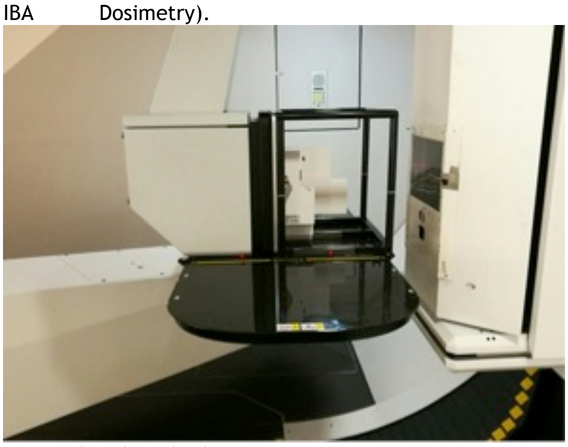
IBA Dosimetry).



Material and Methods

The phantom includes 4 wedges of different thickness, allowing verification of the range for 4 energies within one integral image. Each wedge was irradiated with a line pattern (19 spots with 5mm separation) of suitable clinical energy (120,150,180 and 230MeV). In order to test reproducibility, the equipment was aligned to the isocenter using lasers, and delivery was repeated for 5 consecutive days, repeating delivery 4 times each day. Position of range (R) at distal fall-off (depth corresponding to the 80% in the distal part of the Bragg peak) was determined (myQA software, IBA Dosimetry) and inter- and intra-setup uncertainty calculated. Dependence of R on energy was performed delivering the same spots pattern but with energy variation in steps of ±0.2MeV for all the nominal energies, up to ±1.0MeV. Possible range uncertainties, caused by a daily setup error, were then simulated: inclination of the phantom (0.6° and 1° slope), spot shift (±0.5mm, ±1.0mm, ±2.0mm) and couch shift (2.0mm, 5.0mm and 10.0mm) simultaneously with an increased and fixed spot separation (10mm).

Results

Inter and intra position setup shows a maximum in plane difference within 1mm. Reproducibility test results are shown in Fig. 2, in terms of mean (μ) and the standard deviation (σ) of the R. Energy resolution was expressed as γ factor (γ=σ/ α, where α is the slope of the range dependence on energy): γ defines what energy change would create the same effect as a 1 sigma outlier. Daily setup uncertainties results are also reported in Fig. 2 (β is the slope of the range dependence on the simulated daily setup error). An inclination of 1° leads to a maximum R variation of 0.2mm, 1.1mm, 0.5mm and 1.3mm for a 120MeV ,150MeV, 180MeV and 200MeV energy respectively. A slope of 0.6° leads to R variation less than 0.4 mm for all the energies. R biggest variation was 0.4 mm, only for a spot shift of +2.0mm for 150MeV and 200MeV energies. A spot separation of 15mm leads to R deviation of 0.6mm, 0.4mm, 0.6mm and 0.3mm for all the energies. A combination of 10mm couch shift and a 10mm spot separation lead to R deviation from the reference value of 1.4mm, 1.9mm, 1.2mm and 2 mm respectively, for the already mentioned correspondingly increasing energies.

Energy (MeV)	120	150	180	200
Distal range reproducibility				
μ (mm)	96.74	145.95	202.50	244.87
σ (mm)	0.05	0.09	0.11	0.11
α (mm/MeV)	1.66	1.77	2.03	2.15
γ (MeV)	0.03	0.05	0.05	0.05
Distal range: daily setup error				
β - Inclination (mm/deg)	-0.02	-0.11	0.05	0.24
β - Spot shift (mm/mm)	-0.06	-0.08	0.01	-0.07
β - Couch shift + 10 mm spot separation (mm/mm)	0.08	-0.21	0.07	-0.28

Conclusion

Inter position setup error can be easily improved by positioning the system also matching the laser with the beam and imaging system, achieving a sub-millimetre accuracy. Taking also into account different day-to-day setup errors, their influence on the range determination can be ignored.

OC-0064 A Fano test for proton beams and the influence of nuclear interactions on ionization chamber factors

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Purpose or Objective

In this work, the accuracy of particle transport in th e FLUKA Monte Carlo code for proton beams was evaluated by performing a Fano cavity test.

Ionization chamber perturbation factors were also computed for the PTW 34070 Bragg peak chamber, typically used for integral depth dose measurements in clinical proton beams, with particular attention to the influence of nuclear interactions.

Material and Methods

To implement the Fano cavity test in FLUKA, a routine was written to generate a uniform, mono-directional proton source per unit of mass. Geometries were defined with homogeneous material interaction properties but varying mass densities. Simulations were performed for mono-energetic protons with initial energies of 60 MeV to 250 MeV. To study the influence of different subsets of secondary charged particle **types, three simulations with** different charged particle transport were performed for each proton energy considered; (i) all charged particles transported, (ii) alpha particles discarded and (iii) nuclear interactions discarded. Ionization chamber perturbation factors were also computed for the PTW 34070 Bragg peak chamber for proton beams of 60 MeV to 250 MeV using the same transport parameters that were needed to pass the Fano test.

