Detection of explosives and landmine using neutron sources: A simulation study

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The problem of landmine and illicit trafficking of explosives represents a real challenge to civil security. Neutron based detection systems are being actively explored for such applications worldwide as a confirmatory tool. In order to design such systems, it is necessary to optimize a source and detector system for each specific application. The present paper deals with such optimization studies using a Monte Carlo technique for landmine detection using backscatter neutrons and tagged neutron system for explosives hidden in a cargo.

I. INTRODUCTION

Neutrons are considered to be a confirmatory tool for the detection of explosives and landmines when used in combination with other conventional methods such as metal detector or x-ray based technique etc [1, 2, 3]. However in order to design a neutron based device for such purpose, it is required that a detailed simulation study be carried out to choose and optimize the neutron source and detector combination. Such a simulation study not only helps in choosing the best suited method for a particular application but also helps in correct use of chosen method [4, 5, 6].

Aim of this work is to know potentials and limitations of tagged neutron technique for cargo scanning and neutron backscatter technique for landmine. We have carried out simulation studies for tagged neutron system by varying the detector location, change of surrounding matrix and amount of explosive in large cargo. Similarly preliminary simulation using a DD neutron generator has been carried out for simulated anti-personnel mine buried at various burial depths and in different moisture conditions inside soil using backscattered neutrons The effect of depth at which landmine is buried inside ground and moisture content of ground is investigated using Monte-Carlo simulations.

II. TAGGED NEUTRON BASED DETECTION TECHNIQUE FOR CARGO CONTAINERS

Neutron based detection techniques have shown to be very promising candidates for detection and identification of hazardous and illicit materials. Due to their good penetration capabilities, these materials can be detected even if they are hidden under a large thickness of soil, metallic structure etc [7, 8]. Among the various neutron detection techniques, we are working on simulation studies of the Tagged neutron imaging technique to understand its potentials and limitations. The main idea of this method is to irradiate a suspect volume with the neutrons and measure the distribution of secondary gamma rays in a particular time window. The secondary gamma rays are the characteristics of the compounds/elements as they are produced, due to the transition between two discrete nuclear energy levels. If this spectrum is properly analyzed or unfolded, then it contains the valuable information about structure or chemical composition of the materials. The advantage of Tagged neutron imaging is that it can detect the true signal in the presence of large gamma background. This is achieved by detecting the alpha particle generated in the DT neutron generators using suitable position sensitive detector. The signals from those secondary gamma rays are counted which fall in time window set in coincidence with the detected alpha particle. This helps to detect the presence of the necessary signal even in the presence of large background [9, 10].

We have simulated a cargo container having different amount of explosives in a metallic matrix using the Monte Carlo technique. The dimension of the cargo matrix was chosen to be 250(W) $\times$ 250(H) $\times$ 100(L) cm^3 for the simulation purpose. The cargo was assumed to be filled with a uniform density of metallic/organic matrix and different quantities of explosive were placed at different locations. A typical sketch of the system under study is

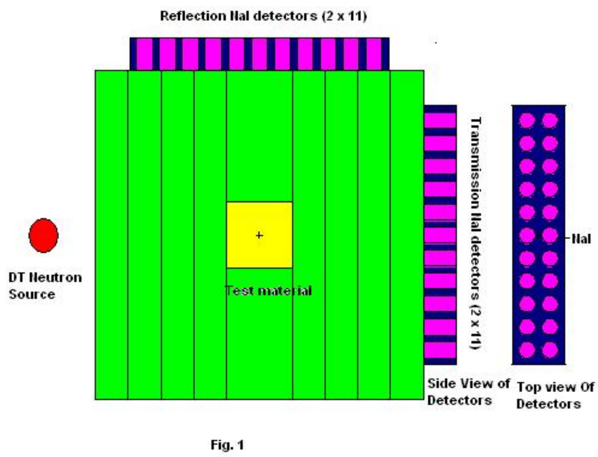

FIG. 1: Schematic model of scanning system for explosive detection and top-view of the detector assembly.

