ON THE POSSIBILITY OF DETERMINING THE MOISTURE CONTENT IN FURNACE COKE WITH A BGO SCINTILLATION GAMMA-DETECTOR AND A ^{239}Pu-Be NEUTRON SOURCE

Grozdanov D.N.[1,2*], Aliyev F.A.[1,3], Hramco C.[1,4],
Kopatch Yu.N.[1], Bystritsky V.M.[1], Skoy V.R.[1], Gundorin N.A.[1], Ruskov I.N.[1,2]

[1]*Joint Institute for Nuclear Research, Joliot Currie 6, 141980 Dubna, Moscow region, Russia*
[2]*Institute for Nuclear Research and Nuclear Energy of Bulgarian Academy of Sciences, Tzarigradsko chaussee, Blvd., 1784 Sofia, Bulgaria*
[3]*Institute of Geology and Geophysics, Azerbaijan National Academy of Sciences, Azerbaijan, AZ1143, Baku, H. Javid Av., 119*
[4]*Institute of Chemistry of the Academy of Sciences of Moldova Academiei str., 3; MD-2028 Chisinau, Republic of Moldova*

Abstract

In the Joint Institute for Nuclear Research (JINR) some experiments were conducted to study the possibility of determining the moisture content in furnace coke [1], soil, paper and other materials.

The proposed method for determining the moisture content is based on the analysis of spectra of prompt gamma-rays emitted from the test samples when they are irradiated by fast and/or thermal neutrons. The moisture content can be determined from the characteristic gamma-lines of hydrogen and oxygen.

This paper presents some preliminary results from the test measurements with furnace coke samples of different humidity.

Keywords: Gamma-rays, spectrometry, multichannel analyzer, neutron source.

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* Corresponding author Tel.: + 7-496-216-2131; fax: +7-496-216-5085.
email: dimitar@nf.jinr.ru.

1. Method of measurement

This method is aimed for a quantitative determination of moisture (H_2O) in the furnace coke. It is based on the registration of the γ-rays from the interaction of neutrons from a ^{239}Pu-Be with the coke nuclei as result of the following reactions:

- Inelastic scattering of fast neutrons on the nuclei of oxygen (^{16}O) with the emission of characteristic gamma-rays with energy of 6.13 MeV, $^{16}O(n,n`\gamma)\ ^{16}O^*$-reaction;
- Radiative capture of thermalized neutrons by the hydrogen nuclei with emission of γ-rays with energy of 2.22 MeV, $^{1}H(n_{th}, \gamma)\ ^{2}H$-reaction.

These reactions are pictured in Fig.1 (inelastic scattering) and Fig. 2 (radiative capture).

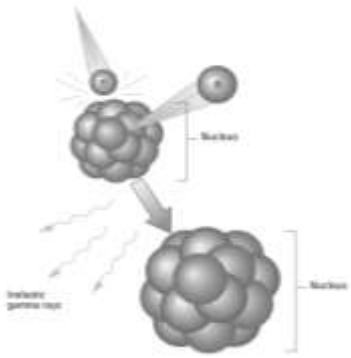

Fig. 1. Inelastic scattering.

Fig. 2. Radiative capture.

2. Experimental setup

The experimental setup consisted of (Fig. 3): ^{239}Pu-Be neutron source, BGO γ-detector, signal processing and data collecting system, a passive shielding of the γ-detector from the direct radiation emitted by the ^{239}Pu-Be neutron source.

