CONTRABAND DETECTION THECHNOLOGICAL COMPLEX WITH ION LINAC

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The contraband detection technological complex (CDTC) to detect explosives, fission materials, and vegetable drugs is proposed. Our approach employs the pulsed neutron source. The CDTC employs the rf linac to provide a beam of deuterons of 1 or 3.5 MeV, which impinge upon a target giving birth pulsed neutron flow. Explosives are identified by the matrix detection system with gamma registration under interaction of neutron on N, O, C nuclei. Experimental verification of main principles of matrix detection system is presented.

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INTRODUCTION

NPK LUTS (Scientific Production Complex of Linear Accelerators and Cyclotrons) is Division of D.V. Efremov Scientific Research Institute of Electrophysical Apparatus. Contraband Detection Technological Complex is designed to detect explosives, fission materials, and in future vegetable drugs. Conceptual scheme of CDTC is given in Fig.1. CDTC comprises the rf linac capable to provide a beam of deuterons with the output energy up to 3.5 MeV; neutron producing target; matrix detection system; system of data processing, biological shield blocks. The acceleration system consists of 1 MeV 433MHz RFQ and 433 MHz IH-resonator with drift-tubes and alternating phase focusing (APF) as the second stage of acceleration from 1 MeV up to 3.5 MeV. The njection system of the linac provides a double-modulated beam with the output normalized emittance $5\cdot10^{-7}$rad·m. Duration of macropulse is 100 μsec, duration of micropulses is 1 μ sec. Intervals between micropulses and length of micropulse are determined by the trade-off of detector possibility to process the maximal information against the necessity to detect delayed neutrons between pulses. The matrix detection system detects registers secondary gamma radiation; which appear under interactions of neutrons and nuclei of the investigated object. For monitoring the explosives a complex neutron method is used [1]. Secondary gammas is resulting inelastic scattering of fast neutrons on N, O, C nuclei during beam pulses. N, O, C nuclei are main components of explosives. Intervals between pulses are used for detection of gammas from short-lived isotopes of the neutron-activation analysis and from radiation capture of thermal neutrons with ^{14}N nuclei. The fission is identified by detection and processing of energy and time spectra. If the object being investigated includes the fission, then the total yield of neutrons is enhanced and high-energy neutrons appear during neutron pulse measurements. Delayed neutrons are detected by measurements between pulses. CDTC includes a local biological shield. Distribution of shield blocks along the complex is optimized. A proposed principle of the contraband detection system has the Russian patent [1].

Fig.1. Conceptual schematic of the contraband detection technological complex: 1 - injector; 2,3 - 433MHz RFQ and 433 MHz IH-resonators; 4 - RF power supply system; 5 - γ-radiation detector; 6-inspected object; 7 - transport system; 8 - radiation shielding

ACCELERATING SYSTEM

Major components of the rf linac are: injector with a deuteron duoplasmatron type source and a system of beam forming and preacceleration; RFQ as the first stage of acceleration; RF system; feeding system of the injector and special extraction source system-modulator. Special modulator provides beam dividing on macro and micropulses. RFQ provides acceleration of deuterons up to 1 MeV with the output pulsed current 20 mA and beam emittance which must be matched with IH-resonator acceptance. Construction of RFQ has eight main parts: four rigid flanges and four vanes. Length of vanes is 2.3 m. Basicmaterial of constructive elements is chromium copper. Mathematical simulation shows [2] possibility to transport a 20 mA deuteron beam with the phase length 0.6 rad after RFQ via the IH-resonator. Its effective length is 0.9 m that corresponds to 54 accelerating gaps. Main characteristics of the linac are given in table.

Main characteristics of the accelerating system

Characteristic	Type or value
Deuteron source type	Duoplasmatron
Extracting voltage	15…20 kV
Extracting pulse current	25 mA
Preaccelerating system type	Electrostatic

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Deuteron energy at RFQ input	60 keV
RFQ output energy	1 MeV
APF cavity output energy	3.5 MeV
Working frequency of resonators	433 MHz
Intervane voltage in RFQ	98 kV
Maximal electric field strength on z-axe of IH-resonator	120 kV/cm
Macropulse current duration	100 μsec
Pulse repetition	Up to 150 Hz
Pulsed power of output amplifier	400 kW
Length of rf power pulse	130 μsec
Output beam emittance (norm., theor.)	$1.5\cdot10^{-6}$ rad·m
Output energy spread (theor.)	± 1.4%

The construction of NPK LUTS IH-resonators was described in principle in paper [3]. There were given results of testing of samples too. Only rf beam focusing is used in the accelerating cavities therefore additional permanent magnetic focusing is absent. Enhancing of the deuteron energy on the target from 1 to 3.5 MeV must increase the neutron yield at least in several times as much. For example, for beryllium target the neutron yield will be enhanced by an order of magnitude. The RF system consists of two amplifications lines with the multiple-beam tetrode "Congress" as a power amplifier by SED SPb. Stock Company. Principle of feeding of H-resonators (RFQ and IH-cavity) was described in paper [4].