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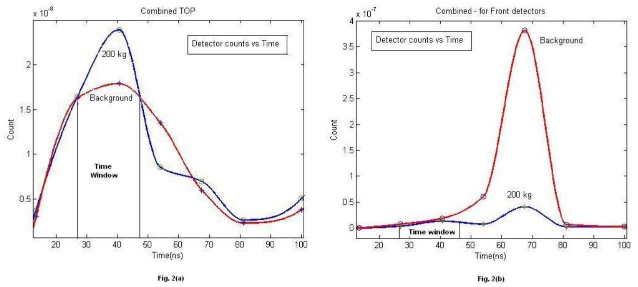

FIG. 2: Plot of detector counts vs. time for (a) Reflection mode detectors (b) Transmission mode detectors.

shown in Fig. 1. We have used NaI detector of 5" diameter having length of 10" each and total of 44 detector set were used for simulation purpose with 22 detectors each for the transmission and reflection mode. The top view of detector assembly is shown in Fig. 1. The detectors were put in front (transmission) and top (reflection) geometry in order to increase the efficiency of detection process. The NaI detectors are kept in a matrix of lead which helps to protect the detectors from counting the unwanted scattered signal. Hence this helps to achieve not only the collimation but improves signal to background ratio.

We evaluate photon flux in the volume of detector using a simulated cargo containing metallic matrix of 0.2 g/cm^3 of iron and explosive at the centre of the cargo. In order to study the importance of tagging, we have calculated the distribution of photon flux as function of time. The zero time is defined by detecting the emitted alpha particle using suitable detector. It can be seen from the plots (Fig. 2) that the there is an increase in signal over the background only when a suitable time window is selected. Hence the detector has to be gated in coincidence with the detection of alpha particle. Figure 2 shows the result of detector count as a function of time for reflection and transmission mode detectors. It can be seen from these calculation that signal to noise ratio increases in $30-50$ ns time interval indicating presence of an anomaly. This timing information thus provides a direct tool in localizing the explosive or illicit material. Moreover it can be seen that the signal is more prominent in the reflection mode as compared to transmission mode. Once this time window and time delay is suitably decided then one has to count only those secondary photons which arrive at the detectors in a particle time interval. This window is of the order of few ns which are decided by speed of neutron and the location of voxel under investigation. In our study, we have selected a time window of ~ 20 ns which is sufficiently large to detect the volume of $50\times 50\times 50$ cm^3 of explosive material provided the suspect voxel is located at the centre of cargo. The time delay and window indicates that the signal will consist only of gammas coming from in-elastically scattered neutrons.

Figures 3– 5 show the plot of sum of counts of all the

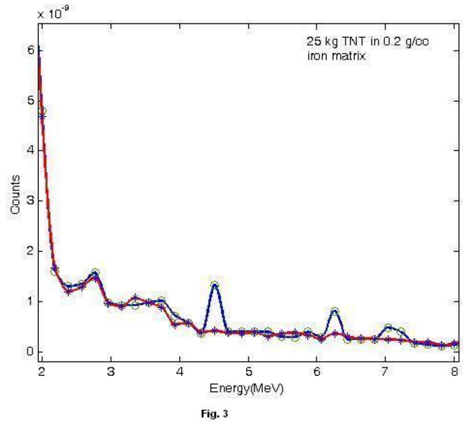

FIG. 3: Plot of detector counts for top detectors with 25 kg TNT in 0.2 gm/cm^3 iron matrix at the centre of cargo.

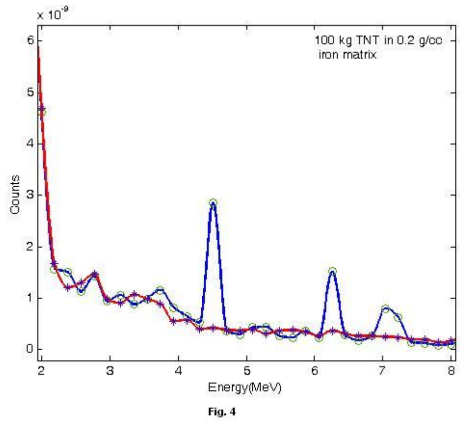

FIG. 4: Plot of detector counts for top detectors with 100 kg TNT in 0.2 gm/cm^3 iron matrix at the centre of cargo.

