# NON-DESTRUCTIVE ANALYSIS OF ELEMENT AND ISOTOPE COMPOSITION BY NEUTRON SPECTROSCOPY METHOD.

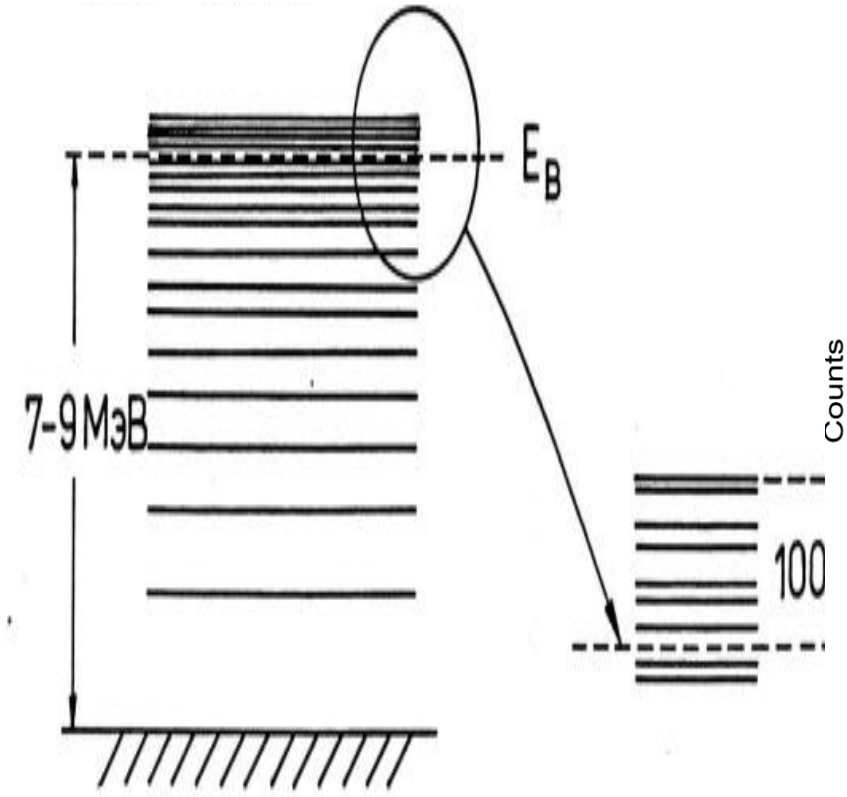
# Abbreviations

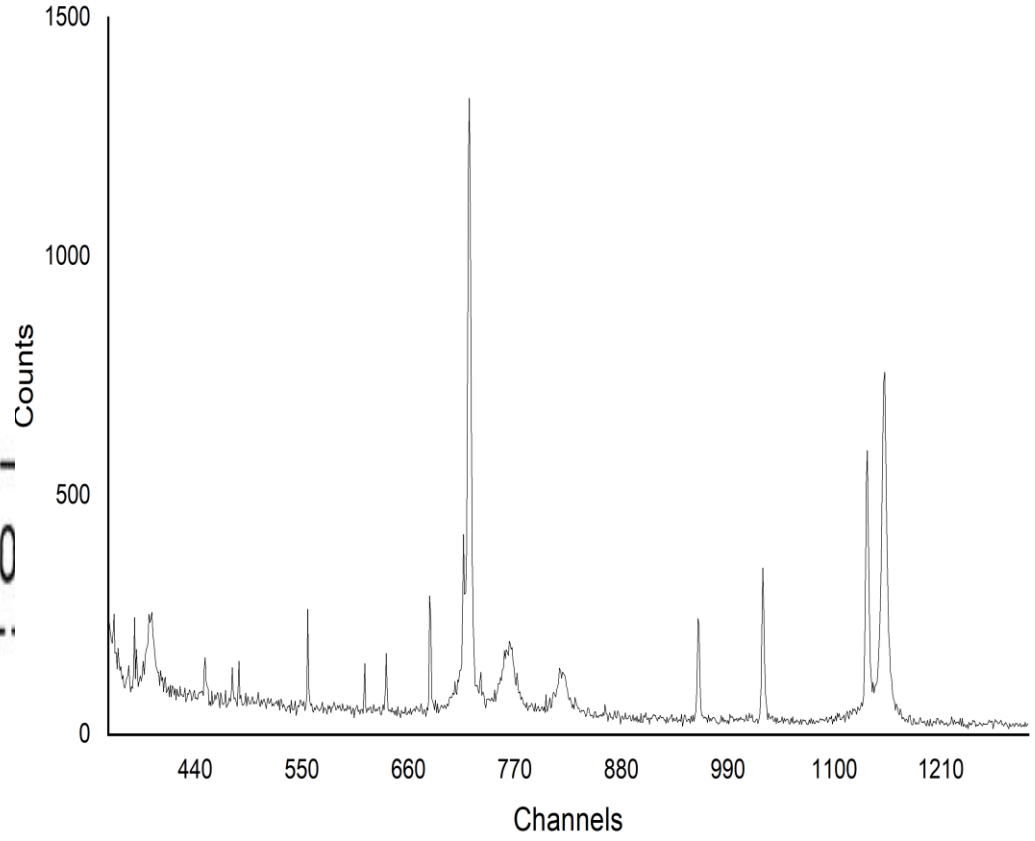
- IREN – Intense REsonance Neutron source
- FLNP – Frank Laboratory of Neutron Physics
- TOF – Time of Flight
- TDC – Time Digital Converter
- NRCA – Neutron Resonance Capture Analysis

