

International Student Practice 2017, JINR, Dubna

# NEUTRON ACTIVATION ANALYSIS FOR LIFE SCIENCES

By

MacDonald, R. T; Zimri, M. N; Mukaba, JL; Tsewu, A. and Uche, C.C.

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

*Frank Laboratory of Neutron Physics*

*The Sector of Neutron Activation Analysis and Applied Research*

29<sup>th</sup> May – 16<sup>th</sup> June 2017



# GROUP MEMBERS



*Riccarda Thelma MacDonal*  
*University of the Western Cape*  
*BSc (Hons) Chemical Sciences*  
*MSc Nanoscience*



*Monushia Natasha Zimri*  
*University of the Western Cape*  
*BSc (Hons) Biotechnology*  
*MSc Nanoscience*



*Ayabulela Tsewu*  
*University of Fort Hare*  
*BSc Physical Sciences*  
*BSc (Hons) Nuclear Physics*



*Muvumbu Jean-Luc Mukaba*  
*University of the Western Cape*  
*MSc Chemistry*  
*PhD*

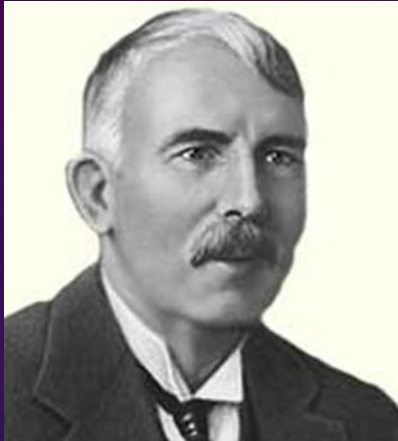


*Cosmas Chinedu Uche*  
*University of the Western Cape*  
*MSc Pollution Control*  
*PhD (In view)*

# Presentation content

- ❖ Introduction
- ❖ Sample Collection and Preparation
- ❖ Sample Analysis and Data Processing
- ❖ Programs for Data Interpretation
- ❖ Conclusions
- ❖ Acknowledgements
- ❖ References

# Neutron Discovery



Ernest Rutherford

1909: scattering of  $\alpha$ - particles

1911: nuclear model of the atom

1919:  $^{14}\text{N} + \alpha \rightarrow ^{17}\text{O} + \text{p}$

p-e model of the atom

1920:  $n = p + e$

1932: “Possible Existence of a Neutron” –  
February

“The Existence of a Neutron” – May

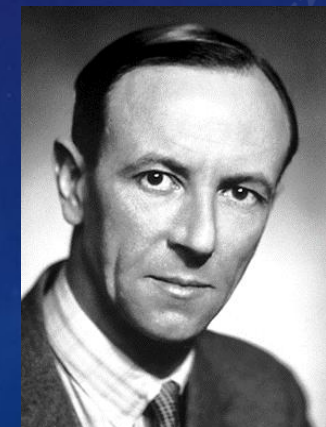
1934: Establishment of newly discovered neutron  
as  
fundamental particle



Frederick Soddy



The Philosopher's Stone



James Chadwick

# Neutron Activation Analysis

- ❖ Is an isotope specific analytical technique for the qualitative and quantitative determination of elemental content
- ❖ Discovered in 1936

P. Bode, J.J.M. de Goeij,  
'Activation Analysis',  
Encyclopedia of  
Environmental Analysis and  
Remediation, J. Wiley & Sons,  
New York, 1998, ISBN 0-471-  
11708-0, pp 68-84

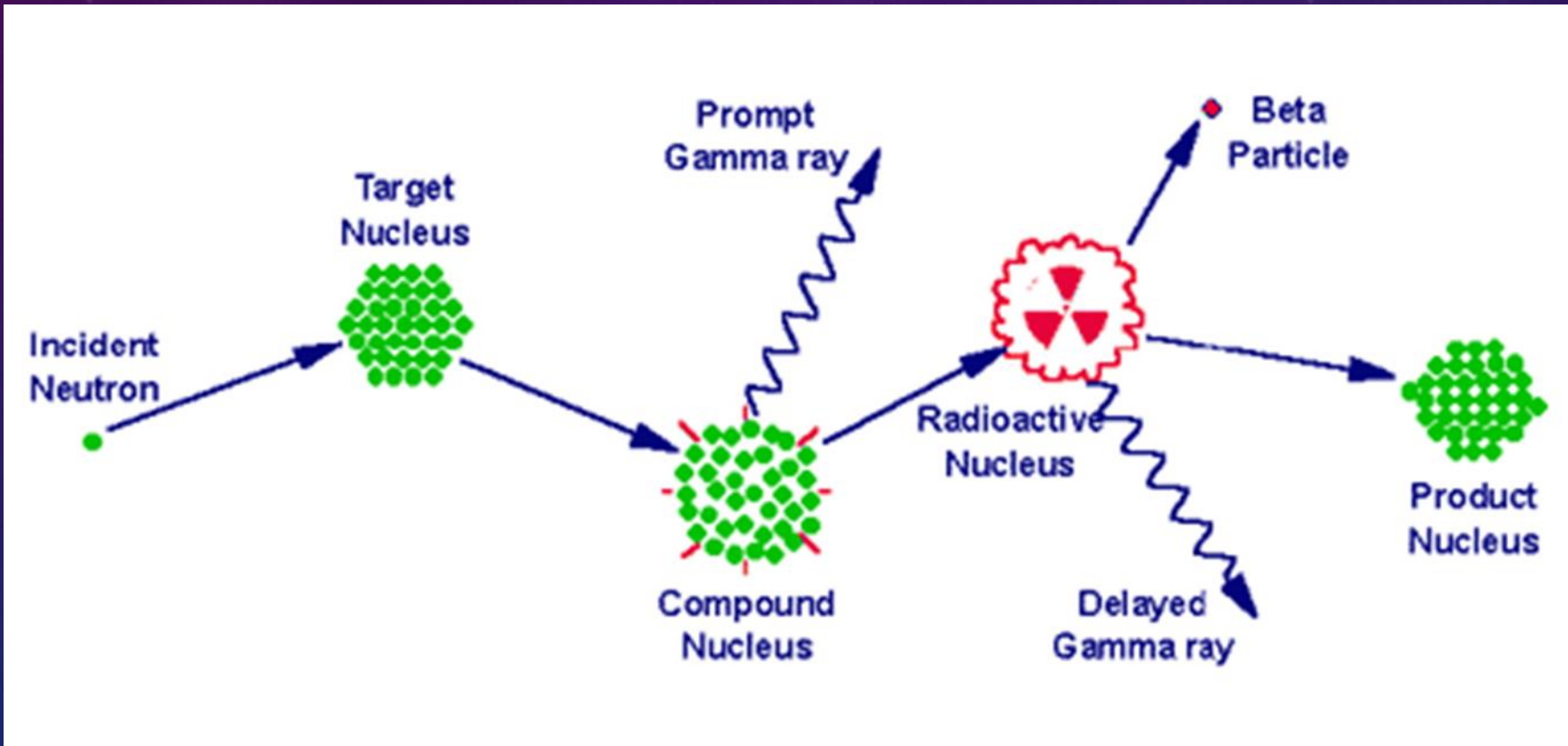


George Charles de Hevesy



Hilde Levi

# Fundamentals of NAA



# Types of NAA

```
graph TD; A[Types of NAA] --> B[Destructive (radiochemical)]; A --> C[Non-destructive (instrumental)];
```

