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Development of a portable gamma camera with coded aperture

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Abstract

Since the beginning of the 1990s, the CEA is being involved in the development of compact gamma cameras based on a pinhole collimator, a scintillator and an intensified CCD. In collaboration with the Kurchatov Institute, the CEA has recently developed a miniature coded mask, which significantly improves sensitivity and angular resolution. Laboratory tests have demonstrated excellent performance. They are summarized, accompanied with on-site test results. We also present preliminary results of Medipix2/CdTe, a semiconductor pixel detector.

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Keywords: Radiation-imaging detectors; Gamma mapping; Coded-mask aperture; Semiconductor pixel detector

1. Introduction

Gamma imaging nowadays is widely used in nuclear facilities for decontamination or dismantling operations. Tools like portable gamma cameras make it possible to quickly and simply perform the gamma mapping of an area to be processed, with the advantage of remote measurements of hot spots, not necessarily on contact. However, the use of such cameras on site sometimes comes up against an insufficient sensitivity or space resolution, or against their excessive bulk. This is why CEA, which is involved in the development and industrialization of compact cameras for these applications, undertook studies and developments aiming at improving the performance and compactness of these cameras.

2. Compact gamma-imaging systems developed at CEA

Since the beginning of 1990s, CEA is involved in the development of compact gamma-imaging devices using a pinhole collimator, a scintillator and

an intensified CCD. This has led to the ALADIN camera, 37 kg, a prototype mainly used on CEA working sites [1], and to the CARTOGAM camera, 16 kg, object of a technology transfer to Canberra, presently commercialized [2]. The mass is essentially that of the Denal shielding (tungsten alloy), which, for CARTOGAM, is 8 cm in external diameter and about 2 cm in thickness. The energy range in nuclear facilities is typically 50 keV–1.5 MeV, the main emitters being ¹³⁷Cs at 662 keV and ⁶⁰Co at 1.17 and 1.33 MeV. In their present configuration, ALADIN and CARTOGAM are operable at dose rates from a few 100 nGy/h up to more than 1 Gy/h.

As an illustration of the application, a scene recorded by CARTOGAM is shown in Fig. 1, with the useful part of the gamma image superimposed on the corresponding visible image. The latter is recorded by means of either an additional camera (ALADIN), placed near the view axis of the gamma camera or with the same detector, through the scintillator (CARTOGAM).

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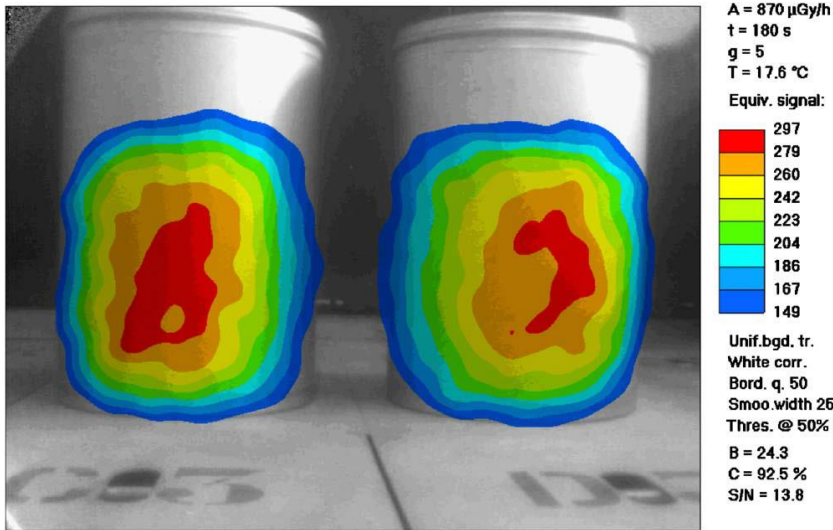


Fig. 1. View of two bituminized waste drums seen from 2 m. The dose rate is 870 $\mu\text{Gy/h}$ and the exposure is 3 min.

