Improving X-Ray Material Separation in Cargo Screening with Fast Scintillators

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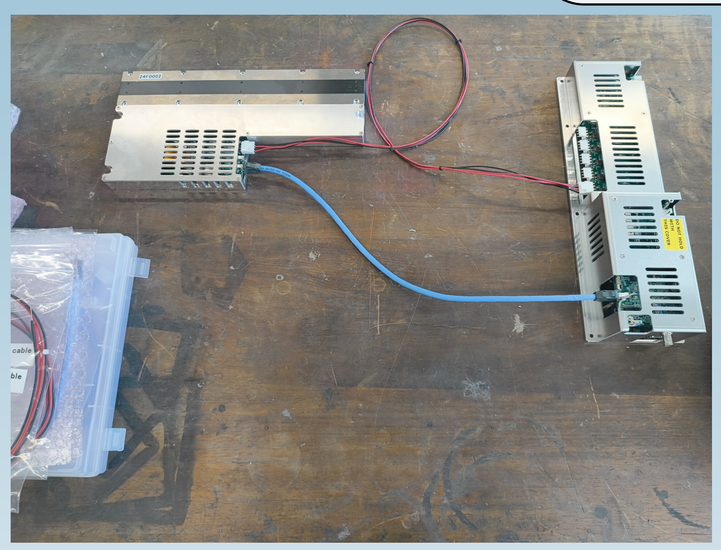
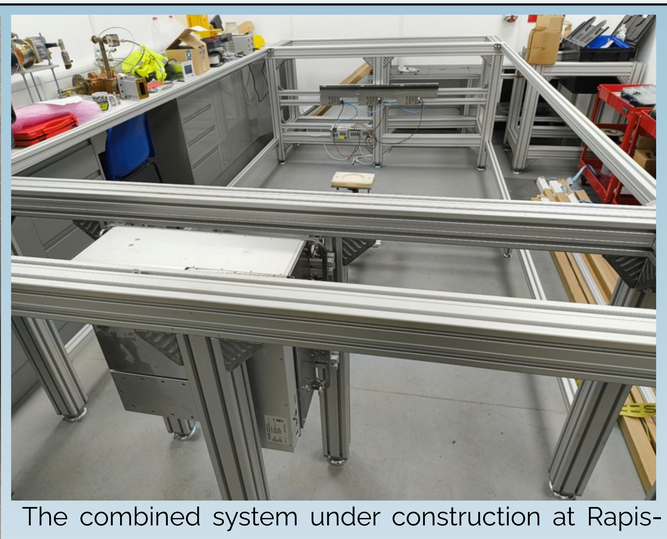


A LYSO scintillator sub-array and control board set up on the desktop.



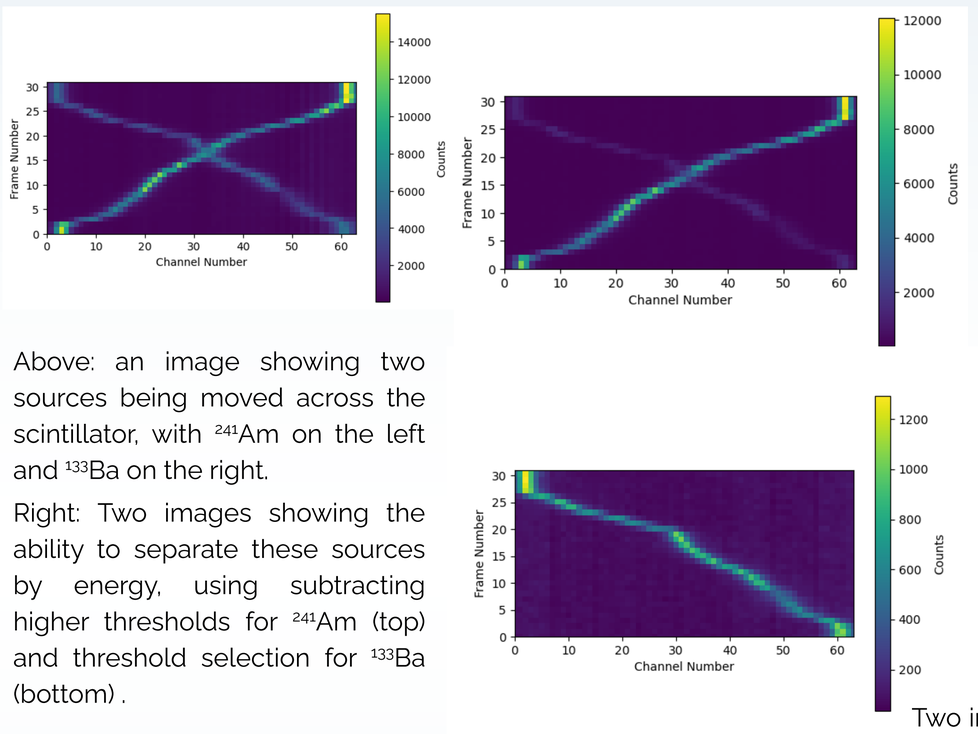
The combined system under construction at Rapiscan, combining a 320 keV X-ray tube (foreground) with LYSO scintillator array (background)

