American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Effectiveness of X and Gamma Rays for Scanning Cargo Containers

Wagdy Kansouh[a]*, Mohamed Ahmed[b], Ibrahim Bashter[c], Riad Megahid[d]

[a,d]*Department of Reactor Physics, Nuclear Research Centre, Atomic Energy Authority, Cairo, Egypt*
[b]*Department of Research and Development, Egyptian Custom Authority, Alexandria, Egypt*
[c]*Department of Physics, Faculty of Science, University of Zagazig, Zagazig, Egypt*
[a]*Email: kansouh2573@gmail.com*, [b]*Email: ma77eg@gmail.com*
[c]*Email: ibashter@hotmail.com*, [d]*Email: rmegahid2573@hotmail.com*

Abstract

This paper describes the work performed to assess the effectiveness of scanners based on X-ray and gamma-ray transmission techniques for scanning cargo containers before entering different ports. Scanning by X-rays was done using X-ray machine operating at 135 KV and current of 4 mA. However, Scanning by gamma-rays was performed using collimated slit beam of 1 cm width and 5 cm height emitted from 0.5 Ci Cobalt-60 source. The transmitted gamma-rays through the container and the hidden object was measured by a gamma counting system applies NaI(Tl) detector. Objects of different physical and chemical composition were used in this study. The obtained images by X-ray transmission technique show incapability to distinguish between objects of nearly the same density. However the obtained images resulting from scanning by gamma-rays shows more capability to distinguish between all the examined objects.

Keywords: X-ray; Gamma-ray; Inspection; contraband; Scanner; Containers security.

1. Introduction

It is estimated that 500 million containers accounting for 90% of the world's cargo are shipped around the world every year virtually uninspected, allowing consignments of narcotics, weapons and other illegal materials to enter countries undetected [1].

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* Corresponding author.

The manual inspection of large containers is not practical because of the time constrains and the high labor requirements for unpacking and repacking the cargo contents. Therefore, there is a great need for nonintrusive scanning systems to do this job at acceptable time and with low cost. Most non-intrusive cargo screening systems are based on the use of X or gamma-rays radiation. These systems can provide high-resolution intensity images of the cargo contents and are well suited for detecting metal-based objects such as weapons. The images obtained from the systems are easy to interpret due to the high contrast shapes obtained from the scanning. The most used technologies are based on X and gamma-rays [2,3,4,5]. Security screening is a broad term which encompasses intelligent logistics, sniffer dogs and X-ray inspection at ports, airports, borders and mail depots. X-ray inspection systems offer rapid, non-invasive detection of contraband and explosive devices, and can be combined with other techniques to identify nuclear materials [6]. Until now X-ray inspection techniques are the most widely used since they have many advantages, particularly their high speed, their high resolution images and controlled exposure dose. However the limitations of X-ray inspection techniques to distinguish objects of nearly densities. This can be overcome by use of developed additional methods capable to identify the suspected objects like neutron based techniques [7].

2. Material and methods

The applied scanning techniques to allocate hidden illicit materials in cargo containers are given and discussed in the following sections. A brief description of these techniques are given below.

2.1 Inspection objects

Objects of different physical and chemical properties are chosen to tested by X and gamma-ray systems. These include materials of different compositions and of different densities in the form of solid, liquids and powders as shown in table (1). The thickness of the solid objects under test was 1 cm while the liquids and powders were put in aluminum crucible of dimension 10 cm length, 10 cm height and 5 cm width.

2.2. X-rays scanning technique

The objects under investigation were first scanned by X-rays based on transmission technique. An X-ray beam of single energy was used to examine the above mentioned objects. A fan beam of X-rays was incident on the inspected container and the transmitted X-rays through the hidden object were measured. The degree of attenuation of the incident beam can be used to know the differences in densities between the objects under test. The used scanning system is of the type 101 Van manufactured by American Science & Engineering Company. The system works at operating voltage of 135 KV and current of 4 mA [8]. A schematic diagram of the used X-ray scanner is shown in figure (1).

2.2.1. System description

The Model 101 series of Micro-Dose inspection system uses AS&E’s patented “flying spot” X-ray scanning technology. Radiation generated by an X-ray tube is collimated by combining a long stationary slit and a rotating wheel with four slits to produce a pencil-size X-ray beam. This X-ray beam rapidly scans a parcel as it moves through on a conveyor belt [9].

