Multiwalled Carbon Nanotubes and Radiation Dose Enhancement

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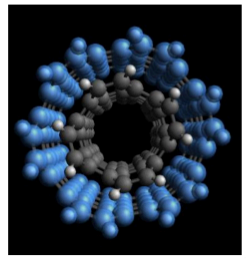
INTRODUCTION

Carbon nanotubes (CNTs) have already shown that they behave differently when exposed to low energy x-rays , in comparison to bulk material, due to their special morphological characteristics. In this work, we show their effect on the measured dose, when exposed to MV beams.



Double-walled CNTs

METHOD

Graphite:	**Powder form with < 20 µm diameter.**
MWCNTs:	Powder with dimensions of O.D. x L = 7-15 nm x 0.5 - 10 µm
Water cylinder:	Acrylic with dimensions of 8.8 cm diameter, 4 mm wall thickness and 11.5 cm height.
Water box surrounding the cylinder:	Acrylic with dimensions of22 cm length, 19cm width and 12 cm height.
Ion chamber holder:	Acrylic, two holders. One places the chamber at the bottom of the cylinder while the other places it midway.
Backscatter material:	Acrylic, 10 cm.
Ion chamber:	A12 Farmer type chamber
Gantry angle:	270°, such that the beam is entering from the side wall of the water box.
Field size (cm²):	20 x 20
SSD (cm):	90

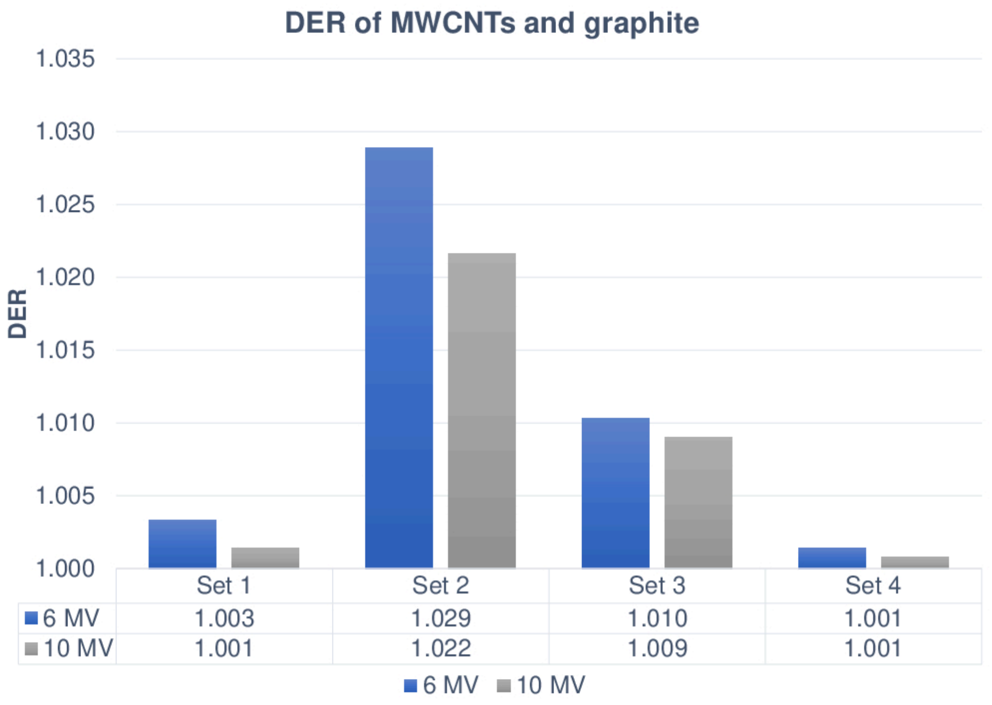
RESULTS

Set# 1,2 and 3 are MWCNTs

Set# 4 is synthetic graphite

Set 1	The ion chamber is at the bottom of the water cylinder, 1.5 cc of MWCNTs
Set 2	The ion chamber is midway of the depth of the water cylinder, 1.5 cc of MWCNTs
Set 3	The ion chamber is midway of the depth of the water cylinder, 1 cc of MWCNTs
Set 4	The ion chamber is midway of the depth of the water cylinder, 1.5 cc of graphite

