Radiochemistry for Underground Physics

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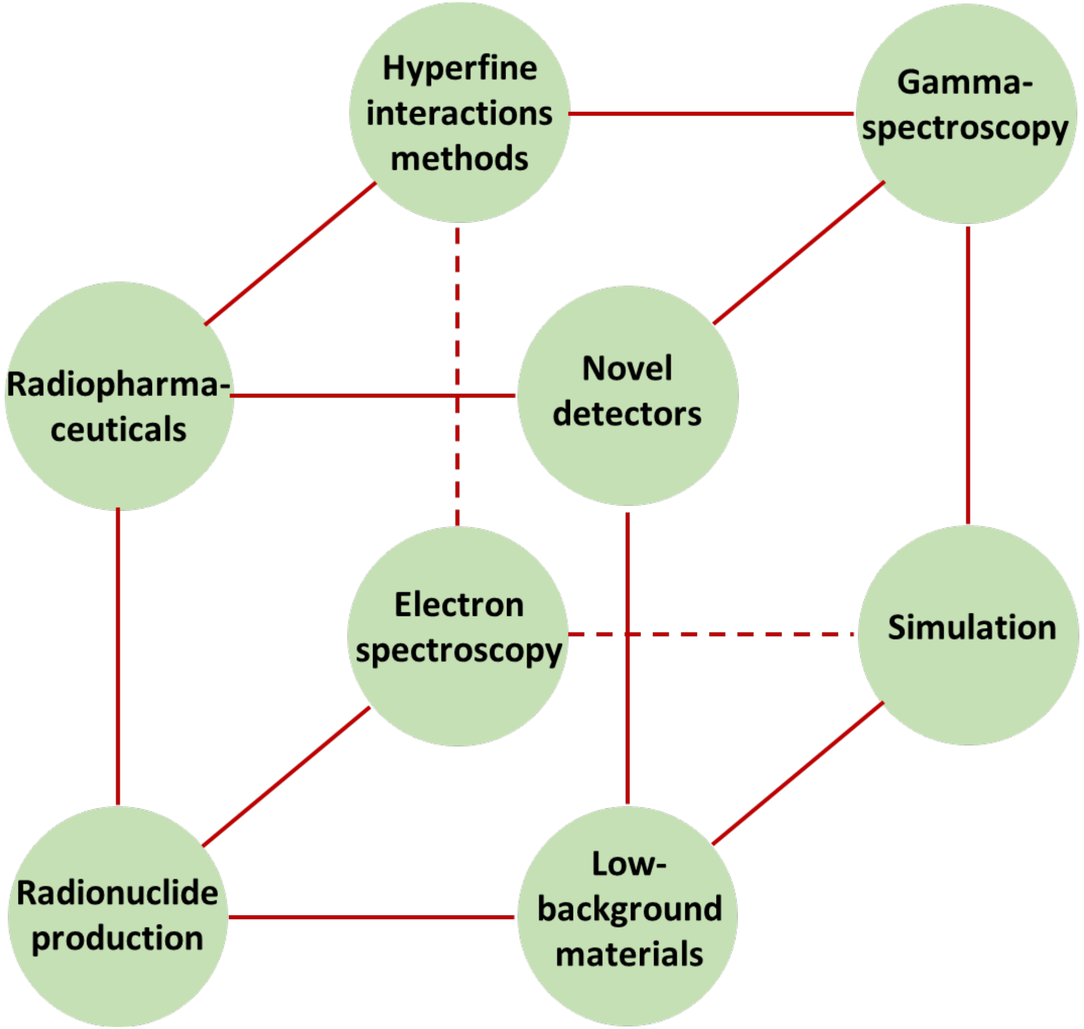
Radiochemistry and spectroscopy for astrophysics and nuclear medicine

Scientific directions



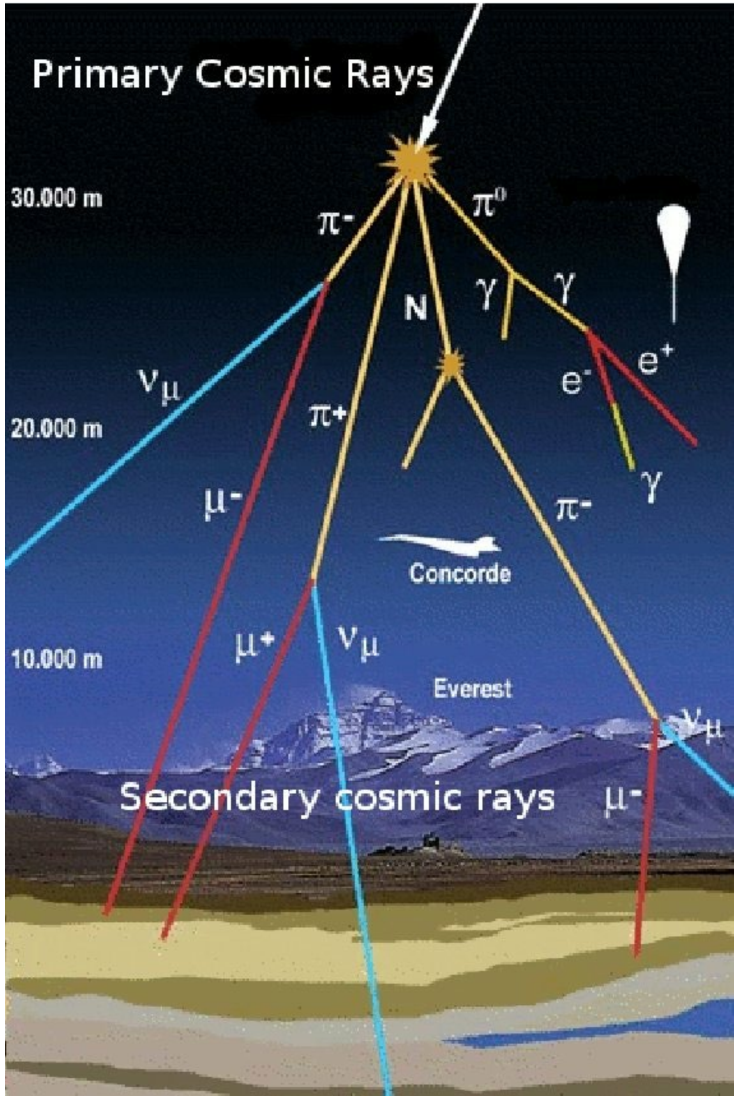
Low-Background Experiments

Background sources:

1. Cosmic rays.
2. **The presence of radioactive impurities in detector materials, in measured samples and in structural materials of experimental facilities and laboratories.**
3. Radioactive gases in the atmosphere (radon and its decay products: $^{210,214}Bi$, $^{210,214}Pb$, $^{210,214}Po$).

