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NEUTRON PHYSICS

Stationary Setup for Identifying Explosives Using the Tagged Neutron Method

V. M. Bystritsky[a], N. I. Zamyatin[a], E. V. Zubarev[a], V. L. Rapatsky[a], Yu. N. Rogov[a], I. V. Romanov[b], A. B. Sadovsky[a], A. V. Salamatin[a], M. G. Sapozhnikov[a], M. V. Safonov[b], V. M. Slepnev[a], and A. V. Philipov[b]

[a]*Joint Institute for Nuclear Research, Dubna, 141980 Russia*
[b]*Federal Security Service of the Russian Federation, Moscow, 107031 Russia*

Abstract—The results of using a stationary setup for detecting and identifying explosives using the tagged neutron method (or associated particle imaging (API) method) have been presented. The source of 14.1-MeV tagged neutron beams is an ING-27 portable neutron generator made by VNIIA (Moscow). It contains an embedded 64-pixel silicon α detector with double-sided strip readout developed by the Joint Institute for Nuclear Research (JINR). The setup was tested for the identification of more than 30 explosives.

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INTRODUCTION

Detectors of explosive materials (EMs) based on the tagged neutron (or associated particle imaging (API)) method have obtained widespread use recently [1–5]. The main advantage of the API is its ability to measure the elemental composition of a material instead of just sensing the density contrast like typical X-ray scanners do.

The API method uses fast neutrons with energy 14 MeV produced in a binary nuclear reaction $d + t \rightarrow \alpha + n$. A special alpha detector is used to tag the outgoing neutrons by detecting the associated alpha particle and to determine the direction in which the neutrons escape. The tagged neutrons irradiate the object of inspection and induce inelastic scattering reactions $A(n, n'\gamma)A$, resulting in the emission of photons with energy spectra that are characteristic to each chemical element contained in the inspected object. The characteristic photons are detected with coincident α particle impulses. Since the neutron speed is constant and equal to 5 cm/ns, by measuring time lapses between the impulses of the alpha and photon detectors, the distance to the point of photon emission can be measured. Thus, the API method makes it possible to determine all three coordinates of the photon emission point.

Tagging the neutrons makes it possible to measure the time of flight, which can be used to select only the events from a certain time interval. This leads to a dramatic reduction in background. It has been shown [6–9] that using the (α–γ) coincidences helps reduce the signal-to-noise ratio by more than 200 times and significantly improves the conditions of identifying of hidden materials.

It is important to note that the identification is performed automatically, without the need for attention from an operator.

A stationary setup for identifying EMs using the API method was developed at the Joint Institute for Nuclear Research (JINR) in Dubna for the Federal Security Service (FSB) of the Russian Federation. The stationary setup was deployed and tested at the Interregional Center for Analysis and Neutralization of Explosives of the FSB [10]. The setup consists of a portable neutron generator with a built-in 9-channel α detector. It was subsequently upgraded with a neutron generator that makes it possible to produce 64 beams of tagged neutrons, and a new decision program was developed. The present work reports the results of operating the modified stationary setup.

1. DESCRIPTION OF THE SYSTEM

The stationary setup is installed in a special laboratory box of the Interregional Center for Analysis and Neutralization of Explosives of the FSB. A general view of the system is shown in Fig. 1.

Photons produced during the irradiation of the ispection object by tagged neutrons are detected using two BGO crystal-based photon detectors. Coincidences between the photon and alpha detector impulses are analyzed by a data acquisition and analysis system (DAS) and then sent to the main analysis computer, where a decision program (DP) analyzes the composition of the inspection object. Results of the analysis are represented on a user interface.

