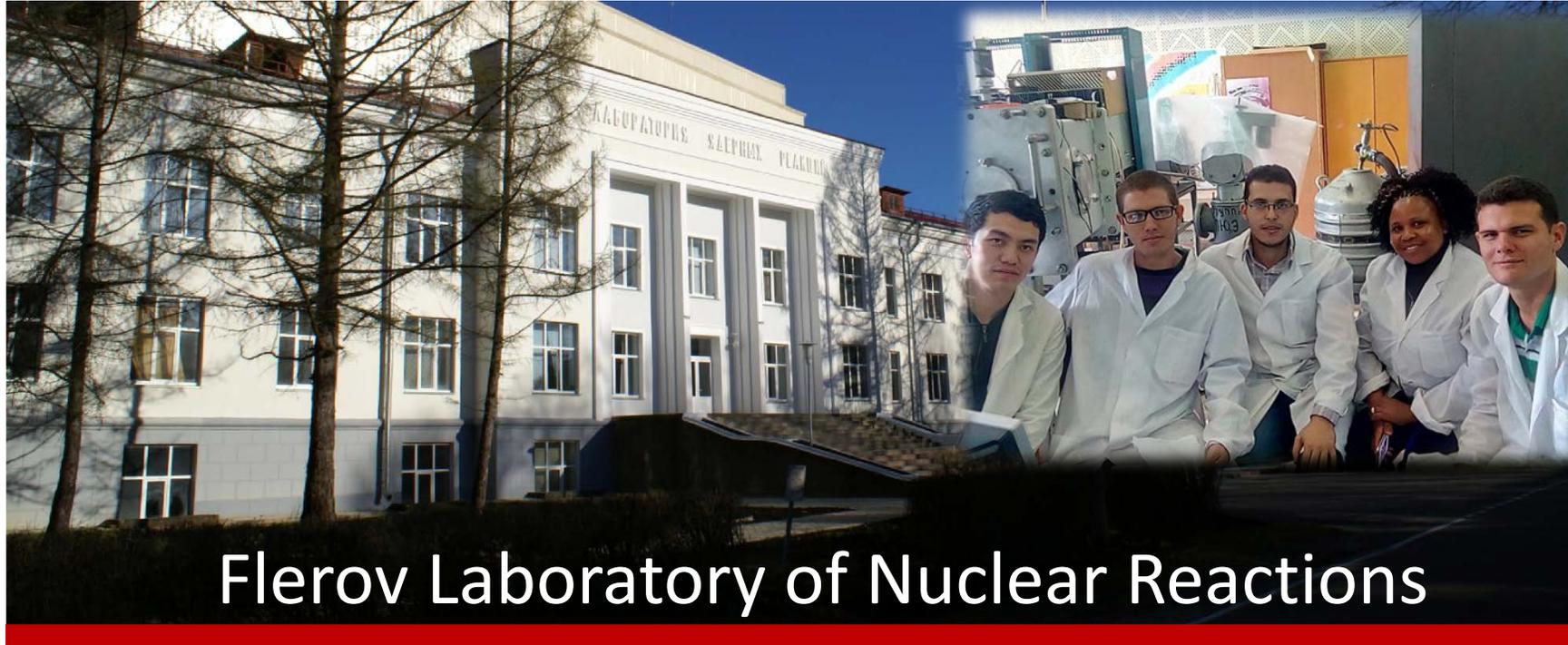
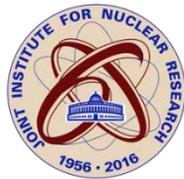


STAGE 3 INTERNATIONAL STUDENT PRACTICE 2017



Flerov Laboratory of Nuclear Reactions



Joint Institute for Nuclear Research in Dubna



science & technology

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Science and Technology
REPUBLIC OF SOUTH AFRICA



iThemba LABS
Laboratory for Accelerator Based Sciences

Joint Institute for Nuclear Research
Flerov Laboratory of Nuclear Reactions
University Center

PROJECT TITLE

- HpGe – detector for energy measurements of gamma-activity
 - Study of the operation principles of X-ray detectors
 - Moseley's Law in Action
 - Alpha Spectroscopy

SPEAKERS

Aurelia Genu – RSA

Igor Moroz – Belarus

Madian Pino Peraza – Cuba

Luis Enrique Llanes Montesino - Cuba

SUPERVISORS

S. Lukyanov

K. Mendibaev



Introduction

3 Types of semiconductor detectors



1. X-ray HpGe detector



3. Alpha Si spectroscopy detector



2. HpGe Gamma detector

History of Moseley's Law



Henry G.J. Moseley's
1887 - 1915

- In his early 20's, he measured and plotted x-ray frequencies for about 40 elements of the periodic table and was described by Rutherford as his most talented student.
- Based on his experiments, this is known as Moseley's law
$$E = a (Z - b)^2$$
where a and b are constants depending upon the particular spectral line, E is the energy of characteristic x-ray and Z atomic number.
- Moseley volunteered for combat duty during World War I and was killed in action at the age of 27 during the attack on the Gallipoli in the Dardenelles.



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Moseley Plot of characteristic X-rays

- His data Moseley plot is still standard feature of physics textbooks (Figure 1).

- Photographic recording of $K\alpha$ and $K\beta$ x-ray emission lines for a range of elements (Figure 2).

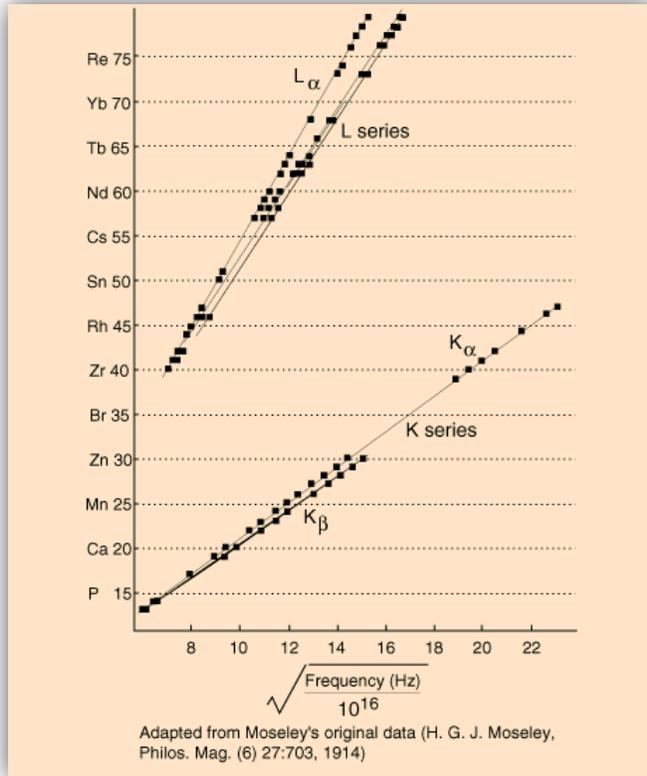


Fig. 1 Moseley plot of characteristic X-rays

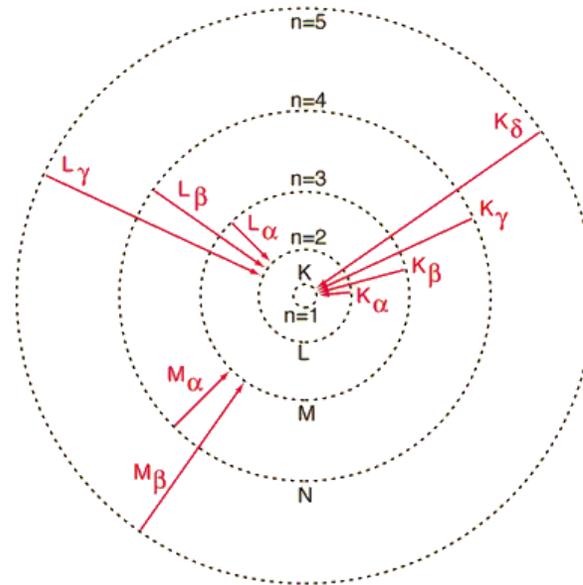


Fig. 3 X-ray transitions

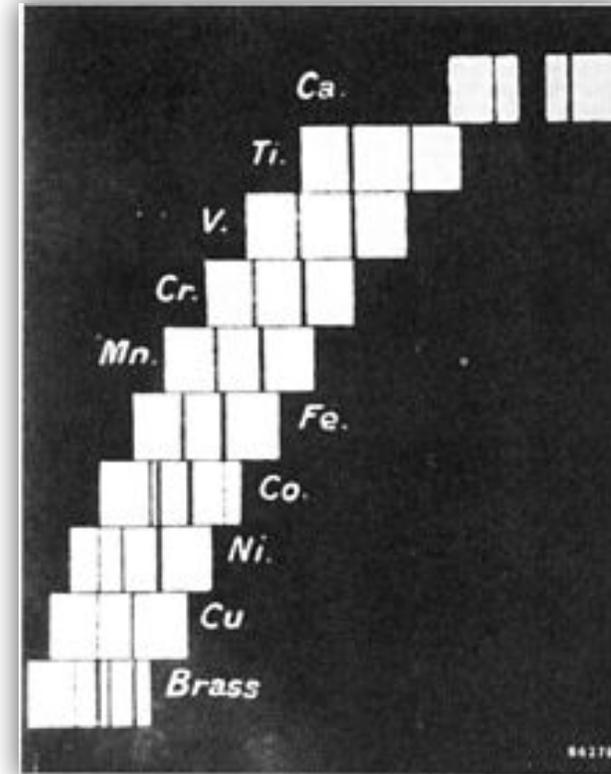


Fig. 2 Moseley step ladder of elements

Applications of Moseley's Law

- Any discrepancy in the order of the elements in the periodic table can be removed by Moseley's law by arranging the elements according to the atomic numbers and not according to the atomic weights.
- Moseley's law has led to the discovery of new elements like hafnium (72), technetium (43), rhenium (75) etc.
- This law has been helpful in determining the atomic number of rare earths, thereby fixing their position in the periodic table.

Moseley Law in action

Element Z (Atomic No.)	Energy (keV) K(α)	Energy (keV) K(β)
$_{38}\text{Sr}$	14.1	15.8
$_{47}\text{Ag}$	22.0	24.9
$_{49}\text{In}$	24.2	27.2
$_{57}\text{La}$	33.4	37.8
$_{62}\text{Sm}$	40.1	45.4

Table 1: Energies of K (α) and K (β) transitions in keV and elements listed with increasing atomic number obtained from nuclear data.