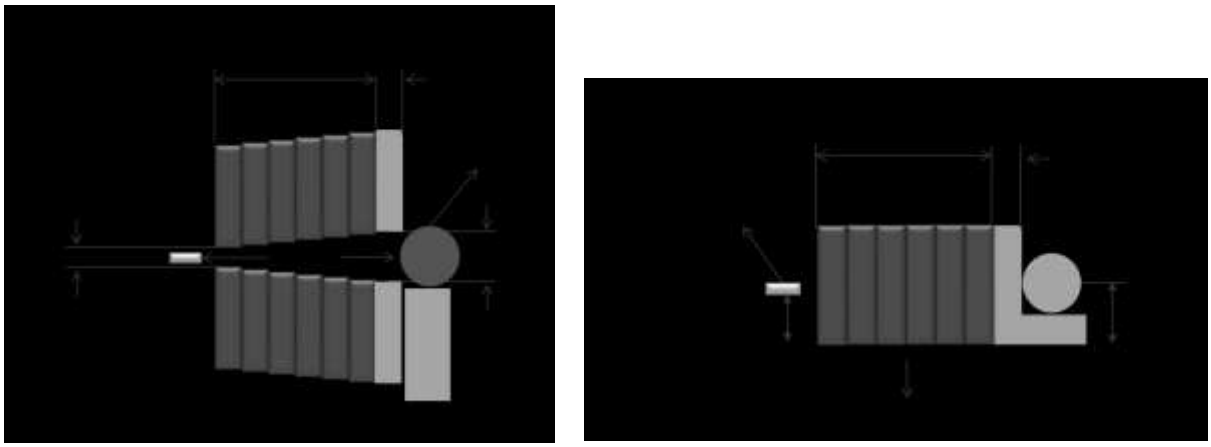

Fig. 3. The scheme of the experimental setup for determining the moisture content: top-view (left) and side view (right).

- The ^{239}Pu-Be neutron source had an intensity of $5 \cdot 10^6$ n/s;
- The shielding was constructed from Iron (Fe) and Bismuth (Bi) bricks;
- A computerized 16-channel digital readout system, utilizing one ADCM16-LTC (16-channel/14-bit/100MHz) ADC-board from AFI Electronics© [2], was used for signal processing and data acquisition;
- For registering the high-energy characteristic gammas, a γ-ray detector based on the BGO-scintillator (∅76×65mm^2) was used.

3. Energy calibration of gamma-ray detector

For identification of the characteristic gamma-radiation from ^{1}H* and ^{16}O* nuclei, we made an energy calibration of the pulse amplitude spectra using "gamma-lines" with well-determined energies, form the following reactions:

1) The fast neutron inelastic scattering on ^{56}Fe. In ^{56}Fe(n,n'γ)^{56}Fe-reaction the γ-quantum has an energy of 846.77 keV [3];

2) The thermal neutron capture by ^{56}Fe nuclei. In ^{56}Fe(n,γ)^{57}Fe-reaction γ-quanta with an energy of 7631.18 keV [3] are emitted;

3) The ^{9}Be(α,n)^{12}C-reaction in the ^{239}Pu-Be neutron source produces gammas with energies of 4438.91 keV [4];

4) The ^{74}Ge(n_{th},γ)^{75}Ge-reaction in the BGO-crystal gives γ-rays with energies of 10202 keV [5].

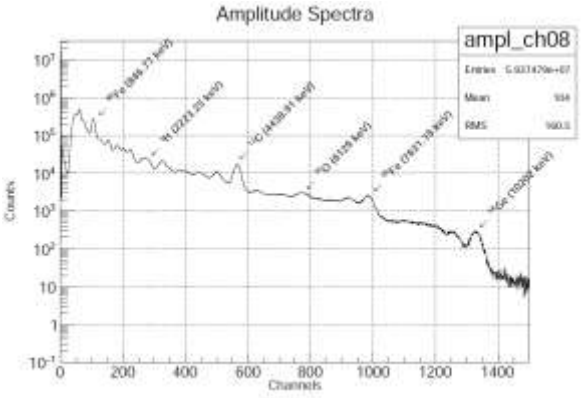

Fig. 4. The amplitude spectrum recorded by the BGO detector without sample (Background).

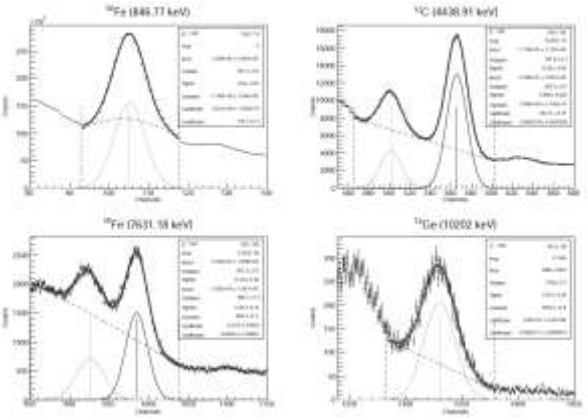

Fig. 5. Fitting the characteristic γ-peaks in the amplitude spectra, ^{56}Fe (843 keV), ^{12}C (4439 keV), ^{56}Fe (7631 keV) and ^{74}Ge (10202 keV).

