GAMPIX: a new generation of gamma camera for hot spot localisation

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Abstract

The respect of the ALARA principle is a main challenge during decontamination and dismantling activities. New radioprotection tools are required to reduce the dose received by operating people. Gamma imaging systems are a solution of great interest in the field of these activities. For many years, CEA has been working to develop such systems. For instance, the ALADIN system and the CARTOGAM system (commercialized by AREVA CANBERRA) are intensively used for in situ measurements. Despite their satisfying performances, the weight of these tools remains an issue for operations requiring portable devices. For several years, CEA LIST has developed a new generation of gamma camera, called GAMPIX. This system is based on the Timepix chip, hybridized with a 1 mm thick CdTe substrate. A coded mask is used instead of a pinhole collimator in order to increase the sensitivity of the camera. Moreover, due to the USB connection with a standard computer, this gamma camera is immediately operational and user-friendly. The final system is a very compact gamma camera (global weight is less than 1 kg without any shielding) which could be used as a portable device for radioprotection purposes. In this article, we present the main characteristics of this new generation of gamma camera and we expose experimental results obtained in laboratory and during in situ measurements.

1. Introduction

The respect of the ALARA principle (which stands for As Low As Reasonably Achievable) is a main challenge during decontamination and dismantling activities. New radioprotection tools are required to reduce the dose received by operating people. Gamma imaging systems, called gamma cameras, are a solution of great interest in the field of these activities. These devices enable the superimposition of a gamma image with a visible image, which is of great help to locate radioactive hot spots in a given area. For many years, CEA has been working to develop such systems. For instance, the ALADIN system and the CARTOGAM system (the last one being commercialized by AREVA CANBERRA), are intensively used for in situ measurements [1, 2]. Despite their satisfying performances, the weight of these tools, 15 kg in the CARTOGAM's case, remains an issue for operations requiring portable devices. Moreover, significant improvements can be done in terms of sensitivity, angular resolution and ease of use of these tools. Finally, end-users are often asking for new functionalities, like the possibility to carry out spectrometric measurements, in order to obtain an evaluation of the dose rate.

In this article, we present a new generation of gamma camera developed by CEA LIST and called GAMPIX. First, we remind of the main characteristics of this new device. We present then the experimental performances of this camera, in terms of sensitivity, angular resolution and linearity according to the dose rate. Finally, we expose results obtained during in situ measurements carried out in CEA Valduc, the latter illustrating the interest of using GAMPIX in several application fields.

2. GAMPIX: main characteristics

The GAMPIX gamma camera is based on three main components:

- The Timepix chip [3]: this pixellated chip, developed by the CERN in the frame of the international collaboration Medipix [4], is hybridized with a 1 mm thick CdTe substrate. The active area is divided into 256 × 256 pixels (55 µm side) working in single photon counting mode, each pixel being an individual detector with its own electronics (analog and digital part).

- The coded mask [5]: this multi-pinhole collimator enables to improve drastically the sensitivity of the camera but requires a decoding step in order to convert the raw image into a decoded gamma image. Several parameters can be adjusted (thickness, rank), according to the need of the end-users, in order to improve the performances of the gamma camera for a given application.
- The USB interface [6]: GAMPIX can be connected in a very easy way to a standard laptop, which greatly simplifies its use.

Fig. 1 illustrates the three main components of this gamma camera.

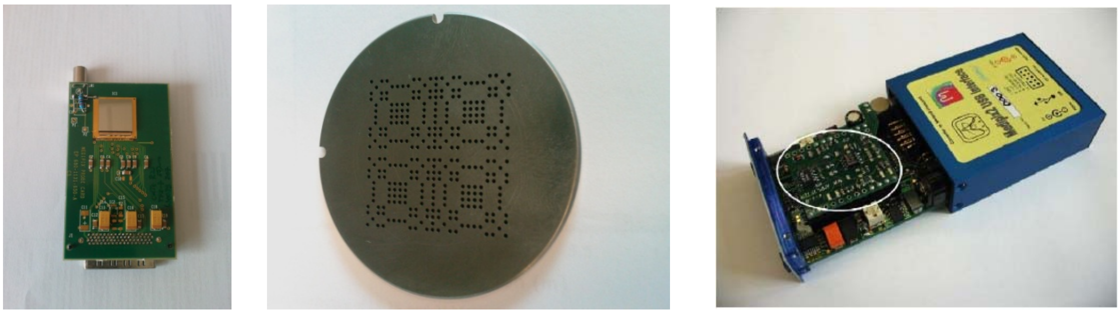

Fig. 1: On the left: the Timepix chip. On the middle: coded mask of rank 13, 2 mm thick. On the right: the USB interface.

