Cluster pattern analysis of energy deposition sites for protons, other light ions and brachytherapy sources

Fernanda Villegas[1], Gloria Bäckström[1], Nina Tilly[1,2], and Anders Ahnesjö[1]

[1] Department of Radiology, Oncology, and Radiation Science, Uppsala University Sjukhusfysik, Akademiska Sjukhuset, SE-75185 Uppsala, Sweden

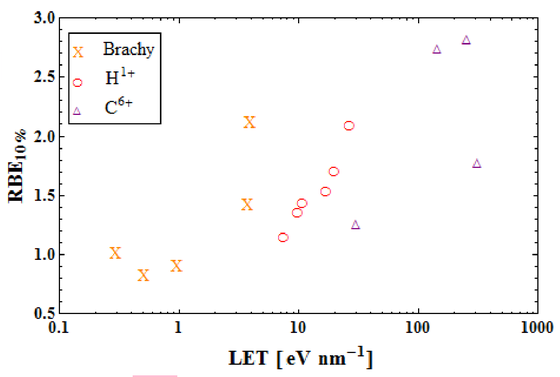
[2]Elekta Instrument AB, Box 1704, 75147, Uppsala, Sweden

Contact email: fernanda.villegas-navarro@onkologi.uu.se

gloria.backstrom@gmail.com

Background

The spatial pattern of energy deposition (ED) sites formed by the interactions of ionizing particles within a cell nucleus relates to the severity of the initial DNA damage and influences the relative biological effect (RBE). RBE data can improve the accuracy of radiotherapy treatment planning. RBE is usually characterized by the linear energy transfer (LET) but several radiation qualities of equal LET can have different RBE values (see figure below) making LET an imprecise predictor of RBE. Clustering of EDs in water might be a more accurate descriptor of radiation quality and its quantification may be useful for development of RBE models for radiotherapy treatment planning.



Aim

To analyse the cluster patterns of EDs in liquid water formed by proton and other light ions as well as five of the most frequently used brachytherapy sources, ^{103}Pd, ^{125}I, ^{192}Ir, ^{137}Cs and ^{60}Co.

Methods

- Monte Carlo (MC) transport code LIonTrack (Bäckström *et al* 2013) was used for simulation of ion tracks while the secondary electron transport was done with a modified version of PENELOPE MC code (Fernández-Varea *et al* 2012, Bäckström *et al* 2013). The latter code was also used for simulation of the brachytherapy sources.

- A novel cluster method that relies on a characteristic cluster distance d_c, was used. d_c is the maximum distance allowed between two neighbouring EDs in order to belong to the same cluster. The cluster order (CO) is equal to the amount of EDs constituting the cluster.

- The frequency distribution of distances to the nearest neighbouring ED per total energy deposited $f(d_{NN_1})/\varepsilon$ was calculated yielding the probability of finding the nearest ED within a distance of d and $d+\Delta d$.

References:

Fernández-Varea J M, González-Muñoz G, Galassi M E, Wiklund K, Lind B K, Ahnesjö A and Tilly N 2012 Limitations (and merits) of PENELOPE as a track-structure code *Int. J. Radiat. Biol.* **88** 66-70

Bäckström G, Galassi M E, Tilly N, Ahnesjö A and Fernández-Varea J M 2013 Track structure of protons and other light ions in liquid water: applications of the LIonTrack code at the nanometer scale *Med. Phys.* **40** 064101

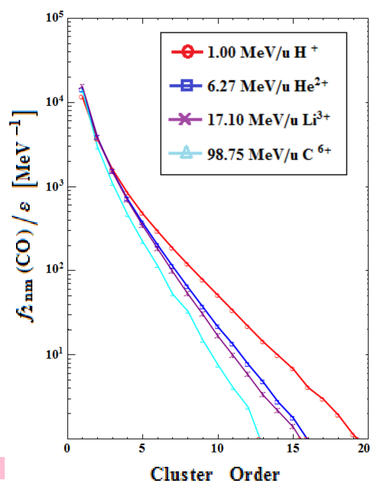
Conclusion

The cluster analysis applied here can distinguish ED patterns between ions with the same LET correlating to differences in RBE. Differences in the cluster pattern of brachytherapy sources were also determined. This encourages us to investigate the use of these cluster order distributions as possible RBE descriptors instead of the commonly used LET.

