



list



International Conference on Nuclear Decommissioning  
Addressing the Past and Ensuring the Future

## 3D reconstruction and localization of radioactive sources using a single gamma camera

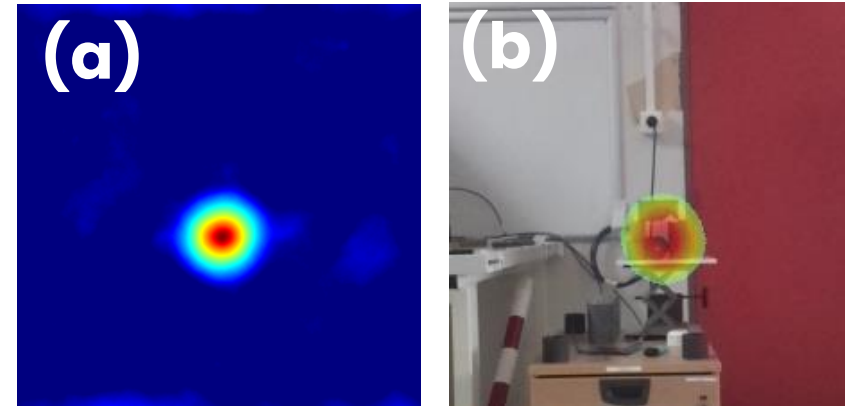
Kamel BENMAHI<sup>1</sup>, Vincent SCHOEPFF<sup>1</sup>,  
Guillaume AMOYAL<sup>1</sup>, Frédérick CARREL<sup>1</sup>.

(1) Université Paris-Saclay, CEA, List, F-91120 Palaiseau, France.

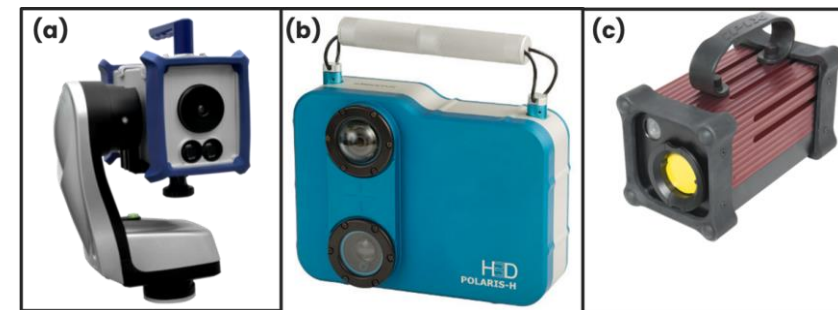
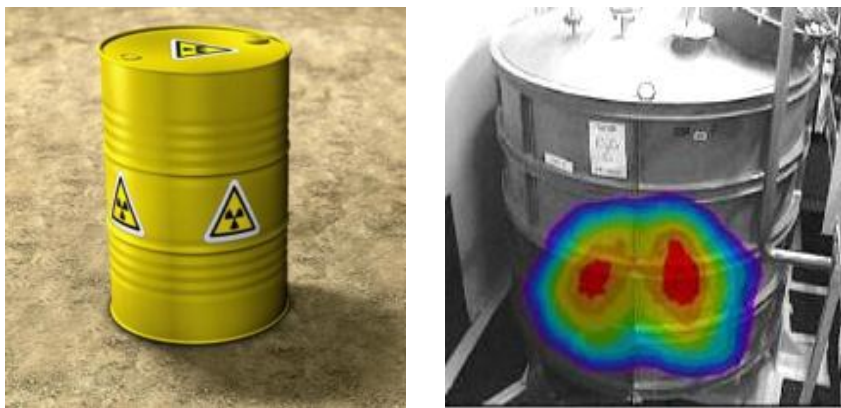


# Introduction, context, purposes

- **Localization of radiological hot spots**
  1. Superimposing a gamma image on a visible image
  2. Respecting ALARA\* principle
- **Applications:**
  1. Nuclear decommissioning
  2. Radiation protection
  3. Accidental situations
  4. Nuclear waste management applications



(a): Hot spot reconstruction using the coded-aperture method via Nanopix. (b): Superimposition of a gamma image on a visible image to locate the hot spot.

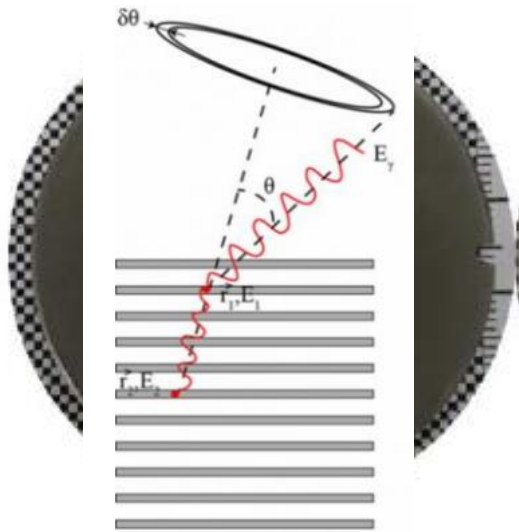


Gamma imagers pictures (a) Nuvision. (b) POLARIS. (c) IPIX.

\* As Low As Reasonably Achievable

# Introduction, context, purposes

- **Localization in our current compact imaging systems:**
  1. Stationary measurements;
  2. Two distinct **2D** localization techniques.
    - Coded-aperture;
    - Compton scattering.



Extracted from: <http://www.univearths.fr/>

- **Development of a new generation of gamma imager:**
  1. Moving system
  2. **3D** localization

