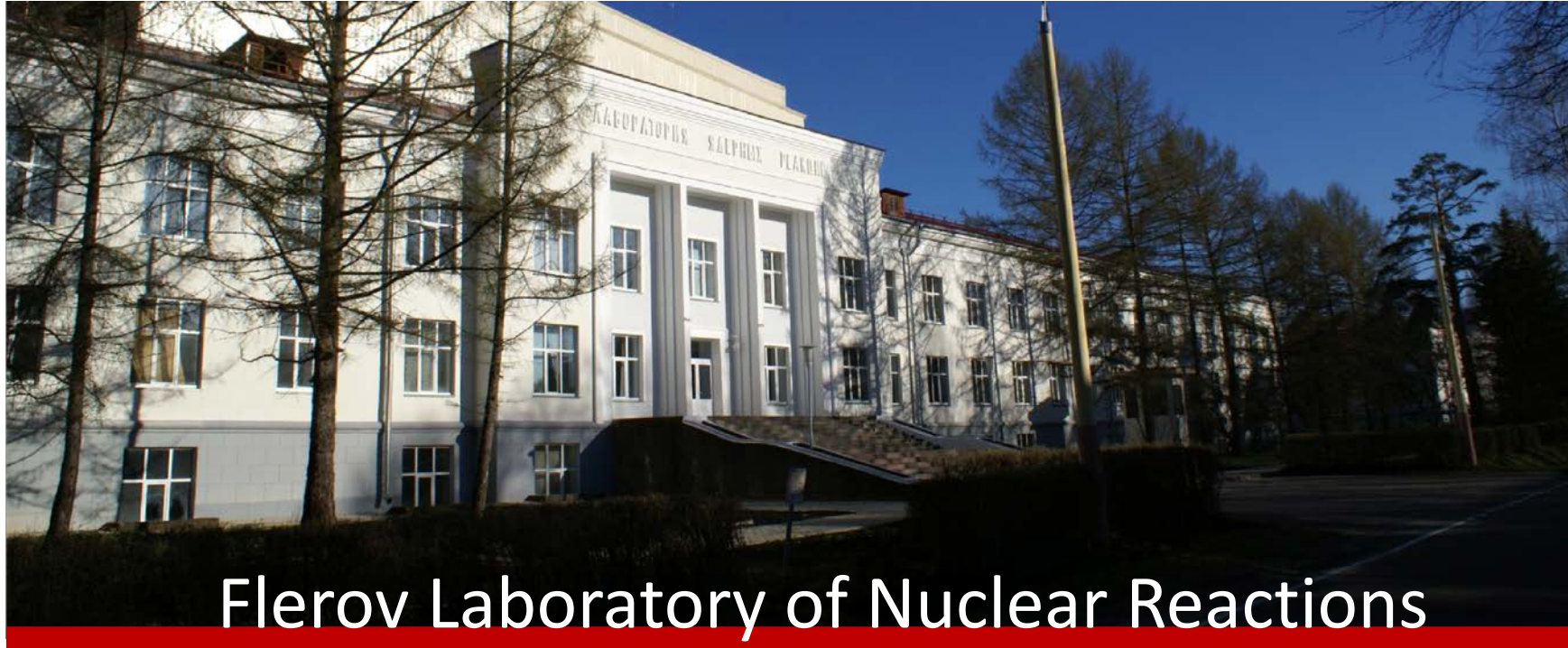


# STAGE 3 INTERNATIONAL STUDENT PRACTICE 2018



The Joint Institute for Nuclear Research in Dubna



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

## PROJECT TITLE

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

## SPEAKERS

Maysoun Mourad Egypt

Madian Pino Peraza – Cuba



## SUPERVISORS

S. Lukyanov

K. Mendibayev

T. Issatayev

# Introduction

## 3 Types of semiconductor detectors



**1. X-ray Ge(Li) detector**



**3. Si Alpha spectroscopy detector**

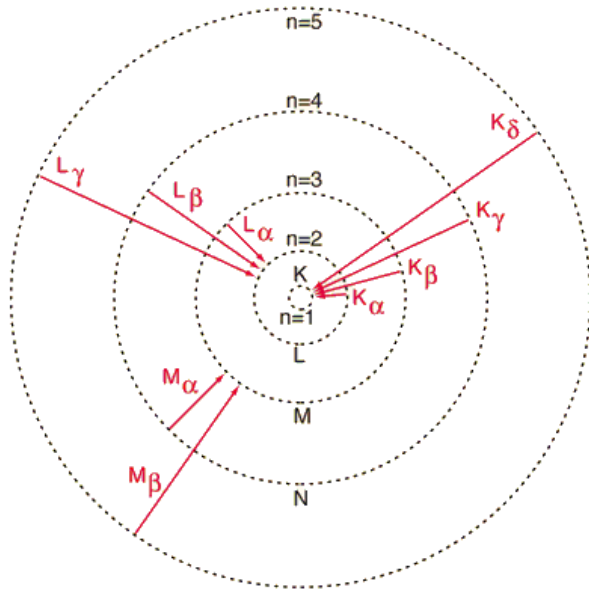


**2. Ge(Li) Gamma detector**

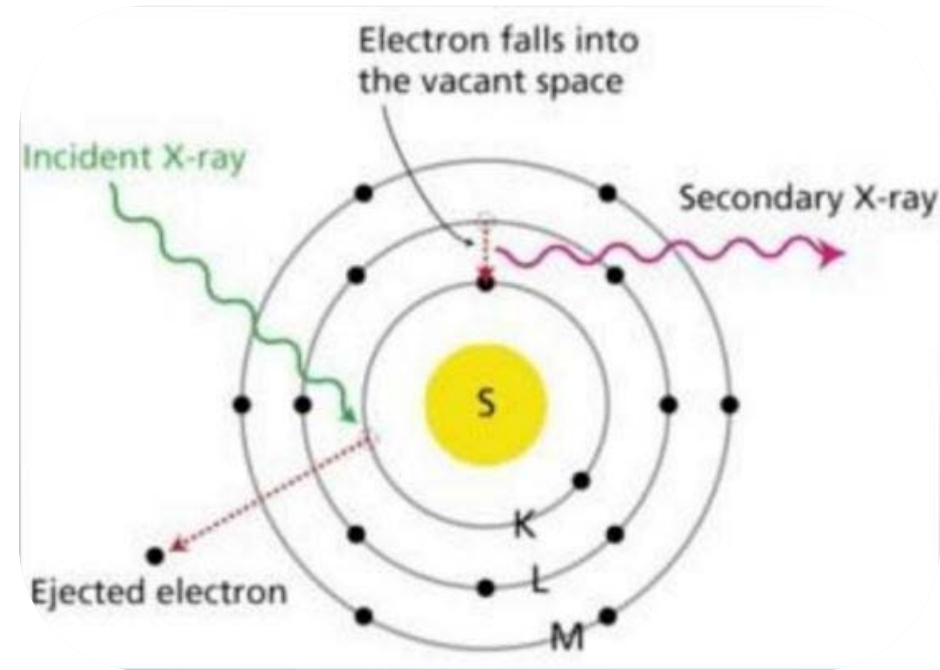


# X-rays

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.



X-ray transitions



# History of Moseley's Law



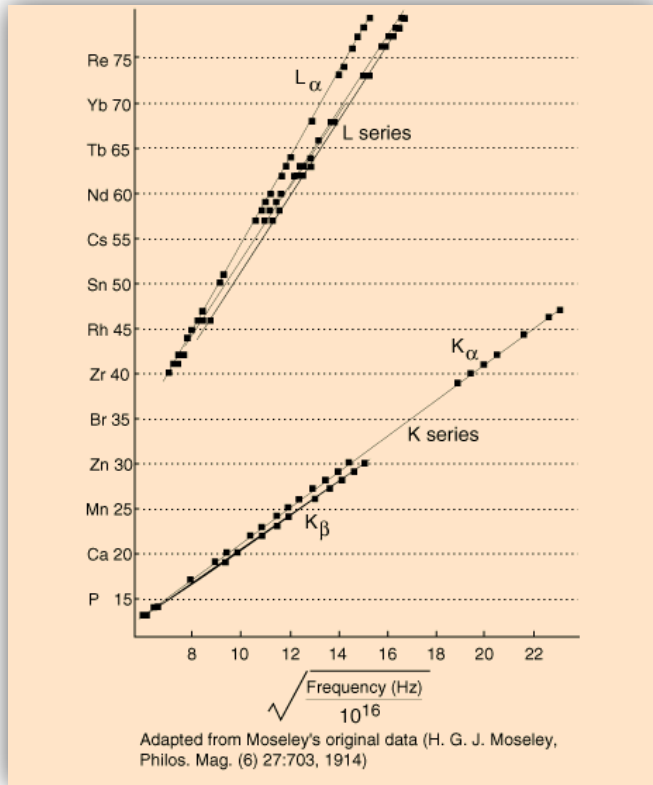
Henry G.J. Moseley's  
1887 - 1915

- 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.



