STATIONARY SETUP FOR IDENTIFICATION OF EXPLOSIVE SUBSTANCES BASED ON THE TAGGED NEUTRON METHOD

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Abstract
The results of operation of a stationary setup for detection and identification of explosive substances (ES) using the tagged neutron method (TNM) are discussed. VNIIA-made ING-27 portable neutron generator (NG) with a built-in 64-pixel silicon α-detector with doubled-sided strips developed at JINR is used as a source of 14.1 MeV tagged neutron flux. The setup was tested for identification of over 30 explosive substances.

1. Introduction

Explosive substance detectors employing the tagged neutron method have become widespread in recent years [1-5]. The main advantage of TNM is that it allows determining the elemental composition of a substance rather than density contrast as conventional X- и γ-ray scanners do.

TNM employs 14 MeV fast neutrons produced in the binary nuclear reaction d+t→α+n. Each neutron is tagged through detection of an associated α-particle by a special α-detector, which enables determination of the direction of neutron escape. Tagged neutrons irradiate an object to be inspected and induce the inelastic scattering reactions A(n,n'γ)A that result in emitting γ-rays with an energy spectrum characteristic of each chemical element that is an object under inspection. Characteristic γ-rays are detected in coincidences with a signal from an α-частицы. With time intervals between signals from α- and γ-detectors measured, it is possible to measure the distance to the point from which a γ-ray was emitted as the neutron velocity is constant and equal to 5 cm/ns. Thus, the possibility exists of determining all the three coordinates of the region from which γ-rays escaped.

Neutron tagging provides a possibility of measuring the time between neutron production and its interaction with the substance of the irradiated object, which, in its turn, allows selecting events detected by a γ-detector in coincidences with a signal from an α-detector for a certain time interval. This sharply reduces the background level. It was demonstrated [6-9] that the use of (α-γ)-coincidences reduces the background-signal ration by more than 200 times, that significantly improves the conditions of detection of hidden substances.

It is important that hidden ES are identified in the automatic mode without participation of an operator.

The stationary setup for ES identification using the TNM technique was developed at JINR (Dubna) by request of RF FSS. The stationary setup was installed and tested at the RF FSS Interregional Centre for Investigation and Neutralization of Explosive Devices [10]. The setup employed a portable neutron generator with a built-in 9-channel α-detector. Later it was improved through the use of a neutron generator capable of generating 64 tagged neutron beams and a new decision-making program was developed.

This paper presents the results of operation of the modified stationary setup.

2. Setup Description

The stationary setup is placed in a special laboratory bay of the RF FSS Interregional Centre for Investigation and Neutralization of Explosive Substances. Fig. 1 shows the general view of the setup.

Fig. 1. General view of ES Identification Stationary Setup

The setup comprises a portable neutron generator with a built-in α-detector that provides for generation of 64 tagged neutron beams. Gamma-rays produced at irradiation of an inspected object by tagged neutrons are detected by two γ-detectors based on BGO crystals. Signals from α- and γ-detectors in coincidences are analyzed by the system for data acquisition and processing (SDAP) and are transferred to the main computer where the decision-making program analyzes the substance of the inspected object. The results of processing are displayed on the user interface.

ING-27 neutron generator is developed at the All-Russia Institute of Automatics (Moscow) and possesses the following characteristics:

Maximum intensity	1×10^{8} s^{-1}
Neutron energy	14.1 MeV
Neutron emission mode	continuous
Power supply	200±5 V
Maximum power	40 W
Neutron generator dimensions	130×279×227 mm
Weight	8 kg
Lifetime	800 h

JINR developed and designed a silicon α-detector that is built in a neutron generator. This doubled-sided strip detector has 8 mutually perpendicular strips on each side that form an array 8×8, the size of each element - 4×4 mm^2. The total sensitive area of a 64-element α-detector is equal to 32×32 mm^2. The α-detector is positioned at a distance of 80 mm from the tritium target. Fig. 2 shows a general view of an α-detector.

Preamplifiers of α-detector signals are mounted at the NG rear.