Introduction:

Current techniques for material separation with transmission X-ray imaging requires taking multiple images with different X-ray energies. This is effective, but slow. Fast scintillators, with decay times on the order of nanoseconds, can be used for spectroscopic imaging, especially when combined with silicon photomultipliers (SiPMs). This would allow material separation to be carried out using an X-ray beam at a single energy. This project will investigate this possibility, using an array of LYSO (lutetium–yttrium oxyorthosilicate) scintillator crystals coupled to SiPMs, as well as simulations using Geant4.

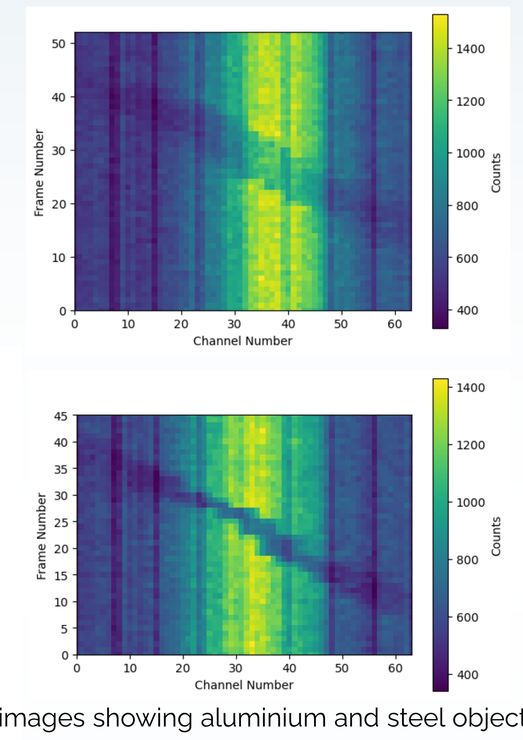
Experiments:

The project uses a Hamamatsu scintillator array. This has three sub-arrays, each with 32 5.12 mm×5.12 mm×7 mm LYSO crystals coupled to individual SiPMs. Commissioning experiments were carried out at the University of Manchester, using gamma-ray sources. These showed the ability to separate sources with peaks at different energies. Initial material separation tests were also carried out using these sources, showing the ability to effectively separate materials. This array was then integrated with a 320 keV X-ray tube for further experiments with materials, including drug and explosive simulants. These experiments are currently ongoing.

