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

STAGE 3 INTERNATIONAL STUDENT PRACTICE 2017

Flerov Laboratory of Nuclear Reactions

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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

SUPERVISORS
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SPEAKER
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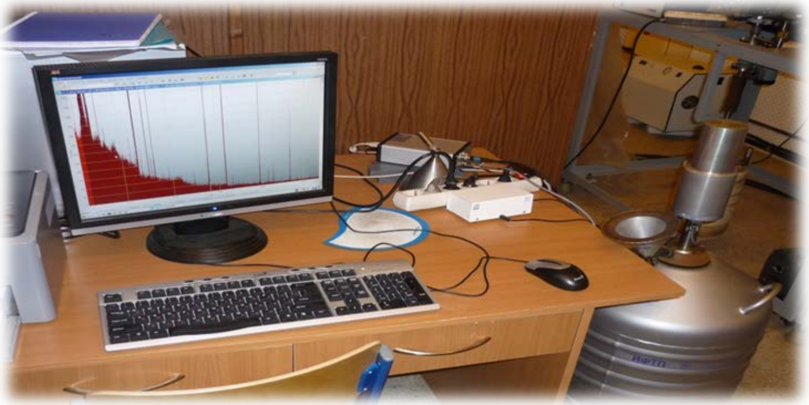
Egypt

Introduction

3 Types of semiconductor detectors

1. X-ray 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

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

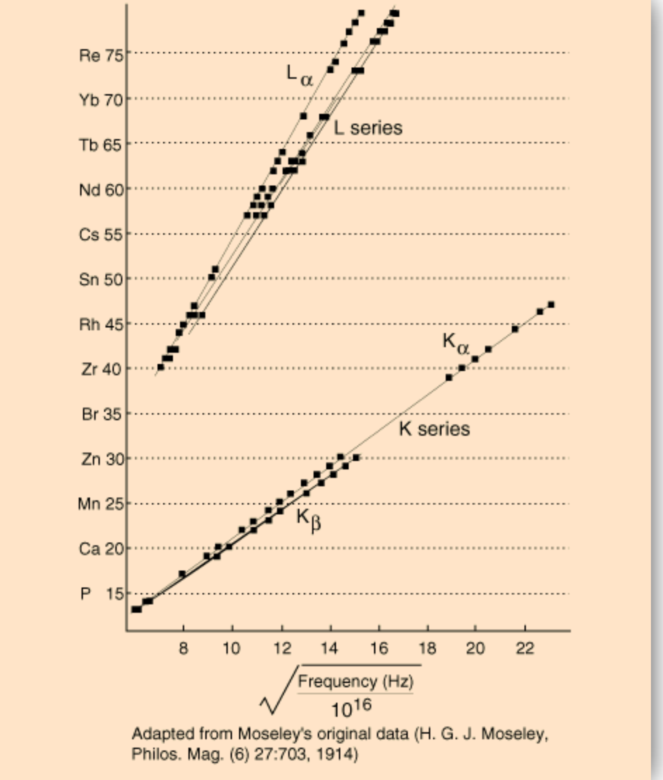
where *a* and *b* are constants depending upon the particular spectral line, E is the energy of characteristic x-ray and Z atomic number.

- 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.

Moseley Plot of characteristic X-rays

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

- Photographic recording of Kα and Kβ x-ray emission lines for a range of elements (Figure 2).



Adapted from Moseley's original data (H. G. J. Moseley, Philos. Mag. (6) 27:703, 1914)

Fig. 1 Moseley plot of characteristic X-rays

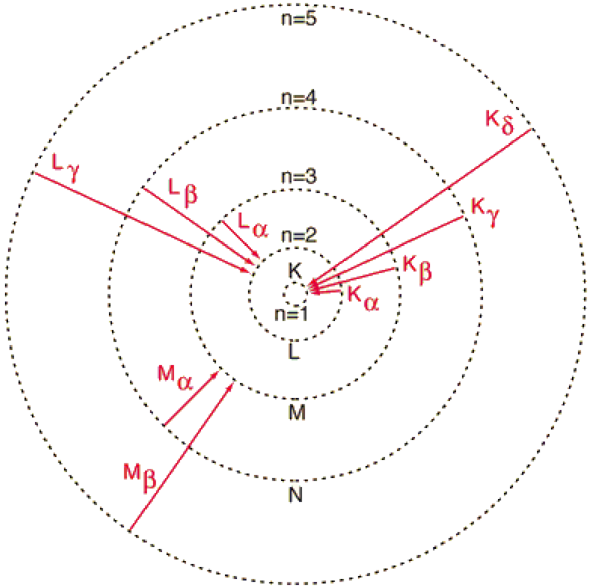


Fig. 3 X-ray transitions

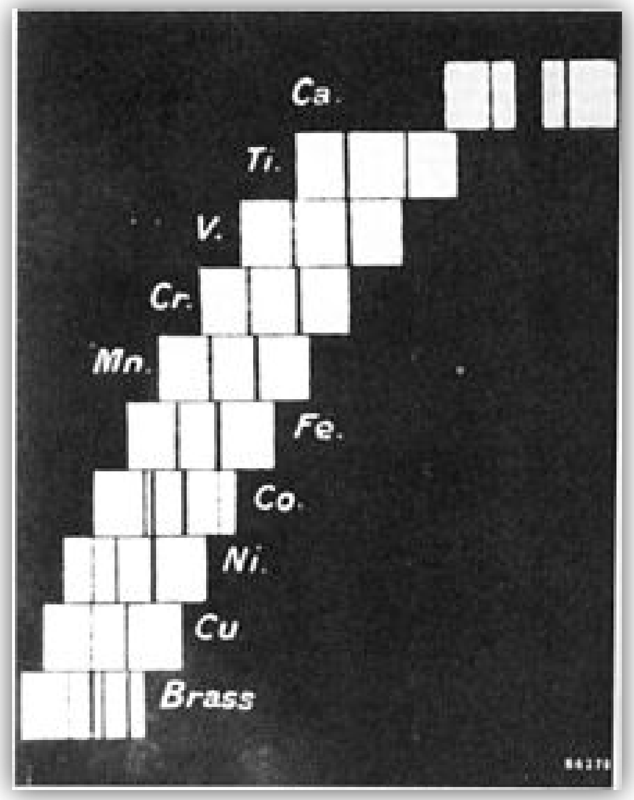


Fig. 2 Moseley step ladder of elements

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.

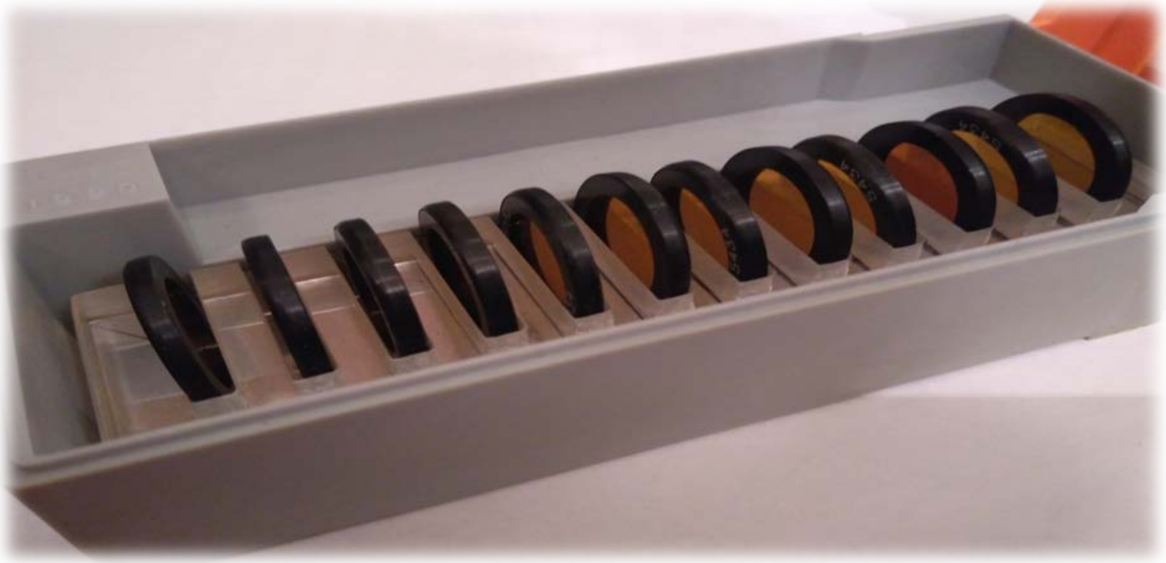
- Moseley's law has led to the discovery of new elements like hafnium (Z=72), technetium (Z=43), rhenium (Z=75) etc.

- This law has been helpful in determining the atomic number of rare earths, thereby fixing their position in the periodic table.