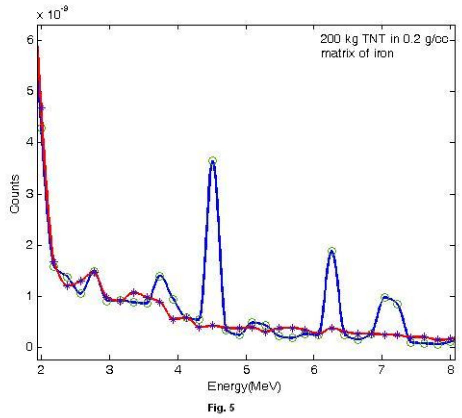

FIG. 5: Plot of detector counts for top detectors with 200 kg TNT in 0.2 gm/cm^3 iron matrix at the centre of cargo.

top detectors in the time interval of $27-45$ ns for different explosive concentration (25200 kg) kept at the centre of the cargo (0.2 g/cm^3 of iron matrix). It can be seen

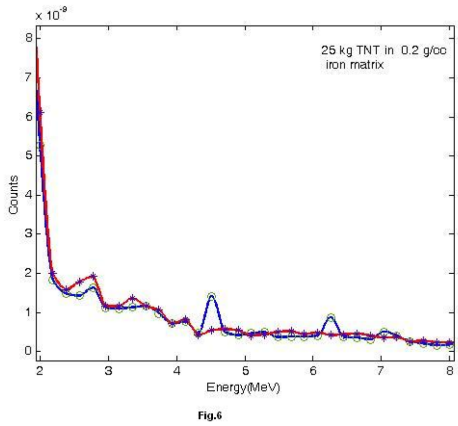

FIG. 6: Plot of detector counts for transmission detectors with 25 kg TNT in 0.2 gm/cm^3 iron matrix at the centre of cargo.

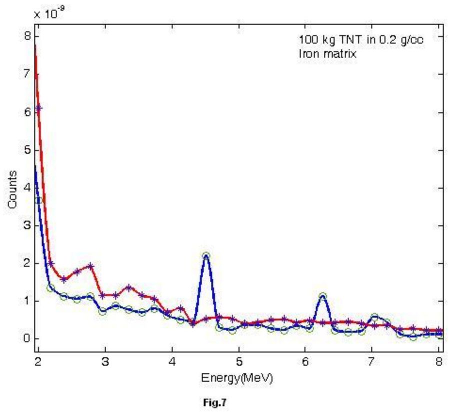

FIG. 7: Plot of detector counts for transmission detectors with 100 kg TNT in 0.2 gm/cm^3 iron matrix at the centre of cargo.

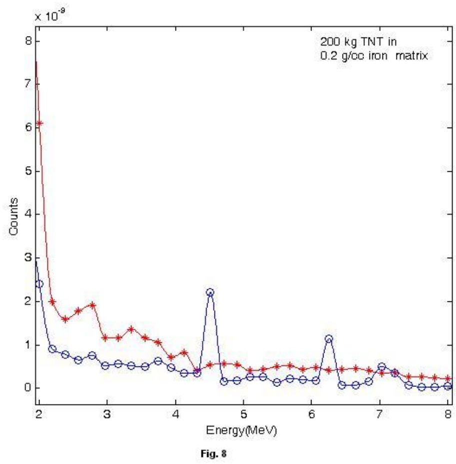

FIG. 8: Plot of detector counts for transmission detectors with 200 kg TNT in 0.2 gm/cm^3 iron matrix at the centre of cargo.

