monte Carlo simulation is the most accurate calculation approach.

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45 - Development and analysis of the track-LET, dose-LET and RBE calculations with a therapeutical proton and ion beams using Geant4 Monte Carlo code

Presenter: Dr. PETRINGA, Giada (LNS; Università degli Studi di Catania)

A reliable prediction of the spatial Linear Energy Transfer(LET) distribution in a biological tissues is a crucial point for the estimation of the radiobiological parameters on which are based the current treatment planning[1]. Nowadays, the accuracy and approach for the LET calculation can significantly affect the reliability of the calculated Relative Biological Effectiveness(RBE)[2].
The LET is not a physical quantity that can be easily measured, and therefore, values are usually estimated by calculating stopping power based on the Bethe-Bloch equation. Its definition, as reported in ICRU Report No.85, is related to a non-stochastic quantity that describes the average energy transfer from electronic interactions per unit length travelled by charged primary particles.
The Monte Carlo(MC) technique is the most accurate method to account for complex radiation transport effects and energy losses in a medium.However, as a computation method, the accuracy and precision of the MC calculation results strongly depend on the physics interaction cross sections applied as well as on the simulation algorithms used and the transport parameters chosen[3]. The main aim of this study was to develop a completely open source tool based on Geant4 code for the calculation of the LET-track and LET-dose distributions of therapeutic proton and ion beams.Furthermore, the main parameters that can influence the LET calculation in a typical MC simulation based on a voxelized equivalent tissue phantom, were identified and investigated. Particular attention was given to the energy loss process due to the electronic interactions such as ionization and excitation of the primary incident particles and to the production cut and step dependence.Moreover, the secondary nuclei generation was considered and opportunely weighted to the computational total-LET-dose calculation.A module to couple the MC calculation to LEM radiobiological model has been studied and a series of calculations were performed to illustrate the impact of different LET values on the RBE-weighted dose.

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46 - Monte Carlo software for patient dosimetry in interventional radiology

Presenter: Mr. DESCHLER, Thomas (IPHC/CNRS - ALARA Expertise)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

Monte Carlo software for patient dosimetry in interventional radiology

Thomas Deschler (1,2,*), Nicolas Arbor (1), Sara Beilla (2), Pierre Dillenseger (2), Stéphane Higueret (1), Ziad El Bitar (1), Emmanuel Medernach (1), Fanny Carbillet (2) and Abdel-Mjid Nourreddine (1)
(1) Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France
(2) ALARA Expertise, 4 rue La Fayette, 67100 Strasbourg, France
*presenting author

Interventional radiology procedures present a significant irradiation risk for the patient. In case of overexposure, it would be necessary to estimate precisely the patient dose distribution in order to prevent deterministic effects. In this context, a Monte Carlo software has been developed to allow a fast and accurate post-operative calculation of patient dosimetric quantities (organ and skin dose, dose maps).

The developed software is based on the Monte Carlo code GATE v8.0 [1], supplemented by various original developments to allow a modeling of the full procedure. The X-ray beam, obtained from the widely-used spectrum generator SpekCalc [2], is processed and oriented following the parameters contained in DICOM files and a wireless device especially designed for this application. The patient is simulated from XCAT phantoms [3] or from CT-scan when available. Several variance reduction methods are used (Track Length Estimator (TLE), split exponential TLE) to calculate patient dose maps. A GPU algorithm is also currently being developed to complete those methods.

After a scaling of the X-ray spectra based on the quality control of the machine, the first results comparison, with on-site ionization chamber measurements, showed a difference lower than 5% for the reconstruction of the air kerma in the primary beam. The use of variance reduction methods allows to compute the dose of the main exposed organs with a statistical uncertainty lower than 5% in less than 5 minutes. With the GPU algorithm, a reduction of the computing time by a factor of 50 can be expected.

By combining a precise modeling of the machine and a fast dose calculation, this software makes possible the clinical use of Monte Carlo simulation for an accurate estimate of patient organ and skin dose.

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47 - Modelling of a novel x-ray source for MR-guided radiotherapy

Presenter: Ms. ROBERTS, Natalia (Centre for Medical Radiation Physics, University of Wollongong, Wollongong, NSW, Australia, Ingham Institute for Applied Medical Research, Liverpool, NSW, Australia)

The purpose of this work was to model a novel x-ray source that is the current linear accelerator in use for the Australian MRI-linac system. MR-guided radiotherapy is an advanced technique which combines the excellent soft tissue contrast and high temporal resolution of MR imaging with the therapeutic benefits of radiotherapy. This system will achieve real-time tumor tracking, where the treatment beam can be adapted to shifts in the tumor geometry enabling tighter dose margins with a subsequent reduction in dose to healthy tissue surrounding the target. However, the transport of radiation is influenced by the strong magnetic fields produced by the MRI-scanner and needs to be accounted for in dosimetric calculations.

The experimental setup for commissioning of the system at zero field (0T) was modelled with the Monte Carlo toolkit Geant4. This configuration includes the linac, multileaf collimators (MLCs) and the phantoms used during the measurements. The simulations were two stages: an electron beam hitting the target and scoring all particles in a phasespace that cross a plane before the MLCS, in the second stage the particles pass through the MLCs and dose deposited inside the phantoms is stored. Simulations were run for open fields and MLC defined field sizes, profiles at various depths were acquired as well as percentage depth dose (PDD) curves. These results were then compared to measurements taken with a CC13 ion chamber in a water tank and Gafchromic film in solid water.

To date the simulated results are in good agreement with the measured data, for open field data agreement between PDDs was within 2%. The nominal energy of the system has been determined to be within the range of 5.6–6MV, which matches the specifications of the linac. Analysis of the energy spectrum showed the photons downstream of the linac contained a higher low energy component compared with typical clinical radiotherapy beams due to the absence of a flattening filter.

This phase of the project is essential to obtain a comprehensive model of the complete system which will be used to develop a Monte Carlo treatment plan verification tool for the Australian MRI-linac.

48 - Estimation of backscatter from internal shielding in electron beam therapy using Monte Carlo simulations and Gafchromic film

Presenter: Mr. SINGH, Sukhvir (Institute of Nuclear Medicine and Allied Sciences, New Delhi, India)

Superficial lesions of lip, eyelid, buccal mucosa, earlobe, and nose are widely treated with the electron beam. Electron beam provides the advantage of rapid dose fall off beyond a certain depth in tissue. However, in some clinical situations where critical normal tissues lie in close vicinity to the treatment target, internal shielding of lead/tungsten is employed to protect the critical tissues. The backscattered electrons from the internal shielding enhance the dose considerably in the upstream direction. This dose enhancement, especially at lower energy electron beams, depends on the characteristic spectrum of the electron beam from individual linear accelerators (linac)1,2. Therefore, detailed investigation of the backscatter from a linac may show specific interesting values useful while designing the internal shielding.

In the present study, the backscattered electron dose was estimated using Monte Carlo (MC) simulations and compared with Gafchromic film measurements. 6 MeV and 9 MeV electron beams generated by a Varian 2100 C/D linac were simulated using EGSnrc based MC code BEAMnrc. Multiple MC simulations using code DOSXYZnrc were run to simulate a water phantom containing 2 mm lead at different depths namely 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 cm. The electron backscatter factor (EBF), defined as the ratio of the dose at tissue/lead interface to the dose at the same point without the presence of lead shielding, was calculated. The effectiveness of 2 mm aluminum on the upper surface of the lead shield in the reduction of electron backscatter dose and the range of the backscatter towards the surface were also assessed. The Gafchromic film measurements were performed in a water phantom with the geometries similar to the MC simulations and compared with corresponding MC estimated values.

The MC model was validated using measured percentage depth dose (PDD) values in a water phantom. The MC calculated and diode measured PDD values agreed well within 2% and 2 mm distance to agreement (DTA). The EBF estimates showed that for a particular beam energy, the EBF value initially increased with depth in the build-up region and then decreased rapidly. The highest value of EBF for both the energies is nearly same (1.56 for 6 MeV and 1.55 for 9 MeV) though at different depths. There is decreased EBF for 9 MeV electron beam as compared to 6 MeV electrons for the lead shielding placed at a fixed depth. 2 mm aluminum reduces the backscatter by nearly 25% at maximum backscatter condition for both the energies, though the effectiveness slightly decreased at higher energy beam (9 MeV). At shallower depths, the reduction in backscatter due to the aluminum sheet is less because the backscatter in this range consists of relatively higher energy electrons. The range of backscatter electrons was found to be varying from 5 mm to 12 mm in the upstream direction from the interface. The Gafchromic film measured relative PDD values with lead shielding, normalised at maximum dose without the lead shield, were compared with the MC calculated relative PDD values and were found to be well within ±3% except in the close vicinity of the lead-water interface. The film measured EBF was 7% lower at the lead interface. The PDD difference is acceptable in most of the clinical situations.

The MC estimated EBFs, also verified with Gafchromic film measurements, for the two electron energies (6 and 9MeV) from a Varian 2100 C/D provide the important clinical information at the local clinical setup while considering the effect of backscatter electrons from internal shielding. The study can be further extended for all electron energies available with the local linac to customize the internal shielding design.

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49 - Monte Carlo simulation of breast screening programmes

Presenter: Prof. LALLENA, Antonio M. (Universidad de Granada)

INTRODUCTION

Although breast screening programs are widespread in developed countries, there is still some controversy about which is the most suitable configuration and whether they are fully justified. Aspects such as the age of the patients for whom the screening test is effective, specially in case of women aged between 40 and 49 and older than 65, and how often women should undergo mammography are still under discussion.

In this work we have developed a Monte Carlo tool able to reproduce the outcomes of a given screening program: annual detection rate, average diameter of invasive tumors, invasive/in situ rate, interval cancer rate, etc. Once tuned, this tool can be used to evaluate the mortality reduction rate and the overdiagnosis for different configurations that include different age ranges and mammography frequencies. We have also adapted it to simulate the main randomized controlled trials on breast screening programs and this has permitted us to assess their internal and external validity by comparing the central values and confidence intervals of the relative risk obtained in the simulations with those quoted for the trials analyzed.

MATERIAL AND METHODS

The tool is structured in four parts according to the type of data or assumptions considered:

(i) parameters related to the women involved in the screening (woman ages or incidence of breast cancer as a function of the woman age);

(ii) tumor characteristics ruling the detection probability by mammography (tumor growth model, tumor size, breast histology and density);

(iii) aspects related to the screening program configuration (mammography frequency, age limits for the participating women), and

(iv) a model of the detection probability by mammography based on known values of sensitivity and specificity.

In the simulations a total of 50 million of candidate women were followed, keeping into account, during the development of the programme, the tumors detected within it as well as those clinically detected (cancers of interval for women within the program). This permits to estimate the annual reduction in breast cancer mortality due to mammographic screening for any configuration, that is for any age range of the women undergoing the programme and any mammography frequency. In addition, the comparison of the results obtained with those found for the same population in the absence of screening provides with an estimation of the overdiagnosis due to breast screening programs.

The tool has been adapted to simulate various randomized controlled trials providing us with the relative risks, which have been compared to those quoted for the trials. As the simulations consider the same population characteristics for the different configurations of these trials, their external validity has been addressed. On the other hand, the relative risks obtained were compared to those quoted for the trials and this allows to analyze their internal validity by further investigating the reasons of the disagreements observed.

RESULTS

With our Monte Carlo tool the results of breast cancer screening programmes are consistently reproduced. Specifically, the annual detection rate of different actual programmes and the ratio of invasive ductal carcinoma (DC) to ductal carcinoma in situ (DCIS) found agree with those found for actual programmes. The average tumour size of invasive and in situ detected tumors was also estimated without being necessary to assume a quicker growth for the invasive DC cancers.

A reduction in breast cancer mortality up to 29% has been found for a configuration that includes women aged between 50 and 70 years, with a screening interval of two years and 100% acceptance rate. For a 70% acceptance the percentage reduces to 20%. If, in the same conditions, the program starts at 40 years, the reduction of the mortality reaches 24% while if the screening interval is one year, it raises to 28%.

In the case of the age group between 50 and 70 years, our results provide estimates of the overdiagnosis of 20%, 15% and 11% when mammography tests are carried out every 1, 2 and 3 years, respectively. For the 40-70 years group, overdiagnosis results in 17%, 12% and 10% for the same interval times.

The results of most of the various randomized trials are nicely reproduced with the Monte Carlo tool. This is an indication of their methodological quality and external validity. A reduction of the breast cancer mortality around 20% appears to be a reasonable value according to the results of the trials that are methodologically correct. Discrepancies observed with some of the trials may be attributed to a low mammography quality and/or some methodological problems.

CONCLUSIONS

In this work we have developed a model based on Monte Carlo simulation that is able to reproduce the results of breast cancer screening programs in a consistent way. Different screening configurations have been studied in order to compare their respective efficiency.

One of the main points is that is not necessary to assume a quicker growth of the invasive cancers to reproduce results. Mortality reductions of 12%–20% (between two and four deaths per year and 100000 women) are obtained only for acceptances above 50%. This could be considered as a threshold for the acceptance, which appears to be a critical parameter.

Our tool allows to reproduce the known results of overdiagnosis. This varies between 10 and 20%, depending on the configuration. It is found that, after the end of the screening program, the number of invasive cancers detected is similar in the control and in the screening group, which implies that overdiagnosis is almost exclusively associated with in situ tumors.

Monte Carlo simulations appear to be a very powerful tool to investigate breast screening controlled randomized trials, helping to establish which of their results may be extrapolated to other populations, to design the trial strategies and, eventually, to adapt them during their development.

50 - Application of a Monte Carlo algorithm in dosimetric verification of pencil beam scanning proton therapy treatments

Presenter: Mr. FRACCHIOLLA, Francesco (Protontherapy Department - APSS Trento)

Purpose: to show the validation, clinical application and implications of a Monte Carlo (MC) dose calculation algorithm used for dosimetric verification of proton therapy (PT) treatment plans delivered with pencil beam scanning.

Methods: Patient Specific Quality Assurance of 70 patients with head-and-neck and brain lesions were selected for this study. 530 measurements of 2D planar distributions at three depths per field in a water equivalent phantom with an array of ionization chambers were carried-out. The comparison between measured and calculated (via TPS – RayStation, RAYSEARCH v5.0.2) 2D-distributions is done via γ analysis (3%,3mm) setting the minimum acceptable passing rate (γ-PR) at 90%. The MC algorithm (based on TOPAS), previously characterized and validated, was used to simulate the actual QA measurements for a subset of 38 patients from the cohort. 262 simulations were compared with measurements and with TPS calculations via γ analysis. To evaluate if the MC was predictive of the results of the reference test (TPS vs measurements) we performed a sensitivity/specificity test on the comparisons between TPS and MC.

Results: The 530 comparisons between TPS and measurements gave a median γ-PR and a 10° percentile of 98.05% and 91.81%, respectively. The agreement between MC and measurements evaluated via the γ passing rate was always very high: the median γ-PR over 262 comparisons was 99.44% while the 10° percentile of results was 96.36%; TPS vs MC comparison gave a median γ-PR and a 10° percentile of 95.86% and 80.98%, respectively. We estimated that the sensitivity and specificity of the test were 42.9% and 69.8%.

Conclusions: We developed a MC algorithm to verify the dose distribution of PT treatments. By using the γ analysis as metric, we validated the code with an high level of agreement, better than the TPS. If the MC is used to replace measurements in comparisons with TPS calculations it shows a low sensitivity and specificity in detecting correct results when using γ test as the metric. This study highlights the limitations of the gamma analysis and underlines the need to define a new and more robust metric for such comparisons.

51 - Monte Carlo optimization of a neutron beam from 5 MeV ^{9}Be(p,n)^{9}B reaction for clinical BNCT

Presenter: POSTUMA, Ian (PV)

Boron Neutron Capture Therapy (BNCT) is an experimental radiotherapy that uses the combination of neutron irradiation and ^{10}B to treat neoplasms.
By means of this technique, many clinical trials were performed worldwide with promising results[1] using research nuclear reactors as
neutron sources. Anyhow, these machines have several problems that hinder the development of dedicated BNCT hospitals.
This issue can now be overcome by using intense-current proton accelerators, which coupled with beryllium or lithium targets
yield more than 10^{14} neutron per second. This can be a boost to BNCT because accelerators are more compact and can be installed
within hospitals.

The Italian National Institute of Nuclear Physics (INFN) designed and manufactured a Radiofrequency Quadrupole proton accelerator
(RFQ) [2], which delivers 5 MeV protons with 30 mA current in a Continuous Wave (CW) mode and it is coupled to a beryllium target.
This accelerator could be installed at Centro Nazionale di Adroterapia Oncologica (CNAO) in Pavia.

In this work we present the MC calculations for the tailoring of a BNCT neutron beam obtained by the described RFQ.
Firstly, we show that MC transport codes such as MCNP and PHITS are not able to simulate the correct
neutron spectra from 5 MeV protons interacting on beryllium. Therefore, the neutron double differential source implemented in
MCNP was extracted from the measurements performed by Agosteo et al.[3]. As the energy range goes up to 3.5 MeV, neutrons need
to be moderated and collimated by a Beam Shaping Assembly (BSA), because BNCT requires a spectrum peaked between 1 and 10 keV.
Differently from the past, where the optimal configuration was chosen according to physical characteristics of the beam, in this
case the results were evaluated on the basis of the dosimetry obtained in a real clinical case by treatment planning simulation.
What emerges, is that the classical figures of merit employed for the tailoring of a clinical BNCT [4] should be taken as a first
guideline, while the dosimetric assessment on realistic clinical scenarios is the most appropriate criterion for beam evaluations.

53 - Impact of the true sensitive volume on ion chamber response in magnetic fields

Presenter: Mr. MALKOV, Victor (Carleton University)

Development of magnetic resonance guided radiation therapy (MRgRT) has sparked interest in evaluating the performance of ion chambers in the presence of magnetic fields. The effect of the field on electron trajectories alters ion chamber response [1]. In most Monte Carlo (MC) simulations, the geometric sensitive volume, often beginning at the edge of chamber's stem, is used instead of the potentially unknown true collection volume [2]. This work evaluates the sensitivity of chamber response in the presence of magnetic fields to the collection volume used in the MC calculation. The egs_chamber application of the EGSnrc system is used with a recently validated magnetic field transport algorithm [3] to simulate the response of several ion chambers. The chambers are simulated in a PMMA phantom with an incident Co-60 photon beam and magnetic fields between 0 and 2 T, perpendicular to both the incoming photon field and the long axis of the ion chamber. The dose, normalized to 0 T, is calculated in the geometric sensitive volume with either the first 0, 0.5, or 1.0 mm of the volume away from the stem excluded. Increases in chamber response with a maximum of 1.77 +/- 0.03 % and 3.33 +/- 0.03 % are observed for a reduction in the length of the collection volume by 0.5 mm and 1.0 mm, respectively. For four chambers, the reduced volumes generally give better agreement with experimental results [4]. Various chamber orientations are under investigation to minimize the effect. This is an important effect that must be addressed to ensure proper calibration of MRgRT machines.

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55 - Beam characterization for the TULIP accelerator for protontherapy through Full Monte Carlo simulations

Presenter: Ms. CUCCAGNA, Caterina (TERA Foundation/ University of Geneva)

TULIP, Turning LInac for Protontherapy, is a novel accelerator systems for protontherapy mounted on a rotating gantry designed by the TERA Foundation and CERN [1]-[2].
TULIP is natively designed with a 3D active scanning system that, besides the transverse scanning with fast magnets, features a fast beam energy variation from the linac to scan in the longitudinal direction in few ms.
The main goal of this research is to characterize TULIP's beams, through Full Monte Carlo (MC) simulations.
The study combines two multi-particle tracking programs, RF Track [2] and TRAVEL [3]), and the FLuka Monte-Carlo code [4-5], enabling to follow each particle from the source through the linac, the beam transfer lines and the nozzle elements, until the isocenter such that transverse and longitudinal phase space characteristics are accounted for each particle.
The work includes the Fluka modelling of the last magnets of the gantry line characterized by complex magnetic field map.
The particle fluence results in air at the isocenter and in upstream and downstream positions along the beam direction and the depth-dose curves are obtained and presented in a beamline model for a set of beam energies, foci and scanning magnet kick strengths.
The results, suitable for characterizing in detail the beam spots for this particular accelerator system, can be used as input to generate a beam model in a commercial TPS and thus to allow the comparison with Fluka results in real patient case scenarios.

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56 - Large scale Monte Carlo recalculation/evaluation of AAA lung SBRT cases

Presenter: Mr. DIAMANT, André (McGill University)

Purpose:
To perform and evaluate a large-scale Monte Carlo (MC) recalculation of lung SBRT plans originally calculated with Analytical Anisotropic Algorithm (AAA).

Methods:
89 stage I non-small cell lung cancer SBRT plans were included in this study. Each plan was initially calculated using AAA, then recalculated on the exact same grid dimensions using an MC algorithm (egsNRC) with validated beam models. The parameters of the MC algorithm were as follows: 50,000,000 histories, a phantom voxel size of 0.25x0.25x3 mm, an electron cut-off energy of 189 keV and a photon cut-off energy of 10 kV. Both heterogeneity corrections and the boundary crossing algorithm were incorporated. The dose difference was calculated on a voxel-by-voxel basis for every plan. The regions that were considered were the planning target volume (PTV) and an accumulative region extending isotropically outward from the PTV. In each of these regions, the mean/median/maximum dose difference was computed and the value averaged over all patients was reported. Finally, correlation with the PTV volume was evaluated to determine whether lesions of varying sizes could accentuate this inaccuracy.

Results:
AAA was found to consistently underestimate the dose to regions close to a high-density/low-density boundary. The magnitude of this underestimation increases as we approach the boundary, reaching a maximum within the PTV itself. The mean (range) relative underestimation within the PTV was 5.8%(1.5%,9.2%). The correlation coefficient (95% CI) between the dose difference and the PTV size was found to be -0.47(-0.29,-0.62), p-value of <0.0001.

Conclusion:
We performed a large-scale MC recalculation of AAA-calculated lung SBRT plans. It is hypothesized that AAA underestimates the dose due to a combination of factors; notably backscatter and re-buildup within the high-density region. Due to the correlation with PTV volume, caution should be taken particularly while treating small lesions within the lung.

57 - Allowing for crystalline structure effects in Geant4

Presenter: BAGLI, Enrico (FE)

A fundamental aspect of a successful physics experiment is the availability of a reliable and precise simulation code. In particular, Geant41,2,3 has seen a large expansion of its user community in recent years. The GECO project has been devoted to the development of a general framework for the management of solid-state structures in the Geant4 kernel and to validate it against experimental data4. The development of a Geant4 extension for the handling of crystal structures allows the simulation of the mutual influence of various physics fields, and the exploration of novel applied physical effects. The enhancement of the Monte Carlo permits to study the influence of solid-state effects on the physics for medical application, e.g. the variation of the nuclear interaction rate in crystals with respect to amorphous materials.

58 - Extending the Low Energy Particle Track Simulation (LEPTS) code to higher energies

Presenter: Prof. GARCIA, Gustavo (Instituto de Física Fundamental (IFF)-CSIC)

Some inconsistencies found during the integration of LEPTS with GEANT4 in order to simulate single particle tracks from the high energy of the primary beam down to the final thermalisation of the secondary electrons have been solved by extending the LEPTS procedure to higher energies. New processes as multiple ionisation and radical generation have been implemented to provide accurate energy deposition data and also additional information on the number and type of interactions occurring in selected nanovolumes.

60 - Monte Carlo simulation and experimental validation of glandular dose coefficients in digital breast tomosynthesis

Presenter: METTIVIER, Giovanni (NA)

The mean radiation dose to the glandular tissue and its dependence on the irradiation geometry, beam quality, breast size and composition in digital breast tomosynthesis (DBT) exams have been studied extensively via Monte Carlo calculations [1]. On the other hand, there are few comprehensive studies on the dose distribution within the irradiated breast [2]. The distribution of glandular dose for breast irradiation from a plurality of angles, as occurs in DBT, may be of large interest in scanner optimization as well as for developing suitable models for the evaluation of the cancer risk related to the X-ray exposure for non-homogeneous irradiation. For this reason, it is of interest to evaluate the level of homogeneity of the dose spread, via the assessment of 3D dose maps in breast models during a DBT scan.
This work aimed at evaluating, via Monte Carlo (MC) simulations and measurements using radiochromic films, the dose distribution within compressed layered breast phantoms during DBT scans. For this purpose, two phantoms were employed: a PMMA homogeneous phantom and a heterogeneous phantom simulating a 50% glandular breast. A series of pre-calibrated (vs free-in-air air kerma) film pieces were inserted between the phantom slices and the 3D dose maps were measured for a set of DBT scans on different commercial units, for different sample thicknesses, at various exposure technique factors. We developed an MC code based on GEANT4 toolkit ver. 10.00, simulating the clinical setup specifications, whose results have been compared to measurements.
This project received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 692097 for the MaXIMA project: Three dimensional breast cancer models for X-ray imaging research.

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61 - Validation of Geant4 nuclear reaction models for hadrontherapy and preliminary results with SMF and Blob

Presenter: MANCINI TERRACCIANO, Carlo (ROMA1)

Reliable nuclear fragmentation models are of utmost importance in hadrontherapy, where MCs are used to compute the input parameters of the treatment planning software, to validate the deposited dose calculation, to evaluate the biological effectiveness of the radiation, to correlate the β+ emitters production in the patient body with the delivered dose, and to allow a non-invasive treatment verification.
Despite of its large use, the models implemented in Geant4 have shown severe limitations in reproducing the measured secondaries yields in ions interaction below 100 MeV/A, in term of production rates, angular and energy distributions. We will present a benchmark of the Geant4 models with double-differential cross section and angular distributions of the secondary fragments produced in the C12 fragmentation at 62 MeV/A on thin carbon target, such a benchmark includes the recently implemented model INCL++. Moreover, we will present the preliminary results, obtained in simulating the same interaction, with SMF and Blob. Both, SMF and BLOB are semiclassical one-body approaches to solve the Boltzmann-Langevin equation. They include an identical treatment of the mean-field propagation, on the basis of the same effective interaction, but they differ in the way fluctuations are included.
In particular, while SMF employs a Uehling-Uhlenbeck collision term and introduces fluctuations as projected on the density space, BLOB introduces fluctuations in full phase space through a modified collision term where nucleon-nucleon correlations are explicitly involved. Both of them, SMF and BLOB, have been developed to simulate the heavy ion interactions in the Fermi-energy regime. We will show their capabilities in describing C12 fragmentation foreseen their implementation in Geant4.

62 - A GEANT4 Tomotherapy model to evaluate a patient-specific dose QA program

Presenter: Dr. ESPOSITO, Alessandro (Azienda Ospedaliera Santa Maria - Terni)

Introduction.
Helical Tomotherapy (HT) combines a fan-beam delivery in a helical fashion with a MegaVoltage Computed Tomography (MVCT) imaging in order to treat complex tumours. For a high quality and safe treatment, a machine Quality Assurance (QA) program and patient-specific dose verifications are requested. Monte Carlo (MC) method is nowadays the key issue in patient-specific dose verifications [1] because of its most detailed and complete description of radiation-matter interaction. In this work we present a complete validated GEANT4 numerical MC model of a HT for QA and treatment plan dose check.

Materials and methods.
The HT model, firstly adjusted and commissioned on the basis of reference experimental data in water tank, was used to verify two plans through comparison with the HT treatment planning system (TPS) on water equivalent dedicated phantom.
Gamma function approach (2%, 2mm) was applied in both model commissioning and treatment verification. In addition, a MVCT image was reconstructed by acquiring simulated sinograms on a digitally constructed water equivalent phantom with high and low density inserts. Easy configuration of the simulation by non-expert users is possible without the need of writing code by the usage of command text files interpreted by the software.

Results.
The commissioning of the beam HT head parameters resulted in 97.5% of Gamma Points < 1. The treatments simulations assessment showed similar results with the TPS calculation in terms of dose profiles at the target location in water equivalent phantom. The simulated MVCT image allowed identifying both the low- and high-density details. A visual interface is in development to allow a faster and easier usage compatible with the clinical timelines.

Conclusion. The HT model is validated and the software demonstrated to be a solid tool to implement and evaluate a patient-specific dose QA for the HT plans given the high agreement level with the HT-TPS.

Acknowledgments.
We would like to thank Mauro Iori and the Medical Physics Unit, IRCCS - Arcispedale Santa Maria Nuova, Italy for their support and clinical data used in this study.

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63 - Monte Carlo modelling and experimental verification of a high resolution silicon diode array performance in proton beams and magnetic fields

Presenter: Dr. OBORN, Brad (Illawarra Cancer Care Centre)

Purpose: To present Geant4 Monte Carlo modelling and experimental verification of the performance of a high resolution silicon diode array for proton beam dosimetry inside a magnetic field. This experiment emulates the challenging dosimetry conditions expected in future real-time MRI-guided proton therapy.

Materials/Methods: Geant4 (version 10.1) was used to model an experimental beamline which consisted of 10 mm collimated proton beams of 90, 109, and 125 MeV. These beams were incident upon a PMMA phantom which held a novel high resolution epitaxial silicon diode array (“DUO”). The DUO detector contains two 52 mm strips of sensitive volumes spaced at 0.2 mm pitch. These form a cross-hair and so enabled the Bragg-peak of proton beams to be mapped out in the depth-dose direction and cross-profile direction at high resolution. The entire phantom was also tested inside a 0.95 T magnetic field which was generated by a C-shaped permanent magnet. This induced a small but easily resolvable deflection of the proton beams. The Monte Carlo model also included a map of the magnetic field and all detector phantom components, as well as the C-shape permanent magnet.

Results: A pristine Bragg-peak was not observed for each proton beam energy due to the various different mediums contained within the detector and phantom. Monte Carlo modelling matched well to the experimental results and was extremely helpful in detailing the origins of the various partial Bragg-peaks induced by the complicated detector and phantom geometry. The magnetic deflection of the proton beams matched to within <0.5 mm between the Monte Carlo model and experimental results.

Conclusions: Monte Carlo modelling of a complex experimental setup involving proton beams, magnetic fields, and high resolution silicon based dosimetry has been successfully performed. These early efforts are important steps in the pathway forward towards successful dosimetry in future real-time MRI guided proton therapy.

65 - Dosimetry for treatment of retinoblastoma with external photon beams

Presenter: Prof. LALLENA, Antonio M. (Departamento de Física Atómica, Molecular y Nuclear, Universidad de Granada, E-18071 Granada, Spain)

to the treatment. However, owing to the genotype of children suffering hereditary retinoblastoma, the risk of secondary radio-induced malignancies is high. The University Hospital of Essen has successfully treated these patients on a daily basis during nearly 30 years using a dedicated "D"-shaped collimator inserted in the head of a Varian Clinac 2100 C/D operating at 6 MV. The collimator conforms a "D"-shaped off-axis field whose irradiated area can be either 5.2 or 3.1 cm^2.

In order to better exploit the advantages of external beam radiotherapy, it is necessary to improve current techniques by reducing the irradiated volume and minimizing the dose to the facial bones. In this work we have

(i) performed a dosimetric analysis of the technique as it is used;

(ii) proposed a modified version of the "D"-shaped collimator that reduces even further the irradiation field maintaining the dose levels in the therapeutic target, and

(iii) analyzed the absolute dosimetry corresponding to this paticular collimator.

All calculations have been carried out by using the Monte Carlo code PENELOPE.

Experimental depth dose distributions and lateral profiles were compared with Monte Carlo simulations and with calculations performed with the analytical anisotropic algorithm (AAA) implemented in the Eclipse treatment planning system. PENELOPE simulations agree reasonably well with the experimental data with discrepancies in the dose profiles less than 3 mm of distance to agreement and 3% of dose. On the other hand, discrepancies between the results found with the analytical anisotropic algorithm and the experimental data reach 3 mm and 6%.

Monte Carlo simulation has been also used for optimizing the dedicated collimator. The new "D"-shaped collimator permits to reduce the risk of radio-induced secondary malignancies and may be easily built. It produces dose distributions that only differ on the field size with respect to the dose distributions obtained by the current collimator in use thus permitting to continue using the clinical experience gained in more than 30 years. The new collimator delivers a dose distribution which is 2.4 cm wide along the inferior/superior direction of the eyeball, that is 0.3 cm narrower than that of the dose distribution obtained with the current collimator. The other relevant dosimetric characteristics, namely, depth doses at clinically relevant positions, penumbrae width, and shape of the lateral profiles, are statistically compatible with the results obtained for the collimator currently in use. As a consequence, the proposed collimator still fully covers the planning target volume with at least 95% of the maximum dose at a depth of 2 cm and provides a safety margin of 0.2 cm, so ensuring an adequate treatment while reducing the irradiated volume.

Finally, absolute dosimetry has been carried out for the collimator currently in use by means of two Monte Carlo approaches. The absolute doses (in Gy per monitor unit) for the field sizes considered are obtained within the approach of Popescu et al. in which the tallied backscattered dose in the monitor chamber is accounted for. The results are compared to experimental data, to those found with a simpler Monte Carlo approximation for the calculation of absolute doses and to those provided by AAA. The Monte Carlo results for the absolute doses differ from the experimental ones by 2.6% and 1.7%, depending of the tracking parameter sets used for the electron transport in the target of the linac head. For the studied radiation fields, the simpler approach produces absolute doses that are statistically compatible with those obtained with the approach of Popescu et al. The AAA underestimates the experimental absolute doses with discrepancies larger than those found for Monte Carlo results.

66 - Monte Carlo and Analytical Validation of a Software Breast Phantom for X-ray Mammography Imaging

Presenter: Dr. BLIZNAKOVA, Kristina (Technical University of Varna)

Nowadays, technology for breast screening is mainly limited to use of 2D mammography techniques. In the developed countries, tomosynthesis has already entered in the routine examination. New breast modalities are emerging like breast Computed Tomography and phase contrast imaging. The development of new x-ray breast imaging techniques and procedures as well as their optimization stage, requires a design phase to evaluate concepts and ideas that could be taken forward to the prototype stage. The most common way to do this is by using dedicated breast physical phantoms. Often, the use of physical phantoms in experimental work turns out to be very time consuming due to experimental and radiation safety procedures, as well as, the time needed for processing of the results. On the other side, 3D computational breast models gives versatility, time efficiency, precision, avoiding unnecessary patient exposure, and are very useful when scan data do not exist, under the condition that these computational models are well validated.

This work presents the validation of a realistic software breast phantom. It was generated with the BreastSimulator software application [1]. The breast initially was created in uncompressed form. Generated components included breast tree, adipose tissue, skin, and Cooper ligaments. Subsequently, the uncompressed breast was subjected to compression simulation to compress the breast as it is during the mammography procedure. Then, the external shape of the model together with the breast was printed with a stereolithographic printer and filled with animal fat. The physical model was imaged both at ESRF, Grenoble with energy of 30 keV and at clinical mammography unit. In parallel, the imaging procedure was simulated under the same clinical conditions by using the computational model. Simulations were carried both by Monte Carlo and analytical approaches [2].

Images obtained at experimental and simulated conditions were compared quantitatively and subjectively. A very good visual similarity is observed between the images, with an excellent visual agreement of the breast tree structure on the images. Quantitative assessment of images was also performed. This included comparison of several extracted features such as profile comparison, power spectrum and fractal dimension analyses. The validated software breast phantom is currently used in experimental work related to the design of new breast physical phantoms dedicated for novel imaging techniques.

This project received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 692097 for the MaXIMA project: Three dimensional breast cancer models for X-ray imaging research.

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67 - MC codes and Range Monitoring in Particle Therapy: the case of secondary charged particles

Presenter: MURARO, Silvia (PI)

Particle therapy planning gets fundamental information from MC codes. Its millimetric precision needs the assurance of the successfulness of the treatment session.
Different range monitoring techniques are under development exploiting secondary particles which are generated in the patient during the treatment: prompt gammas, annihilation gammas from beta+ induced activity, charged fragments.
The yield of produced particles and their propagation in the human tissue must be studied with MC codes.

In this contribution, in the framework of the INSIDE collaboration (Innovative Solutions for In-beam Dosimetry in hadrontherapy), the case of secondary charged fragments emission during the treatment is considered[1].

A detector named Dose Profiler (DP), able to track secondary charged fragments (mainly protons) emitted at large angles with respect to the beam direction, is under construction and test. The tracker is made by six layers (20 × 20 cm2) of BCF-12 square scintillating fibers (500 μm) coupled to Silicon Photo-Multipliers, followed by two plastic scintillator layers of 6 mm thickness.
The detector characterization with cosmic rays has been performed and a calibration data taking campaign with protons is currently undergoing.

The attenuation of the secondary charged particles emission profile due to the crossed material is studied and parametrized with the FLUKA MC code.
A full simulation of a treatment in a realistic patient-detector system and the secondary charged fragments reconstruction is presented.
Track reconstruction is performed by means of a Kalman filter algorithm using the GenFit code. The on-line operation of DP requires the real-time reconstruction of the amount of material crossed in the patient by each detected proton. This task will be accomplished using FRED, a fast GPU-MC code.

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68 - Heterogeneous multiscale simulations of radiation therapy with gold nanoparticles

Presenter: Mr. MARTINOV, Martin (Carleton University)

Purpose: An outstanding challenge for gold nanoparticle (GNP) dose-enhanced radiation therapy (GNPT) is accurate computation of energy deposition in microscopic volumes of interest within macroscopic tumour and normal tissues. This work presents calculations for GNPT within the Heterogeneous MultiScale (HetMS) model, a general Monte Carlo framework.

Methods: The HetMS approach involves combining distinct models of varying level of detail on different length scales within a single simulation. Using EGSnrc, GNPT HetMS models considering varying extra/intracellular GNP distributions are implemented. Groups of >3000 cells containing discretely-modelled GNPs are embedded at different positions throughout a cylindrical phantom (2 cm diameter, 3 cm length) consisting of a gold-tissue mixture. Dose enhancement factors (DEFs; ratios of doses with and without gold present) are calculated for cell nucleus and cytoplasm compartments for various photon source energies, cell/nucleus sizes, and gold concentrations. HetMS simulations are validated via comparisons with simulations of >1.5E10 discretely-modelled cells and GNPs throughout the cylindrical phantom.

Results: DEFs are highly sensitive to depth in phantom, GNP distribution and concentration, cell/nucleus size, and source energy. Considering an isolated cell (not at depth in phantom), nuclear DEFs change with cell/nucleus and GNP intracellular distribution, ranging from 1.6 (GNPs in an endosome, 5 mg of gold/g of tissue, 50 keV photons) to 18.7 (GNPs just outside the cell nucleus, 20 mg/g, 20 keV). Nuclear DEFs are consistently higher for GNPs clustered about the nuclear membrane compared to GNPs within endosomes in the cell cytoplasm. Nuclear DEFs decrease considerably with depth in the phantom, e.g., changes of up to 64% are observed over the first centimeter. HetMS simulation results are in agreement (within statistical uncertainties) with those of simulations of discrete cells and GNPs throughout the phantom, but are considerably more efficient with HetMS simulations >1000 times faster.

Conclusions: This work demonstrates considerable variation in DEFs, due to effects such as decreasing fluence because of gold in the macroscopic phantom and local enhancement because of nanoparticle distribution within cells. Results underline the importance of quantifying DEFs across tumour volumes while considering intracellular GNP distribution. The HetMS approach enables accurate and relatively efficient simulations of GNPT.

69 - Validation of XRMC Monte Carlo toolkit for external dosimetry applied to mammography

Presenter: Dr. HOFF, Gabriela (Università di Cagliari - Dipartimento di Fisica)

The objective of this project is to validate for macroscopic quantities the xrmc toolkit version 6.5.0-2[1], comparing against experimental data collected for dosimetric applications in mammography (external dosimetry). The xrmc is focused on x-ray photon transport simulation, and makes extensive use of variance reduction techniques. To validate the simulated quantities the database was organized with experimental data collected from three different mammographic equipments (Mammomat Inspiration, Mammomat 3000 and LORAD MIII). The KERMA, exposure, half-value-layer(HVL) and backscattering (BSF) were the quantities used in the study. The evoked modes on simulation transport for xrmc toolkit were: transmission mode and mode with scattering. This is an ongoing work and at the moment the data analyzes have been partially performed. To evaluate the differences in results due the differences on description of the incident spectra it was modeled spectra from two different resources: catalogue IPEM Report 78 [2] and the spectra generated to Lorad MIII equipment based on model published by Tucker et al 1991[3]. The preliminary results show good agreement between xrmc and experimental data. We are planning to present the complete set of absolute and derived quantities comparing each transport model. This is a preliminary evaluation of the toolkit where its interface and its options in the devices are being tested and few changes in the code are being defined to make xrmc more user friendly and more adequate to simulate external dosimetry in mammography.

Research developed with the partial support of the National Supercomputing Center (CESUP), Federal University of Rio Grande do Sul (UFRGS).

