Monte-Carlo Simulation of Heavy Ion Track Structure
Calculation of local dose and 3D time evolution of radiolytic species

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Importance of heavy ions
- Heavy ions have gained considerable importance in radiotherapy due to their advantageous dose distribution profile and high Relative Biological Effectiveness (RBE)
- Heavy ions are difficult to produce on Earth, but they are present in space and it is impossible at this moment to completely shield astronauts from them
- The risk of these radiations is poorly understood, which is a concern for a 3-years Mars mission [1]

Monte-Carlo track structure simulations can be used to calculate dose deposited in an irradiated volume by high and low-LET radiation
These simulations can contribute significantly to the understanding of DNA damage and non-target effects of ionizing radiation by providing important information such as the dose distribution as well as the 3D time evolution of the radiolytic species

Interaction of radiation with biological media
- The effects of radiation are mainly due DNA damage such as DNA double-strand breaks (DSBs), although non-targeted effects are also very important
- DNA can be damaged by the direct interaction of radiation and by reactions with chemical species produced by the radiolysis of water [2]
- The energy deposition is of crucial importance to understand biological effects of radiation
- Therefore, much effort have been done recently to improve models of radiation tracks

Discussion
- The 3D distribution of dose voxels calculated by RITRACKS have an appearance very similar to DSB observed with γ-H2AX experiments
- In addition, since high-dose voxels appears only in high-LET radiation and DSBs which are difficult to repair are found only in high-LET tracks, we may hypothesis that DSBs created within these high-dose voxels may be of different nature than those created by low-LET radiation.
- Heavy ions are used in radiotherapy because of their dose distribution profiles and high RBE; however, they may also pose a substantial but poorly understood risk for astronauts on a 3 years Mars mission

Conclusion

References

Simulation of heavy ion tracks
- The radiolysis of water is simulated by Monte-Carlo methods, a mathematical technique used to simulate stochastic systems
- A cube of 5µm x 5µm x 5µm is irradiated by a $^{56}$Fe$^{25+}$, 1 GeV/amu ion (LET~150 keV/µm) and by 450 $^1$H+, 300 MeV/amu ions (LET~0.3 keV/µm) for a total dose of ~100 Gy
- The dose is calculated in voxels of 20 nm x 20 nm x 20 nm
- The spatial distribution of dose is different for high and low-LET radiations
- In both high and low LET radiations, many voxels receive a low dose.
Voxels which receive very high dose appears only in high-LET tracks.

Experimental distribution of DSBs in fibroblast nuclei observed in γ-H2AX experiments for γ-rays and 36Fe$^{25+}$, 1 GeV/amu ions (left). DSBs remaining as a function of time for these ions (right) [7]

Distribution of DNA damage within cell nuclei

450 $^1$H+, 300 MeV/amu ions (LET~25 keV/µm) in liquid water

3D irradiation of a 5 µm cube by a $^{56}$Fe$^{25+}$, 1 GeV/amu ion (top) and by 450 $^1$H+, 300 MeV/amu (bottom). The tracks are simulated (left) and the corresponding voxel dose is calculated. By applying a threshold on the dose voxels, the distribution of track end appears.

Conclusion

- Monte-Carlo track structure simulations can be used to calculate dose deposited in an irradiated volume by high and low-LET radiation
- These simulations can contribute significantly to the understanding of DNA damage and non-target effects of ionizing radiation by providing important information such as the dose distribution as well as the 3D time evolution of the radiolytic species

References