Radioactivity and dose concept

<u>Ionizing Radiation:</u> Radionuclides are species of atoms that emit radiation as they undergo radioactive decay. There are two types of radiation; particle and electromagnetic (EM) radiation. The most common particle radiation is alpha (consist of 2 neutrons and 2 protons) and beta (positive and negatively charged electrons) emission. EM radiation is gamma rays which are individual bunch of photons. These radiations occur naturally (X-rays are man-made). Each photon or particle individually have the sufficient energy to ionize the molecules. That means radiation has an energy to eject an electron from its orbit. Covalent bond breaking will result in DNA strand breaks, protein destruction or free radical production. These mechanisms are the origin of radiation injury. The speed and the mass of the particle radiation defines its energy whereas in EM spectrum, photon's wavelength or frequency (inversely related). In EM spectrum, only UV band or shorter have the ability to ionize the molecules. Longer wavelengths than UV (e.g. microwaves, visible light), even though they have higher intensity (quantity) or at extreme exposures, DO NOT ionize atoms. Note that, the total energy transferred to the tissue may be excessive but the situation does not change.

All types of radiation are attenuated according to the Lambert-Beer law. Law states that; the intensity of radiation moving towards the tissue (incident radiation, I_0) will be either absorbed or will continue its pathway without any interaction (transmitted radiation, I). For each unit cross section the ratio of transmitted radiation to incident radiation (I/I_0) is constant. I/I_0 is called transmission and negative logarithm of transmission gives absorption ($-\log I/I_0$). The main factors affecting transmission are; <u>1-Molecular structure:</u> Visible light can pass through the window but in contrast it can be effectively absorbed by soft tissue although they have similar density. 2- <u>Radiation energy</u>: In general, lower energies of gamma radiation are better absorbed in the soft tissue when compared to higher energy gamma rays. 3- <u>Radiation type:</u> Alpha can be easily stopped by a piece of paper. However, gamma radiation of the same energy can only be attenuated by thick lead blocks.

<u>Radiation dose units</u>: Radiation terms historically has older units which have been used for many decades. Also, today the new unit system has been introduced based on SI (standard international) system. Since in practice both units are currently being used, it is necessary to understand both sets. The basic radiation quantities are <u>exposure, absorbed dose, dose equivalent</u> and <u>activity</u>. **Activity** is the incidence of radiation per second and its unit is becquerel (Bq) in SI system. Thus, radiation per second is 1 Bq. The older unit is **curie** (Ci) and it is defined as the activity of 1 gr of radium (Ra) atom in one second which is $3{,}7\times10^{10}$ Bq. Activity unit doesn't give information about the energy, absorption or the harmful effects of radiation. Obviously, we need other units to define the radiation energy. To measure radiation energy, we actually measure the amount of ionization as charge in the air (exposure). In cgs (old unit) system the charge is represented in electro static charge (esu)/cm^3 air. 1 esu/cm^3 equals to 1 **roentgen** (R). In SI (new unit) unit system charge is measured as **Coulomb/kg** air. Note that, the new unit doesn't have a special name. $1R=2{,}58\times10^{-4}$ C/kg. Charge to energy conversion for air is given as an example, the amount of energy needed to be transferred to air molecules to produce 1R of ionization is calculated below.

Number of electrons in 1 R exposure in per gram of air is=

$$\frac{2{,}58.10^{-7} \quad \text{Coulomb/gram}}{1{,}6\text{x}10^{-19} \quad \text{Coulomb (the charge of a single electron)}} = 1{,}6.10^{12}\text{electrons per gram}$$

$1{,}61.10^{12}e^{-}$/gram x 33,7 eV = $5.44.10^{13}$ eV/gram=87 erg/gram ≅ 100 erg/gram
eV=33,7 is the energy needed to eject 1 e^{-} (this is given)
(erg is another energy unit)

In cgs (old unit system) approximately 100 erg/gram is defined as 1 **rad** (radiation absorbed dose). Thus, 1 R exposure in air corresponds to 1 rad of energy transfer to air molecules. The absorbed dose in air is important since air absorption and soft tissue absorption are very similar. That means roughly that, 1R=1 rad (air)= 1 rad (soft tissue)**.** The critical think to understand here is; we need absorbed dose units (rad) to measure how much energy (roentgen) in air is deposited in our tissues to have an idea about the radiation damage. Because same exposures may result in different absorption dose according to the tissue type. For example, 1R exposure results in 3 rad in bone. In SI (new unit system) dose is expressed in joule/kg and has a special name **Gray** (Gy). 1rad=10^{-2} Gray. Finally, we need another unit to measure the exact damage. Radiation type is an important factor in determining tissue damage. Equal absorbed doses of different types of radiation will not necessarily be equally harmful to tissues. Thus, we need to consider radiation type while estimating radiation injury. For this purpose, a factor is added to calculations (Quality factor) (Figure 1). The product of total absorbed dose and quality factor will be proportional to the biological effects. The name of this product is named as dose equivalent. If we measure absorbed dose in grays the unit of dose equivalent will be **sievert (Sv)** in SI system. If we measure absorbed dose in rads then the unit for dose equivalent will be **rem**.

Dose equivalent =Absorbed dose x Quality factor
Sievert (Sv)=Gray x Quality factor
rem=rad x Quality factor

Radiation	*Energy*	*Q*
gamma	all	1
beta	all	1
neutrons	slow	5
neutrons	fast	20
alpha	all	20

Figure 1: Quality factors (Q) of different radiation types.

References

1. “Biyophysics” Lecture book. Prof. Dr. Ferit Pehlivan

2. Markus-Korner et. al Advances in digital radiography: Physical principles and system overview Radiographics 2007;27:675-686.

Assoc. Prof. H. Burak Kandilci
Department of Biophysics
November 2019