INTRODUCTION TO NEUTRON ACTIVATION ANALYSIS AT THE IBR-2 REACTOR, FLNP JINR

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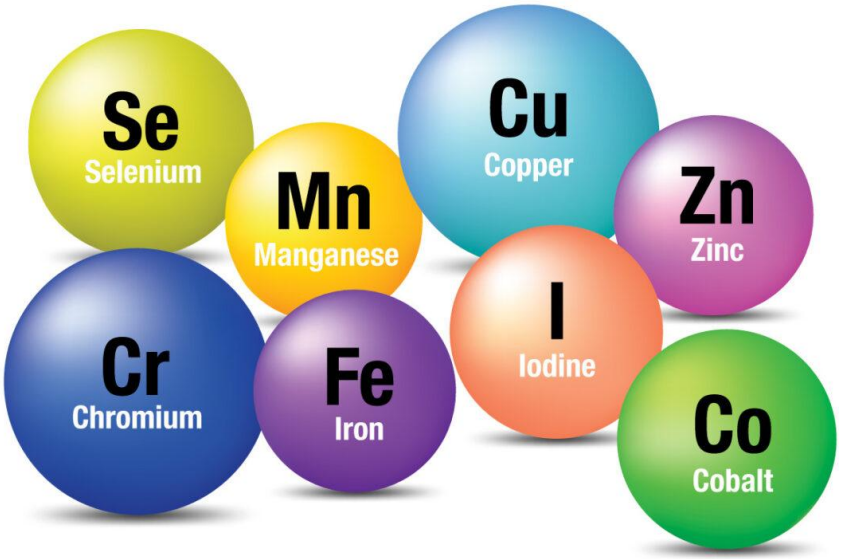
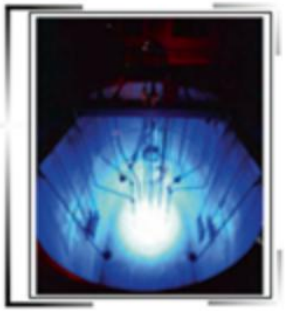
Elemental analysis



- geology
- environment
- materials science
- forensics
- archeology
- nanotechnology

Analytical techniques applied for element analysis

Neutron activation analysis (NAA)



Inductively coupled plasma mass spectrometry (ICP-MS)

Graphite furnace atomic absorption spectrometry (GFAAS)

Inductively coupled plasma optical emission spectrometry (ICP-OES)

Flame Atomic Absorption Spectroscopy (FAAS)

X-ray fluorescence (XRF)

0.01 0.1 1 10 100 1000 [ppm]

Comparison of elemental analysis techniques

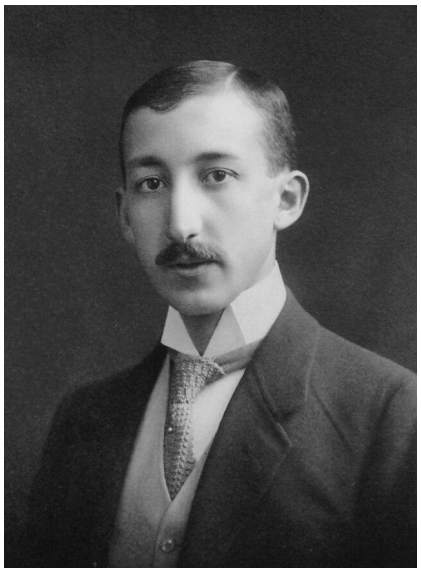
Method	Detectable elements	Sensitivity*
ICP-OES/MS/SFMS	Li to U	ppm to ppt
NAA	H to U	ppm to ppt
AAS	Mainly metallic elements, up to 70 elements	ppm
CHNOS	C, H, N, O, S	0.05–0.1 wt%
XRF	Be to U	10 ppm–1 at%
SEM-EDX	All except H, He, and Li	0.1–1 at%
ERDA	H to U	0.1–0.5 at.%
RBS	Be to U	0.1 at%

https://measurlabs.com/blog/elemental-analysis-applications-and-method-comparison/

Neutron activation analysis

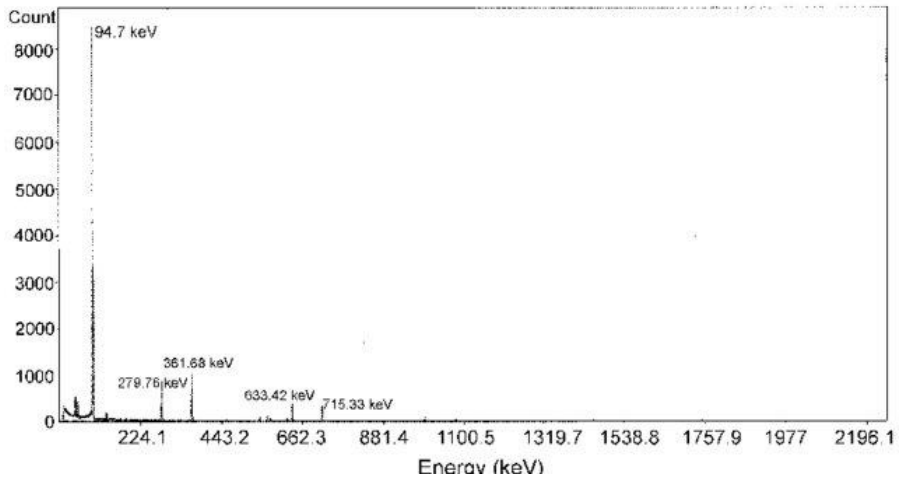
Neutron activation analysis was first developed by G. Hevesy and H. Levi in 1936. They used a neutron source (226Ra + Be) and a radiation detector (ionization chamber) and promptly recognized that the element Dy (dysprosium) in the sample became highly radioactive after exposure to the neutron source.

