What is 'radiation quality' ?

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What is ‘radiation quality’ ?

Let’s start at the very beginning….

A very good place to start….

When you read you begin with ABC

When you sing you begin with...

Do Re Mi

8.7.13

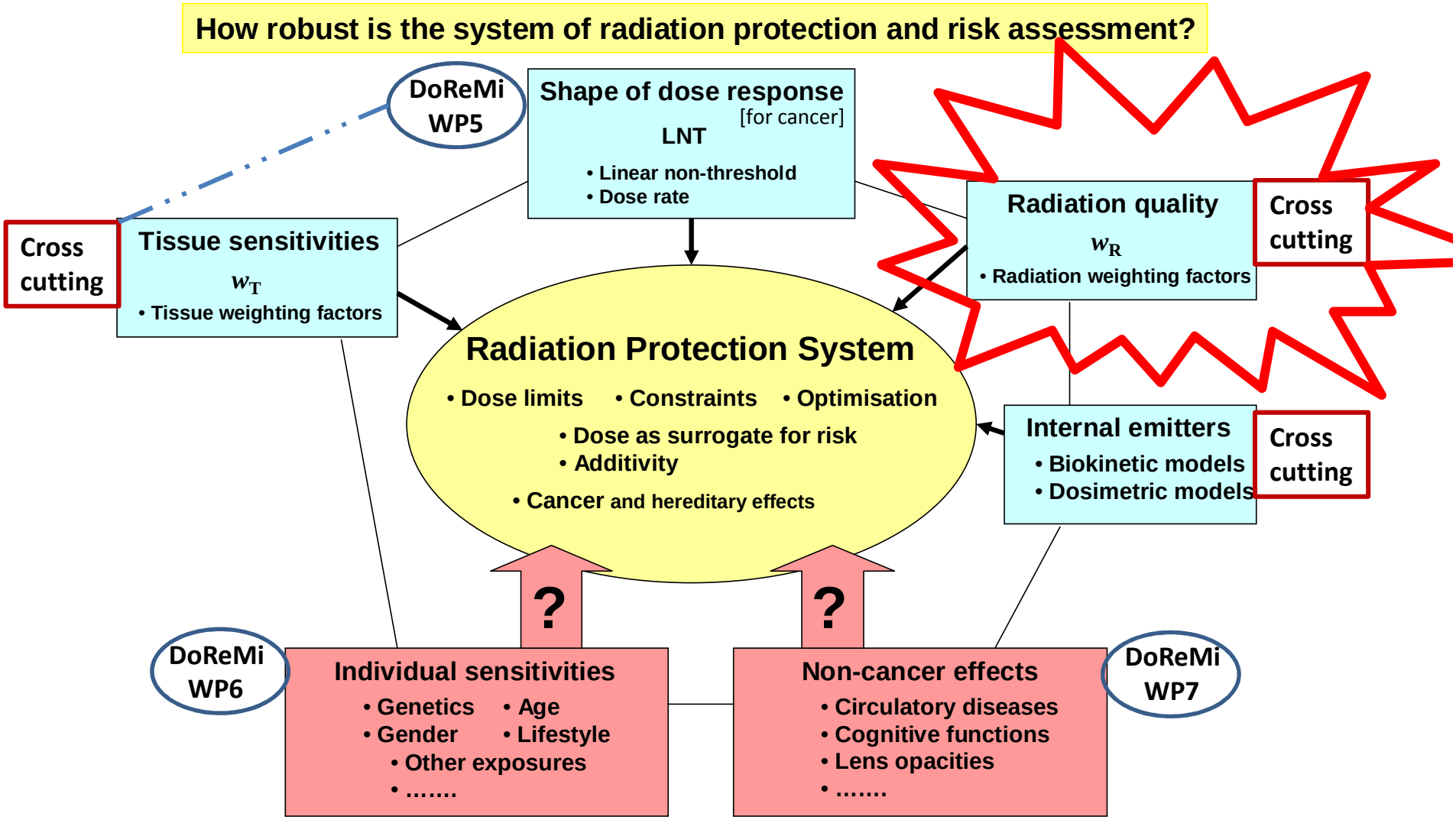


Figure 1: The main issues where judgements are made in the current system of radiation protection. The four upper boxes denote judgements that fall directly within the main ICRP dosimetric system, while the two lower boxes include issues that are at present included only to a relatively minor degree. **[HLEG Report, 2009]**

What is 'radiation quality' ?