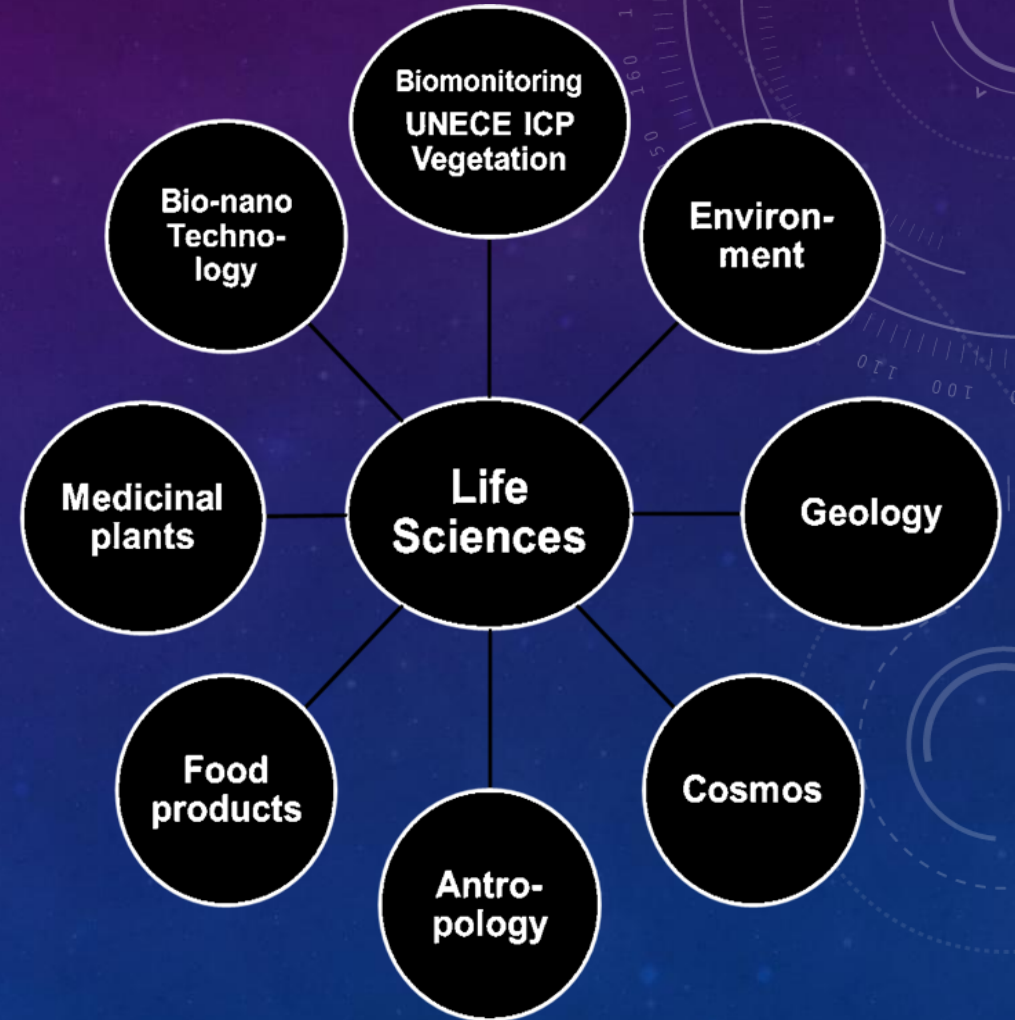
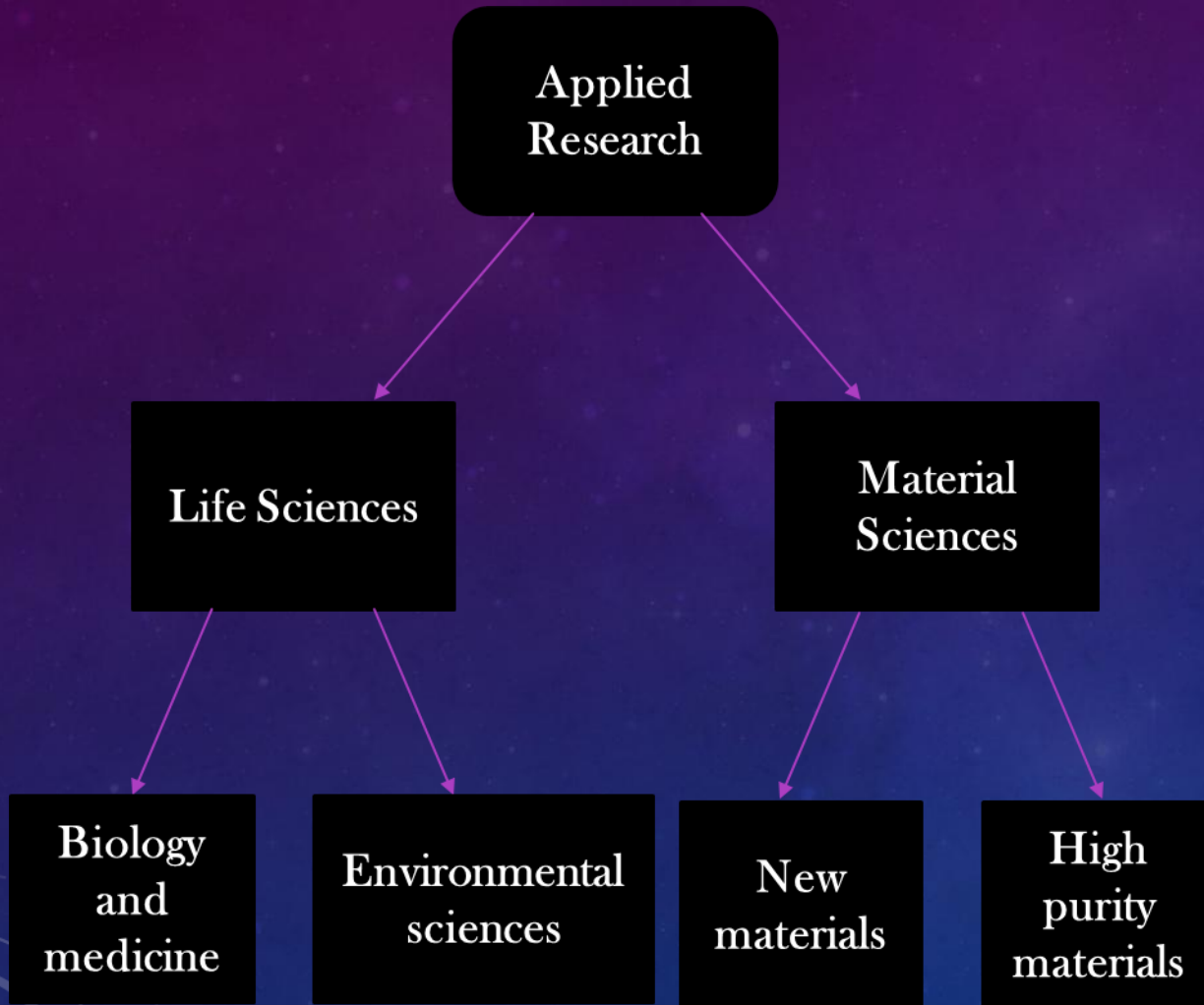
## **Destructive (radiochemical)**

the resulting radioactive sample is chemically decomposed and the elements are chemically separated

## **Non-destructive (instrumental)**

the resulting radioactive sample is kept intact and the radionuclides are determined, taking advantage of the differences in decay rates via measurements at different decay intervals

# Applications





# Sample Collection

❖ *Hylocomium splendens* and *Pleurozium Schreberi*



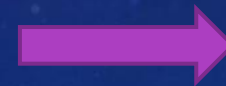
# Sample Preparation

- ❖ Samples air-dried and cleaned from roots of plants and wastes
- ❖ Sample weighed and homogenized by an agate ball mill



