

# The Physics Behind Environmental Radioactivity Measurement

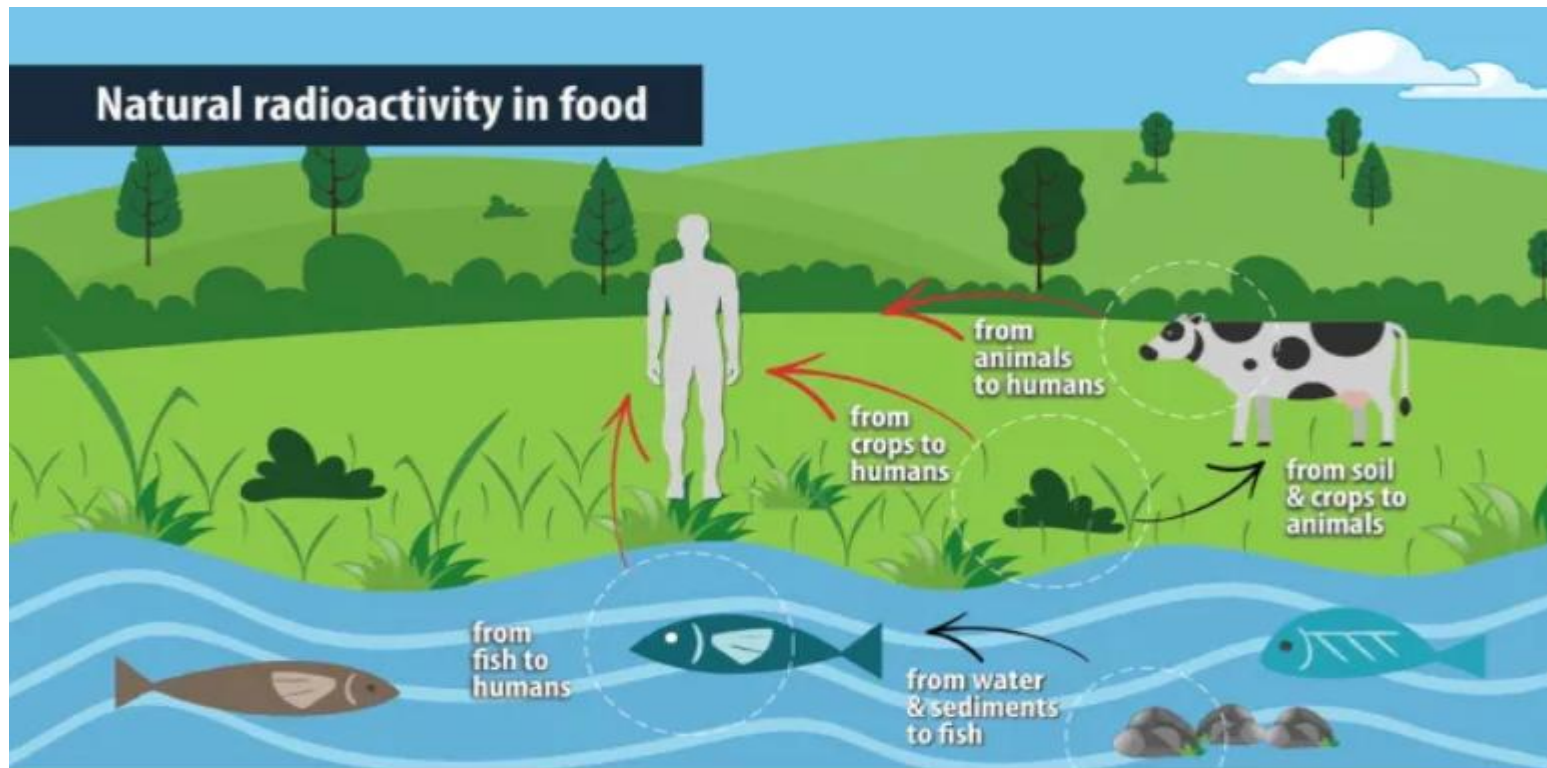
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# Introduction

- All foods contain natural radionuclides, which are transferred from the soil to the crops on land and from water to fish in rivers, lakes and the sea



# Definition of Terms

- **Radiation** is the energy emitted from a source as electromagnetic wave or particles through a material medium or space e.g X-ray, gamma-ray, alpha, electron, radiowave, microwave, visible light.
- **Radioactive material** is material that emits radiation.
- **Radioactivity** is the natural process by which unstable atoms (called *radioactive isotopes*) lose energy by emitting radiation.
- **Absorbed dose** is the amount of energy deposited by ionizing radiation in a material or tissue per unit mass.

# Radioactive Decay

- Radioactive decay is the **spontaneous transformation of an unstable atomic nucleus into a more stable nucleus**, accompanied by the emission of radiation such as alpha particles, beta particles, or gamma-rays.
- The process is random and cannot be predicted for a single atom, but the decay behavior of a large number of atoms follows a definite statistical law.

$$N = N_0 e^{-\lambda t}$$

Where:

N = number of undecayed nuclei remaining after time t

N<sub>0</sub> = initial number of radioactive nuclei

λ = decay constant

t = time elapsed

# Activity(A)

- Activity is the **rate at which radioactive nuclei decay in a radioactive material.**
- It represents the number of disintegrations occurring per second.

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

Where:

A = activity

$\lambda$  = decay constant

N = number of undecayed nuclei

- **The SI Unit is Becquerel (Bq)**

$$1 \text{ Bq} = 1 \text{ disintegration per second}$$

- The Older unit is **Curie (Ci)**

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$$

# Specific Activity

- Specific activity is the **activity per unit mass of a radioactive substance**.
- It indicates how radioactive a material is relative to its mass.

$$\text{Specific Activity} = \frac{A}{m}$$

Where:

A = activity

m = mass of the sample

- **The Units are** Bq/g, Bq/kg, Ci/g

Example

Sample A:

10 g material → 1000 Bq

Specific Activity = 100 Bq/g

Sample B:

10 g material → 5000 Bq

Specific Activity = 500 Bq/g

Sample B is more radioactive per unit mass.

# Half-Life

- Half-life is the **time required for half of the radioactive nuclei in a sample to decay.**
- It is represented by  $T_{1/2}$ .

$$N = N_0 \left(\frac{1}{2}\right)^{t/T_{1/2}}$$

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

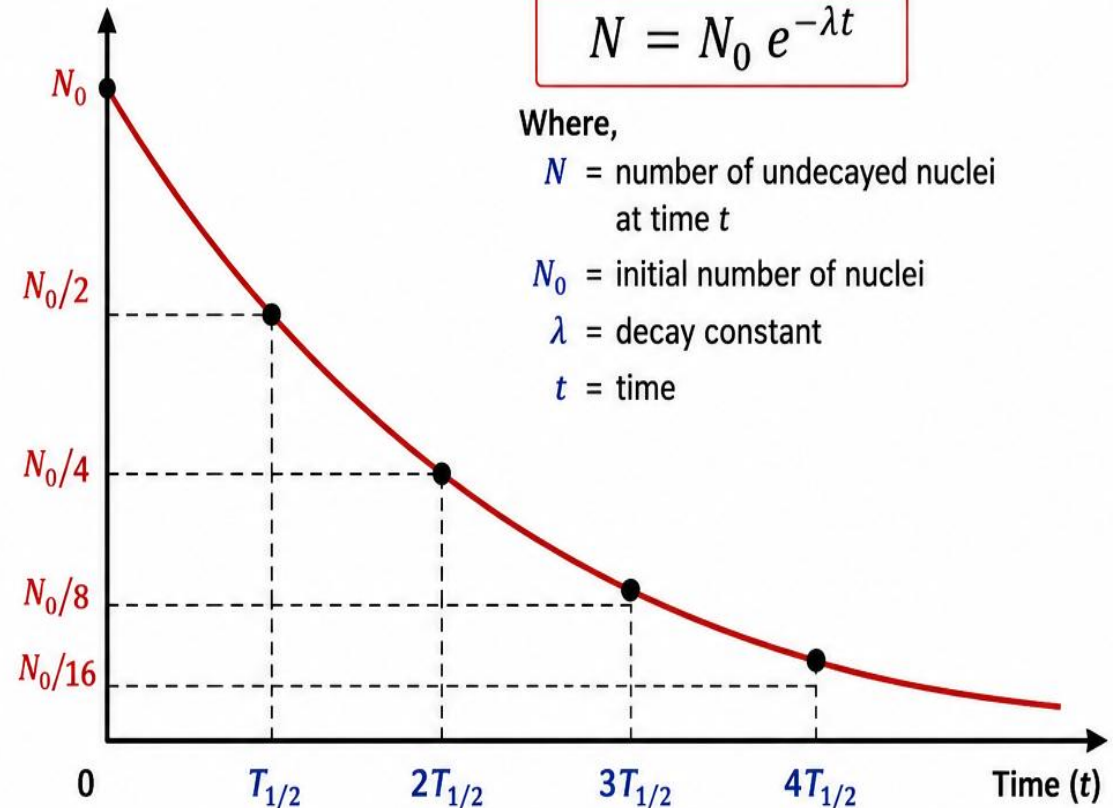
Where:

$N_0$  = initial number of nuclei

$N$  = remaining nuclei after time  $t$

$\lambda$  = decay constant

Number of undecayed nuclei ( $N$ )



Radioactive Decay Law

$$N = N_0 e^{-\lambda t}$$

Where,

$N$  = number of undecayed nuclei at time  $t$

$N_0$  = initial number of nuclei

$\lambda$  = decay constant

$t$  = time

# Environmental Radioactivity

Environmental radiation originates from:

