Detection of explosives and other illicit materials by a single nanosecond neutron pulses – Monte Carlo simulations of the detection process

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Abstract

Recent progress in the development of a single-pulse Nanosecond Impulse Neutron Investigation System (NINIS) intended for interrogation of hidden objects (explosives and other illicit materials) by means of measuring elastically scattered neutrons is presented in this paper. The method uses very bright neutron pulses having duration of the order of few nanoseconds, generated by a dense plasma focus (DPF) devices filled with a pure deuterium or deuterium-tritium mixture as a working gas. Very short duration of the neutron pulse, its high brightness and mono-chromaticity allow to use time-of-flight method with bases of about few meters to distinguish signals from neutrons scattered by different elements.

Results of the Monte Carlo simulations of the scattered neutron field from several compounds (explosives and everyday use materials) are presented in the paper. The MCNP5 code has been used to get info on the angular and energy distributions of neutrons scattered by the above mentioned compounds assuming the initial neutron energy equal to 2.45 MeV (D-D). A new input has been elaborated that allows modelling not only a spectrum of the neutrons scattered at different angles but also their time history from the moment of generation up to detection. Such an approach allows getting approximate signals as registered by hypothetic scintillator+photomultipler probes placed at various distances from the scattering object, demonstrating a principal capability of the method to identify an elemental content of the inspected objects. Preliminary results of the MCNP modelling of the interrogation process of the airport luggage containing several illicit objects are presented as well.

Introduction

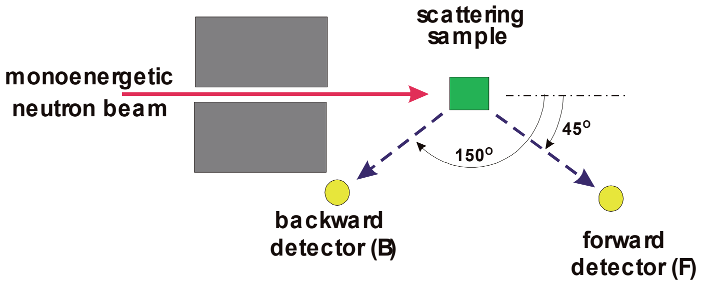
Fight against terrorism is a complicated, multidisciplinary task involving political, economical, psychological, organizational, scientific, technical, etc., issues. An efficient method of detection of explosives and other illicit materials is of principal importance. Despite of long lasting efforts of scientists and engineers such a method still does not exist. Existing prototypes are far from maturity, different methods used in such devices have they advantages and disadvantages, so still there is a space for new ideas, new inventions [1-5].

A new approach to explosives and other illicit materials detection was proposed in [6]. Taking advantage of capabilities of modern neutron generators (based on the Plasma-Focus principle) that are capable to produce flashes of very intense and very short neutron pulses (<10ns) it is possible to determine elemental content of unknown bulk samples from information existing in a field of scattered neutrons. The flush intensity reaches up to 10^9 of 2.45 MeV neutrons per shot from the D-D reaction and up to 10^{11} of 14 MeV neutrons from the D-T reaction. The time-of-flight method can be involved in the identification procedure due to the short neutron pulse duration. It seems that a single shot inspection systems can be elaborated on the basis of the method proposed, limited in time only by computer data processing

Method

The method is based on the well know fact that nuclide-specific information is present in the scattered neutron field. By detecting neutrons elastically and in-elastically scattered at different laboratory angles for two different incident neutron energies (2.45 MeV and 14 MeV), the amounts and positions of the scattering nuclides may be determined.

