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DViN — STATIONARY SETUP FOR IDENTIFICATION OF EXPLOSIVES

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Быстрицкий В. М. и др. E18-2007-142
ДВиН — стационарная установка
для идентификации взрывчатых веществ

Стационарная система для обнаружения и идентификации взрывчатых веществ разработана и изготовлена в Объединенном институте ядерных исследований. В статье приведено описание принципа работы системы, устройство основных элементов и результаты проведенных испытаний.

Работа выполнена в Лаборатории физики частиц ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2007

Bystritsky V. M. et al. E18-2007-142
DViN — Stationary Setup for Identification of Explosives

A stationary system for identification of hidden explosives has been developed and constructed at the Joint Institute for Nuclear Research (JINR). The results of the examination of the system as well as the operation principle of the system and design of the main elements are presented in this paper.

The investigation has been performed at the Laboratory of Particle Physics, JINR.

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INTRODUCTION

A stationary system to identify explosives has been constructed at JINR (Dubna) and tested at the laboratory of the Federal Security Service of RF. The system is based on a portable neutron generator with a built-in 9-pixel α detector which tagged 14 MeV neutrons produced in the binary nuclear reaction $d + t \rightarrow \alpha + n$. The 14 MeV neutrons hit the inspected object and induce an inelastic scattering reaction of the $A(n, n'\gamma)A$ type with emission of the nuclear γ radiation with energies characteristic for each chemical element of the interrogated object. The characteristic γ radiation is recorded in coincidence with the signal from the α detector. The measurement of the time interval between the signals from α and γ detectors gives a possibility to reconstruct the three-dimensional position of the hidden object.

This approach is called the Tagged Neutron Method (TNM), sometimes it is also named the Associated Particle Imaging Method [1–5].

The main advantage of the TNM is the sensitivity to the elemental content of the hidden substances rather than to its density contrast as many X- and γ-rays introscopes can define.

Tagging of the neutrons provides the time information, which could be used to select the events from a particular time interval and results in the drastic decrease of the background. It is shown [6–9] that the use of $(\alpha{-}\gamma)$ coincidences reduces the background-to-signal ratio by a factor of more than 200, which allows one to identify small quantities of explosives.

The fast 14 MeV neutrons are suitable for interrogation of the hidden objects because of their high penetration into the bulk material. They are specially convenient to inspect the medium (luggage) and large (cargo containers) scale objects.

The development of the system is being successfully performed in a collaborative project between the Joint Institute for Nuclear Research (Dubna) and the Federal Security Service (FSS) of the Russian Federation. The project is called DViN after the Russian acronym for the Detector of Explosives and Drugs. This paper presents the results obtained in the tests on the detection of explosives hidden in luggage.

1. DESCRIPTION OF THE APPARATUS

The system has been installed into a specialized box of the FSS laboratory for tests with explosives. The overall view of the system is shown in Fig. 1.

Fig. 1. General view of the DViN setup

It consists of a portable neutron generator (NG) with a built-in silicon alpha detector providing 9 beams of tagged neutrons. The gamma quanta, excited by tagged neutrons in the inspected object, have been detected by two BGO γ detectors. The α and γ signals, being in coincidences, have been processed by the data acquisition (DAQ) system and sent to the main PC. The decision-making software (DMS) identified the hidden substance by using the Neural Net (NN) method. The results were displayed at the user interface (UI).

The neutron generator is ING-27, produced by the All-Russia Institute of Automatics (Moscow). It has the following characteristics:

Maximum neutron intensity	$5{\cdot}10^7$ s^{-1}
Neutron energy	14.1 MeV
Operation mode	DC
Power supply	200$\pm$10 V DC
Maximum power consumption	30 W
Neutron generator dimensions	$145 \times 215 \times 300$ mm
Weight	$\sim$ 6 kg

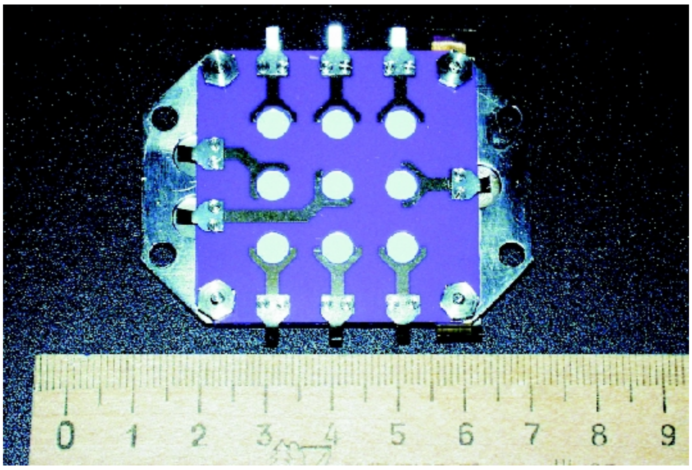

Fig. 2. Nine-pixel alpha detector viewed from the back

The tritium target is electrically isolated from the ground and has a potential of –80 kV which can be varied. The neutron generator is controlled by the PC. Up to now the NG has operated during 350 h.