Methods of analysis:

ICP-MS, ICP-AES with chemical preparation, neutron activation analysis, gamma-ray screening and etc.



Giving new life to old equipment. F. Barradas-Solas .
Physics Education 2007, V. 42, N. 1, P. 9-11. DOI 10.1088/0031-9120/42/1/F03

Materials and Methods Developed in JINR

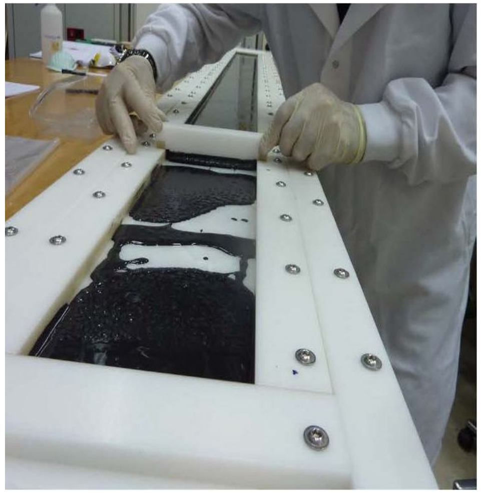
Samples for measurement

^{48}Ca

^{82}Se

^{96}Zr

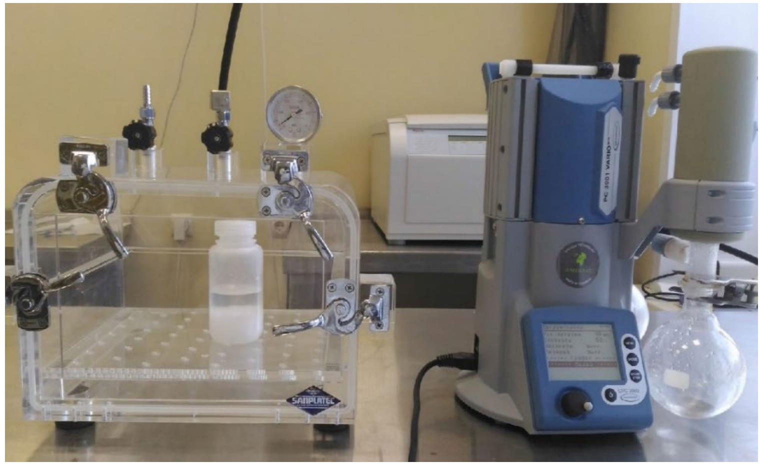
^{106}Cd



Solders and fluxes

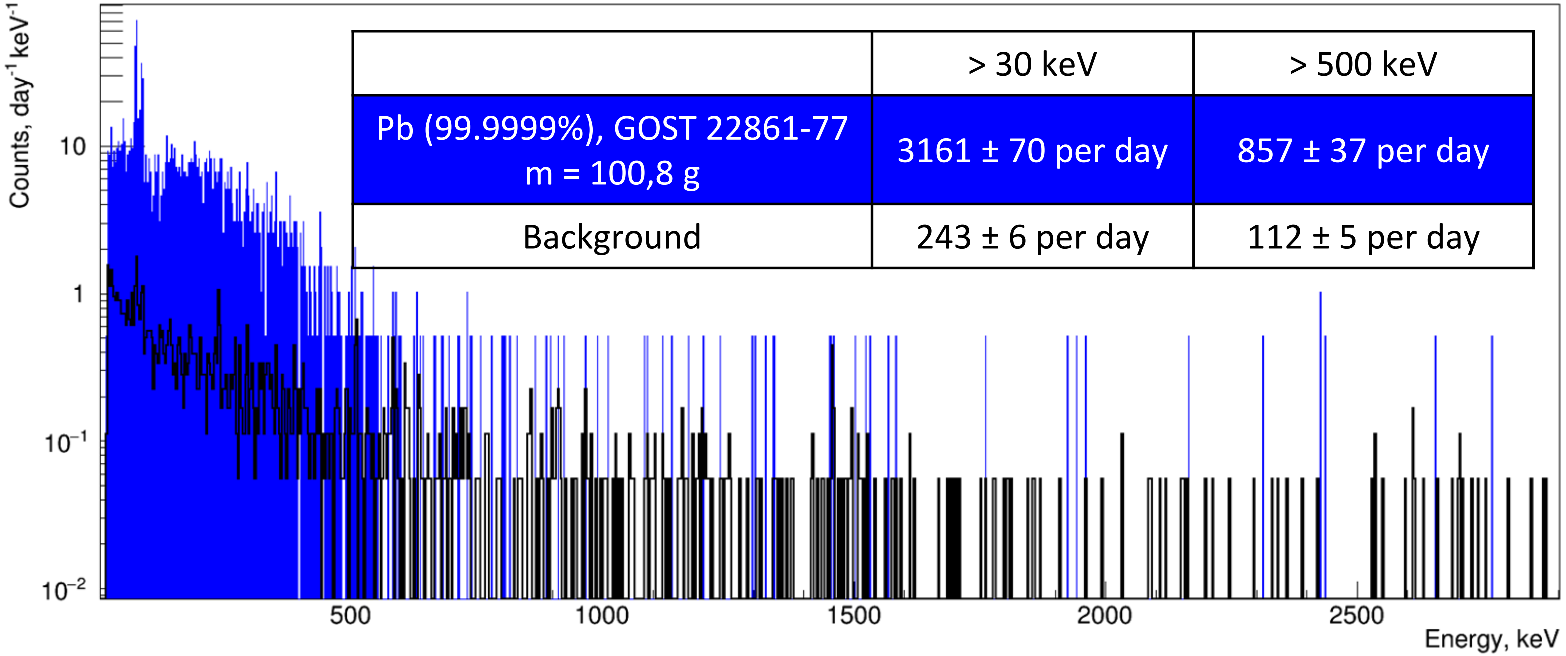
archaeological Pb+Sn

NH_4Cl, CH_3COONH_4



Detector, protection and construction materials
Etching methods for copper surface
Protocols of surface cleaning

