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 \(\gamma\)-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 RITTRACKS[4]. A cubic volume of 5\(\mu\)m edge (Figure 1) is irradiated by a \(^{56}\text{Fe}^{26+}\) ion of 1 GeV/amu (LET\(\sim 150\) keV/\(\mu\)m) and by a fluence of 450 \(^1\text{H}^+\) ions, 300 MeV/amu (LET\(\sim 0.3\) keV/\(\mu\)m). 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].

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. Voxel 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 \(\gamma\)-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