# Introduction

- **Neutron resonance capture analysis** is used for non destructive determination of the isotopic composition of samples.
- **Non-destructive**, because there is no sample pre-treatment needed.
- It allows one to analyse relatively large and radioactive objects.
- Neutron spectroscopy provides information about the excited state of a compound nucleus produced after neutron capture (by a parent nucleus).
- The idea of the method is based on observation of neutron resonances, i.e. peaks of energy dependant on the cross-section of neutrons interacting with nucleus.

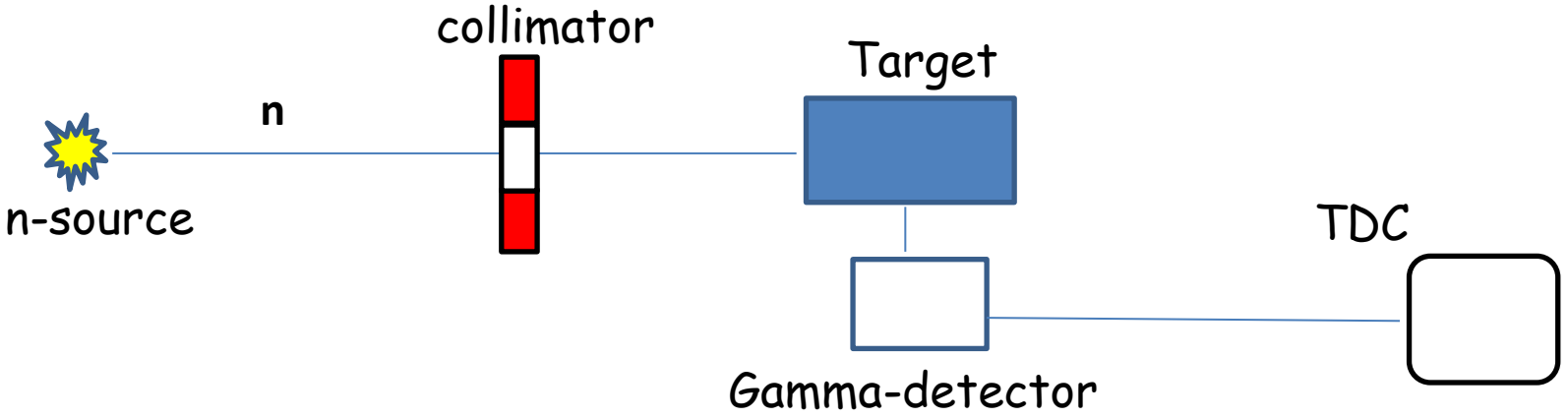
# A typical energy spectrum of isotopes.