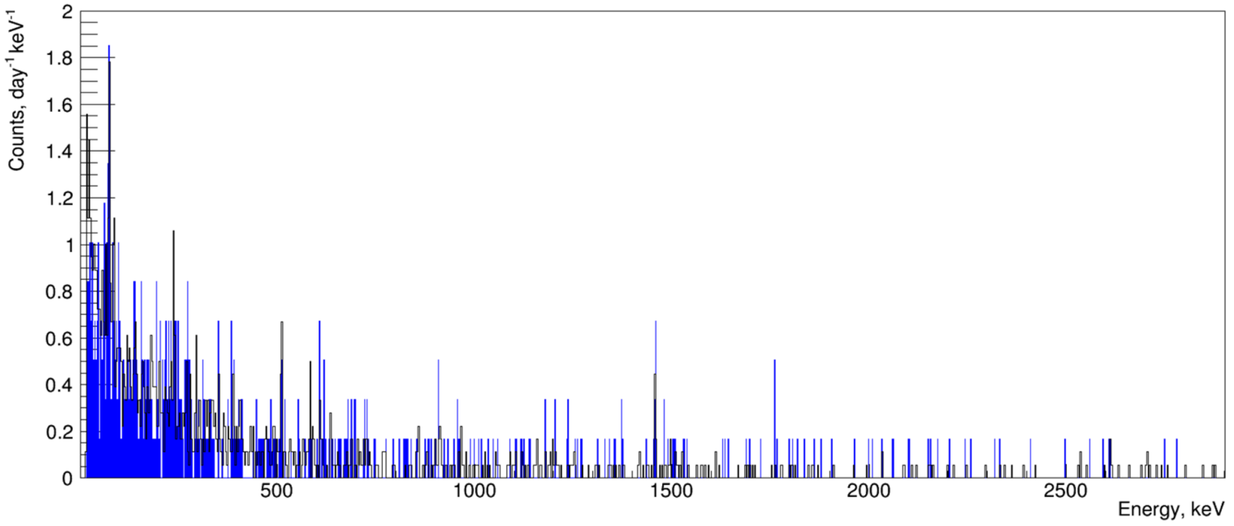
Preparation of the Solder Made of Archaeological Pb and Sn. Part 1

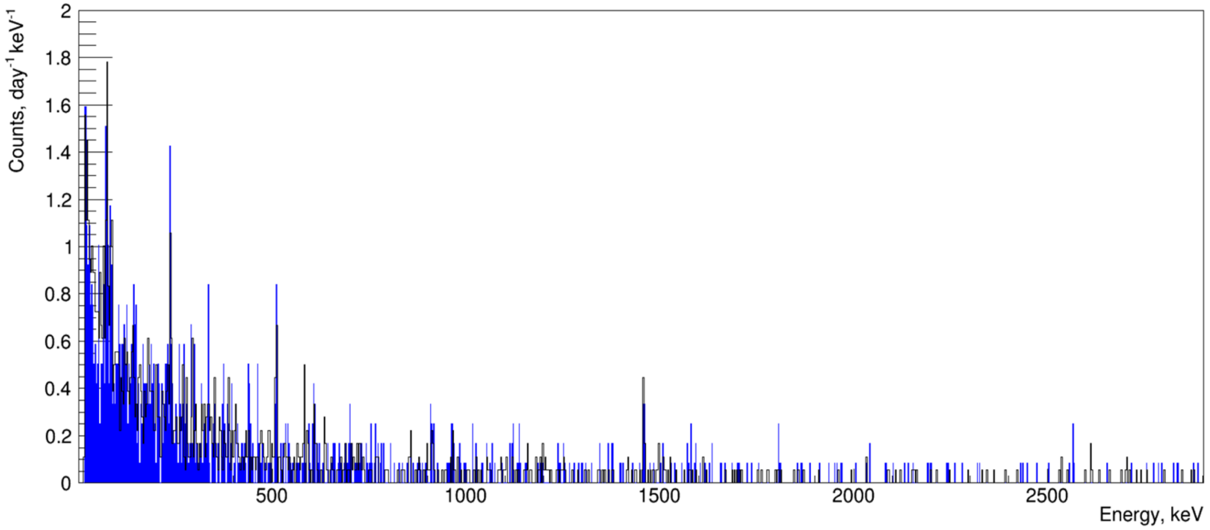


	> 30 keV	> 500 keV
Pb (99.9999%), GOST 22861-77 m = 100,8 g	3161 ± 70 per day	857 ± 37 per day
Background	243 ± 6 per day	112 ± 5 per day

^{232}Th decay chain		^{238}U decay chain	
Radionuclide	Activity, mBq/kg	Radionuclide	Activity, mBq/kg
^{208}Tl	< 18	^{214}Pb	< 17
^{208}Tl	< 27	^{214}Bi	< 13
^{212}Bi	< 144	^{210}Pb	< 78
^{212}Pb	< 34	Radionuclide	Activity, mBq/kg
^{228}Ac	< 79	^{40}K	< 94

Preparation of the Solder Made of Archaeological Pb and Sn. Part 2





	> 30 keV	> 500 keV
Tin (99.9999%), GOST 860-75 m = 75,1 g	269 ± 12 per day	139 ± 9 per day
Background	243 ± 6 per day	112 ± 5 per day

	> 30 keV	> 500 keV
Arch. Lead m = 114 g	243 ± 7 per day	112 ± 5 per day
Background	243 ± 6 per day	112 ± 5 per day

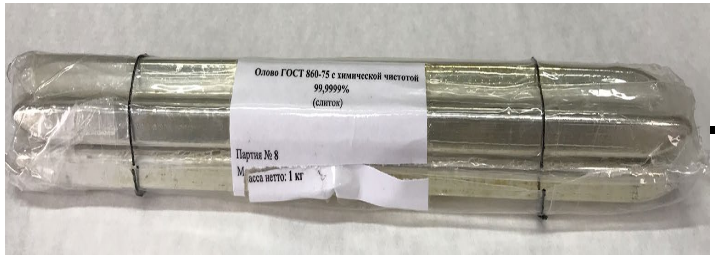
Preparation of the Solder Made of Archaeological Pb and Sn. Part 3

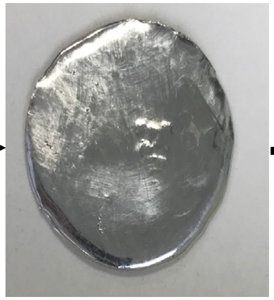
I.