The combination of these three components in the GAMPIX gamma camera corresponds to a technological breakdown in comparison with the CARTOGAM system. These components have been integrated in a camera's body, including a visible camera, required for the superimposition of the gamma image with the visible image. Fig. 2 illustrates the current prototype version of the GAMPIX gamma camera and gives an overview of the Matlab interface developed in our laboratory for post-processing.

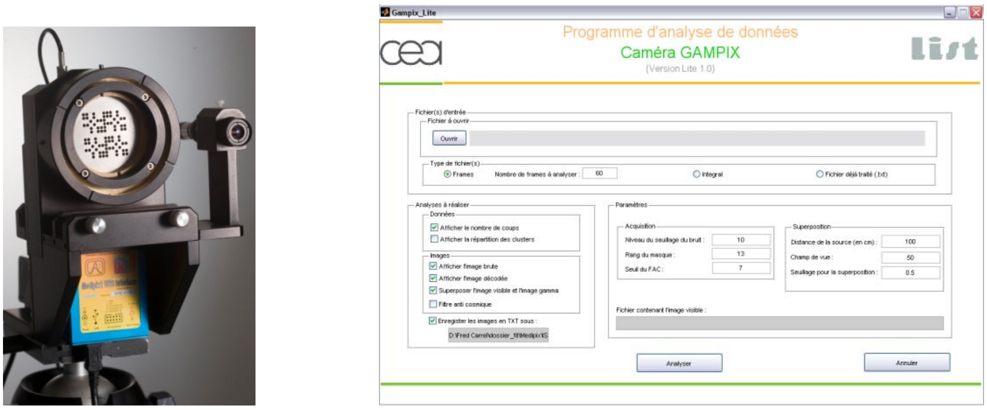

Fig. 2: On the left: the GAMPIX gamma camera. On the right: the Matlab interface used for post-processing.

Fig. 3 gives an example of the images obtained during the different steps of the analysis: raw gamma image, decoded gamma image and superimposition with a visible image for the localization of a given hot spot.

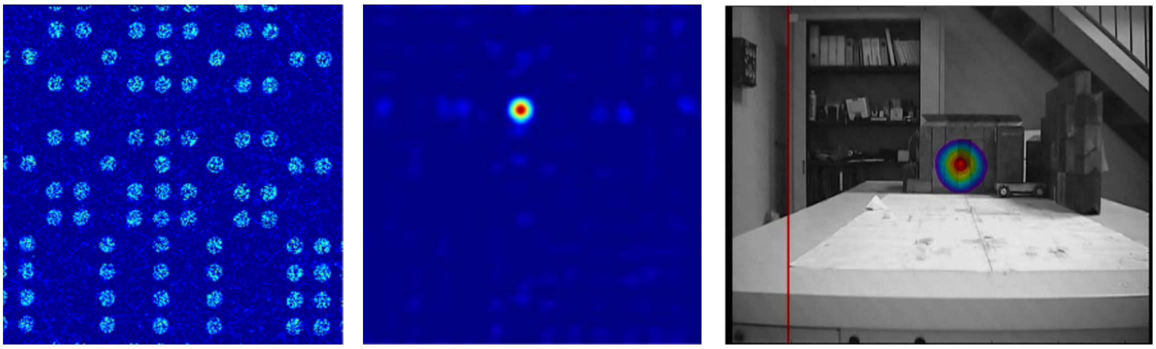

Fig. 3: On the left: raw gamma image. On the middle: decoded gamma image. On the right: decoded gamma image superimposed with a visible image.

3. GAMPIX: main performances

Two parameters have been mainly evaluated during the characterization of GAMPIX: the sensitivity and the angular resolution. In this article, we define the sensitivity as the shortest time required to detect a radioactive source of a given activity. Practically, the radioactive source is considered as being detected if the position of the rebuilt hot spot in the decoded image is unchanged on several acquisitions and consistent with the real position of the radioactive source.

