Radiation Track Structure

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Abstract

Track structure is the key property that gives ionizing radiation its considerable potency in causing biological effects and determines the relative effectiveness of different types of radiation for a wide variety of effects. The tracks are the stochastic patterns of the interactions of the charged particles as they pass through matter. The patterns are highly diverse and they of importance at all levels of biological organization, from sub-nanometre dimensions upwards. Space radiation contains a unique variety of particles and energies that are not experienced on earth, and this fact poses a major challenge to understanding and estimating the risks of such radiation. High-charge-and-energy (HZE) particles produce an enormous diversity of track structures that contain tight clusterings of ionizations on the nanometre scale and also long-ranged secondary electrons that can spread the track width to millimetres or even centimetres.

This lecture discusses selected aspects of track structure of common radiations on earth compared to those in space and it illustrates some of the consequences for DNA damage and conventional DNA-damage-related biological effects. Students are invited to think for themselves about possible wider implications for other biological effects, tissues, and pathways, including so-called non-targeted effects and system-wide effects.

In summary, radiation tracks drive the biological outcomes with production of clustered DNA damage, including complex varieties, sparse ionizations potentially contributing to some sensing and signaling pathways (via large amounts of minor molecular damage) and by determining the temporal and spatial patterns between separate tracks. Near to the primary ionizations along the trajectory of an HZE particle are overlapping low-energy electrons, while far from the trajectory are individual delta-ray electrons similar to those produced by X-rays and gamma-rays on earth. But here ‘near’ and ‘far’ are relative terms that depend strongly on the velocity of the particle, as well as its charge and also the sizes of the biological target materials of interest for particular biological effects. The nuclei of cells traversed by an HZE particle will experience regions of very high ionization density, but nevertheless as much as 50% of the deposited radiation energy may fall outside of the nucleus and in other cells up to a centimetre away (for a particle of energy 1 GeV/u). The likely impact of this spread will depend on the particular biological effects under study.

Linear energy transfer (LET), or stopping power, is commonly used as a parameter to describe and compare the qualities of different radiations and their relative biological effectiveness. However, LET falls very far short of what is needed to specify all the relevant properties of radiation tracks. Neither LET, nor any one of the other single parameters that have been proposed, is sufficient alone as a descriptor of radiation quality for biological effects in particular or in general. Additionally, different biological effects and mechanisms will emphasize different aspects of track structure.

An important part of the research challenge is to gain sufficient understanding of the radiobiological pathways and their dependence of radiation quality so as to enable accurate extrapolation and generalization of experimental or epidemiological results across the wide array of space and earth radiations for estimation of risk and medical implications.

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