The ING-27 neutron generator was developed by the Dukhov All-Russian Research Institute of Automatics (VNIIA, Moscow). Its specifications are shown below:

Maxiumum neutron flux, s^{-1}	1×10^8
Neutron energy, MeV	14.1
Neutron emission mode	Continous
Power source, V	200 ± 5
Maximum power, W	40
Dimensions of the neutron generator, mm	$130 \times 279 \times 227$
Weight, kg	8
Operational life, h	800

The built-in silicon α detector of the neutron generator was developed and constructed at the Joint Institute for Nuclear Research (JINR). The two-sided strip detector has eight mutually orthogonal strips on each side which form a 8×8 matrix with the size of the element 4×4 mm. The total size of the sensitive region of the 64-element alpha detector is 32×32 mm. The alpha detector is positioned 80 mm away from a tritium target. A general view of the alpha detector is shown in Fig. 2.

Alpha detector preamplifiers are mounted in the rear side of the NG.

A special test bench was arranged to measure the spatial properties of tagged beams (Fig. 3). It consists of two plastic strip scintillators with orthogonally positioned strips. Each detector has 16 strips with fibers embedded into the scintillator. Each strip is 7.5×15 mm in size and 5 mm in thickness. The fibers are attached to a 16-channel PMT, and a special electronic board with adjustable threshold in each channel is used for readout. The test bench greatly simplifies measurement of the spatial distribution of tagged beams, making it possible to simultaneously determine two spatial coordinates in the plane orthogonal to the neutron-beam direction.

Figure 4 shows the spatial distribution of the tagged beams produced by coincidences of impulses from eight vertical strips with a single horizontal strip. The width of the tagged beams is $\Gamma_X = (14.6 \pm 0.9)$ mm and $\Gamma_Y = (14.8 \pm 1.1)$ mm at 300 mm from the NG. This is consistent with the value expected from a pointlike deuteron beam striking the target.

Two BGO crystal-based photon detectors were used to register the photons from irradiated inspection objects. The crystals were supplied by the Nikolaev Institute of Inorganic Chemistry (Siberian Branch, Russian Academy of Sciences). Each crystal is 100 mm in diameter and 70-mm-thick. The energy resolution at the energy of carbon $E_\gamma = 4.43$ MeV is $\Gamma = (5.4 \pm 0.2)\%$.

The DAS is based on a 32-channel data acquisition board. It also includes a companion software package consisting of a main module (driver), a control program, and a reconstruction program. The data acqui-

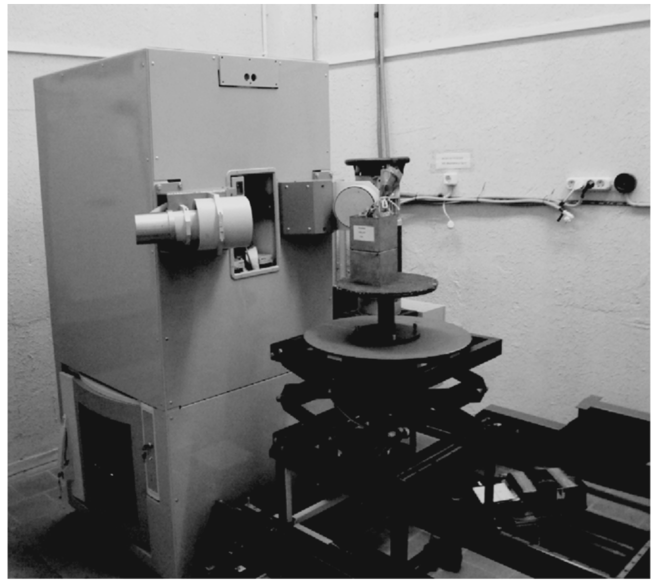

Fig. 1. General view of the statitionary setup for identifying EMs.

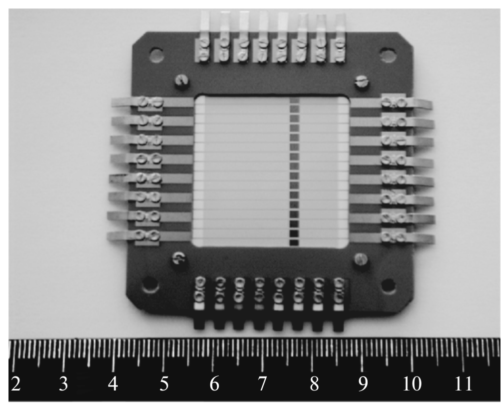

Fig. 2. General view of the 64-element α detector.

