

Monte-Carlo simulation of radiation track structure and calculation of dose deposition in nanovolumes

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INTRODUCTION

The radiation track structure is of crucial importance to understand radiation damage to molecules and subsequent biological effects. Of a particular importance in radiobiology is the induction of double-strand breaks (DSBs) by ionizing radiation, which are caused by clusters of lesions in DNA, and oxidative damage to cellular constituents leading to aberrant signaling cascades. DSB can be visualized within cell nuclei with γ -H2AX experiments [1].

MATERIAL AND METHODS

In DSB induction models, the DSB probability is usually calculated by the local dose obtained from a radial dose profile of HZE tracks [2,3]. In this work, the local dose imparted by HZE ions is calculated directly from the 3D Monte-Carlo simulation code RITRACKS[4]. A cubic volume of $5\mu\text{m}$ edge (Figure 1) is irradiated by a $^{56}\text{Fe}^{26+}$ ion of 1 GeV/amu (LET \sim 150 keV/ μm) and by a fluence of 450 $^1\text{H}^+$ ions, 300 MeV/amu (LET \sim 0.3 keV/ μm). In both cases, the dose deposited in the volume is \sim 1 Gy. The dose is then calculated into each 3D pixels (voxels) of 20 nm edge and visualized in 3D[5].

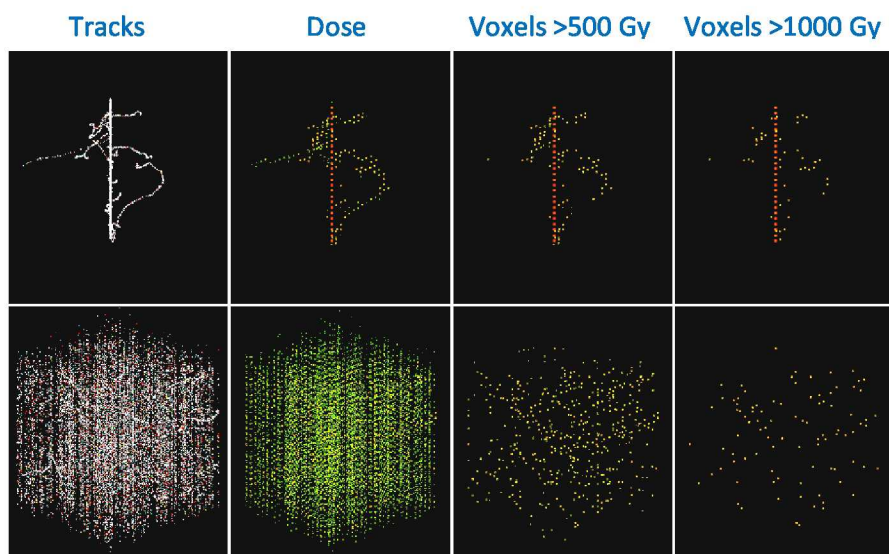


Figure 1: Simulation of the irradiation of a $5\mu\text{m}$ cube by a $^{56}\text{Fe}^{26+}$ ion, 1 GeV/amu (top) and by 450 $^1\text{H}^+$ ions, 300 MeV/amu (bottom). The radiation track structures are shown in the left pictures and the corresponding dose deposited in voxels are shown in the right pictures. The intensity of the dose is represented by a color scale varying from green to red. The same 3D dose maps are also shown by applying a threshold on visualization (>500 Gy and >1000 Gy).

RESULTS AND DISCUSSION

The dose is deposited uniformly in the volume by the $^1\text{H}^+$ ions. The voxels which receive a high dose (orange) corresponds to electron track ends. The dose is deposited differently by the $^{56}\text{Fe}^{26+}$ ion. Very high dose (red) is deposited in voxels with direct ion traversal. Voxels with electron track ends (orange) are also found distributed around the path of the track. In both cases, the appearance of the dose distribution looks very similar to DSBs seen in γ -H2AX experiments, particularly when the visualization threshold is applied.

CONCLUSION

The refinement of the dose calculation to the nanometer scale has revealed important differences in the energy deposition between high- and low-LET ions. Voxels of very high dose are only found in the path of high-LET ions. Interestingly, experiments have shown that DSB induced by high-LET radiation are more difficult to repair. Therefore, this new approach may be useful to understand the nature of DSB and oxidative damage induced by ionizing radiation.

REFERENCES

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