DOSIMETRIC AND RADIOBIOLOGICAL ASPECTS OF CELL MONOLAYER IRRADIATION WITH 14 MEV NEUTRONS IN THE PRESENCE AND ABSENCE OF PROTON EQUILIBRIUM

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Introduction

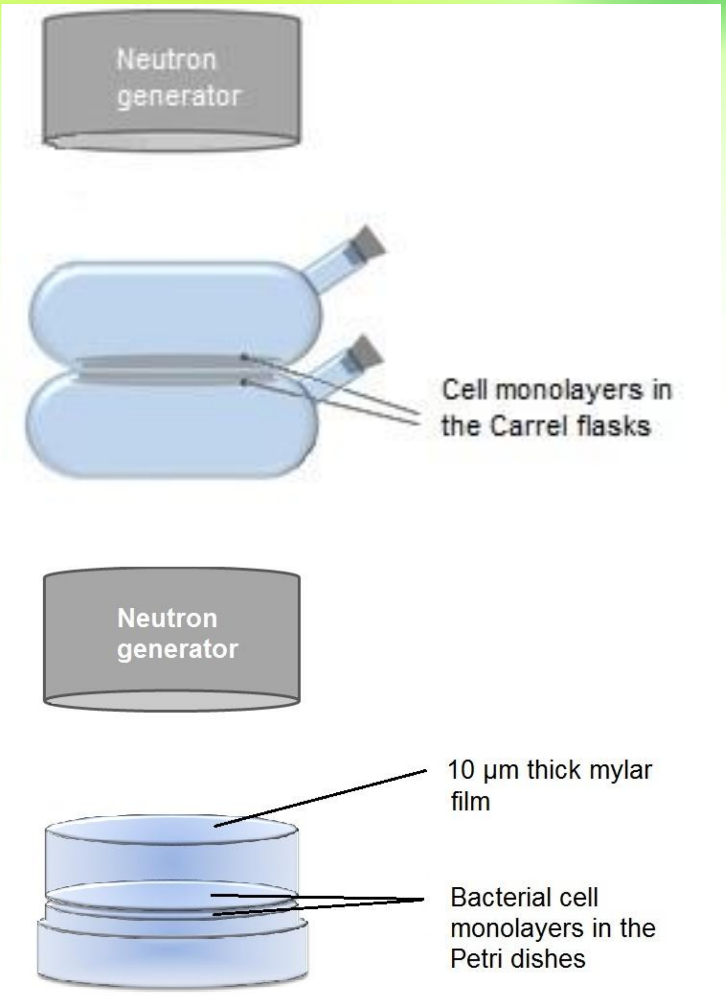
Cell irradiation with 14.5 MeV neutrons in the absence of proton equilibrium allows to investigate radiobiological effects of light ions C, N, O with energies at the Bragg peak and behind it. The situation is close to that in the distal region of carbon ion SOBP. We studied cell survival of two Chinese hamster cell lines, CHO-K1, V-79, and two bacterial strains, E.Coli B_{s-1} and E. Coli WP2, irradiated with 14.5 MeV neutrons in the presence and absence of proton equilibrium.

Materials and methods

Mammalian cell monolayers in Carrel flasks were irradiated with neutrons either through a layer of Hank's solution under conditions of proton equilibrium (CPE) or through a flask glass bottom (absence of CPE).

