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SCANNING OF CARGO CONTAINERS BY GAMMA-RAY AND FAST NEUTRON RADIOGRAPHY

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Abstract–This paper describes the combined systems which were installed and tested to detect contraband smuggled in cargo containers. These combined systems are based on radiographers work by gamma-rays emitted from point source 60Co with 0.5 Ci activity and neutrons emitted from point isotopic sources of 252Cf and Pu-α-Be as well as 14 MeV neutrons emitted from sealed tube neutron generator. The transmitted gamma ray through the inspected object was measured by gamma detection system with NaI(Tl) detector while the transmitted fast neutron beam was measured by a neutron gamma detection system with stilbene organic scintillator. The later possess the capability of discrimination between gamma and neutron pulses using a discrimination system based on pulse shape discrimination method. The measured intensities of primary incident and transmitted beams of gamma-rays and fast neutrons were used to construct 2D cross-sectional images of the inspected objects hidden directly within benign materials of the container and for object screened by high dense material to stop object detection by gamma or X-rays. The constructed images for the inspected objects show the good capability and effectiveness of the installed gamma and neutron radiographers to detect illicit materials hidden in air cargo containers and sea containers of med size. They have also indicated that the developed scanning systems possess the ease of mobility and low cost of scanning.

***Keywords*:** Cargo containers, gamma-rays, 14-MeV neutron generator, organic scintellator, 2D-cross-sectional image

1. Introduction

In advertent movements of illicit materials such as explosives, chemical weapons, narcotics and radioactive materials in the form of radiation sources and contaminated metallurgical scrap have become a problem of increasing importance. Illicit trafficking in nuclear and other radioactive materials is not a new phenomenon, concern about a nuclear ‘‘black market’’ has increased in the last few years particularly in view of its terrorist potential. After the terrorism at September 11, 2001, the illicit materials have been the threaten thing to a human beings in a modern society, so the homeland security has been underlined more and more. A method of nuclear technique has been considered and developed as an inspection system [1,2]. At present, the normal inspection techniques are using X-ray which has the limitation of material specificity. Several features are required in nuclear based inspection system: deep penetration, high accuracy (low false alarm rate), specificity and practicality (cost, size). Nuclear techniques [3-11] using neutrons such as PFNA, TNA, FNSA, etc. are preferred because those can determine the contents of many of the light elements of interest, such as carbon, nitrogen, and oxygen. Some kind of commercial products using neutrons from proton or deuteron beam have been installed at an airport or a harbor. However, still these have some disadvantage in the aspect of cost and size [9].

Fast neutron radiography technique is an effective and a powerful tool for screening cargo for contraband such as narcotics, chemical weapons, and explosives. Neutrons have the required penetration, they interact with matter in a manner complementary to gamma-rays and they can be used to determine elemental composition. Compared to gamma ray radiography, neutron radiography systems are much more efficient especially in case for the detection of nuclear materials smuggling where the traditional methods like X-rays or gamma-rays radiography are fogging.

In this work, the combined systems were installed in the feasibility condition of developing a low cost, fast and effective system to locate and distinguish explosive and illicit materials hidden in cargo containers of varied size and shape are given and discussed with more details in the next section [12].

2. Experimental Setup and Measurements

The installed combined systems consist of container manipulator system and radiography scanners. Figure 1 shows a schematic diagram for these systems. Brief descriptions of the combined systems are given below.