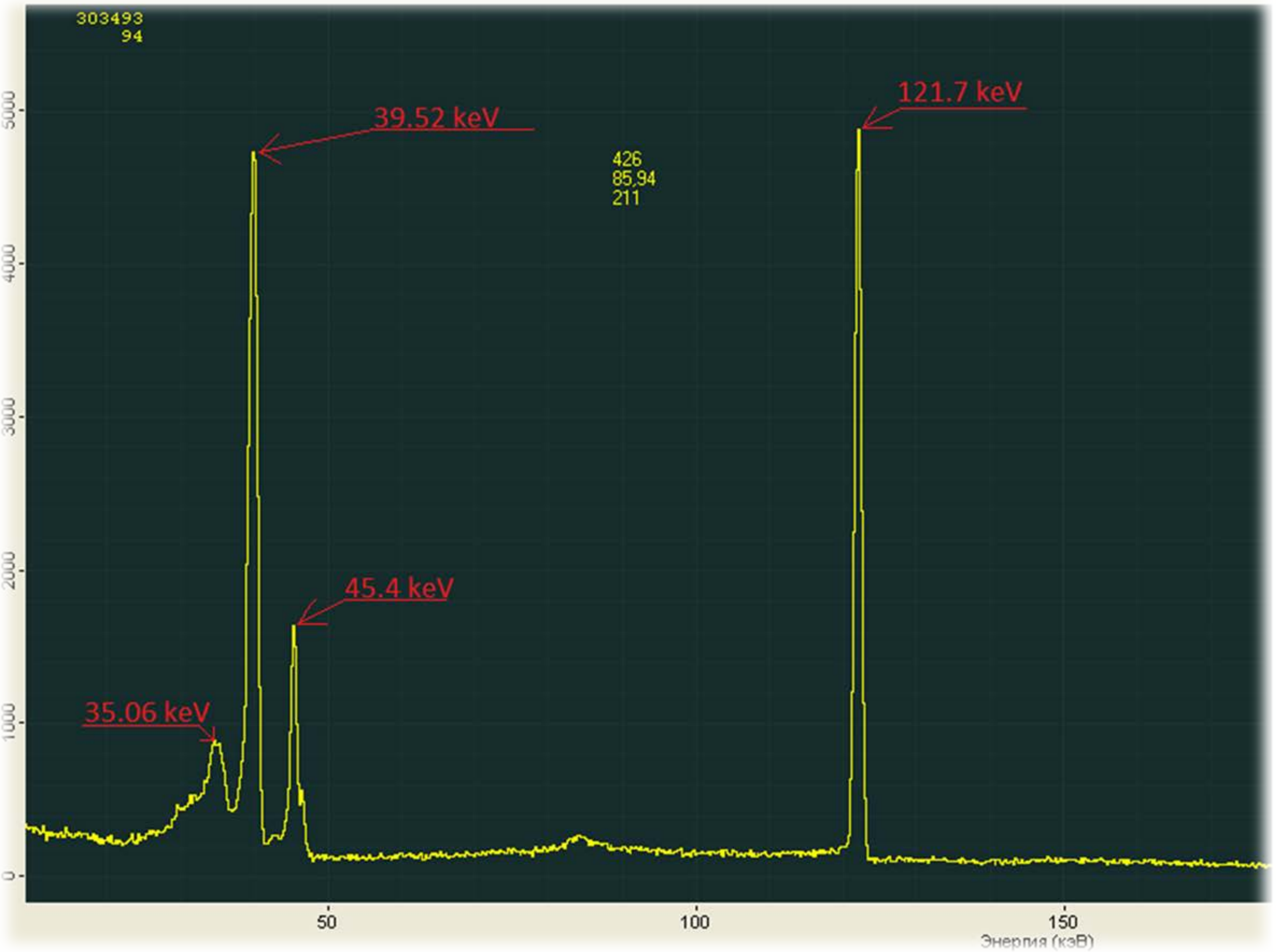
General view of the X-ray spectrometer

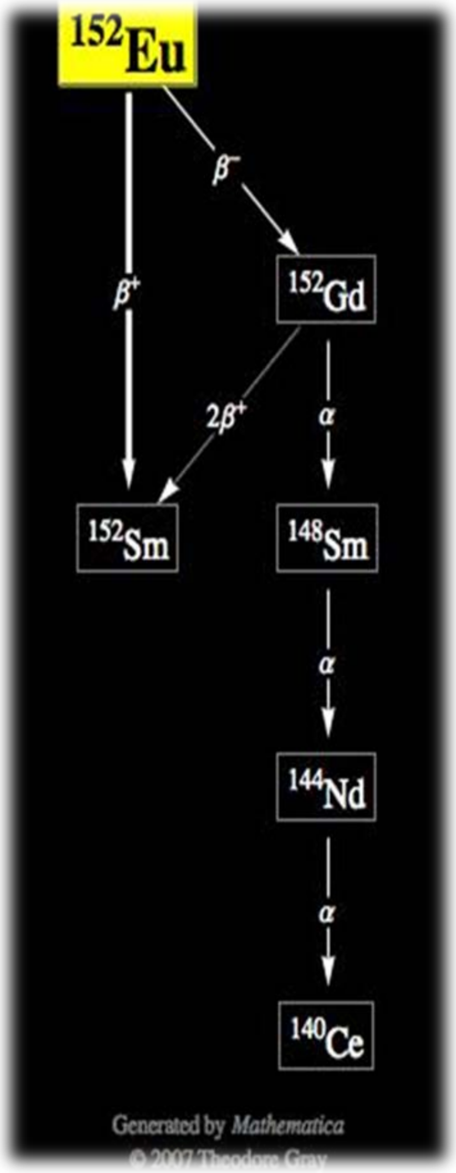
Preparation for measurement

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.



X-ray specter Eu-152





Moseley Law in action

Z	K	L
Am 95		13.946
Si 50	24.21	3.287
Ba 56	30.973	4.286
Mn 25	5.415	0.572
Y 39	14.165	1.806
Th 90		15.236
Cd 48	22.163	2.984
Cs 55	32.194	4.466
Eu 63	40.118	5.636

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

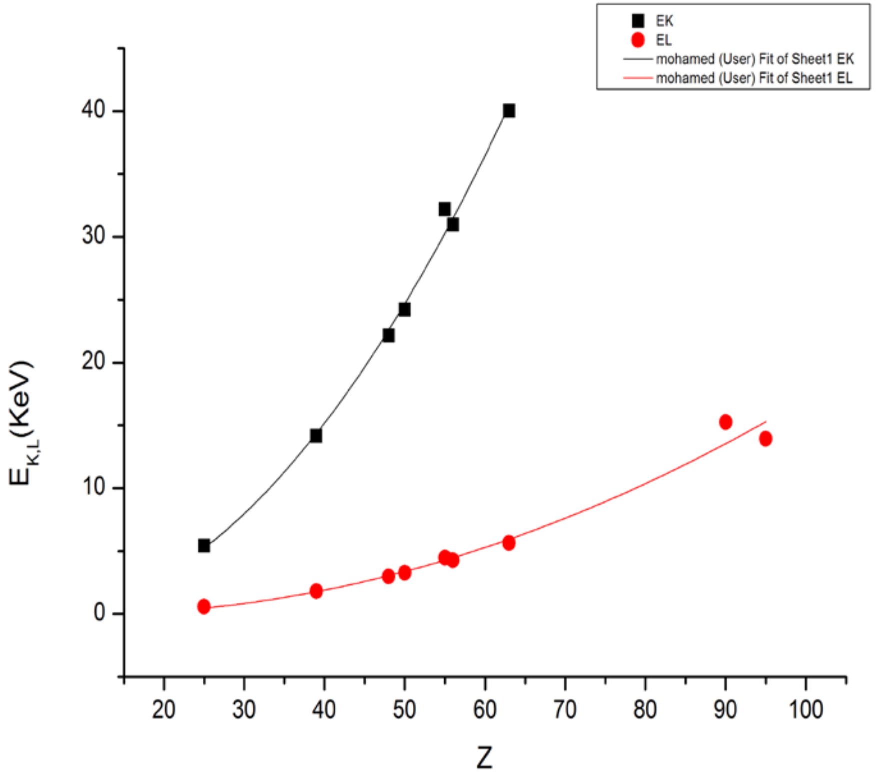
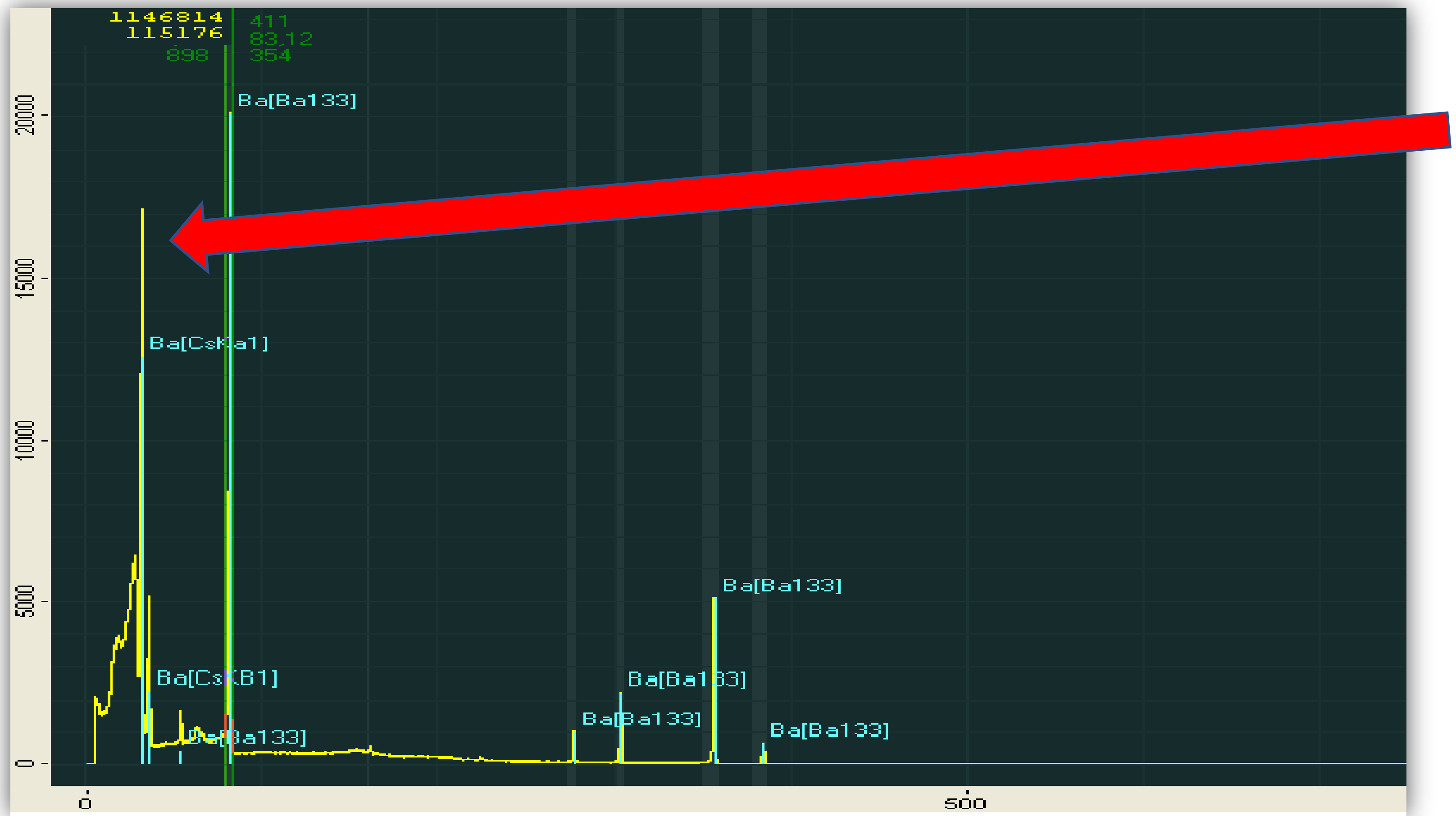


Figure 4: K (α) and K (β) lines fit to Moseley's Law. We confirm the functional form of the law but different values for the constants (a & b).