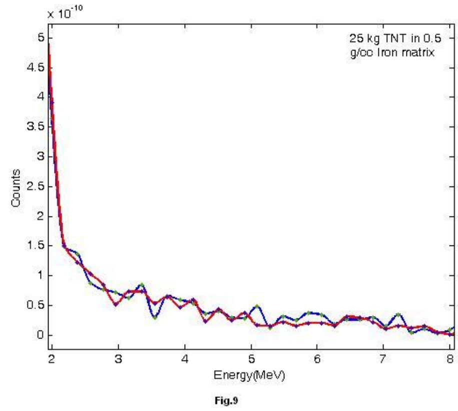

FIG. 9: Plot of detector counts for top detectors with 25 kg TNT in 0.5 gm/cm^3 iron matrix at the centre of cargo.

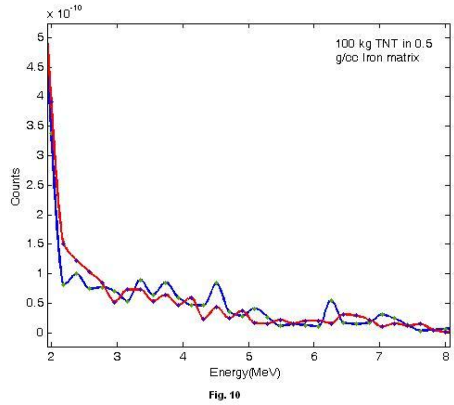

FIG. 10: Plot of detector counts for top detectors with 100 kg TNT in 0.5 gm/cm^3 iron matrix at the centre of cargo.

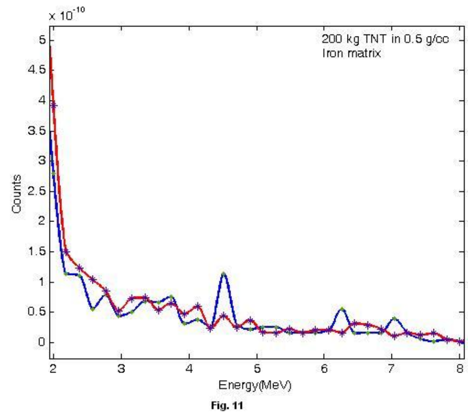

FIG. 11: Plot of detector counts for top detectors with 200 kg TNT in 0.5 gm/cm^3 iron matrix at the centre of cargo.

that the signal from C^{12} (4439 keV) and O^{16} (6130 keV) are major lines which can be easily resolved while signal from N^{14} (2313 and 5106 keV) is too weak to be resolved. Moreover the background has been reduced as we are detecting photons from tagged neutrons only. Similar calculations were done for all the transmission mode

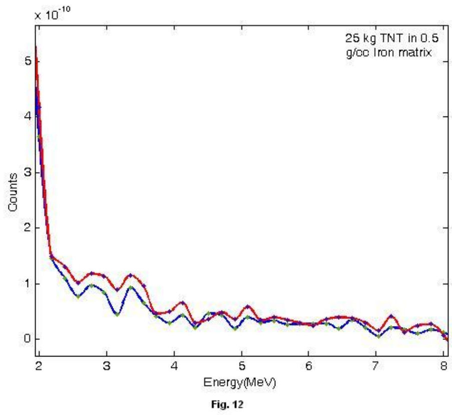

FIG. 12: Plot of detector counts for transmission detectors with 25 kg TNT in 0.5 gm/cm^3 iron matrix at the centre of cargo.

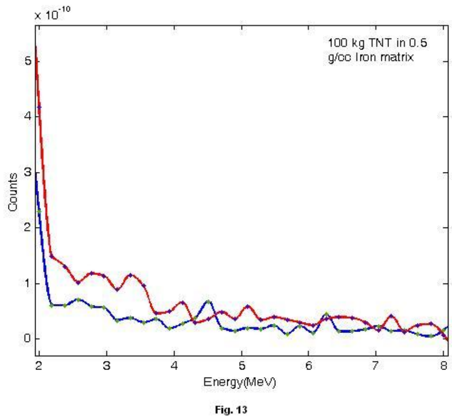

FIG. 13: Plot of detector counts for transmission detectors with 100 kg TNT in 0.5 gm/cm^3 iron matrix at the centre of cargo.