For three radioactive sources (^{241}Am, ^{137}Cs, ^{60}Co), Table 1 gives an example of the GAMPIX's performances in terms of sensitivity according to two different coded masks: rank 11 (4 mm thick) and rank 13 (2 mm thick). These sources were located at 1 m from the gamma camera. The dose rate in the vicinity of the gamma camera is also indicated in Table 1. Table 2 reminds of the performances of the GAMPIX gamma camera, according to the rank of the coded mask, for a FOV equal to 30 degrees.

Sources	**Dose rate at 1 m (μSv.h^{-1})**	**Coded mask rank 11**	**Coded mask rank 13**
^{241}Am	0.25	3 s – 5 s	2 s – 4 s
^{137}Cs	2.50	60 s – 100 s	300 s
^{60}Co	3.84	10 min	Undetectable

Table 1: Performances of the GAMPIX gamma camera in terms of sensitivity.

Sources	**Dose rate at 1 m (μSv.h^{-1})**	**Coded mask rank 11**	**Coded mask rank 13**
^{241}Am	0.25	2.12°	1.38°
^{137}Cs	2.50	2.06°	1.35°
^{60}Co	3.84	2.57°	Undetectable

Table 2: Performances of the GAMPIX gamma camera in terms of angular resolution.

Several conclusions can be drawn from these results. The best results in terms of sensitivity are obtained for ^{241}Am because of the low energy gamma-rays emitted by this nuclide. Hence, this camera can be of great interest in order to detect plutonium, with high ^{241}Am concentrations, as illustrated in the next paragraph. The detection of high-energy gamma-ray emitters, like ^{137}Cs or ^{60}Co, requires thicker masks. From Table 1, we can see that the best performances for both these nuclides are obtained using the coded mask of rank 11, due to its higher thickness in comparison with the mask of rank 13. However, two major drawbacks are inherent to the use of such a mask: auto-collimation effects, degrading the sensitivity according to the position of the radioactive source, and loss in terms of angular resolution (see Table 2). Concerning the second parameter, the greater the rank, the better the angular resolution. For this reason, the choice of the mask will be always a trade-off between rank and thickness and will depend on the need of end-users.

Additional experiments have been carried out in CANBERRA Loches, in order to evaluate the linearity of the detector, according to the dose rate. A ^{137}Cs irradiator has been used in the frame of these measurements. Fig. 4 illustrates the total number of counts recorded on the Timepix detector, according to the dose rate received by the gamma camera. The dose rate is contained between 100 mGy.h^{-1} and 4.895 Gy.h^{-1}.

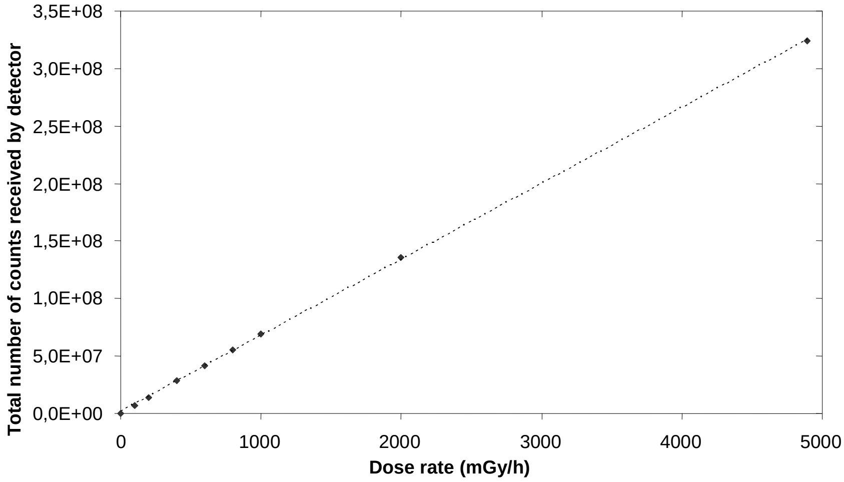

Fig. 4: GAMPIX's counting rate according to the dose rate received by the camera. The average counting rate is calculated over 10 s of acquisition time.

Results exposed in Fig. 4 confirm the linearity of the Timepix detector on a large range of dose rates.

