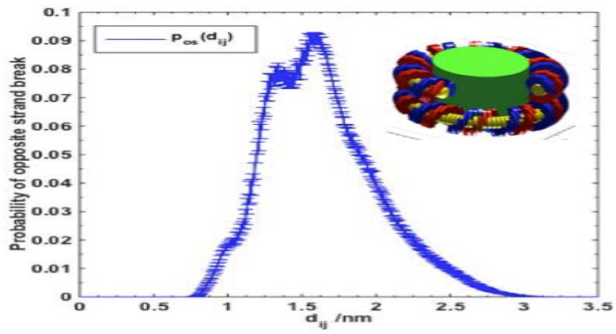

Results: The geometrical DNA model with single-track analysis shows that the number of dsb clusters decreases from 1.89 dsb/Gy/Gbp for 1 MeV protons, to 0.74 dsb/Gy/Gbp for 17 MeV/u Li^{3+} ions (same LET than the protons) and to 0.2 dsb/Gy/Gbp for Co-60 irradiation. In addition, the ssb yields tend to increase for Co-60 and Li^{3+} ions compared to protons. The probabilistic model shows that the expected dsb yields are 2.75, 1.89, and 0.64 dsb/Gy/Gbp respectively for protons, Li^{3+} ions and Co-60, following the same trends as the geometrical model. The absolute differences are due to slightly different irradiation setups, which affect the incident energy fluence. Finally, inter-track effects are observed as a systematic increase in dsb yields and a decrease in ssb yields for 2 Gy fractions compared to single-track analysis.

	source	G_{ssb} [/Gy /Gbp]	G_{dsb} [/Gy /Gbp]	P_{ssb} [/Gy /Gbp]	P_{dsb} [/Gy /Gbp]
Single-track	1 MeV protons	50.5 (0.6)	1.89 (0.07)	55.85 (0.08)	2.75 (0.03)
	17 MeV Li ions	60.8 (1.3)	0.74 (0.06)	57.77 (0.07)	1.89 (0.04)
	Co-60	60.6 (4.3)	0.2 (0.1)	56.42 (0.07)	0.64 (0.02)
2 Gy fractions	1 MeV protons	49.4 (0.3)	1.94 (0.06)	-	-
	17 MeV Li ions	53.6 (0.3)	1.58 (0.06)	-	-
	Co-60	35.3 (2.1)	0.5 (0.2)	-	-

G_{ssb}, G_{dsb}, P_{ssb}, and P_{dsb} are respectively the number of ssb and dsb clusters using the geometrical DNA model (G) and the probabilistic DNA model (P). One standard error on the mean is given in parenthesis.

Conclusions: The models presented herein would allow linking experimental measurements of ionization cluster distributions, such as obtained by the nanodosimeters presented by the BioQuaRT project, to relevant initial biological radiation damage patterns in DNA such as ssb and dsb. This could provide a straightforward comparison of experimentally measured ionization clusters and MC simulated tracks, allowing a description of beam radiation quality and, potentially, biological effectiveness.

OC-0158

Proton and photon Minibeam Radiation Therapy (MBRT): a micro and nanodosimetry Monte Carlo study

