Is Microdosimetry Important When Evaluating Dose to Wildlife from Chronic, Low Level Exposures?

Leslie Braby

Texas A&M University

Microdosimetry often serves two functions

- Characterizing radiation quality in an unknown radiation environment
- Helping us understand biological significance of a low level radiation exposure

Microdosimetry is used in situations such as

- Exposures including neutrons and other radiations
- Exposures in space involving very high energy heavy ions

Is it relevant to environmental issues?

First, what is microdosimetry

- An experimental technique for characterizing unknown radiations
- A technique for characterizing “dose” to individual cells
- An approach to dosimetry where probability distributions replace average values, such as absorbed dose and LET

I think microdosimetry is relevant because

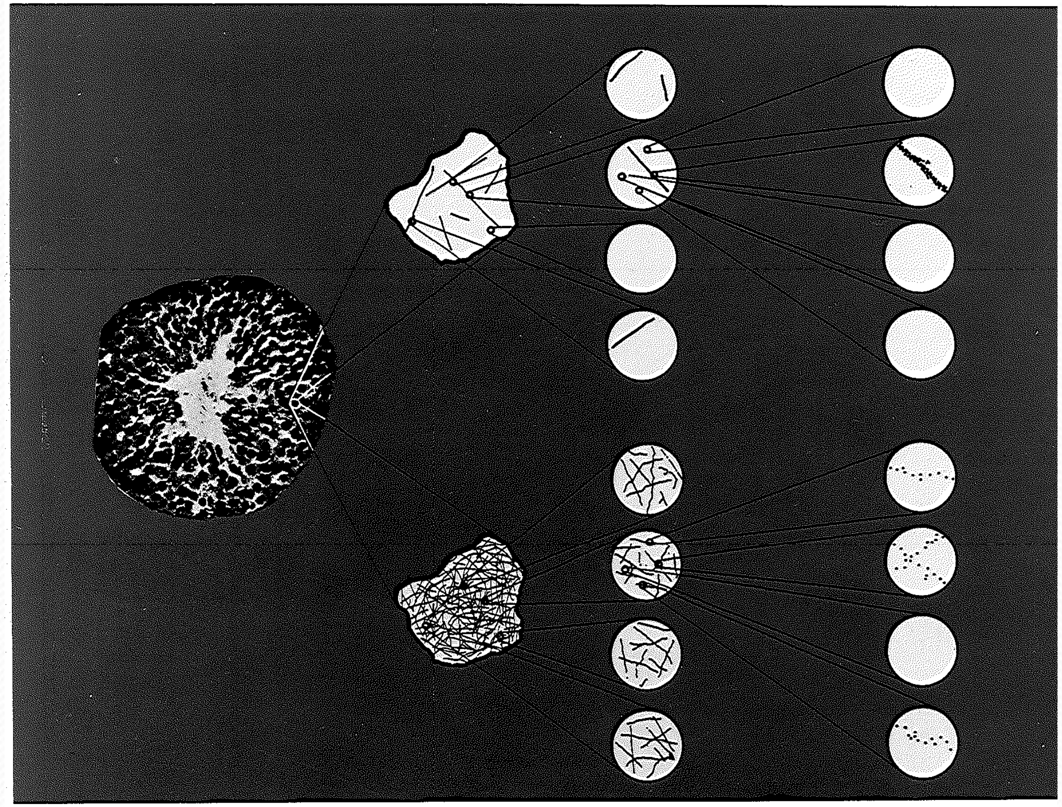
- Ionizing particles deposit energy in random interactions