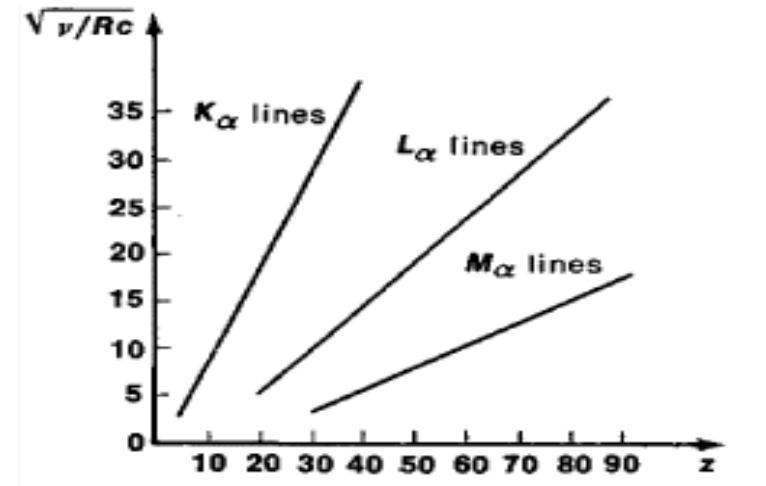
# Moseley Plot of characteristic X-rays

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



$$\sqrt{f} = a(Z - b)$$

$\sqrt{f}$  is proportional to  $Z$  a particular line (say,  $K_{\alpha}$ -line)



Moseley plot of characteristic X-rays



# 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.

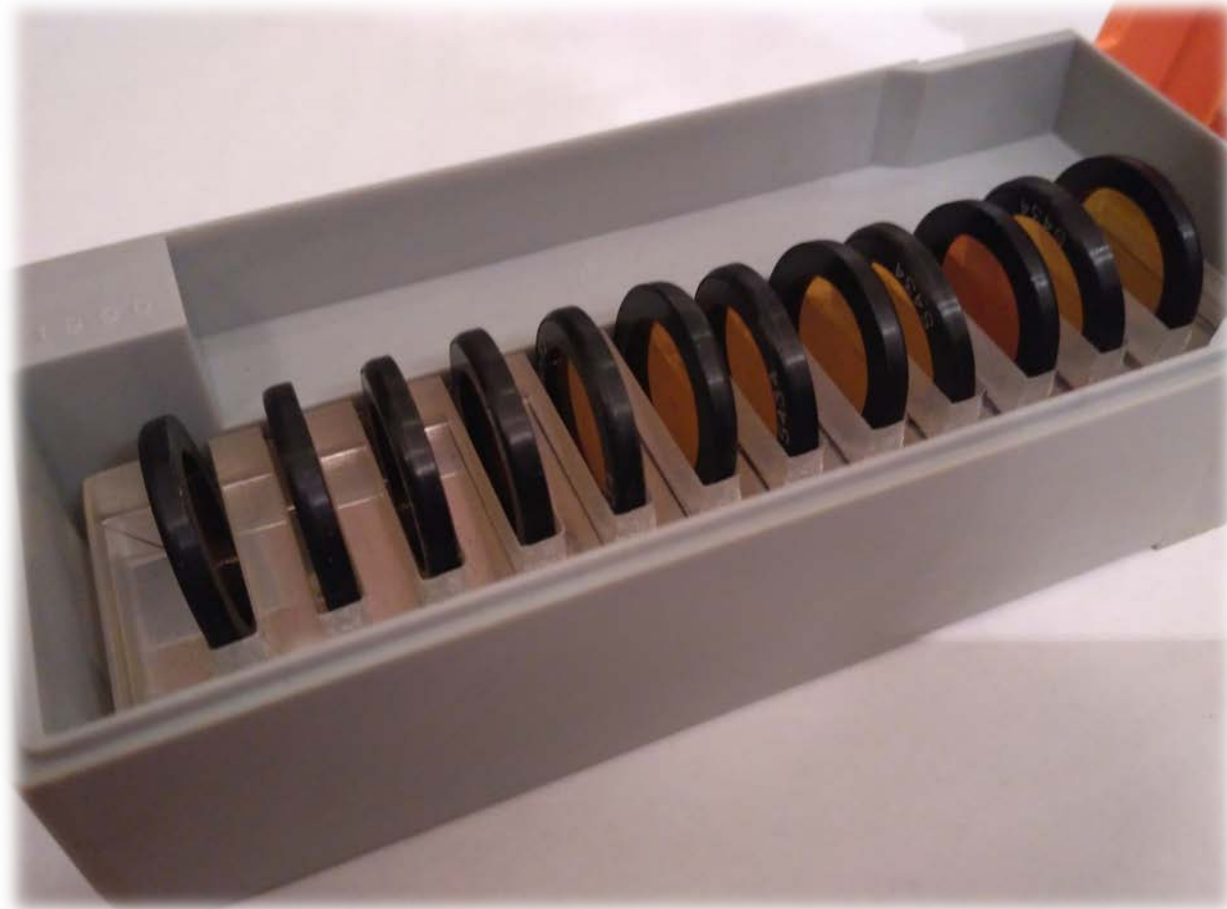


# General view of the X-ray spectrometer





# Source



# 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.
4. Find a Z number of an unknown source.



# Moseley Law in action

Element Z (Atomic No.)	Energy (keV) K( $\alpha$ )	Energy (keV) K( $\beta$ )
Y 39	14.1	15.8
Cd 48	22.0	24.9
Sn 50	24.2	27.2
Ce 58	33.4	37.8
Eu 63	40.1	45.4

Table 1: Energies of K ( $\alpha$ ) and K ( $\beta$ ) transitions in keV and elements listed with increasing atomic number obtained from nuclear data.

