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V.V. Dyachkov[1*], Yu.A. Zaripova[1], M.G. Ahmadieva[1],
M.T. Bigeldiyeva[1], A.V. Yushkov[1,2]

[1]Al-Farabi Kazakh National University, Almaty, Kazakhstan
[2]Science Research Institute of Experimental and Theoretical Physics, Almaty, Kazakhstan
[*] e-mail: slava_kpss@mail.ru

Study of the natural radioactivity of ore deposits

Abstract. In the article, the authors present experimental data on the specific power equivalent dose (EDR) of radiation gamma, beta, and alpha radiation in samples containing copper, zinc and lead of pyrite-polymetallic ores, which were mined at the Zhezkent mining and processing plant (The East Kazakhstan region, Borodulikhinsky district). The measurements were carried out by dosimeters and radiometers "RKS-01-SOLO" with alpha, beta and gamma scintillation detectors. For ores, the dependences of the specific power of the equivalent dose of gamma radiation on the content of various concentrations of copper, zinc and lead were revealed. The analysis of natural decay chains, the daughter products of which are stable isotopes of copper and zinc, is carried out. A relationship has been proposed between the concentrations of nickel, copper, lead and EDR, which gives prospects for further spectrometric studies of these samples to identify the corresponding lines of accompanying gamma radiation during decays of radionuclides contained in the samples under study and radiation conversion of stable isotopes. The results of this work will make it possible to build a model for studying the radiation of ores, the distribution of natural radionuclides in the earth's crust, which will undoubtedly provide prerequisites for the verification and clarification of the sources and mechanisms of emanation and coagulation of radon isotopes, which form the natural radiation background of the surface atmospheric layer.

Key words: equivalent dose rate; pyrite-polymetallic ore; radioactivity of minerals; geology of the Earth.

Introduction

The study of natural radioactivity is extremely important due to the direct effect of radiation from natural radionuclides on human health [1-21]. From the very beginning of its formation, the Earth's crust contains natural radioactive elements [22-23], which create a natural background radiation. The radioactive isotopes of potassium-40, rubidium-87 and members of three radioactive families originating from uranium-238, uranium-235 and thorium-232 are present in rocks, soil, atmosphere, waters, plants and tissues of living organisms. Studying the own radiation of rocks, various ores and minerals, minerals will help to supplement the existing geological models on the formation and geological structure of the earth's surface with experimental data. It is of great interest to study the content of various radionuclides in these terrestrial samples. In this work, an attempt has been made to determine the relationship between the decays of radionuclides included in chains, which lead to the current concentration of certain impurities in rocks, ores and minerals, by radiometric measurement of gamma radiation.

In addition, in the geological structure of the Earth, in addition to the elements of the three main radioactive families, the existence of other chemical elements contained in minerals in various geological layers of the Earth, there is a basic hypothesis for the formation of the latter during the formation of planets from stellar material by accretion from a protoplanetary disk, a disk-like mass of gas , dust left over from the formation of the Sun. The study of natural radiation of ore rocks will explain these concentrations in deposits from the standpoint of nuclear-physical mechanisms. Such prerequisites follow from the fact that the formation of light nuclei occurs due to fusion reactions. The formation of medium and heavy occurs due to the capture of neutrons and further beta decay or other nuclear reactions occurring in the evolution of Stars.

Material and Methods

Samples of pyrometallic ore were taken at the Zhezkent mining and processing plant (East Kazakhstan region, Borodulikhinsky district), Figure 1. The main ore bodies of the deposits are confined to zones of interlayer disruption and are characterized

by ores close in material composition, differing mainly in the ratios of the main components (copper: lead : zinc) and the presence of pyrite in varying amounts. Rocks containing ore deposits are volcanic-sedimentary formations of the Middle and Upper Devonian [24].