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70 - Investigating variable RBE in particle mini-beam radiation fields using Geant4 and the Microdosimetric Kinetic Model

Presenter: Ms. DEBROT, Emily (Centre for Medical Radiation Physics, University of Wollongong, NSW, Australia)

Particle therapy is a radiation therapy modality with several advantages over conventional photon modalities due to its physical dose characteristics and greater biological effectiveness. The benefits of spatially fractionated radiation fields due to dose-volume effects have been studied in micro-beam radiation (MRT) therapy using synchrotron produced x-rays. Particle Mini-Beam Radiation Therapy is a novel concept that combines the benefits of a highly conformal dose deposition to the specified target volume by use of charge particle beams with the tissue sparing benefits for healthy tissue proximal to the target volume due to spatially segmented radiation fields.

Like MRT, arrays of particle mini-beams produce regions of high and low dose across the radiation field referred to as peaks and valleys respectively. Studies with MRT have shown that healthy tissues have a greater tolerance to spatially fractionated radiation fields compared with malignant cell lines. It is anticipated that a bystander effect could account for this increased tolerance whereby surviving cells in valleys that receive relatively low doses help facilitate repair to damaged cells in peak region of high dose. In contrast to MRT, charged particle mini-beams exhibit a small amount of lateral scattering that results in the formation of a homogenous radiation field with increasing penetration depth. As such the radiation field at the depth of tumour no longer has spatial fractionation. The combination of the above factors accentuates the ability to reduce radiation damage resulting in cell death to healthy tissue while increasing it to the target volume.

The relative biological effectiveness (RBE) for a 10% cell survival endpoint was calculated for arrays of proton, 12C and 16O particle mini-beams at energies of 150MeV, 290MeV/u and 400MeV/u respectively in a water phantom using Geant4 and the Microdosimetric Kinetic Model. The mini-beam arrays were produced by shooting the primary particle broad beam at a multi-slit brass collimator. Silicon sensitive volumes were used to score the lineal energy spectra in the peak and valley regions of the mini-beam field as a function of depth in the phantom. This investigation demonstrates a first attempt to characterise the biological effectiveness for spatially fractionated particle radiation fields.

71 - CONFIGURATION OF VOLUMETRIC ARC RADIOTHERAPY SIMULATIONS USING PRIMO SOFTWARE: A FEASIBILITY STUDY

Presenter: Mr. OLIVEIRA, Jorge (Medical Physics, Radiobiology and Radiation Protection Group, IPO Porto Research Center (CI-IPOP), Portuguese Oncology Institute of Porto (IPO Porto), Porto, Portugal)

Introduction.
Volumetric Modulated Arc Therapy (VMAT) uses non-uniform intensity fields allowing complex dose distribution patterns. The synchronized MultiLeaf Collimator (MLC) motion and Gantry rotation pose difficulties in the dose distribution calculation by Treatment Planning Systems (TPS). Furthermore, a dedicated Quality Assurance (QA) program and patient-specific dose verifications are requested. Monte Carlo in Radiotherapy (RT) is a key issue in dose calculation [1] given its most detailed description of radiation-matter interaction. Recently, the PRIMO software was proposed [2], providing several built-in RT units models, including TrueBeam. Nevertheless, VMAT is not implemented yet.

Materials and methods.
TrueBeam was simulated in PRIMO using 6 and 10MeV in Flatness Filter Free mode and at 15MeV with Flatness Filter. The results were validated by Gamma Function (2%, 2mm) based on reference measurements in water tank. The dynamic delivery is divided into a customizable number of probabilistically sampled static configurations of jaws, leaves and gantry angles. In-house algorithms were developed to interpolate the LINAC geometrical information along the procedure once the planned information is retrieved from the DICOM plan file.
A graphical user interface (GUI) was developed to assist non-expert users to configure PRIMO to simulate complex deliveries.

Results.
Static simulations in reference conditions showed always > 97% of Gamma points < 1 for PDD and profiles at various depths and fields sizes for the 6, 10 and 15MeV primary beam respectively. The GUI properly read, manipulated and wrote the configuration data in a .ppj format, which was accepted by PRIMO. The dynamic jaws, MLC and gantry motion were positively assessed by visual inspection of the static beam configuration in PRIMO. Dynamic simulations are still in progress.

Conclusion.
A user interface to configure PRIMO allowed filling the gap in the workflow to drive it to simulate a general dynamic treatment. Static TrueBeam simulations gave reliable outcome and further results on dynamic VMAT procedure will be provided.

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72 - Monte Carlo simulations as a tool for guidance in planning pelvic Intra Operative Radiation Therapy

Presenter: Dr. ESPOSITO, Alessandro (CAP / INESC TEC - INESC Technology and Science, Porto, Portugal)

Introduction.
Intra-Operative Electron Radiation Therapy (IOERT) uses high-energy electron beams during surgical interventions. In rectal cancer, IOERT is mostly used on pelvic curve and irregular treatment surfaces, which may cause dose distributions to be different from the reference.
Planning IOERT is usually limited to manual calculations but Monte Carlo (MC) simulations can be a powerful means to study dose distributions in various irradiation scenarios.
This work aims to simulate typical IOERT clinical scenarios, to give radiation oncologists guidance to prescribe the treatment set-up when complex irradiation surfaces are present.

Materials and methods.
The BEAMnrc and EGSnrc MC model implements a Varian CLINAC 2100CD, adapted for IOERT. The model was validated through the Gamma Function (2%, 2mm) based on measurements in water tank.
An irregular surface was created by partially inserting a bolus in the irradiation field. Spherical cap concave surfaces of different radius and depths were modeled to obtain simulated dose distributions. The effect of bone under the tissue was studied by modeling the sacrum curvature on the basis of dimensions from CT of 7 male IOERT patients. Fluid accumulation in the surgical bed was simulated by partially filling the sacrum cavity with specific material. Electron energy of 6, 9 and 12MeV, applicator diameter of 6, 7 and 8cm and bevel angle of 0°, 30° and 45° were considered.

Results.
A local dose increase is observed in the region under the concavity, being larger for smaller radius. These hotspots result from the lateral scatter distortion introduced by step-like surfaces Combinations of bevel angle, concavity radius and energy determine the presence, location and extent of the hotspots. The resulting dose distribution strongly depends on applicator-surface relative positioning. While the bone under the tissue shortens the range of dose deposition, the fluid build-up merely shifts the dose distribution upwards.

Conclusion.
The simulated scenarios provide a useful visual guidance for Radiation oncologists who need to be aware of the influence of the irradiation surfaces on IOERT dose distributions, in order to optimize the effectiveness of the treatment and minimize undesirable effects.

73 - Design of a personal dosimeter for estimating the effective dose of medical staff when wearing radioprotective garments using Monte Carlo simulations

Presenter: Mrs. SALDARRIAGA VARGAS, Clarita (Belgian Nuclear Research Centre (SCK•CEN), Radiation Protection, Dosimetry and Calibrations, Mol, Belgium)

Medical staff performing X-ray guided interventional procedures is exposed to scattered ionizing radiation coming from the patient. Radioprotective garments (RPG) are usually worn as personal radiation protection equipment. Different methodologies have been proposed to estimate the effective dose when RPG are used (ERPG), like applying a correction factor to the dose of a standard Hp(10) dosimeter worn above or below RPG (single dosimetry), or the use of an algorithm combining the dose from two of them: one worn above RPG and the other one worn below (double dosimetry). But even with these methodologies it remains difficult to provide a good estimate of the effective dose (i.e. a conservative estimate with minimized overestimation) under all possible exposure conditions [1].
This study aimed at designing a personal whole body dosimeter capable of estimating ERPG directly (without the intermediate step of Hp(10)) by means of Monte Carlo calculations using MCNPX2.7.0.
The ICRP110 reference male phantom was equipped with a mathematically-defined 0.5mm-thick lead apron and collar and its effective dose (ERPG) was calculated for photon beams with energies in the range of interest in interventional procedures (20-120 keV) and angles of incidence (-60° to +60°) parallel to the transverse plane of the body. The design of the new dosimeter should be such that its energy and angular response is as flat as possible when compared to the calculated ERPG. The following design parameters have been considered in the simulations: material composition, thickness and geometry of elements around the detector and type and number of dosimetric detectors. Current status of the design process and some of the steps needed to reach this status are presented. The photon energy and angular dependences are shown for two dosimeter models consisting of two radiosensitive detectors with different filtration: a simplified model based on thermoluminescent detectors and a more realistic model based on glass radiophotoluminescent detectors. For both dosimeters the energy and angular dependence of the combined dose from the two detectors is usually within ±20% of the calculated effective dose ERPG.

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74 - A Monte Carlo approach to the activation assessment of a PET Cyclotron bunker

Presenter: Dr. MARENGO, Mario (Medical Physics Department, “S. Orsola-Malpighi” Hospital, Bologna, Italy)

When considering the dismantling of a PET cyclotron facility, considerable amount of low level solid radioactive waste has to be characterized and disposed of. The level of activity produced varies considerably, depending on the type of accelerator, on its use and on the specific structure of the bunker, for this reason, each facility needs a specific decommissioning strategy. This work aimed at developing a Monte Carlo approach to preliminary assessing activation in order to define an “ad hoc” decommissioning strategy.
The MC code FLUKA was used to simulate the GE PETtrace cyclotron (16.5 MeV) installed at the University Hospital of Bologna (Italy) and routinely used in the production of positron emitting radionuclides. The model of the cyclotron includes the magnet and magnet poles, the vacuum chamber, an approximation of the coils and the target filling station panel (LTF). The modelled target system is the standard GE assembly including a Niobium chamber filled with O-18-water to produce Fluorine-18 by a (p,n) reaction. A detailed MC model of the cyclotron vault, including the reinforcement rods, was implemented on the basis of the original construction drawings.
Secondary neutrons are mainly responsible for activation, but their production is relatively low (on average 4E-3 neutrons for proton at the energies of interest). An efficient approach was then developed for the simulations: 1) the neutron spectrum released by the target in proton irradiation was scored with a high statistics; 2) this spectrum was resampled as the source term, to obtain faster simulations with good statistics (less than 24 hours using an Intel® Core™ i7-4790 four cores).
Via Monte Carlo simulations, the activation of the cyclotron vault walls and of the reinforcement rods was studied. The principal long-lived radionuclides found in concrete were Eu-152, Mn-54, Co-60, Eu-154, Cs-134 while Mn-54 and Co-60 were found in reinforced roods. The activation was assessed at different positions and for different life expectancies of the cyclotron. After twenty years of operation the expected activity concentration of these radionuclides varies from 0.01 Bq/g to 5 Bq/g.

75 - Validating Geant4-DNA for Double Strand Brakes (DSB): A preliminary study

Presenter: Mr. CHATZIPAPAS, Konstantinos (University of Patras, Department of Medical Physics, Patras, Greece)

The investigation of biological effects in living tissues requires the modeling of physical, chemical, and physico-chemical interactions. Strong effort has been given in the 3D modeling of DNA structure, such as to describe the cell nucleus. In 2015, a new application, Geant4-DNA was presented, enabling the atomic level description of DNA molecules and the possibility of evaluating the direct damage induced on the DNA molecule by ionizing radiation [1]. Recently, a DNA Double-Strand Break (DSB) dosimeter was developed for the detection and quantification of DNA-DSBs after irradiation [2]. Our goal is to validate the simulated data, and standardize the experimental procedure for measuring the biological damage.
In the present study, we investigated the PDB4DNA tool and developed a new G4-DNA class for the quantification of DSBs after irradiation. Experimental measures were used for testing the G4-DNA classes. A DNA molecule (1329 bp, the largest in PDBlib) was irradiated with 3 different absorbed doses equal to 10, 25 and 50 Gy. In our simulation study, we used a structure of a single DNA molecule (based on experimental data), and irradiated it multiple times to quantify the probability of DSBs.
The simulations, on G4-DNA DSB quantification, resulted in DSB probabilities equal to 9.0%, 17.0%, and 31% for doses 10 Gy, 25 Gy, and 50 Gy respectively. Thus, the statistical difference between experimental and simulated DSBs was calculated to 8.09%, 9.23%, and 13,43% accordingly. Comparing our simulations with the standard used PDB4DNA class, differences varied from 40-70%.
This is a preliminary study for the modeling, and the quantification of DNA-DSBs based on experimental data. The limitations of this study need to be addressed, such as the modeling of multiple DNA molecules for accurate statistical simulations, and chemical reactions need to be taken into account for the total quantification of the biological damage on DNA structures.

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77 - Monte Carlo simulation of the Elekta VersaHD linac with Elekta’s Stereotactic Conical Collimation System

Presenter: Dr. ORION, Itzhak (Department of Nuclear Engineering, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel)

Purpose Small field dosimetry remains a challenging task. The difficulties associated with small fields measurements become more pronounced for field sizes less than 1 cm. To overcome these difficaulties it has been suggested to employ Monte Carlo (MC) techniques. The purpose of this work was to report on results of commissioning and MC validation of the new Elekta stereotactic conical collimator system for 6 MV flattening filter free (FFF) beams on Elekta VersaHD linac.
Methods Commissioning measurements for stereotactic cones with diameters of 5 mm, 7.5 mm, 10 mm, 12.5 mm and 15 mm included relative output factor (ROF), percentage depth dose (PDD) and off-axis ratio (OAR) measurements and were performed with SRS diode. MC simulations were performed with EGSnrc. The incident electron beam parameters were adjusted to match the measured data (PDD and OAR) for set of MLC-based open fields. For each cone, aperture size was adjusted to match MC calculated and measured OAR profiles. Penumbra width (defined as 20%-80% distance) comparison of MLC-based and cone-based fields for a static angle case and for a full arc was performed. Angular distribution of photons collimated with MLC and with the cones was calculated. Leakage for the MLC and for the cones was determined.
Results For MLC-based fields, agreement between calculated and measured values was within 1%/0.5mm for PDDs, within 1%/1mm for OARs and within 3% for ROFs. For stereotactic cones, the agreement in PDD and OAR profiles was within 1%/0.5mm and the ROFs agreed within 3%. The measured ROFs were 0.564, 0.645, 0.706, 0740 and 0.770 for the 5 mm, 7.5 mm, 10 mm, 12.5 mm and 15 mm cones, respectively. For one static MLC-based 1x1 cm field, penumbra was 5.6 mm in the in-plane direction and 8.4 mm in the cross-plane direction, compared to 4 mm in both directions for the 10 mm cone. The cone leakage was found to be 0.5% for both energies.
Conclusions Results of our MC calculations were found to be in good agreement with the measurements thus confirming accuracy of our MC model for the Agility MLC.

78 - Time-resolved Monte Carlo simulations of dose delivered to a dynamic thorax phantom verified using scintillator dosimetry

Presenter: Mr. SIBOLT, Patrik (Center for Nuclear Technologies, Technical University of Denmark, Roskilde, Denmark)

Respiratory movement is one of the major challenges in modern lung cancer radiotherapy. Many attempts are made to account for this motion; including different motion encompassing, gating, and tracking methods. The latter is probably the most complex where real-time tumor localization is essential. Additionally, dose calculation algorithms have known issues with heterogeneities, and experimental dose verification is often based only on the accumulated dose. The time-dependent accuracy of treatment delivery is therefore rarely known, making it difficult to locate the underlying cause of a failed delivery. Organic plastic scintillator dosimetry was here used for verification of time-resolved Monte Carlo (MC) calculations. The MC user code 4DdefDOSXYZnrc/EGSnrc enables dose calculation in continuously moving anatomies by sampling a new geometry for each incident particle [1]. The MC code was modified to score the dose in pre-defined voxels for a given temporal resolution. The time-resolved MC dose was compared with scintillator measurements in an in-house developed dynamic thorax phantom containing a tumor (PMMA) embedded in a lung cylinder (Balsa wood) [2]. Measurements were conducted for one conventional and one RapidArc treatment plan with a) the phantom static and tumor centered at the isocenter, b) the phantom moving (sinusoidal; 25 Hz, 20 mm peak-to-peak amplitude) around the isocenter, and c) the phantom moving according to b) with a 2.5 cm longitudinal isocenter shift. Corresponding MC calculations were based on linac logfiles acquired from the measurement sessions, during which also the motion of the phantom was logged. Potential calculation and measurement deviations were separated from those due to motion and delivery of the dynamic treatment, verifying the accuracy of the time-resolved MC calculations. This study proposes a new method for time-resolved dose verification of advanced dynamic treatments and highlights the potential of both 4DMC simulations and the scintillator dosimetry for taking on this task.

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79 - Virtual source model for stereotactic radiosurgery with a dynamic micro-multileaf collimator.

Presenter: Dr. GONZÁLEZ, Wilfredo (Laboratoire d'Imagerie et Modélisation en Neurobiologie et Cancérologie. CNRS-IN2P3. F-91405 ORSAY CEDEX. France.)

A virtual source model recently developed for external radiotherapy, which includes two photon sources [1] and two electron sources [2], is tested for stereotactic radiosurgery with a dynamic micro-multileaf collimator. A 6 MV Elekta Precise linac that incorporates a 3Dline L'Arancio dynamic micro-multileaf collimator was considered [3]. The capabilities of the virtual source model have been tested against full simulations performed with the Monte Carlo simulation code PENELOPE using both PENELOPE itself and the rapid Monte Carlo code DPM. The reference 10cmx10cm radiation field as well as small fields of 1.2cmx1.2cm, 2.9cmx2.9cm and 5.8cmx5.8cm were considered. The dynamic micro-multileaf collimator effect can be included in the virtual source model by reducing the width of the photon primary source by a factor 3. In all cases the virtual source model simulations were in very good agreement with the complete ones including the linac and collimator geometries.

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80 - Charged particles grid and minibeam radiation therapy: Monte Carlo dosimetry evaluations.

Presenter: Dr. GONZÁLEZ, Wilfredo (Laboratoire d'Imagerie et Modélisation en Neurobiologie et Cancérologie. CNRS)

The dose tolerances of normal tissues continue being the main limitation in radiotherapy. As a strategy to overcome it we propose to ally inherent physical advantages of protons and heavy ions (up to Fe) with the normal tissue preservation observed when irradiated with submillimetric spatially fractionated beams (minibeam radiation therapy, MBRT) [1, 2]. This would allow the use of higher and potentially curative doses in the treatment of radioresistant tumors. This was the motivation for the exploration of this new radiotherapy approach. In this presentation we will summarize the main dosimetric features of this promising strategy evaluated by Monte Carlo simulations (GATE/Geant4), including the influence of the projectile fragmentation on low dose areas. We also will report on the dose distributions in high-resolution computer tomography analysis used to guide the pre-clinical trials in proton MBRT. In addition, the results of our studies on the minimum beam size compatible with proton and heavier ions MBRT will be presented.

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81 - Monte Carlo simulations for boron neutron capture therapy to assessment absorbed dose of pancreas cancers

Presenter: Prof. KRSTIC, Dragana (University of Kragujevac, Faculty of Science)

Boron neutron capture therapy (BNCT) is a type of radio therapy, based on nuclear capture reaction that occurs when non-radioactive boron- 10B is irradiated with neutrons with the appropriate energy to yield high energy alpha particles and recoiling lithium nuclei. Monte Carlo simulations by using MCNP5/X code were applied for boron neutron capture therapy (BNCT) to estimate the dose for possible treatment of various cancers. The computational ORNL (Oak Ridge National Laboratory) phantom was used to simulate tumour on the pancreas. Epithermal neutrons were considered in this simulation. As a product of neutron capture by 10B, alpha particle and 7Li are obtained. Since 7Li and 4He obtained after capture of neutron on 10B, have path lengths of approximately one cell diameter, their lethality is primarily limited to boron containing cells. The selective boron uptake in the pancreas metastases comparing to normal tissue makes BNCT a potentially advantageous technique, especially in treatment of whole organ.
For the BNCT treatment planning it is important to determine the spatial distributions of absorbed dose which is determined by MCNP software in this work. Neutron beam parameters were defined by International Atomic Energy Agency (IAEA). The obtained theoretical results show that the BNC therapy may be used for the treatment of pancreas cancers.

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83 - Hybrid Monte Carlo for low-energy X-rays intraoperative radiation therapy dose calculation

Presenter: Ms. IBÁÑEZ, Paula (Grupo de Física Nuclear, Universidad Complutense de Madrid, CEI Moncloa, Madrid, Spain)

Motivation/Objective: Intraoperative Radiation Therapy with low energy X-rays (XIORT) is largely used in oncology (ex: INTRABEAM®, Carl Zeiss), and could benefit from a dose calculation tool. A high level of accuracy is reached with Monte Carlo (MC) simulations, however it is a time-consuming technique and consequently it is not suitable for real-time dose planning of a XIORT treatment. This work presents a dose calculation algorithm based in MC phase-space information to compute dose distributions for the INTRABEAM device within minutes, fully taking into account the different structures of the patient.

Materials and Methods: The Hybrid Monte Carlo (HMC) code takes into account the photoelectric and the Compton effects for X-rays up to 50 keV. The tissue assignation from the CT numbers is done following the method described in [1] for 24 different materials. Savings in computation time are possible by taking some variance reduction techniques to the extreme, such as the use of meta-histories, each one representing the fate of many particles, or dose normalization, which allows statistic noise-free dose distributions with a low number of initial meta-histories. Detailed MC simulations have been generated with penEasy [2] to validate our tool in homogeneous and heterogeneous conditions with the different INTRABEAM applicators.

Results: Dose distributions computed by the HMC are in good agreement (2%-1mm) with penEasy detailed simulations in homogeneous and heterogeneous media. Accurate dose distributions were obtained with the HMC in 5 minutes using a single core of a modern PC (i7@2.5 GHz), compared to 10 days simulations with penEasy.

Conclusion: The HMC provides accurate dose distributions within minutes. Its high speed allows an on-the-fly dose calculation which includes the realistic effects of the beam in patient voxelized geometries.

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84 - Development of the 2-dimensional MLC movement technique to improve radiation treatment quality

Presenter: Mr. PARK, Hyojun (Yonsei University)

In radiation therapy, leaf width of the multileaf collimator (MLC) determines the resolution of the beam fluence in the vertical direction of the leaf movement. The resolution can be improved by using the MLC with thinner leaves but there is limitation on reducing the width due to spatial constraint of the gantry and increasing leakage dose [1]. The aim of this study was to develop the two-dimensional (2D) MLC movement technique using Monte Carlo (MC) simulation in order to improve the fluence resolution and to minimize unnecessary dose without changing the MLC leaf width. The Varian Trilogy 6MV linear accelerator equipped with the virtual millennium 120 MLC that moves toward 2D direction was modeled by using Geant4 MC tool-kits. The MC-based automatic decision algorithm of the MLC opening was developed to decide the optimal MLC position by comparing the opening at each MLC position. For the patient study to evaluate the developed technique, the patient who received brain 3D conformal radiotherapy was selected. The planning target volume (PTV) was decided with 3-mm-margin and the beam was delivered from 177 directions with the gantry angle from 0 to 360 degree in 2 degree steps. Total 5■108 photons were generated in the simulation. By using the 2D optimized MLC, the PTV homogeneity index was improved from 0.123 to 0.125. Mean dose to the PTV was not really changed, from 24.11 Gy to 24.08 Gy when the 2D optimized MLC was used. Meanwhile, the percent volume of the tissue nearby the PTV that was irradiated more than 20.56 Gy (80 % of the maximum dose to the tissue with the 1D conventional MLC) was reduced from 5.66 % to 0.81 % by using the 2D optimized MLC. Mean dose to the normal tissue was also decreased from 11.59 Gy to 9.75 Gy. The results show that the 2D MLC movement technique could improve the radiation treatment quality by reducing normal tissue dose while maintaining the PTV dose.

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85 - Investigating the physics of a CBCT projection shading correction based on a prior CT

Presenter: Dr. LANDRY, Guillaume (LMU Munich)

The adoption of cone beam computed tomography (CBCT) image guidance in proton therapy has spurred research on CBCT image correction for dose calculation. Initially, methods based on deformable image registration gained attention [1], however projection correction approaches based on prior CT information [2] have been shown to perform well for several body sites [3]. The shading correction algorithm used in [2,3] relies on image processing of the subtraction of digitally reconstructed radiographs (DRR) of a DIR-registered prior CT, and CBCT projections. In this study we have performed Monte Carlo (MC) simulation of CBCT imaging to disentangle the different sources of projection degradation, and to evaluate the physicality of the shading correction.
The GATE MC toolkit's fixed-forced-detection actor was employed, along with source and detector models optimized for an Elekta XVI CBCT system, to simulate CBCT imaging of an electron density phantom. The shading correction algorithm was applied to the measured projections and the so-called scatter component (SCA) was compared to the MC simulated scatter.
Measured and simulated CBCT projections (scatter + primary) agreed well, with the largest discrepancy found for a bone insert (3% of log transformed projections). Important disagreement was observed with the MC scatter signal when the contribution from beam hardening was kept in the SCA. Undoing the beam hardening correction from the SCA using functions derived from MC primary projections and DRRs greatly improved agreement of scatter signals from MC and SCA (3% on average), with the largest discrepancy found for the bone insert (12%). Residual discrepancies were shown to stem from the intrinsic limitations of the SCA.
Proton therapy dose calculations on corrected CBCT will be presented in addition to the results above.

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86 - Status and latest developments of GAMOS/GEANT4 framework

Presenter: Mr. ARCE, Pedro (CIEMAT)

GAMOS (Geant4-based Application for Medical-Oriented Simulations) from its conception was meant to provide a framework not only easy to use, as other GEANT4-based frameworks, but also flexible, with the aim of avoiding a common problem: that the use of a framework prevents the user from taking advantage of all the potentiality that GEANT4 provides. We describe here the main functionality of GAMOS, paying special attention to the latest developments.

87 - Brachytherapy source and applicator models for diverse Monte Carlo simulations with egs_brachy

Presenter: Prof. THOMSON, Rowan (Carleton University)

Purpose: To describe the development and benchmarking of a library of brachytherapy sources and applicators for use with egs_brachy, a new open-source code for brachytherapy calculations.

Methods: egs_brachy is a modern EGSnrc application employing the EGSnrc C++ class library (egs++) [1]. The extended egs++ framework (new geometry and shape classes developed with egs_brachy) is used to construct detailed models of sources and applicators. Source models are constructed for 52 photon brachytherapy sources (radionuclides Pd-103, I-125, Cs-131, Cs-137, Ir-192, Yb-169, and Co-60). A generic miniature x-ray tube source is modeled. Eye plaque applicators include 10 to 24 mm diameter Collaborative Ocular Melanoma Study (COMS) plaques (containing I-125 or Pd-103 seeds) and BEBIG Ru-106 beta-emitting plaques (diameters 11.6 to 25.4 mm). The generic high-dose rate (HDR) Ir-192 shielded applicator of the AAPM-ESTRO-ABG Working Group on Dose Calculation Algorithms for Brachytherapy (WG-DCAB) is modeled. Dose distributions and TG-43 parameters (photon sources only) computed with egs_brachy are compared with published values.

Results: For photon (radionuclide) sources, dose-rate constant, radial dose function, and anisotropy function values are generally in excellent agreement with published values [2]. Miniature x-ray tube results for egs_brachy agree with BrachyDose results within statistical uncertainties. Ocular plaque dose distributions show excellent agreement with published values. For COMS plaques, egs_brachy results agree with BrachyDose and MCNP5 published values within statistical uncertainties <1% in the tumour [3]. For Ru-106 beta-emitting plaques, egs_brachy results agree within sub-2% statistical uncertainties with PENELOPE results [4], and this agreement is notable due to the historically poor agreement between results from different publications. Dose distributions about the WG-DCAB applicator agree with results from other MC codes.

Conclusions: egs_brachy can model diverse source and applicator models and dose distributions are in excellent agreement with published values, demonstrating the code’s versatility and accuracy. Source and applicator models will be included in future egs_brachy distributions.

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88 - Quantum versus classical Monte Carlo simulation of low energy electron transport in condensed media

Presenter: Prof. THOMSON, Rowan (Carleton University)

Purpose: Monte Carlo simulations are being applied to study radiation interactions and energy deposition on sub-micron length scales within cells, e.g., DNA, in diverse contexts across medical physics. While these classical trajectory Monte Carlo simulations ignore the quantum wave nature of the electron, quantum effects may become non-negligible as electron energy decreases below 1 keV, with electron wavelength becoming considerable relative to the size of biological targets. This work investigates quantum mechanical (QM) treatments of low energy electron transport in condensed media and compares results with those from the corresponding classical trajectory Monte Carlo (MC) model.

Methods: For QM calculations, a simplified model of electron transport in water is developed consisting of a plane wave (representing an electron) incident on a collection of ~1000 point scatterers (molecules) representing a water droplet. Scatterer positions are random but are constrained by a minimum scatterer-to-scatterer separation, dmin, in some simulations. Cross sections for isotropic elastic and inelastic (absorption) interactions are varied. QM calculations involve numerically solving the system of ~1000 coupled equations for the electron wavefield incident on each scatterer. Results are averaged over 10,000 droplets with different point scatterer positions but otherwise same parameters (incident electron energy, cross sections). Average QM droplet incoherent cross sections and scattering event densities are compared with analogues computed within the corresponding classical MC model, and estimates of relative errors on MC results are computed.

Results: Relative errors on MC results vary with electron wavelength, droplet shape and structure (dmin), and interaction cross section. Relative errors on droplet differential cross sections generally differ from errors on scattering event density. The introduction of inelastic scatter generally increases relative errors (compared to calculations with the same elastic scatter cross section) with some exceptions (e.g. longer wavelength, relatively large inelastic cross section). Accounting for structure (non-zero dmin) enhances differences between QM and MC results.

Conclusions: The quantum wave nature of electrons may be non-negligible for simulations of electron transport within small-scale biological targets. Future work will involve the development of more realistic models of electron transport in condensed media.

89 - Investigation of Conformal Arc therapy utilizing Cobalt 60 beams

Presenter: Dr. ELDIB, Ahmed (Fox Chase Caner Center)

Purpose: The trend today in modern radiation therapy is toward conformal therapy with static and dynamic delivery techniques. Generally, this requires multifield irradiation or the use of arc/rotation therapy. Many recent studies have demonstrated that novel Co-60 machines equipped with state of the art MLC and imaging guidance may provide similar quality radiotherapy treatment as modern linacs. In comparison, Co-60 units will have the advantage of simple and robust design, easy operation and minimal maintenance. In this work we conduct a dosimetric comparison between conformal arc therapy utilizing Co-60 gamma rays and 6MV linac beams.

Material and Methods:
CT scans were unarchived for patients previously treated by SBRT for lung, breast, and head and neck cancers. All of these SBRT patients were previously planned on an Eclipse planning system (Varian Medical Systems, Palo Alto, CA). New treatment plans were generated using the same clinical dosimetric parameters/constraints with multiple conformal Co-60 arcs. Dose distributions for all plans were calculated using Monte Carlo simulation for both 6MV and Co-60 beams.

Results
As the number of fields increases, the advantage of higher energies over lower radiation energies decreases on the peripheral dose. In all studied cases, conformal arc plans utilizing Co-60 beams achieved almost the same conformity as the plans with 6MV beams. Isodose distributions were tailored similarly around the PTV. On reviewing the minimum and maximum doses to all targets, it was found that both Co-60 and 6MV plans met our clinical acceptation criteria for the target coverage. The DVH of Co-60 plans showed slightly lower doses to the critical structures but the differences were small in most cases.
Conclusion
Our results showed the potential of newly designed Co-60 machines as a practical modality to treat a large fraction of cancer patients. The overall performance of conformal arcs using Co-60 beams was encouraging when compared to the 6MV treatments. There were no clinically significant differences between the 6MV plans over the Co-60 plans for SBRT treatments.

90 - Accounting for radiation-induced indirect damage on DNA with the GEANT4 code

Presenter: Mrs. DE LA FUENTE ROSALES, Liset (Institute of Physics Gleb Wataghin, Unicamp)

The use of Monte Carlo (MC) simulations remains a powerful tool to study biological effects induced by ionizing radiations on living beings. Several MC codes, with different level of complexity, are commonly used in research fields such as nanodosimetry, radiotherapy, radiation protection, and space radiation. This work performed an upgrade of an existing model developed by Bernal et al.[1] for radiobiological purposes, for accounting for the indirect DNA damage produced by ionizing particles. The Geant4-DNA simulation toolkit was used to simulate physical, pre-chemical and chemical stages of the early DNA damage induced by protons. Liquid water was used as the medium for simulations. Two phase-space files were generated, one containing energy deposition events inside the region of interest(ROI), and another one with the position of chemical species produced by water radiolysis from 0.1ps up to 1ns. The information contained in both files was superposed on a genetic material model with atomic-resolution,consisting of several copies of 30-nm chromatin fibers. The B-DNA configuration was used. This work focused on the indirect damage produced by the hydroxyl radical (OH.) at the deoxy-ribose sugar sites, normally trough hydrogen abstraction. Corresponding damage yields were determined. The approach followed to account for indirect damage in DNA was the same used by other radiobiological codes [4,5]. The critical parameter considered here was the reaction radius, which was calculated from the Smoluchowski's diffusion equation. Single, double, and total strand break yields produced by direct, indirect, and mixed mechanisms are reported.

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91 - Image acquisition and material differentiation for Dual Energy Computed Tomography by Monte Carlo simulations

Presenter: Dr. COSTA, Paulo (Physics Institute of São Paulo University, Department of Nuclear Physics)

Dual Energy Computed Tomography (DECT) is an innovative and developing technique that uses two different x-spectra to get material differentiation in diagnostic imaging [1]. As a different modality from standard CT it requires specified phantoms for quality control. Currently, there are few phantoms specialized for DECT and its price is quite high. Therefore, the aim of this study is simulate the CT images of a DECT phantom whose compounds are combination of thermoplastic materials that could be easily manufactured.
The present work uses Phase Space Files (PSF) computed from PENELOPE/PenEasy Monte Carlo code as a validated x-ray source model to obtain DECT images. The simulation process is divided in two steps: the first one compute the PSFs for two different x-ray spectra and the second one simulate the radiation transport in the phantom and detectors.
The particles stored in PSFs were used to compute the energy deposition in each detector after the interaction with the phantom. For each angular projection it was used one of the two PSF. As a result, two sinograms were obtained and two images were reconstructed, each one representing the attenuation properties its respective spectrum.
The thermoplastic material combinations were obtained using a methodology developed by our group [3]. Differentiation characteristics of the DECT were determined for materials commonly used in clinical practice as uric acid, iodine and calcium.
The results demonstrate the capabilities of DECT/MC simulation for improving material visualization and identification, development of dedicated phantoms and for educational purposes.
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92 - Skin Model and its impact on Mean Glandular Dose in Digital Mammography

Presenter: Prof. TOMAL, Alessandra (Instituto de Física Gleb Wataghin - Universidade Estadual de Campinas)

The Mean Glandular Dose (MGD) is the main physical quantity used in mammography dosimetry [1]. The skin plays an important role, absorbing part of the incident radiation and, its traditional thickness is overestimated with recent findings [1]. This work investigates the influence of breast skin models on the MGD using the PENELOPE (2014)+penEasy (2015) Monte Carlo code. The simulated geometry includes: a source 66 cm above the detector, a compression and a breast support paddle (PMMA 2 mm thick), the breast (a semi-cylinder with 8 cm radius), and the a-Se detector. The total thickness of the breast varied from 2 to 9 cm and its central region is composed by a homogeneous mixture of glandular and adipose tissue with different proportions [1]. Four breast skin models were implemented: 4 mm skin tissue (I), 5 mm adipose tissue (II), a combination of 1,45 mm skin plus 2 mm adipose (III) and 1,45 mm skin (IV) [2]. Simulations were made with monoenergetic beams from 8 to 60 keV and polyenergetic beams with different Anode/Filter combinations (Mo/Mo, Mo/Rh, Rh/Rh, W/Rh, W/Ag, W/Al) and a potential from 22 kV to 35 kV. For a 2 cm breast, a maximum MGD difference of 80% between the skins models (I) - (II) at 8 keV, decreasing energy increases. For the polyenergetic spectra (Mo/Mo), a mean difference of 28%, 16% and 16% in comparing the models (II), (III) and (IV), with the model (I), respectively. The MGD differences between the models decreases while increasing tube potential. The composition and thickness of the breast has an impact up to 10% and 15% on the results, respectively. The results highlight the importance of the skin for accurate dosimetry in mammography.

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93 - Improved kerma calculations with EGSnrc

Presenter: Prof. ROGERS, David (Physics Dept, Carleton University)

Kerma calculations in the applications DOSRZnrc and g from the EGSnrc 2016 release exhibited unusual dependencies on the threshold for production of secondary electrons (AE) and the cutoff energy for transport (ECUT) under certain conditions. For example, in the case of 25 MeV photons incident on aluminum, the kerma changed by 2.6% (<0.1% statistics) as the value of ECUT was changed from 512 keV (total energy) to 513 keV with an AE value of 512 keV. Similarly, as AE was changed from 512 keV to 521 keV with ECUT fixed at 521 keV, the kerma changed by 3.5%. This was perhaps a worst case scenario since the K-shell binding in Al is 1.5 keV (k.e.). In other materials such as water, the effect is negligible. The sensitivity was eventually traced to how EGSnrc previously handled the discard of energy below cut-off thresholds after atomic relaxation events (IARG=4 discards) – it was all considered part of kerma. However, only a subset of these sub-threshold energy depositions should have been included in the kerma. Namely, the sub-threshold contributions of fluorescent photons should have been excluded from kerma, along with any energy from relaxations after electron impact ionization. By introducing new calls to AUSGAB, the EGSnrc scoring routine, it is now possible to properly allocate the discarded energy to kerma or radiative losses as appropriate. The DOSRZnrc and g applications have been modified to track which interaction type initiated the relaxations, so that the sub-threshold depositions from fluorescent photons and Auger electrons can be treated correctly. With the improved code, the kerma calculated in the examples mentioned above are stable at the 0.04% level against changes in ECUT and the radiative losses to fluorescent photons decreases (by roughly 20% for electrons in aluminum where this represents roughly a 0.1% loss). The changes do not affect dose calculations. These improvements are available in the 2017 release of EGSnrc and affect the g and DOSRZnrc applications.

94 - Development of a methodology for formulating radiologically equivalent materials to human tissues

Presenter: Dr. COSTA, Paulo (Physics Institute of São Paulo University, Department of Nuclear Physics)

The study and development of phantom materials is central to the calculation of patient doses in medical imaging applications. To ensure tissue-equivalence, these materials should have radiation attenuation and scattering properties similar to water or human tissues[1-3]. Additionally, Monte Carlo techniques are useful to evaluate the radiation transmission and scattering properties of different formulations in order to assure their tissue equivalence when compared with real tissues.

In this work the authors evaluate the use of the least squares method as a tool to optimize the formulation of phantom materials. There were developed water-equivalent materials for diagnostic imaging energy range (10-150 keV) as well as mammography phantom formulations for different glandular/adipose breast tissue compositions[4] for the energy range 8-28keV.

The developed materials are constituted by a thermoplastic base and some additives. The methodology consisted in fitting by the Least Square Method the volume fractions of the components of the phantom material in order to make their linear attenuation coefficient[5] as close as possible to the linear attenuation coefficient of the reference material such as breast tissue or water.

A weight function which reflects the contribution of the X-ray spectra in the suitable energy range was also introduced. The weight function used represents the standard radiation spectra qualities RQR10 and RQR-M2 according to TRS 457 (IAEA)[6].

The transmitted and scattered X-ray spectra of the developed compositions were simulated as well as their dose profiles using the PENELOPE Monte Carlo code.

The linear attenuation coefficient obtained using the least squares method is in good agreement with the reference material for both water and breast tissue with relative differences lower than 2%. The Monte Carlo method is very useful in determining the X-ray transmission and scattering properties of the materials, before the manufacture of the physical phantom.

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96 - Feasibility study of in-vivo dose verification by analyzing time-structure of the prompt gammas in cancer treatment using proton beam.

Presenter: Mr. SHIN, Wook-Geun (Yonsei University)

In the cancer treatment using the proton beam, in-vivo dose verification is one of the most important in utilizing the characteristics of the proton beam delivering high dose to the target, called as Bragg peak. Measuring the prompt gammas generated along the beam track with the proton-induced nuclear interaction is one of the most prefered method. However, the detection efficiency is very low with their high energy (2-10 MeV), espetially measuring the distal dose edge location is currently challengeable. In the current study, the relationship between the time-structure of the prompt gamma and proton dose distribution was evaluated, and the feasibility of in-vivo range verification by measuring the prompt gamma time-structure was evaluated with Geant4 Monte Carlo (MC) simulation.
A detection system selectively measuring prompt gammas on 90 deg with tungsten collimators was employed, and the detector measured the time-structure depending on the measurement position along the beam direction. The water phantom and lung phantom representing the homogeneous and the heterogeneous were used, respectively. In the current MC results, the time-structures of the prompt gammas in the both of the water phantom and lung phantom were clearly discriminated according to the detector position within 2 cm. Moreover, the depth resolution of less than 5 mm was achieved in the water phantom. It was observed that the patterns of the time-structures generated by the range modulation wheel step could potentially predict the beam current and the dose distribution. This study verified the feasibility of the in-vivo dose verification by measuring the time structure of the prompt gammas. For the clinical use of this method, various background reduction techniques such as time-of-flight and pulse shape discrimination would be required.

