- Radiation Exposure and Dose -

Measurable effects of radiation on living matter depend upon the amount of energy deposited in tissue. The concern here is on ionizing radiation. To begin with it may be a bit easier to think of the incident radiation as being X-ray or gamma rays; the extension to particles, alpha, beta, neutrons, etc. will follow easily.

An incident X-ray on an atom of tissue produces ionization by dislodging one or more electrons. As a rule only some of the incident ray’s energy is utilized. The scattered ray can ionize an adjacent atom, loosing more of its energy then scatter off to another atom and so forth producing a series of ionizations along its path until it has been completely absorbed or exits the tissue. The incident X-ray may have sufficient energy to break the bonds in a water molecule leaving the free radicals H⁺ and OH⁻, which are very reactive and damaging to tissue. Or it could break the bonds in a complex molecule such as a protein or the DNA molecule. If, for instance, the bonds in a DNA molecule are broken several possibilities exist. A) The bonds rejoin leaving no permanent result. B) The bonds rejoin in a new configuration resulting in the death of the cell of which it is a part, or perhaps a cancer will begin. A healthy organism is continually replacing dead cells but if the intensity of the radiation is sufficiently great more cells are destroyed than the organism can readily replace resulting it the death of the organism.

The “absorbed dose” of radiation by matter is the amount of energy per unit mass imparted and is measured in “rads”. One rad, which stands for radiation absorbed dose, is defined as 0.01 joules absorbed per kilogram of matter, (0.01j/kg). The rad is an older unit but still in use. The newer unit of absorbed dose is the “gray”, (Gy) and is equal to 100 rad, (1Gy = 1j/kg absorbed).

For living organisms the “biologically equivalent dose”, or “dose equivalent” is measured in “rem” which stands for roentgen equivalent man. The rem is an older unit but still in use. The newer unit is the “sievert”, (Sv) and is equal to 100 rem. Because some types of radiation produce greater ionization along their paths through tissue they are more damaging. For example, alpha particles passing through tissue are 10 to 20 times more damaging than X-rays or gamma rays. For this reason alpha particles are assigned a “relative biological effectiveness” (RBE) or “quality factor” (QF) of 10 to 20, depending on their energy. X-rays and gamma rays have an RBE = QF = 1. The biologically equivalent dose, in rem, is obtained by multiplying the absorbed dose, in rad, by the RBE. For example, an absorbed dose of one rad of X-rays results in a biologically equivalent dose of one rem (0.01 sievert). The RBE for various types of ionizing radiation are:

1. X-rays  \[ \text{RBE} = \text{QF} = 1 \]
2. gamma rays  \[ \text{RBE} = \text{QF} = 1 \]
3. betas  \[ \text{RBE} = \text{QF} = 1 \text{ to } 2 \]
4. alphas  \[ \text{RBE} = \text{QF} = 10 \text{ to } 20 \]
5. protons \hspace{1cm} \text{RBE} = \text{QF} = 10

6. neutrons (slow) \hspace{1cm} \text{RBE} = \text{QF} = 4

7. neutrons (fast) \hspace{1cm} \text{RBE} = \text{QF} = 10

Another example is: A 2 rad absorbed dose of slow neutrons results in a biologically equivalent dose of 8 rem. In the newer units this is: A 0.02 gray absorbed dose of slow neutrons results in a biologically equivalent dose of 0.08 sievert.