BACKSCATTER X-RAYS AND AIRPORT SECURITY

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1. Introduction

Due to increased concerns about airport security after September 11, 2001, backscatter x-ray devices have seen widespread implementation in airports around the United States. These devices use Compton scattered x-rays to create computerized outlines of airline passengers and any explosives or weapons they might be carrying. However, there are concerns over the detector's abilities to always detect hidden explosives. There are also concerns about radiation exposure and the long term health effects of that exposure.

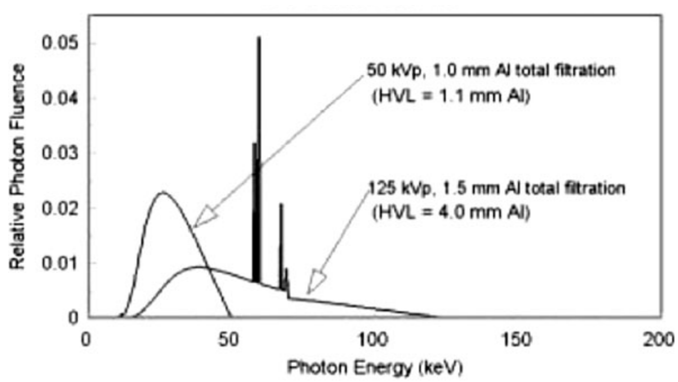

Figure 1. X-ray spectra for low and high energy sources [1].

2. X-ray Source

Figure 1 show the energies of two different x-ray sources used in airport backscatter detectors. The higher-energy source, which runs at 125 kVp, has a higher voltage than that used in mammography. The lower-energy source, which runs at 50 kVp, has a voltage about equal to the voltages used during CAT scans [1].

There are two methods for moving the source past the object to be imaged. One method involves moving the imaged object in a plane perpindicular to the x-ray beam, as seen in figure 2. The second setup involves moving the x-ray source over the target, as seen by Herr et al. [3]. This is similar to what is used in current detectors seen in airports.

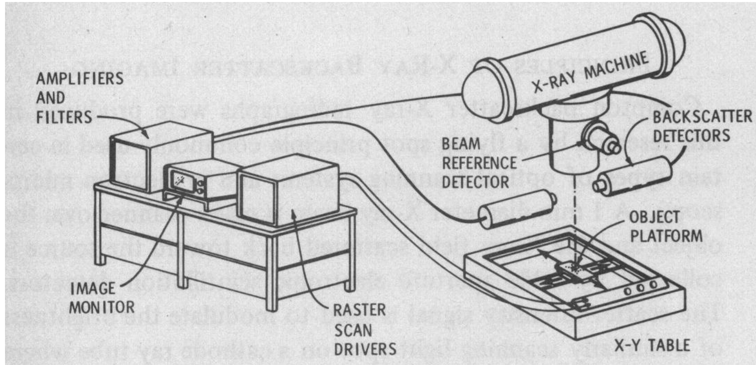

FIGURE 2. Basic setup of a backscatter x-ray detector [2].

3. Compton Scattering of X-rays

Compton scattering occurs when photons interact with the electrons in an atom's shell. The photons scatter off at an angle with respect to the original direction of motion. The Compton scatter coefficient, μ_c, is given by $\mu_c = K_1 \rho n f(E)$. K_1 is a constant in the region of energies used, n is the electron density of the imaged material, ρ is the mass density, and $f(E)$ is a sensitivity to energy [2]. The difference in penetration depths between two energies is based on the change in μ for the two energies, along with the change in tube output flux (I_2/I_1). The change in penetration depth is given by $x_2 = x_1 \frac{\mu_2}{\mu_1} \ln(I_2/I_1)$. This results in a change in signal intensity due to thickness or density of the imaged object, the beam energy, and the beam intensity [2]. Figure 3 shows the backscattered image intensity as a function of object thickness.