Spectrum from X-ray detector



Calculation and results.

E = 30.64 keV
A & B = constants obtained from Kα Moseley's plot.

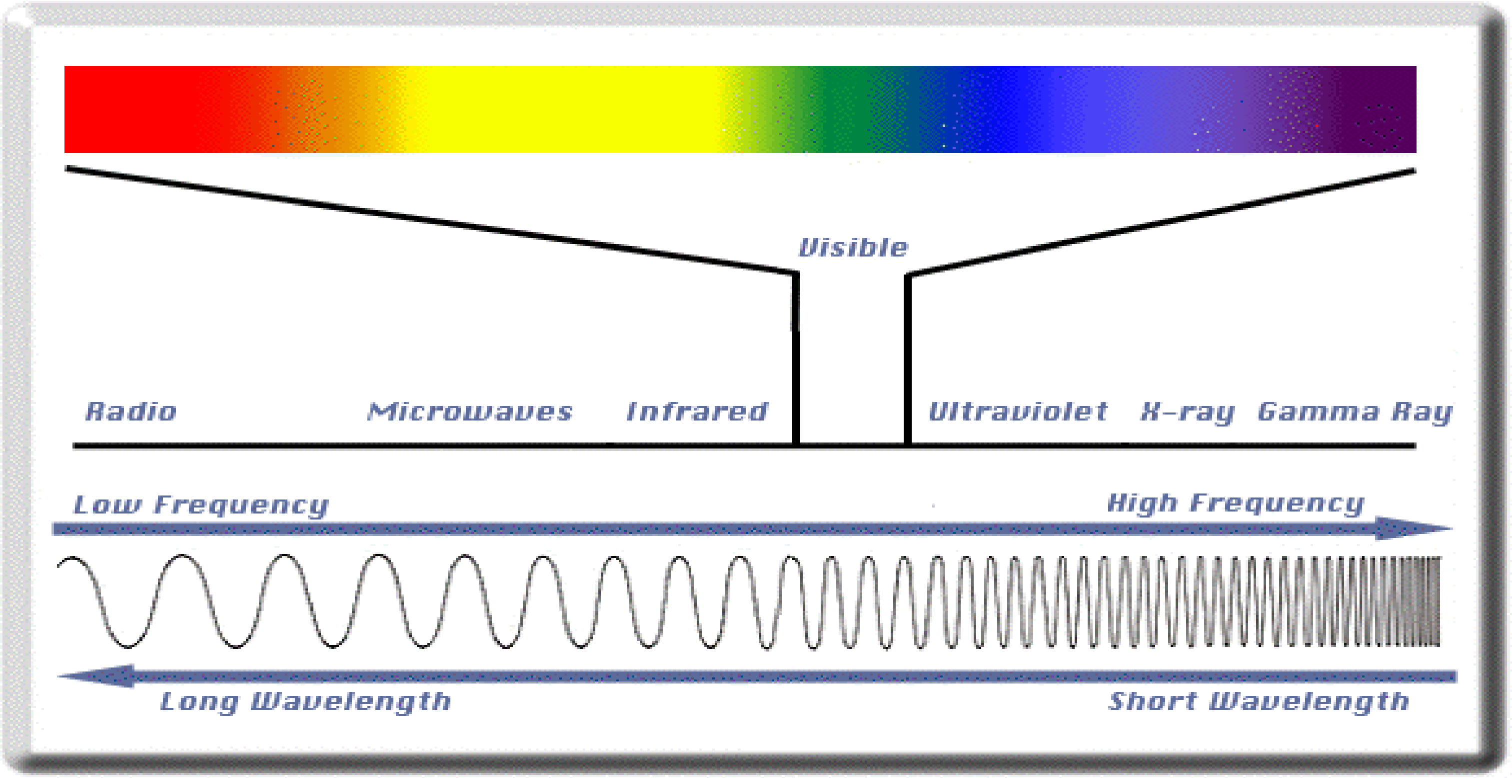
$$E = a\,(Z - b)^2$$

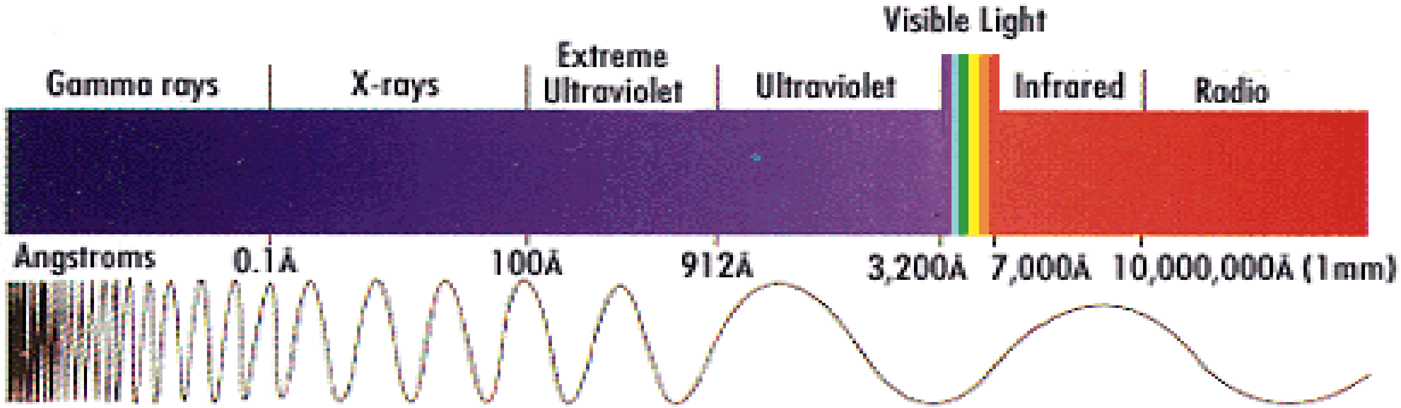
$$Z = \frac{\sqrt{E}}{a} + b$$

$$= \frac{\sqrt{30.64}}{0.0115} + 4.0137$$

$$= 55.60$$

Nuclear data: Z = 55.60
Element is Cs


Visible
Radio
Microwaves
Infrared
Ultraviolet
X-ray
Gamma Ray
Low Frequency
High Frequency
Long Wavelength
Short Wavelength

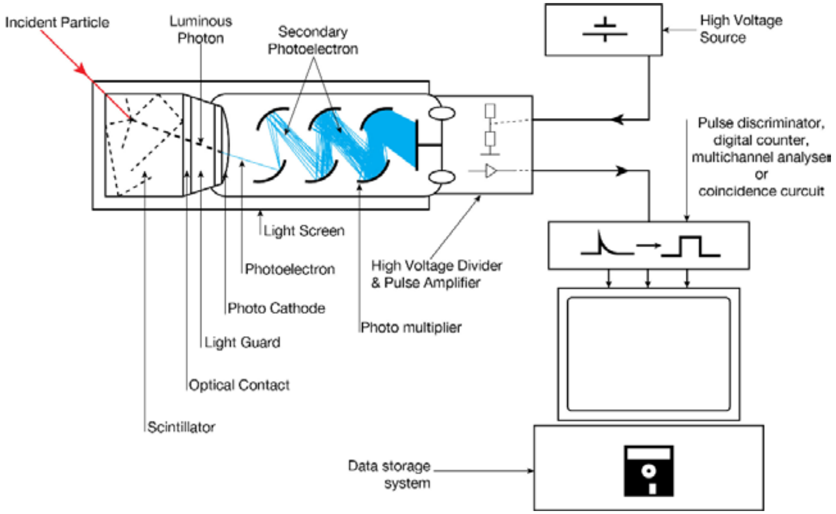

Visible Light
Gamma rays
X-rays
Extreme Ultraviolet
Ultraviolet
Infrared
Radio
Angstroms
0.1Å
100Å
912Å
3,200Å
7,000Å
10,000,000Å (1mm)

Main detectors used for gamma

- **Scintillators detectors**

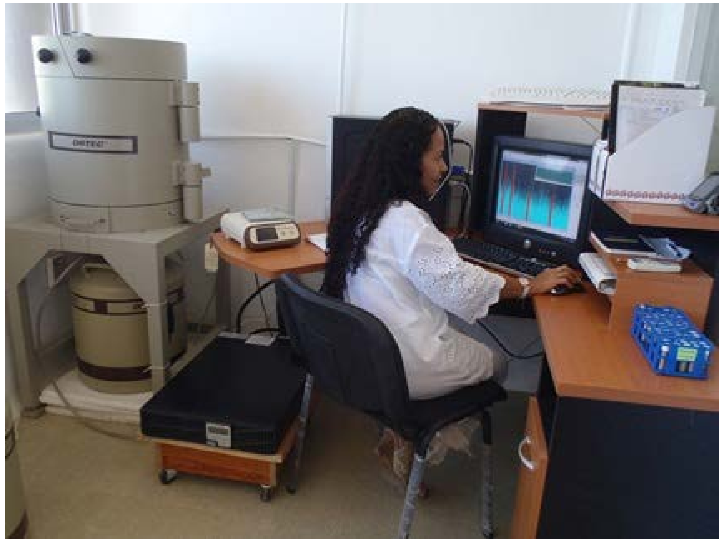
Organic (plastic, organic cristal, liquids)