- **Terrestrial sources**

- Uranium series
- Thorium series
- Potassium-40

- **Cosmological sources**

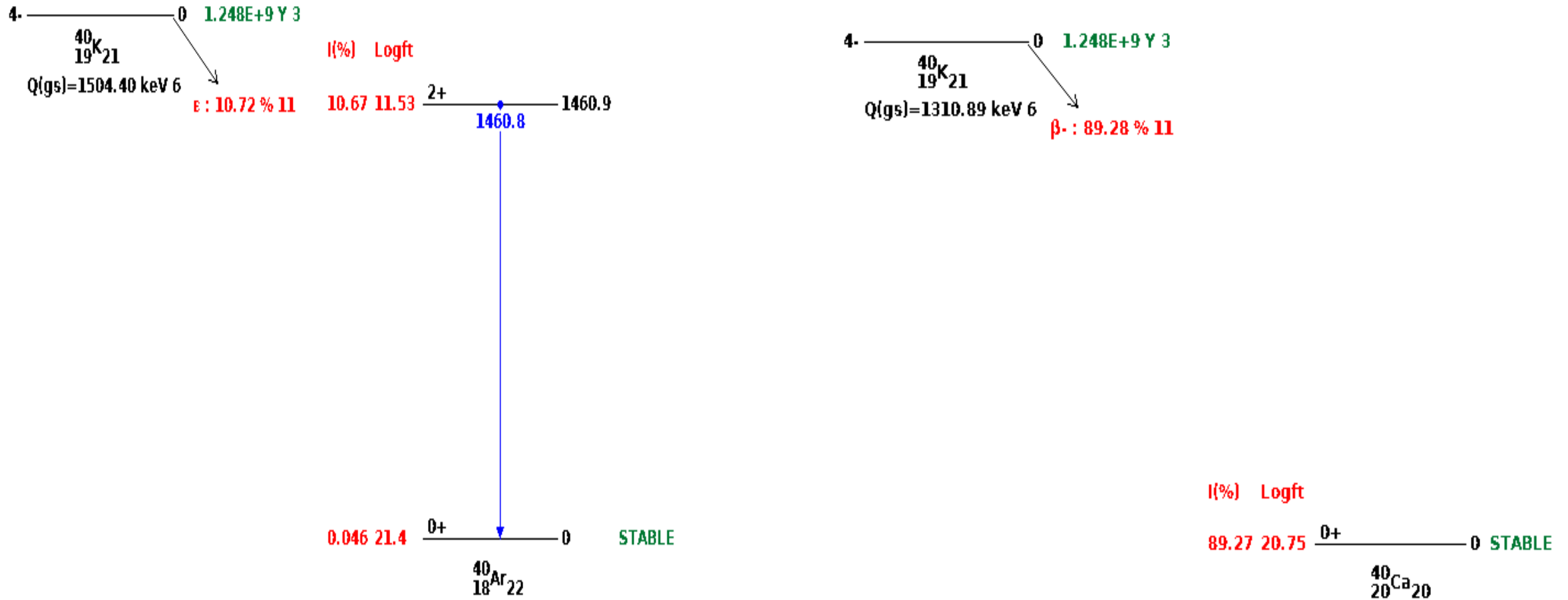
- Galactic cosmic-rays
- Solar cosmic-rays

- **Anthropogenic sources**

- Nuclear medicine
- Mining activities
- Nuclear power operations

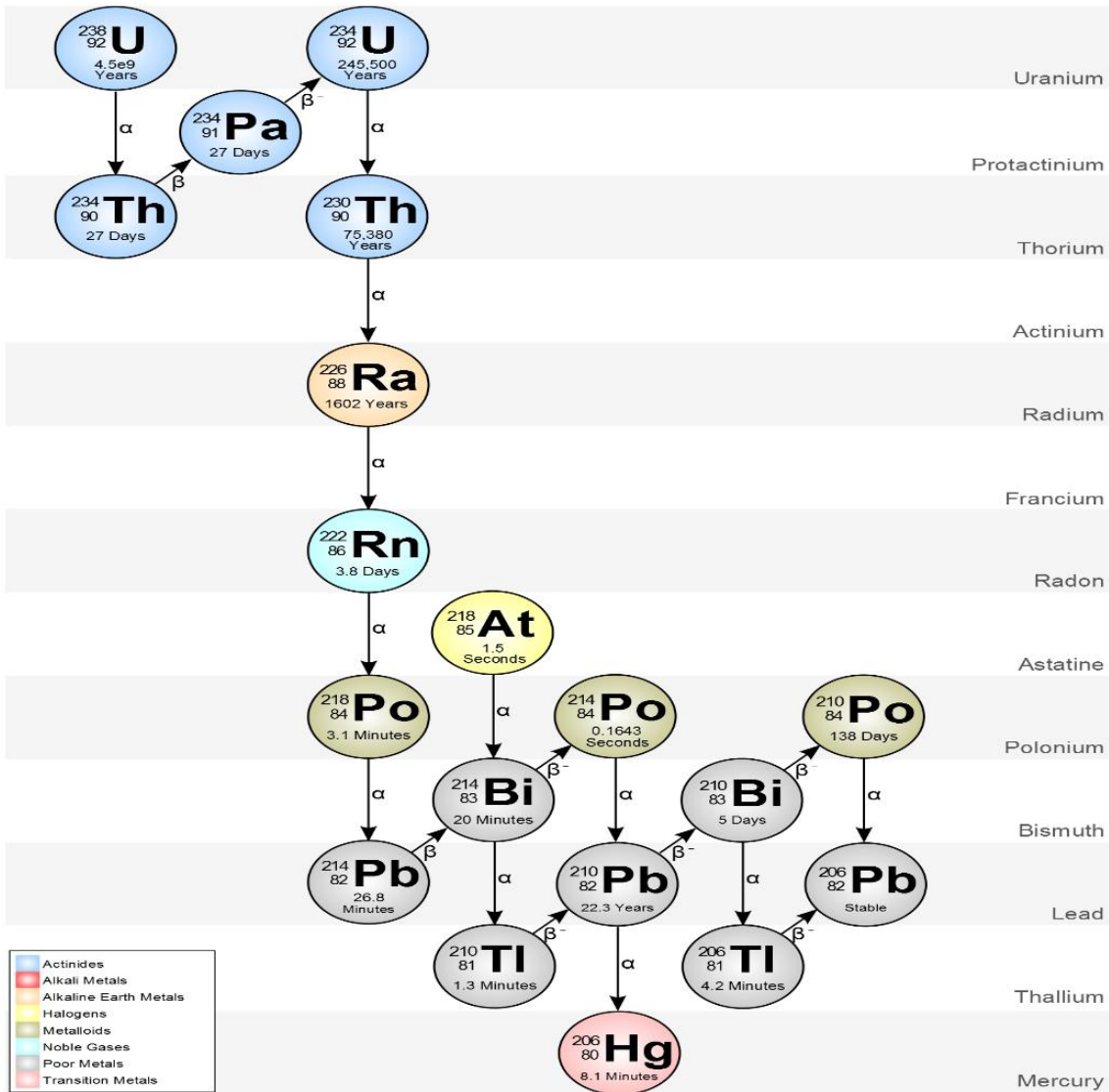
# Terrestrial Sources of Radiation

- ❖ The abundant terrestrial radionuclide occurring naturally in the environment are; U-238 and Th-232 series and K-40

