PROMPT-GAMMA NEUTRON ACTIVATION ANALYSIS IN MINING

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Abstract

In the Frank Laboratory of Neutron Physics (FLNP) of the Joint Institute for Nuclear Research (JINR) we performed some experiments for studying the possibility of determining the elemental content of mineral ores.

To achieve the goal, we used the Prompt-Gamma Neutron Activation Analysis (PGNAA) [1] to determine the elemental composition of bulk samples of materials. Applied reactions: inelastic scattering of fast neutrons (FNIS) (n,n'γ) and thermalized neutron's capture (TNC) (n_{th},γ).

The scheme of FNIS (n,n'γ)-reaction, is shown in Figure 1. The gamma rays emitted in this reaction represent the unique characteristic for each nucleus and act as a "finger prints".

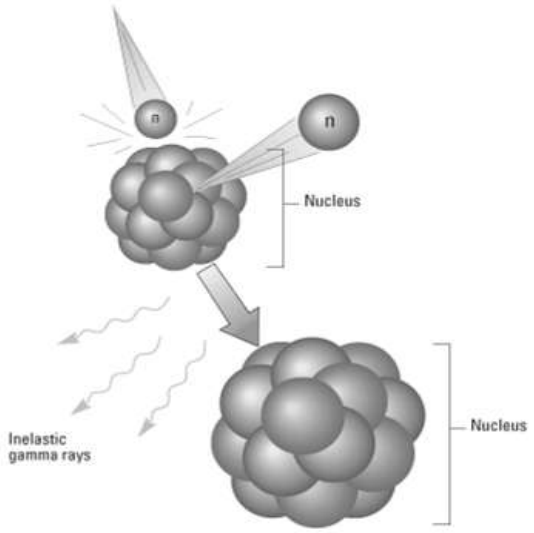

Figure 1. *Fast neutron inelastic scattering reaction (n,n'γ).*

Here we present the results from the test irradiations of apatite (phosphorite) ore.

1. Method of measurement

The method is based on the analysis of the γ-rays that are emitted from the irradiated sample. We used ^{239}Pu-Be neutron source, which emits ~5*10^{6} n/s with average neutron energy around 4.5 MeV.

2. Experimental setup

In Figures 2 and 3 we show the drawings of the experimental setup. It consists of:

- ^{239}Pu-Be neutron source with a shielding from borated polyethylene (BPE);
- High-Purity Germanium detector (HPGe) from ORTEC with the following characteristics for detecting the gamma-rays from ^{60}Co: full-energy absorption peak FWHM=1.9keV@1.33MeV and relative efficiency of about 36%;
- Sample– a polyethylene sac filled with 10 kg of apatite ore.

Combined shielding, composed from lead (Pb) and bismuth (Bi) bricks, significantly reduced the neutron-gamma background in the place of HPGe-detector.