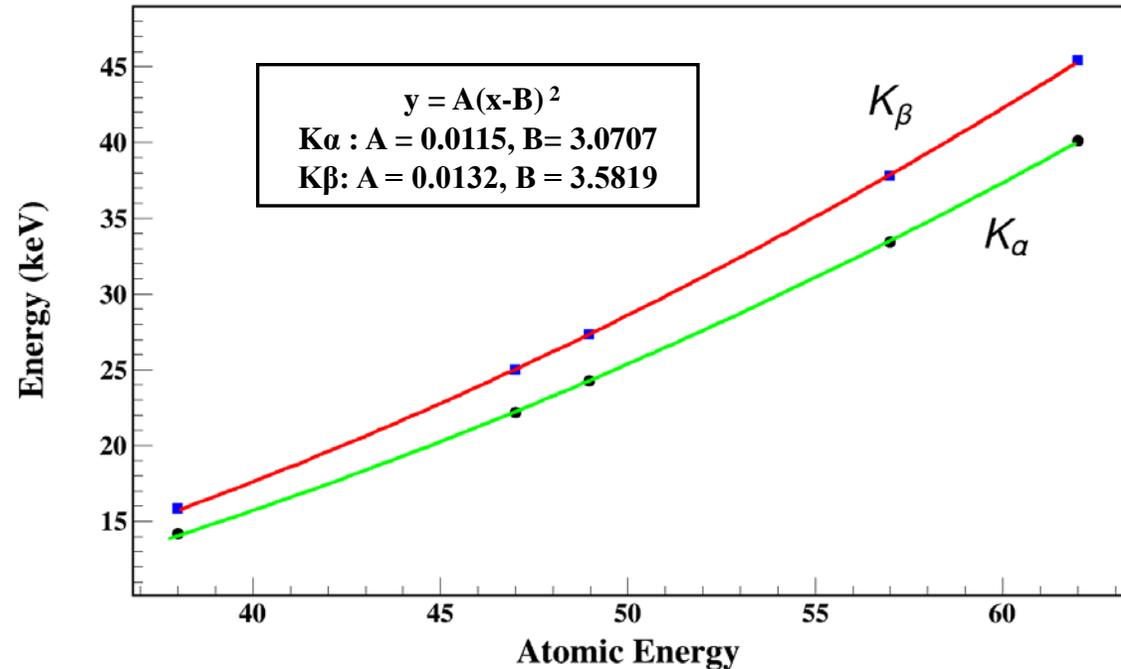
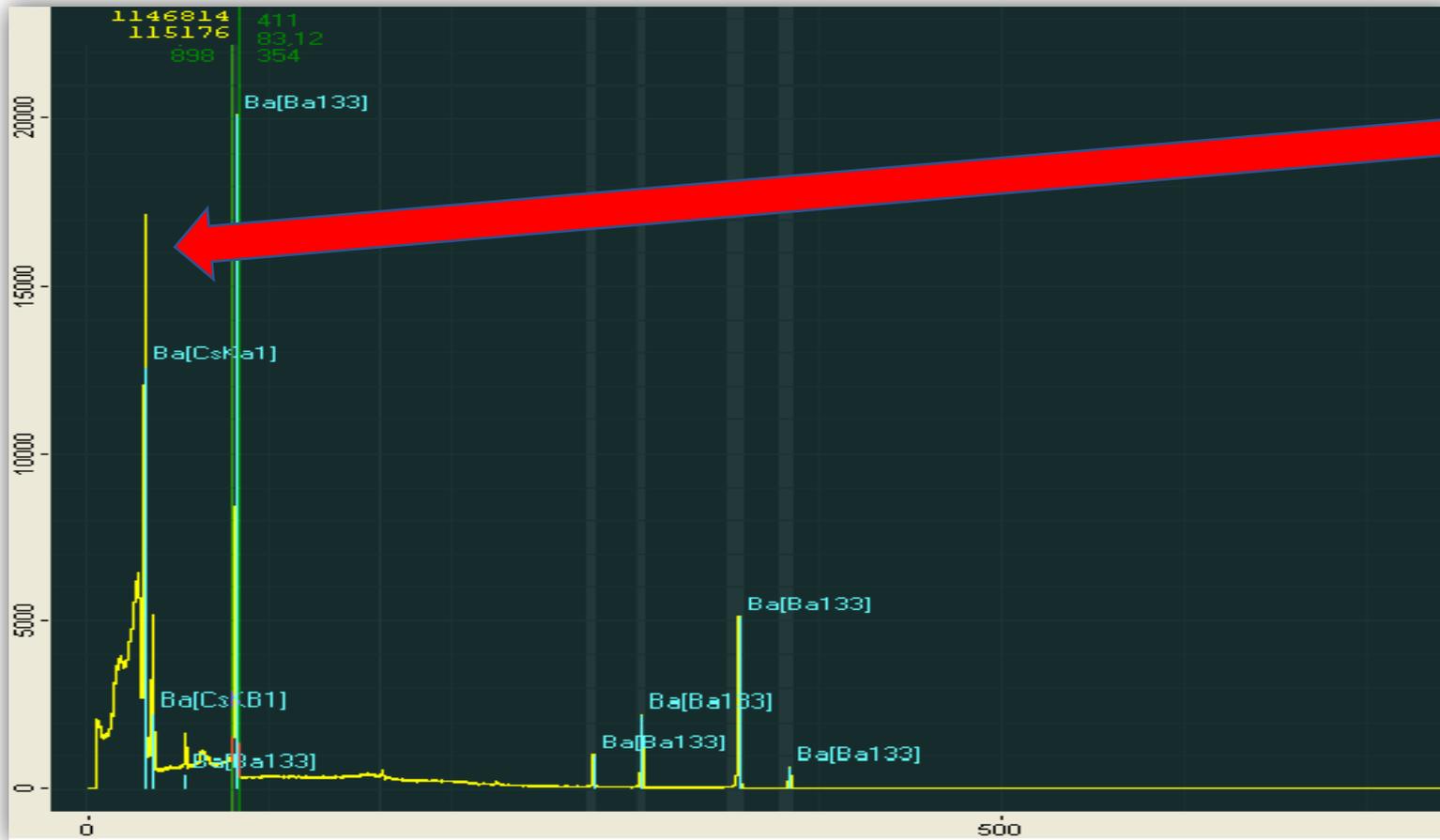


Figure 4: K (α) and K (β) lines fit to Moseley's Law. We confirm the functional form of the law but different values for the constants (a & b).

Spectrum from X-ray detector



Calculation and results.

$E = 30.97 \text{ keV}$
 A & B = constants obtained from $K\alpha$
 Moseley's plot.

$$E = a (Z - b)^2$$

$$Z = \sqrt{\frac{E}{a}} + b$$

$$= \sqrt{\frac{30.97}{0.0115}} + 3.0706$$

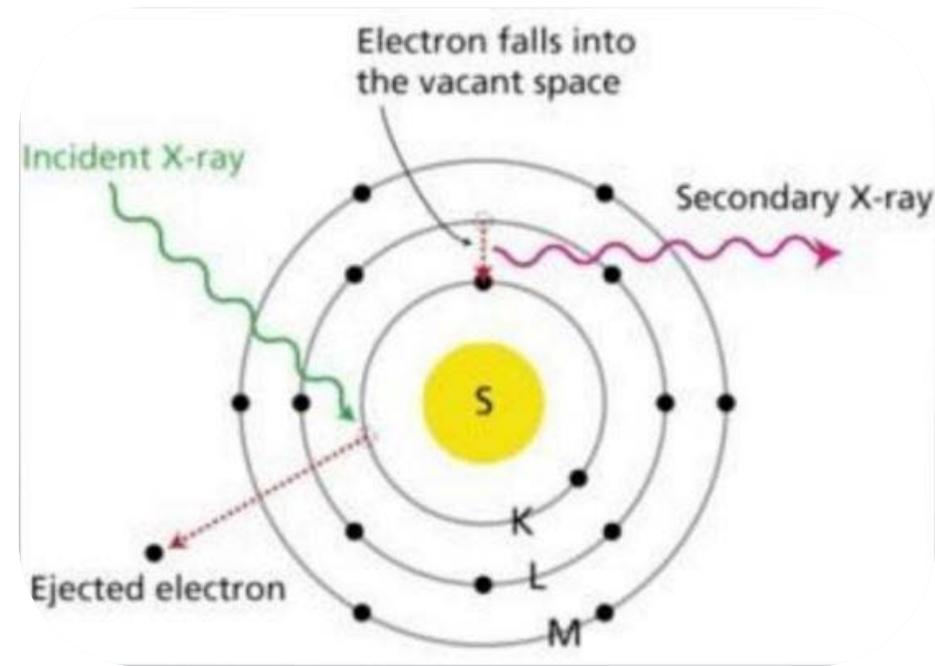
$$= 54.9$$

Nuclear data: $Z = 55$
 Element is Cs

X-rays

X-rays are emitted when outer-shell electrons fill a vacancy in the inner shell of an atom, releasing X-rays in a pattern that is "characteristic" to each element.

Detectors are manufactured with thin face and side contacts. The area of the rear contact is less than the total area, so the capacitance of such a detector is small. And this means that the resolution will be high at low and medium energies than detectors of other geometries.



General view of the X-ray spectrometer



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DE TECNOLOGÍAS
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BSU



