Physics as a basis to understand biology: Monte Carlo approaches to investigate ionizing-radiation effects at the level of DNA, chromosomes and organs.

F. Ballarini[1,2], G. Battistoni[2], F. Cerutti[2,3], A. Ferrari[2,4], E. Gadioli[2,3], M.V. Garzelli[2,3], A. Mairani[1,2], A. Ottolenghi[1,2], L.S. Pinsky[5], P.R. Sala[2], S. Trovati[1,2]

1 University of Pavia, Nuclear and Theoretical Physics Department
2 INFN (National Institute of Nuclear Physics)
3University of Milano, Physics Department
4 CERN, Geneva, Switzerland
5 University of Houston, Physics Department

Exposure of biological structures to ionizing radiation can induce different damage types at various levels, from DNA and chromosomes up to tissues, organs and entire organisms. These multi-step processes, which are still not known in detail, involve different orders of magnitude both in the space and in the time scale. However, the pattern of initial energy deposition in matter, which is completed at 10^{-15} s after irradiation, strongly influences the subsequent evolution of the process.
Great help to elucidate the underlying mechanisms and to perform reliable predictions is provided by mechanistic models and Monte Carlo codes, which allow one to take into account the stochastic aspects that characterize energy deposition in matter. Concerning damage at the cellular and sub-cellular level, herein we will present and discuss examples of application of an "event-by-event" approach to the simulation of radiation-induced chromosome aberrations, with focus both on the role played by the particle track structure at the nm level and on the relationship between specific aberrations and cancer (typically Chronic Myeloid Leukemia). Main assumption of our model is the hypothesis that only clustered lesions (CLs) of the DNA double-helix can evolve and lead to aberrations.
Concerning radiation-induced damage at the level of tissues and organs, possible criteria on the inclusion of radiobiological effects into transport codes will be discussed. In particular, we have developed an approach consisting of on-line integration of data from "event-by-event" codes into "condensed-history" codes like FLUKA, which can deal with transport and interaction of electromagnetic and hadronic particles over a wide range of energies and materials, also taking into account nucleus-nucleus interactions down to a few tens MeV/n. This way we can calculate distributions of organ doses in astronauts exposed to space radiation, for which there exists now a renewed interest due to a possible mission to Mars. More specifically, different dose types (absorbed, equivalent and "biological", the latter defined as the average number of CLs per cell in a given organ) were calculated following exposure to Galactic Cosmic Rays and Solar Particle Events under different shielding conditions. The contributions from secondary particles produced in nuclear interactions were calculated separately with respect to the primaries, and neutrons were scored separately with respect to all other secondaries. Finally, the relationship between "biological dose" and chromosome aberrations (and thus cancer risk) will be discussed.