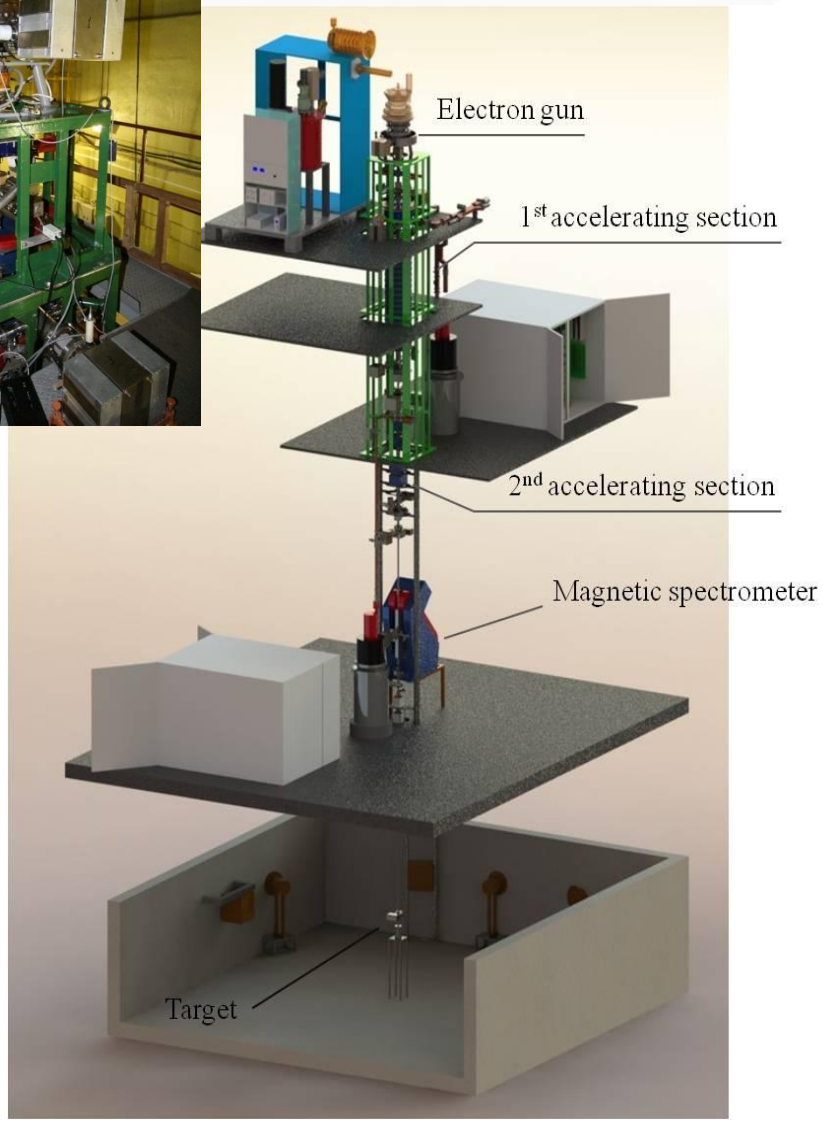
# Neutron Resonance Spectroscopy Technique

- **TOF** technique is the most reliable method in identification of resonances.




- $E = \frac{(72.3L)^2}{t^2}$

# IREN parameters




The main part of the IREN facility is a linear electron accelerator. The bunched electron beam generates bremsstrahlung in the tungsten target and it produces the neutron pulses via (γ,n)-reaction in the same target.

