ASSOCIATED PARTICLE IMAGING (API) DETECTORS

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Abstract
Associated Particle Imaging (API) detectors are known as a detection tool for hazardous substances (explosives, highly toxic, radioactive substances and drugs) hidden in various inspected objects. Different API detectors are reviewed. Their use in the portable, stationary, mobile and portal systems is discussed. Prospective application of the API to other purposes of a remote non-destructive monitoring of the elemental composition is regarded.

1. Introduction

An Associated Particle Imaging had been offered quite long ago [1-3], but a lack of robust and portable neutron generators prevented its proliferation.

The API neutron source is a portable accelerator that accelerates the deuterons to 100 keV (Fig.1). The deuterons bombard a tritium target and generate the 14 MeV neutrons in cause of $d+t \rightarrow \alpha+n$ reaction. This reaction is unique because α-particle and a neutron fly apart a half way. Therefore with the known direction of α-particle one can define a flight path of a neutron. The API is so distinguished because it enables to get data on the third spatial value directed along the neutron flight path. For it a flight time between the moments when α-particle goes through alpha-detector and gamma-photon comes from the inspected object to a respective gamma-detector should be measured. The flight time known helps to calculate a span to an origin of gamma-photon, as a neutron velocity is constant and equal to $v=5$ cm/ns.

The standard sources of fast neutrons emit the neutrons around and above alike the usual bulb ejects the photons. The API allows irradiating the inspected object by a train of narrow neutron beams as if laser pointers (Fig. 1).

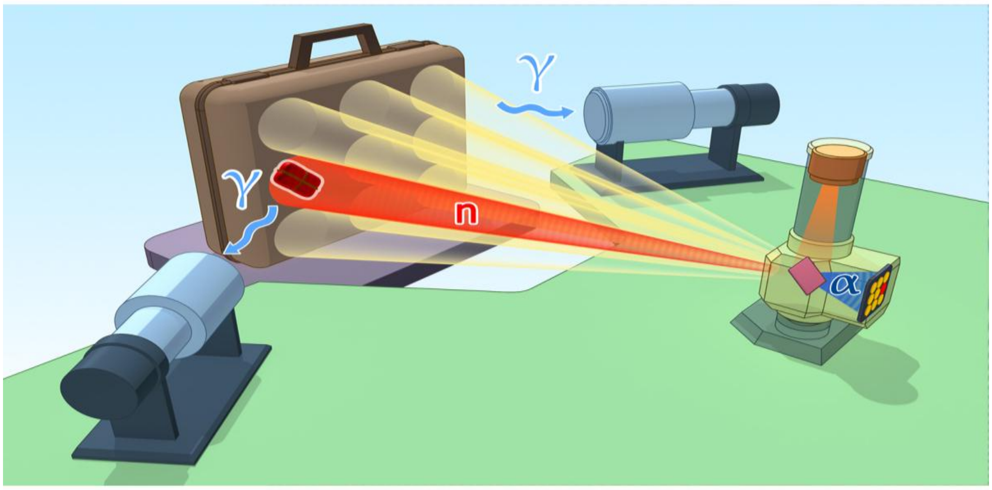

Fig. 1. The API: a source of neutrons generated from a reaction of deuterons (d) and tritium target (t) – right; an alpha-detector is shown as 3×3 array. Two gamma-detectors detect a characteristic emission from the inspected object.

The API is specific because a matter is identified by its elemental composition instead of the density contrast relied on in X-ray Imaging. Fast neutrons excite the matter nuclei in inelastic scattering reaction A(n, n'γ) A*. The excitement dies out when the gamma-photons with energy spectra respective to different elements are emitted.

An example of gamma-photons for TNT and RDX is shown at Fig. 2.

