Research of influence of monocrystal thickness NAJ(TL) on the intensity of the integrated flux of scattered gamma radiation

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Abstract
Methodical bases and description of the vehicle providing for determination of optimum thickness of monocrystals on the basis of NAJ (TL) are expounded.
Key words: THE OPERATIVE CONTROL, A MONOCRYSTAL, INTENSITY, SCATTERED GAMMA RADIATION

Control and quality management of mineral raw material at extraction and processing was and remains an actual problem. It is known that, for the operative control and quality management of hematite (oxidized) ores the most effective are geophysical methods with use of gamma radiation. Realization of the given problem needs development, both means, and methods of the operative control and quality management of mineral raw material. Thus it is important to take into account parameters of scintillation gauge detector source of gamma radiation and geometrical sizes of system.

Now there is a lot of publications on a problem of development of methods and means of the operative control and quality management of mineral raw material [1, 2, 4-9]. However, these works carry applied character and there is no information on absorption of light scintillation flashes in a body of a monocrystal.

The purpose of the work is definition of the monocrystal thickness, providing peak efficiency of registration gamma rays with various energy.

The radiometric devices used for research of material is characterized by the following operating parameters: sensitivity of the device, its efficiency, resolution time and capability in energy and loading , the level of noise etc. Basic unit of radioisotope devices (RID) is the detector and its characteristics, i.e. probability of registration of the gamma quantum getting in sensitive volume of the detector. Considering, that the basic radiometric equipment works with diffuse gamma radiation, then for registration of gamma rays, nonorganic monocrystals are applied. For usual monocrystals on the basis of alkaline halides NaJ (Tl) efficiency of registration gamma rays of average energy makes about 30%. Scintillator should have thickness, which is equal to the maximal run of gamma quantums of the given radioactive isotope. Each gamma quantum during interaction with scintillator should follow one of three ways: cause a photoeffect, test Compton dispersion or not react with the crystal and fly out.

Considering, that radioisotope devices (RID) work basically with radioactive isotopes of small energy (Am-241), interaction of gamma quantum with scintillator will be expressed basically by a photoeffect and Compton dispersion. Time of flash shedding by scintillator after passage of gamma quantum is not enough and for crystals based on NaJ (Tl) it varies within the limits $10^{-6} \div 10^{-7}$s, which allows to register great activity and not to be afraid of imposing flashes from various particles against each other [1]. For choosing of scintillation monocrystal geometrical parameters it is necessary to develop a laboratory setup, which can help to define the scintillation detector parameters under the basic characteristics (count rate, background energy and thermal noise value).
The research results of monocrystal (NaJ) thickness influence on intensity registration efficiency of diffuse gamma radiation at energy 60-120 keV are given below.

The effectiveness of gamma-rays registration by scintillation crystal is determined by [2]

$N = 1 - \exp(-\mu d.)$ (1)

where μ - is the linear attenuation coefficient of gamma-ray by crystal substance, 1/cm, d - is the thickness of a crystal.

Theoretically, not all photons produced in the scintillator reach the photomultiplier cathode, since there are losses of the emitted light, depending mainly on the optical transparency of the scintillator to its own light emission from the luminescence spectrum and light collection conditions.

According to the Bouguer-Lambert law the light beam intensity of *N* during the passage in medium with thickness *L* varies exponentially due to absorption [3, 10]

$N = N_0 e\text{-}kL$ (2)

where N_0 – is the intensity of the wave at the entrance to the medium, *k* - is the natural parameter of absorption.

Formula 2 is correlated with the expression of the optical transparency of the scintillator [1].

$C_p = \exp(-\mu_1 x)$ (3)

where μ_1 – is the factor of optical absorption, 1/cm, *x* – is the photon path length in a crystal.