The original piece of archaeological lead

The molten lead

II.





Tin with chemical purity 99.9999%

III.

Pb, 60%

Sn, 40%

metal cutting and weighing

↓

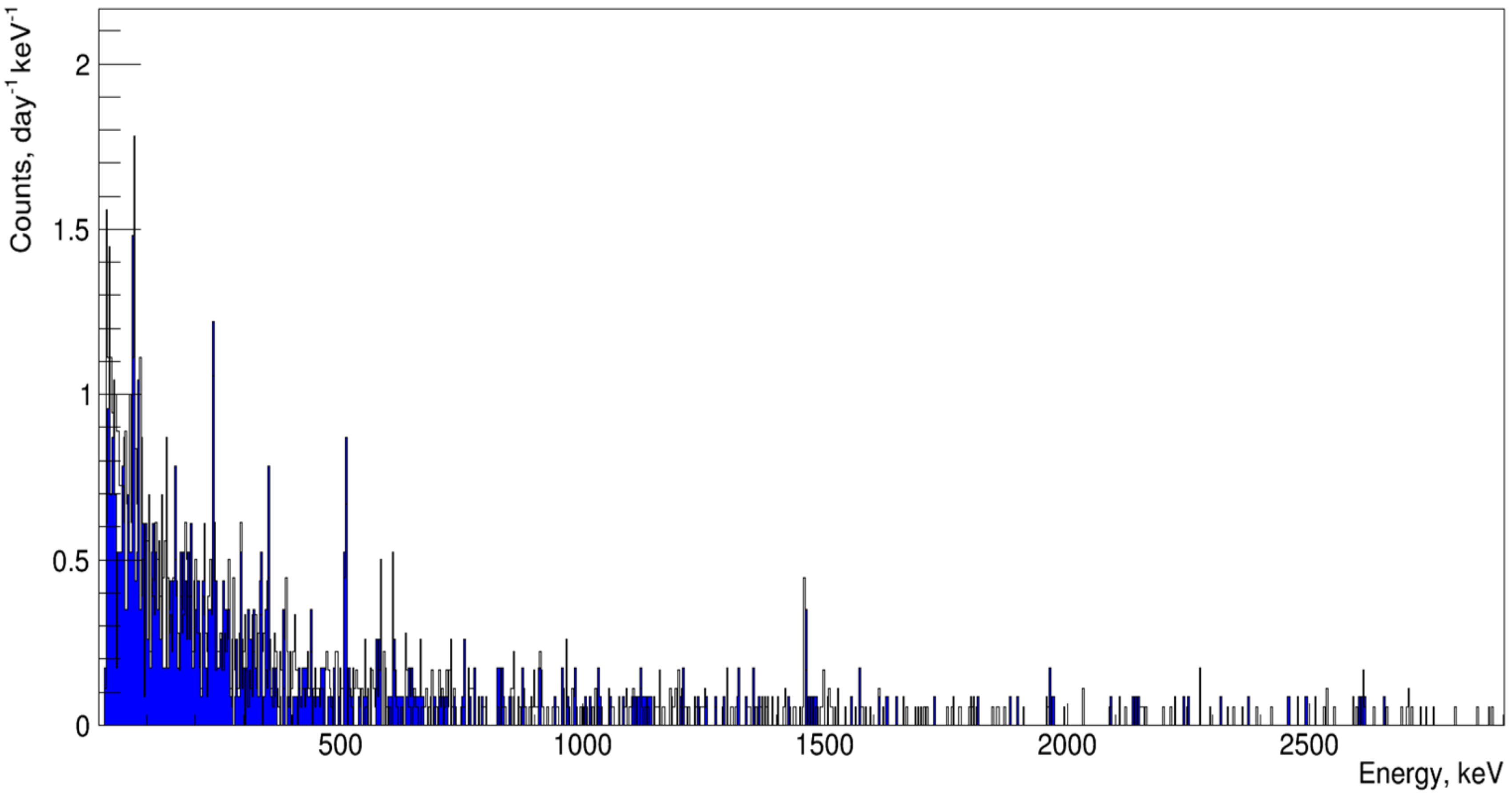
melting at T=400 °C

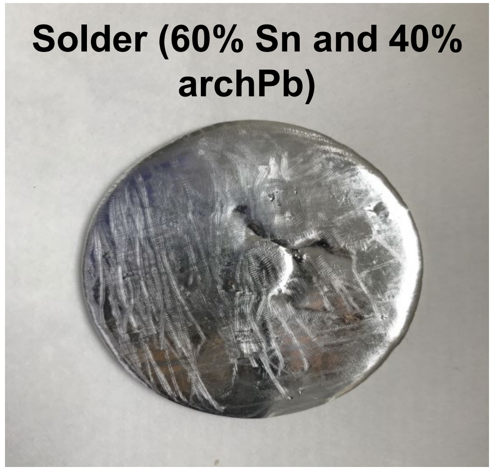
↓

pouring into a Teflon cup

→

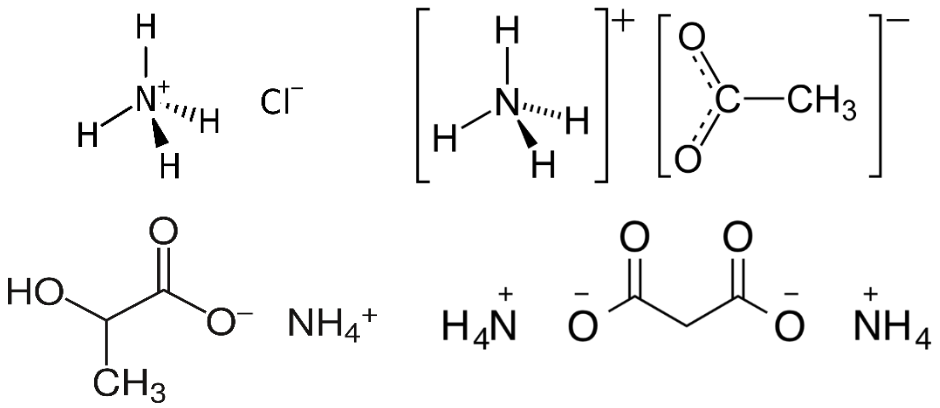
Preparation of the Solder Made of Archaeological Pb and Sn. Part 4