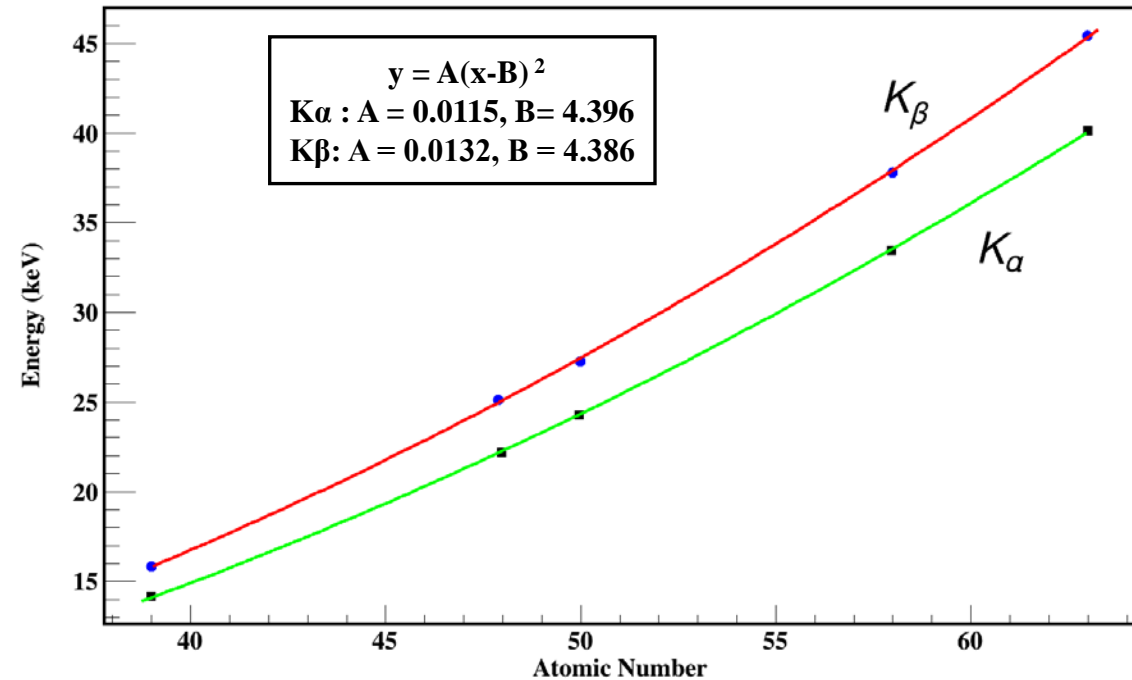
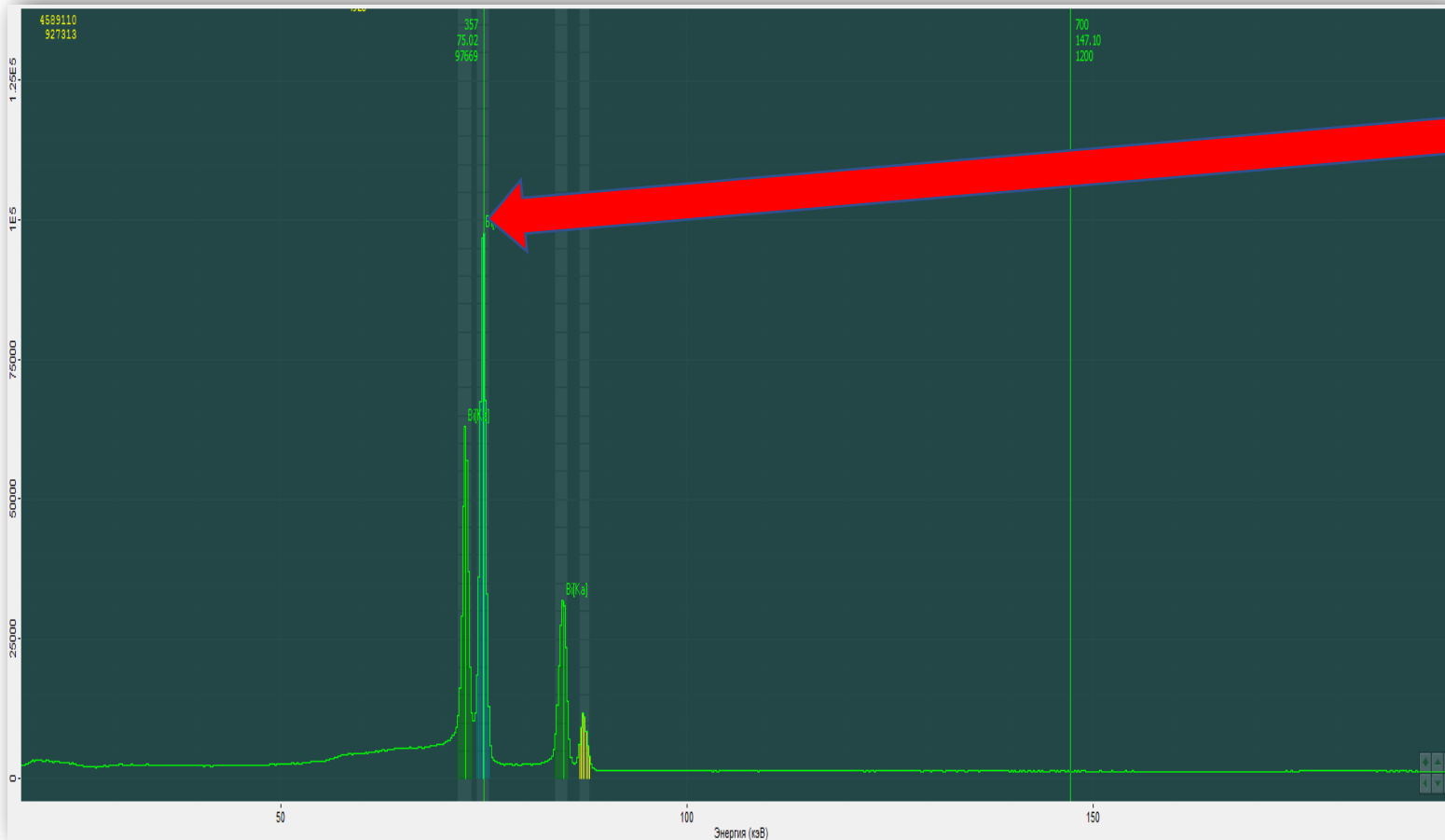


Figure 4: K ( $\alpha$ ) and K ( $\beta$ ) lines fit to Moseley's Law. We confirm the functional form of the law but different values for the constants ( $a$  &  $b$ ).



# Spectra from X-ray detector of unknown source



## Calculation and results.

$E = 74.956 \text{ keV}$   
 A & B = constants obtained from  $K\alpha$   
 Moseley's plot.

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

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

$$= \frac{\sqrt{74.956}}{0.0115} + 4.0137$$

$$= 83.66$$

Nuclear data:  $Z = 83$   
 Element is Bi



# Ge(Li) semiconductor detector

## ➤ Germanium detector

is a solid state detector with P-n junction structure

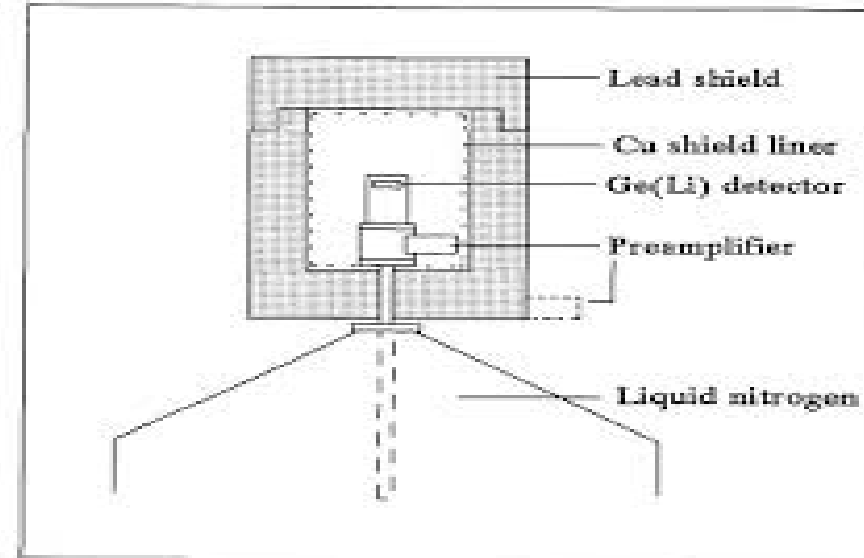
In which the built in area is sensitive to ionizing radiation.

## ➤ It consists of:

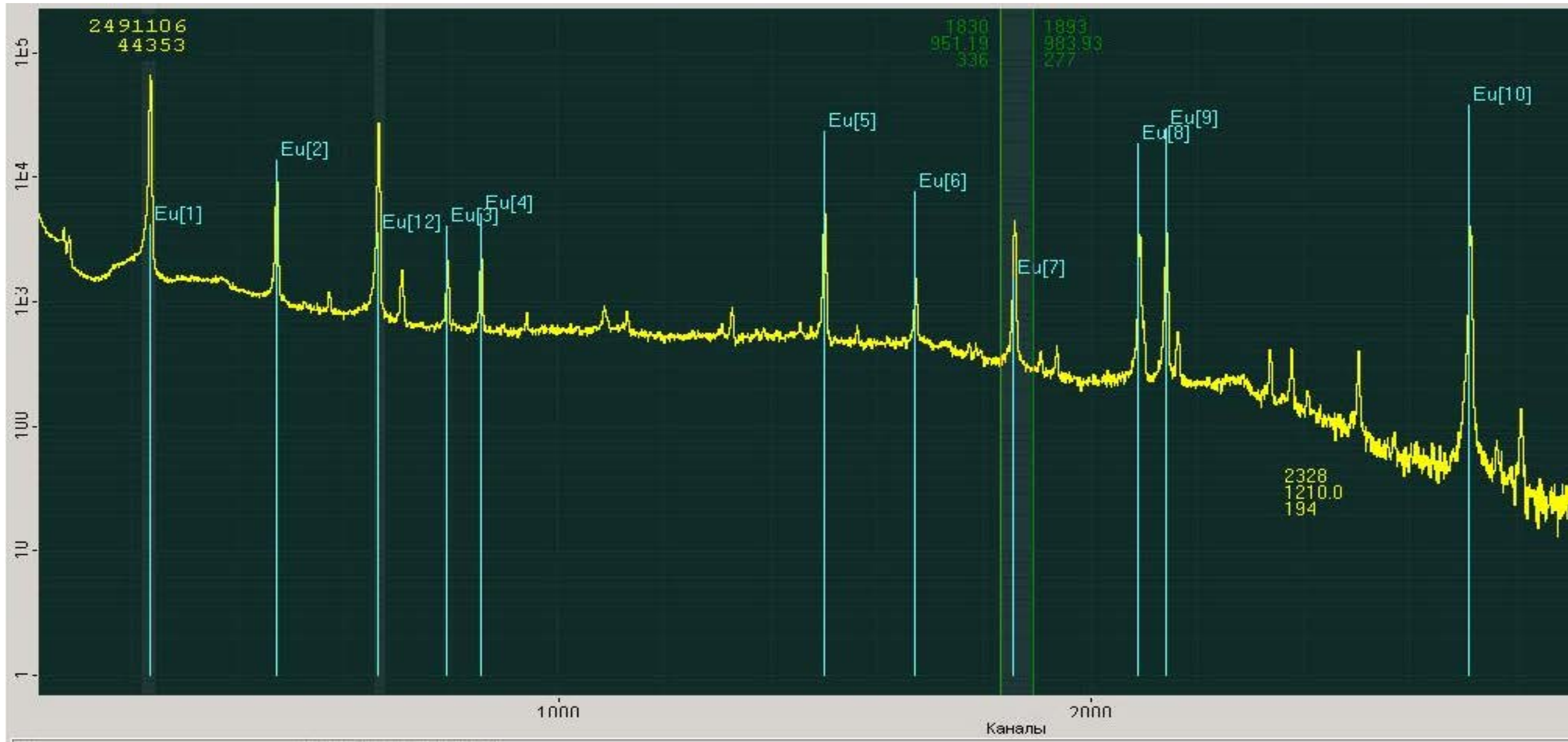
Semiconductor detector crystal.