DETECTION AND PROCESSING SYSTEMS

Yield and time distributions of neutrons and gamma radiation are measured by the synchronous detector method. This method gives the result as for as the neutron source is pulsed one and measurements are produced under conditions of microstatistics. The detection system for detection of explosives is the scintillation counter matrix which is placed behind of the object being investigated and "looks over" it in full. The layout of the detection system is shown in Fig.2. Each of matrix sells consists of CsI crystals with the electron photomultiplier. Cell dimensions are 63× 100 mm, number of cells can change from 32 (8×4) up to 256. Enhance of the number of detectors is necessary when objects of large sizes are investigated.

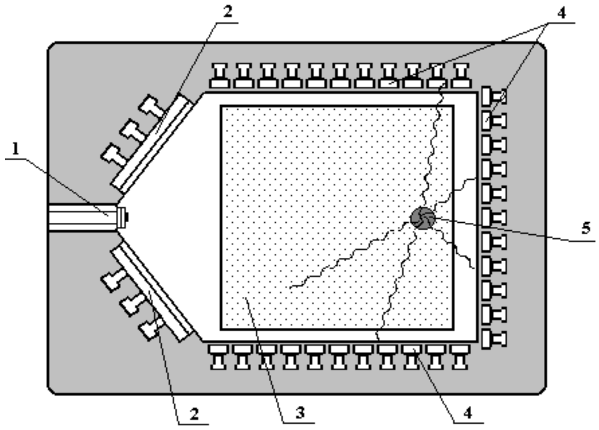

Fig.2. Layout of the detection system: 1-target device; 2-fission monitoring; 3-investigated object; 4-explosive monitoring; 5-location of the fission or explosive inside the object being investigated

Signals of detectors are transmitted into the A/D converter via the tract of signal amplification and normalization. Information is stored in the on-line memory modulus and then is processed by the special code. This code provides selection and summation of digital spectrometric signals during neutron pulses just as between them. Maximal information is given by the characteristic lines 2.31 MeV – for nitrogen, 4.44 MeV – for carbon, 6.31 MeV for oxygen. These gammas gave the maximal yield under target irradiation with fast neutrons of a continuous spectrum. As a result of processing of the energy gamma spectra spatial and quantifiable distributions of N, O, C elements inside the object are determined.

Values of relative detector signals under characteristic gamma radiation detection from N, O, C are given in fig.3, as coordinates used are the relations of separate element concentrations to sum concentrations of N, O, C. One can see the good separation explosives. This property is used for data processing. The system of fission detection consists of two effective detectors made from "fast plastic". Detector signals are transmitted on summation via the tract for amplification and normalization and then on the time analyzer. Start of the analyzer is performed by the synchronizing pulse from the accelerator. After the analyzer information is accessed into the computer memory and processed by the special code.

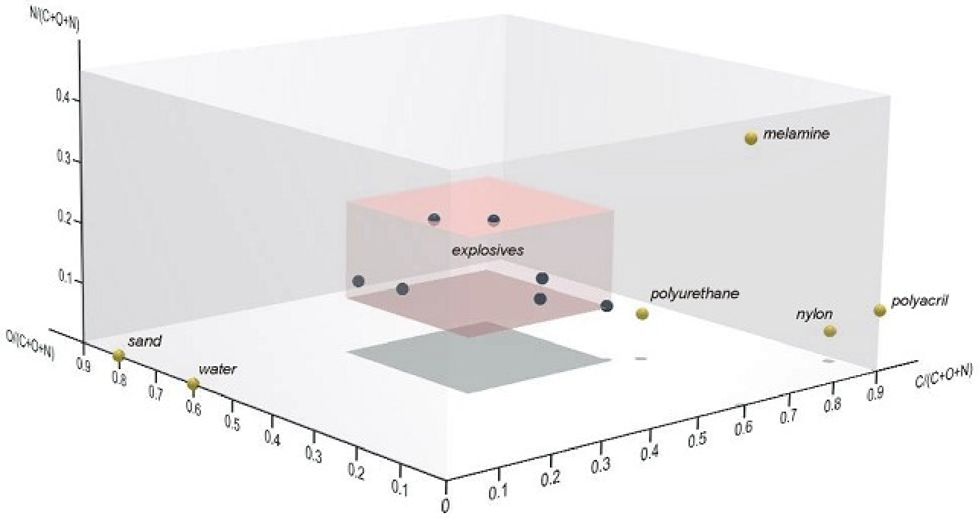

Fig.3. Characteristic γ-radiations from N, O, C for explosives and other substances