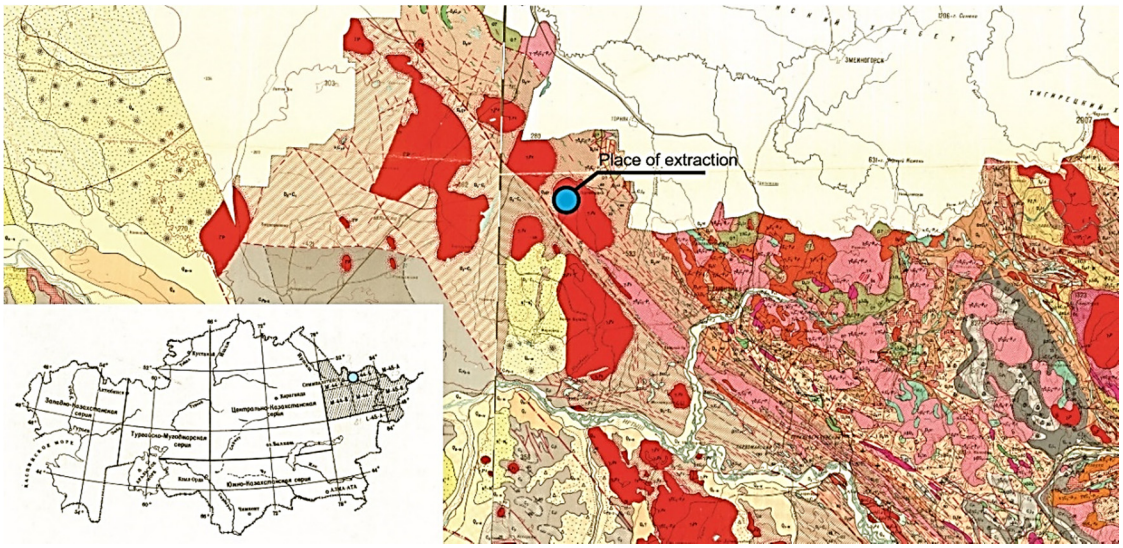

Figure 1 – Geological map and location of the Zhezkent mining and processing plant [25]

The measurements were carried out with RKS-01-SOLO dosimeters and radiometers with alpha, beta and gamma scintillation detectors in contact with the sample surface. These devices are designed for radiation monitoring of the environment and various surfaces. The sensitivity of devices for measuring the equivalent dose rate from 0.05 to 10^2μSv/h with a relative measurement error limit of ±15%.

The measurement technique for colche – polymetallic ores was as follows. The maximum possible surface was chosen on the sample to cover the working sensitive part of the detector. Within ten days, with a step of two days, a series of measurements of the gamma background and gamma radiation of the surface of the samples were carried out. The statistical error in measuring the gamma background and gamma radiation of the samples did not exceed 10%. Measurements of alpha and beta radiation were carried out during the day, while fluctuations in the background and self-radiation reached 50%, but on average did not exceed the background value. This error is explained by the relatively low values, which leads to a corresponding uncertainty in the measurement results.

Fig. 2 shows the selected samples of pyrite – polymetallic ore. Samples were taken from various parts of the mine. On average, the depth of mining ranges from 200 to 500 m.The chemical composition of ore samples is given in Table 1.

Table 1 – Composition of samples of pyrite – polymetallic ore

samples	Plot	Cu, % kg	Pb, % kg	Zn, % kg	Fe, S % kg	m, kg	Cu, %	Pb, %	Zn, %
1	1	5.08	0.048	0.165	94.707	0.865	4.39	4.15	0.143
9	1	1.215	0.93	4.29	97.426	0.534	0.65	0.497	2.29
10	1	1.215	0.93	4.29	97.426	0.458	0.55	0.426	0.196
3	2	2.08	1.83	5.26	90.83	1.056	2.2	1.93	5.55
4	2	2.08	1.83	5.26	90.83	0.256	0.53	0.46	1.35
6	2	2.08	1.83	5.26	90.83	0.25	0.52	0.458	1.32
7	2	2.08	1.83	5.26	90.83	0.309	0.64	0.565	1.63
2	3	4.72	0.11	0.58	94.59	0.592	2.79	0.028	0.343
5	3	4.72	0.11	0.58	94.59	0.613	2.89	0.067	0.356
8	3	4.72	0.11	0.58	94.59	0.648	3.06	0.071	0.376