Pre amplifier unit.

Data spectra analyzing system.



# Gamma spectra calibration



# Use of Nuclear Data Search

## The Lund/LBNL Nuclear Data Search

Version 2.0, February 1999

S.Y.F. Chu<sup>1</sup>, L.P. Ekström<sup>1,2</sup> and R.B. Firestone<sup>1</sup>

<sup>1</sup> LBNL, Berkeley, USA

<sup>2</sup> 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:  -

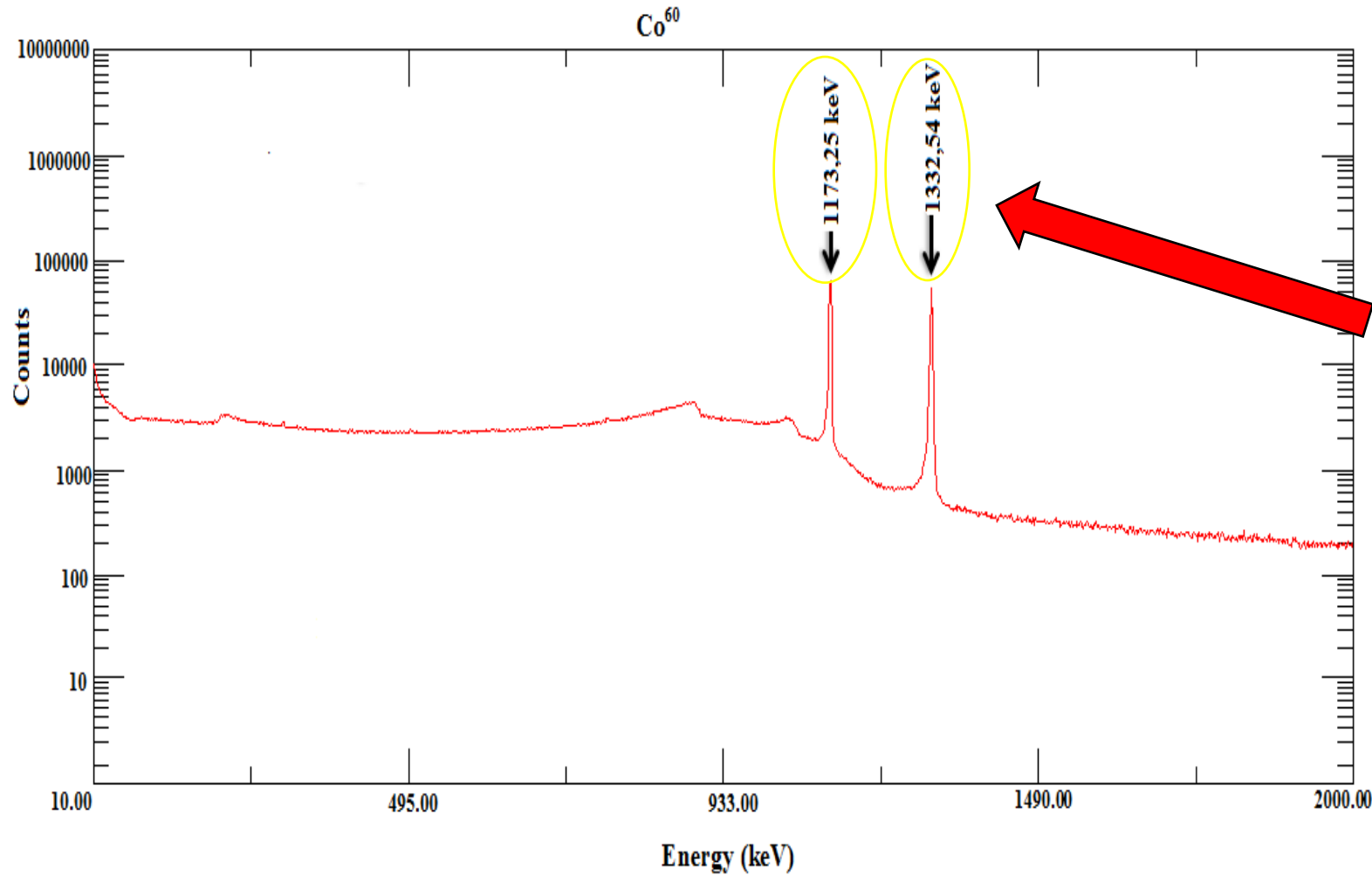
Z:  or Element:

N:

Sort by:  Energy, Intensity  A, Z

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

# Gamma spectra of unknown source



WWW Table of Radioactive Isotopes

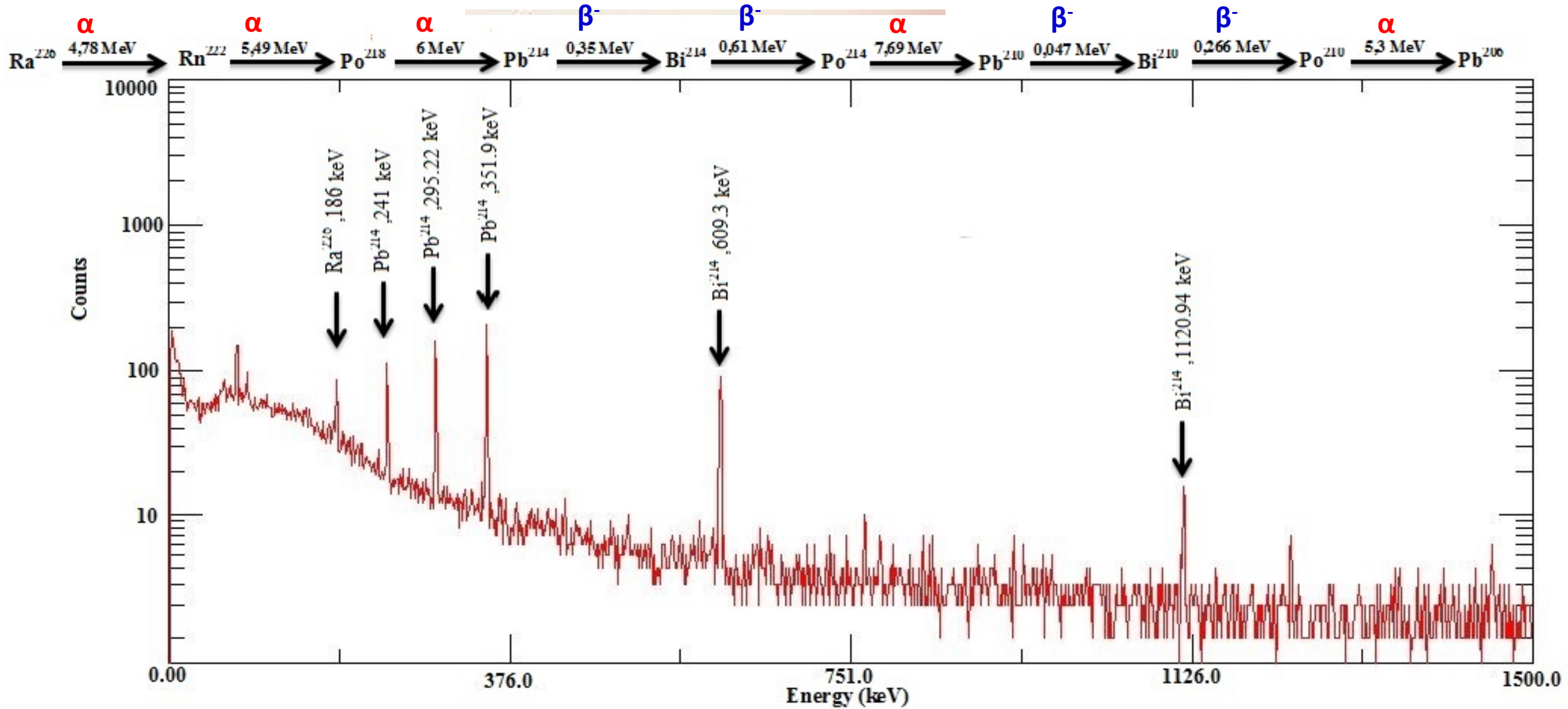
Gamma energy search

A=60;

