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Detector Response to Swift Heavy Ions*

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1) INTRODUCTION

Track theory is a description of the structure of particle tracks which characterizes the response of many different sorts of "detectors" to energetic heavy ions. It is a parametric rather than a mechanistic description. The medium is a black box containing targets whose response to gamma rays is described by the cumulative Poisson distribution. The response to swift heavy ions is intimately related to the response to gamma rays through the radial distribution of dose about the ion's path.

Most physical systems are 1-hit in their response to gamma rays. We have found 2-hit physical systems and hittedness as high as 8 in desensitized nuclear emulsions. In this model of particle tracks each detector is represented by experimental parameters, with no attempt to analyze mechanism (1). The model for physical detectors utilizes 3 parameters, E_0, the dose at which there is an average of 1 hit per target, C, the hittedness, and a_0, the target size. In simplest approximation we may imagine that the hittedness is the number of electrons which must pass through a target to activate it. The model for biological cells requires a fourth parameter σ_0 to approximate the size of the region in which the targets are contained, often the cell nucleus. The cell model has also been used to describe the damage done to photoresists by swift heavy ions (2).

Here we are only concerned with the initiation event and the observed end point. Unlike mechanistic models we are not at all concerned with the manifold of intermediate steps between initiation and observation. There is often confusion about the relationships of mechanistic to parametric ideas. Thus, supralinearity in TLD-100 is mechanistically explained by a "track interaction model" in which the supralinearity arises in the heating stage. To the parametric description this is simply a 2-hit process, corresponding to the need for a pair of interacting electron tracks. It is of no consequence that the interaction took place in a heating stage.

2) THE G VALUE

If N is the number of undeveloped grains per unit volume, and σ is the action cross section then the number of detectable events per unit pathlength is σN. To get a G value (most frequently used in radiation chemistry) we divide by the stopping power, L, to find

$$G = \sigma N/L \tag{1}$$

For such calculations we need to know the size of a target and the number of targets per unit volume. Where there are no obvious grains the "grain size" may be an approximation to some characteristic distance, like a diffusion length, and the number of targets per unit volume can be taken to be the reciprocal of the target volume. Such an approximation been made for heavy ion radiolysis in water and benzene. In these detectors there may be different response characteristics for different end-points. The production of $HO_2\cdot$ radicals in water is a 2 hit process as is the production of H_2 from benzene (3). In the Fricke dosimeter, the creation of Fe+++ from Fe++ ions by the products of water radiolysis is a 1 hit process (4) . Thus the same substance, liquid water, can behave like a 2 hit or a 1 hit detector depending on the observed end point.

3) THE TRACK WIDTH REGIME

With heavy ions the track in emulsion (and in some other detectors) often looks like a hairy rope, as large numbers of energetic secondary electrons are produced, some of which can penetrate to considerable radial distance from the ion's path perhaps to hundreds of grain diameters. We refer to such tracks as being in the "track width" regime.

With heavy ion tracks the appearance of the track critically depends on hittedness. When C=1, grains will be developed to the outermost reach of delta ray penetration. At higher C single electron tracks may be unobservable, and the track of a heavy ion is observable only where the density of delta rays is sufficiently high that C electrons are likely to pass through a grain. A C-hit detector gives the appearance of having a "track core" effect for there are always many more low energy delta rays of limited radial penetration than there are high energy delta rays. Such words as "track core effect", "thermal spike", and "ion explosion spike" have been used as qualitative descriptions of events taking place close to the ion's path. We know of no valid evidence for a track core in energy deposition or a thermal spike or an ion explosion spike.

In the track width regime in a nuclear emulsion the innermost part of the track is nearly opaque. The probability for grain activation, P, is nearly 1 close to the ion's path, where many electrons may pass through a grain, is some lesser value at larger distances, and is 0 beyond the maximal radial distance, T, to which secondary electrons can penetrate. Since the action cross section is found as the radial integral of the activation probability, P, we have

$$\sigma = 2\pi \int_{t=0}^{t=T} P(t)tdt \qquad (2)$$

The greatest possible value of the cross section is πT^2. This limiting value decreases as the ion slows down as it approaches the end of its range where the number of delta rays increases but their maximum energy decreases. Visually we see the track end of a heavy ion in electron sensitive emulsion looking like a sharpened pencil. This is called the region of "thin-down".

We note that in the thin down region the cross section decreases as the stopping power increases. Thin-down has been observed with emulsion, scintillation counters, TLD's, and for several radiobiological end points (5).

4) COMMENTS

The track model is global. But we must remember that global models cannot be mechanistic, nor can mechanistic models be global. It has frequently been the case in physics that parametric fits to data have served to stimulate a mechanistic understanding. Witness the relationship between the Balmer formula and the Bohr model of the hydrogen atom. Hopefully our present parametric model of particle tracks will serve to stimulate a mechanistic understanding of the behavior of the many detectors to which it has been applied.

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References

1. R. Katz, "Track Structure Theory in Radiobiology and in Radiation Detection," Nucl. Track Detection 2,1-28 (1978).

2. R. Katz, "Formation of Etchable Tracks in Plastics," Nuclear Tracks and Radiation Measurements **8**,1-4 (1984).

3. R. Katz and GuoRong Huang, Effects in Heavy Ion Radiolysis"" "Track "Core" Effects in Heavy Ion Radiolysis," Radiation Physics and Chemistry (in press) (1989).

4. R. Katz, G. L. Sinclair, and M. P. R. Waligorski, "The Fricke Dosimeter as a 1-hit Detector," Nucl. Tracks Radiat. Meas. **11**,301-307 (1986).

5. R. Katz, D. E. Dunn, and G. L. Sinclair, "Thindown in Radiobiology," Radiat. Prot. Dosimetry **13**,281-284 (1985).