

BEAM APPLICATIONS

THE USE OF ELECTRON LINACS FOR DETECTION OF C-, N-, O- CONTAINING SUBSTANCES

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The detection of concealed explosives (CE) has presently become the burning problem for the mankind. In particular, the problem is related to both clearing the open country of plastic mines and the detection of any CE, drugs, etc. The creation of compact 60...100 MeV electron accelerators makes it possible to produce sharply directed bremsstrahlung beams. For identification of ^{14}N nuclei as main CE constituents, the following reactions are used with production of ^{12}B and ^{12}N . Electrons were accelerated up to energies between 22 and 40 MeV at a pulse length of 3.8 μs , a pulse-repetition frequency from 6.25 to 50 Hz, and a pulse current of ~ 20 mA. The bremsstrahlung gamma-rays were detected by a NaJ(TL) detector. Carbamide $[(\text{NH}_2)_2\text{CO}]$ was used as a nitrogen target. For identification of ^{12}N and ^{12}B decay curves were measured. The signal/noise was 5. Results suggest the conclusion that the present method of detecting CE and C-,N-,O- containing substances has encouraging prospects.

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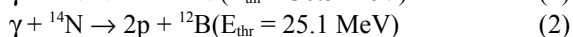
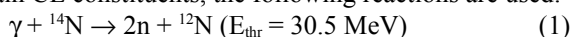
The detection of concealed explosives (CE) has presently become the burning problem for the mankind. In particular, the problem is related to both clearing the open country of plastic mines and the detection of any CE, drugs, etc. at stationary conditions. At the International CE Detection Conference (St. Petersburg, Russia, 2001) it was indicated that the efficiency of mine detection and disposal by the existing methods ranges between 60 to 80% instead of the required 99.6%. The most advanced methods of detection, including the nuclear magnetic resonance method, the nuclear quadrupole resonance technique and the method of gas analysis have essential restrictions on the volume of medium to be inspected. Besides, many technical difficulties occur in the treatment of useful signals, in the creation of a slow-moving gaseous medium over the broken country, etc.

With nuclear-physical methods, preference is given to neutron-activation methods. However, the presence of hydrogen-containing substances (moisture) in the medium (soil) or in the object under investigation leads to noncontrolled neutron absorption by those substances, and, as a consequence, to impossibility of a reliable identification of the object composition under study, to a sharp decrease in the CE detectability depth (≤ 20 cm), etc. Besides, the formation of neutron fields, especially of directed neutron beams, presents significant difficulties.

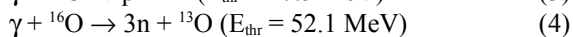
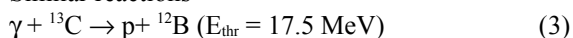
The creation of compact 60...100 MeV electron accelerators [1], as opposed to isotropic neutron sources, makes it possible to produce sharply directed bremsstrahlung beams. Thus, at accelerated electron energies of 60 MeV and higher, the bremsstrahlung beam intensity at an angle of 0° is 1000 times higher than at angles between 90 and 180° . The object can be scanning with γ -quanta beam, when the direction of the pulsed electron beam varied using the magnetic field. And,

thus, the position of the concealed C-, N-, O-containing object can be determined to an accuracy of few cm.

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 reaction products occurring here are such that prevent the realization of quick detection methods, they call for the use of special geometries and prevent the CE from being identified. And, this method, too, gives only indirect information on the CE presence. The most promising method of CE detection was proposed by L. Alvarez [3], which was further evolved by Trower and others, refs. [4,5,6]. The essence of the method is as follows. For identification of ^{14}N nuclei as main CE constituents, the following reactions are used:



Similar reactions



can, in principle, serve to determine the content of carbon and oxygen present in the CE. (Explosives have anomalously high concentrations of N and plentiful O, but less than usual amounts of C).

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 factor of several tens) than the cross sections for the escape of single neutrons (γ_n) and protons (γ_p) from the ^{14}N nucleus. Therefore, there will be a great background due to 0.511 MeV gamma-quanta. The half-life of ^{12}N and ^{12}B nuclei is, respectively, 11 ms and 20.2 ms, that enables one to scan the samples, to realize quick detection methods, and to

attain an essential excess of signal over the background in the bremsstrahlung 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.

So, the detection technique is based on the registration of gamma-quanta produced as a result of deceleration of electrons and positrons arising from the beta-decay of ^{12}B and ^{12}N . The amount of bremsstrahlung gamma-quanta should, in general, substantially exceed the amount of electrons and positrons. We have calculated (by the GEANT code) the spectra of bremsstrahlung gamma-quanta resulting from the interaction of 17.34 MeV positrons and 13.37 MeV electrons with the CE and other substances. The calculations were performed for real experimental conditions in order to determine the effective coefficients of electron/positron conversion into gamma-quanta.

