Compton scattering as a probe for materials investigation

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Abstract
This article investigates into the feasibility of using gamma radiation Compton backscatter spectra as a means of material characterization, with the view to developing a portable, hand held probe for investigative purposes such as searching for illicit substances hidden in wall or car door cavities.

Keywords: Compton scattering, material characterization, portable system, illicit substances

1. Introduction

There are several methods for material investigations based on nuclear techniques. One of them which is very common in landmine detection is neutron source [1]. But, the disadvantages of using a neutron source are 1-it is only used for non-metallic objects, 2-the detection system is not very portable and 3- it will produce unwanted radioactive materials. Another method for materials investigation is Compton scattering. Using gamma radiation with energies up to 384 keV, and materials with Z less than about 60, which includes the majority of everyday materials, the predominant interaction process for the radiation will be Compton scattering. A relatively high-energy source is required to achieve the necessary penetration, and so ^{133}Ba with energies in the range 50 to 384 keV and a half-life of 10.8 years are ideal. The spectra, which result from the incident radiation scattering from a medium, will be the basis of the material characterization. Figure 1 shows diagrammatically the setup, which was employed to generate these scattered spectra experimentally.

This geometry allows a minimum scatter angle for a single interaction to reach the detector of 45 degrees, producing a path length through the material of 2.5 cm.

All the experiments involved this setup, only varying the material or the distance of the detector to source. The experiment was designed such that the source and detector were as close to the scattering material, and as close together as possible, so that only a negligible amount of gamma rays reached the detector directly, that is without scattering.

2. Detector Selection

There are many radiation detector types available, and choosing the correct one for the job is most important. The final product is required to be hand held and portable, so it must work at room temperature. For the purpose of this investigation, the emphasis of detection is not entirely on spectroscopic clarity, but also on effective gamma-ray detection efficiency per unit volume. The most suited candidates are NaI(Tl) and CdTe detectors [2, 3, 4]. In this article spectra are taken of the Barium source of 1MBq activity using the NaI(Tl) detector. This is a scintillator with an excellent light output and efficiency. The NaI crystal had a diameter of 60 mm, thickness 51 mm and a resolution power of 7.5% at 662 keV energy.

But, the disadvantage of this detector is that it does not easily allow angular data to be obtained. Figure 2 shows calculated efficiencies for a 76 mm diameter, 76 mm high (3" × 3") NaI(Tl) crystal as a function of the gamma-ray energy and the source to detector distance [5]. Figure 3 shows a ^{133}Ba spectrum using this type of detector: the top figure is for direct ^{133}Ba spectrum and the bottom figure is after scattering from organic fertilizer.

3. Experimental Techniques

Using the setup shown in figure 1, spectra were accumulated for sufficient time to produce reasonable plots with different materials as scattering media. The materials chosen to give a general cross section of relevant substances were: Organic fertilizer, wood,
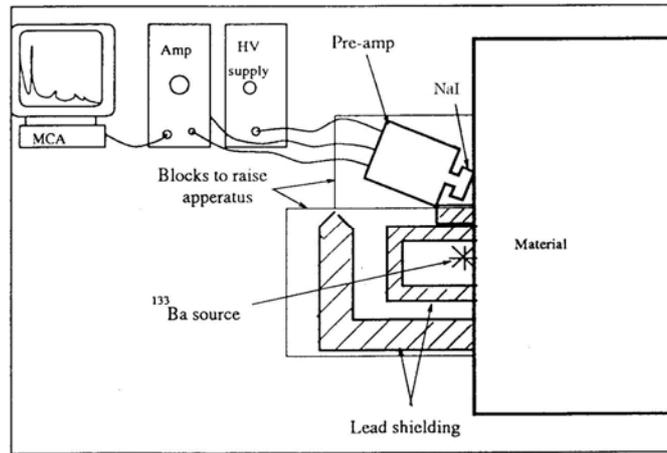
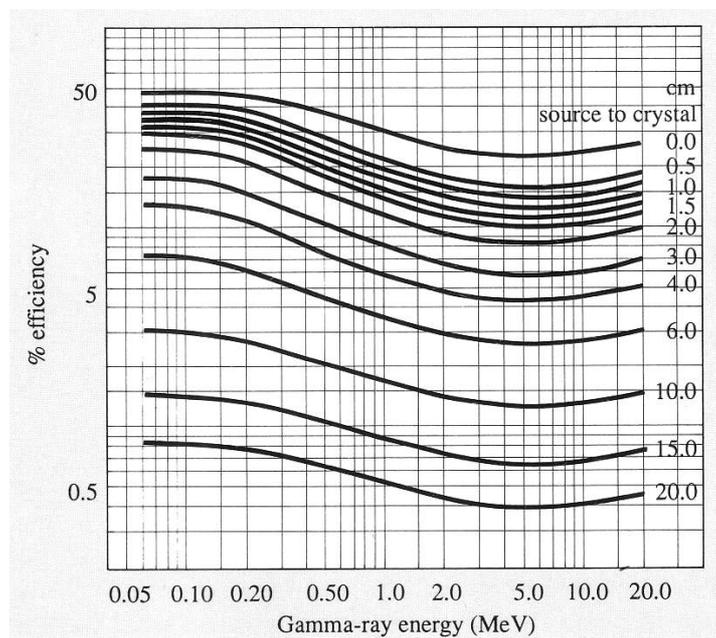**Figure 1**: Experimental setup.

