ASSOCIATED PARTICLE IMAGING APPLIED TO INSPECTION SYSTEM FOR BULKY CARGO AND LARGE VEHICLES

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Abstract

Features of inspection system based on the Associated Particle Imaging (API) for explosives available if any in bulky cargo and large vehicles are discussed. The system is designed for automatic detection and localization of substances hidden in the inspected object. The detection of hidden substances lies in analysis of gamma-spectra drawn when the inspected object is exposed to 14.1 MeV ‘tagged’ neutron emission. It encompasses a portal, two inspection modules and a control module. Each module contains a VNIIA-made neutron generator ING-27 with 64-pixel silicon alpha-detector embedded, 24 BGO gamma-detectors, data acquisition and processing electronics as well as power supply units and neutron generator.

The paper describes the chief properties of the system and compares them with that of foreign equivalents.

1. Introduction

The paper describes the features of the ‘tagged’ neutron inspection system for explosives available in bulky cargo and large vehicles. The system is intended for automatic detection and localization of masked matters in the inspected object. The hidden substances are detected using a spectrum analysis of characteristic nuclear gamma-rays generated from irradiation of the inspected object with 14.1 MeV fast ‘tagged’ neutrons. A similar system was constructed under EURITRACK [1-2].

The Associated Particle Imaging (API or ‘tagged’ neutron method) [1-13] rests on detection of accompanying emission of alpha-particles from binary reaction d+t ----> α + n that coincides with characteristic gamma-rays from inelastic scattering of 14.1MeV neutrons in the nuclei of the irradiated sample (reaction A(n,’nγ)A). By measuring an intensity of gamma-lines of C, N, O and other elements in coincidences with signals from alpha-detector as well as a time span between detections, it is possible not only to suppress a background but also to identify a 3-d spatial location of the suspicious object as well as its elemental composition.

The detailed description of the technique with various modifications can be found in papers [3 - 13].

2. System Design

A general view of the system is shown at Fig.1. The chief system components are:

- a position control system;
- two portal inspection modules;
- a control module to move a portal and two inspection modules;
- a control module for the system parameters, alpha- and gamma-detector data acquisition and processing.

The position control system is a movable frame portal that has the rails to move along the static inspection object at distance up to 22 m. The portal moves with speed equal to 50 cm/s. The inspection modules can cruise along the portal in two directions: to 4 m up and down from the floor and to 0.5m in direction of the ‘tagged’ neutron.

The portal and the inspection modules are automatically positioned in the required point with accuracy equal to ±5 mm. X-ray scanner is used to define the point.

The motion of the inspected modules is remotely controlled by means of PC.

Fig. 1. General View of System

2.1. Inspection Module

A general view of the inspection module is presented at Fig.2. It consists of:
a) a portable neutron generator with 64-pixel alpha-detector embedded;
b) 24 gamma-detectors;
c) an acquisition system for alpha- and gamma-detectors;
d) a thermal response correction system for gamma-detector;
e) a power supply system for the neutron generator, alpha- and gamma-detectors;
f) a gamma-detector crystal protection from direct neutron emission.

Fig. 2. Inspection Module

Dimensions of the inspection module are 1171×910×1432 mm (H×W×L), its weight is ~ 1000 kg

2.1.1. Neutron Generator

All-Russia Research Institute of Automatics (VNIIA, Moscow) developed a neutron generator ING-27M of high neutron yield (Fig.3) for the project. The neutron yield of the generator for the solid angle 4π is 2×10^8 neutron/s. The neutron generator incorporates a 64-pixel silicon alpha-detector developed by the specialists from JINR (Dubna).

Fig. 3. Neutron Generator ING-27M

An operation life of ING-27M expressed as a time when intensity falls twofold is at least 800 hours.

2.1.2. Alpha-Detector

A general view of two-coordinate silicon alpha-detector is illustrated at Fig.4.

