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A dynamic radio-aerosol deposition and clearance model for the quantification of radiation burden and biological effects in the central airways

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Elucidation of health effects of low dose radiation exposures is one of the most challenging issues of current radiation biology. Establishment of plausible dose-effect relationship for the range of low doses is hampered by numerous factors. Irradiation of humans for experimental purposes has serious ethical barriers. Animal experiments are also restricted. In these circumstances epidemiology, in vitro cell/tissue irradiation experiments and modelling are the suitable and complementary tools of radiation research.
In this work, a numerical model has been developed in order to simulate the simultaneous action of particle deposition and clearance in the central airways. Particle deposition within a characteristic airway bifurcation (generations 4-5) was studied by computational fluid and particle dynamics methods. Clearance was modelled by determining the trajectories of particles trapped and propelled by mucus. Sources of radioisotopes were the deposition sites in the bifurcation and the radioactive particles cleared up from the deeper regions of the airways. These isotopes may decay while travelling through the studied bifurcation. Alpha decay of short lived radon progenies has been modelled by Monte Carlo techniques. Alpha tracks were generated. Their origins were the locations of the decays, while their direction was randomly selected. The 3D bronchial epithelium has been digitally reconstructed. The radiosensitive epithelial cells had ellipsoidal shapes. Cellular and cell nucleus doses were determined based on the intersections of alpha-tracks with the cells. Cell killing and transformation were determined based on the computed cell nucleus doses. The model has been applied for exposure conditions characteristic of homes.
Based on our simulations the deposition of radioisotopes is highly inhomogeneous. Clearance is also nonuniform. Mucus velocities can be two orders of magnitude lower in the close vicinity of bifurcation peak resulting in delayed clearance of particles deposited nearby. The results demonstrate that the contribution of upclearing particles to the total activity in a central airways bifurcation is similar to that of the primarily deposited particles. Furthermore, decay patterns are less inhomogeneous than the deposition patterns. Cell inactivation and cell transformation curves seem to be linear, at least for the modeled very low doses. Present results may serve as inputs for complex radiation induced cancer models.

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