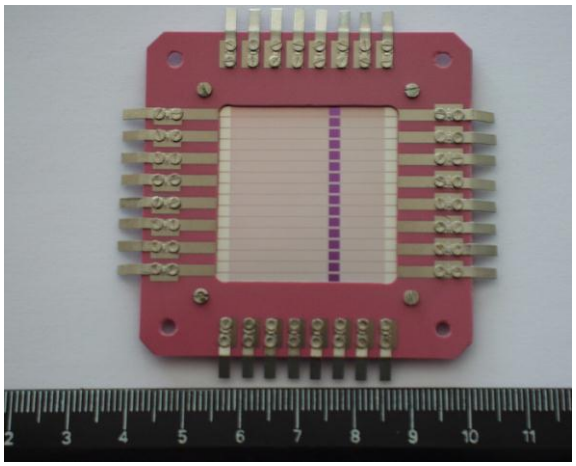

Fig. 2. General view of 64-element α-detector

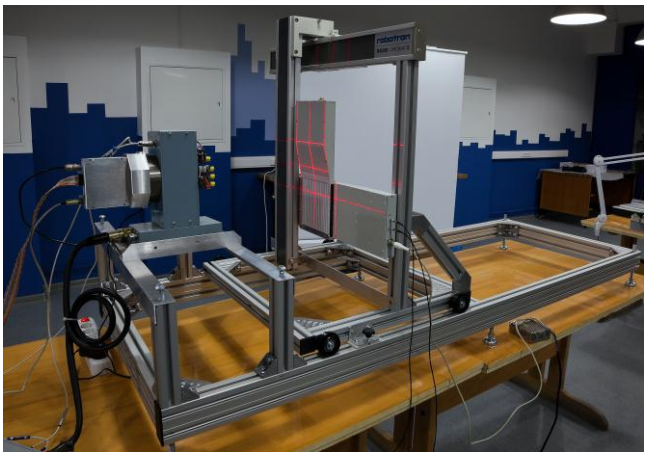

Fig. 3. Bench for measurement of tagged beam space characteristics

A special bench is designed for measurement of space characteristics of tagged neutron beams. It consists of two neutron detectors based on plastic scintillators in the form of strips with orthogonal orientation. Each detector has 16 light-insulated strips the light from which is read onto a photomultiplier tube (PMT) with the help of fibers. The strip dimensions are 7.5×15 mm, strip thickness - 5 mm. Fibers are scanned by 16-channel PMT and readings are taken by a special electronics board with a variable amplitude threshold in each channel. This bench significantly lightens measurement of space characteristics of tagged beams as it makes it possible to simultaneously determine both spatial coordinates of every tagged beam on the plane perpendicular to the direction of a neutron beam.

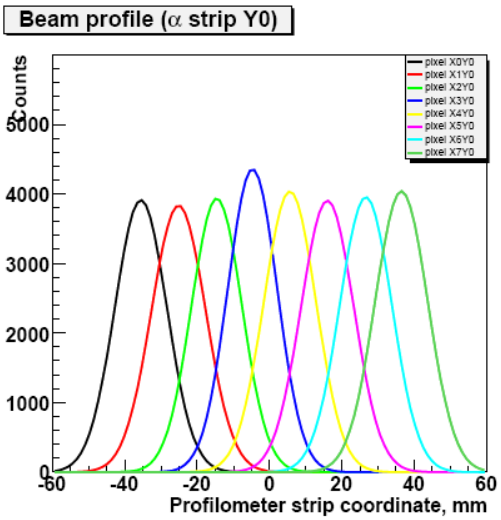

Fig. 4. Space distribution of 8 tagged beams

Fig. 4 presents space distributions of tagged beams obtained in coincidence of signals from each of 8 vertical strips with a signal from one and the same horizontal strip. At a distance of 300 mm from NG the widths of tagged beams, on the average, amount to Γ_X = 14.6±0.9 mm and Γ_Y = 14.8±1.1 mm, respectively. The measured values match well the calculation results in assumption of a point deuteron beam coming on the target.

Two γ-detectors based on BGO crystals 100 mm in diameter and 70 mm in thickness are used for detection of γ-rays produced at irradiation of inspected objects by a tagged neutron flux. The crystals were fabricated by the Institute of Inorganic Chemistry of the RAS Siberian Branch. Energy resolution of γ-detectors on the carbon line E_γ = 4.43 MeV amounts to Γ=5.4 ± 0.2 %.

The system for data acquisition and processing was developed based on a 32-channel data acquisition electronic board. It also comprised the appropriate software including the main module (driver), control program and reconstruction program. The data acquisition board is responsible for direct digital conversion of signal pulses from α- and γ-detectors. It has built-in trigger circuits for operation in three modes: time mode, single-channel energy mode and (α-γ)-coincidence mode. Using the software, one can accurately restore amplitude and time characteristics of a signal.

The developed power supply system for γ-detectors, output electronics of α-detectors and NG together with PC and SDAP occupy a crate in the bottom part of the setup (see Fig. 1).

Fig. 5 shows a general view of the user interface. The inspection area is divided into 64 elementary volumes - voxels. The voxel size on the plane perpendicular to the direction of a neutron beam is determined by the size of the corresponding tagged beam. The inspection area in depth is divided into 7 regions that are schematically shown on the left-hand stripe of Fig. 5.