- Each charged particle track is different

- Tracks are randomly distributed in time and space

At environmental doses these stochastic features dominate energy deposition

The number of tracks depends on the dose, the site, and the radiation



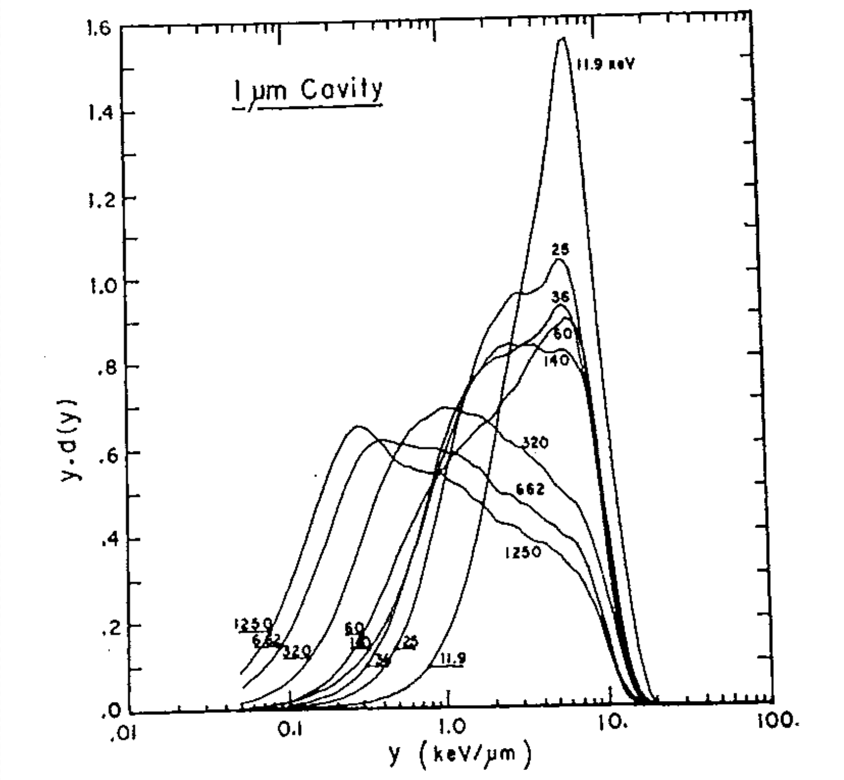
To determine if microdosimetry will help, we need to define some quantities

- Energy imparted, ε, is the difference between the energy entering a site and the energy leaving it
  - Site can be any size or shape
  - Absorbed dose is the expectation value of ε at a point, per mass
- Lineal energy, $y = \varepsilon / \bar{l}$
  - ε is for a single event
  - Stochastic equivalent of LET

Definitions, continued

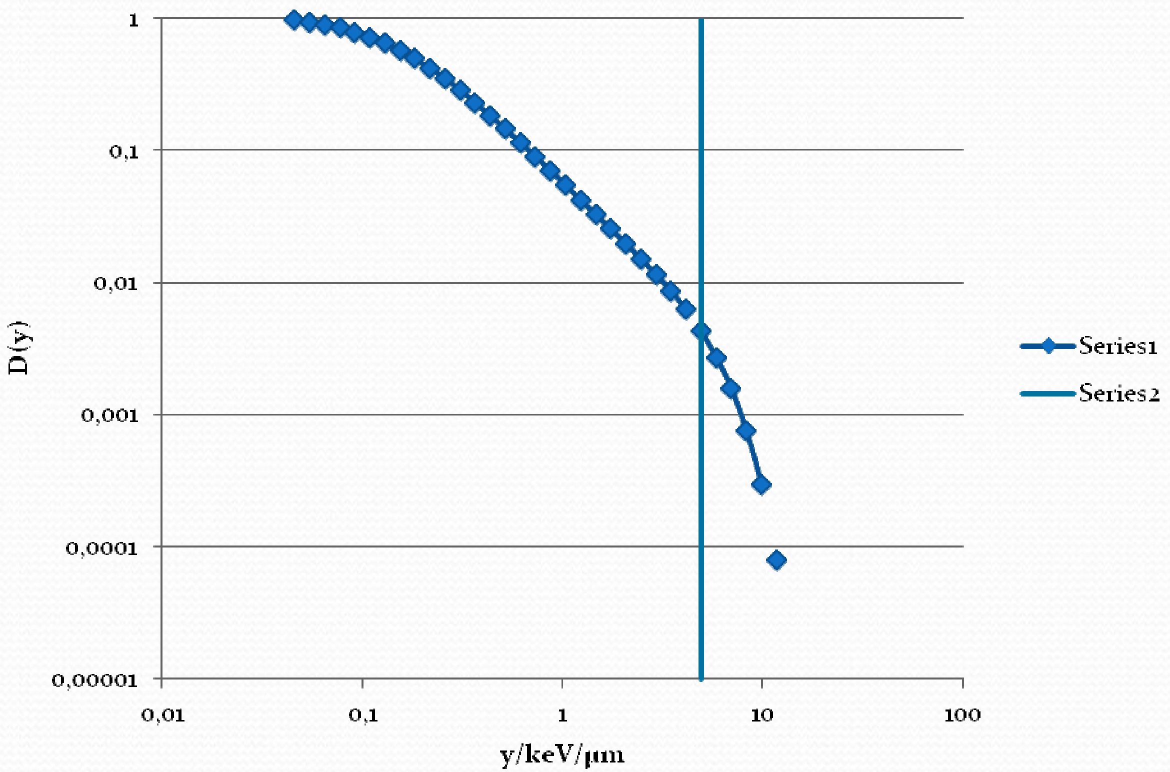
- Probability Density Function, f(*y*)
  - Probability that *y* falls between *y* and *y* + d*y*
  - Normalized to unit area (by definition)
  - Provides no information about the probability of an event occurring
- Specific energy, $z = \varepsilon / m$
  - Equivalent to D
  - For spherical sites $z_1 = 0.204 y / d^2$ with *y* in keV/μm and *d* is the site diameter in μm of unit density material

Even low LET radiations produce a wide range of *y* values



- Biological effect is probably related to energy deposited (ϵ or *z* or dose in a small volume)
- Need a log scale for the wide range of *y* values
- Plot *y*d(*y*) so that area under curve is proportional to dose

For example, we might ask what fraction of the energy deposited by ^{60}Co is in events larger than 5 keV/µm?