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



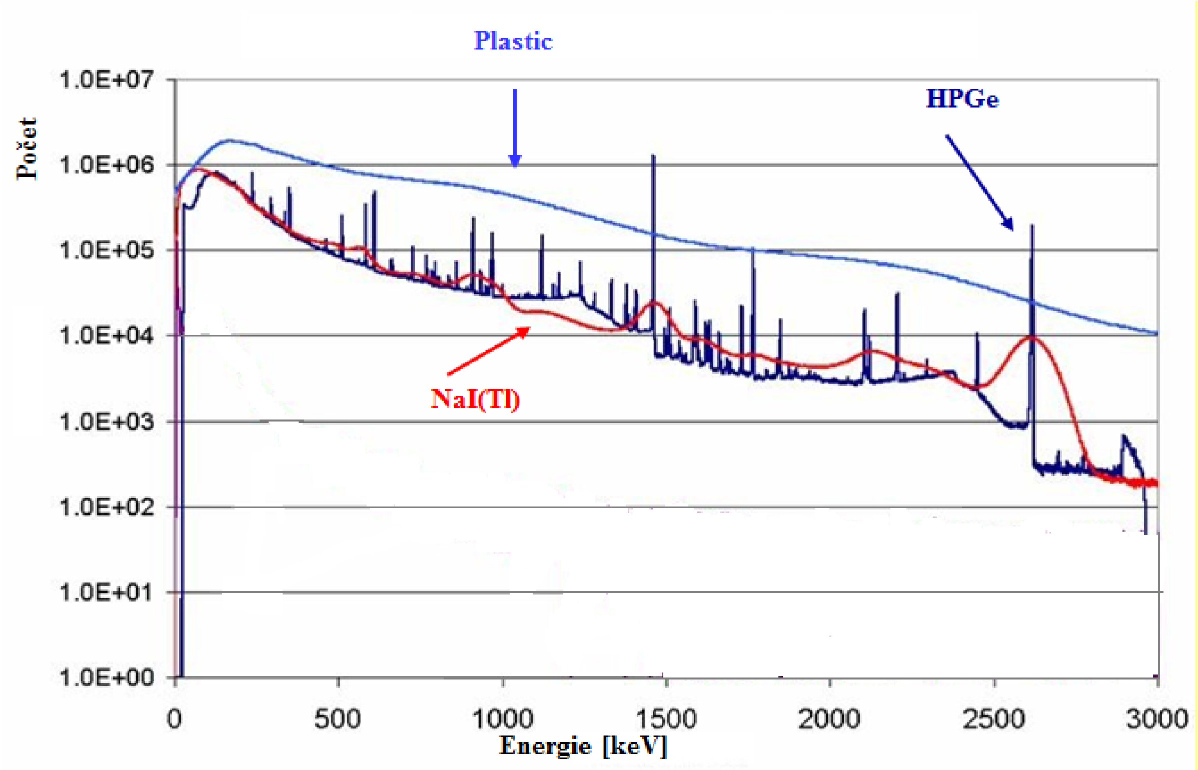
- **Solid State detectors**

HPGe detector, Si



Comparison of detectors

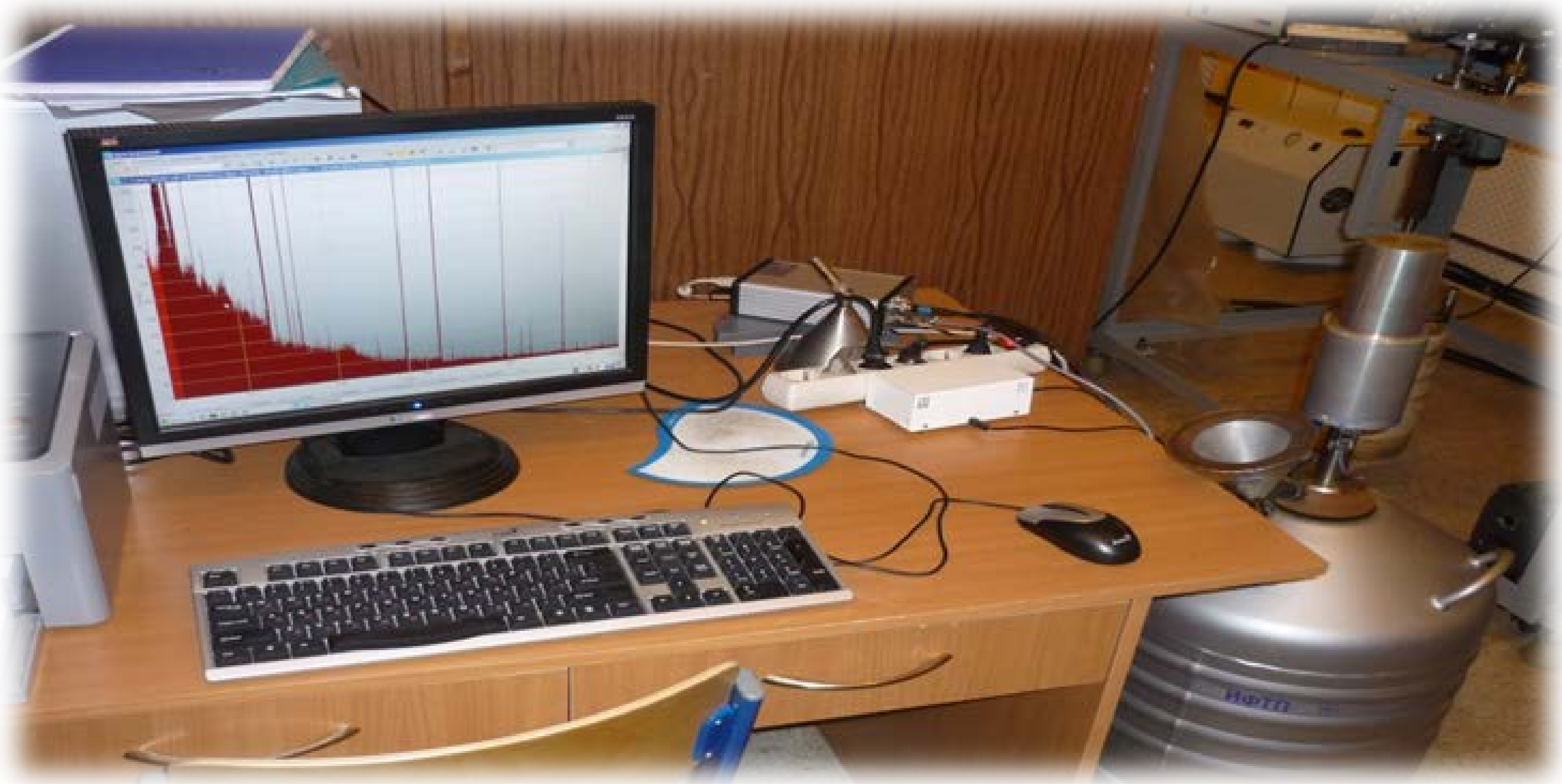
	Pure Ge-detector	Plastic Scintillator
	Price	Cheaper
Size	Restricted a few cm^3	No size limitation
Neutron-gamma separation	Not need	Need
Efficiency	Less 10 %	Large due to Z and size
Resolution	1 keV	Bad resolution



Resolution comparison

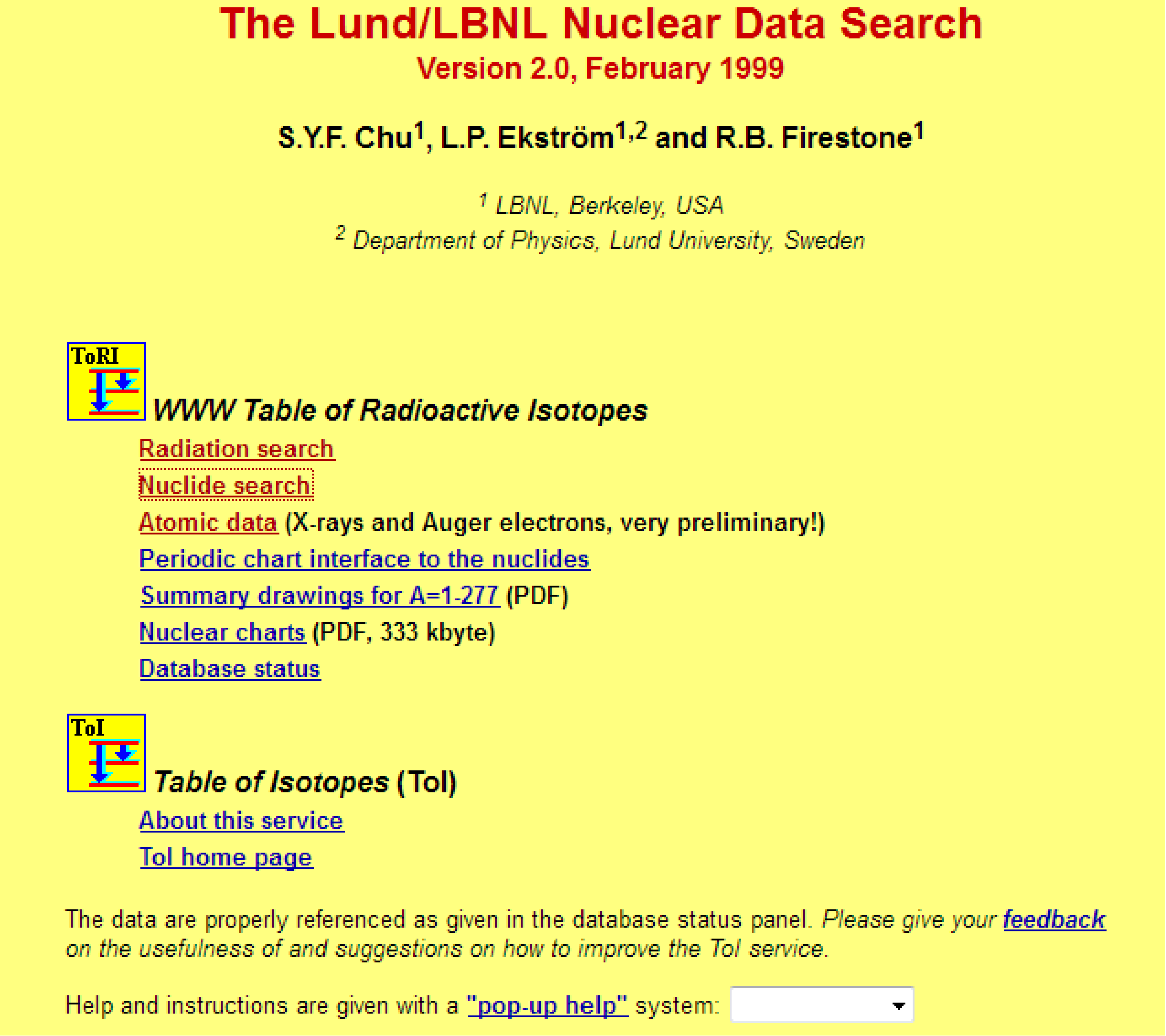
General view for HPGe Detector

To identify for Z and A



Gamma spectra calibration

Use of Nuclear Data Search



The Lund/LBNL Nuclear Data Search

Version 2.0, February 1999

S.Y.F. Chu[1], L.P. Ekström[1,2] and R.B. Firestone[1]

