Simulation of Electron Beam Irradiation of a Skin Tissue Model

John Miller[1], Seema Varma[1], William Chrisler[2], Xihai Wang[2] and Marianne Sowa[2]

[1]Washington State University Tri-Cities, Richland, WA
[2]Pacific Northwest National Laboratory, Richland, WA

Monte Carlo simulations of electrons stopping in liquid water are being used to model electron-beam irradiation of the full-thickness (FT) EpiDerm™ skin model (MatTek, Ashland, VA). This 3D tissue model has a fully developed basement membrane separating an epidermal layer of keratinocytes from a dermal layer of fibroblasts embedded in collagen. The simulations have shown the feasibility of exposing the epidermal layer to low linear-energy-transfer (LET) radiation in the presence of a non-irradiated dermal layer (Miller et al. 2011). The variable-energy electron microbeam at PNNL (Sowa et al. 2005) was used as a model of device characteristics and irradiation geometry. At the highest beam energy available (90 keV), we estimate that no more than a few percent of the beam energy will be deposited in the dermal layer.

Keratinocytes in the epidermis of the Epiderm™ FT skin model are in various states of differentiation. The stratum spinosum and stratum basale layers contain keratinocytes that are undergoing replication and growth; hence, they are the primary targets of the experiments being simulated. To reach these targets, the beam must pass through the stratum corneum, where lose intercellular adhesion between multiple layers of terminally differentiated cells produces air gaps that contribute to the overall thickness of 40 to 50 μm. By image analysis, we determined the density equivalent of the stratum corneum so that we could accurately calculate the energy dependence of beam penetration and the quality of radiation reaching the targets of interest.

The size, shape, and spatial distribution of keratinocyte nuclei in the stratum spinosum and stratum basale layers have been determined by confocal microscopy. These data will enable simulations to calculate the likelihood that a nucleus will be traversed by an electron and the characteristics of energy deposition in those traversals. The primary objective of these simulations is to determined the experimental conditions where nuclei will be traversed by many tracks, producing a narrow distribution of target doses, and conditions when the likelihood of traversal is low, producing a broad distribution of target doses and many bystanders. In all cases, tissue dose is expected to be substantially greater than mean target dose due to screening by the stratum corneum. We are interested in assessing which of these doses is more relevant to the observed responses.

References

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