**EP-1943**

**Implications of gold nanoparticles used for dose enhancement in proton radiotherapy**

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**Purpose or Objective:** Heavy metal nanoparticles (NPs) have been widely investigated within x-ray radiotherapy as radiosensitisers, where gold NPs (GNPs) have been deemed to be effective at enhancing the dose to the tumour. Few studies have been carried out for protons, where an extensive investigation of the enhancing factors needs to be carried out to determine the implications that introducing GNPs can have on known dose profiles. In the present work, we demonstrate our model which uses Geant4 to carry out Monte Carlo simulations of NP concentrations being irradiated by a proton beam. These simulations offer an indication as to

the macroscale effects that occur with varying concentrations of GNPs.

**Material and Methods:** Within our model, concentrations of NPs were simulated by calculating the inter-particle spacing of various concentrations, where this spacing was used to model a controllable concentration, whilst minimizing computational time. Investigations were carried out on the effect of concentration over a range of clinically relevant concentrations in line with previous studies (0.01 mg/ml, 0.1 mg/ml and 6.5 mg/ml) [1], [2], [3] at two incident proton energies (60 MeV and 226 MeV). Various results were recorded, such as the energy deposited across the phantom, types of secondary particles produced, the particle track lengths and energy deposited by secondary particles.

**Results:** The results highlight a measurable shift of the distal edge (Fig.1) in the order of millimeters due to the introduction of gold, which can be seen predominantly at high concentrations (6.5 mg/ml) achievable through direct injection. This shift was deemed to be energy dependent, where at lower energies (60 MeV) it was on the order of microns. As demonstrated by other groups, the enhancement was attributed to an increase in the number of secondary electrons, which was proportional to GNP concentration as expected. Our model demonstrates that the magnitude of the effects observed can be related to the concentration.

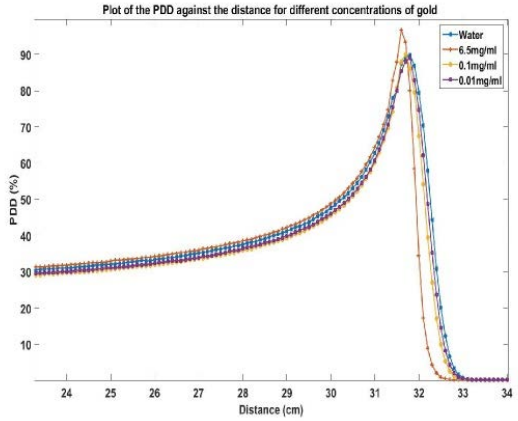


Figure 1: A zoomed in section of the peak, where the plot shows readings at every millimeter using a 226 MeV proton beam, highlighting the differences due to gold concentrations.

**Conclusion:** This study has demonstrated bulk effects of multiple NPs on dosimetry, extending previous work on single NP models by other groups [4]. Results show that injectable concentrations can affect the range of protons, proving to be more significant at higher energies. Future work will investigate the effects that GNPs can have on treatment plans, assessing any changes that need to be made.

References: [1] N. Khlebtsov & L. Dykman, Chem. Soc. Rev. 40 (2011) 1647 [2] J. Hainfeld et al, Phys. Med. Biol. 49 (2004) N309 [3] J.K Kim, et al. Phys. Med. Biol. 57 (2012) 8309 [4] Y. Lin et al, Phys. Med. Biol. 59 (2014) 7675.