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HEAVY ION PHYSICS

The use of neutrons for the detection of explosives in Civil Security Applications

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Abstract. The search for hidden explosives has been simulated in laboratory conditions by using our Tagged Neutron Inspection System (TNIS. Applications of the TNIS concept to Civil Security problems are discussed in the light of our projects for cargo container inspections. Moreover, neutron attenuation and scattering can be used to search in real time for large quantity of explosive hidden in vehicles

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1. Introduction

The threat of terrorist actions against civil populations was indicated as one of the most important issues on the political agenda of European Union already before the recent London bombing [1]. After that event, the detection of materials and/or devices that can be used in terrorist actions becomes a primary need of the society.

A first important task in Civil Security is the contrast of illicit trafficking of explosive materials or, more generally, the search for contraband. In this respect, currently used X-ray or γ-ray based systems provide precision density measurements with high-resolution three-dimensional images, but only limited information on the elemental content of the inspected item. Fast neutron interrogation, on the contrary, offers the possibility of measuring the elemental density of the elements contained in explosive materials or narcotics by using the well known technique of recording the induced γ-rays [2,3,4]. Furthermore, with the use of 14 MeV neutrons tagged by using the well known associated particle technique, it is possible to determine the local elemental distribution inside large volumes or to inspect a precise portion

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of the volume (voxel) that has been identified as suspect by an X-ray scan. In this case it is possible to implement the already existing X-ray systems in operation at the ports of entry with an additional neutron device used mainly as verification tool.

A second aspect of the problem is the detection of hidden explosive in vehicles that are used in suicide bomber attacks worldwide. A specific requirement in this case is the fast scan of vehicles operated at sufficiently large distance from the target itself, to avoid damage in case of explosion. Neutrons are also in this case an interesting probing radiation, thanks to their penetration capabilities. On the other hand, the technique of looking to the gamma rays to perform elemental analysis is to slow to be applied in such context. Less specific but rapid signature of the presence of large quantity of hydrogenated materials can be obtained by looking to the transmission and scattering of fast neutrons [5].

During the last years, we have developed a prototype of Tagged Neutron Inspection System (TNIS) using fan beams of 14 MeV neutrons, produced by the D+T reaction [6-8]. Tests on the detection of hidden explosives with TNIS have been published recently [8]. New developments are now underway within the NATO Science for Peace program and EURITRACK (EURopean Illicit Trafficking Countermeasures Kit), a project approved in the 6th Framework Program of the European Union. Such developments are presented in this work. Moreover, the possibility of using fast neutron transmission to detect bomb cars is also discussed.

2. General capability of the TNIS

The TNIS system, as operated at the Neutron Generator Laboratory of the Ruder Boskovic Institute (IRB) in Zagreb, is presented in ref. 8. Generally, the TNIS improves the signal to noise ratio with respect to untagged neutron systems by electronically selecting the γ-rays from the voxel defined by the geometry of the tagging detector and by the neutron time of flight. Consequently, the minimum volume to be interrogated depends on the segmentation of the tagging detector and on the overall time resolution of the alpha-γ coincidences.

The YAP:Ce scintillators has been selected for the detection of the alpha particles. YAP:Ce exhibits several characteristics well suited for this task: excellent mechanical and chemical properties, radiation hardness, fast response and high light output [9]. The first prototype of a portable neutron generator with integrated alpha particle detector for production of tagged neutron beams has been recently tested [10]. It is also important to mention that a study of the position sensitivity of the γ-particle detector has been successfully performed [11]. Moreover, the use of fan beams allows the simultaneous measurement of gamma-rays emitted also in neighbouring voxels thus allowing the online subtraction of the background in the spectrum from the suspect item.

As γ-ray detector, an array of BaF_2 detectors has been used in our past work. In this case the measured overall time resolution between the alpha particle and the gamma ray emitted by a graphite sample was measured to be δt=1.6 ns [FWHM] [8]. By subtracting the time uncertainty due to the size of the sample, the intrinsic time resolution of the system was evaluated to be δt=0.9 ns [FWHM], which corresponds to a position resolution of about 5 cm along the neutron flight path. The results in ref. 8 have been obtained by using a neutron flux of about 5×10^6 neutron/s. In such condition, the counting rate of the YAP:Ce and of each BaF2 detectors were about 10^4 c/s. It is clear that practical applications of TNIS require a substantial improvement of the neutron flux. To this end, a specific test has been successfully performed, exploring the system performance at higher rates, by varying the neutron flux in the range 2×10^7 - 2×10^8 neutron/s [12].

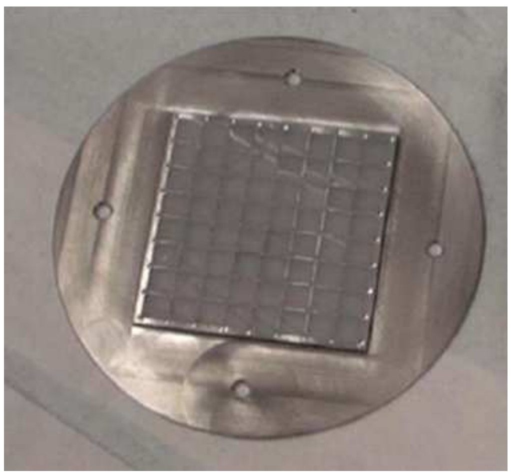

Fig. 1. The matrix of 64 small (6 mm × 6mm) YAP:Ce crystals that will be used to produce tagged neutron beams for the inspection of cargo containers.