We have developed and constructed a silicon α detector implemented into the neutron generator. It consists of 3×3 elements which form matrix with the size of each pixel 10×10 mm. All the nine pixels of the alpha detector are manufactured on a single wafer. Figure 2 shows the α detector before being installed into the NG. The frontend electronics have been developed and constructed for the alpha detector. It is mounted at the rear side of the neutron generator, as shown in Fig. 3.

Fig. 3. The box of the frontend electronics of the alpha detector mounted on a neutron generator with ground target

Figure 4 shows the amplitude spectrum of the signals recorded by one pixel of the α detector. Line *1* corresponds to the spectrum at the beginning of the work of the neutron generator. Line *2* shows the spectrum of the same pixel after 100 h of its operation.

One could see that the amplitude spectrum is changing with time in a non-trivial manner: more energetic α particles start to appear. These α particles are formed in the $d + t \to \alpha + n$ reaction on the surface of the alpha detector covered by the tritium evaporated from the target.

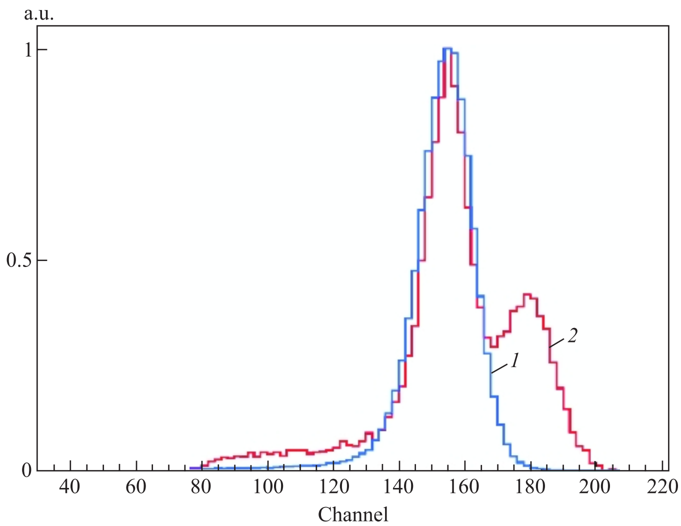

Fig. 4. Amplitude spectrum of the signals recorded by an α pixel without coincidence with the signal from the gamma detector

Curiously, not all pixels exhibit changing of the α-particle energy spectrum with time. The spectra from the upper row of pixels do not change and demonstrate spatial non-uniformity of the effect.

The alpha detector allows one to form nine beams of the tagged neutrons. For fast measurement of their spatial distributions, we have constructed a specialized device called a profilometer, shown in Fig. 5.

Fig. 5. The profilometer to measure spatial distributions of the neutron tagged beams. The working area is marked by the white sheet with the cross

It consists of 16 plastic scintillator strips with fibers, embedded in the scintillator. The profilometer aperture is 120×150 mm. The fibers are coupled to the 16-channel photomultiplier tube read-out by a dedicated electronic plate providing an adjustable threshold to each channel. The profilometer significantly facilitates measurements of the tagged beam spatial characteristics.

We have used two gamma detectors based on the BGO scintillators to register γ rays excited by tagged neutrons in the inspected objects. The crystals were produced by the Institute of Inorganic Chemistry of the Siberian branch of RAS. Each crystal is 100 mm in diameter and 70 mm thick. The light decay time of the BGO scintillators is 300 ns. Figure 6 presents the energy spectrum of characteristic γ rays detected by the γ detector in coincidence with the signal from an alpha channel. The spectrum was obtained in irradiation of a ^{12}C sample $(10 \times 10 \times 10)$ cm with a tagged neutron beam.

