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Basic Principles of Nuclear & Radiation Physics Used in Radio¬isotope Imaging

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Abstract **Original Research Article**

Radio-isotope used in Medicine in different fields. In this article basic terms of nuclear & radiation physics use for diagnostic radio-isotope imaging will be discussed for basic knowledge & idea among all the discipline of radiation fields. Basic physics of radioisotope & basic electronics is urgent need for radioisotope imaging. These are in short of primary knowledge & information. Everyone should earn detail knowledge for better understanding of isotope imaging.

Keywords: Nuclear & Radiation Physics, Radio¬isotope Imaging, Diagnostic.

INTRODUCTION

Radio-isotope imaging is a branch of diagnostic imaging which deals with the use of radio-isotope for diagnosis of disease. Radio-isotope used in Medicine in different fields. In this article basic terms of nuclear & radiation physics use for diagnostic radio-isotope imaging will be discussed for basic knowledge & idea among all the discipline of radiation fields. Before details discussion everyone should understand the following terms related to radioisotope imaging.

Atom & Nuclides

Atom & atomic structure

Atoms are the smallest bits of element that still retained the unique properties of that element. They are complex structure and composed a central nucleus that composed of proton & neutron (which also called nucleons) and peripheral orbital electron. Electrons are distributed within the different shell (such as K L M N.) & sub-shell (s p d f.) of atom **of** different energy state.

Elements & Nuclides

The term *element* refers to the classification of substances according to the number of protons and the term *nuclide* refers to the classification by both number of protons & number *of* neutrons. There are at least 106 different elements, but there are about 1300 known different nuclides.

Atomic number & mass

Atomic number (z)- The number of protons or positively charged particles, which defines the specific element. Neutron number (N)- The number of Neutrons Atomic mass (A)- The number of protons plus Neutron, refers to Atomic mass. A = Z+ N

Isotopes

Nuclides of same element, that have same number of protons (Z), but different number of neutrons (N) thereby different atomic mass. Such as ^{12}C6,^{13}C6,^{14}C6 etc.

Isotones

Nuclides that have same number of neutrons, but different number of protons. Such as $^{7}B_{4}$, $^{8}/B_{5}$, $^{9}C_{6}$ etc.

Isobars

Nuclides that have same mass number (A), but different number of protons (Z). Such as ^{6}He2,$^{6}Be_{4}$,$^{6}Li_{3}$ etc.

Isomers

Nuclides that have same number of A, Z & N, but have different energy states. Such as $^{99m}T_{C43}$ & $^{99}T_{C43}$ etc.

Binding energy

Binding energy of electron

The energy required to remove anelectron from an atom is called the binding energy of that electron. This binding energy is depending on the shell & orbit. So remove of an electron of a definite shell is called the binding energy of that shell.

Binding energy of nucleus

The energy required to separatethe nucleons, which is equal to the difference between the sum of mass of nucleons and the mass of nucleus X C^2

Binding energy of atom

The energy required to separate the particles of atom, which is equal to the difference between the sum of mass of particles of atom and the mass of atom **X C^2**

Energy States

Nuclides have three energy states- Unstable, meta-stable & stable states, which depend on neutron-proton ratio within the nucleus.

Unstable state

There are numerous, Hypothetical nuclear composition (neutron-proton mixture), which are completely unstable and cannot exist as intact nuclei more than 10-^{6} seconds, called unstable state

Meta-stable state

Nuclides have a finite life time and remain unchanged for some period (longer than $10^{‘6}$ seconds), before undergo a transformation in to a more stable or completely stable state with emission of a burst of energy.

Stable state

Nuclides do not go spontaneous transformation without application of external forces[1,2].

Radioactive transition or decay Alpha decay

Alpha decay is a process by which a radionuclide drops in to a lower energy level with the emission of a large alpha (α) particle.

Such as ^{226} Rags $\longrightarrow$ ^{222} Rn_{86} + Alpha (α)

Alpha particles are typically emitted with a velocity of 3-6% of light and mono energetic.