3. Open problems in the inspection of cargo containers

The inspection of cargo container is one of the applications where neutrons have been already successful applied. It is worth noting, indeed, that a large commercial plant for custom inspection has been realized by the ANCORE Corporation and is in operation at the US-Mexican border near El Paso [3]. The current European projects in this fields foreseen the use of a neutron inspecting system that is much smaller respect to the ANCORE design, using sealed tube neutron generators to reduce cost and complexity of the systems.

In exploring practical application of the TNIS concept, it is worth considering the constraints that would arise in inspecting a suspect voxel inside a massive payload as the cargo container. It has to be noted, indeed, that the background produced by the part of the neutron field that is not tagged and hit the container is expected to contribute significantly to the count rate of any γ-ray detector placed around the cargo. Such background would depend not only on the inspection geometry, but also on the goods inside the container. The count rate of the gamma ray detectors will certainly determine one important limit in the system performance.

On the other hand, the design for a second generation system is based on an array of 64 YAP:Ce scintillators to produce fan beams each having a small size (see Fig.1). The read out of such scintillation array is simplified by the use of the newly developed multi-anode photomultipliers. By selecting a suitable distance between the tritium target and the YAP:Ce array, this system should be able to deliver neutron fan beams with dimensions that will allow the inspection of objects placed inside a cargo container, i.e. having a distance from the neutron source ranging between 0.5 and 3 m. Assuming that the size and the position of the suspect item is defined by a preliminary X-ray scan, a suitable software might determine the optimal selection of the neutron beams to inspect both the object and the surrounding materials. Monte Carlo simulations of such source of tagged neutrons have been recently completed [13]. Results indicate that it is possible to maintain the dimension of the single neutron beam within values compatible with the search for hidden explosive material for parameters of the neutron source that are compatible both with standard electrostatic neutron generators and with sealed tube portable generators.

4. The neutronic check point

The detection of Improvised Explosive Devices is one of mayor tasks in the contrast of terrorist actions. In this respect, a specific case is the inspection of vehicles at check points to prevent attacks with explosive cars against sensitive targets. The quantity of explosive material used in such attacks ranges from 200 kg to several tons. Such large quantity of hydrogen rich material hidden in vehicles can be detected in very short time by looking to the transmitted and scattered neutrons.

Detailed GEANT Monte Carlo simulations have been recently performed in the case of a car having explosive hidden in the trunk. A source of tagged neutrons using both the D+T and the D+D source reactions have been considered, assuming the maximum production of 10^8 neutron/s on 4π. Tagged neutrons transmitted trough the vehicle are detected in coincidence with the associated particles by using position sensitive neutron detectors covering an area of 110 x 110 cm^2. Four large pad detectors, each having an area of 120 x 50 cm^2, are used to detect scattered neutrons at the road level below the car.

In the simulation, we scanned the car with irradiations each 40 cm for a number of neutrons that corresponds to few seconds, recording the transmission of the neutrons and the distribution of the scattered neutrons in the pad detectors. Both observables are used to discriminate the presence of light Z material (as the explosive) from other thick absorbers as the vehicle engine. Sample of numerical results are presented in Fig.2 in term of attenuation of the neutron beam (upper panel) and of asymmetry of scattered neutrons in the pad detectors calculated as sum of counts in the first two detectors (A1+A2), that are closer to the neutron sources, divided by the sum of counts in the other two detectors (A3+A4). Both observables are reported as a function of the position along the car, with x=0 corresponding to the trunk and x=380 to the car engine, respectively. As a result, a very large attenuation of the neutron beam appears in scanning the trunk and the engine. However, the asymmetry of the scattered neutrons is completely different, allowing the discrimination between engine and the transported explosive. Simulation suggest that such system is able to scan a car in 10 s, easily identifying a quantity of explosive as low as 100 kg.

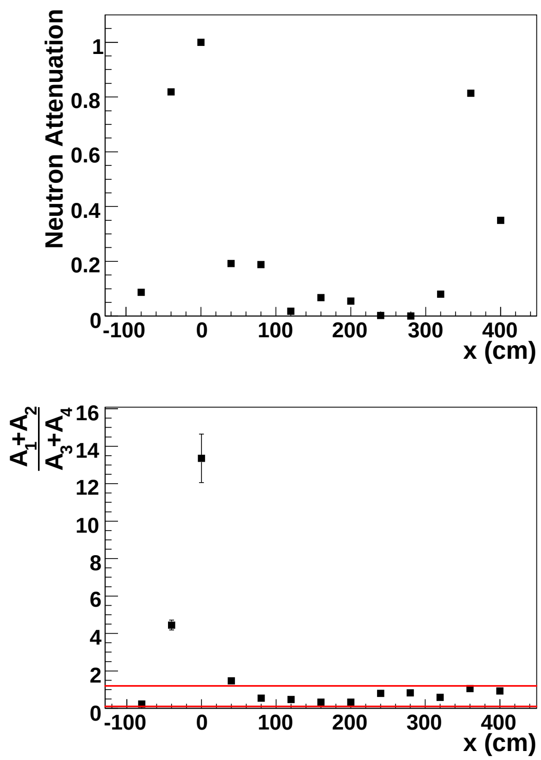

Fig. 2. Monte Carlo simulation results of the neutronic check point. For details see the text.

5. Conclusions

The use of tagged neutron beams to search for hidden explosives is one of the available technology that might in future be used to implement the existing tools (as the X-ray scanners). The derived information is highly specific in the case of the gamma ray spectra induced by fast neutrons and allows the elemental analysis of the inspected voxels. Alternatively, fast neutron transmission and scattering measurements can be used to perform fast scan of suspect vehicles.

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Notes

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