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Comparison of the time behavior in the separation of light and heavy materials in X-ray backscattered method as a diagnostic tool in inspection

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ABSTRACT

X-ray backscattered method based on Compton backscattering is used in the inspection field. In contrast to transmission method, source and detectors are positioned on one side of the target, so in the situation that transmission inspection is difficult, X-ray backscattered method can be provided suitable data in the inspection field. Also, detection of hidden explosives and narcotic materials are very difficult or impossible in transmission methods. High intensity backscattered beam from light materials (low-Z), such as explosives and narcotics, in comparison to the heavy materials (high-Z), made this method as the strong technique in inspection. X-ray and gamma photons scattered by the light material (such as PE and PTFE) as well as heavy material (such as Fe and Cu) were studied using MCNPX2.6 Monte Carlo code. The results showed that rise time of pulse from light materials are slower than that of from heavy materials due to multi scattering of low energy photons in the light ones, so time expansion would occur in signals from light elements. If measurement is possible, the difference in time behavior can be used as a novel method in complementary diagnostic tool beside the use of pulse height in X-ray backscattered method.

1. Introduction

Nowadays, X-ray systems have a great use in industry, medicine and inspection centers [1]. The most common method in inspection over objects like bag, baggage, cargo and container, is the conventional radiography which is based on the amount of transmitted intensity of radiation through the materials [2,3], but the major problem in this method is its inability to accurately recognize and detect the hidden low-Z materials such as explosives and narcotics. In return, high intensity backscattered beam from these low-Z materials, in comparison to the high-Z materials, made X-ray backscattered method as a powerful technique in X-ray inspection technique [4,5]. The practical advantage of the X-ray backscattered method is to inspect an object from only one-side. Backscattered X-ray imaging is a unique X-ray imaging technique whereby the scattered X-rays from an object are detected in the generally backward direction [6]. In the more common X-ray transmission method, an X-ray source is placed on one side of the inspected object and an X-ray transmission detector is placed on the opposite, far side of the object [7,8], as shown in the upper left of Fig. 1. This is particularly useful when an object has limited access points or when the interior of the object is complex in terms of overlaying details that an interpretation of a transmission image would be too difficult [9,10]. According to the red area specified in Fig. 2 [11], high-Z materials in widespread range of energy have a great photoelectric cross section, hence, photons, after an interaction with material, are filtered and are scattered with a low probability [12]. Low-Z materials, like organic materials, have low photoelectric cross sections, then Compton scattering are dominant through them. The Compton scattering cross section is given by the Klein–Nishina formula which is nearly isotropic at these low energies. On this basis, organic materials with high density (like narcotic and explosive ones) can generate strong signals due to the high scattering in backward detector which can be considered as the parameter in X-ray backscattered systems [5,13].

According to the different scattering behaviors in light and heavy materials which generate various intensities of signals, shaping times of these signals have been also studied in this paper. So, time parameters related to the interactions of the photon through different materials including high and low atomic numbers have been calculated to evaluate the application of timing

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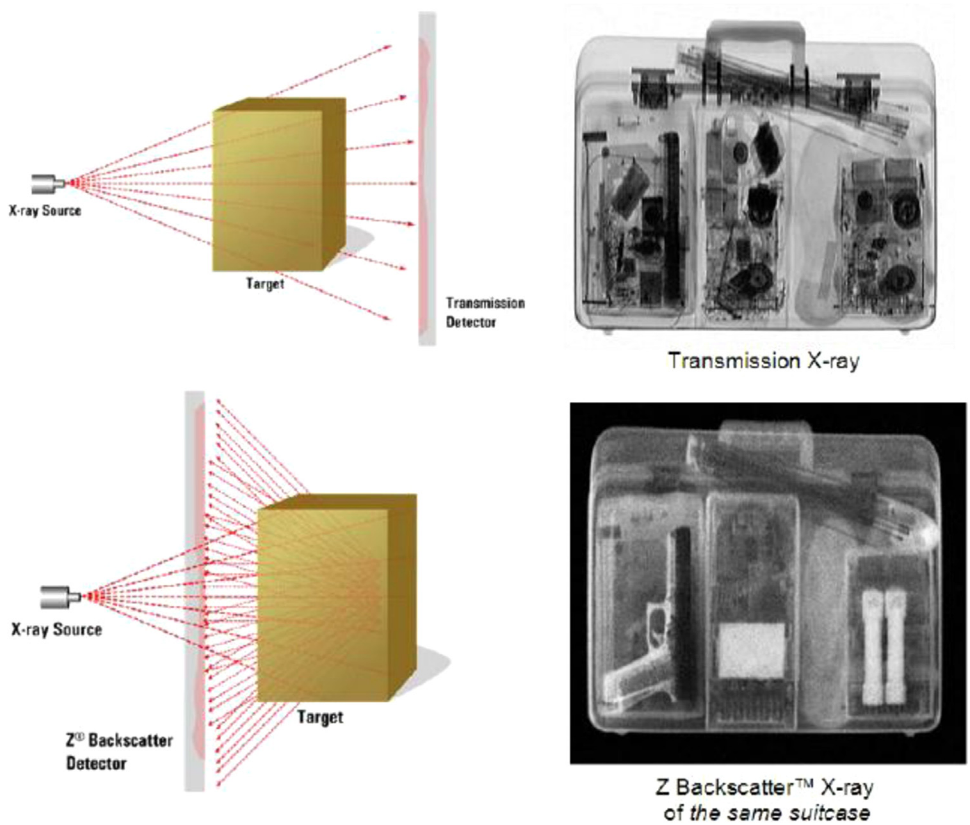