E <sub>g</sub> (keV)	I <sub>g</sub> (%)	Decay mode	Half life	Parent
58.603 7	2.0	IT	10.467 m δ	<u><a href="#">60mCo</a></u>
346.93 7	0.0076 5	b <sup>-</sup>	5.2714 y 5	<u><a href="#">60Co</a></u>
826.06 3	0.0076 8	b <sup>-</sup>	5.2714 y 5	<u><a href="#">60Co</a></u>
826.06 3	~0.008	b <sup>-</sup>	10.467 m δ	<u><a href="#">60mCo</a></u>
1173.237 4	99.9736 7	b <sup>-</sup>	5.2714 y 5	<u><a href="#">60Co</a></u>
1332.501 5	0.24	b <sup>-</sup>	10.467 m δ	<u><a href="#">60mCo</a></u>
1332.501 5	99.9856 4	b <sup>-</sup>	5.2714 y 5	<u><a href="#">60Co</a></u>
2158.57 10	~0.0007	b <sup>-</sup>	10.467 m δ	<u><a href="#">60mCo</a></u>
2158.57 10	0.00111 18	b <sup>-</sup>	5.2714 y 5	<u><a href="#">60Co</a></u>
2505	2.0E-6 4	b <sup>-</sup>	5.2714 y 5	<u><a href="#">60Co</a></u>



# Disintegration chain of $^{226}\text{Ra}$



0 Us	<b>Pa221</b> 5.9 Us 9/2- $\alpha$	<b>Pa222</b> 2.9 ms $\alpha$	<b>Pa223</b> 6.5 ms EC, $\alpha$	<b>Pa224</b> 0.79 s $\alpha$	<b>Pa225</b> 1.7 s $\alpha$	<b>Pa226</b> 1.8 m EC, $\alpha$	<b>Pa227</b> 38.3 m (5/2-) EC, $\alpha$	<b>Pa228</b> 22 h 3+ EC, $\alpha$	<b>Pa229</b> 1.50 d (5/2+) EC, $\alpha$	<b>Pa230</b> 17.4 d (2-) EC, $\beta$ , $\alpha$ ,...	<b>Pa231</b> 32760 y 3/2- $\alpha$ , $\beta$	<b>Pa232</b> 131 d (2-) EC, $\beta$ -	<b>Pa233</b> 26.967 d 3/2- $\beta$ -	<b>Pa234</b> 6.70 h 4+ $\beta$ , $\alpha$ *	<b>Pa235</b> 24.5 m (3/2-) $\beta$ -	<b>Pa236</b> 9.1 m 1(-) $\beta$ -	<b>Pa237</b> 8.7 m (1/2+) $\beta$ -	
9 Us	<b>Th220</b> 9.7 Us 0+ EC, $\alpha$	<b>Th221</b> 1.68 ms (7/2+) $\alpha$	<b>Th222</b> 2.8 ms 0+ $\alpha$	<b>Th223</b> 0.60 s (5/2)+ $\alpha$	<b>Th224</b> 1.05 s 0+ $\alpha$	<b>Th225</b> 8.72 m (3/2)+ EC, $\alpha$	<b>Th226</b> 30.57 m 0+ $\alpha$	<b>Th227</b> 18.72 d (1/2+) $\alpha$	<b>Th228</b> 1.9116 y 0+ $\alpha$	<b>Th229</b> 7340 y 5/2+ $\alpha$	<b>Th230</b> 7.538E+4 y 0+ $\alpha$ , $\beta$	<b>Th231</b> 25.52 h 5/2+ $\beta$ , $\alpha$	<b>Th232</b> 1.405E10 y 0+ $\alpha$ , $\beta$ 100	<b>Th233</b> 22.3 m 1/2+ $\beta$ -	<b>Th234</b> 24.10 d 0+ $\beta$ -	<b>Th235</b> 7.1 m (1/2+) $\beta$ -	<b>Th236</b> 37.5 m 0+ $\beta$ -	
8 Us	<b>Ac219</b> 11.8 Us 9/2- EC, $\alpha$	<b>Ac220</b> 26.4 ms (3-) $\alpha$	<b>Ac221</b> 52 ms (3/2-) $\alpha$	<b>Ac222</b> 5.0 s 1- EC, $\alpha$ *	<b>Ac223</b> 2.10 m (5/2-) EC, $\alpha$	<b>Ac224</b> 2.78 h 0- EC, $\beta$ , $\alpha$ ,...	<b>Ac225</b> 10.0 d (3/2-) $\alpha$ , <sup>14</sup> C	<b>Ac226</b> 29.37 h (1) EC, $\beta$ , $\alpha$ ,...	<b>Ac227</b> 21.773 y 3/2- $\beta$ , $\alpha$	<b>Ac228</b> 6.15 h 3+ $\beta$ -	<b>Ac229</b> 62.7 m (3/2+) $\beta$ -	<b>Ac230</b> 122 s (1+) $\beta$ -	<b>Ac231</b> 7.5 m (1/2+) $\beta$ -	<b>Ac232</b> 119 s (1+) $\beta$ -	<b>Ac233</b> 145 s (1/2+) $\beta$ -	<b>Ac234</b> 44 s $\beta$ -	<b>Ac235</b>	
7 Us	<b>Ra218</b> 25.6 Us 0+ $\alpha$	<b>Ra219</b> 10 ms (7/2)+ $\alpha$	<b>Ra220</b> 18 ms 0+ $\alpha$	<b>Ra221</b> 28 s 5/2+ $\alpha$	<b>Ra222</b> 38.0 s 0+ $\alpha$ , <sup>14</sup> C	<b>Ra223</b> 11.435 d 3/2+ $\alpha$ , <sup>14</sup> C	<b>Ra224</b> 3.66 d 0+ $\alpha$ , <sup>14</sup> C	<b>Ra225</b> 14.9 d 1/2+ $\beta$ -	<b>Ra226</b> 1600 y 0+ $\alpha$ , <sup>14</sup> C	<b>Ra227</b> 42.2 m 3/2+ $\beta$ -	<b>Ra228</b> 5.75 y 0+ $\beta$ -	<b>Ra229</b> 4.0 m 5/2(+) $\beta$ -	<b>Ra230</b> 93 m 0+ $\beta$ -	<b>Ra231</b> 103 s (7/2-,1/2+) $\beta$ -	<b>Ra232</b> 250 s 0+ $\beta$ -	<b>Ra233</b> 30 s $\beta$ -	<b>Ra234</b> 30 s 0+ $\beta$ -	
6 Us	<b>Fr217</b> 22 Us 9/2- $\alpha$	<b>Fr218</b> 1.0 ms 1- $\alpha$ *	<b>Fr219</b> 20 ms 9/2- $\alpha$	<b>Fr220</b> 27.4 s 1+ $\beta$ , $\alpha$	<b>Fr221</b> 4.9 m 5/2- $\alpha$	<b>Fr222</b> 14.2 m 2- $\beta$ -	<b>Fr223</b> 21.8 m 3/2(-) $\beta$ , $\alpha$	<b>Fr224</b> 3.33 m 1- $\beta$ -	<b>Fr225</b> 4.0 m 3/2- $\beta$ -	<b>Fr226</b> 49 s 1- $\beta$ -	<b>Fr227</b> 2.47 m 1/2+ $\beta$ -	<b>Fr228</b> 38 s 2- $\beta$ -	<b>Fr229</b> 50 s $\beta$ -	<b>Fr230</b> 19.1 s $\beta$ -	<b>Fr231</b> 17.5 s $\beta$ -	<b>Fr232</b> 5 s $\beta$ -		
5 Us	<b>Rn216</b> 45 Us 0+ $\alpha$	<b>Rn217</b> 0.54 ms 9/2+ $\alpha$	<b>Rn218</b> 35 ms 0+ $\alpha$	<b>Rn219</b> 3.96 s 5/2+ $\alpha$	<b>Rn220</b> 55.6 s 0+ $\alpha$	<b>Rn221</b> 25 m 7/2(+) $\beta$ , $\alpha$	<b>Rn222</b> 3.8235 d 0+ $\alpha$	<b>Rn223</b> 23.2 m 7/2 $\beta$ , $\alpha$	<b>Rn224</b> 107 m 0+ $\beta$ -	<b>Rn225</b> 4.5 m 7/2- $\beta$ -	<b>Rn226</b> 7.4 m 0+ $\beta$ -	<b>Rn227</b> 22.5 s $\beta$ -	<b>Rn228</b> 65 s 0+ $\beta$ -					
4 Us	<b>At215</b> 0.10 ms 9/2- $\alpha$	<b>At216</b> 0.30 ms 1- EC, $\beta$ , $\alpha$ ,...	<b>At217</b> 32.3 ms 9/2- $\beta$ , $\alpha$	<b>At218</b> 1.5 s $\beta$ , $\alpha$	<b>At219</b> 56 s $\beta$ , $\alpha$	<b>At220</b> 3.71 m $\beta$ , $\alpha$	<b>At221</b> 2.3 m $\beta$ -	<b>At222</b> 54 s $\beta$ -	<b>At223</b> 50 s $\beta$ , $\alpha$									
3 Us	<b>Po214</b> 164.3 Us 0+ $\alpha$	<b>Po215</b> 1.781 ms 9/2+ $\beta$ , $\alpha$	<b>Po216</b> 0.145 s 0+ $\alpha$	<b>Po217</b> 10 s $\beta$ , $\alpha$	<b>Po218</b> 3.10 m 0+ $\beta$ , $\alpha$													
2 m	<b>Pb211</b> 36.1 m 9/2+ $\beta$ -	<b>Pb212</b> 10.64 h 0+ $\beta$ -	<b>Pb213</b> 10.2 m (9/2+) $\beta$ -	<b>Pb214</b> 26.8 m 0+ $\beta$ -														