4. In situ measurements using the GAMPIX system

In this part, we present results obtained during a measurement campaign in CEA Valduc and dedicated to the evaluation of the GAMPIX performances in several application fields (dismantling, management of nuclear waste packages). The main challenge of these measurements concerns the localization of plutonium radioactive hot spots. First tests have been carried out in order to locate radioactive hot spots inside nuclear waste packages. An example of results is given in Fig. 5.

Fig. 5: Example of localization of a radioactive hot spot inside a 220 l nuclear waste package. The measurement duration is equal to 1 s. The dose rate near the hot spot is about 300 µSv.h^{-1}.

This result shows the possibility to obtain a very fast localisation of radioactive hot spots using GAMPIX. Next measurements consisted in locating radioactive hot spots in a dismantling cell during the dismantling process. Fig. 6 illustrates a part of the results obtained during these experiments. The counting time for these measurements is equal to 3 s.

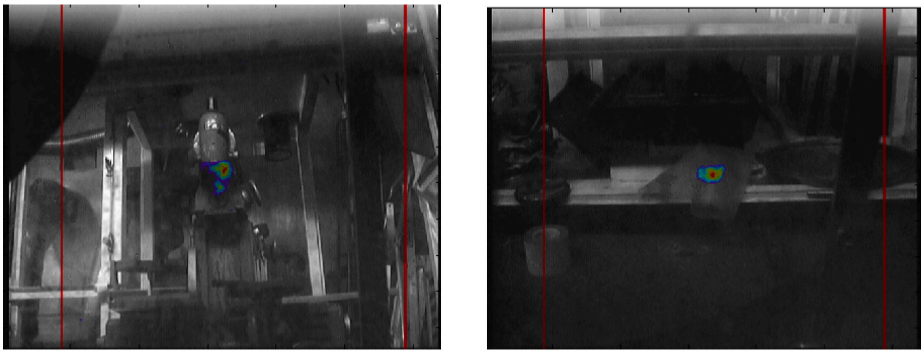

Fig. 6: On the left: identification of a radioactive hot spot on the top of a milling machine. On the right: identification of a radioactive hot spot contained in a bag.

The two hot spots mentioned above have been checked during the dismantling process and the accuracy of their localization has been confirmed. The dose rate in the vicinity of the low hot spot is about 300 $\mu Sv.h^{-1}$. The mass of plutonium corresponding to the highest hot spot was evaluated later to less than 1 g. The use of a coded mask of rank 13 is well adapted to these measurements and enables to improve the localization of the hot spot, due to a better resolution, in comparison with the coded mask of rank 11. These results illustrate the great potential of GAMPIX in the frame of dismantling activities and for the detection of plutonium hot spots. A real time localization of radioactive hot spots is conceivable using GAMPIX, which will enable to greatly reduce the dose received by operating people.

5. Conclusions and future developments

In this article, we present a new generation of gamma camera, developed by CEA LIST and called GAMPIX. This system is based on the Timepix chip, hybridized with a 1 mm thick CdTe substrate and associated to a coded mask. The main improvements of this gamma camera are linked to its compactness and its performances in terms of sensitivity. A first evaluation of the GAMPIX's performances has been presented in this article and show promising performances, especially for the detection of low-energy gamma-ray emitters. Finally, we exposed results obtained with GAMPIX during in situ measurements. The latter showed a real benefit of using this new system in the frame of the dismantling process, in order to reduce the dose received by operating people.

Future developments, dedicated to the improvement of GAMPIX's performances, are currently in progress. The time over threshold mode (TOT mode) of the Timepix chip is under investigation, in order to add spectrometric ability to the gamma camera. The improvement of the performances for high-energy gamma-ray emitters, such as ^{137}Cs or ^{60}Co, is also considered and several solutions are studied: hybridization of the chip with a thicker substrate (2 mm CdTe instead of 1 mm), increase of the high-voltage bias applied to the detector (300 V instead of 100 V) and development of new coded masks (lower rank, greater thickness). Moreover, one interesting feature of coded masks, the mask-anti mask procedure, enabling to remove the part of the signal that is not modulated by the mask, is tested too. Finally, portable measurements using the GAMPIX system are also planned at the end of this year, in order to evaluate the feasibility of using this gamma camera as a portable radioprotection tool.

6. Acknowledgements

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7. References

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