Beta decay

Beta decay is a process in which a neutron is transformed in to a proton by the emission of a negatively charged electron and a neutrino. It occurs when N-P ratio of the nucleus is higher the level of stability.

Such as $^{32}P_{15} \longrightarrow {}^{32}P_{16} + \beta^{-ve} + y$

The combined energy imparted to the beta particle and the neutrino is called the transitional energy. The spectrum of energies carried by the beta particles varies from zero to maximum transition energy (MTE). It is usually in between 30-40% of MTE.

Positron decay

Positron decay is a process in which a proton is transformed in to neutron a by the emission of a positively charged electron and a neutrino. It occurs when N-P ratio of the nucleus is lower the level of stability.

Such as ^{18}F9 -------------▶ $^{18}O_8 + \beta^{-ve} + y$

The combined energy imparted to the beta particle and the neutrino is called the transitional energy. The spectrum of energies carried by the beta particles varies from zero to maximum transition energy (MTE). It is usually in between 30% of MTE. Positron travels very short distance before its kinetic energy is expended. When zero energy level is reached positron combine with a negatively charged electron in a phenomenon called- annihilation and total mass are converted in to two gamma photon of 511 kev, which are used in positron emission tomography (PET) in many radioisotope imaging.

Electron capture

Electron capture is a process in which an orbital (usually from K-shell) electron is captured by a proton is transformed in to neutron and released energy is carried away by neutrino plus characteristic X-ray and gamma ray. It occurs when N-P ratio of the nucleus is lower the level *of* stability.

Such as ^{51}Cr24 $\longrightarrow$ $^{51}V_{23}$+ X-ray +*y* ray + *V*

The combined energy imparted to the beta particle and the neutrino is called the transitional energy. The spectrum of energies carried by the beta particles varies from zero to maximum.

Gamma decay

Gamma decay is a process in which a radioactive isotope undergoes isomeric transition by release of gamma photon. It usually followed by previous other decay procedure. Such as-

$^{99}MO_{44} \longrightarrow {}^{99m}T_{C43} + \beta^{-ve}$

$^{99m}Tc_{43} \longrightarrow {}^{99m}T_{C43}$+ y(140 Kev)

Radioactivity of isotopes & life time Radioisotopes

The isotopes having radio active properties are called radioisotopes.

Radioactivity

The rate at which the radioisotopes within a sample undergo transition or decay is called radioactivity. Activity can be expressed in terms of number of transition per second (tps). There are two special units used to express the activity of radio isotopes.

Bequerel (Bq)

Which is equivalent to one million (10^6) transition per second.

Curie

Curie is equivalent to 3.7 X 10^{10} transitions per second.

Decay constant

The probability that a nucleus undergo a transition in a stated period of time

Average life

The average life of a of a population of radioactive isotopes is the average time that the numbers of population remains at the higher energy level before transition.

Half-life

The half-life is the time required for one half of the nuclei present to undergo transition. The half is shorter than average life. The relation between them, T_a = 1.44 X T1/2

Physical half-life (T_p)

The physical half-life is the time required for one half of the nuclei undergo physical rate of decay.

Biological half-life (T_b)

The biological half-life is the time required for one half of the nuclei excreted from body by normal biological process.

Effective half-life ($T_e$ff)

The effective half-life is the time required for radioactivity reduced to one half both by physical decay & biological excretion from the body. The relation in between them are expressed as 1/Teff = 1/ Tp + 1/Tb

Interaction radiation with matter

Interaction by alpha particle

Alpha particles are positively charged heavy particles that produce excitation and ionization of atoms within the matter.

Interaction by β- particle

Beta- particles is a negatively charged particle and produce excitation and ionization of atoms within the matter. It also produces *white radiation by* deflection of nucleus in the nuclear field.

Interaction by β+ particle

Beta+ particles are a positively charged particle and produce excitationand ionization of atoms within the matter. It also undergoes pair productionafter losing it energy combining with an orbital electron within the matter.