# Sample Packing

- ❖ Moss samples wrapped in polyethylene bag and aluminium pan for short- and long-lived irradiations respectively.
- ❖ Samples placed in transport capsules
- ❖ Short-lived isotopes - samples irradiated for 60 seconds
- ❖ Long-lived isotopes – samples irradiated for 4 days



# Sample Information Sheets

**New sample acceptance**

Country-Client-Year-Set ID-Set index Sample ID  
 ZA 09 17 13 m 31

Client sample ID: 30  
 Sample type: soils

Latitude: \_\_\_\_\_ Longitude: \_\_\_\_\_

Collection place: Nigeria

Cupboard: \_\_\_\_\_ Box: \_\_\_\_\_ Received by: \_\_\_\_\_

Notes: SOS 41T

Sample preparation:
 

- cleaning
- drying
- evaporation
- freeze(drying)
- homogenizing
- pelletization
- fragmentation

Determined elements: all elements

Group of elements:
 

- halogens
- heavy metals
- short-lived
- long-lived

Separate elements:
 

<input checked="" type="checkbox"/> F	<input checked="" type="checkbox"/> Cu	<input checked="" type="checkbox"/> In	<input checked="" type="checkbox"/> Tm
<input checked="" type="checkbox"/> Na	<input checked="" type="checkbox"/> Zn	<input checked="" type="checkbox"/> Sn	<input checked="" type="checkbox"/> Yb
<input checked="" type="checkbox"/> Mg	<input checked="" type="checkbox"/> Ga	<input checked="" type="checkbox"/> Sb	<input checked="" type="checkbox"/> Lu
<input checked="" type="checkbox"/> Al	<input checked="" type="checkbox"/> Ge	<input checked="" type="checkbox"/> I	<input checked="" type="checkbox"/> Hf
<input checked="" type="checkbox"/> Si	<input checked="" type="checkbox"/> As	<input checked="" type="checkbox"/> Cs	<input checked="" type="checkbox"/> Ta
<input checked="" type="checkbox"/> S	<input checked="" type="checkbox"/> Se	<input checked="" type="checkbox"/> Ba	<input checked="" type="checkbox"/> W
<input checked="" type="checkbox"/> Cl	<input checked="" type="checkbox"/> Br	<input checked="" type="checkbox"/> La	<input checked="" type="checkbox"/> Re
<input checked="" type="checkbox"/> K	<input checked="" type="checkbox"/> Rb	<input checked="" type="checkbox"/> Ce	<input checked="" type="checkbox"/> Os
<input checked="" type="checkbox"/> Ca	<input checked="" type="checkbox"/> Sr	<input checked="" type="checkbox"/> Pr	<input checked="" type="checkbox"/> Ir
<input checked="" type="checkbox"/> Sc	<input checked="" type="checkbox"/> Y	<input checked="" type="checkbox"/> Nd	<input checked="" type="checkbox"/> Pt
<input checked="" type="checkbox"/> Ti	<input checked="" type="checkbox"/> Zr	<input checked="" type="checkbox"/> Sm	<input checked="" type="checkbox"/> Au
<input checked="" type="checkbox"/> V	<input checked="" type="checkbox"/> Nb	<input checked="" type="checkbox"/> Eu	<input checked="" type="checkbox"/> Hg
<input checked="" type="checkbox"/> Cr	<input checked="" type="checkbox"/> Mo	<input checked="" type="checkbox"/> Gd	<input checked="" type="checkbox"/> Th
<input checked="" type="checkbox"/> Mn	<input checked="" type="checkbox"/> Ru	<input checked="" type="checkbox"/> Tb	<input checked="" type="checkbox"/> U
<input checked="" type="checkbox"/> Fe	<input checked="" type="checkbox"/> Pd	<input checked="" type="checkbox"/> Dy	
<input checked="" type="checkbox"/> Co	<input checked="" type="checkbox"/> Ag	<input checked="" type="checkbox"/> Ho	
<input checked="" type="checkbox"/> Ni	<input checked="" type="checkbox"/> Cd	<input checked="" type="checkbox"/> Er	

Buttons: Save sample, Close, Fill in from file

**Sample preparation**

Country-Client-Year-Set ID-Set index  
 ZA 09 17 13 m

Sample ID	Client sample ID	Cleaning	Drying	Evaporation	Freeze drying	Homogenizing	Pelletization	Fragmentation	Weight SLI, g	Weight LLI, g	Sample preparation date	Maked
01	1	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.1039	0.1083	13.02.2017	Yushin N.S
02	2	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.0956	0.1082	13.02.2017	Yushin N.S
03	3	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.0967	0.0961	13.02.2017	Yushin N.S
04	4	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.1043	0.1162	13.02.2017	Yushin N.S
05	5	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.1042	0.1033	13.02.2017	Yushin N.S
06	6	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.1045	0.0993	13.02.2017	Yushin N.S
07	7	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.1011	0.1046	13.02.2017	Yushin N.S
08	8	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.0916	0.0964	13.02.2017	Yushin N.S

Buttons: Check selected 'Cleaning', Check selected 'Drying', Check selected 'Evaporation', Check selected 'Freeze Drying', Check selected 'Homogenizing', Check selected 'Pelletization', Check selected 'Fragmentation', Fill in weights from file, Check selected 'Maked by', Select all rows, Save, Close

**NAA DataBase - 5.8.9.0 iiz**

Samples in NAA DB: 11539 tple sets

Country code	Client ID	Year	Sample set ID	Sample set index
RS	05	17	26	z
RU	33	17	27	a
GR	01	17	28	b
FR	01	17	29	c
PL	08	17	30	d
MD	01	17	31	e

Color: \_\_\_\_\_ Description: \_\_\_\_\_

Color	Description
_____	sample set accepted
_____	sample preparation carried out
_____	irradiation SLI
_____	irradiation LLI
_____	SLI or LLI plus results
_____	SLI and LLI plus results
_____	Show all

SRM sets

Name	Number	Type	Weight, g	Purchasing date
Si	01	metal	0,02	01.11.2016
SI1	01	soil	10	21.12.2012
Tc	01	metal	1	23.03.2015
W	01	metal	5	23.03.2015

Monitor sets

Name	Number	Type	Weight, g	Purchasing date
Zr	05	foil	15,89	19.01.2010
Zr	06	foil	15,89	19.01.2010
Zr	07	foil	14,76	19.01.2010
Zr	08	foil	14,76	19.01.2010

SLI log: 18.05.2015, 09.12.2015  
 LLI log: 04.04.2017, 07.04.2017, 10.04.2017

Buttons: New SRM set acceptance, Select SRM set, Refresh, Physical environment, Search, Close

Фильтрация списка партий: Выберите поле для фильтра, Choose type of filter, Показать все