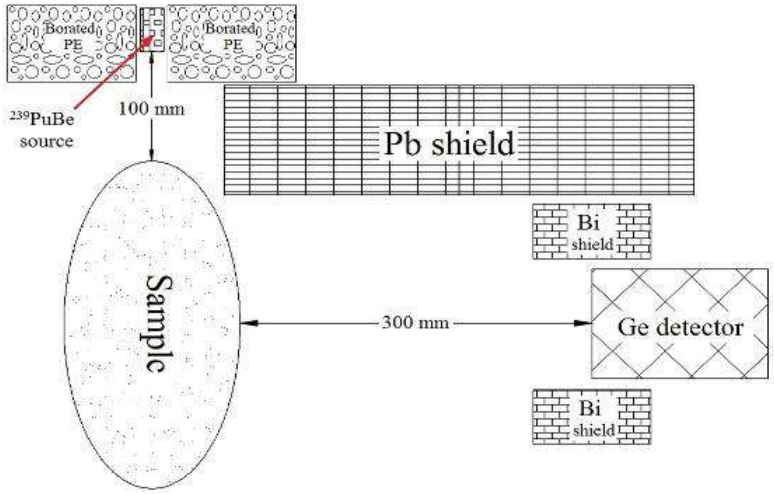

Figure 2. *The setup for PGNAA (scheme) [6].*

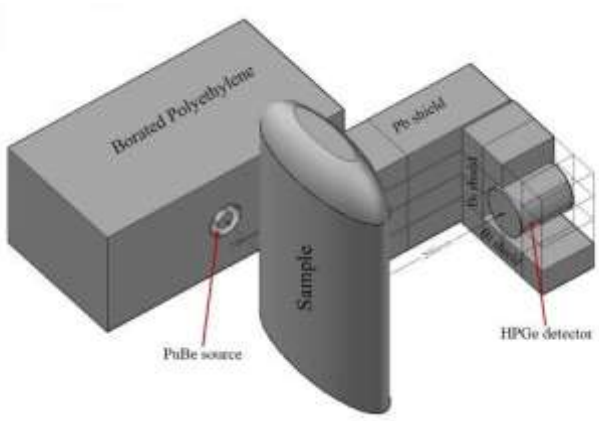

Figure 3. *The setup for PGNAA (3D view) [6].*

3. HPGe gamma-ray spectrometer "channel-energy" calibration

For energy calibration of the HPGe gamma-ray spectrometer we were using:

1. Standard gamma-ray "point" sources of ^{60}Co (1173.2 and 1332.5 keV [2]) and ^{137}Cs (661.7 keV [2])– for energy calibration bellow 3 MeV;
2. Prompt gamma-rays emission from the neutron irradiated Cd and Pb samples [3] - for energy-calibration above 3 MeV.

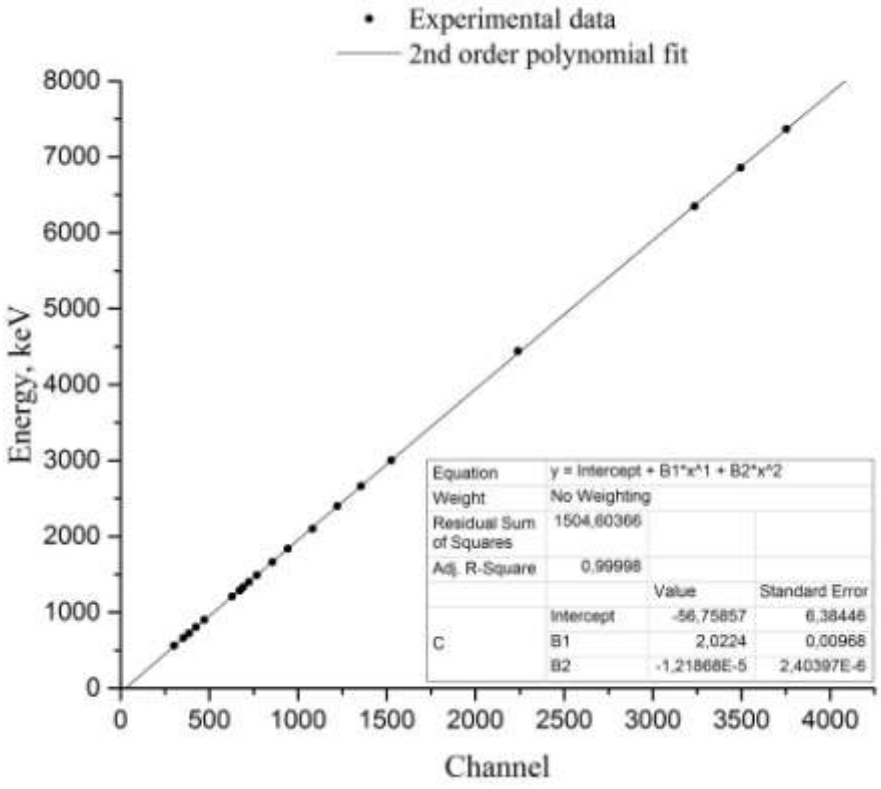

Figure 4. *Channel-Energy calibration of HPGe detector with Origin software [5].*

The data acquisition was done by COCOS (COmbined COrrelation System) computer program developed at JINR FLNP, while the data analysis was performed with Canberra's Genie™ 2000 software [4].

4. Experimental results

The samples with ore were irradiated for about 15 hours. For comparison, all the experimental spectra we normalized to 1 hour of irradiation time.