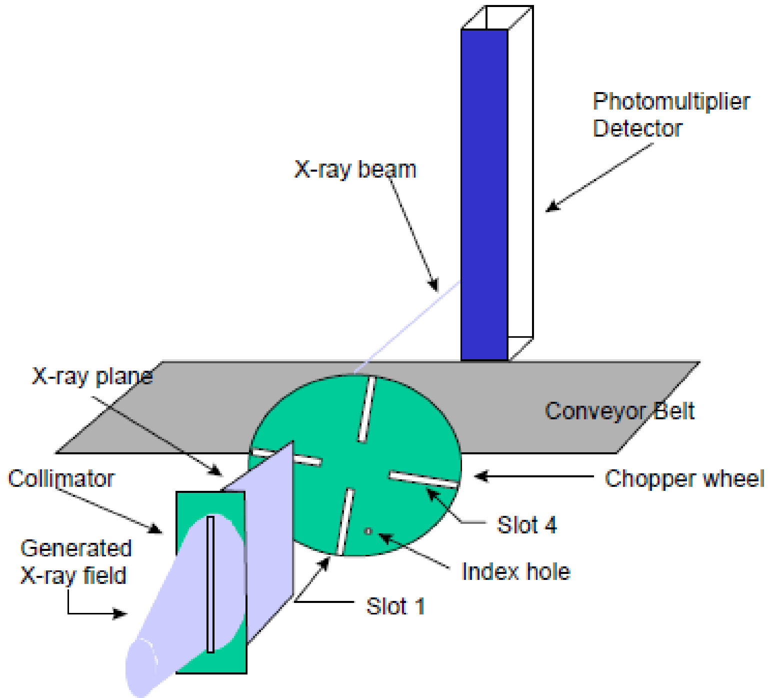

Figure 1: A schematic diagram of the X-ray transmission imaging system.

2.2.2. X-rays transmission imaging

When X-ray beam strikes an object, the individual X-ray photons pass through the object may be absorbed or scattered. To produce X-ray transmission images, a transmission detector is positioned to collect all the X-ray photons that pass through the scanned object. The detector output signal is sampled, digitized, and displayed as a pixel on the monitor. The obtained image indicates that bright regions of the image are those where most of the photons pass through to the detector and the dark regions are those where most of the photons are absorbed or scattered. [10].

2.3. Gamma-ray scanning technique

A gamma scanner was used to transmit gamma rays through objects hidden inside the container. The scanning system consists of manipulating mechanism, gamma radiation source with collimator, gamma radiation detector with collimator and electronic modules to measure the number of counts produced by the transmitted gamma photons. A brief description of scanner's different parts is given below.

2.3.1. Mechanical manipulating system

This system includes a specially designed transfer table where the inspected container is fixed and moved between the radiation source and detector. The table is moving during the scanning processes by a stepper motor. An electrical controller unit was used to adjust the movement increment of inspected container and time of measurement. The displacement increment can be varied from 0.05 mm to 100 mm. the time of measurement for each adjusted position can be varied from 1 sec to 10 minute.

2.3.2. Gamma source and collimator

A Cobalt-60 point gamma source of activity 0.5 Ci was used during the scanning process. The source is fixed in a especially designed shield made of lead and of outer walls of 2.2 mm thick stainless steel. The source shield has a horizontal opining where a gamma collimator with slit of fan beam can be inserted to perform the measurements.

2.3.3. Gamma-ray detector and collimator

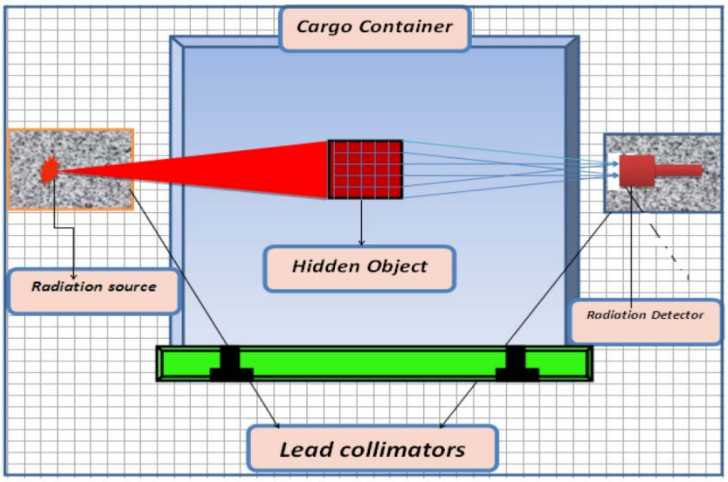

Figure 2: Schematic diagram of gamma-ray scanner.