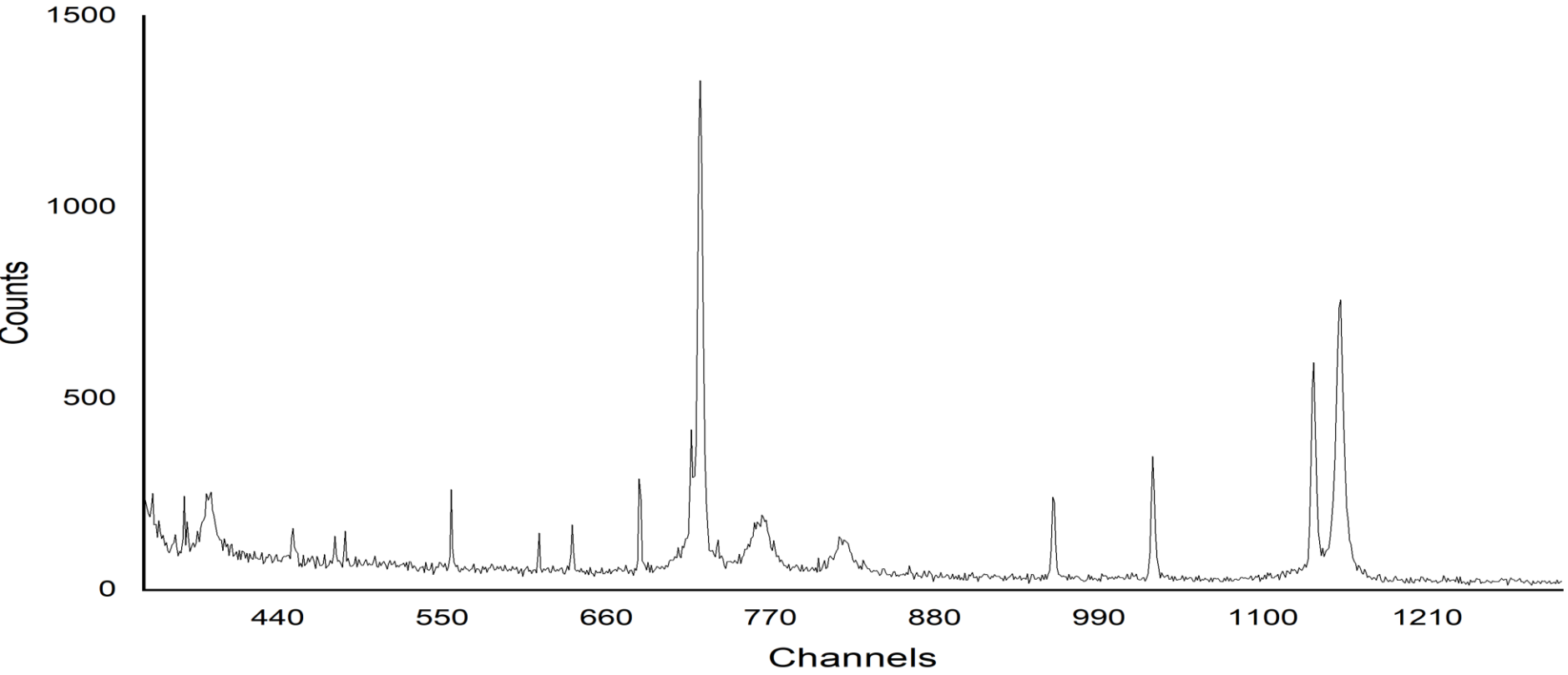
| | |
|---|---|
| Peak current, A | 3 |
| Repetition rate, Hz | 50 |
| Electron pulse duration, ns | 100 |
| Electron energy, MeV | 60 |
| Neutron intensity, n/s | $4 \cdot 10^{11}$ |

# General view of the detector

- Detector contains 6 sections forming together the cylinder with the channel along the neutron beam direction
- There are photomultipliers in both ends of each section. The signals from two photomultipliers of each section are summarized on output load resistor. Then after amplification and shaping they go to the majority coincidence circuit. The majority coincidence circuit is applied to observe radiative capture of a neutron. Various combinations of coincidence of pulses in different sections are possible.

# TOF spectrum

Unanalysed spectrum.