Figure 1: Main idea of the neutron scattering detection

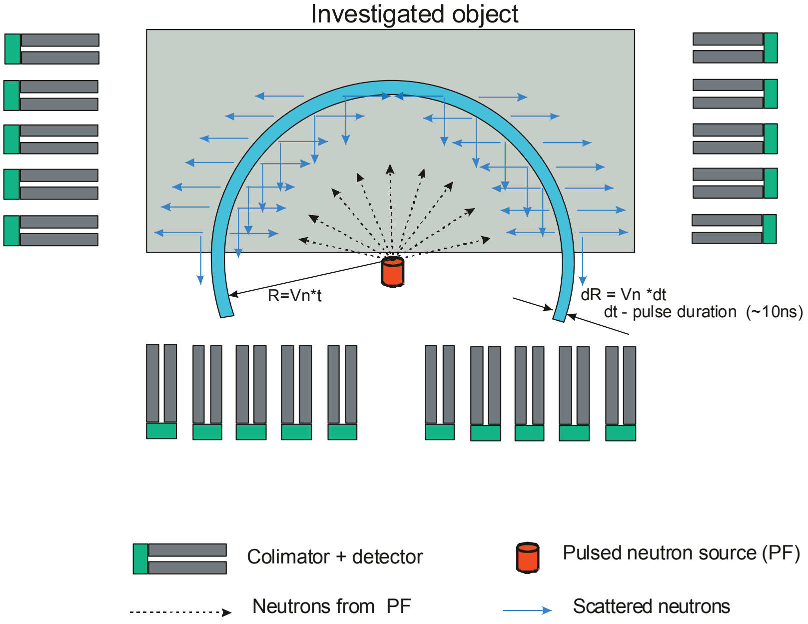


Scattering signatures of different elements (especially H, C, N and O) should be precisely determined and data basis of such signatures created. Then, using the data basis, scattering signatures measured for unknown samples are unfolded to determine their elemental composition.

The method proposed belongs to a wider group of approaches that make use of specific interaction of neutrons (fast or thermal) with different materials. As a result of such interaction the induced gamma radiation is emitted from an object irradiated as well as a field of scattered neutrons appears (due to elastic and inelastic scattering of primary neutrons). The information on elemental composition of the object can be drawn from both the gamma radiation and the scattered neutron field.

We propose to bring into play a neutron source based on a *plasma accelerator*, which generates very powerful pulses of neutrons in the nanosecond range duration. New generation of powerful neutron sources of the Plasma Focus type can generate neutron pulses not only short by its duration (in the *nanosecond range*), but provides *a very high neutron yield* in these pulses. For example our device PF-6, operating at the Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland, with 7.4 kJ of energy in its capacitor storage is capable to generate in one pulse of ~10 ns duration up to 10^9 D-D neutrons (2.5-MeV) or 10^{11} D-T neutrons14-MeV). This feature gives a principal possibility to create a **"single-shot detection system"**. It means that all necessary information will be received using a single (or maximum few) very bright pulses of neutrons having duration in a nanosecond range and registered by means of the time-of-flight technique. A proposal of the general scheme of such detection system is presented in Figure 2.

Figure 2: General scheme of the detecting system



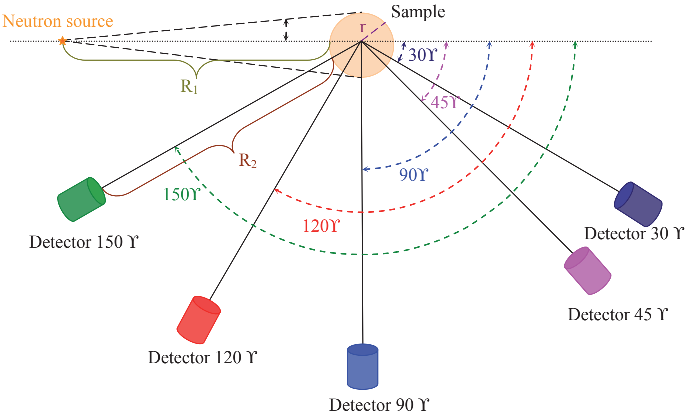
Monte Carlo modelling of the method

The MCNP (version5) standard code [7] has been used to investigate various features and properties of the method. Inputs to the MCNP code evolved in time from simple ones to more and more complicated together with increasing knowledge of the working team. The most important progress with the inputs development was an achievement of the capability of simulating scattered neutron signals as registered by factious scopes (time-amplitude signals).