A NaI(Tl) crystal detector of 12.5 cm diameter and 5 cm thick was used to measure the transmitted gamma-rays through the container during the scanning process. The crystal was coupled to ten stage photomultiplier tube base where the dynode chain and preamplifier are fixed. The detector is surrounded by lead shield on the side directions of 5 cm thick. The detector was shielded from the front side by lead shield with slit opening of 1 cm width and 10 cm height to reduce gamma rays coming from the side directions and to enhance the spatial resolution. The preamplifier output was fed to an amplifier module Ortec 572 A where its output is connected to a counter/timer NIM module type, Ortec 776. Figure (2) shows a schematic diagram of installed gamma scanner.

2.3.4. Image reconstruction from Fan-Beam gamma-Rays

The gamma scanning is performed by moving the container in steps shifted by 1 cm and the transmitted gamma-rays are measured for 60 sec interval. A Cross-sectional 2D image for the suspected object were constructed from the measured transmitted gamma-rays. These images are function of the attenuation profiles of the transmitted photons. The attenuation of the incident photons is given by the Beer –Lambert's law.

$$I = I_0 \exp(-\mu x) \qquad (1)$$

Where, I and I_0 are the transmitted and incident intensities of gamma rays respectively. x is material thickness, and μ is the energy dependent linear attenuation coefficient which depends on the nature of the interrogated material (Panagiotis, 1997; American Science & Engineering, 2001; Lekeaka, 2011). Equation (1) indicates that the number of transmitted photons depends on the attenuation factor and thickness of the interrogated object. The measured photons through the inspected object carry most of information about shape and density of the suspected object. For each pixel the quantities $R=-\log(I/I_0)$ is calculated to construct a two dimensional image with different color zones using MATLAB program version 7.10.0.499 (R2010a).

3. Results and discussion

The photographs obtained for hidden objects of different physical and chemical properties during scanning by X-rays and gamma-rays are given and discussed in the following sections.

3.1. Images Obtained for solid objects Scanned by X and Gamma Rays

The images obtained by the transmitted X-ray technique for the investigated solid objects with different physical and chemical properties are shown in figures (3), (6) and (9). The numbers of transmitted gamma photons through the inspected objects are used to reconstruct the 2D images and attenuation profile displayed in figures (4), (7) ,(10) and figures (5), (8), (11) respectively.

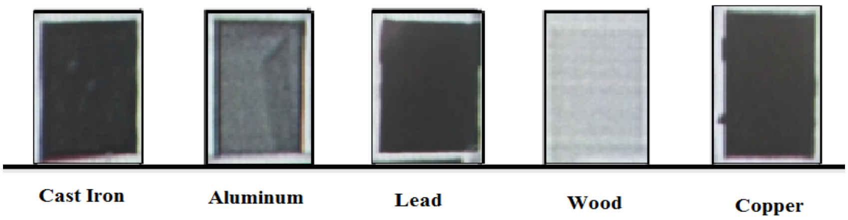

Figure 3: Images of different solid materials obtained by X-ray scanning.