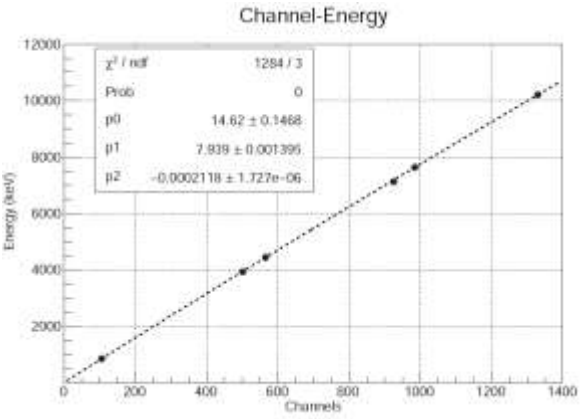

Fig. 6. Channel-Energy calibration.

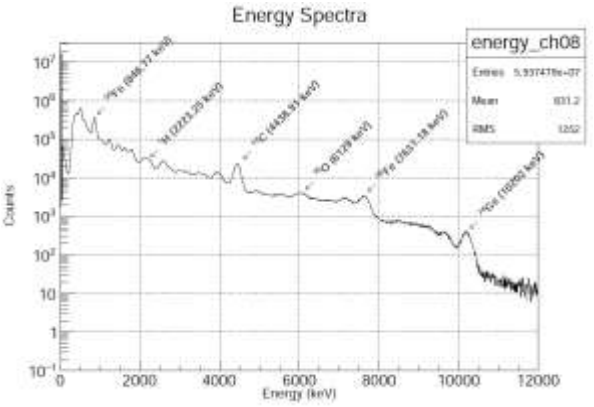

Fig. 7. Energy distribution of events recorded by the BGO detector without sample (Background).

4. Measuring conditions and some experimental results

A 3kg sample containing a variable amount of water (from 2% up to 80%) was irradiated by ^{239}Pu-Be neutrons every time for 10 hours.

The recorded with BGO detector gamma-ray spectra are shown in Fig. 8. The background gamma-radiation spectrum was subtracted from these characteristic gamma-ray spectra and all the net-spectra are shown in Fig. 9.

By fitting ^{1}H and ^{16}O peaks (Figs. 10 and 11) and net-spectra (Figs. 12 and 13), the area under each of them was calculated.

The dependences of ^{1}H and ^{16}O peak areas on the amount of H_2O added into the coke sample are shown in Figs. 14 and 15, respectively.

In Table 1 a comparison between the characteristic gamma-peak areas of ^{1}H and ^{16}O is shown.

In Table 2 the relative "effect-to-background" ratios for ^{1}H and ^{16}O as a function of H_2O content are shown.