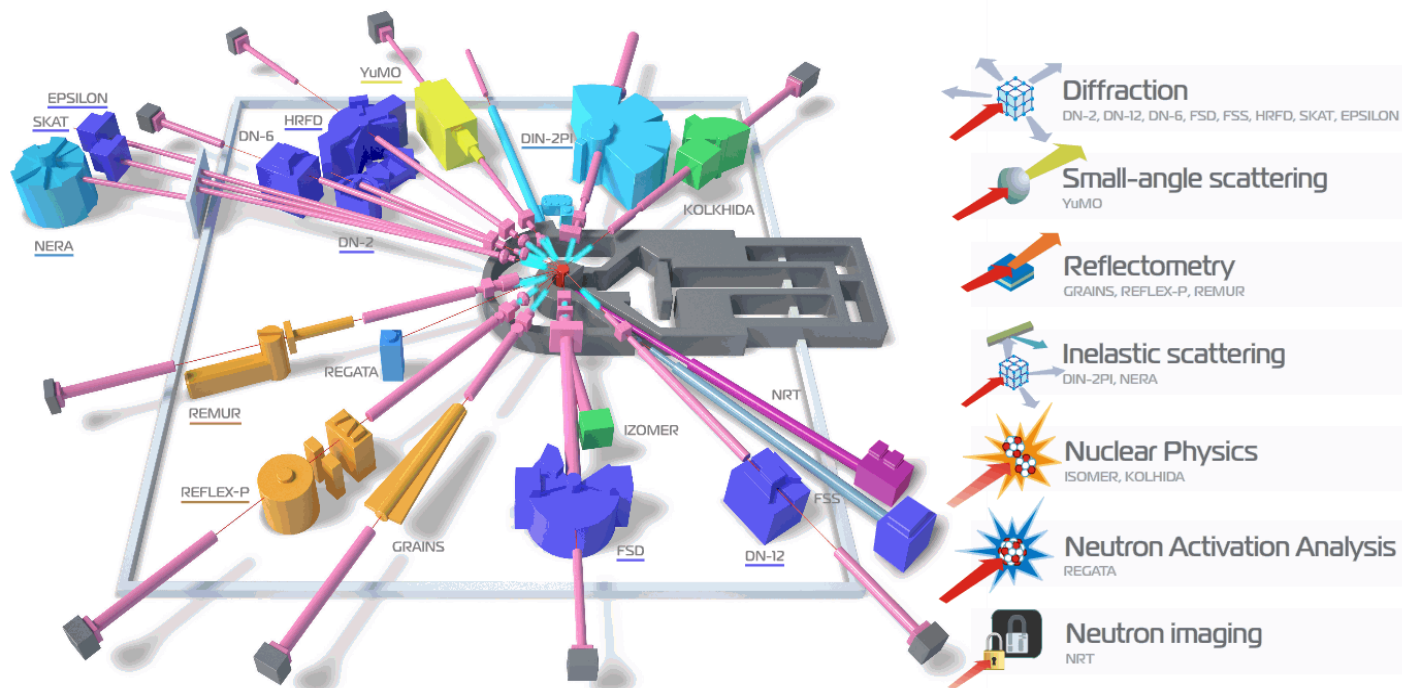
Информация о выбранной партии: Страна: Moldova, Организация: Institute of Microbiology and Biotechnology, Фамилия: Zinicovscaia, Кол-во образцов: 18, Тип образцов: vegetation, Дата КЖИ: 17.05.2017, Дата ДЖИ: 19.05.2017, Обработчик: Результаты:

SLI irradiation logs: 18.01.2017, 20.01.2017, 23.01.2017, 25.01.2017, 26.01.2017, 09.02.2017, 10.02.2017, 14.03.2017, 17.03.2017, 22.03.2017, 06.04.2017, 07.04.2017, 10.04.2017, 12.04.2017, 14.04.2017, 17.05.2017, 18.05.2017, 19.05.2017, 22.05.2017, 23.05.2017

LLI irradiation logs: 17.01.2017, 20.01.2017, 23.01.2017, 08.02.2017, 11.02.2017, 15.02.2017, 16.03.2017, 20.03.2017, 24.03.2017, 04.04.2017, 07.04.2017, 10.04.2017, 15.05.2017, 19.05.2017, 22.05.2017, 23.05.2017

Buttons: Select SLI irradiation log, Select LLI irradiation log, New SLI irradiation log, New LLI irradiation log

# IBR-2 Reactor



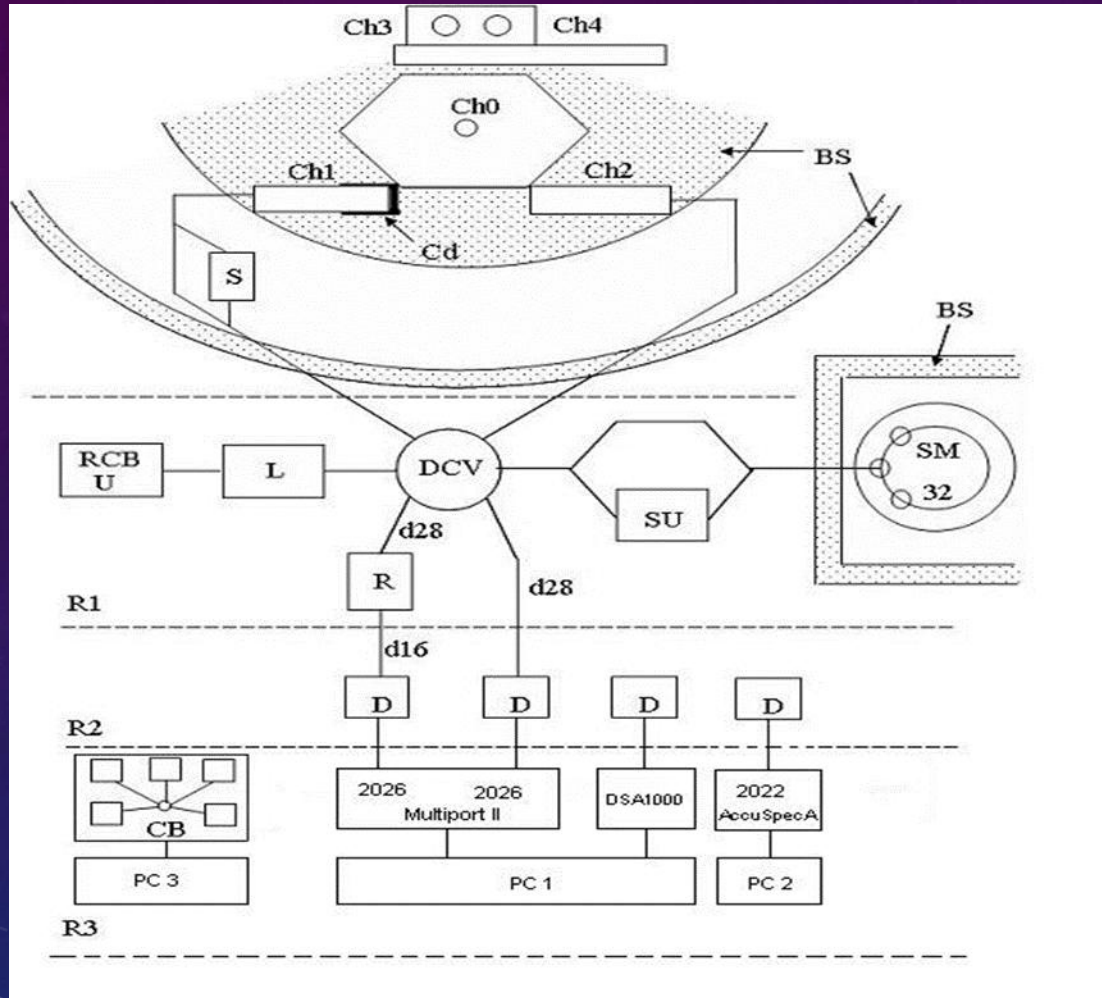
❖ Average power 2 MW

❖ PuO<sub>2</sub> fuel

❖ <sup>252</sup>Cf

❖ Neutron density flux:  
~ 10<sup>16</sup> n/cm<sup>2</sup>/s

# Radioanalytical complex REGATA



**Ch1-Ch4:** Irradiation channels

**S:** storage (intermediate)

**DCV:** Directional Control Valves

**L:** Loading unit

**RCB:** Radiochemical glove-cell

**U:** Unloading unit

**SU:** Separate unit

**SM:** Storage Magazine

**R:** Repacking unit

**D:** Detector

**CB:** Control Board

**R1-R3:** Rooms location of the system

# Analysis of Samples



**Sample Irradiation**

**Decay Time**

**Measurements (HP Ge  
detector)**

**Gamma-Ray spectra processing  
(Genie2000)**

**Determination of Elemental Content**



# Processing of Gamma-Ray Spectra

**A full computer spectrum analysis includes 3 steps**

- 1. Set up data libraries for energy, peak width and efficiency calibration and for sample analysis.**
- 2. Use spectra of reference sources to generate energy, width and efficiency calibration data files**
- 3. Analyze sample spectra by referring to those data libraries and calibration files.**