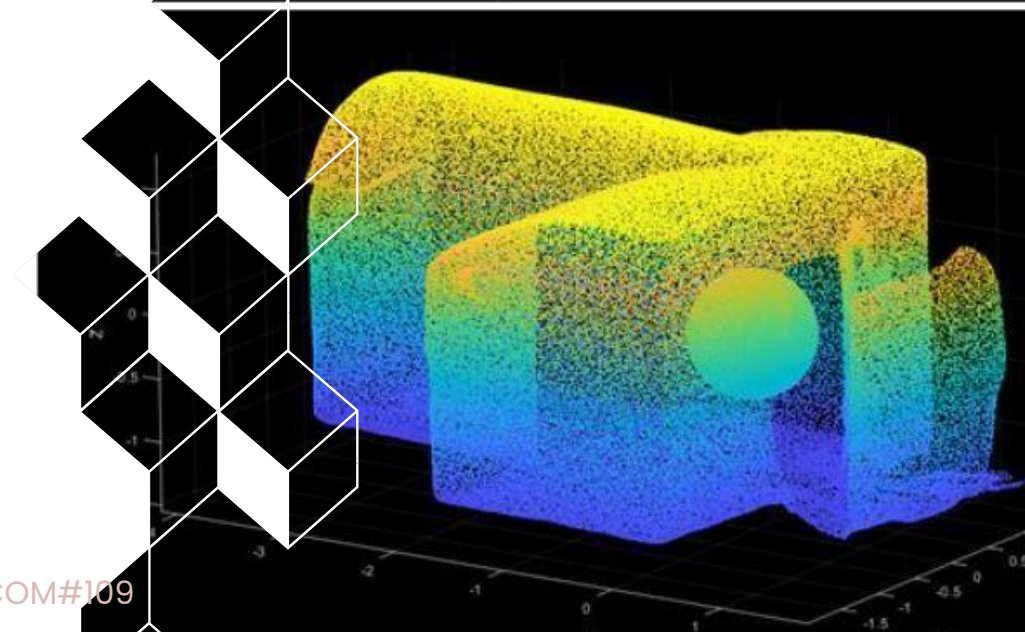
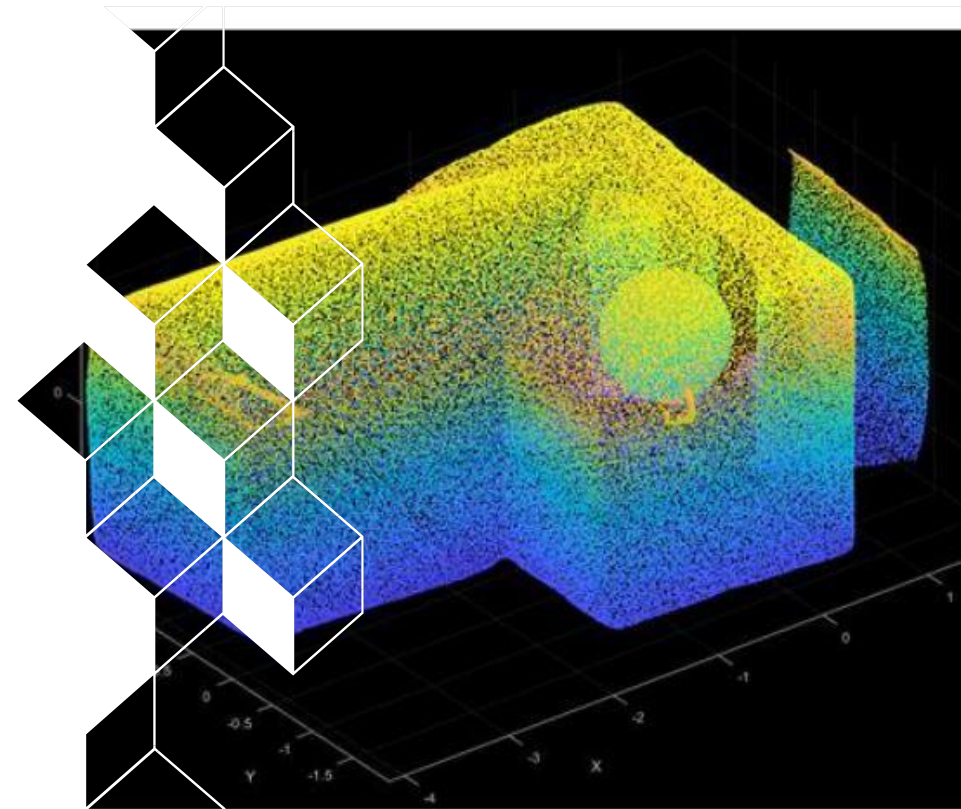


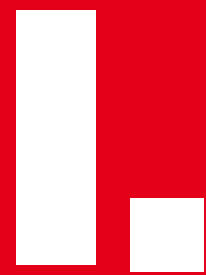
Source to detector distance ??

**Gamma camera Nanopix**

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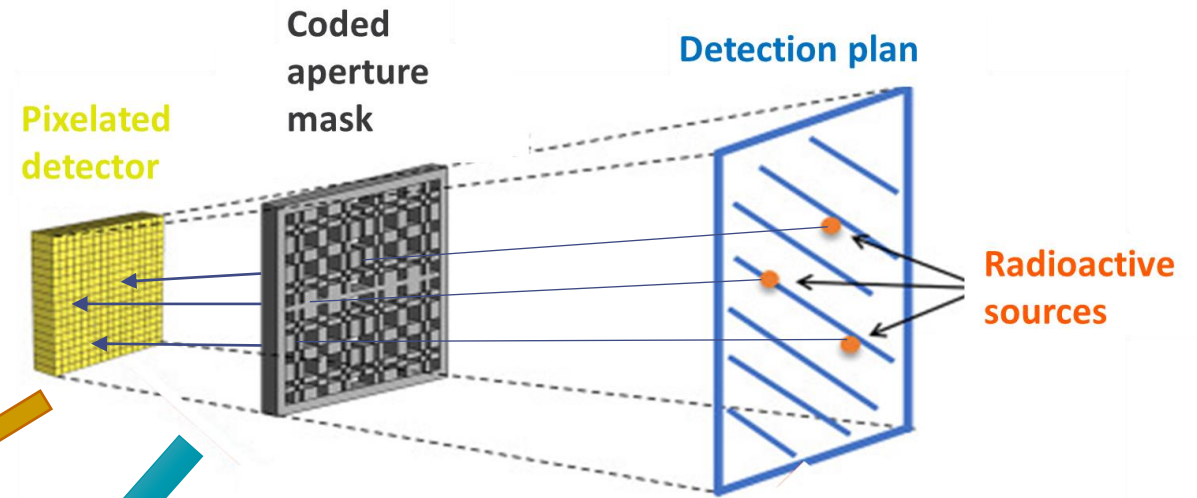


# Coded aperture imaging technique

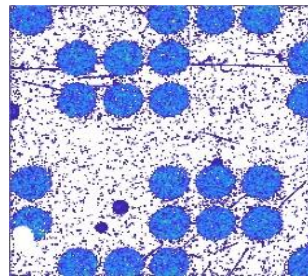
# Coded aperture imaging technique

## ■ Coded-aperture imaging:

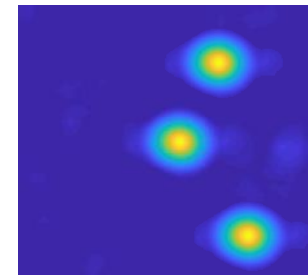
1. Spatial modulation of the incoming flux of  $\gamma$ -rays and x-rays
2. Masks: multi-holes collimators
3. Projection on the pixelated detector
4. Decoding the pattern of the projected shadow
5. Superimposing on a visible image

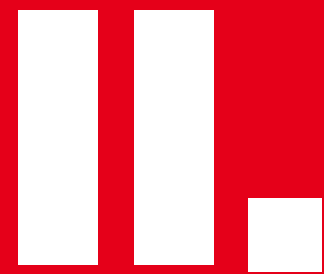


Extracted from: M. J. Cieślak, "Coded-aperture imaging systems: Past, present and future development – A review," Radiat. Meas.