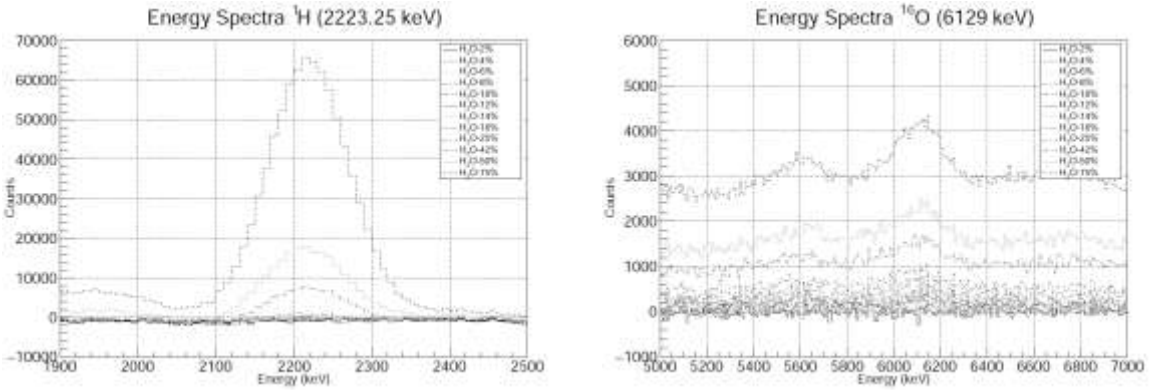

Fig. 8. The energy distributions of events recorded by the BGO detector (H_2O: from 2% up to 80%): ^{1}H-peaks (left) and ^{16}O-peaks (right).

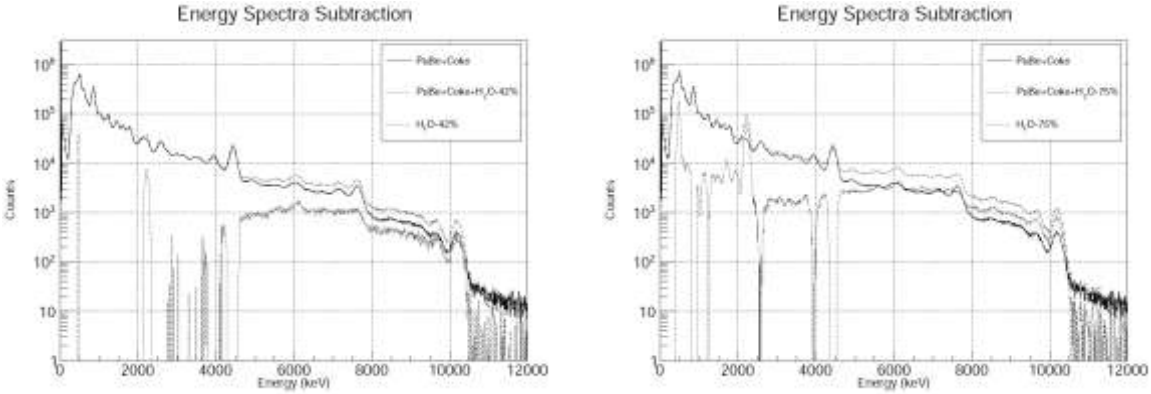

Fig. 9. Gamma-ray energy net-spectra of events recorded by the BGO detector, H_2O: 42% (left) and 75% (right).

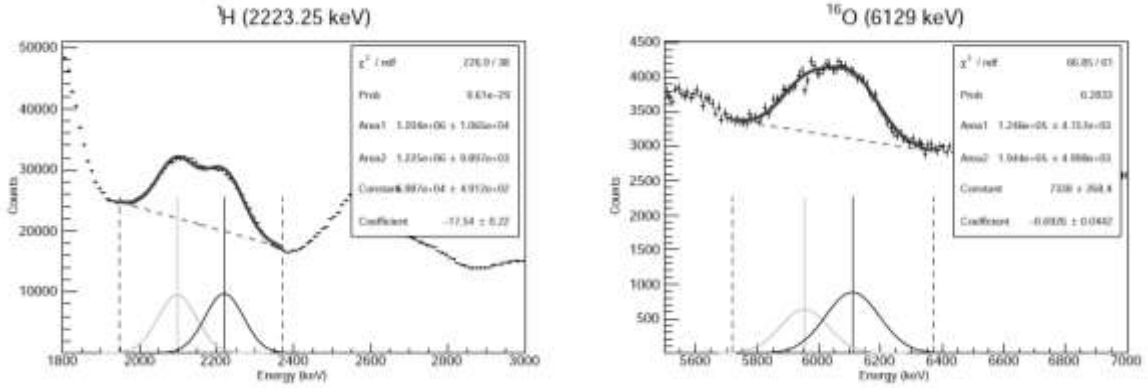

Fig. 10. Fitting the ^{1}H and ^{16}O characteristic gamma-peaks in the full-spectra (H_2O: 8%).