# Genie2000

Gamma - TEST\_SPC.CNF

File MCA Calibrate Display Analyze Edit Options Datasource Help

Idle Channel: 270 : 138.7 keV Counts: 232 Preset: 0/1000.00

Acquire

Start Stop

Expand Off

Clear

ROI Index:

- +

Datasource

Prev Next

VFS = 4K

TIME INFO

Next

Prev

Acq. Start:	05/05/1983 08:53:00	Elapsed	Preset
Dead Time:	0.50%	Live (secs.):	1000.000
Comp. Preset Region:		Real (secs.):	1005.000
0 - 0 (channels)		Total (cnts.):	0.00

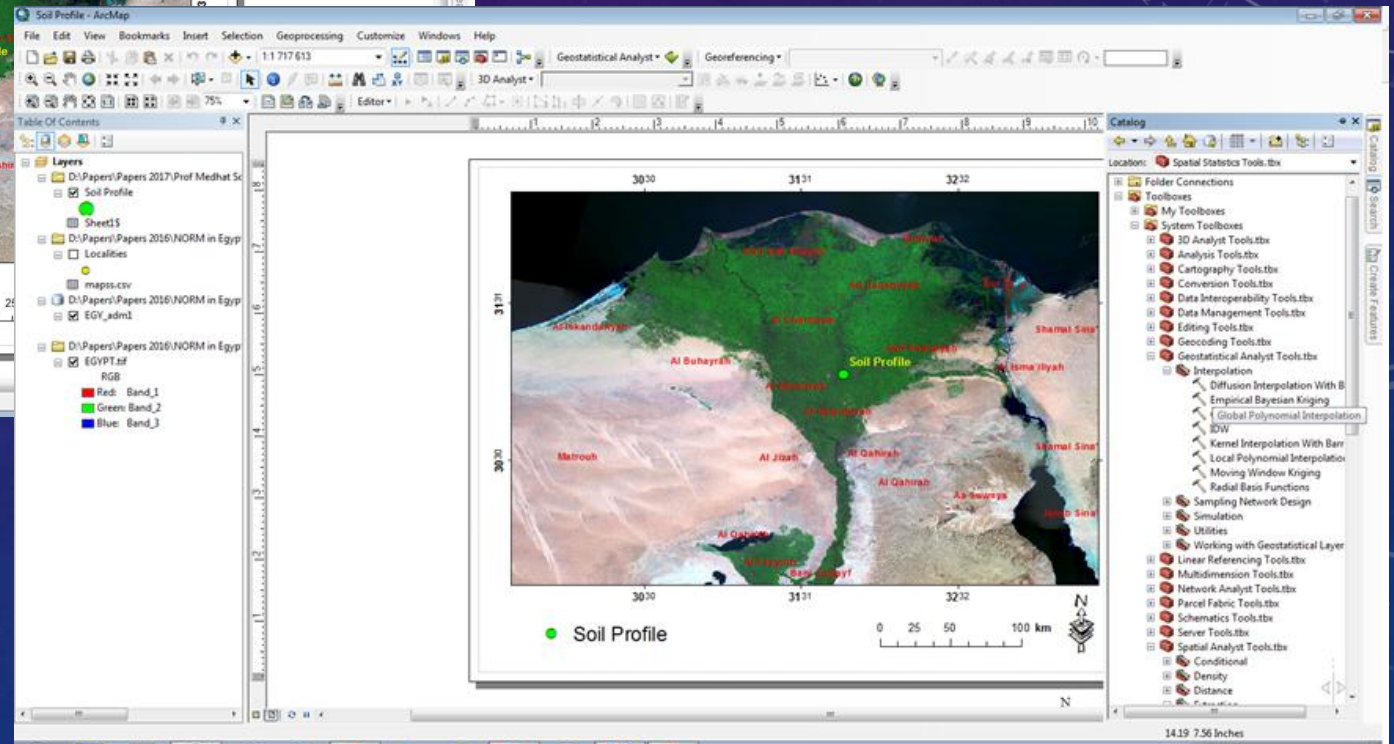
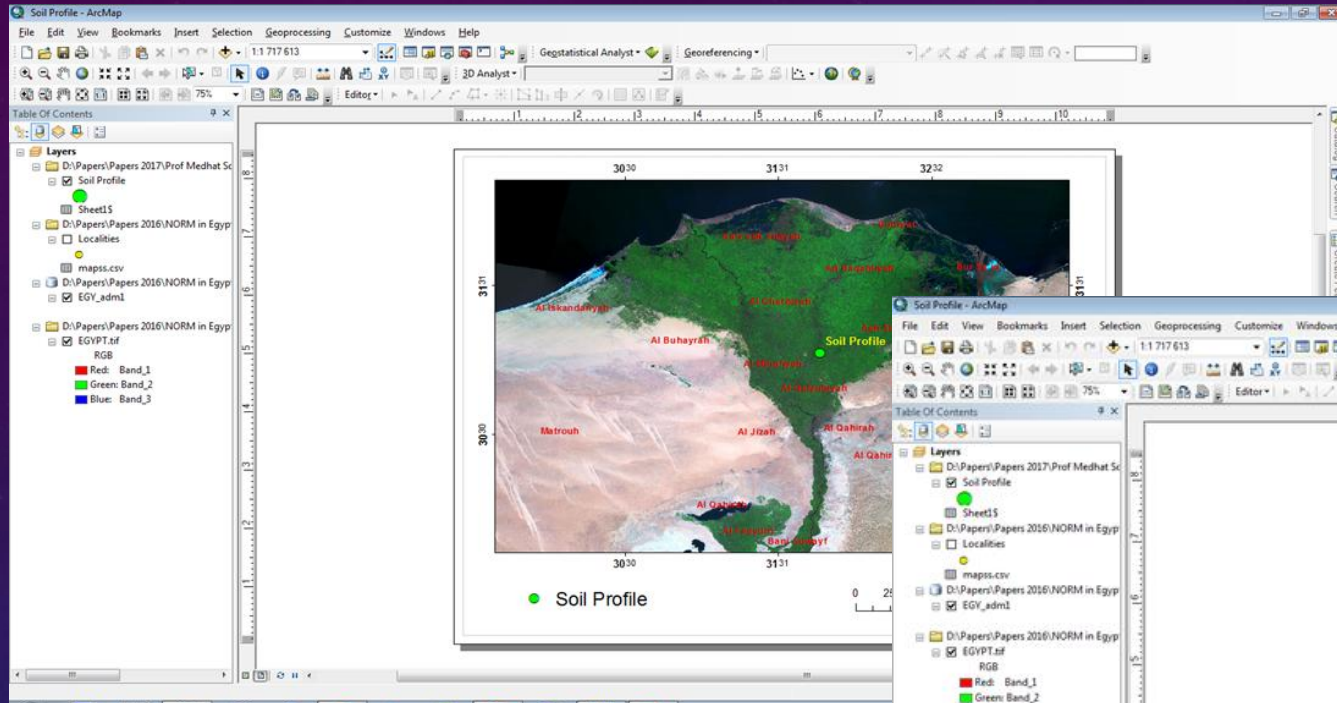
For Help, press F1