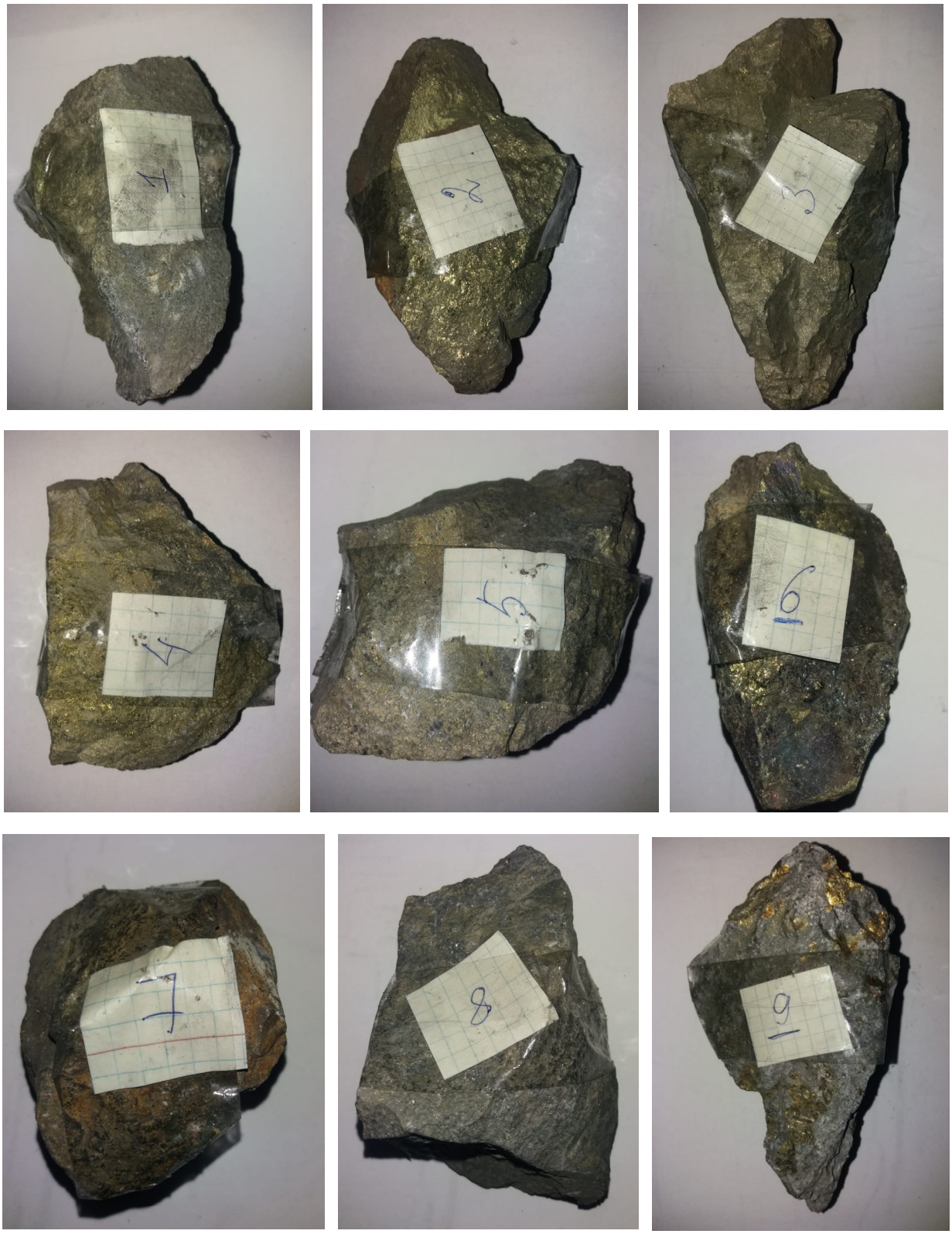

Figure 2 – Appearance of samples of pyrite – polymetallic ore

Results and Discussion

Fluctuations in the background EDR values over the entire measurement period ranged from 0.107 μSv/h to 0.113 μSv/h. Figure 3 shows the results of measurements of the intrinsic gamma radiation of all samples. Figures 4-6 show the dependences of the specific EDR measurement results on the percentage of lead, copper and zinc.