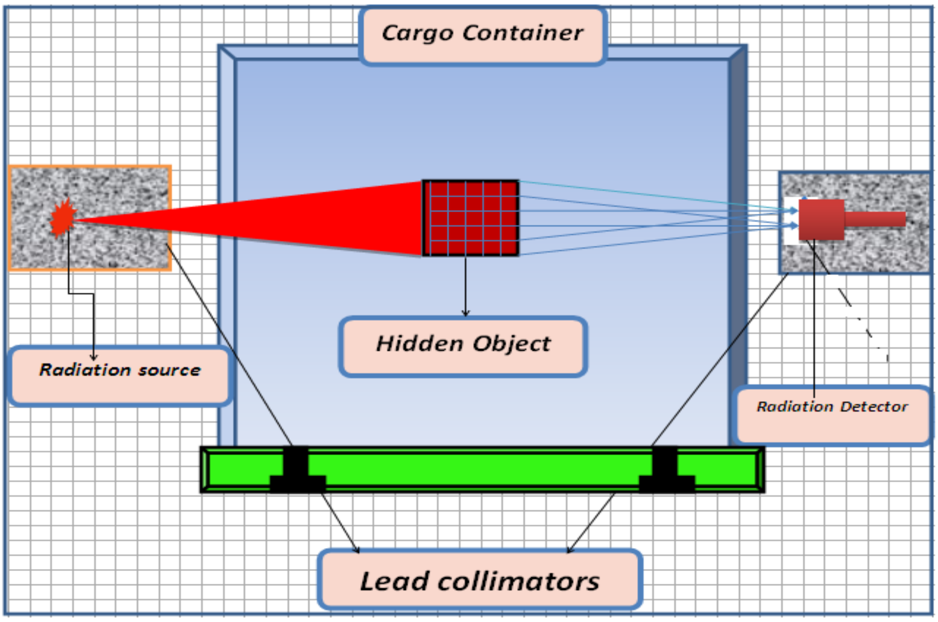

Fig. 1. Schematic diagram of the radiologic scanner.

2.1. Container Manipulating System

The system consists of a transfer table that moves on a steel frame by step motor. The inspected container is fixed on a transfer table which can be moved between radiation source/sources and detector/detectors in step increment that can be varied 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 measurements are changed and adjusted by a control unit.

2.2. Gamma and Fast Neutron Radiographers

In this section, development, adaptation and implementation of radiographers based on measuring the transmitted photons and/or neutrons emitted from different sources are given and discussed. This objective was achieved by gamma or fast neutron radiography methods to locate the position of hidden object. A brief description of the installed gamma and fast neutron radiographer systems are given below

2.3. Gamma-Ray Scanner

A gamma scanner based on using slit beam of gamma-rays emitted from 60Co source of 0.5 Ci activity was built and tested. The source was fixed in a lead shield with horizontal channel where gamma-ray collimators of different geometries can be inserted to have gamma-ray beams of different geometries. The gamma-rays transmitted through the inspected container are measured by a NaI(Tl) detector housed in lead shield with central slit collimator fixed in front of the detector lead shield to enhance the spatial resolution of the 2D image constructed from the transmitted gamma beam. The output signals of NaI(Tl) detector were amplified and fed to the input of a radiation analyzer to only count signals of gamma-rays of energy ranges from 1.1 to 1.4 MeV. The output of scan is fed to a counter/timer NIM module type, Ortec 776, and its output is fed to the input of a PC for signal processing and image reconstruction.

2.4. Fast Neutron Scanner

To improve the scanner workability for detection of objects hidden within thick and high dense materials, a fast neutron radiography system was installed and tested. This system works by using slit collimated beam of fast neutrons of 10 mm width and 20 mm height emitted from 14 MeV neutron generator, Pu-α-Be and 252Cf neutron sources. The transmitted fast neutron beam was measured by a neutron/gamma spectrometer with stilbene scintillator coupled to PMT fixed in high density polyethylene shield with slit opening of the same dimension of the incident neutron beam. The method PSD was applied to achieve discrimination between neutron and gamma peaks.

To have a good quality image by fast neutron radiography a fast neutron source with high emission rate and neutron detector of high efficiency must be used. These two requirements could not be achieved in the installed fast neutron radiography scanner which uses a 5 Ci Pu-α-Be source and organic scintillator with efficiency ~ 20% for neutrons of average energy ~4 MeV. The incident fast neutron flux was enhanced by surrounding the Pu-α-Be source directly with lead of spherical shape to work as fast neutron reflector.

The fast neutron count rate given by the neutron gamma spectrometer was only measured for fast neutrons of energies higher than 3 MeV to avoid artifact in the 2D image due to neutron multiple scattering. Figure 2 shows the circuit diagram of neutron/gamma spectrometer used to measure fast neutron transmitted through the inspected container.