Decoding



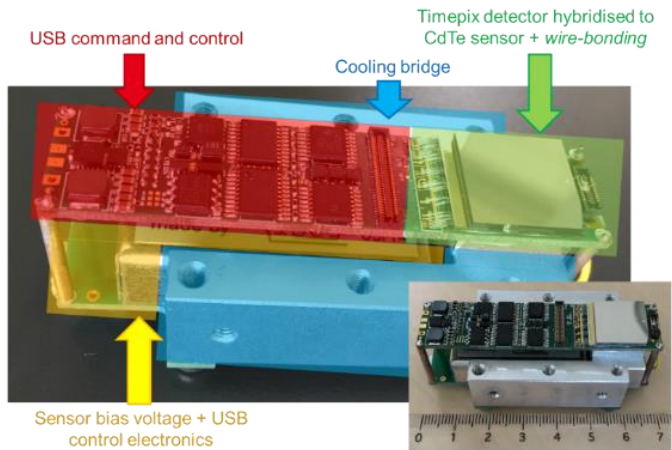


# Technological systems: Nanopix

# Technological systems: Nanopix

- The operating gamma imager:

Gamma Imager	Imaging technique	Integrated counting chip
Nanopix	Coded mask	Timepix + 1 mm CdTe



**10 × 7 × 5,5 cm<sup>3</sup>**  
**413 g**  
**Field of view: 50°**



Nanopix © CEA List



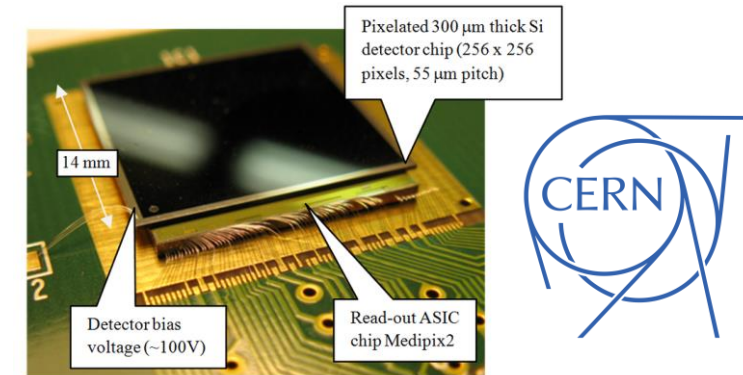
Nanopix embedded on a drone – 50 m TERRIFFIC H2020 project



# Technological systems: Nanopix

- The operating gamma imager:

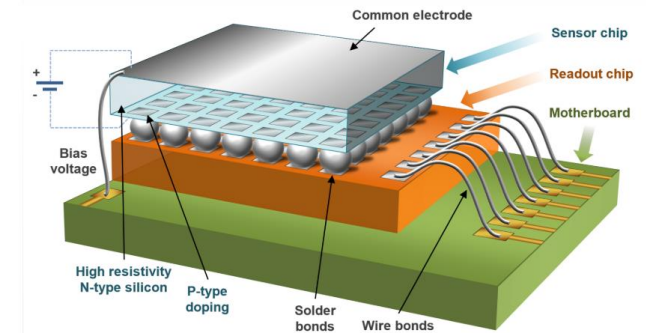
Gamma Imager	Imaging technique	Integrated counting chip
Nanopix	Coded mask	Timepix + 1 mm CdTe



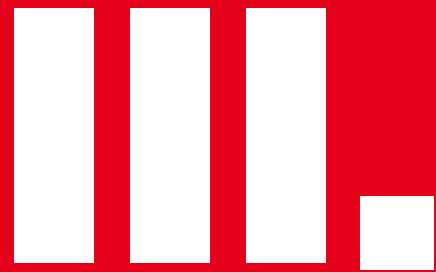
Medipix2 © Jakubek, 2009

- Features:

- Counting (Medipix) mode  
each incident event above the threshold increments the counter.
- Time over Threshold (ToT) mode  
the energy of the incident photons can be obtained from ToT counts.
- Time of Arrival (ToA)  
the counter works as a timer and measures the arrival time of the event.