JINR
JOINT INSTITUTE FOR NUCLEAR RESEARCH
RUSSIAN FEDERATION



CENTIS
Centro de Isótopos

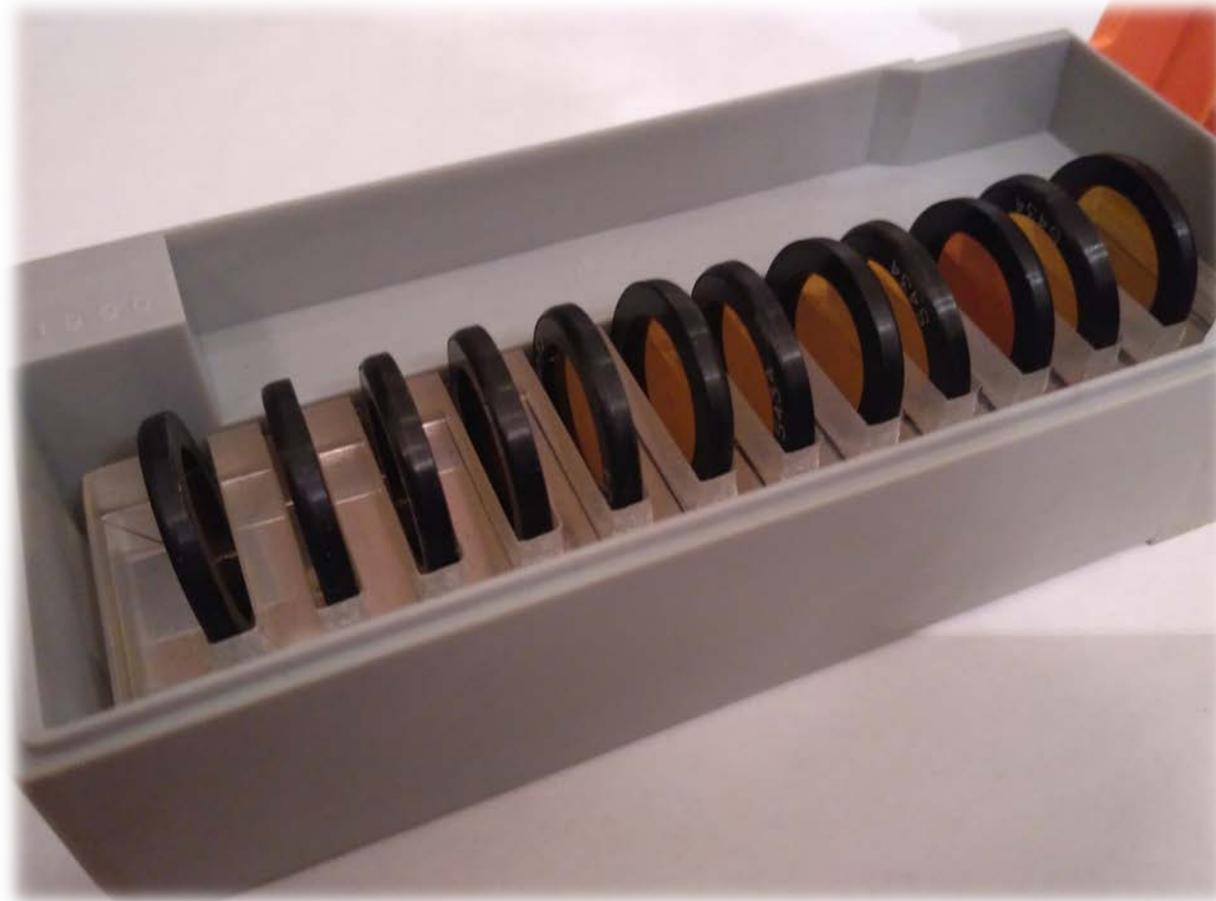


NRF
National Research
Foundation
iThemba
LABS
Laboratory for Accelerator
Based Sciences

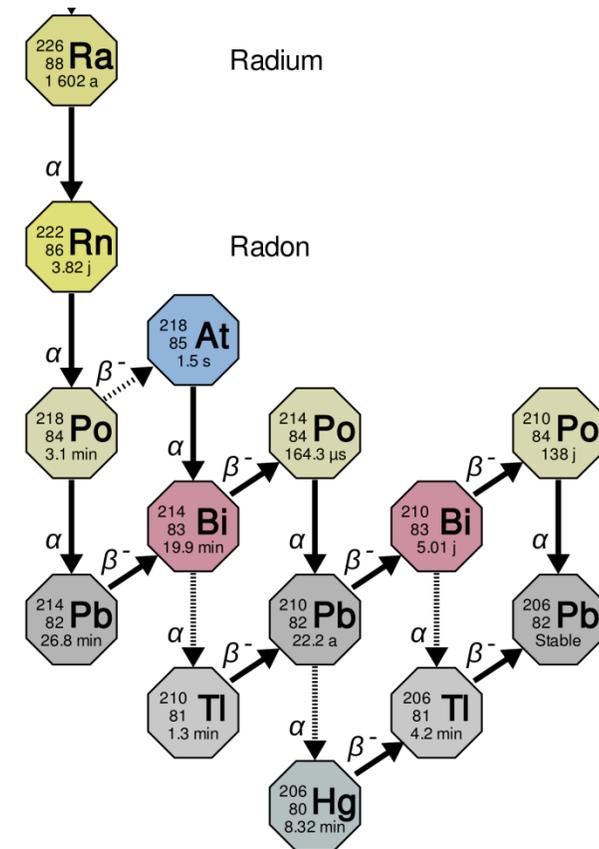
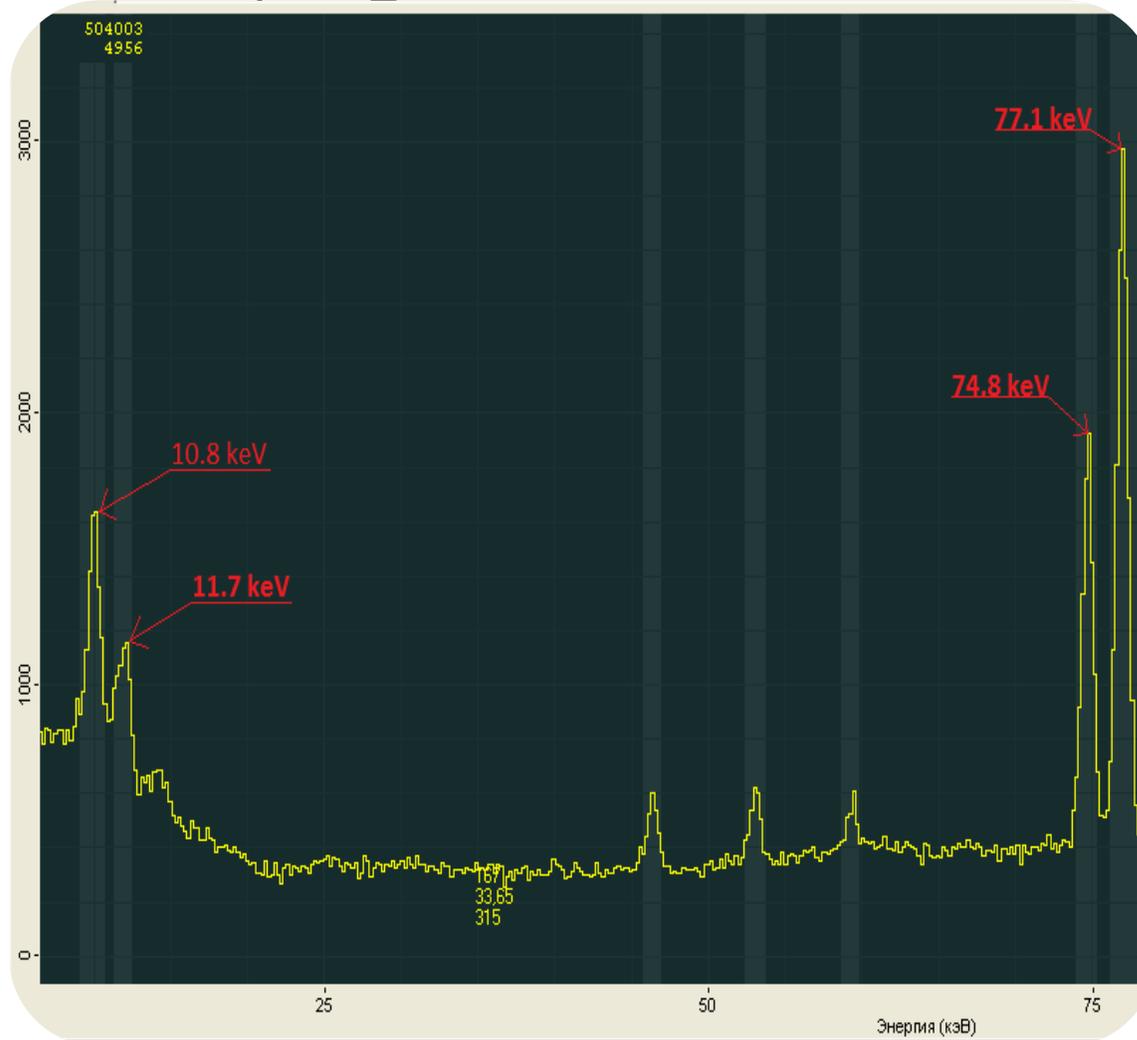
Preparation for measurement

1. Cool the detector, fill the vessel with liquid nitrogen.
2. Place a calibration source in the detector.
3. Calibrate the energy X-ray spectrometer.

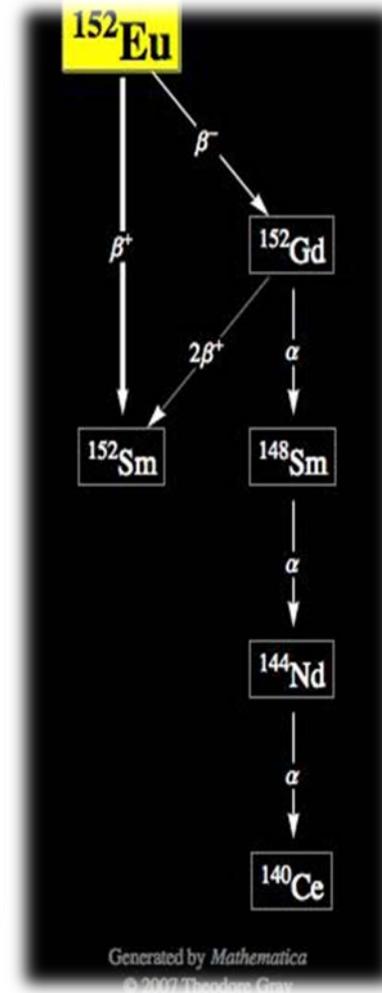
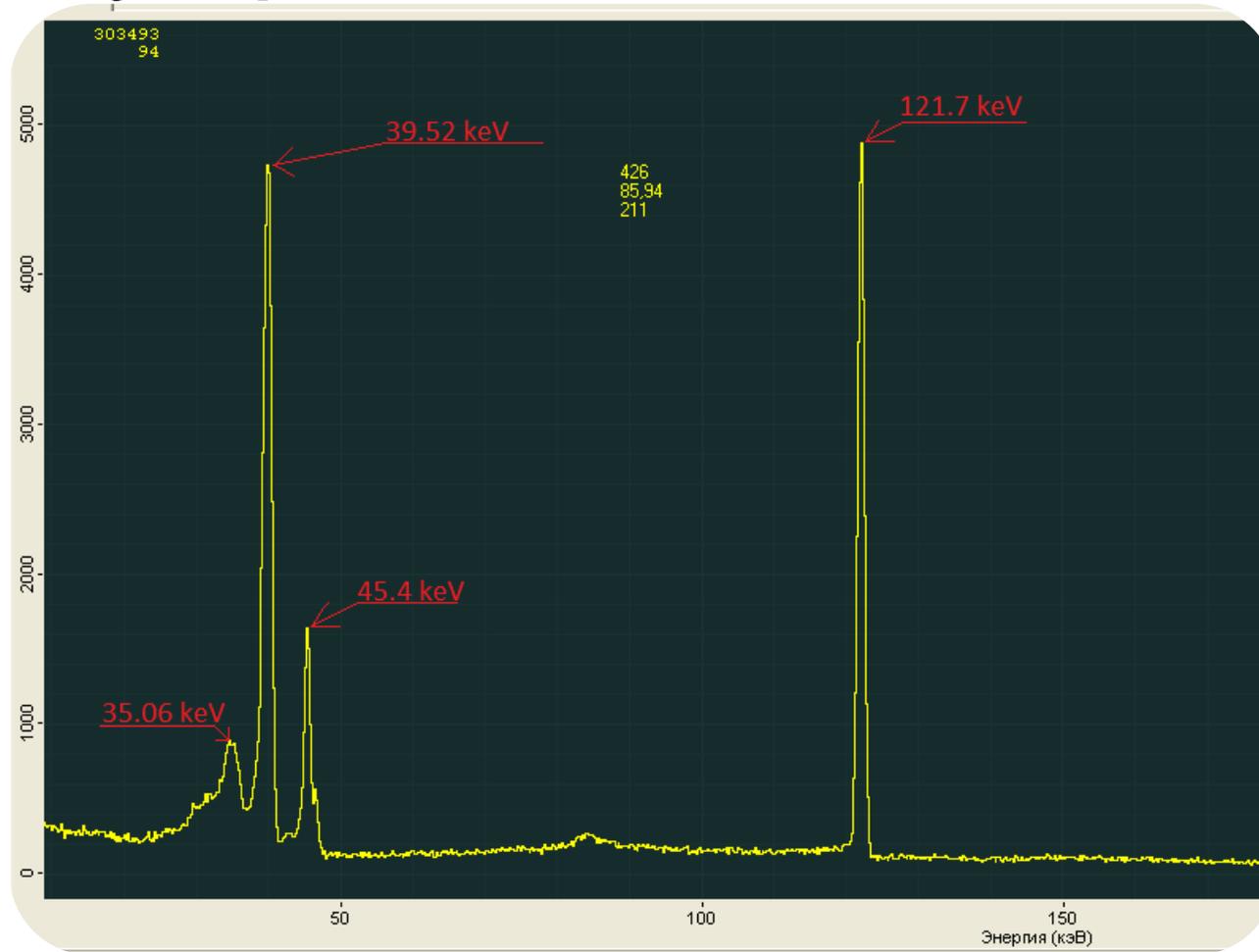
Source

