SUBMICRON FOCUSED LOW LET PROTON SHOW ENHANCED RBE*

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Due to their physical and radiobiological properties, in particular their increased relative biological effectiveness (RBE), high linear energy transfer (LET) radiation qualities are of special interest for tumour therapy. The aim of the present investigation is to quantify the influence of spatial dose distribution on the RBE of heavy ions. The ion microprobe SNAKE at the Munich tandem accelerator is a unique and ideal tool for this purpose. By focusing low LET 20 MeV protons (LET in water of 2.65 keV/µm) the spatial dose distribution of protons can be modified towards that of heavy ions, e.g. 55 MeV Carbon ions, where the dose deposition is concentrated around the ion tracks [1]. This is illustrated in Fig. 1, where the expected spatial dose distribution for randomly distributed as well as focused 20 MeV protons and single 55 MeV Carbon ions (LET in water of 310 keV/µm) is plotted.

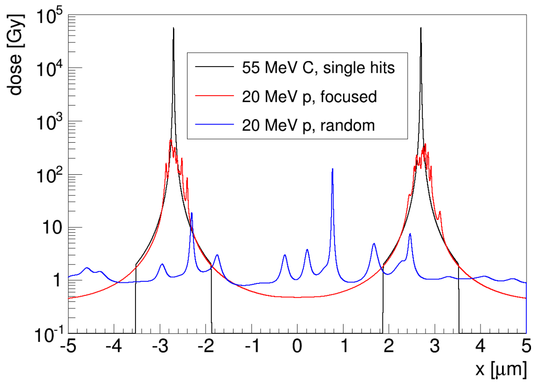

Figure 1 Averaged dose profile resulting from a 1.7 Gy irradiation either with single 55 MeV Carbon ions or 117 protons (20 MeV) focused to each point of 5.4x5.4 µm² matrix or with randomly distributed protons. Focused protons approximate the spatial dose distribution of heavy ions but do not reach the extreme high doses in the track core. Dose profiles are calculated according to the amorphous track structure model of [2]. The proton distribution at each point is assumed to follow a Gaussian distribution with 300 nm full with at half maximum.

In this work the influence of spatial dose distribution is studied on the endpoint of induction of dicentric chromosomes. Human-hamster hybrid (AL) cells were irradiated with randomly distributed 20 MeV protons at a fluence of 4 μm^{-2} or in a quadratic 5.4x5.4 µm² matrix either with focused 20 MeV protons and 117 protons per matrix point or with single 55 MeV Carbon. All three irradiation modes deposit the same mean dose of 1.7 Gy. For comparison a dose effect curve with 200 kV x-rays were measured.

Figure 2 shows the pooled results from two independent experiments. For induction of dicentrics the yield per metaphase is enhanced due to the focused dose deposition by more than 60% from 0.051 after random proton irradiation to 0.083 in focused mode. The RBE is increases from 1.41 to 1.92. Carbon ion irradiation is more effective and induces 0.197 dicentrics per metaphase resulting in an RBE of 3.21 with respect to 200 kV x-ray.

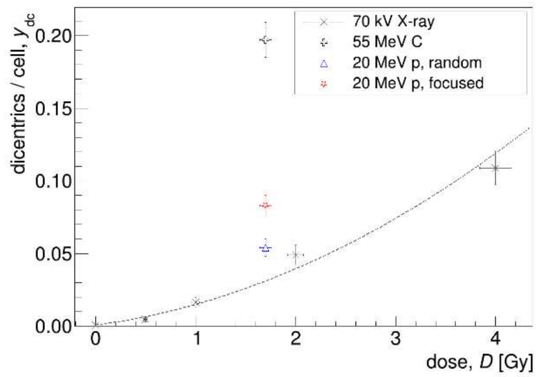

Figure 2 Yield of dicentrics after irradiation with 200 kV x-ray, random and focused 20 MeV protons and 55 MeV Carbon.

The increased effectiveness in the induction of dicentrics between random and focus proton irradiation is attributed to and locally enhance double strand break (DSB) density at the matrix points. This enhances the probability for dicentrics for which at least two DSB at different chromosomes in spatial proximity are necessary. The total amount of DSB is assumed to be unchanged for protons but not from heavy ions. The very high doses in the track core of Carbon ions lead to nonlinear induction of DSB by two single strand break in spatial proximity forming a DSB [3]. This enhance number of DSB explains the even higher RBE for Carbon.

REFERENCES

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