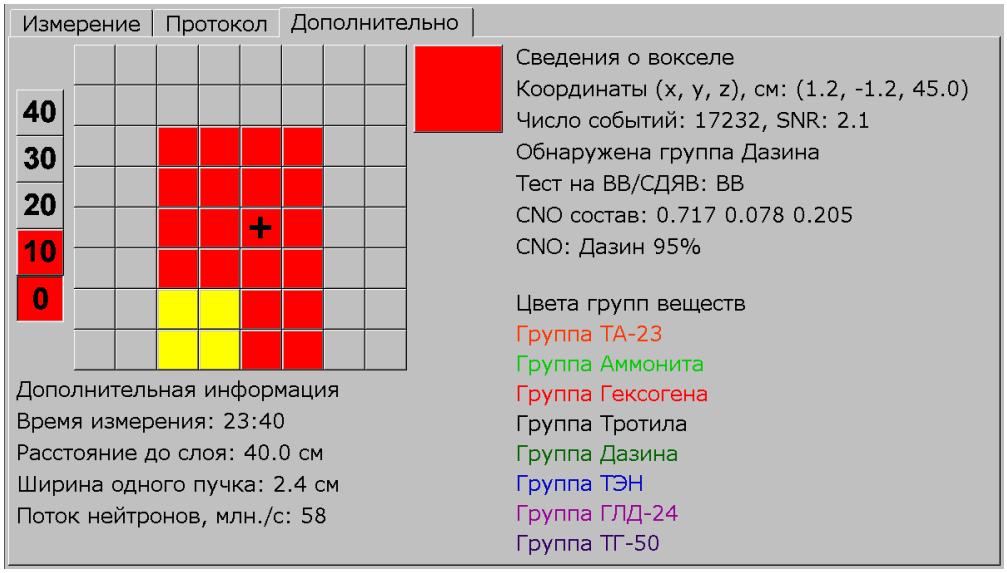

Fig. 5. General view of user interface

Is suspicious substance is in one of the voxels, an appropriate cell of the user interface turns red. The energy spectrum of detected γ-rays can be displayed in an additional box of the interface.

3. Test Results

The stationary setup has been in operation for two years. A great number of tests with different types of ES and ordinary substances have been performed for this time.

ES that were used to check the decision-making algorithm are listed in Table 1.

Table 1

A list of ES that can be detected by the stationary setup

#	Substance	#	Substance
1	Tetryl	16	A-IX-3T
2	Okfol	17	GLD-24
3	Hexogen	18	Isopropyl nitrate
4	Trinitrobenzol	19	Okfol-20
5	TNT	20	OLA-8T
6	Tetranitropentaerytrite	21	Seismon
7	Octogen	22	Pentolite
8	LD-70 (VX)	23	PVV-85
9	Hexanitrostibene	24	TGA-16
10	Dazin	25	TM
11	TATB	26	Tokaf
12	PVV-5A (IES-5A)	27	Ammonium nitrate
13	TS	28	TA-23
14	Okfol-3.5	29	Ammonite-19
15	TG-50	30	PVV-7

Analysis of γ-rays was made in the two modes: ES detection and identification. In the ES detection mode the decision-making system must determine if the substance is hazardous or not. The typical detection time is 4 min. In the identification mode the substance must be related to one or other ES group. For the purpose of identification statistics should be acquired for 16-20 min.

A standard approach consists in ES identification through determination of relative yields of characteristic radiation of carbon, nitrogen and oxygen (CNO-method). However some ES have absolutely identical C:N:O yield ratios. For instance, it is impossible to distinguish octogen ($C_4H_8O_8N_8$) from hexogen ($C_3H_3O_6N_6$) in the CNO-method. Therefore the explosives from Table 1 were divided into 9 classes of substances with similar C:N:O ratios in order to facilitate ES identification.

Some mixed ES contain, besides the main explosive, various additions the presence of which can be used at identification. For instance, 60% of tokaf is octogen and the remaining part consists of different additions including aluminum (17%). These additions change the tokaf energy spectrum and permit in principle its identification. In Fig. 6 the tokaf spectrum is compared with the hexogen spectrum.