97 - A Monte Carlo study of resolving the radiation dose through the detection of Cerenkov radiation in Boron Neutron Capture Therapy

Presenter: Mr. SHU, Diyun (Nanjing University of Aeronautics and Astronautics)

Radiation dose in boron neutron capture therapy (BNCT) is determined by both the epithermal neutron beam and Boron-10 distribution. It is thus more complex and important to monitor the radiation dose comparing to other radiation treatment modalities. In this study, we investigated the feasibility of resolving the radiation dose with respect to the change of beam property and Boron-10 concentration through the detection of Cerenkov radiation during BNCT. Monte Carlo toolkit Geant4 was used to simulate the irradiation of epithermal neutron beam on phantom containing tumor region. Cerenkov can be generated during BNCT and it is expected to be correlated with gamma dose. The depth and radial distributions of gamma dose were obtained under different characteristics of boron concentration and epithermal neutron beam. The relationship between the number of Cerenkov photons and gamma dose was explored based on simple phantom and Chinese reference radiation phantom. Results showed that the gamma dose is almost unchanged under different boron concentration distributions, even if the relative change of boron concentration reached 60 percent. The changes in the characteristics of epithermal neutron beam directly leads to the changes in the gamma dose. This indicated that gamma dose can be used to reflect the stability and delivery accuracy of epithermal neutron beam. Meanwhile, the response relationship between the number of Cerenkov photons and gamma dose was observed. As a preliminary result, it suggests the potential feasibility to monitoring the gamma dose and the stability of the epithermal neutron beam through the detection of Cerenkov radiation emitted during BNCT.

98 - Measurement of the induced neutron ambient dose equivalent during proton therapy in scanning mode

Presenter: Dr. LEE, Chaeyeong (Department of Radiological Science, Yonsei University, Wonju 26493, Korea); Prof. KIM, Jin Sung (Department of Radiation Oncology, Yonsei Cancer Center, Yonsei University College of Medicine Seoul, Republic of Korea)

The purpose of this study is to evaluate secondary neutron ambient dose equivalent, which simulated and measured four positions around a plastic water phantom on a couch. We compared and analyzed the secondary neutron dose during proton treatment with scanning mode of each gantry.
The volume of the plastic water phantom was 30 × 30 × 60 cm3 and was located at the isocenter. The phantom was irradiated by a proton beam at 190 MeV. Proton beams were used to irradiate a volume of 10×10×10 cm3 centered at the isocenter in each nozzle. In addition, WENDI 2 detector was used as a neutron measuring device to measure the neutron ambient dose equivalent. We performed experiments under the same conditions as those of FLUKA simulation.
The ambient dose equivalent value was normalized to the maximum value at each nozzle of scanning mode. Each normalized neutron flux in the simulation and experiment showed similar tendencies.
We successfully simulated and measured the neutron ambient dose equivalents at four positions generated by the scanning mode. These results prove that the simulation data provides reliable data of the induced neutron dose. Our results provide sufficient reference for the occurrence of secondary neutron during proton therapy.

99 - Dosimetric impact of Statistical Uncertainty on Monte Carlo dose calculation in Monaco TPS volumetric modulated arc therapy for prostate cancer

Presenter: Mr. P, Mohandass (1 Department of Radiation Oncology, Fortis Cancer Institute, Fortis Hospital, Mohali, Punjab, India, 2 Department of Physics, School of Science and Humanities, Karunya University, Coimbatore, Tamilnadu, India)

Purpose: To study the dosimetric impact of statistical uncertainty (SU) per plan on Monte Carlo calculation in Monaco™ TPS during volumetric modulated arc therapy (VMAT) for prostate cancer.

Methods: Three prostate cancer patients treated with 79.2Gy/44fractions were chosen for the study. VMAT plans were generated with Monaco™ treatment planning system (TPS-V5.10) for Elekta Synergy™ linear accelerator with 1cm leaf width. Plans were generated using dual full arcs with 2% statistical uncertainty per plan. By keeping all other parameters constant, plans were recalculated only by varying the SU, 0.5, 1, 2, 3, 4, and 5%. For plan evaluation, conformity index (CI), Homogeneity index (HI) to planning target volume (PTV), dose coverage to PTV (D98%) was analyzed. Mean and max dose to organ at risk (OAR) was analyzed for bladder, rectum, left femur, right femur and bowel bag. The normal tissue volume receiving dose >5Gy&>10Gy and normal tissue integral dose (NTID) (patient volume–PTV), calculation time (mins), gamma pass rate (<1.00) (3%/3mm) and point dose measurement were compared. In addition, calculation reproducibility and energy dependency with 15MV were analysed.

Results: CI and HI improve as the SU increases from 0.5 to 5% (P>0.05). Dmax to PTV increases as SU increases (P<0.05). No significant dose difference was observed in Dmean, D98% to PTV, mean and volume dose to bladder, rectum, left femur, right femur, bowel bag, normal tissue volume receiving dose >5Gy&>10Gy and NTID (P>0.05). Decrease in dose calculation time was observed with increase of SU (P<0.05). Gamma pass rate was observed as 99.90±0.20%, 99.70±0.30%, 98.966±0.56%, 99.400±0.60%, 99.30 ± 0.07%, and 99.30 ± 0.50%. Similarly, point dose verification was observed within ±1%. No significant dose difference was seen in calculation reproducibility and independent of photon energy (P<0.05).

Conclusion: For prostate VMAT plans, SU can be accepted up to 3% per plan with reduced calculation time without compromising target coverage, OAR doses and plan delivery. Only variations in point dose and inhomogeneous dose within target was observed. There is no significant variation in calculation reproducibility and energy dependency was found.

100 - Monte Carlo simulation of dose conversion coefficients for radiation exposure from medical diagnostic imaging

Presenter: Prof. QIU, Rui (Department of Engineering Physics, Tsinghua University, Beijing, China)

In China, the current standard for estimation of the examinee's organ doses in X-ray diagnosis was developed based on ICRP Publication 34. A project is carried out to update this standard with the development of the more precise phantoms and the latest dose estimation method. In this paper, the organ and effective dose conversion coefficients of the examinee for the CT scanning, X-ray radiography and mammography are calculated.
The Chinese reference adult male (CRAM) and female (CRAF) voxel phantoms and a series of pediatric phantoms at different ages were developed in our research group. All the phantoms consist of more than 90 organs and tissues, including all the radiosensitive organs and tissues for effective dose calculation. In addition, a 3D detailed breast model was constructed for mammography simulation, which contains subcutaneous fat, Cooper’s ligaments, fibroglandular region, and so on.
All the simulations were performed with Geant4. In CT simulation, the CT scanner model was based on GE LightSpeed 16. In order to provide a fast dose estimation for CT scans with different scan lengths, a series of simulations for axial scans was performed. Thus, a database was built for each phantom and CT scanning parameter. Using the database, organ and effective doses in any scan mode can be obtained easily. In X-ray radiography simulation, cone beam emitted from a point source forms a regular rectangular field on the surface of phantom after going through a lead collimator. The organ and effective dose conversion coefficients of chest, abdomen, lumbar spine and pelvis X-ray radiography with different field sizes were simulated. In mammography simulation, the calculations using the compressed breast models of different glandularity and thickness were performed at different X-ray tube voltages for the Mo/Mo X-ray spectrum. The absorbed dose of glandular tissue was calculated and the dose conversion coefficients were obtained.
In summary the dose conversion coefficients of the examinee for the CT scanning, X-ray radiography and mammography are calculated. The data calculated in this paper will provide references for the revision of the national standard for the estimation of the examinee's organ doses generated by X-ray diagnosis.

101 - Comparison of dose calculation between AAA algorithm and Monte Carlo calculation for prostate cancer

Presenter: Prof. KHELIFI, Rachid (Université Blida1)

In radiotherapy, the accuracy of dose calculation is very important for a treatment success. Analytical algorithms implemented in commercial Treatment Planning Systems (TPS) achieve this calculation .In order to reduce time calculation; these algorithms do some assumptions, which cause important errors, especially in the cases with high heterogeneities. The aim of our study is to evaluate the AAA analytical algorithm of dose calculation using a Monte Carlo method, which is the most accurate, and considered as a reference in dose calculation. To accomplish this purpose, we started by the modeling of the treatment machine (Varian 2100C LINear ACcelerator) for the photons mode and the energy of 18MV, using EGSnrc Monte Carlo code. After that, we used this model to calculate dose distribution in patients treated for prostate cancer. Finally, the results are compared to those of Eclipse AAA TPS.

102 - Optimization of Megavolt unflattened photon beams: A Monte Carlo study

Presenter: Mr. MOHAMMED, Maged (Radiations and Nuclear Systems Laboratory, University Abdelmalek Essaadi, Faculty of Sciences, Tetouan, Morocco)

The components of the medical accelerator play a prominent role to improve the quality of treatment in radiation therapy. This study aims to investigate the physical characteristics, such as surface dose, dose profile, depth dose, energy spectra and dose rate, of 12 MV photon beam with flattening (FF) and without flattening filter (FFF). The Monte Carlo code EGSnrc (Kawrakow and Rogers, 2017) under the platforms BEAMnrc (Rogers et al., 2017) and DOSXYZ (Walters et al., 2005) were employed for modeling a Saturne43 Linac to simulate 12 MV photon beam. The results obtained in this study showed that the removal of flattening filter leads to increasing the surface dose by 10.4% and the dose rate increases 4.06 times when flattening filter removed compared to the flattened beam. The dose of unflattened beam at 4cm from the central axis reduced 15.2% compared to flatten one. Furthermore, we have succeeded to reduce surface dose that increased by removing the flattening filter by a factor of 2.5%. Due to the Air column, between the jaws and the phantom, replaced by Helium column. We conclude that the lower dose in the out-of-field, the high dose rate and reducing the head scatter of unflattened beam contribute to add new features to photon beams that will improve the quality of treatment.

Keywords: flattened beam; dosimetric properties; Monte Carlo; medical accelerator, helium

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103 - GAMOS: Implementation of a Graphical User Interface for Dosimetry Calculation in Radiotherapy

Presenter: Mr. ALAOUI ABDALAOUI SLIMANI, Faiçal (Faculty of Medicine and Health Sciences, university of sherbrooke); Prof. BENTOURKIA, MHamed (Faculty of Medicine and Health Sciences, university of sherbrooke)

There are several computer programs or combination of programs for radiation tracking and other information in tissues by using Monte Carlo simulation. Among these are GEANT4 programs provided as classes that can be incorporated in C++ codes to achieve different tasks in radiation interactions with matter. GEANT4 made the physics easier but requires often a long learning-curve that implies a good knowledge of C++ and the Geant4 architecture. GAMOS, the Geant4-based Architecture for Medicine-Oriented Simulations, facilitates the use of Geant4 by providing a script language that covers almost all the needs of a radiotherapy simulation but it is obviously out of reach of biological researchers. The aim of the present work was to report the design and development of a Graphical User Interface (GUI) for absorbed dose calculation and for particle tracking in humans, small animals and phantoms. The GUI is based on the open source GEANT4 for the physics of particle interactions, on the QT cross-platform application for combining programming commands and for display. The calculation of the absorbed dose can be performed based on 3D CT images in DICOM format, from images of phantoms or from solid volumes that can be made from any pure or composite material to be specified by its molecular formulas. The GUI has several menus relative to the emitting source which can have different shapes, positions, energy as mono- or poly-energy such as X-ray spectra; the types of particles and particle interactions; energy deposition and absorbed dose; and the output results as histograms. In conclusion, the GUI we developed can be easily used by any researcher without the need to be familiar with computer programming, and it will be freely proposed as an open source.

104 - Efficiency improvement in proton dose calculations with an equivalent restricted stopping power formalism

Presenter: Mr. MANEVAL, Daniel (Université Laval)

To maintain the dose accuracy of Monte Carlo simulations, the mean energy loss calculation usually requires a step restriction (dmax). It leads to a O(n) algorithmic time complexity, where n is the subdivision number imposed by dmax. A new formalism is proposed to accelerate Monte Carlo dose calculations, allowing the removal of dmax in the step selection leading to a O(1) algorithmic time complexity. In this formalism, the midpoint rule of the Newton-Cotes formulae was used to solve the integral equation relating the mean energy loss to the step. The fractional energy loss was obtained with a secant method and a Gauss-Kronrod quadrature, revealing within the midpoint rule the equivalent restricted stopping power (Leq), used here as a key physical quantity. For any step, the mean energy loss was simply defined as the product of the step with Leq. Proton inelastic collisions with electrons were added to GPUMCD, a GPU-based Monte Carlo dose calculation code. The proton continuous slowing-down was modelled with the Leq formalism. First, the dose and time impacts of dmax were studied within Geant4. Second, in voxelized geometries, GPUMCD was compared to Geant4 using a high accuracy simulation setup (dmax=10 μm). The ionization processes alone were activated and the energy straggling was first switched off to validate alone the Leq formalism.
The default settings (dmax=1 mm) in Geant4 led to an error of up to 16.5% in the falloff region, up to 4.8% elsewhere and the computation times were inversely proportional to the maximal step length allowed. Dose differences between Geant4 and GPUMCD were smaller than 0.31% in the Bragg peak for the Leq formalism. GPUMCD 80% falloff positions (R80) matched Geant R80 within 1 μm. With the energy straggling, dose agreements were within 2.7% in the falloff, below 0.83% elsewhere and R80 positions matched within 100 μm. The overall computation times per million transported protons with GPUMCD were 31-173 ms. Under similar conditions, Geant4 computation times were 1.4-20 hours.
The Leq formalism allows larger steps while preserving the accuracy. It significantly accelerates Monte Carlo proton transport. The Leq formalism constitutes a promising variance reduction technique for computing proton dose distributions in a clinical context.

105 - Monte Carlo Based Evaluation of Spherical Applicators for Low-kV IORT of Breast Cancer

Presenter: Dr. BAGHANI, Hamid Reza (Radiation Medicine Department, Shahid Beheshti University, Tehran, Iran)

Monte Carlo Based Evaluation of Spherical Applicators for
Low-kV IORT of Breast Cancer

Hamid Reza Baghani (1, 2, *), Zhila Ghorbani (2) and Seyed Mahmoud Reza Aghamiri (2)

(1) Physics Department, Hakim Sabzevari University, Sabzevar, Iran
(2) Radiation Medicine Department, Shahid Beheshti University, Tehran, Iran
* presenting author: Hamidreza.baghani@gmail.com

One the recent radiotherapy modalities for breast cancer is the low-KV IORT [1]. In this method, the created lumpectomy cavity, after the tumor resection, is filled by some dedicated spherical applicators. Then, the X-ray source is introduced to the applicator and a high single fraction of radiation dose (20 Gy) is administered to the patient [1]. The aim of this study is to determine the dosimetric characteristics of dedicated spherical applicators through Monte Carlo simulation and comparing the obtained results with those of ionometric dosimetry.

X-ray probe and employed spherical applicators were simulated by Monte Carlo MCNPX code. The diameter of studied applicators ranged from 1.5 cm to 5 cm with 0.5 cm increments. Then, the dosimetirc parameters including percentage depth dose (PDD), transfer function and anisotropy were calculated for each applicator inside the water. To practically measure the mentioned dosimetric parameters, soft X-ray ion chamber (TM 34013, PTW, Germany) was employed. All of the measurements were performed inside a dedicated water phantom.

The results showed that with increasing the applicator diameter, surface dose and dose gradient in depth is decreased. Obtained anisotropies at various distances and angles were in accordance to the confident intervals reported by manufacturer (Carl Zeiss, Germany). Furthermore, there was a reasonable agreement between the measured and calculated dosimetric parameters.

The results of this study confirmed the applicability of dedicated spherical applicators for partial breast irradiation. Furthermore, the Monte Carlo simulation can be considered as a reliable method for applicator commissioning and obtaining the corresponding dosimetric data where experimental setup of applicator and ion chamber dosimeter could be sophisticated and time-consuming.

Keywords: Low-kV IORT, breast cancer, spherical applicator, dosimetric characteristics

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106 - Performance Evaluation of Two Dedicated Radioprotective Disks in Breast Intraoperative Electron Radiotherapy

Presenter: Mrs. GHASEMI, Shiva (M.S.C of Radiation Biology and Radiation protection, Paramedical department, Shahid beheshti University of Medical Sciences, Tehran, Iran)

Performance Evaluation of Two Dedicated Radioprotective Disks in Breast Intraoperative Electron Radiotherapy

Shiva Ghasemi (1), Hamid Reza Baghani (2, 3, *), Seyed Rabi Mahdavi (4), Mohsen Bakhshandeh (1), Nahid Nafissi (5)

(1) Radiation Technology department, Shahid Beheshti University of Medical Sciences, Tehran, Iran
(2) Radiation Medicine Department, Shahid Beheshti University, Tehran, Iran
(3) Physics Department, Hakim Sabzevari University, Sabzevar, Iran
(4) Medical Physics Department, Iran University of Medical Sciences, Tehran, Iran
(5) Surgery Department, Iran University of Medical Sciences, Tehran, Iran
* Presenting author: Hamidreza.baghani@gmail.com

The aim of breast intraoperative electron radiotherapy is to deliver the prescribed dose to the tumor bed during surgery. In this method, sensitive organs such as pectoral muscles, heart and lungs may be exposed to radiation. Therefore, a radioprotective disk is commonly used to protect the underlying healthy tissues. In this study, the performance of two employed radioprotective disks for breast intraoperative radiotherapy in terms of transmission factor (TF) and backscatter factor (BSF) were compared and the optimum disk was introduced.
TF and BSF of the disks understudy, first disk consisted of PTFE-stainless steel and the second one consisted of PMMA-Copper, were determined through irradiating the disks by LIAC mobile accelerator inside the water phantom and Advanced Markus ion chamber dosimetry.
According to the obtained results, the BSF values of second disk in energies of 6, 8, 10 and 12 MeV was 4.5%, 2.8%, 3.8% and 2.9% lower than the first disk, respectively. In addition, the TF values of second disk in energies of 6, 8, 10 and 12 MeV was also 100%, 20%, 60% and 71% lower than the first one, respectively.
Based on the results, it can be concluded that the second radioprotective disk (consisted of PMMA and Copper) has the better protecting performance and in addition to the dose uniformity inside the tumor bed, will minimize the received dose to the organs at risk.

Keywords: Radioprotective disk, Intraoperative electron radiotherapy (IOERT), breast cancer

107 - Dosimetric Comparison of Electron Beam from LIAC TM Intraoperative and ONCOR TM Conventional Accelerator: A Monte Carlo Study

Presenter: Dr. BAGHANI, Hamid Reza (Radiation Medicine Department, Shahid Beheshti University)

Hamid Reza Baghani (1, 2, *), Seyed Mohammad Ali Vakil (2) and Seyed Mahmoud Reza Aghamiri (2)

(1) Physics Department, Hakim Sabzevari University, Sabzevar, Iran
(2) Radiation Medicine Department, Shahid Beheshti University, Tehran, Iran
* presenting author: Hamidreza.baghani@gmail.com

LIAC (Sordina, Italy) is a newly introduced electron accelerator for intraoperative radiotherapy. In this type of accelerator, a special design is employed for electron beam collimation which is completely different from that of conventional accelerators. This fact can considerably change the dosimetric characteristics of intraoperative electron beam from those of conventional one. The aim of this study is to compare the dosimetric parameters of LIAC and ONCOR (Siemens, Germany) accelerators through Monte Carlo simulation.

To this end, the head of both accelerators with their associated components were simulated by MCNPX Monte Carlo code. Then, the percentage depth dose (PDD), transverse dose profile (TDP) and output factors (OF) related to the accelerators understudy at different energy and field sizes were calculated inside a cubic water phantom and compared. It should be mentioned that the TDPs were calculated at depth of maximum dose for each energy/field size combination.

The results showed that R100, R90, R50 and Rp related to the LIAC electron beam were lower than those of ONCOR one at the same energy and field size. Furthermore, at all of studied energies, the surface dose for LIAC electron beam was higher than that of ONCOR electron beam. In comparison to the conventional electron beam (ONCOR), the symmetry and flatness of intraoperative electron beam (LIAC) was more desirable at all of studied energies and field sizes. Unlike the ONCOR accelerator, the OFs related to the LIAC electron beam increased with decrement of field size.

Based on the obtained results, it can be concluded that the dosimetric properties of intraopreative electron beam are substantially different from those of conventional electron beam. This fact is mainly due to the different beam collimation system and absence of bending magnet in design of LIAC accelerator.

Keywords: LIAC accelerator, ONCOR accelerator, electron beam, dosimetric parameters, Monte Carlo simulation

108 - Study on conformal proton therapy using multileaf-collimated beams without tumor-specific range compensators via flat dose-layer stacking

Presenter: Dr. SHAO, Wencheng (Department of Nuclear Science and Engineering, Nanjing University of Aeronautics and Astronautics)

Purpose: In traditional conformal proton therapy (CPT), proximal dose conformity of tumors is sacrificed for achieving distal dose conformity due to tumor-specific range compensators. This study investigated whether CPT can be realized without tumor-specific range compensators using multileaf-collimated proton beams, and whether range-compensator-free CPT (RCF-CPT) can improve the proximal dose conformity without sacrificing distal conformity.
Methods: First, geometric configurations of a virtual multileaf-collimator (MLC) and three tumor cases (brain, liver, and prostate) were adopted during Geant4 geometry setup. Second, conformal proton radiation fields were generated for tumor CT slices based on the predesigned MLC using Geant4. Third, flat dose-layers corresponding to these tumor slices were produced using dose patching method in which MLC-collimated subbeams can be utilized to modulate the dose uniformity of these flat dose-layers. Forth, these flat dose-layers were stacked and integrated throughout the tumors for obtaining sufficient tumor dose coverages. Furthermore, dosimetric comparisons between the RCF-CPT and traditional CPT were performed to detail the dosimetric advantages of RCF-CPT.
Results: For the three tumor cases, the tumors can be sufficiently covered by 95% relative doses through RCF-CPT, and the maximum tumor doses were smaller than 110% relative doses. Approximately, the proximal doses of RCF-CPT were controlled to 60% relative doses, and 95% dose lines fit with the tumor profiles at proximal tumor regions.
Conclusions: Compared with traditional CPT, RCF-CPT can highly enhance the proximal dose conformity of tumors without sacrificing distal conformity. Moreover, the workflows of CPT can be largely simplified based on the range-compensator-free characteristic of RCF-CPT.

109 - A MONTE CARLO MODEL OF THE ELEVATED TRACE ELEMENT CONCENTRATION FOR DIAGNOSIS OF THE BREAST CANCER

Presenter: Dr. OH, Kyuhak (Republic of Korea Army)

Using neutron capture reactions designed by Monte Carlo simulation toolkit, this research investigates the influence of one of trace elements, chlorine, for diagnosis of breast cancer having the highest death rate of women. Abnormal concentration of particular trace elements has been used as a kind of warning system for specific diseases or disorder since the small amount of change in concentration of the trace element gives effects on the human physiological system [1]. One of trace element, Chlorine, was used to diagnose breast cancer because it is highly concentrated in the breast tissue and has large neutron capture γ-ray cross-sections as well as significantly different concentrations between normal and tumorous breast tissues [2]. Using the GATE (GEANT4 Application for Emission Tomography)[3], one of Monte Carlo simulation programs, optimized thermal neutrons were designed for interactions with samples of both normal and tumorous breast tissues including Chlorine. Spectra for characteristic γ-rays emitted by thermal neutron capture reactions were analyzed and specific peaks at energy levels such as 6.12, 7.80 and 8.58 MeV were observed. Significant differences of net count area between normal and tumorous tissues proved that Chlorine could be defined as a signal element for the diagnosis of breast cancer. Although various mechanisms have been developed for diagnosing cancer, there are still many blind spots. However, the method introduced in this research could reduce errors and help correctly diagnose.

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111 - Monte Carlo modeling of Orthovoltage treatment fields

Presenter: Prof. SUMINI, Marco Sumini (University of Bologna - INFN)

Computational power and anthropomorphous phantoms advances in the last years have extended greatly the number of potential applications of Monte Carlo methods in the medical field. Aiming at an orthovoltage treatment plan definition, the results of Monte Carlo simulations performed with the MCNP6 code on two different typologies of computational models have been compared: Unstructured Mesh (UM) model and Voxel model. The capability to simulate the particle transport directly on the unstructured mesh model geometry has been recently introduced in the release 6 of MCNP[1], which has been chosen for this study. These kind of models overcome the insurgence of voxel effects[2] and provide a more accurate description of volumes and complex surfaces.
The simulations were performed on anthropomorphous models based on anonymous CT scans. Firstly, the UM model was obtained from the CT scans thanks to the SCAN-IP mesh tools (Simpleware), and secondly the CT was voxelized with different voxel sizes in order to compare and gauge the voxel effects. The radiation source simulates the Orthovoltage X-Ray tube in use at IRCCS-ASMN in Reggio Emilia, tested in different configurations and tube voltages. The computational source has been validated with experimental measures on the real one applied on heterogeneous slab phantoms. The validation showed good agreement of the simulated setups with the experiments, with deviations varying accordingly to the source configuration, but always below 5-6%. The comparison between the two models showed how, with decreasing voxel sizes, the voxel models results partially converge to the UM models values. Furthermore, it was highlighted that the major deviations between the models resulted where the dose gradient is higher, along the field borders and when tissue heterogeneity is more and more considered. The study shows how the UM model can be implemented for evaluating the dose deposition within anthropomorphous phantoms and, in perspective, be used in treatment planning.

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112 - Validation of Statistical Uncertainty on Monte Carlo dose calculation in two different Monaco TPS versions

Presenter: Mr. P, Mohandass (1 Department of Radiation Oncology, Fortis Cancer Institute, Fortis Hospital, Mohali, Punjab, India), (2 Department of Physics, School of Science and Humanities, Karunya University, Coimbatore, Tamilnadu, India)

Purpose: To validate the statistical uncertainty (SU) per plan on two different Monte Carlo calculation versions in Monaco™ TPS during volumetric modulated arc therapy (VMAT) for lung cancer.

Methods: To compare Monaco™ treatment planning system with two different versions TPS-V5.10.02 (old) and TPS-V5.11 (new), VMAT plans were generated for Elekta Synergy™ linear accelerator with 1cm leaf width. New version includes refactoring changes as compared to its previous versions, which introduces a change to the random number sequence used in the MC calculation code that needs to be validated by clinical physicists as mandated by vendor. Hence, three lung VMAT plans from each version with the prescription of 60Gy/30fractions were chosen for the study. Plans were generated using partial arcs with 2% statistical uncertainty per plan. By keeping all other parameters constant, plans were recalculated only by varying the SU, 0.5, 1, 2, 3, 4, and 5%. For plan evaluation, conformity index (CI), Homogeneity index (HI) to planning target volume (PTV), dose coverage to PTV (D98%) was analyzed. Mean and max dose to organ at risk (OAR) was analyzed for spinal cord, pericardium, both lungs-PTV, esophagus and liver. Normal tissue integral dose (NTID) and volume receiving dose >5Gy&>10Gy, calculation time (mins), gamma pass rate (3%/3mm) and point dose measurement were compared.

Results: In both versions, CI and HI improve as the SU increases 0.5–5%. No significant dose difference was observed in Dmean to PTV, both lungs-PTV dose, mean dose to pericardium, esophagus, liver and normal tissue volume receiving dose >5Gy&>10Gy and NTID. A consistent observation with both versions is increase of SU leads to decrease in dose calculation time and increase in Dmax to PTV & spinal cord. ≥98.2% gamma pass rates and <3% variations in point dose verification were observed in both versions.

Conclusion: No significant difference in plan quality and deliverability was observed, besides the change in the refactoring changes in new Monaco TPS version. In both versions, SU can be accepted up to 3% per plan with reduced calculation time without compromising target coverage, OAR doses and plan delivery by accepting variations in point dose and inhomogeneous dose within target.

113 - Accurate extraction of tissues parameters for Monte Carlo simulations using multi-energy CT

Presenter: Mr. LALONDE, Arthur (Universite de Montreal)

Purpose: Robust tissue characterization is essential for accurate dose calculation [1,2]. In this work, we present a novel method called Bayesian eigentissue decomposition (BETD) [3] to extract Monte Carlo inputs from computed tomography (CT) data having an arbitrary number of energies.

Method: Principal component analysis is applied on a reference dataset of human tissues to define eigentissues which are used as an optimal base of materials representing tissue compositions. To ensure robustness against CT noise, the Bayesian estimator is constructed and resolves the maximum a posteriori fraction of eigentissues in each voxel. The performance of the method in deriving proton beam interaction properties is evaluated with dual-energy CT (DECT) data and compared to a state-of-the-art elemental composition parameterization. Comparison is made with several levels of noise and in the presence of statistical variations in tissue composition and density. The performance of the BETD to an arbitrary number of energies is also investigated by simulating CT data with two to five energy bins with equivalent noise levels.

Results: Using simulated noise-free CT numbers for 43 reference soft tissues, the BETD and parameterization methods give equivalent results for stopping powers estimation (0.11% and 0.13% respectively). However, when noise and tissue variation are present, the BETD reduces the RMS error on stopping powers from 2.79% for parameterization to 1.88% for the proposed approach. The BETD method also shows potential for using CT with more than 2 energies, where a number of four energy bins is shown to reduce proton beam range uncertainty by a factor of up to 1.5 compared to the parameterization method used with DECT.

Conclusion: This work proposes a general approach to determine elemental compositions and density for Monte Carlo inputs using CT data in a clinical context, where noise and tissues variations significantly degrade the performance of currently known methods.

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114 - The impact of dual-energy CT tissue segmentation for low-dose rate prostate brachytherapy Monte Carlo dose calculations

Presenter: Mrs. REMY, Charlotte (Universite de Nantes)

Purpose: To evaluate the impact of a novel tissue segmentation method based on dual-energy CT (DECT) for low-dose rate (LDR) brachytherapy dose calculations, by comparison with a reference single-energy CT (SECT) segmentation method.

Methods: A virtual patient geometry is created using the DICOM-RT of a real patient pelvis SECT scan, where known elemental compositions and varying densities are overwritten in each voxel to define a reference phantom. Simulated CT images are generated using XCOM attenuation coefficients, with a 100 kVp spectrum for SECT, and 80 and 140Sn kVp for DECT. Tissue segmentations for Monte Carlo (MC) dose calculations are performed with both SECT and DECT and compared with the reference geometry. For SECT, the method of Schneider et al. [1] is used and for DECT, the eigentissue decomposition of Lalonde & Bouchard [2] used in combination with a Bayesian estimator. A LDR prostate brachytherapy treatment is planned with 125I sources and calculated using the MC code Brachydose for all three cases. Dose distributions and dose-volume histograms (DVH) are compared to the reference dose distribution to investigate the accuracy of the tissue segmentation methods.

Results: For noiseless images, DECT-based tissue segmentation outperforms the SECT procedure with a relative dose distribution root mean square error (RMSE) of 3.08% versus 8.02%, and provides DVH closest to the reference for all tissues. For a medium level of noise (12 HU), Bayesian eigentissue decomposition performs better with a dose calculation RMSE of 6.11% and 8.49% for DECT and SECT, respectively. Both methods yield similar DVHs for the prostate while DECT segmentation remains more accurate for organs at risk.

Conclusion: Our study shows that DECT-based tissue segmentation has the potential to provide LDR brachytherapy dose distributions with higher accuracy that conventional SECT in a clinical context, even in the presence of noise.

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115 - A Monte Carlo-based eigenspectrum decomposition technique for computed tomography

Presenter: Mr. SIMARD, Mikael (Universite de Montreal)

Purpose: The characterization of computed tomography (CT) X-ray spectra is important for beam-hardening correction techniques and raw-data reconstruction methods [1,2]. In this work, we propose a novel spectrum estimation approach based on transmission measurements and the use of Monte-Carlo (MC) to generate basis spectra.

Methods: The EGSnrc/BEAM MC code is used to generate basis X-ray spectra. The XTUBE component module is used to produce bremsstrahlung photon energy spectra from monoenergetic electrons transported through a tungsten target (10 degrees), a beryllium window (1 mm) and additional filtration. To ensure that the modelled spectra cover the features of the unknown spectrum, a total of 40 spectra with various levels of filtration are generated using different thicknesses of aluminum and carbon, ranging from 2 mm to 18 mm. Principal component analysis is performed on the MC-generated model spectra to extract a set of linearly independent basis functions, each called eigenspectrum, which reduces the dimensionality of the problem and allows stable fitting. Transmission measurements of a calibration phantom are simulated using ray-tracing with an 80-kV source and added Poisson noise. The estimated spectrum is expressed as the weighted sum of eigenspectra and reconstructed through a constrained least squares technique.

Results: Using 8 eigenspectra, the 80-kV spectrum is reconstructed with a RMS error (RMSE) of 3.8%. The difference between the mean energy of the estimated and true spectrum is 0.01 keV. Reproducing the same methodology for a 140-kV spectrum yields a RMSE of 4.5% and mean energy difference of -0.1 keV.

Conclusion: The proposed method is shown promising to accurately characterize X-ray spectra with transmission data. With limited details on the X-ray tube and relying solely on calibration scans, our methodology provides robust spectrum estimation and is promising for reducing the known ill-posedness [3,4] of known transmission-based approaches. Applications of the technique to CT are expected to improve the accuracy of quantitative imaging for radiotherapy.

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116 - Comparison of beam output factors in MCNP6 and Geant4 based IAEA phase-space files.

Presenter: Mrs. SANCHEZ-ESTRADA, Raquel Ivon (Escuela Superior de Física y Matemáticas)

Monte Carlo (MC) dose calculation algorithms demand an accurate characterization of the radiation beam. At present, three MC-based beam models are commonly used for dose calculation; namely, full MC simulation, virtual source model, and phase space (phsp) files. The first two require detailed information of the LINAC head: information that is not always available from vendors. Therefore, properly validated phase-space data for external beam radiotherapy, available from the IAEA Nuclear Data Services section, remains a valuable alternative for MC beam simulation. The aim of this work is to compare the beam output factors obtained by MC-based phsp simulations in MCNP6 and Geant4. The simulations were performed with the photon mode energies of 6, 10, and 25 MV on the ELEKTA Precise. The simulations are divided into two steps: (1) the development of a method for directly reading the phase-space files provided by the IAEA in MCNP6, and (2) the determination of cut-off values, variation reduction techniques, and field size. Patient-specific beam line devices (blocks, jaws, wedges, etc.) were not simulated. The comparison of the output factors as percentage depth dose (PDD), lateral dose profiles, and dose distributions for different field sizes were computed using Geant4 and MCNP6. Both calculations generate matching PDD for a range of open-field sizes within the statistical uncertainties. Variation in lateral dose profiles varies up to 5% in the 25 MV energy mode. Comparison of dose distributions for an open 10x10 field by the gamma evaluation test returns a value of 0.93. Despite the lack of a user-friendly MCNP6 interface, this work shows that MCNP6 is suitable for beam simulation based IAEA-phsp.

117 - An MCNP6 suite of visualization tools for computed tomography data

Presenter: Mr. BETANCOURT, Enrique (IPN - ESFM)

Although Monte Carlo N-Particle (MCNP) is the leader in nuclear and radiological science, the use of MCNP in medical-related research has increased considerably since the introduction of electron transport in the 2000s. Due to the necessity for proper visualization of individualized medical physics models and phantoms, various packages became available for visualizing patients' computed tomography (CT) images. Nonetheless, in most cases, the maximum resolution provided by these packages is less than the resolution of the original CT images. This work introduces a set of tools for generating a highly detailed MCNP input file from imported medical CT images. These tools are divided according to their function into four categories: (a) discretization and classification of CT numbers to MCNP materials and mass density, (b) automatic generation of the MCNP input file according to the resolution provided by the CT image, (c) simulation of the input data into MCNP for calculating the quantities of interest, and (d) visualization of the CT images along with the results of a tally type in the MCNP simulation. Either the sagittal, coronal, and axial planes or a 3D visualization of the patient's volume can be displayed. Calculations for various monoenergetic beams were performed and properly visualized. These tools are not yet implemented with a friendly-user interface. Regardless, they demonstrate the capabilities of MCNP6 for large calculations inherent with medical CT image simulations.

118 - Internal Dosimetry of 68Ga-DOTATATE Using Monte Carlo GATE simulation For XCAT Phantom

Presenter: Ms. MOKRI, Mersede (Research Center for Nuclear Medicine, Shariati Hospital, Tehran University Of Medical Sciences, Tehran, Iran)

Mersede Mokri1, Mohmmad Reza Ay2 3, Sima Taghizade4, Marzieh Ebrahimi5, Parham Geramifar6
1 Research Center for Nuclear Medicine, Shariati Hospital, Tehran University of Medical Sciences, Tehran, Iran
2 medical physics and biomedical engineering department, school of medicine, Tehran University of medical sciences, Tehran, Iran
3 Research center for molecular and cellular imaging, Tehran, Iran
4 medical physics research center for science and technology in medicine RCSTM, Tehran, Iran
5 Research Center for Nuclear Medicine, Shariati Hospital, Tehran University of Medical Sciences, Tehran, Iran

6 Research Center for Nuclear Medicine, Shariati Hospital, Tehran University of Medical Sciences, Tehran, Iran

Introduction: The improvement in PET imaging leads to advancement in the quality of information obtained from patients with somatostatin receptor–expressing tumors. These synthetic somatostatin analogs can be labeled with β-emitting radionuclides, such as 68Ga(1). In addition, proper evaluation of the absorbed dose in critical organs is also one of the topics studied in the field of dosimetry. Monte-Carlo simulations and applying phantoms for dosimetry can give in hand rough estimates of absorbed dose in critical organs which can be helpful for researchers(2).
We intend to calculate absorbed dose from 68Ga source of activity in default male and female XCAT phantoms – the most accurate phantom that resembles human anatomy- in critical organs for this agent including spleen, bladder, kidneys and liver, pituitary gland and thymus.
One of the advantages of our work over dosimetry with patients is that we can easily estimate absorbed doses in pituitary gland and thymus which are important targets in 68Ga-DOTATATE dosimetry.
Materials and Methods: We generated two total body XCAT phantoms with 128×128 matrix size and 600 slices and 3.125 mm3 for voxel dimension. The energy of positron emitter was inserted 1.9 MeV that corresponds to 68Ga. 1mCi activity of 68Ga-DOTATATE was chosen, and this was assumed to be uniformly distributed in the source organs. GATE Monte-Carlo code; as dedicated code to nuclear medicine, was employed for dosimetry calculations. Based on MIRD schema, we reported s-values of self-absorption and cross-irradiation in spleen, bladder, kidneys and liver, as well as cross-irradiation in pituitary gland and thymus.
Results: We find out that S-value in spleen; the most critical organ in 68Ga-DOTATATE PET/CT scanning, from the source of spleen, is 13.7e004mGy/MBq-s in male phantom and 15.6e-004 mGy/MBq-s in female phantom. The highest amount of cross-irradiation in spleen is from Kidney with the amount of 0.097e-004 mGy/MBq-s. The most amount of self-absorption and is in Bladder with the amount of 42.1e-004 in male phantom and 50e-004 mGy/MBq-s in female phantom.
The absorbed dose in thymus from spleen is 2.3710e-006 mGy/MBq-s in male phantom and 3.1138e-006 mGy/MBq-s in female one. Absorbed dose of pituitary gland from spleen is 0.53e-007 mGy/MBq-s. Accuracy and validation was compared with other studies.
Conclusion: We performed internal dosimetry using XCAT phantoms and GATE Monte-Carlo code for 68Ga. Our results could help us estimating absorbed dose in critical organs. Also our method would calculate absorbed dose in some organs that could not be considered in conventional method like patient specific dosimetry that was done before in some studies.
Key Words: Internal Dosimetry, XCAT Phantom, Ga-68, PET Imaging, GATE Simulation

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119 - Effects of heterogeneities in dose distributions: Monte Carlo simulation vs dose calculation algorithms

Presenter: Dr. REIS, Cristiano (Brazilian National Institute of Cancer)

Purpose: Evaluate the performance of dose calculation algorithms used in radiotherapy treatment planning systems (TPSs) in comparison to Mont Carlo (MC) simulations in regions of heterogeneities.

Methods: Monte Carlo simulations with PENELOPE code were performed for either validation of a 6 MV spectrum of a VARIAN Trilogy linear accelerator and for comparison with dose calculated by the algorithms Pencil Beam Convolution (PBC), Analytical Anisotropy Algorithm (AAA) and Acurus XB commercially available in most TPSs. Relative depth dose curves were calculated in heterogeneous water phantoms with layers of bone (1.8 g/cm3) and lung material (0.3 g/cm3).

