Neutron activation analysis (NAA) for life sciences

Frank Laboratory of Neutron Physics
The Sector of Neutron Activation Analysis and Applied Research

Supervised by: Prof. M.V. Frontasyeva and Dr. W. Badawy

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27.7.20

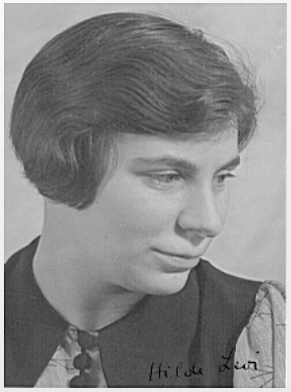
Content

- Introduction to NAA
- Sample collection and preparation
- Irradiation of samples using REGATA – IBR2m.
- REGATA
- Spectra processing using Genie-2000
- Concentration program
- Acknowledgement

Introduction to NAA

- Is an isotope specific analytical technique for the qualitative and quantitative determination of elemental content
- Was discovered in 1936 by George Charles de Hevesy and Hilde Levi
- Is based upon the conversion of stable atomic nuclei into radioactive nuclei by irradiation with neutrons and the subsequent detection of the gamma radiation emitted during the decay of these radioactive nuclei

George Charles de Hevesy
1885-1966



Hilde Levi
1909-2003

Types of NAA

Non destructive

The resulting radioactive sample is kept intact

- **Instrumental Neutron Activation Analysis Activation INAA**
- Epithermal Neutron Activation Analysis Activation ENAA
- Fast Neutron Activation Analysis Activation FNAA
- Cyclic Neutron Activation Analysis Activation CNAA
- In Vivo - Neutron Activation Analysis Activation In-vivo NAA

Destructive

The resulting radioactive sample is decomposed

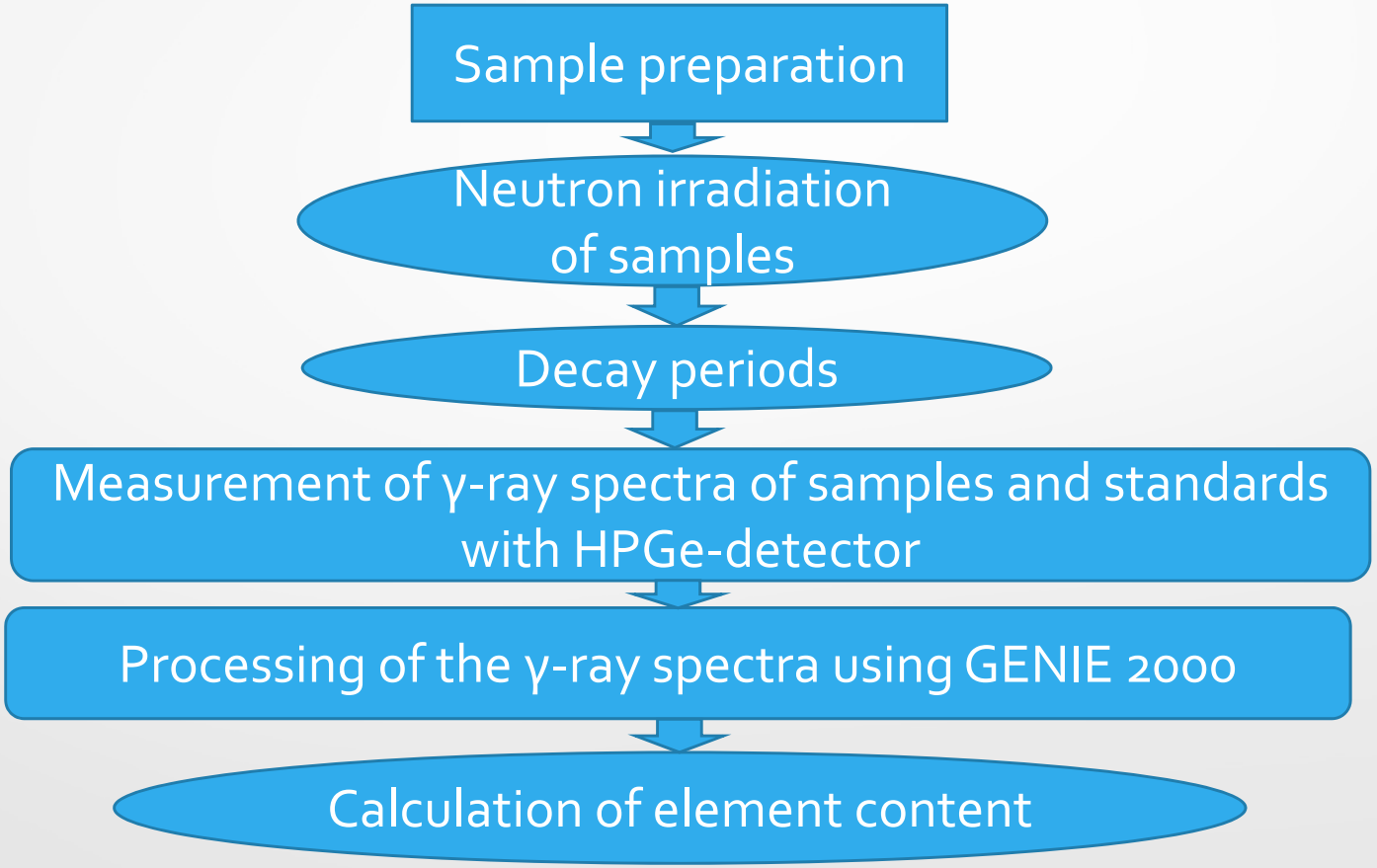
- Radiochemical or destructive neutron activation analysis RNAA or DNNA

Elements obtained by NAA

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac**											Rf	Db	Sg	Bh	Hs
	*	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
	**	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lw		