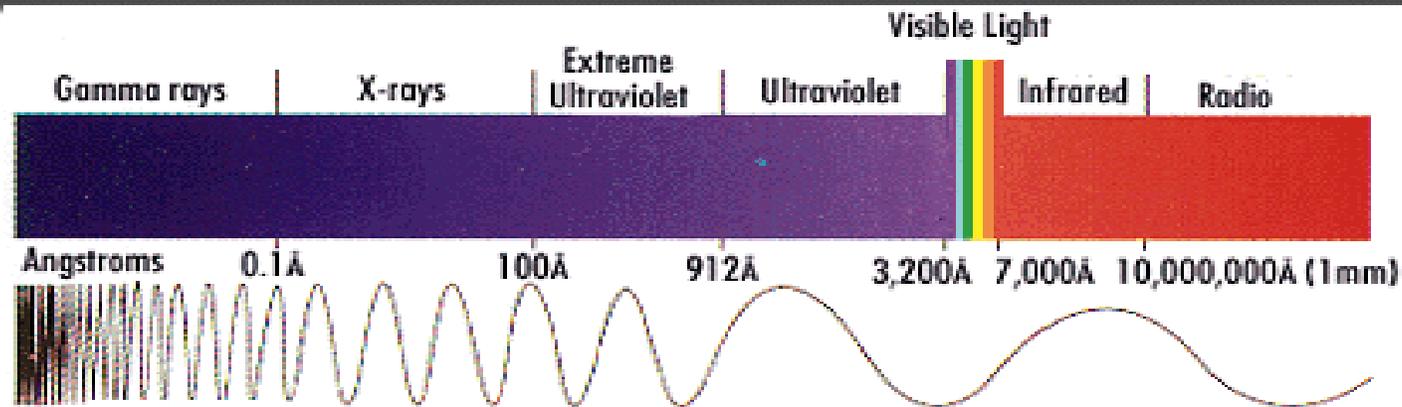
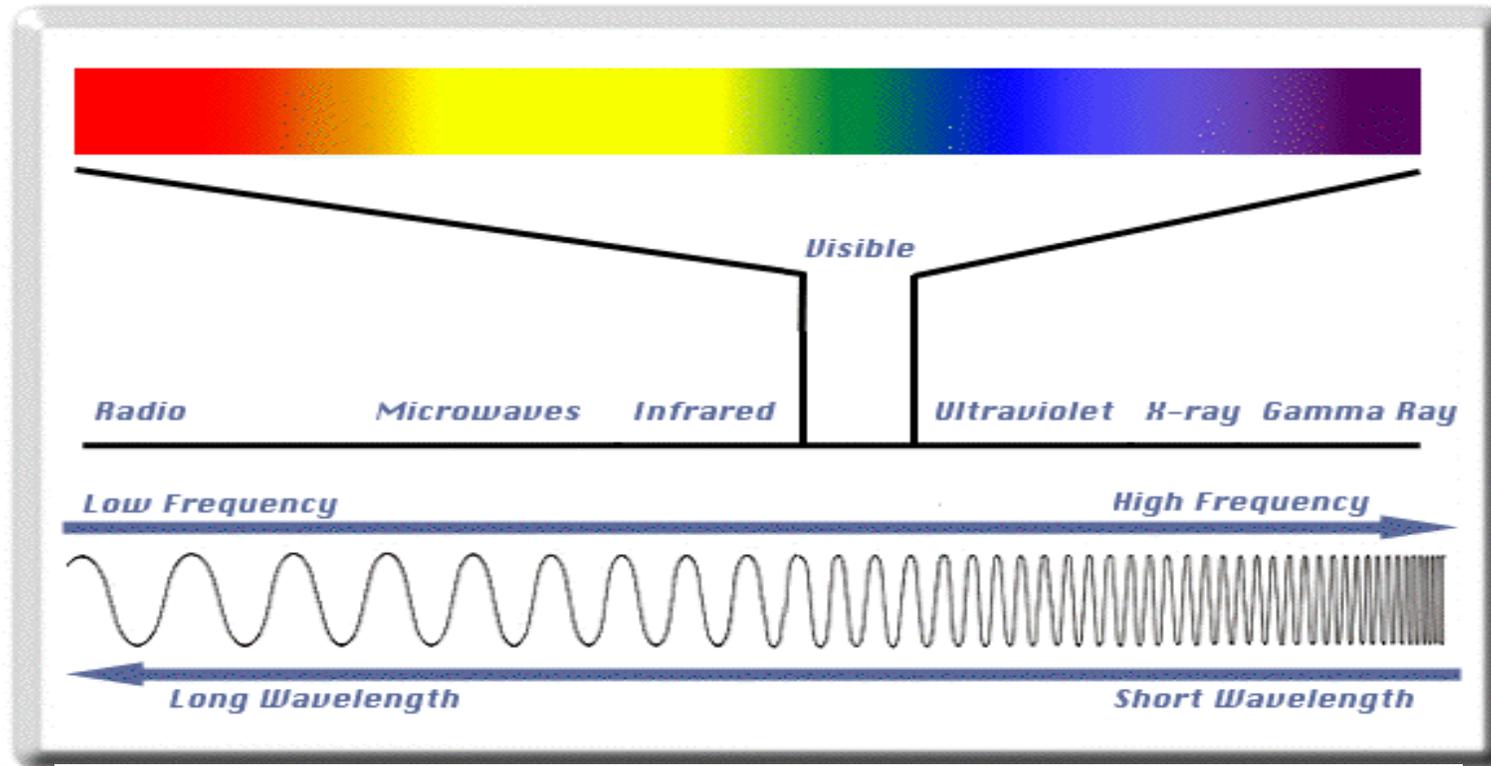


X-ray specter Ra-226



X-ray specter Eu-152



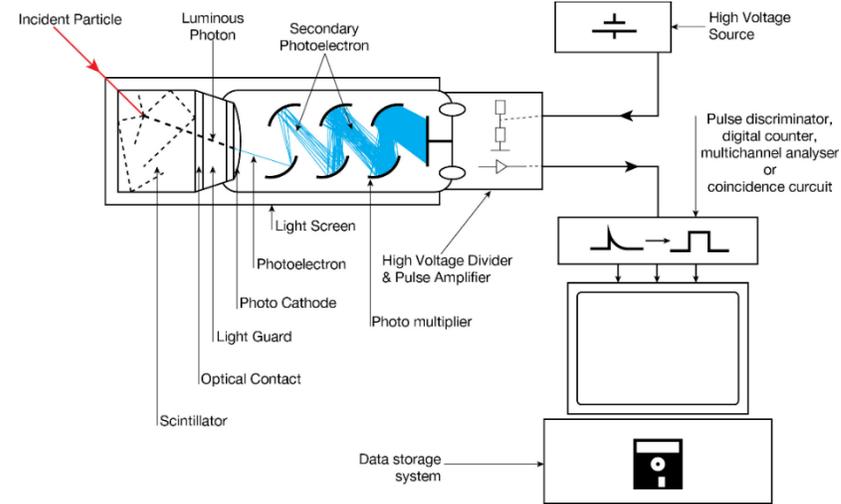


Main detectors used for gamma

➤ Scintillators detectors

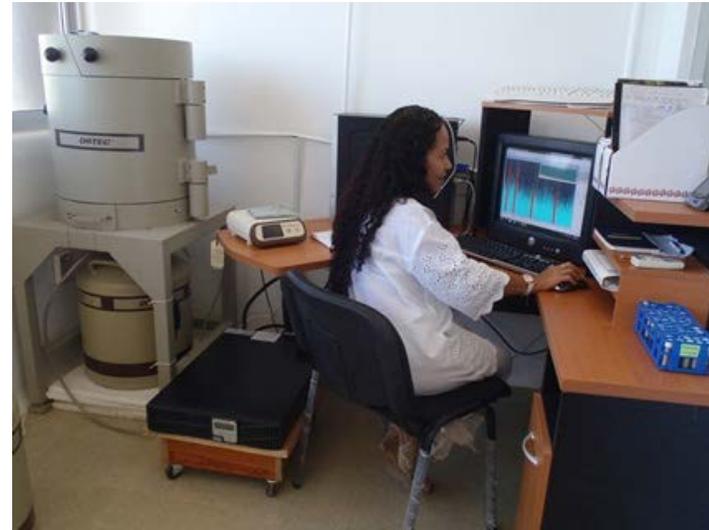
Organic (plastic, organic crystal, liquids)