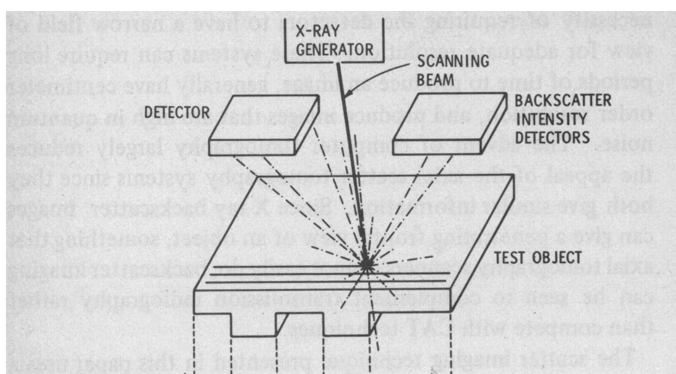

FIGURE 3. Image showing intensity of the backscatter signal as a function of object thickness [2].

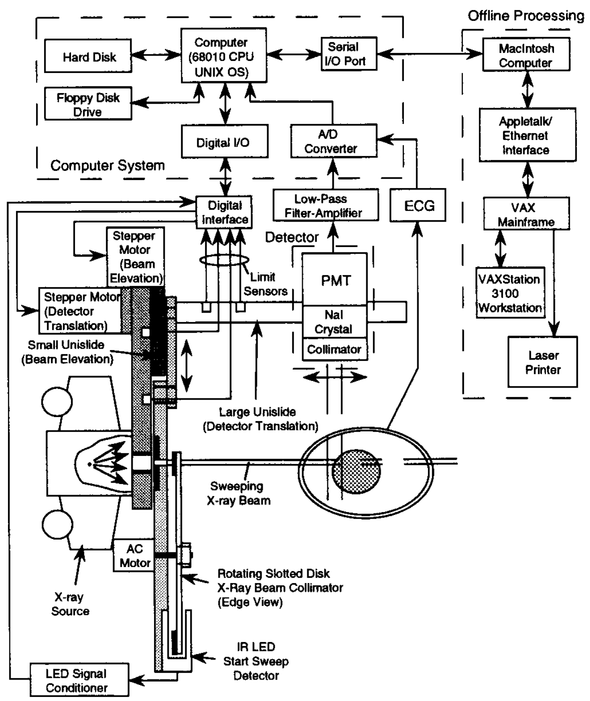

Figure 4. Basic setup of a backscatter x-ray detector [3].

4. Detection and Image Processing

Backscatter detection only focuses on the portion of photons scattered back towards the x-ray source. This can be done with scintillators made out of materials such as sodium iodide. The signals from the scintillators are then passed to photomultiplier tubes. These signals are amplified and then converted to digital signal for processing, as seen in figure 4.

X-ray backscatter imaging can be used to see through objects. This can be done by subtracting a lower energy scan from a higher energy scan. This removes the nearer object from the image, leaving the object visually masked from the detector [2]. The results of this can be seen in figures 5 and 6.

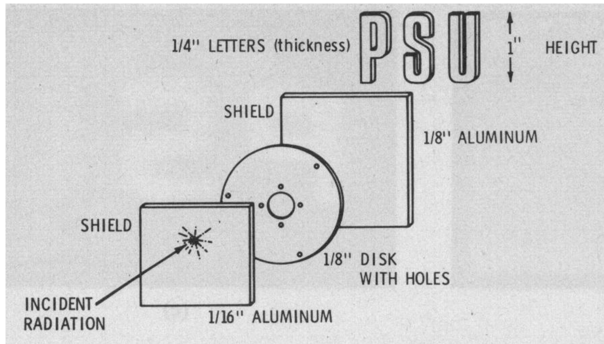

FIGURE 5. Image (a) shows an image of the setup made at 40kVp. Image (b) shows an image made at 90 kVp. Image (c) shows the results of subtracting image (a) from image (b) [2].