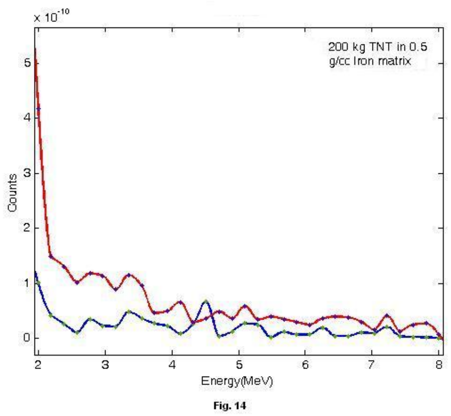

FIG. 14: Plot of detector counts for transmission detectors with 200 kg TNT in 0.5 gm/cm^3 iron matrix at the centre of cargo.

detectors and the results are shown in Figs. 6– 8.

These results show that the top (reflection) detectors

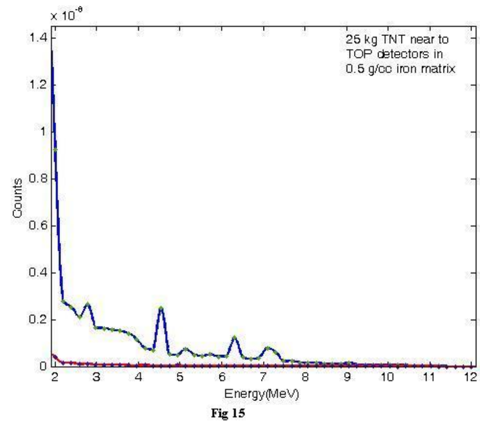

FIG. 15: Plot of detector counts for top detectors with 25 kg TNT in 0.5 gm/cm^3 iron matrix placed near the top detectors.

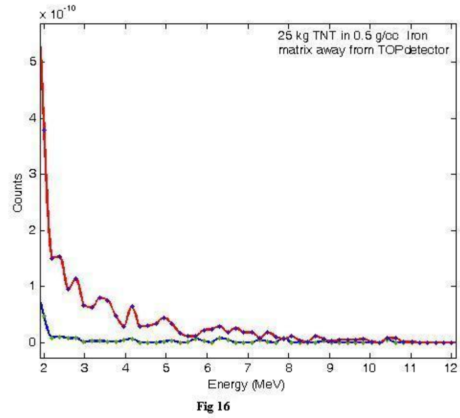

FIG. 16: Plot of detector counts for top detectors with 25 kg TNT in 0.5 gm/cm^3 iron matrix kept at the bottom of iron matrix.

show a much better signal to noise ratio as compared to transmission detectors. It can be seen that for this density of metallic cargo (0.2 g/cm^3), even small quantity of $\sim 25 - 30$ kg of explosive material may be properly detected (for the suspect voxel located at the centre of cargo matrix) if the random background or other scattering signals can be properly minimized.

A case study of metallic matrix with high metallic concentrations was also carried out in order to study the limitation of this technique. We have taken the metallic matrix density to be 0.5 g/cm^3 which is 2.5 times the previous value. The results of these simulations are shown in the Figs. 9– 11 for top detectors and Figs. 12– 14 for front detectors. These results clearly show that for high density metallic matrix, the presence of small amount of explosive/drugs ($25 - 50$ kg) can not be detected and even presence of large quantity (100 kg) may not be detected with high degree of confidence. These results are important for the detection of small but distributed explosive materials hidden inside a high density cargo. Hence the tagged neutron technique may not be

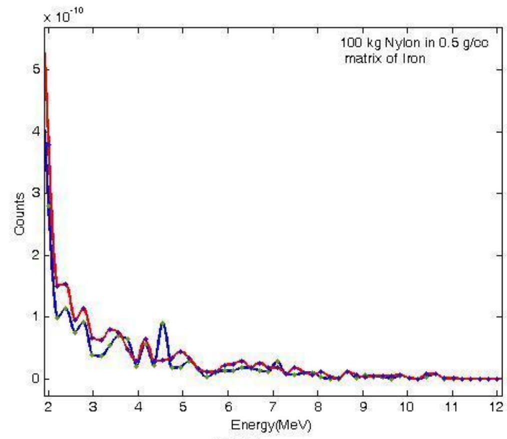

FIG. 17: Plot of detector counts for top detectors with 100 kg Nylon in 0.5 gm/cm^3 iron matrix kept at the centre of cargo.