$$^{4}He + ^{9}Be \rightarrow ^{12}C + ^{1}n$$



George de Hevesy

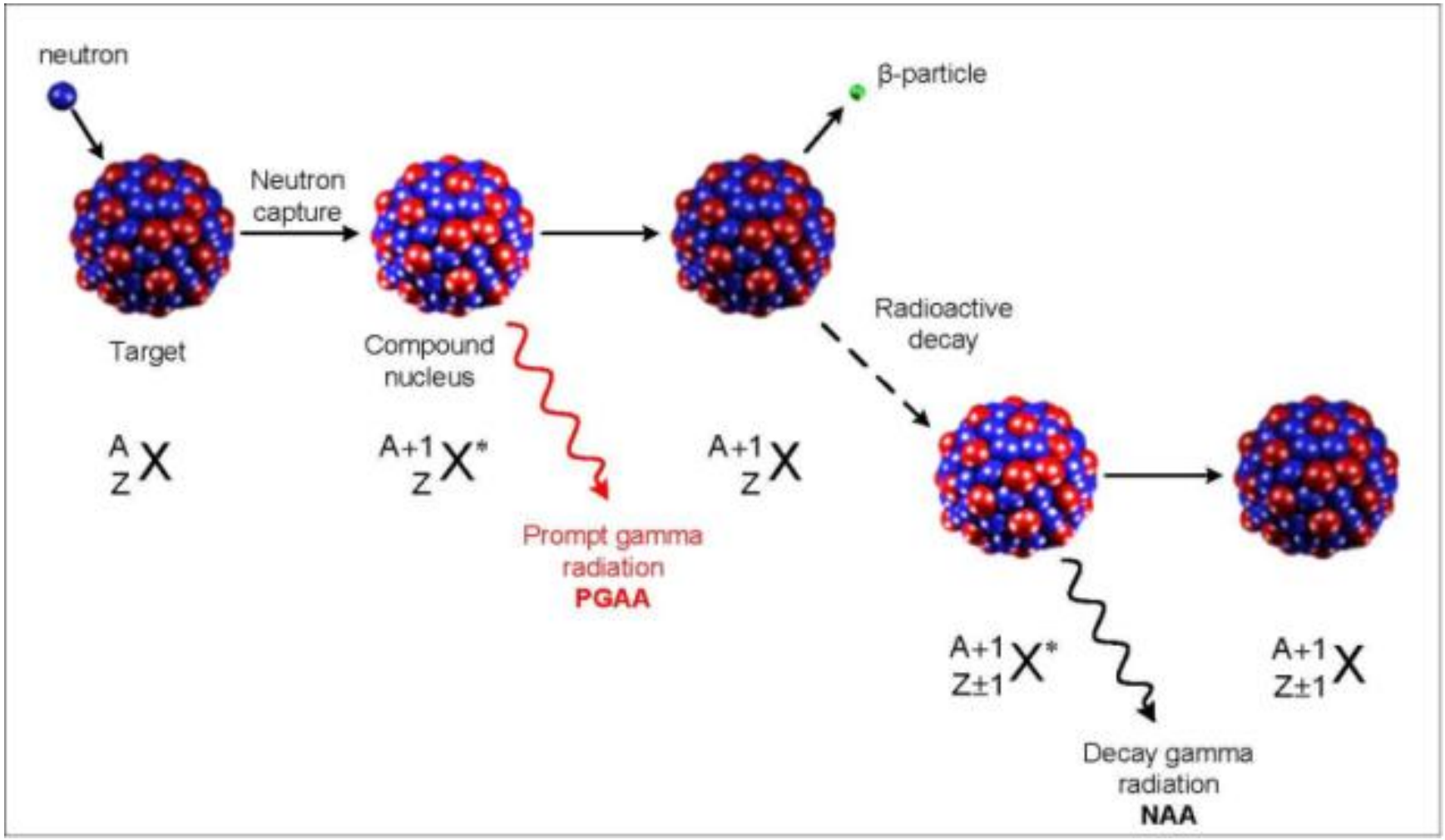
Hilde Levi



Gamma spectrum of dysprosium-165

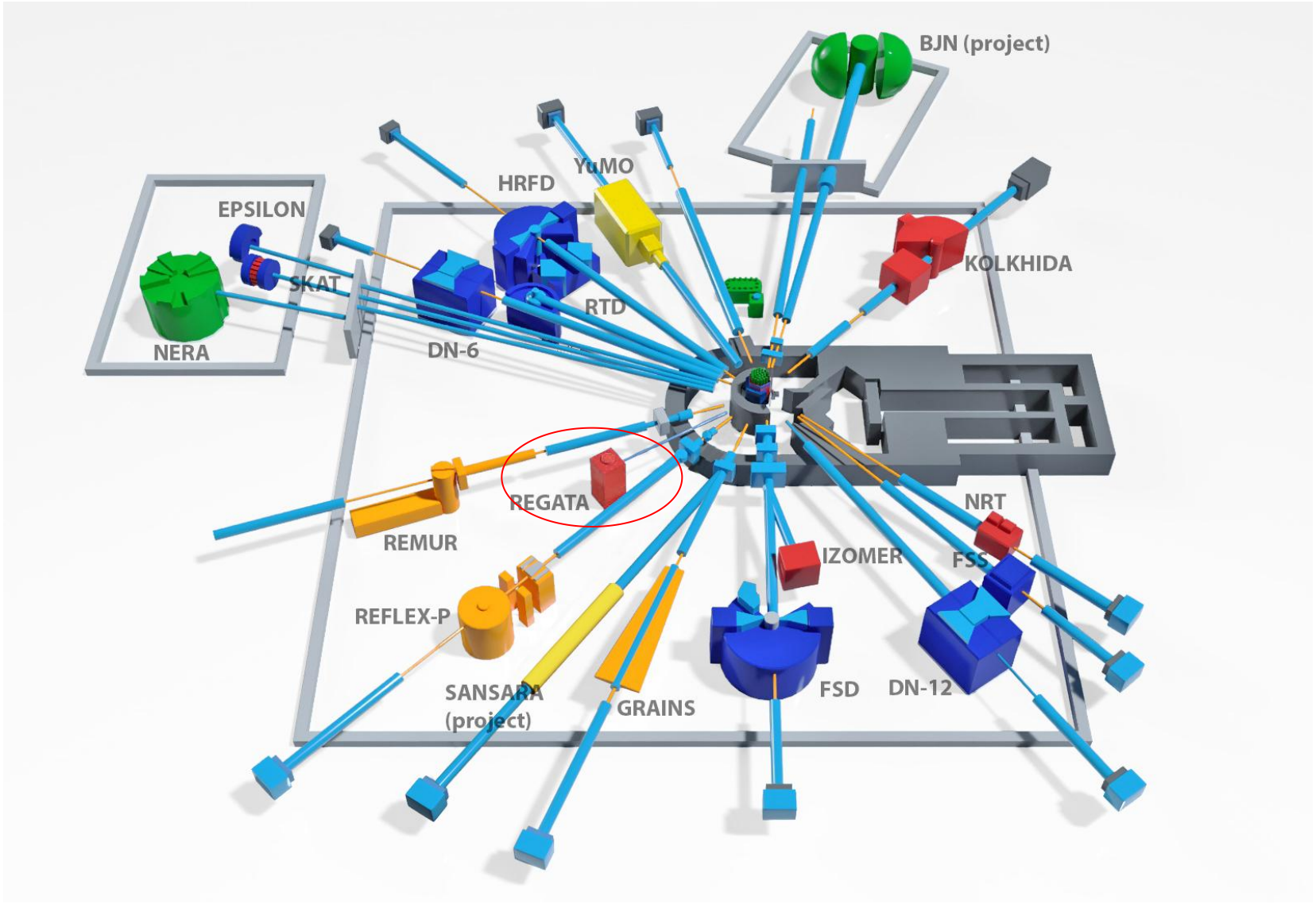
G. Hevesy, Hilde Levi, The Action of Neutrons on the Rare Earth Elements, Det. Kgl. Danske Videnskabernes Selskab, Mathematisk-fysiske Meddelelser XIV, 5 (1936) 3–34

Diagram illustrating the process of neutron capture by a target nucleus followed by the emission of gamma rays

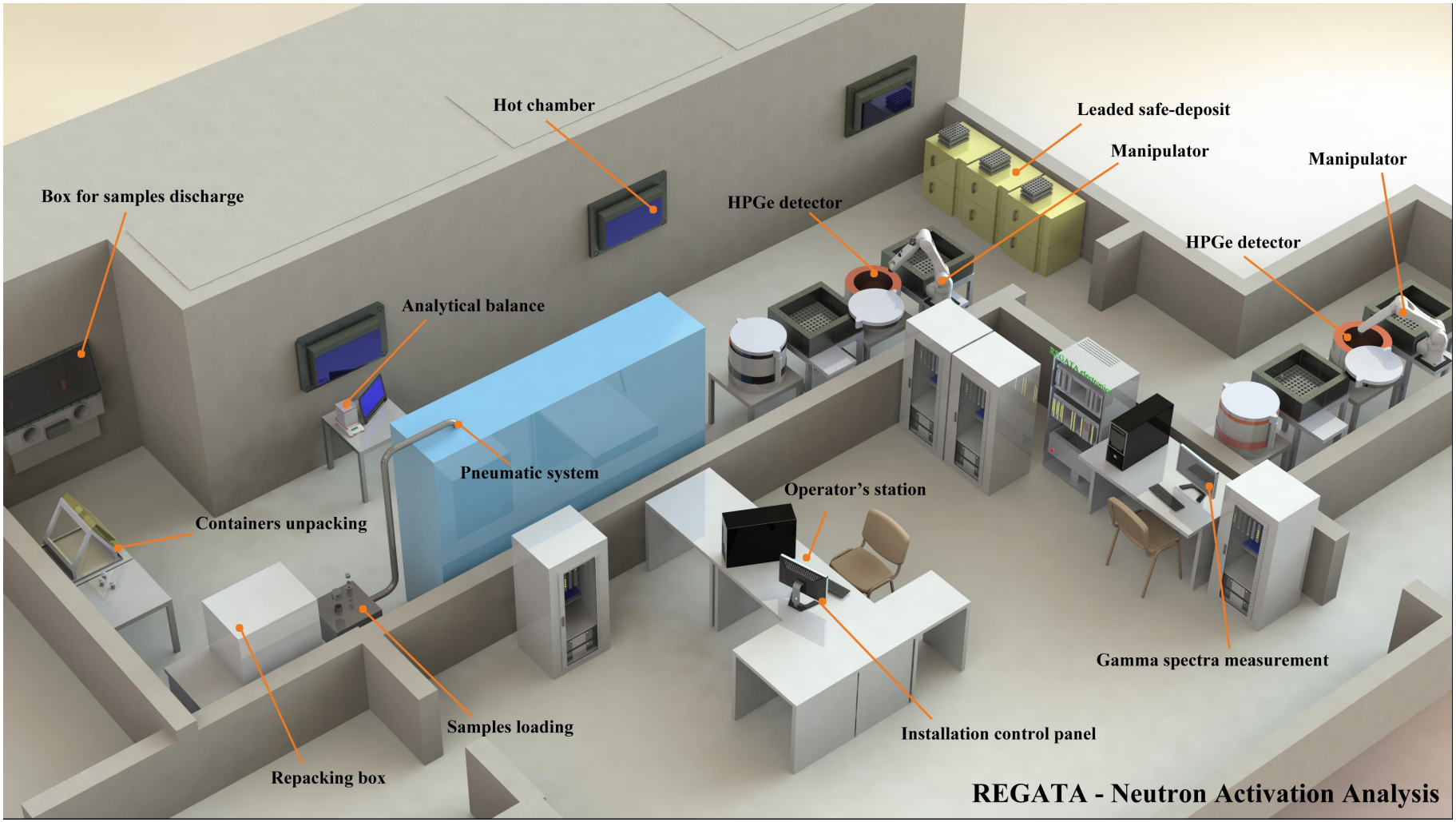


The most common reaction occurring in NAA is the (n,γ) reaction, but also reactions such as (n,p), (n,α), (n,n′) and (n,2n) are important.

Reactor and Radioanalytical complex REGATA



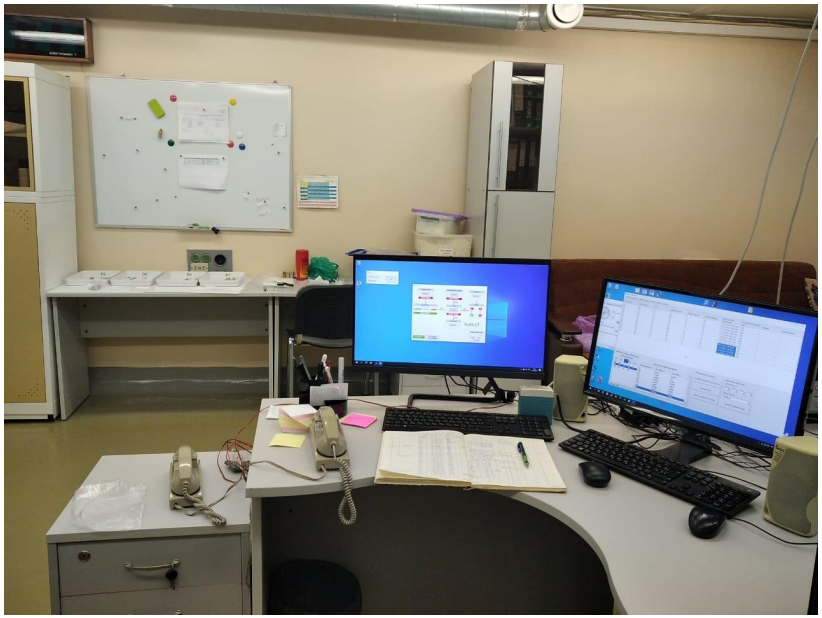
Reactor and Radioanalytical complex REGATA

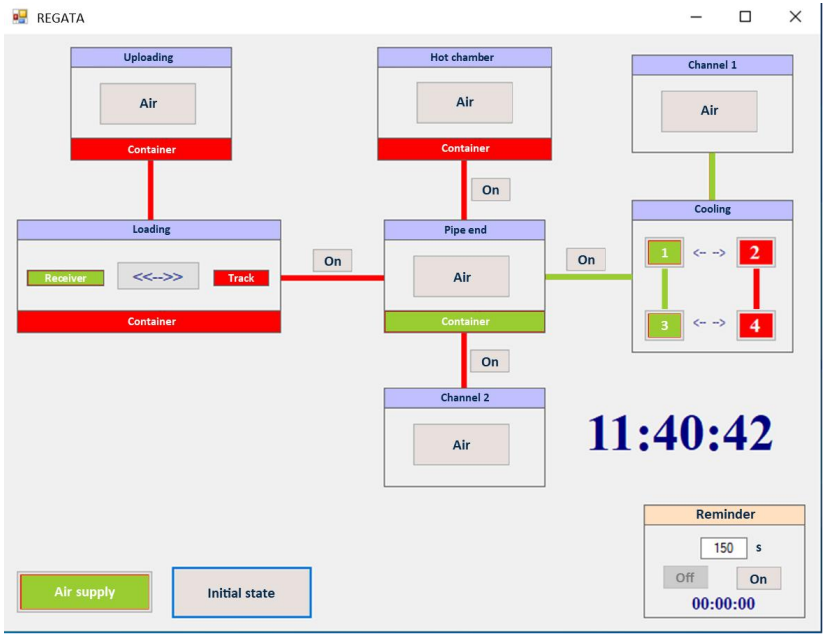


2 channels for irradiations, one with Cd shield.