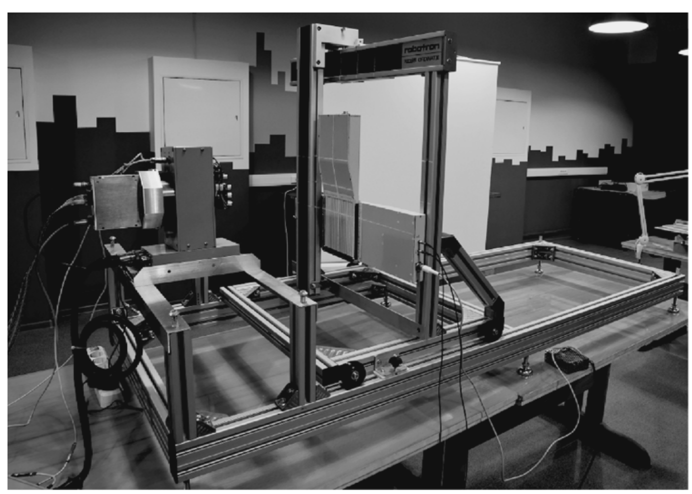

Fig. 3. Test bench for measuring the spatial properties of tagged beams.

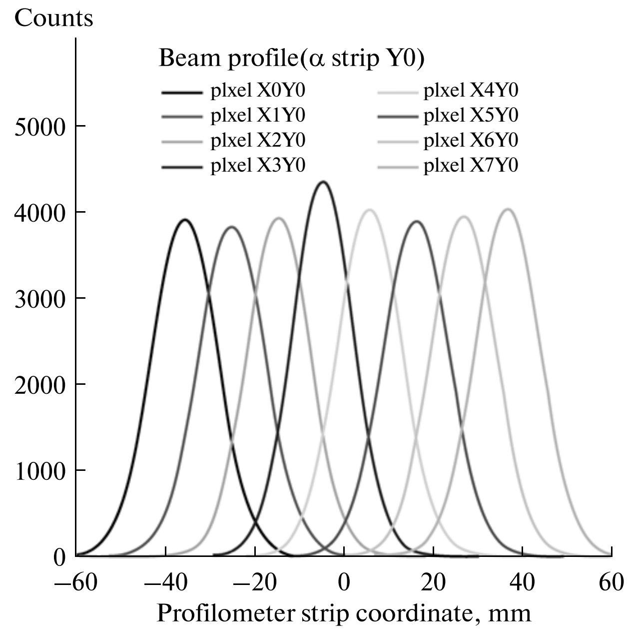

Fig. 4. Spatial distribution of eight tagged beams.

sition board performs direct digital conversion of the impulses from the alpha and photon detectors. It includes trigger circuits functioning in three modes: time mode, single-channel energy mode, and (α–γ) coincidence mode. Using the provided software, one can accurately reconstruct the amplitude and temporal properties of the signal.

The power supply system developed for the photon detectors, output circuits of the alpha detectors, and the neutron generator is placed in a crate in the lower part of the setup with the PC and the DAS (Fig. 1).

A general view of the user interface is shown in Fig. 5. The inspection region is divided into 64 elementary volumes, or voxels. The dimensions of the voxel in the plane, orthogonal to the direction of the neutron beam, are defined by the dimensions of the corresponding tagged beam. Along the z axis, the inspection object is divided in seven regions that are shown schematically in the frame in the left of Fig. 5.

If a suspicious material is found in a voxel, the corresponding cell of the user interface turns red. The energy spectrum of the photons can be viewed in an additional window of the interface.

