Summary

- Context and state of the art
- The GAMPIX gamma camera: main characteristics
- Experimental performances obtained in laboratory
- Dismantling and decommissioning applications
- Radiation protection in Nuclear Power Plants (NPP)
- Homeland Security applications
- Conclusions and future developments
What is gamma imaging?

Purpose: localization of radioactive sources

Visible image

Gamma image

Superimposition
A lot of potential applications

- Localization of radioactive hot spots: A major issue in several application fields

- D&D activities
- Radiation protection
- Homeland Security

And many other applications: safeguards for IAEA, nuclear waste packages characterization …
What is a gamma camera?

- A system enabling to locate radioactive hot spots

What are the main characteristics of a gamma camera?

- A **detector**: scintillator, pixellated detector …
- An **optical part**: pinhole, coded mask …
- An **acquisition and processing software**
State of the art

- CARTOGAM: an industrial standard

Developed by CEA\(^{(1)}\), industrialized by AREVA CANBERRA

Performing but:
- **Sensitivity** has to be improved at low-energy
- **Weight** is too high for a portable use
- Improve the interface

A new gamma camera: but what do you want?

First generation

More sensitive

Lighter

Cheaper

Second generation

Pu

Pu

KG

KG

$\text{EDF}$

$\text{CANBERRA}$

Characterization and Visualization Technologies in DD&R, 5th October 2011
GAMPIX: a new generation of gamma camera

- Timepix chip
- Coded Mask
- USB interface
- Camera’s body

Characterization and Visualization Technologies in DD&R, 5th October 2011
**What is Medipix?**

- A photon counting chip (PCC) developed in the framework of the Medipix collaboration (CERN + 15 partners)
- Matrix of 256 x 256 pixels (side 55 µm)
- Hybridization to CdTe (thickness 1 mm) using indium contacts

Enables a **direct conversion** from gamma to electrical signal
Timepix: a performing chip

- Each pixel has an **analog and a digital part**
- **500 transistors** on 55 µm²...

... Each pixel is an **individual detector**
Why a coded mask?

- Great improvement of the **sensitivity** in comparison with a pinhole
- Need for a **decoding step**
- **Optimization** of the coded mask (thickness/rank) for a dedicated application
Connectivity aspects

- USB connection

Standard laptop

USB cable

GAMPIX: a plug-and-play system
GAMPIX: how does it work?

- Principle of gamma imaging using GAMPIX

  Raw gamma image
  Decoded gamma image
  Superimposition gamma image / visible image

- What are the main benefits of GAMPIX?
  - Low weight (~ 1 kg)
  - High sensitivity
  - Plug-and-play system
  - Easy to deploy / easy to use
Thickness of the coded mask vs signal to noise ratio

Increase the thickness of the mask: required to improve the performances at high-energy ($^{137}\text{Cs}, ^{60}\text{Co}$)
Sensitivity performances (2)

- **Sensitivity: current performances**
  - **Punctual sources**
  - **No gamma background**
  - **Distance of 1 m** between the source and the gamma camera
  - **Dose rate measured** in the vicinity of the GAMPIX gamma camera

<table>
<thead>
<tr>
<th>Source</th>
<th>Dose rate ($\mu$Sv.h$^{-1}$)</th>
<th>Coded Mask Rank 13 – e=2 mm</th>
<th>Coded Mask Rank 7 – e=4 mm</th>
<th>Coded Mask Rank 7 – e=8 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}$Am</td>
<td>0.25</td>
<td>~3 s</td>
<td>1 s</td>
<td>1 s</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>2.50</td>
<td>300 s</td>
<td>60 s</td>
<td>20 s</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>3.84</td>
<td>Not detectable</td>
<td>400 s</td>
<td>60 s</td>
</tr>
</tbody>
</table>

- **Optimal performances for low-energy** gamma-ray emitters ($^{241}$Am)
- **Able to cover a large energy range** (from $^{241}$Am to $^{60}$Co)
Reference values

- **$^{241}$Am: experimental conditions**
  - $^{241}$Am, 74 MBq, distance of 1 m between the source and the gamma camera, no background

  - **Minimal localization time: 1 s**

- **« Aged » plutonium: link between the Pu mass and the $^{241}$Am content**
  - ~500 mg Pu, $^{239}$Pu(%)=65.1 %, $^{241}$Am(%)=7.9 %

  - **Act($^{241}$Am)~4.8 GBq**

- **Conclusion**

  - If plutonium is hidden somewhere, GAMPIX can find it!
Angular resolution (1)

Impact of the rank of the mask

Increase of the rank = Improvement of the resolution
Angular resolution (2)

Angular resolution for a FOV of 30 degrees

<table>
<thead>
<tr>
<th>Mask/Source</th>
<th>Rank 7</th>
<th>Rank 11</th>
<th>Rank 13</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}\text{Am}$</td>
<td>3.81°</td>
<td>2.12°</td>
<td>1.38°</td>
</tr>
<tr>
<td>$^{137}\text{Cs}$</td>
<td>3.68°</td>
<td>2.06°</td>
<td>1.35°</td>
</tr>
<tr>
<td>$^{60}\text{Co}$</td>
<td>3.41°</td>
<td>2.57°</td>
<td>-</td>
</tr>
</tbody>
</table>