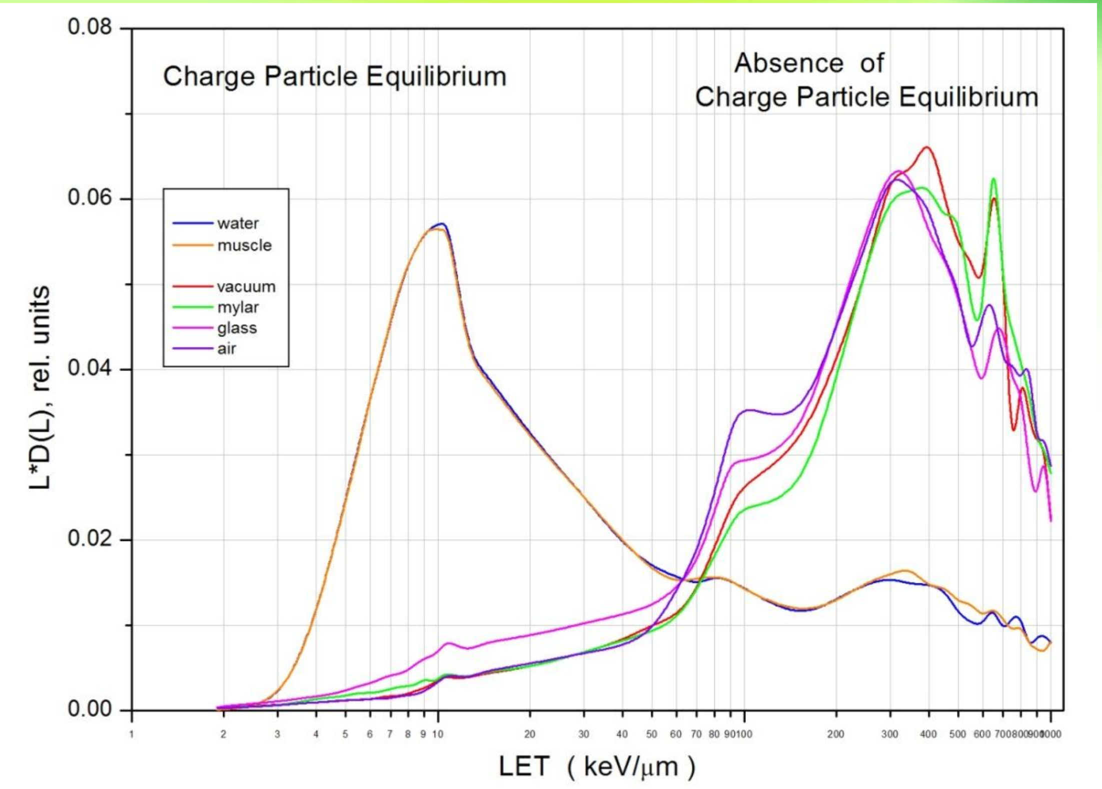
Bacterial cell monolayers were irradiated with neutrons either through polystyrene bottom of Petri dishes plus agar layer (CPE) or through a 10 μm thick mylar window plus 5 mm air gap (CPE absence).

Doses, particles energy and LET spectra with and without CPE were estimated with the GEANT4.



Results

Both charged particles spectra and neutron dose distribution in LET are very dependent on whether charged particle equilibrium (CPE) in material irradiated is provided. In the case of CPE the proton dose (LET< 70–80 keV/μm) dominates (70%) with alphas and heavy recoils contributions being nearly equal.



When the CPE is deliberately avoided by placing a cell monolayer on the border with non-hydrogenous materials, on the contrary, alphas and heavy recoils doses prevail (>80%). Details of different secondary charged particles doses and LET under various irradiation conditions are presented in the tables.

Results

Table 1. Relative dose contribution (%) of different secondary charged particles in a 5 μm thick cell monolayer irradiated with 14.5 MeV neutrons through various materials

Secondary charged particles	Muscle, 3 mm	Water, 3 mm	Vacuum	Glass, 1 mm	Mylar, 10 μm	Glass, 100 μm	Mylar, 5 μm
electrons	0.19	0.17	0.56	0.57	0.43	0.36	0.44
protons	67.5	68.0	11.6	16.4	12.0	13.6	11.1
α-particles	14.6	14.5	28.0	30.8	27.0	31.5	26.6
C, N, O heavy recoils	17.7	17.2	59.8	52.2	60.5	54.6	61.8
D_{absPE}/D_{PE}*	1.0	1.10	0.21	0.35	0.275	0.362	0.266

* D_{absPE}, D_{PE} – absorbed doses under conditions of CPE absence and presence

Results

Table 2. Track-average ($\langle L_t \rangle$) and dose-average ($\langle L_d \rangle$) LET values of the particles spectra in a 5 μm thick cell monolayer irradiated with 14.5 MeV neutrons through various materials

Secondary charged particles	Muscle		Water		Vacuum		Glass		Mylar	
	$\langle L_t \rangle$	$\langle L_d \rangle$	$\langle L_t \rangle$	$\langle L_d \rangle$	$\langle L_t \rangle$	$\langle L_d \rangle$	$\langle L_t \rangle$	$\langle L_d \rangle$	$\langle L_t \rangle$	$\langle L_d \rangle$
electrons	0.37	0.71	0.37	0.71	0.32	0.63	0.38	0.73	0.32	0.63
protons	11.1	18.9	11.1	18.9	19.6	34	17.3	31.5	18.4	34
α-particles	115	129	115	129	128	143	127	141	129	143
C, N, O heavy recoils	391	463	395	471	401	470	389	461	403	477
neutrons	14.8	114	14.8	113	37	325	35.8	289	43	331

Results

To summarize the calculations, under conditions of proton equilibrium partial doses of protons, α-particles, and C, N, O heavy recoils in the 5 μm thick mammalian cells monolayer were 67.5, 14.6 , and 17.7 %, respectively. In the absence of CPE on the glass-muscle interface the doses changed to 16, 31, and 52%, respectively. Protons and α-particles originating in glass increased their partial doses in cells by ≈55 and ≈18 %.