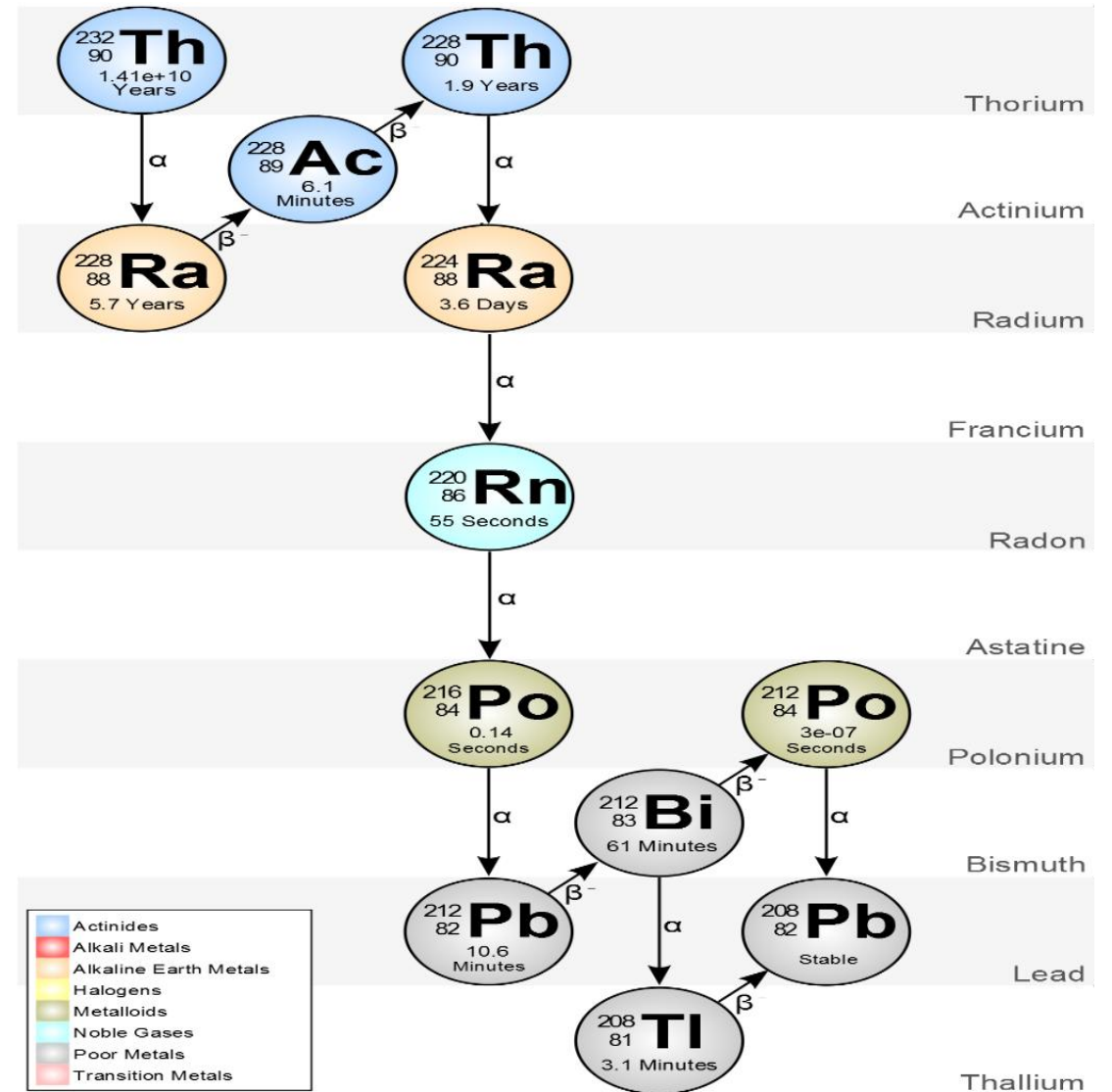


Source: Jun Chen; Nuclear data sheets for A=40. Nuclear Data Sheets vol. 140, 1, 2017

# U-238 decay series

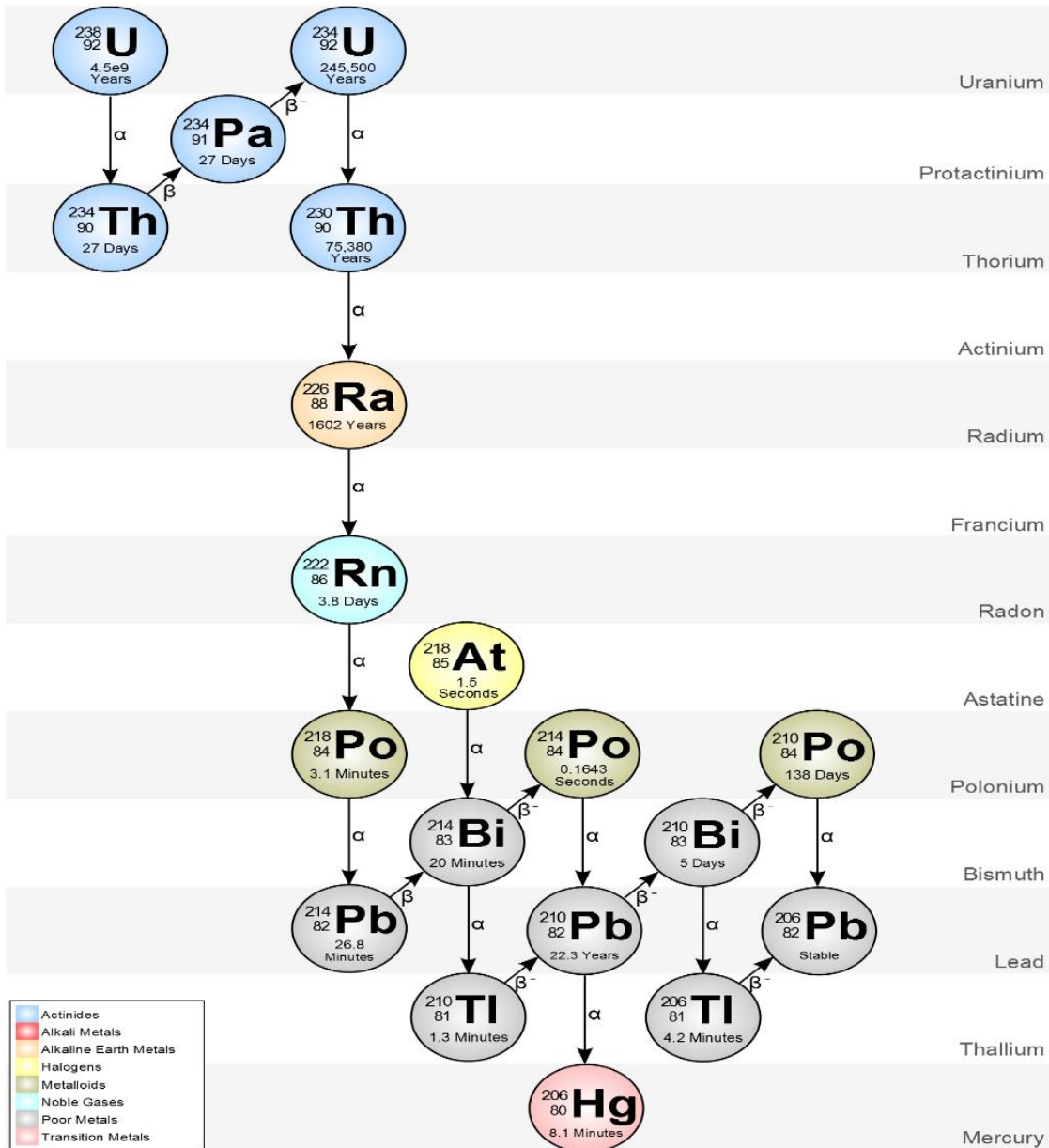


# Th-232 decay series

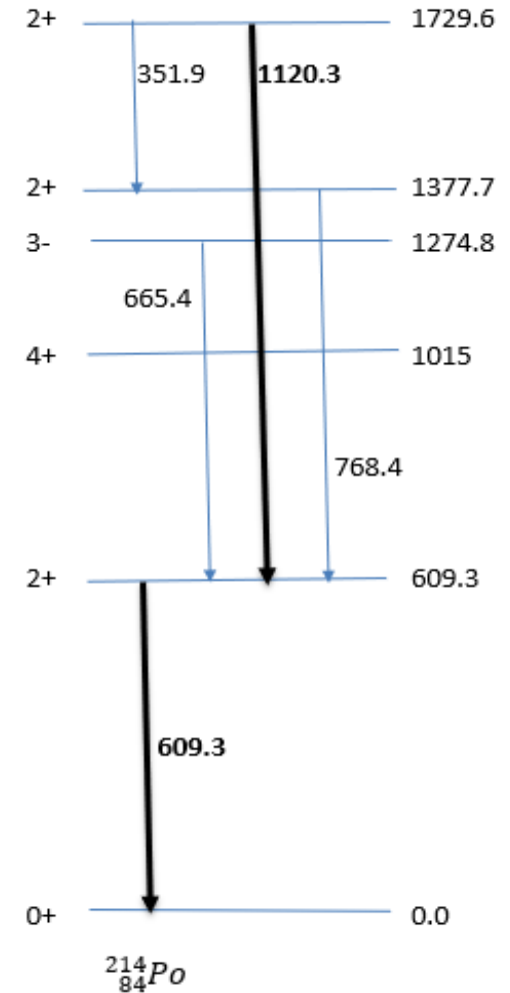


Source: <http://metadata.berkeley.edu/nuclear-forensics/Decay%20Chains.html>.