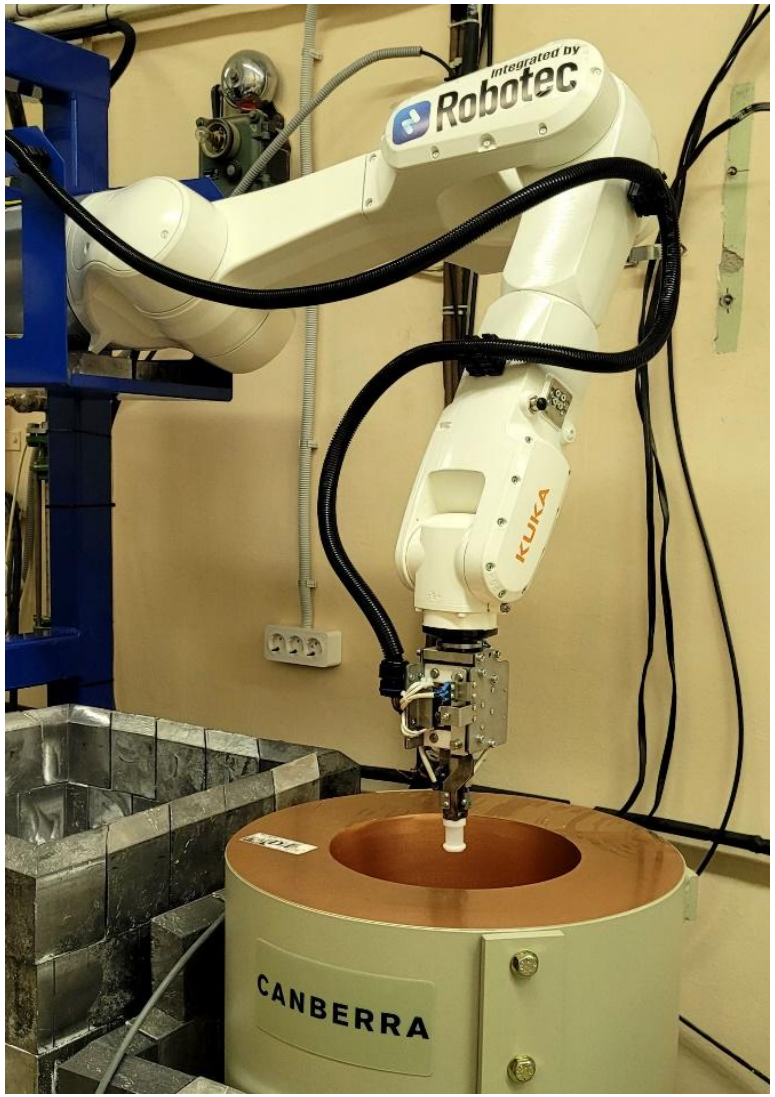
Thermal neutrons flux: ~ 10^{12} n/cm^2·s

Resonance neutrons flux: ~ 10^{11} n/cm^2·s





Regata Control program interface



Left photo: KUKA KR 10 R1100 manipulator mounted on a stand.
Right photo: Manipulator gripper and cassette holder with containers

Procedures of samples irradiation

Short irradiation

Mg, Al, Si, Cl, I, Ti, V, Cu, Mn, Ca, S and Dy

- ✓ Irradiation channel: Ch 2 (full neutron spectrum)
- ✓ Weight of samples: 0.05-0.5 gram
- ✓ Irradiation time: 1- 30 min

Long irradiation

Na, K, Sc, Cr, Fe, Co, Ni, Zn, Ga, As, Se, Mo, In, Sn, Br, Rb, Sr, Zr, Sb, Cs, Ba, Ag, Cs, La, Ce, Sm, Tb, Hf, Ta, Nd, Nb, Y, Yb, W, Re, Ir, Hg, Au, Th and U

- ▶ Irradiation channel: Ch 1 (Cd- screen, epithermal and fast neutrons)
- ▶ Weight of samples: 0.05-0.5 gram
- ▶ Irradiation time: 3- 5 days
- ▶ Cooling -3.5 days/ Repacking
- ▶ First measurement- 30 min, directly after repacking
- ▶ Cooling time – 20 days after the end of irradiation/ Second measurement – 2.0 hours

Certification of the methodology of INAA

ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ БЮДЖЕТНОЕ УЧРЕЖДЕНИЕ
«ВСЕРОССИЙСКИЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ МИНЕРАЛЬНОГО СЫРЬЯ им. Н.М. ФЕДОРОВСКОГО» (ФГБУ «ВИМС»)
119017, г. Москва, Старомонетный пер., д.31
аттестат аккредитации в области обеспечения единства измерений № 01.00115-2013

СВИДЕТЕЛЬСТВО

об аттестации методики (метода) измерений

№ 348/2021-01.00115-2013

Определение содержаний (массовой доли) химических элементов (Na, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Sr, Rb, Sb, Cs, Ba, La, Ce, Tb, Hf, Ta, Th, U) в твердых объектах окружающей среды и технологических сред инструментальным нейтронно-активационным методом

Разработчик

Международная межправительственная организация «Объединенный институт ядерных исследований (ОИЯИ)»

Российская Федерация, 141980, Московская область, Дубна, ул. Жолио-Кюри 6

Обозначение

МП ОИЯИ 01-2021. Определение содержаний (массовой доли) химических элементов (Na, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Sr, Rb, Sb, Cs, Ba, La, Ce, Tb, Hf, Ta, Th, U) в твердых объектах окружающей среды и технологических сред инструментальным нейтронно-активационным методом, 2021 г., на 32 листах

аттестована в соответствии с Приказом Минпромторга № 4091 от 15 декабря 2015 года и ГОСТ Р 8.563-2009.

Аттестация осуществлена: по результатам экспертизы, теоретических и экспериментальных исследований, выполненных при разработке методики (метода) измерений

В результате аттестации установлено, что методика соответствует предъявляемым к ней метрологическим требованиям и обладает основными метрологическими характеристиками, приведенными в приложении к настоящему свидетельству.

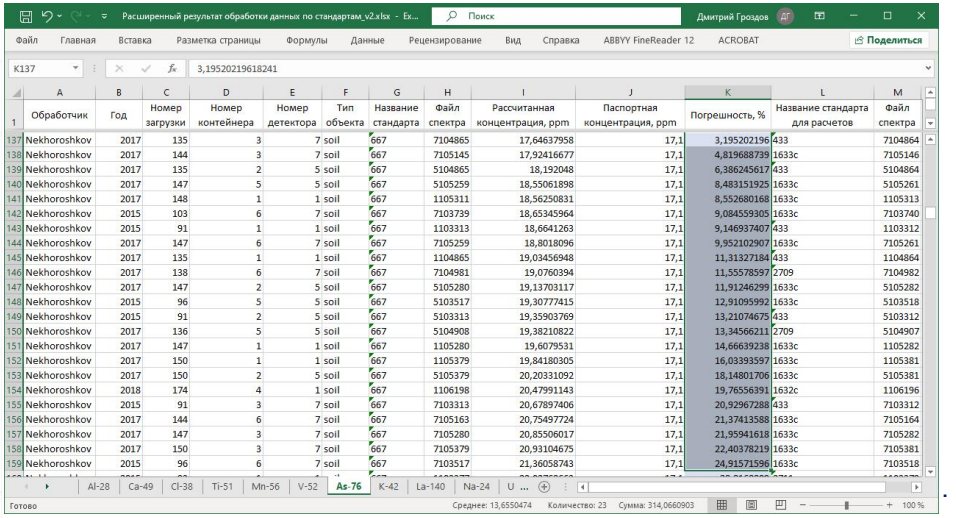
Метрологические характеристики методики (метода) измерений приведены в Приложении №1 к свидетельству (на 6 листах).

Бюджет неопределенности приведен в Приложении №2 к свидетельству (на 6 листах).

Дата выдачи свидетельства: « 31 » мая 2021 г.

Первый заместитель генерального директора по основной деятельности ФГБУ «ВИМС» А.А. Рогожин

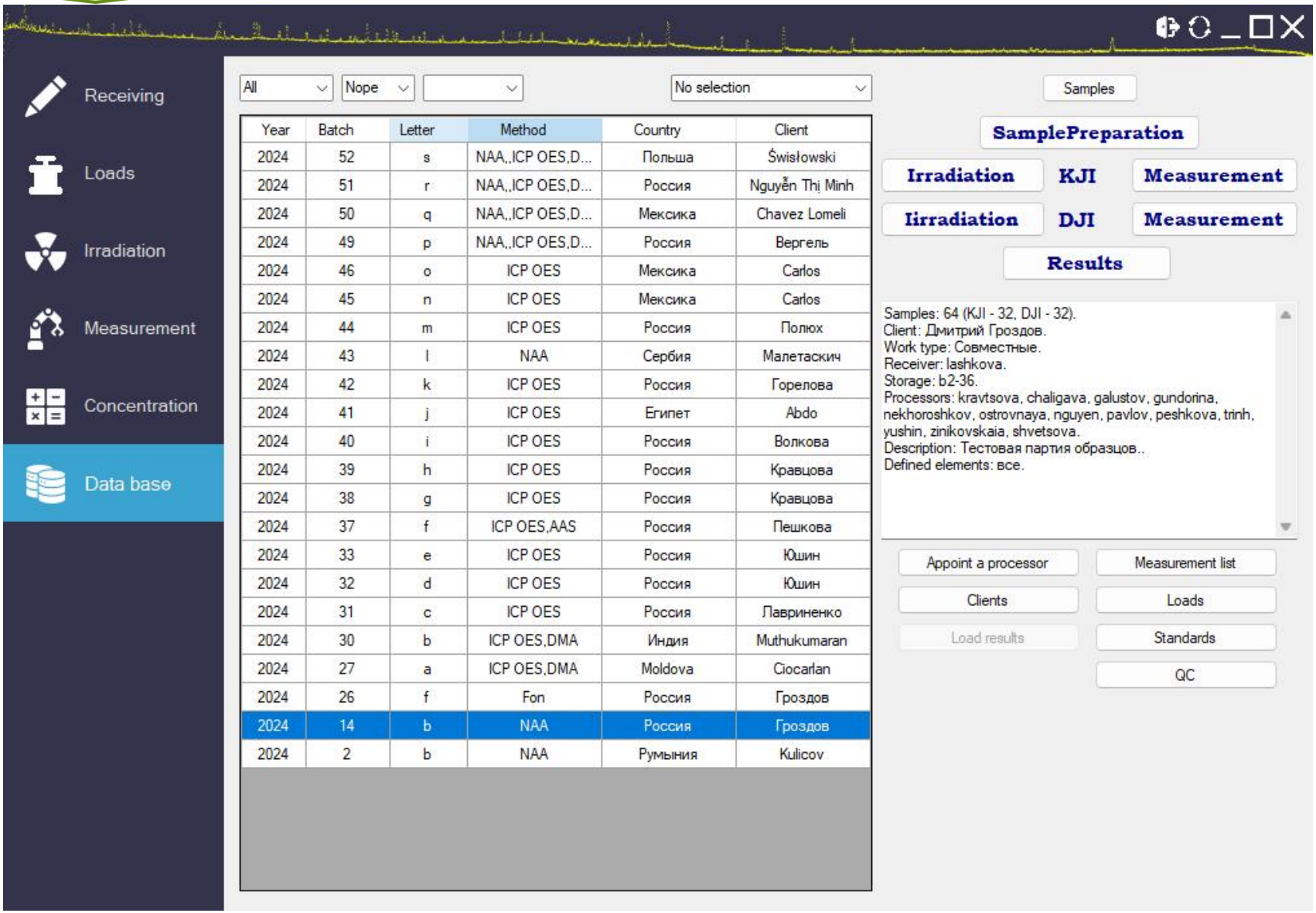
Главный метролог ФГБУ «ВИМС» М.И. Лебедева