2.5. Image Reconstruction from Fan-Beam Projected Data

Assuming a narrow beam geometry in which the scattered radiation dose not reach the detector, the transmission of photons/neutrons through an object of density ρ (g/cm^3) and thickness X can be calculated using the attenuation relation:

$$I_n = I_0 e^{-\mu x} \tag{1}$$

where I_n is the measured photons or neutrons intensity through the object across X and Y-directions, and the subscript n are refer to the pixel number ($n = 1, 2, 3, \ldots$), I_0 is the incident measured photons or neutrons intensity (the container removes), and μ is the gamma mass attenuation coefficient.

The measured photons or neutrons transmitted through the inspected object carry most of the information about shape and density of the suspected object. For each pixel the quantities $R = -\ln\left(I_n / I_0\right)$ is calculated to construct a two-dimensional image with different color zones using MATLAB program. A hot zone indicated a high density materials or hidden (shielded) organic materials.

3. Results and Discussion

2D images and its projections for ATM with 2.5 kg explosive material hidden in a container filled with foam and other foregoing materials such as rice or ceramic powder are constructed from the measured transmitted gamma-rays and fast neutrons using the MATLAB program. Measurements were performed with a bare object and with the object hidden in rice as a foregoing material and screened in a steel box with a wall thickness of 1 cm.

3.1. Gamma Scanning

Figure 2 show the constructed images and its projections for bare, shielded with rice and steel screened ATM and hidden inside a cargo container. The displayed images give a good indication about the position of the hidden object inside the container.

3.2. Fast Neutron Scanning

Neutron radiographs of bare ATM, shielded with rice and ATM screened with steel and hidden inside a cargo container are given in Figs. 3 and 4 using 14 MeV neutrons and fast neutrons emitted from Pu-α-Be respectively. The displayed images indicate the good detection capability of the neutron scanner using fast neutrons emitted from radio-isotopic sources. They also indicate that the images obtained with the Pu-α-Be neutron source are nearly of the same quality as those obtained by 14 MeV neutrons.

