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Detection of diamonds in kimberlite by the tagged neutron method

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ABSTRACT

A new technology for diamond detection in kimberlite based on the tagged neutron method is proposed. The results of experimental researches on irradiation of kimberlite samples with 14.1-MeV tagged neutrons are discussed. The source of the tagged neutron flux is a portable neutron generator with a built-in 64-pixel silicon alpha-detector with double-sided stripped readout. Characteristic gamma rays resulting from inelastic neutron scattering on nuclei of elements included in the composition of kimberlite are registered by six gamma-detectors based on BGO crystals. The criterion for diamond presence in kimberlite is an increased carbon concentration within a certain volume of the kimberlite sample.

1. Introduction

At present kimberlite ore is processed in crushers or grinding rolls with subsequent grinding in wet mills down to a size of 0.2 mm [1]. The basic disadvantage of the standard diamond processing technology is that crushing kimberlite ore can break the most valuable large diamonds of few carats.

We propose a new procedure for non-destructive detection of large-sized diamonds in kimberlite. The main idea of the proposed method is the irradiation of large kimberlite pieces with fast neutrons with an energy of 14 MeV produced in the nuclear reaction

$$d + {}^{3}H \rightarrow {}^{4}He + n. \quad (1)$$

Direction of a neutron is determined by detecting (tagging) the α-particle that accompanies the neutron using a special α-detector. Interacting with kimberlite, tagged neutrons induce inelastic scattering reactions

$$n + A \rightarrow n` + A^{*}, A^{*} \rightarrow \gamma + A. \quad (2)$$

During de-excitation of nuclei A^{*} γ-rays are emitted with an energy spectrum specific for each chemical element present in the kimberlite. Characteristic γ-rays are registered by γ-detectors in coincidence with the signal from the α-detector. Measurement of the time interval between the signals from the α- and γ-detectors allows determining the distance from the neutron source to the point from which the γ-quantum is emitted since the neutron speed is constant and equals 5 cm/ns. Thus the tagged neutron method makes it possible to determine all three spatial coordinates of the examined sample volume.

The tagged neutron method (also called the Associated Particle Imaging (API) method) has been widely used [2–9] for constructing explosives and drug detectors, which allow determining elemental composition of the substance hidden in the examined objects of various sizes from hand luggage to shipping containers.

The search for diamonds by the tagged neutron method is reduced to detection of excess carbon at a particular point of the kimberlite sample. Large penetrability of fast neutrons makes it possible to examine appreciably large samples of kimberlite. Thus, rock pieces containing large-size diamonds can be identified before the crushing stage.

We developed a method for automatic detection of diamonds in kimberlite and created an experimental diamond detection setup, which we used to carry out experiments on estimation of detectable diamond size for various background conditions.

2. Description of the setup

The experimental setup for diamond detection in kimberlite consists of a portable neutron generator ING-27 with a built-in

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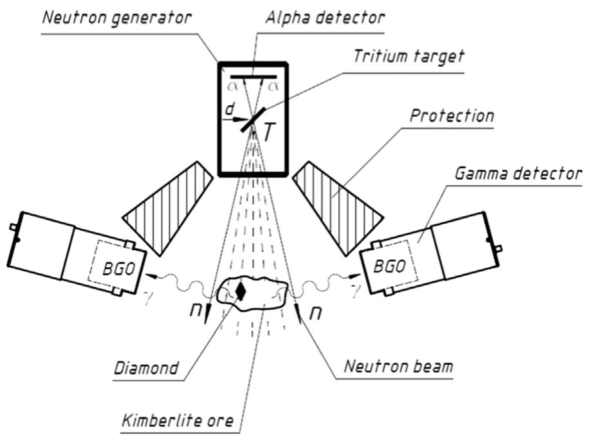

Fig. 1. General view of the experimental setup (top view).

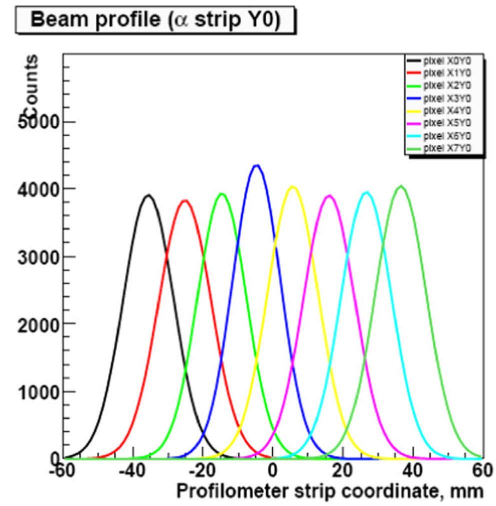

Fig. 2. Spatial distribution of eight tagged beams.

