5 Sources & Precautions

5.1 Precautions

Radioactive sources handled in the lab are and do not pose any serious health threat unless exposed/contact directly. Sources are very weak and the amount of dose one might get is very less and much below the **prescribed safe-limit.** For more details on Biological effect, check **Leo's** Chapter 3

1. **Don't** hold the source in your hand for a **long-time.**
2. **Don't** the source in your pocket.
3. **Avoid** taking the source **outside** the Lab **(strictly probihited)**
4. **As soon as** data taking/gathering is **completed**, return the source immediately and do the plotting or calculation part.

   **** Don't forget to Sign** the source issuance log-book.

   !!!!! Action will be taken in case of improper handling/misuse !!!!!

5.2 Radioactive Sources and Decay Channels

Radioactivity: Spontaneous emission of matter/radiation from the nucleus of an atom.

- Atoms with neutron to proton ratio either too high or too low undgo the process of radioactive decay.
- The radioactive decay may transform the atom into a different element, which can be either radioactive or stable.
- decay is a random/stochastic process. One cannot predict with certainity the time at which a particular nucleus will undergo decay.
- For sufficient number of atoms/nucleus, the probability of decay becomes well defined.

Nuclear Level Diagram: Energy on y-axis and atomic number Z on the x-axis (increasing left to right).

- **Alpha Decay:** Ejection of a nuclei of ^{4}He from a nucleus (usually a very heavy nucleus)

  (Z, A) $\longrightarrow$ (Z-2, A-2) + $^4_2$He (or α)
- **Beta Decay:** Fast electrons resulting from the weak-interaction decay of a neutron or proton in a nuclei with excess of the respective nucleon.

  $n \longrightarrow p + e^- + \bar{\nu}_e$

  (Z, A) $\longrightarrow$ (Z+1, A) + e^- + $\bar{\nu}_e$
- **Electron Capture (EC):** Capture of one of the atomic orbital electrons by the nucleus (common in proton-rich nucleon)

  – energy level diagram similar to beta decay except that the emitted particles are neutron and electron-neutrino

  $p + e^- \longrightarrow n + \nu_e$

  (Z, A) + e^- $\longrightarrow$ (Z-1, A) + n + ν_e
- **Gamma Emission:** Photon emitted as a result of de-excitation of a nucleus from a higher energy state to a lower state (nuclear de-excitation). The typical energies are in the range of a few 100s of keV to a few MeV.
- **Annhilation Radiation:** Radiation emitted as a result of annhilation of an electron with a positron.

  – when a positron source is enclosed in an electron-rich absorbing material

  – 2 photons of equal energy (equal to the electron rest mass: 511 keV)

  $e^- + e^+ \longrightarrow \gamma + \gamma$

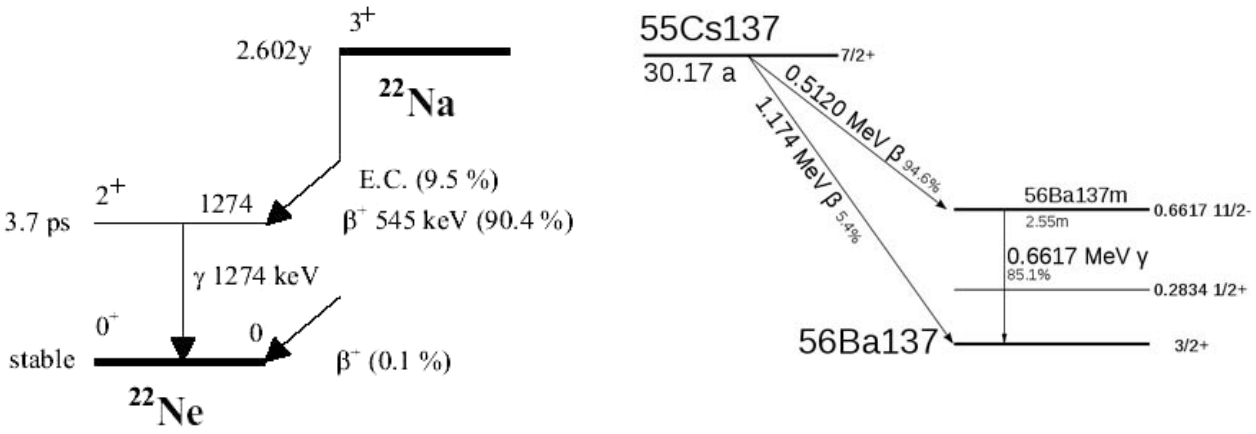

Figure 1: Decay schemes of Sodium ($^{22}_{11}$Na) and Cesium ($^{137}_{55}$Cs).