Interaction by X ray & gamma photon

X ray and gamma photon having no charge and interact with matter by the way of coherent scattering, photoelectric effect, Compton scattering, pair production and photodisintegration

Factors of interaction

Interaction of photon depends on number of factors- the energy of photon, density of material, atomic number of material and thickness of material. The rate at which photons interact with per unit thickness of material is called linear attenuation coefficient. The linear attenuation coefficient divided by density is called mass attenuation coefficient.

Radiation & dose

Corpuscular radiation

High energetic radiation of charged particles (such as alpha, beta & positron) is called corpuscular or particulate radiation

Electromagnetic radiation

A packet of energy or photon traveling at the speed of light (3 X 10^8 m/sec), as a combination of electric and magnetic field, Such as X-ray, Gamma ray, Cosmic ray, Ultra-violet ray, Radio wave, etc.

Characteristic X-ray

X-ray photon originating outside the nucleus as the result of electron transition.

Breamsstrahlung

X-ray photon produced by deceleration of beta particle in the nuclear field when deflected by the nucleus of atom.

Gamma ray

Photon originating inside the nuclear as a result of nuclear transition

Auger electron

Electron ejected as a result of electron transition following electron captured and internal conversion.

Electron volt

The kinetic energy gained by an electron when falls by a potential difference of one volt. 1 kev= 1000ev, 1 mev= 1000kev

Neutrino (*v*)

An uncharged particle with undetectable small mass that account for the difference between maximum energy and the kinetic energy of beta particle that ejected during beta & positron decay.

Ionizing radiation

Ionizing radiation is the corpuscular or non-corpuscular radiation, which can ionize the nearby atom, when it traverses through the matter, is called ionizing radiation.

Ion pair

Ion pair is defined as the ejected electron plus positive atom that remains after ionization.

W-quantity (W)

The average energy expended by aparticle per ion pair production.

Specific ionization (SI)

The number of primary and secondary ion-pairs produced per unit path length of a particle.

Linear energy transfer (LET)

The average loss of energy per unit path length of an incident particle it is expressed as Kev/ micron.

Transitional energy

The total energy released during radioactive decay of a nucleus is called transitional energy.

Roentgen ®

The Roentgen is defined as a unit of radiation exposure that will liberate a charge of 2.58 $X10^4$ coulomb per kilogram of air.

RAD

The RAD is the unit of absorbed dose. One rad is equal to the radiation necessary to deposited 100 ergs in one gram of radiation material (100 erg/gm).

REM

The REM is a unit of dose equivalent. It is equal to the absorbed dose multiplied by a quality factor (QF). REM = RAD X QF the REM is a measurement of biological effectiveness. In soft tissue, it is considered, that IR= I RAD= !REM

MPD

MPD is the maximum permissible dose which is taken in a year of occupational radiation exposure. The recommended dose is 5 rem per year. 0.5 rem /year is recommended for occasional exposure and 0.17 rem /year is recommended for population.

Genetically significant dose (GSD)

GSD is defined as the dose that, if received by the every member of the population, would be expected to produce same total genetic injury as the actual dose received by the various individuals.

Image production

Radio-isotope imaging

The image production by injection of suitable dose of radio-isotopes in the circulation is called radio-isotope imaging.

Gamma image

Gamma ray interacts with the biological tissue. The energy remnant emitted by the organ, bears various biological information is refers to gamma image. In X-ray refers to aerial image.

Light image

Gamma image after proper coliimation interact with the crystal and produces light image.

Electronic image

Light image produces electric impulse which corresponds to the intensity & location of light image refers to electronic image.

Pixel

The unit of memory of computer which is used to store the information as electrical signal obtained from gamma image is called pixel.

Voxel

The volume of biological tissue, from which images is obtained and stored in one pixel is called voxel.

Visible image

Electronic image interact with screen of CRT and produce image called visible image [3,4].

CONCLUSION

Basic physics of radioisotope & basic electronics is urgent need for radioisotope imaging. These are in short of primary knowledge & information. Everyone should earn detail knowledge for better understanding of isotope imaging.

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