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RESEARCH ARTICLE

OPTIMIZATION OF ^{241}Am-NaI(Tl) GAMMA BACKSCATTERING SYSTEM FOR DETECTION OF HIDDEN EXPLOSIVES AND DRUGS

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ABSTRACT

Experiments were carried out to explore the performance of the gamma back-scattering technique in detection and localization of contrabands such as; TNT ($C_7H_5N_3O_6$), codeine ($C_{18}H_{21}NO_3$) hidden in hollow plastic tubes. This is done using an assembly consisting of ^{241}Am gamma source, producing about 5×10^7 photon.s^{-1}, in conjunction with a NaI(Tl) detector. The source-detector distance was optimized and the optimal configuration was selected to scan the two samples each in turn. The results in terms of contrast ratios and Figure of Merit verified the capability of the proposed device to detect and localize the targeted samples when sealed in plastic discs as small as 2.8 cm in diameter. In addition, the high contrast ratios achieved; 30% for TNT and 25% for codeine demonstrated the good distinction ability of the device.

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INTRODUCTION

The search for hidden contraband materials, such as explosives and drugs is one of the most interesting and worthwhile applications of nuclear techniques. TNT ($C_7H_5N_3O_6$) and codeine ($C_{18}H_{21}NO_3$) have densities of about 1.65g.cm^{-3} and 1.34g.cm^{-3}, respectively. This makes them lighter than most of metals, but heavier than and different in density from common materials such as polyethylene and air. Therefore, density variations can be used to detect the presence of such contrabands when hidden inside hollow plastic tubes. Gamma backscatter density gauges use the Compton scattering of c ray photons in bulk material to measure density. Since the cross-section for Compton scattering is proportional to the number density of electrons, and the ratio of atomic mass to atomic number is 2.0,or nearly so, for all elements (except hydrogen), the backscattered count rate is a function of the bulk density (Ball *et al*.,1998). Therefore, the change in the flux of scattered photons can be used to indicate the presence of an anomaly, possibly contraband concealment. The magnitude of this change can be used to discriminate between different hidden concealments. In such technique, a source of gamma photons is placed at the surface of the bulk sample to inject gamma photons into the material. A detector is placed a short distance along the surface from the source to count photons scattered out of the material. Shielding of the source prevents photons reaching the detector directly (Ball *et al*., 1998). Unlike transmission densitometers, where the linear geometry of source, sample and detector can be a limitation, backscatter density gauges can be applied to semi-infinite bulk materials where the other side is inaccessible (the walls of long tubes, for example) (Ball *et al*., 1998). Several geometries of photon backscattering systems for explosives and drug detection have been reported by others (Campbell *et al*., 1994; Van Wart, 2001; Smith, 1990; Harding, 2004; Vogel, 2007). For example, Photon backscattering was used for detecting contraband materials, mainly drugs, hidden in spare automobile tires, vehicle walls, truck trailer walls, etc. (Campbell *et al*., 1994). The device known as the "Buster" consists of a small (3.7 MBq) and a CdZnTe detector, housed in a small hand-held container. The device is equipped with a microprocessor that provides both a digital display and an audio alert when the inspected object is not empty. A similar device was developed for detecting visually obscured objects hidden within extended

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walls (Van Wart, 2001). Since for most materials, Compton scattering is the dominant mode of interaction at photon energies from 50 keV to 1.5 MeV (Hussein, 2004), gamma sources such as ^{241}Am, ^{137}Cs and ^{60}Co are suited for this purpose. Furthermore, isotopic photon sources were utilized to take advantage of their small size, light weight, self-powered nature and low-cost.

On the bases of such considerations, this work examines the possibility of employing a shielded ^{241}Am source and a well collimated NaI(Tl) detector in a suitable arrangement for detection and localization of TNT($C_7H_5N_3O_6$) and powdered codeine ($C_{18}H_{21}$ NO_3**)** samples**,** hidden in a hollow plastic tube made of high density polyethylene (HDPE). The results of measurements are analyzed considering three indicators: (i) the magnitude of the backscattering photon flux (Φ); (ii) the difference between the detector response obtained in the presence of a target and that obtained in target-free tube, normalized to that of target-free tube to define a contrast ratio, (c); (iii) the shape of the change of the detector response in term of a figure-of-merit (fom) defined as fom = $\Phi \times c$. Good detection capability was defined by the ability to obtain a contrast ratio greater than 10%. A high flux reduce the required counting time and/or source strength (hence shielding requirements and device weight), while a high contrast shows good distinction ability between materials. Therefore, an optimized device should provide simultaneously a high flux and contrast, i.e., a high value of fom (Shuo-Sheng Tang and Esam, M.A. Hussein, 2004). To optimize a gamma-ray backscattering system we should also attend to two points: (a) isolation of detector from direct exposure to source radiation and (b) focusing the detector's filed-of view on the region of interest. This work explores such possibility.