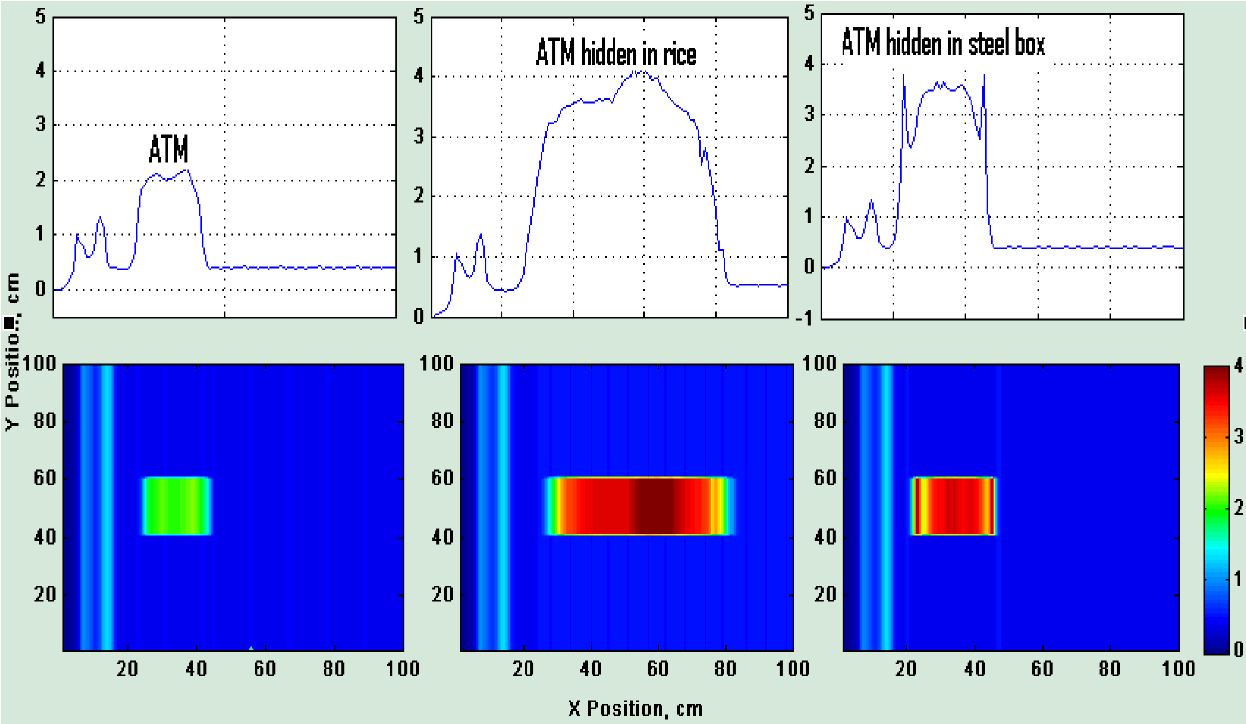

Fig. 2. Spatial distribution and 2D-images constructed from gamma ray scanning of ATM bare, shielded with rice and screened with steel box of 1 cm thick hidden inside cargo container.

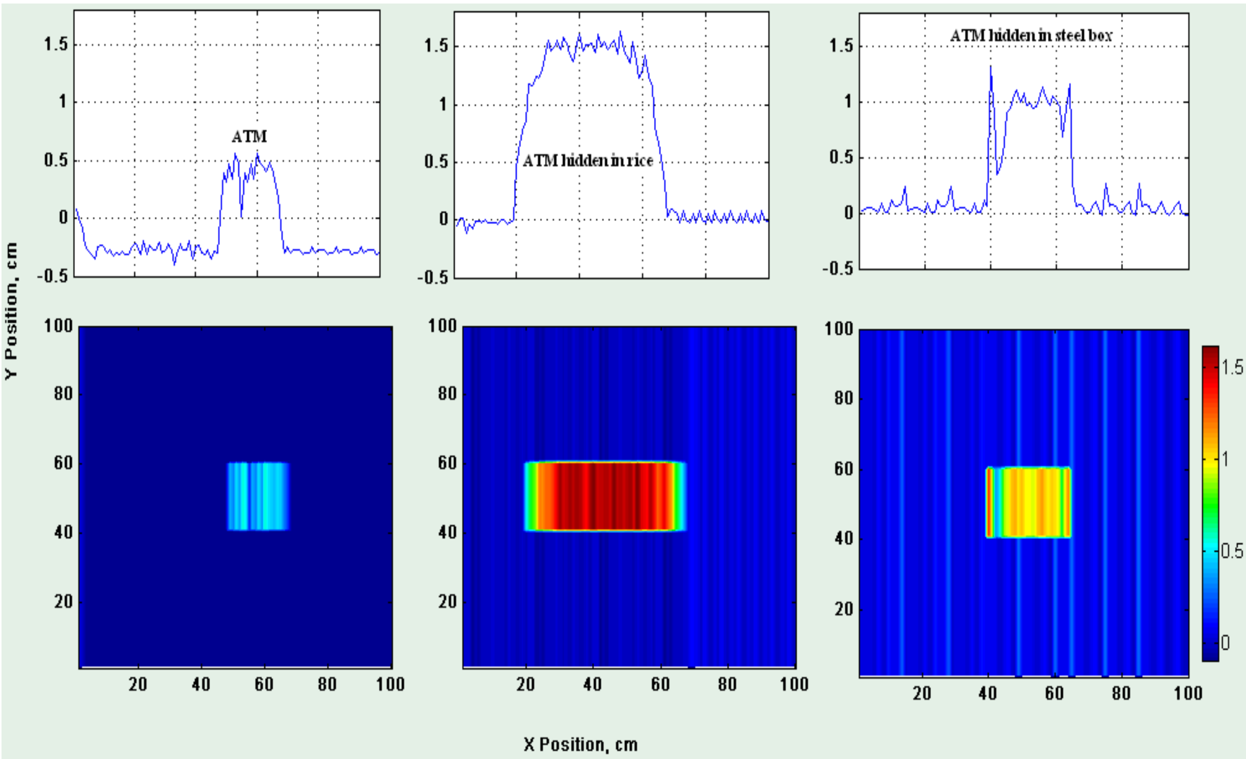

Fig. 3. Spatial distribution and 2D-images constructed from 14-MeV neutron generator scanning of ATM bare, shielded with rice and screened with steel box of 1 cm thick hidden inside cargo container.