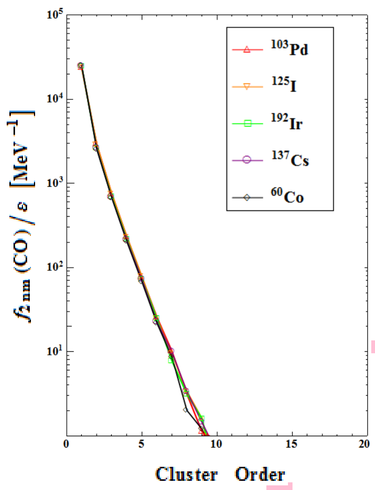
Results and discussion

- Frequency distribution of cluster order with d_c equal to 2 nm i.e. the distance between DNA strands:

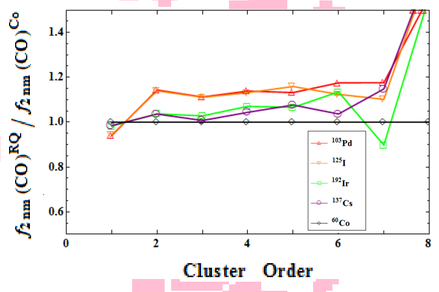
Ions with LET = 25.7 eV/nm



Brachytherapy sources



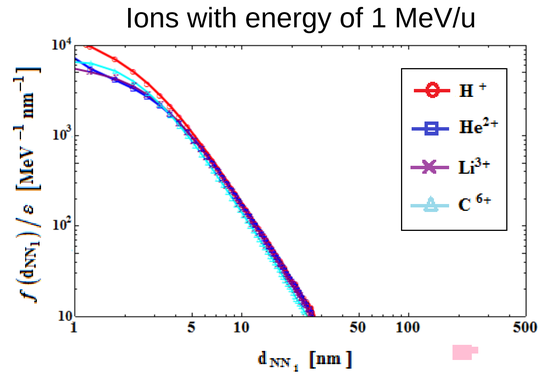
Ratio of distributions with ^{60}Co as reference



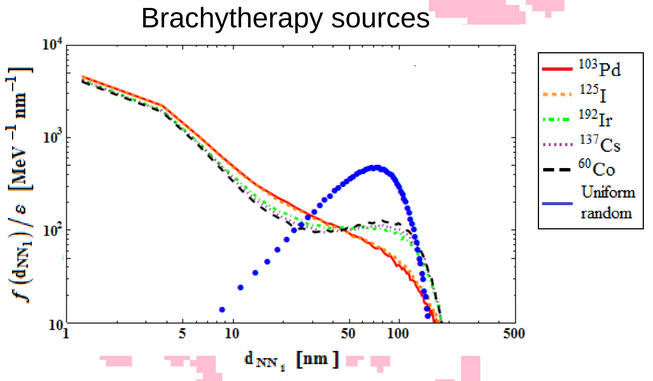
➡ Frequencies decrease rapidly as CO increases for both ions and photons. Clusters with CO>10 are rarely formed by photons regardless of their initial kinetic energy.

- Frequency distribution of the nearest neighbour $f(d_{NN_1})$ for 2 Gy:

Ions with energy of 1 MeV/u



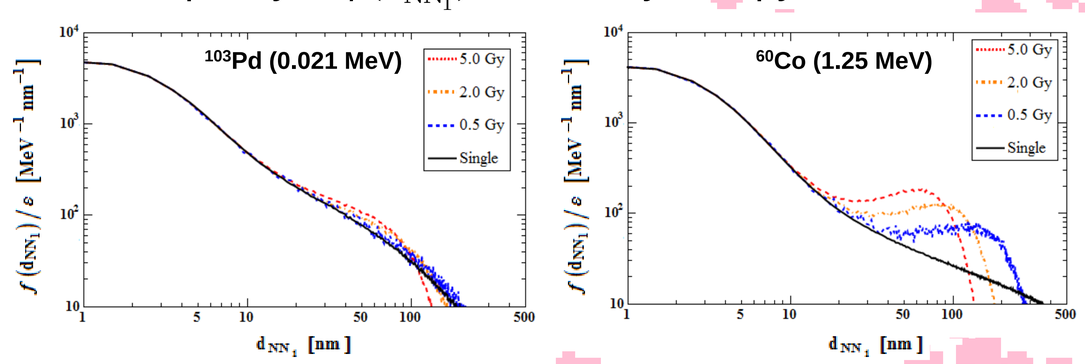
Brachytherapy sources



➡ The $f(d_{NN_1})$ of a uniform random distribution of EDs (blue dots in the figure above) presents a peak that coincides with the peak located at large distances of ^{192}Ir, ^{137}Cs, and ^{60}Co sources.

➡ Photons present a uniform random component at large distances and a non-uniform (structured) random component at short distances. The ions only present the non-uniform random component.

- Dose depency of $f(d_{NN_1})$ for brachytherapy sources:



➡ The uniform random component of $f(d_{NN_1})$ is mainly composed by the electrons produced by the first photon interaction. This component decreases with dose.

➡ The single-track (black line) represents the lowest possible dose and lacks the uniform random component. Inter-track interactions only happen at distances where the multi-track distributions diverge from the single-track distributions (>20 nm).