Ministry of higher education & scientific research
AL-Mustaqbal University College
Radiology Technique Department

RADIATION PROTECTION

Class : 2

Prepared By:

Asst. Lecturer Tabarek Falah Naji

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Radioactivity

Introduction

The rate at which a sample of radioactive material decays is not constant. As individual atoms of the material al decay, there are fewer of those types of atoms remaining. Since the rate of decay is directly proportional to the number of atoms, the rate of decay will decrease as the number of atoms decreases.

Radioactive Decay Rates

Radioactivity is the property of certain nuclides of spontaneously emitting particles or electromagnetic waves, or is the process in which an unstable atomic nucleus loses energy by emitting radiation in the form of particles or gamma radiation. This decay, or loss of energy, results in an atom of one type, called the parent nuclide transforming to an atom of a different type, called the daughter nuclide. This is a random process on the atomic level, in that it is impossible to predict when a particular atom will decay.

Units of Radioactivity:

The activity (A) of a sample of any radioactive nuclide is the rate of decay of the nuclei of that sample. If N is the number of nuclei present in the sample at a certain time, the change in number of those nuclei with time, rate of decay, is the activity A, and can be given by:

$$A = -\frac{dN}{dt}$$

The minus sign is used to make A a positive quantity since dN/dt is, of course, intrinsically negative. The relationship between the activity A, number of atoms N, and decay constant λ is given by:

$$A = \lambda N$$

Since λ is a constant, the activity and the number of atoms are always proportional. Two common units to measure the activity of a substance are the Curie (Ci) and Becquerel (Bq). The conversion between Curie and Becquerel is shown below.

Curie = 3.7×10^{10} radioactive disintegrations per second (1 Curie = 3.7×10^{10} Bq)

Becquerel = one disintegration per second (1Bq= 1 dis/sec)

Radioactive Decay Law: can be calculated the number of atoms present will change over time.

$$-dN = N\lambda\, dt$$

$$-\frac{dN}{N} = \lambda dt$$

we can say that for the period of time from t = 0 to any later time t, the number of radioactive nuclei will decrease from N0 to Nt , so that:

$$N_t = N_0 \exp(-\lambda t)$$

This final expression is known as the Radioactive Decay Law.

Since the activity A and the number of atoms N are always proportional, they may be used interchangeably to describe any given radionuclide population. Therefore, the following is true:

$$A_t = A_0 \exp(-\lambda t)$$

Where :

A_t : activity present at time t

A_0 : activity initially present

The radioactive half-life is defined as the amount of time required for the activity to decrease to one -half of its original value. Now if A is equal to onehalf of A_0, A/A_0 is equal to one half. Substituting this ratio in the above equation yields an expression for $t_{½}$:

$$t½ = -\frac{Ln\,(½)}{\lambda} = \frac{Ln\,(2)}{\lambda} = \frac{0.693}{\lambda}$$

Another useful term is the mean lifetime of the nuclei, which is given by the total time of existence of all nuclei divided by the number of nuclei present initially. Since the decay process is a statistical one, any single atom may have a life from zero to ∞. Hence, the mean lifetime τ is given:

$$\tau = \frac{1}{No} = \int_0^\infty No\,\lambda\, te^{-\lambda t} dt = \lambda \int_0^\infty t\, e^{-\lambda t}\, dt = \frac{1}{\lambda}$$

The specific activity of a radioactive source is defined as the activity per unit mass of the radioactive sample :

$$S.A = \frac{Activity}{mass} = \frac{\lambda N}{m} = \frac{\lambda\, N_{Av}}{M} \quad Bq/g$$

where $m = NM/N_{Av}$ is the mass of the sample in g, N_{Av} is the Avogadro's number= 6.023×10^{23} nuclei/g and M is the molecular weight, can be replaced by the mass number A for the pure radioactive isotope. Compared with ^{226}Ra, a nuclide of shorter half-life and smaller atomic mass number A will have, in direct proportion, a higher specific activity than ^{226}Ra. The specific activity of a nuclide of half-life (expressed in years) $t_{1/2}(y)$ and atomic mass number A is therefore given by:

$$S.A = \frac{1620\ years}{t_{1/2}\ \text{years}} * \frac{226}{A}\ Ci/g$$

Exposure X:

A measure of the amount of ionization produced in air by photons. In other words, the exposure is the absolute value of the total charge of the ions produced in air per unit mass of air.

$$X = \Delta Q/\Delta m$$

ΔQ: is the sum of the electric charges of all the ions produced in the air when all the electrons liberated by photons in a volume of air.