2. TEST RESULTS

The stationary setup has been in use for 2 years. A large number of tests with different EMs and conventional materials have been performed during this period. A list of EMs used to check the decision algorithm is given in table below.

The photon spectra were analyzed in two modes: the detection and identification of EMs. In the detection mode the decision program (DP) has to determine if the material is dangerous or not. A typical detection time is 4 min. In the identification mode, the dangerous material is classified into groups of explosives. For identification it takes 16–20 min to collect the statistics.

The standard approach is to identify EMs by determining the relative yields of carbon, nitrogen, and oxygen (CNO method). However, some EMs have the exact same C : N : O yield ratios. For example, in the CNO approach it is not possible to distinguish between octogen ($C_4H_8O_8N_8$) and cyclonite ($C_3H_3O_6N_6$). Therefore, for identification, the EMs were split into nine classes with similar C : O : N ratios.

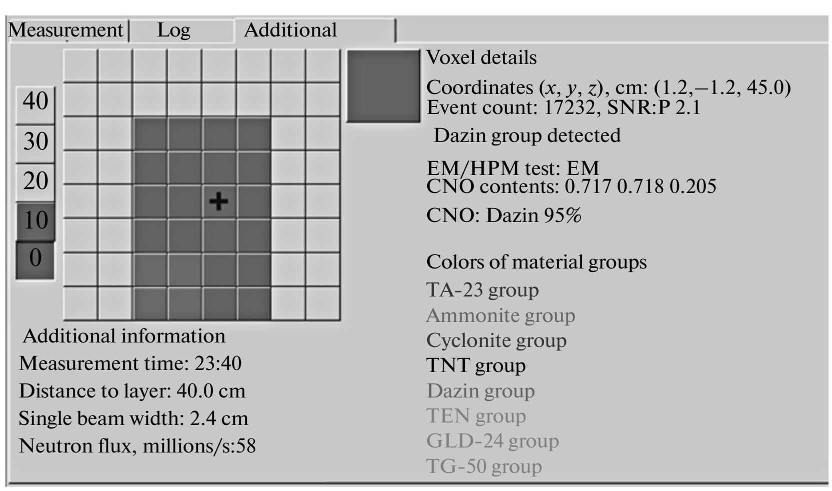

Fig. 5. General view of the user interface.

Certain compound EMs contain admixtures to the main EM which can be used for identification. For example, tokaf is 60% octogen, with the rest being different admixtures, including aluminum (17%). The admixtures change the energy spectrum of tokaf and, in theory, could be used to identify it. The tokaf spectrum is compared to the cyclonite spectrum in Fig. 6.

It can be seen that the tokaf and cyclonite spectra are very similar in the region of the carbon (4.43 MeV), nitrogen (5.1 MeV), and oxygen (6.13 MeV) lines. However, the presence of aluminum in tokaf is revealed through the peaks at low photon energies of about 2.2 MeV.

A similar picture can be seen when comparing the spectra of TNT and TA-23, which is 77% TNT and 17% aluminum. The TNT and TA-23 spectra are compared in Fig. 7.

The developed DP compares the photon spectra in nine comparison regions.

Another distinguishing feature of the developed stationary setup is the large granularity: the inspection zone is divided into many elementary volumes, or voxels, in which the analysis is performed. The total number of voxels is $64 \times 7 = 448$.

The small size of alpha detector pixels and the large distance from the alpha detector to the tritium target lead to a small size of a single tagged beam. This simplifies the identification of small masses of material. For example, 393 s were needed to detect 25 g of TNT and 250 s to detect 50 g TNT with an intensity of the NG $I = 4 \times 10^7$ s^{-1}.

In total, using the stationary setup, 64 measurements were performed in 2011 and 83 measurements in 2012. The measurements were performed for different EMs from the table and also for ten different conventional materials. The EMs were detected correctly in 97% of cases. The ratio of false detections, when a conventional material was detected as an EM, was 2%.