Analysis using NAA requires

Neutron Activation Analysis is not a "Push-Button" Technique



Sample collection and preparation

I.Collection

Moss

Soil

Con't

Drying

II. Preparation

Pelletizing

Optimal temperature for NAA-40 °C

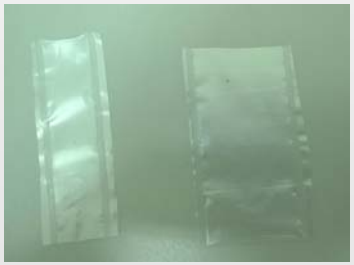
Con't

II. Preparation

Weighing

Packing

For short irradiation



For long irradiation

Con’t

Irradiation of samples

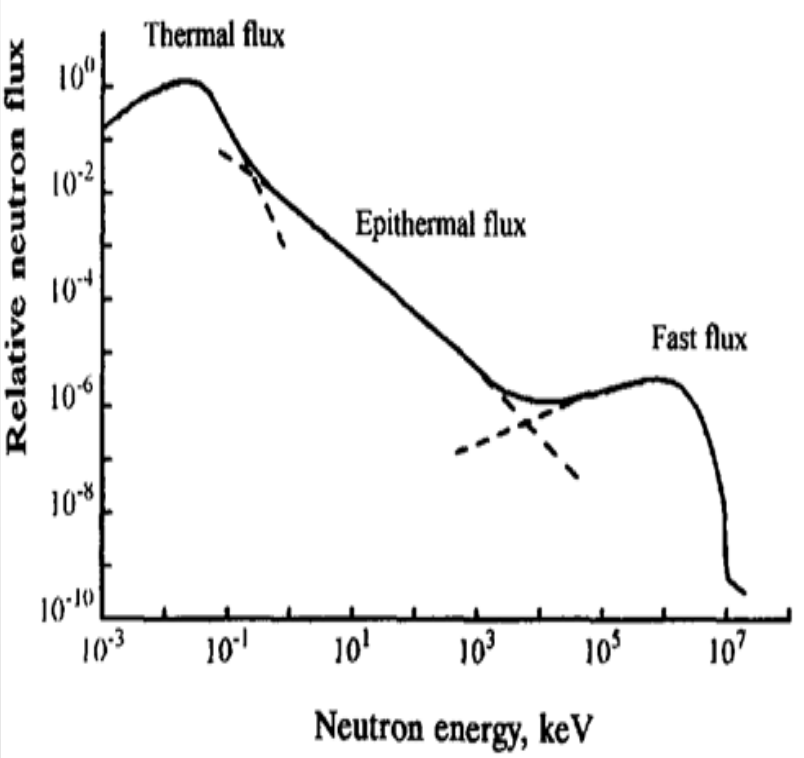
Transport capsules

TO IRRADIATE

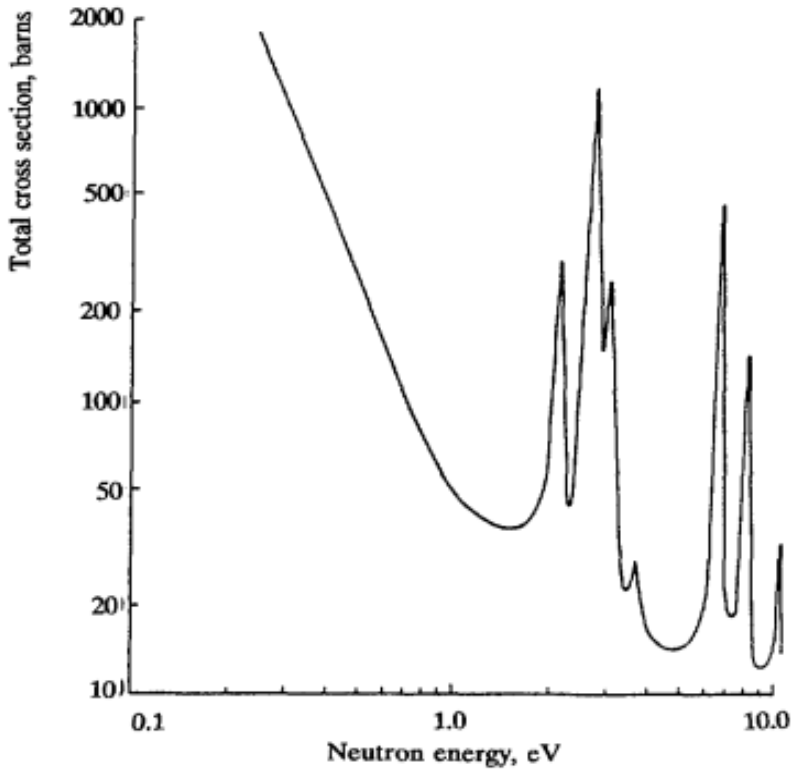
- The process of irradiation is based upon processes in the atomic nucleus when the samples are bombarded with neutrons from the reactor
- Neutron source : reactor IBR-2 (pulsed type)

Irradiation of samples

Neutron energies



Neutron energy Vs cross section

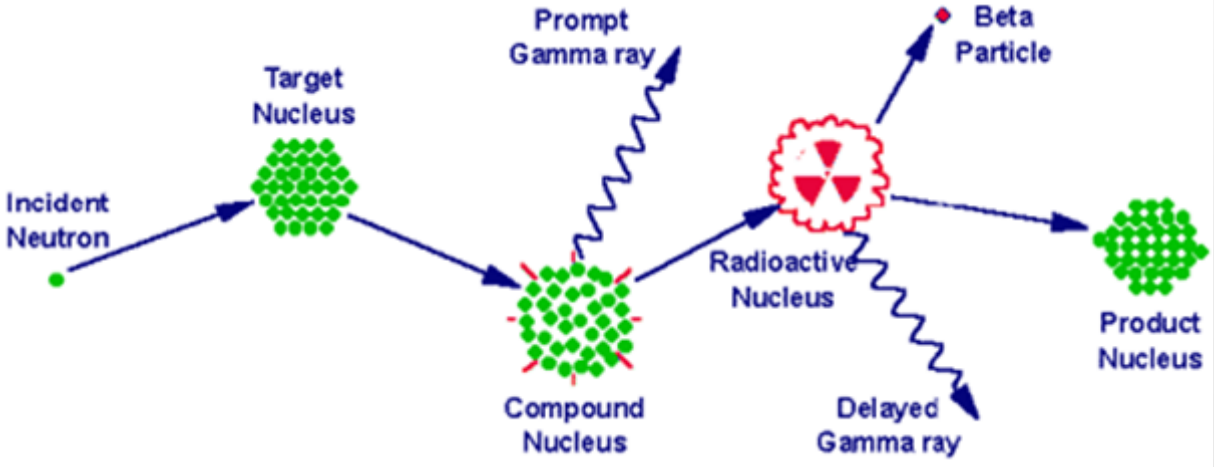


Thermal 0,025 eV - 0,5 eV
Epithermal 0.5 eV - 100 keV
Fast 100 keV-25 MeV

Irradiation of samples

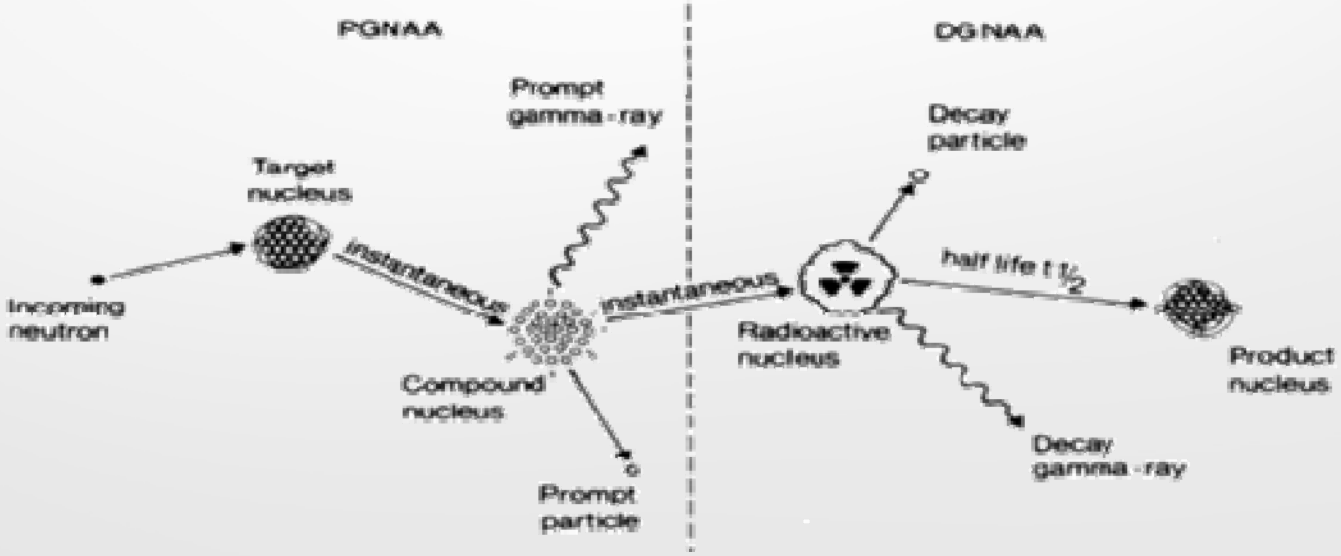
- Radioactive capture: $${}^{A}_{Z}X + n \rightarrow {}^{A+1}_{Z}Y + \gamma$$

- We obtain new isotope which is radioactive and during its radioactive decay emits gamma ray with energy which is specific for every radioisotope.