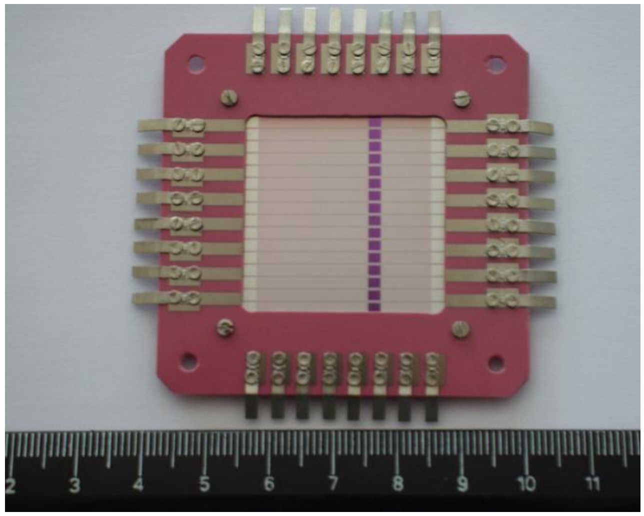

Fig. 4. 64-Pixel Silicon Alpha-Detector

A design of alpha-detector has 8 vertical and 8 horizontal strips 30×4 mm in size located on the silicon crystal opposite each other. 64 pixels 4×4 mm each are formed on a cross line of 8 vertical Y0-Y7 (8n+) and 8 vertical X0-X7 (8p+) strips of alpha-detector that are normal to each other.

The detection electronics of alpha-detector comprises 16 autonomous amplifiers for signals from 16 strips of alpha-detector. The unit with electronics for alpha-detector is fixed right on the neutron generator.

The spatial characteristics of 64 'tagged' beams were measured using a scintillation strip detector (profile meter). Each strip in the profile meter made as a rectangular prism of plastic scintillator is 150×7.5×5 mm in size (a strip is 5 mm thick along the direction of 'tagged' neutron beam). All 16 strips of profile meter are light-insulated. Fiber optic LEDs transfer the light from them to a multianode photomultiplier.

Fig. 5 demonstrates a spatial distribution of 'tagged' neutron beams in a plane normal to the beam direction. The spatial distributions of detected events equivalent to the signal from one Y-script coincided with that from 8 X-scripts are built as an example.

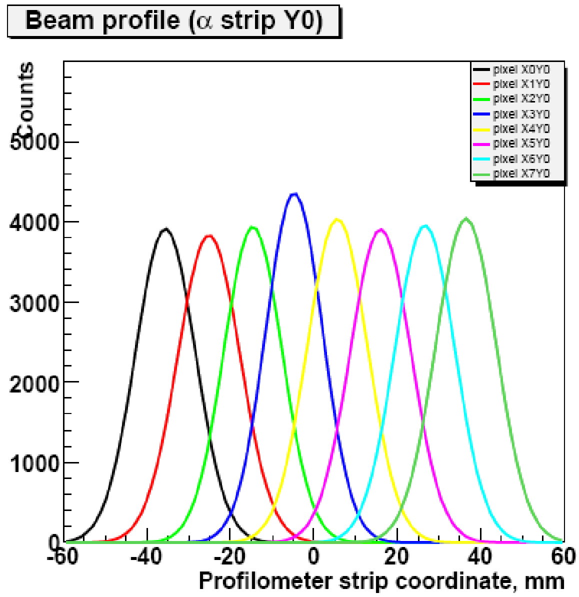

Fig. 5. Spatial Distribution of 'Tagged' Neutron Beams

It is important that the spatial distributions of 'tagged' beams entirely match a simple geometric distribution of point-like deuteron beam on the target. The 'tagged' beam is 10×10 cm at 2 m distance from the target of the neutron generator.

2.1.3. Gamma-Detectors

The gamma-detectors are based on BGO 76 mm in diameter and 65 mm thick. Hamamatsu R6233 is used as photomultiplier.

Every inspection module detects gamma-photons by means of 24 scintillation detectors located in three vertical lines 8 detectors in each (Fig. 2). Three lines of gamma-detectors are separated from each other by metal and lead collimators 30 mm thick in total. The gamma-detectors have the following properties:

a) an energy resolution (8-2.5%) is within 1-12 MeV; (It should be stressed that the energy resolution of gamma-detector is $\Gamma = (4.4\pm0.1)$ % in average for the gamma-line of carbon ($E_\gamma = 4.43$ MeV)).

b) a high effective detection of gamma-photons for the indicated energy range;

c) a low sensitivity to the neutron background detected.

