DETECTION OF EXPLOSIVES

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The extensive literature on the methods of detection of explosives under the stationary and field conditions is reviewed. Today, there are hundreds of publications on detectability of explosives by different methods, but none of the methods gives a 100% guarantee of explosives detection. Consideration has been given to advanced high-technology methods of explosives detection: nuclear quadrupole resonance method, nuclear physics methods (slow and fast neutrons, gamma-quanta), biological methods. Notice that the danger of newly created explosives, including land mines, increases. The actuation systems are also constantly improved. Most difficulties with detection, extraction and deactivation of explosive devices can be overcome with the help of updated methods and techniques. The present review calls attention primarily to the possibility of solving the pressing and complicated problems using charged particle accelerators.

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The problem of detection of concealed explosives (CE) year after year assumes ever greater urgence. On the one hand, it is connected with clearing of landmines, remaining at the open places after military conflicts, on the other hand - with increasing a number and forms of acts of terrorism. Metallic mines and mines with a high proportion of metallic components in their construction can be detected with the help of a current detector of mines operating on the principle of low-frequency induction and electric impedance. Some handy detectors of the magnetic anomaly are capable to detect less than 1 g of metal [1]. For detection and neutralization of antipersonnel (AP) and antitank (AT) mines there are complete mechanical computerized complexes. Small sizes of nonmetallic AP, burying them and AT in the hard-packed and rock ground make the process of mine clearing very dangerous.

It should be noted that simultaneously with development of the methods of mine detection one upgrades mines and detonators. Mines that are actuated by the magnetic field of passing devices are not only more dangerous but possess an attacking capacity of the full width of the mechanism. Most part of these mines has warheads which strike moving armored equipments. For liquidation of these mines there are available antimagnetic mine devices. They detonate magnetic blasting cups for firing mines creating the magnetic field before the device itself. However, complex mine detonators can be actuated after the second or the third time.

Although the world literature contains many publications on CE detection under field conditions in the home literature the problem of CE detection by advanced methods is described insufficiently. In this connection the authors intend to give a brief review of nuclear-physics methods of CE detection including the accelerating technique being under development or under field tests.

Hi-tech methods of landmine detection include methods based on passive IR, electro-optical, millimeter/microwave radiation, biological methods, nuclear methods and nuclear quadrupole resonance (NQR) method.

Biological methods of CE detection were introduced at first with the use of dogs. At present bacteria are found that glow in the dark while feeding on CE fumes. Scientists are now working to find or even create microbes that are not only naturally luminous in the dark but also feed on the carbon and nitrogen fumes from TNT. The studied types of bacteria reproduce themselves naturally. Such organisms can be sprayed from the airplane in the day-time, and at night a topographical survey can be carried out to make a topographic map. However, these bacteria may be seen also in broad daylight with the unaided eye. Other biological methods use insects, in particular, bees and their ability to detect the smallest dust quantities.

The first works on mine detection with the help of radiolocators were carried out to orders of military departments of USA, Great Britain and USA and, therefore, the results of investigations were little published. Since 1990 the interest to such works arose in Japan, China, Poland and other countries. The Britishes successfully applied the radiolocation (GPR) for detection of AP and AT mines during the Balkan War [1]. The French reached significant results too [2].

A circularly polarized wide-band antenna is used as a radiator. A radar transmitter comprises a RF-transmitter and a receiver, a digital controller and a processor. Spectral characteristics of the scattered signal were defined as a function of the mine thickness. It has been established that the frequency of 0.5…1.5 GHz is sufficient for the classification of the target. For normal ground conditions the detection was rather good at a depth down to 10…15 cm. The most part of CE contain nitrogen atoms that allow one to detect them by the NQR method [3]. The essence of the NQR method consists in the following. In the nonuniform electrostatic field of an electron shell the "nonsphericity" of a nucleus determines the energy of interaction between the nuclear quadrupole moment Q with the gradient of this electrostatic field (GEF) [4]. As the tensor of GEF is symmetrical relatively to x, y, z, it can be reduced to the major axes. The tensor of GEF is determined by two independent components $eq = q_{zz}$ and $\eta = (q_{xx} - q_{yy}) / q_{zz}$ where the axes of coordinates are designated so that $|q_{xx}| \geq |q_{yy}| \geq |q_{zz}|$. The quantity eq is GEF, and η is the parameter of the GEF tensor asymmetry. To find eigen values of the Hamiltonian of quadrupole interac-