The dose enhancement ratio is defined as: **DER** = $\frac{Average\ reading\ of\ water+MWCNTs}{Average\ reading\ of\ water\ only}$



Energy	Volume of MWCNTs	DER	S.D.	P-value
6 MV	1.5 cc	1.029	0.0058	0.0001
10 MV	1.5 cc	1.021	0.0058	0.0001
6 MV	1 cc	1.010	0.0058	0.0001
10 MV	1 cc	1.009	0.0058	0.0001

The statistical significance of the samples that result in radiation dose enhancement. (i.e. measurements with ion chamber placed at mid-way between the surface and the bottom of the cylinder, sets # 2 & 3).

The novel finding of the dose increase when pure MWCNTs cannot be explained by the classical model, since the atomic number of carbon (6) is less than the effective atomic number of water (7.4). This should result in reduction (or no change) in the measured dose but our measurements show a dose increase, when CNTs are added to water. There is no clear understanding, at this time, for this phenomenon but we suggest that the effect is seen due to:

a. Alteration in Compton scattering probability due to the special characteristics of the carbon nanotubes.

b. The secondary electrons in the beam react with nanoparticles in a different way than they would in bulk material. Owing to the large surface area of the nanotubes, the probability of interaction increases. Furthermore, electron-electron coulomb interaction is a function of the effective mass, such that it changes with increasing the mass and decreasing the radii of the CNTs

CONCLUSIONS

Defying classical expectations, adding MWCNTs to water has created noticeable dose increase. This increase decreases with decreasing the MWCNT's concentration and with distance from the MWCNTs. The energy of the beam has an inverse effect as well.

FUTURE DIRECTIONS

Measuring the dose enhancement for variable concentrations of Cu-CNTs in water and comparison between simulation values of the dose enhancement vs. measured data. In addition, it is intended to study the effect when the copper filling is replaced with a higher Z material and when MWCNTs are replaced by other carbon-based nanoparticles and find a quantitative measurement for a precise filling mass.

This work focuses in the radiation dose enhancement, the physical radiation dose increase.

REFERENCES

Baskar, e. a. (2012). Cancer and radiation therapy: current advances and future directions. *Int J Med Sci*, 193-199.

Chatterjeea, B. K., , L. A. L., & , S. C. R. (2006). Investigations on compton scattering: New directions. *Radiation Physics and Chemistry, 75*, 2165 - 2173.

Gadoue, Z. S. (2018). The dichotomous nature of dose enhancement by gold nanoparticle aggregates in radiotherapy. *Nanomedicine.*

Krasheninnikov, A. V., & Nordlund, K. (2004). Irradiation effects in carbon nanotubes. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 216*, 355-366. doi:https://doi.org/10.1016/j.nimb.2003.11.061

Kunert, T., & Schmidt, R. (2001). Excitation and Fragmentation Mechanisms in Ion-Fullerene Collisions. *Physical Review Letters, 86*(23), 5258-5261. doi:10.1103/PhysRevLett.86.5258

Kwatra. (2013). Nanoparticles in Radiation Therapy: A Summary of Various Approaches to Enhance Radiosensitization in Cancer. *Transl Cancer Res, 2 (4)*, 330 - 342.

Lu, D., Yan, X. H., & Ding, J. W. (2004). Electron effective mass of single-wall carbon nanotubes. *Acta Physica Sinica -Chinese Edition-, 53*, 527-530.

Maksym, M. R. a. P. A. (2012). Effective mass theory of interacting electron states in semiconducting carbon nanotube quantum dots. *Physical Review B.*

McMahon, S. J., Paganetti, H., & Prise, K. M. (2016). Optimising element choice for nanoparticle radiosensitisers. *Nanoscale, 8*(1), 581-589. doi:10.1039/c5nr07089a

Pastore, R., Micheli, D., Marchetti, M., & Angelini, E. (2016, 22-23 June 2016). *X-ray attenuation properties of carbon nanotubes filled composite materials.* Paper presented at the 2016 IEEE Metrology for Aerospace (MetroAeroSpace).

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