Scattering from simple objects

For the start up the MCNP code was used to simulate scattering of neutrons from objects (cubes 3–5 cm) made of pure basic elements, like Oxygen, Nitrogen, Carbon, Sulphur, as well as of some compounds, *e.g.* explosives (RDX) and everyday use materials like melamine, glucose and acetamide. The aim of these investigations was to examine dependence of the registered neutron signals on angles and distances: neutron source – sample, sample – detector etc. The neutron pulse from the point D-D source ($E_n = 2.45$ MeV) was assumed to be Gaussian in time with the realistic full width at half maximum (FWHM) of 10 ns. The geometry of computation was as follows in Figure 3:

Figure 3: Geometry of the MCNP calculations



The first question was how a capability of the method to distinguish basic elements of explosives (C, N, O) depends on a scattering angle. From the results presented in Figure 4 it is evident that rather high scattering angles 150^0–170^0 should be used for the determination of the elemental content of unknown objects as for lower angles the signals originated from various elements merge gradually. In Figure 5 the time – amplitude signals from scattered neutrons for several compounds are presented showing the principal capability of the method to determine elemental content of irradiated objects. One can see from Figure 5 that for ideal conditions assumed in the computation the compounds filling the irradiated objects can be easily identified.

Figure 4: Time-of-flight signals from neutrons scattered by the sphere (r = 5cm) filed with the RDX explosive ($C_3H_6N_6O_6$)

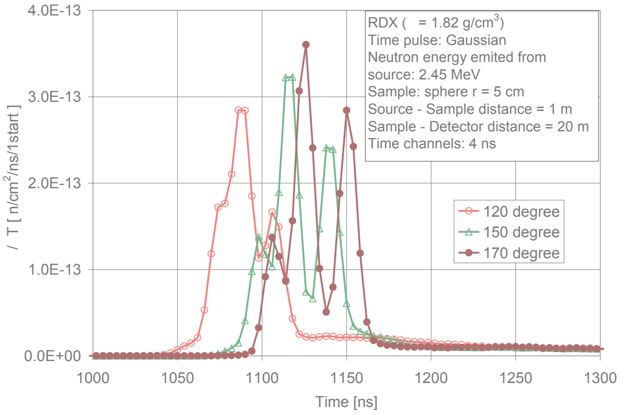


Figure 5: Comparison of the time-of-flight signals from neutrons scattered by spheres filled with various materials – a) RDX ($C_3H_6N_6O_6$), b) acetamide (C_2H_5NO), c) melamine ($C_3H_6N_6$), d) glucose ($C_3H_{12}O_6$)