The greater the rank of the mask, the better the angular resolution.
Gamma background impact

Potential solutions

- Shielding: **increase of the weight**
- Mask/anti-mask procedure

- **Benefit:** remove the gamma background located outside the FOV
- **Drawback:** the acquisition time is increased by a factor 2
Mask/anti-mask: a first illustration

First experimental results of the mask/anti-mask procedure

- \( ^{241}\text{Am} \)
- 74 MBq
- \( d = 150 \text{ cm} \)
- PIDIE 7
- 4.7 GBq \(^{241}\text{Am} \)

Raw image

Mask 200 s

Mask/ Anti-mask 2x200 s
The main drawback of coded masks

Position 28 degrees  Position 26 degrees  Position 24 degrees

Profil de l'image au niveau du point chaud
Le maximum se situe au point [15, 128] et vaut 9806.

Profil de l'image au niveau du point chaud
Le maximum se situe au point [3, 128] et vaut 4964.

Profil de l'image au niveau du point chaud
Le maximum se situe au point [254, 131] et vaut 3254.
Partially coded sources (2)

- Hardware and software solutions

Random mask

EM algorithms

No shadow source

Right position

Shadow source
Decommissioning purposes

Fast and accurate localization of plutonium hot spots

300 μSv.h⁻¹ contact

m (Pu)< 1 g

Contact
Results obtained in AREVA LPC Cadarache (1)

- Pipe measurements

- Increase of the counting time = improvement of the decoded gamma images

- Results obtained in AREVA LPC Cadarache (1)
Results obtained in AREVA LPC Cadarache (2)

- Impact of the rank of the coded mask

**Rank 7**
- 1 s
- 6 mSv.h\(^{-1}\) contact

**Rank 13**
- 3 s
- 0.35 µSv.h\(^{-1}\) contact
- 160 s
- 250 s
Results obtained in AREVA LPC Cadarache (3)

- Real time gamma imaging measurements

200 ms !

1 s

30 s

Ability to detect extended sources
Main characteristics of a measurement in a NPP

- Detection of $^{60}$Co (« high-energy » gamma-ray emitter)
- Two measurements campaigns (January 2011 / May 2011)
- Constraints for the deployment of a gamma camera
Deployment of two generations of gamma camera

Example of application:
expansion leg of the pressurizer

100 µSv.h\(^{-1}\) contact
Benefits of the mask/anti-mask procedure

Without correction

Mask/Anti-mask procedure

2×30 s

2×200 s

90° Rotation

80 mSv.h\(^{-1}\) contact
Detection of contaminated pipes

- 41 mSv.h\(^{-1}\) contact
- 10 mSv.h\(^{-1}\) contact
- 4 mSv.h\(^{-1}\) contact

Measurement times:
- 2×120 s
- 2×120 s
- 2×300 s
New way of use for a new generation of gamma camera

Light...and handheld system!

GAMPIX system

Operating people

15 s
Homeland Security applications

Main purpose

Detection of **illicit nuclear materials** (SNM, radioactive sources …)

Potential applications

- **SNM detection**
  - Natural uranium, metallic form
  - 600 s

- **Luggage monitoring**
  - $^{241}$Am, 74 MBq
  - 20 s

- **Vehicle monitoring**
  - $^{241}$Am, 18 GBq
  - 1 s
Conclusions and future developments

Conclusions

- **GAMPIX**: a new generation of gamma camera based on the *Timepix pixellated chip*
- **Low weight (~ 1 kg), high sensitivity, plug-and-play system**
- Several application fields can be addressed (*radiation protection, D&D, Homeland Security*) using this gamma camera
- **Industrial transfer** currently in progress, industrial system *expected in 2012*

Future developments

- Development of **spectrometric properties** using the Timepix chip (*Time-Over-Threshold* mode)
- Development of **3D abilities**
- Integration of the future **Medipix 3 chip**

GAMPIX’s product manager: Roger Abou Khalil
[roger.aboukhalil@canberra.com]
What do you want for Christmas 2012?

GAMPIX: an industrial system in 2012

Benefits of the industrial system

- New design \((L \times W \times P = 8 \times 8 \text{ cm} \times 15 \text{ cm})\)
- Automatic mask/anti-mask procedure
- Optimized shielding
- Simplified connectivity (only one cable)
- A single software for the acquisition and decoding steps
Road map of gamma imaging developments

**Generation 1**
(Pinhole / Scintillator / CCD)

1990

**Generation 2**
(Coded mask / Pixellated detector / USB interface)

2000

**Generation 3**
Spectro-imaging system
(1 spectrum/pixel)

2006

Industrial transfer CANBERRA
Cartogam: ~ 40 units

2001

Industrial transfer GAMPIX

2011

CEA: more than twenty years of expertise in this field

1990 Canbera
Combining measurements

3D Gamma Imaging → Localisation

Geometry

Spectrometry → Isotopic composition → Quantification

Simulation

(MCNP, MERCURAD, ...)

MGA / IGA
Thanks a lot for your attention