In the Figures 5 to 12we present a comparison of gamma-spectra collected with HPGe gamma-ray spectrometer from the irradiated samples with concentrate, with tails and without any sample in the beam (the radiation background).

In the experimental spectra figures, we labeled only the gamma-lines of interest [3].

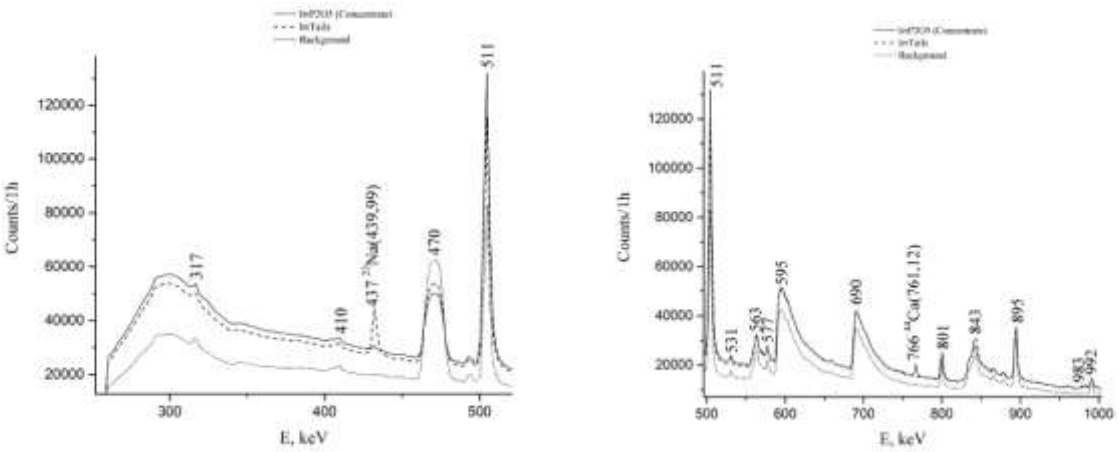

Figure 5. *Comparison of γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~50 – 500) keV (left) and (~0.5 – 1)MeV (right).*

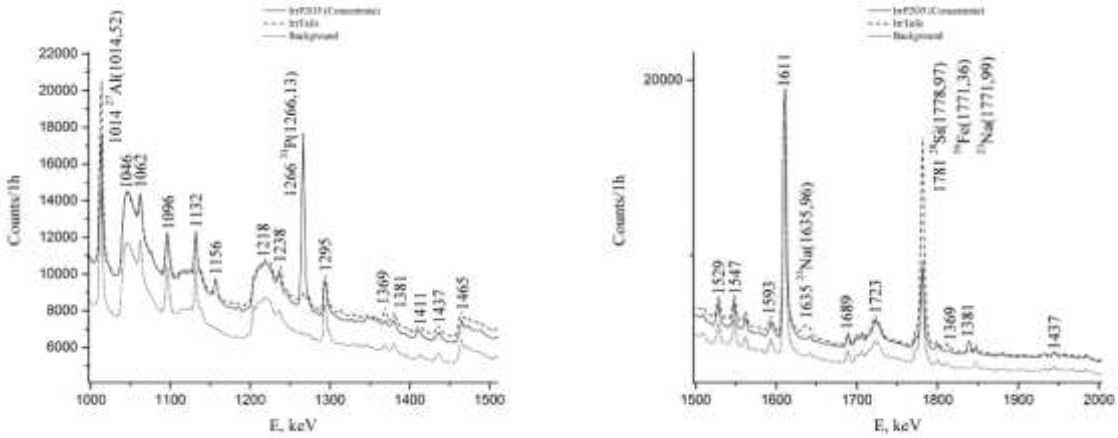

Figure 6. *Comparison of γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~1 – 1.5) MeV (left) and (~1.5 – 2) MeV (right).*