It is inconvenient to show the distributions at all times

Mean values are useful in some cases

- Frequency mean, $\bar{y} = \dfrac{\int y\mathrm{f}(y)\mathrm{d}y}{\int \mathrm{f}(y)\mathrm{d}y} = \int y\mathrm{f}(y)\mathrm{d}y$ since

  normalization has made $\int \mathrm{f}(y)\mathrm{d}y = 1$

- Dose mean, $y_d = \int y^2\mathrm{f}(y)\mathrm{d}y \Big/ \int y\mathrm{f}(y)\mathrm{d}y$

Mean values can be very useful

- $\overline{z_1}$ is the average "dose" due to a single event in a specified volume
- D is the absorbed dose (an average quantity), the result of a number of events
- $D = \overline{z_1}\, n$ where n is the number of events

At low doses *n* can be small

If $\overline{z_1}$ = 0.01 Gy (typical of low energy x rays in a 10 μm site) and the absorbed dose is 1 mGy

$n = D/\overline{z_1} = 0.1$

- The average number of events in a site is 0.1
  - Only about 10% of the sites will have an event
- The probability of a site having 2 events is 0.01
- For smaller sites (small cells or molecules) $\overline{z_1}$ is larger and the probability of being hit becomes even smaller

Since ε is determined by

- Stopping power (an average quantity)
- Straggling (the random component of stopping power)
- Delta ray escape
- Site size and shape

y is roughly related to L and quality factor

That makes measurement of f(y) useful in complex radiation fields

- Around neutron sources
- In space
- For ion beam therapy
- In environments with dispersed α, β, and γ sources

$\bar{y}$ can be used as an approximation to LET

Frequently a tissue equivalent proportional counter can be used to measure D and f(y), an estimate of radiation quality

Results also give the probability that a target of specified size (molecule, cell nucleus, cell, or larger) will be hit

But

Direct measurements are generally not practical for directly ionizing particles with short ranges

Fortunately direct measurement is not needed to determine f(y) and related quantities

If source of radiation is known f(y) can be calculated by Monte Carlo methods

If we knew the biochemical processes leading to biological effect, microdosimetry would provide the information to calculate RBE

Since we do not know all the mechanisms, we can use microdosimetry to determine characteristics of the mechanisms

Consider four examples

Maximum frequency of an event if you know the size of the target

The average number of events per target, *n*, depends only on f(*y*) of the radiation and the size of the target

Comparison of *n* with frequency of a biological effect may rule out some mechanisms

Frequency of an event (continued)

- Genomic instability can be observed after 1 Gy
- Can instability be due to inactivation of one of a few genes responsible for stabilizing chromatin?
- Assume order of 20,000 genes make up 2% of nuclear volume, each gene is no more than 0.05 μm diameter
- For y=5 keV/μm $\overline{z_1}$ =400 Gy and n=0.0025
- But incidence of instability is much higher

Dose rate

- A target must receive two energy deposition events for it to recognize a dose rate
- $n \geq 2$
- Assume you know $\overline{y}$
- If you know the target you can calculate z

$$z_1 = 0.204 y / d^2$$

and the minimum absorbed dose rate

$$D = \overline{z_1}\, n$$

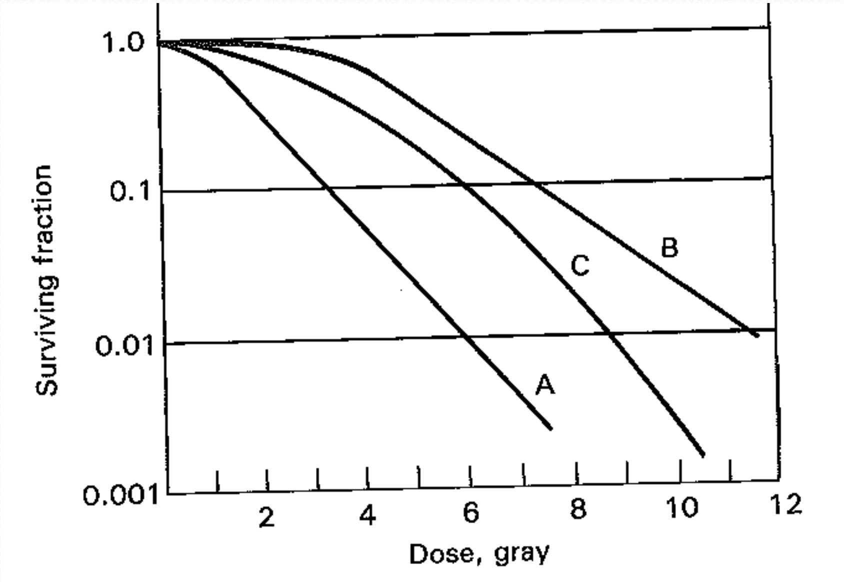
Dose rate (continued)