[1] LBNL, Berkeley, USA
[2] Department of Physics, Lund University, Sweden

WWW Table of Radioactive Isotopes

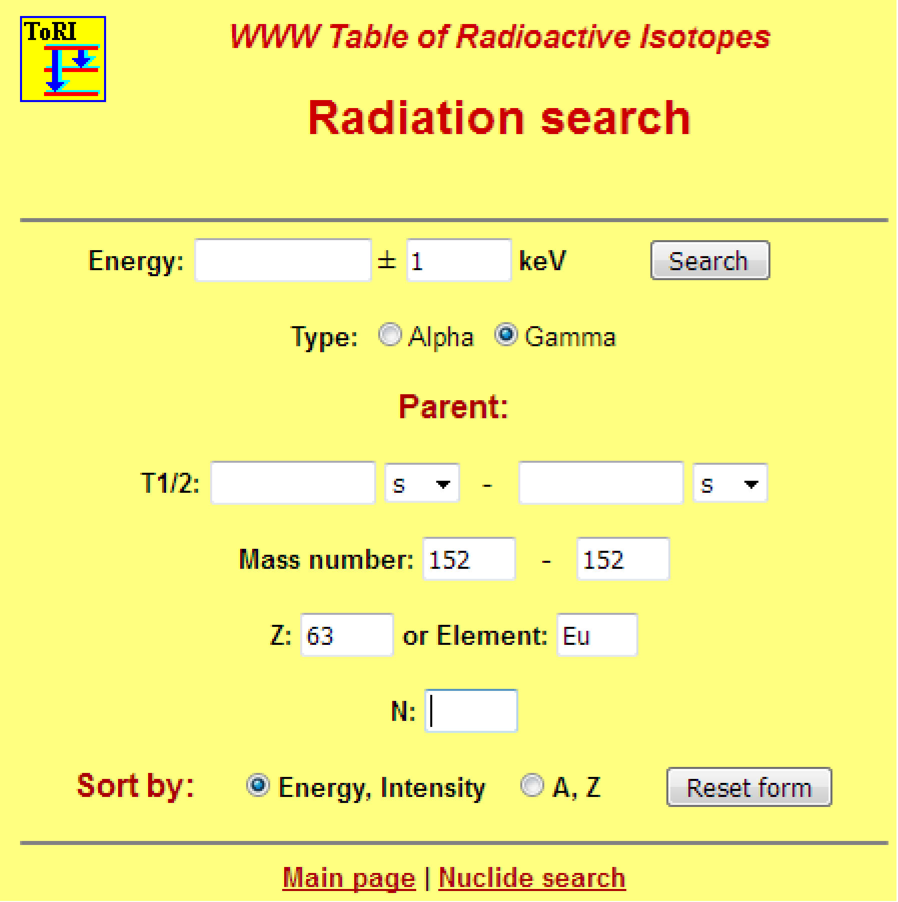
- Radiation search
- Nuclide search
- Atomic data (X-rays and Auger electrons, very preliminary!)
- Periodic chart interface to the nuclides
- Summary drawings for A=1-277 (PDF)
- Nuclear charts (PDF, 333 kbyte)
- Database status

***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: ± 1 **keV**

Type: ○ Alpha ● Gamma

Parent:

T1/2: s - s

Mass number: 152 - 152

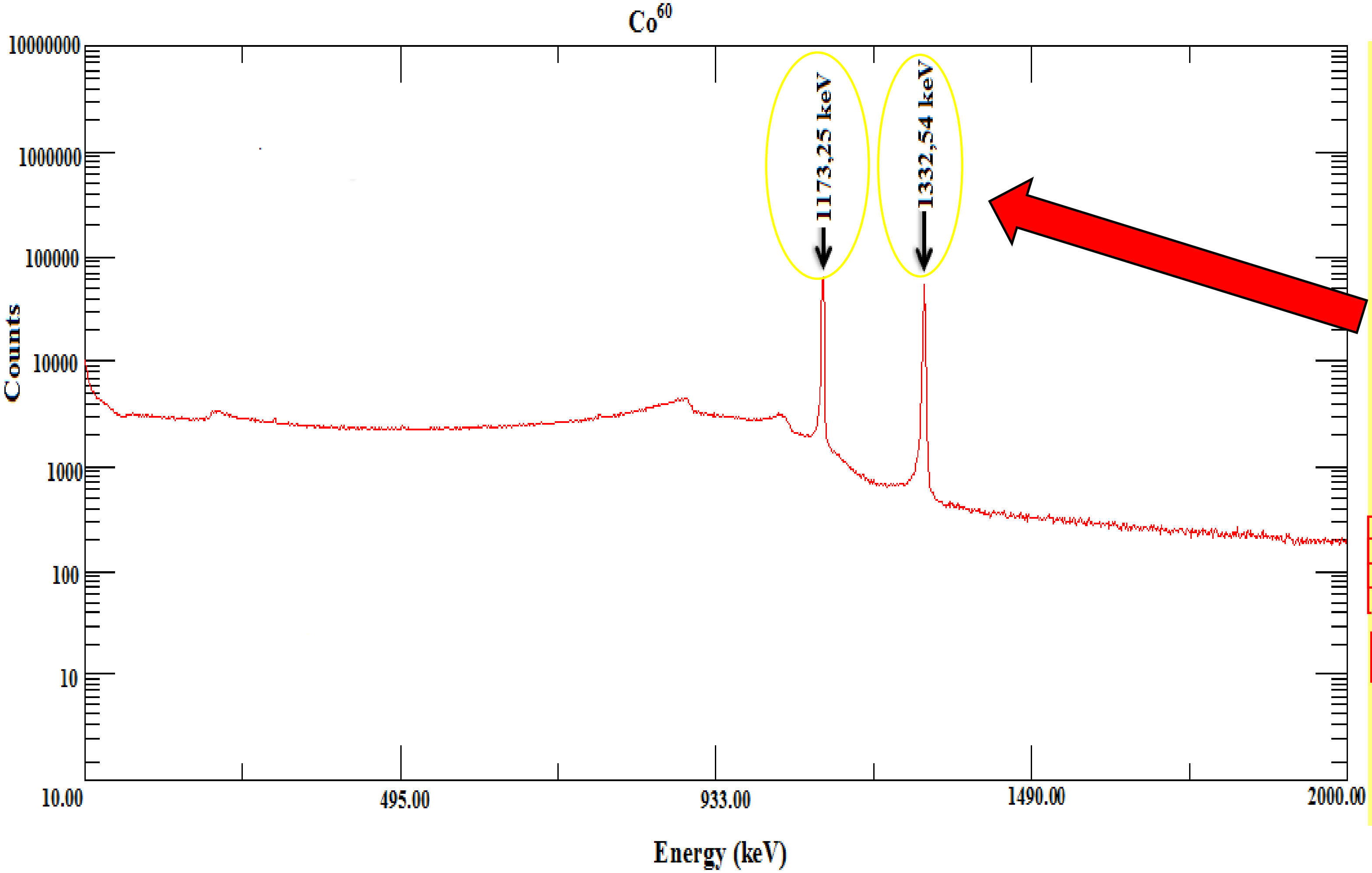
Z: 63 **or Element:** Eu

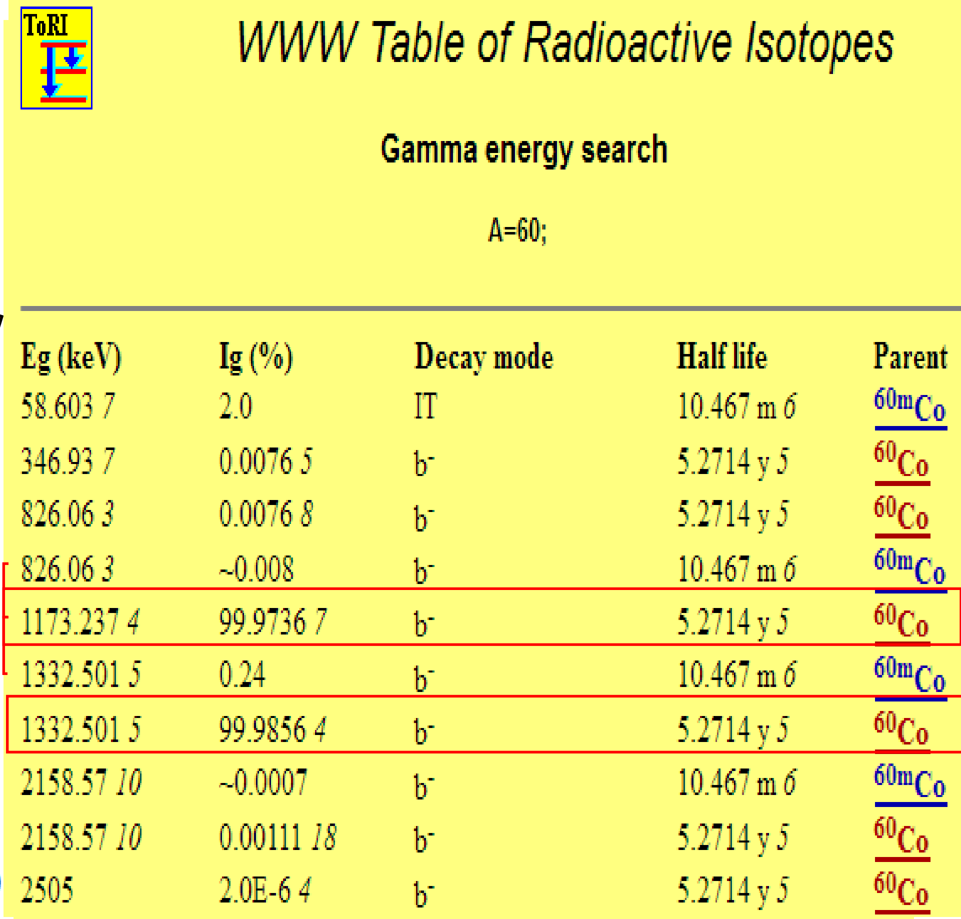
N:

