Calculation of Absorbed Dose Coefficients for Internal Ex Vivo Irradiation of Lymphocytes Using GATE and Geant4-DNA

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Background: This study describes a method to calculate the absorbed dose coefficient to lymphocytes per milliliter of blood (d_{lymph}) for 1 h of internal ex vivo irradiation of whole blood with radionuclides used in Nuclear Medicine. Using GATE at the macroscopic level and Geant4-DNA at the cellular level, we want to establish a relationship between activity and absorbed doses in the nucleus of lymphocytes.

Material and Methods: The simulation at the macroscopic level was performed in a cylindrical water equivalent medium contained in an 8 ml vial. The lymphocytes were simulated as 1000 spheres of 3.75 μm radius [1] randomly distributed in the water equivalent medium and defined as cold sources. A phase-space actor was attached to each sphere to register all the entering particles. Using the GATE ion source definition, the radioactive decay of ^{18}F, ^{68}Ga, ^{90}Y, ^{99m}Tc, ^{123}I, ^{124}I, ^{131}I, ^{177}Lu, ^{223}Ra, and ^{225}Ac was simulated. For ^{223}Ra, and ^{225}Ac $1x10^9$ events were simulated; for the others $2x10^9$ events. The simulation was performed using the physics list QGSP_BIC_EMZ. A second simulation for each radionuclide was performed using Geant4-DNA. The 1000 phase spaces were summed in one single phase space and used as a source by Geant4-DNA inside the *clustering* example (using the G4EmDNAPhysic physics constructor). The target (lymphocyte nucleus) was defined as a water sphere of a 3.1 μm radius [1]. The deposited energy per sphere was calculated by dividing the total deposited energy by the number of spheres in the vial. Lastly, the d_{lymph} values were calculated and compared with a previous study where the absorbed dose to the whole blood (d_{Blood}) was calculated [2].

Preliminary results: The d_{lymph} values differed from the d_{Blood} values in the order of 10% for ^{99m}Tc, ^{223}Ra, and ^{225}Ac; 17% for ^{177}Lu and ^{123}I; 27% for ^{18}F and ^{131}I. Most considerable differences (more than %50) were observed for high-energy beta- and positron-emitting radionuclides (^{90}Y, ^{124}I, and ^{68}Ga). Further studies using other physics constructors are required to evaluate these differences.

[1] V. Loiko et al. J. Quant. Spectrosc. Radiat. 2006.
[2] M. Salas-Ramirez, et al. Z Med Phys. 2022.