

# note technique

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## **Nuclear fragmentation models and uncertainties in cosmic ray transport and radiobiology studies\***

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The biological effects of relativistic nuclei are of interest because of their potential hazards to astronauts during spaceflight and for possible radiotherapy treatment for cancer patients. Nuclear fragmentation alters the composition of relativistic ion beams as they pass through tissue or other shielding materials, providing a mixed radiation field and complicating the understanding of biological effects. For high energy proton beams, production of high linear energy transfer (LET) secondaries in tissue is responsible for the increase in relative biological effectiveness (RBE) above unity and is observed to reach values above 2 for some endpoints at low doses [2]. In survival studies along the Bragg curve, fragmentation effects cause moderately charged beams to alter their shoulders as they progress through the plateau region. Higher charged beams, which are normally exponential, also undergo a change in their slope [5]. The description of the transport process, including the complications of mixed radiation fields, is accurately described by the Boltzmann equation [9] ; however, the accuracy of the solution is largely dependent on the nuclear fragmentation cross sections.

For the study of transport processes in radiobiology, track-structure models are required in order to consider the lateral extension of an ion track due to secondary electrons. The Katz parametric formalism for the action cross section [4] has been used in a linear kinetics model to provide a description of dose-rate and cell cycle effects [10]. The mutation rate at the HGPRT locus has been modeled using data for human lung [1] and skin [8] fibroblasts in the kinetics model. As a test of the importance of fragmentation parameters on prediction of biological effects during spaceflight, the physical bounds on the fragmentation process have been considered [7] and are used to evaluate the uncertainty in mutation rates in deep space. Here, the upper bound considers only the removal of one nucleon in each fragmentation event, while the lower bound considers the complete dissociation of the projectile nucleus in the

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event. Results with the present model of cosmic ray transport [9] indicate mutation rates of about  $5 \times 10^{-6}$ /year for nominal shields and an uncertainty larger than 50 % for shields with depths greater than  $20 \text{ g/cm}^2$  from the fragmentation parameters alone. Fragments produced with the greatest mass are much more effective in producing mutations and also control the growth of lighter particles which become important for thick shields.

The dominance of peripheral events in nuclear fragmentation and the importance of the heavy fragments in biological studies indicates that models of this process will be very useful. Traditionally, the abrasion-ablation models [3] have been the most successful and are quite convenient for application, since they require only the one-body density, energy dependent, two-body amplitudes and a standard evaporation code. One of the drawbacks of these models is that the excitation energy of the pre-fragment that results from abrasion is not determined by the model and is treated in an *ad hoc* fashion. Recent progress in the modeling of light ion breakup suggests that the abrasion step can be re-formulated in terms of many body response functions and the distribution in excitation energies found as a function of the number of abraded nucleons [3]. ■

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