Results: Comparison of Monte Carlo calculated percentage depth dose (%dd) curves are found to agree within 1.6% with the clinical curve used in the radiotherapy service. Maximum difference between our results and Monte Carlo data from the literature [1] are of 0.4% of maximum dose after the build up region. Analysis of the relative depth dose curves at the water-bone interface shows that the PBC and AAA algorithms present the farthest values when compared to MC calculations (uMC=0.93%) with maximum differences of up to 4.2% and 3.8% of maximum dose respectively. Between the three algorithms investigated the Acuros presented the best agreement with Monte Carlo data with maximum difference of 1.6% of maximum dose. Calculations on a heterogeneous water-lung interface phantom were found to agree with MC calculations (uMC=1.1%)) to within 2%, 1.7% and 0.5% for PBC, AAA and Acurus algorithms respectively.

Conclusions: The results presented in this study show that the dose calculation algorithm Acurus presents the best agreement with Monte Carlo simulation data with equivalent accuracy for modeling radiotherapy dose deposition especially in regions where electronic equilibrium does not hold such as that in the presnce of inhomogeneities. However, both AAA and PBC algorithms can also exhibit reasonable agreement with MC results for standard fields (grater than 3 cm x 3 cm) use in radiotherapy.

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120 - Performance evaluation of the Siemens Biograph6 PET/CT Imaging system using GATE Monte Carlo simulation

Presenter: Ms. JOZI, Hanieh sadat (Science and Research Branch, Islamic Azad University, Tehran, Iran)

Introduction: As the performance of a PET scanner depends not only on the scintillating material but also on the scanner design, researchers use the Monte Carlo simulation in designing the scanners or evaluating their performance and optimizing the functional parameters before commercialization. In this study, was simulated a clinical PET/CT scanner with LSO crystal using Monte Carlo method for the purpose of investigation of the performance and obtaining the optimal patient injected activity.
Methods: The PET scanner of the Siemens Biograph6 PET/CT system was simulated using GATE Monte Carlo simulation code [1]. Sensitivity, scatter fraction (SF) and the noise equivalent count rate (NECR) metric were derived by the simulation of the standard sensitivity and count rate phantom in accordance with the NEMA NU 2-2001 protocol. GATE results were compared and validated against the published data in accordance with the vendor's specifications [2].
Results: The simulated NEMA standard phantoms showed scatter fraction and sensitivity of 36%, and 4.16 cps/kBq respectively. The difference between the measured and simulated sensitivity of system was less than 1%, and scatter fraction was within the accepted range. Also maximum NECR value in 35 kBq/cc activity concentration was 92060 cps results in less than 5% difference between simulated and measured data.
Conclusion: Our results demonstrated an excellent agreement between GATE simulated data and measured data. The evaluation of the PET scanner performance in the Siemens Biograph6 PET/CT scanner using Monte Carlo modeling shows that GATE is adequately accurate to describe the performance of PET system.
Keywords: Monte Carlo, GATE, PET scanner
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122 - Verification of dose estimation for Monte-Carlo based treatment planning system for boron neutron capture therapy

Presenter: Prof. KUMADA, Hiroaki (University of Tsukuba)

University of Tsukuba is developing a treatment device for accelerator-based treatment device for boron neutron capture therapy (BNCT). The project is developing not only the treatment device but also several peripheral devices needed in BNCT treatment [1]. A Monte-Carlo based treatment planning system (Developing code: Tsukuba-Plan) is also being developed for BNCT. Tsukuba-Plan has employed PHITS as Monte-Carlo dose calculation engine. PHITS as the multi-purpose Monte Carlo Particle and Heavy Ion Transport code System can calculate behaviors of neutrons and photons as well as protons and heavy-ions. Therefore Tsukuba-Plan with PHITS enables to perform dose estimations for not only BNCT (neutron) but also particle radiotherapy and X-ray therapy. A prototype of the Tsukuba plan has been completed. To apply the Tsukuba Plan to actual BNCT clinical trial, we are currently conducting several verifications.
To confirm dose estimation performance of Tsukuba-Plan, several verifications have been conducted. To verify dose estimation accuracy, calculations of Tsukuba-Plan were compared with experimental values. To measure distribution for thermal neutron flux and gamma-ray dose in human body, neutron irradiation with a water phantom were performed. Gold foils and TLDs are set in the phantom, and the phantom was set to irradiation position with beam aperture. Neutron beam was irradiated to the phantom. Regarding the calculation by Tsukuba-Plan, CT images of the water phantom were loaded to Tsukuba-Plan, and the irradiation conditions were represented, the experiment was simulated properly by Tsukuba-Plan. Two-dimensional distributions for both of thermal neutron flux and gamma-ray dose in the phantom were determined by calculating PHITS. The calculation results from Tsukuba-Plan were compared with the experimental values. The calculation values were in good agreement with the experimental values. The verification results demonstrated that Tsukuba-Plan enables to perform dose estimation for BNCT.
University of Tsukuba plans to perform clinical trial for BNCT by using the Linac-based BNCT treatment device. Treatment plans with Tsukuba-Plan will be applied to the clinical studies in the near future.
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123 - Planning of mixed electron-photon radiotherapy using the column generation method

Presenter: Mr. RENAUD, Marc-Andre (McGill University)

Purpose: Mixed electron-photon plans could provide dosimetric advantages for sites with a superficial component. Unlike photons, creating electron beamlets for inverse planning purposes requires a commissioned MC beam model as analytical methods cannot adequately model electron transport inside patients. To address the increase in the number of degrees of freedom for mixed beam planning, we investigate the performance of the column generation (CG) optimisation method, which is an iterative method that constructs apertures with the largest potential to improve the cost function. A subset of these apertures are added every iteration.

Methods: For a chest wall patient, MC-calculated electron beamlets were generated for five 80-cm-SAD beam angles for energies of 6, 9, 12, 16, and 20 MeV using a commissioned Clinac 21EX electron BeamNRC beam model. The average uncertainty in beamlet voxels was lower than 0.75%. Voxels inside contoured lung and bone structures were assigned realistic material compositions, with the rest of the body modelled as water, and voxel densities were mapped from the patient CT Houndsfield units. A photon MLC acted as the sole collimating device for electrons. In addition, 6 MV photon beamlets were created for a coplanar distribution of beam angles every 20º around the patient.

A dose-normalization-independent formulation of the CG pricing problem was used as a heuristic to rank the apertures generated at every iteration. Plans were created for four aperture addition schemes which incorporated a subset of the apertures generated from the pricing problem.

Results: Mixed plans produced the best target coverage and homogeneity while preserving the normal tissue-sparing advantages of modulated electrons. The heuristic ranking schemes yielded a 32% lower cost function compared to the scheme which added all generated apertures. All heuristic ranking schemes converged to a similar cost function after 125 apertures with one scheme having a 3x shorter runtime.

Conclusion: Electron-photon planning using the column generation method produced high quality chest wall plans combining the advantages of photon and electron radiotherapy, paving the way towards automatic delivery of mixed-beam treatments using standard accelerator hardware without electron-specific accessories.

124 - Application expansion of the Monte-Carlo based treatment planning system for BNCT to particle radiotherapy and X-ray therapy

Presenter: Prof. KUMADA, Hiroaki (University of Tsukuba)

University of Tsukuba is developing accelerator-based treatment device for boron neutron capture therapy (BNCT). As part of the development for BNCT, treatment planning system for BNCT (developing code: Tsukuba-Plan) is also being developed [1]. Tsukuba-plan has employed PHITS as the Monte-Carlo transport calculation code. PHITS can calculate neutron, photon as well as proton and heavy-ions including carbon-ions. Thus, Tsukuba-Plan with PHITS enables to perform dose estimations for not only BNCT but also particle radiotherapy and X-ray therapy.
In BNCT protocol, X-ray therapy is added after BNCT to enhance the treatment effect. And proton therapy may be also combined in the future. Therefore, Tsukuba-Plan is required dose estimation for the combined multi-modality therapy. Based on this background, the aim of this study is to expand application field of Tsukuba plan to conventional external radiotherapies. University of Tsukuba Hospital has X-ray therapy, proton therapy and BNCT. Thus, first, we have expanded Tsukuba-plan to proton therapy and X-ray therapy.
Regarding proton therapy, we constructed 155 MeV and 200 MeV proton beam source and a geometry data for the proton therapy device installed in our Hospital. Verification for calculation accuracy for proton irradiation were performed. Phantom experiments performed in advance were represented by Tsukuba-Plan. The proton dose distributions in the phantom were determined, and the calculations were compared with the experimental values. Regarding X-ray therapy also, the geometry of the X-ray therapy device and 6 MV and 10 MV X-ray beam source were made along PHITS format. The calculations were comparable with the experiments.
Calculations for proton and X-ray were in good agreement with experimental values, respectively. The results demonstrated that Tsukuba-Plan enables to estimate accurately doses for proton irradiation and X-ray irradiations. To put Tsukuba-Plan to practical use for proton therapy and X-ray therapy, Tsukuba-Plan is improved further and several verifications are performed.
This work was supported by JSPS KAKENHI Grant Numbers JP16K15343.

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125 - Fundamental Study for Practical Application of Radiotherapy Treatment Planning System Capable of Evaluating Neutron Dose Generated by Various Radiotherapy Beams

Presenter: Dr. TAKADA, Kenta (University of Tsukuba Hospital, Proton Beam Therapy Center)

There are many papers focused on secondary neutrons by calculation or measurement in high-energy radiotherapy fields [1, 2]. Monte Carlo calculation is easy to acquire the three-dimensional spatial distribution of the neutrons and is considered to be particularly useful tool for evaluating the “on-axis” of the primary radiotherapy beam.
In this study, basic calculations were performed for practical application of treatment planning that can take three-dimensional neutron dose into account by combining with new treatment planning system "Tsukuba-Plan" currently developed by University of Tsukuba. The incident radiotherapy beams were X-rays and “passive” particle beams (proton beam, carbon-ion beam). Particle and Heavy Ion Transport code System (PHITS) [3] was used as Monte Carlo code. We constructed calculation geometries that reproduces the actual beam delivery systems of these radiotherapy fields as precisely as possible, and confirmed consistency by comparing with measured percentage depth absorbed dose. The neutron doses and energy spectrums of "on-axis" and "off-axis" in homogeneous water phantom were calculated by irradiating each primary beams. Calculated neutron doses were compared with some published literatures. As next step, we used the Tsukuba-Plan to obtain the three-dimensional neutron dose distributions in human-shaped phantom in case of irradiating clinical beams with patient-specific devices such as bolus and collimators.
We achieved a relative comparison of the secondary neutron doses and energy spectrums at "on-axis" and "off-axis" of each incident beams by using PHITS code. Additionally, the three-dimensional neutron dose distributions in the human-shaped phantom by each beams were obtained by combining the Tsukuba-Plan. In the future, this function can be used for various evaluation of the secondary neutrons in radiotherapy fields under individualized irradiation conditions.

Acknowledgment
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126 - Evaluation of the clinical translation of an optimized Compton Camera during Boron Neutron Capture Therapy for melanoma patients

Presenter: Dr. GONG, chunhui (Nanjing University of Aeronautics and Astronautics)

Purpose: Boron Neutron Capture Therapy (BNCT) [1,2] is considered as a binary radiotherapy based on 10B(n ,α)7Li reaction. As other radiation therapy modalities, the clinical outcome will depend on the deposited dose, which is associated both with the boron concentration distribution and the thermal neutron flux. However, there is an on-going challenge to develop a technique that can be used to verify the boron concentration in real time during BNCT. Measurement of the 0.478-MeV prompt gamma rays emitted from de-excitation of 7Li is the feasible method to monitor the boron concentration in-vivo. Comparing to the collimator based SPECT technique [3,4], Compton camera based prompt gamma tomography is expected to be with higher efficiency. Based on our previous optimized Compton camera, which is dedicated for the considered energy, this study focuses on the evaluation of the clinical translation of an optimized Compton Camera for Melanoma patients in a clinical setting.

Method and materials: An optimized Compton camera, 3-cm thick and 10-cm wide for Silicon (scatter detector), 10-cm thick and 10-cm wide for Germanium (absorb detector), and 1-cm distance between them, was simulated in the Monte Carlo toolkit Geant4 [5]. A virtual patient with a melanoma was constructed and irradiated with epithermal neutron beam. The boron concentration was set as from 30 to 100 ppm. The Compton camera was detected from 36 directions (with an interval of 10 degree) in order to perform the 3D reconstruction. The List-Mode Ordered Subset Expectation Maximization (LM-OSEM) image reconstruction algorithm [6] was implemented to obtain the 3D image.

Results: With simulated melanoma patient, the detect efficiency of “True” events is approximately 0.15% with the boron concentration of 30 ppm. With different boron concentration, the detector efficiency is stable. The reconstructed image matches well with the profile of the capture location scored in the patient geometry. The pass rate of gamma index analysis of 3mm/3% for the relative distribution is about 90% with the prescribed dose level.

Conclusion:

The study shows that multiple direction based Compton camera can be used to reconstruct the location of the capture reaction, which can be further used for the dose calculation, in BNCT. The neutron background is considerable, which needs to be further considered and shielded. LM-OSEM is an efficient reconstruction method to perform the reconstruction for this application. The results provide the fundamental basis for further clinical translation of the Compton camera in BNCT.

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128 - Proton imaging system using collimator with small holes

Presenter: Mr. TANAKA, Sodai (The University of Tokyo)

Proton range calculation error of several percent is serious problem in dose calculation of proton therapy [1]. A margin for range uncertainty is usually set, however it may also produce excessive irradiation to normal tissue. One of ways to reduce the range calculation error is proton imaging, in which we can acquire proton stopping power directly. We have developed proton imaging system using thick scintillator and CCD camera [2]. In this system, all protons after traversing an object stop in scintillator and scintillation light corresponding to the energy deposit is detected. Due to the property of this detection system, deterioration caused by lateral scattering of proton is difficult to prevent. In this study, we considered a collimator to remove scattered protons and to improve the spatial resolution of the proton imaging system. The collimator was set just before the scintillator and the hole diameter is 1 mm. We evaluated the characteristics of this collimator with 70-MeV proton beam using PHITS (Particle and Heavy Ion Transport code System [3]). The lateral scattering of proton in scintillator was regarded as less than 2 mm diameter at 10e-2 of a maximum, which showed that holes at every 3 mm could be many data points. We also could acquire a one-to-one relationship between the light intensity and residual range of proton as our conventional method. Using this relationship, we can derive proton radiography/CT quantitatively with 1 mm spatial resolution.

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129 - Monte Carlo calculation of RBE and in-vitro validation for helium ion-beam therapy

Presenter: Mr. MEIN, Stewart (DKFZ)

Despite evidence of variable relative biological effectiveness (RBE) in proton therapy, RBE of 1.1 is an accepted clinical standard worldwide. However, this assumption is not applicable to heavier ions due to multivariable dependencies of RBE: radiation quality, linear energy transfer (LET), dose, and tissue type. In preparation for upcoming 4-He ion treatments at the Heidelberg Ion-beam Therapy Center (HIT), evaluation and comparison of RBE models coupled to Monte Carlo (MC) calculation engines is in progress. Experimental RBE measurements are compared to a data-driven phenomenological model (DD) and two biophysical models (MKM & LEM-IV) integrated in the FLUKA MC code.

Previous works parameterized 4-He RBE through construction of a phenomenological model and performed in-vitro validation using a cell-line with a mid-range photon (α/β)ph ratio of 5 [1, 2, 3]. Here, a comprehensive evaluation of RBE-He prediction is performed for a low (α/β)ph, an in-vitro surrogate for late responding tissues, a clinical case in particular which is absent in the literature.

Limitations of constant RBE for protons have been presented via comparative investigation of survival fraction variations along monoenergetic beams and spread-out Bragg peaks (SOBP) [4]. In this work, a similar approach was implemented for helium ions by collecting cell-kill measurements with pristine beams and modulated fields at dose levels ranging from 0 to 3.5Gy. Renal adenocarcinoma cells (Renca ATCC ® CRL-2947™) were cultured in RPMI-1640 Medium (Gibco) and seeded in 96-well plates. Photon (6MV) irradiations were delivered up to 8Gy for determination of linear quadratic parameters, (α/β)ph=1.8Gy. All experimentation was performed in triplicates and post-irradiation image acquisition took place with the IncuCyte® System. FLUKA Monte Carlo simulations, validated against experimental measurements [5], were performed for prediction of dose, dose-averaged linear energy transfer (dLET) and RBE-weighted dose (DRBE) for DD, MKM and LEM-IV. Results confirmed the expected enhancement of cell kill with increased dLET for helium ions.

Before 4-He ion-beam therapy is clinically translated, comprehensive dosimetric and biological evaluation of the variable RBE models is critical. Preliminary work demonstrates variability between the approaches to modeling but relatively good agreement between RBE predictions and experimental data. With the support of experimentally validated MC, further in vitro studies of the existing models is crucial.

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130 - Energy response correction for EPID dosimetry in photon radiation therapy

Presenter: Dr. TAKEI, Hideyuki (University of Tsukuba Hospital)

Purpose
Electronic portal imaging device (EPID) is a popular tool for a verification of the patient setup for radiation therapy. Recently, it is grabbing attention as a tool for in vivo dosimetry. It detects therapeutic photons which penetrated the patient body to acquire an image. Conversion to absorbed dose is required from the digital pixel value. However, the response of the EPID is susceptible to the energy spectrum changes through the body. The purpose of this study was to perform the energy response correction of the EPID image using Monte Carlo simulation (MC) to improve the accuracy of the EPID dosimetry.

Methods
Geant4.9.6 patch04 was used for the MC with a combination of a HTCondor 7.6 parallel computing software. The MC simulated the 6 and 10 MV photon beams from Trilogy (Varian Medical Systems) linear accelerator. The EPID response to the energy spectrum was evaluated. CT DICOM data set of a chest phantom was imported to the MC, and the simulated EPID images were acquired after irradiating 6 and 10 MV photon beams. The measurement was performed with the same setup as the MC and obtained the EPID images. The energy response correction was performed to the measured images to obtain the absorbed dose and compared with that measured with 2D array detector (PTW) as a reference.

Results
EPID was more sensitive to the photons penetrated the mediastinum than those penetrated the lung due to the contamination of the scattered photons with the energy of <0.1 MeV. The maximum differences between the doses measured with EPID and those measured with 2D array was 5.8% in mediastinum area with the 6 MV photon beam. The difference was less than 1.5% in average in lung area. The agreement of the corrected EPID dose and 2D array improved within 2.5% in mediastinum area for the 6 MV beam.

Conclusion
The EPID response to the energy spectrum was evaluated using MC. The corrected EPID dose agreed well with that measured with 2D array detector. The response correction using MC improved the accuracy of the EPID dosimetry.

131 - Improved Woodcock tracking on Monte Carlo simulations for medical applications

Presenter: Dr. BEHLOULI, Abdeslam (LaTIM-INSERM); Dr. BERT, Julien (LaTIM-INSERM)

Monte Carlo Simulations (MCS) are associated with long execution times, which is one of the major issues preventing their use in routine clinical practice. To accelerate MCS, variance reduction techniques (VRT) can be used. Within this context, the Woodcock Tracking method [1] allows improving particle navigation through a CT image. However, this method presents only a very small efficiency gain compared to the standard navigation method. Indeed, particle transport is oversampled even if a small part of the phantom contains a high density region. We address this issue by proposing a new VRT called Super Voxel Woodcock (SVW) which combines both standard and Woodcock tracking navigation methods by introducing the super voxel concept used in [2].
This method consists in grouping the voxels of the volume in a super voxel grid (pre-processing step) by associating to each of the super voxels a local maximal density which later serves in the interaction distances' sampling. The proposed methodology was compared to the performance of other methods within the context of a low dose rate brachytherapy application using 109 photon particles. All the methods were implemented within the GGEMS platform [3] running on NVIDIA GTX1050.
The SVW efficiency gain as a function of the result uncertainty and the simulation time was 3.7 with respect to the standard navigation and 2.7 with respect to the classical Woodcock tracking. Results show a real improvement of the SVW compared to standard navigation and Woodcock tracking methods without introducing any approximation in the simulations.

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132 - Improvements in the radiographic image quality using an anti-scatter grid prototype. Monte Carlo approach.

Presenter: Mrs. INMACULADA, Jerez-Sainz (UGC Radiofisica y Oncologia Radioterapica. Hospital Virgen de la Victoria. Málaga. Spain.)

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Improvements in the radiographic image quality using an anti-scatter grid prototype. Monte Carlo approach

I Jerez-Sainz(1,*), JC Ramirez-Ros(2), A Perez-Rozos(1,3) and A Lallena(4)
(1) ServicioHospital Virgen de la Victoria, Servicio de Radioterpia, Campus Universitario de Teatinos s/n, E-29010 Málaga
(2) Hospital Regional de Málaga, Dr. Esquerdo, 83, E-28007, Madrid
(3) Departamento de Radiología y Medicina Física, Universidad de Málaga, Campus Universitario de Teatinos, E-29010 Málaga
(4) Departamento de Física Atómica, Nuclear y Molecular, Universidad de Granada, Campus Universitario de Fuentenueva, C/ Severo Ochoa, E-18071 Granada
* presenting author

In this work we have analyzed how X-ray spectra, generated by clinical tubes used in conventional radiography, are modified when they found, in their path toward the detector the patient and the anti-scatter grid. We have paid special attention to both the primary and scattered radiation and the spectrum of the transmitted radiation.
The study has been carried out by using the Monte Carlo code PENELOPE. Three spectra corresponding to different kilovotage are considered to impact on a water phantom and four focalized anti-scatter grids: N36r21, N25r15, N44r15 and N80r15.
The benefit of an anti-scatter grid is well characterized by the quantum signal-to-noise ratio improvement factor (KSNR) provided by the grid. We have used our result to calculated KSNR of prototype grids.
The primary and scatter transmission properties of the grids were calculated, and KSNR was evaluated over a phantom thickness range of 20-40 cm. For SNR improvement factor of the prototype N36r21 was 19% and 32% higher than that of the N44r15 and N80r15 grids, respectively; for N25r15 13% and 25% higher.
We have shown that highest septa reduce the scatter radiation in a nonnegligible way, keeping the primary photons attenuation.

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133 - Fast and accurate 3D dose distribution computations using artificial neural networks

Presenter: Dr. LENI, Pierre-Emmanuel (Laboratoire Chrono-Environnement/Universite de Bourgogne Franche-Comte)

In radiation therapy, the trade-off between accuracy and speed is the key of the algorithms used in Treatment Planning Systems (TPS). For photon beams, commercial solutions generally relies on analytic algorithms, biased Monte Carlo, or heavily parallelized Monte Carlo on Graphics Processing Units (GPU).

Alternatively, we propose an algorithm using Artificial Neural Network (ANN) to compute the dose distributions resulting from ionizing radiations inside a phantom [1]. We present an evolution of this platform taking into account modulated field sizes and shapes, and various orientations of the beam to the phantom. Firstly, tomodensitometry-based phantoms are created to validate the dose distribution computed for a square beam in heterogeneous areas (head and neck, lungs). Secondly, IMRT treatments are simulated in these phantoms.

To validate our approach, we compare our results with the Analytical Anisotropic Algorithm (AAA) and Monte Carlo simulations. Cross-comparisons are performed for square beams and IMRT treatments. The dose distributions are evaluated using gamma indices and profile extractions.

The dose distributions computed from IMRT treatments require less than two minutes using a standard Central Processing Unit (CPU). We aim at providing a fast and accurate solution for TPS quality control.

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134 - Ant colony algorithm for driving variance reduction techniques in Monte Carlo simulations

Presenter: Dr. GARCÍA-PAREJA, Salvador (Hospital Regional Universitario de Málaga)

The use of variance reduction techniques (VRTs) in Monte Carlo calculations is mandatory in different situations in which low scoring statistics occurs, for example, when the dose deposited by radiation in small detectors in complex geometries is calculated. The efficiency of this kind of simulations could be extremely low because a huge amount of CPU time is spent on tracking particles that do not contribute to deposited dose. VRTs (e.g. Russian roulette and splitting) can improve the efficiency in this type of calculations, but unfortunately, these techniques are extremely problem-dependent, and general recipes to minimize the variance cannot be given.

To solve this problem, we propose to use a method based on an ant colony algorithm that allows driving the application of VRTs with minimal user intervention and is able to increase the efficiency in low statistics Monte Carlo simulations independently of the geometry. These kind of algorithms are inspired by the behavior of actual ant colonies and permit to create optimization tools to solve complex problems such as those of finding global minima.

The ant colony optimization algorithm (ACOA) here developed "learns" where to apply VRTs to favor the increase of efficiency, obtaining information from the simulation itself and generating the so-called importance maps.

ACOA has been successfully employed in calculations regarding the study of dose deposition in different problems: electron beams from linear accelerators, dose deposition calculations on MOSFET detectors [1], radiosurgery photon beams [2], improvement of dose distribution on monoisocentric beam split technique [3] and calculations of specific absorbed fractions in non-sealed radioisotope treatments [4]. The efficiency improvements range from 10 to 100 times or even more in case of high energy photon beams.

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135 - Characterization of an X-ray source based on laser-target interaction using the Geant4 Monte Carlo toolkit.

Presenter: Dr. PISCIOTTA, Pietro ((1) University of Catania, Department of Astronomy and Physics, Catania, Italy (2) National Institute of Nuclear Physics, South National Laboratory (LNS-INFN), Catania, Italy (3) Institute of Molecular Bioimaging and Physiology, National Research Council(IBFM-CNR), Cefalù (PA), Italy)

The aims of our work was to design, study and optimize the main characteristics of an X-ray bremsstrahlung source based on a laser-driven electron beam accelerated via Laser Wake-Field Acceleration. This study is performed using a custom Monte Carlo-Geant4 application, called IORT-Laser-therapy.

The X-ray source is designed on top of the laser-driven electron accelerator already running at the Intense Laser Irradiation Laboratory of the INO-CNR in Pisa. It is based upon a 10 TW laser system delivering <40 fs duration pulses with >400 mJ energy at a 10 Hz repetition rate. This accelerator has been already proved to be able to deliver electron bunches with up to around 80 MeV with energy spread down to around 25% and bunch charge ranging from few tens of pC up to few nC.

Electron interactions are simulated, starting form an exponentially decreasing e- energy spectrum; a thin tungsten foil has been used in order to generate X-rays via bremsstrahlung.

The Monte Carlo application allows studying many features of the resulting X-ray beam such as (i) the conversion efficiency using different foil thicknesses, (ii) the X-ray source size (iii) the particle contamination of the output beam, (iv) the out-of-beam scattered radiation for external shielding design. The need for a dipole magnet to get rid of residual electrons in the output beam is also investigated. Besides conversion efficiency, the simulation of different scatter foil thicknesses will also enable us to investigate the dependence of the beam divergence upon this parameter.
Radiation protection is another important design goal that can take advantage of our application. More specifically, we will study the dose distribution around the chamber which main contribution comes from back-scattered electrons by scatter foil and other collimation elements, as well as potential contributions of neutrons produced by photonuclear reactions from the high energy tails of the X-ray beam.

The final project aims are design and optimization a proof-of-principle micro-CT/RT platform for small animals exploiting the unique features of a novel concept all-optical bremsstrahlung X-ray beam.
This research was supported by the Italian Ministry of Research (MIUR) within the PRIN project “PRELUDE” (PRIN-2015, n.20154F48P9).

136 - Kompeito-Shot System: Evaluation of the systematic error caused by beam incident angle using Monte Carlo simulation

Presenter: Mr. TSUNEDA, Masato (Tokyo Women's Medical University)

We developed a novel verification system and method for verifying 3D/4D beam alignment. The purpose of this study is to evaluate the systematic error of the measurement system we developed using Particle and Heavy Ion Transport code System (PHITS) [1]. Our newly method enables to quantitatively and directly evaluate the gantry rotation axis as angle information. In short, this method enables to measure directly sagging angle of gantry head. This system was composed of truncated cone-shaped mirror, column-typed plastic scintillator (Co-typed PS) and a CCD camera. Co-typed PS emitted the scintillation light generated by photon beams, and the static image of the scintillation light was measured using the camera through the mirror. We obtained a simulation image that is similar to measurement image. Therefore, we calculated the energy deposition in Co-typed PS by PHITS (ver. 2.84) Monte Carlo simulation code. Photon beams with TrueBeam 6MV energy spectrum was irradiated for Co-typed PS that placed on center of truncated cone shaped mirror. We created 2D simulation image using geometric transformation from 3D voxel data. The calculation grid was 0.5x0.5x0.5 mm3. And we compared the measurement and simulation images to convert energy deposit to light intensity. We analyzed these simulation images using analysis algorithm that we developed and evaluated the systematic error. We could obtain the simulation image without taking into consideration of the optical element, manufacture error and setup error. The relationship between irradiated beam angle (IA) and calculated beam angle (CA) had good linearity and accuracy. However, the difference between IA and CA tended to increase with increasing in irradiated angle and the maximum difference was -0.8 degree. This systematic error was caused by the scintillation light integrated in all layer of Co-typed PS. We calculated simulation image using one-layer of Co-typed PS and compared the difference. The difference was decreased to ± 0.1 degree. We developed the simulation image generator system using PHITS and evaluate the systematic error.
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137 - Fixed Forced Detection for fast SPECT Monte-Carlo simulation

Presenter: Dr. SARRUT, David (Creatis)

Monte-Carlo simulations of SPECT images are notoriously slow to converge due to the large ratio between the number of photons emitted and detected in the collimator. This work proposes a method to accelerate the simulations based on Fixed Forced Detection (FFD) combined with an analytical response of the detector. FFD is based on a Monte Carlo simulation but forces the detection of a photon in each detector pixel weighted by the probability of emission (or scattering) and transmission to this pixel. The method was evaluated with numerical phantoms and on patient images. We obtained less than 2 % difference with analog Monte-Carlo simulations. The overall computing time gain can reach up to 5 orders of magnitude. Source code and examples are available in the last Gate V8.0 release.

138 - Fluence modulated proton computed tomography

Presenter: Dr. DEDES, George (LMU Munich)

Proton computed tomography (pCT) has recently seen considerable research interest as a means of reducing range uncertainties in proton therapy, by reconstructing directly relative stopping power to water (RSP). Recent detector developments have permitted the development of two list-mode pCT scanner prototypes based on broad (passively scattered) proton beam delivery [1][2]. In this Monte Carlo (MC) simulation study, the application of fluence field modulated computed tomography (FFMCT), initially developed for x-ray CT [3], to pCT is presented. Fluence modulated pCT (FMpCT) scans can be acquired by utilizing pencil beam (PB) scanning and can achieve variable image quality in a pCT image. Dose calculation accuracy may thus be simultaneously preserved in the beam path in parallel with imaging dose reduction

Using MC simulations of an ideal list-mode pCT scanner, a uniform cylinder and two patients were studied. Regions of interests (ROI) were selected for high image quality and only PBs intercepting them preserved full fluence (FF). Image quality was investigated in terms of accuracy and noise of the reconstructed RSP. Dose calculation accuracy on FMpCT images was evaluated in terms of dose volume histograms (DVH), range difference (RD) for beam-eye-view (BEV) dose profiles and gamma evaluation. Furthermore, the concept of FMpCT was tested on experimental data by creating pseudo FMpCT scans from broad beam scans acquired with a pCT prototype.

For the virtual phantoms, FMpCT noise in ROIs at 1% of FF was equivalent to that of FF images. Integral imaging dose reduction up to 56% was achieved for the two patients for that modulation. Corresponding proton dose calculations on FMpCT images agreed to those from reference images. Applying FMpCT to preliminary experimental data showed that low noise levels and accuracy could be preserved in a ROI.

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139 - Monte Carlo simulations for imaging in proton therapy

Presenter: Dr. ESPOSITO, Michela (University of Lincoln)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

Monte Carlo simulations for imaging in proton therapy

Michela Esposito (1,*), Tony Price (2), Jon T. Taylor (3), Chris Waltham (1), Sam Manger (4), Ben Phoenix (2), Gavin Poludniowski (5), Stuart Green (2), Philip M. Evans (6), Philip P. Allport (2), Spyros Manolopoulos (7), Jaime Nieto-Camero (8) and Nigel M. Allinson (1)
(1) University of Lincoln, School of Computer Science, Lincoln, UK
(2) University of Birmingham, School of Physics and Astronomy, Birmingham, UK
(3) University of Liverpool, Department of Physics, Liverpool, UK
(4) University of Warwick, Department of Physics, Warwick, UK
(5) Karolinska University, Department of Medical Physics, Stockholm, Sweden
(6) University of Surrey, Centre for Vision, Speech and Signal Processing, Guildford, UK
(7) University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK
(8) iThemba LABS, Somerset West, South Africa

*presenting author

Proton therapy is rapidly gaining importance in the field of radiotherapy, because of its potential to deliver the planned dose over a small depth range and sparing dose to healthy tissue, when compared to conventional radiotherapy. Proton therapy, however, makes the need of new imaging modalities for treatment planning, based on direct measurements of tissue stopping power and eliminating the need to convert tissue density – as measured in conventional X-ray Computed Tomography) – to stopping power, upon which treatment planning is based [1]. The expected benefits of proton CT (pCT) for treatment planning in Proton Radiotherapy are producing great interest worldwide to develop instruments for clinical-quality pCT.

The PRaVDA (Proton Radiotherapy Verifications and Dosimetry Applications) consortium has developed a novel purely solid state system and associated image reconstruction for pCT [2,3]. Custom detectors for the PRaVDA instrument include Silicon Strip Detectors (SSDs) and Monolithic Active Pixel Sensors (MAPS). To assist design decisions, detector development and development of image reconstruction algorithms, comprehensive Geant4-based Monte Carlo simulations were developed, comprising realistic beam-line sources for two proton sources where the PRaVDA instrument has been tested (MC40 cyclotron at the University of Birmingham and iThemba LABS cyclotron), full device geometry and realistic readout for both SSDs and MAPSs.

The full paper will focus on simulations of MAPS for imaging proton therapy. The full read-out chains of a MAPS – including charge diffusion, collection, sharing and digitalization, has been simulated through the development of ad-hoc classes integrated in the standard Geant4 toolkit.
An experimental validation of the model (at two different proton sources) will be provided and the contribution of these simulations to assess imaging capabilities of MAPS, in the context of proton therapy, will be highlighted.

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140 - A study of tissue inhomogeneity correction in a commercial treatment planning system for stereotactic radiosurgery

Presenter: Mr. MORALES, Johnny (Chris O'Brien Lifehouse)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

A study of tissue inhomogeneity correction in a commercial treatment planning system for stereotactic radiosurgery

Johnny Morales (1,2,*), Martin Butson (1), Robin Hill (1), Scott Crowe (2), and Jamie Trapp (2)
(1) Chris O'Brien Lifehouse, Department of Radiation Oncology, Sydney, Australia
(2) Queensland University of Technology, School of Chemistry, Physics and Mechanical Engineering, Brisbane, Australia
*presenting author

In this study, we investigate the accuracy of the Clarkson pencil beam algorithm in iPlan treatment planning system (Brainlab, Germany) for calculating dose in high and low density media using the Brainlab circular cones of 4, 7.5 and 10 mm diameter. The comparison was performed in relation to a previously validated Monte Carlo algorithm for Brainlab circular cones [1]. In the comparison, PDDS and dose profiles were calculated using DOSXYZnrc. In order to compare both iPlan and Monte Carlo calculations we used the MMCTP platform [2] which enables the user to import DICOM dose files into the same CT DICOM image set. MMCTP allows the user to produce PDDs and cross profiles at any depth. We also calculated treatment plans on an anthropomorphic phantom which contain low density media using the iPlan algorithm for Brainlab cones. These treatment plans were calculated with Monte Carlo in the MMCTP environment to make a comparison of the iPlan algorithm versus Monte Carlo. The results in our study show that the percentage difference between iPlan and Monte Carlo simulations in low density media can potentially be as high as 20% for a single static beam. This difference is reduced when dose is delivered using arc treatments.

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141 - ORACLE: A DVH-based inverse planning system for LDR prostate brachytherapy using MC dosimetry

Presenter: Mr. MOUNTRIS, Konstantinos A. (LaTIM INSERM UMR 1101 Brest, France)

Low-dose-rate (LDR) brachytherapy is a standard treatment option for non-metastatic prostate cancer patients. It consists of permanent implantation of radioactive seeds in the prostate using needles. LDR seeds offer locally-confined dose deposition, sparing organs at risk (rectum, urethra). Selecting the implantation sites manually is a laborious task. Inverse planning algorithms aiming to achieve the optimal implantation automatically have been proposed, based on dose calculation following the dosimetry formalism of the TG43 report [1]. TG43 over-estimates the actual deposited dose leading to sub-optimal plans. Inverse planning based on Monte Carlo Dose Kernels (MC-DK) has been proposed [2]. Due to the computational burden of MC methods, a pre-calculating step of 78h was required. Furthermore, optimization was based on indirect dose criteria. To address current planning limitations we developed ORACLE, an inverse planning system using fast simulated annealing (FSA) and GPU-accelerated MC dosimetry. Using GGEMS platform [3], we can generate MC-DKs for a number of 424 possible implantation sites in intra-operative time (42.4s) with ≈ 2% statistic uncertainty in the prostate. The optimization is based on DVH quality criteria. Implantation configurations are evaluated iteratively by accumulating MC-DKs in a total dose map. Introducing a compression of the MC-DKs, allowed us to accelerate further the overall process, providing plans that satisfy the DVH criteria, given by the TG137 report, in only 15s. Comparing ORACLE-generated plans with clinical plans of 10 patients we were able to provide improved quality plans using fewer needles (10.5% less). A fast and efficient inverse planning system based on MC dosimetry is proposed, reducing planning dose over-estimation. Optimizing the DVH eliminates any learning-curve for the operator. In addition, delivering high-quality plans with the least number of needles can reduce the induced trauma (edema), decreasing deviation between planning and post-operative dosimetry.

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142 - Monte Carlo modeling of Varian TrueBeam photon beams with Geant4-based VirtuaLinac and comparison to experiments

Presenter: Dr. IKONEN, Timo (Varian Medical Systems)

Monte Carlo simulations can provide powerful insight into the physical phenomena and geometrical interactions of linear accelerator beams. This insight can be used to understand the phenomena that govern the beam characteristic and, for instance, to guide the development of treatment planning systems. In this study, we use the VirtuaLinac, a cloud-based application to model the treatment head of the Varian TrueBeam linear accelerator. VirtuaLinac implements the treatment head geometry into the Monte Carlo code Geant4, which is then utilized to provide the physics and numerical engine for the simulations. We consider both open fields and fields limited by multi-leaf collimators and compute the dose deposited in a water phantom. We then compare the simulation results with experimental measurements. The simulated data are also used to extract some of the characteristics of the multi-leaf collimators and to evaluate their impact on the beam properties and the dose distribution.

143 - Monte Carlo simulation tool for online treatment monitoring in hadrontherapy with in-beam PET

Presenter: FIORINA, Elisa (TO)

Hadrontherapy permits treating cancer with very conformable dose distributions and increased radiobiological effects. Monitoring systems to verify particle range while treating are needed to fully exploit these advantages. The INSIDE project aims at building a bimodal system to acquire photons, coming from positron annihilations, and prompt charge particles related to the beam position inside patients [1].
In January 2016, the in-beam PET detector was installed at the Italian Center of Oncological Hadrontherapy (CNAO) and characterized with phantoms [2][3]. In December 2016, the INSIDE in-beam PET monitored two consecutive treatment sessions with protons on its first patient.
In-beam PET images must be compared with an expected prior image, therefore a FLUKA-based [4][5] simulation tool has been developed. The framework includes the simulations of the patient/phantom, the detector, the beam line and temporal structure.
The beam delivery follows either the treatment plan or the measurements from the Dose Delivery System and the detector geometry and resolution are taken into account.
During the characterization phase, a good agreement between measurements and simulations was found [2][3].
Preliminary results on the first patient treatments indicate that after about two minutes of a four-minutes long irradiation the PET image has significant statistics to be compared with the prior image.
During the 2017, the INSIDE in-beam PET system and simulation tool will be further tested in-vivo and optimized for clinical routine.

