Monte Carlo modelling of fast neutron scattering by various compounds in view of elaboration of a single shot inspection system

Urszula Wiącek[2], Krzysztof Drozdowicz[2], Barbara Gabańska[2], Vladimir Gribkov[3], Ryszard Miklaszewski[1]

[1] *Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland*
[2] *The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland*
[3] *Institute for Theoretical and Experimental Physics, Moscow, Russia*

E:mail contact of main author: rysiek@ifpilm.waw.pl

Abstract. Modern, portable or transportable neutron generators, based on the Plasma-Focus principle, are capable to produce a flash of the very intense (up to 10^9 of 2.45 MeV neutrons from D-D and up to 10^{11} of 14 MeV neutrons per shot from D-T reactions) and very short neutron pulses (~10 ns). Taking advantage of these capabilities it is possible to determine the elemental content of unknown samples from information existing in a field of scattered neutrons. It allows proposing an alternative approach to the detection of explosives and other illicit materials. The time-of-flight method can be involved in the identification procedure due to the short neutron pulse duration. It is expected that a single shot inspection system can be elaborated on the basis of the proposed method.
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 modeling 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.

1. Introduction.

The objective of the research is to elaborate a new method of explosives and other illicit materials detection called Nanosecond Impulse Neutron Inspection System (NINIS). The method proposed [1] belongs to the wider group of approaches that make use of specific interaction of neutrons (fast or thermal) with different materials. As a result of such interaction an 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 (ns) range duration. New generation of powerful neutron sources of the Plasma Focus type [2] can generate neutron pulses not only short by its duration (in the *nano-second 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 circa 10^9 D-D (2.5-MeV) neutrons or 10^{11} DT (14-MeV) neutrons. This feature gives a principal possibility to create a "single-shot detection system". It means that all necessary information will be received during a single very bright

pulse of neutrons having duration in a nanosecond range by means of the time-of-flight technique with a short flight base.

2. The method.

The method proposed is based on the well know fact that nuclide-specific information is present in the scattered neutron field. By detecting neutrons elastically and inelastically scattered at different laboratory angles for the amounts and positions of the scattering nuclides may be determined (*FIG.1.*).

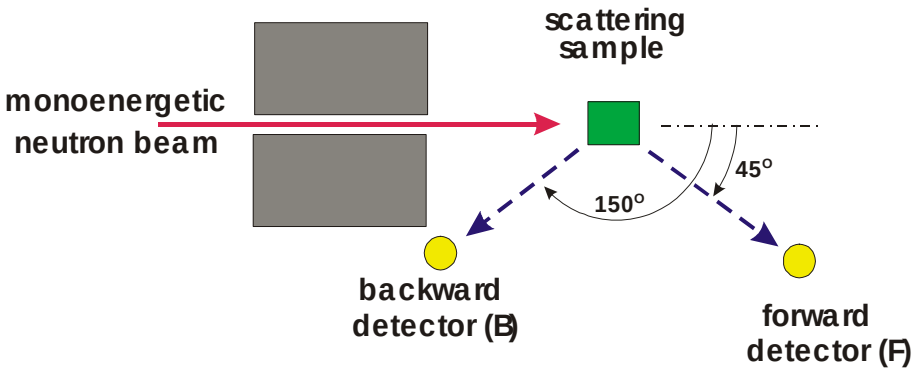


FIG. 1. The principle of the method.

Scattering signatures of different elements (especially H, C, N and O) should be precisely determined and data basis created. Then scattering signatures measured for unknown samples are unfolded to determine their elemental composition. As the neutron pulse to be used is very short (few up to 10ns), bright and quasi-mono-chromatic the advantage of the method proposed is that time-of-flight concept to separate scattered neutrons having different energies can be used. So, detectors B and F are fast scintillator + photomultiplier systems.
A signal registered by a fictitious oscilloscope placed 20m from the small (5cm radii) sphere containing RDX ($C_3H_6N_6O_6$) explosive is presented in *FIG. 2.* as an illustration of the above idea, Neutrons scattered by the sphere after travelling the scatterer-detector distance exhibits three separate picks that correspond to its elemental content (O, N, C). Knowledge of the appropriate cross sections allows recovering proportions between these three elements and identifying illicit materials.