Measurement of Gamma

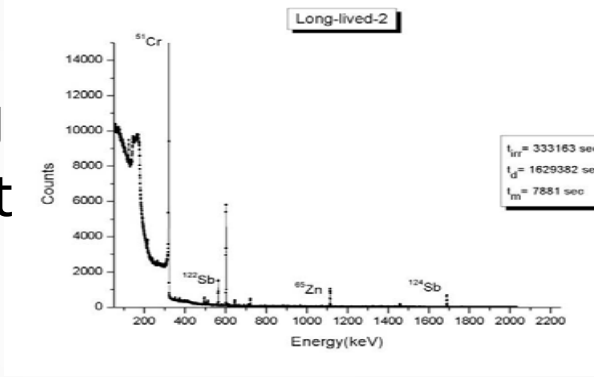
- With respect to the time of measurement, NAA falls into two categories:
  - → **Prompt gamma - ray neutron activation analysis** (PGNAA), where measurements take place during irradiation
  - → **Delayed gamma - ray neutron activation analysis** (DGNAA), where the measurements follow radioactive decay

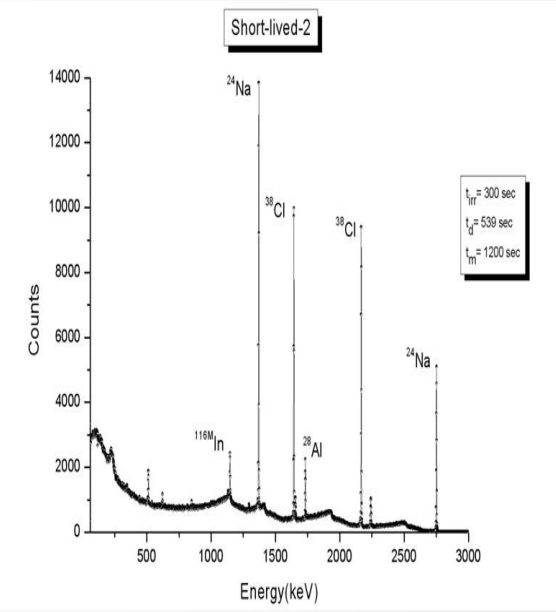


Measurement of Gamma

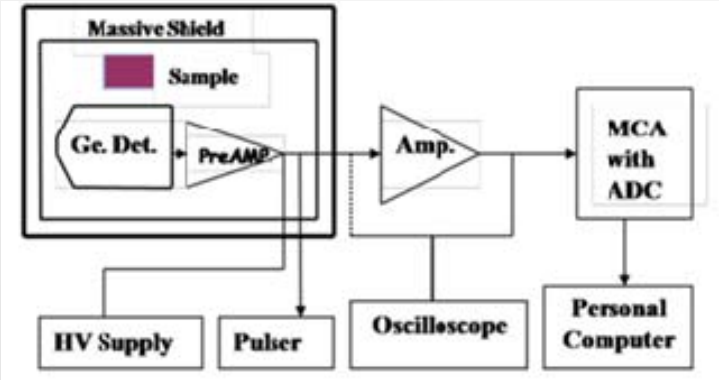
- Photons are measured by HPGe

→ Compton scattering
→ Photoelectric effect
→ Pair production





- For energy and efficiency calibration we use standard reference sources with similar matrix to the measure samples



Processing of Gamma-ray spectra

- A full computer spectrum analysis includes 3 steps:

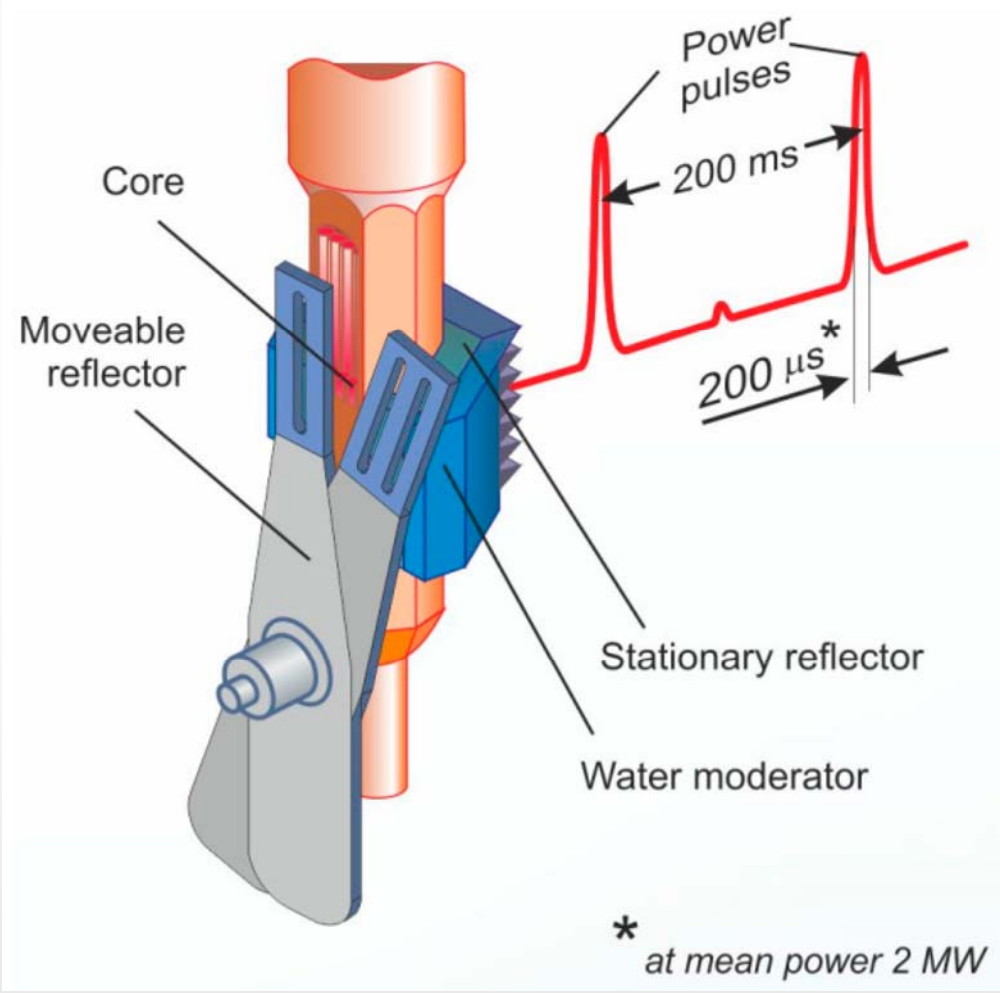
→ Set up data libraries for energy, peak width and efficiency calibration and for sample analysis

→ Use spectra of reference source to generate energy, width and efficiency calibration data files

→ Analyze sample spectra by referring to those data libraries and calibration files

IBR-2 reactor

- Main parameters
  - Average power- 2 MW
  - Fuel- PuO_2
  - Rotation rate rev/min
    - Main reflector- 600
    - Auxiliary reflector- 300
  - Neutron flux density- $10^{16}\ n \cdot m^{-2} \cdot s^{-1}$