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144 - An equipment-specific Geant4 model for the Elekta Agility collimator

Presenter: Ms. MARTINS, Juliana Cristina (LMU Munich, Faculty of Physics, Chair of Experimental Physics - Medical Physics, Munich, Germany); Dr. VELOZA, Stella (LMU Munich, Faculty of Physics, Chair of Experimental Physics - Medical Physics, Munich, Germany)

The present study aims to develop and validate a linac-specific Geant4 Monte Carlo (MC) model of an Elekta Agility collimator (Elekta AB, Stockholm, Sweden) to be used for dose distribution simulations of IMRT and VMAT radiotherapy procedures. The Elekta Agility collimator consists of two diaphragms mounted orthogonally to two pairs of 80 interdigitating leaves.
Elekta Precise IAEA phase space files for 6 MV photon beam were used as primary beam generator. The diaphragms and leaves were primarily modeled according to vendor-provided geometry, designed specifically for clinical implementation of MC-based Treatment Planning Systems. However due to small differences in installation and setting, geometric parameters are necessarily linac-specific. Hence such parameters have been defined as tunable mathematical functions, so the user can find the best fit for an individual installation. For validation of the model, dosimetric characteristics of the system were simulated in Geant4 v.10.01.p02. Rectangular fields ranging from 2x2-20x20 cm2 were delivered to a virtual water phantom. Percentage Depth Dose (PDD) curves and lateral profiles were compared to corresponding measurements conducted with a water phantom (Blue Phantom2, IBA Dosimetry, USA) in an Elekta Synergy (Eleka AB, Stockholm, Sweden) coupled with Elekta Agility. Intraleaf and interleaf leakage and tongue and groove (T) effect were also investigated.
The results show good agreement between measurements and simulations and are comparable to results reported in literature [1]. In both cases the maximum transmission and the underdosage due to T effect were 0.55 % and 20 %, respectively. Small discrepancies between measured and simulated PDDs and lateral profiles were observed in small fields, which could be attributed to the use of unsuited phase spaces.
The developed MC model was proven able to reproduce the Elekta Agility collimator. Modeled electron source parameters, such as energy of incident electron beam and electron beam shape, can significantly influence the output of a linac dose simulation [2]. A more adequate phase space for 6 MV photon beam, which matches the specific configuration of the linac in use, is under development. Validation for IMRT and VMAT plans and for 15 MV photon beam are foreseen.

145 - Monte Carlo for CyberKnife Radiosurgery with the InCise Multileaf Collimator

Presenter: Dr. DOOLEY, John (Accuray Incorporated)

J R Dooley (1*), J M Noll (1), W Kilby (1), W Fong (1), T Yeung (1), L M Goggin (1), D Spellman (1), J S Li (2), C-M Ma (2), C R Maurer Jr (1)

(1) Accuray Incorporated, Sunnyvale, CA, USA

(2) Radiation Oncology Department, Fox Chase Cancer Center, Philadelphia, PA, USA

*presenting author

This work investigates the accuracy and efficiency of Monte Carlo dose calculation with the Incise™ 2 Multileaf Collimator (MLC) for the CyberKnife® M6™ System in Accuray Precision Treatment Planning System 1.1. Phase space above the MLC is derived from a virtual source model calculated from beam commissioning measurements (profiles, TPRs, and output factors). Transport through the MLC is performed by ray tracing, accounting for leaf tip geometry, leaf-bank tilt, beam hardening, and shifts applied by the MLC controller to compensate for variable offset between the radiographic and geometric beam edge at each leaf tip.

Patient model transport uses material and density specific photon mean-free-paths in combination with track-repeating of precomputed electron tracks from mono-energetic photon beams in water, modified using local density. Variance reduction techniques include forced interaction, particle splitting, and range rejection. This version improves on previous implementations by linearly propagating electrons below a cutoff energy in some circumstances instead of depositing their remaining energy in one voxel. The algorithm is implemented in C++, multithreaded over 12 CPU cores, and can be used pre- or post- beam weight optimization.

Calculations were compared against measurement for single beams and composed plans in homogeneous and inhomogeneous phantoms. Single beam measurements included central axis percent depth dose (PDD) using diode and microdiamond detectors, and planar dose distributions with EBT3 film. For composed plans, point measurements were performed using air-filled micro-ionization chambers and TLD. Calculation speed was characterized by evaluating lung SBRT plans consisting of between 13 and 126 treatment beams.

The PDD curves showed good agreement in solid water and water-lung-water phantoms between calculation and measurement. Films had ≥90% pixels meeting a 2%/2 mm gamma criterion for all 12 aperture shapes in similar phantoms. Composite plans had point dose differences ≤3% in heterogeneous lung phantoms. Calculation speeds at native 512 x 512 CT resolution (approximately 1 mm3 voxels) and 2% requested uncertainty were 9 minutes on average, reducing to 3 minutes when medium resolution (approximately 4 mm3 voxels) was used. Methods to reduce calculation times are under investigation. Preliminary results suggest possible 40% - 75% reductions without underlying algorithm or hardware changes.

146 - Application of Monte Carlo techniques for airborne radioactivity monitoring systems calibration

Presenter: Dr. SARNELLI, Anna (Istituto Scientifico Romagnolo per lo Studio e la Cura dei Tumori (IRST) IRCCS, Medical Physics Unit, Meldola, FC, Italy.)

Air monitoring systems are mandatory in all areas potentially contaminated with airborne radioactivity, such as hot laboratories, treatment rooms, and radioactive waste storage areas. In some cases, the calibration of such systems may be practically complicated or may require the application of correction factors, obtained by means of approximate analytical calculations. Monte Carlo techniques provide an effective way to check the calibration of such systems and the potential impact of the approximations used in the calculation.
At IRST we recently dealt with two issues regarding the calibration of air monitoring systems using Geant4.
In the first case, self-absorption correction factor for a Marinelli beaker system are derived for gamma and beta+ radiation and compared with approximated analytical calculation available for gamma. A 7% difference is observed between the correction factor for F18 and the one for 511 keV gammas.
In the second case, a continuous air monitoring system is composed by a NaI detector located into a chimney, collecting air from a cyclotron radiochemistry. The system efficiency can be analytically calculated assuming that positrons uniformly annihilate on the duct surface, this assumption however does not hold for ducts with transverse size comparable with the positron range in air. Efficiencies and calibration constants of such system for different geometrical conditions are obtained using Geant4. These values may provide an initial guidance in the design and calibration of real time air monitoring systems in ducts.

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147 - CloudMC, a cloud-based solution for Monte Carlo radiotherapy calculations

Presenter: Mr. MIRAS, Hector (University Hospital Virgen Macarena. Seville, Spain.); Mr. JIMÉNEZ MARRUFO, Rubén (Icinetic TIC SL, R division, Sevilla, Spain.)

Monte Carlo algorithms are considered the gold standard for radiation transport calculations, but they are not widely used in clinical radiotherapy (RT) calculations due to their high computational cost. CloudMC, presented in previous works [1], is a cloud-based platform, developed on Microsoft Azure Cloud, which uses the Cloud Computing technology to drastically reduce MC computing times. CloudMC is designed following three basic principles:
- Accessibility: The front-end is a web-application that is accessible to any user through internet.
- Multi-application: CloudMC is independent on the MC code.
- Elasticity: Computational resources are provided dynamically.
CloudMC has been recently updated with new features that allow to perform MC verification of RT treatments. Once the user has generated in CloudMC a MC LINAC model from its own MC programs, it is just required to upload the TPS treatment and dose files and the CT image set to perform a MC verification. Then, the calculations are distributed in as many virtual machines as the user selects.

Microsoft Azure offers a variety of VM types and sizes. We have run some tests to determine the best VM type according to our necessities. Dv2-series VMs have been finally chosen, as they offer a better CPU performance than the original A-series.
MC verification of IMRT treatments has been implemented in our institution. MC models have been created for our LINACs using different MC codes. For the PRIMUS LINAC we used BEAMnrc+DOSxyz. For the ONCOR LINAC a combination of a Geant4-based program and PenEasy was used instead. Times and costs are very depending on the MC code, the simulation parameters and the type, size and number of VMs used. Typical calculation times using 200 D1_v2 VMs are 15-20 min for achieving a 1.5% dose uncertainty in the PTV in a 2x2x5 mm3 phantom generated from the CT image set. The associated cost is 7-10€.

CloudMC has been proved to be a feasible solution for performing RT MC calculations in a fast, easy and cheap way.

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148 - Calculation Backscatter factors for pediatric diagnostic radiology using Monte Carlo Methods

Presenter: Prof. TOMAL, Alessandra (Instituto de Física Gleb Wataghin - Universidade Estadual de Campinas)

Dosimetry in pediatric radiology is essential since children present greater radiosensitivity in relation to adults. The dose is estimated from the entrance dose to the skin, calculated from air kerma and backscatter factor (BSF). However, the backscatter factors presented in guidelines for use in pediatric radiology were calculated for adults [1]. The purpose of this work is to calculate backscatter factors for children and adults, comparing the influence of patient dimensions on dose estimation in pediatric radiology. Monte Carlo simulation was used for calculations, using the PENELOPE 2014 code with the penEasy 2015 extension. The geometric model consists of a box simulating the chest with dimensions 30×30 cm^2 and 10 cm thick for a newborn child and 15 cm thick for an adult, with homogeneous composition: soft tissue and PMMA. An ionization chamber was modeled having dimensions 2.5×3.8×2.5 cm^3. Monoenergetic beams with energy between 10 and 100 keV and polienergetic beams with a tube potential between 50 and 130 kV were simulated. Three field sizes were used 10×10, 20×20 and 25×25 cm^2. The code was modified to provide the entrance skin dose and incident air kerma. The BSF were determined from the ratio between these quantities. The BSF values obtained in this work were compared with was validated with values from the literature, showing differences smaller than 4%. For monoenergetic beam, BSF increases with energy increasing up to approximately 60 keV, where a maximum value is observed. For the polyenergetic beam, BSF increases monotonically with the potential of the tube. The BSF for acrylic are around 9% higher than for soft tissue, due to its higher density and effective atomic number. BSF increases up to 20% with field size. Comparing the results for children and adults, it is observed that the BSF values calculated for the adult are up to 15% higher than those calculated for children. These results point to the need for using appropriate BSF for children's dimensions.

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, “Dosimetry in Diagnostic Radiology for Paediatric Patients”, IAEA Human Health Series No. 24, IAEA, Vienna (2014).

149 - Calculation Backscatter factors for pediatric diagnostic radiology using Monte Carlo Methods

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, “Dosimetry in Diagnostic Radiology for Paediatric Patients”, IAEA Human Health Series No. 24, IAEA, Vienna (2014).

150 - Evaluating the performance of different fluence to dose conversion factor data libraries in Monte Carlo Based photon dosimetry

Presenter: Ms. NASROLLAHI, Shiva (Radiation Medicine Department, Shahid Beheshti University, Tehran, Iran); Dr. BAGHANI, Hamid Reza (Radiation Medicine Department, Shahid Beheshti University)

Evaluating the performance of different fluence to dose conversion factor data libraries in Monte Carlo Based photon dosimetry

Shiva Nasrollahi (1, *), Hamid Reza Baghani (1, 2) and Seyed Mahmoud Reza Aghamiri (1)

(1) Radiation Medicine Department, Shahid Beheshti University, Tehran, Iran
(2) Physics Department, Hakim Sabzevari University, Sabzevar, Iran
* Presenting author:shiva.nasrollahi@gmail.com

Monte Carlo (MC) simulation is a reliable technique for photon beam dose calculations. MCNP is one of the interested MC codes for such purposes. The standard scoring tally for dose calculations in MCNP code is energy deposition (*F8 tally). Due to the full transportation of generated particles for calculating the energy deposition, absorbed dose determination using this tally is very time consuming and is often associated with large statistical uncertainty at the short running times. To overcome this problem, one can use the fluence to dose conversion method for dose calculation through employing fluence scoring tally (F4 tally) and corresponding fluence to dose conversion factors. There are several data libraries for fluence to dose conversion factors of photon beam which have been reported by various organizations. The aim of this study is to evaluate the accuracy of these recommended data libraries for photon dosimetry.

Two different radiotherapy units including INTRABEAM IORT machine (50 kV photon beam) and Varian 2100C/D Clinac (6 MV photon beam configuration) were simulated by MCNPX code. Then, the depth dose distribution (PDD) for mentioned radiotherapy machines was obtained through recommended fluence to dose conversion factors including ICRP 21, ICRP 116, ANSI/ANS-6.1.1 and mass absorption coefficients provided by the NIST. Finally, PDDs resulted from each data library were compared with the results of ionometric dosimetry through gamma analysis.

The results showed that the calculated PDD based on the ANSI/ANS-6.1.1 conversion factors for INTRABEAM, has the best agreement with the measured data. There was no agreement between the PDDs calculated by libraries understudy and measured data in buildup region of 6 MV photon beams (Varian 2100C/D), while, in transient equilibrium region, the PDD obtained by the ANSI/ANS-6.1.1 conversion factors had the best accordance to the measured data.

From the results, it can be concluded that the fluence to dose conversion method can be considered as a substitution for energy deposition method in photon dosimetry by MCNPX code, provided the presence of electronic equilibrium condition. The ANSI /ANS-6.1.1 data library has the best performance in both low and high energy region.

151 - Monte Carlo MCNP calculation of absorbed dose for 90Y

Presenter: Mrs. JEREMIC, Marija (Clinical Centre Kragujevac, Centre for Nuclear medicine, Serbia)

After the introduction of new therapeutic methods the nuclear medicine has experienced a renaissance. Strong beta emiteres, like 90Y, 177Lu and 188Re labeled on peptide (DOTATOC, DOTATATE) are used for treatment of neuroendocrine tumours (NET). However, this therapy is renotoxic and there is a limit for kidney exposure. For this therapy dosimetric studies are very important.
Absorbed dose due to 90Y was calculated using MCNP and ORNL human phantom. Tumour was simulated as a sphere with the diameter of 3 cm in the centre fo abdomen. Tumour, kidney and liver are treated as a sources of beta radiation.
To estimate the number of beta particles emitted in each organ, it is necessary to develop biokinetic model which describes behavior of radionuclide 90Y in human body. Transfer parameters of biokinetic model were determined based on activity of 90Y measured in urine and blood of patients.
For the calculations, a spectrum of electrons emitted by 90Y is needed. Particle energy was sampled according to yields using random method incorporated in MCNP software. In order to simulate emission of whole spectrum of β-radiation, large number of histories was created (about 108) to ensure uncertainty lower than few percent.
The results of MCNP calculations were obtained MeV/g per particle. This work shows shows that the largest dose in tumour, which is the main target of this therapy.

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152 - Modeling of a New Multihole Rod Collimator Low Energy High Resolution using Monte Carlo Simulation

Presenter: Ms. MAT JUNOS, Siti Aisah (Universiti Putra Malaysia); Prof. SARIPAN, M Iqbal (Universiti Putra Malaysia)

Multihole Collimator is the most commonly used in gamma camera for nuclear medicine imaging. Designing collimator part is the main element for image acquisition of the gamma camera. This paper presents the initial results of modeling a new Multihole Rod Collimator Low Energy High Resolution (LEHR) for gamma camera. The gamma camera and collimator are simulated by using the Monte Carlo N-Particles Code version 5 (MCNP5) with a point source 140keV photons of Technetium-99m radionuclide tracer. The model is constructed based on the Millennium VG Gamma Camera H3000YA VG3 0.9525cm detector. The result is analysed based on the spatial resolution of the images detected by the Sodium Iodide (NaI) detector using point spread function. The performance evaluation in term of resolution and signal to noise ratio is compared with a conventional multihole collimator. In our assessment, the proposed new multihole rod collimator that produces the image of comparable quality with the conventional multihole collimator.

153 - Monte Carlo Simulation Study of Orthogonal Ray Imaging for Monitoring Head Radiotherapy

Presenter: Mr. SIMÕES, Hugo (LIP - Laboratory of Instrumentation and Experimental Particles Physics)

Monte Carlo Simulation Study of Orthogonal Ray Imaging for Monitoring Head Radiotherapy

Hugo Simões (1,2,*), Ana Luísa Lopes (1), Carolina Travassos (1) and Paulo Crespo (1,2)
(1) Laboratory of Instrumentation and Experimental Particles Physics (LIP), Coimbra, Portugal
(2) University of Coimbra, Department of Physics, Coimbra, Portugal
*presenting author

OrthoCT (based on orthogonal ray imaging) is a novel imaging system under study at LIP that consists on the detection of radiation scattered in the patient and emitted perpendicularly to the incident beam [1]. This technique was designed to potentially assist external-beam radiotherapy (EBRT) treatments, being useful for on-board imaging and/or real-time EBRT monitoring. Such orthogonal rays can be collected by positioning a multi-sliced, collimator-based detector system parallel to the beam axis. OrthoCT provides computed tomography-like images without rotating the X-ray source about the target (patient) which highly decreases the irradiated region. Simulation studies have evaluated the feasibility of OrthoCT for monitoring possible variations that may occur in lung [2] and prostate irradiations [3]. In both studies, this technique has shown to be fully capable of detecting possible organ deviations and tumor size variations. In this work, the capability of OrthoCT to detect morphological variations during a pituitary-like irradiation was evaluated through GEANT4-based simulations. For that, an anthropomorphic phantom was used and two different scenarios were implemented: (1) phantom with empty nasal sinuses and (2) filled with biological tissue. Regarding the features of the simulated detection system, a realistic full OrthoCT detector was implemented including the multi-slice collimator, the scintillator crystals, and the charge electronic readout mode. The results show that the signal distribution provided by such radiation present a good visual agreement with the simulated dose and the phantom structures, with a clear detection of the changing morphological scenarios here studied.

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154 - Evolutionary Algorithms for Monte Carlo Treatment Planning

Presenter: Mrs. KOZLOWSKA, Wioletta (CERN / Medical University of Vienna)

With an increased accuracy of Monte Carlo Treatment Planning Systems (MC TPS),the possibility of improved dose calculation arises. Deterministic algorithms are the workhorse for clinical treatment planning, however with enhanced simulations techniques one can benefit from highly optimized plans. The scope of this work, based on a MC engine, is to present the feasibility of the stochastic optimization with Evolutionary Algorithms (EA), known for good convergence in complex optimization problems[1].

On the baseline of the FLUKA[2][3] MC Code, a Quality Assurance and Treatment Planning System was developed. The system was validated with clinical patient data and it includes TPS standard functionalities, such as structure handling and objective function definition. An available optimization framework[4], was refactored and currently is fully coupled with FLUKA and its GUI Flair[5].

Three classical EA were implemented and examined with clinical proton and carbon treatment plans (TP): Genetic Algorithm, Particle Swarm and Differential Evolution. The evaluation included the search of the best set of EA settings and comparison of their performance. Finally the optimized TP were re-simulated with FLUKA and compared with deterministic solutions.

The proposed FLUKA QA and TPS system with its optimization techniques, can take full advantage of the Monte Carlo simulations. With the information from the MC engine, the dose delivered by pencil beam scanning is determined more precisely, and with the support of the EA the optimization through the full space of solutions leads to better treatment plans.

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155 - OpenDose: a Collaborative Effort to Produce Reference Dosimetric Data with Monte Carlo Simulation Software.

Presenter: Dr. CHAUVIN, Maxime (Centre de Recherches en Cance■rologie de Toulouse, Toulouse, FRANCE)

Radiopharmaceutical dosimetry for diagnostic and therapy uses reference data describing energy deposition from a source to target tissues. Reference data are usually expressed as S-values, i.e. mean absorbed dose in a target from a source decay (Gy.Bq-1.s-1). The OpenDose project aims at providing an open database of robust reference S-values generated from different Monte Carlo (MC) software, through an international collaboration.

The ICRP 110 reference adult female [1] was chosen as the first model, with 140 segmented tissues-organs and a voxel size of 1.775x1.775x4.84 mm^3. Specific Absorbed Fractions (SAFs) are being computed for different sources, with mono-energetic photons and electrons. S-values will be generated by interpolating these mono-energetic SAFs for isotope decay schemes [2]. Producing data with different software using various physics lists will allow a cross-verification of the results and their associated uncertainties.

The OpenDose project already includes 12 research teams and 5 of the most popular MC software used in radiopharmaceutical dosimetry: Geant4/GATE, Fluka, EGSnrc/EGS++, MCNP/MCNPX and Penelope. A total of 46 source tissues-organs have so far been simulated with GATE for mono-energetic particles (photons + electrons) from 5 keV to 10 MeV. Each simulation requires ~1 day of computation on a single CPU for 10e8 primary particles and produces a 3D map (voxel-based) of absorbed doses and uncertainties. When available, the data from the other software will be analysed and compared in terms of SAFs for different targets and energies. Next steps include the integration of SAFs to provide S-values and build the database to allow Nuclear Medicine centres to easily access and use the data.

Through a collaboration of research teams using different MC techniques, we are developing a freely accessible database of reference dosimetric data. A preliminary study using the ICRP adult female model is ongoing. The project is open to new research teams to increase the variety of software and will expand to more computational models and studies.

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156 - Optimization of SPECT Collimators Using Monte Carlo Approach

Presenter: Prof. SARIPAN, M Iqbal (Universiti Putra Malaysia)

Monte Carlo N-Particle code, version 5 (MCNP5) is a general-purpose Monte Carlo code and it can be used for design of imaging systems. In this paper, a realistic SPECT model was developed referred to the SIEMENS Symbia T imaging system. The most important components of the SPECT camera were modelled, especially a LEHR collimator with hexagonal-hole were simulated as closely as possible to its shape and dimensions. The photoelectric effect, Compton and coherent scattering were included in the gamma transport process. In order to validate the SPECT model, specifications in terms of intrinsic spatial resolution, energy resolution, sensitivity, system spatial resolution and tomography spatial resolution were measured in comparison with experimental data. Overall results showed good agreements between the simulations and experimental results provided by SIEMENS. The simulated intrinsic resolution matched well with experimental data. For the system spatial resolution, it differed about 3% compared with the experimental result. The tomographic results showed difference of 5.9%, 5.6%, 0.3%, 10.7%, 0.2% for the five average resolution, respectively. In summary, the results demonstrated the flexibility and accuracy of MCNP5 to simulate the basic features of SIEMENS Symbia T SPECT Camera.

157 - Development of Geant4-based Patient-Specific QA System of Gamma Knife Treatment Plans using Automated DICOM-RT Interface

Presenter: Mr. CHOI, Hyun Joon (Yonsei University, Republic of Korea)

Gamma knife system which uses 192 small photon beams is widely considered as a very precise modality for intracranial radiosurgery. However, there are still limitations in current treatment planning system (TPS) for accurately estimating the absolute dose in the small volume, or the dose distribution in the inhomogeneous area such as the case of embolization of arteriovenous malformations and the located target volume behind an air cavity. The purpose of this study is to develop quality assurance (QA) system of gamma knife treatment plans based on a patient-specific model constructed by an automated DICOM-RT interface in Geant4.

The Leksell Gamma Knife Perfexion was designed in Geant4.10.00 based on the manufacturer's detailed information. Dose distributions in the spherical water phantom with a diameter of 16 cm were compared between Geant4 and the film measurement for the validation system. For extracting the patient-dependent parameters, automated DICOM-RT interface was developed for constructing the patient-specific model. In-house developed system is able to manually define the physical property of a special volume using the region of interest (ROI) contour data stored in a DICOM file. The dose distributions in the water phantom were compared between Geant4, measurement data and manufacture's values in terms of full width at half maximum (FWHM). FWHM of Geant4 and measurement were quite well matched with manufacture's value within 0.3, 0.2 and 0.7 mm in both the x and y direction for 4, 8 and 16 mm, respectively. Furthermore, the dose distributions of Geant4 and commercial TPS were well matched for different beam size combinations for each of the eight sectors.

The developed QA system shows the potential to precisely estimate the dose distribution in the patients. In the future, assessment of the absolute dose distribution calculated by Geant4 and commercial TPS for the clinical cases will be performed. Moreover, magnetic resonance (MR) images will be employed in our system for sophisticated modelling the heterogeneities in the patients.

158 - Towards a fully Monte Carlo-based method for RBE estimation.

Presenter: Prof. BERNAL, Mario A (Universidade Estadual de Campinas)

Determination of the relative biological effectiveness (RBE) of ionizing particles is an intense current research topic, mainly for heavy charged particles. We have developed a method base on Monte Carlo simulations that allows the estimation of the number of lethal lesions in an irradiated cell. It is also based on the Dual Radiation Action Theory. The phase-space of the energy depositions produced by the primary radiation is superposed on an atomic-resolution geometrical model of the genetic material. The position of each double DNA strand break is determined according to a biophysical model. These breaks are regarded as sub-lethal lesions, which may interact each other in a pair-wise fashion to produce lethal lesions. The number of lethal lesions is plotted as a function of dose and squared dose so that alpha and beta parameters are determined, respectively. These parameters are used for estimating the RBE of heavy charged particles and neutrons. The behavior of RBE as a function of heavy particle LET and as a function of neutron energy are reproduced with success.

159 - Contribution of coherent and incoherent scatter in grating-based phase-contrast imaging

Presenter: Ms. VIGNERO, Janne (KULeuven, Oude Markt 13 – bus 5005, B-3000 Leuven, Belgium)

AIM. Grating-based phase-contrast imaging (GB-PCI) is a recent development in x-ray imaging. Using three gratings, a highly periodic intensity pattern is created and measured. The amplitude (visibility) of this pattern is an important system parameter that determines image quality and scatter degrades this system visibility. Two GB-PCI setup aspects are expected to reduce the scatter fraction in the image: grating G2 can be considered an anti-scatter grid while large object-to-detector distances (D) will limit large angle scatter contributions. The aim was to quantify the efficiency with which these two aspects reduce both coherent and incoherent scatter in GB-PCI.

METHOD. PENELOPE Monte Carlo simulations were used with a realistic GB-PCI imaging geometry: gratings G1 and G2 had pitches of 4 and 2 μm, respectively, heights of 35 and 26 μm and duty cycles of 0.5. The trenches of the silicon gratings were filled with air in G1 and gold in G2. The G1-to-detector distance was 4.53 cm, while G2 was fixed to the detector. A 40 kVp x-ray tube was simulated in a plane wave geometry. Three different cases were evaluated for two objects, a finger imaged in air and a 5 cm thick PMMA slab. Case 1 had G2 in place and D was 9.5 cm, G2 was removed for case 2 and D was 9.5 cm, while case 3 had G2 removed and D was 4 cm.

RESULTS AND CONCLUSION. Coherent scatter-to-primary ratio (SPRcoh) for the finger was 1.63%, 0.56% and 0.77% for cases 1,2,3 respectively. Similarly the incoherent SPR (SPRincoh) was 0.29%, 0.20% and 0.67%. For the PMMA slab, SPRcoh was 6.65%, 7.67% and 10.50% for cases 1, 2 and 3, while SPRincoh was respectively 2.26%, 3.05% and 7.86%. The uncertainty was <5%. Increasing D from 4 to 9.5 cm reduces both scatter-to-primary ratios (SPRcoh by 27% and SPRincoh by 65%). G2 will only reduce scattered radiation for larger objects with higher exit scatter fractions(consistent with [1]) due to absorption of primaries and the creation of scatter in the grating.

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160 - Advanced personalised 3D dosimetry based on Monte Carlo simulation for Peptide Receptor Radionuclide Therapy

Presenter: Mr. BERENATO, Salvatore (School of Engineering, Cardiff University, Cardiff, UK)

Molecular radiotherapy (MRT) is an effective technique for the treatment of several oncological diseases, based on the delivery of radiation to malignant tissues via the interaction of an agent with molecular sites and receptors. (1)
In the clinical practice, the calculation of the absorbed dose is performed using the Medical Internal Radiation Dose (MIRD) scheme, based on pre-calculated transfer functions determined on standard anthropomorphic phantoms. The MIRD scheme assumes that radiopharmaceutical activity is distributed uniformly inside the organs (2). For this reason, dose calculation is not planned or optimised for patients' specific characteristics. To increase the efficacy and quality of clinical trials, a detailed and reliable 3D patient specific dosimetry is required. Monte Carlo techniques are shown to provide the most accurate approach for the radiotherapy dose calculation.
In this work, we used Raydose Monte Carlo code (3) to provide a patient specific 3D dose distribution in MRT at the voxel level for patients enrolled as part of a clinical trial on Peptide Receptor Radiotherapy (PRRT) with 177Lu and we compared doses to lesions and OARs with standard dose calculations obtained using the MIRD method.
One hundred patients were enrolled in a clinical trial in PRRT with an activity prescription of 3.7-5.55 GBq of 177Lu-DOTA-Tyr3-octreotide. All patients were scanned five times with a SPECT/CT scanner and both lesions and OARs were drawn manually on fused images. Sequential scans were co-registered using a non-rigid registration algorithm. Raydose 3D dose maps were compared with dose calculations obtained using the OLINDA/EXM software.
Preliminary results for the first 20 patients show that mean doses calculated with OLINDA/EXM are significantly higher than mean doses calculated with Raydose.
Initial data based on Monte Carlo dose calculations suggest a possible underestimation of the dose to OARs in PRRT treatments. More accurate dose calculation could be used on a patient by patient basis to increase the prescribed activity, maintaining a safe level of toxicity. A complete analysis that includes doses to lesions is in progress.

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161 - Fred: A new GPU-based fast-MC code and its applications in proton beam therapy

Presenter: Dr. SCHIAVI, Angelo (SBAI Department, Sapienza University of Rome)

This contribution will present the fast-MC GPU-accelerated code FRED [1], developed by the University of Rome, and its potential towards an improved patient treatment in proton beam therapy centers.
Proton therapy has rapidly grown in the past thirty years and it has become a superior alternative to conventional radiotherapy for certain clinical indications. Proton therapy offers high dose selectivity due to the protons' distinct depth dose profile which potentially allows to deliver high dose to the tumor while sparing healthy surrounding tissue. Monte Carlo (MC) simulations, which take explicitly into account all the details in the interaction of particles with human tissues, are considered to be the most reliable tool to reproduce the complexity of mixed field irradiation in a non-homogeneous environment. The advent of general-purpose programming GPU cards prompted the development of trimmed-down MC-based dose engines, which can significantly reduce the plan recalculation time with respect to standard MC codes on CPU hardware.
In this contribution, the results of the validation of Fred against FLUKA and Geant4 MC codes will be shown for lateral and depth-dose distributions of proton pencil beams as well as for patient dose distributions. The application of the new dose engine to the recalculation of proton verification plans in the patient-specific QA protocol of Centro Nazionale di Adroterapia Oncologica (CNAO) will be described. The status of the implementation in Fred of the experimentally measured physical beam model data used for treatment planning at the Bronowice Cyclotron Center (CCB) in Krakow will be reported. Different proton radio-biological models available in the literature are currently being implemented in Fred to clinically quantify the impact of biologically optimized treatment planning in proton therapy.
Finally, it will be reported how Fred significantly improves and accelerates important computational tasks in proton imaging.

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162 - Radionuclide decay scheme modelling in EGSnrc

Presenter: Dr. TOWNSON, Reid (National Research Council, Canada)

The ability to simulate radionuclide emissions with complete decay scheme modelling has been added to EGSnrc. Decay pathways are obtained from the LNHB DDEP recommended data [1] for 220 radionuclides in ENSDF format. This data set is an extensive compilation of empirical measurements of the radionuclide decay process. The new radionuclide source model in EGSnrc includes support for beta plus and minus decay, electron capture decay, alpha decay and decays from metastable levels. The theoretical Fermi spectrum is used to determine the initial energies of electrons and positrons resulting from beta decays. Since EGSnrc does not transport alpha particles, these emissions are absorbed locally in the source region. Internal transition emissions are correlated with disintegration events and assigned a decay index to allow for exact coincidence counting. Atomic relaxations from sub-shell vacancies are also correlated with disintegration events, and modelled using transition probabilities and binding energies from the EADL library. Optionally, EADL relaxations can be switched off for radionuclide emissions and replaced with statistically sampled Auger electron and fluorescent photon emissions using data provided in the LNHB ENSDF files. All emitted particles are assigned an emission time based the atomic and nuclear lifetimes.

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163 - Geant4 Monte Carlo simulations of prompt gamma and neutron yield during proton irradiation of homogeneous and inhomogeneous phantoms

Presenter: Dr. GUTIERREZ, Andrea (University College London)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

Geant4 Monte Carlo simulations of prompt gamma and neutron yield during proton irradiation of homogeneous and inhomogeneous phantoms

Andrea Gutierrez (1,*), Savanna Chung (1) and Robert Speller (1)
(1) University College London, Medical Physics and Biomedical Engineering, London, United Kingdom
*presenting author

Worldwide, the number of proton beam therapy facilities for cancer treatment is increasing considerably. The increasing demand is not surprising since proton beam therapy has considerable clinical benefits over photon therapy. Proton beam therapy enables a more localised deposition dose and spares surrounding healthy tissue and critical organs from radiation. The full potential of proton beam therapy is currently limited by uncertainties associated with the patient setup, dose calculation, organ motion and anatomical variations [1]. Prompt gamma imaging is a promising approach for in vivo real-time proton range verification [2]. Prompt gamma-rays are produced during nuclear de-excitation of the tissue, a few nanoseconds after proton irradiation. The prompt gamma rays' intensity and emission spectrum depend on the proton beam energy and the elemental composition of the tissue.

The Geant4 toolkit [3] was used to perform Monte Carlo simulations of prompt gamma and neutron emission. A comparison of gamma yield between Geant4 10.2.p3 and new data sets in the hadronic physics lists included in Geant4 10.3.p1 was performed. Homogeneous plastic phantoms, as well as multi-layer phantoms with different materials such as plastic, water, graphite and paraffin were used with the aim of identifying compositional and density changes through gamma emission. Furthermore, the gamma energy spectrum (e.g. 2.2 MeV peak) could provide information about neutron capture in the tissue. Preliminary results of experimental validation will be presented. We also investigated the sensitivity of gamma emission fall-off near the Bragg peak for proton range verification applications.

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164 - Detector MC study for measurement of nuclear reaction cross sections relevant in particle therapy

Presenter: VALLE, Serena Marta (Università di Milano e INFN Sezione di Milano)

In protontherapy, proton beams are used to treat deep-seated tumors, exploiting the charged particles characteristic depth-dose deposition profile. In clinical practice a constant RBE equal to 1.1 is adopted, regardless of the demonstrated RBE variations [1], which depends on physical and biological parameters. In particular, nuclear interactions might influence the proton RBE due to secondary heavier particles produced by target fragmentation that can significantly contribute to the total dose. Nuclear interactions especially affect the dose delivered in the entry channel, corresponding to healthy tissues preceding the tumor region [2]. As a consequence, an unwanted and undetermined increase of normal tissues complications probability (NTCP) may occur. At present, experimental data on target fragmentation are scarce. In fact, at therapeutic proton beam energy, fragments identification would be difficult due to their low energy and short range. The main goal of the FOOT (FragmentatiOn Of Target) experiment of INFN is to measure fragment production cross sections, to improve the proton radiobiological characterization and the NTCP control. Target (16O and 12C nuclei) fragmentation induced by 150-250 AMeV proton beams will be studied via an inverse kinematic strategy: 16O and 12C beams impinge on hydrocarbon and graphite targets to provide, by subtraction, fragmentation cross sections on hydrogen. A dedicated experimental setup is currently being developed and optimized. A magnetic spectrometer, a ΔE detector with TOF capabilities and a calorimeter will be used to measure fragments momenta, ΔE, TOF and kinetic energy. Precisions of ~2-3% and ~5% are required for fragment charge and isotopic identification respectively.
In this work we will present the results of a Monte Carlo study, based on the FLUKA code [3], which aims to evaluate the detector perfomances and the expected resolution on nuclear cross sections relevant for chrged particle therapy.

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165 - Assessment of RBED electron-impact ionization cross sections for Monte Carlo electron transport

Presenter: Ms. WANG, Xiaoya (McGill University)

Electron-impact ionization cross sections for atoms and molecules are essential for the modelling of radiation effects in a wide range of applications. Current state-of-the-art theoretical calculations are based on the distorted-wave Born approximation (DWBA), which provides an improvement in accuracy and validity range over the plane-wave Born approximation (PWBA) by accounting consistently for exchange effects as well as the distortion of the projectile wave functions by the field of the target atom. However, numerical DWBA calculations are elaborate and slow, and tabulated data only exist for integrated cross sections, whereas differential cross sections are also needed in Monte Carlo simulations.

The relativistic binary-encounter-dipole (RBED) model combines classical binary-encounter theory with Bethe's PWBA-based dipole model without the need for any empirical adjustable parameters [1]. The analytical RBED model provides integrated as well as differential cross sections and is much simpler than the DWBA [2], requiring as input only the binding energy, average kinetic energy, and optical oscillator strength (OOS) for each atomic subshell. Due to the difficulty of obtaining accurate OOSs, simplified models (known as RBEB and RBEQ) which assume a simple functional form for the OOS have also been proposed, and have been employed almost exclusively in studies since then. Here we calculate electron-impact ionization cross sections for a set of atoms spanning the periodic table using the more accurate RBED model, relying on OOSs obtained numerically with self-consistent potentials as described in [3].

Compared to RBEB, we find that the RBED results show better agreement with DWBA data for the K-shell of all atoms and over the entire energy range. The improvement is more pronounced for lower-Z elements, where the agreement between RBED and DWBA is near perfect. For higher shells, there is also better agreement at high energies for all elements, but near the threshold the improvement is less consistent and depends on the specific atomic shells. The disagreements between the RBED and DWBA cross sections near the threshold are due to the interplay between Coulomb and exchange effects, and highlight the limitations of using semi-empirical scaling factors. In the near future we will compile tables of RBED data for biologically-relevant elements, and ultimately implement them in Monte Carlo track-structure codes.

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[3] S. Segui et al., J. Phys. B: At. Mol. Opt. Phys. 35, 33-53 (2002).

166 - Assessment of factors contributing to detector response in high energy photon fields

Presenter: Ms. WEGENER, Sonja (University of Wuerzburg, Radiation Oncology)

There is no perfectly water-equivalent radiation detector for the use in radiotherapy. Volume averaging in a finite detector volume, energy dependence due to detector materials or the influence of additional parts such as shielding can lead to enormous response differences, especially under non-equilibrium conditions found for example in small fields. Using an experimental approach, we previously analyzed the role of scattered and primary radiation and the geometric volume effect for a variety of common small field detectors including shielded and unshielded diodes, the microDiamond and an ionization chamber[1]. Monte Carlo simulations are used as a tool to further investigate the reasons for the observed response differences.

Instead of a detailed beam model, monenergetic rings are used in the simulation. Fields of different sizes can be constructed from those rings, giving also the flexibility to omit central parts of the field to rebuild the setup used in the previously mentioned experiment to analyze scatter contributions. Geometries were built in egs_chamber and detectors were based on simple models starting with just the chip geometries so far, but will become increasingly detailed as needed based on microCTs. For a stereotactic diode, it was already shown that the energy- and field-size dependence could be adequately modelled even in the MV range by a combination of rings according to the beam spectrum even for a very simple detector model[2].

Simulation results contribute to the understanding of the experiments. Both agreed that the need for detector corrections compared to water was largely caused by scattered radiation and became more evident when the central part of a field, i.e. primary radiation, was removed. Diamond water-equivalent behavior observed over a range of field sizes and silicon diode over-response in large fields was explained by the chip material as expected. The monoenergetic ring approach further confirmed the hypothesis that the high-energy portion of the incident beam with its resulting low-energy scatter caused the over-response below the block. What yet remains to be clarified by more detailed models are the observations in small fields (<2 cm) and the response of the shielded diodes in the scatter experiment that heavily depended on the detector type.

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167 - Assessing the CTDIVOL and SSDE from dose profiles in cylindrical phantoms of water equivalent materials

Presenter: Mr. LOPEZ, Alejandro (Physics Institute of University of Sao Paulo)

The assessment of the Computed Tomography (CT) radiation output has become a challenge to researchers and technicians due to the rapid evolution of the technology incorporated in CT machines. To guarantee the correct functioning and to avoid accidents in CT examinations, the novel CT units require the use of specific phantoms for dosimetry and imaging evaluations. Nevertheless, such phantoms are expensive or they are unavailable in the market. In this work, water equivalent materials produced in the Medical Physics and Radiation Dosimetry Group of the University of Sao Paulo[1] will be evaluated in order to demonstrate their use in phantom fabrication for dosimetry and imaging purposes. Dose profiles along the central and peripheral axis of cylindrical phantoms of water equivalent material were computed in order to assess the metrics: volume CT Dose Index (CTDIvol) and Size Specific Dose Estimate (SSDE). The CTDIvol and SSDE are used as CT radiation output and patient dose descriptors, respectively. Three water equivalent materials: H2O_1 (Propylene + Chloroethylene + Sodium hydroxide), H2O_2 (Propylene + Phosphorous acid + Sodium hydroxide) e H2O_3 (Polyethylene + Sodium hydroxide + Calcium Fluoride) were evaluated in this work. X-ray source models based on phase space files generated by Monte Carlo simulation for 80, 100, 120 and 140 kV were used to scan the cylindrical phantoms. The x-ray source model was implemented following the technical specification of the GE Lightspeed Ultra CT machine (General Electric Company, Boston, USA) and It incorporate the anode self-attenuation, anode angle and the bowtie filters for head and body examination. The CTDIvol was computed in a cylindrical phantom of 15 cm length and the SSDE was achieved varying phantom diameters of 5 to 40 cm. CTDIvol and SSDE results were compared with literature data for reference materials. Finally, the results of this work will be used as reference to guarantee the usefulness of the materials developed in the GDFM in the manufacture of phantoms for CT quality control.