3. Development and tests of a camera with coded mask

Using a pinhole to form gamma images is very simple in principle but very inefficient. A highly attractive alternative consists in replacing the collimator by a mask with a great number of holes, following a special arrangement that allows some decoding procedure to recover an image. Such coded masks have been designed and used for several decades, mainly for astrophysical applications, but in most cases their size is of the order of 1m. The Kurchatov Institute, which has a long experience in the development of compact gamma cameras, has a particular expertise in designing compact coded masks [3]. That is why our teams decided to collaborate in the framework of an INTAS contract to develop and test a very compact coded-mask configuration for the CEA cameras.

Three HURA (hexagonal uniformly redundant array) masks have been fabricated and tested, with different numbers of holes and thicknesses (see Fig. 2), and fitted to ALADIN and CARTOGAM. The results of the first tests in laboratory showed a gain of a factor between 5 and 20 in sensitivity (according to the exposure) compared to the pinhole configuration, and a factor between 2 and 2.5 in angular resolution (according to gamma energy) [4]. They also demonstrated the ability of this device to efficiently remove the background noise, thanks to a mask pattern antisymmetric by 60° rotation.

These laboratory results were confirmed by various onsite tests performed in a nuclear reactor, on radioactive waste containers, or on glove-boxes. Images obtained in the BR2 reactor in Mol (Belgium) are shown in Fig. 3. The lower face of

three heat exchangers was inspected, in particular hot spots due to contamination accumulation in plugs. For the first view (Fig. 3, top), the camera was located just under a hot spot and looked at a farther one. Thus the ambient dose rate was so high that in the pinhole configuration the camera was unable to detect the hot spot aimed at (top left). On the contrary, in the coded-mask configuration and using the mask–antimask procedure, the hot spot is clearly detected and located (top right). In the second view (Fig. 3, bottom), the camera looks at the nearest hot spot. The pinhole gives a good-quality image of the source (bottom left) but obviously the angular resolution is much better with the coded mask (bottom right). These on-site tests have also underscored the problem with the partially coded sources, which are placed just beyond the limits of the field of view and do not project a complete mask pattern onto the detector useful area, thus producing artifacts in the decoding procedure. We are studying the applicability of correction algorithms.

4. Gamma imaging with a semiconductor pixel detector

Another logical way towards a more compact and powerful camera consists in replacing the present detector, with its multiple conversion stages at rather low efficiencies, by a semiconductor detector directly converting the gamma photons into electrical signal. The difficulty here is that, due to the small size and the high dynamical range aimed at, the read-out electronics must be a pixelated photon-counting ASIC hybridized on the detection substrate.

Such a development has been performed in the framework of the Medipix Collaboration [5]. The Medipix2 chip developed has 256×256 pixels at a

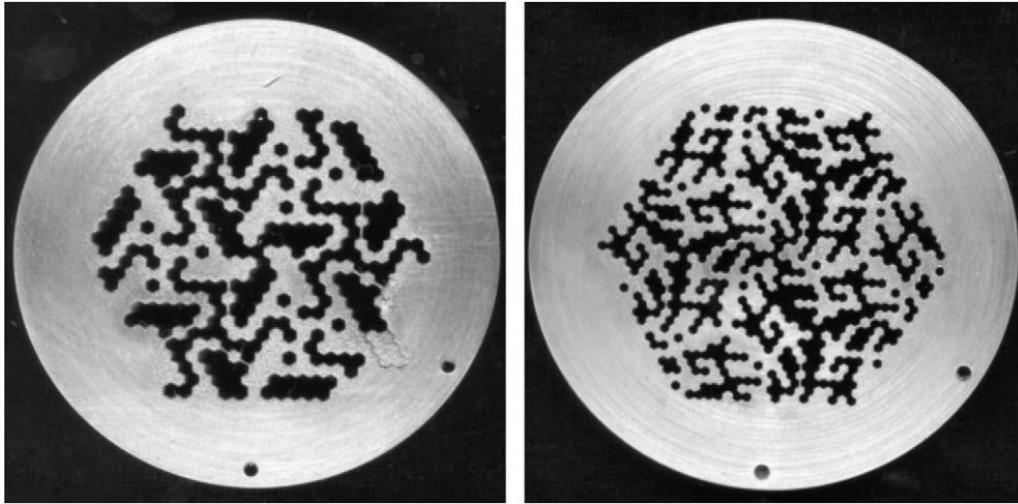


Fig. 2. Photographs of the HURA masks designed in tungsten, (left) of rank 6 (12 mm-thick) and (right) of rank 9 (6 mm-thick).