Обработчик	Год	Номер загрузки	Номер контейнера	Номер детектора	Тип объекта	Название стандарта	Файл спектра	Рассчитанная концентрация, ppm	Паспортная концентрация, ppm	Погрешность, %	Название стандарта для расчетов	Файл спектра
Nekhoroshkov	2017	135	3	7	soil	667	7104865	17,64637958	17,1	3,195202196	433	7104864
Nekhoroshkov	2017	144	3	7	soil	667	7105145	17,92416677	17,1	4,819688739	1633c	7105146
Nekhoroshkov	2017	135	2	5	soil	667	5104865	18,192048	17,1	6,386245617	433	5104864
Nekhoroshkov	2017	147	5	5	soil	667	5105259	18,55061898	17,1	8,483151925	1633c	5105261
Nekhoroshkov	2017	148	1	1	soil	667	1105311	18,56250831	17,1	8,552680168	1633c	1105313
Nekhoroshkov	2015	103	6	7	soil	667	7103739	18,65345964	17,1	9,084559305	1633c	7103740
Nekhoroshkov	2015	91	1	1	soil	667	1103313	18,6641263	17,1	9,146937407	433	1103312
Nekhoroshkov	2017	147	6	7	soil	667	7105259	18,8018096	17,1	9,952102907	1633c	7105261
Nekhoroshkov	2017	135	1	1	soil	667	1104865	19,03456948	17,1	11,31327184	433	1104864
Nekhoroshkov	2017	138	6	7	soil	667	7104981	19,0760394	17,1	11,55578597	2709	7104982
Nekhoroshkov	2017	147	2	5	soil	667	5105280	19,13703117	17,1	11,91246299	1633c	5105282
Nekhoroshkov	2015	96	5	5	soil	667	5103517	19,30777415	17,1	12,91095992	1633c	5103518
Nekhoroshkov	2015	91	2	5	soil	667	5103313	19,35903769	17,1	13,21074675	433	5103312
Nekhoroshkov	2017	136	5	5	soil	667	5104908	19,38210822	17,1	13,34566211	2709	5104907
Nekhoroshkov	2017	147	1	1	soil	667	1105280	19,6079531	17,1	14,66639238	1633c	1105282
Nekhoroshkov	2017	150	1	1	soil	667	1105379	19,84180305	17,1	16,03393597	1633c	1105381
Nekhoroshkov	2017	150	2	5	soil	667	5105379	20,20331092	17,1	18,14801706	1633c	5105381
Nekhoroshkov	2018	174	4	1	soil	667	1106198	20,47991143	17,1	19,76556391	1632c	1106196
Nekhoroshkov	2015	91	3	7	soil	667	7103313	20,67897406	17,1	20,92967288	433	7103312
Nekhoroshkov	2017	144	6	7	soil	667	7105163	20,75497724	17,1	21,37413588	1633c	7105164
Nekhoroshkov	2017	147	3	7	soil	667	7105280	20,85506017	17,1	21,95941618	1633c	7105282
Nekhoroshkov	2017	150	3	7	soil	667	7105379	20,93104675	17,1	22,40378219	1633c	7105381
Nekhoroshkov	2015	96	6	7	soil	667	7103517	21,36058743	17,1	24,91571596	1633c	7103518

Показатель	Диапазон измерений, млн$^{-1}$ (мг/кг)	Показатель внутрилабораторной прецизионности в относительных единицах $\sigma_{Rл}$, %
Na	100-1000	26,0
	1000-40000	11,5
	40000-500000	3,86
Al	1000-500000	19,3
Cl	1000-5000	11,2
K	1000-3000	20,5
	3000-30000	14
	30000-100000	8,08
Ca	1000-15000	18,8
	15000-35000	11,4
	35000-400000	10,1
Sc	1,0-50	11,4
Ti	100-1000	17,9
	1000-10000	15,3
	10000-20000	6,78
V	10,0-50	17,3
	50-500	13,6
Cr	10-100	27,2
	100-500	15,6

Software of the SNAAPI



Year	Batch	Letter	Method	Country	Client
2024	52	s	NAA,,ICP OES,D...	Польша	Świsłowski
2024	51	r	NAA,,ICP OES,D...	Россия	Nguyễn Thị Minh
2024	50	q	NAA,,ICP OES,D...	Мексика	Chavez Lomeli
2024	49	p	NAA,,ICP OES,D...	Россия	Вергель
2024	46	o	ICP OES	Мексика	Carlos
2024	45	n	ICP OES	Мексика	Carlos
2024	44	m	ICP OES	Россия	Полюх
2024	43	l	NAA	Сербия	Малетаскич
2024	42	k	ICP OES	Россия	Горелова
2024	41	j	ICP OES	Египет	Abdo
2024	40	i	ICP OES	Россия	Волкова
2024	39	h	ICP OES	Россия	Кравцова
2024	38	g	ICP OES	Россия	Кравцова
2024	37	f	ICP OES,AAS	Россия	Пешкова
2024	33	e	ICP OES	Россия	Юшин
2024	32	d	ICP OES	Россия	Юшин
2024	31	c	ICP OES	Россия	Лавриненко
2024	30	b	ICP OES,DMA	Индия	Muthukumaran
2024	27	a	ICP OES,DMA	Moldova	Ciocarlan
2024	26	f	Fon	Россия	Гроздов
2024	14	b	NAA	Россия	Гроздов
2024	2	b	NAA	Румыния	Kulicov

Scientific directions

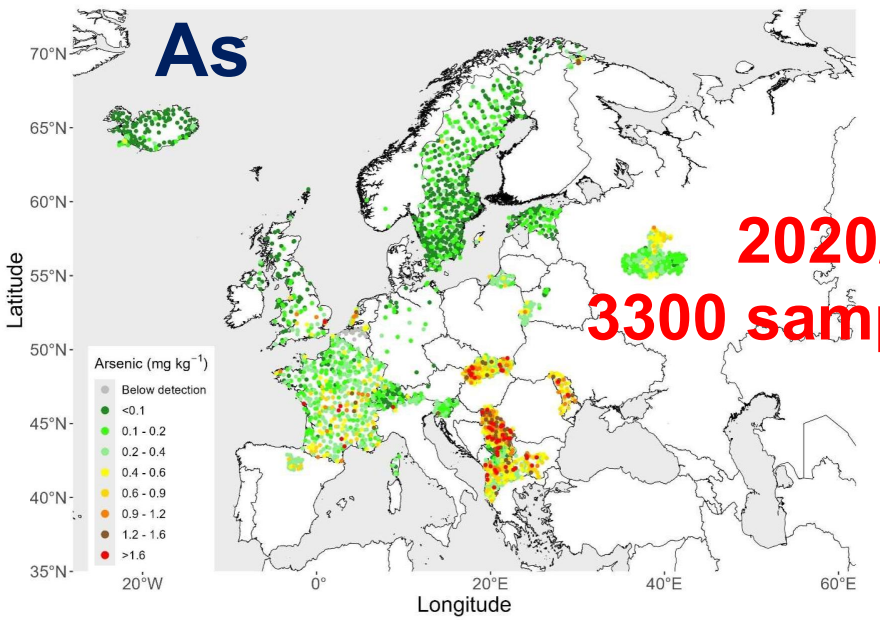
Passive biomonitoring

UNECE

United Nations Economic Commission for Europe

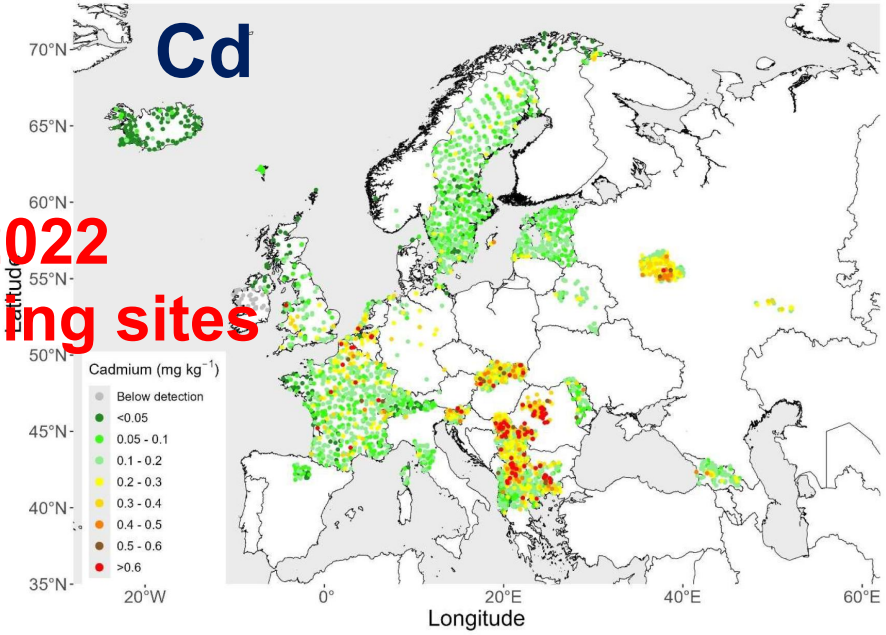
International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops

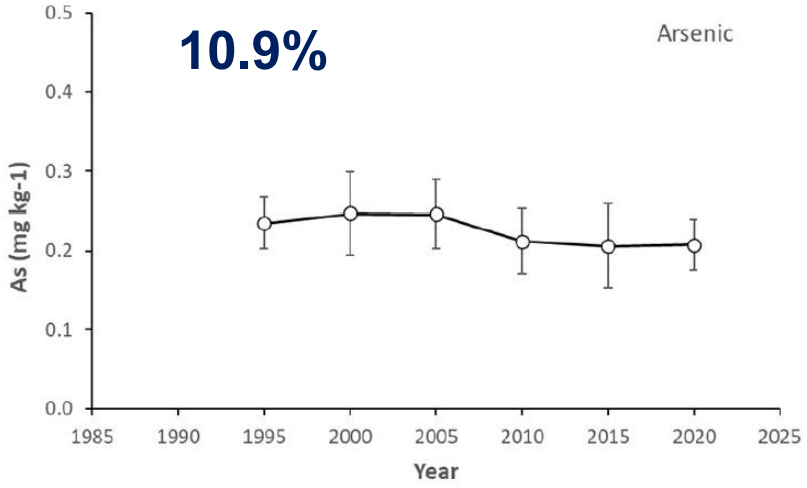
Working **G**roup on **E**ffects - 1981

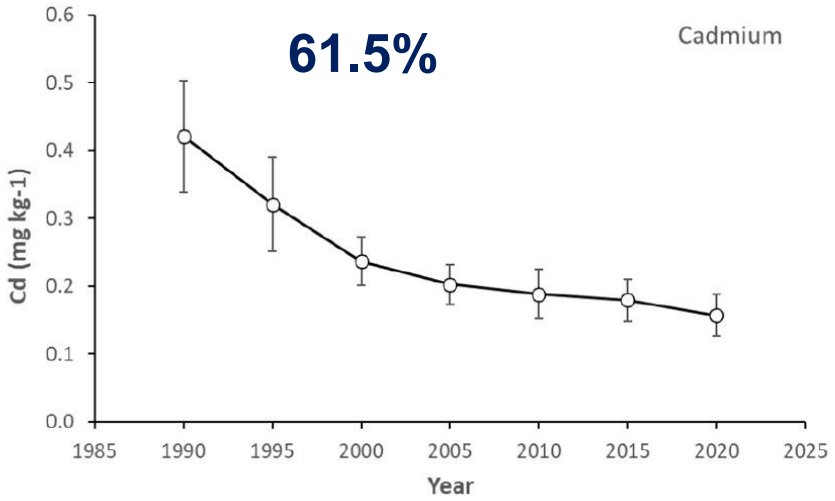


2020/2022

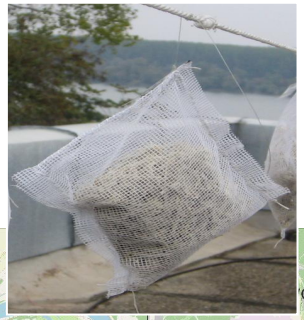
3300 sampling sites

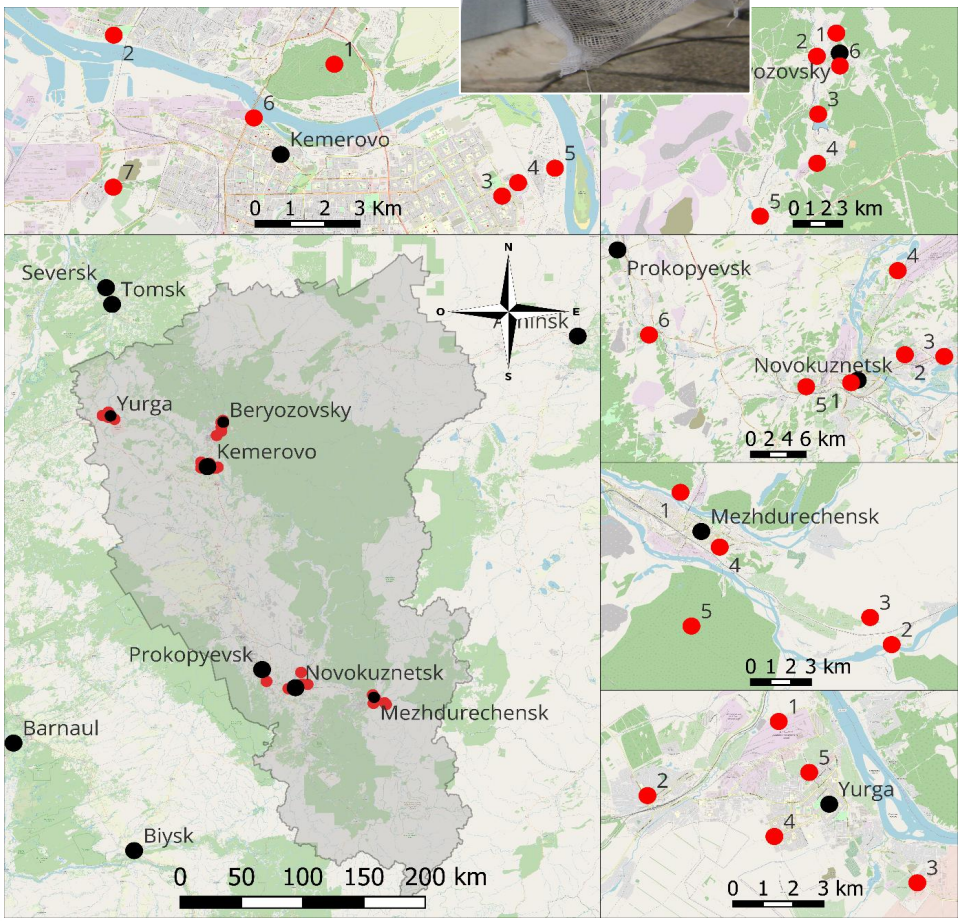




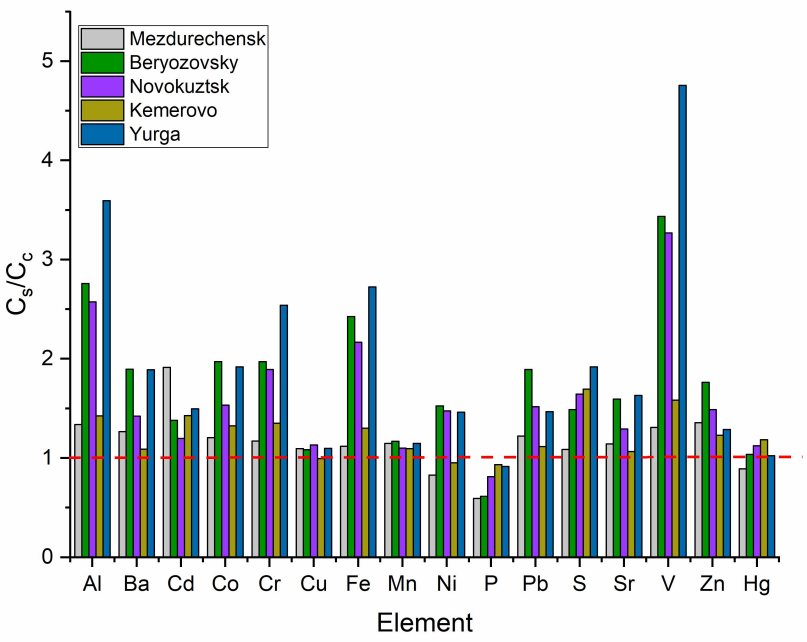


Active biomonitoring

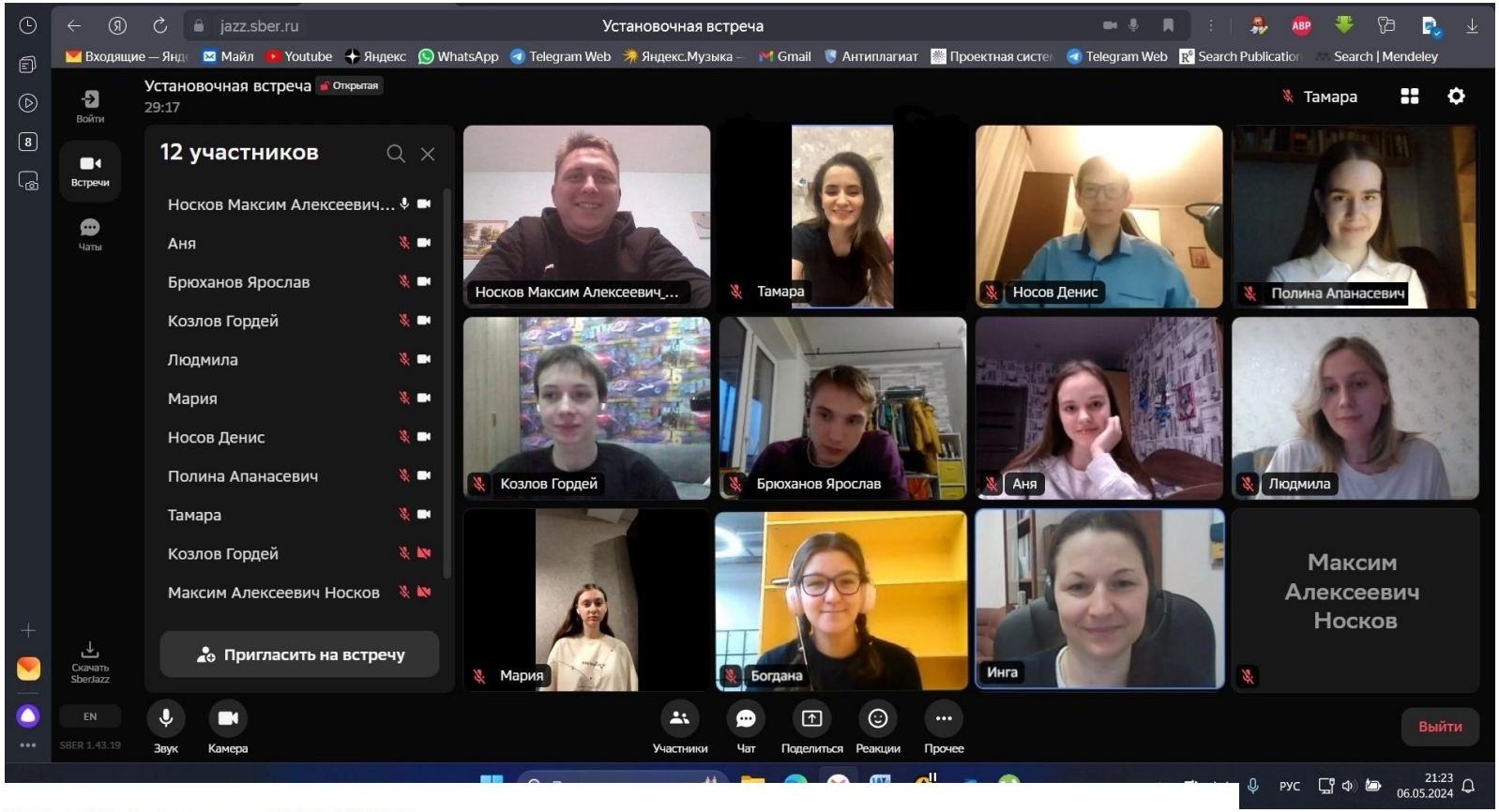




Map of samples exposure in Kemerovo region



Content of the elements in exposed moss samples compared to control



Environ Monit Assess (2025) 197:158
https://doi.org/10.1007/s10661-024-13439-8

RESEARCH

Application of active biomonitoring technique for the assessment of air pollution by potentially toxic elements in urban areas in the Kemerovo Region, Russia

Inga Zinicovscaia · Nikita Yushin · Alexandra Peshkova · Maxim Noskov · Vladislav Koshelev · Denis Nosov · Bogdana Maksimova · Anna Dyakova · Polina Apanasevich · Ekaterina Dmitrieva

