Imaging of a 30 kBq ^{22}Na source from 3 meters with a Temporal $CeBr_3$ Compton camera

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***Abstract*– For waste management operations, to avoid expensive nuclear storage of weakly contaminated material, there is a need for an equipment able to image weak activity contamination. We have been designing in collaboration with the French Agency for Nuclear Waste Management (ANDRA) a Compton camera specially designed for that purpose. As the number of photons crossing the detector by second is very low, a key feature of our camera is its high efficiency: valid interactions must not be lost. A second key feature is an exceptional signal-to-noise ratio. To meet those targets, we use fast scintillating monolithic crystals read-out by a digital SiPM. $CeBr_3$ was selected for its high, fast light-output and for the absence of intrinsic background. In this experiment the scattering plate was 5 mm thick $CeBr_3$ crystal and the $CeBr_3$ absorber plate was 12 mm thick. Our algorithms record for each scintillation event the full position and energy of the event including DOI, even in the thin plate, and the relative detection times between the two plates. Our CTR amounts 180 ps FWHM without DOI correction. This good coincidence time resolution allows for a stringent time window on real Compton event that must be recorded simultaneously in both the scattering and the absorber plates, thus reducing background very efficiently. A list-mode maximum likelihood iterative reconstruction algorithm is applied to better estimate the gamma source activity distribution. The source was detected for a 15 h acquisition after selecting the 511 keV annihilation peak of the ^{22}Na energy spectrum. To confirm the detection, a second acquisition was done after shifting the camera by 30 cm to the right. By comparing the two Compton images, we have been able to triangulate the source position to 3 m. We believe our camera can open new fields of application to gamma ray imaging.**

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Key words: Waste management operations, Compton camera, monolithic crystal, gamma ray imaging.

I. Introduction

Compton cameras based on CZT are starting to be used in the nuclear industry [1]. However, even if they are portable, their sensitivity is limited and their signal-to-noise ratio is too low to efficiently detect weak radioactive sources. Our goal is to realize a Compton camera using three-dimensional (3D) position sensitive scintillator plates that can both provide a good angular resolution (< 7° FWHM at 1 MeV), a high efficiency detection for valid events and a very high signal-to-noise. For this, we have chosen $CeBr_3$ as scintillating material because of its high yield of fast photons and its absence of natural background radiation. We have also a time window < 300 ps between the scattering and the absorber plates to exclude non-coincident events. To get high quality interaction positions, we take advantage of "Temporal Imaging", a new concept for gamma ray imaging, which exploits both the scintillation photon spatial distribution and their time of arrival distribution in monolithic scintillators [2]. The camera is portable and fully integrated.

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II. Materials and Methods

The Compton camera Temporal consists of two monolithic scintillator crystals. The scattering, located in front of the source, is a $(32 \times 32 \times 5)\ mm^3$ $CeBr_3$ crystal plate from Hellma materials. The absorber is a $(32 \times 32 \times 12)\ mm^3$ $CeBr_3$ crystal plate. Each scintillating crystal plate is coupled optically to a Philips Digital Photon Counter tile, DPC-3200-22 sensor. Both the absorber and the scattering crystals are encapsulated hermetically in an Aluminum housing. The distance between the two plates is 27 mm. The first plate is 3 meters distant from a 30 kBq ^{22}Na source. The Compton camera is integrated in a system whose mass is < 4 kg that includes acquisition and processing electronics, detector cooling and power supply (figure 1).

Fig. 1. Portable Compton Camera Temporal V2.2.1

The energy resolution of both plates was evaluated with 511 keV gamma rays: energy resolution was 8 % FWHM for the scattering plate and 7 % FWHM for the absorber plate.

The coincidence time resolution (CTR) measured by placing a ^{22}Na source between the 2 plates amounts 180 ps FWHM without corrections. The positions of the events in both plates were calculated using time corrected light distributions. The spatial resolution was 1 mm FWHM along

X and Y for the scattering plate and 1.5 mm FWHM along X and Y for the absorber plate.

Our algorithms record for each scintillation event the full position and energy of the event including depth-of-interaction (DOI), even in the thin plate, and the relative detection times between the two plates.