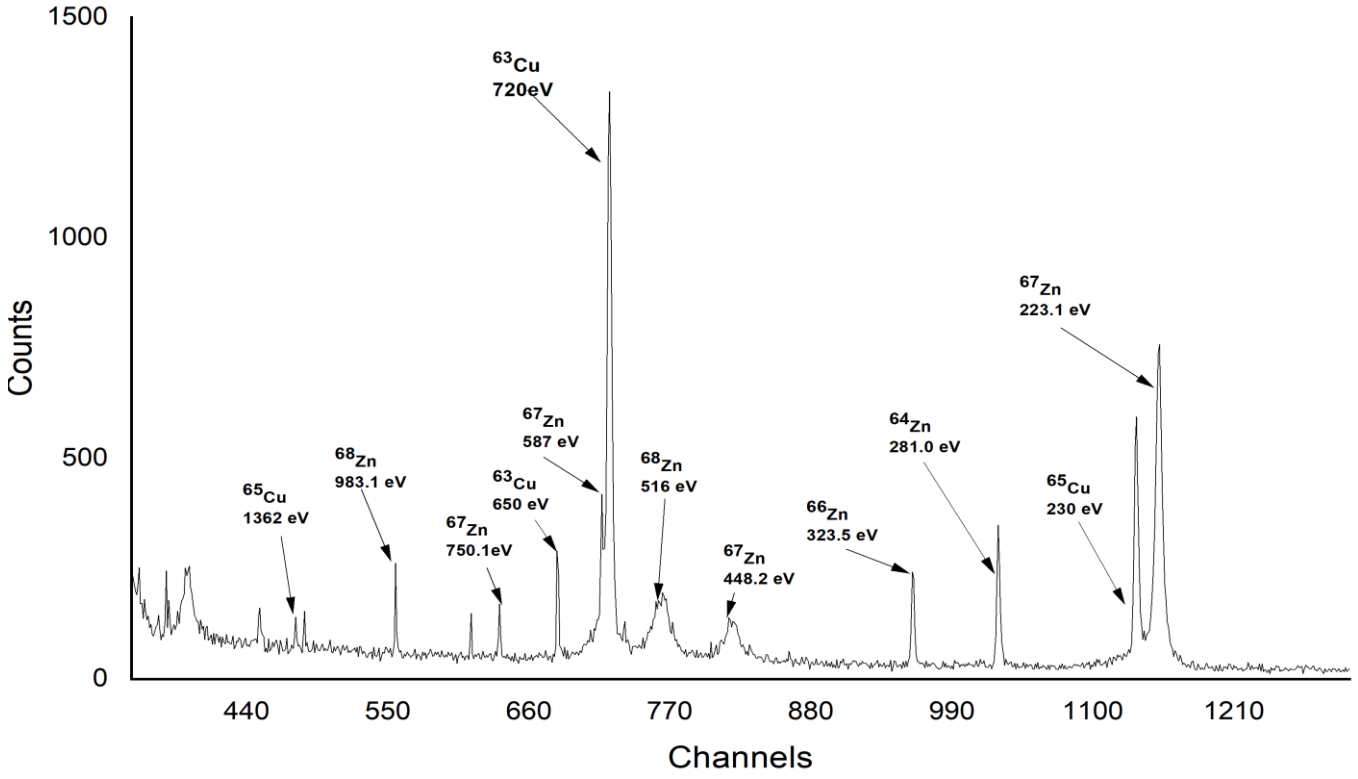


# Energy calculations using channel

- Using the relation below, one can calculate energy corresponding to a channel.
- $E = \frac{(72.3L)^2}{t^2}$

