6.3 Biological Effects of Radiation

High energy particles associated with radioactivity and X rays can penetrate deep in the body and have deleterious effect on living organisms. Other high energy particles such as neutron are also harmful to human tissue. Sometimes one refers to them as ionizing radiation due to their tendency to ionize molecules in the medium in which they travel. When we are concerned with the effect of radiation on biological organisms, the term radiation includes all these various particles and electromagnetic radiation.

The photons of X rays and gamma rays have sufficient energy to knock off electrons from molecules through the process of photoelectric effect. The charged particles of the alpha and beta decay interact with atoms and molecule and create ions. The neutral particles such as neutron react with the nuclei and cause nuclear reaction in the body.

The biological effect of radiation exposure depends on the amount of energy absorbed by the body and the effectiveness of a particular radiation to ionize or alter the tissue. The effect may vary from a simple burn to the destruction of tissue and death.

6.3.1 Radiation Dose

When a tissue is exposed to an ionizing radiation, the tissue absorbs energy from the radiation. The amount of energy absorbed by the tissue per unit mass of the tissue is called the radiation dose or absorbed radiation dose. The quantitative description of radiation exposure is called **radiation dosimetry**. The SI unit for the radiation dose is called **gray (Gy)**. One Gy is a dose of 1 J of radiation energy absorbed per kg of the tissue.

$$1.0\,\text{Gy} = 1.0\,\frac{\text{J of radiation}}{\text{kg of tissue}}.$$

A centi-gray is often used instead of Gy. A centi-gray is called a **rad**.

$$1.0\,\text{rad} = 1.0\,\text{cGy} = 0.01\,\frac{\text{J}}{\text{kg}}.$$

An old unit of radiation dosage is one **röntgen (R)**, which is defined by the ionizing ability of the radiation when it passes through matter, e.g., air. One röntgen (R) is the amount of radiation that will generate $\frac{1}{3} \times 10^{-9}$ C of charge in 1 cubic cm of air under standard conditions.

Different types of radiation have different effectiveness when interacting with the tissue. For instance, alpha particles are about 20 times more harmful than beta particles for the same amount of energy deposited in the tissue. To take into account the difference among the types of radiation, we define an effective dosage

Table 6.3: Relative Biological Effectiveness (RBE)

Radiation	RBE
200 keV X rays	1.0
Gamma rays	1.0
Beta rays	1.0 - 1.5
Alpha rays	20
Slow neutrons	4-5
Fast neutrons and protons	10
Heavy ions	20

by multiplying the absorbed dosage by a factor, called the **relative biological effectiveness** (RBE) or the quality factor (QF).

$$\text{Effective Dosage} = \text{Absorbed Dosage} \times \text{Relative Biological Effectiveness.} \quad (6.52)$$

For comparison purposes, the factor is taken to be 1.0 for 200-keV X rays and the RBE of other radiations are determined by experimentation and comparison to the effect on the same tissue by 200-keV X ray. The RBE of different types of radiation are shown in Table 6.3.

The SI unit for effective dosage is **sievert** (Sv). That is, when absorbed dosage is expressed in J/kg or Gy and RBE is taken from Table 6.3, the result is automatically in the sievert unit. However, if rad is used for absorbed dosage and RBE is taken from Table 6.3, the result has the unit called **rem** which stands for röntgen equivalent for man.

$$\text{Effective Dosage [Sv]} = \text{Absorbed Dosage [Gy]} \times \text{Relative Biological Effectiveness}$$
$$\text{Effective Dosage [rem]} = \text{Absorbed Dosage [rad]} \times \text{Relative Biological Effectiveness}$$

Since 100 rad = 1 Gy, the relation between Sv and rem is similar.

$$1\,\text{Sv} = 100\,\text{rem}$$

When we take the RBE of different radiation types into account we can compare the effects of different radiations. Thus, 1 rem of effective radiation by X rays is equivalent to 1 rem of effective exposure by alpha rays, although it will take about only $\frac{1}{20}$ of the energy if delivered by alpha particles.

Example 6.11. In a prostate cancer treatment patients were given six injections of radium-223 chloride, an α-emitter of RBE 20 at a dose of 50 kBq per kilogram of body weight intravenously in each injection. What was the dosage in (a) sievert (b) rem. Assume all radiation from radium-223 was absorbed and α particle energy = 5.8 MeV.

Solution.

(a) Each decay produces one alpha particle of energy 5.8 MeV, which is 9.7×10^{-13} J. The dose of 50 kBq per kilogram of body weight will deliver the absorbed dosage to be

$$\text{Absorbed dosage/injection } = 50 \times 10^3 \times 9.7 \times 10^{-13} \text{ J per kg} = 4.8 \times 10^{-8}\,\text{Gy}.$$

The total in six injections

$$\text{Absorbed dosage} = 6 \times 4.8 \times 10^{-8}\,\text{Gy} = 2.9 \times 10^{-7}\,\text{Gy}.$$

Now, we can multiply this by the RBE for alpha particles to obtain the effective dosage in Sv.

$$\text{Effective Dosage } = 2.9 \times 10^{-7}\,\text{Gy Sv/Gy} = 5.8 \times 10^{-6}\,\text{Sv}.$$

(b) to convert this into rem unit we just multiply this by 100.

$$\text{Effective Dosage } = 5.8 \times 10^{-6}\,\text{Sv} = 5.2 \times 10^{-4}\,\text{rem}.$$

Radiation Hazard

It is worth noting that we are being constantly exposed to radiation by cosmic rays and other radioactive materials in our environment. The effective exposure for each of us is about 2-3 mSv/year. For a point of comparison, note that the dental X ray causes an exposure of 0.15 mSv. That is, one dental X ray is equivalent to about two weeks of background radiation. We say that the **Background Equivalent Radiation Time** (BERT) of one X-ray is two weeks. Ingesting and breathing even small amounts of alpha emitters such as ^{210}Po is very harmful and is known to have killed people.

Are there safe levels of radiation exposure? Clearly, we cannot avoid the background radiation of 2-3 mSv/year. The exposure of the whole body at 200 mSv does not seem to have an immediate effect. However, an exposure of 5 Sv or more can cause death within a few days. Although the long term effects of low-level exposures is not known, it is safe to assume that one should restrict exposure to 2-3 mSv/year, the average exposure by background radiation. Workers in the US that work with nuclear material are permitted to have exposure of 50 mSv/year.

Medical uses of radiation

Radioactive materials ahve found numerous applications in medicine. For instance, nuclear medicine uses radiation from radioactive materials to selectively destroy tissue that are malfunctioning. Radiation is also used for imaging the interior of the body.