Many *ad hoc* answers from colleagues:

RBE (relative biological effectiveness)
Q (quality factor)
w_R (radiation weighting factor)
fluence
track structure
changes in biological effects
……..
……..
etc

?

Quality, **NOT** 'Quantity' (so NOT dose, fluence, etc.)

radiation quality ?

Try the web:

radiation quality,

a descriptive specification of the penetrating nature of an x-ray beam. It is influenced by kilovoltage and filtration: a higher kilovoltage produces more penetration, and filtration removes selected wavelengths and "hardens" the beam. medical-dictionary.thefreedictionary.com

The ability of a beam of x-rays to allow the production of diagnostically useful radiographs. Usually measured in half-value layers of aluminum and controlled by the kilovolt peak.

Mosby's Dental Dictionary

The spectrum of radiant energy produced by a given radiation source with respect to its penetration or its suitability for a specific application.

McGraw-Hill Science & Technology Dictionary

Try: International Commission on Radiological Protection (**ICRP**)
International Commission on Radiation Units and Measurements (**ICRU**)

ICRP Publication 92 (2003): Relative Biological Effectiveness (RBE), Quality Factor (Q), and Radiation Weighting Factor (w_R)

ICRP Publication 103 (2007): The 2007 Recommendations of the ICRP.

ICRU Report 16 (1970): Linear Energy Transfer.
ICRU Report 36 (1983): Microdosimetry.
ICRU Report 40 (1986): The Quality Factor in Radiation Protection.
ICRU Report ICRU 60 & 85 (1998 & 2011). Fundamental Quantities and Units for Ionizing Radiation.

ICRP Publication 60 (1991): 1990 Recommendations of the ICRP

"The probability of stochastic effects is found to depend, not only on the absorbed dose, but also on the type and energy of the radiation causing the dose. This is taken into account by weighting the absorbed dose by a factor related to the quality of the radiation."

But, what is "quality of the radiation"?

When x rays and γ rays were the only types of ionizing radiation available to the therapist, the term "quality" was used to describe the penetrating power of the radiation. Quality was usually expressed in terms of the half-value layer in copper or aluminium (i.e., the thickness of material required to reduce the intensity to half). With the extension of radiotherapy and radiobiology to other types of radiation it was realized that the biological effect per unit absorbed dose depended on the radiation used. The term "quality" became a description of the radiation as it affects the biological response; (Bewley 1973)

From "Radiation Quality and its Influence on Biological Response"

"The pioneering experiments by Zirkle (1935) and a multitude of succeeding studies have established that the **biological effectiveness of ionizing radiation depends** not only on the amount of energy absorbed but **also on the spatial distribution of energy deposition.** Since the **energy is imparted in or near the tracks of charged particles**, it has been considered convenient to express the **heterogeneity of energy deposition** in terms of the linear density of energy loss in these tracks. The term linear energy transfer (LET) has been coined by Zirkle et al. (1952) for this purpose. Using this concept one may express **radiation quality** as a distribution of dose in LET, specifying the fraction of the dose deposited in each LET interval."

From "Specification of Radiation Quality" (Rossi 1959)

- **We now know, of course, that LET is far from adequate to specify radiation quality.**

Biological/health effects of ionizing radiation depend on:

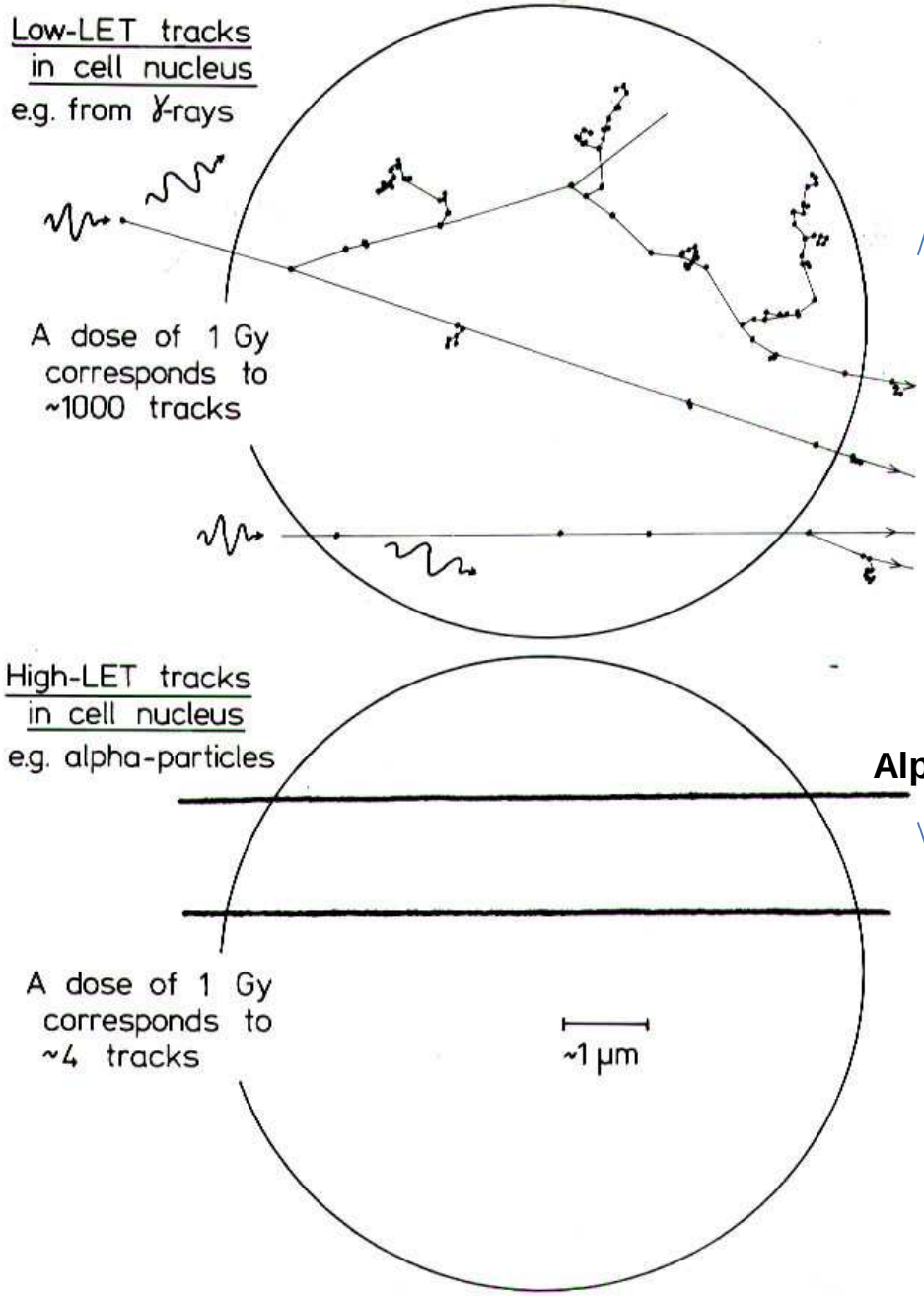
1. **<u>Quantity</u> of radiation:** **Absorbed dose,** or fluence, …
   ~ number of interactions/energy-depositions
   ⟶ Dose response curves

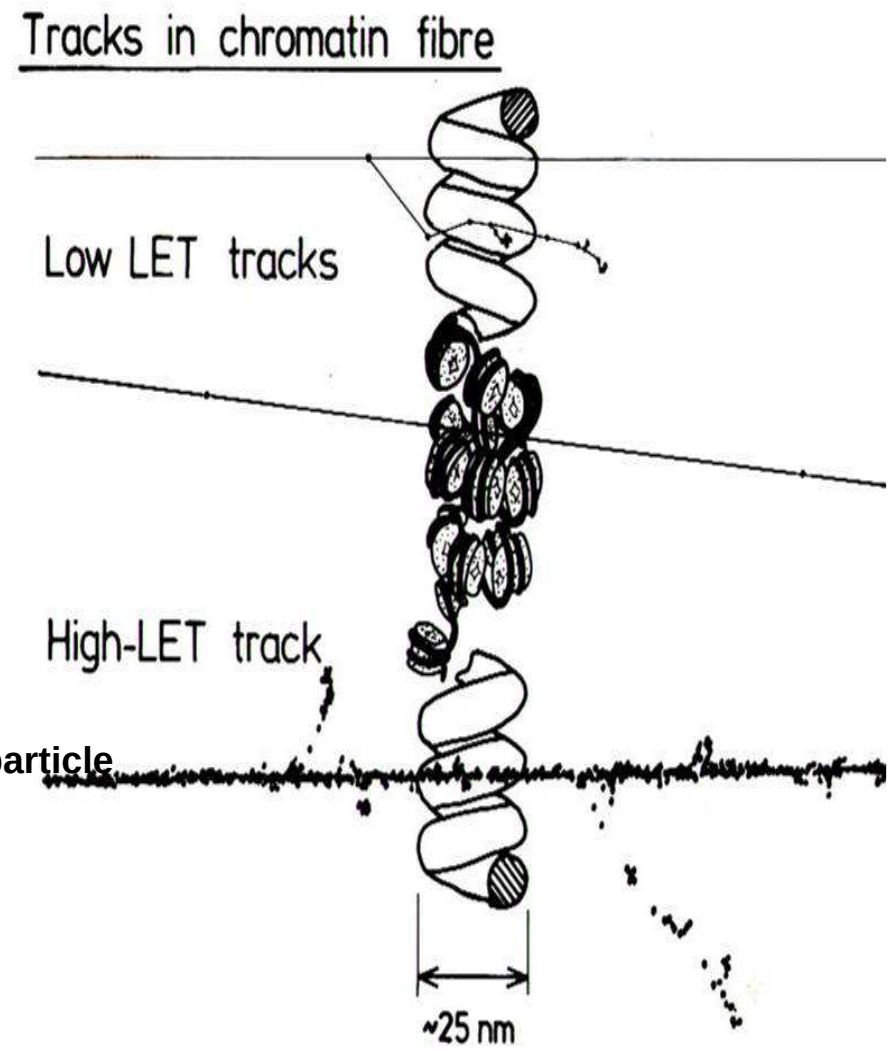
2. **<u>Temporal</u> pattern :** **Dose rate**, fractionation