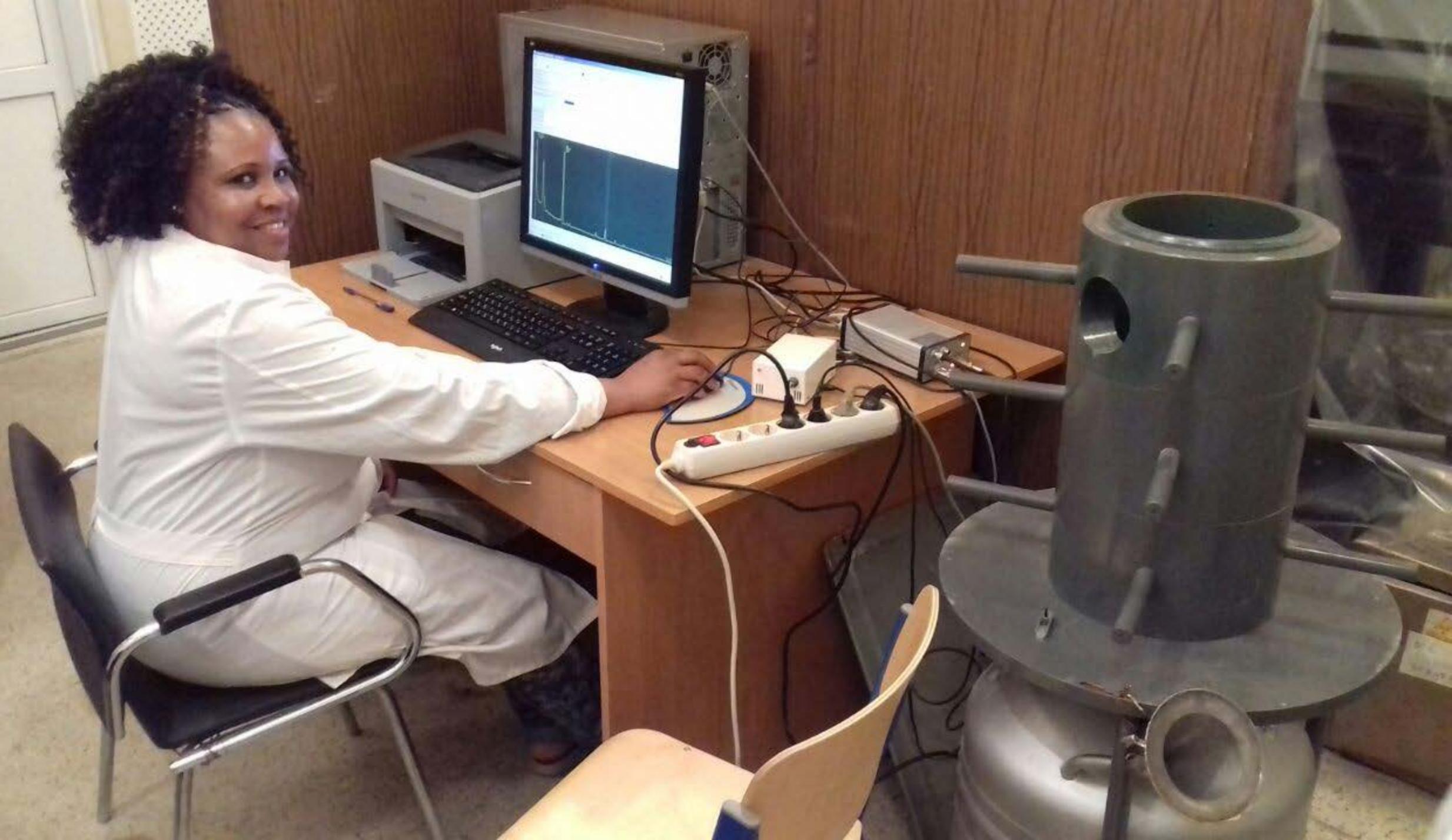
Inorganic (NaI(Tl), CsI(Tl), BaF₂, BGO, etc)



➤ Solid State detectors

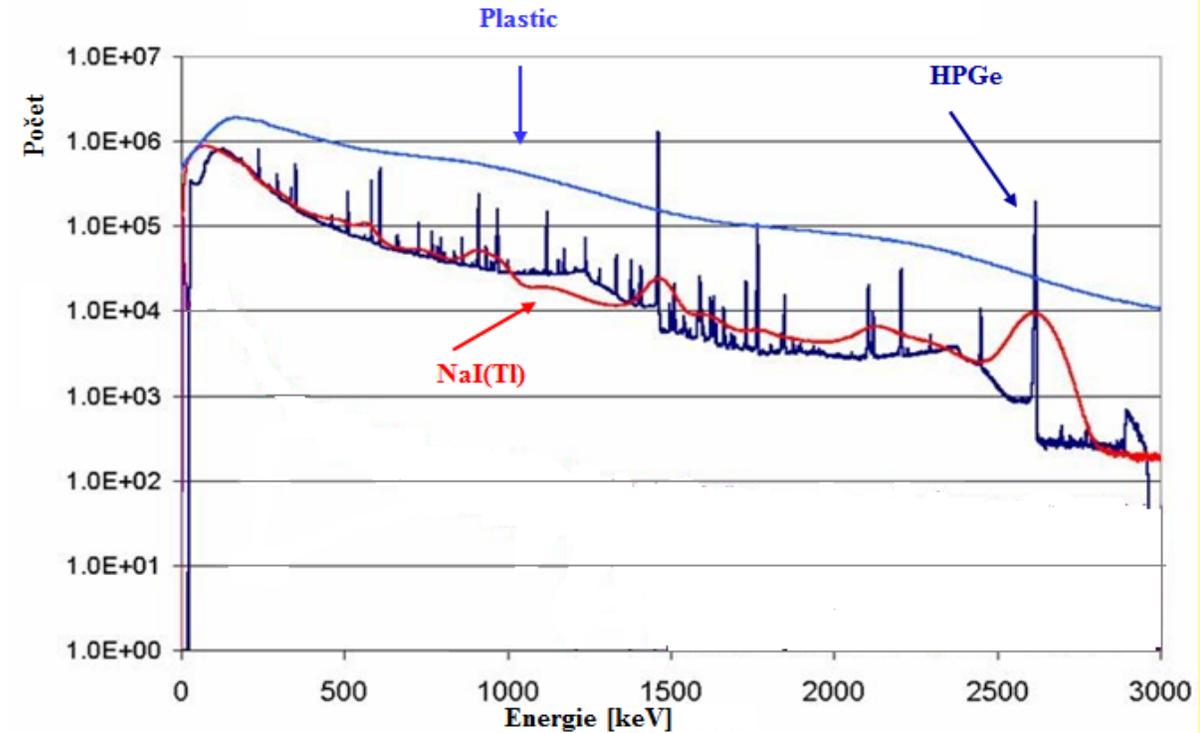
HPGe detector, Si





Comparison of detectors

	Pure Ge-detector	Plastic Scintillator
	Price	Chipper
Size	Restricted a few cm ³	No size limitation
Neutron-gamma separation	No need	Need
Efficiency	Less 10 %	Large due to Z and size
Resolution	1 keV	Worst resolution



Resolution comparison

Use of Nuclear Data Search

The Lund/LBNL Nuclear Data Search

Version 2.0, February 1999

S.Y.F. Chu¹, L.P. Ekström^{1,2} and R.B. Firestone¹

¹ LBNL, Berkeley, USA

² Department of Physics, Lund University, Sweden



WWW Table of Radioactive Isotopes

[Radiation search](#)

[Nuclide search](#)

[Atomic data](#) (X-rays and Auger electrons, very preliminary!)

[Periodic chart interface to the nuclides](#)

[Summary drawings for A=1-277](#) (PDF)

[Nuclear charts](#) (PDF, 333 kbyte)

[Database status](#)



Table of Isotopes (ToI)

[About this service](#)

[ToI home page](#)

The data are properly referenced as given in the database status panel. Please give your [feedback](#) on the usefulness of and suggestions on how to improve the ToI service.

Help and instructions are given with a "[pop-up help](#)" system:



WWW Table of Radioactive Isotopes

Radiation search

Energy: ± keV

Type: Alpha Gamma

Parent:

T1/2: s - s

Mass number: -

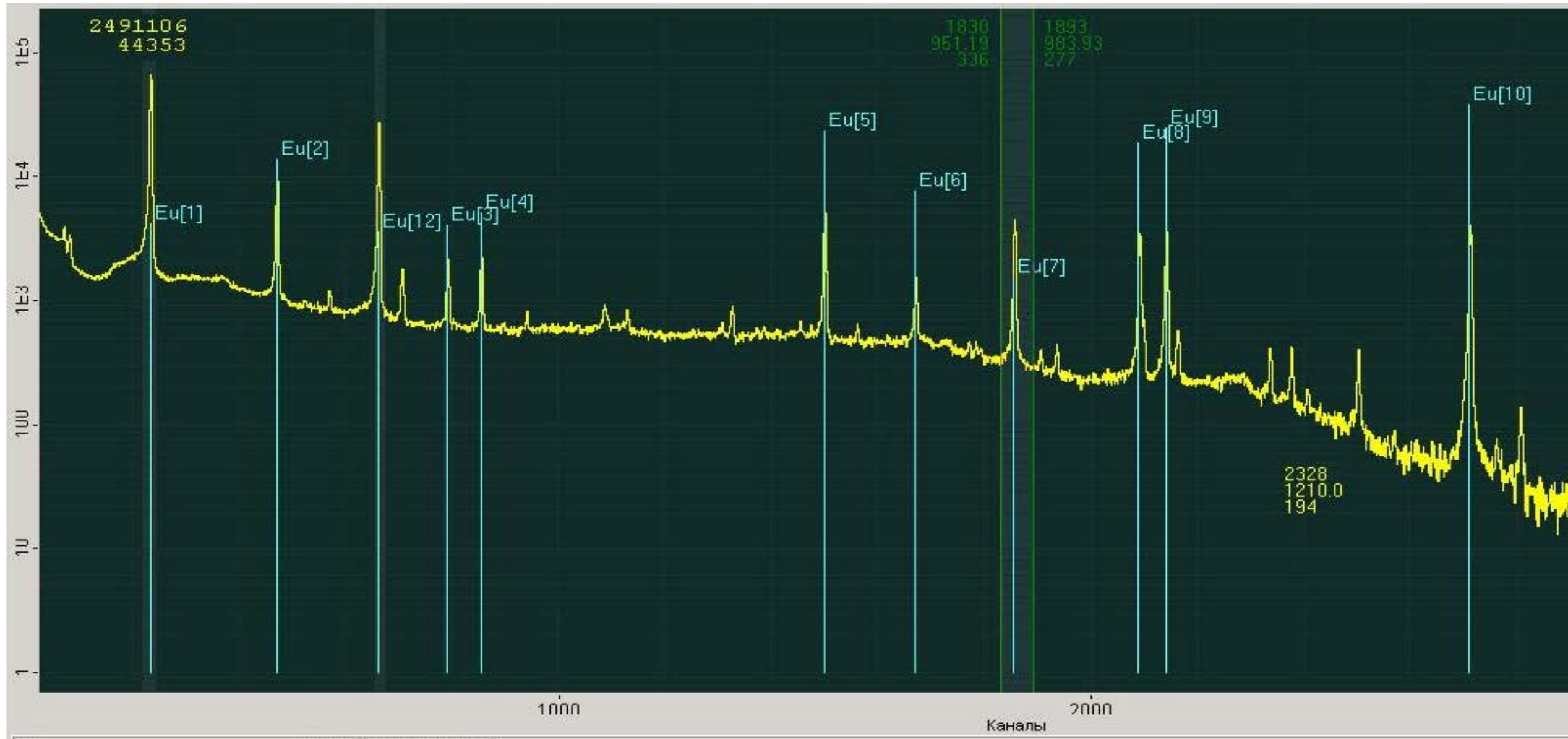
Z: or Element:

N:

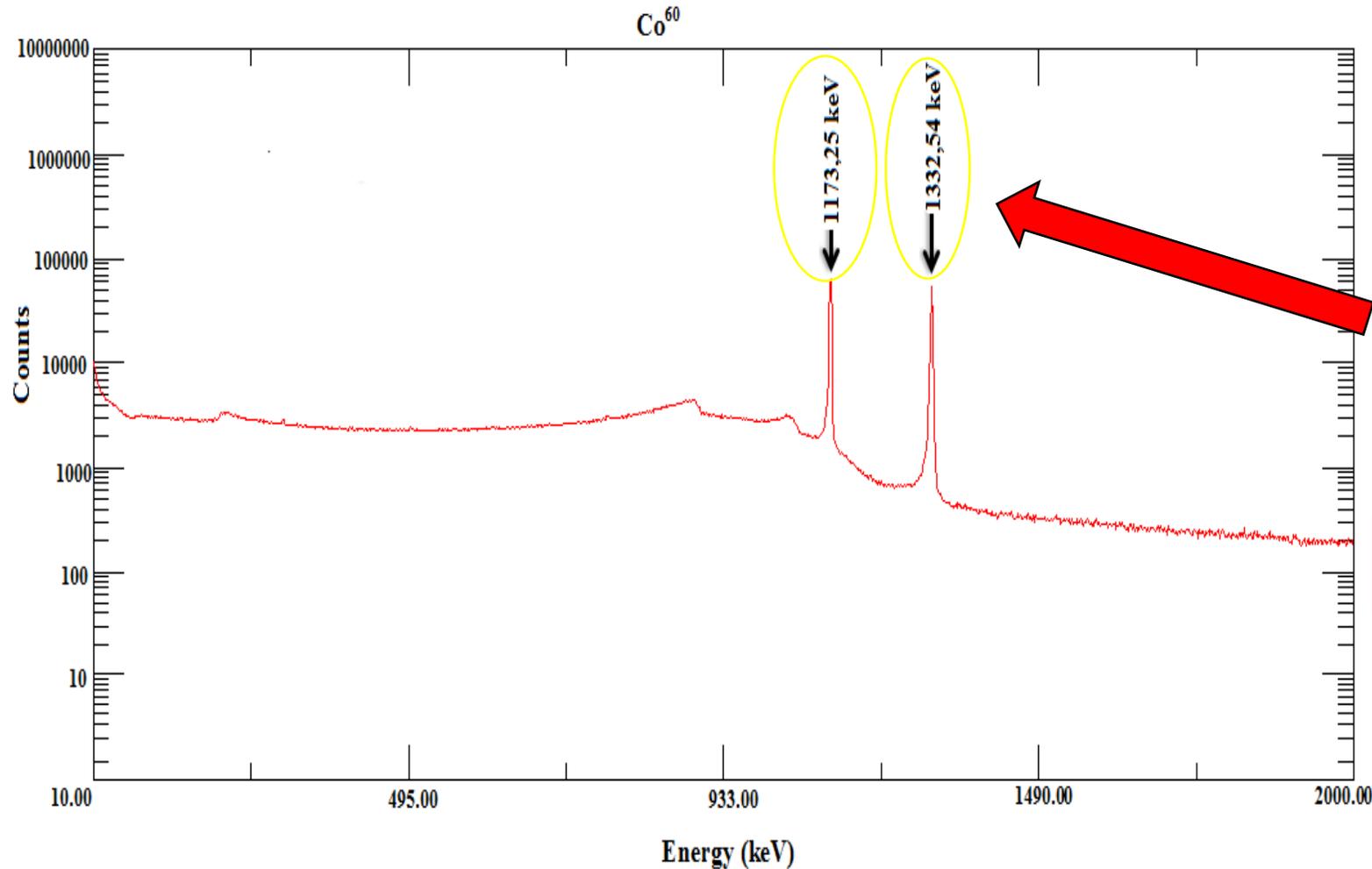
Sort by: Energy, Intensity A, Z

[Main page](#) | [Nuclide search](#)

Gamma spectra calibration



Gamma spectra of unknown source



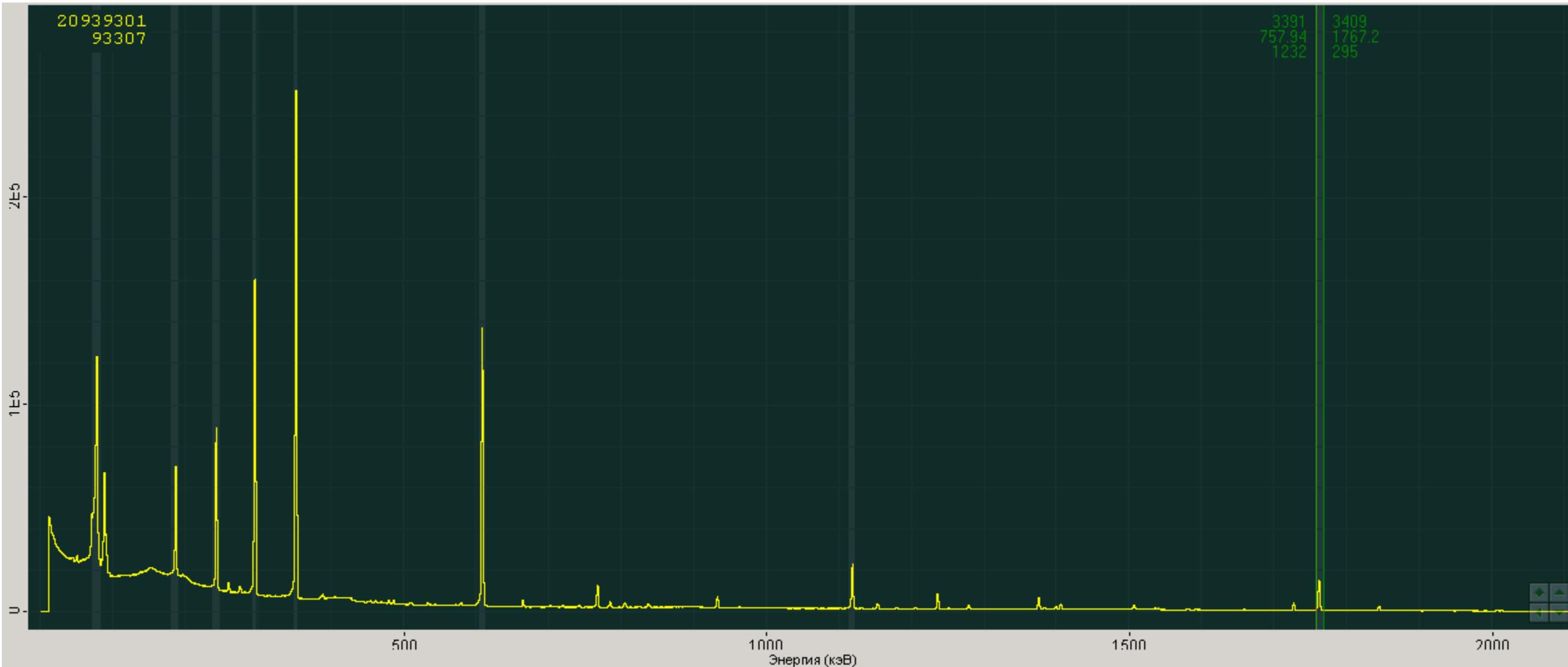
WWW Table of Radioactive Isotopes

Gamma energy search

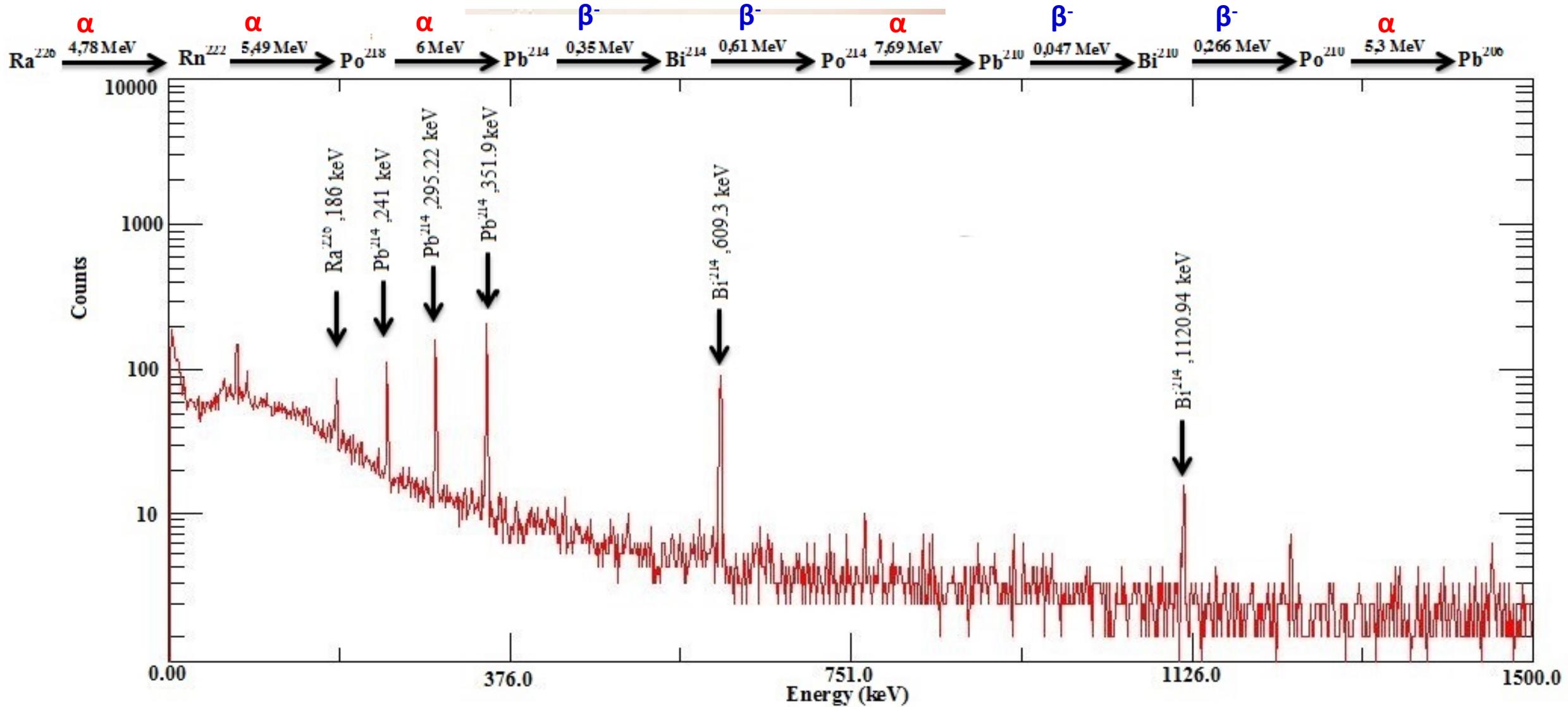
A=60;