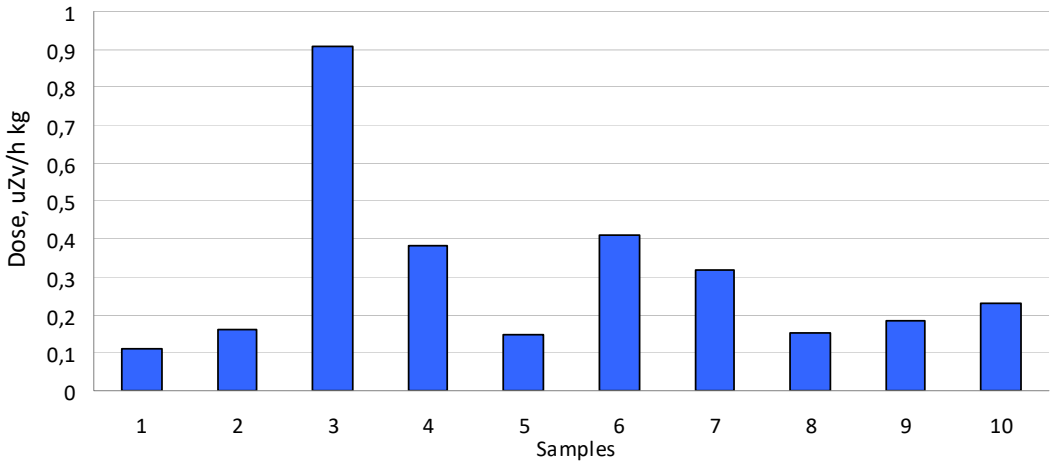

Figure 3 – Values of specific EDR in all studied samples

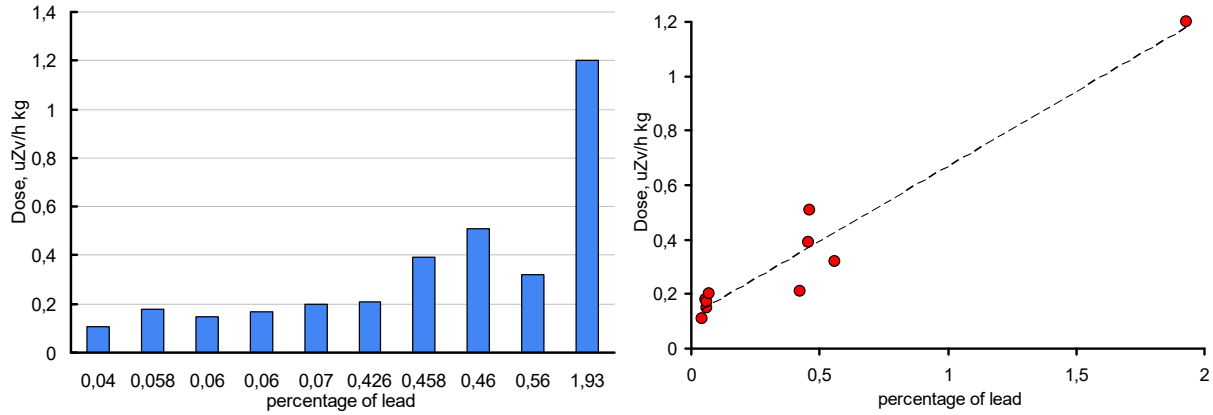

Figure 4 – Dependence of the specific EDR on the percentage of lead in the samples.
From left to right, sample numbers: No.1, No.9, No.8, No.2, No.5, No.10, No.6, No.4, No.7, No.3

