# Low Cost Combined Systems for Detection of Contraband Hidden in Cargo Containers

R. M. Megahid, A. M. Osman and W. A. Kansouh

Reactors and Neutron Physics Department, Nuclear Research Centre, Atomic Energy Authority, Cairo, Egypt

E-Mail : rmegahid2573@hotmail.com

**Abstract.** The fruitful cooperation between Egypt and International Atomic Energy Agency IAEA through the Coordinated Research Project ( Contract No.13497/RO ) which is concerned with the use of neutron based techniques for the detection of illicit materials and explosives tends to design and construct combined systems to search the contents of cargo containers for illicit trafficking. The systems consist of a scanner based on using gamma-rays emitted from $^{60}$Co source to locate the position of contraband hidden within the payload and an identifier based on using neutrons emitted from Pu-α-Be source to distinguish the suspected object through elemental analysis by fast and thermal neutrons. The systems include as well a especially mechanical system to move the inspected container between radiation sources and detectors. The mechanical system is equipped with an electrical controller unit to adjust the movement increment of the inspected container and time of measurement. A gamma-ray measuring system with NaI(Tl) detector is used to measure the gamma-rays transmitted through the container during the scanning process. The same gamma detector is used to measure the gamma spectrum resulting from neutron interrogation. The measured gamma-rays are fed to two counting stations, the first one is used to count gamma-rays during the scanning process, while the second one is used to record the spectrum of gamma-ray emitted from the suspected object during the identification stage. Results of gamma scanning are presented in the form of 2D images while the results of identification are presented in the form of spectra for gamma-rays emitted from the suspected objects. The obtained results directly indicate that the constructed combined systems are quite reliable, very fast and efficient for detecting contraband screened by steel shield of 1 cm thick. In addition, the systems weight is very low compared with other scanners and therefore can be used as mobile or fixed scanner and can be easily installed at different locations.

## 1. Introduction

The threat of terrorist use of explosives, chemical, biological and radioactive materials has become realistic on the international and national levels especially in Egypt. This makes from the possibility of terrorism attack against civil and strategy targets one of the most important issues on the international political agenda. Therefore illicit trafficking of explosives, chemical and biological weapons, radioactive (mainly fissile materials) through the conventional commercial networks became a real challenge to security of the future.

The inspection techniques which are applied till now are non specific because they are based on using electromagnetic radiation (1,2,3). The only specific method is based on manual inspection which is ineffective solution from cost and time considerations. Inspection systems based on X and γ-rays are only effective for locating position of hidden object, even they lose their effectiveness if the smuggled object is screened by material or materials of high absorption process to X or gamma-rays (4,5). Others technical limitations of inspection by electromagnetic radiation are the small mass attenuation coefficients for light elements (H and N), high mass attenuation for heavy elements, Fe, Pb and U. Further, X and gamma rays posses regular mass attenuation on passing through matters. The latter, makes them incapable to distinguish between elements having nearly mass numbers. In addition, inspection by these methods can not distinguish some types of explosives where TNT, PETN and C4 are somewhat denser while some others have significantly lower densities similar to many common benign materials like common plastics and liquid substances. Further, narcotic materials have a wide range of densities up to 1 g/cm$^3$ and can be molded to any form and therefore eliminating their recognition by shape. Accordingly, development of non-destructive techniques to locate and identify contraband hidden in objects (parcels, trucks, containers) of different size become and are very essential for the success of counter terrorism efforts(6,7).

Nuclear techniques based on using neutrons emitted from different sources, show a number of advantages for non-intrusive analysis, including high penetrability specificity and speed. Therefore, they can be used in combined systems for inspections of objects of different sizes and shapes (8,9) . Accordingly, great research efforts are now running to develop detection systems based on using neutrons with X-ray or gamma-ray scanner to locate and identify smuggled objects for illicit trafficking. Figure 2 shows a schematic diagram for installed systems.

## 2. Description of Installed Combined Systems and Scanning Procedures

The installed combined systems consist of a manipulator system, electronic controller unit, gamma scanner and neutron identifier system. Figure 1 shows a photograph of these systems.

The manipulator system consists of a transfer table which is moved by a step motor. The controller unit allows reproducible position of the inspected container between the radiation source and gamma detectors in step increment varies from 0.05 mm to 100 mm. The system works as well in continuous mode in the backward and forward directions. The movement increment and time of measurement are fixed and controlled by the control unit.