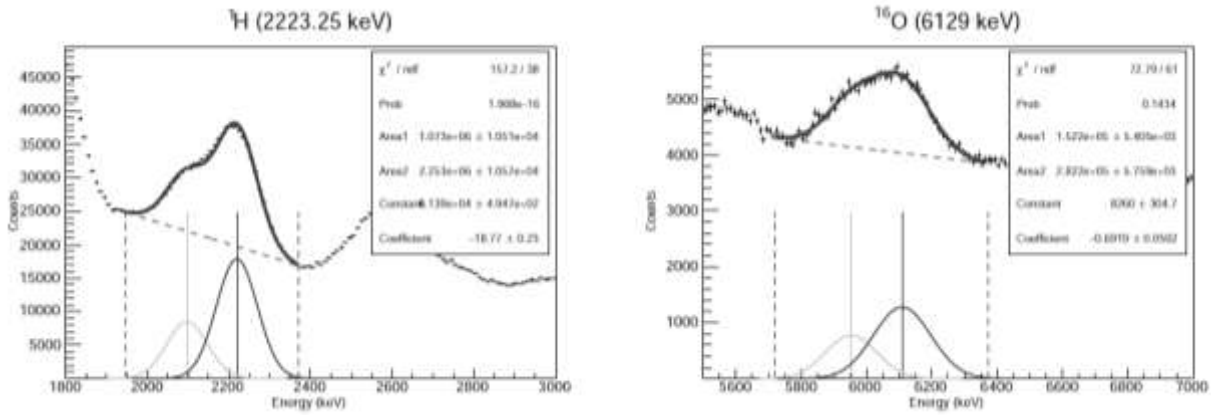

Fig. 11. Fitting the ^{1}H and ^{16}O characteristic gamma-peaks in the full spectra (H_2O:42%).

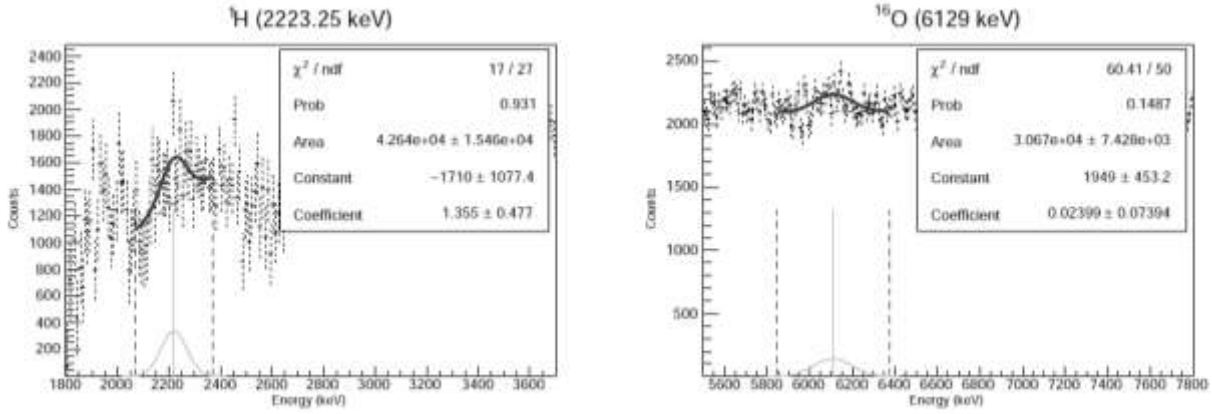

Fig. 12. Fitting the ^{1}H and ^{16}O characteristic gamma-peaks in the net-spectra (H_2O: 8%).