The realization of the method is not trivial, since aside from low cross sections there are many other restrictions. As indicated at the St.-Petersburg Conference, at the present time there are no experimental data. Trower's results were published only recently, that would confirm its feasibility [7]. Therefore, it is essential to perform systematic studies, to develop highly efficient methods of detection and signal handling, etc.

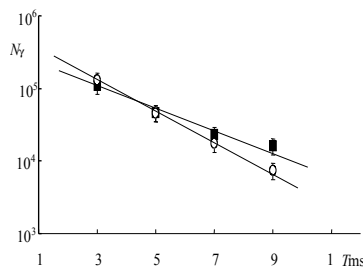


Fig. 1. Dependence of gamma-quanta amount produced by neutrons decelerated in the substance. The data are given for four groups, $t_{\text{obs}}=2$ ms. Here \square is the amount of γ -quanta with $E_{\gamma}=1.94$ to 9.13 MeV, and \blacksquare - $E_{\gamma}=0.511$ MeV, $T_{1/2}=1.3 \pm 0.3$ ms

Our first experiments at conditions approaching reality were performed with the electron linac "EPOS" [3]. Electrons were accelerated up to energies between 22 and 40 MeV at a pulse length of $3.8 \mu\text{s}$, a pulse-repetition frequency from 6.25 to 50 Hz, and a pulse current of ~ 20 mA. The electron beam was ejected through a titanium window $40 \mu\text{m}$ thick. Then it hit a 1 mm thick tantalum converter. Carbamide $[(\text{NH}_2)_2\text{CO}]$ with a nitrogen content of $> 45\%$ was used as a nitrogen target. Measurements were also performed with carbon, water and aluminum. The target was scanned with γ quanta produced in the tantalum converter. The bremsstrahlung gamma-rays produced by 17.34 MeV positrons and 13.37 MeV electrons were detected by a NaJ(TL) detector being located at 0.8 m from the target. The signal from the detector was applied to the discriminator with a constant gamma-energy "cut-off" (up to 1 MeV) and then it arrived at the spectrometric amplifier being on the same board with the analog-digital converter. The

analyzer was controlled with an IBM-type PC using the board controller.

For identification of ^{12}N and ^{12}B , decay curves were measured. For this purpose, the period between the accelerator beam pulses was split into several equal intervals (4 to 8), and thus the bremsstrahlung spectrum generated by positrons and electrons resulting from beta-decay of ^{12}N and ^{12}B nuclei was recorded into different parts of the analyzer's memory. The identification of ^{12}N and ^{12}B is based on the difference between time characteristics of the decay curves (Fig. 1). During the accelerator pulse, the operation of the photomultiplier was interrupted to ensure it against overload or a failure due to a high-power burst of bremsstrahlung from the converter and the interrogated object, and also against neutron irradiation.

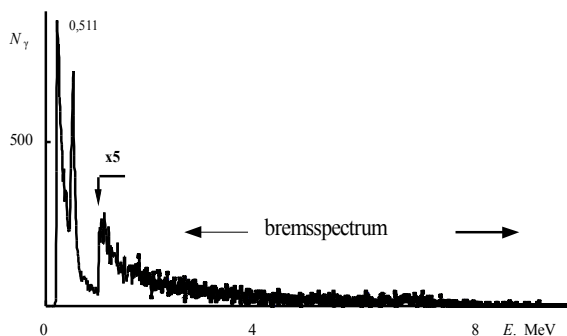


Fig. 2. Gamma-spectrum out irradiated of $[(\text{NH}_2)_2\text{CO}]$ sample, 150 g in mass recorded between accelerator pulses. The bremsstrahlung γ -spectrum is generated by β -particles produced in the decay of ^{12}N and ^{12}B

The decay curves were obtained after subtraction of background produced by neutrons decelerated in the substance with the half-life $T_{1/2}=1.3 \pm 0.3$ ms. The short-lived high-activity γ -radiation is generated by thermal neutrons produced as a result of fast neutron deceleration ($E_n \sim 1$ MeV) in the surrounding materials. After subtraction, the resulting yields of photons fit well into the curves corresponding to the decay times of ^{12}N and ^{12}B .

The gamma spectrum from $[(\text{NH}_2)_2\text{CO}]$ carbamide exposed to the bremsstrahlung gamma-rays with the maximum energy of 40 MeV ($I_{\text{pulse}}=18$ mA, $f=12.5$ Hz, $\tau_{\text{pulse}}=3.8 \mu\text{s}$) is given in Fig. 2. To improve the signal/noise ratio, the time delay after the accelerator pulse was set. The long-lived isotopes produced in the structural materials of the measuring complex also form the γ -background. The latter grows as a function of the accelerator operation time, and also increases with an increasing substance density of the object under examination.