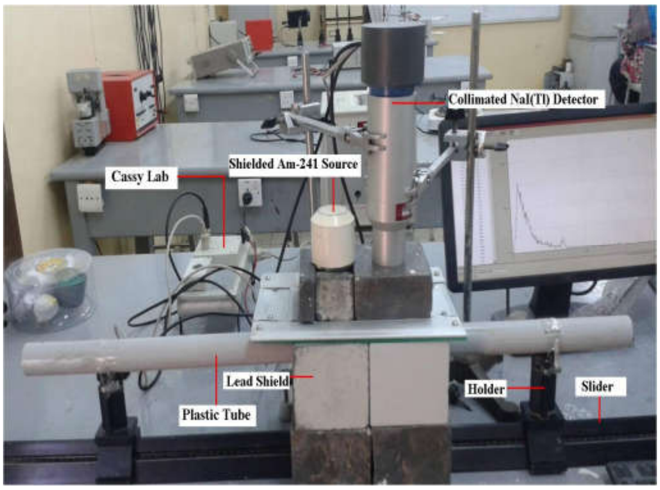

Fig.1. A photograph for the experimental setup

Instrumentation

An experimental setup was designed to determine the practicality of employing Compton backscattering in detecting and discriminating between samples of TNT($C_7H_5N_3O_6$), and powdered codeine ($C_{18}H_{21}$ NO_3**)** hidden in a hollow plastic tube of 100cm length and 5cm diameter. A photograph for the set-up used for the tests is shown in Fig. 1. ^{241}Am source (7.3GBq) from AEA Technology (Model: AMC26) producing about 5 $\times 10^7$ photon.s^{-1} was utilized. The source was enclosed in a 0.6cm inner radius and 3cm outer radius lead capsule, a sufficient amount for source shielding since the half value layer of lead at the source energy of 60 keV is only 0.01 cm (Tang and Hussein, 2004). Removing the cap of the shielding allowed exposure of the tube to radiation.

In a Cartesian system of reference where the y-axis coincides with the cylindrical shield axis and is directed upwards, the source was located 3 cm above the top surface and in the midpoint of a hollow plastic tube of 100cm length and 5cm diameter. A single NaI(TI) photon detector from LAYBOLD DIDACTIC GmbH (Model:559901) was employed. The detector was collimated by a cylindrical cavity centering a lead cube of dimensions 10cm ×10cm ×5cm and was located 3cm above the top surface of the tube and at different positions along the X-axis away from the source. To provide further protection for the operator and the surrounding environment, extra lead shields were located at back and front sides below the (^{241}Am-NaI(Tl)) assembly. The samples under test; 30g of TNT ($C_7H_5N_3O_6$) and 24 g of powdered codeine ($C_{18}H_{21}$ N O_3**),** were sealed in two plastic discs each of 1.4cm radius and 3cm thick. Each in turn, a sample is located inside the tube with its center coincides the midpoint (0cm) of the tube. The loaded tube was then moved horizontally along the slider to position the center of the hidden sample exactly below the source and record the NaI(Tl) detector response. The compositions of samples and materials of interest are presented in table 1.

Table 1. Composition of samples and materials of interest, rounded off

Sample/Density (g.cm^{-3})	Mass fractions H	C	N	O
TNT 1.65	0.022	0.370	0.185	0.423
Codeine 1.34	0.071	0.722	0.047	0.160
HDPE 0.955	0.143	0.857		
Air 0.00122			0.780	0.220

The signal output from the NaI(Tl) detector was processed by The computer-assisted measuring and evaluation system CASSY-S consisting of the CASSY Lab software (524 200),Sensor-CASSY module (524010) and Power-CASSY (524011), connected to a desktop computer. The electronic system was arranged, using suitable operating voltage and gain. Due to the need for sufficient statistics, the acquisition time for all measurements was chosen to be 100s.