64-pixel alpha-detector, six gamma-detectors based on BGO crystals, electronics of the data acquisition system for the alpha- and gamma-detectors, and power supply units for the neutron generator and the alpha- and gamma-detectors. The scheme of the setup is shown in Fig. 1.

The diamond simulant, made from pressed diamond sand, is attached to a set of suspension wires, which can also hold several kimberlite samples. The diamond simulant is typically located behind the kimberlite sample or between two samples of kimberlite.

2.1. Neutron generator

The ING-27 neutron generator is produced by the Dukhov All-Russian Research Institute of Automatics, Moscow. It operates in the DC mode with the maximal intensity $I=7\cdot 10^7\ s^{-1}$. The size of the generator is 130 mm × 279 mm × 227 mm, and the weight is 8 kg.

The ING-27 neutron generator is usually equipped with a 9-channel alpha-detector. A unique 64-pixel silicon alpha-detector has been specially developed for diamond detection.

The 64-pixel silicon α-detector built into the neutron generator is a double-sided stripped detector that consists of eight mutually perpendicular strips on each side forming an 8 × 8 matrix of $4\times 4\ mm^2$ elements. The total sensitive area of the 64-element α-detector is $32\times 32\ mm^2$. The alpha-detector is located 62 mm away from the tritium target of the ING-27. The front-end electronics unit of the alpha-detector consists of 16 independent signal preamplifiers fed from 16 strips of the alpha-detector. The signal preamplifiers of the alpha-detector are mounted in the rear part of the neutron generator.

Spatial characteristics of 64 tagged neutron beams were measured by a scintillation stripped profilometer. Fig. 2 shows the spatial distribution of the tagged beams produced by the coincidences of the pulses from eight vertical strips with a single horizontal strip.

The width of each tagged beam is $\Gamma_X=(14.6\pm 0.9)$ mm and $\Gamma_Y=(14.8\pm 1.1)$ mm at a distance of 300 mm from the NG. This is consistent with the value expected from a pointlike deuteron beam hitting the target.

2.2. Gamma-detector

Six gamma-detectors based on BGO crystals with a diameter of 76 mm and thickness of 65 mm were used to detect gamma rays from the irradiated object.

These detectors have the following features:

- Energy resolution is (8–2.5) % within the energy range of 1–12 MeV. For the carbon gamma line ($E_\gamma=4.44$ MeV) the energy resolution of the gamma-detector is on average $\Gamma_E=(4.4\pm 0.1)$ %.
- High efficiency of gamma rays detection within the specified energy range.
- Low sensitivity for detection of background neutrons.

The time resolution of the (α–γ)-coincidence system averaged over the whole set of the gamma-detectors is $\Gamma_t=(3.1\pm 0.1)$ ns.

2.3. Data acquisition system

The recording electronics of the data acquisition system for the alpha- and gamma-detectors is designed as a single board with 32 inputs, which has the size of a standard PCI card and can be inserted in a PCI-E slot of a personal computer. The hardware data acquisition board utilizes high-speed ADC for sampling of input signals. The system of registration process signal from alpha- and gamma-detectors is based on the principle of waveform-digitizing with subsequent calculation of their time and amplitude characteristics.

Channels of digitizing signals from the detectors are built on the same scheme, which includes an amplifier with 0–20 MHz bandpass filter and ADC measurement interval of 10 ns (100 MHz). The digital code corresponding to each of measurement is fed to ADC programmable logic circuit, in which there is definition of moments of (α–γ)-coincidence in digital form.

Programmable scheme logic of the electronics board of DAQ system organizes the reception of information from the ADC, allocates of coincidence moment definition, prepares a data buffer and provides its transfer to PC memory. Subsequently the exact value of the pulse amplitudes and the time interval between them are calculated.

The special software for selection and signal processing extracts information about (α–γ)-coincidence, determines triggered channel numbers, calculates a time interval between pulses and the area under the pulse envelope, defining thereby an amount proportional to the energy released in the detectors, and counts the pulses detected by each detector individually. These parameters are presented in real-time histograms and stored in the data file.

3. Examined samples

For this investigation ALROSA JSC supplied us with diamond simulants, kimberlite and core samples from wells. At the first