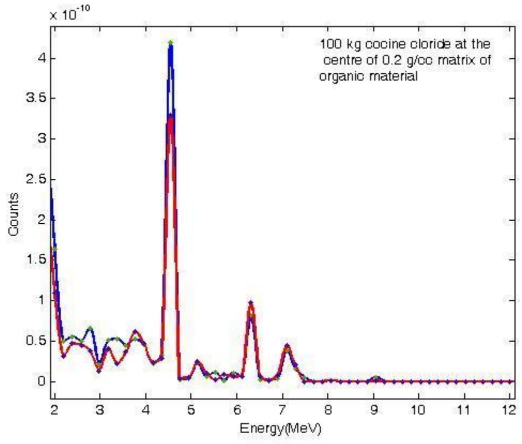

FIG. 18: Plot of detector counts for top detectors with 100 kg Cocaine in 0.2 gm/cm^3 organic matrix at the centre of cargo.

suitable for inspection of such cargo materials.

Thus the study shows that the successful detection of explosive material depends upon parameters such as cargo matrix density, quantity of explosive, location of explosive. Tagged neutron technique may be used to detect the presence of explosives/ illicit materials in only a small subset of all the cases.

Figures 15– 16 further illustrate the comments made in above paragraph. We have performed simulation studies by keeping the explosive near and away from the top detector assembly. It can be seen that when the explosive material kept nearby the top detector array, chances of detection of material is higher (Fig. 15) as compared to the case when it is kept away from these detectors (Fig. 16). Thus tagged neutron based system may fail to detect substantial quantity of explosive, if it is embedded in a high density matrix and kept away from the assembly of detectors. In order to overcome this limitation of the technique, the cargo containers should be scanned from more than one-side.

TABLE I: Composition of dry soil.

Element	% composition
Oxygen	49.52
Iron	4.71
Aluminum	7.5
Magnesium	1.94
Potassium	2.56
Sodium	3.645
Silicon	25.75
Calcium	4.39

We have also done above simulations by keeping a benign material, Nylon ($C_{11}H_{26}O_4N_2$), having composition very similar to that of explosives but it has no explosive characteristics. Figure 17 shows the result of our calculation. It can be seen that the 6130 keV line of O^{16} along with other peaks which are present in explosive spectrum is quite week here and hence may be treated as indication of presence of benign material. A proper spectral fit to the data and determining ratio such as C^{12}/O^{16}, (C^{12} + O^{16}) /N^{14} are some of the techniques which are generally used to distinguish between illicit materials and benign material in a more robust way.

Finally we have also evaluated a case of organic cargo with 0.2 g/cm^3 density. We have put Cocaine chloride as a representative of illicit material. As seen in the Fig. 18, it is difficult to detect the presence of these materials in an organic cargo even when present in large quantities due to the presence of large background. It may be noted that background with organic matrix is sufficiently higher than that of metallic matrix, and hence it can act as very good shield for illicit materials. Thus for screening of an organic cargo, tagged neutron based technique need to supplement with some other methods so that presence of explosives and illicit materials is detected.