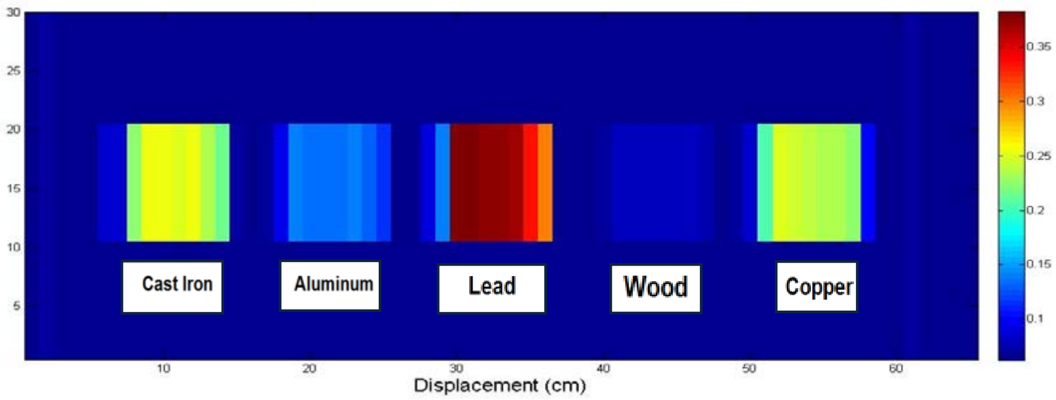

Figure 4: Constructed images of different solid materials by gamma-ray scanning.

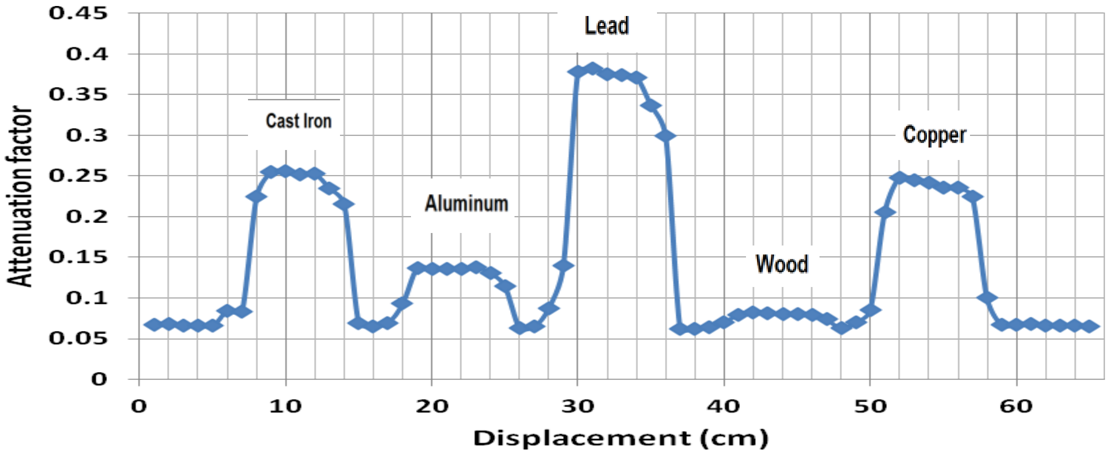

Figure 5: Attenuation profiles of transmitted gamma-rays through different solid materials.

Figure (3) shows that the images obtained by X-ray scanning have small differences in darkness for objects have small variation of density like lead, copper wood can be easily distinguished. However, the constructed images obtained from scanning by gamma-ray transmission given in figure (4) show a very clear and remarkable differences in color for all scanned objects. This means that scanning performed by photons of higher energy are more capable to distinguish objects of different densities even if the differences in densities are very small. The profile of derived attenuation factors from the scanning by gamma rays for the above mentioned objects are given in figure (5). This figure shows a large difference in the value of attenuation factors derived for the investigated materials. These differences agree quite well with color variations observed in figure (4) for the same objects.

Figure 6: Images of different powders obtained by X-ray scanning.

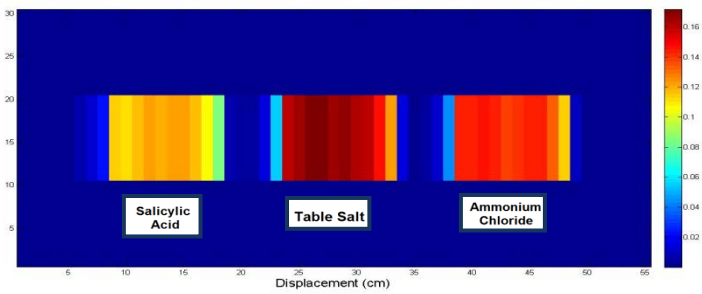

Figure 7: Constructed images of different powders obtained by gamma-ray scanning.