- If you do not know the target but know the minimum dose rate you can calculate the minimum site size

$$\overline{z_1} = D/n$$

$$d^2 = .204y/\overline{z_1}$$

Interaction of damage produced in two events



Dose response curves for 3 different mammalian cell types

If shoulder of response is due to interaction of products of 2 or more energy deposition events (dual radiation action, repair saturation, repair/misrepair models etc) interaction distance must be large enough that $n>1$

Interaction of damage (continued)

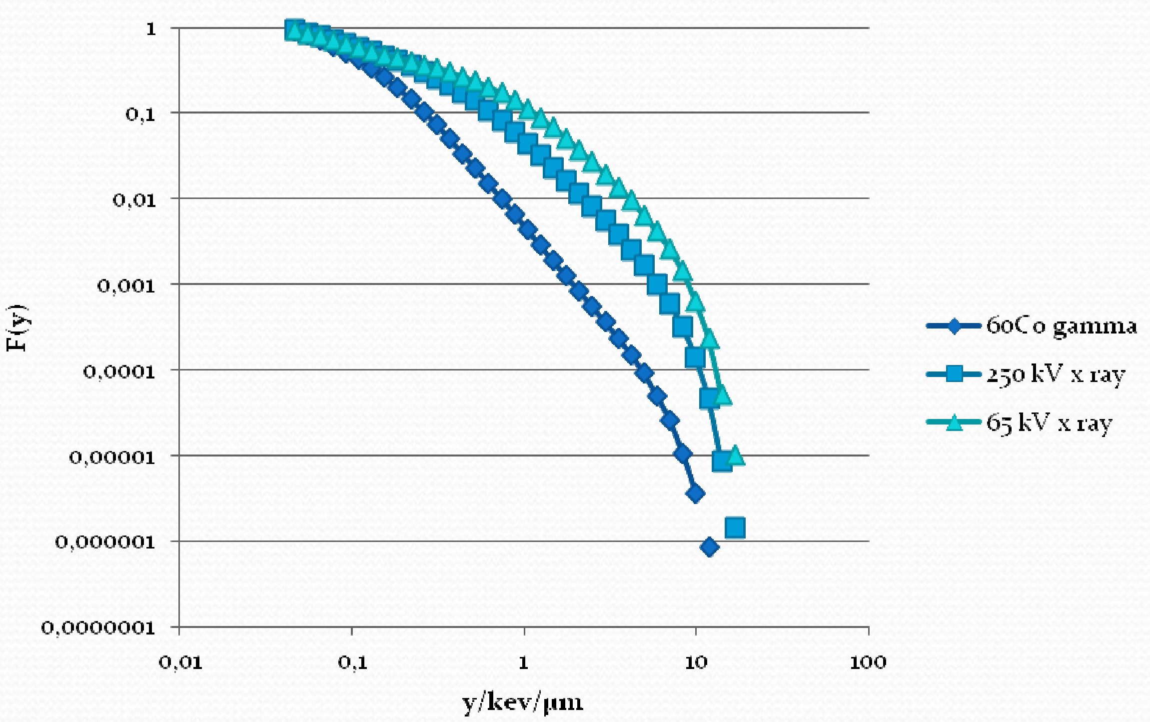
- If increase in slope becomes significant at 1 Gy
- since $d^2 = .204 y/\overline{z_1}$ if $\overline{z_1} = 1$Gy $d^2 = .204\, y$
- If y=5keV/μm then interaction range must be greater than 1μm

Minimum energy required to produce damage

- Some models predict that biochemical changes produced by a single event must exceed a specific level in order to produce an observed effect

- If deposition of a minimum amount of energy is required F(y) provides the fraction of events large enough to initiate the process

Minimum energy required (continued)



Can use this to estimate threshold energy if you have response for several radiations

Microdosimetry simply describes the physical characteristics of energy deposition

These three examples show how those characteristics can be used to improve our understanding of biological responses