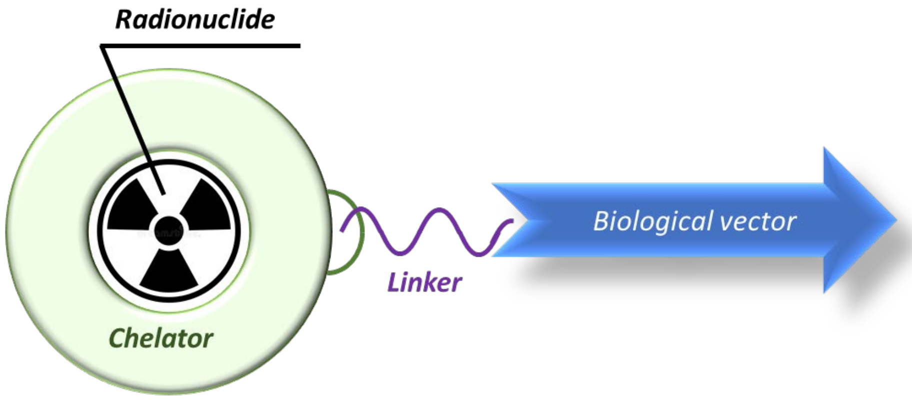




	> 30 keV	> 500 keV
Solder Sn(60%)Pb(40%) m = 154.5 g	222 ± 8 per day	105 ± 6 per day
Background	243 ± 6 per day	112 ± 5 per day

High-Purity Ammonium Salts for Fluxes and Radiolabeling. Part 1





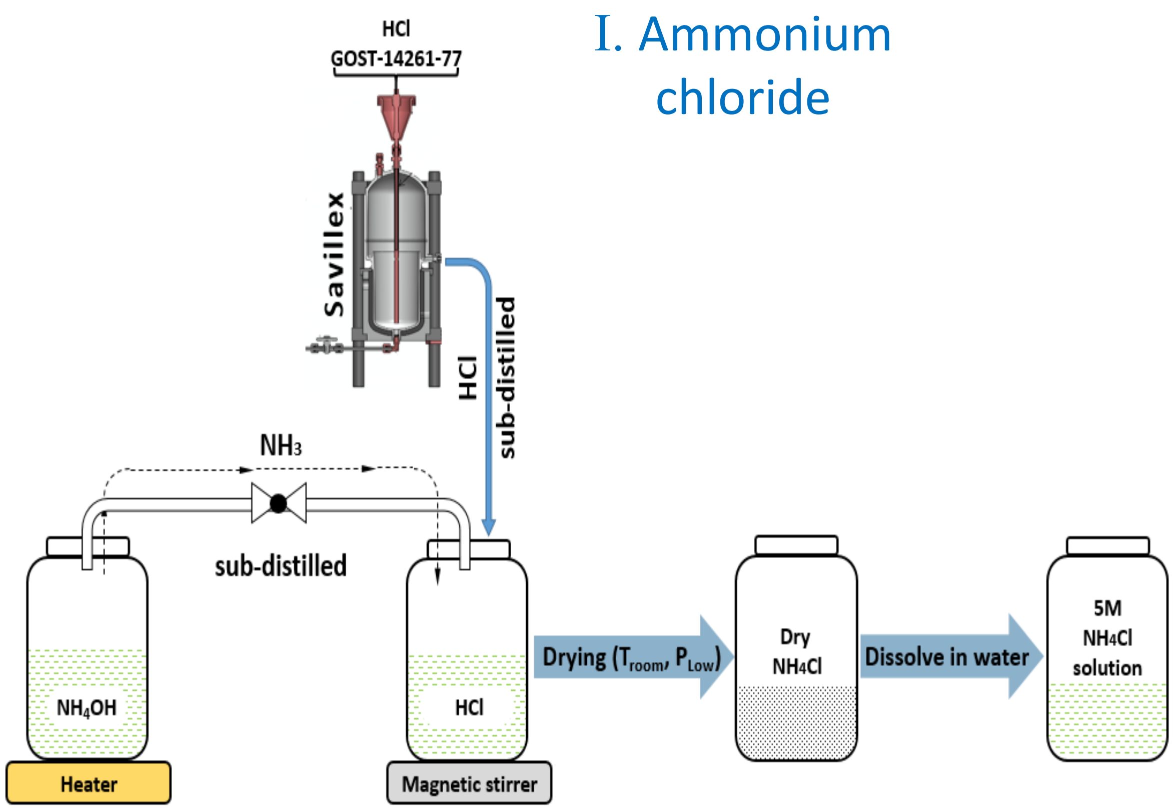
Radiopharmaceutical

Samples	Purity, %	^{238}U		^{232}Th		^{40}K	
		10^{-9} g/g	mBq/kg	10^{-9} g/g	mBq/kg	10^{-9} g/g	mBq/kg
$ZnCl_2$	99.999	55 ± 15	679 ± 185	< 200	< 812	< 64	< 2.0
NH_4Cl	99.999	60 ± 20	741 ± 247	330 ± 140	1340 ± 568	< 72	< 2.2
H_3PO_4	99.998	27±12	333 ± 148	< 74	< 300	< 66	< 2.1
$C_9H_8O_4$	99.9	160 ± 30	1970 ± 370	170 ± 90	690 ± 365	< 44	< 1.4

D.S, Akerib, A. D. Silva, D.L. Herli [et al]. Production of solder and flux with low radioactivity / Nucl Instrum Meth -1997. V. 400, I. 1, P. 181-183