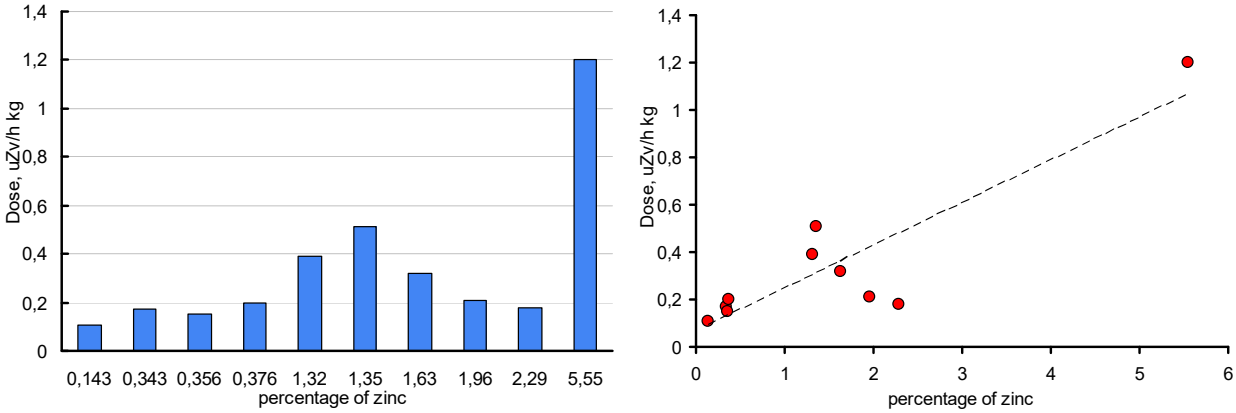

Figure 5 – Dependence of the specific EDR on the percentage of zinc in the samples.
From left to right, sample numbers: No.1, No.2, No.8, No.5, No.6, No.4, No.7, No.10, No.9, No.3

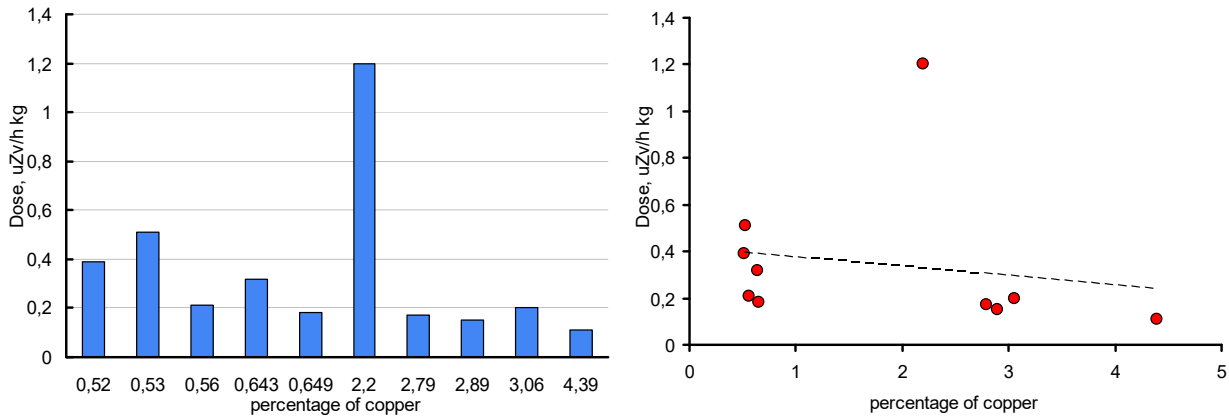

Figure 6 – Dependence of the specific EDR on the percentage of copper in the samples.
From left to right, sample numbers: No.6, No.4, No.10, No.7, No.9, No.3, No.2, No.8, No.5, No.1

From the experimental dependences it can be seen (Fig. 4-6) that the values of the specific EDR in ore samples 3, 4, 6, 7, a stable excess of the gamma background is observed. Figure 4 shows the dependence of the specific EDR on the percentage of lead in ore samples. It can be seen that the relationship between the increase in the concentration of lead and the increase in the specific EDR is traced quite well in the ore samples, the correlation coefficient is 0.97. Figure 5 shows that the relationship between an increase in zinc concentration and an increase in specific EDR is not entirely unambiguous in ore samples, while the correlation coefficient is 0.88. Figure 6 shows the dependence of the specific EDR on the percentage of copper in ore samples, which is practically absent, the correlation coefficient is -0.17. Figure 7 clearly shows the impurities of lead, zinc and copper in the studied ores and their specific EDR values. It can be seen that the relationship between the content of lead and zinc and the specific EDR for the corresponding ore is well traced. As a result of the decays of three natural radioactive families, stable lead isotopes are ultimately formed. This can explain the high correlation coefficient between the concentration of lead and EDR in the samples.