Figure 2. Calculated efficiencies for a typical scintillation detector as a function of the gamma-ray energy and source to detector distance.
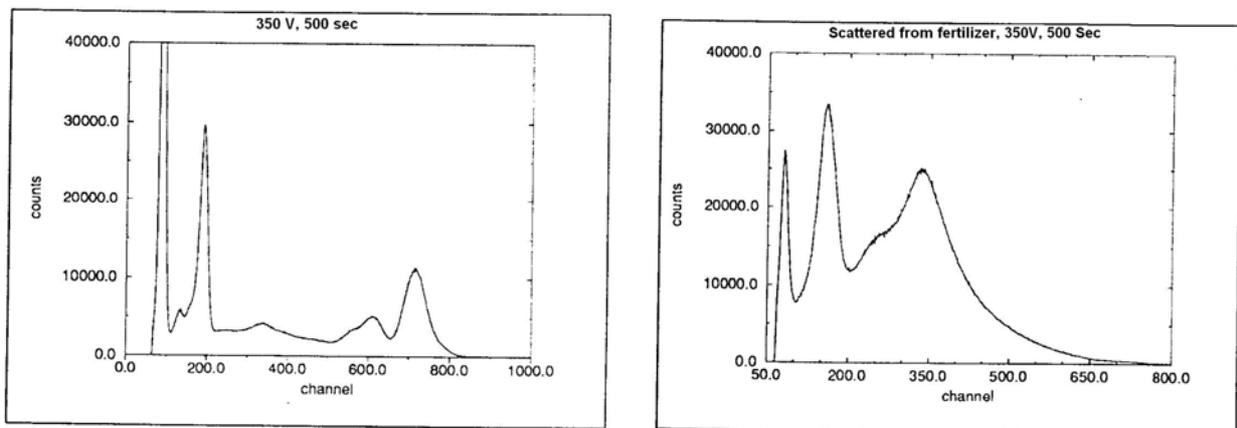

