Development of a portable gamma-imaging device with coded aperture

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Outline

• Gamma imaging in nuclear facilities
• Gamma-imaging systems developed at CEA
• Development and tests of a camera with coded mask
• Gamma imaging with a semi-conductor pixel detector
• Conclusions
Gamma imaging is a powerful tool for radioactivity mapping in irradiating cells:

- measurements from distance
- very little manual operation
- “direct” interpretation of measurements

Applications:
- decontamination
- intervention in hot cell
- dismantling
Since the 90’s, the **CEA** is involved in the development of compact gamma cameras.

- **Aladin 1** (1995) 42 kg
- **Aladin 2/3** (1997) 37 kg
- **Cartogam™** (2000) 16 kg

→ *TT to Canberra-Euriys*
Gamma-imaging systems developed at CEA

Working principle:

- Denal shielding + double-cone collimator (pinhole)
- **Scintillator CsI:Tl 4 mm + intensified CCD camera** (Ø 4 cm)
- Visible and gamma images by the same detection line

Design features (Cartogam):

- 8 cm in ext. diam. ; 16 kg
- Working range:
  - 50 keV – 2 MeV ; ≤ 1 µGy/h – 1 Gy/h
  - (≤ 100 nGy/h in “counting” mode)
- Angular resolution: 1° to 4°
Gamma-imaging systems developed at CEA

Examples of on-site images:

**Bituminized waste drums**
seen from 2 m (870 µGy/h)

**Exposure:** 3 min

(barrelling cell at COGEMA/Marcoule)

**Irradiating case seen through its concrete container**

**Exposure:** 10 min

(waste-container inspection at CEA/Saclay)

**Accumulation of PuO$_2$ powder in bellows**

**Exposure:** 3 min

(glove-box at COGEMA/Marcoule)
Development and tests of a camera with coded mask

Objective:

- Feasibility study of a **coded mask** fitted to the camera
- Expected gain: in **sensitivity**, also in **resolution**
- Difficulties: **miniaturisation** (holes and thickness), effect of **large sources** and of **sources out of the field of view**

*Example: coded mask of the **INTEGRAL telescope** ~ 1 m × 1 m; dist. ~ 3 m*

Cf. presentation by F. Lebrun

Development in the framework of an **INTAS (**) Collaboration:**

- Partners: **CEA (Saclay + Marcoule)**  
  **Kurchatov Institute (Moscow)**  
  **MEPHI (Moscow)**  
  **SCK-CEN Mol (Belgium)**

- End of the project: 2004

(**) *The International Association for the Promotion of Co-operation with Scientists from the New Independent States (NIS) of the Former Soviet Union*
Development and tests of a camera with coded mask

**Principle:**
- Replace the pinhole by **multiple holes**
- Hole positions according to **mathematical rules**

**Decoding algorithm**
\[
d_{ij} = \sum_{kl} r_{kl} a_{k+i,l+j}
\]
(correlation product) [1]

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Development and tests of a camera with coded mask

Resolution limit:
- Varies little with $\gamma$ energy (contrary to pinhole collimator)
- **Significant gain**, especially for $^{60}\text{Co}$ (1.25 MeV): $3^\circ$ vs. $6.7^\circ$

Detection limit:
- The coded mask is at least **5 times as sensitive** as the pinhole collimator
  (10 to 20 times for small dose rates)

Background removal:
- Masks are *anti-symmetric* by $60^\circ$ rot.
  - Make 2 id° images with $60^\circ$ rotation, decode the difference

Ex.: $^{137}\text{Cs}$ in **high $^{60}\text{Co}$ ambiance**

Tests on site SCK-CEN, Mol (Belgium): (1)

- **One-week campaign** realized with the cameras *Cartogam* and *Aladin*.
- Search for **hot spots** on **heat exchangers**, in BR2 reactor.
- Comparison between collimator and coded mask configurations.
Tests on site SCK-CEN, Mol (Belgium): (2)

- Presence of intense hot spots out of the field of view, above the camera
- The camera was often unusable with the pinhole collimator
- Background removal very efficient with the coded mask

With 50° collimator

With coded mask
Development and tests of a camera with coded mask

Tests on site SCK-CEN, Mol (Belgium): (3)

- Gain in angular resolution very significant in comparison with the pinhole collimator

With 50° collimator  
With coded mask
Tests on site SCK-CEN, Mol (Belgium): (4)

Problem of the partially-coded sources:

- Produce artefacts in the image, shifted by one mask period.
- Study of correction algorithms is under way.