A time resolution of alpha-gamma coincidences is averaged for all gamma-detectors and is equal to 3.5 ns.

A characteristic of gamma-detector operation at ambient temperature varied within a broad range should be focused on. A relation of BGO light output to its temperature is known to be about 1.6% per 1°C. This relation leads to considerable change of gravity centers for peaks of characteristic nuclear radiation of ^{12}C, ^{16}O, ^{14}N, therefore most detections of masked explosives are false.

As the inspection systems operate at temperature from -20 °C to +50 °C, the shifts of peaks with BGO temperature changed should be eliminated.

There are two possible solutions: to make the BGO temperature stable and to correct an amplitude response of gamma-detector using the BGO light output to temperature relation.

Fig.6 shows the amplitude distributions obtained when the BGO-detector is irradiated with gamma-photons from ^{137}Cs и ^{60}Co for the temperature of BGO equal to 20, 30 and 54° C. As seen, when the BGO temperature rises, its light output as compared with that at room temperature, falls and the gravity centers of full absorption peaks matching gamma-lines of ^{137}Cs (0.662 MeV) and ^{60}Co (1.17 and 1.33 MeV) are shifted left where the amplitude responses of gamma-detectors are insignificant.

We applied an amplitude correction of the signal from gamma-detector using a measured ratio of its response to the temperature ranged as 20°C < T < +55°C. This ratio was measured with a temperature sensor installed in the thermal contact with BGO. At the same time the gamma-detector was put in the environment chamber to change the crystal temperature within the range indicated.
Fig.6b shows an amplitude spectrum of gamma-detector signals after thermal correction.

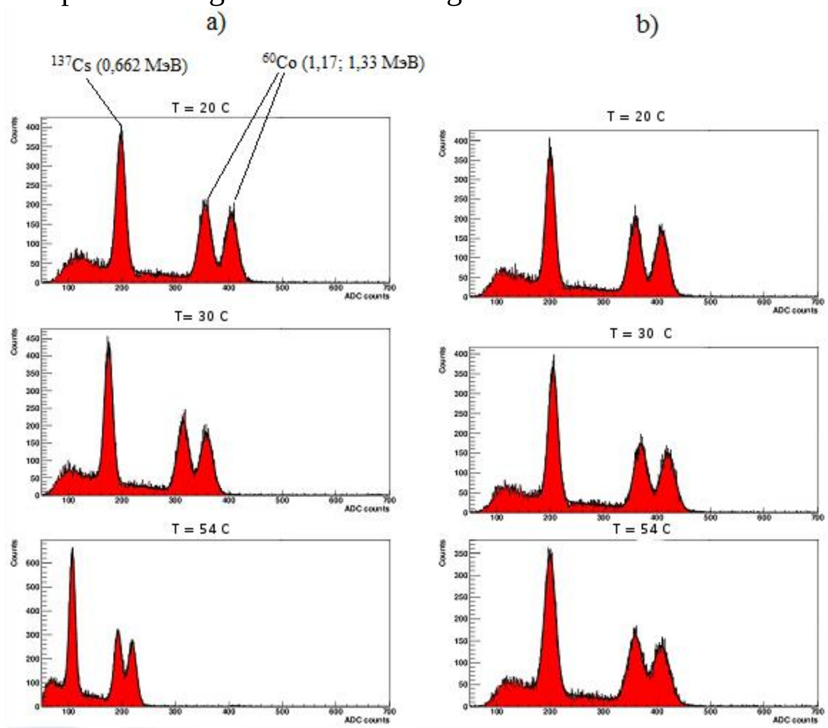

Fig. 6. Amplitude distributions of gamma-detector signals as a result of its irradiation with gamma-photons from ^{137}Cs and ^{60}Co at 20, 30,7 and 54°C: a) before thermal correction; b) after thermal correction.