Execution Status: ready

# Most Common Programmes Used For Data Interpretation

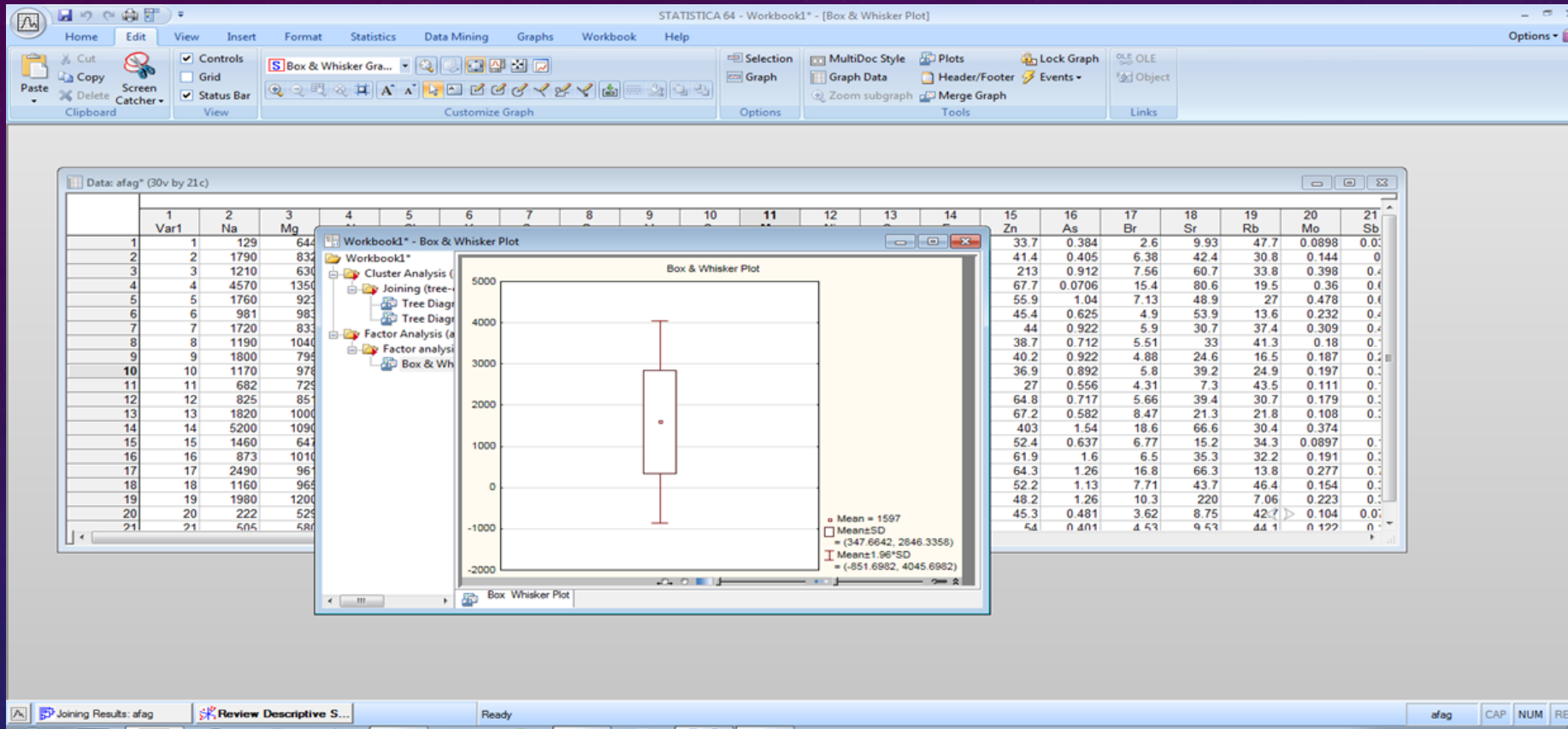
- ❖ **ArcGIS**
- ❖ **Statistica**
- ❖ **Origin-Lab**
- ❖ **CorelDraw**

# ArcGIS



## ❖ Spatial distribution maps

# Statistica



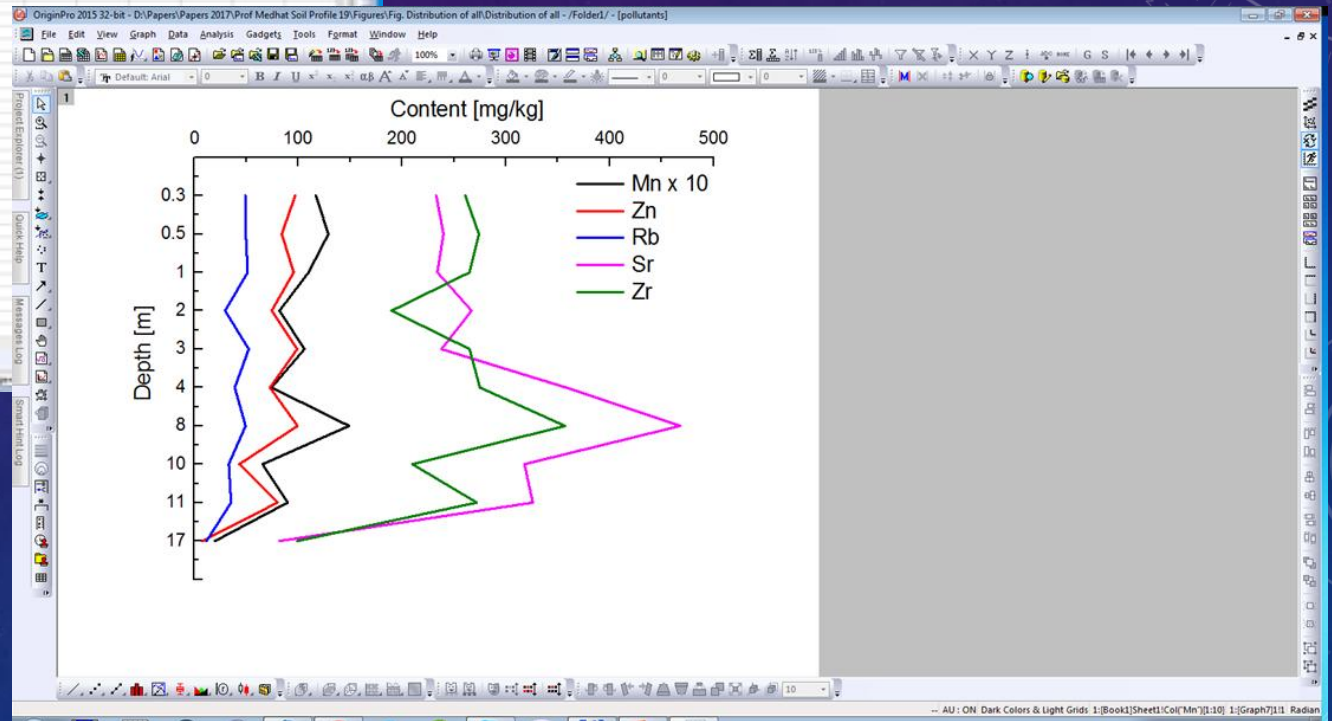
❖ Principal component analysis (PCA)