Where t = $t_{channel} \times No_{channels} - t_{delay}$

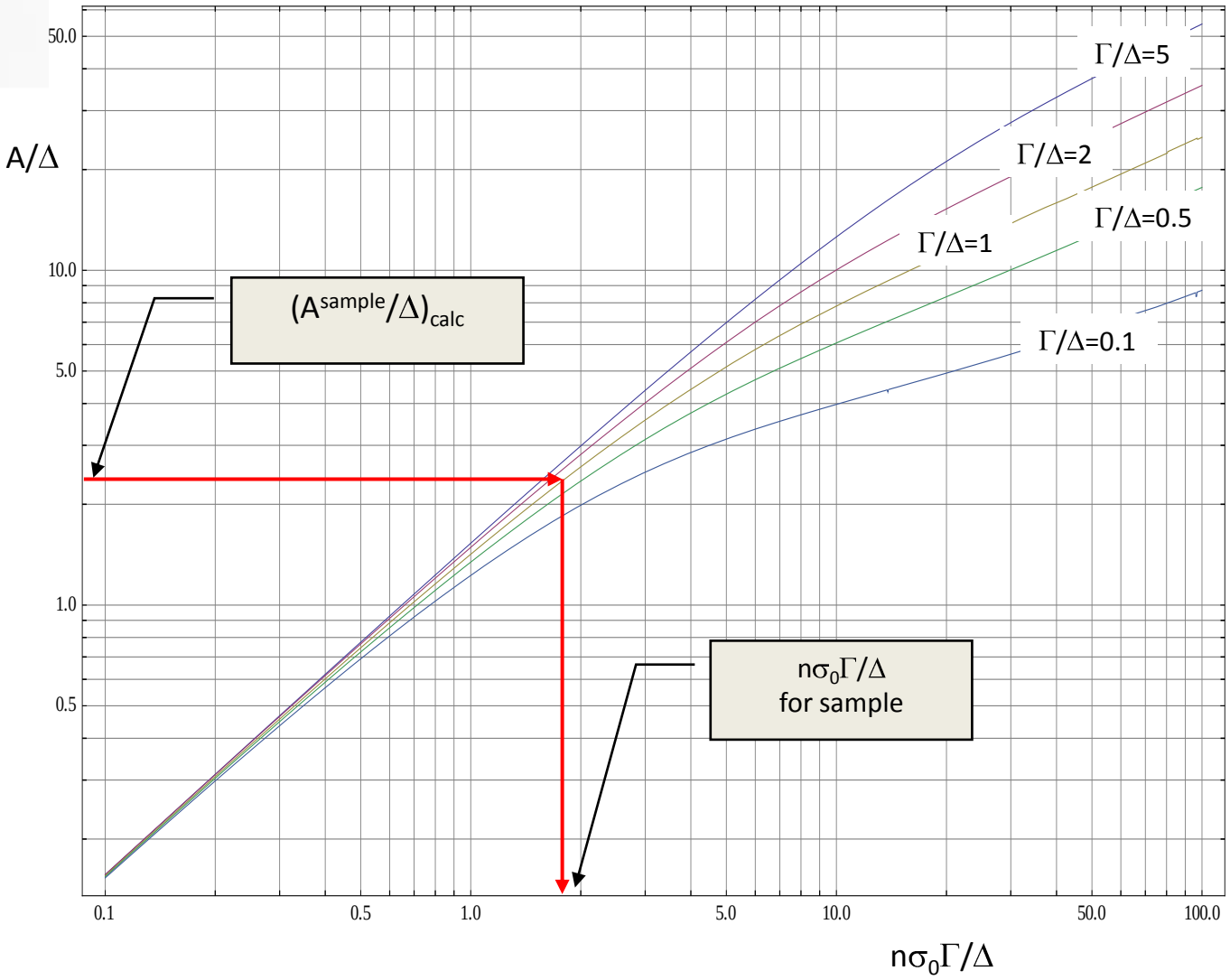
# Labelled spectrum



# Result cont.

- From the labelled spectrum, one can calculate mass composition of each isotope in the spectrum.
- $\sum N = \Pi(E_0)\varepsilon_\gamma \frac{\Gamma_\gamma}{\Gamma} A$
- Where:
  - $\sum N$ - number of nuclei in a sample
  - $\Pi(E_0)$ – no. of neutrons with resonance energy
  - $\varepsilon_\gamma$ -detection efficiency
  - $\Gamma_\gamma, \Gamma$ – radiation and total widths respectively
  - A – resonance area above the transmission curve $A = \int_{-\infty}^{\infty}[1 - T(E)]dE.$

# Used curves for the analysis of neutron resonances



# Calculations

- The table below represent the elements and their calculated masses in the sample.