Figures 8, 9 show the results of radiometric measurements of beta and alpha radiation of the samples under study.

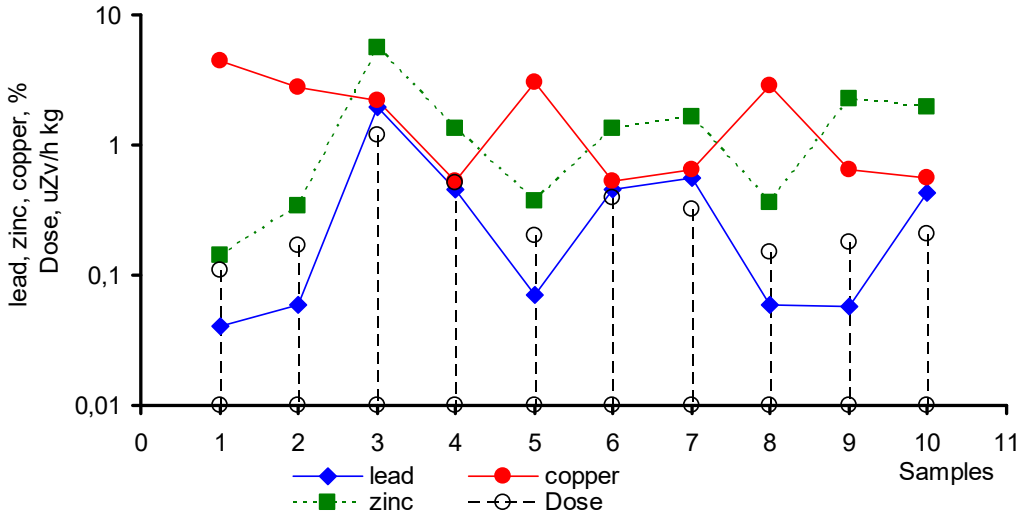

Figure 7 – Relation of specific EDR with the concentration of lead, zinc and copper in ore samples