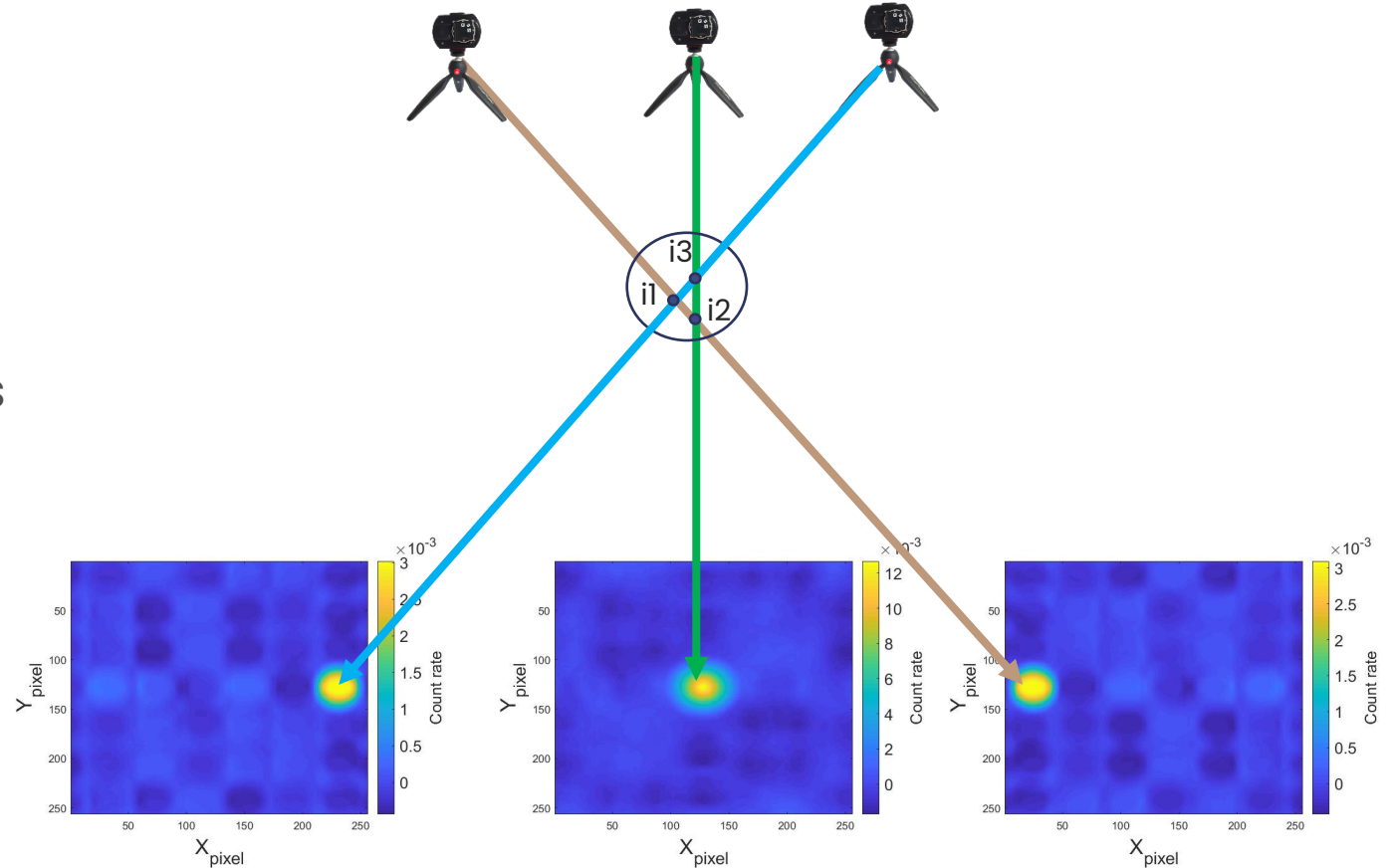
Extracted from: Platkevič, Michal (2014). "Signal processing and Data Read-out from Position Sensitive Pixel Detectors".



# 3D localization of hotspot by triangulation

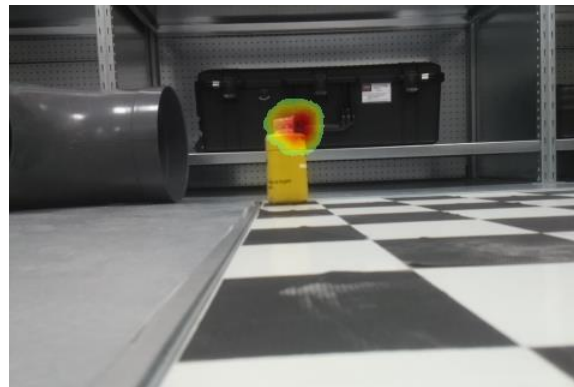
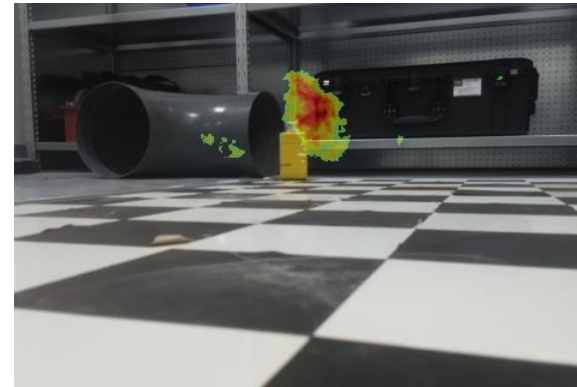
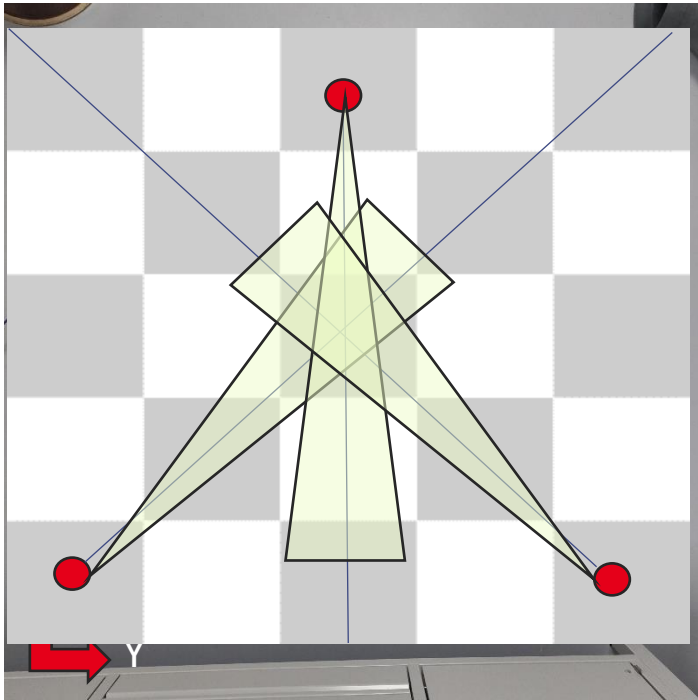
# 3D localization of hotspot by triangulation

- **Triangulation method using a single detector**
  1. Moving the detector to different positions
  2. Recording the coordinates of each position of the detector
  3. Performing several gamma images
  4. Calculating the director vectors
  5. Defining and characterizing the **region of uncertainty**