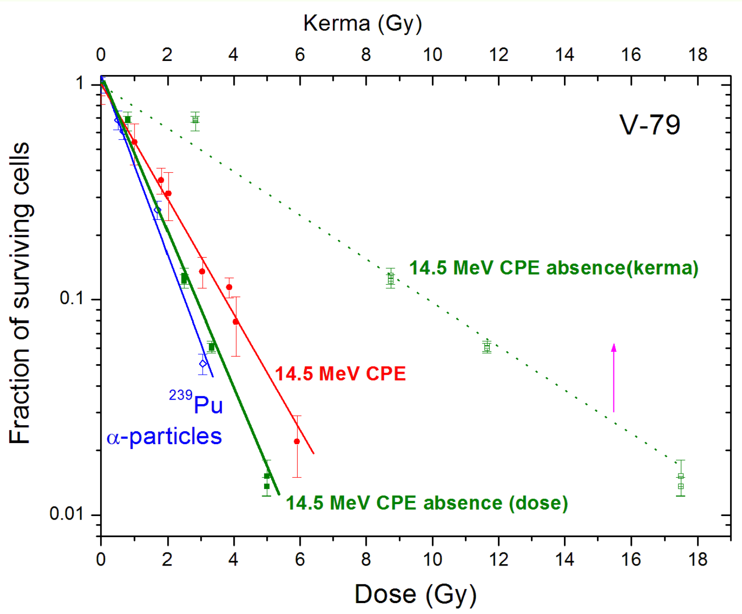
For a thinner bacterial cells monolayer of ≈1 μm the partial dose of C, N, O heavy recoils in the absence of CPE prevailed amounting to 79 % as compared to 5 % and 15 % of proton and α-particles doses.

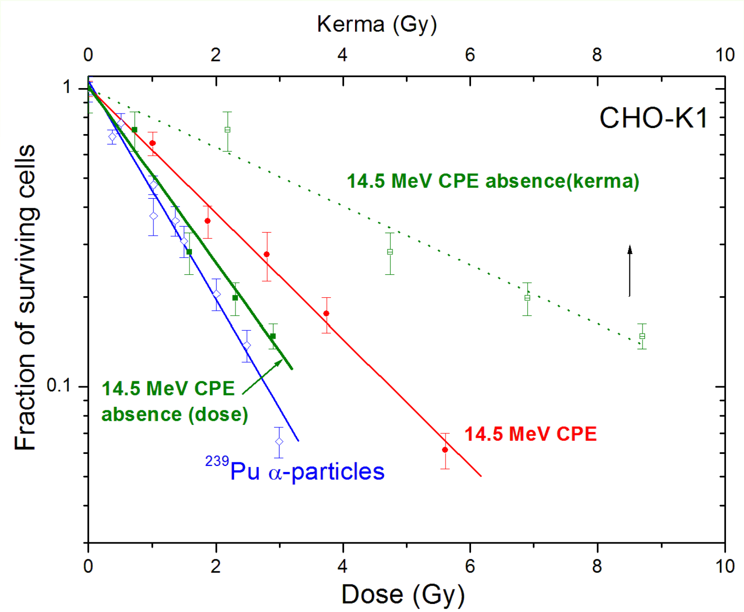
Dose averaged LET values were about 110 keV/μm under CPE conditions, 390 and 660 keV/μm in the absence of CPE for 5 and 1μm thick monolayers, respectively.

In the biological experiments that follow next the neutron doses under conditions of CPE absence were calculated from CPE doses (or kerma) multiplied by the doses ratio from the bottom row of the table 1.