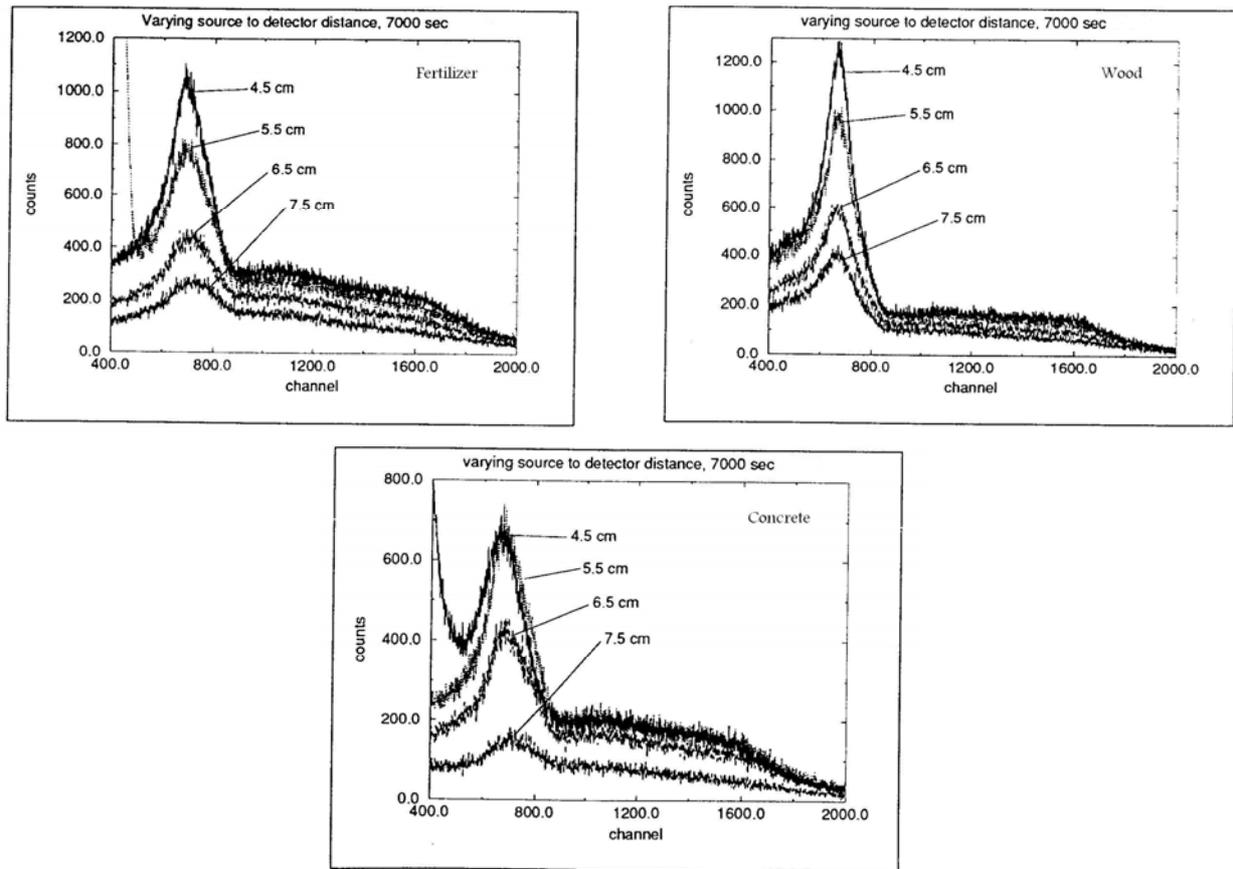**Figure 3.** Barium spectrum before and after using organic fertilizer.

Figure 4. Compton scatter spectra for three materials.

concrete and Steel.

The distance between the source and NaI(Tl) detector was increased in 1 cm increments to determine whether this produced any difference in the resulting spectra, other than simply decreased counts due to the $1/r^2$ dependence of intensity caused by increasing path length. Spectra were acquired for all four materials and for source to detector distances from 4.5 cm up to 32 cm. The spectra for distances above 7.5 cm were poor and noisy. The spectra for steel were all noisy due to the high Z of the material and any differences were indistinguishable above this noise.

Figure 4 shows spectra from different distances for (a) fertilizer, (b) wood and (c) for concrete. As it can be seen from the figures, the 4.5 cm distance had the best outputs. The nearly flat part on the right of spectra is due to pile up and they have no physical meaning.

By trial and error, it was found that in order to accumulate sufficient counts to minimize the statistical fluctuation errors for all materials, a data acquisition time of 7000 seconds was required. It was hoped that the spectra produced by scattering from different materials would be sufficiently different to "fingerprint" the material and allow distinction between them. To test this, the spectra produced from the four materials, which were tested, are plotted together in figure 5.