❖ Graphing

# Origin-Lab

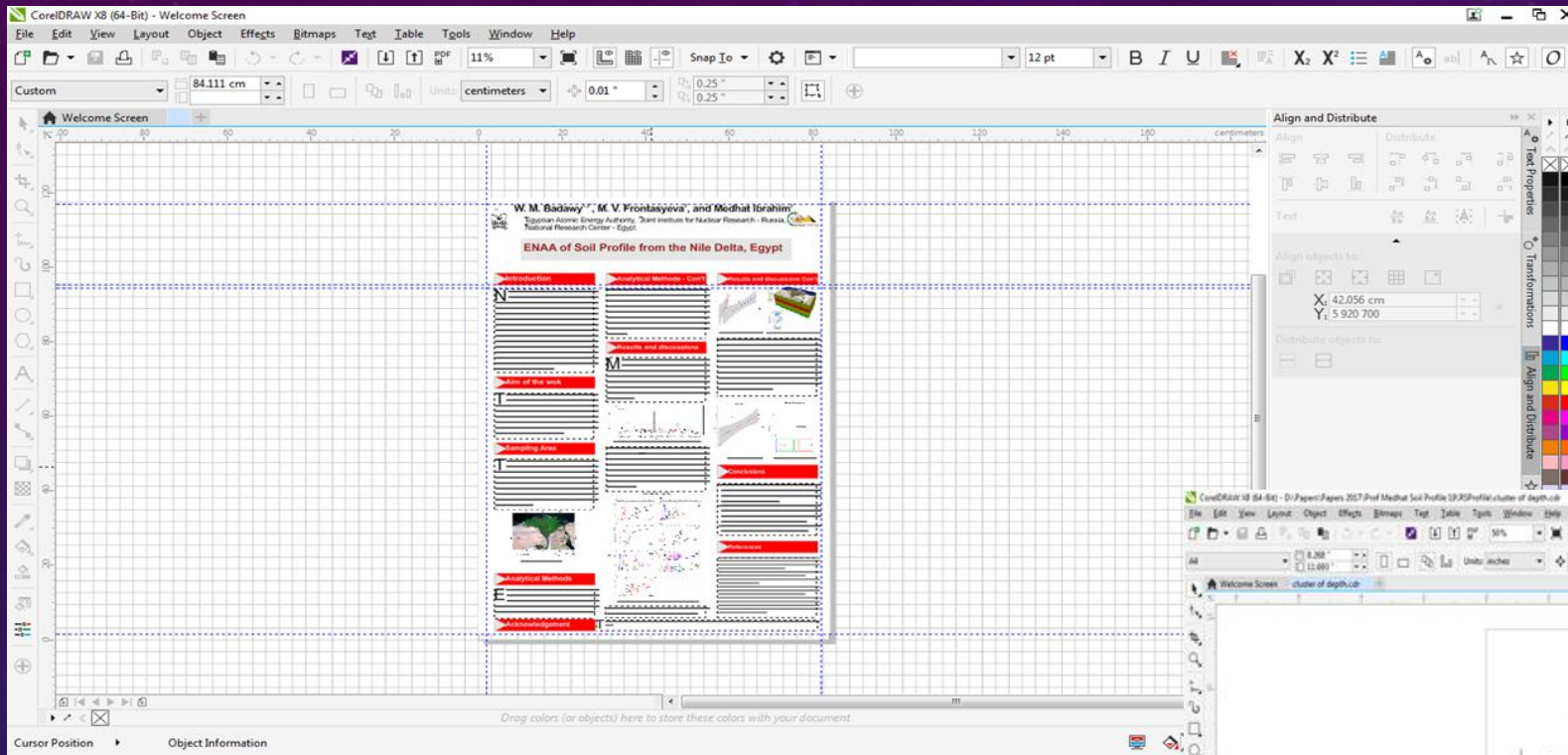
OriginPro 2015 32-bit - D:\Papers\Papers 2017\Prof Medhat Soil Profile 19\Figures\Fig. Distribution of all Distribution of all - /Folder1/ - (Elements)

Long Name	Cr	Hg	Mn	Ba	Ce	La	Co	Pb	Sm	Eu	Gd	Ta	Sr	Sm	Yb	Hf	Ta	Nb	Ti	U	Depth	
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	m
1	281	12.7	0.787	497	1.82	34.6	86.3	54.3	18	2.01	3.02	1.07	7.45	0.387	3.11	3.49	1.48	0.569	6.78	1.87	3.25	
2	274	12	0.894	391	1.89	35.9	88.8	46.3	18.4	2.27	2.73	1.07	19.5	0.34	3.17	3.605	1.56	0.139	6.18	1.87	6.5	
3	285	15	1.17	392	1.82	35.5	87.5	24.9	18.4	2.3	2.85	1.18	6.78	0.391	3.2	3.84	1.56	0.283	6.33	1.88	7	
4	190	8.78	0.490	417	0.74	25	34.9	19.9	10.5	1.58	2.02	0.892	6.52	0.264	2.58	2.735	0.904	0.071	2.88	0.877	2	
5	285	11.1	0.930	410	1.87	36	72.7	31.5	17.3	2.18	4.17	1.21	5.52	0.418	2.25	5.84	1.58	0.135	6.26	1.71	3	
6	275	11.8	0.804	889	3.024	22.1	49.4	27.8	12.2	5.89	3.01	3.824	6.1	0.405	1.89	3.705	0.928	0.5791	3.47	1.12	4	
7	385	14.8	0.769	749	1.22	32.2	96.6	49.9	18.5	2.35	1.8	1.1	10.1	0.419	3.77	5	1.38	0.4857	3.84	1.50	8	
8	210	10.2	0.438	584	0.531	18.3	32.5	18.8	9.74	1.41	2	0.802	3.89	0.305	2.98	2.87	0.84	0.3252	2.88	0.817	10	
9	272	11.4	0.384	534	0.808	23.6	44.4	27.8	12.1	0.919	2.84	0.781	4.27	0.275	2.98	3.82	0.972	0.3210	4.13	1.82	11	
10	99.2	3.7	0.0818	228	0.188	6.89	11.7	8.97	3.12	0.919	0.401	0.221	2.88	0.118	0.813	1.18	0.172	0.0219	0.878	0.3	17	

