Quantitation of DNA Damage by Low-Energy Electrons

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1. Introduction

Electrons are the common product of ionizing radiations interacting with the medium. Low-energy electrons even more attract the interest of radiation biologists and radiation biophysicists because they determine the pattern of local energy deposition and thus the impact on biological targets. Presented in this paper is the quantitative information on DNA damage caused by low-energy electrons via direct action.

2. Methods

2.1 Electron Track Simulation

A Monte Carlo code ETMICRO (Electron Transport code for MICROdosimetry) [1] was employed for tracing the low-energy electron interactions with liquid water medium. In ETMICRO, electron interactions are categorized in total 11 (1 elastic, 5 excitation, and 5 ionization) scattering modes. The tracing cut-off is set at 10 eV in electron kinetic energy. The upper bound of electron energy allowed for simulating interactions is 10 keV. Figure 1 shows one example of electron tracks initiated by a single 10 keV-electron emission at origin in the positive x-direction. A total track consists of a primary electron track and a secondary electron track, or an elastic collision track and an inelastic collision track. An excitation event track and an ionization event track compose the total inelastic collision track.

2.2 DNA Model

A volume model [2] was adopted for DNA geometry. Shown in Figure 2 is the volume occupied by a single chain of sugar-phosphate moieties. The counterpart not shown in Figure 2 is taken up by the other side of sugar-phosphate moieties of DNA molecules. The central core of the cylinder simulates the base molecules. The minimum energy required for either single strand break or base damage was assumed to be 17.5 eV [3]. DNA single strand break and base damage were counted for the electrons approaching DNA from a varying distance, in different angles (see Figure 3), and with different energies ranging from 100 eV to 10 keV.

3. Results

Figure 4 presents the DNA single strand break and base damage in terms of breakage probability per single electron emission heading for the center of a single DNA molecule. The damage probabilities are given for the target DNA layer and its upper and lower layers as well. More energy is delivered to DNA volume when electrons have lower energy at entering DNA. In consequence, more damage is expected. Electrons started in a distance from DNA surface experience many scatterings before entering DNA. Energy deposition area inside DNA is, therefore, broader as compared to that with electrons entering at one spot of DNA surface. Spattered energy delivery leads to a less probable DNA damage. Strand damage is more probable on the side of electrons' entrance.

4. Conclusion

The volume model of DNA can be the first but not be the best choice of model geometry for estimating the radiation impact on biological targets. A preliminary work presented in this paper is going to be followed by the estimation with a revised, more realistic DNA model.

REFERENCES

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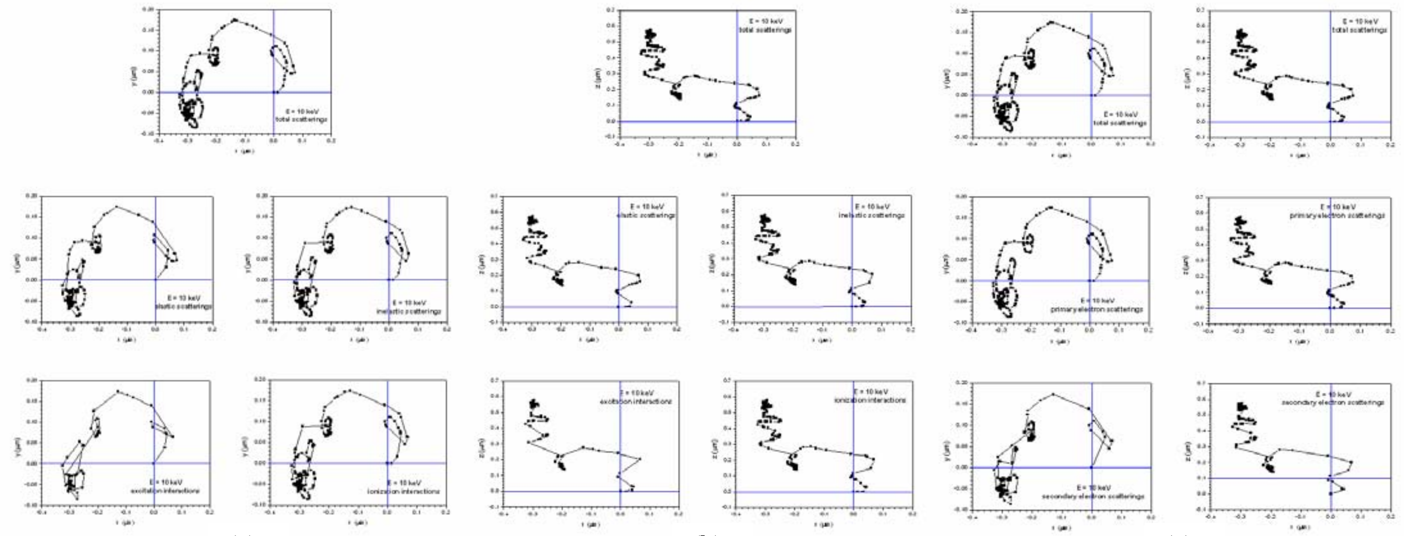
[3] D.E. Charlton and J.L. Humm. A method of calculating initial DNA strand breakage following the decay of incorporated ^{125}I. International Journal of radiation Biology, Vol. 53, p. 353, 1988.