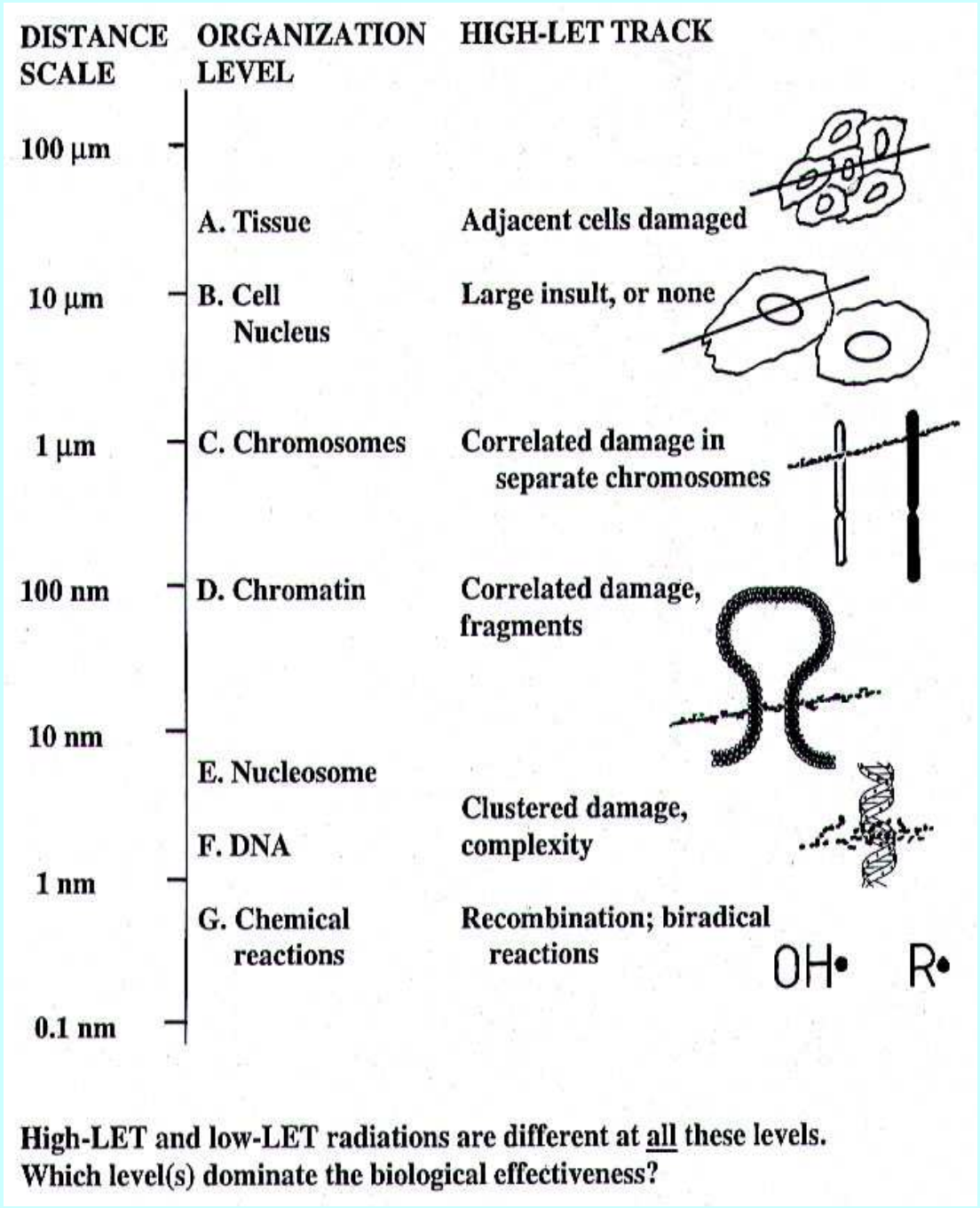
3. **<u>Spatial</u> pattern:** **RADIATION QUALITY**