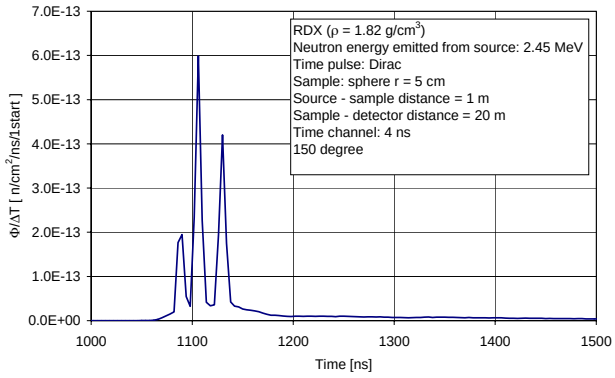


FIG. 2. Signal registered by a fictitious oscilloscope placed 20m from the small (5cm radii) sphere containing RDX ($C_3H_6N_6O_6$) explosive. Neutron source pulse - delta Dirac.

3. Results of the MCNP modeling.

The paper reports results of the MCNP simulations that constitute a foundation of the method proposed. The new MCNP input, allowing to get info at the detection point of the time-energy distribution of scattered neutrons was used to simulate scattering of neutrons from objects (a sphere with a radius of 5 cm) made with one example of an explosive (RDX - $C_3H_6N_6O_6$) and two types of everyday use materials namely melamine ($C_3H_6N_{6)}$ and acetamide (C_2H_5ON). The new input is an improved version of the one used in previous investigation [3-5].

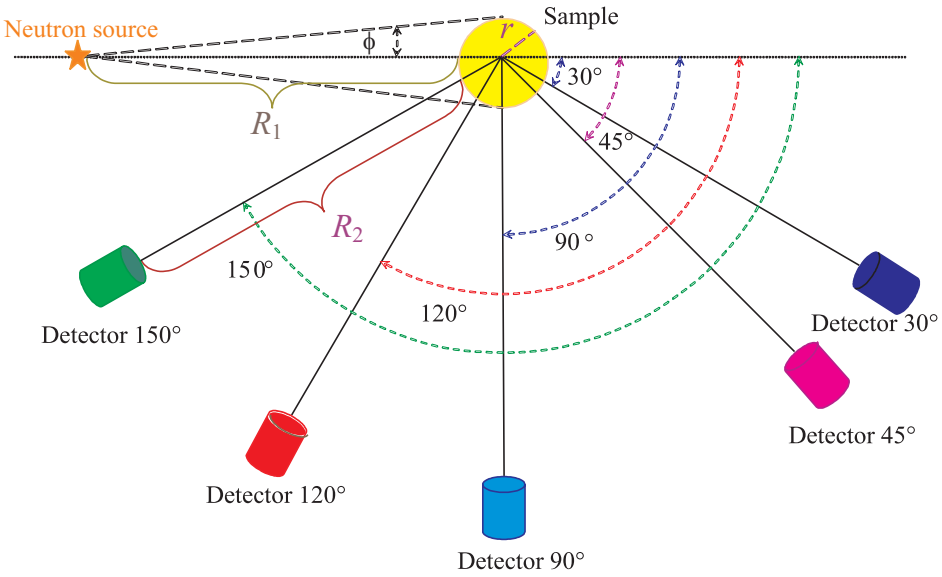


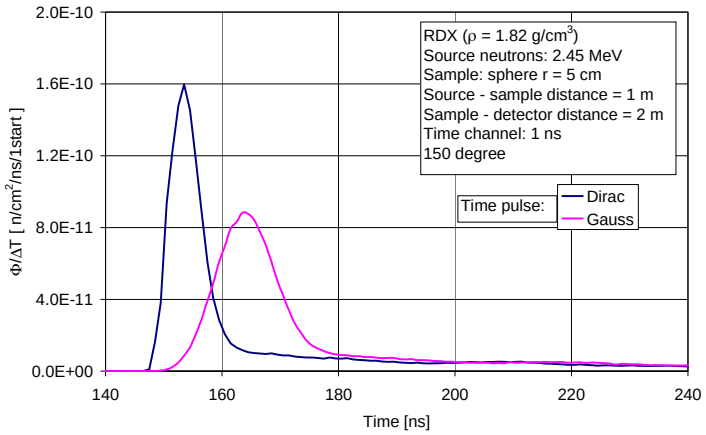
FIG. 3. Geometry of the MCNP computations.