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Purpose/Objective: Nowadays, radiation therapy (RT) is one of the most effective methods to treat cancers. However, for radio-resistant tumors, RT is only palliative due to the tolerances of the surrounding healthy tissues. To overcome this limitation, new techniques of RT are developed, based on a new dose delivery methods leading to different biological outcomes. This work is focused on two innovative approaches under development: photon and proton MiniBeam Radiation Therapy (MBRT). They are based on the combination of a spatial fractionation of the dose and the use submillimetric field sizes (500 – 700 µm). The resulting dose profiles consist of a pattern of peaks (high doses) and valley (low doses) regions [1]. Thanks to the low doses on valleys, this type of dose delivery leads to a remarkable tissue-sparing. In parallel, a significant tumor growth delay was observed in highly aggressive tumor models [2, 3, 4]. However the biological basis are not yet well-understood. In order to deepen the knowledge of the biological effects of the MBRT, a micro and nanodosimetric study has been performed. DNA damages induced by proton and photon MBRT at different depths on peaks and valleys regions have been calculated by using a Monte Carlo method.
Materials and Methods: Irradiations with proton (105 MeV) and photon (mean energy of 70 keV) minibeams were performed using Geant4/Geant4-DNA [5, 6].
As a target of the simulations, a detailed DNA geometrical model of a neuronal cell was generated. This geometry is composed of a spherical nucleus of 10 µm in diameter and fill with nucleosomes composed of a cylindrical histone wrapped by roughly two turns of DNA double helix (200 bp) [7]. The energy transfer points located on the DNA were analyzed with an adapted clustering algorithm allowing the detection of DNA strand breaks [7, 8].
Results: An increase of the number and complexity (number of energy transfer points composing the break) of single and double strand breaks with the depth have been observed in proton MBRT, with a maximum reached at the tumor position. A significant larger number of damages were obtained in the peaks than in the valleys, which would favor healthy tissue sparing.
Concerning photon MBRT, the first results of the microdosimetry study, without DNA structure on the nucleus, show a greater proportion of energy transfer points on peak compare to valley. Thus, the probability to have DNA damages will be larger on peak region. The nanodosimetry study including the detailed DNA geometry is in progress. A detailed comparison with proton MBRT as well as with conventional RT will be performed.
Conclusions :
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OC-0159

Fluence correction factors for graphite calorimetry in clinical proton beams using Geant4

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Purpose/Objective: There are currently no primary standards for the direct measurement of absorbed dose-to-water in proton therapy beams. A primary standard level graphite calorimeter is currently being commissioned for measuring absorbed dose-to-graphite in proton beams. The required conversion of absorbed dose-to-graphite in a graphite phantom to absorbed dose-to-water in a water phantom is performed by water to graphite stopping power ratios. If, however, the charged particle fluence is not equal at equivalent depths in graphite and water, a fluence correction factor, k_{fl}, is required. In this work, k_{fl} has been determined

for graphite (and a number of other materials of dosimetric interest) using Geant4 in a range of clinical proton beams.
Materials and Methods: An application was developed using Geant4 (v9.6.p01) to score both dose and fluence spectra differential in energy for protons, alphas, deuterons and tritons at equivalent depths in water and graphite for a range of incident proton beams energies (60, 140 and 230 MeV). The variation of k_{fl} with depth in graphite (with respect to water) was determined in two ways: (1) by integrating the stopping power data over binned fluence spectra for all charged particles (fluence scoring method), and (2) from the ratio of doses (dose scoring method), at equivalent depths in these materials. Fluence correction factors (or the 'water equivalence') of a number of other materials were also examined using these techniques.
Results: Fluence correction factors determined using both methods were found to be consistent. For graphite, k_{fl}, was found to be close to unity at the surface when only protons are considered and ~0.5% less than unity at shallow depths with all charged particles (due to contributions from short range alpha particles) at all energies. k_{fl}, was found to increase with depth up to a maximum of 1.2% (60 MeV), 2.4% (140 MeV) and 4.5% (230 MeV) just upstream of the Bragg peak region. Water equivalent plastics (WT1, PW, PWDT) designed for photon beams and polystyrene gave similar results at all energies (0.5%-1% up to the Bragg peak) whereas k_{fl} ranged from 0.5% (60 MeV) to -1.5% (230 MeV) for polyethylene. A-150 was found to be the most water-equivalent material with k_{fl} being close to unity at all energies and depths up to the Bragg peak.
Conclusions: The simulation results presented here indicate that water-equivalent depths of 0.6 cm (60 MeV), 3.0 cm (140 MeV) and 6.0 cm (230 MeV) are ideal reference depths for graphite calorimetry since the fluence correction vanishes. To avoid corrections larger than 1%, reference dosimetry should not be performed at water-equivalent depths larger than 9 cm in a 140 MeV beam and 15 cm in a 230 MeV beam. The observed difference between phantom materials warrant further research for tissue materials of importance in treatment planning and dose calculations in proton therapy. The effect of beam modulation will also be studied in future work.