   The spatial patterns of interactions/energy-depositions are critical in causing effective biological damage
   i.e. **tracks structures**

Tracks in human cells



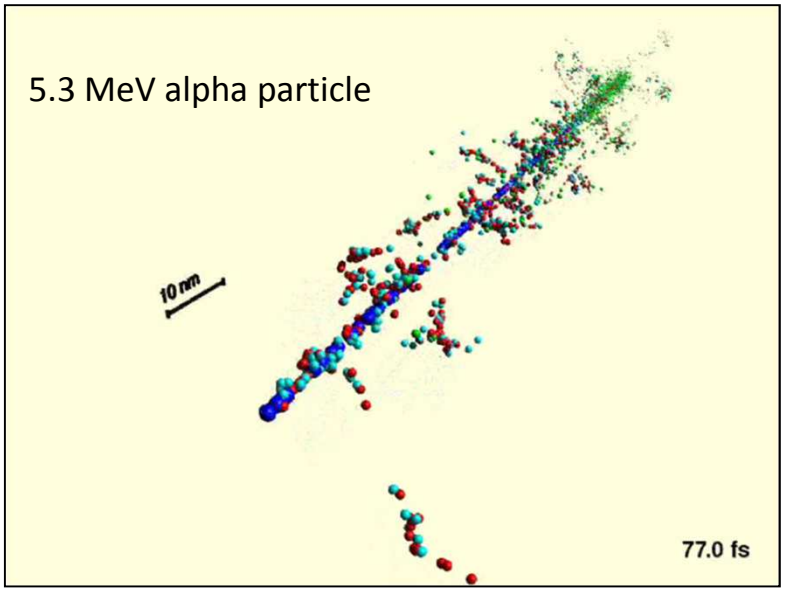


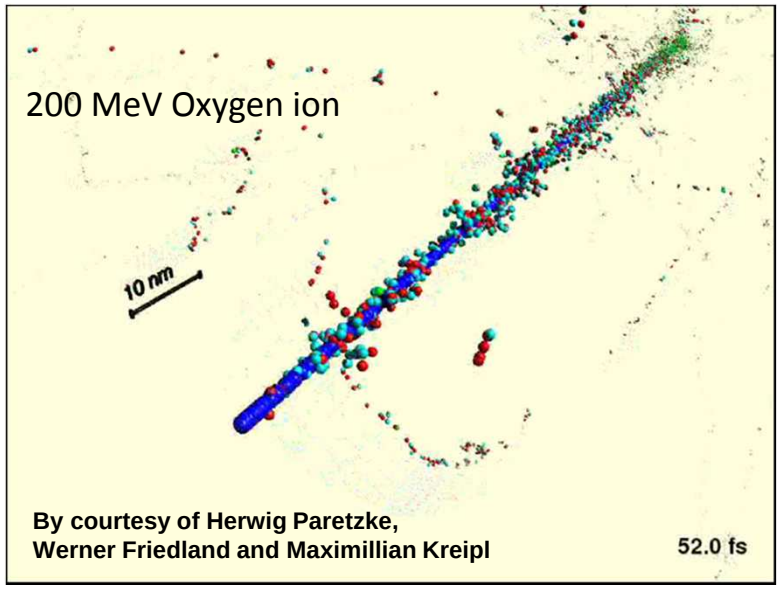


Radiation track structure is important at all levels of organisation,
from molecules to tissue, from sub-nanometres to 100s of micrometres

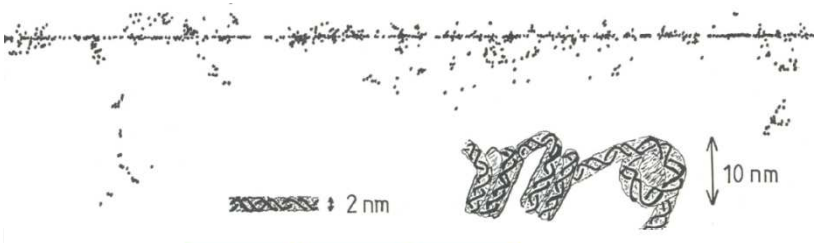
The DNA level (nanometres) is particularly important.