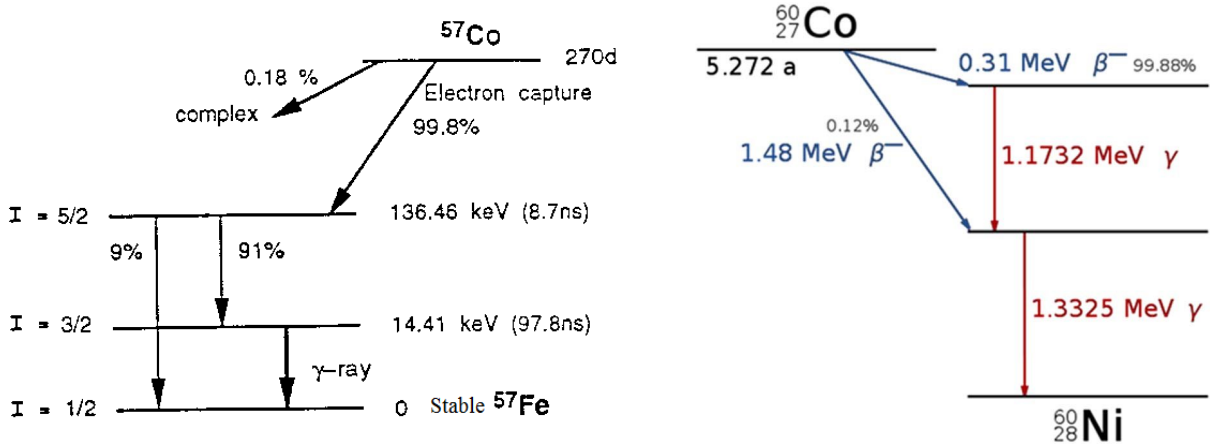

Figure 2: Decay channels of the isotopes of Cobalt (^{57}Co and ^{60}Co).

- **Internal Conversion:** A way of nuclear de-excitation in which instead of a photon, the nuclear excitation energy is transferred to one of the atomic orbital electrons (eventually ejection of an electron).

  – The electron is ejected with an energy equal to the excitation energy minus the binding energy of the electron

  – usually monoenergetic electrons

- **Auger Electrons:** A way of nuclear de-excitation where during internal conversion, an excitation of the *atomic electron shell* is transferred to another atomic electron (rather than by emitting a characteristic photon).

  – energy more typical of atomic processes ($\leq$ a few keV)

Laboratory Sources: ^{22}Na; ^{57}Co; ^{60}Co; ^{90}Sr; ^{137}Cs; ^{133}Ba; ^{147}Pm; ^{204}Tl;

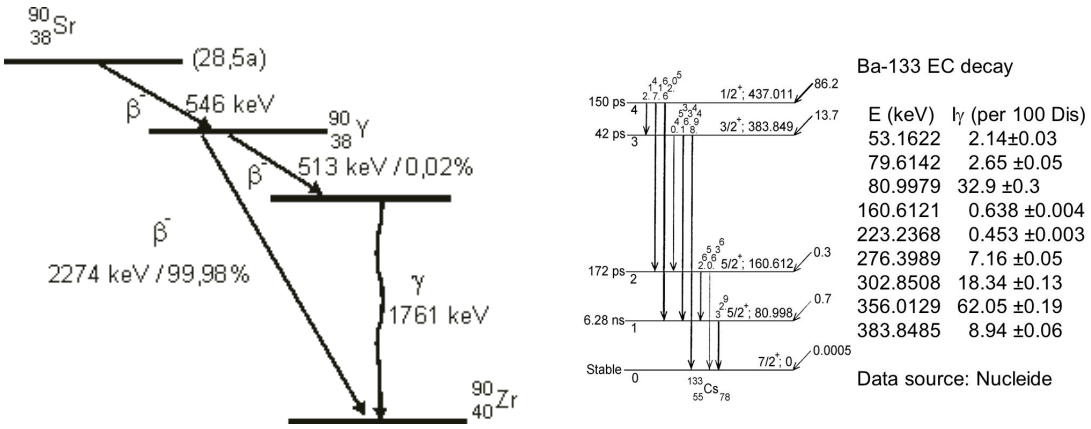

Figure 3: Decay channels of Strontium (^{90}Sr) and Barium ($^{133}_{56}$Ba).