RESULTS AND DISCUSSION

The results are reported in terms of variations in signal-to background ratio (S/B) and Figure of Merit fom with two parameters; the source-detector distance and the sample position with respect to the ^{241}Am source in the ^{241}Am-Na(Tl) assembly. The net counts ($I-I_o$) were determined by subtracting from the measured counts with sample inside the tube, I, the ones measured without the sample, I_o, while the signal-to-background ratio was determined as $S/B=((I-I_o)/I_o)$). Only curves that best fit with the data are plotted and reported. The measurements were started by optimizing the relative distance between the ^{241}Am source and the NaI detector by measuring the average counts while locating the detector at different positions i.e. X=±10cm, ±11cm, ±12cm, ±13cm, ±14cm and ±15cm away from the source. The contrast ratios and Figure of Merit values were then calculated and averaged for measurements taken for a given distance at both sides of the source. The results; contrast (in percentage manner (%)), and fom for both samples are reported in Figs.2 and 3, respectively.

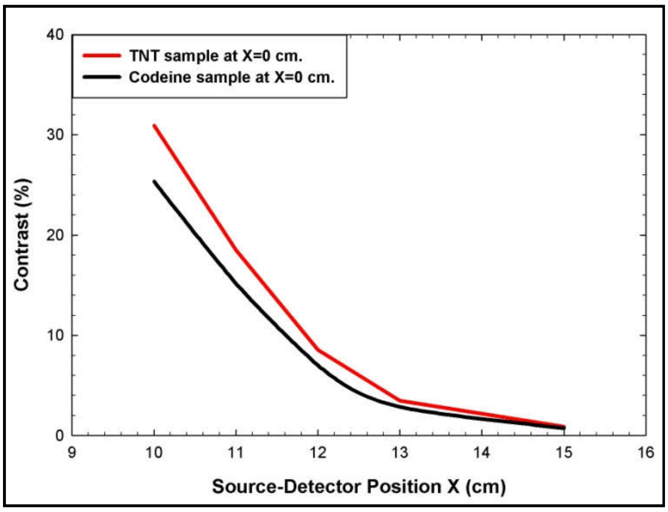

Fig.2. Contrast ratios as a function of source-detector distance

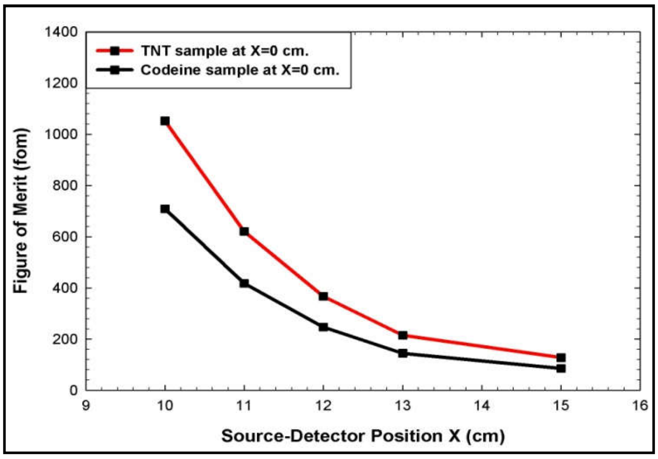

Fig.3. Figure of Merit as a function of source-detector distance

As shown in Figs. 2 and 3, the average contrast ratios and fom values decrease as the source-detector distance increases with maximum values achieved at source-detector distance = ±10 cm. At this optimal source-detector distance, the maximum contrast ratio achieved for TNT (30%) was found to be higher than that of codeine (25%) by a factor of 1.2 providing good distinction ability between the two samples. The corresponding fom value for TNT (1052 counts) was higher and exceeds that of codeine (707 counts) by a factor of 1.5. These results are reasonable since TNT density (1.65g.cm^{-3}) is higher than that of codeine (1.34g.cm^{-3}), and consequently higher backscattered photon flux and thus contrast values are expected in case of TNT. After these observations, the detector was located at X= +10 cm away from the source for the rest of measurements. At this point, the capability of the system to localize both samples when hidden alternatively at different locations was explored. The samples were located alternatively inside the tube at -20cm, 0cm and +20 cm and the tube was moved, using the slider, along the x- axis, 3cm below the (^{241}Am-NaI(Tl) assembly. When the point of interest is positioned under the source, the detector response was recorded at duration of 100s. Results of contrast (in percentage manner (%)), and fom were presented in Figs. 4 and 5, respectively.