146

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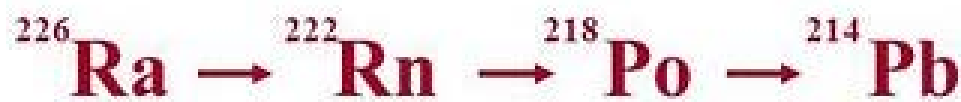
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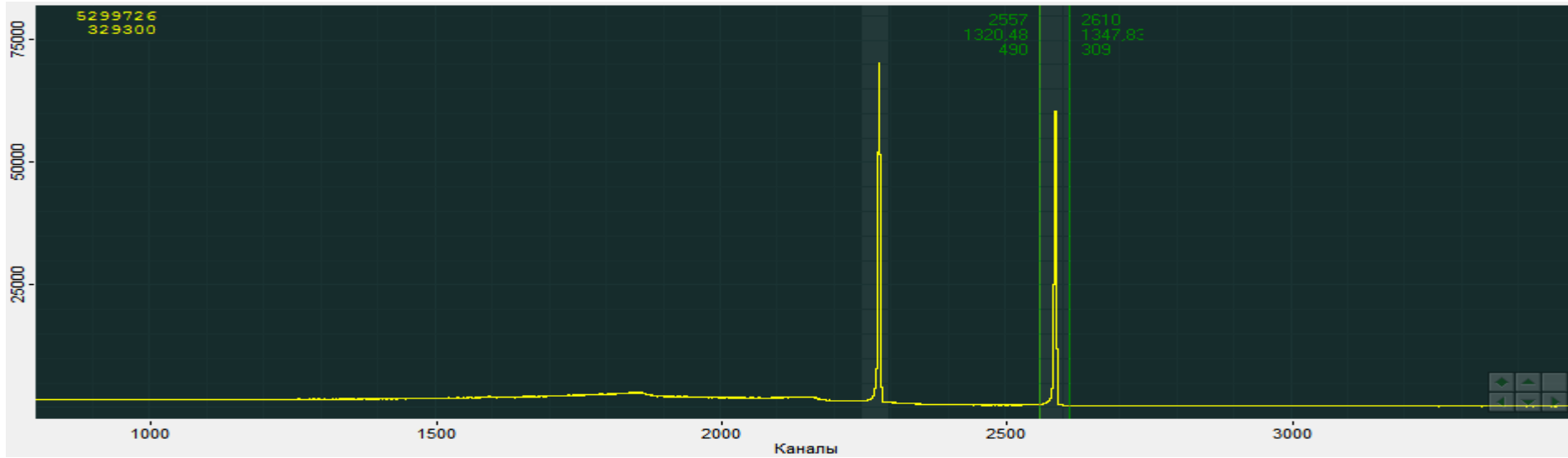
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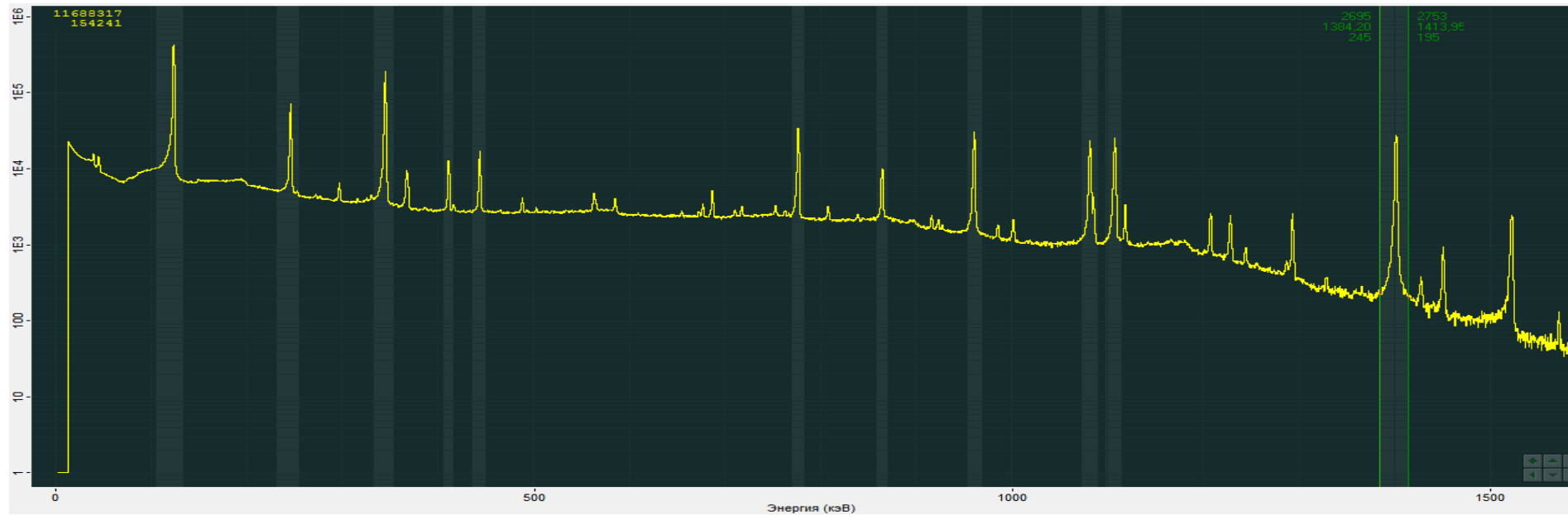
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# Determination of the efficiency



$^{60}\text{Co}$  spectra



$^{152}\text{Eu}$  spectra

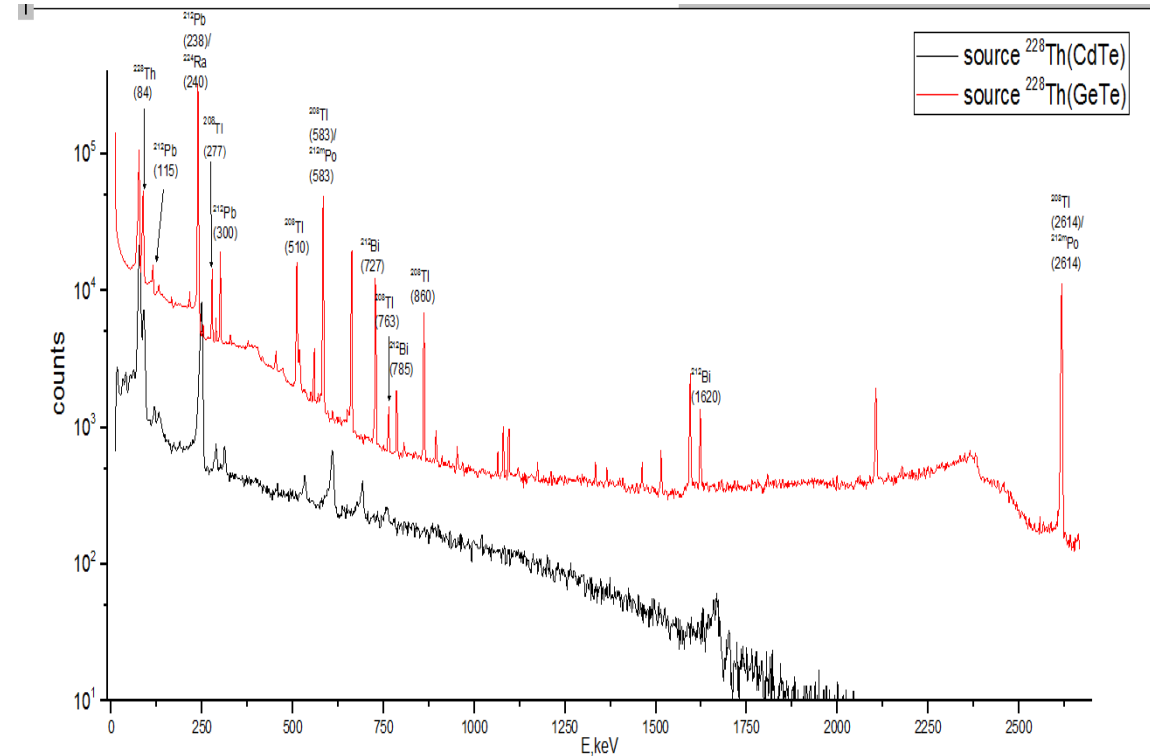
Now we calculate the absolute efficiency and internal efficiency by using these equations

