Analytical calculation of the energy deposition spectrum and average dose to a spherical target by ion tracks at all impact parameters

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Microdosimetry is used to estimate quality factors for risk assessment in radiation protection [1] and to quantify relative biological effectiveness for treatment planning of hadron therapy [2]. Ions deposit energy in a complex manner: the track structure. Amorphous track models like the Local Effect Model (LEM) and the Kiefer-Chatterjee Model (KCM) are often used as an approximation to the track structure [3]. In the LEM and KCM, the radial dose at radial distance r from the track axis is

$$D_r(r) = \begin{cases} \lambda_1/r_{min}^2 & r \le r_{min} \\ \lambda_2/r^2 & r_{min} < r \le r_{max} \\ 0 & r > r_{max} \end{cases}. \quad (1)$$

In the LEM, $\lambda_1 = \lambda_2 = LET/\pi\rho[1 + 2\log(r_{max}/r_{min})]$, and the core radius r_{min} = 0.0003 µm. In the KCM, $\lambda_2 = 1.25 \times 10^{-4}(Z^*/\beta)^2$, $\lambda_1 = [LET/6.24\rho - 2\pi\lambda_2 \ln(r_{max}/r_{min})]/\pi$, β is the ion velocity relative to the speed of light, $Z^* = Z(1 - \exp(-125\beta Z^{-2/3}))$ is the effective charge for an ion of charge Z, and $r_{min} = 11.6\beta$. In both cases, $r_{max} = 0.062 \times E^{1.7}$ µm is the penumbra radius, E is the energy in MeV/n, ρ = 1 g/cm^3 is the density. Using amorphous track models, we calculated an analytical expression of the dose to a spherical target for tracks outside the target (indirect hits) [4] and extended it to tracks inside the target (direct hits). We also obtained a numerical and an approximate expression of the dose spectra to a sphere irradiated uniformly. The expressions are function of λ_1, λ_2, the target radius R and impact parameter b. The results were compared to those obtained with the radiation track structure code RITRACKS [5].

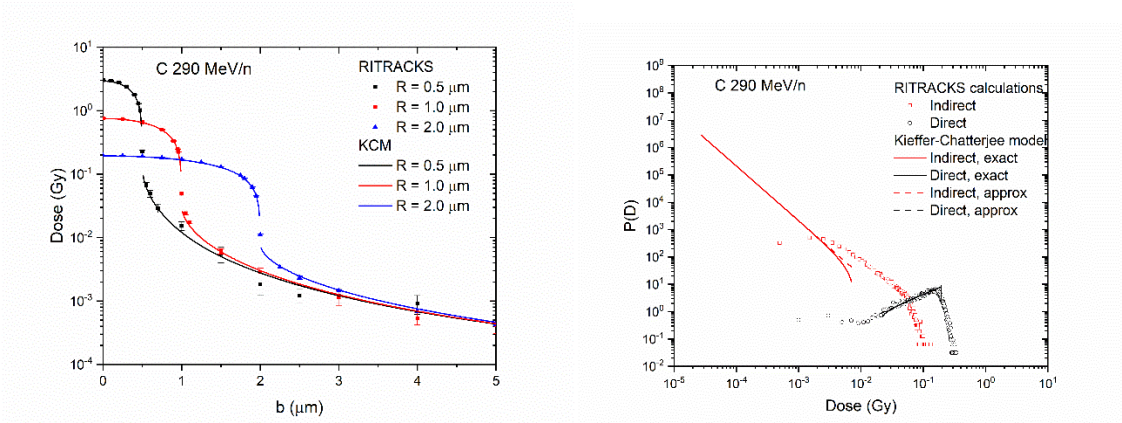

Figure. Left. Dose to a spherical target by a C-290 MeV/n ion as a function of b, calculated by the analytical equations (KCM) and RITRACKS, for three target radii. Right. Dose spectra of a C-290 MeV/n ion in a spherical target (R=2 µm), calculated by the analytical equations (KCM) and RITRACKS.

The analytical model is in good agreement with dose calculation obtained from RITRACKS at all radial distances. The spectrum is in good agreement with RITRACKS for the direct hits, but not as much for indirect hits.

[1] Microdosimetry. ICRU Report 36, Bethesda: ICRU (1983). [2] Inaniwa T. et al. (2010) *Phys Med Biol* 55, 6721-6737. [3] Elsässer T et al. *New J Phys* 10, 075005 (2008). [4]. Plante, I. et al. *Life* 12, 1112 (2021). [5] Plante I. and Cucinotta F.A. (2011) Monte-Carlo simulation of ionizing radiation tracks. In Mode CB (Ed) *Applications of Monte Carlo Methods in Biology, Medicine and Other Fields of Science*, InTech.

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