Assessment of water pollution

Namibia

Mozambique

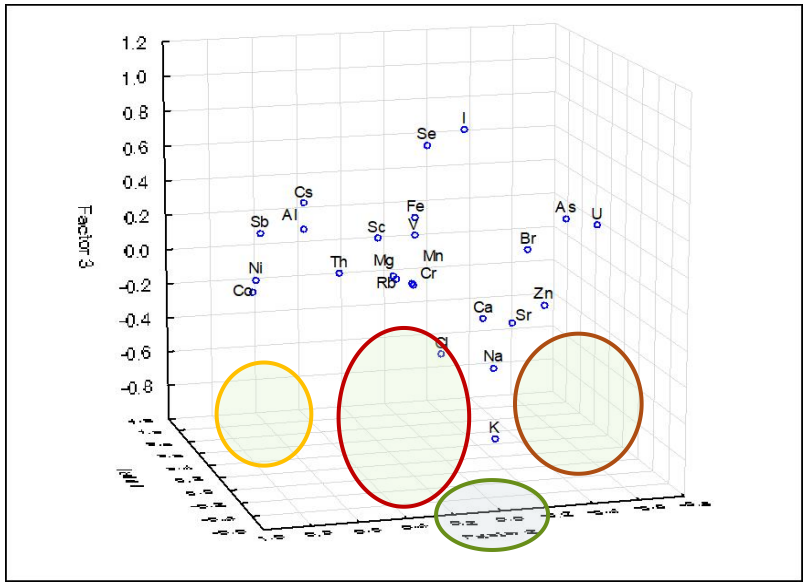
25 stations along South Africa

Saldanha Bay

KwaZulu-Natal

Cape Town

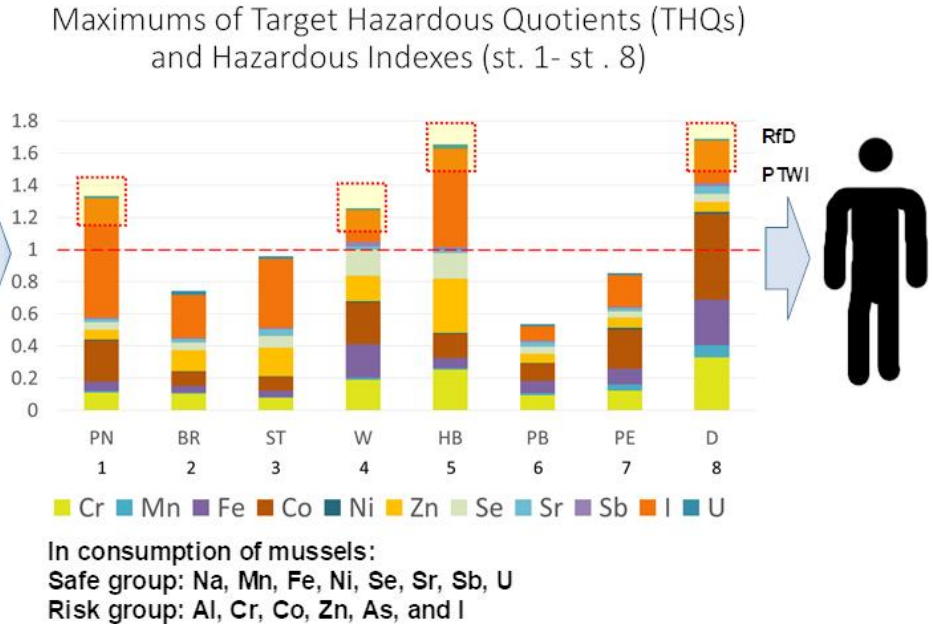
Eastern Cape



East Polluted stations (harbors at eastern coast of South Africa)

- **Al, Sc, V, Cr, Mn, Fe, Co, Th -** terrigenous
- **Na, Mg, K, Cl, As, Br, I -** water salinity
- **Co, Ni, Sb, U** - anthropogenic
- **Ca, Sr** - deposition into shell and its construction
- **Na, Mg, Ca, As, Br, Sr, Cs -** terrigenous (resuspension of bottom sediments)

Hazard indices (THQ and HI)



In consumption of mussels:
Safe group: Na, Mn, Fe, Ni, Se, Sr, Sb, U
Risk group: Al, Cr, Co, Zn, As, and I

Wastewater treatment

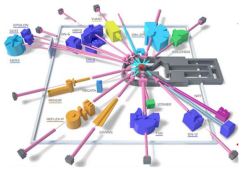
Arthrospira platensis

Ho(III), Er (III), Gd(III)

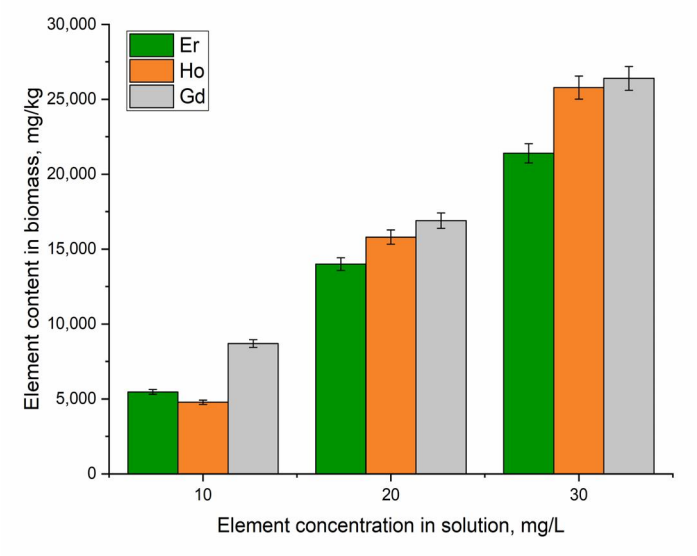
concentrations 10-30 mg/L

Cultivation for five days

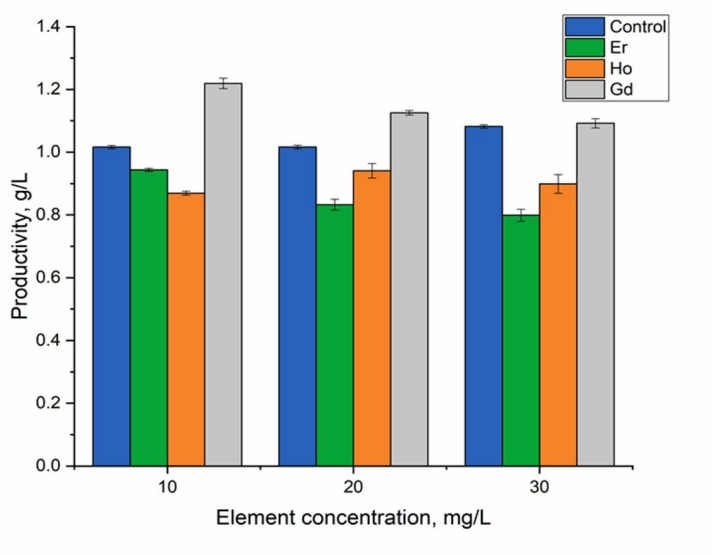
- Elemental analysis
- Biomass productivity
- Antioxidant activity
- Biochemical analysis → Total proteins, carbohydrates, lipids, and malondialdehyde



REGATA, IBR-2 reactor

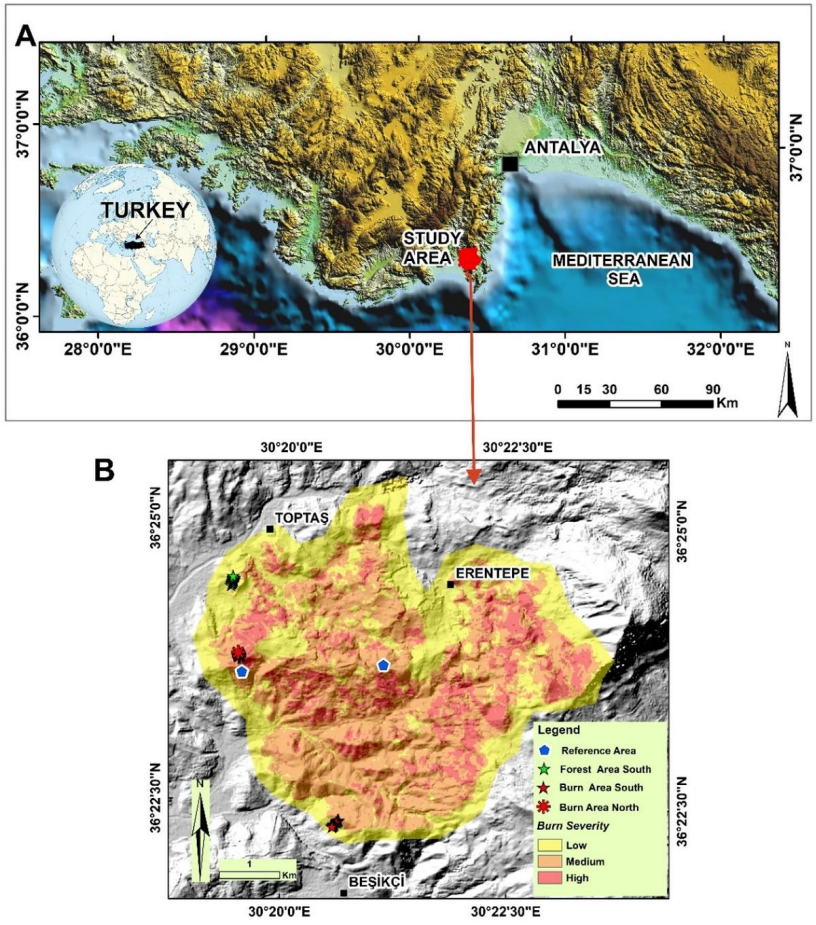


Uptake of Er, Ho, and Gd by *spirulina* biomass cultivated in a medium supplemented with REEs.