It has been assumed that the spectrum remaining after subtraction of the background belongs to carbamide. In fact, the derived half-life (18 ms) has an intermediate value between 11 and 20 ms, this corresponding to the sample under study. So, the presence of nitrogen in the carbamide sample is found from the slope of the decay curve.

The signal from $[(\text{NH}_2)_2\text{CO}]$ is rather intensive. Thus, an object of mass 150 g, being exposed to single pulses of 40 MeV bremsstrahlung ($I_{\text{pulse}}=18$ mA, $f=12.5$ Hz, τ

$\tau_{\text{pulse}}=3.8 \mu\text{s}$), gives 80 counts over 16 counts of γ background in the NaJ(Tl) detector being placed at 0.8 m from the target. These results suggest the conclusion that on a sufficient optimization of the method, the geometry of experiment and the technology of its realization, the present method of detecting CE and drugs with carbon entering into their composition has encouraging prospects.

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ПРИМЕНЕНИЕ ЛИНЕЙНЫХ УСКОРИТЕЛЕЙ ЭЛЕКТРОНОВ ДЛЯ ОБНАРУЖЕНИЯ С-, N-, O-СОДЕРЖАЩИХ ВЕЩЕСТВ

А.Н. Довбня, А.М. Егоров, В.Т. Биков, Г.К. Хомяков, А.Н. Водин, В.В. Жук, Б.В. Зайцев, Б.А. Немашкало, Г.Д. Пугачев

Проблема обнаружения скрытых взрывчатых веществ (ВВ) приобрела в настоящее время для человечества чрезвычайную актуальность. Это связано с разминированием на открытой местности бескорпусных мин и обнаружением ВВ любого типа, в том числе и других С-, N-, O- содержащих веществ. Создание компактных ускорителей электронов с энергией 60...100 МэВ позволяет получить узконаправленные пучки тормозных γ -квантов. Для идентификации ядер ^{14}N – основного компонента ВВ, используются реакции с образованием ^{12}B и ^{12}N . Электроны ускорялись до энергий 22...40 МэВ, при длительности импульса 3,8 мкс, частоте следования от 6,25 до 50 Гц и токе в импульсе ~20 мА. Тормозное γ -излучение регистрировалось детектором NaI(Tl). В качестве азотной мишени использовался карбамид $[(\text{NH}_2)_2\text{CO}]$. Для идентификации ^{12}B и ^{12}N были измерены кривые распада. Соотношение сигнал/шум составляло 5. Результаты позволяют сделать вывод, что данный способ обнаружения ВВ и других С-,N-,O- содержащих веществ имеет обнадеживающие перспективы.

ЗАСТОСУВАННЯ ЛІНІЙНИХ ПРИСКОРЮВАЧІВ ЕЛЕКТРОНІВ ДЛЯ ВИЯВЛЕННЯ РЕЧОВИН, ЩО МІСТЯТЬ С-, N-, O-

А.М. Довбня, О.М. Єгоров, В.Т. Биков, Г.К. Хомяков, А.Н. Водін, В.В. Жук, Б.В. Зайцев, Б.А. Немашкало, Г.Д. Пугачев

Проблема виявлення прихованих вибухових речовин (ВР) придбала в даний час для людства надзвичайну актуальність. Це пов'язано з розмінуванням на відкритій місцевості бескорпусних мін і виявленням ВР будь-якого типу в тому числі й інших речовин, що містять С-,N-,O-. Створення компактних прискорювачів електронів з енергією 60...100 МеВ дозволяє одержати вузькопрямовані пучки гальмівних γ -квантів. Для ідентифікації ядер ^{14}N - основного компонента ВР використовуються реакції з утворенням ^{12}B і ^{12}N . Електрони прискорювалися до енергій 22...40 МеВ, при тривалості імпульсу 3,8 мкс, частоті проходження від 6,25 до 50 Гц і току в імпульсі ~20 мА. Гальмівне γ -випромінювання реєструвалося детектором Na(Tl). Як азотна мішень використовувався карбамід $[(\text{NH}_2)_2\text{CO}]$. Для ідентифікації ^{12}B і ^{12}N були обмірювані криві розпаду. Співвідношення сигнал/шум складало 5. Результати дозволяють зробити висновок, що даний засіб виявлення ВР і інших речовин, що містять С-,N-,O-, має підбадьорюючі перспективи.