# 3D localization of hotspot by triangulation

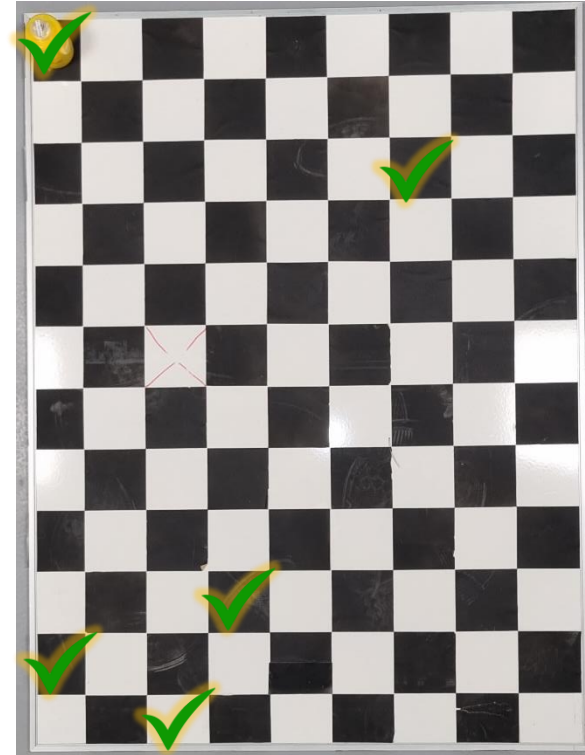
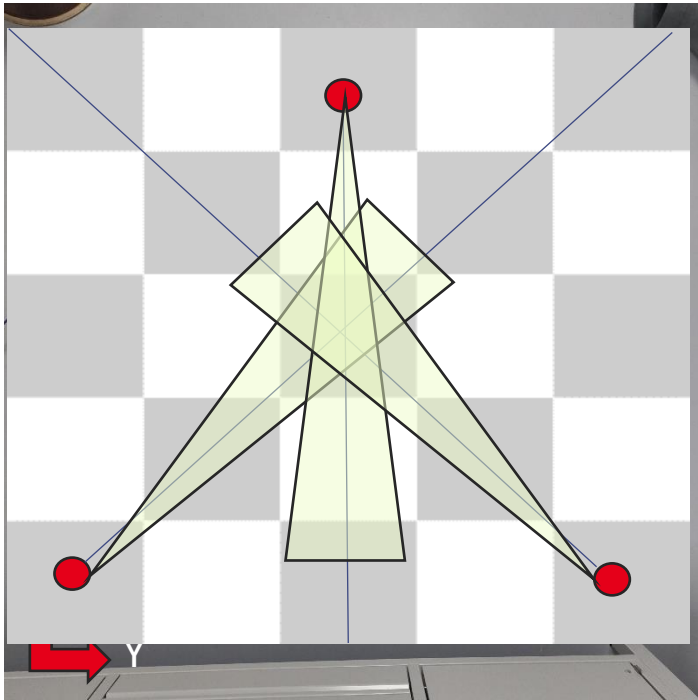
- Experimental study performed with Nanopix



- Use of an Am-241 radioactive source of 74 MBq.
- The measurement time of each projection = 10 seconds in mask and 10 seconds in anti-mask mode

# 3D localization of hotspot by triangulation

- Experimental study performed with Nanopix



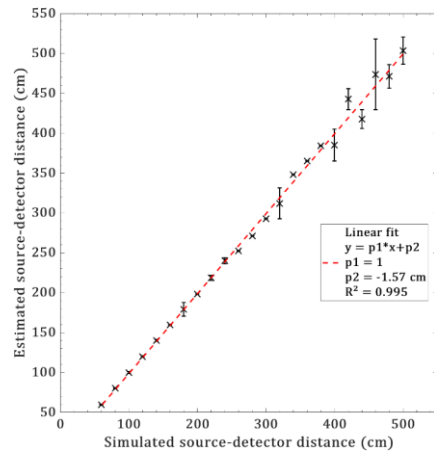
- Use of an Am-241 radioactive source of 74 MBq.
- The measurement time of each projection = 10 seconds in mask and 10 seconds in anti-mask mode

# 3D localization of hotspot by triangulation

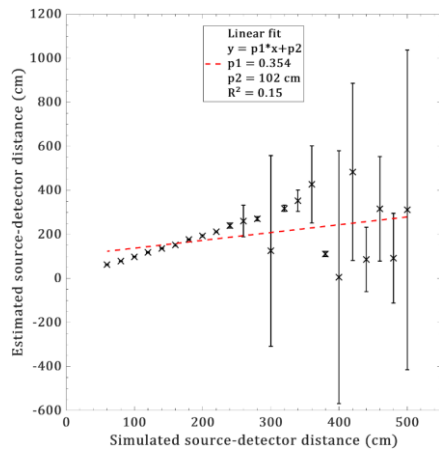
- Monte-Carlo simulation study using the MCNP6.2 calculation code

Displacement = **25 cm**

$^{241}\text{Am}$  (59.5 keV)  
 $H^*(1\text{m}, 1\text{s}) = 2.7 \text{ nSv/h}$



$^{137}\text{Cs}$  (662 keV)  
 $H^*(1\text{m}, 1\text{s}) = 73.3 \text{ nSv/h}$



- Uncertainty:
- Improvement
  - Displacement step
  - Global angular resolution

K factor = 2

# 3D localization of hotspot by triangulation

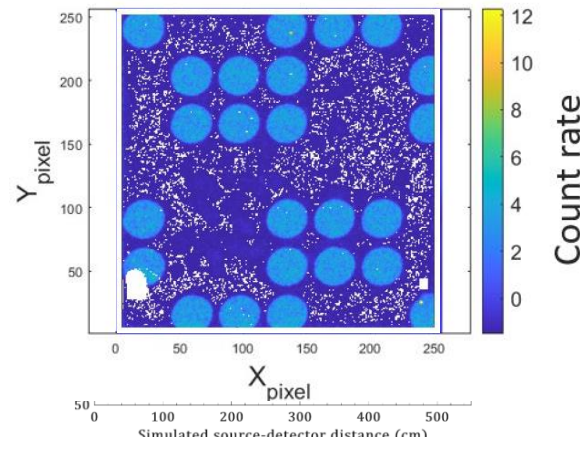
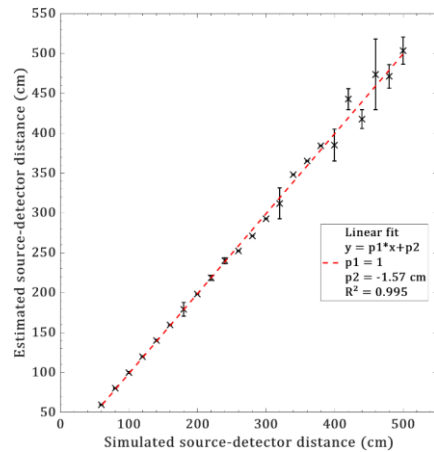
- Monte-Carlo simulation study using the MCNP6.2 calculation code