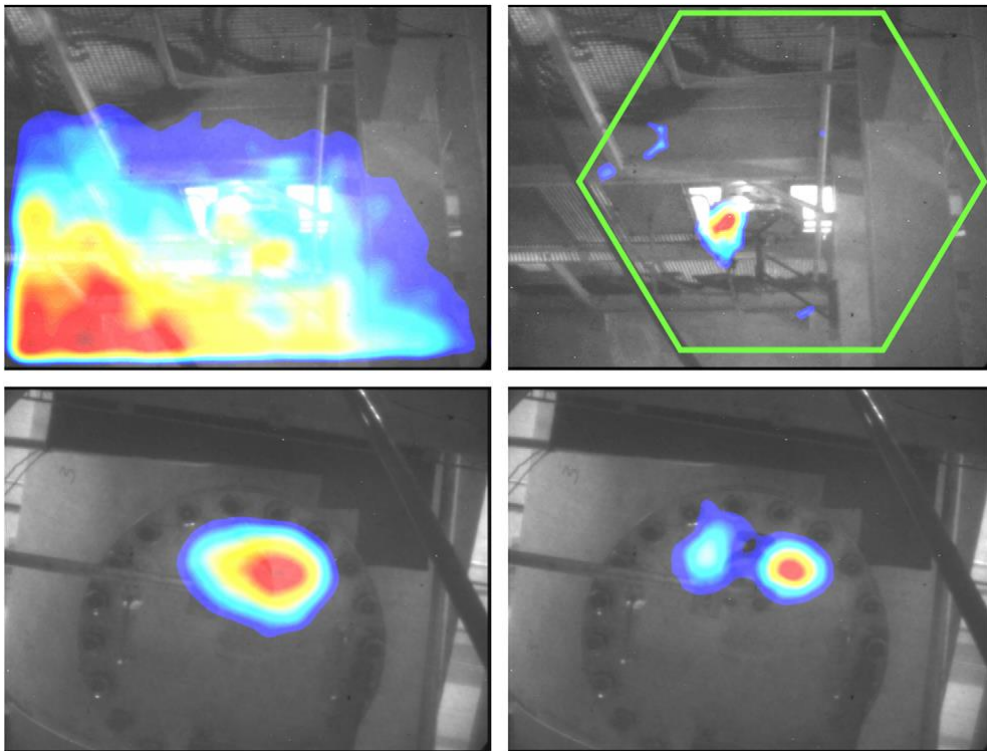


Fig. 3. Views of (top) a hot spot located on a plug under a heat exchanger in a very high-ambient dose rate and (bottom) a hot spot located just above the camera, with (left) the pinhole and (right) the coded-mask configurations.

pitch of $55\ \mu\text{m}$, so an active surface area of $14\times 14\ \text{mm}^2$ [6]. Each pixel comprises two individually adjustable thresholds and a 13-bit counter. The main application is X-ray imaging but we participated in the development of CdTe detectors 1 mm thick bump-bonded on Medipix2 chips for higher-energy applications [7]. Fig. 4 shows one of them mounted on its front-end electronic board.

Despite its small pixel size, optimized for low-energy imaging, Medipix2/CdTe presents

promising performance for gamma imaging [8]. As an illustration, Fig. 5 shows the image of a ^{137}Cs point source obtained with Medipix2/CdTe and a pinhole collimator with 50° aperture, comparable with that of ALADIN and CARTOGAM. Detailed comparative tests between the existing cameras and this detector are still in progress, but the preliminary results already show that the latter gives better-quality images, although its intrinsic detection efficiency is lower than that of the 4 mm CsI:Tl scintillator (4.5% vs. 13% at 662 keV).



Fig. 4. View of a Medipix2/CdTe detector (1 mm thick) mounted on its front-end electronic board.

