First lecture

The principle of Diagnostic Radioisotopes

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Principles of Diagnostic Radioisotopes

Certain natural elements (primarily the very heavy ones) have unstable nuclei that disintegrate to emit various rays :-

1- Alpha particles: positively charged, which stops in a few centimeters of air, are the nuclei of helium atoms.
2- Beta particles: negatively charged, are more penetrating but can be stopped in a few millimetres of tissue, they are high speed electrons.
3- Gamma rays: are very penetrating and are physically identical to x-rays, they usually much higher energies than the x-rays.

For the comparison between them

Each element has a specific No. of protons in the nucleus; for example, Carbon has six protons, Nitrogen has seven protons and Oxygen has eight protons. However, for each element, the No. of neutrons can vary.

Isotopes: Nuclei of a given element with different numbers neutrons. There are two types:

a.Stable isotopes: if they are not radioactive.
b.Radioisotones: if they are radioactiv
e.

Example:

Carbon has two stable isotopes and several radioisotopes (Isotopes referring to a single element).

Radionuclides:- is appropriate when several radioactive elements are involved.

Radioactivity:

All elements can be either stable or not stable depending on the building of the atom and their nucleus. Each atom is composed of nucleus (which contain a number of neutrons and protons) and surrounded by electrons.

Stable elements have normal ratio of n/p ≥ 1.
Its n/p =1 for low atomic No. z = 1 ⟶ 20
And its n/p >1 for elements of z > 20
For none stable elements (radioactive) this ratio either above or below normal.

1- If elements have n/p > normal ratio then they have neutrons more than normal number. Thus will decay (transform) by:

a- Neutron emission

This occur when the No. of neutrons is very high than normal. (n >>> normal). The type of radiation is Neutron particles. Or, b- Neutron disintegration: this occur by transform the Neutron into proton and this will companied by Beta particles.(This happen when n > normal)

$$N \longrightarrow P + \beta$$

Type of radiation:-

1. Electron which called Beta particles (β) because it's from the nucleus.
2. Gamma (γ) ray when the proton goes to stable or lower energy state.

2- For elements which have n/p < normal

The elements decay by either proton emission

a. Proton emission

This occur when the No. of protons is very high than normal.(when p >>> normal). The type of radiation is Protons particles.

Or,

b. Electron capture: (when p > normal)

The proton transform into neutron by capturing electron from the K-shell of the atom.

$$P + e \longrightarrow N$$

In this process of transformation (decay) the following radiation is given:

1. X rays: The vacancy in the K-Shell will be filled from other shells (L, M, N…)
2. Positron (e^+) particles instead of the electron captured by the proton.
   The positron is electron except it has +ve charge.

3. γ- rays: when the neutron goes to stable state.

Note: Positron given by the nucleus because it gained an electron then it will give energy as positron β^{+} which has very short life time. Then it will combine with electron from out side of nucleus to give two photons in different directions (between them 180^{o}) each photon has energy (511 Kev) this process called ***annihilation***.

Decay (transformation process):

Each radioactive atom try to reach the stable state in the following probability:-

dN/dt α No. of total radioactive atoms.

$dN/dt = -\lambda N_o \longrightarrow dN/dt = -\lambda N_o$

or, $N = N_o e^{-\lambda t}$ --- (1)

N= No. of radioactive atoms after (t) time. N_o= No. of radioactive atoms at t = o (originally present).
λ = decay constant. (Units sec^{-1}, min^{-1},… ....) e = Natural logarithm

From equation (1) we can gate:
$dN/dt = dN_o/dt \, e^{-\lambda t}$

dN/dt = A (activity of atoms after t time)

dN_o/dt= A_o (activity of atoms at t = 0 time original activity)

Then, $A = A_o e^{-\lambda t}$ ---(2)

When $N = \frac{1}{2} N_o$ or, $A = \frac{1}{2} A_o$ Then the time of transformation called physical half life (T_{phy})

Physical half life:- is the time needed for either half of the No. of radioactive atoms or the activity to reduce to half its original activity.

$T_{1/2} = 0.693/\lambda$ --- (3)

This means for every radioactive atoms:

$T_{\frac{1}{2}}\lambda$ = constant= 0.693 -------------------------------------- (4)

Note: In equations 1, 2, 3 and 4 the time and decay constant must take the same units of time (time (sec), λ (sec^{-1}); time (min), λ (min^{-1}); etc…).

