

# X-ray radiation vs. Gamma radiation

**Kishor Mehta, Ph.D.**, U of MD, Atomic Energy of Canada (Ret.),  
I.A.E.A. (Ret.)  
email: mehta@aon.at

X-radiation and gamma radiation are both part of the electromagnetic radiation spectrum, which also includes radio waves, and infrared, visible and UV light. Just as we say that matter is made up of atoms, electromagnetic radiation is 'made up' of photons. The difference between the various components of electromagnetic radiation, e.g. radio waves, visible light and gamma radiation, is only their wavelength, and the shorter the wavelength, the higher the energy level. The energy associated with gamma radiation and X-radiation is high enough to break atomic and molecular bonds (that is, to ionize atoms), producing changes in matter including living cells. This high-energy end of the spectrum is referred to as '**ionizing radiation**'.

The amount of radiation energy absorbed in a medium is expressed as **absorbed dose**. The unit of absorbed dose (sometimes referred to simply as 'dose') is gray (Gy), where

$$1 \text{ Gy} = 1 \text{ J/kg}$$

Thus, absorbed dose is the measure of the radiation energy absorbed in a unit mass. The unit used earlier was rad, where  $100 \text{ rads} = 1 \text{ Gy}$ .

However, the same absorbed dose delivered from different types of radiation does not produce similar biological effects. For example, 1 Gy of X-radiation would have less biological effect than 1 Gy of neutrons or protons. The key characteristic which creates this difference is the distribution of the energy deposition by these different types of radiation in the exposed medium (such as tissues). This characteristic can be described by linear energy transfer (LET) (see description below).

When comparing the biological effectiveness of the different types of radiation, traditionally X-radiation is used as the standard against which other radiation types are compared. The **relative biological effectiveness (RBE)** of a test radiation (r) may be defined as:

$$\text{RBE (r)} = D_{250} / D_r$$

where  $D_{250}$  and  $D_r$  are the doses of X-radiation (of 250 keV) and the test radiation, respectively, required for the same biological effect.

The RBE can be different depending on the tissues/cells of interest, and also on the biological effect selected for this comparison.

## Linear Energy Transfer (LET)

Linear energy transfer (LET) represents the amount of energy transferred from radiation to a medium (for example, tissues) per unit length of the path traveled by the radiation (sometimes referred to as 'track'). The commonly used unit is keV/ $\mu\text{m}$ . LET is defined as:

*The linear energy transfer (LET) of a medium for charged particles is the quotient of  $dE/dl$ , where  $dE$  is the energy lost by a charged particle due to electronic collisions in traversing a distance  $dl$ .*

Since energy transfer to the medium is principally via ionization produced, LET is related to the density of ionization along the track. LET gives an indication of the 'radiation quality'.

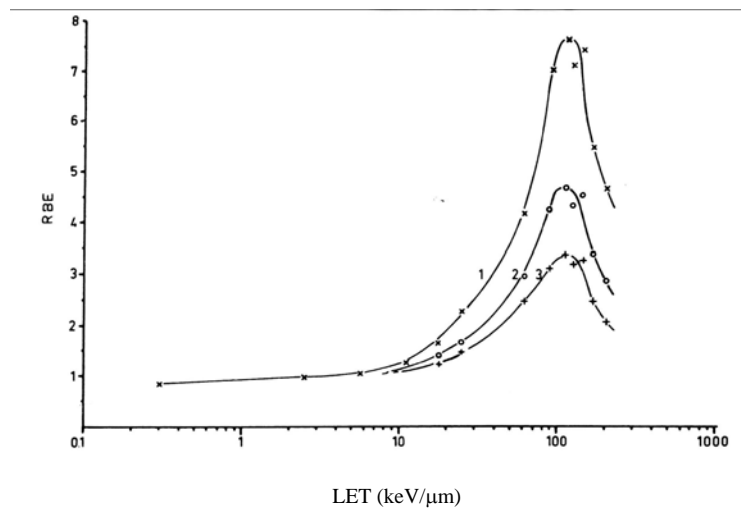
Note that LET is related to energy lost by *charged particles*. Thus, for X-radiation and gamma radiation, the energy of interest is the energy lost by the secondary electrons generated by these photons.

Typical LET values for the types of radiation that are commonly used for industry or medicine are listed in the table below:

Type of Radiation	LET (keV/μm)
Cobalt-60 gamma radiation	0.2
250 keV X-radiation	2.0
10 MeV protons	4.7
150 MeV protons	0.5
2.5 MeV α particles	166

A small value of LET means that there are few ionization events along the radiation track. Thus, X-radiation, gamma radiation and fast electrons are considered sparsely ionizing radiation, unlike neutrons, protons and α particles.

The following figure shows the relation between RBE and LET; it shows three curves for three different biological effects. As mentioned above, RBE depends on the biological effect being considered. From this it is clear that the RBE for 250 keV X-radiation is only slightly higher than that for cobalt-60 gamma radiation (which would be similar to caesium-137 gamma radiation).



*Dependence of RBE on LET (keV/μm) for survival of mammalian cells of human origin. Curves 1, 2 and 3 refer to cell survival levels of 0.8, 0.1 and 0.01, resp. This illustrates that the value of RBE depends on the biological effect selected for comparison (from Radiobiology for the Radiologist, 4<sup>th</sup> Ed, Eric J. Hall; JB Lippincott Co., Philadelphia, 1994)*

All curves in the figure exhibit a maximum around a LET of about 100 keV/μm. The average spacing between ionization events for this LET value coincides approximately with the diameter of the DNA double helix, resulting in maximizing the radiation effect. Radiation with a higher LET has more densely located ionization events than necessary for the biological effect, and thus the energy is 'wasted'. This is manifested as a lowering of the RBE after this optimum value of LET.