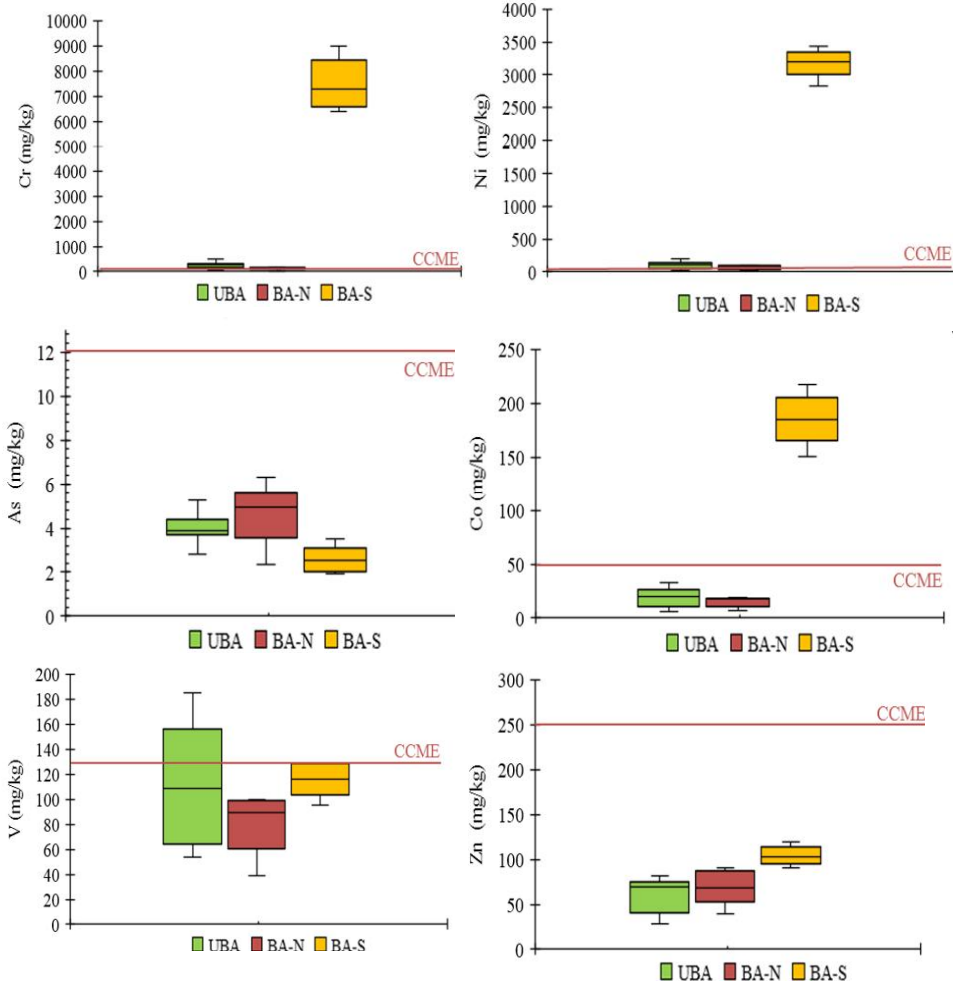


Effects of rare earth elements on spirulina productivity

Assessment of soil pollution

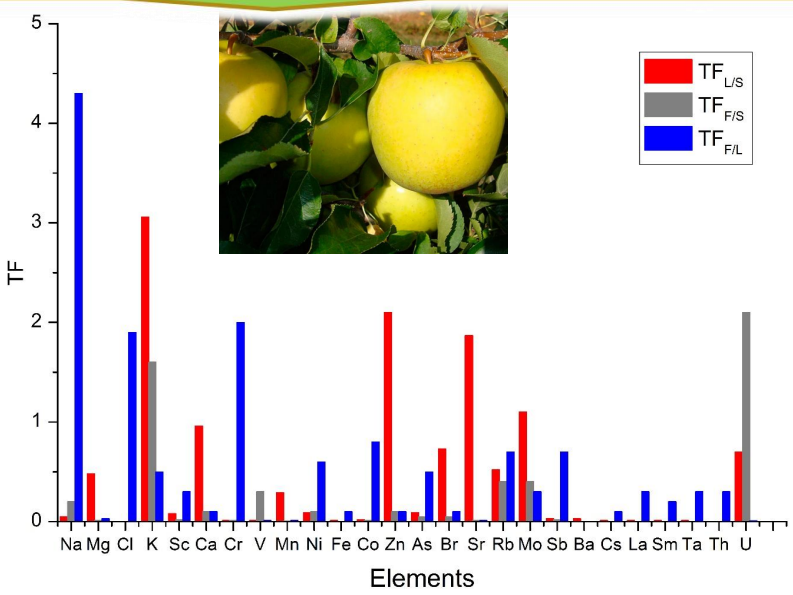


Location of the Kumluca wildfire (a), soil sampling from the study area according to different fire severity levels and aspects (b)



Element concentrations in unburned and burned soils

Control of quality and safety of foodstuffs



Transfer factors in system soil-leaf-apple

Leaves-soil: K ($TF_{L/S}$=3.1), Zn ($TF_{L/S}$=2.1), Sr ($TF_{L/S}$ =1.9), and Mo ($TF_{L/S}$ =1.1) and Ca ($TF_{L/S}$=0.96).

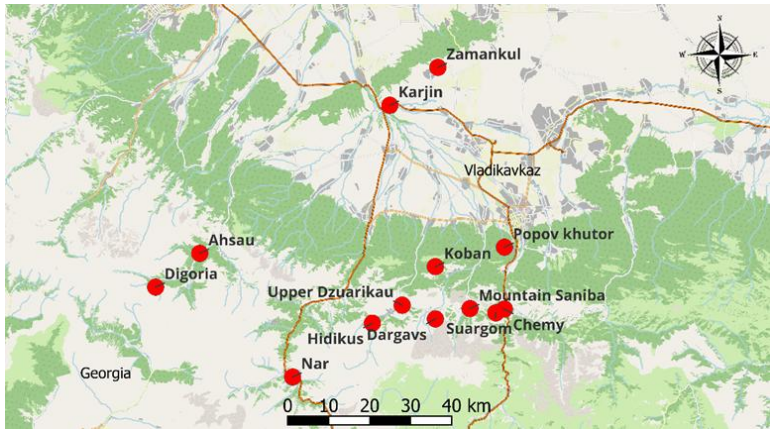
Fruits-soil: K ($TF_{F/S}$= 1.6) and U ($TF_{F/S}$ = 2.1).

Fruits- leaves: TF> 1.0 was obtained for Na, Cl, and Cr.

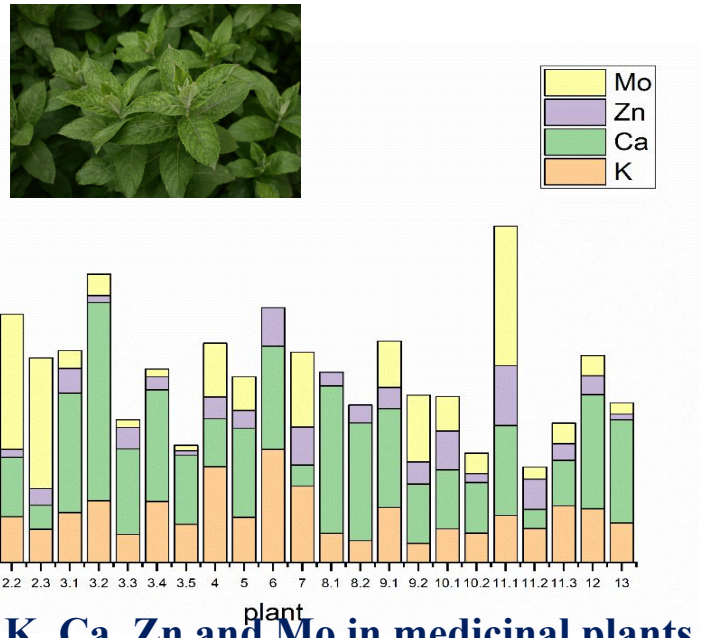
Estimated daily intake of metal (DIM) and potential health hazards (HQ) from fruit

	Apple			Plum			Grape			
Element	C mg/kg f.w.	DIM, mg/day	HQ, mg/kg/day	C mg/kg f.w.	DIM, mg/day	HQ, mg/kg/day	C mg/kg f.w.	DIM, mg/day	HQ, mg/kg/day	R_fD, mg/day
Cr	3.9	1.2	0.01	0	0	0	0.48	0.1	0.004	105
Co	0.5	0.1	0.05	0.7	0.2	0.07	0.6	0.2	0.06	3
Fe	78	23	0.4	151	45	0.75	8.8	2.6	0.04	10-60
Mn	8.1	2.4	0.5	2.2	0.6	0.1	1.7	0.5	0.1	0.5-5.0
Ni	6.7	2.0	**1.4**	1.4	0.4	0.3	1.8	0.2	0.2	1.4
V	0.6	0.2	0.1	0	0	0	1.3	0.4	0.3	1.8
Zn	33	9.9	0.7	25	7.5	0.5	6.4	1.9	0.1	15

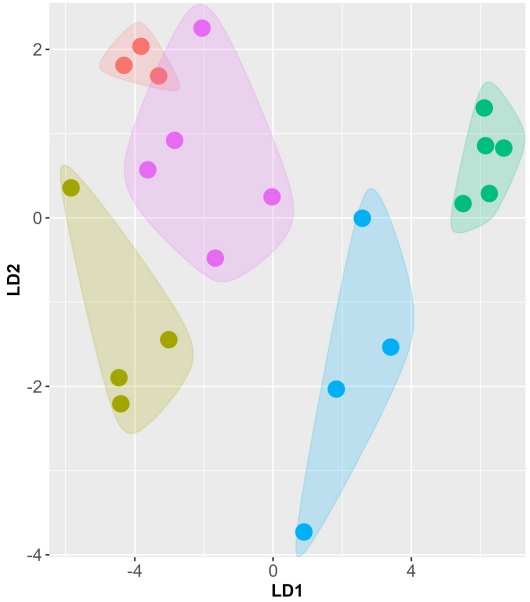
Medicinal plants



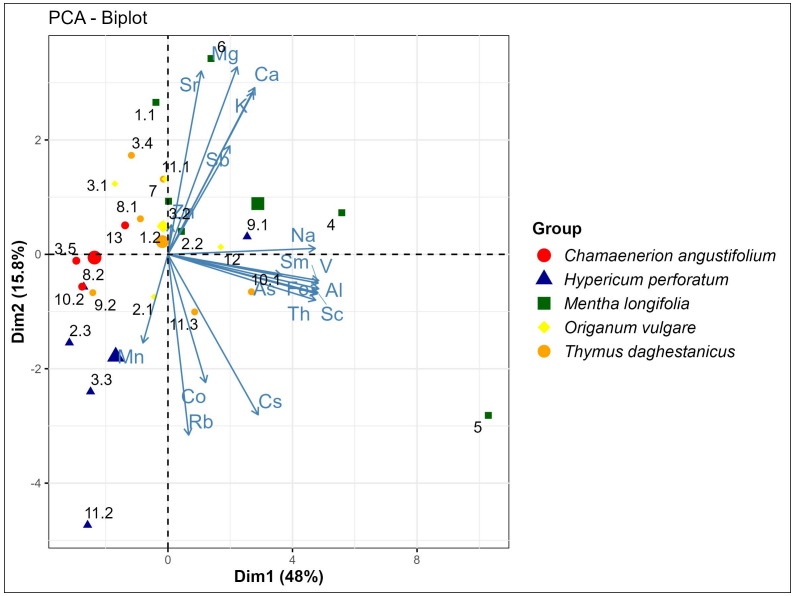
Map of samples collection



TFs for K, Ca, Zn and Mo in medicinal plants



Discriminant Analysis



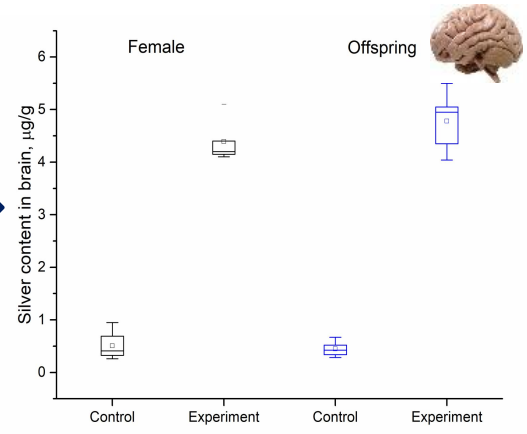
PCA scores plot for medicinal plants

Nanotoxicology

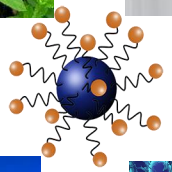
1-100 mg/L
AuNPs

Medicinal plants

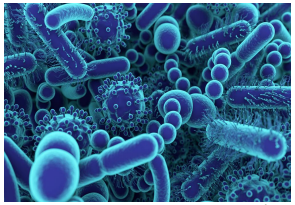
Animals



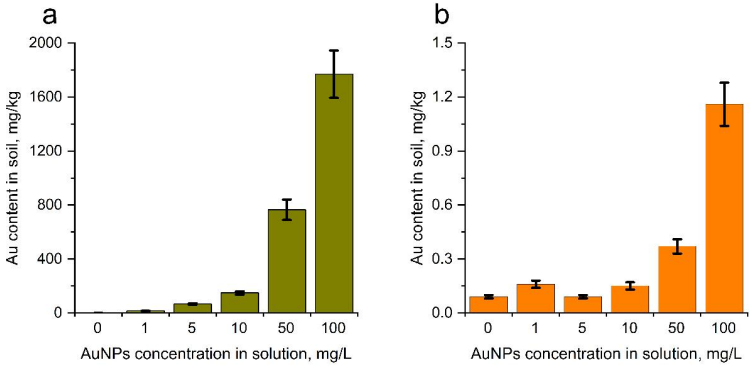
Accumulation of silver nanoparticles in mice and their offspring brain