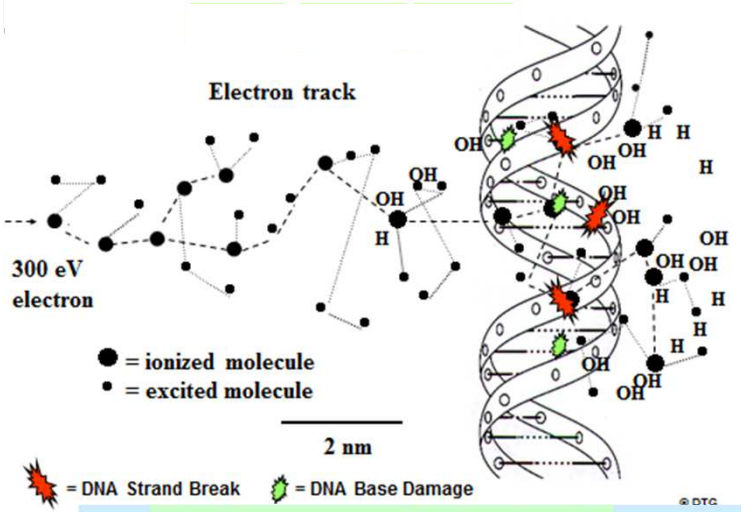
The **variety of radiation tracks** at the location of interest is determined (stochastically) by the types and energies of charged particles at that location, i.e. by the particle **fluence spectrum** at the location.

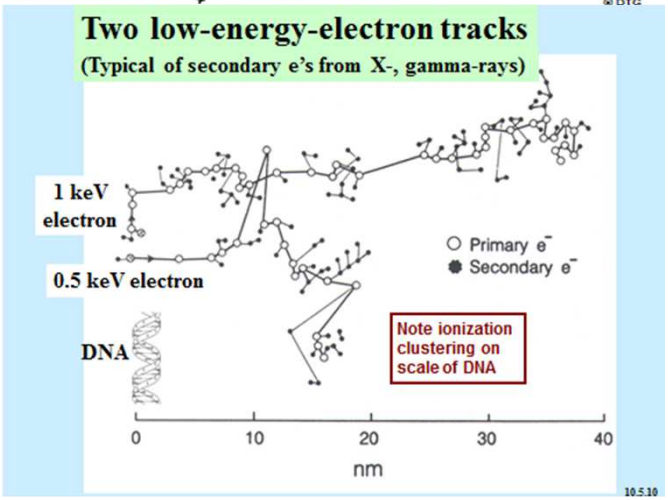




4 MeV alpha particle







Radiation Quality is defined by the fluence spectrum of radiation particles at the locations of interest in the target material.
(biological system)

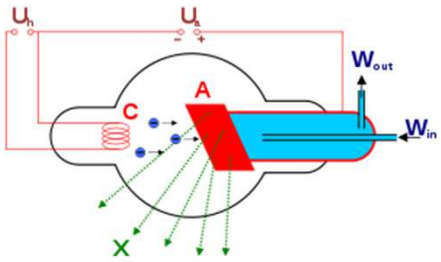
- Depends on characteristics of the radiation source and the intervening material

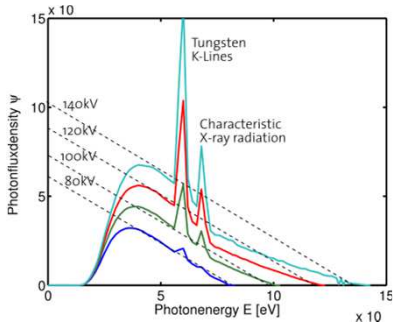
Fluence spectrum:

- specifies the relative numbers of particles according to type and energy
- includes:
  - charged particles ---- of particular importance for most biological effects (e.g. electrons, protons, alpha-particles, heavier ions)
  - (neutral particles also, such as X- & γ-ray photons and neutrons)

