A multiscale nanodosimetric study of GCR protons and albedo radiation in the organs of astronauts on the lunar surface

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The early DNA damage on the surface of the moon due to GCR protons and alpha particles were assessed using a multiscale approach in Geant4. This consisted of three simulation stages. Firstly, a periodic boundary conditions approach was used to obtain the radiation field on the surface and inside a proposed lunar habitat [1]. Then, the radiation field on the cellular scale was obtained in the organs of male and female astronauts using the ICRP145 tetrahedral mesh phantoms [2] with an associated spacesuit geometry [3]. Lastly, this was simulated using a full human cell model [4] in Geant4-DNA to obtain the early DNA damage. A physics list was developed to extend track structure models up to 100 GeV. Hadronic interactions and the modelling of induced radiochemical species were also implemented. The early DNA damage was assessed using the Geant4-DNA *molecularDNA* example. Extension of the track structure models to high energies was found to be critical for simulating the early DNA damage of higher energy protons and ions.

[1] - Grandl, W., 2007. Lunar base 2015 stage 1. *Acta Astronautica*, *60*(4-7), pp.554-560.

[2] - ICRP, 2020. Adult mesh-type reference computational phantoms. ICRP Publication 145. Ann. ICRP 49(3).

[3] - De Angelis, G., Anderson, B.M., Atwell, W., Nealy, J.E., Qualls, G.D. and Wilson, J.W., 2004. Astronaut EVA exposure estimates from CAD model spacesuit geometry. *Journal of radiation research*, *45*(1), pp.1-9

[4] - Chatzipapas, K.P., Tran, N.H., Dordevic, M., Zivkovic, S., Zein, S., Shin, W.G., Sakata, D., Lampe, N., Brown, J.M., Ristic-Fira, A. and Petrovic, I., 2023. Simulation of DNA damage using Geant4-DNA: an overview of the "molecularDNA" example application. *Precision Radiation Oncology*, *7*(1), pp.4-14.