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168 - Monte Carlo assessment of the potential of fiber-coupled organic plastic scintillator dosimetry for direct determination of beam quality correction factors in MV photon beams

Presenter: Mr. VALDES SANTURIO, Grichar (Technical University of Denmark)

In the current dosimetry protocols used in radiotherapy, the beam quality correction factor (kQ,Q0) is needed for the dose determination in MV photon beams relative to a reference beam quality (usually 60Co) [1]. This factor accounts for differences in beam qualities with respect to a reference beam quality in which the detector was calibrated. For its determination, the dose to water needs to be estimated with small uncertainty. Because of the physical properties of organic plastic scintillators, both the density and the sensitive volume size, is a good surrogate for determining the absorbed dose to a point in water almost directly [2]. The objective of this work was to investigate by Monte Carlo the potential use of fiber-coupled organic scintillator for direct determination of kQ,Q0 correction factors or ionization chamber dosimetry in MV photon beams.
Fiber-coupled scintillators present some problems with the signal such as the quenching effect and the Cerenkov parasite-signal. For taking into account the quenching effect, the Birks formalism was implemented in the egs_chamber application of the EGSnrc MC based software through a modification of the source code (c++). Phase spaces from the Varian Truebeam were used as a radiation source in a constant source-to-surface configuration (SSD=100cm). Both detectors; a Farmer-type ionization chamber and the scintillator, were fully simulated using the blueprints. The values for the cutoff energies were set as the secondary production, for the IC was 10 keV and for the scintillator was 1 keV. The variance reduction techniques used were the photon cross-section enhancement and the russian roulette.
For all the computed absorbed doses the uncertainty was less the 0.4%. The used reference beam quality was 6MV. The obtained values were compared with the values determined by the National Physical laboratory (NPL) and the relative discrepancies between them were less than 1%.
The results indicate that the scintillator is a good surrogate for determining the absorbed dose to water.

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169 - Monte Carlo calculated correction factors for a proton calorimeter in clinical proton beams.

Presenter: ROMANO, Francesco (NPL)

Calorimetry is the only fundamental method for measuring the absorbed dose according to its definition.
A calorimeter measures the temperature rise resulting from irradiation in an absorber, assuming all the energy deposited in a material appears as a heat. Unlike other detectors, such as ionization chambers, Faraday cups and Fricke dosimeters, a calorimeter inherently provides a method to measure the energy deposited by radiation directly.
In particular, the National Physical Laboratory (NPL) has developed and is now commissioning a graphite calorimeter as a primary standard of absorbed dose for clinical proton beams.
To determine the absorbed dose to graphite from calorimeter measurements, different correction factors have to be calculated, including the gap correction factor (kgap) and a volume averaging correction factor (kvol) [1]. The former is related to the effect due to the presence of vacuum gaps within the calorimeter, the latter converts the mean absorbed dose in the graphite core to the absorbed dose in a point located at the centre of the core. A separate conversion factor is then applied to convert the absorbed to graphite in the calorimeter to the absorbed dose at the reference depth in water.
Monte Carlo simulations are currently the most precise tool to calculate these corrections in complex experimental configurations.
A Monte Carlo application has been developed with the TOPAS platform, based on the Geant4 toolkit [2,3] to calculate kgap and kvol for monoenergetic proton beams with energies ranging between 60 and 230 MeV [4]. Initial results indicate that kgap ranges from 0.06% above unity at 60 MeV to 0.36% above unity at 230 MeV with kvol being of a similar magnitude at these energies.
Moreover, to obtain the mentioned corrections in a more realistic environment close to clinical conditions, a typical passive proton therapy beam line for ocular melanoma treatment has been simulated in detail and similar results are being obtained for active scanning systems.
The results of the presented work will significantly contribute to the establishment of the NPL calorimeter as a primary standard in proton therapy.

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170 - Planar images on a new hybrid gamma detector MRI compatible.

Presenter: Prof. AGULLES-PEDROS, Luis (Universidad Nacional de Colombia, Physics department, Bogotá, Colombia); Ms. ABRIL, Andrea (Universidad Nacional de Colombia, Physics department, Bogotá, Colombia)

Functional imaging is important for medical diagnosis since it can provide quantitative information. It is mainly based on nuclear medicine (NM) rather than MRI since the NM is more sensitive. However, it lacks on anatomical imaging information. Hybrids systems MRI/NM have been developing in the last decades [1] in order to take advantage of both techniques. Although they are available commercially, their implementation is not massive. The main reason is due to high cost and complexity. The principal component that makes expensive is the photomultiplier based detectors adapted to high magnetic fields. In addition, the MRI coils interfere attenuating the intensity of gamma rays [2].
We proposed a hybrid MRI/NM based on gel dosimetry as a gamma detector [3,4] (patent pending). The readout system is based on the polymerization process induced by gel radiation. A gel dose map is obtained which represents the functional part of hybrid image alongside with the anatomical MRI one. Both images should be taken while the patient with a radiopharmaceutical is located inside the MRI bore with a gel detector matrix. A relevant aspect of this proposal is that the dosimetric gel has never been used to acquire medical images.
GEANT4 Monte Carlo simulations were developed to study the interaction of 99mTc sources with the dosimetric gel in the proposed system. Planar gamma images in different source configurations are studied to explore the ability of the gel as radiation detector through the following parameters; resolution, shape definition and radiopharmaceutical concentration, and sensitivity.

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171 - A Monte Carlo study to reduce range uncertainty in proton beam therapy via prompt gamma-ray detection

Presenter: Ms. PANAINO, Costanza (The University of Manchester)

Proton therapy represents the latest development is radiotherapy treatments. Proton beams stop inside the patient’s body, therefore an accurate detection of the distal fall-off can be extremely difficult. Precise knowledge of the proton beam range is essential to guarantee the treatments efficacy and to avoid toxicities. One way to measure the beam range during the dose delivery is to detect the prompt gamma (PG) rays emitted from the target nuclei excitation after proton bombardment (1). PG emission is almost instantaneous and has a high-production rate. Nevertheless, because of the high energy of the emitted PG rays (4-10 MeV) no optimized detectors are in use clinically. The aim of the present project is to develop and validate, through Monte Carlo simulations and experimental analysis, a PG detection technique. The PG detector system under investigation utilises LaBr3 scintillators arranged in a similar geometry to that of the NANA array (2). This system allows the reconstruction of PG ray emission points through a backprojection algorithm, which is currently under development. The Monte-Carlo work associated with this project will be presented.

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172 - Novel data relevant for helium ion therapy and their comparison with FLUKA nuclear reaction models

Presenter: Mr. HORST, Felix (THM University of Applied Sciences, Institute of Medical Physics and Radiation Protection, Giessen, Germany & GSI Helmholtz Centre for Heavy Ion Research, Biophysics Department, Darmstadt, Germany)

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Title: Novel data relevant for helium ion therapy and their comparison with FLUKA nuclear reaction models

Felix Horst (1,2,*), Giulia Aricò(3), Giuseppe Battistoni (4), Kai-Thomas Brinkmann (5), Francesco Cerutti (3), Alfredo Ferrari (3), Andrea Mairani (6), Katia Parodi (6,7), Paola R. Sala (3,4), Christoph Schuy (2), Thomas Tessonnier (7), Uli Weber (2), Klemens Zink (1,8,9)

(1) THM University of Applied Sciences, Institute of Medical Physics and Radiation Protection, Giessen, Germany
(2) GSI Helmholtz Centre for Heavy Ion Research, Biophysics Department, Darmstadt, Germany
(3) CERN, Geneva, Switzerland
(4) INFN, Sezione di Milano, Italy
(5) JLU University, II. Physics Institute, Giessen, Germany
(6) HIT Heidelberg Ion-Beam Therapy Center, Heidelberg, Germany
(7) LMU University, Munich, Germany
(8) University Hospital Giessen-Marburg, Department of Radiotherapy and Radiooncology, Marburg, Germany
(9) FIAS Frankfurt Institute for Advanced Studies, Frankfurt, Germany

4He ions are considered an attractive modality supplementary to protons and 12C ions for use in cancer radiation therapy. The accelerator and beam application system at the Heidelberg ion-beam therapy center (HIT) are currently commissioned for clinical application of 4He ions, which involves the calculation of basic data for the treatment planning system (laterally integrated depth dose profiles, lateral dose profiles and fragment distributions in water). For the commissioning of protons and 12C ions at HIT the FLUKA code [1,2] has been used [3]. The models for light ion interactions in FLUKA are undergoing several improvements and enhancements [4] particularly for 4He and their performances have already been investigated for calculation of 4He dosimetric data [5]. While the shape of the Bragg peak curve is mostly dominated by the Landau fluctuations in the projectile energy losses, its height is mainly determined by the nuclear interactions undergone by the primary ions. Furthermore, the fragments generated in nuclear interactions can give rise to a fragmentation tail after the Bragg peak and contribute to the quality of the mixed radiation field. Therefore, experimental data about the total nuclear cross section and fragment distributions for He-4 beams are needed to develop and validate the models available for 4He-induced nuclear reactions with the same level of reliability achieved for other ion species (e.g. 12C).
The aim of this work is to present novel fragmentation data [6], in particular mass-changing cross sections for 4He+12C collisions over the entire energy range relevant for therapy, and to compare them with the 4He-nucleus reaction models currently under development for FLUKA. The presented work will have the potential to improve significantly the dose calculation for helium ion therapy and ensure that future basic data will be as reliable as possible.

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173 - Geant4-based Monte Carlo simulations of a transport beam line for multidisciplinary applications of laser-driven proton beams

Presenter: ROMANO, Francesco (NPL; LNS-INFN)

The ELIMED (MEDical and multidisciplinary application at ELI-Beamlines) beamline is being developed with the aim of transport and select in energy proton and ion beams accelerated by laser-matter interaction at ELI-Beamlines (Extreme Light Infrastructure) user facility in the Czech Republic [1]. The beamline will be a key part of the the ELIMAIA (ELI Multidisciplinary Application of laser-Ion Acceleration) user beamline, where experiments will be carried out with the purpose of investigating the feasibility of using laser-driven beams for multidisciplinary applications, including medical ones [2].
A Monte Carlo simulation of the ELIMED beamline has been developed for the following purposes: to support the design of the beamline in terms of particle transport efficiency, to optimize the beam parameters at the irradiation point in air and, finally, to predict the transport elements parameters to deliver dose distributions of possible clinical relevance [3].
The application has been developed with the Geant4 Monte Carlo toolkit [4]. It has been designed in a modular way in order to easily switch on/off geometrical components according to different experimental setups. The application has been preliminary validated comparing particle tracks to results obtained with reference codes for transport of particles in magnetic fields, with a good agreement.
Specifically, energy distributions, lateral beam profiles and longitudinal dose distributions in the in-air final section were simulated for proton beams with energies ranging between 5 and 60 MeV. A transmission efficiency of more than 10% was calculated at 60 MeV, which implies the delivery of up to tens of cGy per pulse at the sample irradiation point. Assuming a repetition rate of 1 Hz, between 1 and 10 Gy/min can be potentially achieved in such conditions. These results are of great importance to assess the possibility of carrying out in-vitro and in-vivo radiobiology experiments aiming to demonstrate the possible future use of optically accelerated beams for therapeutic purposes.
Moreover, a special focus will be given to the possibility to optimize the simulated transport element configurations for actively modulating the beam energy in order to produce longitudinal dose distributions of clinical relevance, and results from preliminary investigations will be shown.

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175 - A EBT3 film calibration approach for the validation of a Monte Carlo internal dosimetry framework

Presenter: Mr. FREZZA, Andrea (Université Laval)

Context and objectives:
Recent studies have shown the potential benefits of using 177Lu-based Peptide Receptor Radionuclide Therapy (PRRT) in neuroendocrine tumors. For 177Lu-based and other radionuclide therapies, it appears that a robust Monte Carlo-based internal dosimetry framework is highly desirable. Gafchromic EBT3 films can potentially contribute to the validation of such a dosimetry framework, but require an appropriate calibration procedure to account for their energy dependence. Monte Carlo simulations were used to investigate this dependence with 177Lu, and to develop a film calibration procedure with an orthovoltage beam having a quality (Q) and a similar energy dependence.
Methods:
The physical quantity evaluated in this work was the film equivalent absorbed dose to water f(Q). This was obtained with Geant4 simulations as the ratio of the absorbed dose in water to the absorbed dose in the film displacing a water volume. f(Q) was calculated with different orthovoltage beams and with a 177Lu source placed in a water filled Jaszczak phantom. X-ray beam qualities ranging from 2.24 to 3.22 mm Cu (HVL) were tested, corresponding to peak voltages of [220-300] kVp and effective energies of [115-142] keV. The simulation input spectra were obtained with the SpeckCalc software. 177Lu disintegrations were simulated with Geant4 RadioactiveDecay5.1.1 data.
Results:
A minimal difference of 0.4% in f(Q) was obtained between 177Lu and an orthovoltage beam quality of 3.07 mm Cu (HVL) having an effective energy of 138 keV (300 kVp). For beams with effective energies ranging from 136 to 142 keV, this difference was <1%.
Discussion and conclusion:
The optimal orthovoltage beam quality for the calibration of EBT3 film to use with 177Lu was found. The f(Q) does not show a strong kVp dependence in the range explored, and calibration can be performed with a beam having an effective energy of approximately 140 keV and a quality of 3 mm Cu (HVL). This represents the first step towards the validation of a fast GPU-based, in-house Monte Carlo code dedicated to accurate internal dosimetry in nuclear medicine.

176 - Geant4 implementation of inter-atomic interference effect in Small-Angle Coherent X-ray Scattering for materials of medical interest

Presenter: Dr. PATERNÒ, Gianfranco (FE)

Advanced applications of digital mammography such as dual-energy and tomosynthesis require multiple exposures and thus deliver higher dose compared to standard mammograms. A straightforward manner to reduce patient dose without affecting image quality would be removal of the anti-scatter grid, provided that the involved reconstruction algorithms are able to take the scatter figure into account [1].
Monte Carlo simulations are very well suited for the calculation of x-ray scatter distribution and can be used to integrate such information within the reconstruction software. Geant4 is an open source C++ particle tracking code widely used in several physical fields, including medical physics [2,3]. However, the coherent scattering cross section used by the standard Geant4 code does not take into account the influence of molecular interference. According to the independent atomic scattering approximation (the so-called free-atom model), coherent radiation is indistinguishable from primary radiation because its angular distribution is peaked in the forward direction. Since interference effects occur between x-rays scattered by neighbouring atoms in matter, it was shown experimentally that the scatter distribution is affected by the molecular structure of the target, even in amorphous materials. The most important consequence is that the coherent scatter distribution is not peaked in the forward direction, and the position of the maximum is strongly material-dependent [4].
In this contribution, we present the implementation of a method to take into account inter-atomic interference in small-angle coherent scattering in Geant4, including a dedicated data set of suitable molecular form factor values for several materials of clinical interest. Furthermore, we present scatter images of simple geometric phantoms in which the Rayleigh contribution is rigorously evaluated.

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177 - A robust Monte Carlo Treatment Planning optimization algorithm for dose painting clinical implementation

Presenter: Ms. JIMÉNEZ-ORTEGA, Elisa (Dpto. Fisiología Médica y Biofísica, University of Seville / IBIS, Seville, Spain)

Purpose

In order to start accurate clinical trials based on treatments more aggressive than traditional margin approaches, a robust optimization algorithm has been developed for dose calculation full Monte Carlo-based. Specifically, the algorithm is presented here to manage uncertainties on dose painting from PET/CT image data.

Material and Methods

CARMEN platform [1] was updated to allow heterogeneous dose prescription by means the recurrent both approaches. For the approach considered as true dose painting by number (tDPBN) where the restriction of dose to volumes makes no sense, it was necessary to develop a novel algorithm including an optimization method at the voxel level under Lineal Programming (LP) formulation [2].

For the approach based on the discretization of functional information into several clusterings (DPBN), instead of a recurrent equidistant isolevel, we implemented several algorithms able to reflect the diffuse and multifocal nature of the uptake regions. For this study, the affinity propagation proposed by Foster [3] in order to reduce random errors due to the PET images registration process.

Full Monte Carlo simulations were performed for pre-optimization and final dose calculation for taking into account the interactions of particles by means an explicit transport along the beam modifiers in the linac head. Axesse/Synergy linacs of Elekta were modellized with the EGSnrc/BEAMnrc code. The dose calculation in patient was carried out with the BEAMDOSE code, a modified version of DOSXYZnr for calculate the specific beamlet dose contribution on each voxel. A grid calculation consisting on 256 × 256 voxels per slice was used from the interpolation of PET/CT images reconstructed by keeping a compromise with EARL (ResEARch4Life®) accreditation requirements.

Linear Programming formulation at voxel level allowed stablishing a tractable robustness of the uncertainties related to the heterogeneous dose prescription, imposing lower and upper-bound constraints to each voxel in accordance to the clustering volume to which they belong.

For tDPBN, an inverse planning schema was previously developed [4]. For DPBN by clusterings approach, a specific direct aperture optimization (BIOMAP) based on the sequencing of biophysical maps [2] has been modified to generate apertures with Boolean combinations of the clustering projections.

Results

tDPBN by means inverse planning showed excellent QVHs, although they were achieved by means of solutions with high MUs (around 2000 MU/ fraction with more than 350 segments). Secondary contribution from MLC meant a high dose spillage to the body, so cannot be directly assumed for clinical implementation. The robust solutions for DPBN by means BIOMAP allow the accurate clinical implementation (around 750 MU/ fraction with less than 200 segments) with Q index (planned_dose_matrix/true_prescribed_dose_matrix) over 95%.

178 - Monte Carlo calculation of absorbed doses due to imaging sessions delivered to patients during Tomotherapy Image-Guided RadioTherapy courses

Presenter: Mr. DELPON, GREGORY (ICO, Centre René Gauducheau, Nantes Saint-Herblain, France)

Introduction: The delivery of complex plans is usually included in an image-guided radiotherapy (IGRT) process that is based on a daily in-room imaging session in order to adjust the tumor position. IGRT strategies lead to deliver additional absorbed doses to treated patients due to these imaging sessions. The aim of this study was to calculate the tridimensional dose distribution due to Mega Voltage Computed Tomography (MVCT) imaging sessions with Monte Carlo (MC) simulations for Tomotherapy (Accuray) courses.
Material and methods: MC modelling of the MVCT with the code GATE/GEANT4 was extensively evaluated by comparing measurements and simulations for percent depth dose and off-axis profiles in water and water-equivalent material for static and rotational irradiations, using two fan beam widths. In the isocenter plane, beam dimensions were 4x400mm2 and 50x400mm2. In addition, measured and MC computed absorbed doses were compared for a helical irradiation delivered to the STereotactic End-to-End Validation anthropomorphic phantom (STEEV, CIRS). Depending on the irradiation settings and the material, dose measurements were performed with an ionization chamber, a diamond detector, radiochromic films or optically stimulated luminescent dosimeters (OSL).
Results: For depth dose profiles acquired with static irradiations, simulations and measurements agreed within 3% for depths varying from 0 to 12cm for both beam widths, but reached 6% at a 20cm depth for the 4mm wide beam. For off-axis profiles acquired with static irradiations, simulations and measurements agreed within 3% in high dose region the longitudinal axis. Discrepancies were slightly higher in the lateral axis. Simulated and measured profiles obtained for a 360° irradiation were also in good agreement. Absorbed doses measured with 27 OSL dosimeters in the STEEV phantom for a 12cm long helical irradiation varied from 13 to 16mGy according to the position. MC calculated doses in the same conditions differed by less than 10%.
Conclusion: The MC modelling of the Tomotherapy MVCT allows to calculate tridimensional absorbed dose distributions in patients. This model can now be used to quantify the absorbed doses due to imaging sessions during Tomotherapy courses and to evaluate the dosimetric impact of different IGRT strategies.

180 - On the use of Monte Carlo techniques to improve particle imaging noise filtering and spatial resolution

Presenter: Mr. COLLINS-FEKETE, Charles-Antoine (Université Laval)

Particle imaging has shown growing interest in the recent literature as it allows direct measurement of the tissue relative stopping power (RSP) within a patient, using either the radiographic or tomographic images [1]. However, its accuracy is limited by the multiple Coulomb scattering (MCS) suffered by the particles transported through the phantom and by the secondary particles noise measured on the detector that creates artefacts in the reconstructed images. Monte Carlo (MC) techniques help investigate the spatial resolution gain obtained by using 1) different path estimate or 2) different ions to reduce the MCS effect on the final images. [2–4]. Furthermore, secondary particles filtering techniques are paramount to achieve high RSP accuracy but may reduce contrast and spatial resolution along the process. The effect of the applied filters can be directly studied on the noise power spectrum (NPS) of perfect images acquired through MC simulations. Initial investigation demonstrates that He ions are the optimal choice between light ions (i.e. 1H to 6C) to achieve the highest path accuracy [2], decreasing the root-mean-square uncertainty between the MC reference and the path estimate from 0.5 mm for protons to 0.18 mm for He. This has been shown to leads to higher spatial resolution radiographic images. On the other hands, the NPS spectrum (mm2) increases due to secondary particles on unfiltered He image is 300 times higher than that of a proton, stressing the need for smart secondary particle filters.

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181 - Individual Computational Human Phantom Made of Indonesian Female Body for Internal Radiation Dosimetry Applications

Presenter: Ms. PINASTI, Sita Gandes (Gadjah Mada University)

In internal radiation dosimetry, determination of individual dosage needs information of biological (radionuclides biokinetic in body) and physical parameters (radionuclide decay and object geometry), which vary in one person to another. Physical parameters are obtained from radiation transport simulation based on probabilistic approach, Monte Carlo methods. The purpose of this research was to improve the accuracy of physical parameters by reconstruction of realistic and man-specific computational human phantom. Reconstruction of the phantom was based on individual Indonesian female medical images (DICOM images) from CT-Scan, which were segmented and converted to NURBS (Non Uniform Rational B-Spline) object in order to meet both realistic and flexibility criteria. Furthermore, the geometry was modified into simulation software MCNPX (Monte Carlo N-Particle eXtended) simulation input. The phantom consists of 23 organs, distributed in 5,364,000 voxels, and employed as the geometry input in radiation transport simulation using MCNPX to evaluate absorbed fraction in some organs during radioiodine therapy for thyroid cancer. The last effort was aimed as a case study to make a better understanding on the differences between Indonesian anthropometry to those Asian and Caucasian body and at once recommend the development of Indonesian reference phantom.

182 - Biophysical modelisation of gold nanoparticles radiosensitizing effects

Presenter: Mrs. POIGNANT, Floriane (IPNL)

The main challenge of radiotherapy is to focus the irradiation dose in cancer cells while preserving the healthy cells surrounding the tumor. Among the different strategies, the use of radiosensitizers aims to amplify the destructive effects of dose in the tumor1. Nanoparticles of heavy metals such as gold and gadolinium, are particularly promising radiosensitizers. If their radiosensitizer effect has been studied for about two decades, the origin of this phenomenon is still quite unknown and barely quantified.

Literature suggests that irradiation would generate a physical effect called Auger cascades. This effect would lead to a local increase of secondary electrons around nanoparticles, thus amplifying the critical damage of direct cell sensible molecules, such as DNA, or through a boost of free radicals. These effects are produced at nanometric scale and within a very short time (10-15 to 10-12 second) but may have consequences at patient scale. Because these physical and chemical effects are not directly observable, the simulation tool is therefore mandatory to better understand the initial mechanisms.

The goal of this study is to first develop a simulation to calculate the spatial dose and free radicals distribution around the nanoparticles, and to quantify the induced boost2,3. To achieve this first step, we developed a low energy Monte Carlo code which can track secondary electrons at nanometric scale down to thermalization energy both in water and gold.

This simulation includes in particular molecular and condensed matter effects: vibrations, molecular excitation, electron attachment, surface/bulk plasmons (gold). The model also accounts for macroscopic potential differences between two media. The output can be used either to calculate energy deposition or for radical production. Secondly, we want to inject these outcomes into the model NanOx4 to quantify some scenarios. The model NanOx was originally developed at IPNL to calculate the biological dose in hadrontherapy.

These calculations may be used in the future to guide the development of nanoparticle-based radiotherapy and, if possible, to provide clinical treatment guidance. We will present the results we produced to face our simulation to experimental data and to explore some of the mechanisms suggested to explain the radiosensitizer effects of nanoparticles.

183 - Advances in the FLUKA PET tools

Presenter: Ms. CUCCAGNA, Caterina (TERA Foundation)

In this work the new developments of FLUKA[1][2] Positron Emission Tomography (PET) tools[3] are presented. FLUKA is a fully integrated Monte Carlo (MC) particle transport code, widely used for an extended range of applications, including medical physics. Recently FLUKA has provided the medical community with dedicated simulation tools for clinical applications, such as DICOM to voxel or PET simulation packages. PET is a well-established imaging technique in nuclear medicine and a promising method for clinical in-vivo treatment verification in hadrontherapy. The application of clinically settled PET scanners to new irradiation environments such as hadrontherapy requires further experimental and theoretical research to which MC simulations could be applied.

The FLUKA PET tools, besides including existing models from PET scanner manufacturers in its library, allows the configuration of new PET prototypes, thanks to its geometry framework supported by FLUKA GUI - Flair. Both the beam time structure and acquisition time can be specified by the user, allowing the correct reproduction of PET acquisitions in time. Furthermore, different scoring routines allow an analysis on single and coincident events, as well as identification of parent isotopes generating annihilation events. Two reconstruction codes are currently supported: the Filtered Back-Projection and the Maximum-Likelihood Expectation Maximization. Compatibility with other reconstruction frameworks is also possible.

The FLUKA PET tools have been successfully tested for different detectors and scenarios, including conventional PET Quality Assurance and in-beam PET, either using as a source radioisotopes density maps, or simulating hadron beams interacting with complex targets, accounting for the various nuclear reactions.

Finally, the results obtained so far confirm that the FLUKA PET tools are suitable to perform PET simulation studies in clinical environment.

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184 - OpenDNA: An OpenCL-based GPU Monte Carlo simulation code for Microdosimetry

Presenter: Dr. MA, Yunzhi ((1) Département de Radio–Oncologie et Axe oncologie du Centre de recherche du CHU de Québec,CHU de Québec, Québec, Québec G1R 2J6 Canada (2) Département de Physique, de Génie Physique et d'Optique et Centre de Recherche sur le Cancer, Université Laval, Québec, Québec G1R 2J6, Canada)

Introduction: Geant4-DNA[1,2] is a Geant4 module that simulates the track structure of charged particles (electron/positron, proton and ions) in water as well as the radiolysis process that follows. Unlike the condensed-history technique in normal Geant4 simulations, Geant4-DNA implements an analogue Monte Carlo (AMC) technique that gives the event-by-event history of primary particle and all its descendants. Due to this, the simulation is extremely slow. To provide a faster alternative, this work implements a GPU-based AMC using the OpenCL parallel programming framework, OpenDNA.

Methods: For electrons and positron, ionization, excitation and elastic scattering were implemented. For protons, ionization and excitation were implemented. The low energy cut is 10eV (10keV) for electron (proton). The physical models and cross section data were extracted from Geant4-DNA. OpenDNA was preliminarily benchmarked against Geant4-DNA by radial dose distribution (RDD) simulations. For electron, a spherical geometry was used for a isotropic point source of E=30keV for both codes. For proton, a cylindrical geometry was used and a E=800keV proton was initiated along its axis. The ratio of OpenDNA RDD over Geant4-DNA RDD was computed to evaluate the consistency. 1,000,000 (and 100,000) primary histories were simulated for the electron (proton) case. The codes were run in a Mac Pro with two AMD FirePro D700 GPUs (for OpenDNA, using 100 threads) and a 2.7 GHz 12-Core Intel Xeon E5 CPU (Geant-DNA).

Results: The RDDs of OpenDNA and Geant4-DNA are consistent with each other within 1% for both particles. The simulation time of the electron (proton) case was reduced to 1/12 (1/10).

Conclusion: An analogue MC code was implemented using OpenCL and therefore is supposed to run in all OpenCL-conformed GPU. Future work include the simulation of physicochemical and chemical processes.

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185 - Monte Carlo Simulation of “out-of-field” dose distributions in a pediatric phantom in External Radiotherapy – comparison with Gafchromic film measurements

Presenter: Mr. GHAREEB, Firass (Instituto Português de Oncologia do Porto Francisco Gentil- EPE Research Center, Porto, Portugal)

Introduction

Patients undergoing radiotherapy are exposed to out-of-field scattered and leakage radiation, which may induce secondary cancer in long-term survivors. The induction of secondary cancer in pediatric patients is an increased concern, because they have increasingly higher life expectancy, and tend to receive higher secondary organ doses than adults due to geometrical factors. Radiation-induced thyroid and breast cancers have been observed in pediatrics after receiving doses as low as 100 mGy[1]. While the dosimetric accuracy of treatment planning systems (TPS) is known to decrease in the out-of-field region, Monte Carlo (MC) is nowadays the most reliable method in dose calculation. A PENELOPE based MC code named PRIMO was tested for out-of-field dose estimation in pediatric irradiation.

Material and Methods:

a 5-year pediatric anthropomorphic phantom was irradiated by Varian Triology linac, using three 6MV static fields beams for a brain tumor. The treatment plan was calculated in Varian Eclipse TPS, using Analytic Anisotropic Algorithm (AAA). The 2D dose distributions at thyroid and lung levels were measured using Gafcromic EBT3 films. The plan was simulated in PRIMO after adjusting the primary beam parameters based on reference data in water phantom. PRIMO output data was reshaped, manipulated and re-written as DICOM files for comparisons with both measured and TPS calculated dose using 2D Gamma Function (3%, 3mm) on DoseLab Pro software.

Results

The maximum measured doses per 1 Gy at isocenter (0 cm) were 1.5 cGy and 8 mGy at thyroid (10.25 cm) and lung levels (15.25 cm) respectively. Comparing simulated and measured dose distribution one obtained 82.6% and 88.8% of gamma points <1 at thyroid and lung levels respectively. The difference between measured and TPS calculated dose distributions could easily be accessed visually.

Conclusion

For secondary induced cancer risk estimation, the present TPS, even using a reliable algorithm as AAA, is not generally satisfactory for out-of-field dosimetry. Alternative tools, like MC simulations are necessary if correct dose estimation must be obtained for risk models application.

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186 - OpenTRAK: An OpenCL-based GPU Monte Carlo simulation Code for Brachytherapy dose calculation

Presenter: Dr. MA, Yunzhi ((1) Département de Radio–Oncologie et Axe oncologie du Centre de recherche du CHU de Québec,CHU de Québec, Québec, Québec G1R 2J6 Canada (2) Département de Physique, de Génie Physique et d'Optique et Centre de Recherche sur le Cancer, Université Laval, Québec, Québec G1R 2J6, Canada)

Introduction: Monte Carlo simulation (MC) is a major type of model-based dose calculation algorithm (MBDCA) in Brachytherapy. However, due to the large number of primary beams (usually hundreds of millions or more) as needed to obtain small statistical errors, MC is usually not practical in clinical applications. Recently, there arise several NVIDIA CUDA-based graphic processing unit (GPU) MC codes that accelerate the simulation such that they suffice clinical requirements in certain situations. In this work, an Open-CL-based MC code that targets Brachytherapy dose calculations, OpenTRAK, was presented.

Methods: OpenTRAK implements all photon interactions (photoelectric effect, compton scatter, rayleigh scatter and pair-production) and computes the spatial energy-fluence distribution. The linear track estimator was then used to calculate the collisional kerma (Dm,m) distribution in phantom. OpenTRAK was preliminarily benchmarked against ALGEBRA, a GEant4-based BRAchytherapy dose calculation code[1], by using a MicroSelectronV2 Ir-192 HDR source. The source phasespace files had been prepared before dose calculations and were used as input for both MC codes. As an preliminary test, a single source was placed in
the centre of a uniform water phantom with dimension of 200x200x200 mm3 with its longitudinal axis aligned with the z-axis of the phantom. Dose ratio map (D_OpenTRAK/D_ALGEBRA) was generated and used for comparison analysis. The codes were run in a Mac Pro with two AMD FirePro D700 GPUs (for OpenTRAK) and a 2.7 GHz 12-Core Intel Xeon E5 CPU (ALGEBRA).

Results: The ratio map shows that the codes are consistent with each other with <1% deviations within the region enclosed by the 20% isodose surface. Beyond the surface, OpenTRAK shows systematic deviations due to unknown reasons. The simulation time of OpenTRAK is 1/13 of that of ALGEBRA.

Conclusion: An OpenCL-based MC code for brachytherapy dose calculation was implemented and preliminarily tested. The code itself needs further fine-tuning/corrections in order to maximize its GPU acceleration. Further benchmarks are planned including source TD-43 parameters extraction, real patient test cases, etc.

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187 - Validation of Dual Energy CT Atomic Composition Extraction using Proton Monte Carlo

Presenter: Dr. O'REILLY, Shannon (University of Pennsylvania, Department of Radiation Oncology, Philadelphia, PA)

Purpose

Proton Monte Carlo (MC) simulations model the physics processes between protons and medium and yield more accurate dose calculation compared to proton stopping power based pencil beam convolution algorithm. MC simulation is also essential for prompt gamma and proton-induced isotope production for in-vivo proton range detection. It requires the tissue element composition to be determined from patient CT images. We propose a new hierarchical clustering based approach in extracting the atomic composition in human tissues from Dual Energy CT (DECT) scans and a method for validation using MC simulations.

Material and Methods

70 published human tissues samples were used for the theoretical study of this approach. The tissues were first clustered by their composition similarities using hierarchical clustering. For each tissue cluster, three base tissues were randomly selected. Other tissues in this cluster were the weighted sum of these base tissues, where the weights were derived by fitting the attenuation coefficients calculated from DECT X-ray spectrums. The derived tissue atomic compositions and effective atomic number were compared with the ground truth. Animal tissues were scanned using a DECT scanner. The tissues were then irradiated using a PBS proton beam. A double Gaussian proton source has been modeled in GEANT4. Using these images, source model and extraction method, Monte Carlo simulations will be run mimicking the experimental setup.

Results

The soft tissues and bones were clustered into 8 subcategories, with cophenetic correlation 0.895 and inconsistency coefficient (IC) > 1.15 (ICmax = 1.1547). The mean and standard deviations of the difference in the derived atomic compositions and the ground truth for H, C, N, O, Ca, P were 0.05% (±0.07%), 1.56%(±2.02%), 0.61%(±0.55%), 1.81%(±2.37%), 0.03% (±0.07%), 0.13% (±0.16%), respectively. The Zeff from derived elemental composition was within 0.04 from the true values.

Conclusions

We have investigated a new approach to extract the atomic composition from DECT scans. The accuracy of the extraction was demonstrated for published tissue samples. This approach will be validated using the DECT scans of animal tissues and GEANT4 source model, by comparing the Zeff derived from this method against measurements from proton beam irradiations.

188 - Monte Carlo Simulation of “out-of-field” dose distributions in a pediatric phantom in External Radiotherapy – couch top impact

Presenter: Mr. GHAREEB, Firass (Instituto Português de Oncologia do Porto Francisco Gentil- EPE Research Center, Porto, Portugal)

Introduction

The scattered radiation from external devices in radiotherapy may cause altered dose distribution among other complications. Although some dose corrections are made for blocking trays, ion chambers, etc. the dose perturbation by the treatment couch top scatter is often overlooked.
This out-of-field scattered radiation may induce secondary cancer, especially in pediatric patients, due to biological and geometric factors. Since the out-of-field dosimetric accuracy of treatment planning systems (TPS) is known to decrease, and many of them do not provide the capability of implementing the actual treatment couch top, a PENELOPE based MC code named PRIMO was used to study the couch impact on the out-of-field dose estimation in pediatric irradiation.

Material and Methods
A treatment plan was designed within PRIMO for a hypothetical brain tumor, using two lateral and one cranio-caudal 6MV beam configuration. The plan was created on a CT dataset of 5-year anthropomorphic pediatric phantom. The original dataset was modified with MatlabTM to: keep the original HU values inside the body contour; introduce a real treatment couch HU values and; define the pixel values outside the body and couch as air. Two simulations were performed: with and without the presence of the treatment couch. The PRIMO output data for both simulations were reshaped, manipulated and written as two single multi-frames DICOM files. The dose distribution outside the body contour in both plans was eliminated, and both dose distributions inside the body along the axial plan were compared using 3D gamma function (2%, 2mm) on PTW-Verisoft.

Results

Within the treatment field, the results showed good agreement between the two dose distributions (over than 99% of points passed 3D gamma test), indicating that no significant attenuation occurred to the lateral beam crossing the treatment couch. The agreement decreased gradually far away from the isocenter to reach 93% at 20 cm away from isocenter, showing a cranio-caudal back-scattered contribution to dose from the treatment couch.

Conclusion

For out-of-field scattered dose estimation it is advisable to include the treatment couch in dose calculations.

189 - Uncertainty estimation of MC simulated mammography spectra

Presenter: Dr. COSTA, Paulo (Physics Institute of São Paulo University, Department of Nuclear Physics)

Novel breast dosimetry applications require the knowledge of incident X-ray spectra, in mammography energy range [1]. Furthermore, the knowledge of the spectra transmitted through breast tissue is important in the phantom development context.

A vast number of MC codes are used as models to generate diagnostic X-ray spectra; however, comparisons of those to experimentally measured X-ray spectra (validations) must be done to assure modeled spectra are representative of real X-ray beams. For these comparisons to be reliable, accurate uncertainty estimation of the counts in the spectra channels is required.

This work's objective was to accurately assess the uncertainties associated to the counts of incident and transmitted mammography MC modeled spectra.

In this work, the PENELOPE MC code was used to simulate a CdTe spectrometer's detection of mammography X-ray spectra, and the attenuation of these spectra after transmitted through commercial breast phantoms. Four anode-filter combinations, three commercial breast phantoms and several attenuation thicknesses were used. Altogether, 108 spectra were simulated. The measured spectra emitted by each X-ray generators were used as the MC simulations input spectra, after escape and efficiency distortion effects were corrected by the stripping method.

The uncertainty of the modeled spectra's channels was estimated through MC uncertainty propagation method. For each condition, 25 simulations were performed, varying the input parameters (input spectra and phantom composition) according to their probability density functions.

The simulated spectra validation was done through the assessment of the mean weighted squared residuals (MWSR). Except for model's inaccuracies, good estimation of the uncertainties yields a MWSR equal to 1, which is this quantity's expected value.

The mean of the 108 calculated MWSRs yielded 3.76(03) when only Poisson's uncertainty was used. Therefore, we conclude Poisson's uncertainty underestimates the uncertainty of the spectra channels' counts. The estimation we performed demonstrated better accuracy, it yielded a mean MWSR of 1.17(01).

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190 - Parametric evaluation of CT dose index (CTDIW) in head phantom using Gate Monte Carlo code

Presenter: Dr. SINA, Sedigheh (Radiation Research Center, Shiraz University)

Gate Monte Carlo code is an accurate, and fast simulation tool which has great advantage over other Monte Carlo codes like MCNP. The purpose of this study is parametric evaluation of computed tomography dose index (CTDI¬W) in head phantom. The variation of CTDIW versus kVp, mAs, and beam width was investigated in this study. The GE LightSpeed, 16-slice CT scan was simulated using GATE Monte Carlo code. The simulation was performed in 3 steps containing 1) CT scan geometry definition i.e. flat filter, bowtie filter, CT detectors, and dosimetry head phantom. 2) Definition of the source spectra, collimation of the source, and rotation of the beam. 3) Calculation of CTDI based on the simulation results in central and peripheral ion chambers, and the normalization factor for converting mAs to incident photon.

The results of the simulation were compared with the results of CT-Expo dosimetry software, to validate the calculations. The impact of different parameters like kVp, and mAs, and beam width on CTDIw was investigated. The results of this study indicate that the CTDI simulated for 80, 100, and 120 kVp, 100 mAs, and 10mm beam width, in central, and peripheral holes were similar to CT-Expo results, with less than 2% discrepancy. The variation of CTDI for different mAs, and beam width is less than 5%. The results indicate that our simulations, have enough accuracy in advance head CT dosimetry.

191 - Comparing the physical characteristics of intraoperative electron beam from circular and beam shaper applicators

Presenter: Mr. HEIDARLOO, Nematollah (Shahid Beheshti Uniersity)

Comparing the physical characteristics of intraoperative electron beam from circular and beam shaper applicators

Nematollah Heidarloo (1, *), Hamid Reza Baghani (1, 2) and Seyed Mahmoud Reza Aghamiri (1)

(1) Radiation Medicine Department, Shahid Beheshti University, Tehran, Iran
(2) Physics Department, Hakim Sabzevari University, Sabzevar, Iran
* Presenting author

Intraoperative electron radiation therapy (IOERT) is one of the specific procedures of radiation therapy that delivers high doses to tumor bed during surgery. Recently, some dedicated accelerators are introduced for IOERT implementation. LIAC is one of these specially designed accelerators which can be used in a standard operating room. Two types of applicators can be used with LIAC including standard applicator and beam shaper one. Standard applicators are cylindrical ones which can produce circular fields. Beam shaper applicator is a device that has the ability of producing various square and rectangular fields through some shielding blades located at the end of applicator. The aim of this study is to compare the physical characteristics of electron beam at the exit of standard and beam shaper applicator through Monte Carlo calculations.