Units of Radioactivity:

1- Curie (Ci):

The No. originally represented the radioactivity of 1g of radium. This is equal to 3.7 x 10 unit which is independent of the disintegration ratio of radium and small unit.

2- Becquerel (Bq):-

The SI unit for radioactivity which is equal to 1 disintegration per second. This can be used for any radioactivity.

So, 1Bq=1 disintegration/sec. And
$1Ci = 3.7 \times 10^{10}$ Bq

Basic characteristic of radioactivity:

1- When an element decays (parent) its daughter which is also radioactive formed.

2- There are over 1000 known radionuclides, most man-made

3- Heavy elements tend to have many more radioisotopes than light elements.

4- Characteristic that helps identify the radionuclides are the type and energy of Its radiation.

5- Some man-made radionuclides emit types of radiation not emitted by natural radioactive which are positron emitters (β^+) such as ^{18}F.

6- Metastable elements are radioactive elements atoms that emit only γ-rays and changed to stable state of the same elements.

$$^{99m}Tc \xrightarrow{\gamma\text{-rays}} {}^{99}Tc \quad \text{stable}$$

7- According to the characteristics of radionuclides (energy and type of radiation) they are divided into three groups:

I- Research:

The radionuclides which are used for this purpose have:

a- very penetrating b- low energies

$^{3}H \xrightarrow{\text{give}} \beta$, and $^{14}C \xrightarrow{\text{give}} \beta$

II- Diagnosis:

The radionuclides which are used for this purpose have: a- long penetrating depth b- short physical half-life.

Such as ^{99m}Tc and ^{32}P are mostly γ-emitters that have enough penetrating depth to detect out of the body and enough physical half life.

III- Therapy:

The radionuclides which are used for this purpose have: a- short penetrating depth b- long physical half-life.
Such as charge particles α, β, protons ,neutrons and ions.

Radiation doses in nuclear medicine:

The radiation dose to the body from nuclear medicine procedure is non uniform since radioisotopes tend to concentrate in certain organs. The organ receiving the largest dose during a procedure is referred to as the ***critical organ*** for that procedure. Keep in mind that these doses can vary considerably from one individual to another.

The dose to a particular organ of the body depends on the physical characteristics of the radionuclide (what particles it emits and their energies) and on the length of time the radionuclide in the organ. Two factors determine the length of time the radionuclide is in the organ, or the effective half - life ($T_{\frac{1}{2}\,eff}$) (the physical half life ($T_{\frac{1}{2}\,phy}$) and the biological half- life ($T_{\frac{1}{2}\,bio}$).

The biological half life: is the time needed for one-half of the original atoms present in the organ to be removed from the organ, and its independent of whether the element is radioactive or not.
Most elements are excreted at an exponential rate. The effective half- life can be calculated as follows:

$$T_{\frac{1}{2}eff} = (T_{\frac{1}{2}bio})\,(T_{\frac{1}{2}phy}) / (T_{\frac{1}{2}bio} + T_{\frac{1}{2}phy})$$

Note that if either the biological or physical half- life is much shorter than the other, the effective half- life is essentially equal to the shorter value

نماذج اسالة

Q1……………..positively charged, which stops in a few centimetres of air, are the nuclei of helium atoms.

A. Beta B. Alpha C. Gamma D. Proton E.Neutron

Q2. …………….occur when the No. of neutrons is very high than normal. (n >>> normal).

A. Neutron particles B. Alpha C. Gamma D. Proton E.Electron

Q3…………….occur when the proton transform into neutron by capturing electron from the K-shell of the atom.

A. Neutron particles B. Alpha C. Gamma D. Proton E.Electron capture

Q4…………… this occur when the No. of protons is very high than normal.(when p >>> normal).

A. Neutron particle B. Alpha C. Gamma D. Proton emission E.Electron capture

Q5- The radionuclides which are used for……………..purpose have a long penetrating depth and short physical half-life. Such as 99mTc and 32P are mostly γ-emitters that have enough penetrating depth to detect out of the body and enough physical half life.

A. Research B. Diagnosis C. Therapy D. Industry E. Trade