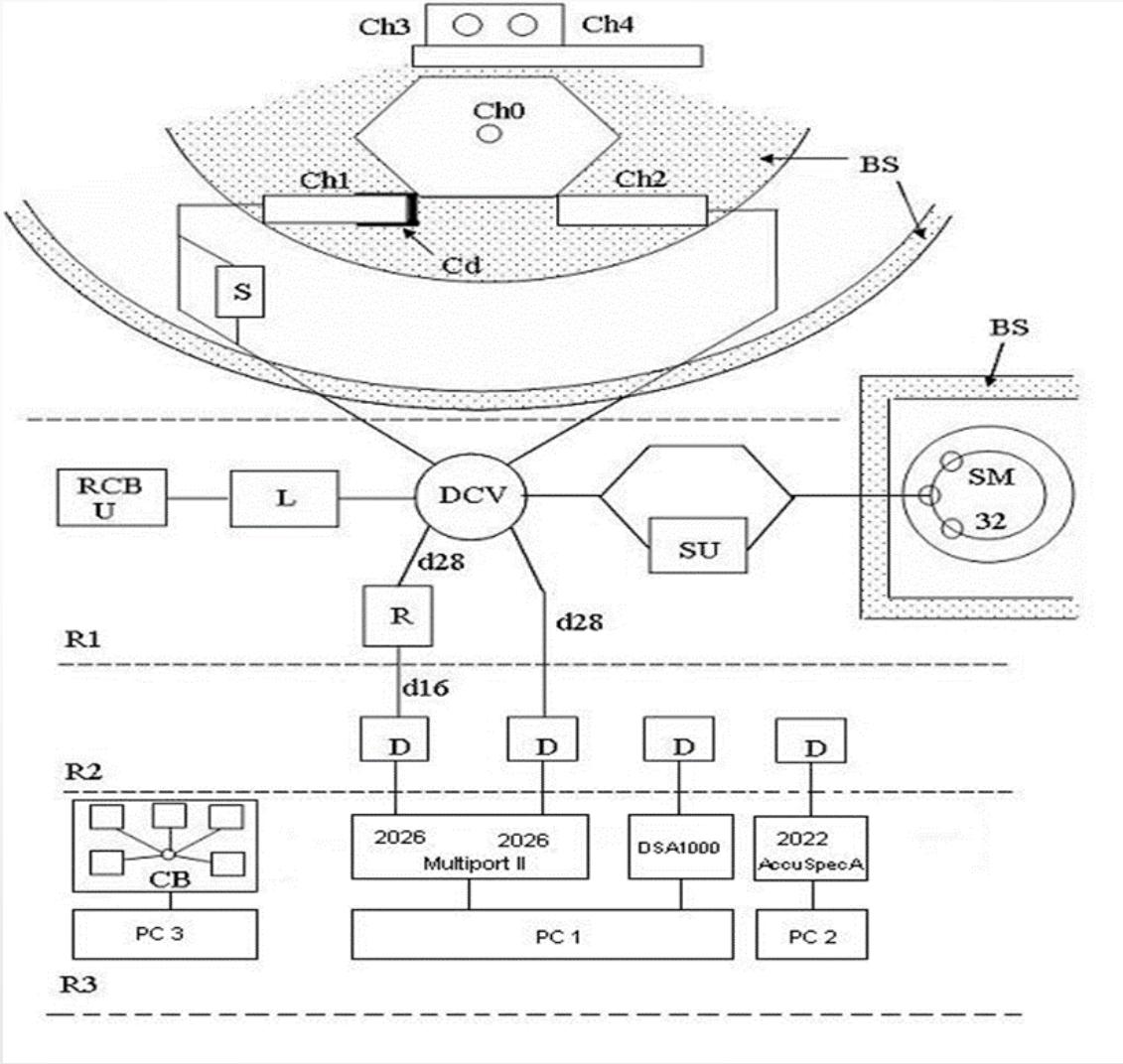


REGATA


YuMO
EPSILON
SKAT
HRFD
DN-6
DIN-2PI
KOLKHIDA
NERA
DN-2
REGATA
REMUR
NRT
IZOMER
REFLEX-P
FSS
GRAINS
FSD
DN-12
Diffraction
DN-2, DN-12, DN-6, FSD, FSS, HRFD, SKAT, EPSILON
Small-angle scattering
YuMO
Reflectometry
GRAINS, REFLEX-P, REMUR
Inelastic scattering
DIN-2PI, NERA
Nuclear Physics
ISOMER, KOLHIDA
Neutron Activation Analysis
REGATA
Neutron imaging
NRT