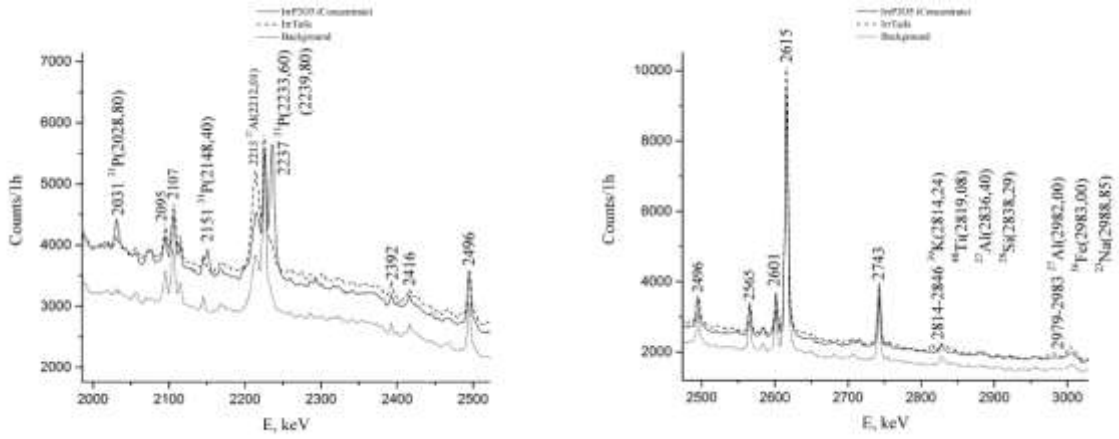

Figure 7. *Comparison of γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~2 – 2.5) MeV (left) and (~2.5 – 3) MeV (right).*

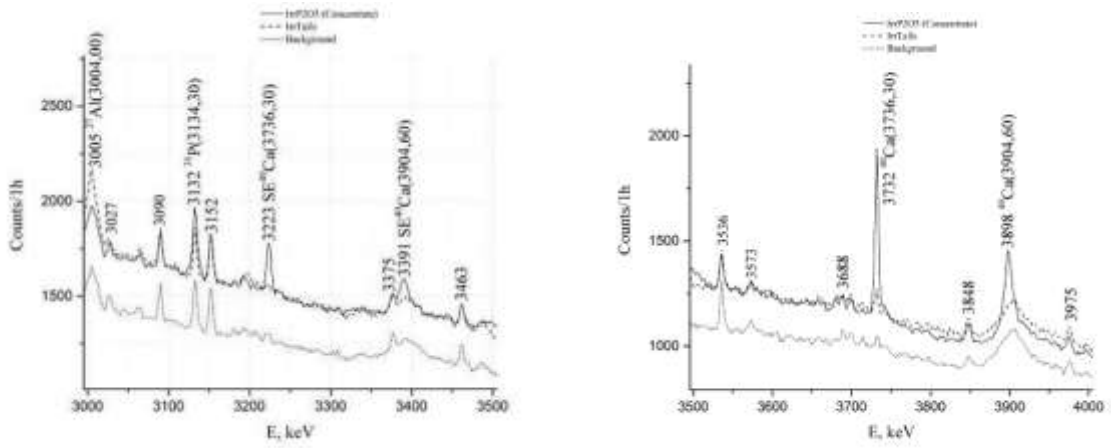

Figure 8. *Comparison of γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~3 – 3.5) MeV (left) and (~3.5 – 4) MeV (right).*