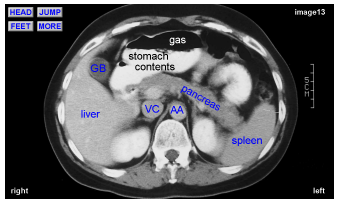
RADIATION QUALITY

Radiation source characteristics

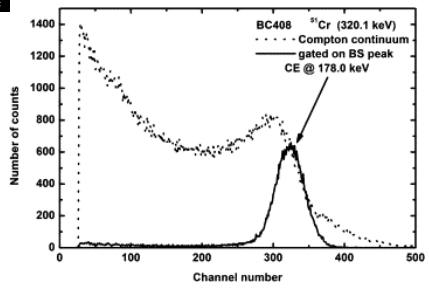


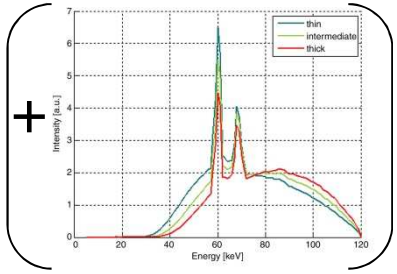


Intervening material

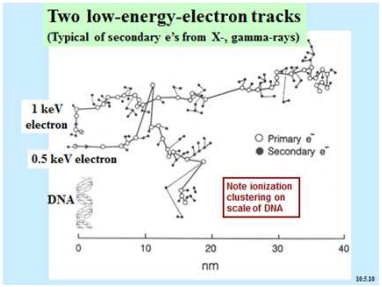


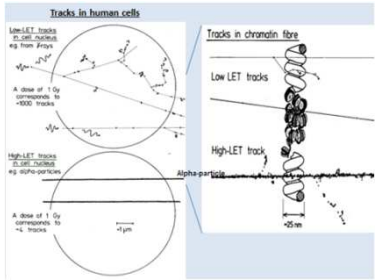
Fluence spectrum of <u>charged</u> and neutral particles (particle types and energies)