Results

FLUKA was found to pass the Fano cavity test to within 0.1%, using a stepsize of 0.01 cm for transport of all charged particles and cut-off energy for protons set to 10 keV. Ionization chamber simulation results show that the presence of the air cavity and the wall produces perturbation effects of the order of 0.2% and 0.8% away from unity, respectively. Results also show that proton beam perturbation factors are energy dependent and that nuclear interactions must be taken into account for accurate calculation of ionization chamber dose response.

Conclusion

Ionization chamber perturbation factors can amount to 0.8% in high-energy proton beams and therefore need to be considered in dosimetry procedures. This work will feed into the development of data for future codes of practice for the dosimetry of proton beams.

OC-0065 Ion recombination in scanned light-ion beams combining Boag's and Jaffé's theory

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Purpose or Objective

As recommended in international dosimetry protocols (e.g. IAEA TRS-398) the response of ionisation chambers (ICs) has to be corrected for influence quantities. In this work, we investigate the ion recombination correction factor (k_s) in scanned light-ion beams. Two contributing processes are distinguished: initial and volume recombination. Initial recombination occurs between ions created within the same track and depends on the ionisation density within the track. Volume recombination takes place between ions originating from different tracks and depends on the dose rate (DR). Numerous theories have been published to describe both mechanisms.

Material and Methods

Measurements were performed in four scanned light-ion beams (proton, helium, carbon and oxygen), using two plane-parallel ICs (one serving as a monitor and the other as the IC under test). The saturation curve was measured at different DRs. Determining the saturation current (I_{sat}) by linear extrapolation of the curve at high voltages, k_s was calculated by dividing I_{sat} by the current measured at the operating voltage (V). Due to the high DRs used with scanned beams and high LET-values, k_s results from a combination of initial and volume recombination: $k_s = k^{ini} k^{vol}$. Experimental results are compared to Jaffé's and Boag's theory for initial and volume recombination, respectively. Jaffé's theory predicts a logarithmic variation of k^{ini} as a function of 1/V, whereas Boag's theory predicts a variation of k^{vol} as a function of 1/V or $1/V^2$, depending on the radiation pulse duration compared to the ion collection time of the IC.

Results

The figures present the theoretical (lines) and the experimental (symbols) variation of k_s as a function of 1/V. Fig 1 shows results obtained in a 96 MeV pulsed PBS proton beam at three DRs and two depths (3.1 cm in black and at the peak in blue). Fig 2 shows results obtained at different DRs at a depth of 1.1 cm in a 115 MeV/n scanned carbon beam (black) and at the middle of a 6 cm SOBP carbon beam centered at 9 cm (blue). Similar graphs are obtained for other beams. Both figures show that initial recombination, which increases with LET, as expected, dominates at the highest voltages. For carbon ions, we can observe an inflection point when volume and initial recombination have similar magnitude.

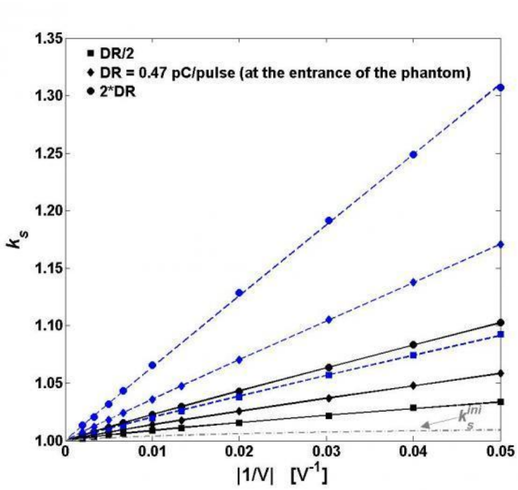

Figure 1. Results obtained in a 96.17 MeV pulsed PBS proton beam.

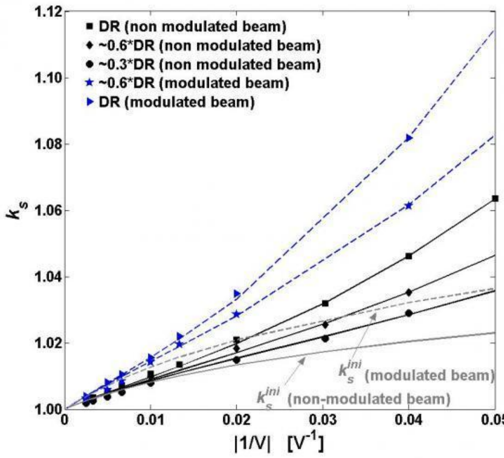

Figure 2. Results obtained in scanned carbon ion beams.

Conclusion

Excellent agreement is found between experimental and theoretical ion recombination correction factors in scanned light-ion beams. Results confirm that k_s cannot be neglected. The solution to minimise k_s is to use the IC at high voltage. However, that brings a risk to observe charge multiplication in the IC. For the IC tested, it was found that a voltage of 300 V can be safety used. Due to the initial recombination contribution, the simple two-voltage method is not applicable to these scanned beams.

Proffered Papers: Quantitative and functional imaging

OC-0066 Are quality improved CBCT images superior for measuring lung ventilation?

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Purpose or Objective

Changes in lung ventilation of lung cancer patients during radiotherapy may predict patient specific toxicities. Ventilation changes during a treatment course can be measured from frequently acquired 4D-Cone Beam CT (4D-CBCT), but as these images are of low quality, improvements in quality may increase the accuracy of the ventilation analysis.