Δm: is the mass of the volume of air under consideration.

The S.I. unit is the coulomb per kilogram (C/kg) and the old unit is the Rontgen (R).

In honor of the discoverer of X-Rays, the unit of exposure is the Rontgen defined as : R: 1 Rontgen = 2.58 x 10^{-4} $\left[\frac{Cb}{Kg}\right]$

Exposure rate

Is the amount of ionizing radiation per hour in a person's vicinity (measured in milli Roentgen per hour, mR/h). The S.I. unit is the coulomb/kg.h (C/kg.h), and the old unit is the Rontgen/h (R/h).

Absorbed Dose (D):

In simple term is the energy imparted by ionizing radiation to unit mass of matter (absorbed). The unit of absorbed dose is gray (Gy) & rad.

Absorbed Dose $$D = \frac{imparted\ energy}{mass} = \frac{\Delta ED}{\Delta m}$$

A unit for the absorbed dose in the conventional system of units is the Rad standing for Radiation Absorbed Dose as :

$$1\ Gray = 1Gy = 1\left[\frac{Joule}{Kg}\right] = 100\ rads$$

– 1 Gy= 100 rad

– 1 gray (Gy) = 1 J/kg

The S.I. unit is the gray (Gy) and the old unit is the rad. the gray is a fairly hefty dose, so for normal practical purposes the milligray (abbreviated mGy) and the microgray (abbreviated µGy) are used.

There are two absorbed doses types :

An acute dose: is the absorption of a relatively large amount of radiation (or intake of radioactive material) over a short period of time.

A chronic dose: is the absorption of radiation (or intake of radioactive materials) over a long period of time, i.e., over a lifetime.

The gray is a physical unit. It describes the physical effect of the incident radiation (i.e., the amount of energy deposited per kg), but it tells us nothing about the biological consequences of such energy deposition in tissue.

Radiation Weighting Factors (WR):

Quality factors (or Weighting Factors) are used to compare the biological effects from different types of radiation. For example, fast neutron radiation is considered to be 20 times as damaging as X-rays or gamma radiation.

It is recognized that different types of ionizing radiations will have a different degree of harmless to human body, even the absorbed dose is the same. For example, alpha and neutron radiation cause greater biological damage for a given energy deposition per kg of tissue than gamma radiation does. In other words, equal doses of, alpha and gamma radiation produce unequal biological effects. Because more biological damage is caused for the same physical one gray of alpha or neutron radiation, and more harmful than one gray of gamma radiation.

Equivalent Dose (HT):

Is a measure of the biological damage to living tissue resulting from exposure, in other words, is a weighted dose in an organ or tissue. It is determined by the product of the average absorbed dose in an organ or tissue with the radiation weighting factor (WR). The unit of equivalent dose is sievert (Sv).

$$HT = \sum WR\ D$$

WR : radiation weighting factor for radiation R.

D : absorbed dose averaged over the organ or tissue T.

Units of Equivalent Dose (HT): rem or Sievert (Sv)

1 Sv = 100 rems

1 mrem = 0.001 rem; 1 mSv = 0.001 Sv

The S.I. unit is the Sievert (Sv), and the old unit is the rem.

Tissue Weighting Factors (WT):

Is a relative measure of the risk of ionizing radiation effects that might result from irradiation of that specific tissue. It accounts for the variable radio sensitivities of organs and tissues in the body to ionizing radiation. Tissue weighting factors are therefore introduced to represent the proportion of the risk resulting from irradiation of an organ or tissue of the body to the total risk when the whole body is irradiated.

Based on the values of tissue weighting factors, tissues are grouped into following to assess the carcinogenic risk:

- High risk(WT = 0.12): stomach, colon, lung, red bone marrow, breast, remainder, tissues, gonads
- Moderate risk (WT = 0.05): urinary bladder, esophagus, liver, thyroid.
- Low risk (WT = 0.01): bone surface, skin, brain, salivary glands

Effective Dose (E):

The effective dose, E, a measure of the whole body dose by the summation of the weighted equivalent factors doses in all the tissues and organs of the body. It represents the total risks to the whole body due to partial irradiation of body organs, and that some human organs are more sensitive to radiation than others. It is given by the expression

$$E = \sum HT\ WT$$

HT : is the equivalent dose in organ or tissue T.

WT : is the weighting factor for that organ or tissue.

The S.I. unit is the Sievert, and the old unit is the rem