The gamma scanner consists of the radiation source and gamma-ray measuring system. The radiation source is 0.5 Ci $^{60}$Co source fixed in special designed lead shield which provides radiation beams of different geometries. The transmitted gamma rays through the inspected container are measured by NaI(Tl) detector housed in lead shield of 5 cm thick. Slit lead collimators are used between the source and detector to enhance the spatial resolution of the constructed 2D image of the hidden object. The amplified detector output is fed to the input of a Single Channel Analyzer (SCA) to only allow the count of gamma-rays of energy ranges from 1.1 to 1.4 MeV. The output of the SCA is counted by a counter/timer NIM module and is fed at the same time to the input of PC for data processing and image display.

The neutron identifier system is composed of a Pu-α-Be neutron source of 5 Ci activity fixed in specially shield house designed to reduce the radiation background around the system to the allowable level and to enhance the intensity of the neutron flux directed towards the inspected container. The neutron house is provided with a polyethylene moderator fixed at the sides and at the back of the source to enhance the number of slow neutron flux directed towards the inspected container. Also specially designed van beam collimator is fixed at the neutron beam exit to irradiate the whole suspected hidden object at the same time. The emitted gamma-rays resulting from the interaction of fast and thermal neutrons are measured at right angle to the direction of the incident beam to avoid detector irradiation by neutrons and to eliminate the detection of primary transmitted gamma-rays. The amplified output signals of the detector are fed to the input of a MCA for spectrum analysis. Figure 2 shows a schematic diagram of the scanning and identifying systems.

FIG. 1. Photograph of the combined systems

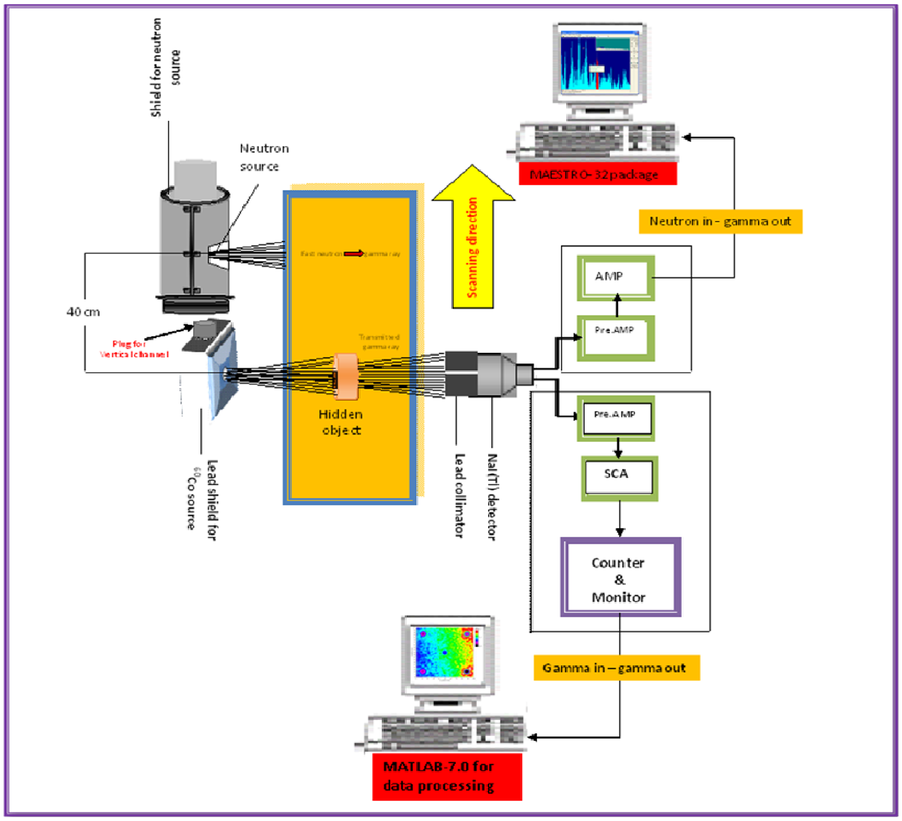

FIG. 2. Schematic diagram for the installed combined systems.

The gamma scanning is performed by moving the container in steps shifted by 2 cm and the transmitted gamma-rays are measured for 20 sec interval. However, the identification of the suspected object is performed by irradiating the whole volume of the suspect object by neutrons emitted from the source through the van collimator and the emitted gamma spectrum was measured for 600 sec. The net gamma object spectrum is obtained by subtracting the spectrum measured at position in the payload far from the object from that measured for the object.

## 3. Results and Discussion

The obtained 2D image for the suspected object constructed from the measured transmitted gamma-rays is displayed in Fig. 3. The image is for an AT mines with 2.5 kg explosive material hidden in container filled with electronic equipment. It is clear that the image gives a good indication of the position of the hidden object inside the container.