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tions the diagonalization is performed for the nucleus spin matrix 1. In the case of 1.=1 there are three levels of the quadrupole energy.

$$E_{\pm} = \frac{1}{4} eQq_{zz}(1 \pm \eta),$$

$$E_o = \frac{1}{2} eQq_{zz}.$$

When the variable magnetic field influences on the nuclear system the transitions between these energy levels are observed in the form of selective absorption of the radio-frequency radiation energy. The frequencies corresponding to them are

$$\omega_{\pm} = \frac{1}{h}(E_{\pm} - E_o)$$

$$\omega_0 = \frac{1}{\square}(E_{+} - E_{-}).$$

Measurement of these frequencies and identification of lines from nitrogroups is a very complex problem because the signals from these nitrogroups are very feeble and lie in the rather low frequency interval from 0.5 to 7 GHz. NO_2 groups are contained in the composition of trotyl, RDX, octogene and PETN. The greatest possibilities of the CE detection by the NO_2 groups are offered by the direct pulse method of NQR detection with the Fourier transformation of time responses for receiving the spectrum. It should be noted that in main the experiments were carried out at low temperatures (77, 120 K). At the same time for CE detection under the field conditions the measurements are conducted under normal temperature conditions and with the single-side access to the specimen.

There are very complex dependencies of NQR signal intensity of ^{14}N in RDX and octogene on the number of pulses, the interval between pulses and the frequency detuning. Therefore, the parameters of many pulse trains should be optimized for every material. Very important problem to be solved is the signal enhancement.

The group of Grechishkin V.S. [5] has tested the NQR detector of landmines based on the coherent pulse NQR spectrometer. Measurements were performed at room temperature at a frequency ω =5.192 in RDX. For signal integration a series of 10 pulses was applied with detuning the frequency of occupation of the relatively accurate resonance. A very important element is the receiving-transmitting coil. It receives the NQR signal from the CE zone restricted by the coil circle into the depth approximately equal to its radius. Investigations were conducted on mines buried into the ground at different depths with different types of soils having different humidity. The time of detection of Italian TS-25 and TS-6 mines in the ground at a depth of 0.1 m was approximately 10 s, probability of reliable detection for 150 measurements was 0.97, investigations of 1 m^2 area for the presence of such mines took 20 s. The device can be installed on the armored carrier capable to move with a speed of 7.6 km/hour providing 100% detection of anti-tank mines in the wheel tracks. Although the frequency of nitrogen in RDX and octogene is suitable for detection of AT mines, an enemy can give a NQR signal artificially by means of pulse radio-frequency interferences. Then it is possible to measure the NQR spectra of ^{14}N from nitrogroups using the method of double nuclear quadrupole resonance with selective magnetic field.

The best results has been reached by the A.D. Hibbs's group from San Diego [6] during field tests in 1999 in Bosnia and at Ft. Leonard Wood MO with the use of a new NQR system for detection of field mines. Nonmetalic AP and AT mines were detected with a probability up to 100%. A significant interval of the detection system false operation was less than 5% and decreased down to zero during subsequent measurements. The tests have been conducted in any sort of weather and in different soils at a typical depth of mine location. The system is withstanding against a high level of metal interferences. The experimental data on the detection of trinitrotoluol by the NQR method are given in Fig.1. It is seen that the number of false operations of the apparatus (PFA) sharply increases while the probability of detection (PD) increases [6].