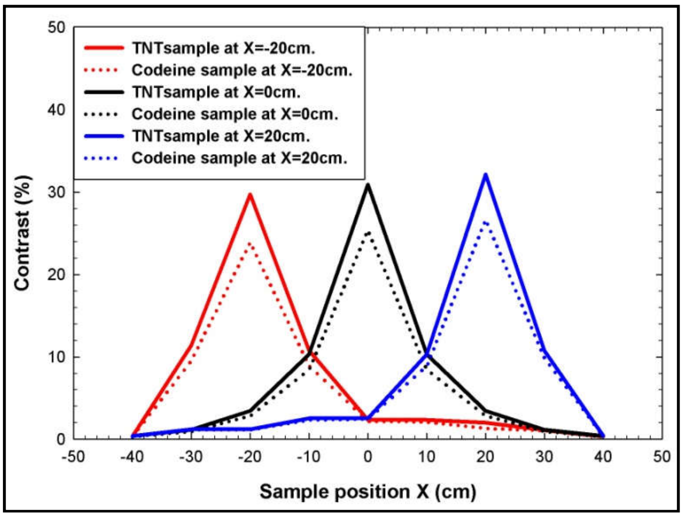

Fig.4. Contrast ratios as a function of sample position

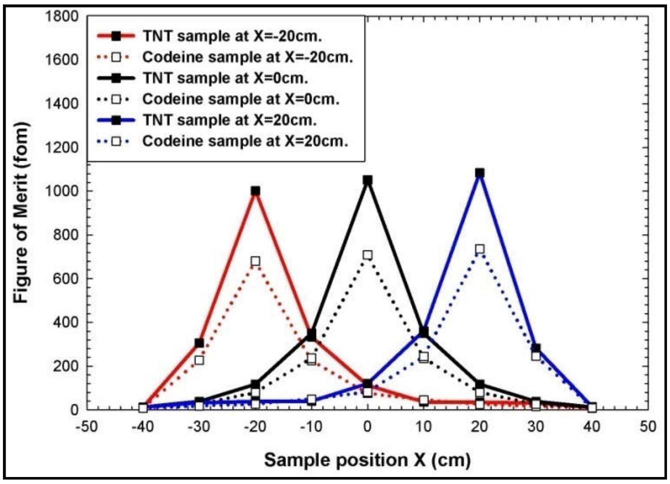

Fig.5. Figure of Merit as a function of sample position

As seen in Figs. 4 and 5, at all locations, the contrast and fom values always peak when the center of the hidden sample passes under the ^{241}Am source. In all cases, as expected, the maximum values of contrast ratios and fom for TNT exceeds that of codeine. The results clearly confirm that our empirically optimized system has positively identified the presence and localities of the two contraband samples with detectable signals.

Conclusion

This work explores the feasibility of developing ^{241}Am-NaI(Tl) gamma backscatter device for detection and localization of

TNT and codeine samples sealed in plastic discs as small as 2.8 cm in diameter and 3cm thick, and hidden inside a hollow plastic tube. The source-detector distance was empirically optimized and the optimal distance was found to be ±10 cm. The measurements were carried out at duration of 100s and the results demonstrated that our optimized ^{241}Am-NaI(Tl) gamma backscatter device has positively identified, localized and discriminated between the TNT and codeine samples with maximum contrast ratios 30% and 25%, respectively. The corresponding maximum fom value for TNT (1052 counts) exceeds that of codeine (707 counts) by a factor of 1.5, providing sufficient detectable signals. Due to the heavy shields used, our proposed ^{241}Am-NaI(Tl) gamma backscatter device may be suitable for use as a stationary unit. The contrast ratios and fom values achieved, suggest future measurements to examine the performance of the current device in the presence of ^{241}Am source producing lower than 5×10^7 photon.s^{-1}, acquisition time less than 100s and thus lighter shields.

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