From the plots it is immediately obvious that there exists a clear difference in the spectra between the different materials. Five features can categorize this difference:

1-Total integral counts
2-Centered low energy peak channel
3-FWHM of the peak

The superior resolution of the NaI(Tl) detector enables peak position to be determined with confidence. The wood has a larger proportion of the counts in the low energy peak, the lowest central peak position, the highest peak value and a narrow FWHM. The ratio of counts in the peak versus counts in continuum will be highest for wood.

The FWHM is greater for fertilizer than the other materials; however, the other materials are not reliably distinguishable by this factor alone.

The difference in the total counts in each spectrum is at least partly due to the Z of the scattering material, as a higher Z will mean an increase in the attenuation, and the probability of photoelectric absorption, both of which will decrease the number of photons reacting the detector. There may also be a separate density relationship. The density of each material was experimentally calculated and is given together with other data in the table 1.

The data suggests that FWHM may be related to the density of the material. More data is needed to produce any certain correlations. To attempt to acquire additional information about the material, spectra were taken with
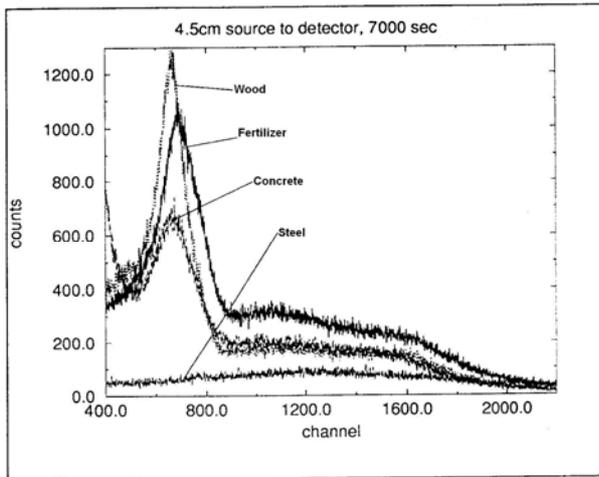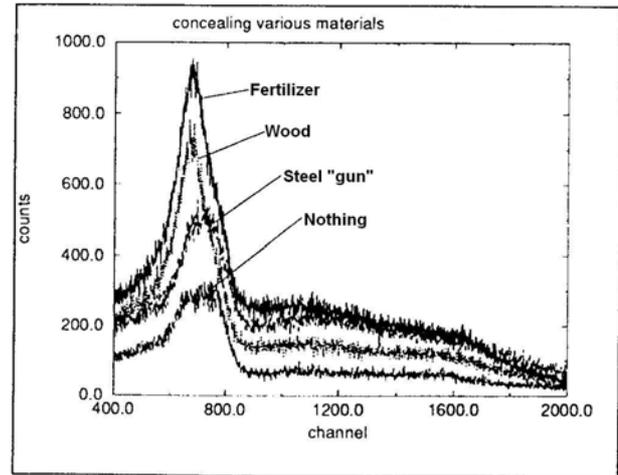
Figure 5. The spectra of four materials.

Figure 6. Compton scattering spectra from plasterboard.

Table1. Data for analysis of any relationship between variables.

Material	Z	Density (g/cm^3)	Total Counts	Peak Channel	FWHM
Fertilizer	~7	1.1 ± 0.1	569631 ± 755	694 ± 3	163 ± 2
Concrete	~20	2.3 ± 0.1	332797 ± 577	662 ± 3	85 ± 2
Wood	~6	0.4 ± 0.1	436308 ± 661	665 ± 3	106 ± 2
Steel	~26	7.8 ± 0.1	13536 ± 368	No peak	No peak

increasing distance of scatter.

4. Data analysis

At the high-energy end of the plots, the distance makes little difference to the spectra. This seems logical as the higher energy photons penetrate further into the material and consequently small changes in the source to detector distance will have small effects compared with the less penetrating low energy photons. Indeed there is a marked difference in spectral peak height at the low energy end of the spectrum. There is no change in central peak position or in the basic shape of the peak with distance and the total integral counts simply decrease fairly uniformly.