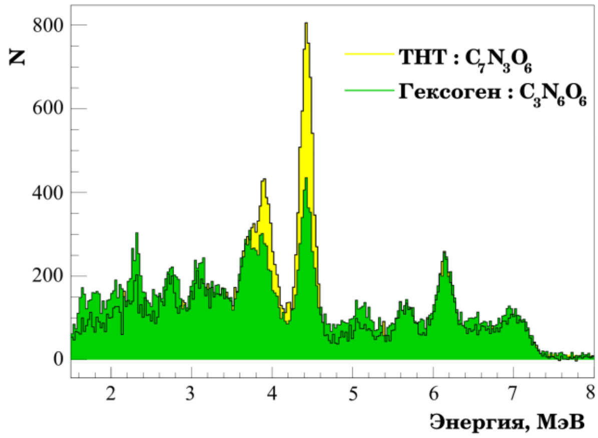

Fig. 2. Energy spectra of gamma-photons for TNT (yellow) and RDX (green)

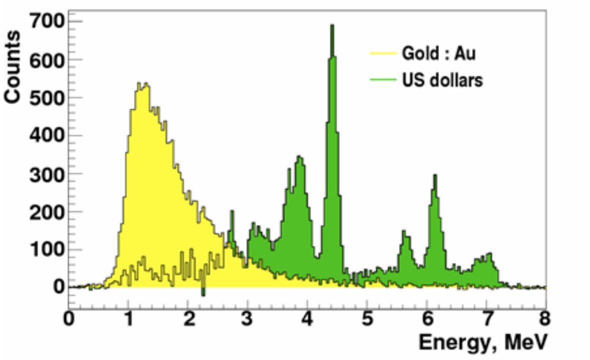

Fig. 3. Energy spectra of gamma-photons for the gold (yellow) and USA dollars (green)

The energy spectrum consists of distinct lines as seen. A large peak at 4.43 MeV is related to carbon. TNT ($C_7N_3O_6H_5$) comprises of more C than that of RDX ($C_3N_6O_6H_6$), therefore the carbon peak in TNT (yellow) is larger than that of RDX (green).

The explosives, drugs and other hazardous matters are identified through their elemental composition different from that of other substances.

It is necessary to emphasize, that the API is not intended for identification of one substance, for instance, N. On the contrary the lines of C, O, N, S, Cl, Si and others are used to identify the matter. Fig. 3 presents the spectra drawn with fast neutron irradiation of gold and USA dollars.

As the API makes it possible to detect the different elements, it can be used for identification of explosives and drugs as well as for a quality control of coal, cement, an oil search (neutron logging). One of the most extraordinary API applications is for identification of fat content in lambs in vivo made by scientists from New Zealand [4]. They proved that a radiation dose absorbed in the lamb irradiated by the associated particles was much less than that by standard radioactive sources. It is another distinguishing property of the API – there is almost no induced activity in the inspected object.

The 14 MeV fast neutrons unlike thermal or slow neutrons weakly interact with a matter. When Rospotrebnadzor certificated the API detector ДВиН-1, they made the measurements to prove that a standard 10 minute inspection lacked the induced activity in the inspected object and in environment.

2. API Detectors for Explosives

Nowadays there are a number of API detection systems for inspection of different objects starting from the lost luggage to sea vessels and long vehicles. A portable detector for explosives ДВиН-1 (Fig. 4) by Neutron Technologies (Dubna) is a best seller.

Fig. 4. Portable Detector ДВиН-1 for Explosives

ДВиН-1 was developed for Comprehensible Traffic Safety Program approved by RF Government in 30.06.2010. According to it all checkpoints at underground entrances should be equipped with the portable API detection systems for explosives.

Currently 76 detectors ДВиН-1 are supplied to railway stations of Severo-Kavkazskaya, Oktyabrskaya Railway, Kazan and Vladivostok as well as to underground stations of Moscow, St-Petersburg, Kazan and Novosibirsk.

ДВиН-1 is based on ING-27 neutron generator with 9-pixel alpha-detector made by VNIIA. The generator intensity is $I=5\times10^7$ s^{-1}. BGO detector 76 mm in diameter is used.

The Federal Security Service of Russia (FSB) ordered a stationary detector for explosives with ING-27 of high intensity $I=1\times10^8$ s^{-1} with embedded 64-pixel alpha-detector made by JINR. Two BGO gamma-detectors 100 mm in diameter are in charge of detection (Fig. 5).