An ability of the method to distinguish signals of neutrons scattered by particular elements, components of given material, depends on several factors. Three of them are the most important, at least in the idealized considerations:

1. distance "scattering object –detector", the longer distance the better separation with the payment of decreasing number of neutrons registered by a detector,
2. angle of observation (the angle between incident neutron path and the detector's observation line),
3. distance "neutron source – scattering object" (in this case detector placed close to the source is preferable from the pint of view of the neutron flounce that are scattered by the object with a payment of the geometrical spread of the scattering angle).

To investigate how the separation of detected signals (TOF) from basic elements (C,O,N) depends on the scatterer-detctor distance several runs of MCNP code has been performed In *FIG.4.* we present results of the ones with RDX explosive type as a scattering medium for scatterer-detector distance of 2m, 10m and20m and two types of the neutron bursts, namely Dirac delta in time and the realistic one (Gauss with 10ns width). From the MCNP modeling one can conclude that for good separation of the scattered signals the object-detector distance should be of the order of 20 m.

a)



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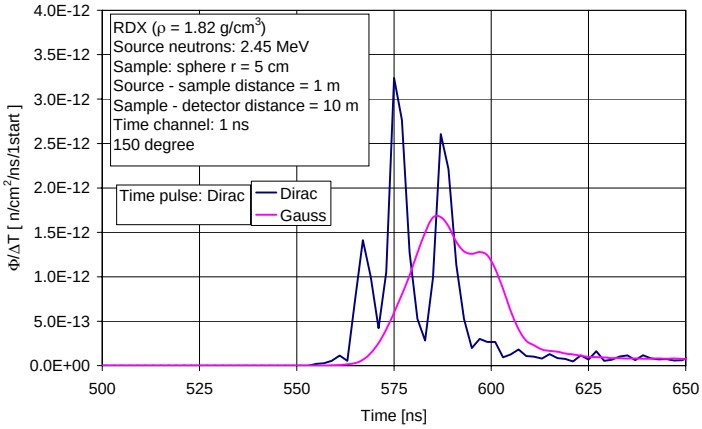

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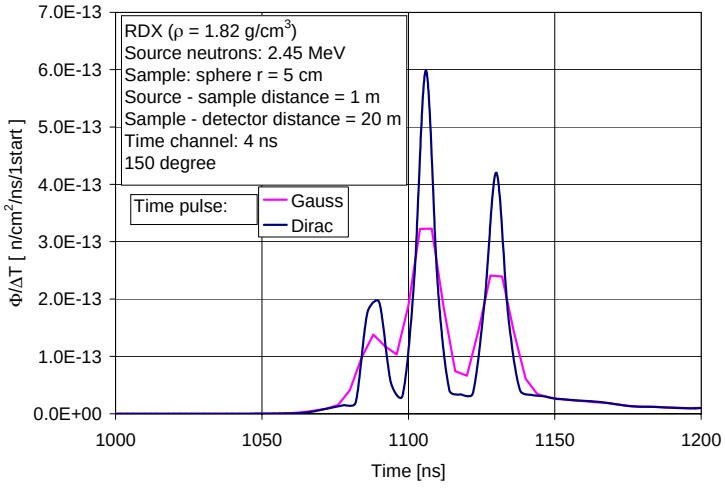
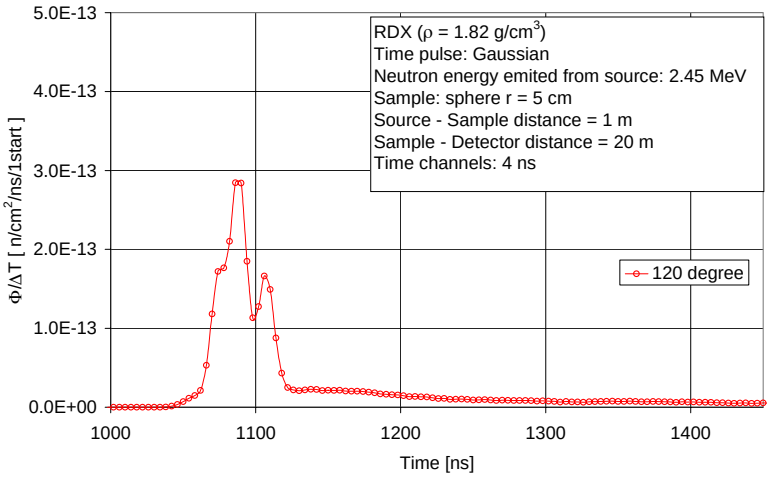


