CPNA-METHOD FOR ES DETECTION USING HYDROGEN ION ACCELERATORS OPERATING IN BATCH-PULSE MODE

Yu.N. Gavrish, A.V. Sidorov, A.M. Fialkovsky
The Scientific Research Institute of Electrophysical Apparatus, Scientific Production Complex of Linear Accelerators and Cyclotrons, Saint-Petersburg, Russia; npkluts@niiefa.spb.su

A new nuclear method CPNA (complex pulsed neutron analysis) for detection of explosive substance (ES) is suggested. The essence of the method is the following. Information on ES presence can be obtained from analysis of energy spectra of γ-quanta produced as a result of nuclear reactions of neutron pulse radiation interaction with nuclei of characteristic elements constituents of ES. Based on optimizing calculations of neutron radiation parameters to provide most effective detection of ES, a batch-pulse operating mode of the hydrogen ion accelerator has been suggested.

PACS: 29.17.+w

INTRODUCTION

The problem of the detection of explosive substances (ES) is currently central in the context of increasing number and variety of forms of terrorist acts assassinated in many regions and countries all over the world, Russia included. Especially dangerous is use of ES at hijacking and in crowded places. To fight successfully against these crimes, corresponding services should be equipped with effective technical means for remote detection of masked ES.

Previously, the problem of ES detection consisted in the search of metallic shells of grenades or mines made of traditional explosive materials, such as dynamite, trinitrotoluene, etc. At present, the problem is much more sophisticated because of application of non-shell ES, for example, on the basis of plastic explosive charges of C-4, Semtex or Detasheet type. These materials are far beyond dynamite and trinitrotoluene in destructive effect, and they can be produced as plates about 5 mm in thickness ("sheet" ES) practically of any shape.

Nuclear methods are highly promising for detection of explosive substances as the majority of ES offers unique combination of high concentrations of carbon, nitrogen and oxygen atoms. High concentration of nitrogen in an inspected object is an indication of probable presence of ES, and high concentrations of carbon, nitrogen and oxygen practically unambiguously testify ES presence. It should be emphasized that only nuclear methods allow one to most effectively detect non-shell plastic explosives and masked ES. Only neutron-radiation method for detection of high nitrogen concentration (the TNA method) has been implemented in practice; unfortunately, experience has demonstrated its unallowable high level of false alarms. Nuclear methods applying fast neutrons as the probing radiation are considered most promising. The Pulsed Fast Neutron Analysis (the PFNA method) provides maximum sensitivity of ES detection.

A great number of methods and means for ES detection have been suggested to date. However, at present, there is no such a method that can provide 100% probability of ES detection. Therefore, new methods are still being devised including nuclear ones offering higher efficiency of ES detection. It should be emphasized that only nuclear methods are effective in detection of masked ES.

CPNA-METHOD FOR ES DETECTION

We analyzed the experience gained when devising methods and creating means for ES detection taking into account the potentialities of modern spectrometric apparatus, which makes possible measurements of photon energy distributions at high background with a high level of reliability. As a result a new method [1] has been suggested the essence of which is the following (fig.1).

Fig.1. Time chart of neutron source: t_1 - time of measurements of γ-radiation produced as a result of inelastic scattering of fast neutrons by nuclei of ES typical elements (nitrogen, oxygen, carbon); t_d - time delay due to neutron thermalization; t2 - time of measurements of γ-radiation produced as a result of thermal neutrons capture with nitrogen nuclei; t_3 - time of measurements of γ-radiation of short-lived radionuclide decay (oxygen, chlorine, etc.); t_{FS} - time of fission substances measurements; T - neutron pulse repetition rate

Information on ES presence can be obtained from analysis of energy spectra of γ-quanta produced as a result of nuclear reactions of neutron pulse periodic radiation interaction with nuclei of characteristic elements-constituents of ES. During pulses of neutron radiation, energy spectrum of γ-quanta produced as a result of reactions of inelastic scattering of fast neutrons by nuclei of nitrogen, oxygen and carbon is measured. Between the pulses, are measured energy characteristics of γ-quanta produced as a result of reactions of neutrons' radiation capture with nitrogen nuclei ($^{14}N(n,\gamma)^{15}N$) and energy spectra of γ-quanta of short-lived radionuclides' decay. Short-lived radionuclides are formed under neutrons' interaction with oxygen nuclei ($^{16}O(n, p)\ ^{16}N(\beta^-,\gamma)$, $T_{1/2}$=7,13 and chlorine (an impurity used at production of new ES) $^{37}Cl(n,\alpha)^{34}P(\beta^-,\gamma)$ $T_{1/2}$=12,4 and $^{37}Cl(n, \gamma)^{38m}$-Cl $T_{1/2}$=0,71c).