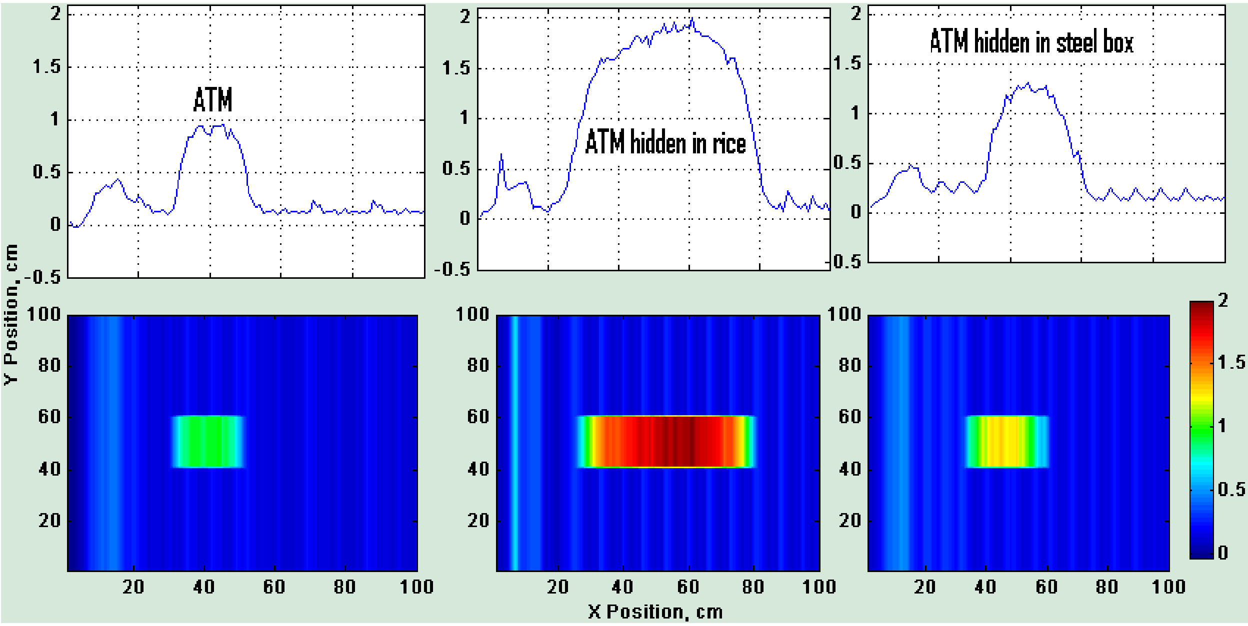

Fig. 4. Spatial distribution and 2D-images constructed from Pu-Be neutron source scanning of ATM bare, shielded with rice and screened with steel box of 1 cm thick hidden inside cargo container.

4. Conclusions and Recommendations

- The installed Radiological scanner can work with either gamma or fast neutron radiography technique. This scanner proves a good imaging capability to locate position of contraband materials hidden in cargo containers, and show nearly the same effectiveness.
- The obtained results indicated that, the use of Pu-α-Be fast neutrons to radiograph objects gives nearly the same image quality obtained by 14 MeV neutrons.
- The effectiveness of scanners working with isotopic fast neutron source can be enhanced to ~40% if the source is surrounded by a fast neutron reflector made of steel.
- An integrated system include this scanner and neutron identifier working with only one Pu-α-Be neutron source possesses highly effective and accurate system to detect and identify different types and shapes of hidden contraband materials.
- To improve the scanning workability and reduce the container scanning time, neutron source of high emission rate ~ 1010 n/s and array of fast neutron detectors with higher detection efficiency should be used.
- Further investigations have to be performed to check the effectiveness of the installed combined system for locating and identifying fertile and fissile materials hidden in cargo containers.

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