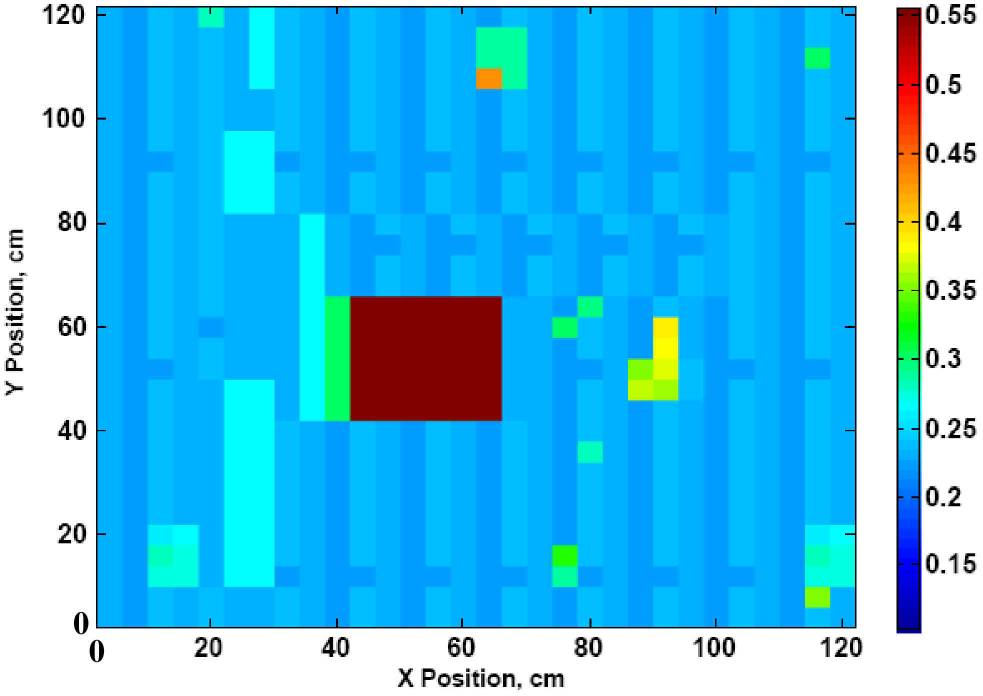

*FIG. 3. 2D-image recnostructed by gamma ray scans of ATM with 2.5 kg explosive hidden inside a container filled with electronic equipement.*

The measured detector response for gamma-rays resulting from fast and thermal neutron interrogation were measured for 600 sec and converted to gamma ray spectrum using Maestro-32 software package. The analyzed data are given as gamma ray spectra i.e. number of gamma photons/s verse photon energy in keV within an energy range varies from zero to 12000 keV. All gamma ray spectra are obtained by subtracting the gamma ray spectrum measured for a position location far from the suspected object from that obtained for position with the suspected object.

Spectra of prompt gamma rays emitted from fast and thermal neutron interactions with the elements of explosive materials and other hidden objects, i.e. $^{1}$H, $^{12}$C, $^{16}$O, $^{14}$N, and $^{14}$Fe are given in this section. Hydrogen can only be detected by measuring γ-energy of 2230 keV emitted from thermal neutron radiative capture. Oxygen and carbon can only be detected by fast neutron interactions with neutrons of threshold energy 6.09 MeV and 4.42 MeV respectively. They have in-elastic scattering reactions, (n, Pγ) and (n, ńγ) with cross sections of 145 mb and 331 mb respectively. However, nitrogen can be detected by measuring gamma rays of several lines emitted from fast and thermal neutron interactions.

Figure 4 shows the net gamma ray spectrum resulting from explosive materials, a landmine (type AT with 2.5 kg explosive) interrogated by 14 MeV neutrons. The spectrum displayed in this figure shows several gamma lines of energy varies from 1 to 5 MeV. The gamma lines shown in this figure are attributed to gamma rays produced from the interaction of fast neutrons with the nuclei of explosive material, i.e. $^{12}$C, and $^{14}$N.