III. NEUTRON BACKSCATTERING TECHNIQUE FOR LANDMINE DETECTION

The presence of Landmines poses a huge security problem due to the fact that their detection is difficult, laborious, risky and time-consuming. Although techniques like metal detectors are used for their detection, these techniques have problems when the landmine is present alongside many other metallic fragments. Neutron backscattering with accelerator based or isotope based sources have shown to be a promising candidate in detecting the presence of the buried landmine [11, 12, 13, 14]. In this paper we present some simulation studies using this technique for the detection of anti-personnel landmines. This technique is based on detection of backscattered neutrons which are moderated

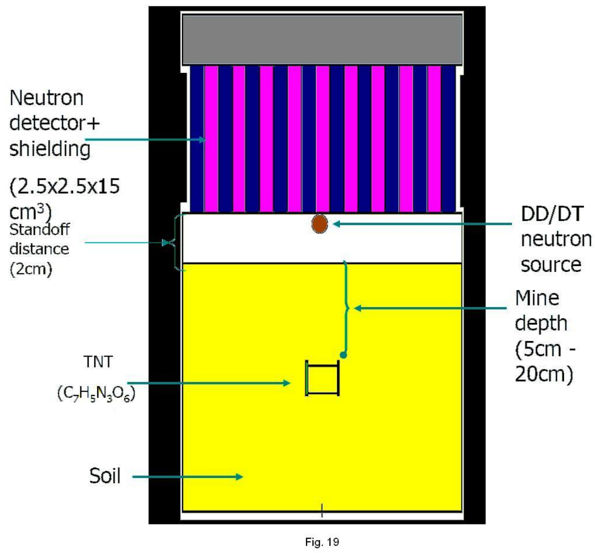

FIG. 19: Schematic of simulation geometry used for simulation of landmine detection using neutron backscattering.

and reflected by the presence of landmines.

For simulation purposes we have modeled an anti-personnel mine (APM), PAM2 ($\sim$ 100 g TNT, diameter $\sim$ 6 cm, ht $\sim$ 3.5 cm in 4 mm thick polythene enclosure), buried in the soil at the depth of $5 - 20$ cm. DD neutron generator was used as a source of neutrons and the stand off distance from the ground was 2 cm. The backscattered neutrons were detected in BF_3 neutron-detector having dimension of $2.5 \times 2.5 \times 15$ cm^3 and a set of nine detectors were used in present studies. A reflector of 5 cm thickness was kept behind these detectors to increase neutron counts. The schematic of the simulation geometry is shown in Fig. 19.The composition of dry soil is listed in Table I.

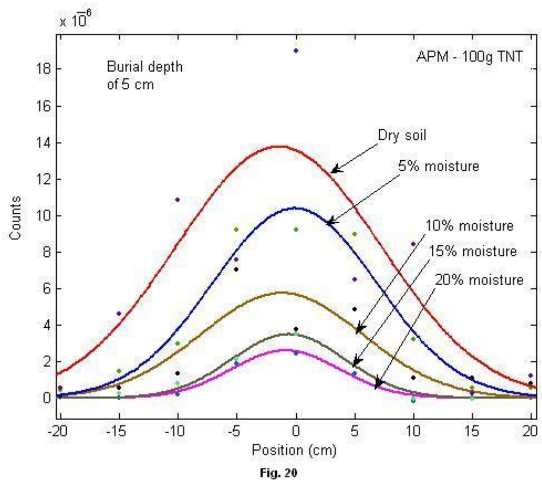

FIG. 20: Plot of detector counts as a function of detector position under different soil moisture conditions.

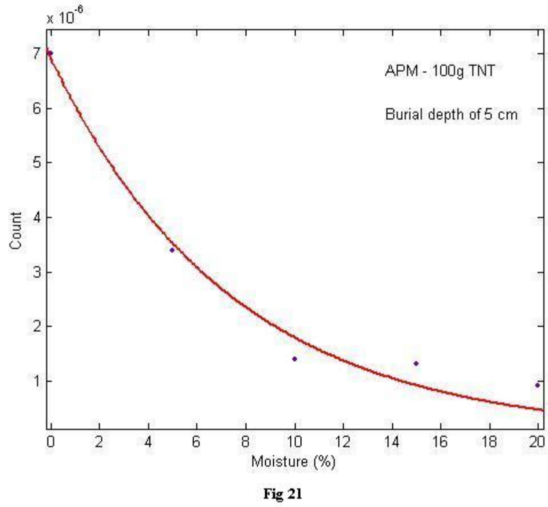

FIG. 21: Plot of detector count as a function of soil moisture for the burial depth of 5 cm.