OC-0160

Beam halo measurement in proton beams: experimental challenges and lessons for dose modelling of pencil beams

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Purpose/Objective: A proton beam deposits a non-negligible amount of dose off the beam axis due to particles scattered at high angles by multiple coulomb scattering or nuclear interactions. Modelling such an effect is particularly challenging for proton pencil beams, which require small field dosimetry and a setup highly sensitive to changes in the deposited dose, spanning several orders of magnitude. We developed an experimental protocol for measuring the lateral distribution of a clinical proton pencil beam, including effects due to particles scattered at large angle because of nuclear interactions or high-energy elastic scattering. Our method is particularly effective with small pencil beams as those used in intensity modulated proton therapy (beam sigma less than 5 mm), and can be easily generalized to other facilities.
Materials and Methods: We measured the dose deposited off axis up to a distance of 6 cm from the beam centre, for different depths in water and different energies. We used a small ionization chamber (PTW PinPoint 31014) in a water phantom in accordance to dosimetry protocols for clinical fields. We estimated chamber effects from simulations and included them in the analysis. To avoid any interference due to materials other than water in the beam path, we placed the chamber directly in water and delivered the beam vertically on the water surface (no entrance window). We optimized our analysis considering the high dynamic range of the data (covering four orders of magnitude), and tested it on MC simulations to study possible biases.
Results: Three regimes are visible in our data: a first contribution dominant within 1.5 cm from the beam axis, made of particles scattered at low angles from the beam, which we modelled as a Gaussian distribution, as commonly done in treatment planning systems; a second contribution, dominant between 2 to 4 cm from the beam axis, made of particles undergoing nuclear or multiple elastic scattering interactions, which we modelled as a Gaussian distribution too; and a long-radii tail, made of particles scattered at high angles (due mainly to nuclear interaction processes), which we modelled as an exponential tail based on physical arguments and MC simulations. The second contribution increases with depth reaching up to 6% of the total dose distribution, while the third is below 1%. We estimated all components within 5% uncertainty for all energies and depth considered.
Conclusions: We designed an experimental setup with an air-vented, small volume ionization chamber allowing a precise estimate of the beam width and lateral spread of a proton pencil beam. Our method has many advantages over films or CCD, used by other institutes, since it is more sensitive to the tails, more precise, and more robust with respect to experimental uncertainties. To achieve even better conformity, proton therapy requires small beam sizes and high precision beam models; our method provides a way to achieve such a goal with an easy experimental setup.

OC-0161

'End to end' validation of a Monte Carlo code for independent dose calculation in a proton pencil beam scanning system

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Purpose/Objective: To validate the Monte Carlo (MC) model of a proton pencil beam scanning (PBS) system in clinical use in our ProtonTherapy (PT) Center.
Materials and Methods: TOPAS [1] (ver12) was used to simulate our proton beam delivery system. The model was obtained starting from the commissioning measurements. Spot shape and size, divergence, integral-depth-dose curve of the beam were studied as a function of energy and gantry angle. Absolute dose calibration was achieved based on ionization chamber and Faraday cup measurements to describe the number of protons per monitor unit (MU) as a function of the beam energy. In this way the results were scored in terms of absolute dose and the comparisons between Treatment Planning System (TPS), MC and measurements did not need renormalization. The TPS used in our center is XiO (Computerized Medical System Inc.). A method to convert XiO-DicomPlan to TOPAS input files was developed. The CT scanner was calibrated and four different cases of Head and Neck (H&N) tumors were simulated. These results were compared with TPS dose calculation and