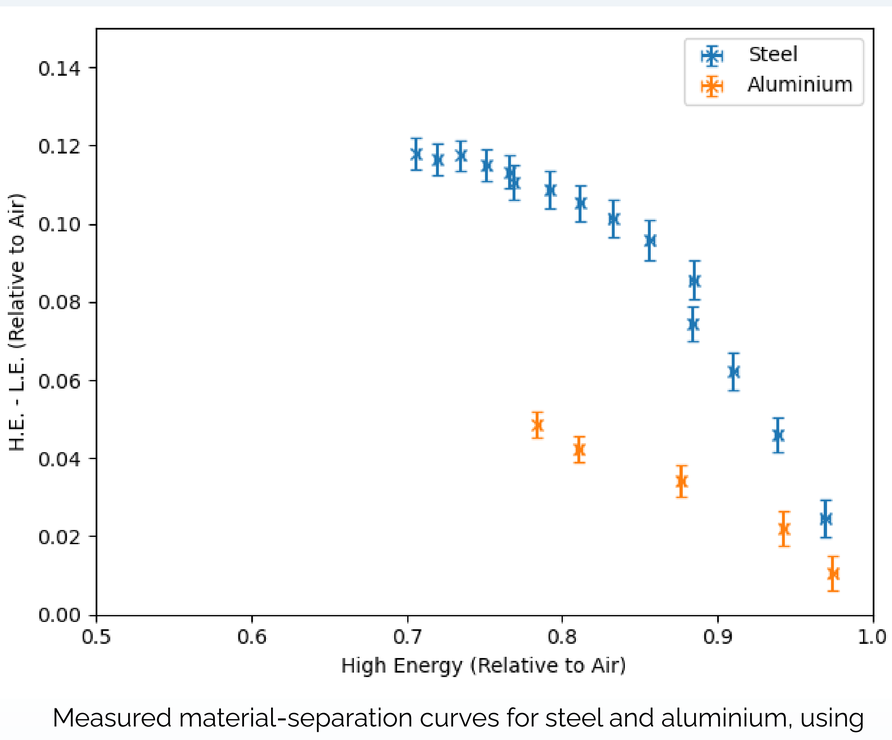


Above: an image showing two sources being moved across the scintillator, with ^{241}Am on the left and ^{133}Ba on the right.

Right: Two images showing the ability to separate these sources by energy, using subtracting higher thresholds for ^{241}Am (top) and threshold selection for ^{133}Ba (bottom) .



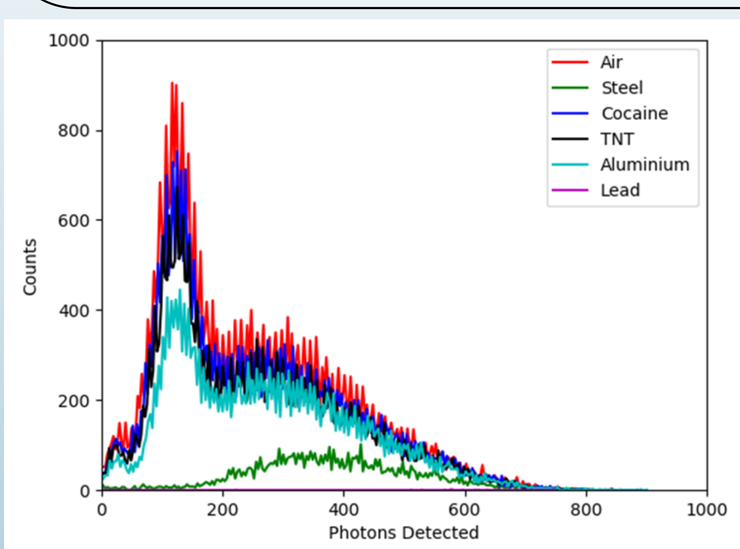
Two images showing aluminium and steel objects moved in front of a ^{152}Eu gamma-ray source.



