Ray tracing to model time of flight effect in square based pyramid scintillators

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Abstract:
Scintillators are regularly used to convert high energy photons into optical emission, which can then be readily detected. Most scintillator based systems are designed for high collection efficiency so that the energy of the incident photon can be resolved. However, in this study we have examined time of flight aspects using a ray tracing model. As new ways of generating ever shorter x-ray pulses become available, measuring the duration of such beams is becoming a critical issue.

Introduction:

The aim of this project was to model the temporal signal generated at the output of an "ideal" scintillator. By "ideal", we assume for the sake of simplicity that there is no delay between the incident X-ray photon exciting the scintillator and the optical emission. We also assume that the scintillator has negligible lifetime so that we are only examining the effects of the detector geometry and boundary scattering/reflection/absorption on the temporal output of the system. The ideal scintillator shape would give high sensitivity and a small amount of afterglow, which allows the scintillator to produce higher time resolution outputs. Optimisation can be done by modelling the optical photons paths and comparing different geometries and surface coatings.

Method:

The scintillator was positioned aligned along the y-axis as shown in **Figure 1**. To simulate the X-ray absorption process, the photons were randomly allocated an interaction location and then given an energy value (according to the material's absorption coefficient for the nominal incident photons energy), which effectively accounts for the deposition process. For the X-rays of interest (10, 14, 50, 100 and 2000KeV), the corresponding mass attenuation coefficient for a plastic scintillator material (BC422Q) was used, to ensure that the code correctly estimated the energy deposition as shown in **Figure 2**.

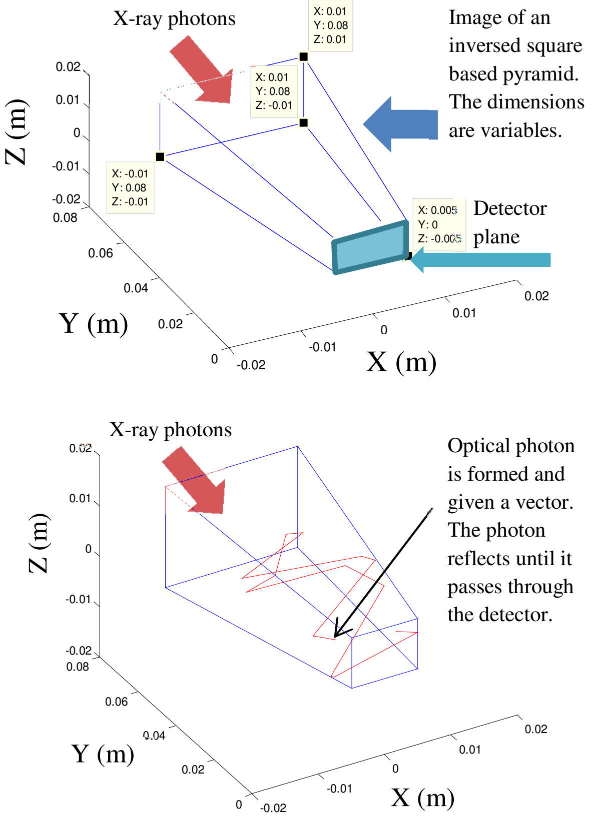

Figure 1. A schematic of the geometry for an inversed square based pyramid. Upper image shows how the scintillator is positioned, which direction the x-rays are incident from and the plane the optical photons are detected through. In the lower image, the red line indicates a typical path the photons travels to reach the detector.

This simulation model assumes that a single "optical equivalent" photon transports all the nominal optical energy, as this was found to be the simplest coding algorithm. As each equivalent photon is reflected, it's value is then appropriately reduced by each reflection off the scintillators walls, until it passes into the detector where the time it takes the photon to reach this point is found by the distance travelled accounting for the refractive index of the material. The temporal energy output graph indicates how the reflected photons decrease the temporal resolution.