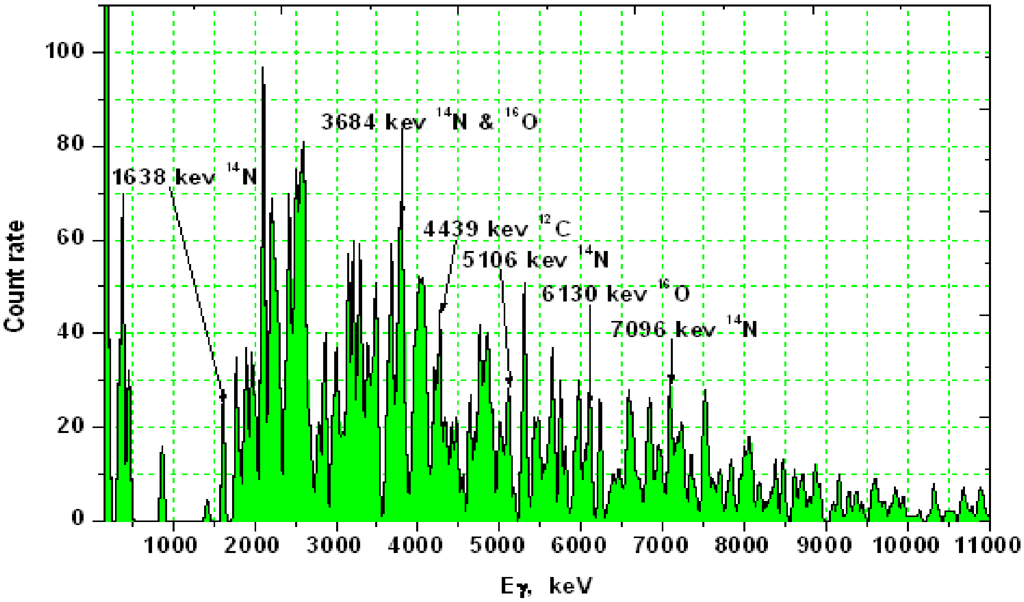

*FIG. 4. Gamma ray spectrum of ATM with 2.5 kg explosive material interrogated with 14 MeV neutrons.*

Figure 5 shows the net gamma ray spectrum resulting from explosive material (the same landmine) interrogated by Pu-α-Be neutrons. The spectrum displayed in this figure shows several gamma lines of energy varies from 2 to 7 MeV. These gamma lines are attributed to gamma rays produced from the interaction of fast and thermal neutrons with the nuclei of explosive material, i.e. $^{1}$H, $^{12}$C, $^{14}$N, and $^{16}$O.

The net gamma ray spectrum for the same mine but hidden inside a steel box with wall of 1 cm thick is shown in Fig.6. The spectrum shows the same gamma lines of energies vary from 2 to 7 MeV shown by the spectrum displayed in Fig.5, but with lower intensities. This is can be attributed due to the attenuation effect of steel box. In addition, the gamma lines resulting from the interaction of fast and thermal neutrons with steel are clearly shown.

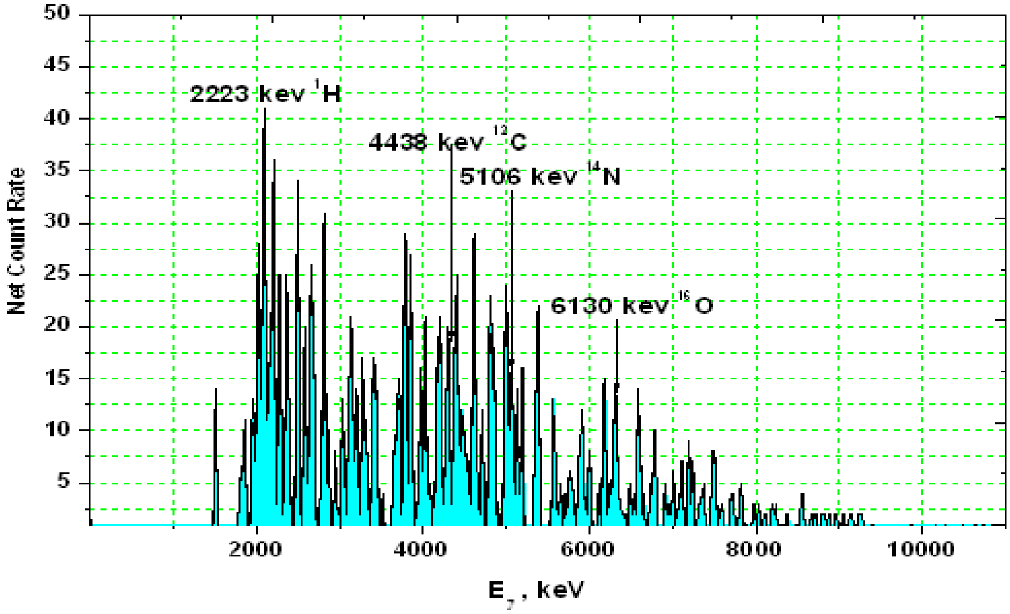

*FIG. 5. Gamma ray spectrum of ATM with 2.5 kg explosive material interrogated with Pu-α-Be neutrons.*