Results

Survival of the Chinese hamster V-79 and CHO-K1 monolayer cells after 14.5 MeV neutron irradiation under conditions of proton equilibrium presence or absence

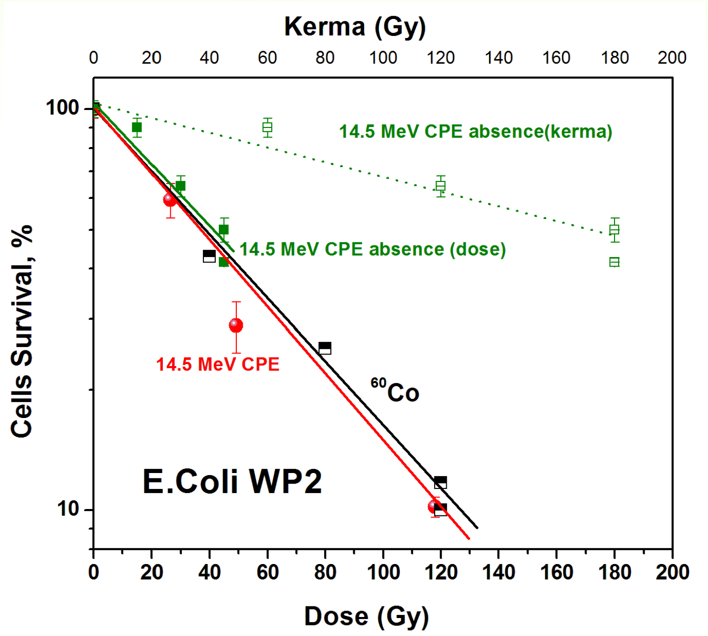


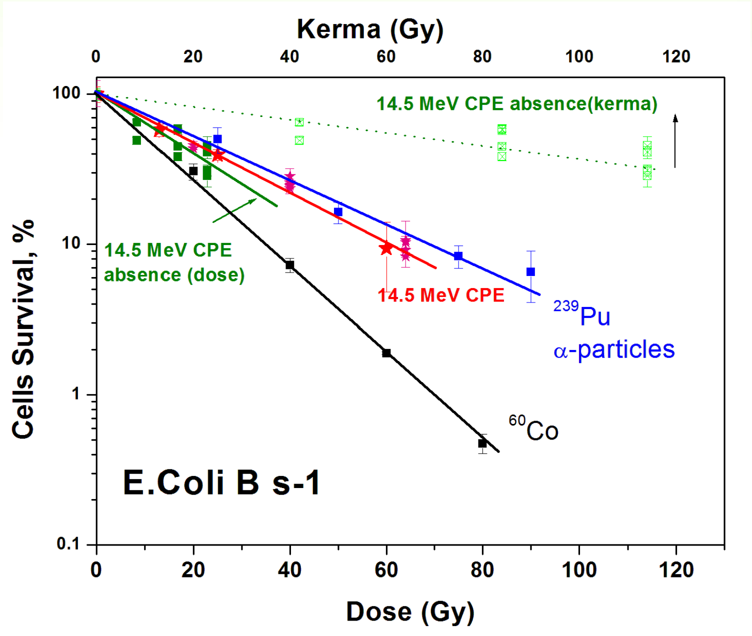


RBE values of 14.5 MeV neutrons under conditions of CPE were 2.1, and 1.7 for Chinese hamster cells CHO-K1 and V-79. In the absence of CPE RBE values increased nearly twofold, 1.85 and 1.6 times, respectively.

Results

Survival of the wild WP2 and radiosensitive mutant B_{s-1} E.coli monolayer cells after 14.5 MeV neutron irradiation under conditions of proton equilibrium presence or absence





For bacterial cells E.Coli B_{s-1} and WP2 RBE were 0.6 and 1.2. In the case of the absence of proton equilibrium RBE increased slightly by only 5–10 %.

Results

It should be noted that RBE values for 14.5 MeV neutrons in the absence of CPE are close to those of α-particles with LET 115 keV/μm, which have the highest RBE as compared to all other particles. It was observed both for mammalian and bacterial cell lines.

Discussion

The calculation and experimental data presented emphasize the importance of CPE provision when dealing with fast neutron irradiation. The survival curves for both bacterial and mammalian cells in monolayer lie much more high if the CPE absence in not considered which can lead to wrong conclusions.

The high biological effectiveness of heavy recoils having ranges ≤ 5 μm raises a question of biological role of particles track-ends in carbon ion therapy as was early pointed for proton track-ends in proton therapy.

Conclusion

The results obtained point out on very high biological effectiveness of slow ions such as C and O with ranges < 5 μm which cannot been predicted from the RBE-LET track-segment relationship. Slow ions track structure and elastic scattering mechanism may partly account for the revealed RBE difference of slow and fast particles.

Thank you for your attention!