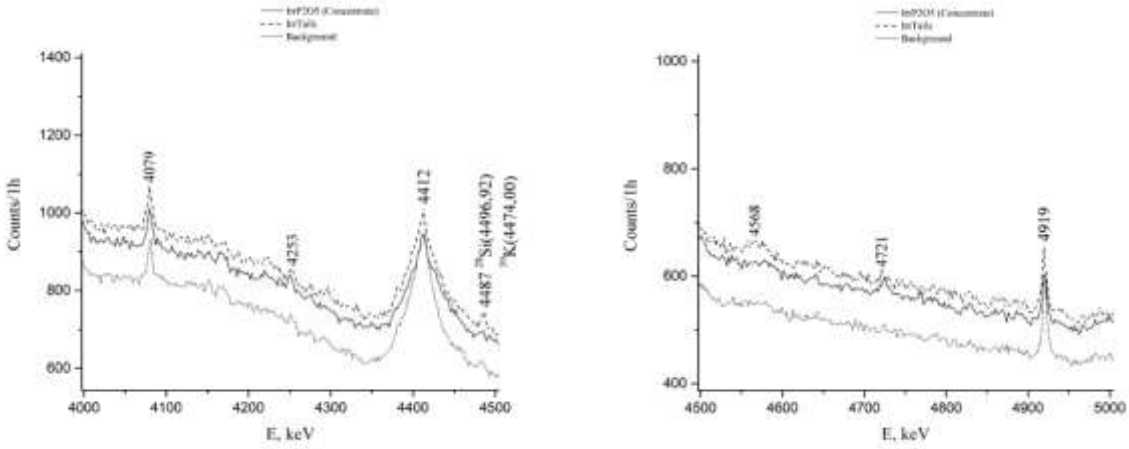

Figure 9. *Comparison of γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~4 – 4.5) MeV (left) and (~4.5 – 5) MeV (right).*

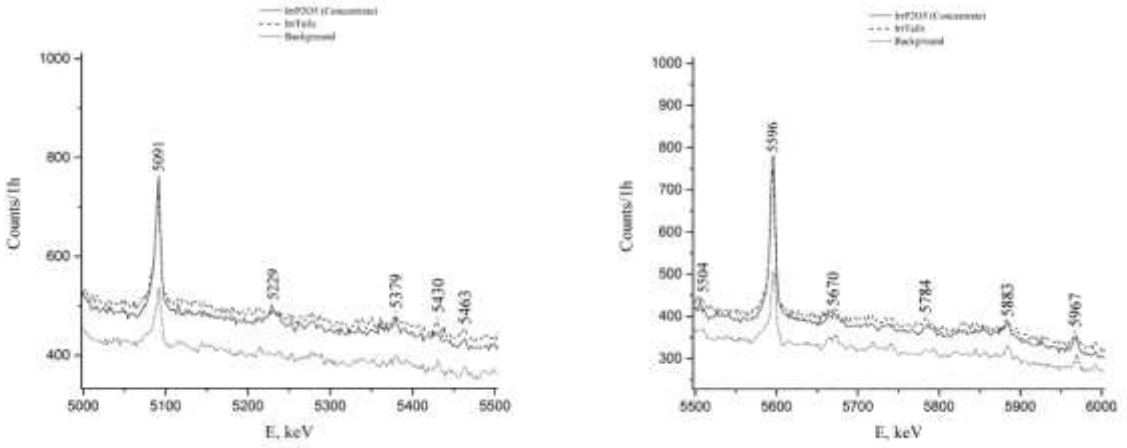

Figure 10. *Comparison of γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~5 – 5.5) MeV (left) and (~5.5 – 6) MeV (right).*

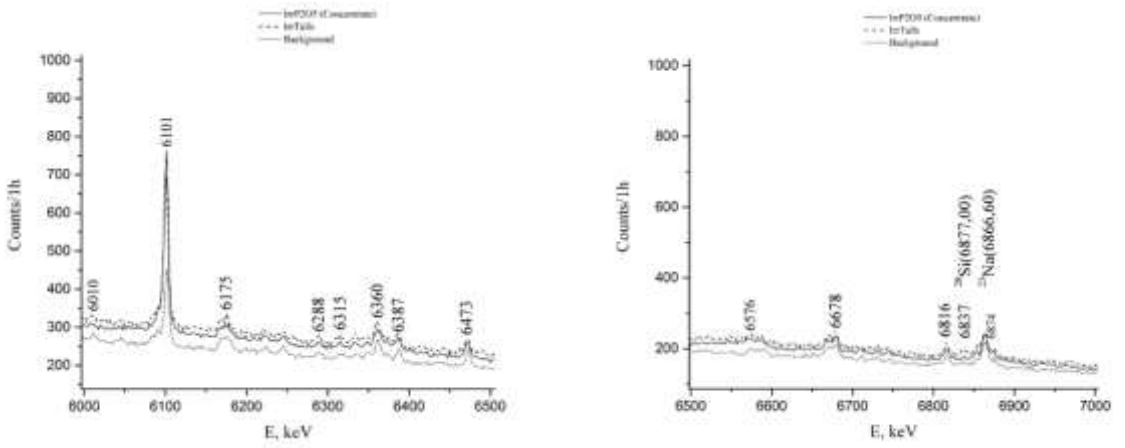

Figure 11. *Comparison of γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~6 – 6.5) MeV (left) and (~6.5 – 7) MeV (right).*