The LIAC head in conjunction with the cylindrical and beam shaper applicator were simulated by MCNP Monte Carlo code. Then, the energy and angular distribution of electron beam at the exit of applicators understudy were calculated for different combinations of energy/field sizes. Finally, the physical characteristics of electron beam for both applicators including mean electron energy and mean scattering angle were derived and compared.

The results showed that with increasing the field size, the mean electron energy increases. Furthermore, with increasing the electron energy, the mean scattering angle of electron beam at the exit of both applicators understudy increments too. For standard applicators, with increasing the electron energy and field size, the mean electron energy ranges was 4.5 to 9.0 MeV and 6.6 to 7.4 MeV from 30 to 10 mm applicators at 10 MeV, respectively. Also, for beam shaper applicator, with increasing the electron energy and field size, the mean electron energy ranges was 4.5 to 8.3 MeV and 6.6 to 8.1 MeV from 3×3 to 9×9 cm2 field sizes at 10 MeV, respectively.

Based on the obtained results, it can be concluded that the physical characteristics of beam shaper applicator are a little different from those of standard applicators which can be attributed to the presence of shielding blades in design of beam shaper applicator.

192 - On the accuracy of TG-43 algorithm in dosimetry of breast accuboost brachytherapy

Presenter: Dr. FAGHIHI, Reza (Shiraz University)

Purpose: Long period treatments in teletherapy are not suitable for old and working patients, and those living far from the clinics. APBI with HDR brachytherapy has been a suitable alternative for these patients because of its limited number of fractions. The objective of this study is To evaluate the effects of breast phantom material composition on dose distribution caused by SAVI-brachytherapy using MCNP5.

Methods: Round accuboost applicators containing 16 Ir-192 sources were simulated besides a cubical breast phantom. To score the dose distribution, the breast phantoms were divided in small cubical cells. The dose distribution inside nine different breast phantoms containing different materials i.e. fat, gland, ICRU-44 breast, and normal breast tissue (as suggested in TG-186), was compared with water phantom (as suggested by TG-43). The dose distribution in these phantoms were also compared with water phantom.

According to the results of the simulations, the percentage difference between the dose in water(TG-43), and the dose in other phantoms are much less than 5% in different points of the phantom.

The results indicate that TG-43-based Treatment planning systems performing their calculations in water phantom, can be used without significant errors relative to model-based TPSs.

193 - Evaluation of doses in healthy organs due to radiotherapy treatment for lung cancer, through computational modeling.

Presenter: Dr. THALHOFER, JARDEL (UNIVERSIDADE FEDERAL DO RIO DE JANEIRO)

According to the International Agency for Research on Cancer (IARC), the number of cancer cases will continue to rise in the world [1]. In Brazil, the National Cancer Institute (INCA) has published estimates of the incidence of cancers in Brazil (2016-2017) indicating lung cancer among the leading in number incidence and lethality [2]. Dosimetry analysis of healthy organs under real conditions is not feasible. Therefore, computational simulations are used to auxiliary in dose verification in organs of patients submitted to radiotherapy. The goal of this study is to calculate the equivalent dose, due to photons and neutrons, in surrounding in healthy organs of a patient submitted to radiotherapy for lung cancer, through computational modeling. The simulation was performed using the MCNPX code [3], treatment protocol adopted at the INCA, Rex and Regina phantom (ICRP 110) [4], radiotherapy room, Varian 2300 linear accelerator operating at 18MV. The results obtained, considering the dose due to photons for both phantom indicate that organs located inside the thoracic cavity received higher dose, being the bronchi, heart and esophagus more affected, due to the anatomical positioning. Clinical data describe the development of bronchiolitis, esophagitis, cardiomyopathies with decreased cardiopulmonary function as one of the major effects of lung cancer treatment. In the Regina phantom, the second largest dose was in the region of the breasts with 568.49 mSv / Gy, while in the Rex 374.58 mSv / Gy, event related to the difference of anatomical structure of the organ. Results obtained from the doses due to neutrons show breasts and thymus as the highest doses, but there is a significant difference in dose values, breasts 68.75 mSv / Gy (Regina) and 3.87 mSv / Gy (Rex). In the thymus the values are close, 2.49 and 1.97 mSv / Gy respectively Regina and Rex. The contribution of equivalent dose due to neutrons was superior to the photons in organs located more at the extremities of the body, bladder and testes in the Rex, only in the bladder in the Regina. We conclude that the dose due to neutrons can’t be neglected and will significantly influence the effective dose calculation.

194 - Validation of GPUMCD for X-ray medical imaging

Presenter: Ms. SAUCIER, Marie Annie (Université Laval, Département de physique, de génie physique et d’optique and Cancer Research Centre, Québec, Canada)

GPUMCD, a fast GPU-based Monte Carlo transport code, was initially developed and validated for photon and electron dose calculations in radiation oncology. In this work, the code was adapted to X-ray medical imaging applications, notably to simulate Cone-Beam Computed Tomography (CBCT) projections.

The photon interaction processes in GPUMCD, initially validated for the therapeutic (megavoltage) energy range, were revisited with imaging and therefore lower energies in mind. Comparisons with physics models available in Geant4 were conducted for the photoelectric effect, Compton and Rayleigh scattering. For Compton scattering, four Geant4 models were used: two from the Geant4 standard physics (G4KleinNishinaModel and G4KleinNishinaCompton), one from Livermore physics (G4LivermoreComptonModel) and one from Penelope physics (G4PenelopeCompton). Three out of the four models consider atomic shells and the energy of the recoil electron. This correction is not considered in G4KleinNishinaCompton and GPUMCD. Tracking of electron was turned off in GPUMCD and Geant4.

The photoelectric and Rayleigh scattering algorithms yielded consistent results in GPUMCD and Geant4. However, significant differences were identified between GPUMCD and Geant4 for Compton scattering. More specifically, differences of up to 15% in energy fluence in simulated projections were observed between simulations with and without atomic shell corrections, consistent with the known overestimation of forward scatter in the plain Klein-Nishina model. Implementing shell correction in GPUMCD would significantly increase computation times but appears necessary for imaging applications.

195 - A fast Cone-Beam CT scatter correction method with Monte Carlo simulation using GPUMCD

Presenter: Ms. SAUCIER, Marie Annie (Universite Laval)

GPUMCD, a fast GPU-based Monte Carlo transport code, was initially developed and validated for photon and electron dose calculations in radiation oncology. In this work, the code was adapted to rapidly simulate realistic X-ray Cone-Beam Computed Tomography (CBCT) projections, and in particular to estimate the scatter component of the signal. This estimate is thereafter filtered and used for scatter correction, which is especially important in a CBCT geometry.

The signal generated by scattered photons on a 1028x768 detector was estimated with GPUMCD. The simulation geometry was derived from actual CBCT reconstructions (pelvis, thorax), with density and materials assigned to each voxel with a HU-electronic density calibration curve. Simulations were conducted on a NVIDIA GTX970m GPU with either 107 or 109 photons per projection. Recursive Gaussian filtering in projections with 107 photons was performed to assess the potential of faster simulations conducted with fewer photons. A simple Gaussian filter was used for the projection of 109 photons. The primary signal was obtained with deterministic ray-tracing, and normalized by the primary signal computed derived from the Monte Carlo simulation.

Simulated projections with 107 photons were obtained in 3.5 s while the primary signal estimation took 0.2s. Recursive Gaussian filtering of projections was shown to be an effective way to reduce the simulation time by a factor 100 and preserve more complex scatter patterns. The simulation times reported here let envision a Monte Carlo-based scatter correction strategies in CBCT reconstruction.

196 - Relation between dose average linear energy transfer and dose-mean lineal energy calculated for proton therapy beams off axis: A study with the Geant4 toolkit.

Presenter: Ms. BARATTO ROLDÁN, Anna (Universidad de Sevilla)

In a previous work we compared various methods to score, in a voxelized geometry, dose average linear energy transfer (LETd) distributions produced by proton therapy beams in water [1]. In that work, in order to determine which method provided more reliable results, we resorted to numerical stability analysis, against changes of geometry and production cuts, and to comparisons against LETd values obtained from microdosimetry calculations according to a formula proposed in [2]. Our simulations, with which we could come up with a robust LETd computation method in good agreement with microdosimetry calculations, were done with the Geant4 toolkit [3-5] at central axis and for primary protons only.
The aim of this work is to further prove the validity of the method, extending the calculation to off-axis voxels and including the contribution of secondary protons. With this purpose, we compared LETd distributions (2D) calculated for clinical proton beams with those computed from microdosimetry spectra obtained for sites of various sizes, whose typical dimension ranged from 0.25 to 10 microns. The microdosimetry calculations were done with the Geant4-DNA physics package, that simulates step by step interactions of particles in liquid water down to the eV scale [6, 7].
Our preliminary results confirmed the overall validity of the method at increasing off-axis distances. However, we could also find a significant dependence on the site size of the deviations reported between our “macroscopic” LETd values and those obtained from microdosimetry calculations.

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197 - Monte Carlo simulations of x-ray grating interferometry based imaging systems

Presenter: Mr. TESSARINI, Stefan (Institute for Biomedical Engineering, ETH Zürich, Zürich, Switzerland; Swiss Light Source, Paul Scherrer Institut, Villigen, Switzerland)

Over the last couple of years the implementation of Monte Carlo (MC) methods of grating based imaging techniques is of increasing interest. Several different approaches were taken to include coherent effects into MC in order to simulate the radiation transport of the image forming procedure. These include full MC using FLUKA [1], which however are only considering monochromatic sources. Alternatively, ray-tracing based MC [2] allow fast simulations with the limitation to provide only qualitative results, i.e. this technique is not suitable for dose calculation in the imaged object. Finally, hybrid models [3] were used allowing quantitative results in reasonable computation time, however only two-dimensional implementations are available. Thus, this work aims to develop a full MC framework for X-ray grating interferometry imaging systems using polychromatic sources suitable for large-scale samples. For this purpose the EGSnrc C++ MC code system is extended to take Snell's law, the optical path length and Huygens principle into account. Thereby the EGSnrc library was modified, e.g. the complex index of refraction was assigned to each region depending on the material. The framework is setup to be user-friendly and robust with respect to future updates of the EGSnrc package. These implementations have to be tested using dedicated academic situations. Next steps include the validation by comparisons of measurements for different setups with the corresponding MC simulations. Furthermore, the newly developed implementation will be compared with other simulation approaches. This framework will then serve as bases for dose calculation on CT data and has further potential to investigate the image formation process in grating based imaging systems.

198 - Monte Carlo and Analytical Simulations of Dose Distribution in Synchrotron Radiation Rotational Radiotherapy of Breast Cancer: an Experimental Phantom Study

Presenter: DI LILLO, Francesca (NA)

External beam rotational radiotherapy of breast cancer with kilovoltage photons (kV-EBRT), with the patient in prone position, has been proposed [1] as a possible alternative to conventional radiotherapy with two tangential 6-MV X-ray beams produced by a medical linac with a supine patient. kV-EBRT uses a dedicated setup initially developed for breast CT, with a 320-kVp beam from an orthovoltage X-ray tube rotating in full circles around the breast; CT for tumour localization can be performed by using the same setup. Though dose build-up is not present, rotational summation of dose delivery allows a skin sparing comparable to conventional radiotherapy.
We proposed to use of a monoenergetic synchrotron radiation (SR) collimated beam for image-guided rotational radiotherapy for the pendant breast (SR3T) [2]. The high-flux of SR permits dose rates even greater to that of conventional radiotherapy, while the optimal photon energy can be selected for the treatment.
In this work, we present Monte Carlo (MC) and analytical simulations for evaluation of the 3D dose distribution in SR3T. The MC code was based on GEANT4 toolkit ver.10.00. We validated these simulations via measurements on breast phantoms performed at the Imaging and Medical Beamline of the Australian Synchrotron. We measured the dose distribution in cylindrical PMMA and polyethylene phantoms at 60 keV, using an ionization chamber, thermoluminescent dosimeters and radiochromic films. This study indicated that for a tumour localized at the centre of a mid-sized breast (14-cm diameter at chest wall), a "skin-to-tumour" dose ratio of 14% can be reached at 60 keV with a collimated SR beam. Non uniform dose distribution to the target (dose painting) can be performed with multiple rotations around the organ. Kilovoltage SR3T with suitable radiosensitizers may exploit the dose enhancement factor due to increased photoelectric absorption, at SR beam energies in the 60-110 keV range.

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199 - Monte Carlo Evaluation of Normalized Glandular Dose Coefficients in Mammography

Presenter: METTIVIER, Giovanni (NA)

This work aimed at calculating the complete set of monoenergetic (DgN) and polyenergetic (DgNp) normalized glandular dose coefficients for mean glandular dose estimate in mammography. We have developed a Monte Carlo code based on GEANT4 toolkit, for DgN calculation, which relies on the standard physics list Option4. Influence of the breast model, the compression paddle and the bremsstrahlung process on DgN and DgNp normalized glandular dose coefficients in mammography was studied. Breast skin thickness was varied in the range 1.45■5 mm. It was modeled both as an adipose skin layer (5 mm thick - as in EU protocols for mammography) and as a real skin composition (as adopted in USA protocols).
Significant differences in the calculated DgN have been observed when 1.45 mm skin thickness is adopted. At 15 keV a skin thickness of 4 mm produces values up to 25% or 20% lower than in the model adopted in the USA or EU protocol, respectively. The discrepancy reduces for higher energies. For routinely used mammographic spectra, a skin thickness of 4 mm produces DgNp values up to 32% lower than those with a breast model with 1.45 mm thickness. The bremsstrahlung processes in the breast tissue had small influence on DgN coefficients. Finally, based on the model consideration, DgNp coefficients for spectra used in mammography were provided and compared with those routinely adopted, based on USA and EU protocols.

200 - Evaluation of key parameters for non-small cell lung cancer treatments using Geant4 as benchmark dose calculation algorithm

Presenter: Mr. PERALES MOLINA, Álvaro (Universidad de Sevilla)

Significant variations in tumor control probability (TCP) have been reported according to differences found at dose calculations between treatment planning system (TPS) and Monte Carlo (MC) method[1].

Our purpose is to quantify dosimetric and radiobiological effects due to divergences between dose distributions calculated by Pinnacle³ TPS (version 9.8) and Geant4 toolkit (version 10.01.p01)[2,3] for lung cancer cases treated with photons.

Three clinical cases with 6 MV photon beams and conventional fractionation were analysed. These cases are distinguished by their tumoral size and localization. From dose distributions calculated through Geant4 and TPS we have obtained conformity index (CI) and homogeneity index (HI)[4]. The TCP was achieved using LQ model[5] with an alpha-beta ratio of 10 Gy and a density of clonogenic cells of 10■ cells/cm³.

For each clinical case the TCP values according to Geant4 calculations against Pinnacle calculations were 93.77 vs 97.74, 92.95 vs 92.79 and 98.31 vs 99.03 respectively. These deviations achieve a maximum value close to 4% and they are in agreement with the CI and HI values obtained in every single treatment.

We have verified lung cancer treatments through Geant4 toolkit and we have found more heterogeneous dose distributions and variations in TCP up to 4% with respect to TPS calculations. These discrepancies are due to incomplete modeling in the TPS algorithm of patient tissue heterogeneities and photon fluences used in modulated beam techniques. A further study including more sophisticated radiobiology models and hypofractionated radiotherapy schemes will be subject of further work.

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201 - Code sharing of MC beam models for advanced radiotherapy.

Presenter: Dr. PRICE, Tony (University of Birmingham)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

Code sharing of MC beam models for advanced radiotherapy.

Tony Price (1,*), Andrea Gutierrez (2), Costanza Panaino (3), Martin Turner (4), and Hywel Owen (5)
(1) University of Birmingham, School of Physics and Astronomy, Birmingham, United Kingdom
(2) University College London, Department of Medical Physics and Biomedical Engineering, London, United Kingdom
(3) University of Manchester, Division of Molecular and Clinical Cancer Sciences, Faculty of Biology, Medicine and Health, United Kingdom
(4) Scientific Computing Department, STFC, United Kingdom
(5) University of Manchester, School of Physics and Astronomy, Manchester, United Kingdom
*presenting author

The development and validation of a beam line MC model is an essential part of many projects, particularly those involving particle therapy. This is often a very time consuming and sometimes costly computational process. However, many experiments use the same beam lines and the medical physics community would benefit greatly from a structured code and data sharing site. A new project [1], funded through the STFC Global Challenge Network+ in Advanced Radiotherapy [2], aims to collate, host, validate experimentally, and disseminate common Geant4 beam line models. We will present an overview of the aims of the project, and details of how to gain access to these structured models; a structured model includes both code and data with related information on use and best practice. To illustrate this, three validation results will be shown; the iThemba LABS proton therapy centre in Cape Town (South Africa), the medical beam line of the University of Birmingham MC40 Cyclotron (United Kingdom), and ongoing work with multiple models of the Clatterbridge Cancer Centre proton eye therapy beam line (United Kingdom). We aim to develop these models in TOPAS/GATE to facilitate their use for non Geant4/C++ experts, for example, medical physicists working in hospitals. A status report of this final step will be provided.
[1] https://trello.com/b/paBx8sJZ/shared-data
[2] https://www.advanced-radiotherapy.ac.uk

203 - Breast Model Validation for Monte Carlo Evaluation of Normalized Glandular Dose Coefficients in Mammography

Presenter: SARNO, Antonio (NA)

In Monte Carlo simulations for estimation of normalized glandular dose coefficients (i.e. the ratio between the mean glandular dose (MGD) and incident air kerma at the breast upper surface), the radiosensitive breast tissue is modelled as a homogeneous mixture of adipose and glandular tissue. However, such an assumption has been shown to lead to an overestimation in MGD by an average of 30% [1,2]. This work aimed at comparing the homogeneous breast models proposed by different authors and in different quality assurance protocols to patient specific breast phantoms. To obtain these phantoms, uncompressed breast images were acquired with a CT scanner dedicated to the breast and segmented to classify each voxel into 4 categories: air, skin tissue, adipose tissue and glandular tissue. Then the compression which breasts undergo during a mammography exams was simulated via software in order to obtain 3D compressed patient specific breast phantoms which present an heterogeneous glandular distribution similar to that of the irradiated breast. The homogeneous breast phantom was simulated either with a 4-mm skin thickness (as adopted in the USA protocol), or with a 5-mm adipose layer simulating the skin and the subcutaneous adipose layer (as adopted in the EU protocol) or with a skin thickness of 1.45 mm (i.e. the skin thickness estimated from 3D breast images). A pre-validated Monte Carlo code based on GEANT4 toolkit ver. 10.00 [3] was employed to calculate the dose differences between the standard models and the patient specific breast phantom. This study provided an insight into possible bias of the standard models for breast dosimetry and an indication of new breast model for future normalized glandular dose calculations.

[1] I. Sechopoulos et al. Characterization of the homogeneous tissue mixture approximation in breast imaging dosimetry. Med. Phys. 39 5050–5059 (2012).
[2] A. Hernandez et al. Breast dose in mammography is about 30% lower when realistic heterogeneous glandular distributions are considered. Med. Phys. 42 6337–6348 (2015).
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205 - Monte Carlo Evaluation of Dose Perturbations in Intravascular Brachytherapy

Presenter: Mr. DECUNHA, Joseph (McGill University Medical Physics Unit)

Purpose: Intravascular Brachytherapy (IVBT) is a form of radiotherapy used to prevent the re-closure (restenosis) of arteries after a stent is inserted. Rapidly proliferating neointimal tissue is a frequently observed effect after stent implantation. IVBT can be used to destroy this neointimal tissue and keep the artery free of occlusions.

Treatment planning in IVBT is extremely limited owing partially to the small size of the vessels treated and the lack of available imaging modalities. For this reason only the diameter of the treated artery is used in treatment planning and determination of dwell time. Heterogenities such as plaque, stent struts, and the presence of a guidewire are all known to cause dose reductions in IVBT. Other than the labour intensive process of harvesting human artery samples or of constructing minuscule artificial phantoms the only other possibility to determine an accurate dose to target in the presence of inhomogenities is to employ a Monte Carlo based approach.

Methods: Geant4, a Monte Carlo particle simulation and the PENELOPE physics package was used to determine the dose of radiation delivered around two commercially developed IVBT devices, the Novoste Beta Cath 3.5F and Guidant Galileo (Sr-90/Y-90, and P-32 active cores respectively) and one proposed device. Dose was calculated in water, in water with a guidewire present, and in a model of a human coronary artery with a calcified plaque, stent, and guidewire present.

Results: In water, the Monte Carlo dose profiles around both commercial devices are in agreement with TG-60 consensus data. By a guidewire alone, dose is reduced by 48% at a distance of 2 mm from the Beta-Cath device. At the same distance, behind a plaque, stent, and guidewire dose is reduced by 62% for the Novoste Beta-Cath and 66% for the Guidant Galileo. The proposed device shows no dose reduction effect due to the presence of a guidewire.

Conclusions: In the absence of patient images Monte Carlo techniques can be applied to estimate the degree of dose reductions from inhomogenities in IVBT. Conventional treatment planning methods in IVBT are inaccurate when inhomogenities are present at the treatment site.

206 - Comparison of constant RBE dose calculation and a novel biological dose calculation model, photon iso-effective dose formalism, for predicting complication probabilities in boron neutron capture therapy (BNCT) of head and neck cancer patients

Presenter: Dr. KOIVUNORO, Hanna (Neutron Therapeutics)

In boron neutron capture therapy (BNCT), radiation dose to patient consists of four main dose components. Conventionally, the biologically effective dose has been derived multiplying each dose component by a constant relative biological effectiveness (RBE) factor, or (boron) compound biological effectiveness (CBE) factor [1]. Fixed RBE and CBE factors are applied, although they depend on the cumulative irradiation time as well as end point, cell type and dose given per fraction, and thus should be derived for each irradiation condition individually.
An alternative biological dose calculation method, photon iso-effective dose formalism, has been proposed for BNCT [2]. The model takes into account dose rate and cumulative dose per fraction using first-order repair of sub-lethal lesions in the modified linear-quadratic model and considers synergistic interactions between low-LET and high-LET radiation. Recently the formalism was extended, defining the photon iso-effective dose as the dose that produces the same tumor control or normal tissue complication rates as a given combination of the absorbed dose components of BNCT.
We applied the extended photon iso-effective dose formalism to calculate the mucosa and the tumor doses for patients with recurrent HN carcinoma, who were treated with BNCT in Finland [3]. The biological doses were used to determine Tumor Control Probability (TCP) and the Normal Tissue Complication Probability (NTCP) for mucosal membrane. Grade 3 mucositis was observed in 8/30 patients. The maximum absorbed dose to mucosal membrane was 3–6 Gy, which correspond to RBE doses of 8–14 Gy-Eq predicting grade 3 mocositis for 0.03 out of 30 patients. The photon iso–effective doses were 12–18 Gy-IsoE predicting grade 3 mucositis for 7 out of 30 patients. For tumor, the photon iso–effective doses were lower than the RBE doses.
Observed clinical outcomes suggest that photon iso–effective dose model may predict mucosal membrane toxicity and tumor control in BNCT more reliably than the traditional RBE dose calculation. Evaluation in a larger patient series is needed to verify these findings.

[1] Coderre et al. IJROBP 27, 1993
[2] González and Santa Cruz, Rad Res. 178, 2012
[3] Kankaanranta et al., IJROBP 82, 2012

208 - Study of sensibility for a new gamma-MRI compatible detector using Monte Carlo simulations

Presenter: Ms. ABRIL, Andrea (Universidad Nacional de Colombia); Prof. AGULLES PEDRÓS, luis (Universidad Nacional de Colombia)

Up today, hybrid nuclear medicine image systems integrate two techniques: X-ray based or MRI for anatomic images and PET for the functional ones [1]. These systems need instrumentation susceptible to be interfered and to interfere with the MRI signal during the photon-charges conversion process in the photomultiplier.
We propose a hybrid system whose main characteristic is that the gamma image is obtained by MRI [2,3] (patent pending). The detector is based on a radiosensitive gel whose absorbed radiation produces chemical changes. These changes are linearly dependent on T2 relaxation time [4].
We explore the capabilities of the gamma detector gel to be used as a hybrid image technique by GEANT4 Monte Carlo simulations of the radiation process and statistical noise on radiation MRI images.
We will present in this work the preliminary designs using two different collimators, comparing the limits and optimal conditions of sensibility as a function of the absorbed dose and SNR in the MRI.
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[1] Andrew B. Rosenkrantz, Kent Friedman, Hersh Chandarana, et al. Current Status of Hybrid PET/MRI in Oncologic Imaging American Journal of Roentgenology. 2016;206: pp 162-172.
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209 - SMALL FIELD OUTPUT FACTORS FOR A LINAC WITH CIRCULAR CONES USING DIFFERENT DOSIMETERS AND MONTE CARLO SIMULATION

Presenter: Dr. FIANDRA, Christian (University of Torino, Department of Oncology, Radiation Oncology Unit, Turin, Italy)

The aim of this work was to determine small field output factors (OFs) with Monte Carlo simulation method compared with several active detectors and one passive dosimeter for an Elekta Axesse linac equipped with an Elekta set of circular cones. The dose response of detectors was investigated for diameter of circular field ranging from 5 mm to 30 mm (5, 7.5, 10, 15, 20, 25 and 30 mm). The 30 mm cone was taken as machine-specific reference field.
The head of the LINAC Elekta Axesse was modelled using GamBet (gamma and beta particles) software suite to simulate the transport of energetic electrons, photons and positrons through matter over the energy range from 50 eV to 1 GeV.
The Penelope routines perform the Monte Carlo tasks in GamBet: generation of atomic cross sections, prediction of single-particle interactions with matter and the creation of secondary particles.
Four types of active commercial detectors dedicated to dose measurements in small beams were used in this study: three micro ionization chambers (Exradin A16, Exradin A26 and PTW 31018 microLion liquid chamber), a high resolution diodes (IBA RAZOR), a plastic scintillator detector (Exradin W1) and one synthetic microdiamond (PTW 60019 microDiamond). Gafchromic EBT3 films were selected as passive dosimeter.
Measured and calculated Output Factors were reported in the table below.

	5	7.5	10	15	20	25	30
Gafchromic EBT3	0.648±0.016	0.720±0.004	0.801±0.009	0.912±0.017	0.957±0.011	0.982±0.016	1.000
Exradin A16	0.563±0.002	0.691±0.002	0.784±0.001	0.897±0.001	0.947±0.001	0.981±0.002	1.000
Exradin A26	0.622±0.001	0.708±0.001	0.793±0.001	0.899±0.001	0.949±0.001	0.980±0.001	1.000
PTW microLion	0.659±0.002	0.733±0.002	0.815±0.002	0.910±0.001	0.954±0.002	0.983±0.002	1.000
PTW microDiamond	0.687±0.001	0.759±0.003	0.828±0.001	0.915±0.001	0.956±0.002	0.983±0.002	1.000
Exradin W1	0.643±0.004	0.719±0.004	0.808±0.004	0.913±0.004	0.959±0.004	0.982±0.007	1.000
IBA RAZOR	0.683±0.001	0.749±0.001	0.815±0.001	0.905±0.001	0.950±0.001	0.982±0.001	1.000
Monte Carlo	0.647 ± 0.040	0.740 ± 0.037	0.814 ± 0.035	0.893 ± 0.024	0.940 ± 0.029	0.979 ± 0.025	1.000

Next step of this work will be the determination of each correction factor for the active detectors in comparison both with Monte Carlo and films measurements following the formalism of Alonso et al; however analyzing table 1 it’s easy to understand the importance of applying the appropriate correction factors in order to provide accurate measurements in small beam geometry, especially for field diameter smaller than 10 mm.

[1] Francesc Salvat, Jos M. Fernndez-Varea, and Josep Sempau, PENELOPE-2006: A Code System for Monte Carlo Simulation of Electron and Photon Transport,(Proceedings of a Workshop/Training Course, July 4-7, 2006), NEA Number 6222).
[2] R. Alfonso, P. Andreo, R. Capote et al. “A new formalism for reference dosimetry of small and nonstandard fields,” Med. Phys. (2008) 35, 5179–5186

210 - Using Monte Carlo simulation as an experimental tool for training of medical physicists in a diagnostic radiological physics residency program

Presenter: Prof. FREITAS, Marcelo (UNIFESP - Federal University of Sao Paulo)

The usefulness of Monte Carlo for solving problems in radiation transport has allowed many applications in the medical physics field. Particularly as a teaching aid, Monte Carlo can be used to demonstrate previously the effects of the interaction of radiation with matter, which can be switched on and off to observe its influence under different conditions of irradiation and geometry. Based on that, this study reports an experience with using of Monte Carlo simulation for training of medical physicists during a program residency in diagnostic radiological physics. The approach was implemented in the EGSnrc Monte Carlo code system [1] to an understanding of the factors affecting quality image and to reduction of patient exposure in radiographic examinations performed in various areas of diagnostic radiology. All simulation conditions were based on the cases provided by the Report of AAPM Task Group 195 [2]. Physical characteristics of primary and scattered x-ray spectra, quantities as radiation dose and contrast-to-noise ratio of imaging systems, among others, could be studied under different radiological conditions by changing the input parameters in the simulation. Results obtained with this approach facilitate resident´s experimental learning curve, contributing to anticipate the discussion about practical problems that would be found in clinical environment. The use of Monte Carlo simulations with educational purposes demonstrated be an efficient and flexible tool for training of medical physicists in a residency program.

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211 - A new tissue-equivalent material applied to radiotherapy treatment: a feasibilty study

Presenter: Dr. ALJAMAL, Mohammad (Arab American University)

The aim of this project is to evaluate the feasibility of using olive wood as tissue-equivalent material instead of Perspex material for radiotherapy dose verification.The mass density of olive wood was determined based on Archimedes' principle.Monte Carlo simulation was also carried out to calculate percentage depth dose (PDD) and beam profiles in the simulated olive wood phantom to verify the data with that calculated using simulated water phantom for the same field size.It was found that the mass density of olive wood was 1024 kg m–3, which is very close to mass density of water and Perspex.The PDD and beam profile calculated using simulated olive wood phantom agreed very well with that calculated using simulated water phantom. In conclusion, the results showed that the olive wood material is water-equivalent material based on density measurement and montecarlo simulation calculation and it could be used as phantom materials for radiotherapy dose verification instead Perspex phantom.

213 - Monte-Carlo based CT Simulation of Virtual Patient Geometries

Presenter: Mr. KIRCHHOF, Simon (Division of Medical Physics in Radiation Oncology, German Cancer Research Center (DKFZ), Heidelberg, Germany; National Center for Radiation Research in Oncology (NCRO), Heidelberg Institute for Radiation Oncology (HIRO), Heidelberg, Germany.)

International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017

Monte-Carlo based CT Simulation of Virtual Patient Geometries

Simon Kirchhof (1,2,*), Kristina Giske (1,2) and Lucas Burigo (1,2)
(1) Division of Medical Physics in Radiation Oncology, German Cancer Research Center (DKFZ), Heidelberg, Germany
(2) National Center for Radiation Research in Oncology (NCRO), Heidelberg Institute for Radiation Oncology (HIRO), Heidelberg, Germany
*presenting author

Modern image guided radiotherapy may feature various types of integrated imaging modalities, such as optical surface imaging, fluoroscopy, CBCT or MRI. As a concept of merging information from these imaging modalities, the use of an in-silico bio-mechanically regularized and multi-parametric patient avatar for the head and neck region is currently developed in our group. As the capability of in-silico patient models in estimating anatomical changes increases, we investigate the possibility of generating artifact-free, high-statistics pseudo-CT images from in-silico patient models. From a multi-parametric patient avatar we create a virtual patient geometry, i.e. a hierarchy of nested tessellated volumes with distinct materials. Using GATE [1], a Geant4 [2] based Monte-Carlo application, we have set up a dedicated simulation of a CBCT. It consists of a point-source and a flat detector panel rotating around the virtual patient geometry. The virtual patient geometry is made available to the simulation using a custom extension to GATE, which allows for importing geometries from GDML [3] files. Generated projection stacks are reconstructed using the algorithm from Feldkamp, David and Kress [4].
The validation of our workflow for generation of pseudo-CT images of simple phantoms and patient-like geometries will be presented, both for monoenergetic and realistic source spectra. As a byproduct, the capability of GATE/Geant4 to simulate CBCT images of complex hierarchic tessellated geometries can be assessed. Possible future applications of our pseudo-CT generation will be discussed. For example: Dose calculation in solely MR-guided radiotherapy; An alternative approach to deformable image registration, when combined with a bio-mechanical model of patient movement.

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215 - MC dose calculation and treatment planning for intensity modulated brachytherapy

Presenter: Dr. RENAUD, Marc-Andre () McGill University, Medical Physics Unit, Montreal, Canada)

Intensity modulated brachytherapy (IMBT) is an application of high dose rate (HDR) brachytherapy where anisotropic dose distributions can be produced at every source position by incorporation of partially-shielded brachytherapy sources. IMBT dynamically directs the radiation into the tumours and away from healthy tissues. Accurately simulating dose distributions with high Z shields can pose problems for analytical dose calculation methods, therefore we investigate a Monte Carlo (MC) approach to address the issues of simulation accuracy. In addition, due to the added variable of shield emission angle, inverse optimisation of IMBT treatment plans involves simultaneously identifying both high quality dwell positions and shield angles (DPSA). The performance of the column generation method applied to IMBT will be evaluated.

A Geant4-based MC engine, BrachySource, was created for the purpose of IMBT dose calculations. The physical dimensions and material compositions of radiation sources are fully modelled based on published data. Radiation shields can be attached to sources and their emission angle can be varied during simulations. Basic validation of TG-43 parameters for the microSelectron-v2 source was performed by comparing BrachySource-calculated radial and anisotropy functions to BrachyDose [1]. BrachySource was coupled with a column-generation-based optimizer to identify high quality DPSAs and optimise their dwell times by repeatedly solving a “pricing problem” to iteratively determine the most effective DPSAs to add to the treatment plan. Original dwell positions used in a conventional HDR prostate interstitial plan were recycled and DPSA dose distributions were created for 16 shield emission window angles per dwell position.

The radial dose and anisotropy functions for the microSelectron-v2 Ir-192 source agreed with BrachyDose within 0.5%. The RSBT plan resulted in a considerable reduction in both rectum and bladder doses without sacrificing target coverage for the prostate case. With 95% of the PTV volume receiving over 15 Gy, only 40% of the rectum volume received more than 2 Gy for the Gd-153 RSBT case, as opposed to 85% for the unshielded Ir-192 conventional plan.

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217 - Consistency of the atomic relaxation algorithm and new photo-electric cross section in EGSnrc

Presenter: Dr. MAINEGRA-HING, Ernesto (National Research Council, Measurement Science and Standards, Ottawa, Canada)

A consolidation of the atomic shell ionization energies in EGSnrc is part of an effort to implement shell-wise photoelectric cross section in EGSnrc allowing a more detailed simulation of this process. The initial implementation of a detailed atomic relaxation in EGSnrc makes use of the EADL library. The binding energies in this library are slightly different from the binding energies used for the simulation of bound Compton scattering, electron impact ionization and photoelectric absorption taken from the XCOM library. This introduces an inconsistency in the energy transmitted to relaxation particles causing an energy conservation violation of about 0.3% for a 1 MeV photon beam in an infinite medium of Z = 99. Another issue is that the x-ray lines will correspond to the EADL radiative transitions regardless of the selection of the photon cross sections. To address these issues, EGSnrc has been modified to make use of a unique set of binding energies depending on the user’s selection of photon cross sections. At the same time, several corrections and modifications have been introduced which resolve the energy conservation violation and make the x-ray lines correspond to the radiative transitions expected from the photon cross section compilation used. The effect of using recent photo-electric cross sections [1] on HVL and attenuation curves is studied by comparing with experimental values.

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218 - Charged particle fluence calculations with EGSnrc

Presenter: Dr. MAINEGRA-HING, Ernesto (National Research Council of Canada)

FLURZnrc is EGSnrc's workhorse for fluence calculations for photons as well as for electrons and positrons. However, it is limited to cylindrical geometries, and cannot be used with egs++ geometries as it is written in Mortran. To overcome this limitation, cavity, a C++ application has been modified to directly calculate charged particle fluence in the cavity regions for arbitrary geometries using stopping powers. This method is more accurate than the one used in FLURZnrc as it does not assume constancy of the stopping power along the charged particle's path. A FLURZ-like algorithm is also implemented in cavity for validation. Comparison of the electron fluence calculated for 1.25 MeV photons and 5 MeV electrons shows excellent agreement between both codes when using the same method and uncovers an artifact in FLURZnrc for low-energy bins which is sensitive to the choice of the particle's step size and the transport and particle creation thresholds. As a result, EGSnrc now offers the possibility to calculate charged particle fluence in arbitrary geometries using a more accurate approach.

219 - Modeling of inelastic collisions of charged particles in condensed matter

Presenter: Dr. SALVAT, Francesc (International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017), Napoli, Italy, October 15th-18th 2017 Modeling of inelastic collisions of charged particles in condensed matter Francesc Salvat Facultat de Física (FQA and ICC), Universitat de Barcelona, Barcelona, Spain)

The theory of inelastic collisions of charged particles in matter is based on the first-order plane-wave Born approximation (PWBA), which
provides a realistic description of the process for projectiles with sufficiently high energies [1]. The differential cross section resulting from the PWBA is expressed as the product of kinematical factors and the generalized oscillator strength (GOS), a function of the energy loss and the momentum transfer that completely characterizes the response of the material. An important result from the theory is the venerable Bethe formula for the stopping power, which is derived by considering general features of the GOS and the Bethe sum rule. An alternative approach is provided by the semi-classical dielectric theory [2], in which the medium is characterized by its dielectric function, depending on the frequency and wave number of the electromagnetic disturbance, and the stopping power is obtained as the force on the projectile caused by the electric field induced in the medium by the projectile charge. The two theories are found to be equivalent (i.e., they give the same stopping power) and a simple relation between the GOS and the dielectric function is obtained. I will briefly describe the calculation of realistic GOSs for atoms [3] and a semi-empirical procedure to "build" the GOS for condensed materials from knowledge of the optical dielectric function[4]. I will use these GOS models to analyze the validity of the Bethe formula, and to discuss the importance and reliability of various corrections to the PWBA.

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[2] J. Lindhard, Dan. Mat. Fys. Medd. 28 (1954) 1–57.
[3] D. Bote and F. Salvat, Phys. Rev. A 77 (2008) 042701(1-24).
[4] J.M. Fernandez-Varea et al., Nucl Instrum. Meth B, 229 (2005) 187-218.

220 - Evaluating the effect of dental implants in the treatment of head and neck cancer using Monte Carlo dose calculation

Presenter: Dr. STATHAKIS, Sotirios (University of Texas Health San Antonio)

Purpose: To quantify and compare the effect of metallic dental implants (MDI) on dose distributions calculated using Collapsed Cone Convolution Superposition (CCCS) algorithm or a Monte Carlo algorithm (with and without correcting for the density of the MDI).
Methods: Seven previously treated patients to the head and neck region were included in this study. The MDI and the streaking artifacts on the CT images were carefully contoured. For each patient a plan was optimized and calculated using the Pinnacle treatment planning system (TPS). For each patient two dose calculations were performed, a) with the densities of the MDI and CT artifacts overridden (12 g/cc and 1 g/cc respectively) and b) without density overrides. The plans were then exported to the Monaco TPS and recalculated using Monte Carlo dose calculation algorithm. The changes in dose to PTVs and surrounding Regions of Interest (ROIs) were examined between all plans.
Results: The Monte Carlo dose calculation indicated that PTVs received 6% lower dose than the CCCS algorithm predicted. In some cases, the Monte Carlo algorithm indicated that surrounding ROIs received higher dose (up to a factor of 2).
Conclusion: Not properly accounting for dental implants can impact both the high dose regions (PTV) and the low dose regions (OAR). This study implies that if MDI and the artifacts are not appropriately contoured and given the correct density, there is potential significant impact on PTV coverage and OAR maximum doses.