E _g (keV)	I _g (%)	Decay mode	Half life	Parent
58.603 7	2.0	IT	10.467 m δ	<u>^{60m}Co</u>
346.93 7	0.0076 5	b ⁻	5.2714 y 5	<u>⁶⁰Co</u>
826.06 3	0.0076 8	b ⁻	5.2714 y 5	<u>⁶⁰Co</u>
826.06 3	~0.008	b ⁻	10.467 m δ	<u>^{60m}Co</u>
1173.237 4	99.9736 7	b ⁻	5.2714 y 5	<u>⁶⁰Co</u>
1332.501 5	0.24	b ⁻	10.467 m δ	<u>^{60m}Co</u>
1332.501 5	99.9856 4	b ⁻	5.2714 y 5	<u>⁶⁰Co</u>
2158.57 10	~0.0007	b ⁻	10.467 m δ	<u>^{60m}Co</u>
2158.57 10	0.00111 18	b ⁻	5.2714 y 5	<u>⁶⁰Co</u>
2505	2.0E-6 4	b ⁻	5.2714 y 5	<u>⁶⁰Co</u>

Gamma spectra of 2-nd unknown source



Disintegration chain of ^{226}Ra



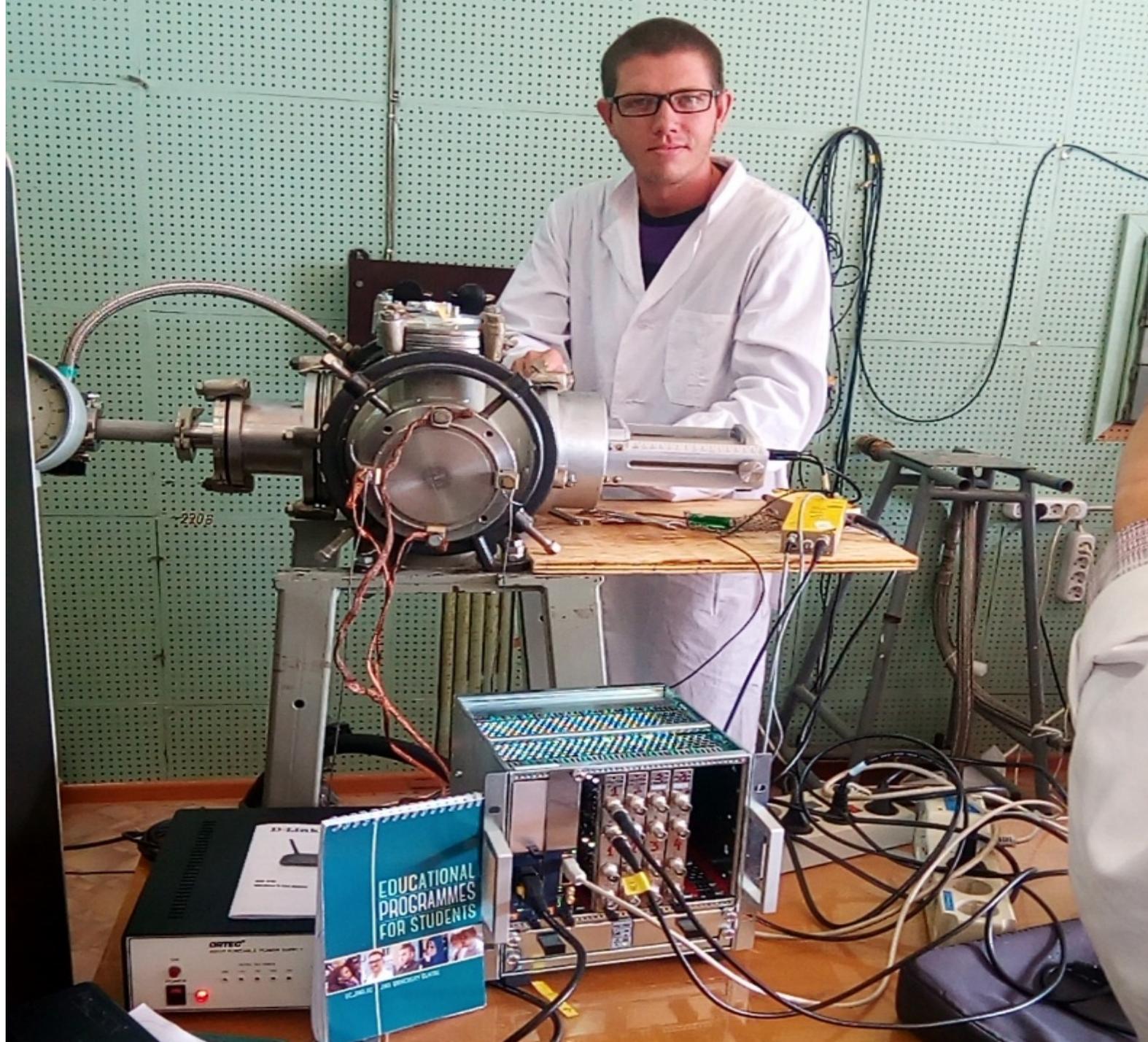
20 Us	Pa221 5.9 Us 9/2- α	Pa222 2.9 ms α	Pa223 6.5 ms EC, α	Pa224 0.79 s α	Pa225 1.7 s α	Pa226 1.8 m EC, α	Pa227 38.3 m (5/2-) EC, α	Pa228 22 h 3+ EC, α	Pa229 1.50 d (5/2+) EC, α	Pa230 17.4 d (2-) EC, β^-,α	Pa231 32760 y 3/2- α,β^-	Pa232 1.31 d (2-) EC, β^-	Pa233 26.967 d 3/2- β^-	Pa234 6.70 h 4+ β^-,α *	Pa235 24.5 m (3/2-) β^-	Pa236 9.1 m 1(-) β^-	Pa237 8.7 m (1/2+) β^-						
19 Us	Th220 9.7 Us 0+ EC, α	Th221 1.68 ms (7/2+) α	Th222 2.8 ms 0+ α	Th223 0.60 s (5/2)+ α	Th224 1.05 s 0+ α	Th225 8.72 m (3/2)+ EC, α	Th226 30.57 m 0+ α	Th227 18.72 d (1/2+) α	Th228 1.9116 y 0+ α	Th229 7340 y 5/2+ α	Th230 7.538E+4 y 0+ α,β^-	Th231 25.52 h 5/2+ β^-,α	Th232 1.405E10 y 0+ α,β^- 100	Th233 22.3 m 1/2+ β^-	Th234 24.10 d 0+ β^-	Th235 7.1 m (1/2+) β^-	Th236 37.5 m 0+ β^-						
18 Us	Ac219 11.8 Us 9/2- EC, α	Ac220 26.4 ms (3-) α	Ac221 52 ms (3/2-) α	Ac222 5.0 s 1- EC, α *	Ac223 2.10 m (5/2-) EC, α	Ac224 2.78 h 0- EC, β^-,α	Ac225 10.0 d (3/2-) $\alpha,^{14}\text{C}$	Ac226 29.37 h (1) EC, β^-,α	Ac227 21.773 y 3/2- β^-,α	Ac228 6.15 h 3+ β^-	Ac229 62.7 m (3/2+) β^-	Ac230 122 s (1+) β^-	Ac231 7.5 m (1/2+) β^-	Ac232 119 s (1+) β^-	Ac233 145 s (1/2+) β^-	Ac234 44 s β^-	Ac235 β^-						
17 Us	Ra218 25.6 Us 0+ α	Ra219 10 ms (7/2)+ α	Ra220 18 ms 0+ α	Ra221 28 s 5/2+ α	Ra222 38.0 s 0+ $\alpha,^{14}\text{C}$	Ra223 11.435 d 3/2+ $\alpha,^{14}\text{C}$	Ra224 3.66 d 0+ $\alpha,^{14}\text{C}$	Ra225 14.9 d 1/2+ β^-	Ra226 1600 y 0+ $\alpha,^{14}\text{C}$	Ra227 42.2 m 3/2+ β^-	Ra228 5.75 y 0+ β^-	Ra229 4.0 m 5/2(+) β^-	Ra230 93 m 0+ β^-	Ra231 103 s (7/2-,1/2+) β^-	Ra232 290 s 0+ β^-	Ra233 30 s β^-	Ra234 30 s 0+ β^-						
16 Us	Fr217 22 Us 9/2- α	Fr218 1.0 ms 1- α *	Fr219 20 ms 9/2- α	Fr220 27.4 s 1+ β^-,α	Fr221 4.9 m 5/2- α	Fr222 14.2 m 2- β^-	Fr223 21.8 m 3/2(-) β^-,α	Fr224 3.33 m 1- β^-	Fr225 4.0 m 3/2- β^-	Fr226 49 s 1- β^-	Fr227 2.47 m 1/2+ β^-	Fr228 38 s 2- β^-	Fr229 50 s β^-	Fr230 19.1 s β^-	Fr231 17.5 s β^-	Fr232 5 s β^-	146						
15 Us	Rn216 45 Us 0+ α	Rn217 0.54 ms 9/2+ α	Rn218 35 ms 0+ α	Rn219 3.96 s 5/2+ α	Rn220 55.6 s 0+ α	Rn221 25 m 7/2(+) β^-,α	Rn222 3.8235 d 0+ α	Rn223 23.2 m 7/2 β^-,α	Rn224 107 m 0+ β^-	Rn225 4.5 m 7/2- β^-	Rn226 7.4 m 0+ β^-	Rn227 22.5 s β^-	Rn228 65 s 0+ β^-	144									
14 Us	At215 0.10 ms 9/2- α	At216 0.30 ms 1- EC, β^-,α	At217 32.3 ms 9/2- β^-,α	At218 1.5 s β^-,α	At219 56 s β^-,α	At220 3.71 s β^-,α	At221 2.3 m β^-	At222 54 s β^-	At223 50 s β^-,α	140		142											
13 Us	Po214 164.3 Us 0+ α	Po215 1.781 ms 9/2+ β^-,α	Po216 0.145 s 0+ α	Po217 10 s β^-,α	Po218 3.10 m 0+ β^-,α	136		138															
12 m	Pb211 36.1 m 9/2+ β^-	Pb212 10.64 h 0+ β^-	Pb213 10.2 m (9/2+) β^-	Pb214 26.8 m 0+ β^-	134																		
								$^{226}\text{Ra} \rightarrow ^{222}\text{Rn} \rightarrow ^{218}\text{Po} \rightarrow ^{214}\text{Pb}$															