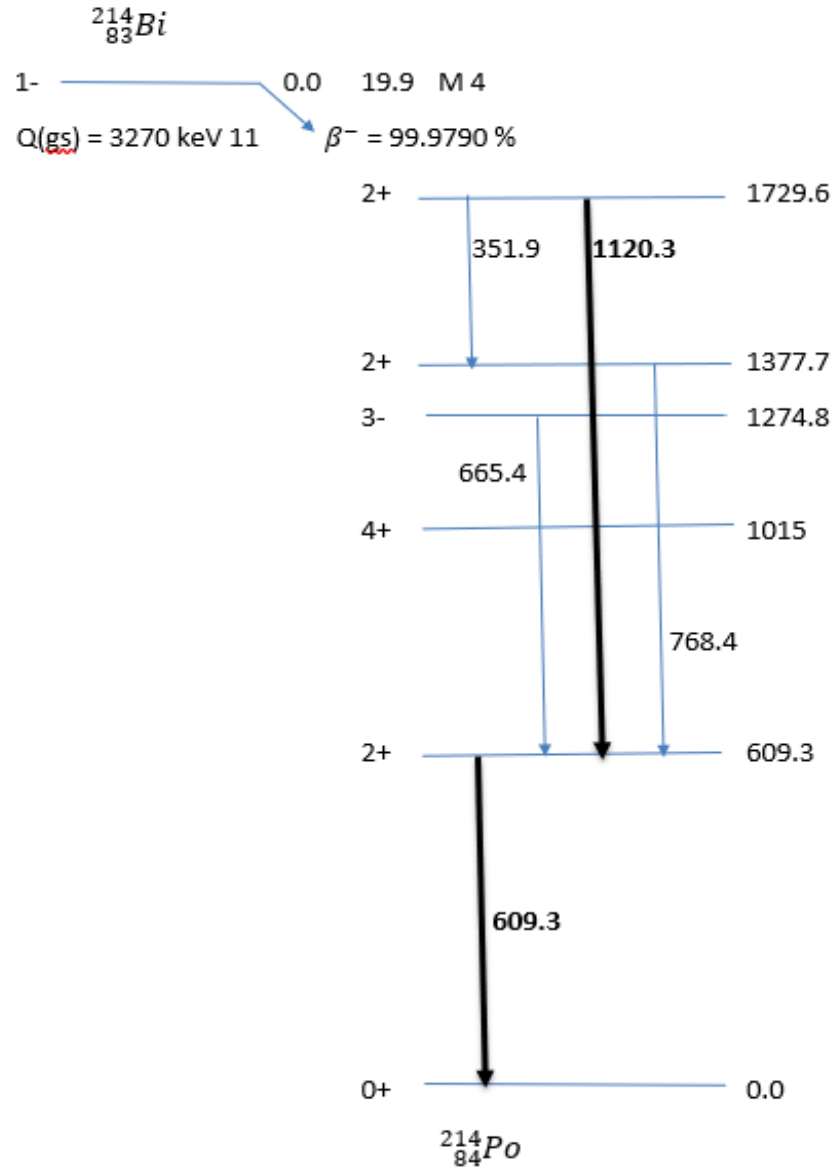
# Bi-214 from U-238 series



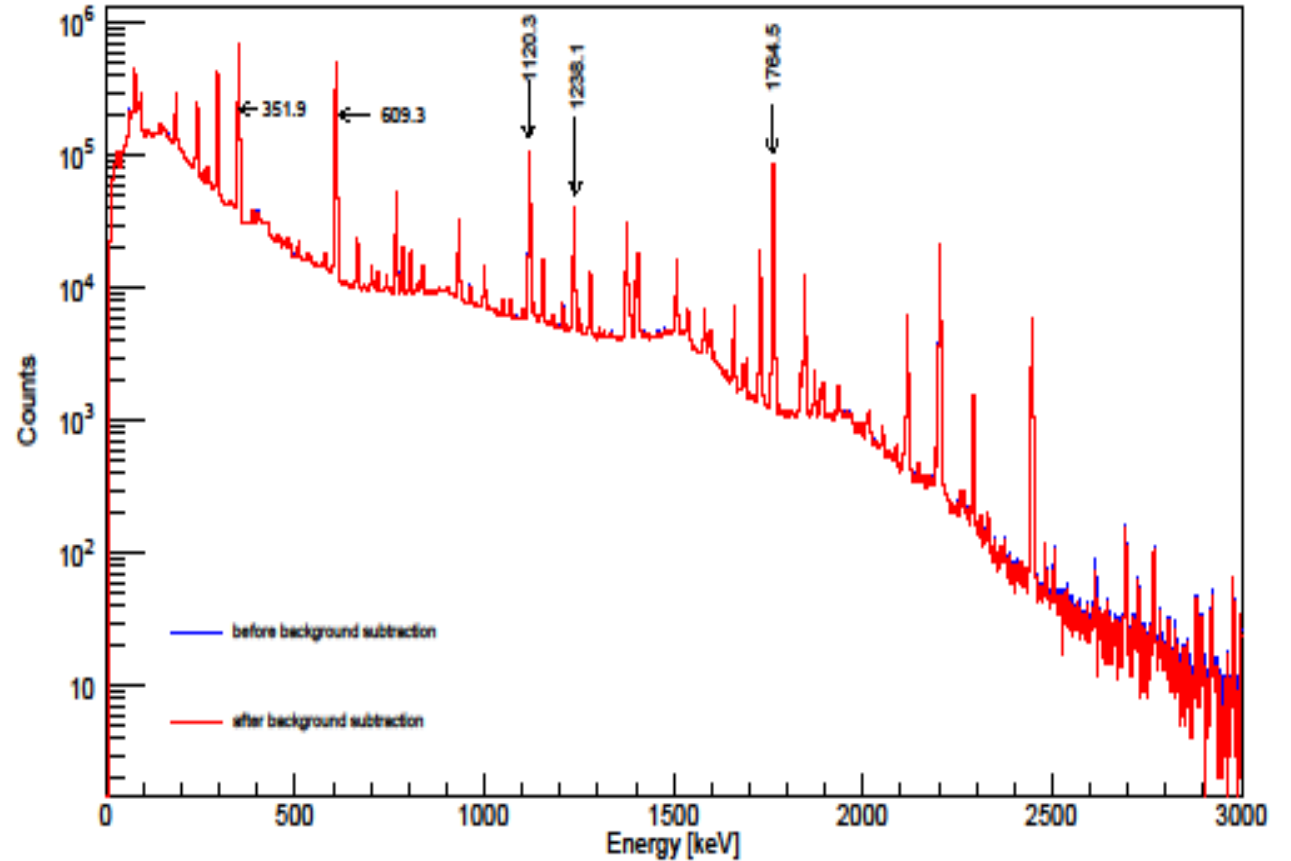
$^{214}_{83}\text{Bi}$   
 1-  $\beta^-$  0.0 19.9 M 4  