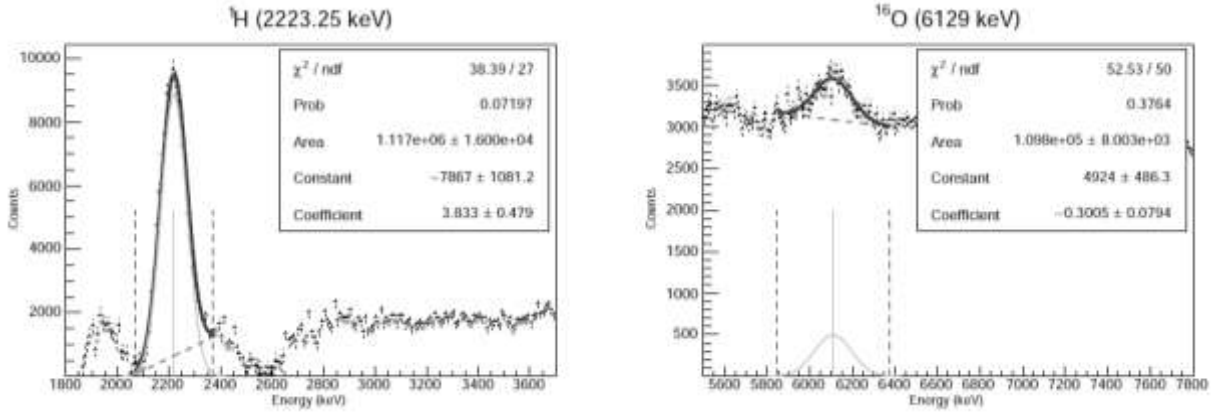

Fig. 13. Fitting the ^{1}H and ^{16}O characteristic gamma-peaks in the net-spectra (H_2O: 42%).

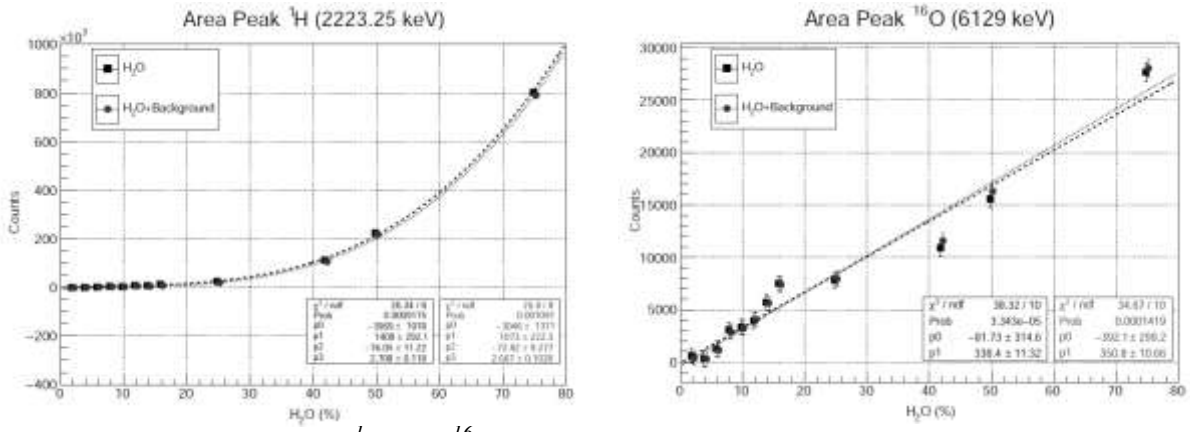

Fig. 14. Dependence of ^{1}H and ^{16}O characteristic gamma-peak areas on H_2O-content.