The angular data appears to add no further material characterization information. The spectrum from one material at a particular angle can be confused with the spectrum from a different material at some other angle. For example, a wooden joist in a wall, at one angle from the direct beam may appear to the detector like a packet of explosives at some other angle. Also, the spectra were similar for wood at 7.5 cm and fertilizer at 6.5 cm, and also for wood at 5.5 cm and fertilizer at 4.5 cm. Inspection of the plots shows that the two can be resolved by taking peak channel and integral counts simultaneously as these two values are different for the two materials in any geometry.

For identification of concealed materials, the same procedure was followed, as for the two previous investigations, with the difference that the scattering materials were composites. To mimic the situation of a wall, a sheet of plasterboard was used to conceal a small packet of fertilizer; a gun shaped piece of steel and a block of wood. To mimic the situation of a car door, two 1-mm thick sheets of steel are separated by a few centimeters of steel block and spectra taken with the cavity filled with the packet of fertilizer and the wood. The results are shown in Figures 6 and 7.

The five important features of the spectra mentioned before can be isolated and determined with relative ease, and it is hoped that they will categorize each individual material type uniquely, even from an angle and through a layer of steel or plasterboard.

There is a difference between the spectra from the different materials with and without plasterboard. Comparing figures 4 and 6, the wood still has the lowest value of peak position, but it is 13 channels higher than without the plasterboard. Simultaneously, the fertilizer has a centered peak position which is 15 channels lower than its corresponding spectrum without plasterboard. There is still a density and Z dependence to the integral counts, with fertilizer recording the most.

The car door effectively masks the material it is hiding of any peak resolution data (figure 7), leaving only integral counts over a broad, dispersed and noisy continuum. The fertilizer yet again produces the largest number of counts, enabling its presence to be determined.

Multi-dimensional analysis may yield more definite trends. The car door analysis is certainly less clear as total counts is the only indication of material. It is certainly possible to specify whether there is something behind the door panel, and so with knowledge of the door structure it seems feasible that this technique may provide some sort of useful information.
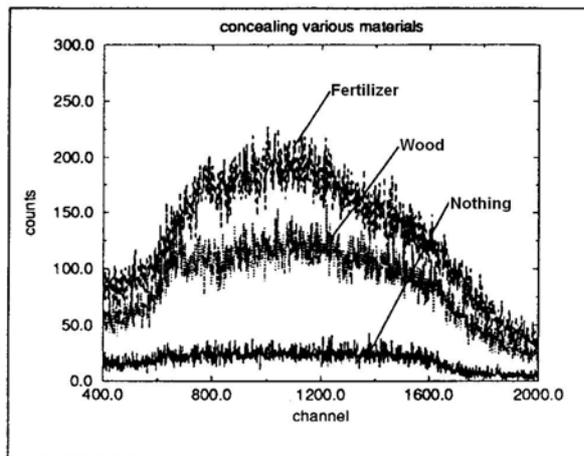
Figure 7. Compton scattering spectra from steel sheet.

5. Conclusions

The process of spectral analysis of Compton scattering may be used as a method for material characterization. It is apparent from the two dimensional data available at this time that fertilizer, or like materials can be identified with some certainty. Distinction between concrete and wood may be uncertain if the data falls into the overlapping area of the two identification regions on the plots, but they can be distinguished if the experimental geometry is known because the integral counts in the peak will always be greater for wood than for concrete at the same scattering angle. It is also clearly possible to state that a material is not present, with varying degrees of certainty, and this could be just as useful for the purposes of probing for illicit substances.

If the efficiency of NaI (Tl) detector can be improved, or other suitable handy detectors can be used such that the acquisition time can be brought down to minutes and even seconds, then from the findings of this preliminary investigation there is the possibility for a hand held material characterizing, non invasive probe.

References

1. D Rezaei Ochbelach, H Miri Hakimabad and R Izadi Najafabadi, *Asian J. of Exp. Sciences*, **20**, No. 2 (2006).
2. G F Knoll, "*Radiation detection and measurement*", 3rd *edition*, John Wiley and Sons, (2000).
3. G Miller, *IEEE Trans. Nuc. Sci.*, **19** (1972).
4. M Richter and P Siffert, *Nucl. Inst. Meth.* A **322** (1992).
5. Scintillation Detectors, HARSHAW Company, the Netherlands (1998).