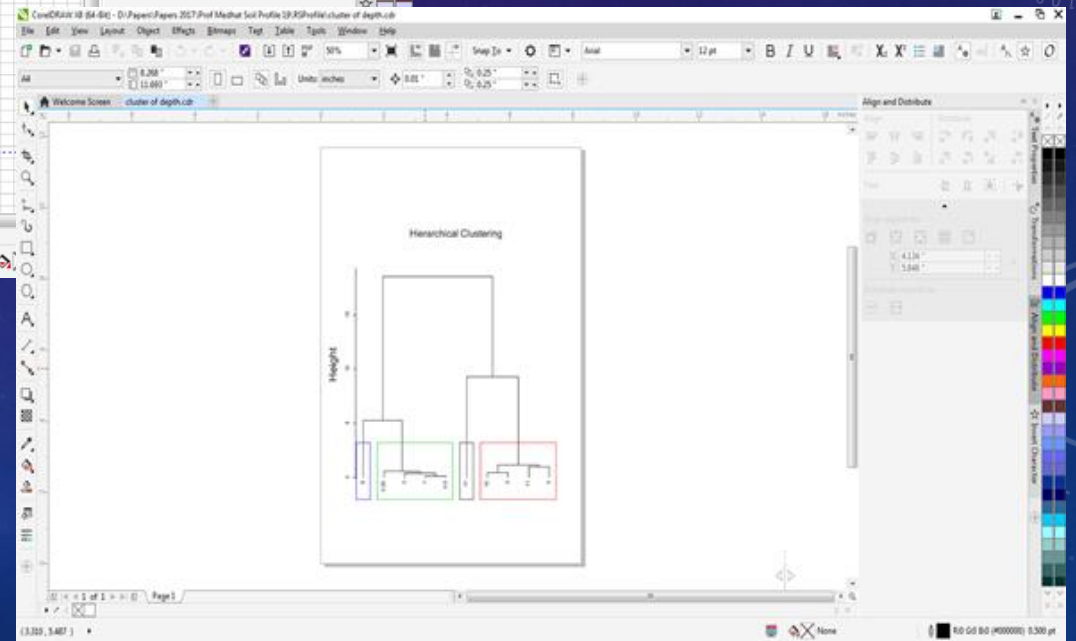


## ❖ Plotting and fitting

# CorelDraw



## ❖ Graphic management and posters

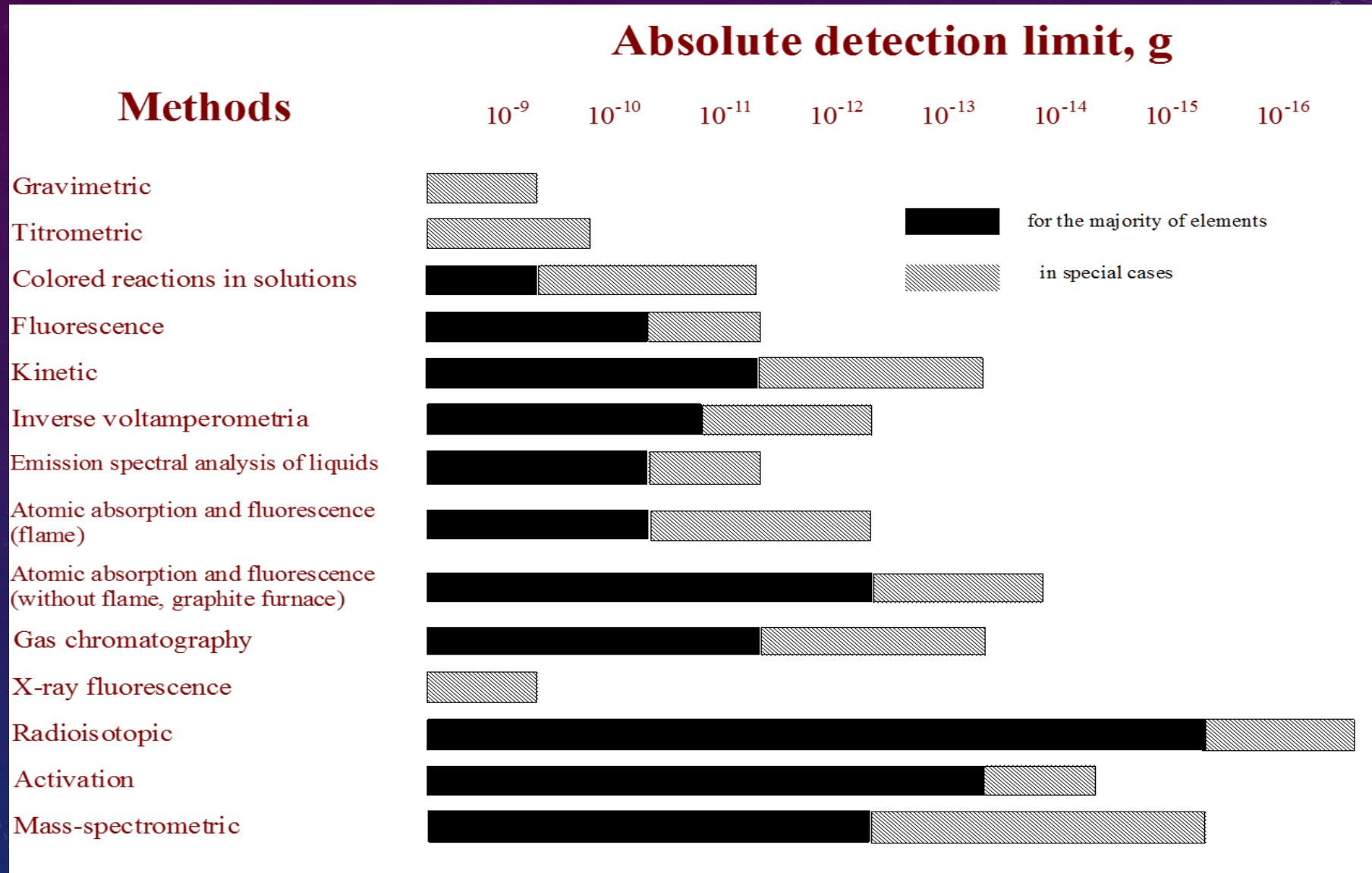


## NAA + AAS

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		

NAA ~ 55 elements  
 ~ 55 elements

# How Powerful is this Analytical Technique?





# Advantages

- ❖ **Primary Analytical Technique**
- ❖ **Wide possibilities of applications**
- ❖ **Non-destructive Analysis**
- ❖ **Multi-element Analysis**
- ❖ **High Sensitivity and Precision**
- ❖ **Limited sample handling**
- ❖ **Simultaneous identification of elements**
- ❖ **Low temperature operation (30-70°C)**
- ❖ **The Chemical form and Physical State of the Elements do not Influence the Activation and decay Process**

# ANALYTICAL INVESTIGATIONS AT IBR-2 REACTOR



## Life Sciences

- ❖ **Biomonitoring of atmospheric deposition of heavy metals and other elements (Project REGATA)**
- ❖ **Assessment of different ecosystems and their impact on human health**
- ❖ **Analysis of extraterrestrial materials**



## Material Science

- ❖ **NAA for technological process of synthesis of diamonds.**
- ❖ **Bio-nano-technologies: synthesis of nanoparticles (Ag, Au, Se, Ti, etc.).**
- ❖ **Materials of high purity.**
- ❖ **Analysis of archaeological and museum objects from Russia and other countries**

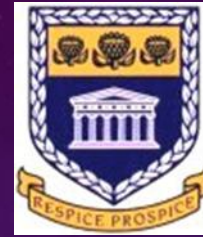
# OUTCOMES

- ❖ **Neutron Activation Analysis (NAA) is a useful method for the simultaneous determination of elemental composition of geological, environmental and biological samples in mg/kg range. It is a powerful analytical tool for monitoring and sustainability studies.**
- ❖ **Data analysis yields concentrations of major, minor, trace and rare earth elements.**
- ❖ **Multi-disciplinary applications (Physics, Chemistry, Biology, Ecology, Soil Science, Material Science, etc.)**
- ❖ **We have learned sample preparation for NAA in the Chemistry Lab. and have enriched our knowledge in this all-important field.**

# CAPACITY BUILDING

## Is this Programme Achieving its Purpose?

- ❖ **The aim of this practice is to expose South African students to scientific research and facilities of world class standard, manned by JINR.**
- ❖ **The practice provides South African students, who will transfer the nuclear technology, to support the development of the entire country.**



## **SA-JINR COLLABORATION FLNP PROJECTS SO FAR**

- ❖ **Atmospheric Deposition of Trace Elements in the Western Cape, South Africa, Studied with the Biomonitoring Technique, NAA, ICP-MS and GIS Technology**
- ❖ **Study on Levels of Priority Aquatic Pollutants in South African Cultivated Bivalve Mollusks (“The South African Mussel Watch”)**
- ❖ **Use of INAA to Determine Rare Earth Element Contents in Different Fresh and Weathered South African Fly Ash**
- ❖ **Elemental Composition of Fly Ash: A Comparative Study Using Nuclear and Related Analytical Techniques**

Chucks P. Eze, Olanrenwaju FATOBA, Godfrey MADZIVIRE, Tatyna OSTROVNAYA, Leslie F. PETRIK, Marina FRONTASYEVA and Alexander NECHAEV (2013)

# Acknowledgements

❖ **Prof. Marina V. Frontasyeva**

❖ **Dr. Wael Badawy**

**Also special thanks to all staff of the Neutron Activation Analysis and Applied Research Unit, Frank Laboratory of Neutron Physics.**

**WE LOVE YOU ALL!!!**

# THANK YOU FOR YOUR ATTENTION!



## Questions?