	$\Sigma = N_{\text{det}} / N_{\text{em}}$ absolute	$\Sigma = N_{\text{det}} / N_{\text{fl}}$ internal
For Co-60	22.30%	53.4%
For Ba-133	20.8%	49.86%



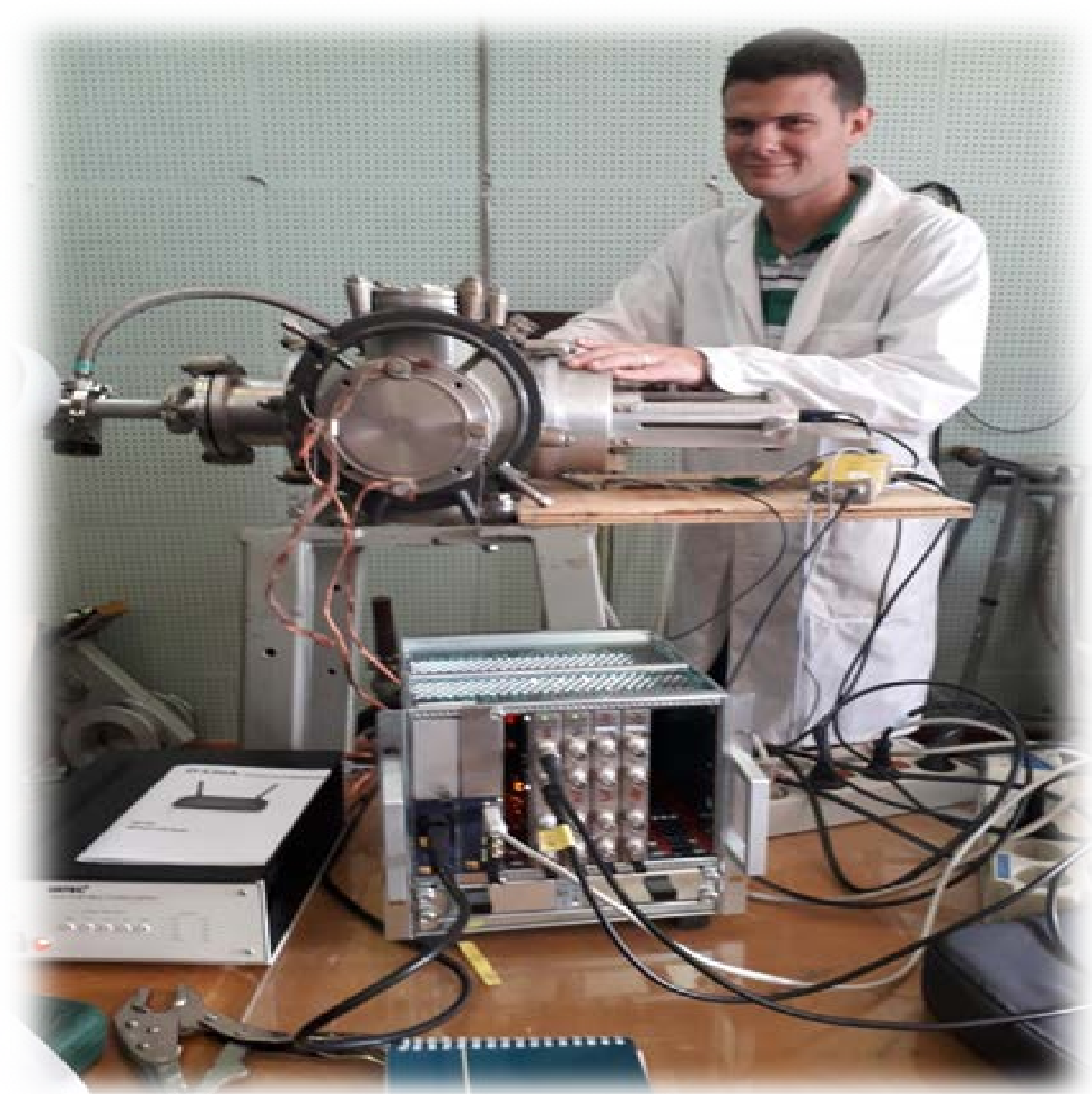
# Comparison of detectors

	Ge(Li)detector	CdZn(Te)detector
<b>Size</b>	Huge	Very compact
<b>Cooling System</b>	Need	No Need
<b>Efficiency</b>	More	Lower
<b>Resolution</b>	More	Lower