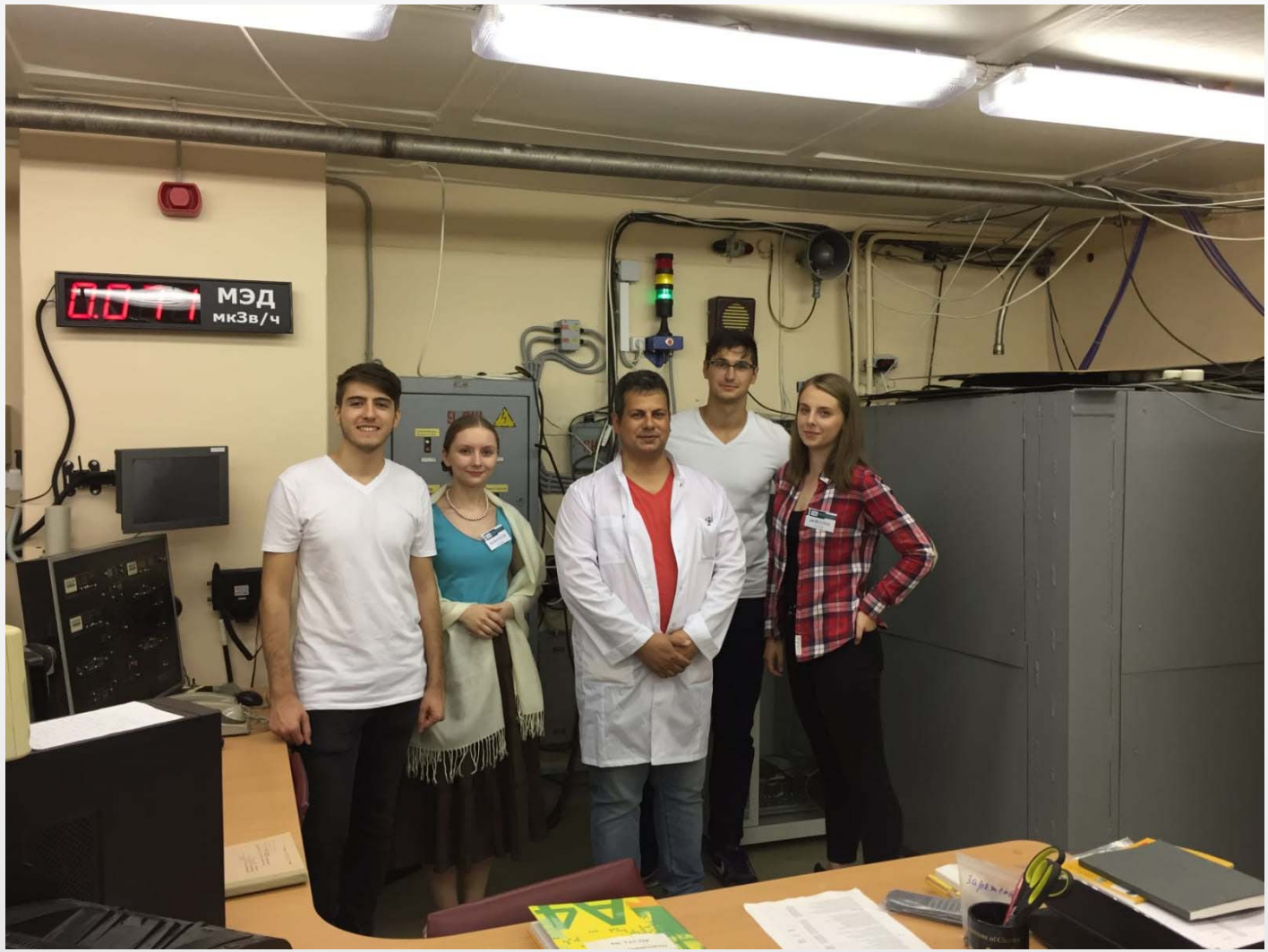
REGATA

CH1- CH4: irradiation channels
S: Storage (intermediate)
DCV: Directional control valves
R: Repacking unit
D: Detector
SM: Storage magazine
CB: Control board
R1- R3: Rooms locations of system



