CHAPTER TWO: RADIATION UNITS

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ABSORPTION OF ENERGY

Just as heat and light transfer energy from the Sun to the Earth and the atmosphere, nuclear radiation transfers energy from a source to an absorbing medium. The source of nuclear radiation may be radioactive atoms or equipment such as X-ray machines.

The effect of absorbing the more familiar types of radiation, such as heat, is to raise the temperature of the absorbing medium. If this medium is the human body, or part of it, the rise in temperature is sensed and, if it becomes excessive, avoiding action can be taken by sheltering under a sunshade (shielding), for example, or by moving further away from a fire (distance). However, a dose of gamma (γ) radiation or other nuclear radiation that is large enough to be lethal to a human being would increase the body temperature by less than one-thousandth of 1°C. The body is therefore unable to sense even very high intensities of these types of radiation.

Nuclear radiation differs from heat and other types of radiation in that each individual particle or photon has a sufficiently high energy to cause ionization. The high energy is due to the very high velocity of the particles or the short wavelength of the X and γ radiation.

IONIZATION

Ionization is the removal of an orbital electron from an atom. Since the electron has a negative charge, the atom is consequently left positively charged. The atom and the electron ,so separated, are known as an ion pair, that is, a positive ion (the atom minus one electron) and a negative ion (the electron). To cause ionization requires energy and this is supplied by the absorption of radiation energy in the medium, which subsequently results in the production of ion pairs. The particles or photons of radiation lose their energy to the medium in the process.

Normally, positive and negative ions recombine to form neutral atoms and the energy originally given to the ion pair is converted into heat energy. If the absorbing medium is a gas, such as air, the ions can be prevented from recombining by applying an electrical field.

This is done by applying a voltage between two plates (electrodes) with a gas gap between them. a system, known as an ionization chamber, in which ion pairs are being produced along the track of an α particle. If the applied voltage is sufficiently high, negative ions produced in the volume between the electrodes are attracted to the positive electrode and positive ions to the negative electrode.

The flow of ions to the respective electrodes constitutes an electrical current and, since this is proportional to the intensity of radiation, ion chambers provide a means of measuring radiation. It should be realized that, although only a few ion pairs in the case of beta (β) particles, several hundreds of ion pairs are formed per centimeter of track in air and, in the case of α particles, some tens of thousands.

In a medium such as water (of which the human body is largely composed), ionization can lead to a breakdown of water molecules and the formation of chemical forms that are damaging to biological material. The harmful effects of radiation on the human system, are largely attributable to such chemical reactions.

As already mentioned, the ionization of a gas provides a means of detecting radiation and the first widely used radiation unit, the **roentgen**, was based on the ionizing effect on air of X and γ radiation. This unit had several limitations and so two further units, the **rad** and the **rem**, were introduced. Later, these two units were replaced in the SI system (Système International d'Unités) by the **gray** (Gy) and the **Sievert** (Sv), respectively. The gray and the Sievert have been approved by the International Commission on Radiation Units and Measurements (ICRU) and used by the International Commission on Radiological Protection (ICRP). However, the older units, the rad and the rem, are still used in some countries

1. ABSORBED DOSE

Absorbed dose is a measure of energy deposition in any medium by any type of ionizing radiation. The original unit of absorbed dose was the rad, which was defined as an energy deposition of 0.01 joule per kilogram (J/kg) .The unit of absorbed dose in SI units is the gray and is defined as an energy deposition of 1 J/kg. Thus: 1Gy = 1 J/kg, When quoting an absorbed dose, it is important to specify the absorbing medium.