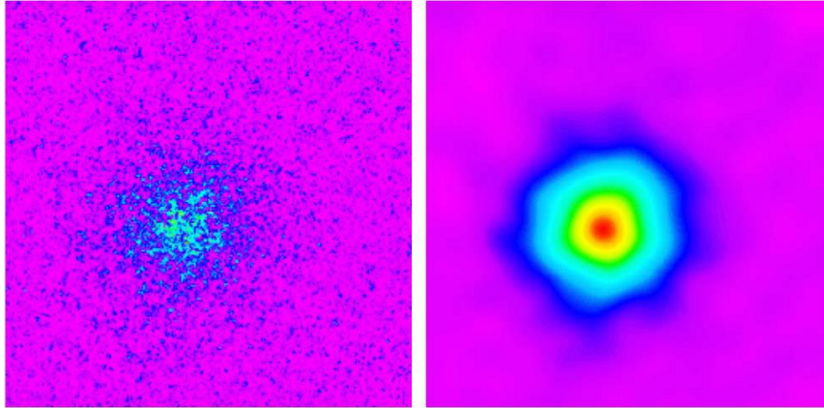


Fig. 5. (left) Raw and (right) smoothed (Gaussian filter, 20 pixel wide) images of a ^{137}Cs point source ($90 \mu\text{Gy/h}$) obtained in 120 s with Medipix2/CdTe and a 50° pinhole collimator.

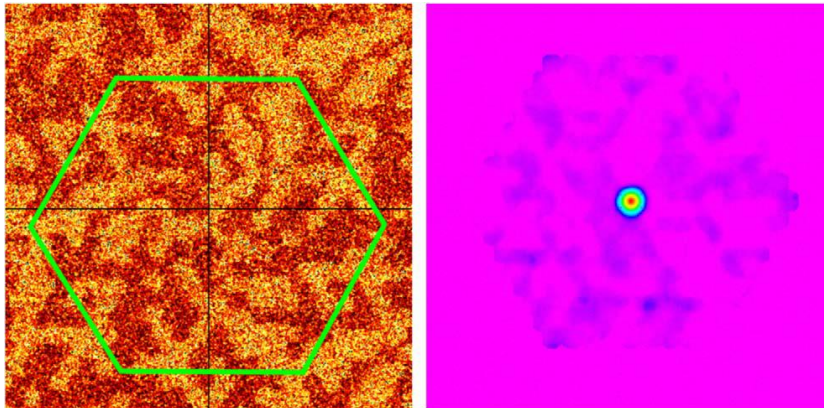


Fig. 6. (left) Raw composite image (2×2 mosaic) and (right) decoded image of a ^{137}Cs point source ($48 \mu\text{Gy/h}$) obtained in 120 s with Medipix2/CdTe and the rank 9 coded mask.

The association of the Medipix2/CdTe detector with a coded mask potentially meets all the requirements to design a very compact and high-performance gamma camera. Preliminary tests of this association have been performed. As the central pattern of the mask (25 mm in diagonal) is greater than the detector (14 mm), several images should be recorded at different detector positions and a composite image reconstituted, with a surface area equivalent to four real images. This is illustrated in Fig. 6, which shows the raw composite image and

the corresponding decoded image of a ^{137}Cs point source obtained this way. Image quality and resolution are very promising.

Further tests with mosaics of 2×2 single chips hybridized with monolithic $28 \times 28 \text{ mm}^2$ silicon substrates, already developed by the Medipix Collaboration, are planned, although the detection efficiency will be very low ($< 1\%$ at 662 keV). In a longer-term future, we envisage testing Medipix2/CdTe mosaics as well.

5. Conclusions

The ALADIN and CARTOGAM gamma cameras developed by CEA have been recently tested in a very compact coded-mask configuration. The first laboratory results were promising, with a great improvement of both sensitivity and angular resolution. In addition, the mask–antimask procedure proved very efficient for background removal. On-site tests have been performed in the BR2 reactor atMol and they confirmed these performances.

Results of gamma imaging with Medipix2/CdTe, a photoncounting pixel detector hybridized on 1 mm of CdTe, associated with a pinhole colimator have been presented as well. They preliminarily suggest that, despite its lower intrinsic efficiency (1 mm CdTe vs. 4 mm CsI:TI), this detector provides better-quality images than the present scintillator-based detector. Results of the first tests of Medipix2/CdTe with a coded mask are also very promising.

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