Fig. 5. General view of stationary identification system for explosives

The stationary system operates in FSB International Center for Identification and Deactivation of Explosive Devices.

An advanced detector was developed for FSB to inspect the mined vehicles. It consists of ING-27 with intensity $I=1\times10^{8}\ s^{-1}$, 64-pixel alpha-detector by JINR and 6 gamma-detectors (Fig. 6).

Fig. 6. Detector for mined vehicles

High penetration of the 14 MeV fast neutrons allows using the API for inspection of long vehicles. On request of FSB a neutron portal for sea vessels 260 cm thick and trucks up to 4 m high was developed. Two inspection units are deployed at each side of the portal. Each of them has a modified ING-27 of high intensity $I=2\times10^{8}\ s^{-1}$, 64-pixel alpha-detector by JINR and 24 gamma-detectors (Fig. 7).

Fig. 7. Neutron portal for large-sized vehicles

3. API detectors for Underwater Search of Hazardous Objects

Owing to high penetration of fast neutrons they can be used for underwater search of hazardous objects. UnCoSS revealed the obvious API pluses [5]. To study the specific underwater use of the API detectors we made an experimental system (Fig. 8).

Fig. 8. Underwater neutron unit

It was based on the portable detector ДВиН-1. The inspection module was placed in the sealed shockproof box. It was coupled with the operation system through flexible concertina hose and put on a platform with rails for the inspected objects. Since the unit was characterized by extreme buoyancy, the platform bottom was ballasted. The hoist was used to submerge the unit in the water pool.

As experiments proved that the full load of gamma-detectors and change of time spectrum of gamma-photons primarily handicapped the underwater operation. Nevertheless all main spectrum lines were managed to visualize.

4. API Detectors for Diamond Search

ALROSA made us an interesting offer to try the API for the diamond search in blue earth. Today the raw material in the diamond industry is grinded to the middle size about 50 mm, milled nearly to the sand and then exposed to X-rays to find the diamonds by their luminescence. This process is profitless because the grinding and milling destroy the most valuable big diamonds of 5 ct and more.

It would be reasonable to extract the big diamonds before to start grinding. The AIP is ideal for it since it allows detecting a diamond by its elemental composition – C. The spectrum of carbon is very simple with one dominating 4.43 MeV line (Fig. 2). It is enough to detect C surplus in the solid piece. Moreover the API enables to make the accurate measurements of the diamond locations.

A small mass of the hidden matter about 1 g and a small space just a few mm it occupies cause a problem. It requires the narrow neutron beams. JINR alpha-detector [6] with extremely small pixels about 4×4 mm meets these requirements. Fig. 9 demonstrates a spectrum of blue earth with a dummy diamond 1.78 g inside. For comparison a thin line is a blue earth spectrum without diamond.

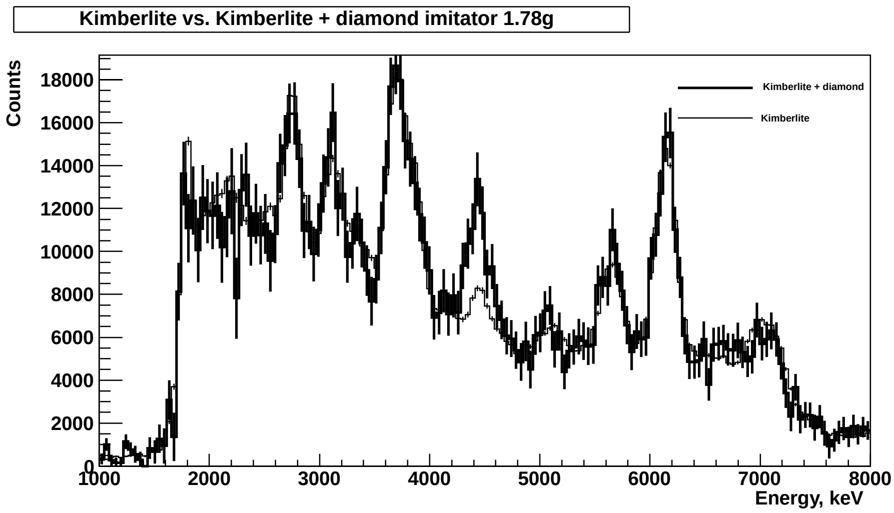

Fig. 9. Energy spectrum of gamma-photons for irradiated blue earth with a dummy diamond 1.78 (thick line). For comparison a thin line is a blue earth spectrum without diamond