Displacement =

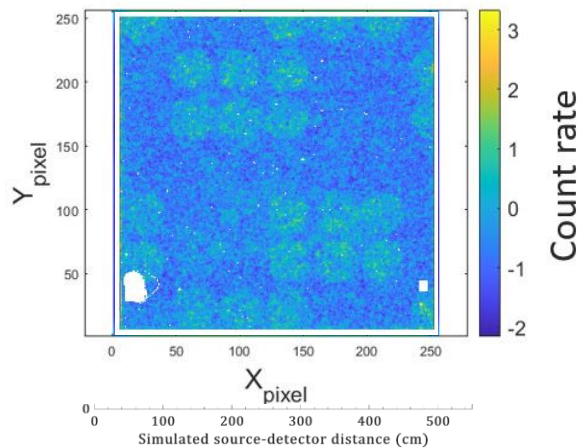
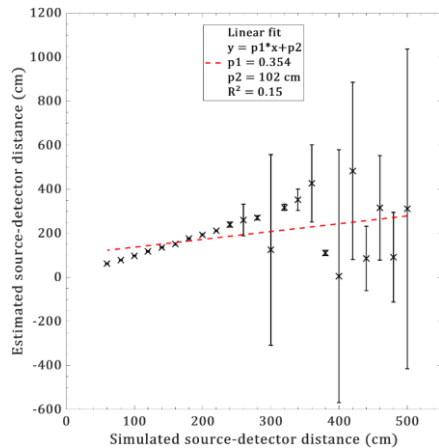
25 cm

35 cm

$^{241}\text{Am}$  (59.5 keV)  
 $H^*(1\text{m}, 1\text{s}) = 2.7 \text{ nSv/h}$



$^{137}\text{Cs}$  (662 keV)  
 $H^*(1\text{m}, 1\text{s}) = 73.3 \text{ nSv/h}$



- Uncertainty:
  - Improvement
    - Displacement step
    - Global angular resolution
  - Increased
    - Long measuring distance
    - Statistical deterioration (transparency of the mask)

K factor = 2



# IV.

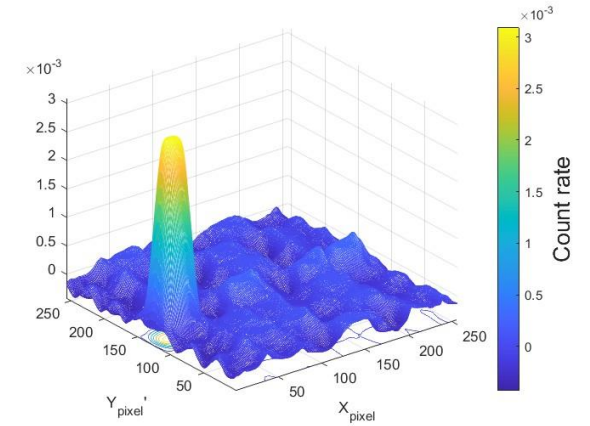
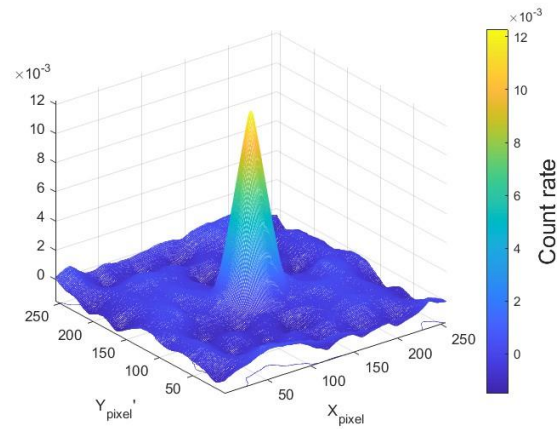
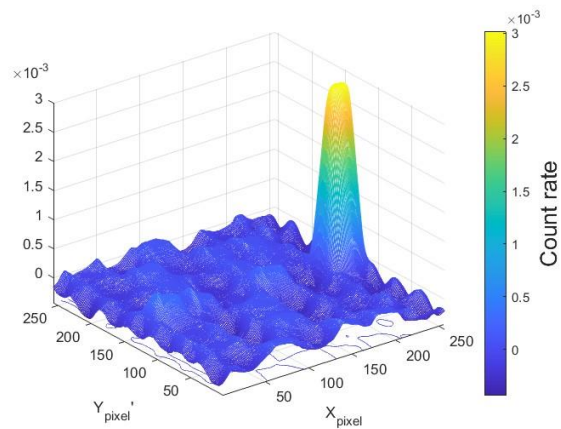
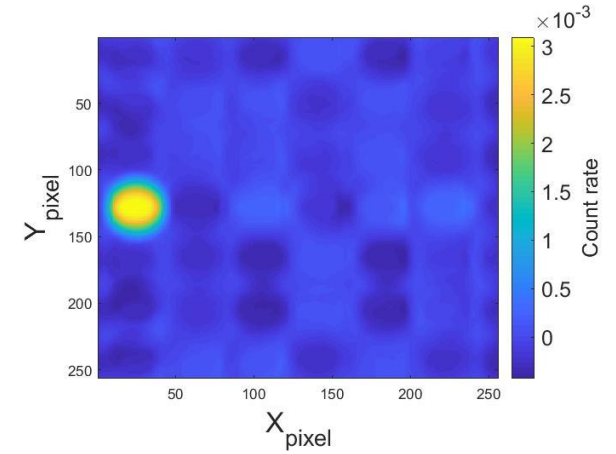
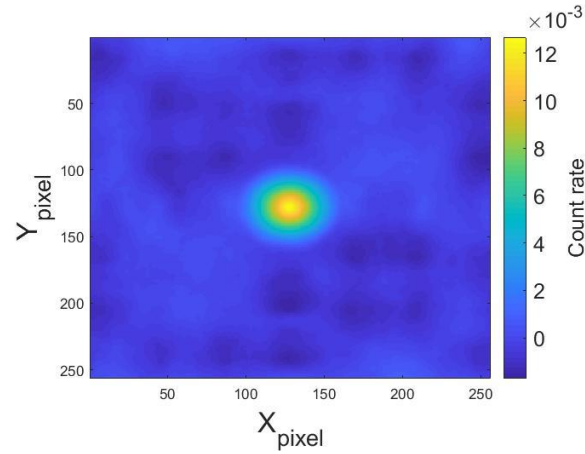
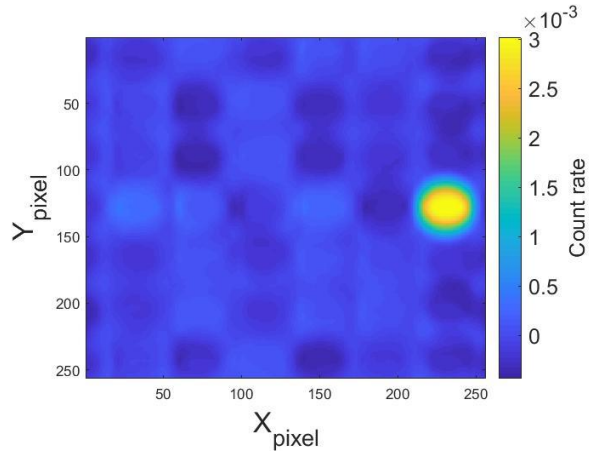
## 3D radiological mapping