As seen from Fig. 6b, a maximum peak shift in corrected amplitude spectra with a total range of temperature (20 – 54 °C) does not exceed 2%. The indicated accuracy to restore the initial amplitude distributions is sufficient for making an adequate processing of experimental data in order to identify explosives.

2.1.4. Data Acquisition System for Alpha-and Gamma-Detectors

The detection electronics is made as a board sized as a typical PCI-card that can be put in PCI-E slot. The data exchange is carried out via PCI-E bus. The detection system for alpha-and gamma-detector signals relies on the signal digitalization with further regeneration of time and amplitude characteristics of alpha-and gamma-detector pulses. To gain a required data transfer rate via PCI-E bus an interface has a direct access to the PC memory. Linux is an operating system used for software.

Fig.7 shows an operator interface that outlines the 64 ‘tagged’ neutron beams projected onto a surface of the irradiated object at right angle to its direction.

Each of 64 beams is relevant to a pixel of alpha-detector. As seen at Fig.7, an irradiation area of the investigated object along the direction of the ‘tagged’ beam is deeply divided into layers 10 cm thick each. Each layer is imaged as a box in left vertical raw at Fig.7. A volume element irradiated by one ‘tagged’ neutron beam is hereafter called as a voxel. Thus a total volume of the irradiated object is divided into 448 voxels in this example. An elemental composition is specified in each voxel. The hidden substances if identified are shown in the right bar. Information on a type of the hidden substance and its 3-d location is displayed. This figure presents the results of experiment with TNT sample irradiated.

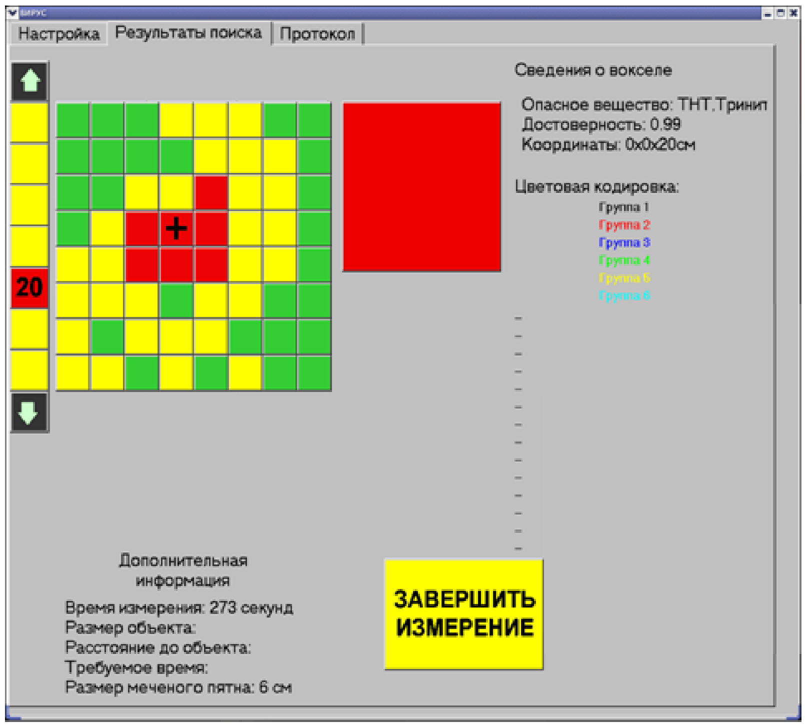

Fig. 7. User interface when irradiating TNT sample

3. Measurement Results

A truck was inspected (Fig.1) with melamine as an explosive simulator used. It was put at different distances from the neutron generator. Melamine was shielded with wood and tissue 25 cm thick in total.

Fig. 8 presents a detection time for melamine with weight varied as a function of distance between the neutron source and the object.