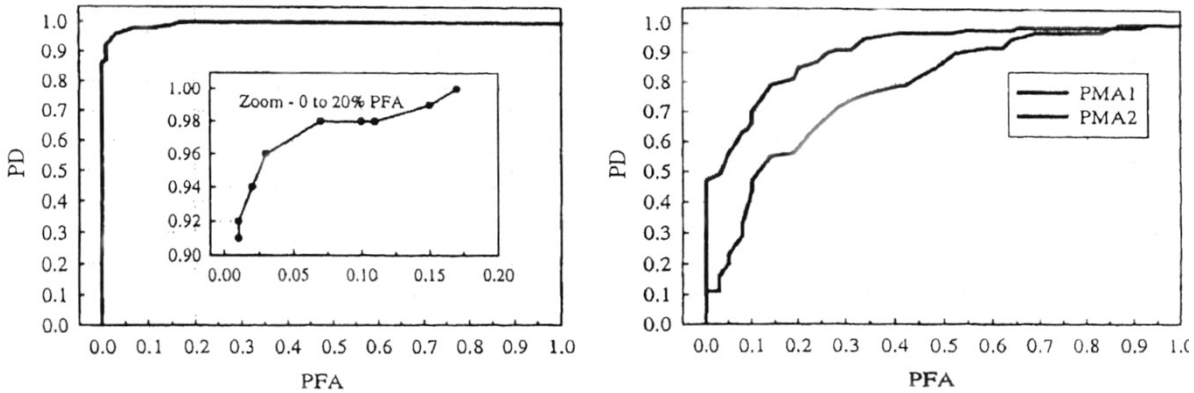

Fig.1. Experimental data on TNT detection by the NQR method: a) The specimen having a mass of 195g is placed at a distance of 6 cm from the center of the detection coil. b) The distance from the top of the mine PMA2AP to the detection coil is 5 cm, and the PMAIAP mine is at a distance of 5 cm. The scanning time is 1 s

Nuclear methods of CE detection include the identification of chemical elements and their relative (qualitative) content. A chemical element, being under bombardment with neutrons or hard gamma-quanta, emits

gamma-quanta, e^-, e^+, having a unique energy spectrum that provides the element's autograph. As neutron sources one uses isotope sources and pulsed neutron generators. The presence of nitrogen is determined by analysis with the help of thermal neutrons and pulsed thermal neutron generators (TNA and PTNA). The presence of nitrogen, carbon and oxigen is determined by analysis with the help of fast neutrons and pulsed fast neutron generators (FNA and PFNA). The chemical formula of an object is PC displayed as a specific spot inside the Dalitz's triangle, every side of which corresponds to one of three chemical elements.

A portable system for CE identification with a radioisotope source of ^{252}Cf neutrons [7] was successfully tested at the Livermore National Laboratory. Thermal neutrons, passing through the object under investigation, were captured by the nitrogen atoms (^{14}N(n,γ)^{15}N), being in the ammunition composition. γ-quanta with an energy of 10.83 MeV were recorded by means of high-purity germanium detector. Depending on the size of ammunition the system could identify the presence of chlorine and hydrogen during 10…1000 s. The spectra of γ-quanta in the range of energies from 0.9 to 1.4 MeV and from 1.5 to 2.3 MeV are given in Fig.2 [7]. One can see clearly the peaks of aluminium, germanium, chlorine and hydrogen after irradiation with thermal yperite neutrons.

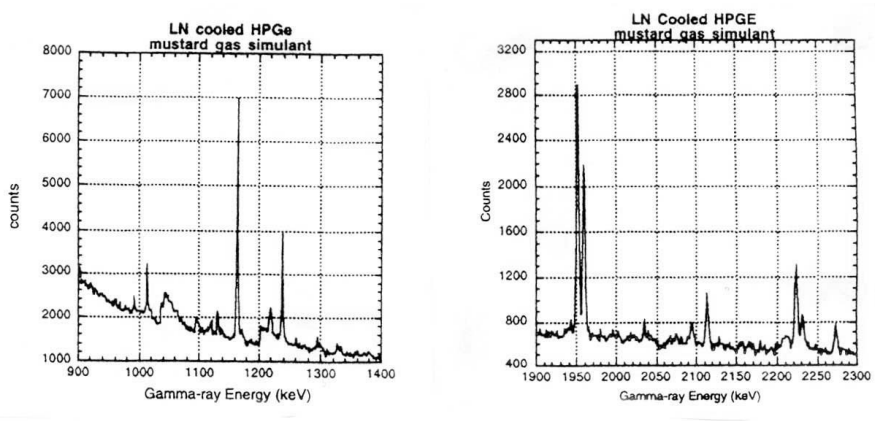

Fig.2. Spectra of γ-quanta from the mustard gas (yperite) irradiated with thermal neutrons for the range of energies: a) from 0.9 to1.4 MeV; b) from 1.9 to 2.3 MeV. One can see the peaks of aluminium 1.014 MeV, germanium 1.039 MeV, chlorine 1.164, 1.95 and 1.959 MeV, iron 1.238 MeV and 2.113 MeV, hydrogen 2.223 MeV

In [8] a deuteron accelerator with a tritium target was used as a neutron source. During the accelerator pulses one measures the energy spectrum of γ-radiation energy spectrum in the reaction of inelastic fast neutron scattering on nuclei of nitrogen, oxigen and hydrogen, and in intervals between the pulses one measures integral and energy characteristics of γ-radiation in the reactions of radiation capture by nitrogen nuclei of slow and thermal neutron. For identification of fissile materials the time distribution of neutron radiation is recorded. In Fig.3 shown are the spectra of γ-quanta obtained after subtraction of the background from the spectra generated by graphite and acrylic plastic after neutron irradiation [8].