Let's note, that $x > d$ - (a crystal thickness) since the photon can undergo the multiple reflection from the inner surface of the crystal.
Considering (1) and (4) the number of photons of p1which will get on the photomultiplier cathode can be written as

$p^1 = \eta\ T_p \sigma\ k = [1 - \exp(-\mu d)] x \exp(-\mu_1 x)\ \sigma\ k.$ (4)

where *k* – is the coefficient of crystal conversion efficiency, σ – is the light collection effectiveness coefficient (depends on contact conditions of a crystal with photomultiplier).

For some crystals (sodium iodide, anthracene etc.) μ_1 - the optical absorption coefficient of light quanta, which has a very small value [1, 2], hence $T_p \approx 1$.

Therefore, when calculating the required crystal thickness NaJ it is competent to use the expression (1), where

$\exp(-\mu d) = 1 - \eta$ (5)

When setting values *μ* and *η*, it is not difficult to calculate the necessary crystal thickness. The calculation was carried out from the condition of the absorption of 99% of the quanta flow (η = 0,99) of the incident radiation by the crystal body.

Initial data for calculations. Crystal density NaJ - 3.67 g / cm3, effective atomic number - 50. (calculated on the photoelectric effect) [11]. The energy of the primary gamma radiation of 60 (Am - 241), 120 (Co - 57), 660 (Cs- 137) keV. Calculation was conducted using (4).

The minimum size of the crystal thickness, providing 99% (η = 0,01) quanta stream absorption is described by $\exp(-\mu_0 d) = 0{,}01$ (5)

The values of the μ coefficients for NaJ taken from [4]. The values of the total radiation attenuation coefficient for the above mentioned photon energies are shown in Table 1

Table 1

Energy of gamma quantum, keV	60	120
Mass attenuation coefficient μ_0/ρ, cm^2/g	6,49	0,9
Linear attenuation coefficient, μ_0, 1/cm	23,8	3,03

Solving the equation 4, we receive, $\mu_0 d = 4{,}6$ or

$$d = 4{,}6/\mu_0 \qquad (6)$$

Hence, the minimum thickness of the crystals*, providing 99% of the gamma-ray photons absorption with specified energies are shown in Line 2 of Table 2. Line 3 of the table additionally shows the thickness of the crystals** providing 99.9% of the incident gamma radiation absorption, i.e. η = 0.999 (μ0d = 6.9).

Table 2. Thickness of a crystal absorbing gamma radiation

Energy of gamma quantum , keV	60	120
Thickness of a crystal, cm*	0,19	1,52
Thickness of a crystal, cm**	0,29	2,28

As the test material the state standard samples containing Fe - 10%, 16%, 40% were used. The closed type radioactive source Am-241 with activity of $4.5 \cdot 10^8$ Bq in a lead container. The experiment was conducted alternately with crystals thickness of 10, 30 and 45 mm. The experiment was started with the installation of a crystal thickness of 45 mm in the counting sensor which was a monoblock consisting of a metal cylinder, in which was scintillator NaJ (Tl), photomultiplier FEU-85, a high-voltage unit, amplifier-shaper. To an end face of a monoblock, by means of threaded connection, the block - container with radioactive isotopes Am-241 is fixed. For each crystal as a diffuser the state standard samples (SSS) with the content of FeO_3 - 40, 16 and 10 % were used.

Analyzing the data obtained, we can confidently assert that the efficiency and sensitivity of scintillation detectors depends on the geometrical parameters of NaJ (Tl), especially when using the low-energy isotopes (Am-241 - of 60 keV).

The analysis of the received results showed that for the increase in the monocrystal thickness from 10 to 45mm the intensity losses is more than 35%, which reduces the sensitivity of the method and thus increases the statistical error.

It is established, that the monocrystal thickness reducing allows to improve the accuracy of operative quality control of mineral raw material, reduces the cost of scintillation detectors and monoblock geometrical dimensions.

To improve the efficiency of gamma radiation registration with the energy of 60 keV is advisable to choose the monocrystals thickness, providing 99.9% of the incident gamma radiation absorption, i.e. η = 0.999 (μ0d = 6.9) in the range 0.29-0.5 mm but not greater than 1.0 mm.

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