221 - The Monte Carlo transport code for proton therapy planning dose calculations in the RayStation treatment planning system

Presenter: Dr. TRANEUS, Erik (RaySearch Laboratories AB, Sveavagen 44, SE-103 65, Sweden)

We present the Monte Carlo code for proton dose calculation and optimization released in the RayStation treatment planning system. The algorithms and their implementation in the MC dose engine are specifically geared to meeting the accuracy requirements of dose calculation and optimization for treatment planning. The goal is to optimize speed while maintaining accurate modelling of the relevant physics processes.
The Monte Carlo code transports primary protons and secondary ions (protons, deuterons and alphas). A Class II transport method is applied for the primary and secondary protons, while the heavier secondaries are transported only accounting for energy loss in a continuous slowing down approximation (CSDA). Nuclear absorption is thus neglected for the secondary deuterons and alphas. The transport simulation is performed in geometries (patient and beam modifiers) represented by rectilinear voxel grids where a voxel is characterized by its mass and material composition. The transport mechanics uses the random hinge method pioneered in MC codes for electron/positron transport. Ion stopping powers are calculated on-the fly by the Bethe-Block equation. Energy-loss straggling is handled by the Bohr approximation. Modelling of multiple scattering uses the theory of Goudsmit-Saunderson. The modelling of non-elastic nuclear reactions is data driven and based on a cross-section data library derived from published ICRU63 data. Elastic scattering of protons on hydrogen and on nuclei are included through parametrized models of the absorption probabilities and angular differential cross-sections. Neutral reaction products (neutrons and gammas) are not transported, but their given fractions of the absorbed energy are included in the energy balance and considered to leak out. Delta electron production is not considered.
The MC dose engine reports physical dose as dose to a small water cavity embedded in the local medium, i.e., as dose-to-water. The code has scorers for dose and track weighted LET, LET and energy spectra per voxel, RBE (several models) and more.
We report validation results and performance for typical clinical cases.

222 - Clinical implementation of a Monte Carlo based QA platform for validation of Tomotherapy and Cyberknife treatment plans

Presenter: Dr. YOUNES, Jourani (Centre Oscar Lambret, Academic Department of Radiation Oncology, Lille, France)

Introduction: This work describes the clinical implementation of a Monte Carlo based platform for treatment plan validation for Tomotherapy and Cyberknife, including a semi-automatic plan evaluation module based on dose constraints for organs-at-risk (OAR).

Methods: The Monte Carlo-based platform Moderato [1] is based on BEAMnrc/DOSXYZnrc and allows for automated re-calculation of doses planned with Tomotherapy and Cyberknife techniques. The Prescription/Validation module generates a set of dose constraints based on the anatomical region and fractionation scheme considered. Upon achievement of the planning, dose results are displayed with visual warnings in case of constraint violation. The system was tested on 83 patient cases in order to evaluate the influence of difference in calculation algorithms on OAR constraints.

Results: The first results with the Tomotherapy plans allowed for detecting and correcting a problem with the CT Hounsfield units when using a large reconstruction diameter (a CT artifact that lead to air voxels with an overestimated density). The Cyberknife results also showed some dose differences associated with different energy thresholds between Moderato and the Monte Carlo algorithm used in the Treatment Planning Station. Regarding OAR constraints, re-calculation generated few violations in thoracic, pelvic and abdominal cases. However, in spinal and head cases, significant differences can appear (-11% to +6%) on optic pathways and spinal cord, leading to doses above the limits.

Conclusions: The Moderato platform constitutes a promising tool for the validation of plan quality, offering both dose re-calculation and OAR constraints evaluation. First results show the importance of this verification for some specific regions. Further work is ongoing to optimize the quantity and relevance of the information displayed, before fully introducing the system in clinical routine.

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224 - Assessment of the glandular dose in scintimammography using Monte Carlo simulation and Finite element analysis

Presenter: Dr. HSIN-HON, Lin (6. Medical Physics Research Center, Institute for Radiological Research, Chang Gung University/Chang Gung Memorial Hospital, Linkou, Taoyuan, Taiwan)

Yan-Lin, Liu 1, Cheng-Ting Shih 2, Yun-Xuan, Tang 3,4, Keh-Shih Chuang 5, Hsin-Hon, Lin 6,*

1. Institute of Nuclear Engineering and Science, National Tsing Hua University, Hsinchu, Taiwan
2. 3D Printing Medical Research Center, China Medical University Hospital, Taichung, Taiwan
3. Department of Biomedical Imaging and Radiological Sciences, National Yang-Ming University, Taipei, Taiwan
4. Department of Diagnostic Radiology, Shin Kong Wu Ho Su Memorial Hospital, Taipei, Taiwan
5. Biomedical Engineering and Environmental Sciences, National Tsing Hua University, Hsinchu, Taiwan
6. Medical Physics Research Center, Institute for Radiological Research, Chang Gung University/Chang Gung Memorial Hospital, Linkou, Taoyuan, Taiwan

Scintimammography are effectively used to define the tumor margin to apply on pre-surgical assessment. The glandular tissues are highly sensitive to radiation, and the resultant glandular dose may increase the risk of developing fatal breast cancer. Thus, it is very important to assess the glandular dose caused by scintimammography. In this study, breast magnetic resonance images were acquired and used to build voxel geometry. These geometries are imported into a finite element analysis software to simulate the deformation of breast with supine position. The final geometries are then imported into the MCNPX to simulate the S value and dose distribution. The difference between the location of reference point and the deformed breast were all less than 8.9 mm. For radiation sources 18F and 99mTc, the maximum difference between the breast's self-absorption S-value and OLINDA/EXM results were 10.2% and 16.8%, respectively. Through this study, we can simulate the deformation of breast tissue and estimate the CBT to improve the dose evaluation accuracy and image quality. Through this study, the breast deformation and Monte Carlo stimulation can precisely evaluate the S value breast of breast tissue before examination and provide the dose evaluation reference of scintimammography.

225 - Development of adjustable model breast using mammographic information for Monte Carlo simulation in nuclear medicine --- impact on dosimetry

Presenter: Dr. LIN, Hsin-Hon (Medical Physics Research Center, Institute for Radiological Research, Chang Gung University/Chang Gung Memorial Hospital, Taoyuan, Taiwan)

Yu-Ching Ni 1,2, Hsin-Hon Lin 3, Siao-Fong Yang 1, Cheng-Chang Lu 4, Meei-Ling Jan 3, Keh-Shih Chuang 1, Shang-Lung Dong 4*

1. Department of Biomedical Engineering and Environmental Sciences, National Tsing-Hua University, HsinChu, Taiwan
2. Health Physics Division, Institute of Nuclear Energy Research, Atomic Energy Council, Taoyuan, Taiwan
3. Medical Physics Research Center, Institute for Radiological Research, Chang Gung University/Chang Gung Memorial Hospital, Linkou, Taoyuan, Taiwan
4. Department of Medical Imaging and Radiological Sciences, Chung-Shan Medical University Taichung, Taiwan

To accurate estimation of the breast dose in nuclear medicine examinations, the development of an adjustable sizes model breast for Monte Carlo simulation is important. The development of the model breast for nuclear medicine studies is difficult because the size of the breast must be known. The purpose of this study is to develop the adjustable sizes model breast using mammographic information for Monte Carlo simulation in nuclear medicine and to investigate its impact on dosimetry using the SimDOSE simulation code. This study constructed two sizes of ORNL phantoms with two radionuclides: 18F and 99mTc. The dimensions of a breast phantom, a semi-oblate spheroid model, were established from the collected breast parameters of a cohort of patients in mammography to provide a model breast allowing for changing sizes. Breast phantoms with various breast sizes, shapes, compositions, and the glandular distribution were created. The preliminary results showed the ratios of S-values of the breast ranged from 0.94 to 1.01 and the difference caused by breast shapes was insignificant. The organ dose of left and right breast may be considered separately due to in the dose difference between left and right breast. For different glandular distributions, the differences in S-values of the gland self-absorbed dose is about 5-8%. We conclude that the breast size has significant impacts on the S-values of the breast while the breast shape, compositions, and the glandular distribution cause less change in the S-value. Therefore, this study provided the new method to assess the breast dose in Nuclear Medicine.

226 - Comparison between Monte Carlo Simulations and Film Dosimetry for a Novel Lip Brachytherapy Applicator Development

Presenter: Dr. JON, Feldman (Nuclear Engineering, Ben Gurion University of the Negev, Beer Sheva, Israel; Sharett Institute of Oncology, Hadassah University Hospital, Jerusalem, Israel)

Jon Feldman1,2, Amichay Meirovitz2 and Itzhak Orion1

1. Nuclear Engineering, Ben Gurion University of the Negev, Beer Sheva, Israel
2. Sharett Institute of Oncology, Hadassah University Hospital, Jerusalem, Israel

Background: Due to its location, lip cancer is usually detected at an early stage and single-modality therapy will usually suffice. Surgery or radiotherapy can be utilized, with similar local control and overall survival results. The extent of surgical resection depends on tumor size, larger lesions may however require wide resections with consequently cosmetic issues, and may result with disruption of the oral sphincter (orbicularis oris muscle). In this study we are looking into a new way to improve brachytherapy homogeneity.
The hypothesis was that novel apparatus using backscattering materials will shape a more homogeneous dose distribution to lip cancer brachytherapy, while protecting the organs at risk.
Method: Backscattering materials with different dimensions, using combination of different metals were utilized on a lip brachytherapy phantom and compared in Monte Carlo simulations. We used the EGS5 code system for calculations. The dose results were normalized for comparisons.
Results: We found that the led backscatter and copper backscatter improve the dose homogeneity in the tissue compared to the central source in the sleeve alone. Moreover the dose beyond the shield markedly reduced, suggesting better protection to the organs at risk, when will use in vivo.
Conclusions: Metal shielding in lip brachytherapy improve dose homogeneity and reduce dose to organs at risk as suggested from our phantom model. Due to the fact that most treatment planning systems for brachytherapy are limited in taking into consideration the different cross-sections of materials, it was essential to use the EGS5 code system for dosimetry calculations. EGS5 Monte Carlo simulation served an important rule for choosing the proper material and thickness of the scattering metal for the lip brachytherapy.

227 - Monte Carlo transport simulations for reference dosimetry in radiotherapy

Presenter: Dr. PALMANS, Hugo (National Physical Laboratory, Teddington, Middlesex, UK)

Reference dosimetry in radiotherapy comprises all measurement activities needed to establish the dosimetric quantity of interest in reference conditions. This includes measurements with primary and secondary standards of dosimetric quantities, their dissemination via instrument calibrations, the establishment of reference conditions, measurements in clinical beams and intercomparisons or audits to verify the accuracy of the measurement chain. All these activities are supported by Monte Carlo transport simulations to understand the experimental data and to determine correction factors.

For primary standards one wants to rely mainly on measurement data. Monte Carlo simulations are used to interpolate or extrapolate measurement data to conditions of interest. Examples are wall perturbation factors in air kerma cavity standards, glass vessel perturbations in water calorimeters and gap corrections in graphite calorimeters. The correct extrapolation function cannot always be deducted from the experimental data and Monte Carlo simulations are indispensable in solving this.

Clinical reference dosimetry for many radiotherapy beams uses calibrated air-filled ionization chambers. It is, however, impossible for standard laboratories to provide calibration coefficients for all radiotherapy beams. Instead, calibrations are provided for representative beams characterized by a beam quality specifier. Use of those calibrations in other radiotherapy beams then relies on adequate characterisation of the beam quality and on correction factors for the difference in ionization chamber response. Monte Carlo simulations are essential to support this process. Since an air-filled ionization chamber is a low-density detector the simulation of radiation transport through its geometry is very sensitive to boundary crossing artefacts as well as to correct modelling of detector materials and dimensions. A widely used test of the correct numerical modelling of boundary crossing by charged particles is the Fano-test. Illustrations are given for light-ions, flattening-filter-free photon beams, plan-class specific reference fields, MRI/linacs and medium-energy X-rays.

The verification of accurate dissemination of dosimetric quantities to the clinic often involves independent auditing using mailed dosimeters such as thermoluminescence detectors and alanine. The contribution of Monte Carlo simulations to this application is mostly related to the calculation of stopping power ratios and beam quality dependent correction factors. Examples are shown for photon and light-ion beams.

230 - Experimental and Monte Carlo investigation of the depth-dependent fluence perturbation of parallel-plate chambers in clinical electron beams

Presenter: Mr. VON VOIGTS-RHETZ, Philip (Technische Hochschule Mittelhessen - University of Applied Sciences, Giessen)

The electron fluence inside a parallel-plate ionization chamber positioned in a water phantom and exposed to a clinical electron beam deviates from the unperturbed fluence in water in absence of the chamber. One reason for the fluence perturbation is the “in-scattering effect” as described in ICRU 35. Aim of this work is a detailed experimental and with Monte Carlo simulations investigation of this effect.
The experiments and Monte Carlo Simulations, with EGSnrc [1], were performed in a solid-water phantom (RW3) sized 30x30x30cm³. One of the RW3 plates of height h=0.5 cm had a hole with radius r=1 cm which acts as the air cavity in the phantom. The phantom was placed below an electron applicator of field size 10 x 10 cm² and irradiated with 6 MeV electrons from an Elekta Synergy accelerator. The air cavity was positioned at depths of 1.0, 1.5, 2.0 and 2.5 cm in the phantom. For the exerpiments the spatial resolved dose directly below the cavity was scored with GAFCHROMIC ETB3 films. The films were scanned with an Epson 10000xl-scanner (resolution 600dpi, color depth 48bit); a dose response calibration curve for the red channel was applied.
At 1.0 cm depth the relative dose profile shows the well known dose increase at the air/RW3 boundary of about 4% relative to the dose at the center of the cavity and a de-crease of about 8% outside the air cavity within the RW3-phantom. The amplitude of this “dose oscillation” decreases with increasing depth of the cavity within the phantom and disappears at about 2 cm, which is less than the half value thickness of the electron beam. The results are in agreement with already published Monte Carlo results [2].
The results are partly in contradiction to the ideas summarized in ICRU 35 but confirm recent Monte Carlo simulations from Zink et al.

[1] Kawrakow I et al. The EGSnrc Code System: Monte Carlo Simulation of Electron and Photon Transport, NRC Report PIRS-701, Ottawa, Canada, (2013)
[2] Zink K et al. Monte Carlo study of the depth-dependence fluence perturbation in parallel-plate chambers in electron beams Med. Phys. 41 (2014) 111707

231 - Monte Carlo based investigation of the beam quality correction factor kQ depending on the chamber's level of detail

Presenter: Ms. PRETZSCH, Tabea (University of Applied Sciences, Institute of Medical Physics and Radiation Protection, Giessen)

Dosimetry protocols, like the TRS-398 and the DIN 6800-2, recommend ionization chambers to measure the dose-to-water Dw. For these measurements ion chambers were calibrated under reference conditions in a 60Co-beam. To obtain the dose-to-water in another beam quality Q, the correction factor kQ is introduced. This correction factor can be calculated with Monte Carlo simulations, in which mostly simplified ion chamber models are utilised. The aim of this study is to investigate the influence of the level of detail of a simulated chamber model.
The correction factor for beam quality kQ was calculated as the ratio of dose-to-water Dw and the dose-to-air Dair within the detector: kQ=(Dw/Dair)Q,Co-60. All simulations were performed with the EGSnrc Monte Carlo code. The simulations were realized in a 30x30x30cm³ water phantom at the reference depth z=10cm. A 60Co-spectrum was used as reference beam quality and for the beam quality Q the photon spectra (6, 10, 15 and 18MV) of a Varian Clinac were applied. The beam was collimated to 10x10cm² on the surface of the water phantom with a SSD of 100cm. To calculate Dw a water voxel was placed at the measurement depth. Two different thimble chambers (air cavity of 0,125cm³ and 0,016cm³) were modeled with the egs++ user code egs_chamber. These chamber models were built in detail provided by blueprints of the manufacturer. To investigate the impact of chamber details on the calculated dose, the chamber models were simplified in five steps: the vent holes were eliminated and then the stem geometry was simplified in severeal steps. For all chamber models the kQ values were calculated.
Depending on the level of detail of the chambers, the calculated kQ values deviate up to 0,5-0,7% for the 0,125cm³ chamber and up to 0,7-1,0% for the 0,016cm³ chamber, especially in case of higher photon energies.

232 - The dawn of PET Monte Carlo: a personal experience

Presenter: Prof. DEL GUERRA, Alberto (Department of Physics, University of Pisa and INFN, Sezione di Pisa)

In the seventies, several Monte Carlo programs were available in radiation physics. I had already developed a home-made Monte Carlo code for neutron transport to validate the experimental measurements of the efficiency of a large neutron counter for 10-200 MeV neutrons in a HEP experiment, when I participated at the first international on “Computer techniques in radiation transport and dosimetry”, organized by Walter R.Nelson and Theodore Jenkins in Erice (Trapani, Italy) in 1978: Graham Stevenson, Keran O’Brien, W.W.Engle, T.A.Gabriel, C.Ponti, Walter R.Nelson, Herbert Dinter, A.Van Ginneken, Tony W.Armstrong and J.Ranft were the speakers. It was there that I met with the EGS code and its author Walter Ralph Nelson. Since then I started my collaboration with Ralph Nelson on the use of the EGS3 Monte Carlo in Nuclear Medicine, with the first paper published in 1980 on Compton Tomography, followed by a series of papers on the simulation of the performance of a human PET based on MWPC’s, the first one in 1981. From these first wails in the PET domain EGS3 became EGS4 and then evolved into GEANT and finally into GATE to become an indispensable code for PET detector simulation. In this talk I will present my pristine research in the field of PET Monte Carlo simulations in the last 20 years of last century.

233 - Study and evaluation of beam-modifying wedge filters of the siemens oncor expression linear accelerator using mcnp

Presenter: Mr. MARQUES, José (Rio de Janeiro Federal University); Dr. THALHOFER, JARDEL (FEDERAL UNIVERSITY OF RIO DE JANEIRO)

In this study, was developed and evaluated computational modeling of wedge filters for radiotherapy using a 6 MV photon beam and reference field measuring 10 x 10 cm2. For this study, it was necessary to model the Siemens Oncor Expression linear accelerator using Monte Carlo code MCNPX. Two variance-reduction techniques were used to optimize the simulation: the bremsstrahlung configuration and the phase space file. The experimental measurements were carried out using EBT2 radiochromic films and PTW 31010 ionization chamber. The results of the dosimetry characterization for each wedge filter modeled were based on the profiles and the percent depth dose (PDD) of the beam. The comparison between the simulated and experimental models for the profile showed percentage differences of 1.5% and 3.5% for the ionization chamber and radiochromic film, respectively, in the region that configures the beam aperture. For the PDD, the percentage difference was 2.8%. Moreover, a study of hardening and degradation of beam energy under the influence of filters shows a proportional decrease of up to 30% in the energy range 1–250 keV and a proportional increase of up to 45 % in the energy range 5.75–6 MeV.

234 - Monte Carlo study on out-of-field exposure in carbon-ion radiotherapy with passive beam: Organ doses in prostate cancer treatment

Presenter: Dr. YONAI, Shunsuke (National Institutes for Quantum and Radiological Science and Technology)

Monte Carlo study on out-of-field exposure in carbon-ion radiotherapy with passive beam: Organ doses in prostate cancer treatment

Shunsuke Yonai*, Naruhiro Matsufuji, Keiichi Akahane
National Institutes for Quantum and Radiological Science and technology
National Institute of Radiological Sciences
Dept. of Accelerator and Medical Physics, Chiba, Japan
*presenting author

Purpose: The aim of this work is to estimate typical dose equivalents to out-of-field organs during carbon ion radiotherapy (CIRT) with passive beam for prostate cancer treatment. In addition, sensitivity analyses of organ doses for various beam parameters and phantom height were performed.
Methods: Since the out-of-field dose in CIRT depends on the beam parameters such as beam energy etc., the typical beam parameters were determined from the statistical data on target properties of selected 165 patients received CIRT with the same treatment protocol at HIMAC. By using the typical beam parameters, we estimated typical out-of-field organ dose equivalents during CIRT for prostate cancer treatment by Monte Carlo simulations with PHITS and the ICRP reference phantom. The calculation method developed in the previous paper [1] was used in this study. Sensitivities of organ doses to beam parameters and phantom height were analyzed by changing the typical beam parameters and the voxel size of the phantom.
Results: The results showed that the organ dose equivalent decreased with the distance from the target organ with a range from 116 mSv in testes to 7 mSv in brain. Also, comparisons with photon radiotherapies showed that the organ dose equivalents per treatment dose in CIRT with passive beam were lower than those in IMRT with 6 MV and those in brachytherapy with Ir-192 source for organs within 40 cm from the target organ. Sensitivity analyses of organ doses for possible beam parameters and phantom height found out that the differences from typical values were within ~30% for organs except for sigmoid colon.
Conclusions: We showed the typical dose equivalents to out-of-field organs during CIRT with passive beam using Monte Carlo simulations. The low sensitivity of the dose equivalent in organs father than 10 cm from the target indicated that individual dose assessments required for the epidemiological study may be limited in organs around the target organ in case of CIRT with passive beam for prostate cancer.

[1] Yonai S, Matsufuji N. and Namba M. Calculation of out-of-field dose distribution in carbon-ion radiotherapy by Monte Carlo simulation. Medical Physics 2012; 39(8):5028-539

236 - Monte Carlo study on the feasibility of mini-beam radiation therapy with ion beams

Presenter: Prof. MATSUFUJI, Naruhiro (National Institute of Radiological Sciences)

Elevating energy loss of swift ion beams traveling in a matter toward their range end, known as Bragg peak, makes cancer therapy with the ion beams (ion-beam RT) advantageous over conventional X-ray. The localized dose delivery to the Bragg peak enables to control deep-seated tumor cells while sparing surrounding benign tissues. The Bragg peak gets shaper for heavier ions; additionally, the biological effectiveness of carbon and its vicinity also increases gradually in accordance with increasing energy loss.
Idea of the mini-beam radiation therapy (MBRT) was initially studied with X-ray as a method to spare proximal normal tissues by irradiating through submillimeter slit collimator. Recent studies try to apply the MBRT concept for proton beam by interlacing multiple sparse heterogeneous fields. The combination of the MBRT with ion-beam RT may lead further reduction of normal tissue toxicities and/or add new aspect for the selection of ion species for cancer therapy. In considering the MBRT with ion beams, it is requisite to precisely evaluate the spatial distribution of each mini beam travelling in a matter. This study aims at demonstrating the efficacy of the ion-beam MBRT for various ion species with Monte-Carlo (MC) transport simulation of the therapeutic ion beams.
A MC code PHITS was used to simulate the spatial dose distribution in water for ion species between proton and neon. Incident energy was selected to reach 15 cm depth in water. As a figure of merit, a peak-to-valley ratio (PVR) by the adjacent mini beams was evaluated at various irradiation depths under the parallel opposing field configuration. The result showed that PVR at the plateau region could be maximized in case of proton beam. The multiple scattering of the proton beam became significant especially around the range end. It enabled in turn to keep plenty of distance of adjacent beams. For heavier ion species, even though the multiple scattering of the primary beam was suppressed, dose reduction at valley by MBRT was found still possible due to the spatial distribution of fragment particles originated from projectile ions. The simulation result with FLUKA is also shown for the sake of comparison.

237 - Study to evaluate the impact of statistical uncertainty for lung cancer using flattening filter free 6MV photon Beam on Monte Carlo dose calculation in volumetric modulated arc therapy

Presenter: Mr. P, Mohandass (1 Department of Radiation Oncology, Fortis Cancer Institute, Fortis Hospital, Mohali, Punjab, India, 2 Department of Physics, School of Science and Humanities, Karunya University, Coimbatore, Tamilnadu, India)

Purpose: To study the dosimetric impact of statistical uncertainty (SU) per plan on 6MV FFF photon beam Monte Carlo calculation in Monaco™ TPS during volumetric modulated arc therapy (VMAT) for lung cancer.

Methods: Five lung cancer patients treated with 60Gy/30 fractions were chosen for the study. VMAT plans were generated with Monaco™ treatment planning system (TPS-V5.10) for Elekta Versa HD™ linear accelerator with 0.5cm leaf width. Plans were generated using dual partial arcs with 2% statistical uncertainty per plan. By keeping all other parameters constant, plans were recalculated only by varying the SU, 0.5, 1, 2, 3, 4, and 5%. For plan evaluation, conformity index (CI), Homogeneity index (HI) to planning target volume (PTV), dose coverage to PTV (D98%) was analyzed. Mean and max dose to organ at risk (OAR) was analyzed for spinal cord, pericardium, both lungs-PTV, oesophagus and liver. The normal tissue volume receiving dose >5Gy & >10Gy and normal tissue integral dose (NTID) (patient volume-PTV), calculation time (mins) and gamma pass rate (<1.00)(3%/3mm) were compared.

Results: CI and HI improve as the SU increases 0.5 to 5% ($P>0.05$). No significant dose difference was observed in Dmean to PTV, both lungs-PTV dose, mean dose to pericardium, oesophagus, liver and normal tissue volume receiving dose >5Gy&>10Gy and NTID ($P>0.05$). Max dose to PTV and spinal cord was increased as the SU increases ($P<0.05$). Decrease in dose calculation time was observed with increase of SU ($P<0.05$). No significant dose difference was observed in calculation reproducibility ($P>0.05$).

Conclusion: For lung 6MV-FFF VMAT plans, SU can be accepted up to 3% per plan with reduced calculation time without compromising target coverage, OAR doses and plan delivery by accepting variations in point dose and inhomogeneous dose within target. There is no significant dose difference in calculation reproducibility.

238 - Study on the relationship between exposure dose and CT dose index for various CT scanners using Monte Carlo simulation and human voxel phantoms

Presenter: Dr. KOBA, Yusuke (National Institute of Radiological Sciences)

Purpose: WAZA-ARI is the web-based open system for X-ray CT dose calculator, which has been developed by NIRS and Oita University of Nursing and Health Sciences and the Japan Atomic Energy Agency(JAEA) [1]. We constructed source models based on actual measurements. The selectable CT scanners in WAZA-ARI are still not enough despite the continuing addition of CT scanners because the CT developers deliver a steady stream of new products. In this study, we investigate the relationship between exposure dose and CT dose index(CTDI) for various CT scanners in WAZA-ARI system and categorized CT sources based on parameter of radiation quality and fluence distribution in order to calculate organ dose for arbitrary CT models.
Methods: The organ doses in CT exposure were calculated using Monte Carlo code, PHITS and Japanese adult voxel phantoms developed by JAEA [2]. We calculated the organ doses and CTDIs for about fifty CT sources. We investigated the relationship between the organ dose and CTDI in typical CT exposure for head and body.
Results: The calculated organ doses per CTDI free air depended on the effective energy and the fluence distribution of X-ray from CT scanner. The radiation quality depended on the ratio of CTDI center and CTDI free air, and the fluence distribution depended on the ratio of CTDI peripheral and CTDI free air. The ratio of CTDI center/peripheral and CTDI free air was useful to categorized CT sources, and CT scanners with near CTDI ratios showed near exposure doses per CTDI free air.
Conclusions: CT sources were categorized using The ratio of CTDI center/peripheral and CTDI free air. Existing calculated organ doses data for CT scanners were diverted to the dose calculation for CT scanner with near CTDI ratios.

[1] Takahashi F, Sato K, Endo A, et al.: Numerical Analysis of Organ Doses Delivered During Computed Tomography Examinations Using Japanese Adult Phantoms with the WAZA-ARI Dosimetry System, Health Phys. 2015; 109, 104-112.
[2] Sato K, Noguchi H, Emoto Y, et al. Japanese Adult Male Voxel Phantom Constructed on The Basis of CT Images, Radiat Pro. Dosim. 2007; 123, 337-344.

239 - Proton-nucleus interactions in non-water materials for proton radiotherapy treatment planning

Presenter: Dr. INANIWA, Taku (National Institute of Radiological Sciences, QST)

To exploit the advantages of proton beam therapy fully, it is necessary to perform three-dimensional treatment planning and optimization. A prerequisite for this is an algorithm for accurate dose calculation. Recently, Monte Carlo (MC)-based dose-calculation systems have been developed for proton radiotherapy treatment planning. The accuracy of the calculation have been confirmed by comparing the MC-simulated and the measured dose distributions in water. This may satisfy the need for proton radiotherapy treatment planning, since tissue heterogeneity is conventionally modeled as water with various densities to reproduce its stopping power, i.e., the stopping effective density. Dose calculation based on this approximation, however, can be erroneous due to the water nonequivalence of body tissues, mainly in nuclear interactions. In absolute dosimetry, similar errors have been reported to occur when, for convenience, solid phantom materials are used instead of water. These errors can be corrected by introducing a fluence correction factor, which is the predetermined ratio of dose-in-water to dose-to-water in the material. The fluence correction factor varies among beams, materials, and depths and can be specifically determined by MC simulation. The accuracy of the MC-based patient dose calculation as well as that of the fluence correction factor depends heavily on the validity of the nuclear model employed by the MC codes. The purpose of this study is to validate the nuclear model employed by Geant4 MC code for proton radiotherapy treatment planning. We performed the irradiation experiments with a 235-MeV proton beam using five non-water materials. These materials were placed in front of a water phantom to measure the planner integrated dose distribution (PIDD) behind the materials. An in-house parallel-plate ionization chamber was used for the measurements. The measured PIDDs were compared with the MC-simulated PIDDs for each non-water materials. We will report the results of the comparisons.

240 - A probabilistic-based nuclear reaction model for Monte Carlo ion transport in particle therapy

Presenter: Ms. GONZALEZ TORRES, Maria Jose (AG Strahlungsphysik, Institut für Kern- und Teilchenphysik, TU Dresden, Germany)

In order to expand the Monte Carlo transport program AMOS to particle therapy applications, the ion module is being developed in the radiation physics group (ASP) at the TU Dresden. This module simulates the three main interactions of ions in matter for the therapy energy range: elastic scattering, inelastic collisions and nuclear reactions. The simulation of the elastic scattering is based on the Binary Collision Approximation and the inelastic collisions on the Bethe-Bloch theory. The nuclear reactions, which are the focus of the module, are implemented according to a probabilistic-based model developed in the group.
The developed model uses probability density functions to sample the occurrence of a nuclear reaction given the initial energy of the projectile particle as well as the energy at which this reaction will take place. The particle is transported until the reaction energy is reached and then the nuclear reaction is simulated. This approach allows a fast evaluation of the nuclear reactions. The theory and application of the proposed model will be addressed in this presentation. The results of the simulation of a proton beam colliding with tissue will also be presented.

241 - Geant4 simulation studies of secondary particles emission in hadron therapy treatments

Presenter: Dr. TAMBORINI, Aurora (INFN Section of Pavia, via Bassi 6, 27100 Pavia, Italy)

The simulation studies of secondary particles production during an irradiation with ions and protons are crucial for a deep understanding of the processes underlying the interaction between hadron beams and a target (water or Plexiglas phantoms).
In this study we investigate the rate of secondary particles produced in the interaction between hadrons and targets of different materials.
The adopted simulation tool is Geant4 (vs. 10.3.p01) and the operational energy range is compatible with the one delivered by CNAO (Centro Nazionale di Adroterapia Oncologica).
Depth dose deposition along the beam axis, energy and angular distributions are analyzed for outgoing protons, neutrons, heavy secondary particles as well as prompt gammas.

242 - Simulation of a Fast Timing Micro-Pattern Gaseous Detector for PET-TOF and future accelerators

Presenter: Dr. RADOGNA, Raffaella (INFN Bari)

A new generation of gaseous detectors, named Micro-Pattern Gas Detectors (MPGDs), has been developed thanks to an improved micro-structure technology.
The main features of the MPGDs are: exible geometry; high rate capability (> 50MHz/cm^2); excellent spatial resolution (down to 50um); good time resolution (down to 3ns); reduced radiation length.
A new detector layout has been recently proposed that would combine both the high spatial resolution (100um) and high rate capability (100MHz/cm^2) of the current state-of-the-art MPGDs with a high time resolution of 100ps. This new type of MPGD is named the Fast Timing MPGD (FTM) detector [1, 2].

The Fast Timing MPGD can potentially reach sub-millimeter spatial resolution and 100 ps time resolution. Such a detector, able to measure photons with excellent time and spatial resolution, will allow the development of an affordable TOF-PET scanner with improved image contrast.

The design of such new detectors and the construction of new prototypes is strongly based on MC simulation. Electric Fields are calculated with ANSYS and validated against a COMSOL simulations, while the simulation of the detector response and detector gain is simulated with Magboltz and Garfield++. Furthermore detector simulations are validated against first measurements of detector prototypes. This contribution introduces the Fast Timing MPGD prototype as an innovative PET imaging detector concept and emphases the importance of full detector simulation to guide the design of the detector geometry.

[1] :: "A novel fast timing micropattern gaseous detector: FTM", Rui De Oliveira, Marcello Maggi and Archana Sharma, CERN-OPEN-2015-002-INFN-15-01-BA. e-Print: arXiv:1503.05330
[2] :: "R on a new type of micropattern gaseous detector: The Fast Timing Micropattern detector", Palma Altieri, Raffaella Radogna, Piet Verwilligen et all., Nucl.Instrum.Meth. A845 (2017) 313-317. DOI:10.1016/j.nima.2016.05.067

243 - Guiding the design of a blood gamma counter with Monte Carlo simulations

Presenter: Mr. ESPAGNET, Romain (Université Laval)

In molecular imaging, a semi-quantitative analysis of uptake is possible with Standardized Uptake Values. To obtain a more robust quantitative analysis, a blood time-activity curve can be used as an input function for pharmacokinetic modelling of tracer uptake. Therefore, a device was developed to determine blood activity as a function of time, and consists in two 20x20x15 mm^3 CZT detectors counting gammas from a blood-filled catheter located in between them. These detectors can be operated in single or coincidence mode. The purpose of this work was to assess the merit of these acquisition modes in terms of background immunity and shielding requirements. Since the device must be as light as possible to be used directly on the patient couch, it is hypothesized that the coincidence mode might require less shielding that the single mode to achieve a given Minimum Detectable Activity (MDA). Geant4 Monte simulations were used to test several acquisition scenarios, and reproduced the detector, patient and PET scanner geometry. 18F sources were distributed to represent a realistic patient and blood circulating in the catheter to simulate, respectively, the background and the signal. The ratio of background and signal activity was determined by considering a blood volume of 5L, a blood catheter volume of 0.079 ml, and an injected activity of 10 mCi. List-mode files (time, energy, detector ID) of all events above 80 keV were obtained for scenarios where the tungsten shielding around the CZT detector was varied from 0 to 40 mm in 5 mm increments. Post-processing of these list-mode files was conducted with coincidence windows of different width, in order to determine the fraction of true signal events among all detected events. Simulations show that the coincidence mode makes the device mostly immune to background radiation, at the expense of a lower sensitivity by a factor 3-4. It appears that the single mode with 10 mm of tungsten shielding is a good compromise to build a sensitive device that is relatively immune to background radiation.

244 - Investigation of Monte Carlo calculations for reference dosimetry regarding new ICRU-90 recommendations

Presenter: Mr. CZARNECKI, Damian (Institute of Medical Physics and Radiation Protection (IMPS), University of Applied Sciences Giessen, Giessen D-35390, Germany)

In 2016 the ICRU published a new report dealing with key data for ionizing radiation dosimetry (ICRU-90) partly updating the data for stopping powers for electrons and positrons given in report ICRU 37. New recommendations have been made for the mean excitation energies I for air, graphite and liquid water as well as for the graphite density to use when evaluating the density effect. The aim of this work was to evaluate the impact of these new recommendations on clinical reference dosimetry for high energy photon and electron beams. For that purpose Monte Carlo simulations using the EGSnrc code were performed for several compact and parallel plate ion chambers (NE2571, NACP, ROOS) used for reference dosimetry. Two different PEGS files containing the cross sectional data for the different materials included in the ion chambers and also water were created according to the recommendations of ICRU-37 and ICRU-90.
The chambers were positioned in a water phantom at the reference depth according to the IAEA TRS-398 code of practice. The field size for all simulations was 10 x 10 cm2 at the phantom surface. In case of photons six phase space files from clinical accelerators and twelve spectra taken from literature in the energy range 4 – 25 MV-X and additionally a Co-60 source were applied. As electron source thirteen electron spectra available in literature were used (E0 = 4 – 21 MeV). The source-surface-distance in all simulations was 100 cm. The Monte Carlo simulations did comprehend the calculation of the stopping-power-ratios water-to-air as well as the calculation of the corresponding beam quality correction factor kQ for the mentioned ion chambers. The results show, that the new ICRU recommendations result in changes of stopping-power-ratios up to 0.6%. The impact on kQ data for the chosen ion chambers is in the range of 0.1 – 0.2% only.

245 - Monte Carlo methods for diagnostic radiology

Presenter: Prof. KALENDER, Willi (Institute of Medical Physics, University of Erlangen-Nuernberg, Erlangen, Germany)

Monte Carlo (MC) methods came into use in diagnostic radiology in the early 1970ies aiming at the determination of scatter radiation intensities and spatial distributions for arbitrary geometries and exposure parameters in order to optimize image quality.
Today, MC methods are in broad use for determining radiation dose to the patient in x-ray computed tomography (CT). It has become a topic of high interest due to the increasing numbers of CT examinations performed worldwide. Estimates of effective dose are established, but they are crude and not patient-specific. Patient- and organ-specific dose estimates can be provided with adequate accuracy by fast MC simulations. Such information, in particular on 3D dose distributions, is important and helpful in optimization of scan protocols.

246 - Advanced dose calculations for clinical brachytherapy

Presenter: Prof. BEAULIEU, Luc (Université Laval, Québec, Canada)

Brachytherapy is the oldest form of radiation therapy and has proven to be a highly successful cancer treatment modality. By positioning a source close to and within a tumor, every treatment automatically benefits from the inverse square law, enabling the spearing of healthy tissue away from the source. Still, tissue heterogeneity, the use of high-Z shielding or the presence of very low-density materials (e.g. air) can produce significant dose differences compared to the clinical standard. These differences will strongly depend on the choice of the isotope used to deliver the required radiation dose. This presentation will go over a few key cases that underlines the importance of Monte Carlo, or any other advanced dose calculation approach, in terms of possible recalibration of dose-outcome (toxicity or survival) relationship as well as underlining the far-reaching impact in terms of current radiobiological modeling and enabling to rethink our current treatment approaches through new applicators and source designs.

247 - Patient specific scatter reduction in SIRT gamma camera images

Presenter: Dr. MESRI, Milad (Faculty of Physics, Ludwig-Maximilians-Universität München, Munich, Germany)

Introduction: Clinical Bremsstrahlung imaging with gamma cameras or SPECT scanners, for example used in selective internal radiation therapy (SIRT) [1], suffers from low contrast due to a continuous spectrum and a high amount of scatter. Information about the scattering of the radionuclide within the patient's body can be obtained from Monte-Carlo simulations and subsequently being used to improve image quality.

Methods: An MAA-acquisition (CT+SPECT) of a HCC patient with a unifocal uptake in the right liver lobe is segmented (lesion) and loaded into the MC simulation framework GATE [2]. The voxelized lesion is used as Y90 source (1.5 GBq, 'fastY90' [3] is used yielding a speedup of 2.3x), the CT dataset is used for attenuation by converting HUs into corresponding materials. A mini gamma camera (Crystal Photonics, Germany) with a LEHR collimator and 4x4cm^2 detector size is positioned close to liver on the patient's skin, pointing towards the lesion. A simulation (60s acquisition time) is performed on a cluster with 512 cores (2.2-2.5 Ghz each). The total number of counts, the energy spectrum and the order of scattered particles within each geometric volume are obtained from the ROOT output. Particles that have not scattered at all are defined as primary events. Scattering is only calculated within the phantom.

Results: The simulation took 172min on the cluster with input data voxel size of 1x1x3.75mm^3. The number of emitted particles is 7.6M with 600k detected counts (~8% ratio). 13.3% of the detected particles are primary events. Additionally, scatter of multiple orders has been observed (41%, 24% and 13% and 8% for the first four orders).

Conclusion: The energy-spectrum of the simulated 2D gamma camera image can be analyzed and used to correct the actual image acquired of that specific patient to achieve improved image quality and subsequently also dosimetry.

[1] Kennedy A et al. Radioembolization (yttrium-90 microspheres) for primary and metastatic hepatic malignancies. The Cancer Journal. 2010;16:163–175.
[2] Santin G et al. GATE: A Geant4-based simulation platform for PET, SPECT integrating movement and time management. IEEE Trans. Nucl. Sci. 2003;50:1516-1521.
[3] Rault E et. al. Fast simulation of yttrium-90 bremsstrahlung photons with GATE. Med. Phys. 2010;37(6):2943-2950.

248 - A Validated MC model of the University of Birmingham MC40 medical beam line

Presenter: Prof. PRICE, Tony (University of Birmingham, School of Physics and Astronomy, Birmingham, United Kingdom)

The University of Birmingham MC40 Cyclotron is capable of delivering up to 40 MeV protons and 53 MeV He ions at a huge range of currents varying from fA to μA. A switching magnet allows the beam to be transported to one of twelve experimental areas. One of these is the medical beam line, which, in recent years has been used for the development of a novel proton CT device, radiobiological experiments, and proton range verification. We will present a validated MC model (using Geant4.10) of the medical beam line, demonstrating the excellent agreement between energy measurements and simulations, beam divergences, and scattering profiles through various materials. These three points are essential for all experiments conducted on the beam line. If time permits, we will also highlight some of the improvements made to the beam line where simulations formed an essential part of the design work such as a beam flattering system.