Synthesis of High-Purity Ammonium Salts. Part 2

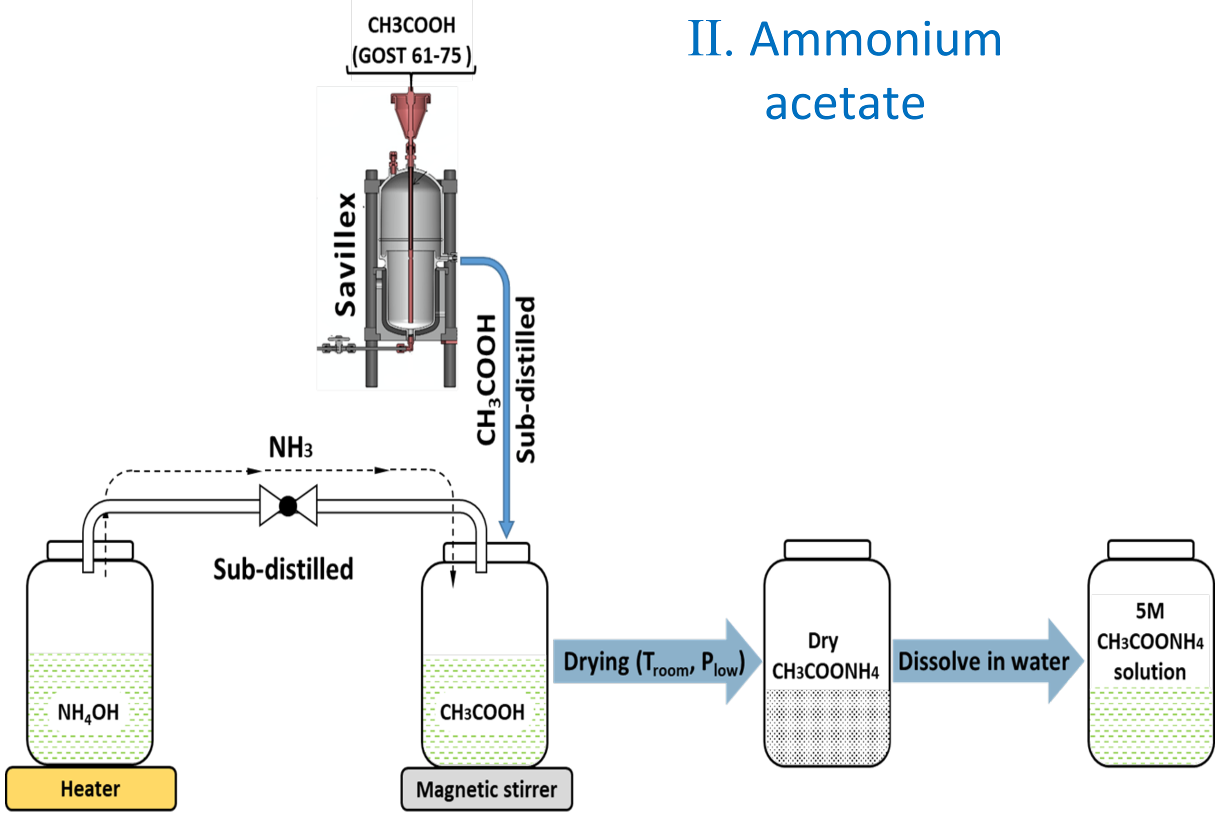
I. Ammonium chloride



$NH_3 + HCl \rightarrow NH_4Cl$

1) purification of HCl;
2) synthesis of ammonium chloride solution (transfer of gas phase ammonia to the acid);
3) obtaining NH_4Cl in the solid state by drying it in a vacuum at room temperature.

II. Ammonium acetate



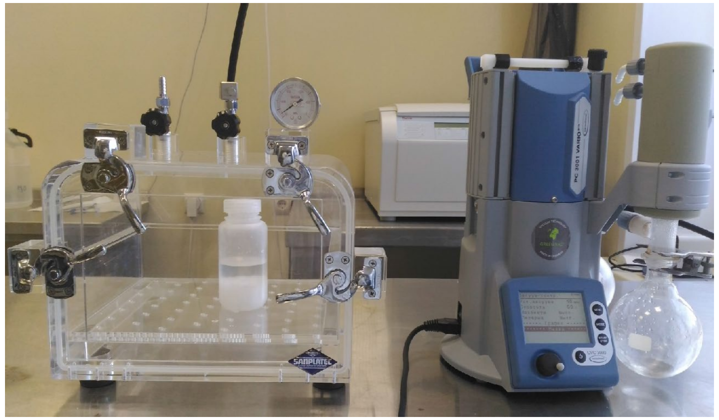
$NH_3 + CH_3COOH \rightarrow CH_3COONH_4$

1) purification of the 16 M CH_3COOH acid;
2) synthesis of ammonium acetate solution (transfer of gas-phase ammonia to the acid);
3) obtaining CH_3COONH_4 in the solid state by drying it under vacuum at room temperature.

Analysis of High-Purity Ammonium Salts. Part 3

Impurities of ^{232}Th, ^{238}U and ^{40}K in the synthesized ammonium salts (ICP-MS, ICP-AES)