Sort by: ● **Energy, Intensity** ○ **A, Z**

Main page | Nuclide search

Gamma spectra of unknown source





WWW Table of Radioactive Isotopes

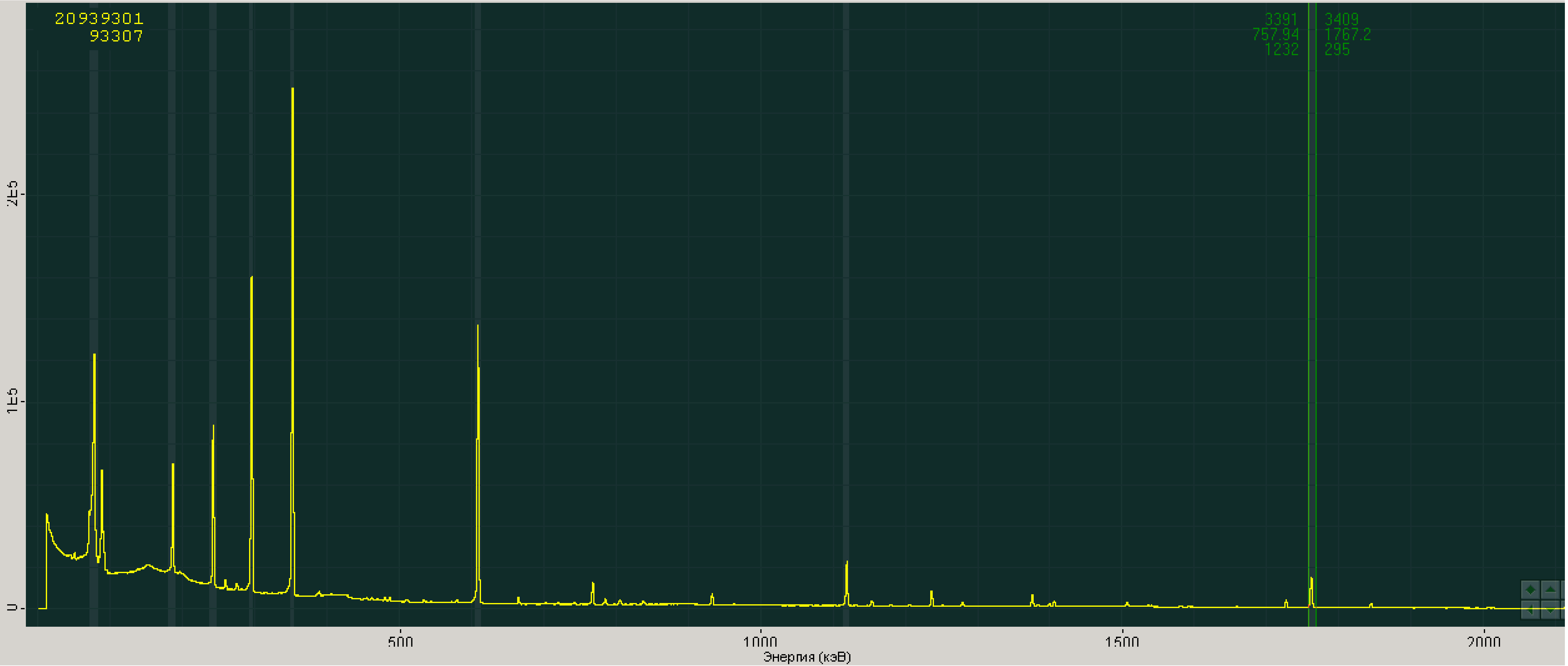
Gamma energy search

A=60;

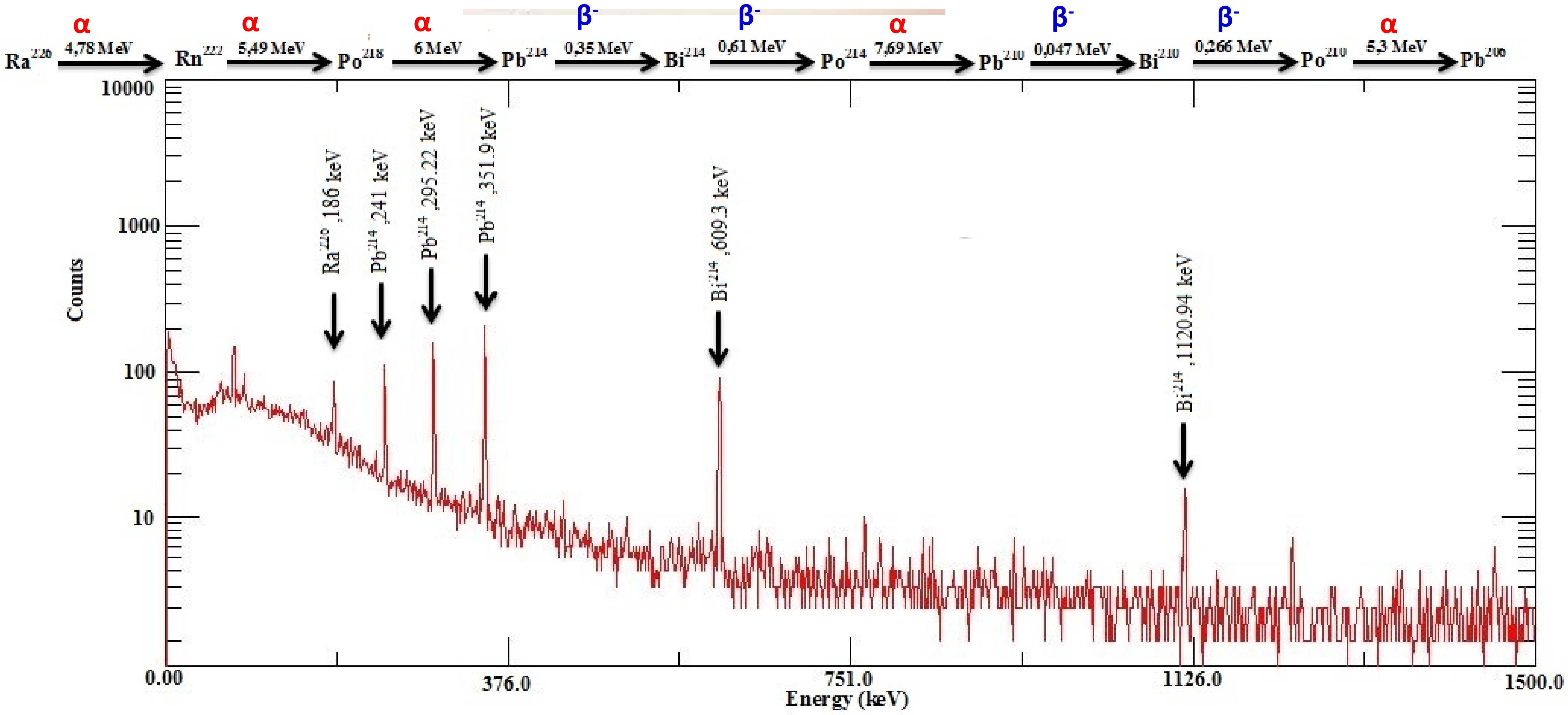
Eg (keV)	Ig (%)	Decay mode	Half life	Parent
58.603 *7*	2.0	IT	10.467 m *6*	^{60m}Co
346.93 *7*	0.0076 *5*	b^-	5.2714 y *5*	^{60}Co
826.06 *3*	0.0076 *8*	b^-	5.2714 y *5*	^{60}Co
826.06 *3*	~0.008	b^-	10.467 m *6*	^{60m}Co
1173.237 *4*	99.9736 *7*	b^-	5.2714 y *5*	^{60}Co
1332.501 *5*	0.24	b^-	10.467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