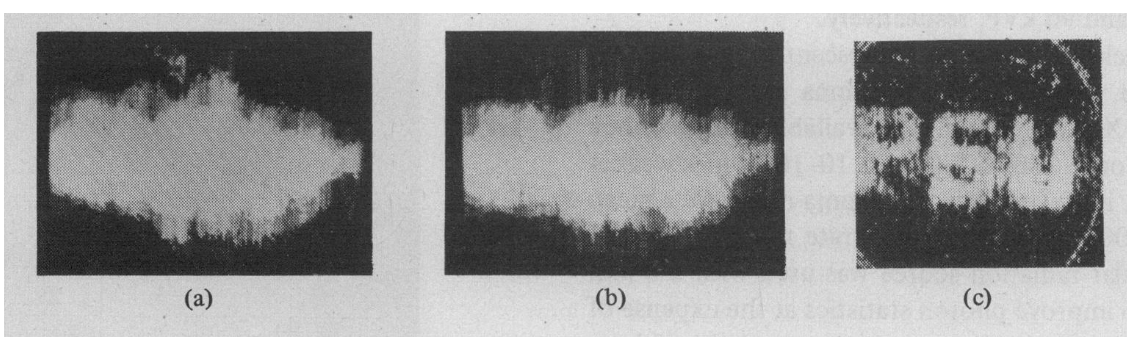

FIGURE 6. Image showing experimental setup for backscatter imaging by subtraction [2].

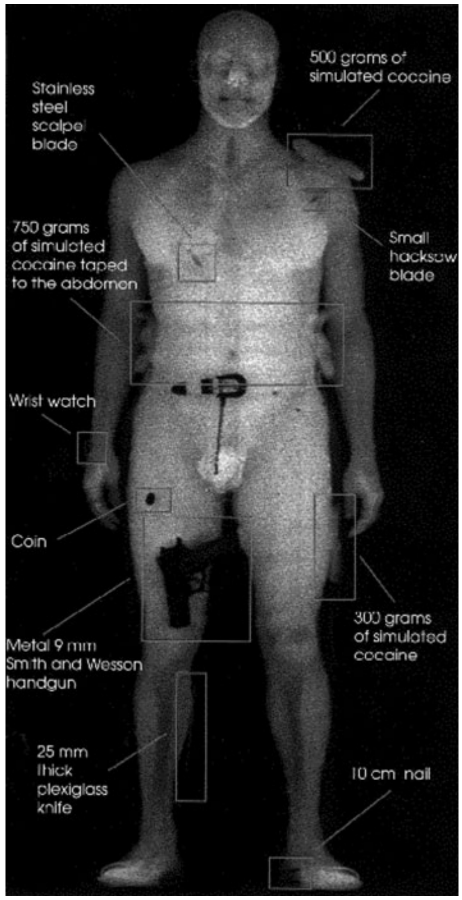

Figure 7. Image showing detected contraband [1].

Modern airport detectors operate on similar principles but produce much higher quality images. They can detect contraband hidden on the body, as seen in figure 7. However, the ability to detect all hidden contraband is under scrutiny. Kaufman L. and Carlson J.W. ran a Monte Carlo program (developed by Agnostinelli et al. [4]) in order to simulate contraband hidden on tissue [1]. The authors created cylindrical tissue to represent the abdomen. They ran the simulation with no added material, 160 g of added tissue, 190 g of added TATP explosive, and 320 g of added PETN explosive. The added objects were formed in a cone 20 cm in diameter and 1 cm in height at the center. Figures 8 and 9 show the results of the simulations. As can be seen, some of the additions are barely or not at all visible. The results question modern airport detector's abilities to image explosives in all situations.

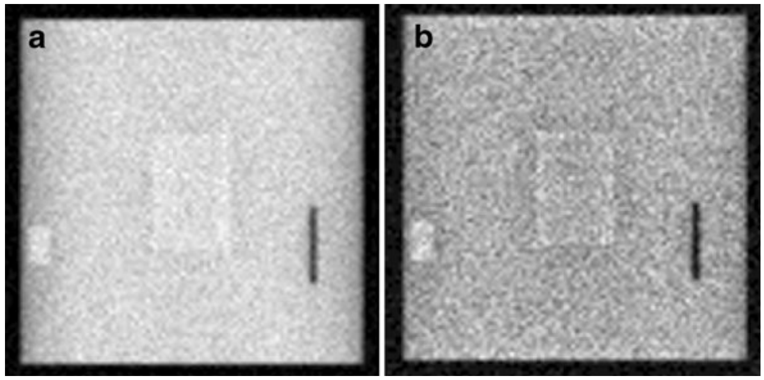

Figure 8. Simulated images showing (a) high and (b) low voltage detections for a 10nGy imaging of 150 g of rectangular tissue (15 x 10 x 1 cm) [1].