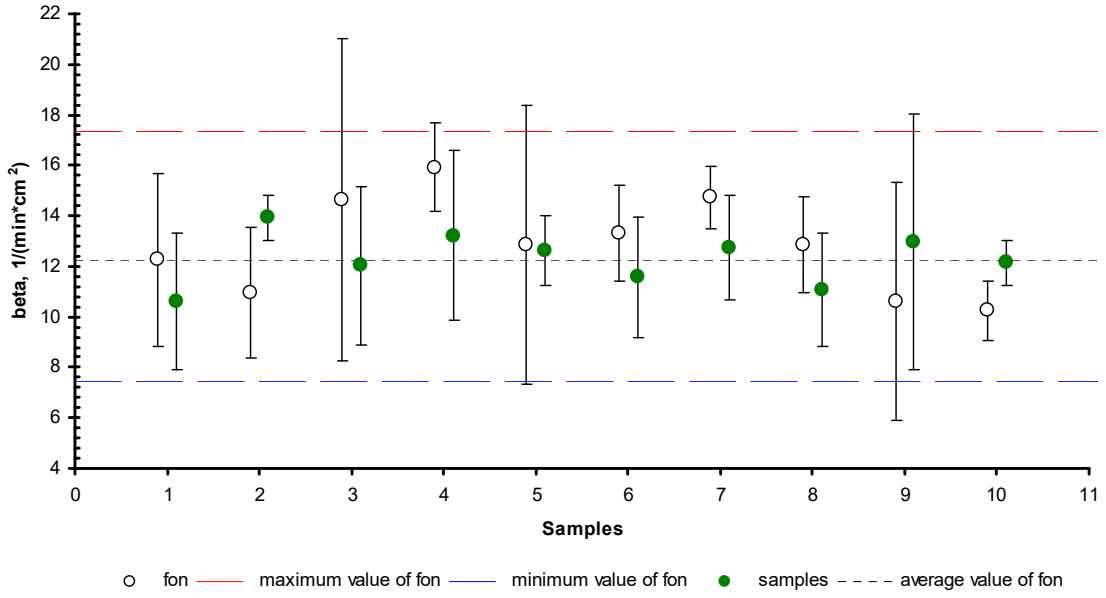

Figure 8 – Values of surface beta radiation in all tested samples

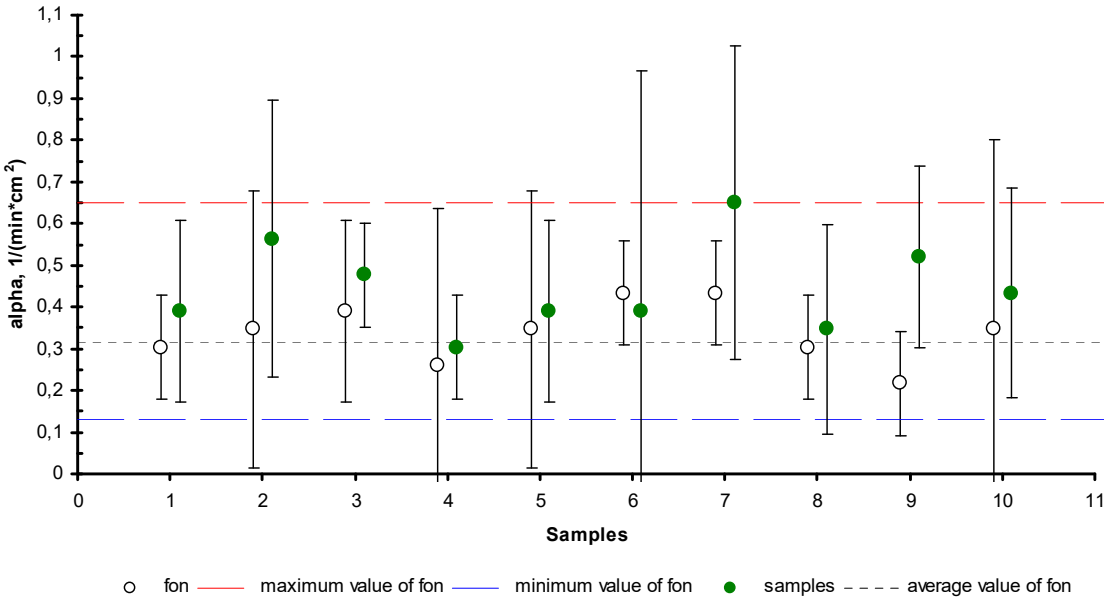

Figure 9 – Values of surface alpha radiation in all tested samples

The figures show that there is no excess over the background level of alpha and beta radiation from the samples under study, obtained by radiometric methods, and is within the measurement error. The effect on the EDR of the samples is indirectly exerted by the concentration of zinc. It can be assumed that, possibly, in the geological structure of the Earth, in addition to the elements of the three main radioactive families, the existence of some chemical elements takes place due to the radiation transformation from one to another. As you know, the nature of the formation of all chemical elements, and as a result, their presence in the chemical composition of the Earth, is the result of the evolution of stars, from the substance of which, subsequently, the planets are formed. But it is worth noting that the formation of nuclei up to A<60 "iron maximum" occurs due to fusion reactions. The formation of nuclei with A>60 occurs due to the capture of neutrons and further beta decay. Such a transformation of the latter is quite possible in the conditions of the formed planets. In addition, the reactions of radiation capture by

elements of high-energy protons in cosmic ray fluxes also make it possible to perform such a transformation. Within the framework of this work, the authors propose a model of the radiation origin of chemical elements of ore rocks, as applied to copper and zinc, not during the birth and formation of the planet, but during its entire life cycle.