Alpha-spectroscopy

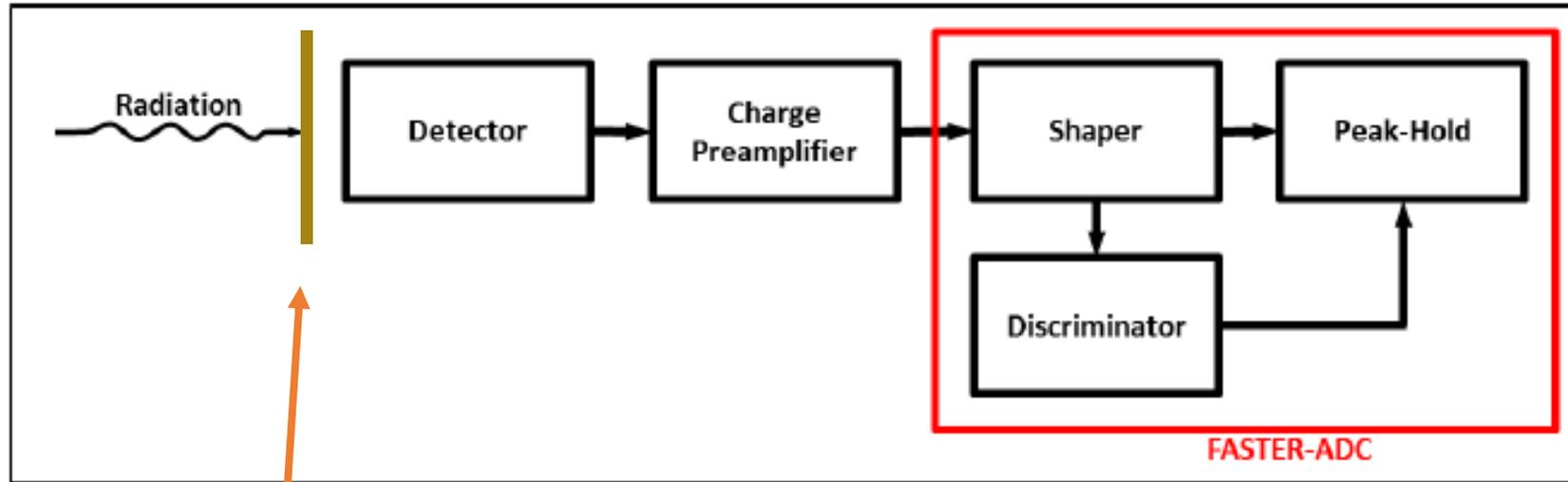
Silicon detector

^{226}Ra ^{222}Rn ^{218}Po ^{214}Pb

^{226}Ra Source



Silicon detector



Measurement of thickness of Aluminium foil

Measurement of thickness of Al-foil by balance weighting



$$L = 28,9 \text{ cm}$$

$$H = 7,8 \text{ cm}$$

$$M = 0,5287 \text{ g}$$

$$S = L * H = 225,42 \text{ cm}^2$$

$$D = M/S = 2,345 \text{ mg/cm}^2$$

$$\rho = 2698,4 \text{ mg/cm}^3$$

$$D/\rho = 8,69 \text{ }\mu\text{m}$$

Measurement of thickness of Al-foil (d)

LISE++ [Noname]

File Options Experiment Settings Physics Models Calculations Utilities 1D-Plot 2D-Plot Databases Help

Set-Up

P rojectile $^{48}\text{Ca}^{20+}$
140 MeV/u 1 pA

F ragment $^{42}\text{Si}^{16+}$

T arget ^9Be
1800 mg/cm²

Str ipper

D 1 Brho
3.2490 Tm

S II $l1_slits$
slits
-100 +100

D 2 Brho
3.2490 Tm

FP_PIN

Al Density [g/cm³] 2.702

calculate reactions in this material

State Solid Gas

Dimension mg/cm² & micron g/cm² & mm

Angle Calculate 0 degrees

Thickness at 0 degrees 8.53 micron 2.304806 mg/cm²

Effective Thickness 8.53 micron 2.304806 mg/cm²

Set the spectrometer after this block using changes Atoms / cm² 5.14e+19

Cut (Slits)

Calibration Resolution Thickness defect

OK Cancel

Compound dictionary

Physical calculator

A Element Z Q Table of Nuclides

4 He 2 2

Stable Ion mass = 4.0015 amu

Energy 1.92178 MeV/u 1.9225 AMeV

Brho 0.39953 Tm TKE 7.69 MeV

Erho 7.69256 MJ/C Velocity 1.92276 cm/ns

P 239.554 MeV/c Beta 0.0641365

p_transp 0.119777 GeV/c Gamma 1.002063

After

Block	Z \ Thickness	MeV/u	MeV	MeV	<Q>
FP_PIN	Al 8.53 micron	1.6427	6.5731	1.1169	1.71
FP_SCI	C9H10 100 mm	0	0	6.5731	0.00

Energy Remain. E-Loss

after/into Si 504 micron

Energy Remain 0 MeV/u

Energy Loss 7.69 MeV

Energy Strag.(sigma) 0.0037879 MeV/u

Angular Strag.(sigma) 34.282 mrad (plane)

Lateral spread (sigma) 0.16256 microns

Brho (for Q=Z) 0 Tm

Equilibrium values for material "Si"

Charge State <Q> 1.75

dQ (sigma) 0.25

Thickness 0.00046577 mg/cm²

Range and Energy Loss to Si

Range dRange (sigma)

10.5073 0.09117 mg/cm²

45.2668 0.39277 micron

Energy Remain. 0.000 MeV/u

Material thickness 10.507 mg/cm²

for energy rest 45.267 micron

Calculation method of

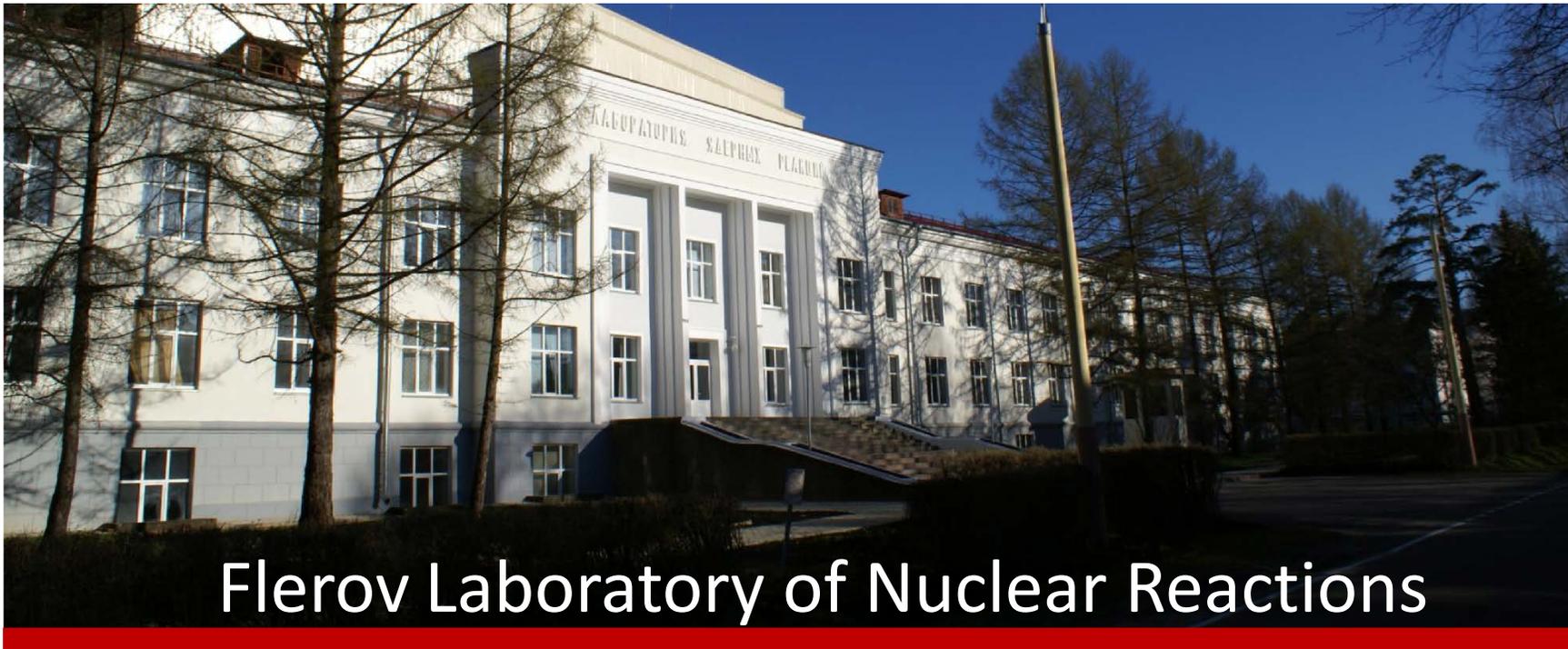
Energy straggling 1

Change States 3

Angular straggling 1

Print Help Quit

1 Origin 8 Software
2 Lise++ Software



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