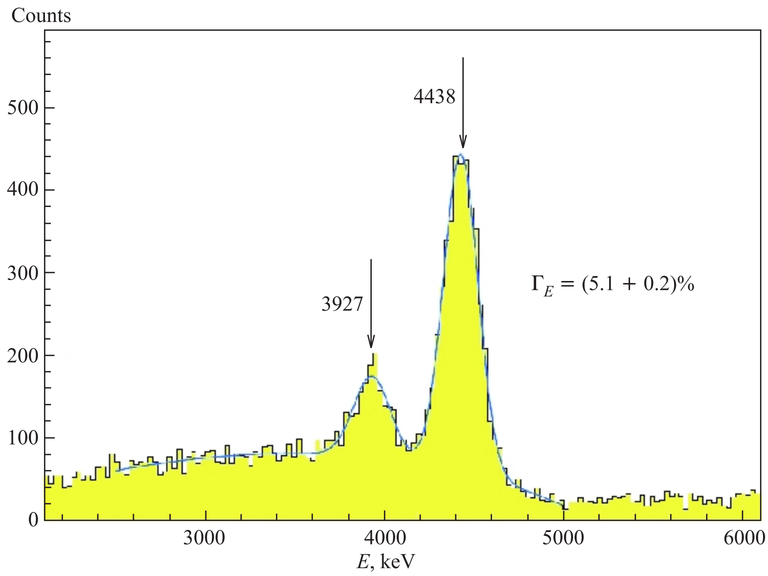

Fig. 6. Energy spectrum of γ rays recorded by the gamma detector in irradiation of a ^{12}C sample with a tagged neutron flux

As seen from Fig. 6, the energy distribution is characterized by two peaks in the spectrum: a peak of the total gamma energy absorption from the line $E_\gamma = 4438$ keV and a single escape peak with $E_\gamma = 3927$ keV, corresponding to leakage of the 0.511 MeV γ quantum formed in the electron–positron annihilation. The energy resolution of the gamma detector for the $E_\gamma = 4438$ keV line is $\Gamma = (5.1 \pm 0.2)\%$.

The data acquisition system (DAQ) has been also developed and constructed. It consists of a data acquisition board with 16 channels for alpha and gamma detector signals (see Fig. 7) and the software package, which includes a kernel module (driver), a control program, and a reconstruction program.

Fig. 7. The data acquisition board with 16 channels for alpha and gamma detector signals

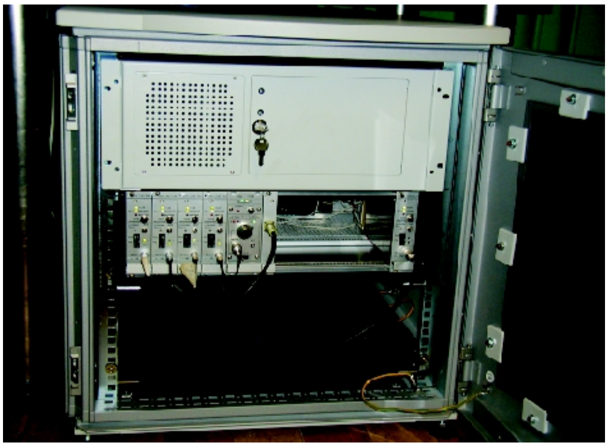

Fig. 8. The DAQ system and the detector power supply

The board has been designed for direct digitizing of signal pulses coming from the alpha and gamma detectors. It has a built-in trigger circuitry for three modes of operation: time-driven, single-channel and alpha–gamma coincidence events. By using the software it is possible to reconstruct accurately the amplitude and time mark of the signal.

The power supply system for gamma detectors, for frontend electronics of the alpha detectors, as well as for some systems of the neutron generator, has been developed and constructed. Together with the PC of the DAQ system it occupies a rack at the bottom of the setup (see Fig. 8).

To identify the explosives, the decision-making software (DMS) based on the Neural Net (NN) method has been developed. To train the NN, one should measure spectra of typical explosives. The present version of DMS is able to distinguish some explosives and innocuous substances.

2. RESULTS OF THE TESTS

The user interface (UI) with results of the typical test is shown in Fig. 9. The surface of the inspected object is divided into nine regions. In the particular test the sample of TNT was positioned in the left bottom corner of the case, whereas the sample of A-IX-2 explosives was placed in the right upper corner. Each of the nine regions of the case was irradiated with the corresponding tagged neutron beam and independently analyzed. Moreover, the volume inspected by each tagged beam was divided along its direction into seven regions, corresponding to 10 cm each. These seven regions are shown in the left band of Fig. 9. Therefore, the inspection of 63 space volumes (called voxels) is going on independently during one test. The size of the inspected volume depends on the distance between the neutron source and the investigated object. Typically, the inspected volume varies from 50 to 600 mm in all three dimensions.