 $Q(\text{gs}) = 3270 \text{ keV}$  11  $\beta^- = 99.9790 \%$



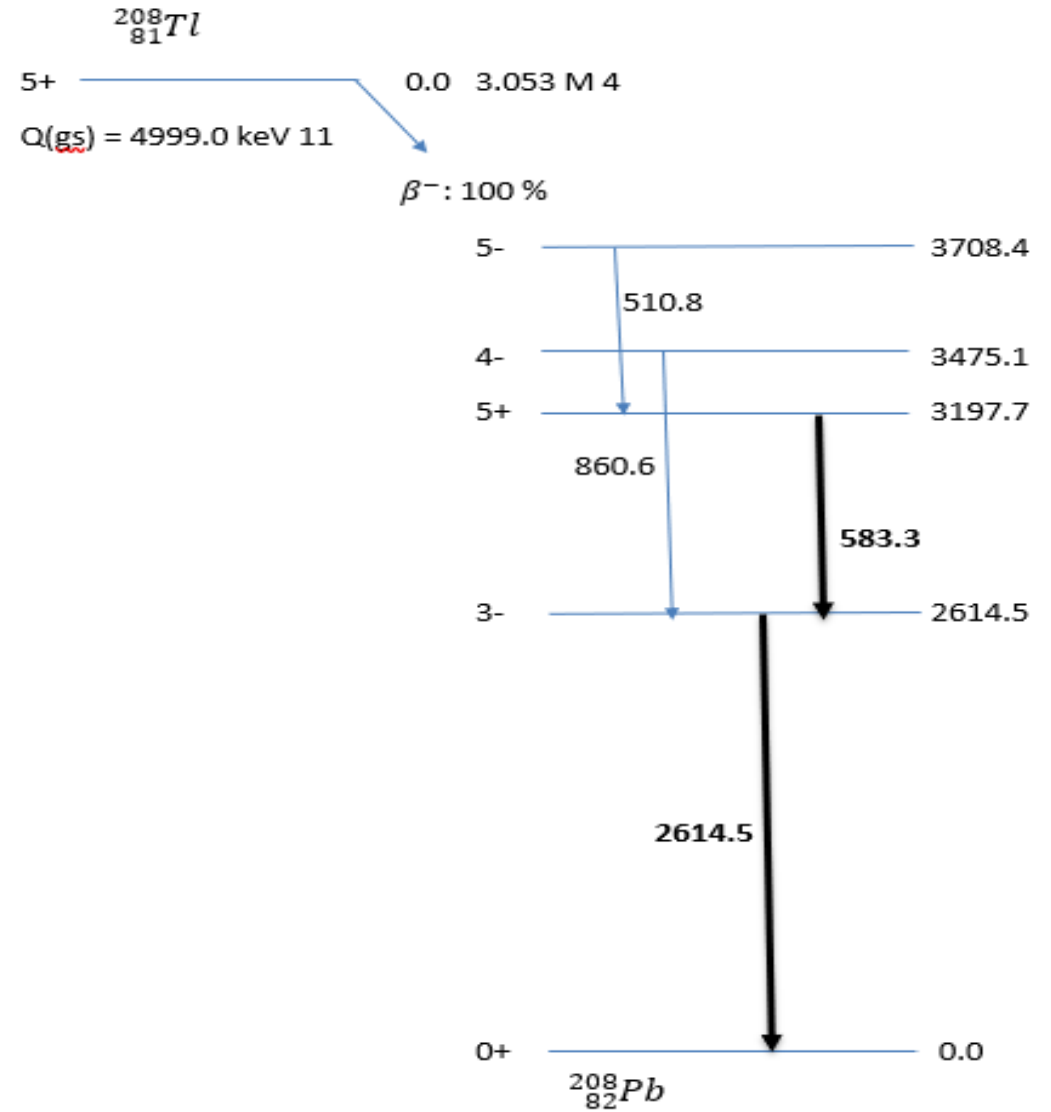
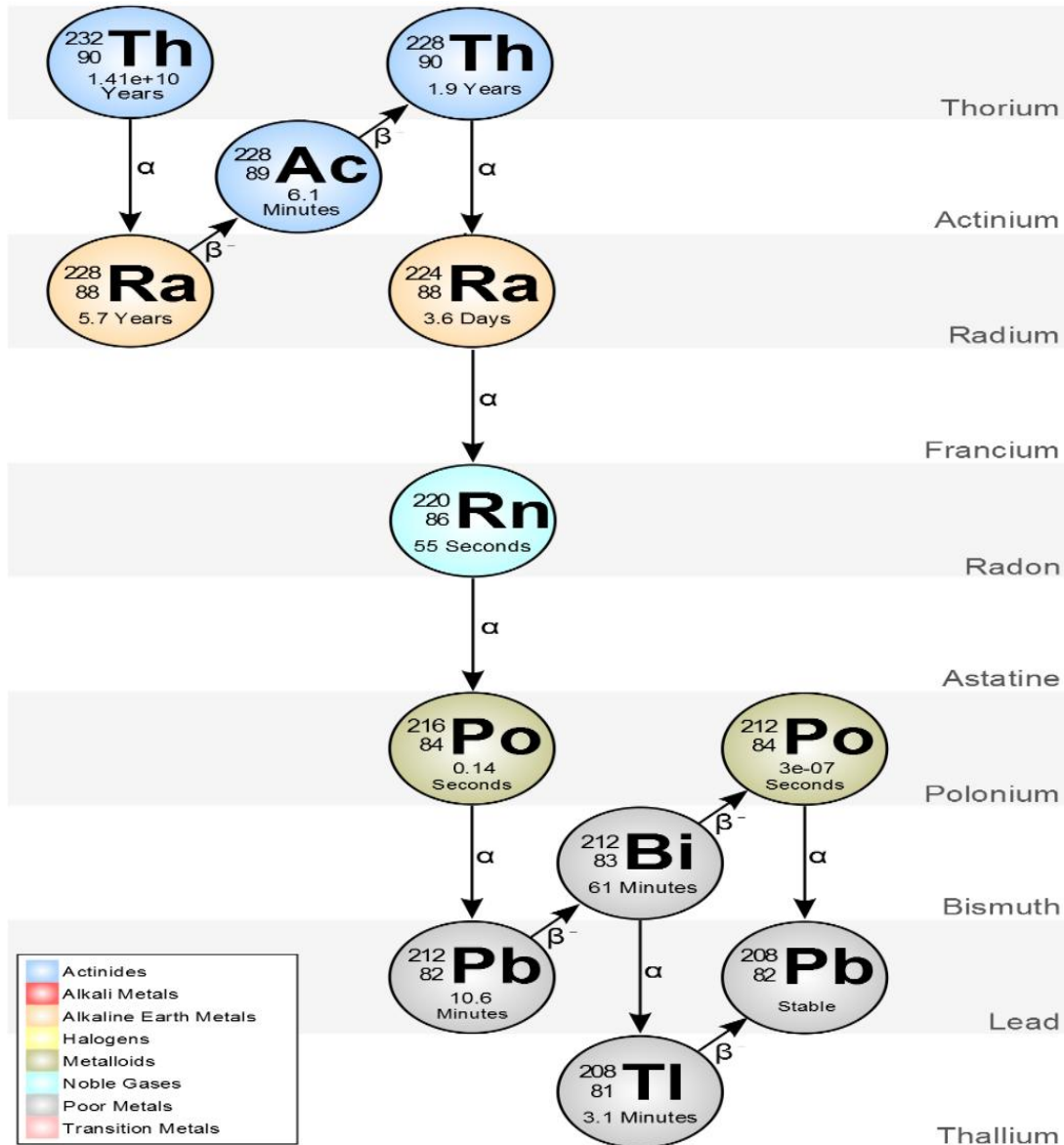
# Bi-214 from U-238 series