Table 1. Energies of characteristic γ-quanta for some elements

Element	γ-quanta energy, MeV
^{16}O	6.13
^{14}N	5.11; 2.31; 1.63
^{12}C	4.44

^{27}Al	3.00; 2.50; 2.30; 2.21; 1.72; 1.01; 0.84
^{56}Fe	2.60; 2.27; 2.11; 1.81; 1.24; 1.04; 0.85
$^{35,37}Cl$	3.16; 3.10; 2.65; 2.35; 1.99; 1.76; 1.22;1.19

Any element can be detected from characteristic γ-quanta produced as a result of inelastic scattering of neutrons. For example, Table 1 demonstrates energies of characteristic γ-quanta produced under inelastic scattering of 3…12 MeV neutrons by nuclei of some elements.

As a result of radiation capture of thermal neutrons with nuclei of ^{14}N (^{14}N (n, γ)^{15}N), 10.83 MeV γ-quanta are produced. The content of ^{14}N isotope in a natural mixture is 99.63%. Reaction cross-section of neutrons' radiation capture with nitrogen nuclei is smaller with higher energy; for thermal neutrons it is 75 mb. Radiation spectrum of ^{15}N-daughter nucleus has a γ-line with an energy of 10,83 MeV and intensity of 14% per one captured neutron. It should be noted that this energy is one of the highest energies of γ-quanta produced under radiation capture of thermal neutrons with different nuclei.

Activation analysis holds a special position among modern analytical methods used for determination of element composition of substances as it allows one to obtain results appreciably surpassing those obtained with methods of analytical chemistry in sensitivity, accuracy and rapidness. Activation analysis, which can use practically all the types of nuclear interactions, is performed in two stages. First-irradiation of an object with a flow of activating radiation and then-study of characteristics of the induced activity The majority of procedures for measuring the induced activity are based on spectrometry of γ-quanta using scintillation or semiconductor spectrometers. As a result of activating radiation interaction with nuclei of various elements, a large amount of radionuclides is produced, as a rule, including short-lived ones. Under all other conditions being equal, larger measured friendly signal corresponds to lower period of half-decay.

Half-decay classification of nuclides in the neutron-activation analysis depends on conditions of the experiment, in particular, time parameters of the source of radiation and time of measurement – t_m. In the general case, as short-lived nuclides are considered those for which $\lambda\, t_m > 1$, where λ is the decay constant related to the half-decay period via ratio $\lambda = Ln(2)/T_{1/2}$. Nowadays, the nuclides which half-decay period is within the range of 10^{-3} with $< T_{1/2} < 10^2$s are considered as short-lived ones.

The use of pulse-periodic source allows the application of cyclic method of neutron-activation analysis from short-lived isotopes. The essence of the method consists in multiple repetition of irradiation-measurement cycle that provides appreciable advantages, especially, when analysis is performed from short-lived nuclides: statistical error of measurements is significantly reduced, sensitivity and accuracy of the analysis are much more higher. The following time mode of the analysis is suggested. An object under inspection is irradiated with a pulse flow of neutrons. Between pulses the induced activity is measured. Then irradiation–measurement cycles are repeated.

Table 2 presents some elements, which can be detected with the neutron-activation analysis from short-lived isotopes at energy of neutron radiation up to 12 MeV [2]. Only elements being of interest for ES detection are shown (oxygen and chlorine, used at production of modern explosive substances) and precious metals: silver, gold and platinum.