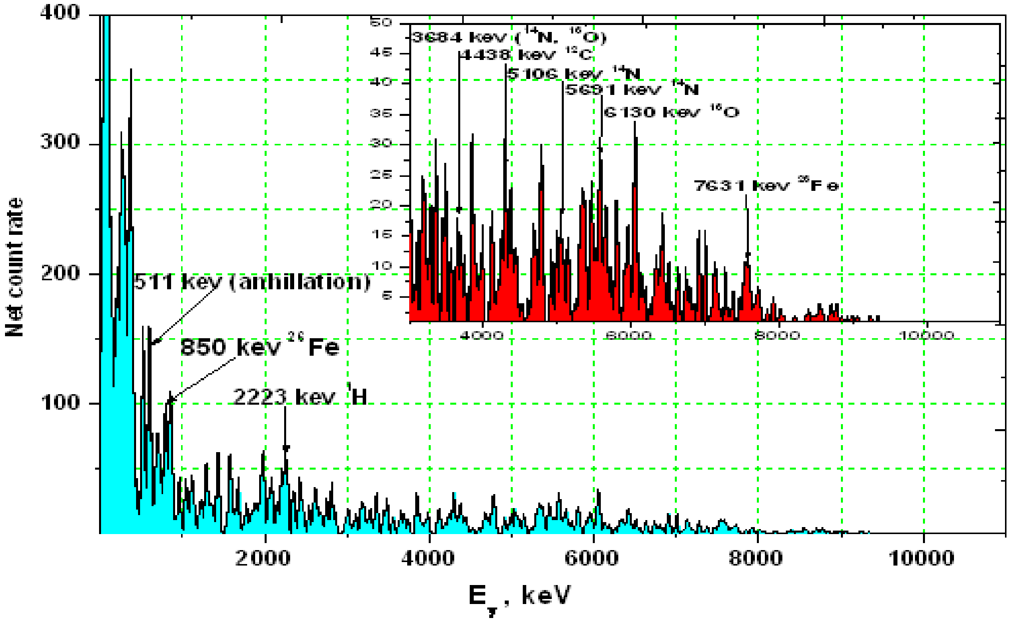

*FIG. 6. Gamma ray spectrum of ATM with 2.5 kg explosive materials shielded with steel box of 1 cm wall thick interrogated with Pu-α-Be neutrons.*

Further, the nitrogen spectrum was also studied using a bottle of nitric acid and the measured spectrum is shown in Fig. 7. The displayed spectrum shows clearly the gamma lines resulting from the interaction of fast and thermal neutrons with $^{1}$H, $^{14}$N and $^{16}$O.

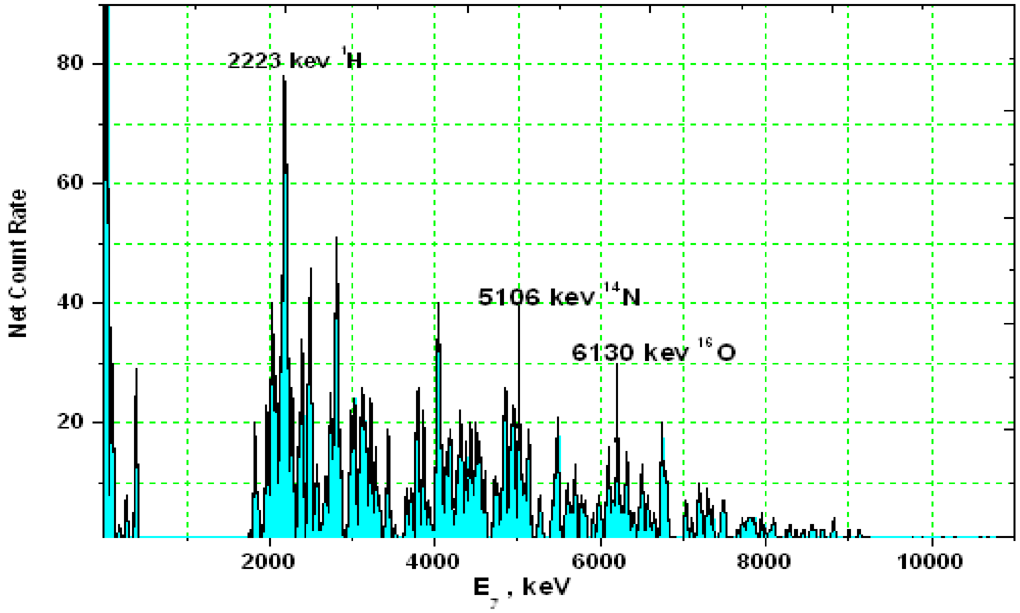

*FIG. 7. Gamma ray spectrum of bottle filled with 2.5 liter of nitric acid interrogated with Pu-α-Be neutrons.*

Figure 8 shows the effect of steel on the gamma ray spectrum for a bottle of nitric acid HNO3 hidden inside a steel box of 1 cm wall thick.