Consider a process of radiation origin ^{64}Zn from ^{63}Cu. In nature, the content of the stable isotope ^{63}Cu is 69.1%. In the process of radiation capture of a neutron, $^{63}\mathrm{Cu}(\mathrm{n},\gamma)^{64}\mathrm{Cu}$ (where En≈0.6 MeV, the reaction cross section σ≈20 mb [26]) a radioactive isotope ^{64}Cu is formed. In turn, ^{64}Cu, with a half-life of 12.7 hours, decays through β + -decay, ε-capture and β-decay into the corresponding decay products of 64Ni $\left(^{64}\mathrm{Cu}\xrightarrow[\mathrm{T}_{1/2}=12,7h]{\beta^{+}+\varepsilon(61,5\%)}{}^{64}\mathrm{Ni}\right)$, which is 0.91% in nature, and 64Zn $\left(^{64}\mathrm{Cu}\xrightarrow[\mathrm{T}_{1/2}=12,7h]{\beta^{-}(38,5\%)}{}^{64}\mathrm{Zn}\right)$, which in nature 48.6%. On the other hand, in the process of radioactive capture of a proton $^{63}\mathrm{Cu}(\mathrm{p},\gamma)^{64}\mathrm{Zn}$, (where Ep = (1.46-3.21) MeV, the reaction cross section σ = (1.2-15.6) μb [27]) a stable isotope 64Zn is formed.

The process of radiation origin of 66Zn from 65Cu, the content in nature is 30.9%, can be described as follows. 1) in the process of radiation capture of a neutron $^{65}\mathrm{Cu}(\mathrm{n},\gamma)^{66}\mathrm{Cu}$, (where En≈0.6 MeV, the reaction cross section σ≈10 mb [26]), a radioactive isotope 66Cu is formed. In turn, ^{66}Cu, with a half-life of 5.12 min, decays through β-decay into ^{66}Zn $\left(^{66}\mathrm{Cu}\xrightarrow[\mathrm{T}_{1/2}=5,12\ \mathrm{min}]{\beta^{-}(100\%)}{}^{66}\mathrm{Zn}\right)$, which is 27.9% in nature. 2 on the other hand, in the process of radioactive capture of a proton $^{65}\mathrm{Cu}(\mathrm{p},\gamma)^{66}\mathrm{Zn}$, (where Ep = (1.3-3.0) MeV, the reaction cross section σ = (1.0-3.8) μb [28]), a stable isotope ^{66}Zn is also formed.

Within the framework of this work, we have limited ourselves to considering only two isotopes of radioactive transformation as an example. Undoubtedly, such an analysis requires a more detailed study with the ability to trace all stable isotopes of copper and zinc.

This process of radiation origin of Zn from Cu can explain the anticorrelation (-0.34) of the content of zinc and copper in the studied ore samples. However, the correlation coefficient of DER from the percentage of copper in ore samples is -0.17, while the percentage of zinc is 0.88.

Conclusion

Thus, in this work, the specific power of the equivalent dose of radiation gamma, beta, and alpha radiation was measured in samples containing copper, zinc and lead of pyrite-polymetallic ores, which were mined at the Zhezkent mining and processing plant (The East Kazakhstan region, Borodulikhinsky district). The measurements were carried out by dosimeters and radiometers "RKS-01-SOLO" with alpha, beta and gamma scintillation detectors. For ores, the dependences of the specific power of the equivalent dose of gamma radiation on the content of various concentrations of copper, zinc and lead were revealed. The analysis of natural decay chains, the daughter products of which are stable isotopes of copper and zinc, is carried out. A relationship has been proposed between the concentrations of nickel, copper, lead and EDR, which gives prospects for further spectrometric studies of these samples to identify the corresponding lines of accompanying gamma radiation during decays of radionuclides contained in the samples under study and radiation conversion of stable isotopes. The results of this work will make it possible to build a model for studying the radiation of ores, the distribution of natural radionuclides in the earth's crust, which will undoubtedly provide prerequisites for the verification and clarification of the sources and mechanisms of emanation and coagulation of radon isotopes, which form the natural radiation background of the surface atmospheric layer.

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