# 3D radiological mapping

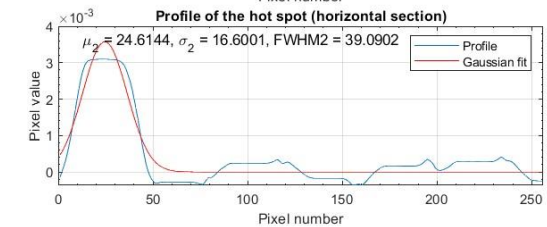
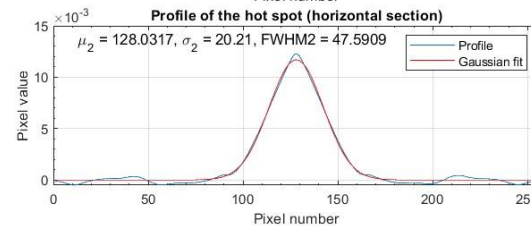
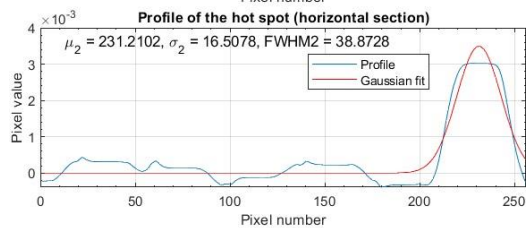
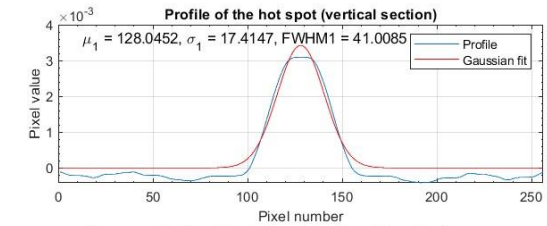
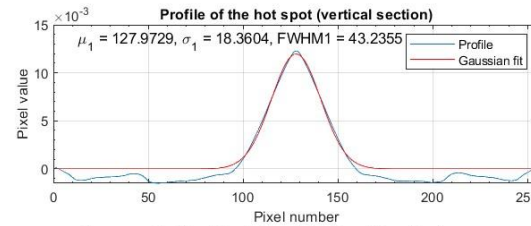
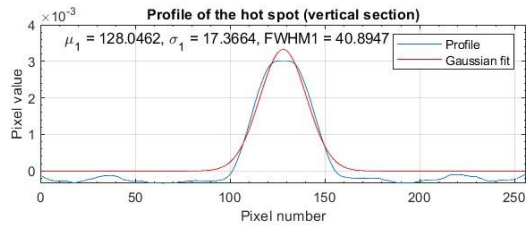
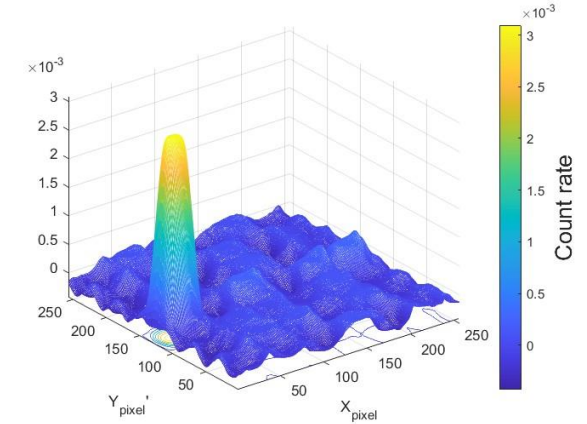
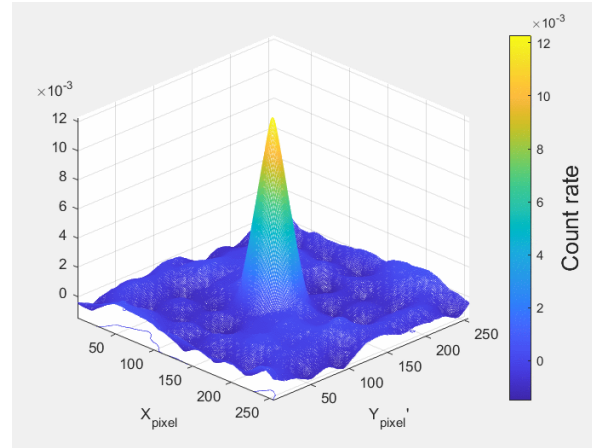
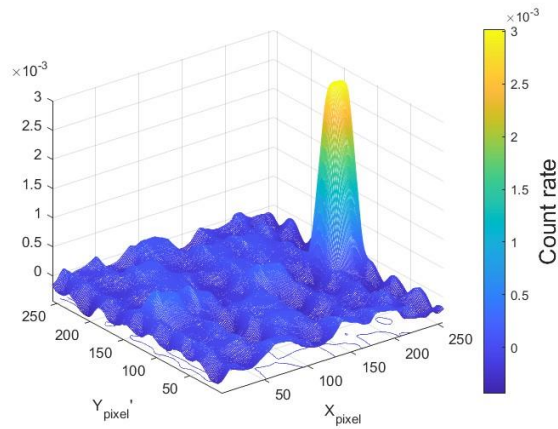