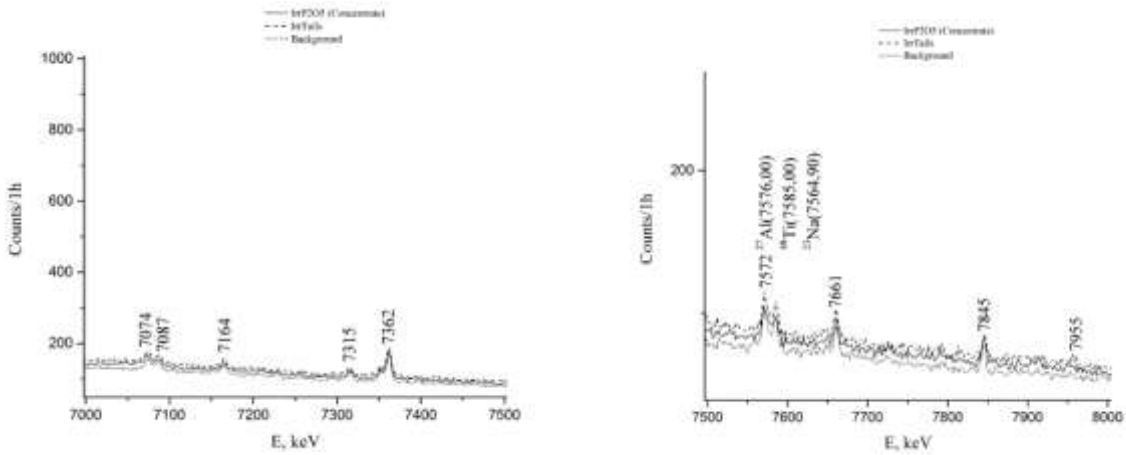

Figure 12. *Comparison of γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~7 – 7.5) MeV (left) and (~7.5 – 8) MeV (right).*

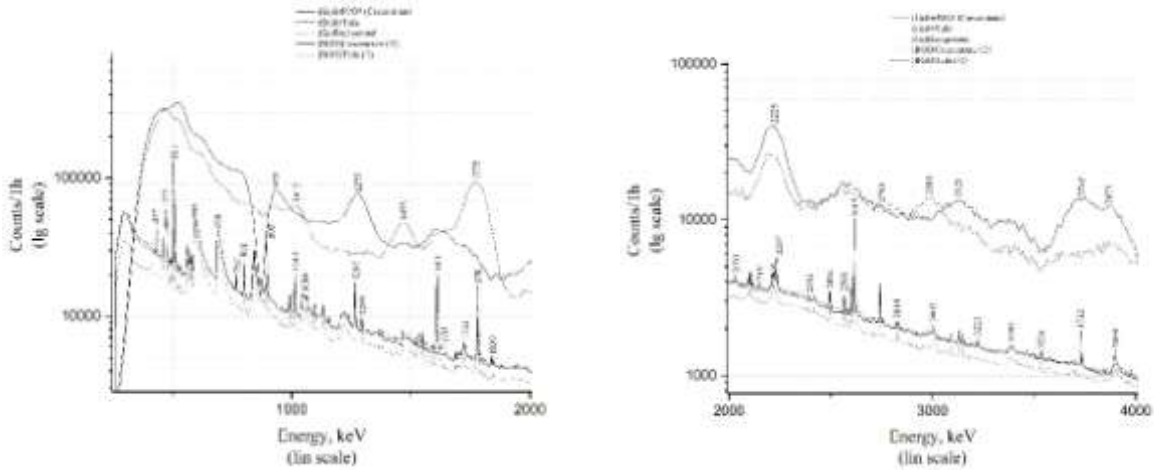

Figure 13. *γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the interval (~0.25 – 4) MeV with BGO (2 top lines) and HPGe (3 bottom lines).*