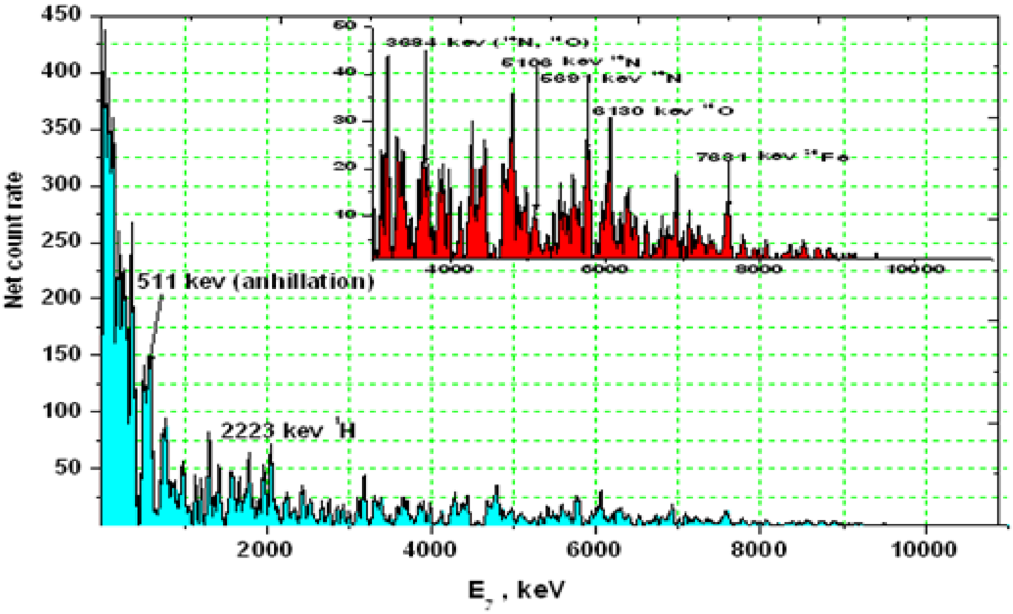

*FIG. 8. Gamma ray spectrum of bottle filled with 2.5 liter of nitric acid shielded with steel box of 1 cm wall thick interrogated with Pu-α-Be neutrons.*

The measured spectra of bare water sample and water sample hidden inside a steel box are displayed in Figs. 9 and 10 respectively. Both spectra show the contribution of gamma ray resulting from $^{1}$H and $^{16}$O. In addition, the attenuation effect of the steel on the emitted gamma lines is clearly shown in Fig. 10.

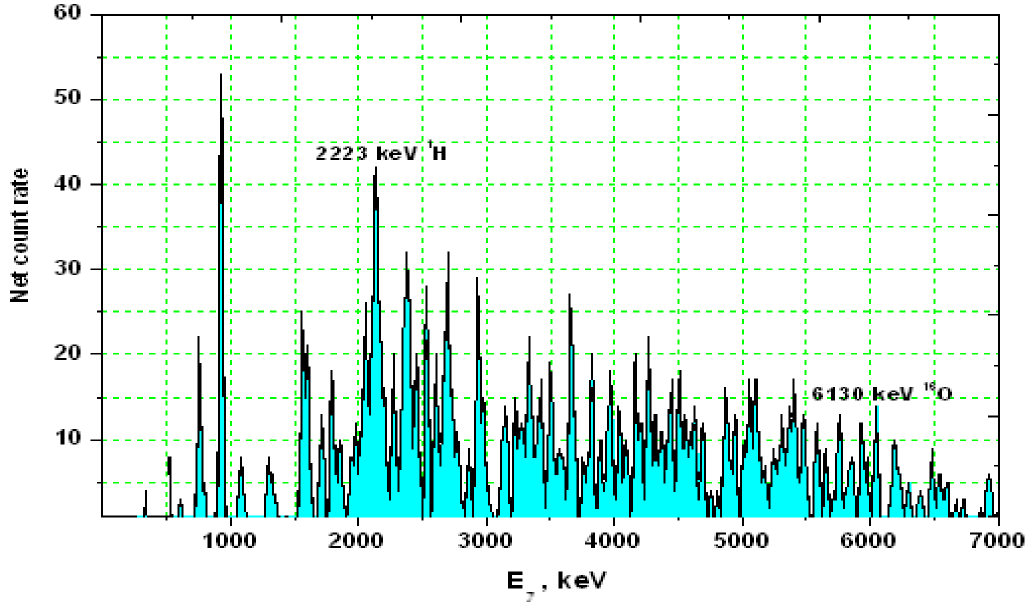

*FIG. 9. Gamma ray spectrum of a bottle filled with 1.5 liter of Water interrogated with Pu-α-Be neutrons.*