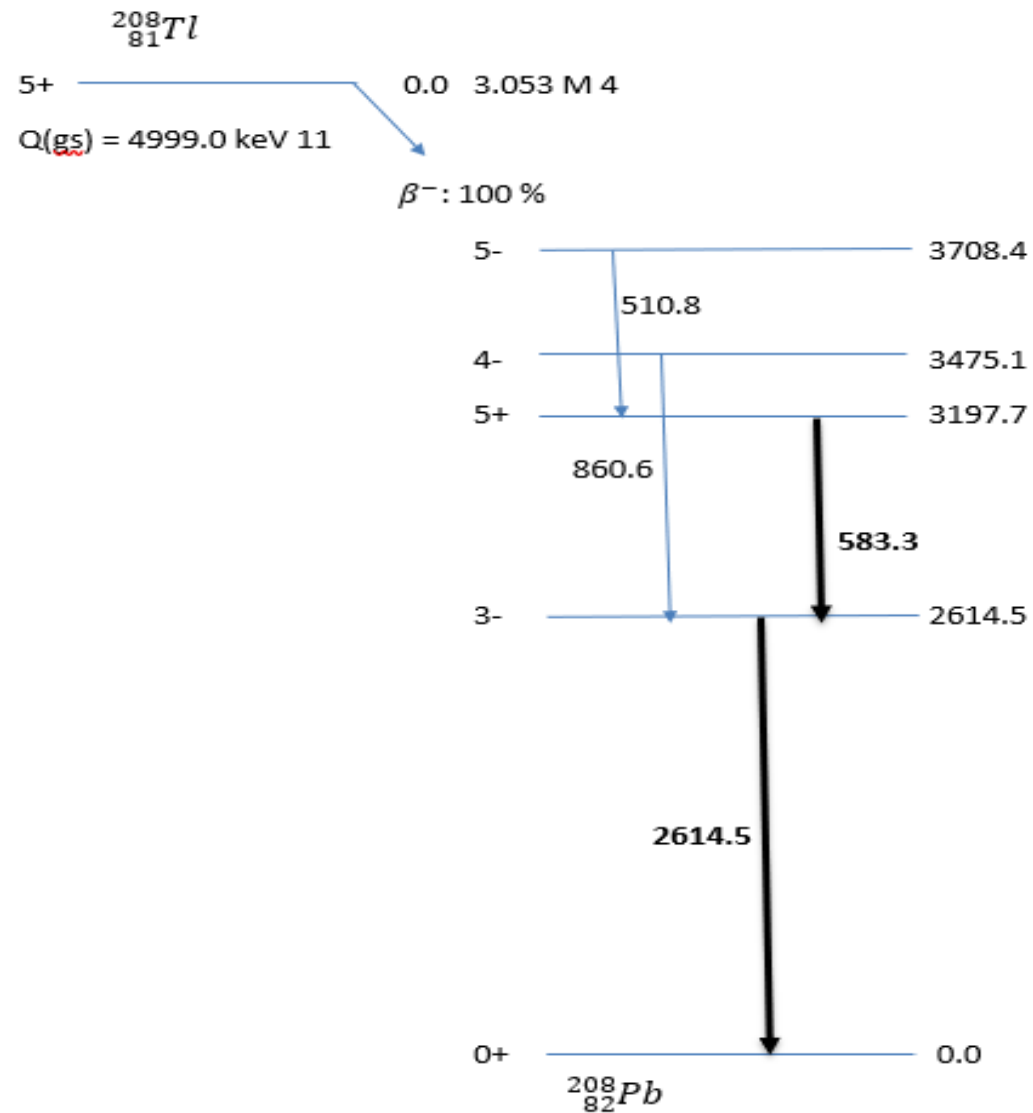
# IAEA Uranium ore spectrum



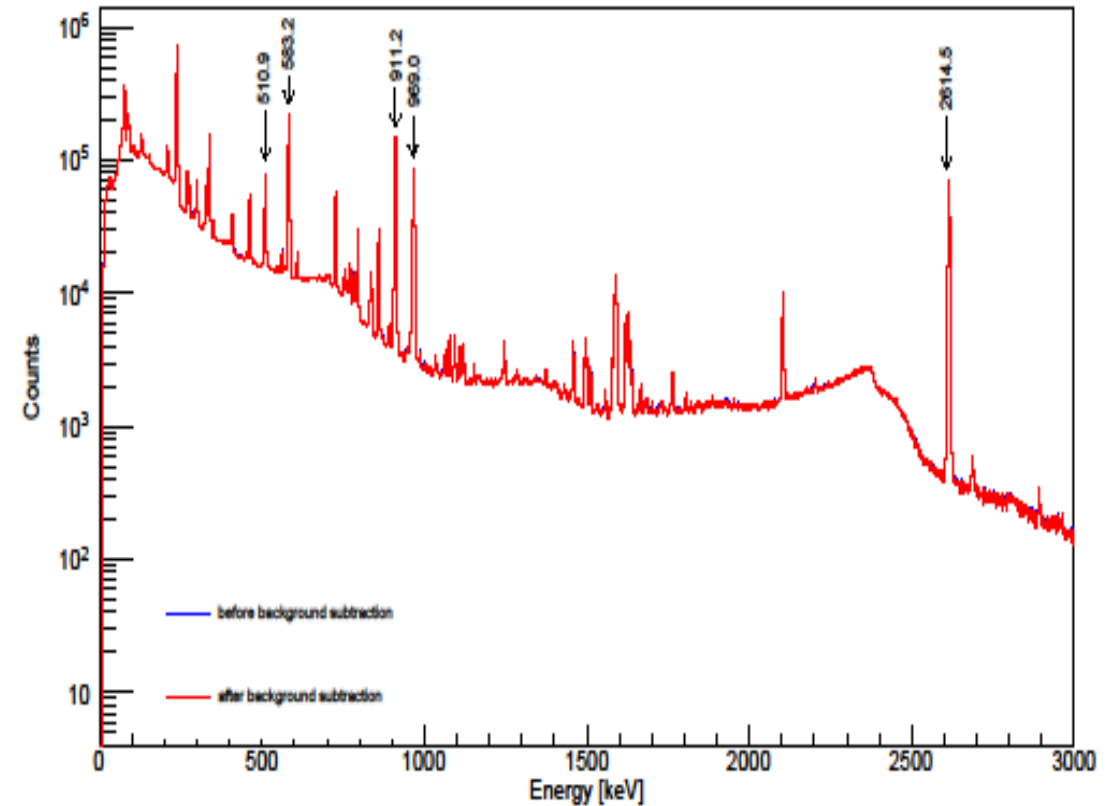
# TI-208 from Th-232 series



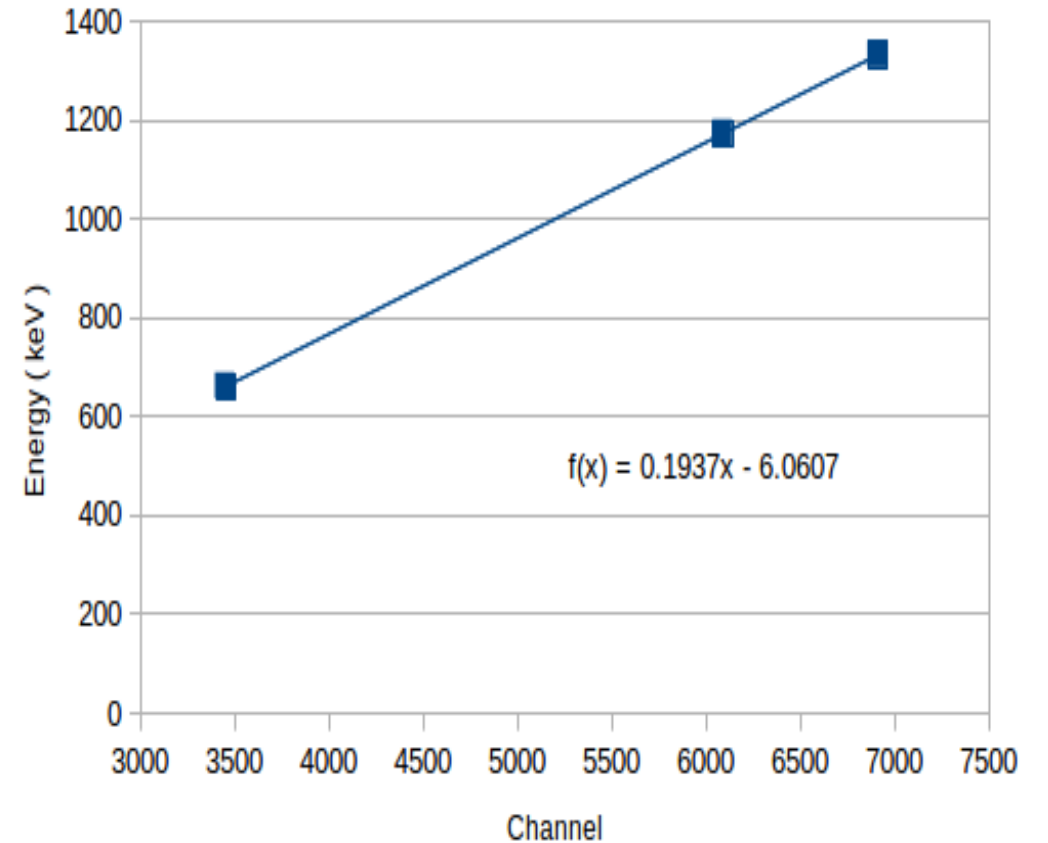
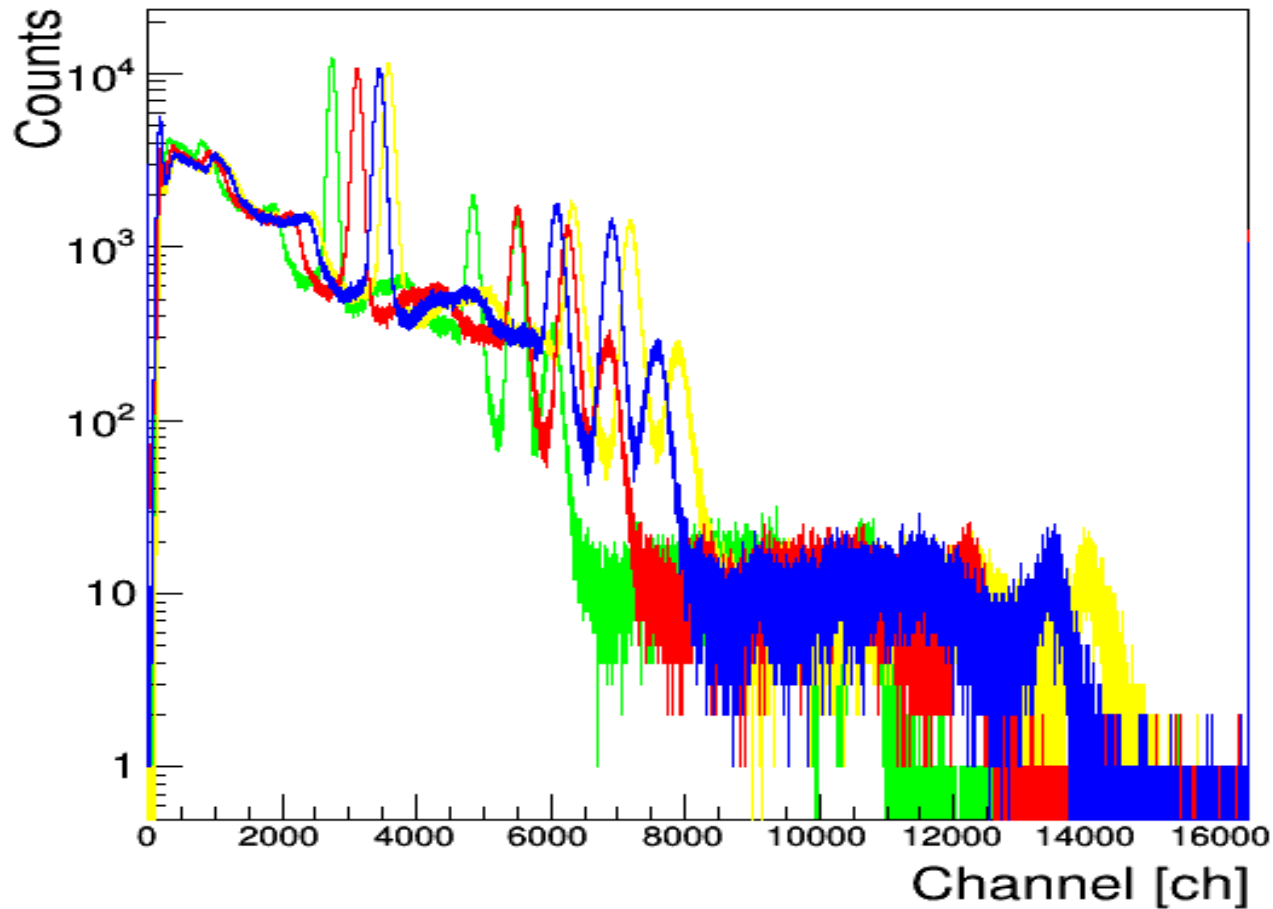
# Tl-208 from Th-232 series