With 50° collimator

With coded mask
Development and tests of a camera with coded mask

Other images (50° pinhole collimator vs. coded mask):

Pu contamination in a glove-box
Exposure: 30 min vs. 20 s
(CEA/Cadarache)

Pu sources (~1 g) in a waste drum
Exposure: 30 min vs. 7 min
(CEA/Cadarache)
Gamma imaging with a semi-conductor pixel detector

Principle:

- Objective: replace the multiple conversion stages by a **direct conversion**, in photon-counting mode
- Advantages: sensitivity (SNR), compactness (camera < 10 kg)
- Difficulty: pixels of ~100×100 µm²

ASIC, hybridization

Participation in the *Medipix Collaboration* (*) for the ASIC development

- **The Medipix2 chip:**
  14 mm × 14 mm
  256×256 pixels of 55 µm
  2 thresholds + 1 counter per pixel (13 bits)

- **Substrate** (for high energy):
  at least 1 mm of CdTe, preferably 4 mm

(*) [http://www.cern.ch/MEDIPIX/](http://www.cern.ch/MEDIPIX/)
Gamma imaging with a semi-conductor pixel detector

Results:

• First detectors hybridized on CdTe (1 mm) delivered in June 03 and November 03
  - pixelated CdTe substrate: Acrorad (Japan) – THM CdTe:Cl
  - hybridization: AIT (Hong Kong) – Indium bump-bonding


+ Presentations by M. Maiorino (Session 2) and C. Fröjdh (Session 5) + Poster P23 (M. Maiorino)
Gamma imaging with a semi-conductor pixel detector

Measurements at high energy with the CdTe detector – 1 mm:

- $^{137}$Cs source (662 keV)
- 90 $\mu$Gy/h (8·10$^3$ ph/cm$^2$/s)
- Efficiency: 4.5%
- 50° pinhole collimator

More sensitive than the present camera, at equal exposure
Detection limit much lower, for long exposures (230 nGy/h in 15 min)
Gamma imaging with a semi-conductor pixel detector

First tests of Medipix2/CdTe with a coded mask: (1)

Detector should be translated to cover the mask central pattern.

Assembly: surface equivalent to 4 images (180 s exposure).

Mask of rank 9

$^{137}$Cs 48 $\mu$Gy/h
Gamma imaging with a semi-conductor pixel detector

First tests of Medipix2/CdTe with a coded mask: (2)

- **Decoded images**, for $^{137}$Cs – 48 µGy/h

![Images showing decoded images after different exposure times](image)

- **Image quality** is very encouraging, particularly the **resolution**
- Some **systematic errors**, possibly due to misalignments in the assembling, mask rotation, sensitivity inhomogeneities…
Conclusions

• Use of miniaturized coded mask for gamma imaging brings important gain in sensitivity (up to 20 times) and in angular resolution (especially at high energy), allows background removal by the mask-antimask procedure.

• Performances quantified in laboratory tests and verified on site.

• The next stage is the realization of a motorized prototype in order to make on-site operation easier.

• At longer term, the use of Medipix2/CdTe instead of scintillator + intensified CCD will increase sensitivity and compactness.

• The association of a Medipix2/CdTe detector with a coded mask could lead to very significant improvements:
  • a factor of 2 on mass
  • a factor ≥ 10 on sensitivity
  • a better angular resolution

• For that, Medipix2/CdTe detectors of greater surface and greater thickness would be preferable.