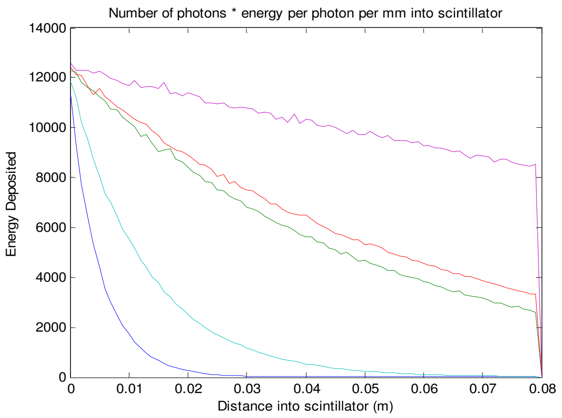

Figure 2. Energy deposited into scintillator per mm from a million tests

Results:

Tests were performed using 3 different coatings dielectric boundary (clear scintillator), scattering (Reflective random, rough) and black (absorbent). For each coating, a cuboid 2x2x8 cm scintillator was tested for 5 different incident X-ray energies of 10, 14, 50, 100 and 2000KeV.

Black Coating:

The black coating scintillator absorbs all photons that collide with the walls of the scintillator, so the temporal resolution is very sharp. The output is much lower than most of the simple boundary and random coating output values.

Dielectric boundary:

A dielectric boundary (assuming a refractive index of 1.58) increases the decay time due to photons being reflected in the scintillator but it does not significantly affect the peak.

Random coating:

With random coatings, the temporal resolution is much worse than either of the other coatings due to the photons reflecting in any direction, resulting in a similar peak to the other systems but an exponentially decreasing tail.

Discussion:

From these tests it has been shown that black coated scintillators have the shortest decay time and so best temporal resolution. The boundary and random scattering coatings primarily act to add to the tail of the signal which does not aid in measuring the emission duration.

Conclusions:

The simple model has been used to demonstrate that an absorbing coating gives the best temporally resolved output for a rectangular scintillator geometry. Further work examining the trade-off between detection efficiency, scintillator shape and temporal resolution will now be undertaken.

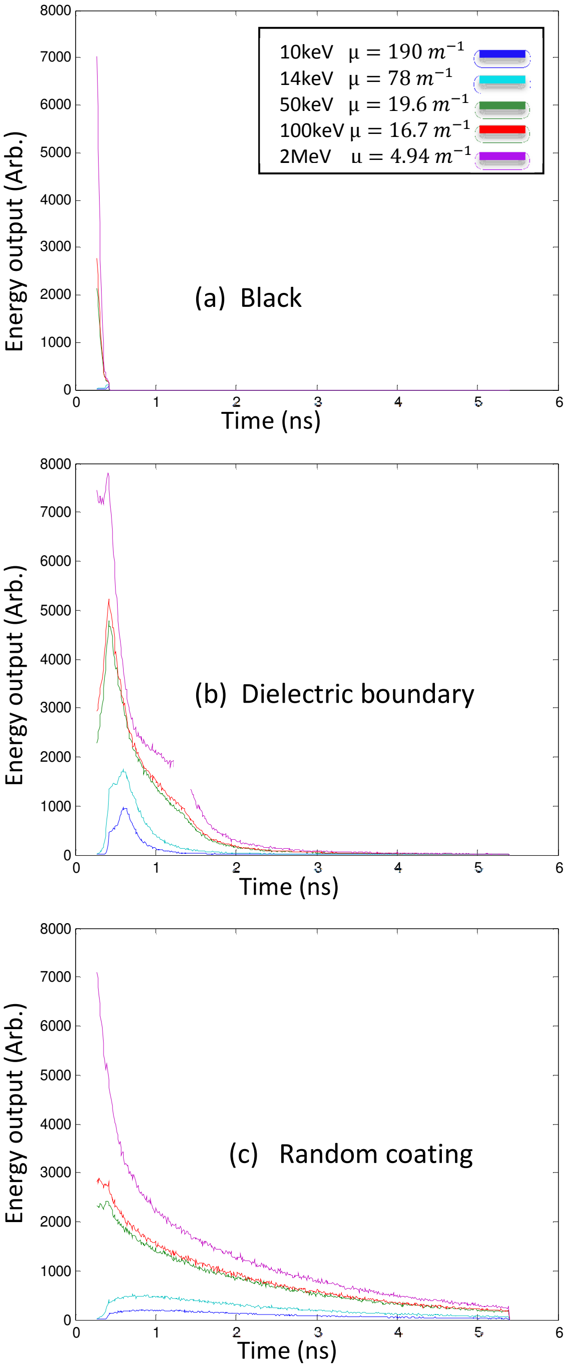

Figure 3. a) Black coating, b) Simple boundary, c) Random coating. All of size X and Z width's 2cm and Y of 8cm with a million tests run for each x-ray energy level.

Acknowledgements:

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