Fig. 1. X-ray transmitted (top row) and X-ray backscattered (bottom row) methods, with simultaneous images of a suitcase taken with both modalities [9].

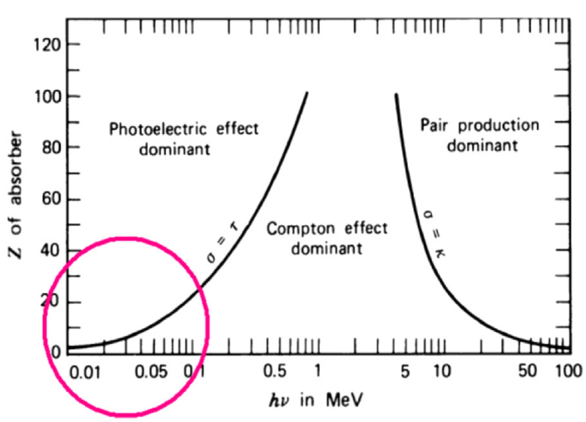

Fig. 2. The relationship between the probability of photoelectric, Compton and pair production based on atomic number and energy [11]. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

techniques in separating light and heavy materials as the complementary data besides signal height analysis (based on pulse intensity). It should be noted that the idea about time behavior methods have not been yet investigated as a diagnostic tool for using in inspection of light elements.

2. Material and methods

The choice of an appropriate X-ray tube (X-ray energy) depends on the type of objects being investigated. Energy selection was performed using MCNPX2.6.

Most of X-ray sources for inspection have Bremsstrahlung X-rays spectrum with peak energy in the range of 50–450 kV,

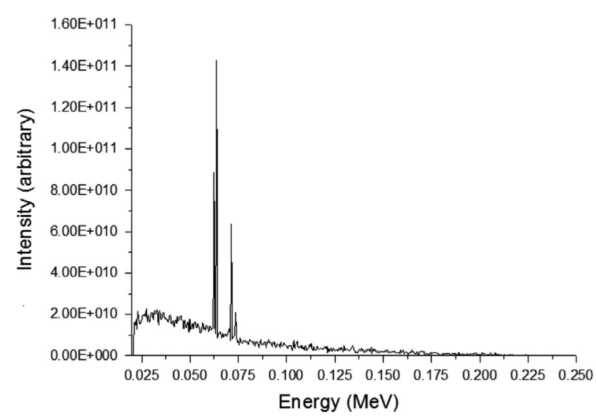

Fig. 3. Simulated energy spectrum of X-ray tube (tungsten anode) with energy of 225 keV.

because penetration falls off rapidly below 50 kV, and tubes with voltage more than 450 kV peak are not easily available for commercial use [4]. Fig. 3 shows the spectrum of X-ray tube with energy of 225 keV (and average energy of 75 keV).

As discussed, the generated photon spectrum from X-ray tube was considered as a beam which was emitted from appropriate collimator. It should be mentioned that the collimator had been designed and optimized to provide the best collimated photon beam. In this study, time behaviors of different materials were investigated, so the simple illustration of collimated X-ray spectrum with required components such as detector were considered (Fig. 4). As shown, intensity of backscattered photons from the sample as well as their time characteristics was recorded in the detector. After studying various materials, iron (Fe, density of 7.87 g/cm^3) and polyethylene (PE, density of 0.93 g/cm^3) were chosen as representatives of heavy and light materials, respectively. Also in a