EXPERIMENTAL VERIFICATION OF MATRIX DETECTION SYSTEM

As it was impossible to run a full-scale experiment, we performed a series of model tests, which gave supporting evidences of the validity of main principles of the method in question. To this purpose, corresponding measurements of a beam of neutrons produced under bombardment of the Be-target with deuterons have been done. A cyclotron operating in the quasi-continuous mode was used as a source of 10 MeV deuterons. To reduce the background radiation, the target was located in the shield channel of 10 cm-thick lead and 16cm-thick borated polyethylene. An object to be inspected was located on the beam axis at a distance of 1.5 m from the Be-target. At a distance of 1m beneath the object there was a shielded detector. A scintillation CsI-detector was used as a detector of γ-radiation produced in the object inspected. Samples of graphite and organic glass were used as references generating γ-radiation of different elements (C, O, H). Fig.4 presents the energy spectra of γ-radiation obtained by subtraction of the background spectrum from the spectra generated under irradiation of samples. Analysis of the results presented in Fig.4 has shown that even in the case of non-optimized neutron source it is possible to identify spectral lines of elements of samples inspected. Under actual conditions γ-radiation background will be reduced due to the pulse mode of the neutron source operation and applied synchronous detector method. The method provides addition of similar energy spectra measured for several similar time intervals in each channel. Using this procedure, one can attain conditions when the favorable signal is "n"-times increased at addition from channel-to-channel, and the background rises as a root of "n". This allows reliable determination of rather small quantities measured even at a high background.

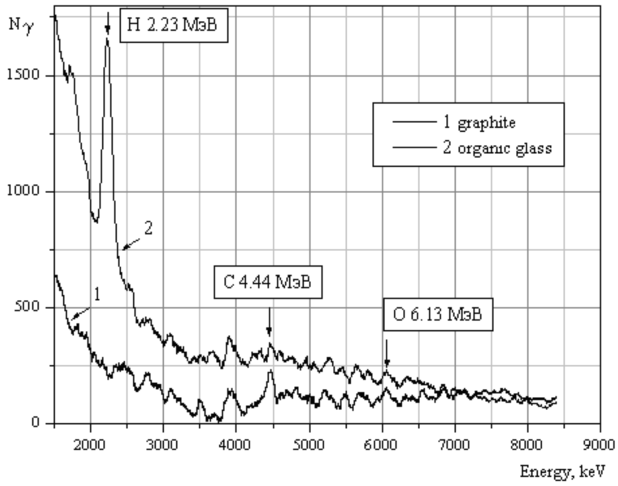

Fig.4. Energy spectra of γ-radiation obtained by subtraction of the background spectrum from the spectra generated under irradiation of graphite (1) and organic glass (2) with neutrons

From measurements of γ-radiation of a short-lived isotope ^{16}N decay, it is seen that oxygen in ES can be identified by registering γ-radiation E_{γ}=6.13 MeV ($^{16}N(\beta^{-},\gamma)$-reaction).

The analysis of experimental data allows us to draw the following conclusion:

- under ES irradiation with fast neutrons there is formed a spectrum of γ-radiation exhibiting specific features (characteristic γ-lines) from which the conclusion on ES presence in the object inspected can be done;
- under FS irradiation the intensity of neutron flow rises due to fission of instantaneous neutrons, and contribution of delayed neutrons appears.

These conclusions confirm the validity of theoretical predictions about the possibility of ES and FS detection using the suggested nuclear method.

STATUS

By now two rf feeding lines and one of two 25 kW modulator have been manufactured and tested on the equivalent load. RFQ had been manufactured, assembled, tuned and tested on the laboratory stand. Blocks of the detection system has been manufactured too and tested with the cyclotron beam in the laboratory of the "Positron" plant. Manufacturing of the new injector with the duoplasmatron type source and special modulator of pulses is completed. The IH-resonator is in the same status.

Testing of the first experimental sample of CDTC will according to the plan will be in the end of 2004.

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КОМПЛЕКС ОБНАРУЖЕНИЯ ВЗРЫВЧАТЫХ, ДЕЛЯЩИХСЯ И НАРКОТИЧЕСКИХ ВЕЩЕСТВ РАСТИТЕЛЬНОГО ПРОИСХОЖДЕНИЯ НА ОСНОВЕ ЛИНЕЙНОГО ВЧ-УСКОРИТЕЛЯ ИОНОВ ВОДОРОДА

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Дано описание комплекса обнаружения взрывчатых, делящихся и наркотических веществ растительного происхождения. Источником зондирующего нейтронного излучения является линейный малогабаритный высокочастотный ускоритель ионов водорода. Представлены результаты испытания системы детектирования и обработки информации гамма-излучения, образуемого при взаимодействии нейтронного излучения с характерными элементами N, O, C, входящими в состав искомых материалов.

КОМПЛЕКС ВИЯВЛЕННЯ ВИБУХОВИХ, ЩО ПОДІЛЯЮТЬСЯ І НАРКОТИЧНИХ РЕЧОВИН РОСЛИННОГО ПОХОДЖЕННЯ НА ОСНОВІ ЛІНІЙНОГО ВЧ-ПРИСКОРЮВАЧА ІОНІВ ВОДНЮ

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Дано опис комплексу виявлення вибухових, що поділяються і наркотичних речовин рослинного походження. Джерелом зондувального нейтронного випромінювання є лінійний малогабаритний надчастотний прискорювач іонів водню. Представлено результати іспиту системи детектування й обробки інформації гамма-випромінювання, створеного при взаємодії нейтронного випромінювання з характерними елементами N, O, C, що входять до складу шуканих матеріалів.