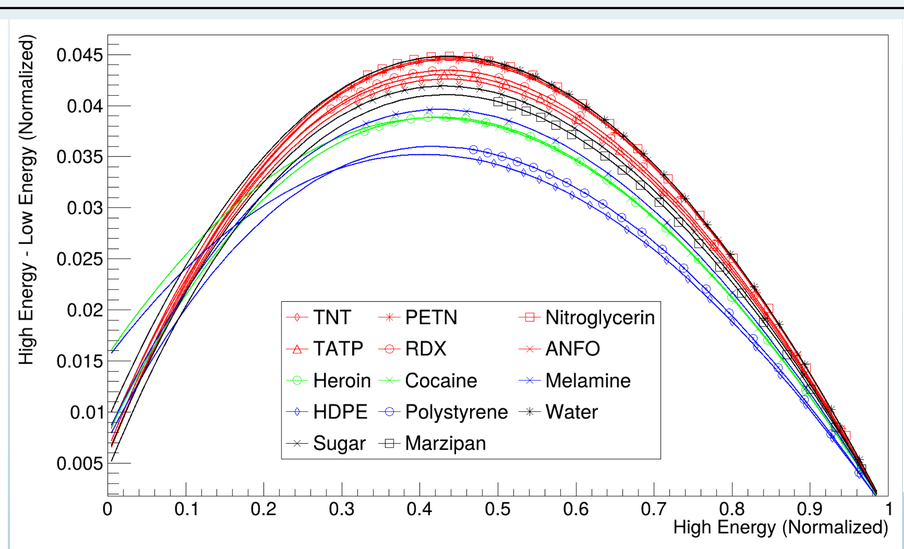
Measured material-separation curves for steel and aluminium, using a ^{152}Eu gamma-ray source.

Simulations:

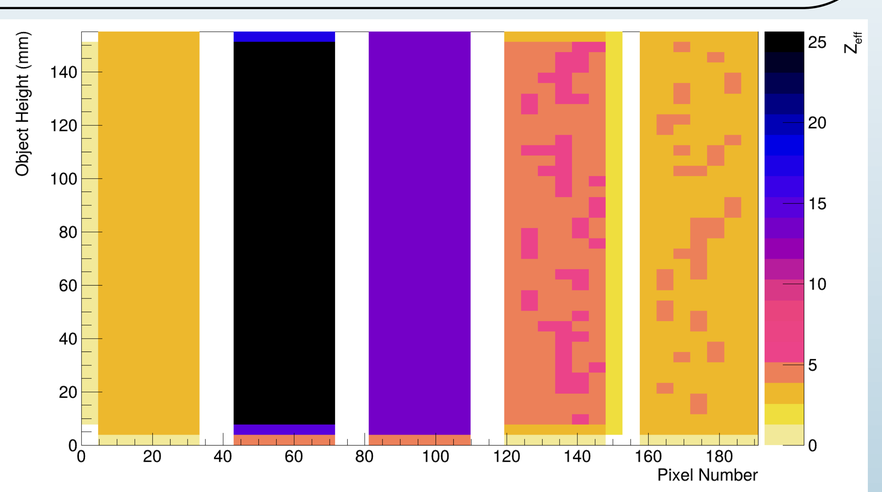
Geant4 was used to simulate the detector array, using the known spectrum of the 320 keV X-ray source. Both individual LYSO crystals and the full 32-crystal array were simulated, allowing for a better understanding of the system and its responses. Various materials were simulated to investigate the detector response. By looking at the simulated spectra, thresholds could be selected for the most effective material separation, with a low threshold of 25 keV and a high threshold of 75 keV being most effective. With this, simulated material separation curves could be plotted, showing a strong ability to separate denser materials, as well as the ability to distinguish between individual organic materials. By interpolating between these curves, estimates of the Z_{eff} of unknown materials could be made, allowing for these materials to be identified. Material stripping was also demonstrated, allowing packing materials to be removed from images. Simulations were also used to verify the results of experiments with gamma sources.



Simulated spectra for 1 cm of various materials exposed to the 320 keV source.



Simulated material-separation curves for various materials, with explosives in red, drugs in green, plastics in blue and possible simulants in black



X-ray Z_{eff} image from fitting for a set of target plates, each 150 mm square and varying thickness. From left to right: 50 mm HDPE (Z_{eff} 2.7), 5 mm steel (Z_{eff} 25), 10 mm aluminium (Z_{eff} 13), 50 mm TNT (Z_{eff} 5.58), and 50 mm cocaine (Z_{eff} 3.82).

Conclusions:

This work demonstrates that fast scintillators capable of multi-energy binning provide an effective system for material separation for security purposes. Small-scale laboratory testing with gamma sources has shown the scintillator array to have good capabilities for material separation. This has been verified with simulations, which have shown strong abilities to distinguish between suspicious and innocent materials. Future work will focus on confirming these simulation results in the laboratory.

Acknowledgments:

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