Table 2

Z	Reaction	$T_{1/2}$, c	E_γ, MeV (relative intensity, %)
O	$O^{16}(n,p)N^{16}$	7,13	7,122(5); 6,134(69)
Cl	$Cl^{37}(n,\gamma)Cl^{38m}$	0,71	0,671(99,9)
Cl	$Cl^{37}(n,\alpha)P^{34}$	12,4	4,00(0,2); 2,127(15)
Ag	$Ag^{109}(n,\gamma)Ag^{110}$	24.4	0.658(5,6)
Au	$Au^{197}(n,n')Au^{197}$	7,2	0,278(72,5); 0,13(3,2)
Pt	$Pt^{198}(n,\gamma)Pt^{199m}$	14	0.393(83), 0.032(5)

Detailed consideration of the activation analysis from short-lived isotopes is given in [2].

NEUTRON SOURCE

Various types of nuclear source can be used for ES detection. Neutron sources based on the use of radioactive nuclides are simplest in design and application**.** The intensity attainable when using a radioactive source is about 10^9 n/s. The source occupies quite a small volume (about 1litre). The main drawback is that isotropic neutrons are emitted in rather wide range of energies.

The neutron generator is relatively small, but power supply and cooling systems make their enlarging contributions to its volume. Neutron generators can operate both in pulse and continuous modes. Angular distribution of neutrons is isotropic, and that is a drawback of the source. Another drawback is short time of tritium targets running (100 hours). In this connection there appears a problem of spent tubes or interchangeable targets disposal. The advantage is that the source can be "switched off".

Neutron sources on the basis of charged particle accelerators are the most complicated devices. The accelerator offer a possibility to produce neutrons in a wide range of energies at a relatively low energy spread, which is its serious advantage. The source anisotropy increases the neutrons' escape predominantly in the forward direction**.** The source can be "switched off', which is also significant merit compared to radioactive source.

Thus it has been found out that linear accelerators of hydrogen ions offer the best capabilities for ES detection. An example of such an accelerator is a radio frequency accelerator of hydrogen ions designed in NPK LUTS, the D.V.Efremov Institute (Fig.2).

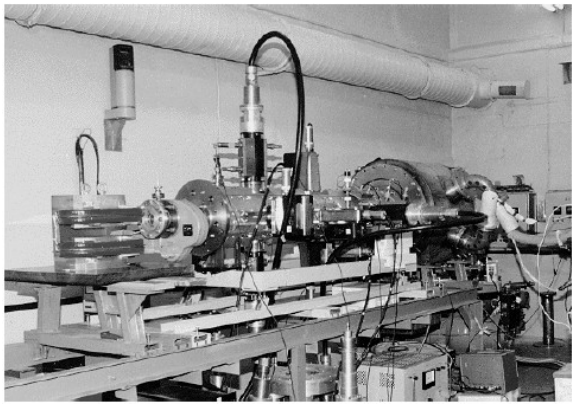

Fig.2. General view of RF accelerator of hydrogen ions

To determine optimal energy parameters of the neutron radiation source, interaction of neutrons with different energies with ES (trinitrotoluene $C_7H_5O_6N_3$) has been studied. Calculations of γ-quanta produced as a result of neutrons' inelastic scattering by N, C and O nuclei have demonstrated that γ-quanta with energies: E_y =1,64; 2,31; 5,11; 7,03 MeV offer the largest yield for nitrogen, with E_y = 2,74; 6,13; 6,92 7,12 – for oxygen and with E_y = 4,44 and 9,64 MeV – for carbon. Optimal energy of the pulse periodic neutron source intended for ES detection using (n,n') reactions is calculated such that cross-section of produced γ-quanta for specified lines is maximum and amounts to 8-12 MeV. The $^{16}O(n,p)^{16}N$ reaction cross-section has its maximum at 12 MeV energy of neutrons. Thus we obtain that 10-12 MeV energy of the pulse- periodic neutron source is optimal for ES detection by the suggested method.

Time parameters of the pulse - periodic source of neutrons have been obtained by minimizing the time for ES analysis at a specified ES detection limit of 10 g of trotyl. Simulation of processes of ES-neutrons interaction has shown that optimal time parameters in case of ES detection by γ-quanta produced as a result of neutrons' inelastic scattering by N, O and C nuclei are: τ~ 1 μs (is defined such that the detector system registers no more than one quanta, otherwise, the information on amplitude will be incorrect because of superposition of two or more events); time interval between pulses is ~3-5 μs, the time necessary for generation of spectrometric signal when registering γ-quanta with a CsI (TI)-based scintillation detector with decay time of 1 μs.