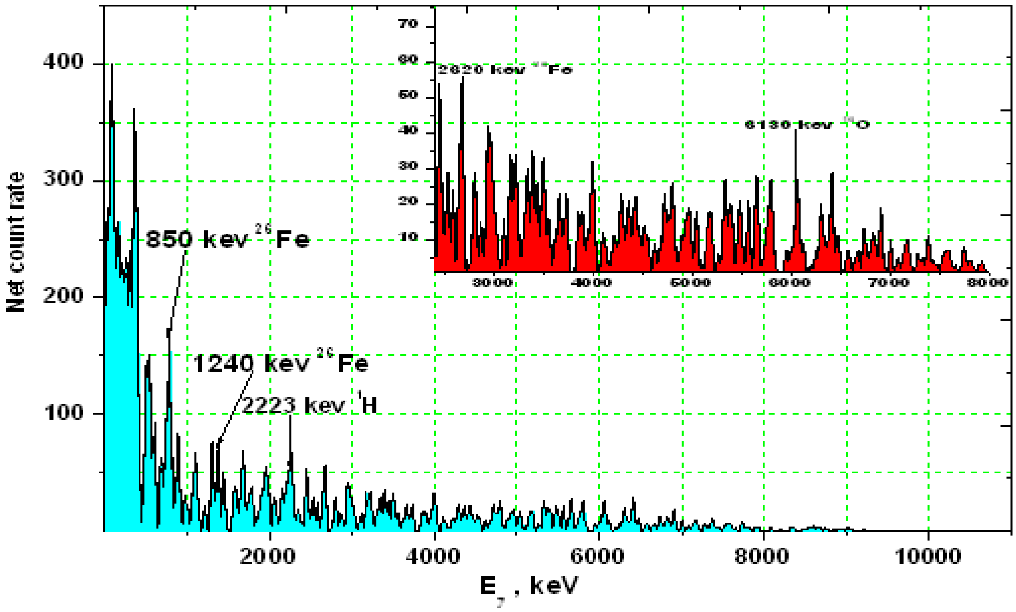

*FIG.10. Gamma ray spectrum of bottle filled with 1.5 liter of water shielded with steel box of 1 cm wall thick interrogated with Pu-α-Be neutrons.*

The net gamma ray spectra given for bare graphite sample and graphite sample hidden inside a steel box (pure carbon signature) are shown in Figs. 11 and 12 respectively. The displayed spectra show gamma lines of energy 3900 and 4438 keV resulting from fast neutron interaction with $^{12}$C.

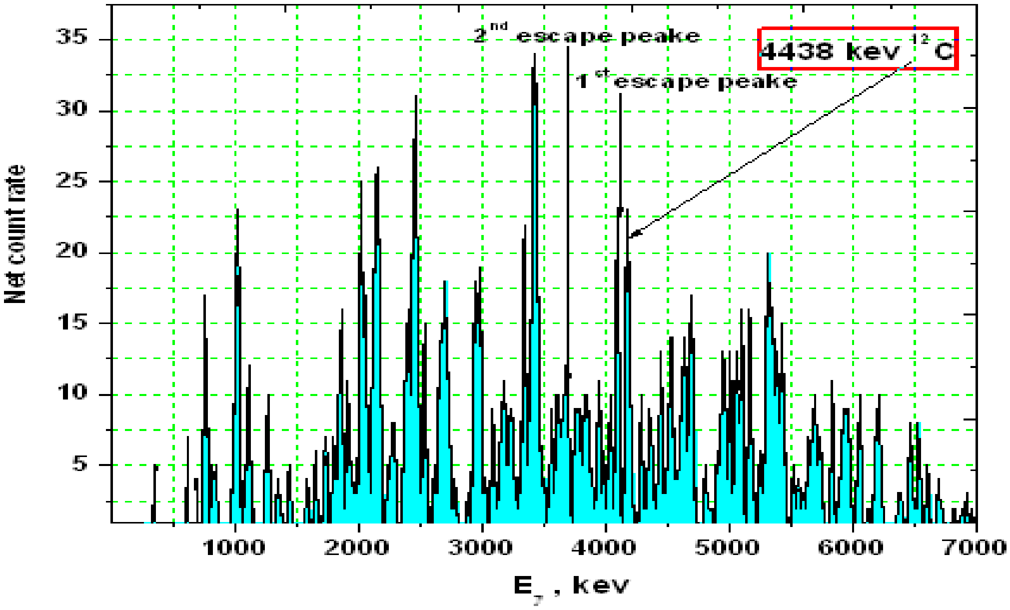

*FIG. 11. Gamma ray spectrum of graphite sample interrogated with Pu-α-Be neutrons.*