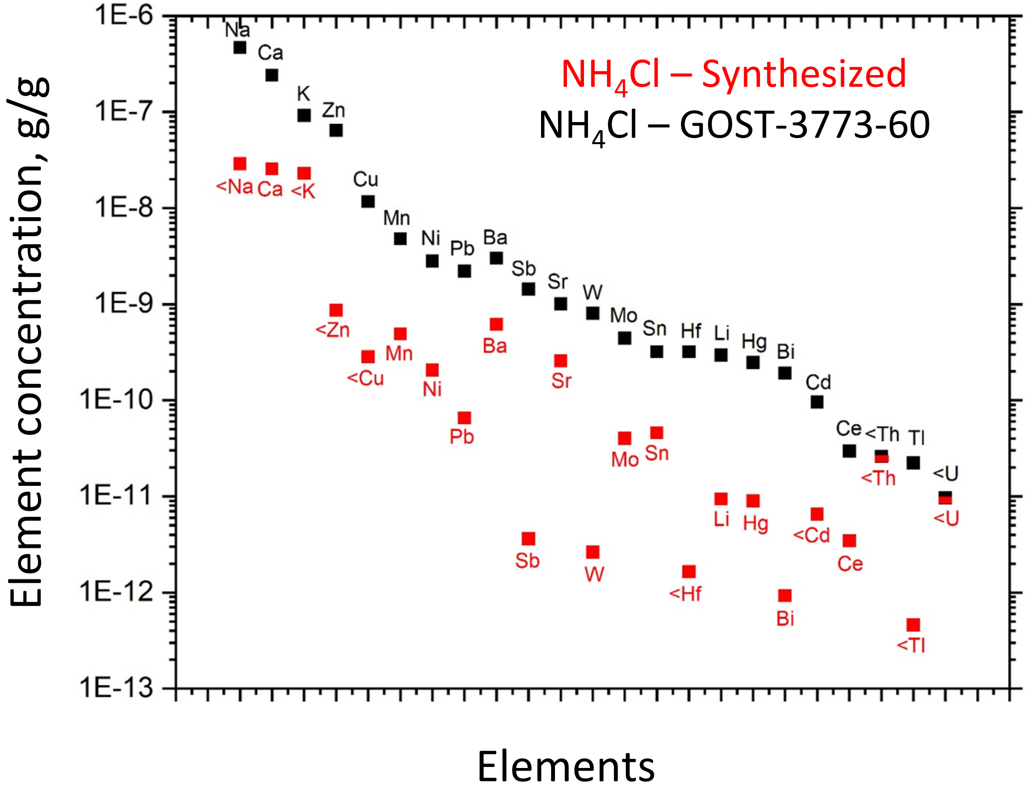
Samples	^{232}Th, mBq/kg	^{238}U, mBq/kg	^{40}K, mBq/kg
NH_4Cl	< 0.1	< 0.1	< 0.7
CH_3COONH_4	< 0.1	< 0.1	< 0.7

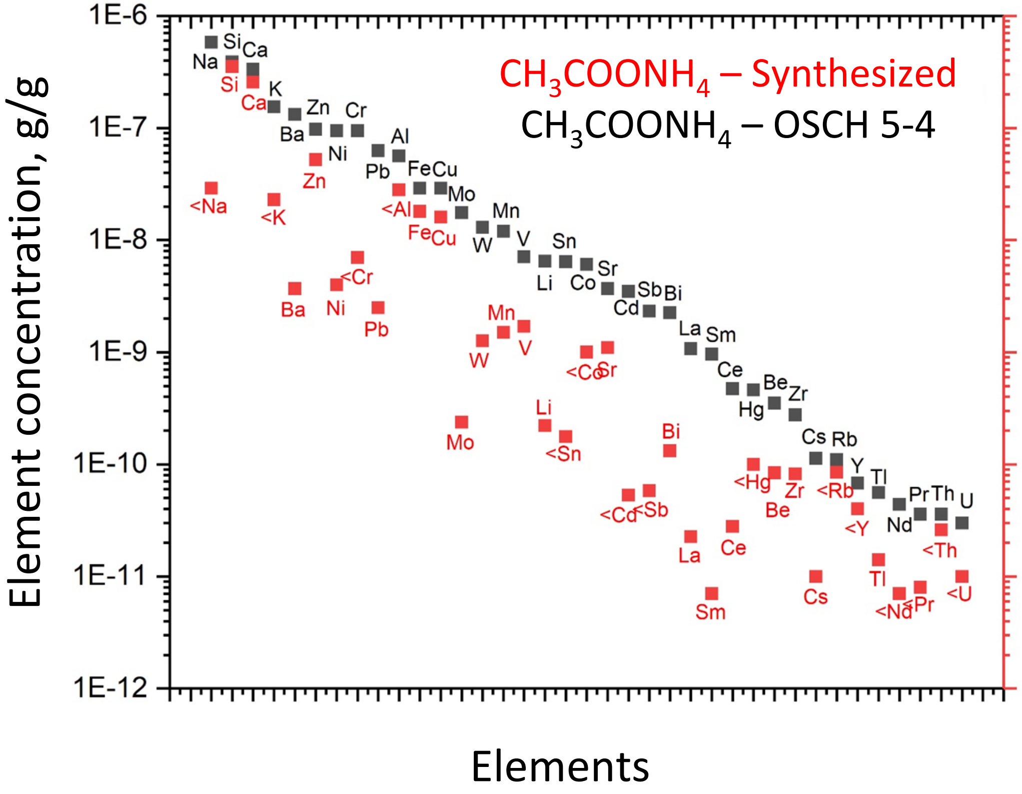


Measurement results of the synthesized NH_4Cl (low-background HPGe)

Radionuclide	E_γ, keV	Activity, mBq/kg
^{40}K	1461	< 77
^{208}Tl	2614	< 5
^{210}Pb	46	< 91
^{212}Pb	239	< 2
^{214}Pb	242	< 10
^{214}Pb	352	< 5
^{214}Bi	609	< 10
^{214}Bi	1765	< 5
^{228}Ac	911	< 5

Analysis of High-Purity Ammonium Salts. Part 4





ICP-MS and ICP-AES results of the commercial (GOST 3773-60) and synthesized NH_4Cl

ICP-MS and ICP-AES results of the commercial (OSCH 5-4) and synthesized CH_3COONH_4

Method for Purification and Conditioning of Selenium. Part 1

II.

III.

IV.

V.

VI.