Rabbit system

Hot cell

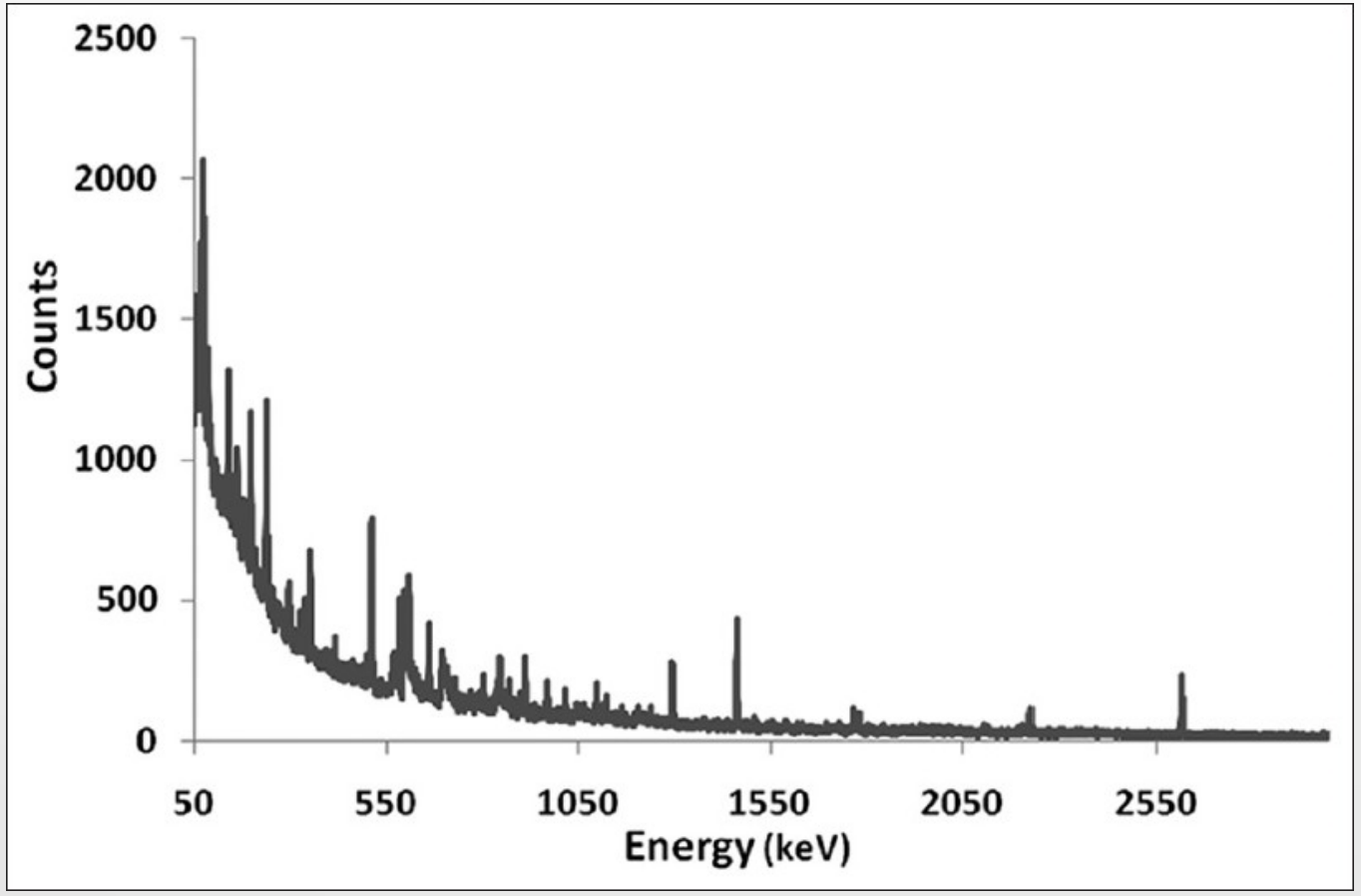


Control board

Sample changer

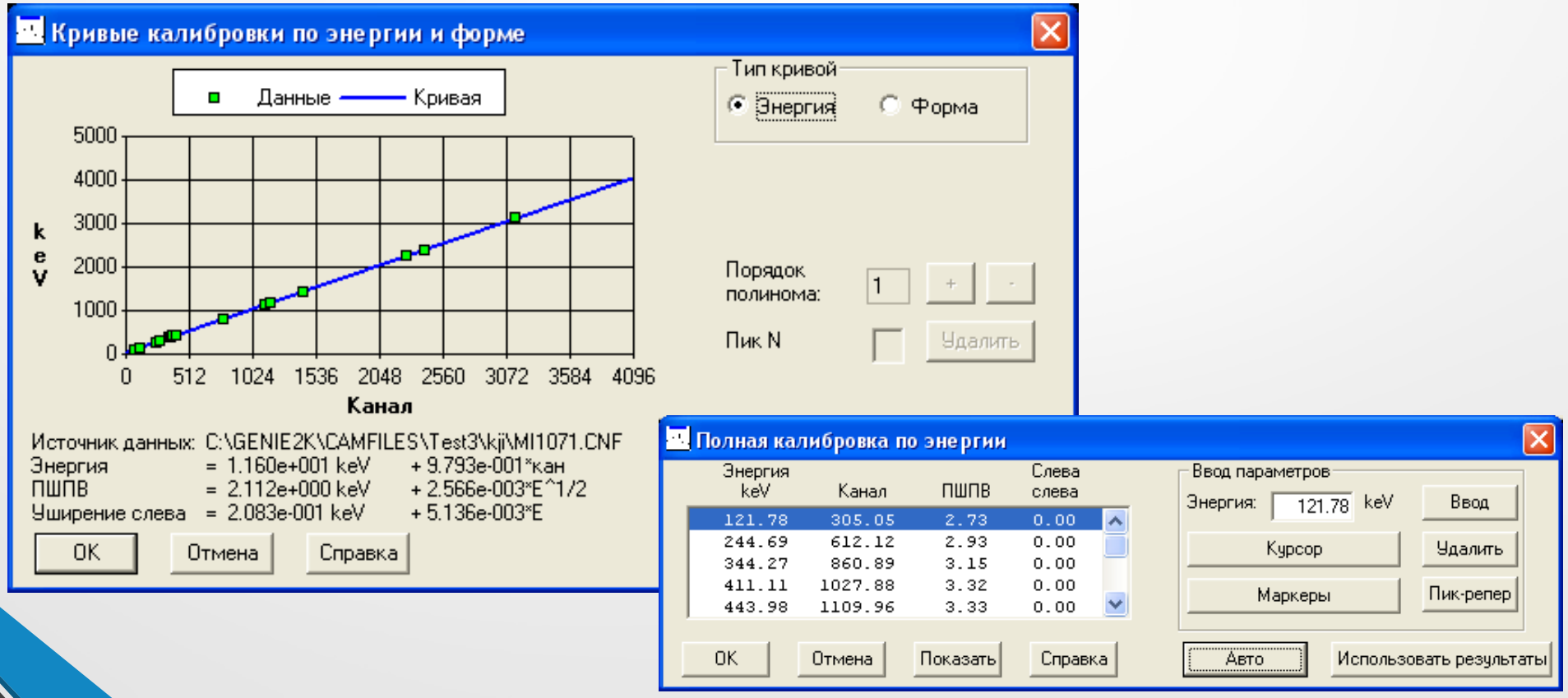
Genie-2000

- Output from the detector: spectrum

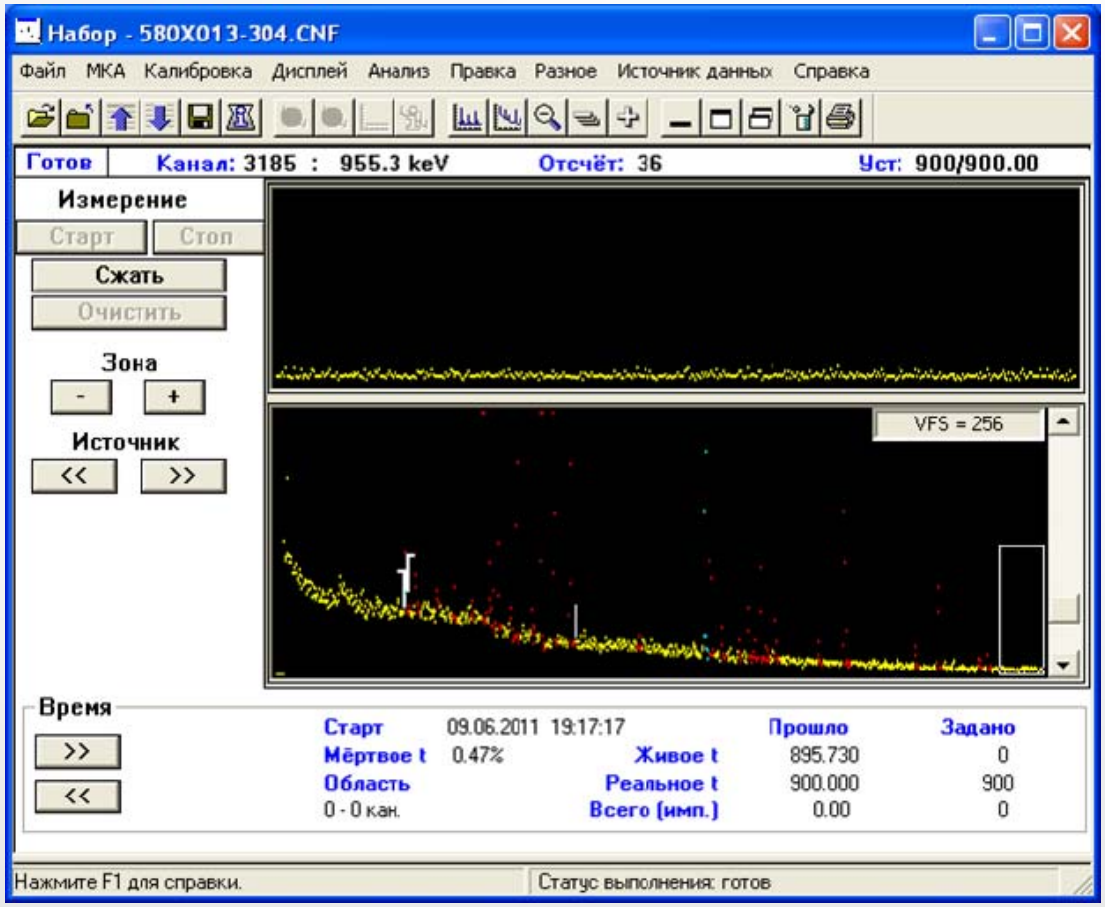


Genie-2000 – energy calibration

- Using 152Eu
- Channels -> energies, calibration curve

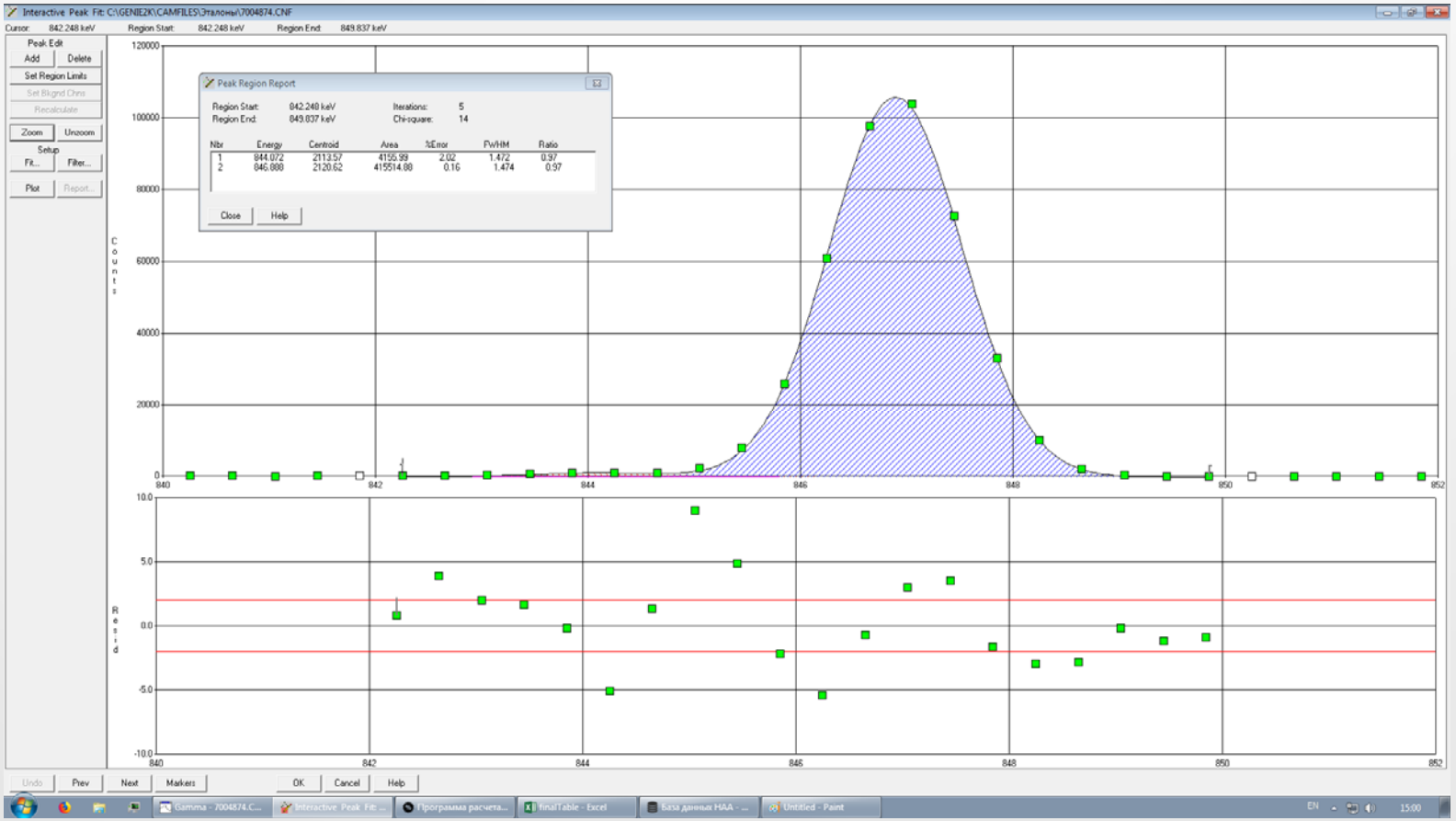


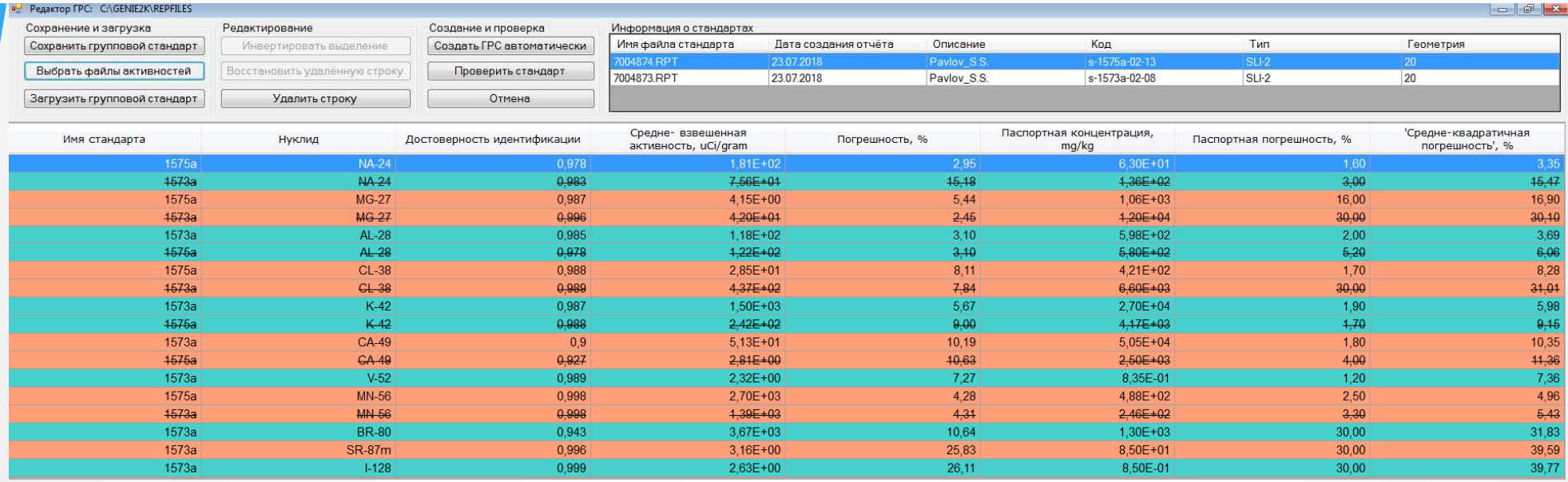
Genie-2000


Набор - 580X013-304.CNF