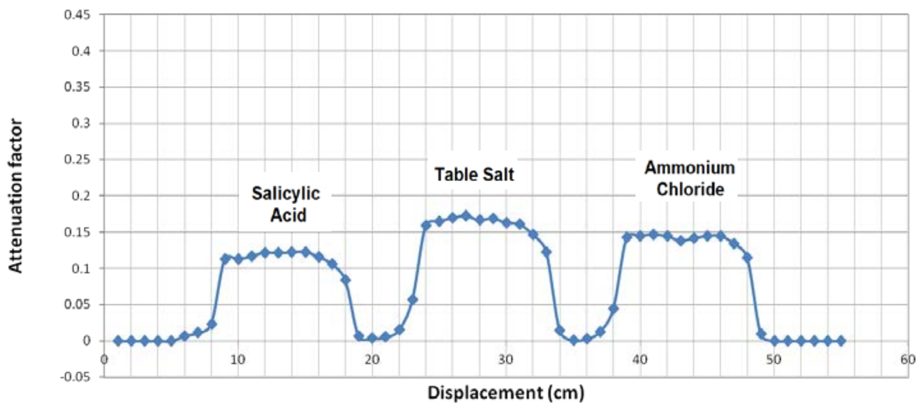

Figure 8: Attenuation profiles of transmitted gamma-rays through different powders.

The obtained images given by X-ray scanning for powder objects of salicylic acid , table salt and Ammonium chloride are presented in figure (6). These images show no appreciable difference in the degree of darkness for the examined objects. The images constructed from transmission of gamma-ray through these objects are given in figure (7). The displayed images show a remarkable difference in color between the examined objects. The profile of derived attenuation factor of these materials is plotted in figure (8). This profile shows a noticeable difference in the values of attenuation coefficients derived for these materials.

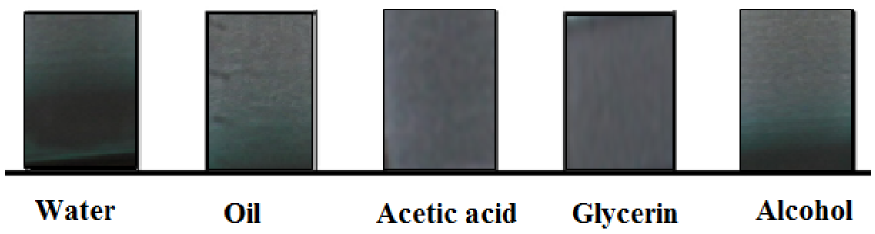

Figure 9: Images of different liquid obtained by X-ray scanning.

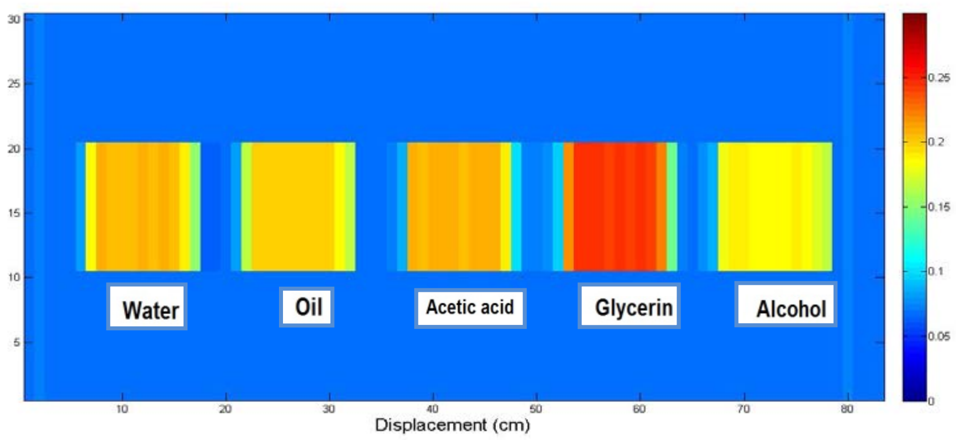

Figure 10: Constructed images of different liquid by gamma-ray scanning.