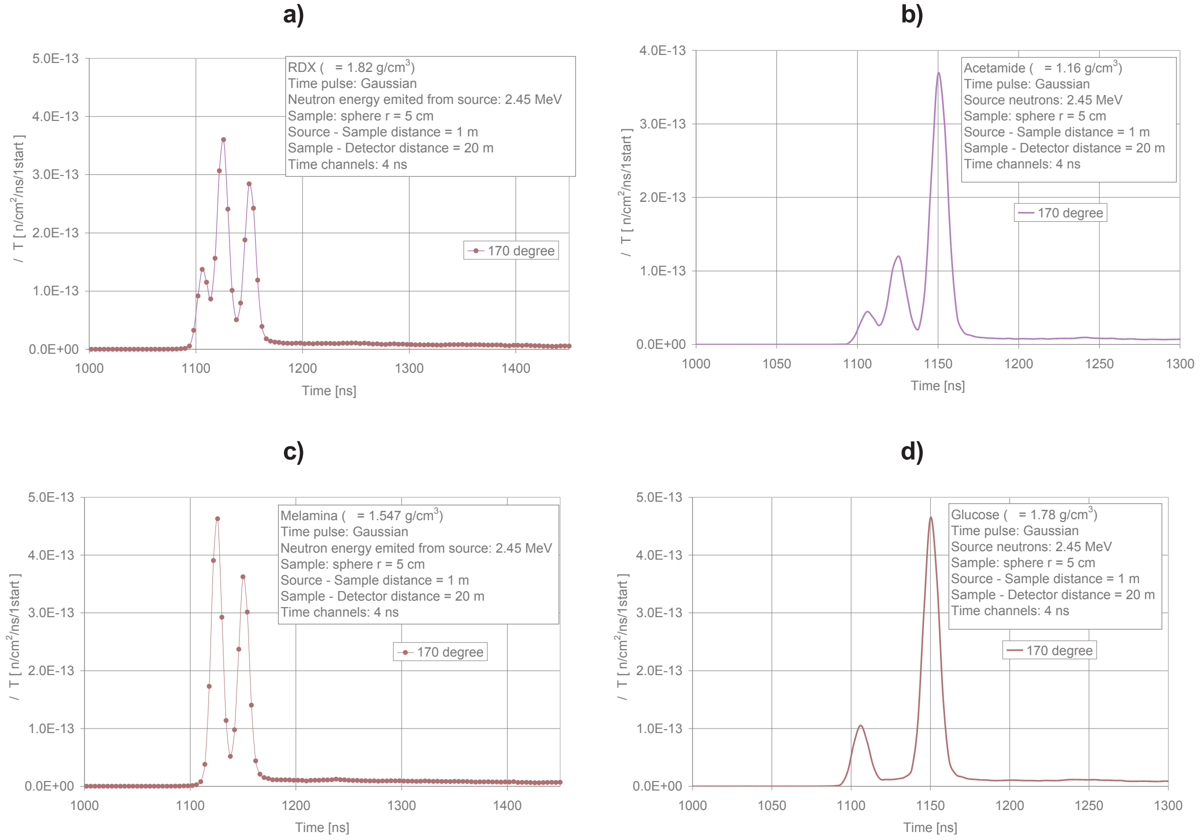

a) b) c) d)

Figure 6: Geometry of the suitcase containing four spheres filled with various materials (RDX, melamine, glucose and acetamide