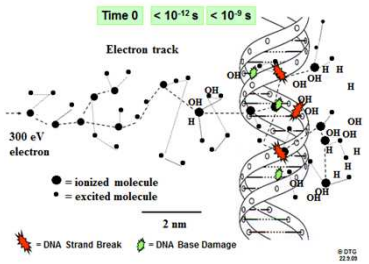


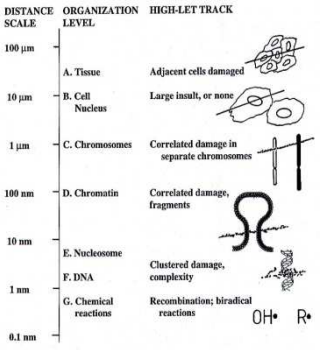
Track structures

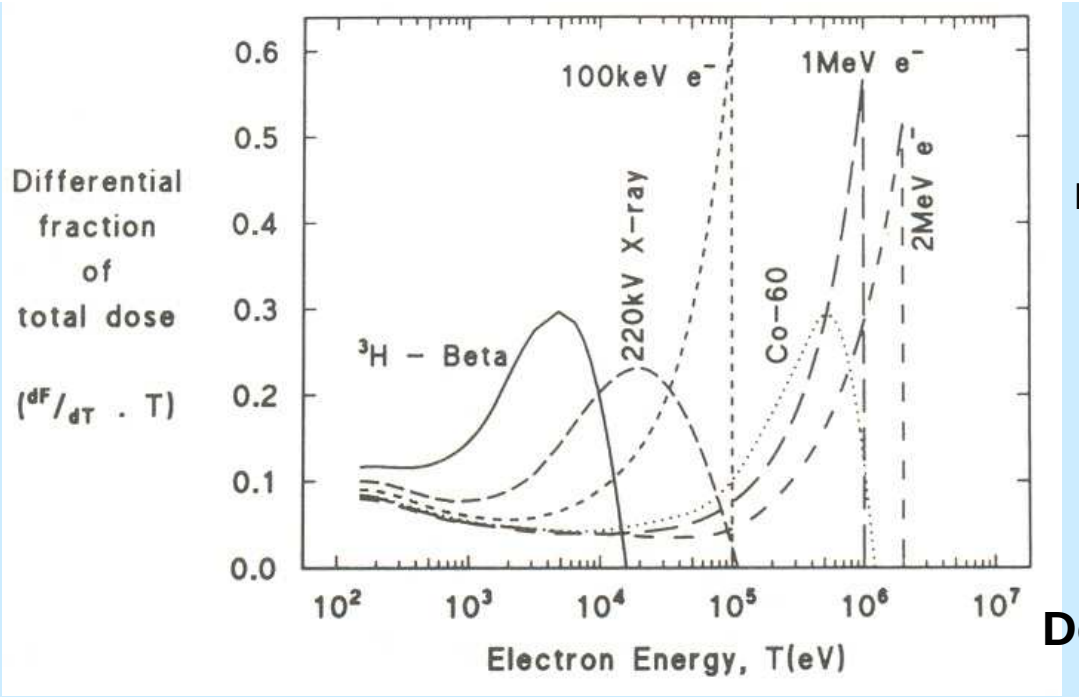


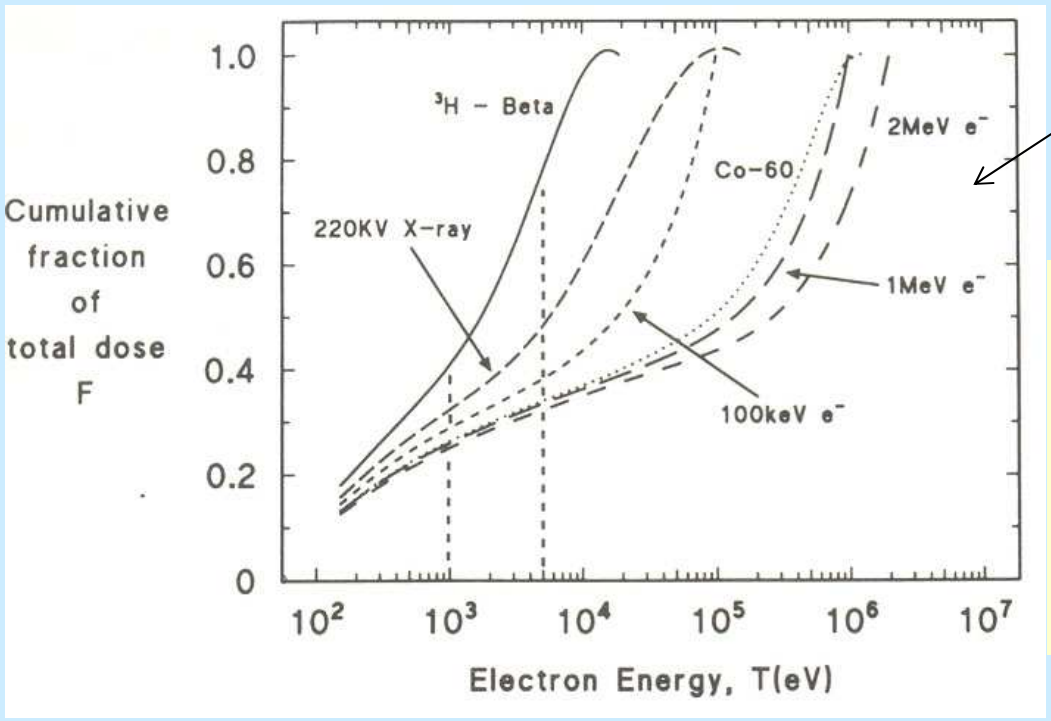


Biological damage and effects









Differences in quality between some low-LET radiations

Low-energy electrons are an important component for dose deposition by all low-LET radiations (X-, γ-rays, beta-emitters)

Such differences in radiation quality can be significant for biological effects

COMPARING LOW-LET RADIATIONS:

Dose fraction deposited by electrons of energies 0.1 to

	5 keV	1 keV
Tritium β	77 %	42%
220 kV X-rays	38 %	33%
Co γ-rays	34 %	27%

NOTE: Low energy electrons are more efficient at producing:

- **DNA double-strand breaks (DSB)**
- **a higher proportion of complex DSB (and other clustered damage)**
- **a wide variety of biological effects in cells (mutations, chromosome aberrations, malignant transformation, killing, etc)**

Closing comments:

Differences in radiation quality can lead to:

- **differences in biological effectiveness for the same quantity of radiation (e.g. the same absorbed dose)** --- can quantify ~as RBEs

- **qualitative differences in biological effects** --- cannot use scaling to specify

Effects of internal emitters depend on

- **Dose localization/inhomogeneity**

AND

- **Radiation quality**

Practical attempts to account for radiation quality include:

Radiation protection (very approx.):	w_R (radiation weighting factor) or Q (quality factor) as function of LET
More detailed risk assessments:	Best available information on specific RBEs
NASA astronauts' risk model:	QF as function of Z^{*2}/β^2
Therapy, non-cancer effects, etc:	e.g. Estimate 'Gy-Equivalent' doses for the system

All have substantial short-comings ---- Much research to be done !!!

Radiation quality also provides an excellent tool for probing

underlying mechanisms of radiobiological effects

Discussion