Файл МКА Калибровка Дисплей Анализ Правка Разное Источник данных Справка
Готов
Канал: 3185 : 955.3 keV
Отсчёт: 36
Уст: 900/900.00
Измерение
Старт
Стоп
Сжать
Очистить
Зона
-
+
Источник
<<
>>
VFS = 256
Время
>>
<<
Старт 09.06.2011 19:17:17
Мёртвое t 0.47%
Область
0 - 0 кан.
Прошло
Задано
Живое t 895.730 0
Реальное t 900.000 900
Всего (имп.) 0.00 0
Нажмите F1 для справки.
Статус выполнения: готов

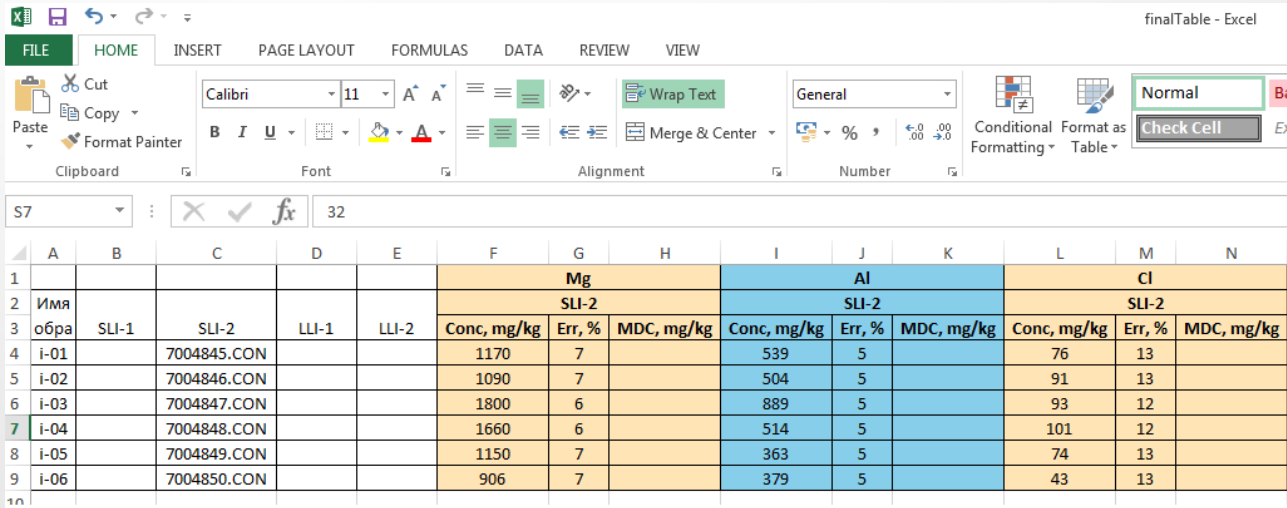
Genie-2000

- How large is the area under the peak?