| Element | Mass(g) |
|---|---|
| Zn | 65.7 ± 2.4 |
| Cu | 45.15 ± 2.26 |

**For number of moles of Zn**

$$n = \frac{m}{M}$$

$$\frac{29.5g}{67g/mol} = 0.44\ moles$$

**For Zn-67 with 4.1% abundance**

$$n_{zinc} = 0.44 \times \frac{4.1}{100}$$

$$n_{zinc} = 0.018\ moles$$

**For number of nuclei**

$$N_{nuclei} = n_{zinc} \times N_A$$

$$N_{nuclei} = (0.018)(6.022 \times 10^{23})$$

$$= 1.1 \times 10^{22} nuclei$$

$$\frac{Nuclei}{cm^2} = \frac{1.1 \times 10^{22}}{100} = 1.1 \times 10^{20} nuclei/cm^2$$

$$g = \frac{2J+1}{2(I+1)} = \frac{2(3)+1}{2\left[2\left(\frac{5}{2}\right)+1\right]} = 0.58$$

**For Neutron width**

$$\Gamma_n = \frac{0.9eV}{2g} = \frac{0.9}{2(0.58)} = 0.78eV$$

$$\Gamma = \Gamma_n + \Gamma_\gamma \quad where\ \Gamma_\gamma = 0.42eV$$

$$\Gamma = 0.78 + 0.42 = 1.2eV$$

**For cross section calculation**

$$\sigma_o = \frac{4\pi\lambda^2 g\Gamma_n}{\Gamma} = \frac{(1.17 \times 10^{-20})(0.42)}{1.2eV} = 4.4 \times 10^{-21}$$

$$\Delta = \sqrt{\frac{0.1E}{A}} = \sqrt{\frac{(0.1)(223.1)}{67}} = 0.58$$

$$\frac{\Gamma}{2\Delta} = \frac{1.2}{2(0.58)} = 1.03$$

$$\frac{n\sigma\Gamma}{\Delta} = \frac{(1.1 \times 10^{20})(4.4 \times 10^{-21})(1.2)}{0.58} = 1$$

$$\frac{A}{\Delta} = 1.4$$

$$A_S = (1.4)(0.58) = 0.81$$

$$A_i = \left(\frac{\sum N_i}{\sum N_s}\right)\left(\frac{M_S S_S}{M_i S_S}\right) A_S$$

$$A_i = \left(\frac{5471.24}{600}\right)\left(\frac{(1.2 \times 10^7)(100)}{(5.2 \times 10^7)(224)}\right)(0.81)$$

$$A_i = 0.76$$

$$\frac{A_i}{\Delta} = \frac{0.77}{0.58} = 1.3$$

Therefore $\frac{n\sigma\Gamma}{\Delta} \approx 1$

$$n = \frac{\Delta}{\sigma_o \Gamma} = \frac{0.58}{(4.4 \times 10^{-21})(1.2)} = 1.1 \times 10^{20} nuclei/cm^2$$

**Let n = N**

$$N = (1.1 \times 10^{20})(224) = 2.46 \times 10^{22} nuclei$$

$$n = \frac{N}{N_A} = \frac{2.46 \times 10^{22}}{6.022 \times 10^{23}} = 0.04$$

**Dividing by the abundance (4.1%)**

$$n = \frac{0.04}{0.041} = 0.98\ moles$$

$$m = nM = (0.98)(67) = 65.66g$$

# Conclusion

- Non-destructive methods of elemental and isotopic analysis using neutron spectroscopy are advantageous.
- They allow us to analyse samples of all shapes and sizes, without pre-treatment.
- Allowing us to study archaeological artefacts and objects of cultural heritage.

# Acknowledgements

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# References


1. Mughabghab, S.F., 2012. Neutron Cross Sections: Neutron Resonance Parameters and Thermal Cross Sections Part B: Z= 61-100 (Vol. 1). Academic press.
2. Bazhazhina, N.V., Mareev, Y.D., Pikelner, L.B., Sedyshev, P.V. and Shvetsov, V.N., 2015. Analysis of element and isotope composition of samples by neutron spectroscopy at the IREN facility. Physics of Particles and Nuclei Letters, 12(4), pp.578-583.


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