Modelling dose distributions in cell nuclei after irradiation with ultrasoft X-rays

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The Local Effect Model (LEM) is a mechanistic model to describe cell survival after ion irradiation. Its basic concept is that the biological effect mainly depends on the spatial dose distribution within a cell nucleus, hereby inducing double-strand breaks (DSB) within DNA substructures called chromatin loops.

By means of experimental data, it is known that ultrasoft X-rays (0.1 – 5 keV) show a higher biological effectiveness than high-energy photons. Similar to high-LET irradiation, this is attributed to a rather inhomogeneous dose distribution due to a considerably smaller range of secondary electrons and the higher significance of attenuation of the photons itself, which results in an increasing yield of DSB.

As an extension of LEM for ultrasoft X-rays, this increasing yield can be obtained if the dose distribution of ultrasoft X-rays is known. Employing the track structure simulation program *TRAX*, which is based on the Monte Carlo method, the dose distribution of ultrasoft X-rays can be examined.

Methods

The Monte Carlo based program *TRAX* was developed at GSI to simulate track structures and dose depositions of ion irradiation [1]. Interaction probabilities of various ions with different targets are hereby used for a step-by-step simulation. Since ultrasoft X-rays mainly deposit dose via photoelectric effect [2, 3], the simulation was done using electrons as projectile and water as the cellular target.

In a first attempt, the emission of the photoelectrons is assumed to be isotropic and simulations are done for energies between 200 eV and 4.5 keV, with the emphasis on lower energies up to 1.5 keV. To obtain sufficiently precise results, each simulation involved 10^4 runs. The data obtained by *TRAX* include the doses for different radii around the emission point of the photoelectron, therefore displaying a spherically symmetric dose distribution D(r).

For the analysis of the dose distribution there are two key quantities that need to be examined - the maximum range of the secondary electrons and the center dose at r = 0. Maximum ranges for different energies were obtained by simply taking the last data point on which the dose is not equal to zero. Center doses however were obtained by fitting a power line to data points of lower radii and taking the ordinate for r = 0.1 nm, since this represents the minimal radial data given out by *TRAX*.

Results and Discussion

The radial dose distributions show similar shapes for all energies. The energy dependence of the maximum range and the center dose are visualized in Fig. 1 and Fig. 2 respectively. It can be seen, that an increasing energy results in an overall more widespread dose distribution, since the increasing range of dose depositions is accompanied by lower dose depositions in the center.

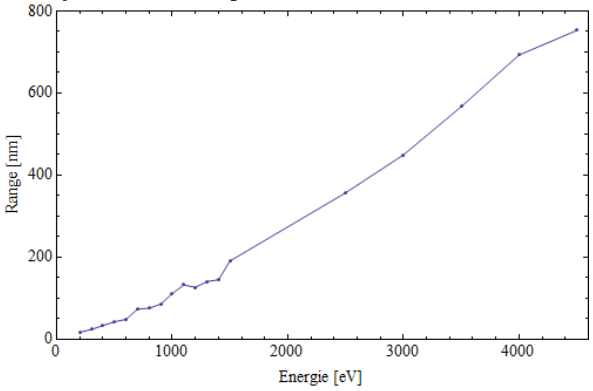

Figure 1: Maximum range over energy

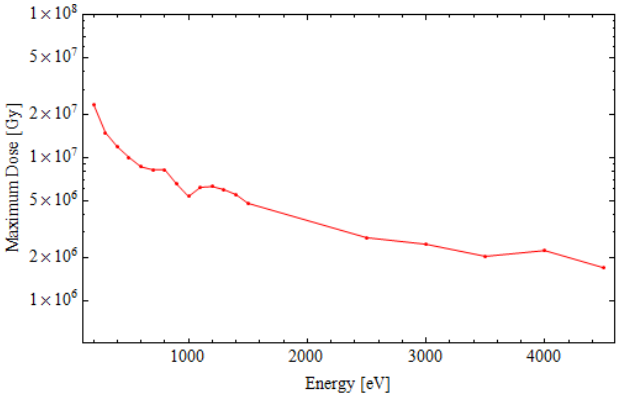

Figure 2: Center dose over energy

As a next step, and hereby presenting a first attempt on the basis of an amorphous track structure, an enhancement factor can be computed that describes the increasing yield of DSB for these distribution patterns due to clustering of single strand breaks on the DNA. Because of the overall broader dose distribution of higher energy photo electrons, it is expected to receive a decreasing enhancement, and therefore a decreasing biological effectiveness with increasing energy. Comparison with experimental data [2] promises to give an instructive insight into the importance of the inhomogeneity for the biological effectiveness of ultrasoft X-rays. Furthermore, since the track ends of ion irradiation also contain low energy photoelectrons, the results may additionally provide further insight into dose depositions induced by ion irradiation.

References

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