Resolution and efficiency comparison





***ALPHA  
SPECTROMETRY  
WITH Si  
DETECTOR***

Pa221 5.9 Us 9/2- $\alpha$	Pa222 2.9 ms $\alpha$	Pa223 6.5 ms EC, $\alpha$	Pa224 0.79 s $\alpha$	Pa225 1.7 s $\alpha$	Pa226 1.8 m EC, $\alpha$	Pa227 38.3 m (5/2-) EC, $\alpha$	Pa228 22 h 3+ EC, $\alpha$	Pa229 1.50 d (5/2+) EC, $\alpha$	Pa230 17.4 d (2-) EC, $\beta$ , $\alpha$ ,...	Pa231 32760 y 3/2- $\alpha$ , $\beta$	Pa232 131 d (2-) EC, $\beta$ -	Pa233 26.967 d 3/2- $\beta$ -	Pa234 6.70 h 4+ $\beta$ , $\alpha$ *	Pa235 24.5 m (3/2-) $\beta$ -	Pa236 9.1 m 1(-) $\beta$ -	Pa237 8.7 m (1/2+) $\beta$ -
Th220 9.7 Us 0+ EC, $\alpha$	Th221 1.68 ms (7/2+) $\alpha$	Th222 2.8 ms 0+ $\alpha$	Th223 0.60 s (5/2+) $\alpha$	Th224 1.05 s 0+ $\alpha$	Th225 8.72 m (3/2+) EC, $\alpha$	Th226 30.57 m 0+ $\alpha$	Th227 18.72 d (1/2+) $\alpha$	Th228 1.9116 y 0+ $\alpha$	Th229 7340 y 5/2+ $\alpha$	Th230 7.538E+4 y 0+ $\alpha$ , $\beta$	Th231 25.52 h 5/2+ $\beta$ , $\alpha$	Th232 1.405E10 y 0+ $\alpha$ , $\beta$ 100	Th233 22.3 m 1/2+ $\beta$ -	Th234 24.10 d 0+ $\beta$ -	Th235 7.1 m (1/2+) $\beta$ -	Th236 37.5 m 0+ $\beta$ -
Ac219 11.8 Us 9/2- EC, $\alpha$	Ac220 26.4 ms (3-) $\alpha$	Ac221 52 ms (3/2-) $\alpha$	Ac222 5.0 s 1- EC, $\alpha$ *	Ac223 2.10 m (5/2-) EC, $\alpha$	Ac224 2.78 h 0- EC, $\beta$ , $\alpha$ ,...	Ac225 10.0 d (3/2-) $\alpha$ , <sup>14</sup> C	Ac226 29.37 h (1) EC, $\beta$ , $\alpha$ ,...	Ac227 21.773 y 3/2- $\beta$ , $\alpha$	Ac228 6.15 h 3+ $\beta$ -	Ac229 62.7 m (3/2+) $\beta$ -	Ac230 122 s (1+) $\beta$ -	Ac231 7.5 m (1/2+) $\beta$ -	Ac232 119 s (1+) $\beta$ -	Ac233 145 s (1/2+) $\beta$ -	Ac234 44 s $\beta$ -	Ac235 $\beta$ -
Ra218 25.6 Us 0+ $\alpha$	Ra219 10 ms (7/2+) $\alpha$	Ra220 18 ms 0+ $\alpha$	Ra221 28 s 5/2+ $\alpha$	Ra222 38.0 s 0+ $\alpha$ , <sup>14</sup> C	Ra223 11.435 d 3/2+ $\alpha$ , <sup>14</sup> C	Ra224 3.66 d 0+ $\alpha$ , <sup>14</sup> C	Ra225 14.9 d 1/2+ $\beta$ -	Ra226 1600 y 0+ $\alpha$ , <sup>14</sup> C	Ra227 42.2 m 3/2+ $\beta$ -	Ra228 5.75 y 0+ $\beta$ -	Ra229 4.0 m 5/2(+) $\beta$ -	Ra230 93 m 0+ $\beta$ -	Ra231 103 s (7/2-,1/2+) $\beta$ -	Ra232 250 s 0+ $\beta$ -	Ra233 30 s $\beta$ -	Ra234 30 s 0+ $\beta$ -
Fr217 22 Us 9/2- $\alpha$	Fr218 1.0 ms 1- $\alpha$ *	Fr219 20 ms 9/2- $\alpha$	Fr220 27.4 s 1+ $\beta$ , $\alpha$	Fr221 4.9 m 5/2- $\alpha$	Fr222 14.2 m 2- $\beta$ -	Fr223 21.8 m 3/2(-) $\beta$ , $\alpha$	Fr224 3.33 m 1- $\beta$ -	Fr225 4.0 m 3/2- $\beta$ -	Fr226 49 s 1- $\beta$ -	Fr227 2.47 m 1/2+ $\beta$ -	Fr228 38 s 2- $\beta$ -	Fr229 50 s $\beta$ -	Fr230 19.1 s $\beta$ -	Fr231 17.5 s $\beta$ -	Fr232 5 s $\beta$ -	
Rn216 45 Us 0+ $\alpha$	Rn217 0.54 ms 9/2+ $\alpha$	Rn218 35 ms 0+ $\alpha$	Rn219 3.96 s 5/2+ $\alpha$	Rn220 55.6 s 0+ $\alpha$	Rn221 25 m 7/2(+) $\beta$ , $\alpha$	Rn222 3.8235 d 0+ $\alpha$	Rn223 23.2 m 7/2 $\beta$ , $\alpha$	Rn224 107 m 0+ $\beta$ -	Rn225 4.5 m 7/2- $\beta$ -	Rn226 7.4 m 0+ $\beta$ -	Rn227 22.5 s $\beta$ -	Rn228 65 s 0+ $\beta$ -				
At215 0.10 ms 9/2- $\alpha$	At216 0.30 ms 1- EC, $\beta$ , $\alpha$ ,...	At217 32.3 ms 9/2- $\beta$ , $\alpha$	At218 1.5 s $\beta$ , $\alpha$	At219 56 s $\beta$ , $\alpha$	At220 3.71 m $\beta$ , $\alpha$	At221 2.3 m $\beta$ -	At222 54 s $\beta$ -	At223 50 s $\beta$ , $\alpha$								
Po214 164.3 Us 0+ $\alpha$	Po215 1.781 ms 9/2+ $\beta$ , $\alpha$	Po216 0.145 s 0+ $\alpha$	Po217 10 s $\beta$ , $\alpha$	Po218 3.10 m 0+ $\beta$ , $\alpha$												
Bi213 45.59 m 9/2- $\beta$ , $\alpha$	Bi214 19.9 m 1- $\beta$ , $\alpha$	Bi215 7.6 m $\beta$ -	Bi216 3.6 m (1-) $\beta$ -													
Pb211 36.1 m 9/2+ $\beta$ -	Pb212 10.64 h 0+ $\beta$ -	Pb213 10.2 m (9/2+) $\beta$ -	Pb214 26.8 m 0+ $\beta$ -													

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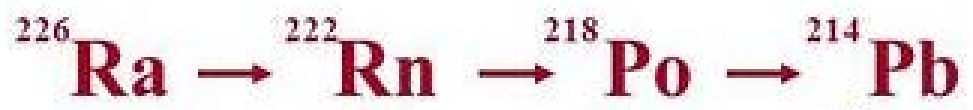
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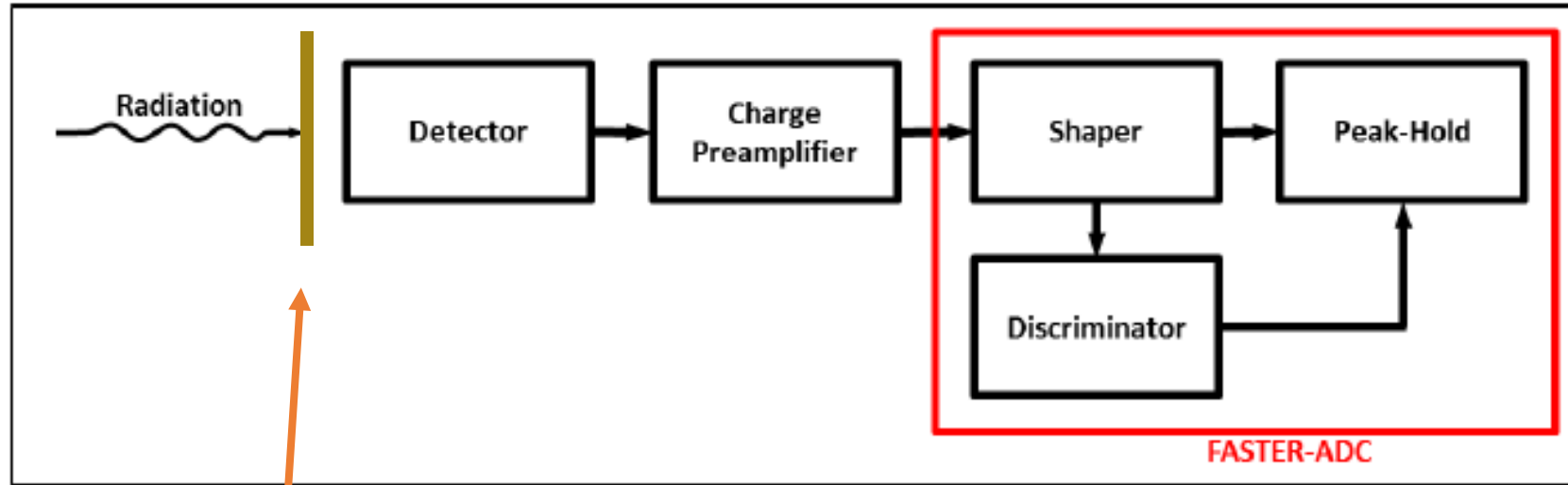
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# Silicon detector



Measurement of thickness of Aluminium foil

$^{226}\text{Ra}$  Source

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



# Measurement of thickness of Al-foil (d)

LISE ++ [Naname]

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

Set-Up

Projectile:  $^{48}\text{Ca}^{20+}$   
 140 MeV/u 1 pA  
 Fragment:  $^{42}\text{S}^{16+}$

Target:  $^9\text{Be}$   
 1800 mg/cm<sup>2</sup>

Stripper

D1 Brho 3.2490 Tm  
 I1\_slits slits  
 -100 +100

D2 Brho 3.2490 Tm  
 I2\_slits slits  
 -25.5 +25.5

PROJECTILE FRAGMENT

Physical calculator

A Element Z Q  
 4 He 2 2  
 Stable 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\_tnspt 0.119777 GeV/c Gamma 1.002063

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/cm<sup>2</sup>

FP\_PIN

Al Density [g/cm<sup>3</sup>] 2.702  
 calculate reactions in this material

State  
 Solid  
 Gas

Dimension  
 mg/cm<sup>2</sup> & micron  
 g/cm<sup>2</sup> & mm

Angle  
 Calculate  
 0 degrees

Thickness at 0 degrees  
 8.53 micron  
 2.304806 mg/cm<sup>2</sup>

Effective Thickness  
 8.53 micron  
 2.304806 mg/cm<sup>2</sup>

Set the spectrometer after this block using changes Atoms / cm<sup>2</sup> 5.14e+19

Cut (Slits)  
 General setting of block

Calibration Resolution Thickness defect

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

Range and Energy Loss to Si

Range dRange (sigma)  
 10.5073 0.09117 mg/cm<sup>2</sup>  
 45.2668 0.39277 micron

Energy Remain. 0.000 MeV/u  
 Material thickness 10.507 mg/cm<sup>2</sup>  
 for energy rest 45.267 micron

Calculation method of  
 Energy Losses 1 Energy Strag. 1  
 Charge States 2 Angular Strag. 1

Print ? Help X Quit

1 Origin 8 Software  
 2 Lise++ Software

# Calculations of error

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

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

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



# Measurement of thickness of Al-foil by balance weighting



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

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

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

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

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

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

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





# Flerov Laboratory of Nuclear Reactions



The Joint Institute for  
Nuclear Research Dubna



# THANK YOU FOR YOUR ATTENTION.