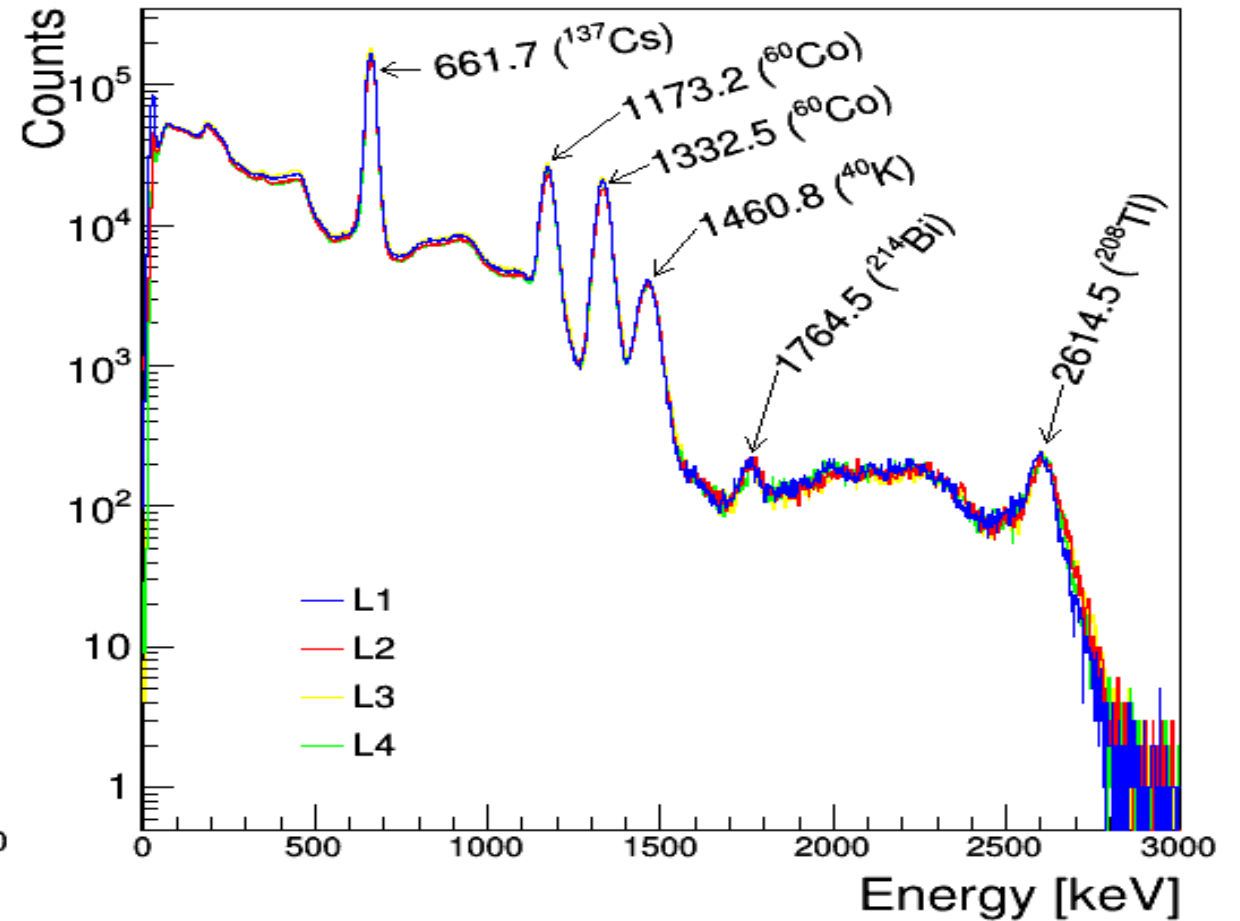
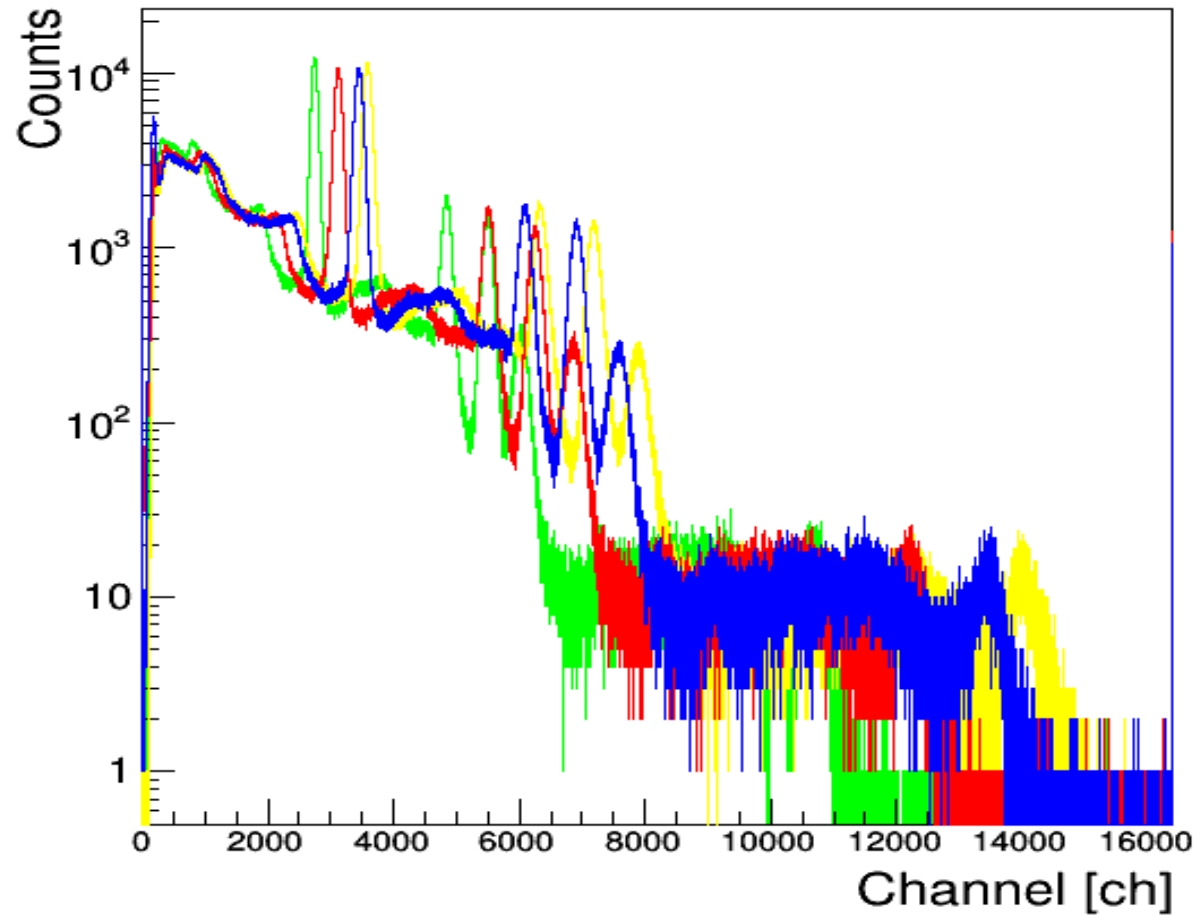
# IAEA Thorium ore spectrum



# Energy Calibration using Cs-137 and Co-60 with four LaBr3(Ce)



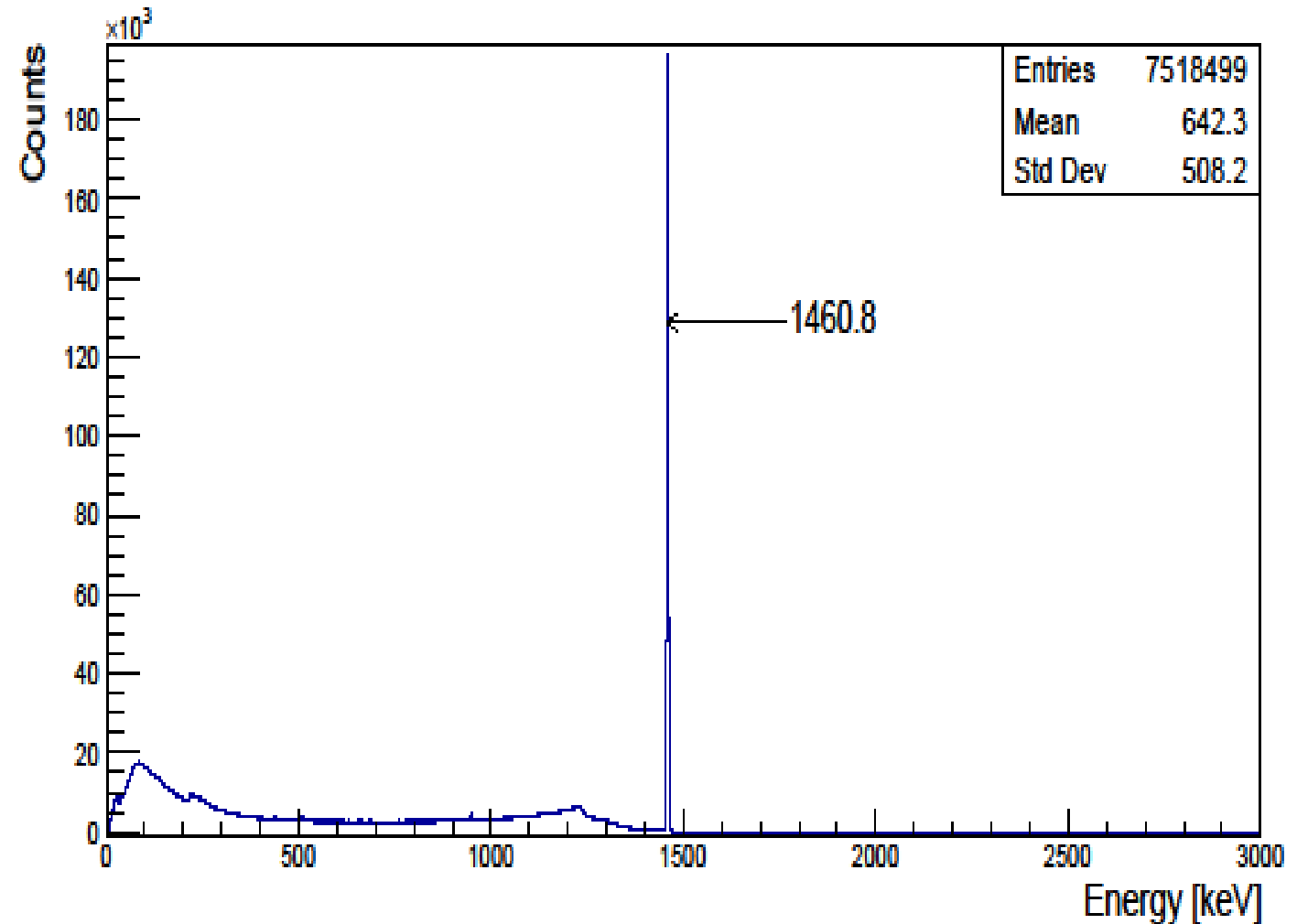
# Energy Calibration using Cs-137 and Co-60 with four LaBr3(Ce)