FIG. 4. Scattered neutrons signals for different distance "object-detector": , a) 2m, b) 10m, c) 20m (observation angle 150^0)

a)



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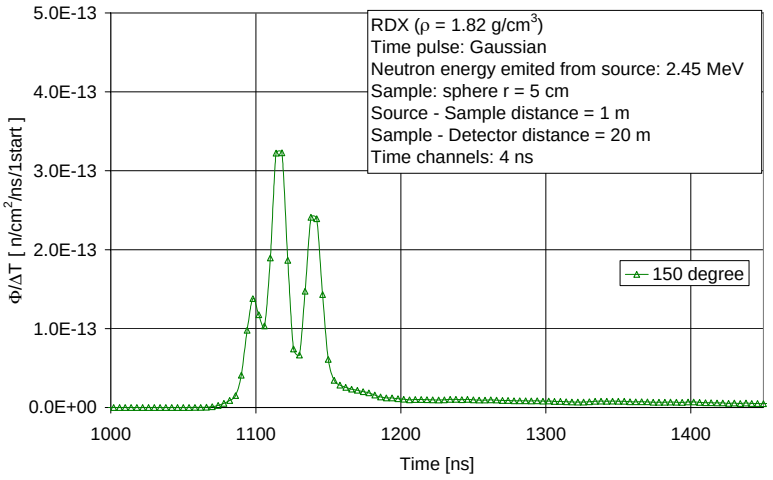

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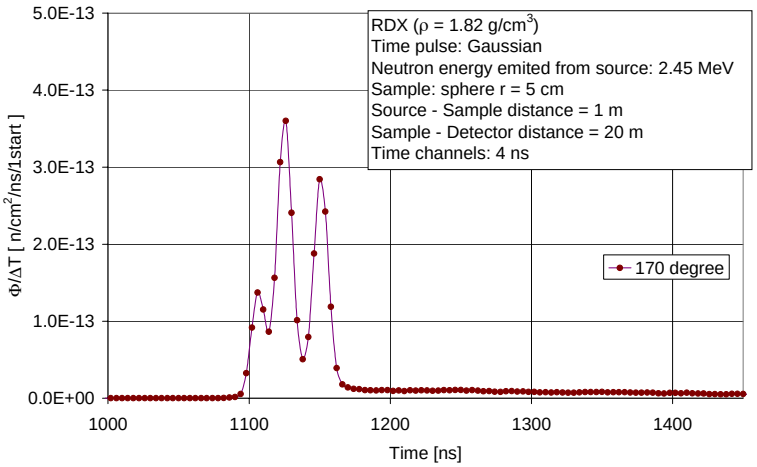

FIG. 5. Scattered neutrons signals for different scattering angles (scatterer RDX-$C_3H_6N_6O_6$): a) 120^0, b) 150^0, c) 170^0 (object – detector distance 20m).

Dependence of the TOF signals recorded by a fictitious detector that register neutrons scattered at several selected angles (120^0, 150^0, 170^0) are presented on *FIG. 5.*

