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RESEARCH ARTICLE

ON THE USE OF AN ^{241}Am-NaI(Tl) ASSEMBLY FOR DETECTION OF HIDDEN CONTRABANDS USING GAMMA-BACKSCATTERING TECHNIQUE

***Nassreldeen Elsheikh**

Al-Baha University, College of Science & Arts in Al -Mikhwah, Department of Physics, Al-Baha, Saudi Arabia

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ABSTRACT

Measurements were carried out to investigate the potentialities of gamma back-scattering technique in detection of hidden contrabands such as codeine ($C_{18}H_{21}NO_3$) and cannabis ($C_{21}H_{30}O_2$). 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. The results in terms of contrast ratios and Figure of Merit verified the feasibility of utilizing the proposed system in detection the targeted samples when sealed in a plastic cylindrical cane. The high contrast ratios achieved; 25% for codeine and 11% for cannabis verified the good distinction ability of the device.

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INTRODUCTION

The search for hidden contraband materials is one of the most interesting applications of nuclear techniques. Codeine ($C_{18}H_{21}NO_3$) and cannabis ($C_{21}H_{30}O_2$) have densities of about 1.34g.cm^{-3} and 1.015g.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 plastic canes. Gamma backscatter density gauges use the Compton scattering of gamma 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). Several geometries of photon backscattering systems for contrabands detection have been reported by others (Campbell *et al*., 1994; Van Wart, 2001; Smith, 1990; Harding, 2004; Vogel, 2007). For example, The device known as the "Buster" (Campbell *et al*., 1994), 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 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 of powdered codeine ($C_{18}H_{21}NO_3$) and cannabis ($C_{21}H_{30}O_2$) samples, hidden in a void plastic cylindrical cane of 2.5cm radius× 4cm height, 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 cane, normalized to that of target-free

****Corresponding author:*** **Nassreldeen Elsheikh,**
Al-Baha University, College of Science & Arts in Al-Mikhwah, Department of Physics, Al-Baha, Saudi Arabia.

cane 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) (Tang and 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.

Geometry & measurements procedure

An experimental setup was designed to determine the practicality of employing Compton backscattering in detecting and discriminating between samples of codeine ($C_{18}H_{21}NO_3$) and cannabis ($C_{21}H_{30}O_2$). A photograph for the set-up used for the measurements 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 shielded by a lead capsule of 0.6cm inner radius, 3cm outer radius and 7cm height, 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 plastic cane to radiation.

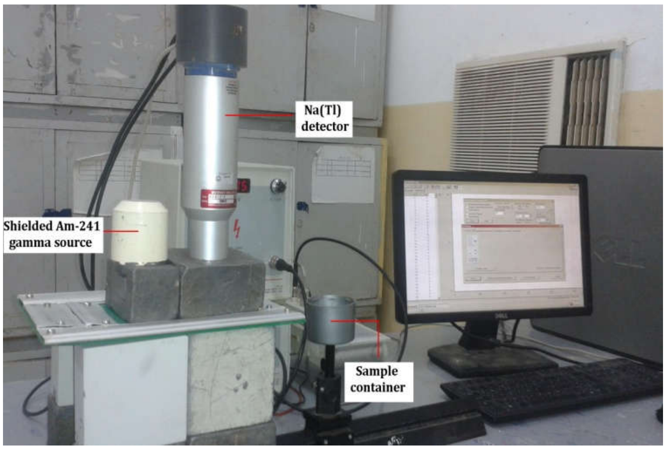

Fig.1. A photograph for the experimental setup

In a Cartesian system of reference where the y-axis coincides with the cylindrical shield axis and is directed upwards, the shielded source was located 2 cm above the top surface and in the midpoint of the plastic cane. 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 2cm above the top surface of the plastic cane 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 were 100g of codeine ($C_{18}H_{21}NO_3$) and 79 g of cannabis ($C_{21}H_{30}O_2$). Each in turn, a sample is located inside the plastic cane. The loaded cane is then positioned with its center exactly 2cm below the source and record the NaI(Tl) detector response. 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 contrast ratios (signal-to background ratios (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. The net counts ($I-I_o$) were determined by subtracting from the measured counts with sample inside the plastic cane, I, the ones measured without the sample, I_o, while the contrast ratio was determined as $S/B=[(I-I_o)/I_o)]\times 100$. 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.