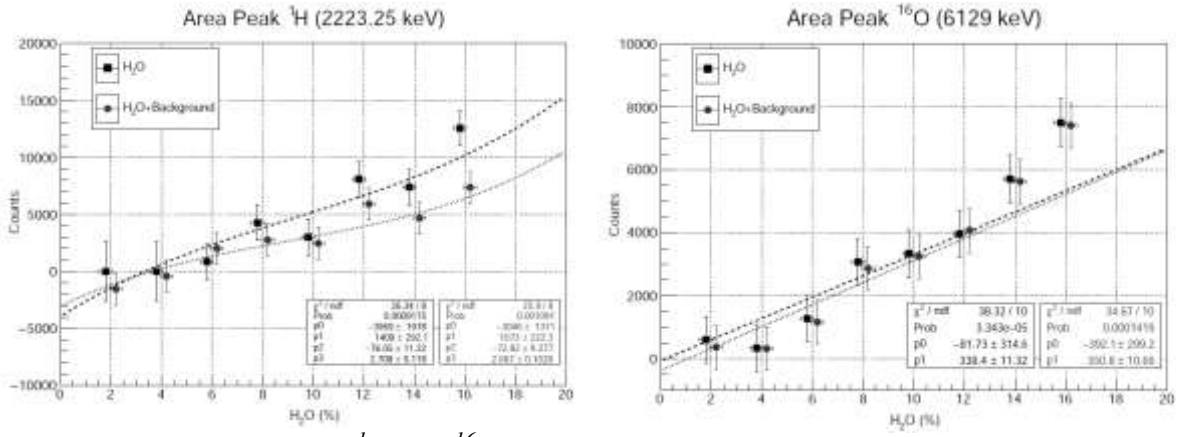

Fig. 15. Dependence of ^{1}H and ^{16}O characteristic peak areas on H_2O-content in the interval from 0% to 20%.

Table 1. Comparison of the main results:

H_20 (%)	^{239}PbBe + Sample		^{1}H		^{16}O	
	Integral All Spectra	Δ Integral	Area under peak	Δ Area	Area under peak	Δ Area
Background	1.16E+07	3.41E+03	1.20E+05	9.93E+02	1.66E+04	4.87E+02
2	1.12E+07	3.35E+03	1.18E+05	9.87E+02	1.69E+04	4.86E+02
4	1.12E+07	3.35E+03	1.19E+05	9.87E+02	1.69E+04	4.92E+02
6	1.13E+07	3.36E+03	1.22E+05	9.90E+02	1.77E+04	5.18E+02
8	1.14E+07	3.37E+03	1.22E+05	9.90E+02	1.94E+04	5.00E+02
10	1.13E+07	3.36E+03	1.22E+05	9.89E+02	1.98E+04	5.03E+02
12	1.14E+07	3.38E+03	1.26E+05	9.92E+02	2.07E+04	5.07E+02
14	1.14E+07	3.38E+03	1.24E+05	9.92E+02	2.22E+04	5.12E+02
16	1.13E+07	3.36E+03	1.27E+05	9.84E+02	2.40E+04	5.22E+02
25	1.14E+07	3.38E+03	1.39E+05	9.96E+02	2.45E+04	5.36E+02
42	1.17E+07	3.41E+03	2.25E+05	1.06E+03	2.82E+04	5.76E+02
50	1.25E+07	3.53E+03	3.38E+05	1.15E+03	3.29E+04	6.09E+02
75	1.44E+07	3.79E+03	9.10E+05	1.50E+03	4.46E+04	6.95E+02

Table 2. The relative "effect-to-background"-ratios

H_20 (%)	^{1}H		^{16}O	
	Ratio of Effect to Background	Δ Ratio	Ratio of Effect to Background	Δ Ratio
Background	*1*	0.012	*1*	0.042
2	*0.987*	0.012	*1.022*	0.042
4	*0.996*	0.012	*1.019*	0.042
6	*1.017*	0.012	*1.070*	0.044
8	*1.023*	0.012	*1.173*	0.046
10	*1.021*	0.012	*1.196*	0.046
12	*1.049*	0.012	*1.246*	0.048
14	*1.039*	0.012	*1.339*	0.050
16	*1.062*	0.012	*1.447*	0.053
25	*1.162*	0.013	*1.479*	0.054
42	*1.882*	0.018	*1.702*	0.061
50	*2.828*	0.025	*1.984*	0.069
75	*7.599*	0.064	*2.692*	0.090

5. Conclusions

This feasibility study shows that we can determine the amount of H_2O, added into the furnace coke sample, from the characteristic gamma-ray spectra with and without radiation background subtraction.

Fig. 15 shows that the minimum amount of H_2O in a 3kg furnace coke sample, which we succeed to determine with an accuracy of 10%, was 6%. For a more precise determination of H_2O content, it is necessary to increase the statistics of detected events from the reactions depicted in Figs. 1 and 2.

One can use this method not only for determining the moisture in the furnace coke, but also the concentration of other elements in it. Of course, this could be possible after improving the experimental conditions and modifying the algorithm of experimental data collecting and analysis.

6. References

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