Figure 20 shows the result of the calculation when the landmine is buried at the depth of 5 cm. The presence of anomaly at the centre of the detector array can be clearly seen from these plots. Moreover as seen from these plots far away detectors (away from location of mine) do not contribute much in increasing the fidelity of the data. Hence one can reduce the number of detectors and can still obtain reliable results. As the moisture content of the soil increases from 5% to 20%, the uncertainty in locating or detecting the landmine increases. These data were fitted with Gaussian function15 to model the response of real detectors.

Figure 21 shows the result of calculation when the landmine is buried at a depth of 5 cm and moisture content of the soil is increased. It can be seen that as the moisture content of the soil increases, the detection of landmine becomes difficult. Hence the neutron backscattering may fail to provide any confirmation about the presence of buried landmines. The plot of backscattered neutron count as a function of burial depth for dry soil and 10% moisture content is shown in Figs. 22 and 23 respectively. The backscattered neutrons were found to follow an exponential decay curve as a function of burial depth. Hence a high degree of moisture content ($> 10\%$) and larger burial depth (> 10 cm) or a combination of the two may obstruct the faithful detection of landmines.

IV. CONCLUSION

We have carried out a systematic simulation study for the evaluation of tagged neutron (API) method for the detection of explosives/illicit materials in a cargo having different variety of matrix. The results of simulation

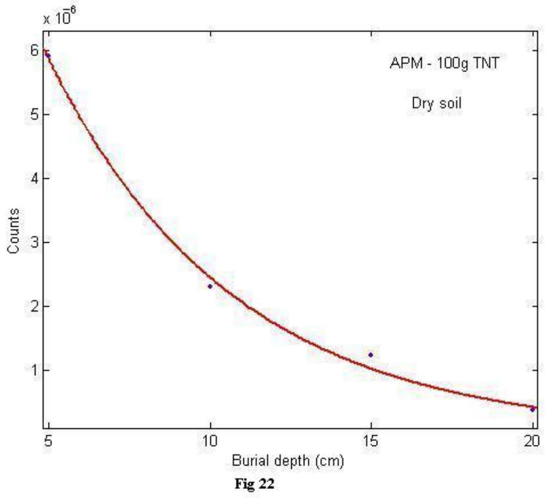

FIG. 22: Plot of detector count vs. burial depth in dry soil.

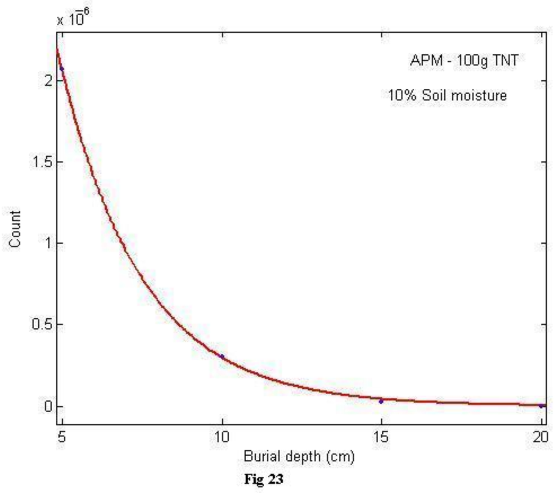

FIG. 23: Plot of detector count vs. burial depth with 10% moisture.

studies show that simple tagged neutron based method need to be augmented by other decision making algorithms so as to make a system with high degree of reliability. There is also a need to introduce techniques which reduce scattered signal by using mechanism such as collimation, reduction in the fraction of non tagged neutron etc. The successful detection of explosives/illicit materials depends upon many parameters such as cargo material density, explosive/illicit material quantity, location of these materials in the matrix etc.

Similarly the study of back-scattered neutron technique shows that this method is suitable for detection of shallow landmine buried in low moisture content soils. If the burial depth is increased beyond 10cm or moisture content is increased beyond 10%, then the detection of landmines becomes difficult.

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