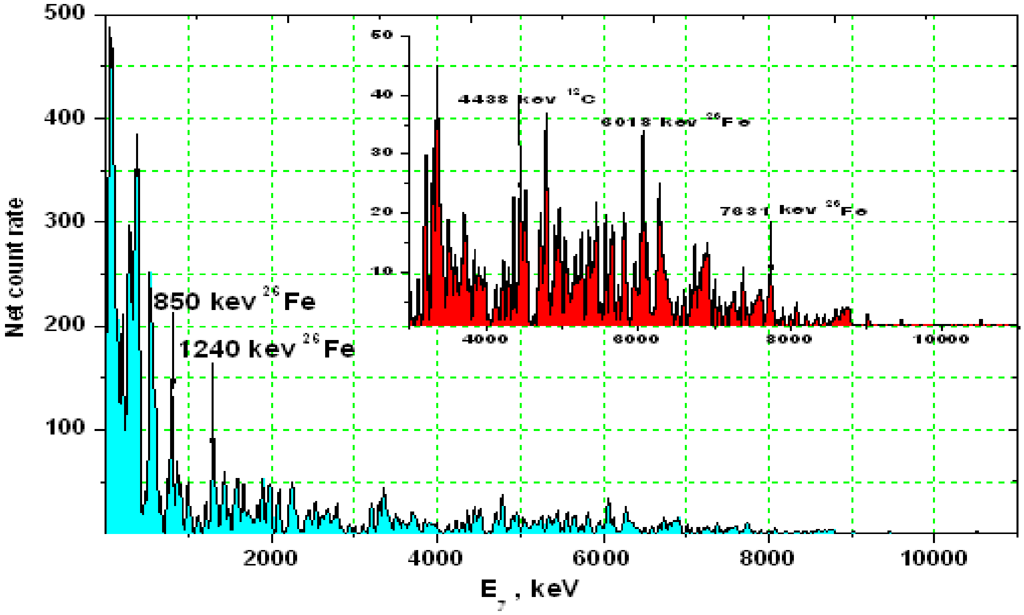

*FIG. 12. Gamma ray spectrum of graphite sample shielded with steel box of 1 cm wall thick interrogated with Pu-α-Be neutrons.*

## Conclusions

The designed, constructed and installed combined systems are effective to locate and distinguish explosives an illicit materials hidden in containers of different size and shape for illicit trafficking. The allocation and identification of the smuggled materials are performed using radio-isotopic gamma and neutron sources. This means that the scanning and identification processes are very simple and of low cost. The systems also show a working reliability and effectiveness for scanning objects screened with materials of high absorption cross section to X and gamma rays.

## References

[1] L. Grodzins, “Detecting Contraband in Luggage”, Nucl. Instr. And Meth. B79, 597-600, (1993).

[2] T. Gozani, et al., “Apparatus and Method for Detecting Contraband Using Fast Neutron Activation”, U.S. Patent #5, 098, 640, field January 1990, awarded March (1992).

[3] Z.P. Sowa, et al., “Contraband Detection System Using Direct Imaging Pulsed Fast Neutrons”, U.S. Patent 5, 076, 993, field January 1990, awarded December (1991).

[4] N. Toyofuku and T. F. Schatzki, “Image feature based detection of agricultural quarantine materials in X-ray images”, Journal of Air Transport Management 13, 348–354 (2007).

[5] H. Vogel and D. Haller “Luggage and shipped goods”, European Journal of Radiology 63, 242–253 (2007).

[6] J.R. Cliffrd, et al., “An Explosive Detection System for Screening Luggage with High Energy x-rays”, Proceeding of the First International Symposium on Explosive Detection Technology, Nov.13-15, (1991).

[7] J.E. McFee and Y. Das, “Advances in the location and identification of Hidden Explosive Munitions”, Report No.548, Suffield, Defence Research Establishment, (1991).

[8] G. Vourvopoulas, “Accelerator based Techniques for Contraband Detection”, Nucl. Instr. Nd Meth. B_89, 388-393 (1994).

[9] G. Vourvopoulos and R. C. Womble, “Pulsed Fast/Thermal Neutron Analysis: A Technique for Explosives Detection”, “ATLANTA”54 (2001) 459-468, G. Eiceman, Editor, ELSEVIER (2001).