# Efficiency Calibration using measured KCl sample with HPGe

Absolute Full-energy detection efficiency ( $\varepsilon(E_\gamma)$ )  
(Gilmore, 2008)

$$\varepsilon(E_\gamma) = \frac{C_n}{AP_\gamma M_s L_t}$$

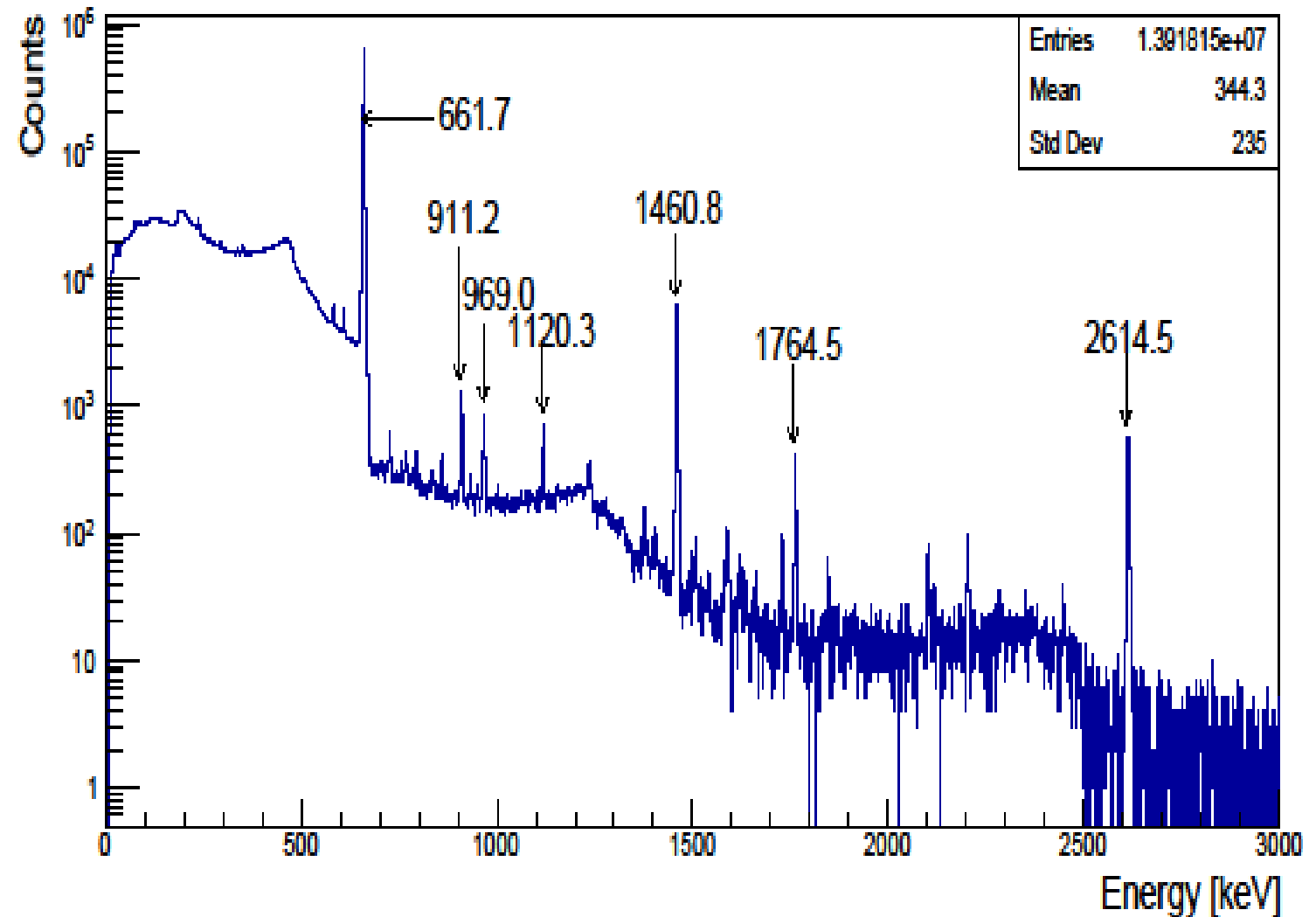


# Specific activity concentration using Beach sand with HPGe

Specific activity concentration (A) in Bq/kg

Gilmore (2008)

$$A = \frac{C_n}{\varepsilon(E_\gamma)P_\gamma M_s L_t}$$



LET MOVE TO THE MEASUREMENT  
NOW

# Measurement Setup

The setup consists of:

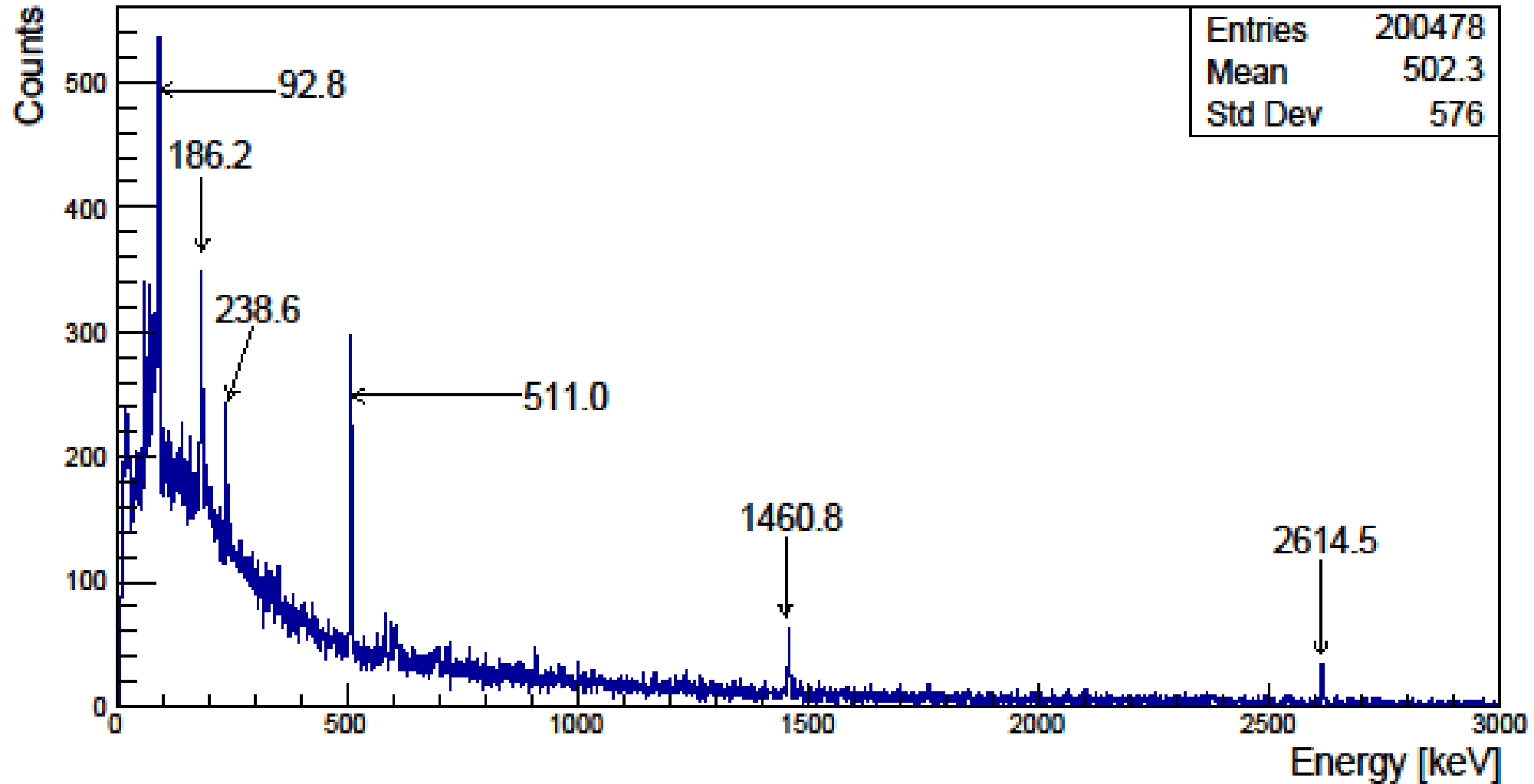
- ❖  $2 \times 2$ " LaBr<sub>3</sub>:Ce detector coupled to a PMT and voltage divider
- ❖ The detector is biased at -1200 V using the CAEN module
- ❖ The CAEN module is controlled via a desktop application on a Windows machine
- ❖ The slow signal is read out, while the fast signal is terminated at 50  $\Omega$
- ❖ The signal is split and fed into Red Pitaya 125 MHz digitisers

# Measurement Instruction

- ❖ Connect to your laptop to the tlabsguest or eduroam Wi-Fi network.
- ❖ Download and extract the release ZIP file (<https://github.com/pavel-demin/red-pitaya-notes/releases/download/20251012/red-pitaya-notes-20251012.zip>).
- ❖ Run the mcpha.exe program located in the control directory.
- ❖ Connect your laptops to the RPI WiFi
- ❖ Enter the IP address of the Red Pitaya board (10.0.0.15 or 10.0.0.16) and press the **Connect** button.
- ❖ Select the **Spectrum histogram 1** tab.
- ❖ Adjust the amplitude threshold and measurement time as required.
- ❖ Press the **Start** button.

Thanks For your Attention

# Measured background using HPGe



# Formulas for calculations in singles mode

Energy resolution (R) in %

Gilmore (2008) and Knoll (1989)

$$R = \frac{FWHM}{E} \times 100$$

$$FWHM = 2.35\sigma$$

Absolute Full-energy detection efficiency ( $\varepsilon(E_\gamma)$ )

Gilmore (2008)

$$\varepsilon(E_\gamma) = \frac{C_n}{AP_\gamma M_s L_t}$$

Minimum detectable activity (MDA)

Gilmore (2008)

$$MDA = \frac{2.71 + 3.29\sigma}{\varepsilon(E_\gamma) P_\gamma M_s L_t}$$

Specific activity concentration (A) in Bq/kg

Gilmore (2008)

$$A = \frac{C_n}{\varepsilon(E_\gamma) P_\gamma M_s L_t} \cdot C_d$$

Self-absorption correction factor ( $C_d$ )

$$C_d = \frac{\varepsilon(E_\gamma, \text{standard})}{\varepsilon(E_\gamma, \text{sample})}$$

# Measurement Instruction

The Red Pitayas are connected via Wi-Fi:

- ❖ Wi-Fi network: RPI
- ❖ Password: gps123gps
- ❖ IP addresses: as indicated on the stickers  
(10.0.0.15 and 10.0.0.16)