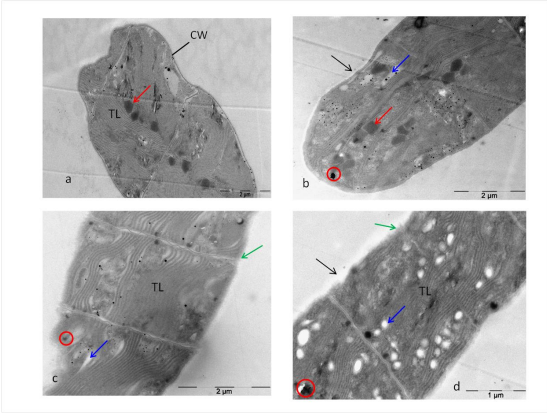
Cereals



Microorganisms



The content of gold in soil samples under root irrigation condition (a) and foliar spraying with AuNPs (b)



Spirulina platensis **exposed to 0.05 µM AgNPs**

Cultural heritage

(a) St. Nicholas

(b) St. Basil the Great

(c) St. John Baptist

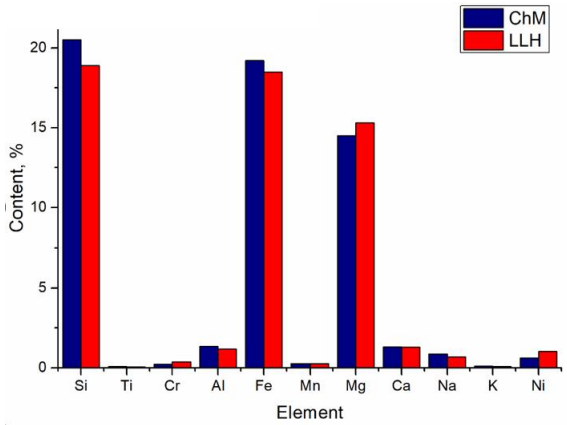
(d) Mater Dolorosa

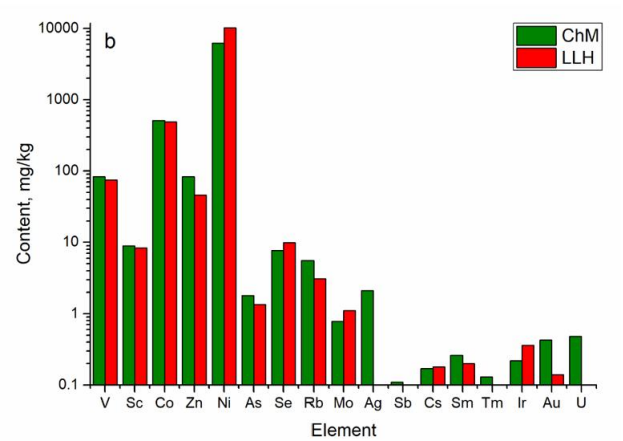
(e) Christ entering Jerusalem

The content of major elements and trace elements as determined by NAA in some fragments of Russian icons.

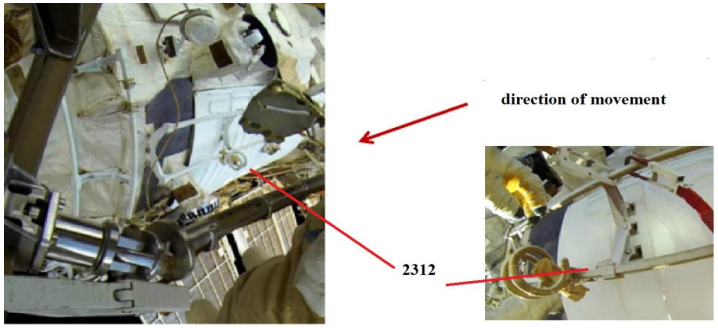
Icon	Elements, mg/kg											
	Na (%)	Mg (%)	Cl (%)	K (%)	Ca (%)	Fe (%)	Zn	As	Sr	Sb	Ba	Au
Christ entering Jerusalem: yellow foil	0.04	0.12	0.6	0.2	42	0.2	65	1	1090	---	---	4
Christ entering Jerusalem: ocher fragment	0.08	---	0.8	---	39	0.1	60	5	950	2	220	1
St. Basil the Great: wood fragment	0.02	---	0.1	---	0.1	---	10	---	2	---		27

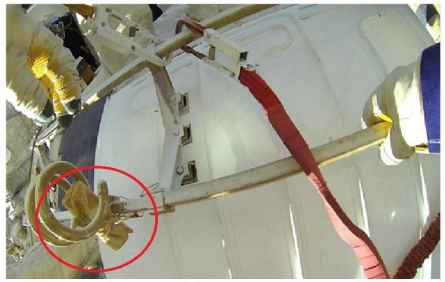
Extraterrestrial materials

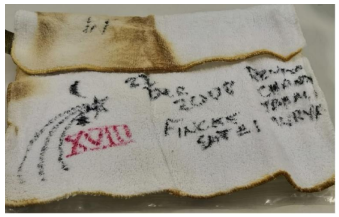


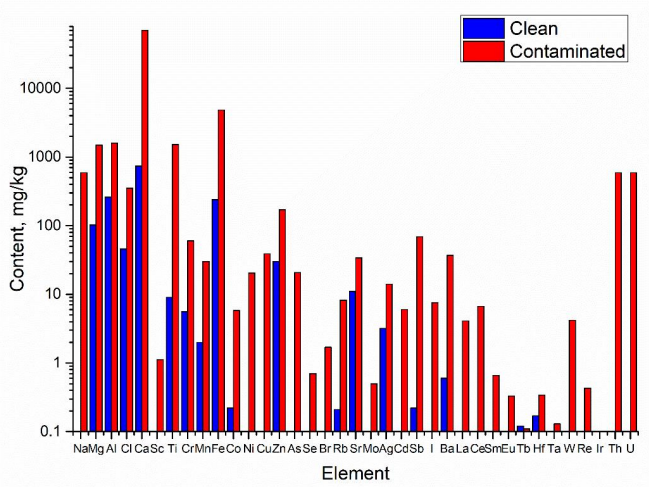


The content of major (a) and trace elements (b) in Chelyabinsk meteorite









Elemental composition of clean and contaminated fragments of the rolled cotton cloth determined by NAA, in µg/g

IBR-2 User Club

Register Enter

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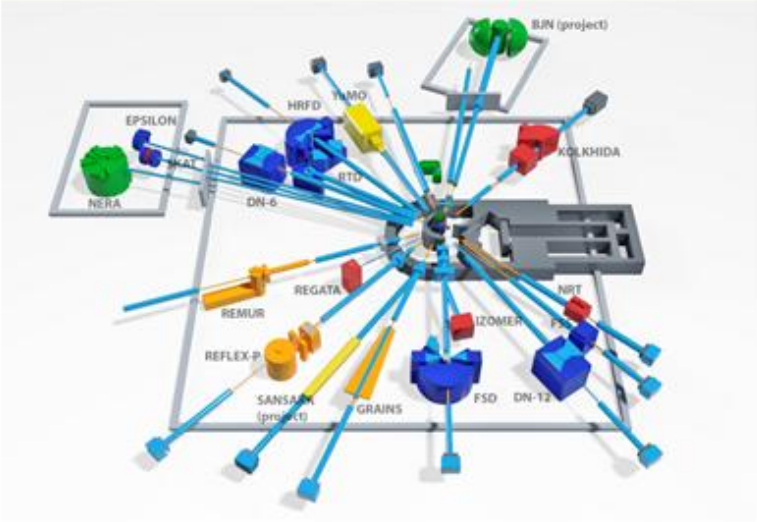

Work schedule of the IBR-2 reactor in 2021

IBR-2 Status: OFF

Current cycle: CANCELED

Useful information

- IBR-2 INSTRUMENTS with the list of REFERENCES and RESPONSIBLE
- CONFERENCE CMR@IBR-2
- FLNP USER GUIDE
- FLNP ANNUAL REPORTS
- FLNP DNICM LABORATORY EQUIPMENT

Information for RNF grant applicants/Информация для грантозаявителей РНФ

ОБЪЕКТ ИНФРАСТРУКТУРЫ - ИБР-2

News of IBR-2 User Club

2024/05/07

Dear IBR-2 users,

FLNP Directorate cordially invites you to the FLNP JINR – CSNS IHEP (China) Workshop on the neutron scattering technology and multi-disciplinary research

	NEUTRON ACTIVATION ANALYSIS		
REGATA	Determination of the elemental composition of environmental, geological, biological, and other types of samples	ФР.1.31.2021.41736 МП ОИЯИ 01-2021. Determination of the content (mass fraction) of chemical elements (Na, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Sr, Rb, Sb, Cs, Ba, La , Ce, Tb, Hf, Ta, Th, U) in solid and technological samples by the instrumental neutron activation. No. of attestation certificate: 348/2021-01.00115-2013 (31.05.2021)	**Dr. Inga Zinicovscaia** inga@jinr.ru/ zinikovskaia@mail.ru

May 27

- **Vladimir Galustov**. Dataset preparation software for training a neural network to determine the boundaries of full energy peaks in gamma spectra.

May 29

- **Marina Frontasyeva**. Air pollution studies in Asia and the Pacific based on moss analysis by nuclear and related analytical techniques.
- **Alexandra Peshkova**. Risks assessment of gold nanoparticles exposure for the soil-plant-consumer system.
- **Margarita Shvetsova**. Assessment of the recreational zones in Moscow using neutron activation analysis and atomic absorption spectrometry.
- **Aleksandra Kravtsova**. Copper and nickel accumulation and translocation in leafy vegetables irrigated with metal-containing effluents.
- **Vladimir Zaichick**. Activation by neutrons and related analitical methods as a tool of medical elementology.
- **Octavian Duliu**. INAA and XRD investigation of the Serbian sector of the Danube river and its tributary.

Thank you for attention!