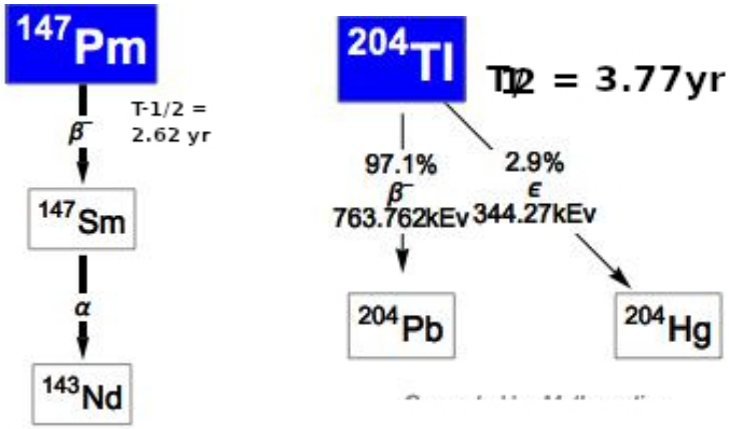

Figure 4: Decay channels of Promethium (^{147}Pm) and Thallium (^{204}Tl).

5.3 Dose Estimation

Ref: Chapter 3 of the book by W. R. Leo

$$\text{Exposure rate} = \frac{\Gamma.\text{A}}{\text{d}^2} \tag{1}$$

$\Gamma \equiv$ *exposure rate constant*, dependent on the decay scheme of the particular source, the energy of the gamma-rays, the absoption coefficient in air and the specific ionization of electrons.

$\text{d} \equiv$ the distance to the source

$\text{A} \equiv$ activity of the source

Units: Gray (Gy; 1 Gy = 1 J/kg) or Sievert (Sv)

Estimate of the Activity of a source:

Activity: mean number of decay per unit time. Measured in *Curie/Becquerel*

1 Curie (Ci) = 3.7×10^{10} disintegrations/s (dps)

1 Becquerel (Bq) = 1 disintegration/s (recommended these days)

$$A(t) = A(t_0)e^{\lambda.(t-t_0)} \tag{2}$$

A(t) ≡ Number of nuclei at time t (relative to t_0)

$\lambda \equiv$ decay constant = $0.693/T_{1/2}$

t ≡ elapsed time since t_0

^{60}Co: 98 kBq activity on July 2016 $T_{1/2}$ = 5.27 years

t = 6 years (July 2022)

N = 98 $\times e^{-0.693/5.27*6}$ kBq $\sim$ 44.5 kBq = 1.2 nCi

$\Gamma_{^{60}Co} = 13.2(R.cm^2/hr - mCi)$; d=60 cm

1 Roentgen (R) = the quantity of X-rays producing an ionization of 1 esu/cm^3

= 12.58 $\times 10^{-4}$ Colu/kg in AIR at STP

Exposure rate (^{60}Co) = 13.2 $\times 1.2 \times 10^{-6}/60^2$ = 4.4 nR/hr = 4.4 $\times$ 0.00877 nSv/hr $\sim$ 0.04 nSv/hr

So holding a ^{60}Co for 3 hours $\times$ 14 lab session = 42 hours, you expect to be exposed to $\sim$ 1.6 nSv of radiation (Check the safety limit on the AERB webpage)

1 R = 1 rad (energy absorbed per unit mass) = 0.877 rem

1 rad = 100 erg/g

1 Sv = 100 rem

NOTE: To convert from *Rad* Rad to *rem* requires multiplication factor representing effective biological damage. For gamma-ray, X-ray and beta, this factor is 1. For alpha, its 20.