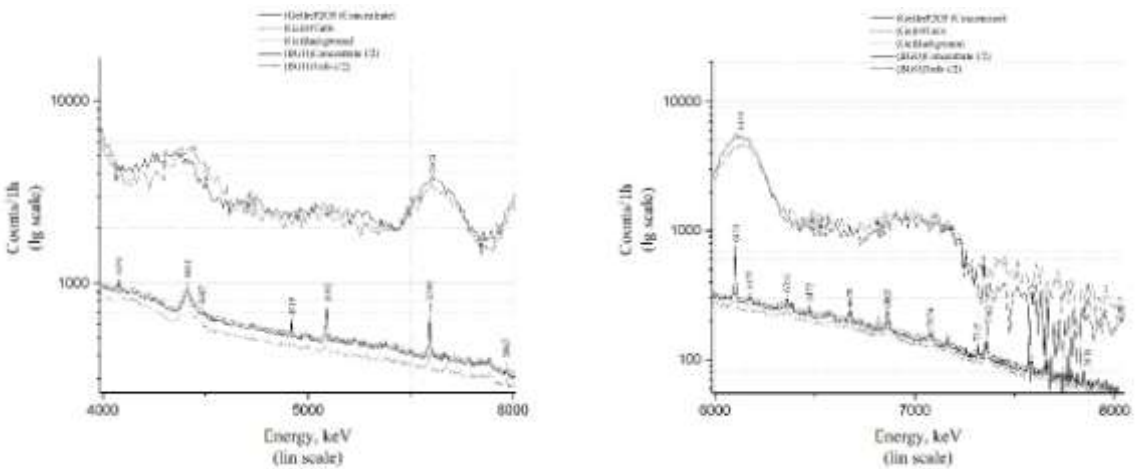

Figure 14. *γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the interval (~4 – 8) MeV with BGO (2 top lines) and HPGe (3 bottom lines).*

The same samples were measured with a BGO detector. In Figures 13 and 14 are shown the gamma-ray spectra obtained with BGO {wide peaks from concentrate ore (solid line) and tails (dotted line)} and with HPGe {narrow peaks from concentrate ore (solid line), tails (dashed line) and background (dotted line)} in the interval (~0.25–8) MeV.

From Figures 13 and 14 one can conclude that, although BGO has a higher efficiency for detection of gamma rays, because of its moderate energy resolution, it is not possible to spot weak gamma-lines.

In Figure 15we show the zoomed (for an easier comparing) Figure 7 HPGe spectra in energy interval from 2MeV up to 2.5MeV.