A list of EMs detectable by the stationary setup

No.	Material	No.	Material
1	Tetryl	16	A-IX-3T
2	Okfol	17	GKD-24
3	Cyclonite	18	Isopropylnitrate
4	Trinitrobenzene	19	Okfal-20
5	TNT	20	OLA-8T
6	TEN	21	Seismon
7	Octogen	22	Pentolite
8	LD-70	23	PVV-85
9	Hexanitrostilbene	24	TGA-16
10	Dazin	25	TM
11	TATB	26	Tokaf
12	PVV-5A	27	Niter
13	TS	28	TA-23
14	Okfol-3.5	29	Ammonite
15	TG-50	30	PVV-7

An iterative procedure of varying the selection criteria during measurement was developed for the identification of EMs. The selection criteria were refined upon each detection of a new dangerous material. At the beginning of the measurements, the probability of correct identification was 65% and at present time, due to the large accumulation of statistics, the proba-

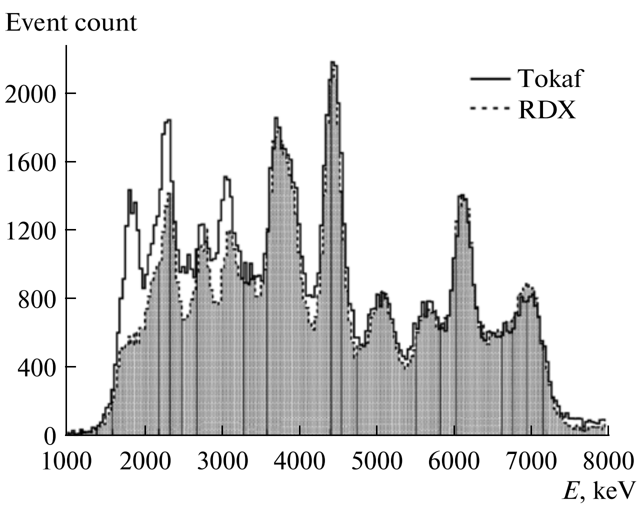

Fig. 6. Energy spectra of photons from tokaf (solid curve) and cyclonite (dashed curve).

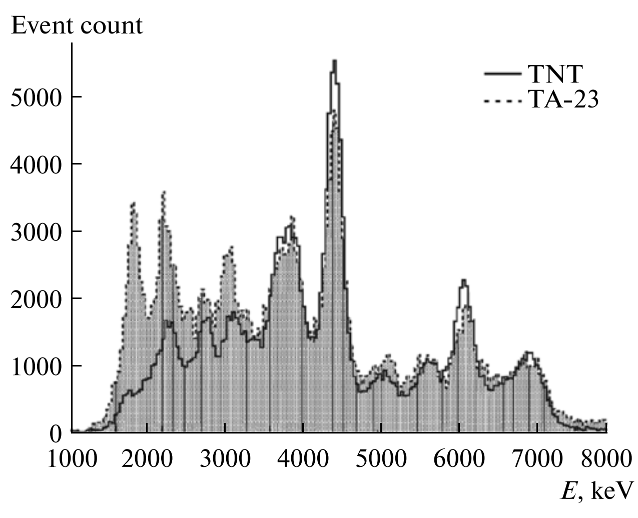

Fig. 7. Energy spectra of photons from TNT (solid curve) and TA-23 (dashed curve).

bility of correct identification over the whole accumulated database is 95%.

CONCLUSIONS

A stationary setup for detecting and identifying explosives based on the tagged neutrons method was created. The main differences between the present setup and the system [10] are the increased (from 9 to 64) number of tagged beams that irradiate the inspected object and the newly developed data processing and decision programs.

The increased granularity of the setup made it possible to detect four times lighter masses when compared to the complex [10].

The setup was routinely used for two years at the Interregional Center for Analysis and Neutralization of Explosives of the FSB. Based on 147 measurements, the probability of detection is 97%, the probability of identification is 95%, and the probability of false alarms is 2%.

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