If the decision-making software (DMS) has found that the spectrum from some voxel is similar to the one from the database of some dangerous substance, the corresponding image in the UI is marked in red. For the unambiguous identification it is required that the similarity of the investigated spectrum to the one from the database be higher than the certain limit and, at the same time, the similarity to every other spectrum from the database be less than some limit. The control window in the right side of the UI shows the results of the DMS work in real time. It shows a probability of the identification of each substance from the database with the acquired statistics.

The tests have been performed with nine explosives. Figure 10 shows the energy spectra of γ quanta for some explosives. The energy spectra of TNT ($C_7N_3O_6$) and saltpeter (N_2O_3) are compared in Fig. 10, *a*. The TNT spectrum is dominated by the carbon line at 4.4 MeV. This prominent peak corresponds to the characteristic line of carbon, it is absent in the saltpeter spectrum providing a clear distinguishing pattern for identification.

The spectra in Fig. 10 illustrate the sensitivity of the tagged neutron method to the elemental content of the explosive. The distinction between different substances depends on the difference in their elemental content. Thus, A-IX-1

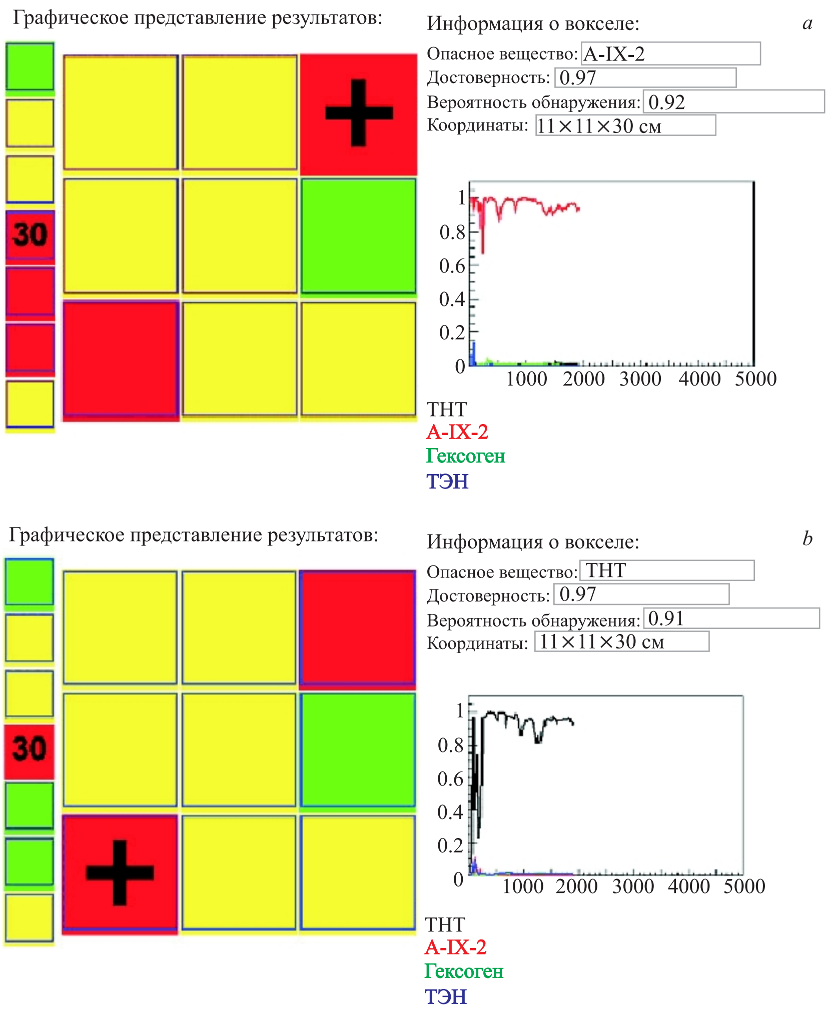

Fig. 9. General view of the user interface for a test with two explosives: A-IX-2 (*a*) and TNT (*b*)

comprises 95% of hexogen ($C_7N_3O_6$) and 5% of a bounded material. Therefore, one may expect that the spectra of hexogen and A-IX-1 should be similar and the spectra shown in Fig. 10, *d* confirm that. The TNT explosive contains more carbon than hexogen and A-IX-1. The spectrum of Fig. 10, *c* confirms that in the region of the carbon line at 4.3 MeV more TNT events are observed. The A-IX-2 explosive contains 80% of hexogen and 20% of aluminum powder. Its spectrum differs from the A-IX-1 one (Fig. 10, *b*).