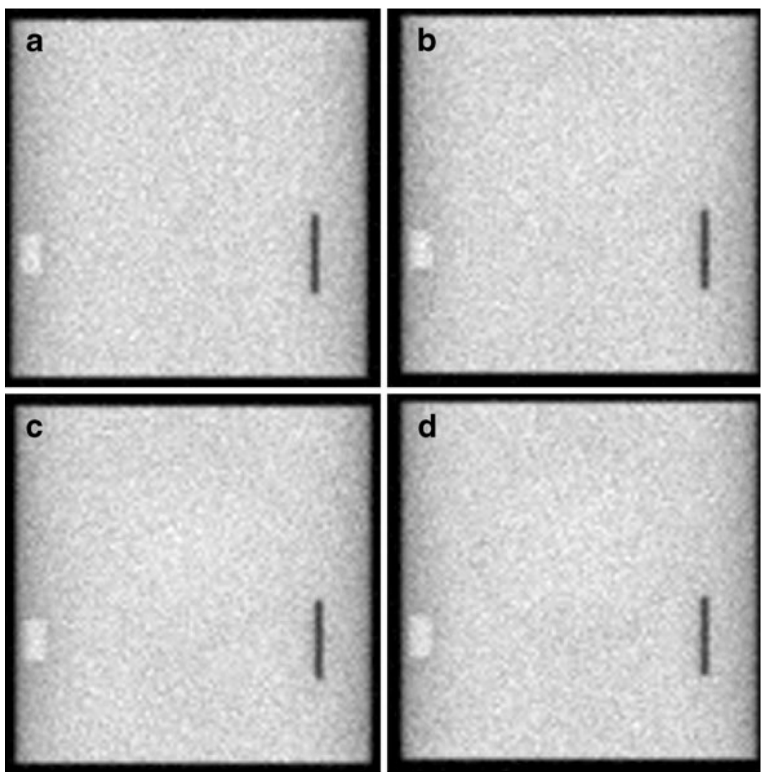

Figure 9. Simulations at high voltage and 10 nGy exposure. (a) Only tissue (b) Added conical tissue (c) Added TATP (d) Added PETN [1].

5. Health Concerns

In addition to concerns about the effectiveness of backscatter x-ray detectors at detecting all explosives, there are concerns about the exposure to radiation experience by millions of airline travelers. Figure 10 shows estimated doses for one backscatter scan. This would result in an increased cancer risk of 10^{-7} for a round trip of two screenings [5]. However, this risk is based on extrapolating higher risks and is therefor uncertain.

While individual risks are low, the population risk is problematic. With 10^9 exposures per year, the exposure level is no longer minimal. However, the TSA has also purchased millimeter-wave imaging devices [6] which are non-ionizing. With the availability of these devices, the use of backscatter detectors, with their potential dangers to public health, seems unfounded.

Estimated Skin and Effective Doses per Scan for X-Ray Backscatter Scanners

Dose	50-kVp Scanner	120-kVp Scanner
Skin (μGy)	2.5	0.7
Effective (μSv)	0.9	0.8

Figure 10. Estimated dose from one backscatter scan [5].

References

[1] Kaufman L. and Carlson W.L., "An evaluation of airport x-ray backscatter units based on image characteristics," *Journal of Transportation Security*, vol. 4, pp 73-94, 2010.

[2] Towe, B. C. and Jacobs, A.M., "X-Ray Backscatter Imaging," *IEEE Transactions on Biomedical Engineering*, vol. BME-28, No. 9, pp 646-654, 1981.

[3] Herr, M. D., McInerney, J. J., Lamser, D. G., and Copenhaver, G. L., "A Flying Spot X-Ray System for Compton Backscatter Imaging," *IEEE Transactions on Medical Imaging*, vol. 13, No. 3., 1994.

[4] Agostinelli, S., et al., "Geant4 - a simulation toolkit," *Nuclear Instruments and Methods in Physics Research A 506*, pp 250-303, 2003.

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[6] Sheen, D. M., McMakin, D. L., and Hall, T. E., "Three- Dimensional Millimeter- Wave Imaging for Concealed Weapon Detection," *IEEE Transactions on Microwave Theory and Techniques*, vol. 49, No. 9, 2001.