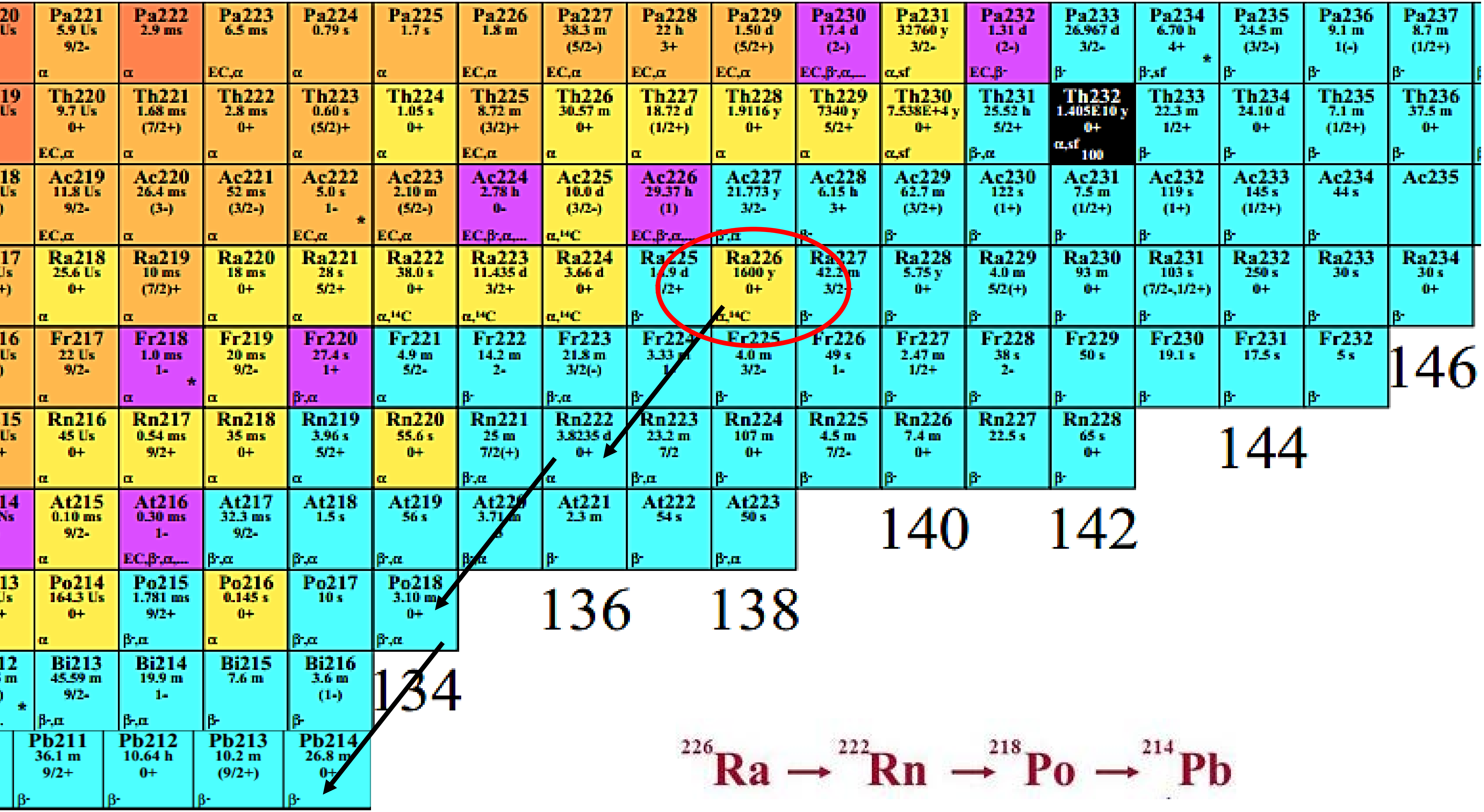
Gamma spectra of 2-nd unknown source

To Identify to know tow unknown sources



Disintegration chain of ^{226}Ra



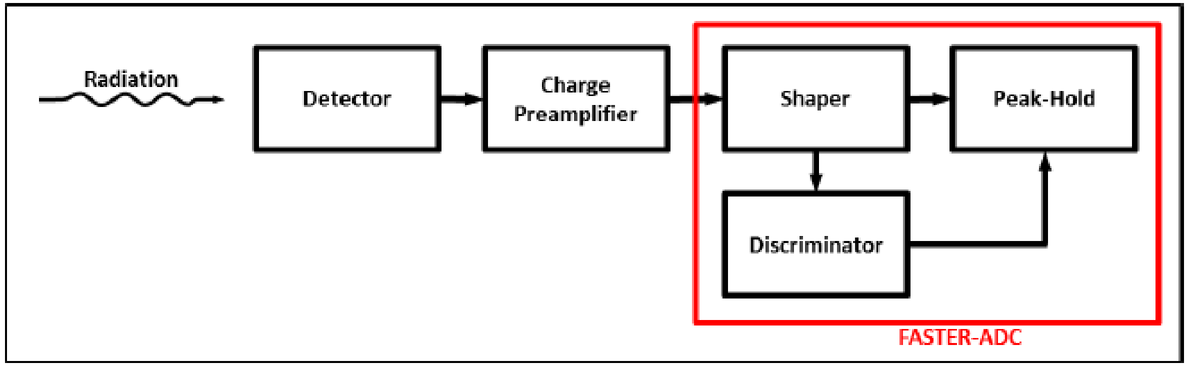


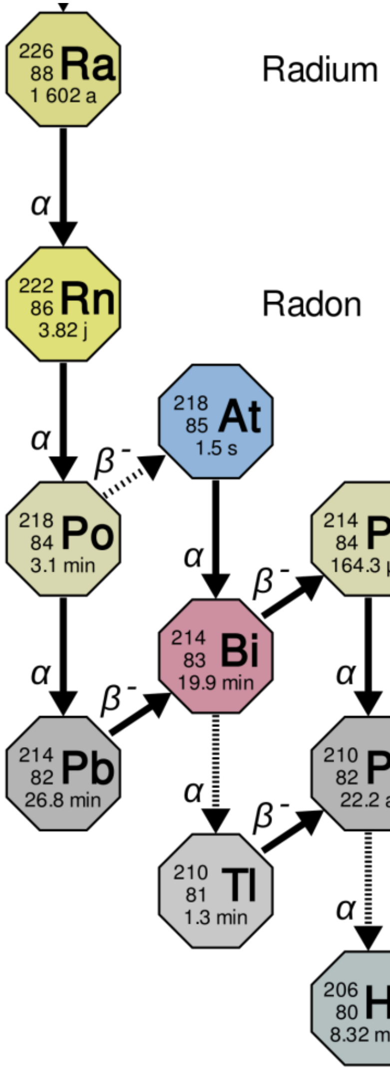
20 Us	Pa221 5.9 Us 9/2- α	Pa222 2.9 ms α	Pa223 6.5 ms EC,α	Pa224 0.79 s α	Pa225 1.7 s α	Pa226 1.8 m EC,α	Pa227 38.3 m (5/2-) EC,α	Pa228 22 h 3+ EC,α	Pa229 1.50 d (5/2+) EC,α	Pa230 17.4 d (2-) EC,β-,α,...	Pa231 32760 y 3/2- α,sf	Pa232 1.31 d (2-) EC,β-	Pa233 26.967 d 3/2- β-	Pa234 6.70 h 4+ * β-,sf	Pa235 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,sf	Th231 25.52 h 5/2+ β-,α	Th232 1.405E10 y 0+ α,sf 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-) α,^{14}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
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+ α,^{14}C	Ra223 11.435 d 3/2+ α,^{14}C	Ra224 3.66 d 0+ α,^{14}C	Ra225 14.9 d 1/2+ β-	Ra226 1600 y 0+ α,^{14}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 250 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 Ns	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 m 3 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) *	Bi213 45.59 m 9/2- β-,α	Bi214 19.9 m 1- β-,α	Bi215 7.6 m β-	Bi216 3.6 m (1-) β-	134												
	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-													

$^{226}\mathrm{Ra} \rightarrow {}^{222}\mathrm{Rn} \rightarrow {}^{218}\mathrm{Po} \rightarrow {}^{214}\mathrm{Pb}$