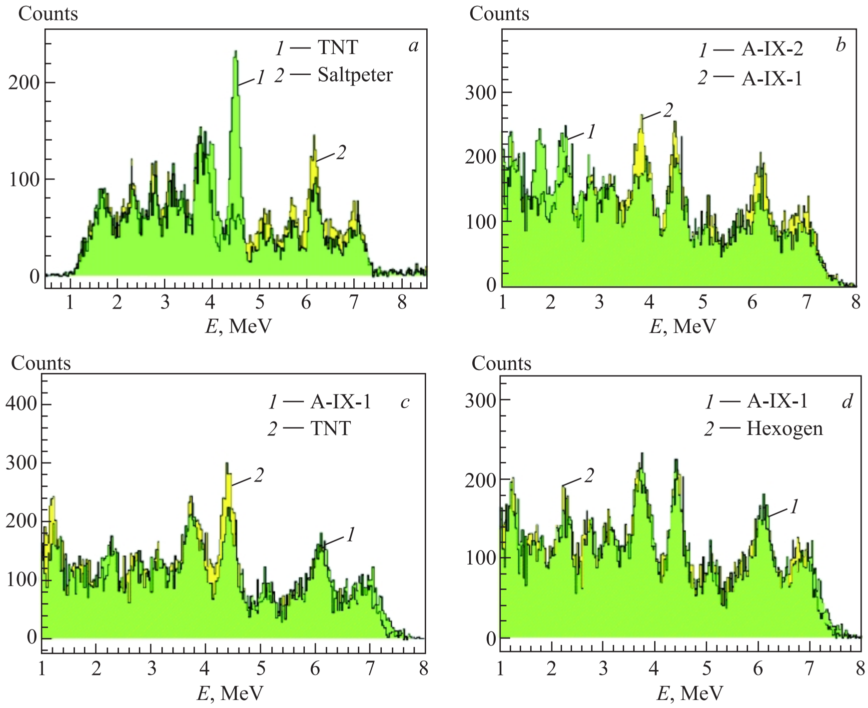

Fig. 10. The energy spectra of γ quanta for different explosives: *a*) TNT (*1*) and saltpeter (*2*); *b*) A-IX-2 (*1*) and A-IX-1 (*2*); *c*) TNT (*2*) and A-IX-1 (*1*); *d*) A-IX-1(*1*) and hexogen (*2*)

Finally, the hexogen and A-IX-1 explosive are not distinguishable, but the hexogen and A-IX-2 are.

The identification time depends on the intensity of NG, total acceptance of the gamma detectors, mass of the illicit substance and shielding conditions. Usually, for intensity of NG $I = 3 \cdot 10^7$ neutrons/s, one gamma detector and 200 g of explosives hidden in a case the identification takes few minutes.

We have tested influence of the shielding material on the identification. The explosives were placed in the container made from different materials such as cartoon, wood, plastic, steel and leather. The thickness of the shielding varied from 4 mm (for leather) to 20 mm (for steel) and 50 mm (for other substances). The identification was performed in all cases where the mass of the explosive in the voxel was larger than the mass of the shielding material in the voxel. Therefore, to identify a small amount of the hidden substances, one should decrease dimensions of the tagged neutron beam and improve the time resolution of the system.

Totally, we have carried out 102 tests to identify different explosives under various shielding conditions. Correct identification was performed in 98% of the cases.

An important problem for reliable identification is false alarms. We define false alarms as a positive signal of the DMS on the innocuous substance, or a positive signal on the explosive but in the wrong cell of the inspected volume. Thus, 776 tests have been performed to determine the rate of the false alarms. The false alarms probability turns out to be less than 2%.

CONCLUSIONS

Main conclusions of the work could be formulated as follows:

- The Tagged Neutrons Method, its advantages and limits have been tested.
- The stationary system to identify explosives has been constructed at JINR and tested at the FSS laboratory.
- The system has demonstrated high efficiency of identification of explosives hidden in a suitcase with a low probability of false alarms.

At present the system is under experimental exploitation at the FSS laboratory.

An up-to-date information about the project could be found at http://nf-100-056.jinr.ru/dvin.

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