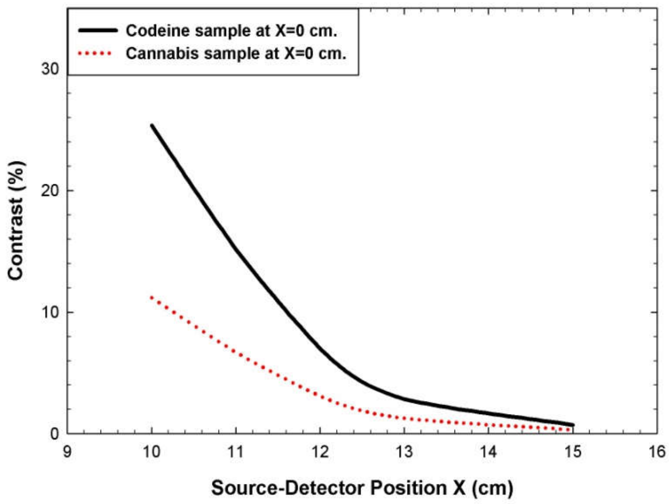

Fig.2. Contrast ratios as a function of source-detector distance

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 codeine (25%) was found to be higher than that of cannabis (11%) by a factor of 2.3 providing good distinction ability between the two samples. The corresponding (fom) value for codeine (708counts) exceeds that of cannabis (90 counts) by a factor of 7.9. These results are reasonable since codeine density (1.34g.cm^{-3}) is higher than that of codeine (1.015g.cm^{-3}), and consequently higher backscattered photon flux and thus contrast and (fom) values are expected in case of codeine. After these observations, the detector was located at X= +10 cm away from the source for the rest of measurements. At this point, the samples were loaded alternatively inside the plastic cane and the cane was scanned along the x- axis and at 2cm below the ^{241}Am-NaI(Tl) assembly. The scans were done over a distance of 80 cm with a step size of 10 cm and an acquisition time of 100s. 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.

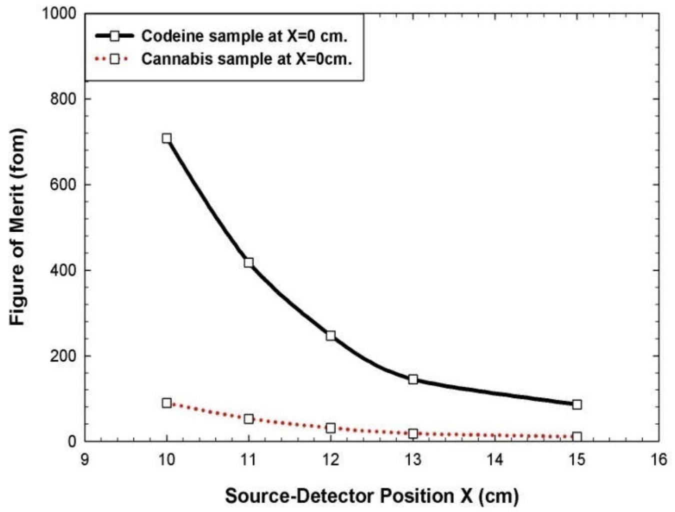

Fig.3. Figure of Merit as a function of source-detector distance

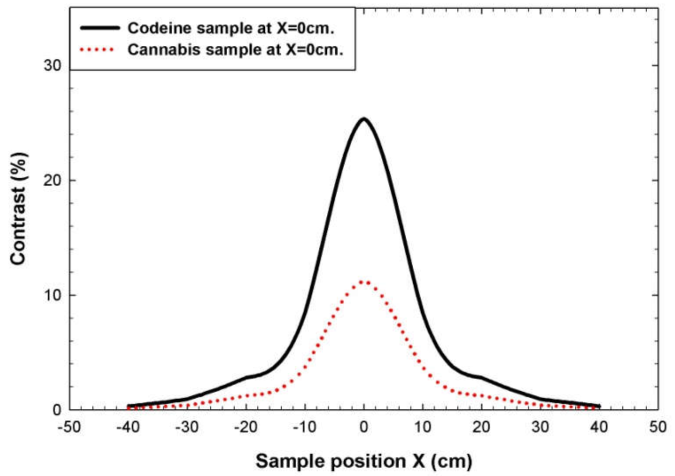

Fig.4. Contrast ratios as a function of sample position

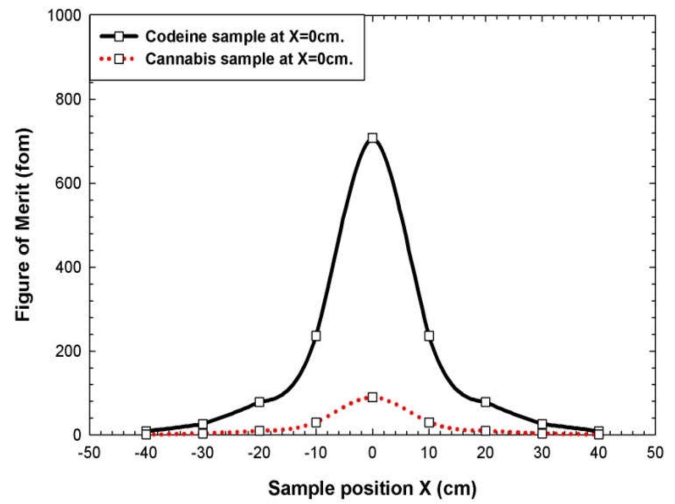

Fig.5. Figure of Merit as a function of sample position

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

Conclusion

This work explores the feasibility of developing ^{241}Am-NaI(Tl) gamma backscatter system for detection of 100g of codeine and 79 g of cannabis samples loaded in a plastic cane as small as 5 cm in diameter and 4cm thick. 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 the proposed ^{241}Am-NaI(Tl) gamma backscatter assembly has positively identified and discriminated between the codeine and cannabis samples with maximum contrast ratios 25% and 11%, respectively. The corresponding maximum (fom) value for codeine (708 counts) exceeds that of codeine (90 counts) by a factor of approximately 7.9, providing sufficient detectable signals.

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