These lines are visible to be matched in all energies except the 4.43 MeV carbon line. Upon this effect it is possible to develop a detection algorithm for areas with high C content in order to identify 1g diamonds in the blue earth.

5. Neutron Checkpoint

The API detectors can be used in stationary inspection systems for light vehicles. We have calculated a radiation environment for the stationary systems shown at Fig. 10.

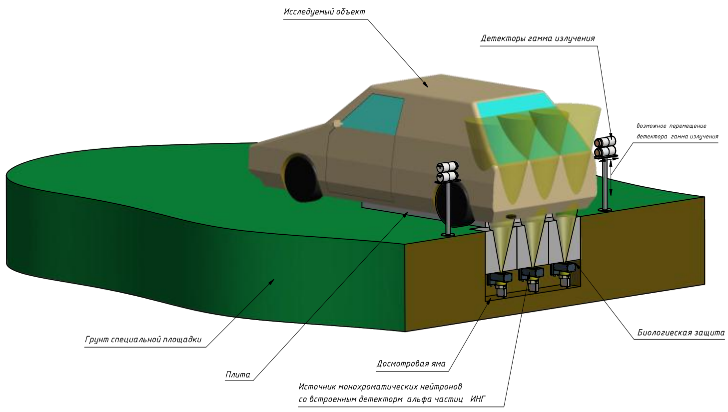

Fig. 10. Stationary Car Inspection System

Several generators deployed underground in the special cavity generate the "tagged" neutron beams. Gamma-detectors are placed at each side of the inspected car. To enhance the biological protection a concrete plate is used. As the calculation shown, the system like that allows inspecting the car trunk for a few minutes and identifying the explosives or drugs inside if any. At the same time a radiation background during inspection is so insignificant, that a driver can stay in the car. The neutron checkpoint can be mounted at the police checkpoints on the main traffic arteries.

6. Upgrade of Neutron Generators

The evolution of API detectors is impossible without robust and qualitative neutron generators. The Russian companies that manufacture the API detectors are fortunate to have a best designer of neutron generators – All-Russian Research Institute of Automatics. There is no company in the world that could deliver a large batch of portable neutron generators with embedded alpha-detectors like ING-27 for the short period as VNIIA did in 2011 when over 70 items of ING-27 were produced. Besides we witnessed only two cases of ING-27 faults when detector was assembled. Routine maintenance we do in different cities proves that all 76 ING-27 function properly.

The advances in the API technique impose requirements to improvement of different properties of neutron generators with embedded alpha-detectors. First of all the API systems can not be operated day-and-night without extension of the neutron generator life. The life time of ING-27 should be increased to several thousands hours.

Other important property to be improved is an inspection area. In the existing ING-27 it is 30×30 cm at distance 60 cm. For most applications it is insufficient. For instance this area makes it possible to inspect the passenger luggage only by stages.

Finally the obtained experience shows that a granularity of alpha-detector should be increased and a time resolution of α-γ coincidence system should be reduced. Both requirements are necessary to enhance a reliable detection of hidden matter. Alpha-detector should guarantee 256 tagged beams and the time resolution of α-γ coincidence system should be about 1ns.

A high cost of neutron generators slows down the API progress. Hence the API detectors cost twice as much as other equipment for transport safety.

7. Conclusion

The API technique has recently become advanced. Different types of API detectors are developed: portable, stationary, for inspection of mined cars, of long vehicles. Railway and underground stations are equipped with 76 portable detectors ДВиН-1. Various versions of detector for instance for diamond search and underwater operation are under development. The progress of the API technique would be impossible without robust portable neutron generators made by VNIIA.

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