To attain maximum sensitivity of the neutron-activation analysis from short-lived isotopes, the dependence of number of counts on pulsed time parameters: pulse duration and pulse repetition rate has been studied. It is shown that the accelerator current pulse duration of t_r ~100 μs at a pulse repetition rate of v<1000Hz corresponds to the optimal mode of the neutron-activation analysis from short-lived isotopes for ES detection.

Taking into account the fact that different time parameters correspond to the optimal modes of the sources used for the analysis from non-elastic scattering of fast neutrons and the neutron-activation analysis of short-lived isotopes, the batch-pulse operating mode of the pulse neutron source is suggested.

CONCLUSIONS

As a result of our intensive efforts we have suggested a new high promising method for ES detection being an advantageous combination of already known nuclear methods. Main advantages of the method are:

- higher reliability of ES detection due to the use of three independent channels, that is PFNA (Pulsed Fast Neutron Analysis), PTNA (Pulsed Thermal Neutron Analysis) and short-lived radionuclide decay;
- may be detection of fissionable substances;
- may be detection of chlorine, which is a component of some explosive substances;
- detection of other substances, such as vegetative drugs, gold, platinum, silver, etc. which are of interest for customs inspection.

Contraband Detection Technological Complex is designed to detect explosives, fission materials, and in future vegetable drugs by .NPK LUTS (Scientific Production Complex of Linear Accelerators and Cyclotrons).

REFERENCES

1. M.F. Vorogushin, Yu.N. Gavrish, A.V. Sidorov, A.M. Fialkovsky. *Method of detection of explosives and fission products*. Russian patent № 2150105. Priority since May 26, 1999 (in Russian).
2. M.F.Borogushin, Yu.N.Gavrish, A.V.Sidorov, A.M.Fialkovsky. *Neutron-activation analysis from short-lived radionuclides on the basis of linear ion accelerator:* Preprint П-0936. M.: "TSNIIatominform", 1995.

CPNA-МЕТОД ОБНАРУЖЕНИЯ ВЗРЫВЧАТЫХ ВЕЩЕСТВ С ИСПОЛЬЗОВАНИЕМ ПАКЕТНО-ИМПУЛЬСНОГО РЕЖИМА РАБОТЫ УСКОРИТЕЛЯ ИОНОВ ВОДОРОДА

Ю.Н. Гавриш, А.М. Сидоров, А.М. Фиалковский

Предложен новый ядерно-физический метод обнаружения взрывчатых веществ (ВВ). Информация о наличии ВВ может быть получена из анализа энергетических спектров гамма-излучения, образуемых в результате ядерных реакций взаимодействия импульсного периодического нейтронного излучения с ядрами характерных элементов, входящих в состав ВВ. На основании расчетов оптимизации параметров нейтронного излучения для эффективного обнаружения взрывчатых веществ предложено использовать пакетно-импульсный режим работы ускорителя ионов водорода.

CPNA-МЕТОД ВИЯВЛЕННЯ ВИБУХОВИХ РЕЧОВИН З ВИКОРИСТАННЯМ ПАКЕТНО-ІМПУЛЬСНОГО РЕЖИМУ РОБОТИ ПРИСКОРЮВАЧА ІОНІВ ВОДНЮ

Ю.Н. Гавриш, А.М. Сидоров, А.М. Фіалковський

Запропоновано новий ядерно-фізичний метод виявлення вибухових речовин (ВР). Інформація про наявність ВР може бути отримана з аналізу енергетичних спектрів гамма-випромінювання, отриманих у результаті ядерних реакцій взаємодії імпульсного періодичного нейтронного випромінювання з ядрами характерних елементів, що входять до

складу ВР. На підставі розрахунків оптимізації параметрів нейтронного випромінювання для ефективного виявлення вибухових речовин запропоновано використовувати пакетно-імпульсний режим роботи прискорювача іонів водню.