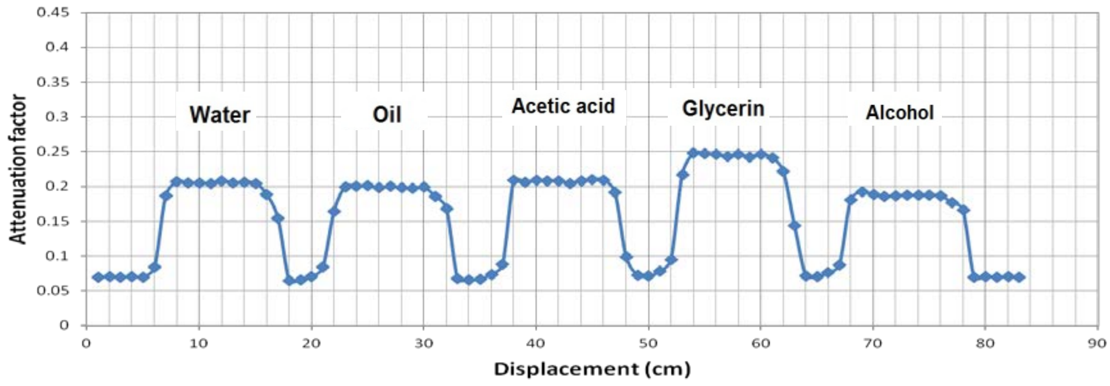

Figure 11: Attenuation profiles of transmitted gamma-rays through different liquids.

The images of similar scanning performed on different liquids of water, oil, acetic acid, glycerin and alcohol by X-rays and gamma-rays scanning are presented in figures (9), (10) and (11). Figure (9) shows that images obtained by x-ray scanning have nearly the same degree of darkness and are very difficult to be distinguished from each other. However, the image obtained from gamma scanning show a noticeable variation in color of these liquids. Further, the attenuation profile relation presented in figure (11) shows a measurable difference in the derived values of the attenuation coefficient. The images displayed in these figures indicate that scanning by gamma photons emitted from Cobalt-60 source give the same information and evidence derived from images obtained by X-ray transmission technique. However, using scanner based on gamma-rays largely decreases the cost of scanning operation and gives more resolved images if the intensity of the incident gammas is stable all over the scanning time. Moreover gamma scanners are more capable for scanning larger objects and heavier materials than the one based on X-rays tube.

Table 1: Density and measured Average attenuation factor of materials scanned objects.

Material	Form	Density, g/cm^3	Average Attenuation Factor
Lead	Solid	11.40	0.3761±0.0043
Copper	Solid	8.92	0.2410±0.0056
Cast iron	Solid	7.86	0.2550±0.0017
Aluminum	Solid	2.70	0.1358±0.0028
Wood	Solid	0.70	0.0801±0.0010
Table Salt	Powder	2.17	0.1596±0.0029
Ammonium Chloride	Powder	1.5274	0.1350±0.0032
Salicylic Acid	Powder	1.4430	0.1102±0.0042
Glycerin	Liquid	1.2610	0.2449±0.0023
Acetic Acid	Liquid	1.0490	0.2078±0.0019
Water	Liquid	1.0000	0.2056±0.0015
Oil	Liquid	0.9188	0.1991±0.0013
Alcohol	Liquid	0.7890	0.1864±0.0041

4. Conclusion

- The following conclusions are derived from the displayed X-ray and gamma-ray images discussed in the previous sections;
- The obtained images by both X-ray and gamma-ray techniques largely depend on the physical and attenuation profile of the interrogated object which in turn depends on the physical and chemical properties of the interrogated object.
- The displayed images obtained by both X-ray and gamma-ray scanners show that both scanners are quite capable to allocate the positions of the hidden objects if the container is loaded with materials having densities differ from these of the hidden objects.
- The ability of the scanning techniques to allocate positions of the hidden objects is vanished if the object is screened by materials of high absorption coefficient.
- A gamma-ray scanner is much cheaper and therefore requires less maintenance than equivalent X-ray scanner. Accordingly, the scanning cost is much less
- Scanners based on gamma- ray emitted from Co-60 source are more capable than their counter parts based on X-ray of 135KV for distinguish objects of small difference in densities. In addition, scanner employing gamma-rays from Co-60 will be more capable to scan containers of larger values.
- Scanners based on X-ray are less hazardous, since X-ray machine is a switch on/off source. However, the scanning by X-ray scanner is more costly than their counterpart based on gamma-rays emitted Co-60 source. Moreover, gamma scanners have the advantages of less weight and size. This make them more suitable for use as mobile scanners.

Acknowledgements

The authors would like to acknowledge the Egyptian Atomic Energy Authority for their support of this work.

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