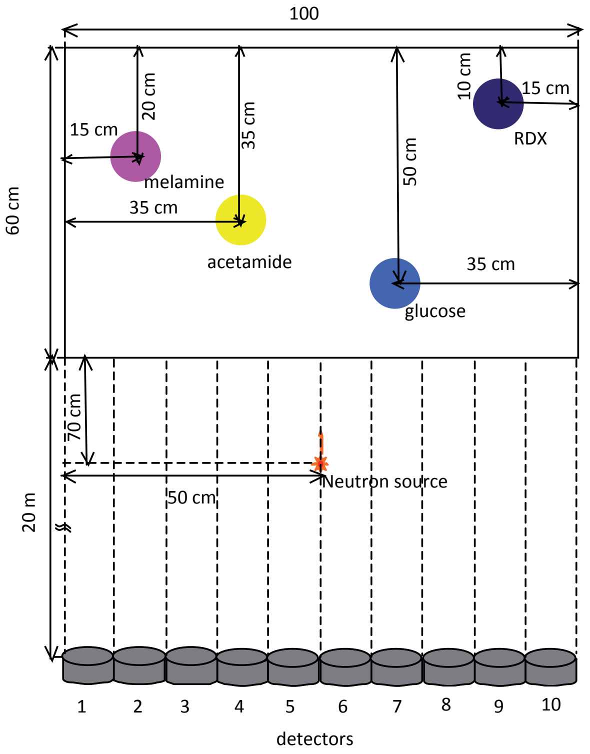
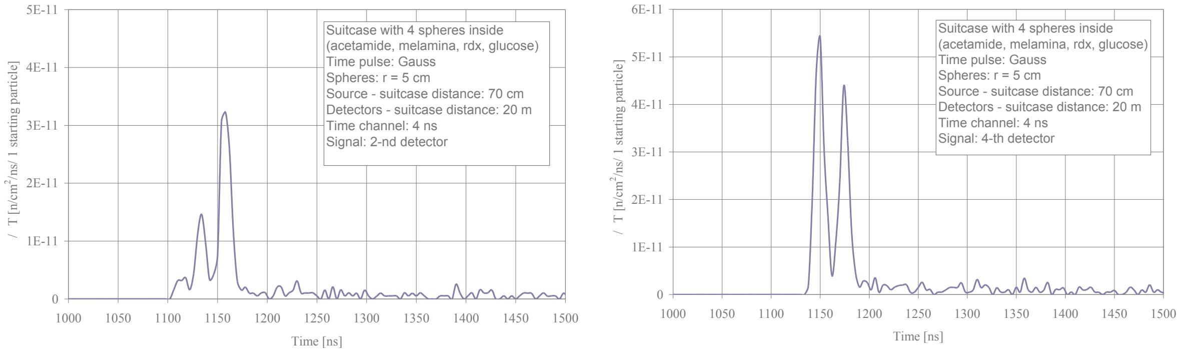
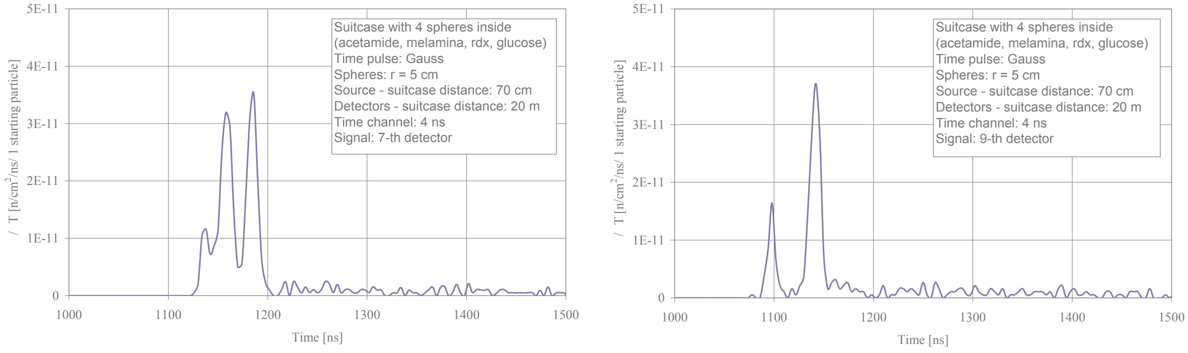


Figure 7: Signals registered by detectors (Nos. 2, 4, 7 and 9)

a) detector No. 2 **b) detector No. 4**



c) detector No. 7 **d) detector No. 9**



Modelling of a real luggage

The next step done in modelling of the various aspects of the method was a simulation of scattered signals from a suitcase containing objects (spheres) filled with different materials (explosive RDX and three types of everyday use materials –melamine, glucose and acetamide). Scheme of the modelling is presented in Figure 6. Collimators were modelled in front of the detectors to avoid registering neutrons from other directions. Signals registered by fictitious multichannel time analyser (detecting system) are presented in Figure 7.

From the signals presented in Figure 7 one can see that the system of detectors and collimators allows getting undisturbed signals that allow to identify the elemental content of spherical objects containing various materials. The system allows to determine position of hidden objects as well (thanks to collimators used) but several discharges associated with rotation of a luggage are necessary in order to get three dimensional positions.

Conclusions

A new method for detection and identification of hidden illicit materials was presented together with the MCNP modelling of some of its features. It seems that results of the MCNP modelling performed up to now justify a conclusion that the method passed the so called “proof of principle”. An extensive programme of further theoretical (MCNP modelling) and experimental investigations of the method is now in preparation.

Acknowledgements

The work was partly sponsored from the research grant of the Polish Ministry of Science and Higher Education (MNiSzW) No. O N202 049735.

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