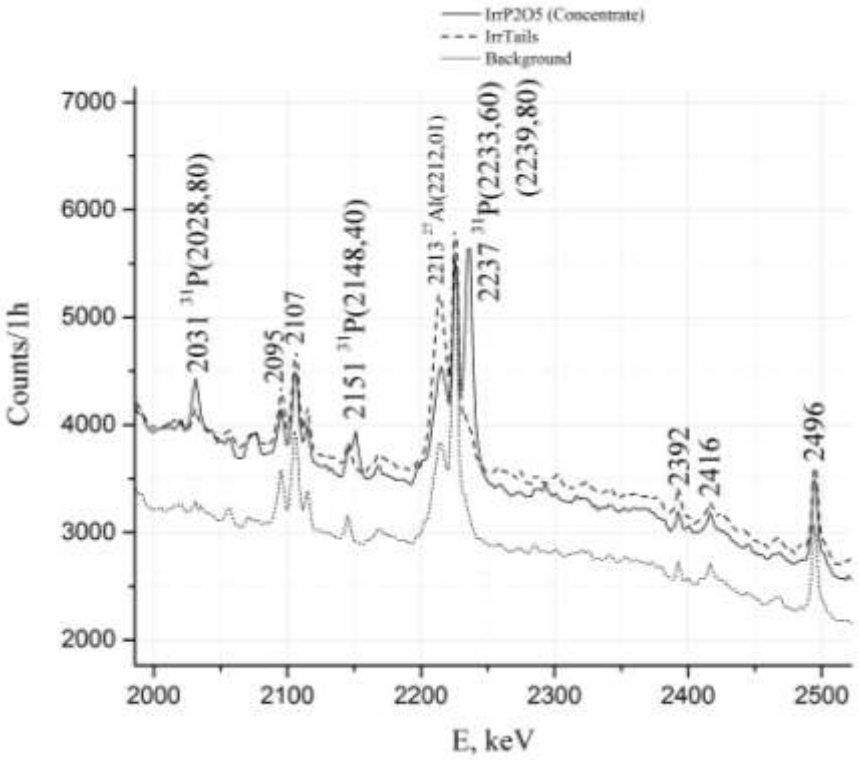

Figure 15. Zoomed *HPGe γ-spectra from concentrate ore (solid line), tails (dashed line) and background (dotted line) in the intervals (~2 – 2.5) MeV.*

The unsigned peak in Figure 15 is from the radiative capture of the thermalized neutrons by hydrogen nuclei, $^{1}H(n_{th},\gamma)^{2}H$ reaction, with irradiation of gamma-quanta with energy E_γ = 2.223 MeV [3]. Because the gamma-line intensity is approximately the same from all the irradiated samples, one can conclude that the samples have the same humidity as the experimental environment.

In Table 1 we show all the identified isotopes after deconvolution of the experimental spectra [4]. Next to be done is a determination of their concentrations.

Table 1. ***Identified r****adioactive isotopes in the experimental gamma-spectra*

γ-line energy in spectrum, keV	Attachment (Concentrate/Tails)	Isotope	Table energy, keV [2]
437	Tails	^{23}Na	439.99
751	Concentrate	SE ^{31}P	1266.13
766	Concentrate	^{44}Ca	761.12
983	Tails	^{48}Ti	983.54
1014	Tails	^{27}Al	1014.52
1156	Concentrate	^{44}Ca	1157.02
1238	Tails	^{56}Fe	1238.27
1266	Concentrate	^{31}P	1266.13
1635	Tails	^{23}Na	1635.96
1778	Tails	^{28}Si ^{56}Fe ^{23}Na	1778.97 1771.36 1771.99
1811	Tails	^{56}Fe	1810.76
1949	Tails	^{23}Na	1950.65
2031	Concentrate	^{31}P ^{23}Na	2028.80 2038.80
2151	Concentrate	^{31}P	2148.40
2213	Tails	^{27}Al	2212.01
2275	Tails	^{56}Fe ^{23}Na	2273.20 2276.13 2263.39
2814-2846	Tails	^{28}Si ^{27}Al ^{48}Ti ^{39}K	2838.29 2836.40 2819.08 2814.24
2979-2983	Tails	^{27}Al ^{56}Fe ^{23}Na	2982.00 2983.00 2988.85
3132	Concentrate	^{31}P	3134.30
3223	Concentrate	SE ^{40}Ca	3736.30
3381	Concentrate	SE ^{40}Ca	3904.60
3499-3507	Concentrate	^{31}P	3506.10
3732	Concentrate	^{40}Ca ^{48}Ti	3736.30 3738.35
3898	Concentrate	^{40}Ca ^{23}Na ^{39}K	3904.60 3913.00 3883.00
4487	Tails	^{28}Si ^{39}K	4496.92 4474.00

6837	Tails	^{28}Si ^{23}Na	6877.00 6866.60
7087	Tails	^{48}Ti ^{23}Na ^{56}Fe	7109.00 7069.75 7080.70 7121.00 7135.00
7572	Tails	^{27}Al ^{23}Na ^{48}Ti	7576.00 7564.90 7585.00
7580	Tails	^{48}Ti	7585.00

5. Conclusions

1) An experimental setup for determining the elemental composition of materials by prompt gamma-ray neutron activation analysis (PGNAA), using ^{239}Pu-Be as a fast neutron source, was commissioned and tested.
2) The acquired spectra was processed and decoded successful by Genie™ 2000 and Origin® softwares [4, 5].
3) The better energy resolution of HPGe comparing to BGO scintillation gamma-detector allowed to determine with a higher accuracy the composition of samples.
4) Some preliminary results were reported and further experiments were proposed.

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6. References

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