2. EQUIVALENT DOSE

Although the quantity absorbed dose is a very useful physical concept, it transpires that ,in biological systems the same degree of damage is not necessarily produced by the same absorbed dose of different types of radiation. It is found, for example, that 0.05 Gy of fast neutrons can do as much biological damage as 1 Gy of γ radiation. This difference in the radiobiological effectiveness must be taken into account if we wish to add doses of different radiations to obtain the total biologically effective dose. To do this, we must multiply the absorbed dose of each type of radiation by a radiation weighting factor (w_R) ,which reflects the ability of the particular type of radiation to cause damage. The quantity obtained when the absorbed dose is multiplied by the radiation weighting factor is known as the equivalent dose, H .The unit of equivalent dose in SI units is the sievert, which is related to the gray as follows :equivalent dose, H (Sv) = absorbed dose (Gy) * w_R

The value of the radiation weighting factor is found to depend on the density of ionization caused by the radiation. An α particle produces about 10^6 ion pairs per millimeter of track in tissue whereas α β particle produces about 10 000/mm. The radiation weighting factor is assigned a value of 1 for γ radiation and the values for other types of radiation are related to this in accordance with their ionization densities. β Radiation causes ionization of a similar density to γ radiation and so its weighting factor is also 1. The value of the radiation weighting factor for neutrons depends on the neutron energy and varies from 2.5 for thermal neutrons to 20 for fast neutrons. For α and other multiply charged particles ,w_R is also taken as 20.

Type of radiation	Radiation weighting factor
X-rays, γ-rays and electrons	1
Protons	5
Thermal neutrons	2.5
Fast neutrons	2.5–20*
α particles, fission fragments	20

Example1:

In 1 year a worker receives a g dose of 0.01 Gy, a thermal neutron (N_s) dose of 0.002 Gy and a fast neutron dose (N_f) of 0.0002 Gy. What is his total equivalent dose?

Take the radiation weighting factor for fast neutrons as 20.

Equivalent dose = absorbed dose * radiation weighting factor

Equivalent dose, γ = 0.01 * 1 = 0.01 Sv

Equivalent dose, Ns = 0.002 * 2.5 = 0.0005 Sv

Equivalent dose, N_f = 0.0002 * 20 = 0.004 Sv

Total equivalent dose = 0.019 Sv

In the remainder of the book, we generally refer to equivalent dose simply as dose, except where this could lead to confusion.

3. EFFECTIVE DOSE

A further complication is that different organs and tissues have differing sensitivities to radiation. To deal with the very common situation in which the body is not uniformly exposed, another concept is needed, which is called **effective dose**, *E*. This is obtained by summing the equivalent doses to all tissues and organs of the body multiplied by a weighting factor w_T for each tissue or organ. This is written as follows:

$$E = \sum_{T} H_T w_T$$

where H_T is the equivalent dose in tissue T. It should be noted that effective dose also uses units of sieverts.

4. SUBMULTIPLES

In terms of the levels of radiation exposure encountered in the working environment, the gray and the sievert are very large units. It is often convenient to have smaller units, and this is done by using the prefixes **milli** (one-thousandth), abbreviated to m, and **micro** (onemillionth), abbreviated to μ. Thus:

1 Gy = 1000 mGy = 1 000 000 μGy

1 Sv = 1000 mSv = 1 000 000 μSv

Example2:

On three successive days, a nuclear reactor operator received the following doses of γ radiation:

Day 1 95 μSv, Day 2 5 μSv, Day 3 1 mSv. What was his total dose in mSv over the 3 days?

Day	Dose	mSv
1	$95\mu Sv = \frac{95}{1000}$ mSv	0.095
2	$5\mu Sv = \frac{5}{1000}$ mSv	0.005
3	1 mSv	1.000

Total dose = 1.100 mSv.

5. DOSE RATE

Grays and sieverts are units that express an amount of radiation which may have been received over any period of time. In controlling the radiation hazard, it is usually necessary to know the rate at which the radiation is being received. The relationship between dose, **dose rate** and time is:

Dose = dose rate * time

Thus, if someone works in an area for 2 h and receives a dose of 4 mSv, then the dose rate in that area is 2 mSv/h. Similarly, absorbed dose rates are expressed in Gy/h.

Example3:

If a person is permitted to receive a total dose of 200 μSv in a week, for how many hours during that week may they work in an area in which the dose rate is 10 μSv/h?