(a) (b) (c)

Figure 1. Electron tracks in liquid water for a 10 keV electron emission at origin in the positive x-direction: a total track, elastic vs. inelastic collision tracks, and excitation vs. ionization event tracks (a) view on x-y plane (b) view on x-z plane; and (c) total vs. primary vs. secondary electron tracks on x-y plane (left) and on x-z plane (right).

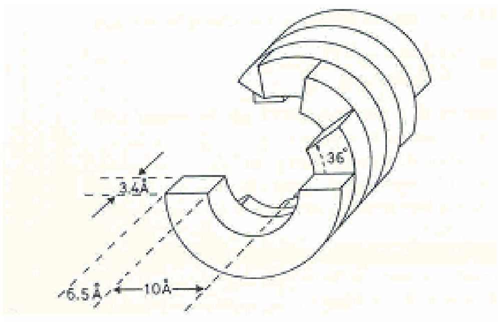


Figure 2. DNA volume model

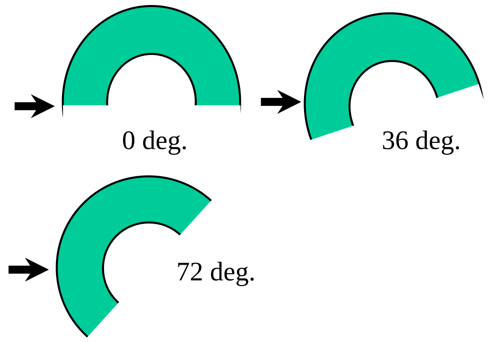


Figure 3. Beam entrance angle

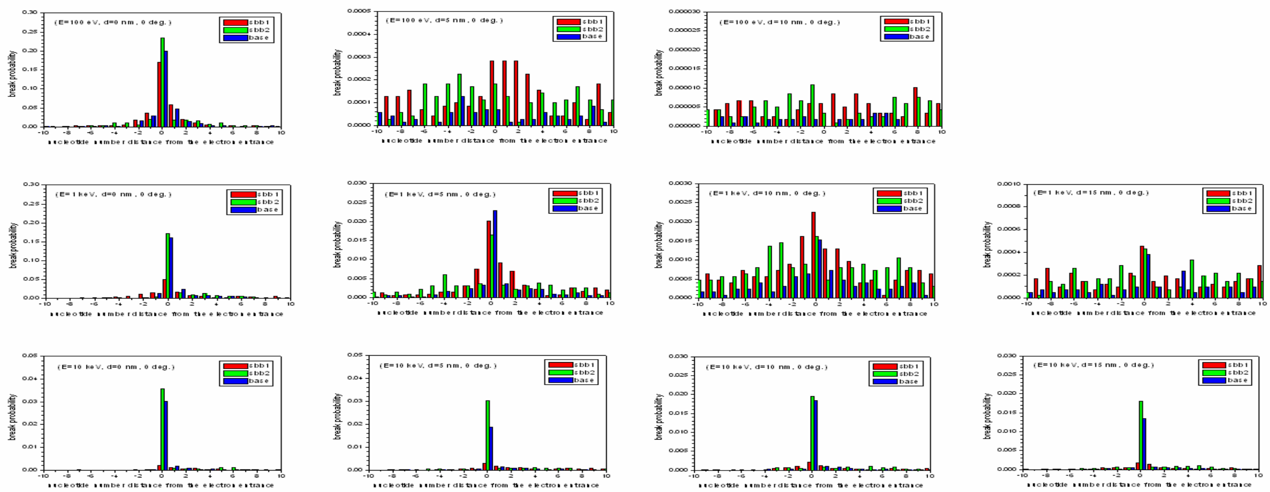


Figure 4. Spatial distributions of DNA single strand break or base damage probability by the electrons approaching from a varying distance with different energies. Different beam entrance angles imply different locations at the single sugar-phosphate chain (SSB1) which electrons initially head for. SSB2 is for the counterpart.