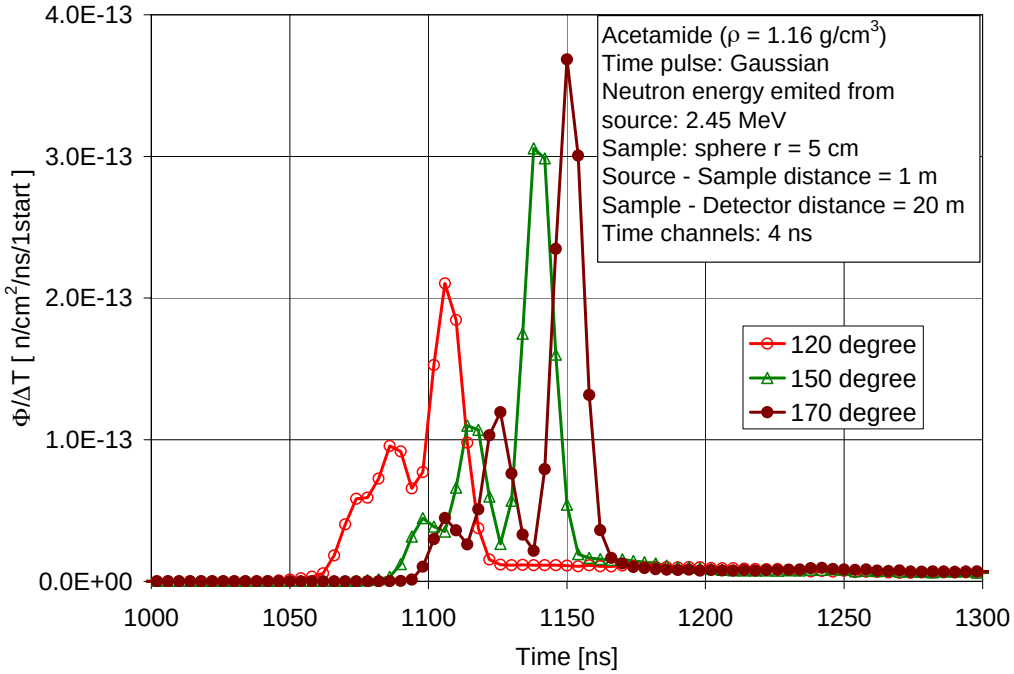

FIG. 6. Scattered neutrons signals for different scattering angles (scatterer –Acetamide- C_2H_5ON), the object – detector distance 20m.

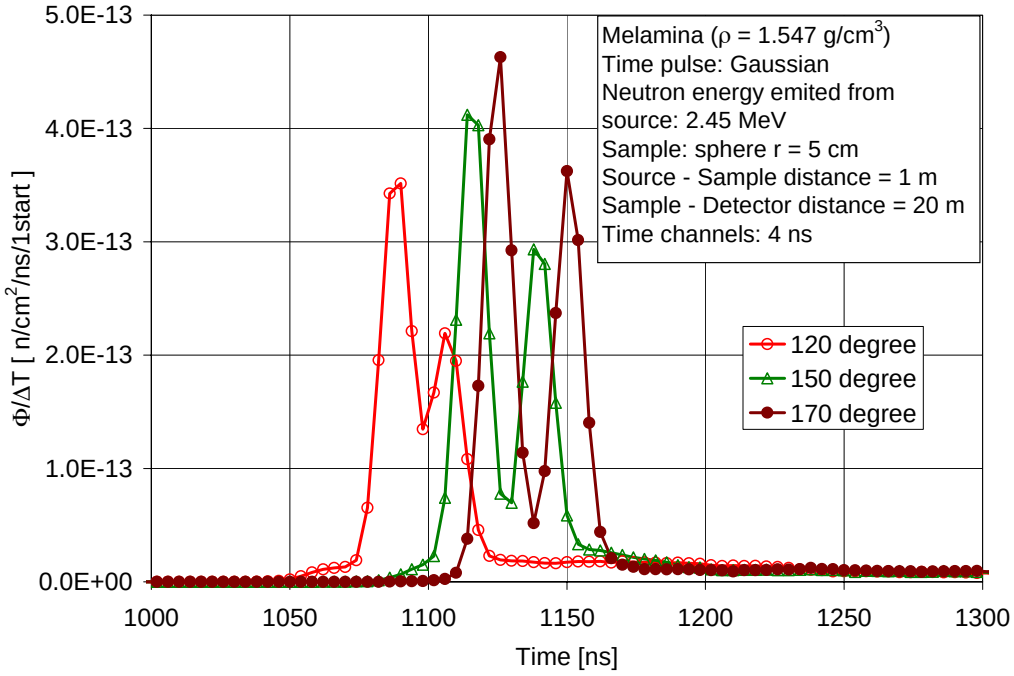

FIG. 7. Scattered neutrons signals for different scattering angles (scatterer –Melamine- $C_3H_6N_6$) the object – detector distance 20m.

One can conclude from the waveforms presented in *FIG. 5*. that the scattering angle of about 150^0-170^0 should be use to ensure good separation of the TOF signals from basic elements of

the RDX. explosive. The same conclusion can be drawn from *FIG .6-7.* where similar signals are presented for everyday use materials like acetamide and melamine.
The next set of two waveforms illustrates dependence of scattered signals on the source – scatterer distance. The advantage of placing the neutron source close to the scattering object is a higher fluence of neutrons that reach the objects resulting in higher number of scattered neutrons registered by the detector. The payment is a geometrical spread of scattering angles that cause an additional smearing of TOF signals.

