01 - Units of radiation measurement and particle sources

Introduction

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Version 2

Radiation types according to the interaction mechanism

- Charged particles
  - Fast electrons (e^+, e^-)
  - Heavy charged particles α, p
- Neutral radiation
  - Electromagnetic radiation (X-rays, γ)
  - Neutrons (fast or slow)
- Energy, natural and industrial, over eV $\rightarrow$ MeV

Law of radioactive decay

- Activity defined as number of decays per unit of time

$$A = - \left.\frac{\mathrm{d}N}{\mathrm{d}t}\right|_{decay} = \lambda N \quad (1)$$

- N is the number of the nuclei and λ is the decay constant
- Units of activity:
- 1 Ci (curie) = 3.7×10^{10} decays/second, based on 1 gram of ^{226}Ra
- 1 Bq = 2.703×10^{-11} Ci, one decay per second
- At the laboratory scale we use kBq or MBq

Lifetime of the radioisotope

- Lifetime τ and half-life $T_{1/2}$ related to the decay constant as

$$\lambda = \frac{1}{\tau} = \frac{\ln 2}{T_{1/2}} \qquad (2)$$

- Solution to 1 with N_0 initial nuclei:

$$N(t) = N_0 \exp(-t/\tau) \qquad (3)$$

- In general, N_0 may depend on time if it is the product of another decay, N of the sample may be reduced by the self-absorption

Specific activity

- Activity per unit unit mass of the sample

$$\text{specific activity} \equiv \frac{\text{activity}}{\text{mass}} = \frac{\lambda N}{NM/A_v} = \frac{\lambda A_v}{M} \tag{4}$$

- M = molecular weight, A_v = Avogadro's number

Absorbed dose D

- Absorbed energy per mass unit

$$D = \frac{1}{\rho} \frac{\mathrm{d}W}{\mathrm{d}V} \tag{5}$$

- W = energy, V = volume, ρ = density
- Measured in Grays, 1 Gy = 1 J kg^{-1}
- Old unit rad, 1 Gy = 100 rad
- Important to biological effects

Equivalent dose H

$$H = w_R \cdot D \tag{6}$$

- Measured in Sievert Sv
- w_R is the radiation weighting factor (quality factor), depends on the radiation species and energy

Fast electron sources

- Beta decay
  - Continues energy spectrum (3-body decay)
  - Often accompanied by nuclear γ
- Internal conversion
  - Monochromatic electrons keV $\rightarrow$ MeV, useful for calibration
  - Energy of nuclear de-excitation transfered to the orbital electron
- Auger electrons
  - Excitation energy from the atom transfered to the outer electron
  - Also monochromatic, energy lower compared to the internal conversion, few keV

Conversion electron sources

Parent Nuclide	Parent Half-Life	Decay Mode	Decay Product	Transition Energy of Decay Product (keV)	Conversion Electron Energy (keV)
^{109}Cd	453 d	EC	^{109m}Ag	88	62 84
^{113}Sn	115 d	EC	^{113m}In	393	365 389
^{137}Cs	30.2 y	β^-	^{137m}Ba	662	624 656
^{139}Ce	137 d	EC	^{139m}La	166	126 159
^{207}Bi	38 y	EC	^{207m}Pb	570 1064	482 554 976 1048

Figure : Some conversion sources, Knoll, Radiation detection and measurement, p. 6

Heavy charged particle sources

- Alpha decay
  - Emission of ^{4}He, monoenergetic
  - Energy mostly 4 up to 6 MeV for practical use
  - Highest energy means the shortest half-life of the parent isotope
- Spontaneous fission
  - Charged particles heavier than α
  - Transuranic isotopes, ^{252}Cf
  - Dominantly α at the same time as fission
  - Two fragments, back-to-back, light group and heavy group

Sources of electromagnetic radiation

- Gamma rays after β decay
  - Result of nuclear de-excitation, monochromatic
  - Common isotopes up to 2.8 MeV
- Annihilation radiation
  - After β^+ decay, e.g. ^{22}Na
  - Monochromatic at 511 keV
- Gamma rays after nuclear reaction
  - The reaction may be induced by α source on ^{9}Be or ^{13}C leaving highly excited isotope and a neutron
  - Energy dispersion about 1% due to the Doppler effect
- Bremsstrahlung
  - Interaction of fast electrons in matter
  - Continues energy spectrum
- Characteristic X-rays
  - Transition in the orbital electrons
  - Tens of keV, increasing with Z, unique for a particular element
  - Vacancy may be result of electron capture or internal conversion, or by an external source
- Synchrotron radiation
  - Electrons beam in a circular orbit
  - Intense and directional source of eV up to tens of MeV

Neutron sources

- Spontaneous fission
  - For ^{252}Cf, the neutron yield is 0.116 n/s per Bq and 2.3×10^6 per µg of the sample
- Radioisotope sources
  - Reaction of α from the radionuclide on the target of ^{9}Be
  - Background from γ radiation
  - Manufactured as an actinide-beryllium alloy
- Photoneutron sources
  - Absorption of gamma-ray photon by a target nucleus while producing the neutron
  - Monoenergetic neutrons by monoenergetic gamma
  - 10^5 gamma interactions needed for one neutron
- Reactions from accelerated charged particles
  - D-D and D-T reactions