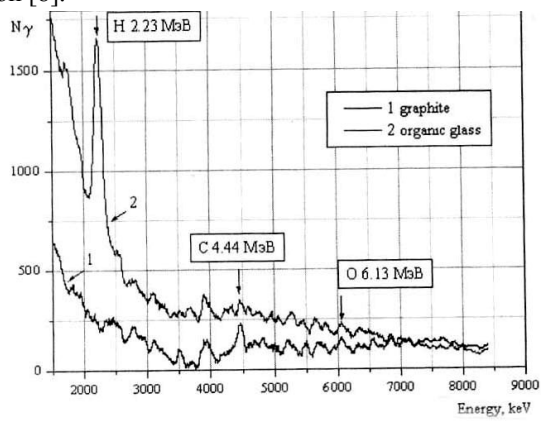

Fig.3. Spectrum of γ-quanta obtained after subtraction of the background from the spectra generated by graphite and acrylic plastic after neutron irradiation

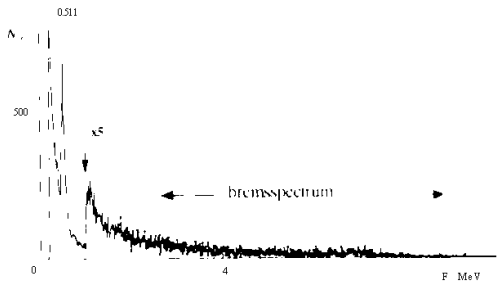

Fig.4. Gamma-quanta bremsspectrum recorded between the pulses of the electron accelerator during irradiation of the carbamide ($(NH_2)_2CO$) specimen with a mass of 150 g

In the materials consisting of light- and medium-mass elements, to which CE belong, the penetrating power of gamma-quanta is higher than that of neutrons. The activation analysis method based on detection of 0.511 MeV gamma-quanta is used for imaging the object (positron tomography) that comprises C, N and O. The properties of products from these reactions are such that do not permit to realize the rapid detection methods, require using special geometries and preventing CE from being identified. And this method, also, gives only indirect information on the CE presence.

Monochromatic gamma-quanta from the isotope sources are more preferable in designing of portable detectors, in particular, for detection of (AP) field mines buried to little depth. Calculations by the Monte Carlo method [9] have shown that for identification and local-

ization of field mines the most effective source of γ-quanta can be a collimated ^{241}Am source. The test has established that in light soils one can detect ∅45 mm mines near the ground surface and ∅80 mm at a depth of 80 mm.

The most promising method of CE detection was proposed by L.Alvaretz [3]. The essence of the method is as follows. For identification of ^{14}N nuclei as main CE constituents, the following reactions are used:

$$\gamma + {}^{14}N > 2n + {}^{12}N \quad (E_{пор} = 30.5\ MeV), \quad (1)$$

$$\gamma + {}^{14}N > 2p + {}^{12}B \quad (E_{пор} = 25.1\ MeV). \quad (2)$$

Similar reactions

$$\gamma + {}^{13}C > p + {}^{12}B \quad (E_{пор} = 17.5\ MeV), \quad (3)$$

$$\gamma + {}^{16}O > 3n + {}^{13}O \quad (E_{пор} = 52.1\ MeV) \quad (4)$$

can, in principle, serve for determining the content of carbon and oxygen being in CE. In 94.55% cases of ^{12}N decay and 97.1% of ^{12}B decay 17.34 MeV positrons and 13.37 MeV electrons are produced, respectively. The cross-sections for the double escape of neutrons and protons in reactions (1) and (2) are significantly lower (by a factor of several tens) than the cross-sections of single neutrons (γ_n) and protons (γ_p) from the ^{14}N nucleus. Therefore, there will be observed a great background due to 0.511 MeV gamma-quanta. The half-life of ^{12}N and ^{12}B nuclei is 11 ms and 20.2 ms, respectively, that enables one to realize rapid detection methods and to attain a significant excess of a signal over the background in the bremsspectrum measurements between the accelerator pulses. It should be noted that at accelerated electron energies up to 100 MeV, no other isotopes with half-lives of less than 100 ms are produced. This method can be used also for detection of carbon-contained narcotics. The detection method is based on the registration of γ-quanta produced as a result of deceleration of electrons and positrons arising from the beta-decay of ^{12}B and ^{12}N. The number of bremsstrahlung γ-quanta should, in general, substantially exceed the number of electrons and positrons. We have calculated (by the GEANT code) the spectra of bremsstrahlung γ-quanta resulting from the interaction of 17.34 MeV positrons and 13.37 MeV electrons with CE and other materials. The calculations were performed for real experimental conditions in order to determine the effective coefficients of electron/positron conversion into γ-quanta. We have conducted experiments under conditions similar to real ones at the linac "EPOS" [10]. Electrons were accelerated up to energies between 22 and 40 MeV at a pulse length of 3.8 μs, pulse repetition rate from 6.25 to 50 Hz and pulse current of ~20 mA. The electron beam was ejected from the accelerator through a titanium window of 40 μm thick. Then it hit a tantalum converter of 1 mm thick. Usual carbamide [$(NH_2)_2CO$] with a nitrogen content of <45% was applied as a nitrogen target. The target was scanned with γ-quanta produced in the tantalum converter. The bremsstrahlung γ-rays produced by 17.34 MeV positrons and 13.37 electrons were recorded by the NaJ(TL) detector being located at a distance of 0.8 m from the target behind the lead collimator. The signal from carbamide [$(NH_2)_2CO$] was rather intensive – the object having a 150 g mass under irradiation with single pulses of the bremsspectra with a maximum energy of 40 MeV ($I_{имп}$ =18 mA, f =12.5 Hz) gives 80 counts as compared to 16 counts of the γ- background in the NaI(Tl) detector. The bremsspectrum of γ-quanta produced by β-particles arising from the decay of ^{12}N and ^{12}B [10] is shown in Fig.4.

Using the electron energy of 50 MeV and pulse current of 8 mA the time spectra were obtained by irradiation of 17 chemical elements and three types of CE [11]. There was not obtained signals similar to nitrogen and carbon. The signal from the specimen with nitrogen having 125 g weight was equal to 100 counts for 5 counts of the background. It should be noted that simultaneously with detection of C, N, O contained materials; it is possible to detect fissile materials too, by the neutron radiation distribution in time.

The present results enable to draw a conclusion that after sufficient optimization of the offered method, parameters of the installation, geometry of the experiment and experimental procedure, this detection technique is promising for detection of C, N, O under field conditions, customs examinations and luggage control in airports.

We apologize to the authors of original publications, the references to which are not given because of the limitations for the paper that can be found in the literature reviews.

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ДЕТЕКТИРОВАНИЕ ВЗРЫВЧАТЫХ ВЕЩЕСТВ

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Проведен обзор литературы по методам детектирования взрывчатых веществ (ВВ) в стационарных и полевых условиях. В настоящее время имеются сотни публикаций по возможности детектирования ВВ различными методами, но 100% гарантии их обнаружения нет. Внимание уделено современным высокотехнологическим методам обнаружения ВВ: ядерному квадрупольному резонансу, ядерно-физическим (медленные и быстрые нейтроны, гамма-кванты) и биологическим. Следует отметить, что опасность вновь создаваемых ВВ, в том числе и полевых мин, увеличивается. Совершенствуются и системы их срабатывания. Большинство трудностей по детектированию, извлечению и деактивации взрывных устройств может быть преодолено с помощью современных методов и технологий. Данный обзор, прежде всего, обращает внимание на возможность решения этой острой и сложной проблемы с помощью ускорителей заряженных частиц.

ДЕТЕКТУВАННЯ ВИБУХОВИХ РЕЧОВИН

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Проведено огляд літератури по методах детектування вибухових речовин (ВР) у стаціонарних і польових умовах. На даний час є сотні публікацій по можливості детектування ВР різними методами, але 100% гарантії їх виявлення немає. Увага приділена сучасним високотехнологічним методам виявлення ВР: ядерному квадрупольному резонансу, ядерно-фізичним (повільні й швидкі нейтрони, гамма-кванти) і біологічним. Слід зазначити, що небезпека створюваних ВР, у тому числі польових мін, збільшується. Удосконалюються й системи їхнього спрацьовування. Більшість труднощів по детектуванню, добуванню і деактивації вибухових пристроїв може бути подолане за допомогою сучасних методів і технологій. Даний огляд, насамперед, звертає увагу на можливість рішення цієї гострої і складної проблеми за допомогою прискорювачів заряджених частинок.