I. Dissolving

$Se + 4HNO_3 \rightarrow H_2SeO_3 + 4NO_2\uparrow + H_2O$

$SeO_2 + H_2O \leftrightarrow H_2SeO_3$

II. Chromatography purification

Conditioning

III. Reduction to elemental Se with SO_2

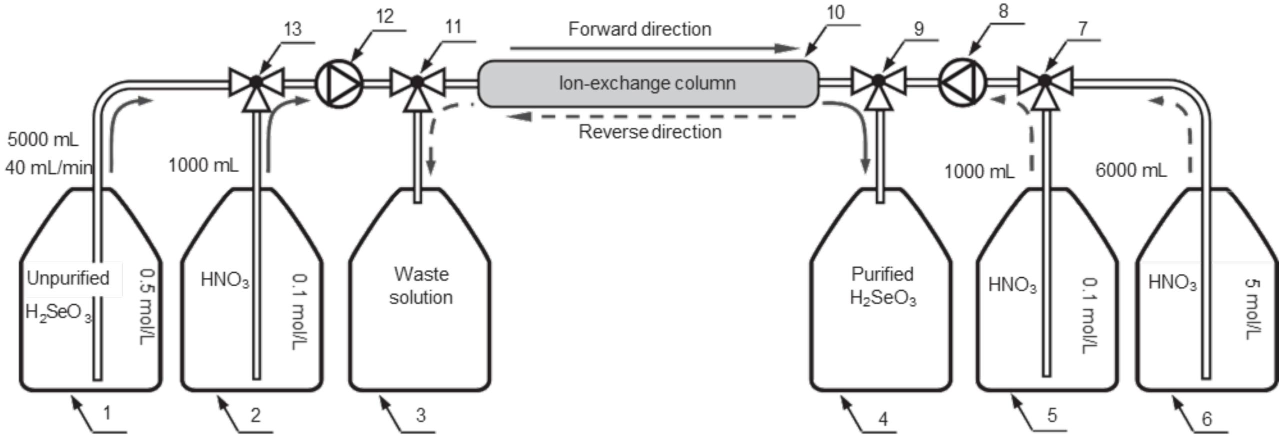
IV. Centrifugation (washing with alcohol, water)

V. Homogenization of selenium (in alcohol)

VI. Vacuum drying

At room temperature

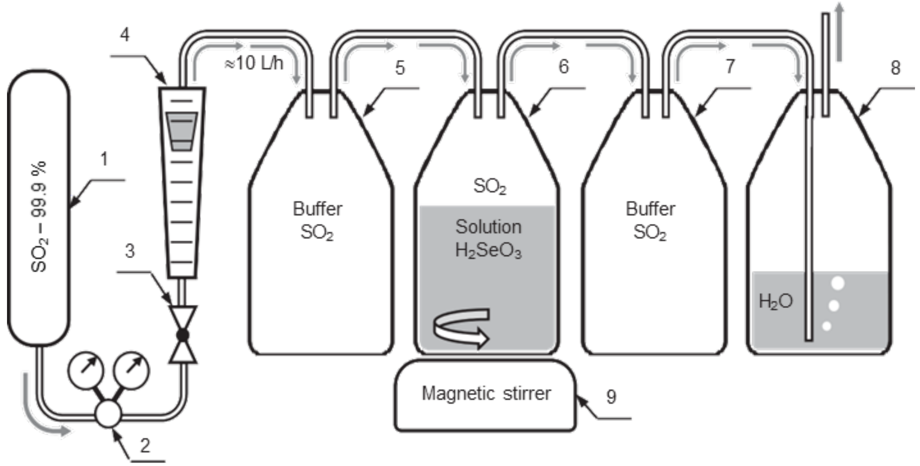
Method for Purification and Conditioning of Selenium. Part 2



1 ÷ 6 – solutions; 7, 9, 11, 13 – triple valves; 8, 12 – pumps;
10 – ion exchange column

Dowex 50W×8, h=500 mm
For m=100 g of selenium → d=10 мм
For m>100 g → d=28 мм.

Reverse chromatography scheme of H_2SeO_3 purification

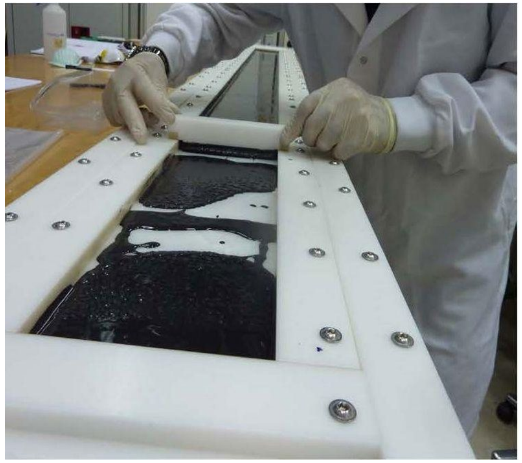


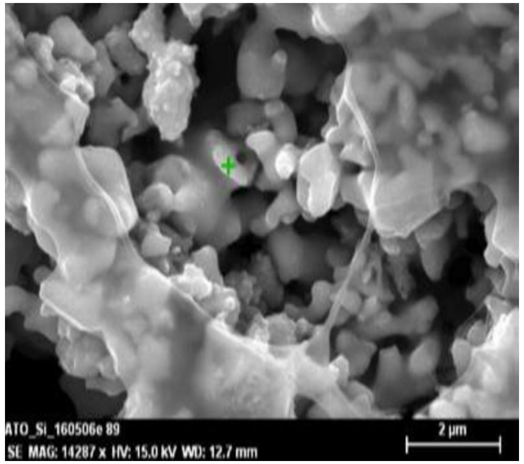
1 - SO_2; 2 - reducer; 3 – valve; 4 – rotameter;
5 ÷ 8 vessels (10 L); 9 - magnetic stirrer

$$H_2SeO_3 + 2SO_2 + H_2O \rightarrow Se + 2H_2SO_4$$

Reduction scheme of selenous acid to elemental state

Method for Purification and Conditioning of Selenium. Part 3





Samples	Specific activities of radionuclide impurities, µBq/kg			
	^{40}K	^{234m}Pa	^{208}Tl	^{214}Bi
^{82}Se	58700 ± 100	17300 ± 100	390 ± 10	1500 ± 40

Samples	Specific activities of radionuclide impurities, µBq/kg			
	^{40}K	^{238}U (^{234m}Pa)	^{232}Th (^{208}Tl)	^{226}Ra (^{214}Bi)
Purified ^{82}Se	< 9300*	< 2500*	22 - 150 (8 - 54)	< 600

Improvement factor of purified ^{82}Se	**> 6**	**> 7**	**7 - 50**	**> 2.5**

** ICP-MS results. Element content converts from g/g to µBq/kg*

< - detection limit

Summary

1. A wide experience in production of low-background materials with the level of impurities of mBq/kg (and lower) has been gained.
2. We have an expertise in separation of radionuclides and their purification with a high level of separation/purification factors.
3. Analytical methods for determination of ultralow concentration of elements/radionuclides (ICP-MS, ICP-AES, NAA, γ-spectrometry) are being developed.