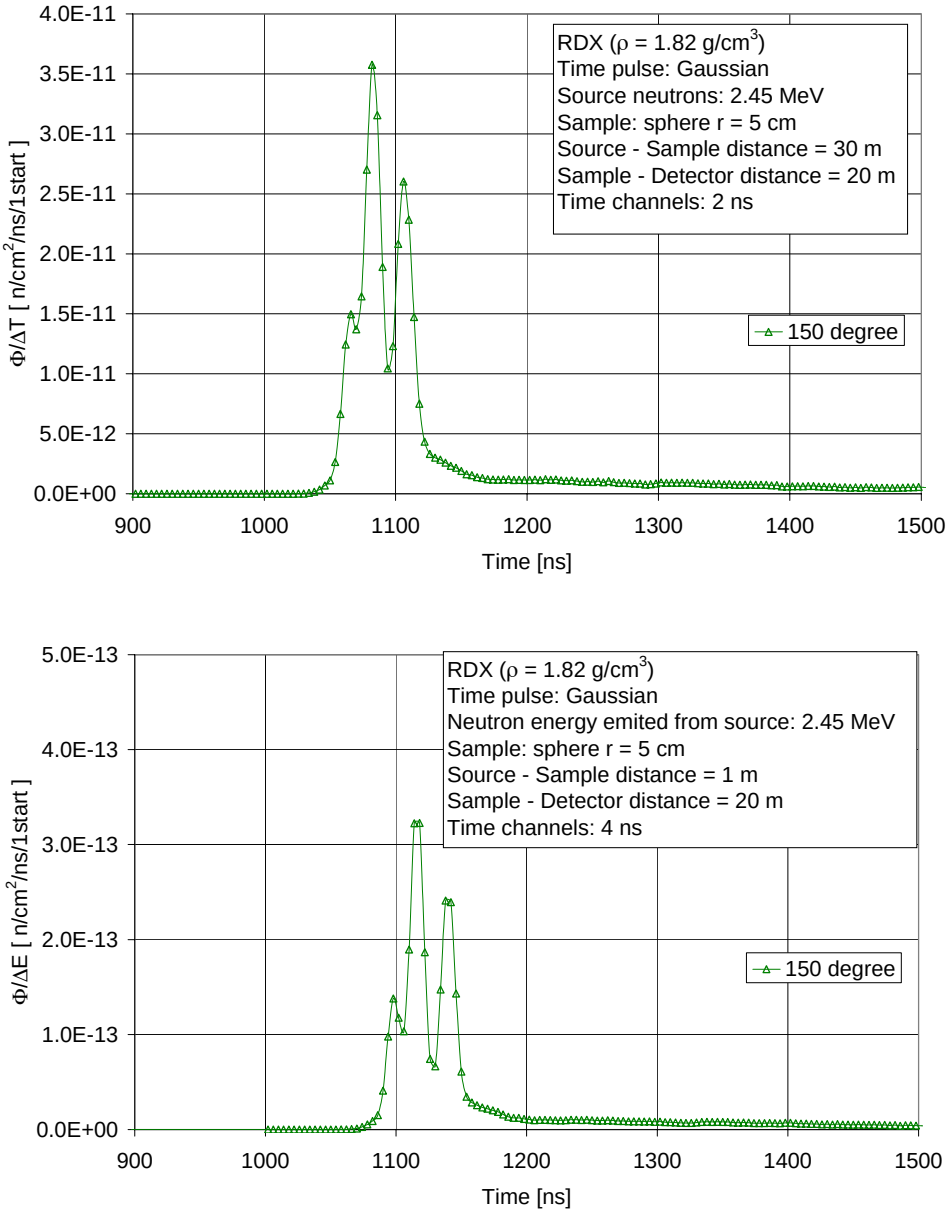

FIG. 8. Scattered neutrons signals for two different source-object distances a) 30 cm and b) 1m (scattering angle 150^0).

4. Conclusions

From the results of MCNP modeling presented above the following recommendations for future, more advanced and precise computations as well as experimental investigations have been elaborated (some of them were not evident beforehand):

1) To distinguish between different substances (nuclei) comprising the scatterer's material the scattering angle should be as large as possible (except the case of hydrogen). In practice, only the angles of the order of 150^0-170^0 allow to get a proper separation of signals.
2) The neutron source pulse duration should be as short as possible (maximum 10ns).
3) For realistic neutron source pulse duration (~10ns) the distance "object-detector" should be of the order of 20m.
4) The distance "neutron source – object" should be not less than ~50cm to avoid geometrical spread of scattering angles.

Acknowlegments

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