Dose = dose rate × time

$$\text{Time} = \frac{200\ \mu\text{Sv}}{10\ \mu\text{Sv/h}} = 20\ \text{h}$$

6. FLUX

It is often convenient to express a radiation field as the number of particles or photons crossing an area of 1 m^2 in 1 s. This is strictly called the **fluence rate**, but is commonly referred to as **flux** (denoted by F). The concept is best illustrated by a practical example.

Consider a point source which emits neutrons at the rate of Q per second. The flux at distance r is the number of neutrons per second passing through an area of 1 m^2. Since the neutrons are being emitted uniformly in all directions, the flux at distance r is the number of neutrons emitted per second divided by the area of the sphere of radius, *r*. This area is $4\pi r^2$ and so the flux F is given by:

$$\Phi = \frac{Q}{4\pi r^2} \text{ neutrons per square metre per second } (n/m^2/s)$$

Note that if r is doubled, r^2 increases fourfold and F reduces fourfold. This relationship is the inverse square law

Example4:

Calculate the flux at a distance of 0.5 m from a source which emits 2×10^7 n/s.

$$\Phi = \frac{Q}{4\pi r^2}$$

$$= \frac{2 \times 10^7}{4\pi \times 0.5 \times 0.5}$$

$$= 6.4 \times 10^6 \text{ n/m}^2\text{/s.}$$

Example5:

Calculate the γ photon flux at 1 m from a 0.1 TBq cobalt-60 source. (Cobalt-60 emits two γ-rays per disintegration.) From Chapter 2, we know that 0.1 TBq = 10^{11} dis/s, but for ^{60}Co there are two γ-photons per disintegration. Therefore:

$$Q = 2 \times 10^{11} \text{ photons/s}$$

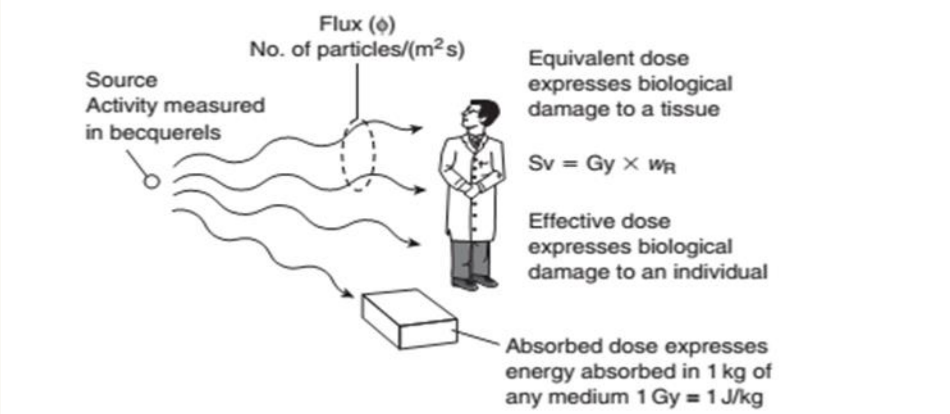
$$\Phi = \frac{Q}{4\pi r^2}$$

$$= \frac{2 \times 10^{11}}{4\pi \times 1^2}$$

$$= 1.6 \times 10^{10}\ \gamma \text{ photons/m}^2\text{/s.}$$

RELATIONSHIP OF UNITS

The relationship of the units which have now been introduced is illustrated in Figure. The gray describes an absorbed dose in any medium and the sievert expresses the biological effect on the human body. In radiation protection, it is clearly the biological effect of radiation that is of interest and so, whenever possible equivalent dose or effective dose should be used.



INTERNATIONAL RADIATION SYMBOLS

The long-established and internationally agreed symbol for ionizing radiation is the trefoil symbol shown in Figure. This symbol is used on packages containing radioactive materials and as a warning sign at the entrance to areas where there is a significant radiological hazard.

In 2007, the International Atomic Energy Agency and the International Standards Organization introduced an additional symbol for use in the special situation where very high-activity radiation sources are in use (see Fig.). The symbol is intended for use on the containers of very high-activity sources such as those in food irradiators, industrial radiography equipment and teletherapy equipment for cancer treatment.