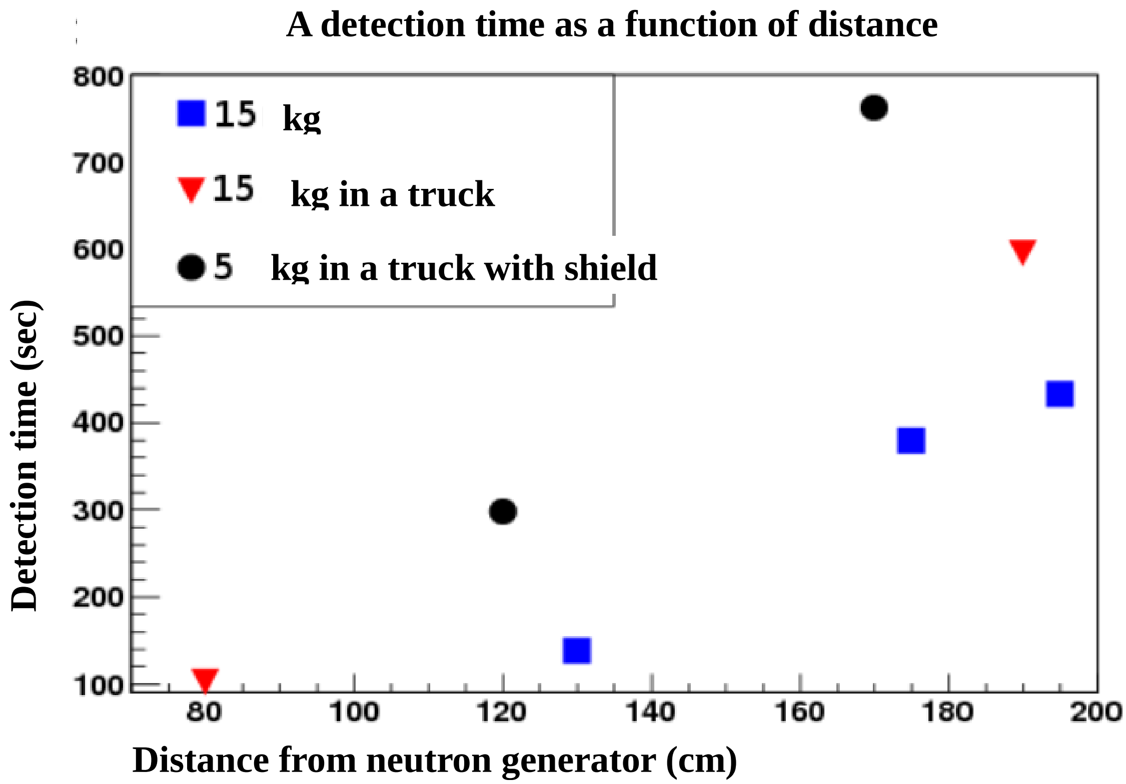

Fig. 8. Detection time for melamine of different mass as a function of distance between the neutron generator and the object irradiated

As seen at Fig. 8, a smallest mass of melamine detected is 5 kg at 170 cm distance from the neutron generator. The detection time for 5 kg melamine is 13 min. When melamine of above mass is 120 cm distant from the neutron source, detection time is 5 min.

Table 1 compares the parameters of the detection system with the main characteristics of the EURITRACK equipment [1, 2].

Table 1

Parameters of the developed system and EURITRACK equipment compared

	EURITRACK	Developed System
Neutron yield	I= 1×10^{7} s^{-1}	I= 2×10^{8} s^{-1}
Quantity of gamma-detectors	22(NaI(Tl))	48(BGO)
Quantity of ‘tagged’ beams	64	64
Dimensions of a ‘tagged’ beam at 2m distance form the source, cm	15×15	10×10
Volume of a voxel in the inspected object at 2 m distance from the source, 10^3 cm^3	3.9	1.7
Minimum mass of explosives detected at 2 m distance from the source, kg	70	5

The data shown in the Table 1 prove that the developed system has better light-grasp transmission and sensitivity to detection of explosives than EURITRACK.

4. Conclusion

The inspection API-system for explosives in trucks was developed and tested. It was designed for automatic detection and localization of the matters masked in the inspected objects with dimensions [L×W×H] 22×3×4 m. A run of trial tests was performed and the main characteristics that are better than that of the existing equipment were specified.

Special courtesy to E.I. Andreev and O.G.Tarasov for assistance in assembly and tests for the system.

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