Редактор ГРС: C:\GENIE2K\REPFILES
Сохранение и загрузка
Сохранить групповой стандарт
Выбрать файлы активностей
Загрузить групповой стандарт
Редактирование
Инвертировать выделение
Восстановить удалённую строку
Удалить строку
Создание и проверка
Создать ГРС автоматически
Проверить стандарт
Отмена
Информация о стандартах
Имя файла стандарта | Дата создания отчёта | Описание | Код | Тип | Геометрия
7004874.RPT | 23.07.2018 | Pavlov_S.S. | s-1575a-02-13 | SLI-2 | 20
7004873.RPT | 23.07.2018 | Pavlov_S.S. | s-1573a-02-08 | SLI-2 | 20
Имя стандарта | Нуклид | Достоверность идентификации | Средне- взвешенная активность, uCi/gram | Погрешность, % | Паспортная концентрация, mg/kg | Паспортная погрешность, % | 'Средне-квадратичная погрешность', %
1575a | NA-24 | 0,978 | 1,81E+02 | 2,95 | 6,30E+01 | 1,60 | 3,35
1573a | NA-24 | 0,983 | 7,56E+01 | 15,18 | 1,36E+02 | 3,00 | 15,47
1575a | MG-27 | 0,987 | 4,15E+00 | 5,44 | 1,06E+03 | 16,00 | 16,90
1573a | MG-27 | 0,996 | 4,20E+01 | 2,45 | 1,20E+04 | 30,00 | 30,10
1573a | AL-28 | 0,985 | 1,18E+02 | 3,10 | 5,98E+02 | 2,00 | 3,69
1575a | AL-28 | 0,978 | 1,22E+02 | 3,10 | 5,80E+02 | 5,20 | 6,06
1575a | CL-38 | 0,988 | 2,85E+01 | 8,11 | 4,21E+02 | 1,70 | 8,28
1573a | CL-38 | 0,989 | 4,37E+02 | 7,84 | 6,60E+03 | 30,00 | 31,01
1573a | K-42 | 0,987 | 1,50E+03 | 5,67 | 2,70E+04 | 1,90 | 5,98
1575a | K-42 | 0,988 | 2,42E+02 | 9,00 | 4,17E+03 | 1,70 | 9,15
1573a | CA-49 | 0,9 | 5,13E+01 | 10,19 | 5,05E+04 | 1,80 | 10,35
1575a | CA-49 | 0,927 | 2,81E+00 | 10,63 | 2,50E+03 | 4,00 | 11,36
1573a | V-52 | 0,989 | 2,32E+00 | 7,27 | 8,35E-01 | 1,20 | 7,36
1575a | MN-56 | 0,998 | 2,70E+03 | 4,28 | 4,88E+02 | 2,50 | 4,96
1573a | MN-56 | 0,998 | 1,39E+03 | 4,31 | 2,46E+02 | 3,30 | 5,43
1573a | BR-80 | 0,943 | 3,67E+03 | 10,64 | 1,30E+03 | 30,00 | 31,83
1573a | SR-87m | 0,996 | 3,16E+00 | 25,83 | 8,50E+01 | 30,00 | 39,59
1573a | I-128 | 0,999 | 2,63E+00 | 26,11 | 8,50E-01 | 30,00 | 39,77

Excel file


finalTable - Excel
FILE
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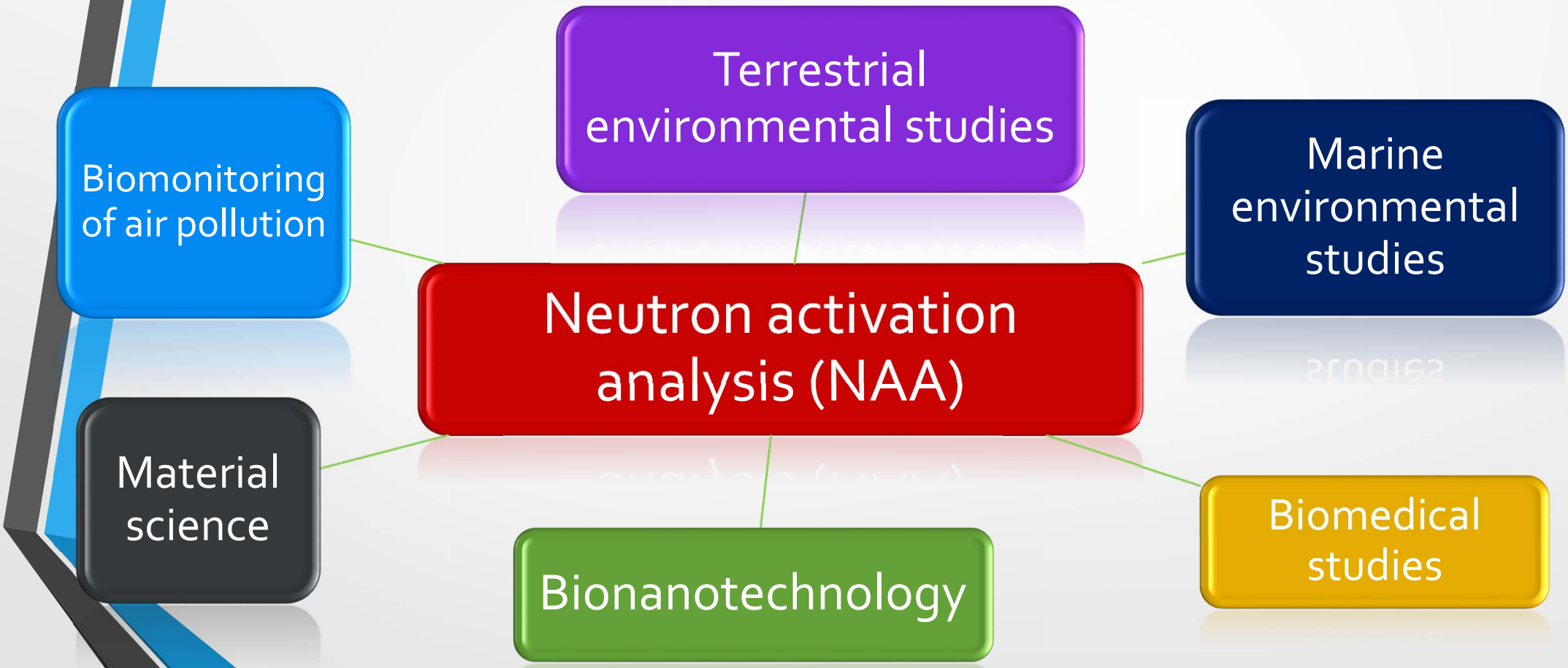
Calibri
11
Font
Wrap Text
Merge & Center
Alignment
General
Number
Conditional Formatting
Format as Table
Normal
Check Cell
S7
32
Mg
Al
Cl
SLI-2
Имя обра
SLI-1
SLI-2
LLI-1
LLI-2
Conc, mg/kg
Err, %
MDC, mg/kg
i-01 7004845.CON 1170 7 539 5 76 13
i-02 7004846.CON 1090 7 504 5 91 13
i-03 7004847.CON 1800 6 889 5 93 12
i-04 7004848.CON 1660 6 514 5 101 12
i-05 7004849.CON 1150 7 363 5 74 13
i-06 7004850.CON 906 7 379 5 43 13

Studies in Sector of NAA & AR



UNECE

United Nations Economic Commission for Europe

International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops

Working Group on Effects - 1981

Advantages

- Primary analytical technique
- Ease of sample preparation
- High sensitivity and precision
- Simultaneous measurement of multiple elements
- Wide possibilities of applications
- Outstanding replicability

Limitations

- Need for nuclear reactor
- Work with radioactive materials
- Time of analysis
- Sample preference

General outcomes

- NAA is a useful method for the simultaneous determination of elemental composition of geological, environmental and biological samples.
- Data analysis yields concentrations of major, trace and rare earth elements.
- Enriched our knowledge in this important field during interesting lessons, learned sample preparaion for NAA.
- It was a great opportunity to exchange experience side by side with scientists from member and associated States in JINR, which helps us to continue our research in home countries and cope with the latest and recent achievements relevant to our scientific areas of interest.
- Visited amazing places, cities, etc.

Acknowledgements

- Prof. Marina V. Frontasyeva
- Dr. Wael Badawy
- All staff of the Sector of Neutron Activation Analysis and Applied Research, Frank Laboratory of Neutron Physics

Thank you for your attention