To be recognized as a valid Compton event, detection must pass the following criteria:

• It must be detected in both plates inside a stringent time window of 300 ps.

• Acquisition must pass quality criteria in both the plates.

• Energy partition between the two plates must correspond to valid Compton scattering angles.

Monte Carlo simulation is used and compared to experimental measurements to characterize efficiency of our Compton imaging system. It was evaluated by a 0.5 MBq ^{22}Na source located at coordinates (0,0,500 mm) from the center of the front face of the camera. Such a position was chosen to test the performance of the data acquisition and processing electronics against a high gamma ray flux.

The efficiency of our Compton camera design determined from Monte Carlo simulations is 4.2 ‰ and the experimental measurement gives 3.7 ‰.

III. RESULTS AND DISCUSSION

Our ^{22}Na source is a disc of diameter 25 mm with an activity of 30 kBq. It is located on a pillar of concrete at 3 meters from the camera front face.

The ^{22}Na source reconstruction is shown on a 100 x 100 image representing the field of view of the camera corresponding to the forward hemisphere. Two acquisitions were performed for 15 hours each for two camera positions shifted by 30 cm as shown in figure 2:

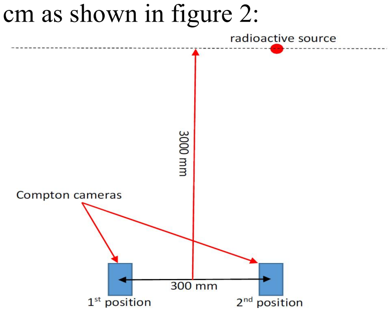

Fig. 2. Description of the experimental setup

In the first position, our camera can detect the weak source and the observe spot was at the correct position in the Compton image. To confirm this measurement, a second acquisition was done after shifting the camera by 30 cm. Figure 3 shows the two Compton images that were obtained at 511 keV.

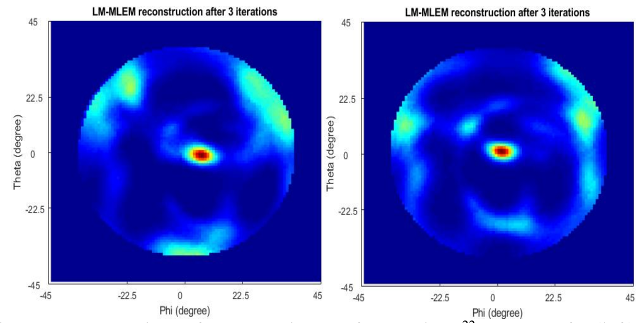

Fig. 3. Reconstructions of Compton images for a 30 kBq ^{22}Na source for (left) the first position and (right) the second position of the camera.

The spherical coordinates (θ,φ) of the source direction are (–1.140°,5.710°) for the first position of the camera and (1.145°,0.146°) for the second position. Knowing that the camera has been shifted by 30 cm, we have measured the distance of the source by using the parallax between the two source directions and have found a distance (3.08 ± 0.21) m FWHM from the front face of the camera.

IV. CONCLUSION

Our target was to develop a portable Compton camera able to image weak contamination with a good angular resolution. Such a camera will be very useful for radioactive waste classification and can even image natural radioactive background.

For this, we used two $CeBr_3$ scintillation crystal mono-blocks: a 5 mm thick scattering plate and a 12 mm thick absorber plate, both read-out by a Phillips Digital Photon Counter SiPM 3200 matrix. We have performed a GATE Monte Carlo simulation of our setup. which was compared against experimental measurements. The measured efficiency was 12 % smaller than expected from Monte Carlo simulations with our crystals characteristics. In order to test low activity imaging, a ^{22}Na source was located in 3 m from the camera front face. The acquisition was run for 15 h for two positions of the camera shifted by 30 cm. Image reconstruction was performed after selecting the 511 keV annihilation peak of the ^{22}Na energy spectrum. 320 Compton events were detected for the first position and 329 for the second position. The source was detected on both the images. The distance of the source measured by using the parallax between the two Compton images is ~3 m.

REFERENCES

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