Alpha-spectroscopy Silicon detector

Alpha-spectroscopy Silicon detector





^{222}Rn

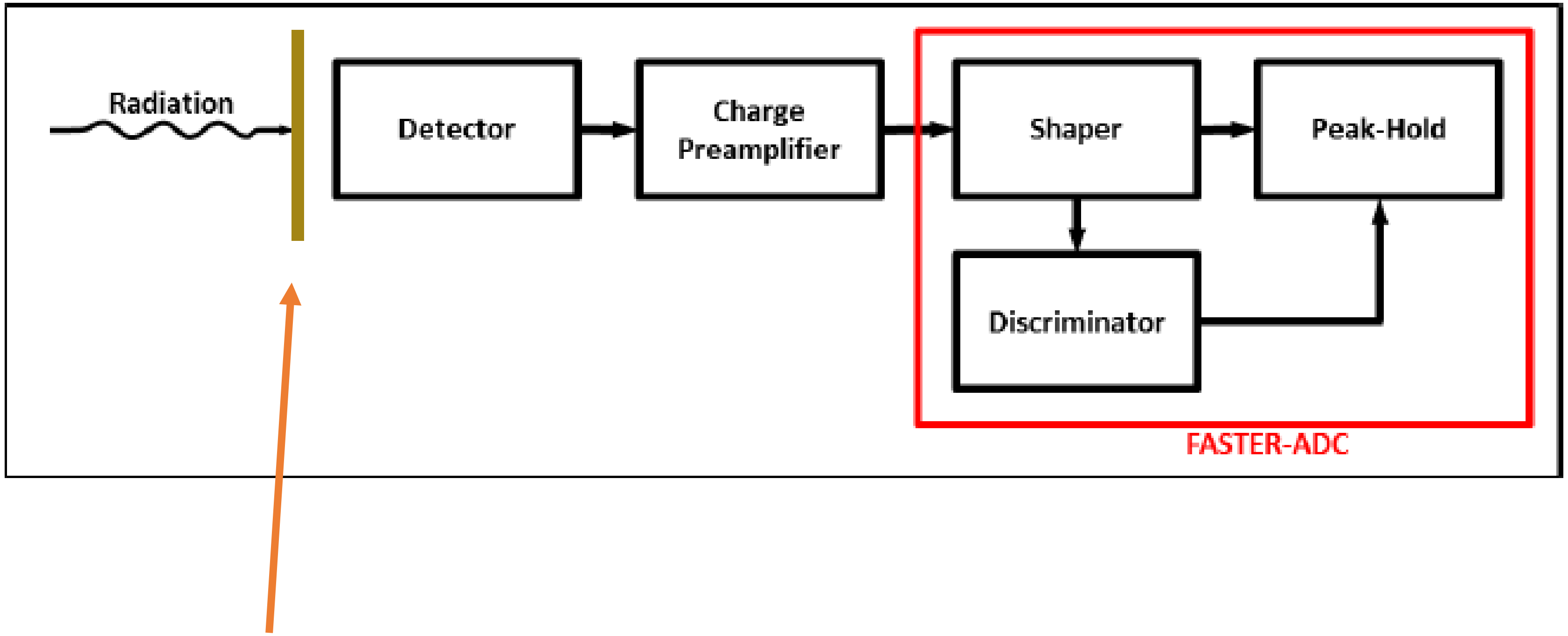
^{214}Pb

^{218}Po

^{226}Ra

^{226}Ra Source

Silicon detector



Measurement
of thickness of
Aluminium foil

Mechanical way:
measurement of thickness of al-foil by balance weighting

L= 28,9 cm

H= 7,8 cm

M= 0,5287 g

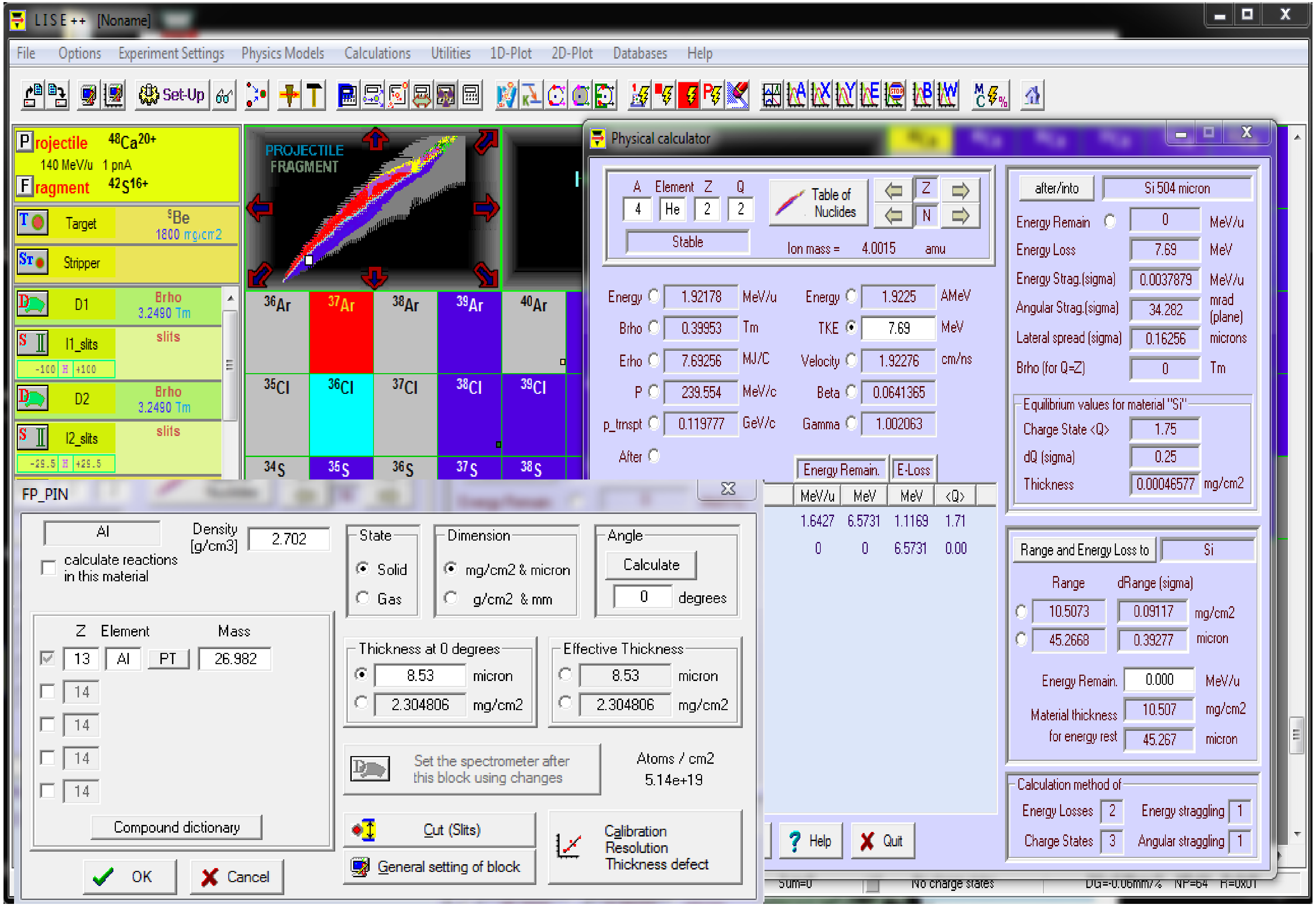
S= L*H= 225,42 cm^2

D= M/S= 2,345 mg/cm^2

ρ= 2698,4 mg/cm^3

D/ρ= 8,69 µm

Measurement of thickness of Al-foil (d)



Projectile $^{48}Ca^{20+}$ 140 MeV/u 1 pnA

Fragment $^{42}S^{16+}$

Target ^{9}Be 1800 mg/cm2

Stripper

D1 Brho 3.2490 Tm

I1_slits: slits -100 H +100

D2 Brho 3.2490 Tm

I2_slits: slits -29.5 H +29.5

Physical calculator

A: 4 Element: He Z: 2 Q: 2 Stable

Table of Nuclides

Ion mass = 4.0015 amu

Energy ○	1.92178	MeV/u	Energy ○	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_trnspt ○	0.119777	GeV/c	Gamma ○	1.002063	
After ○					

Energy Remain. E-Loss

MeV/u	MeV	MeV	<Q>
1.6427	6.5731	1.1169	1.71
0	0	6.5731	0.00

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 for energy rest: 10.507 mg/cm2, 45.267 micron

Calculation method of

- Energy Losses: 2
- Energy straggling: 1
- Charge States: 3
- Angular straggling: 1

Help Quit

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

	Z	Element		Mass
☑	13	Al	PT	26.982
☐	14			
☐	14			
☐	14			
☐	14			

Compound dictionary

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)

General setting of block

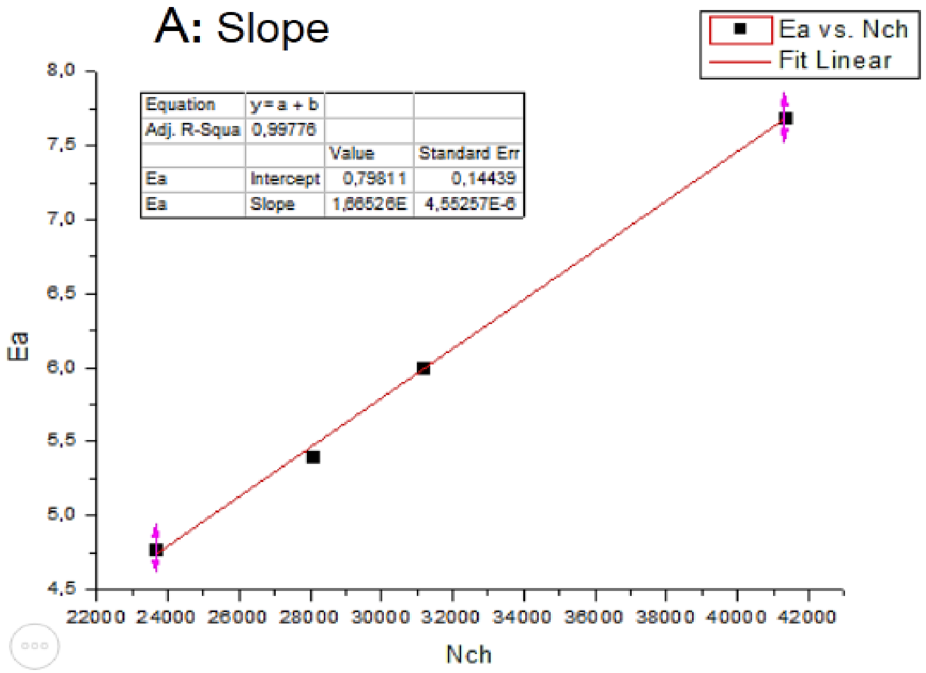
Calibration Resolution Thickness defect

OK Cancel

Sum=0 No charge states DG=0.06mm/% NP=64 H=0x01

Nuclear way Measurement of thickness of Al-foil (d)

Eα	N_{ch}	N_{ch} Foil	$(N_{ch}-N_{ch}\ \text{Foil})*A$[1]	d(µm)[2]	error	weighting(µm)
4,78	2,365E+004	1,354E+004	1,66777593	8,75		
5,49	2,805E+004	1,915E+004	1,4681707	8,52		
6,00	3,115E+004	2,283E+004	1,37249216	8,75		
7,69	4,132E+004	3,456E+004	1,11514988	8,53		
				8,63	**± 0,13**	**8.69**



Equation	y = a + b		
Adj. R-Squa	0,99776		
		Value	Standard Err
Ea	Intercept	0,79811	0,14439
Ea	Slope	1,66526E	4,55257E-6

---

[1] Origin 8 Software

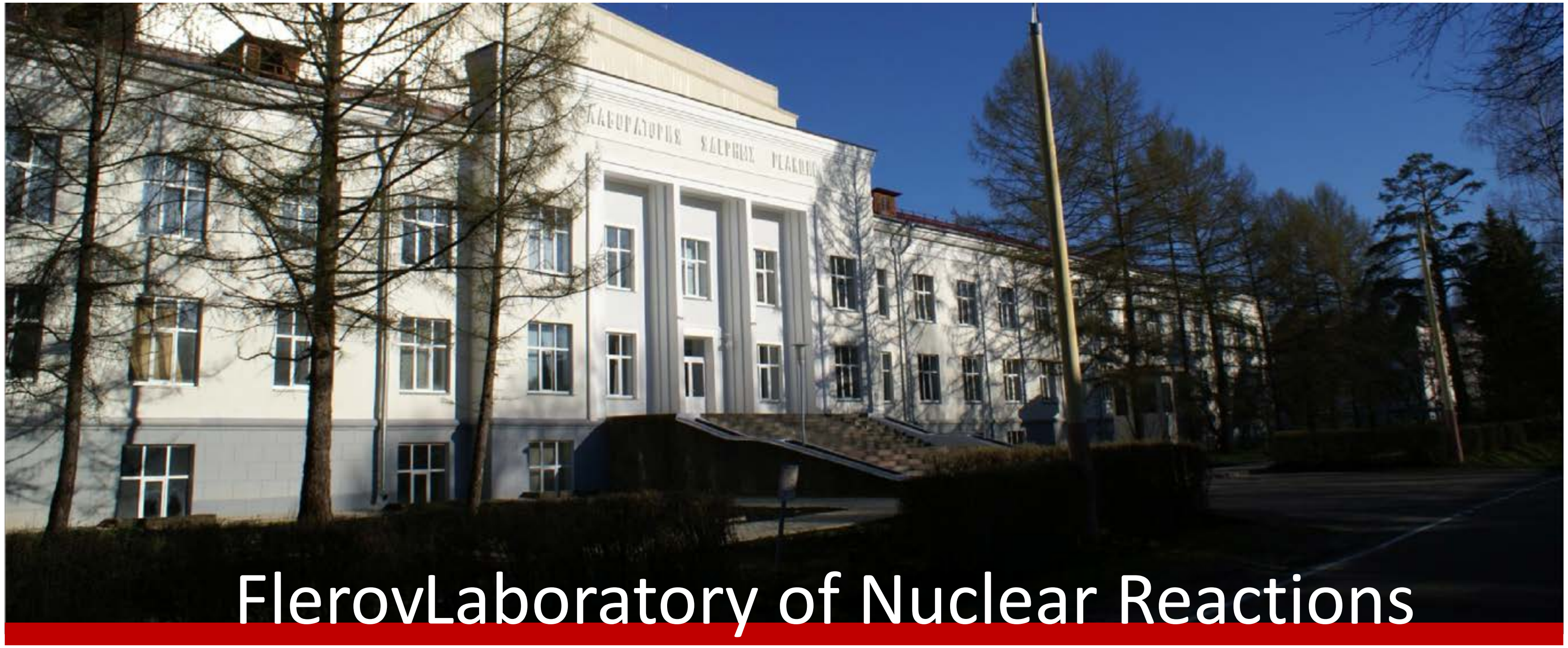
[2] Lise++ Software

Calculations of error

$$\left(\frac{\delta x}{x}\right) = \sqrt{\sigma^2 + \left(\frac{\Delta E}{E}\right)^2}$$

$$\sigma = \sqrt{\frac{(d_1 - \bar{d})^2 + (d_2 - \bar{d})^2 + (d_3 - \bar{d})^2 + (d_4 - \bar{d})^2}{4}}$$

$$\bar{d} = \frac{d_1 + d_2 + d_3 + d_4}{4}$$


FlerovLaboratory of Nuclear Reactions

THANK YOU FOR YOUR ATTENTION.