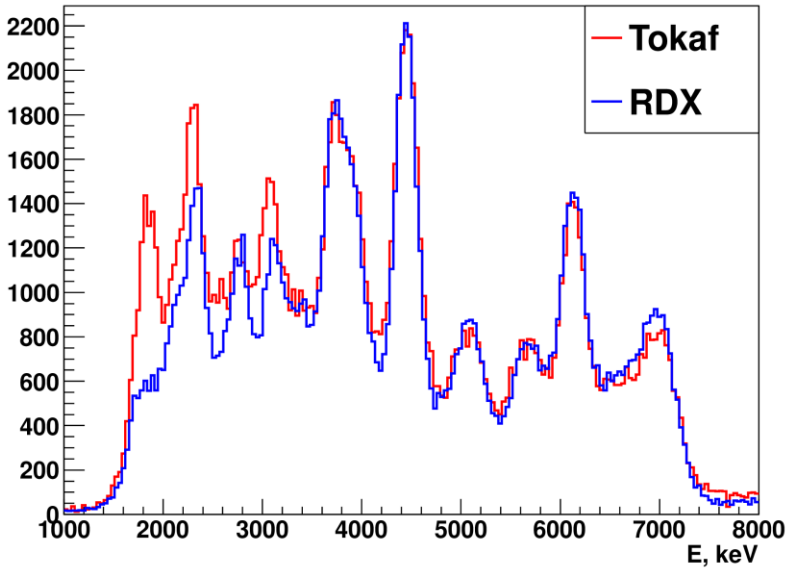

Fig. 6. Energy spectra of γ-rays from tokaf (red) and hexogen (blue)

It can be seen that the tokaf and hexogen spectra are practically coincide in the region of carbon (4.43 MeV), nitrogen (5.1 MeV) and oxygen (6.13 MeV) lines. However the presence of aluminum in tokaf manifests itself in peaks at low γ-ray energy in the 2.2 MeV region.

A similar picture is observed when we compare the TNT and TA-23 spectra that consist 77% of TNT and 17% - aluminum. The TA-23 and TNT spectra are compared in Fig. 7.

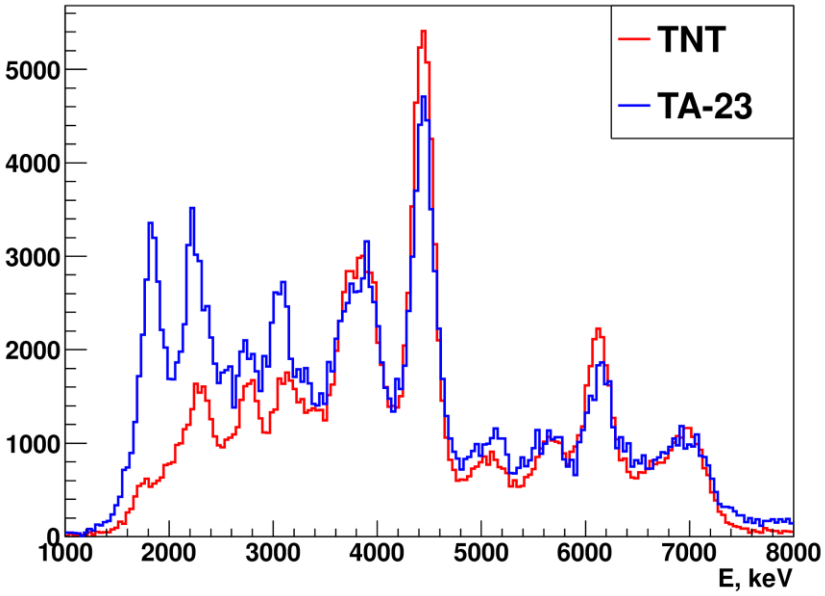

Fig. 7. Energy spectra of γ-rays from TNT (red) and TA-23 (blue)

In the decision-making program 9 regions of γ-ray spectrum comparison are used for ES identification.

The other distinguishing feature of the stationary setup is large granularity of the detection area, the detection area is divided into a great number of elementary volumes – voxels in which elemental assay is made. The total number of voxels is 64×7=448.

A small size of α-detector pixel and a large distance from an α-detector to the tritium target causes a small size of an individual tagged beam. This makes identification of small weights of substances easier. Thus, 25 g of TNT was detected for 393 s, 50 g of TNT – for 250 s at NG intensity of $I= 4 \times 10^7$ s^{-1}.

64 measurements were taken on the stationary setup in 2011 and 83 – in 2012. Measurements were taken for different ES from Table 1 and for 10 different domestic substances. 97% of ES detections were correct. False detections when domestic substances were taken for ES amounted to 2%.

An iteration procedure for changing selection criteria in the process of measurements was developed for ES identification. According to this procedure the selection criteria were defined more accurately with each new measurement of hazardous substance. If at the initial stage of test measurements the probability of correct identification was 65%, with the extension of the database and statistics of detected events the probability of correct ES identification has attained 95%.

4. Conclusions

A stationary setup for detection and identification of explosive substances using the tagged neutron method was developed and manufactured. The main difference of this setup from the complex [10] is an increase of quantity of tagged neutrons that irradiate the inspected object from 9 to 64 and development of a new program of data processing and decision-making.

Increased granularity of the setup allows detecting substances the weight of which by four times less that that detected on the complex [10].

The setup has been in operation at the RF FSS Interregional Centre for Investigation and Neutralization of Explosive Devices for two years. After 147 measurements were made, the detection probability was 97%, the identification probability - 95% and false alarm probability - 2%.

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