- 3D reconstruction of the point source



# 3D radiological mapping

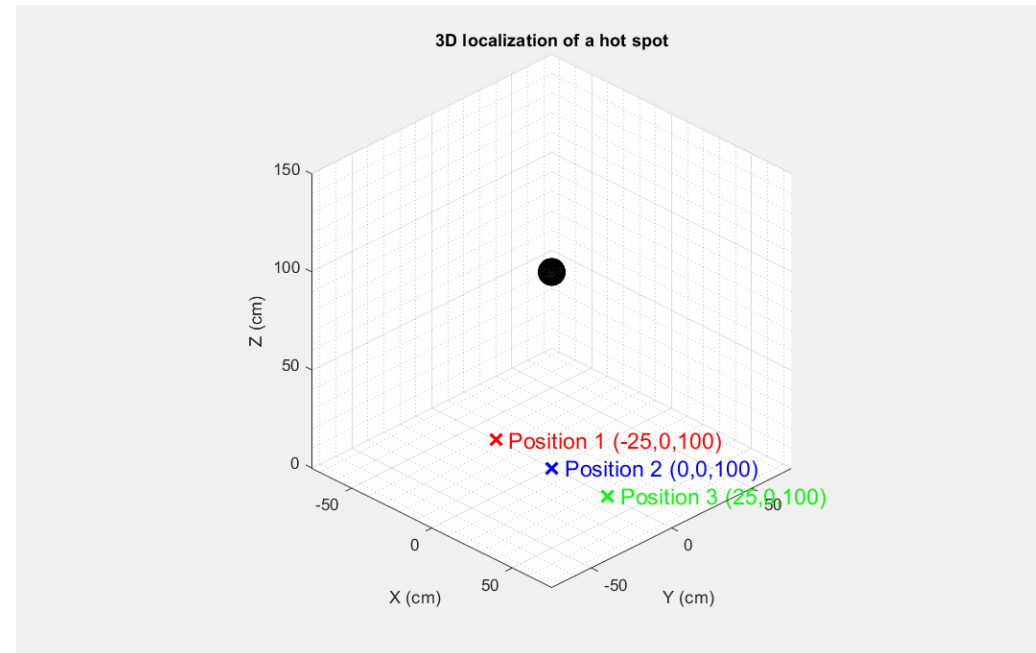
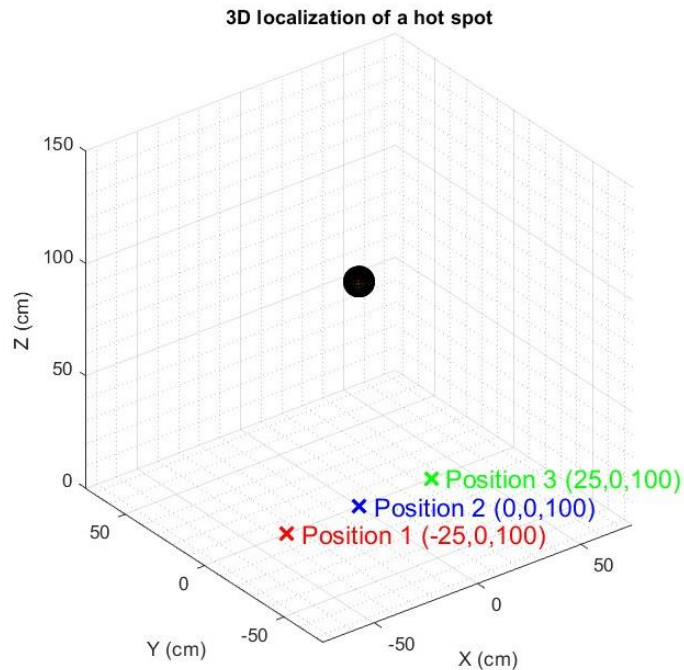
- 3D reconstruction of the point source



# 3D radiological mapping

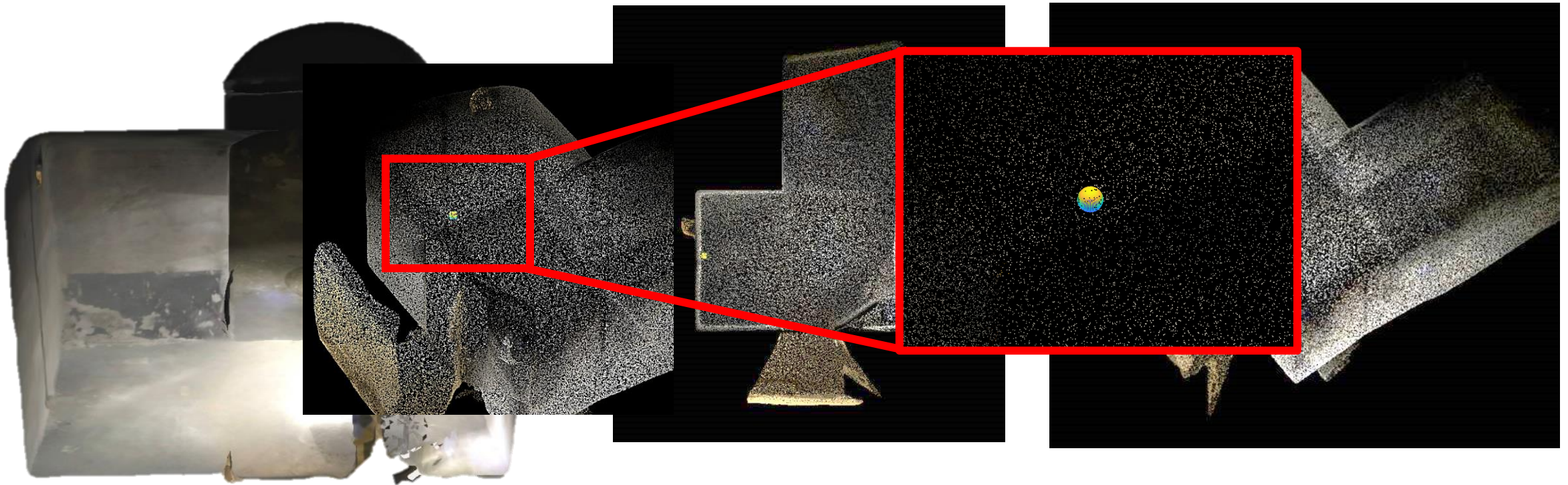
## 3D reconstruction of the point source

- The source is placed in the reference according to its **estimated coordinates**
- Reconstruction of the **point source** in **3D** in **spherical** form
  - (the diameter of the sphere corresponds to the average **FWHM**)



# 3D radiological mapping

- **3D radiological mapping on experimental data**
  - Superimposition of a **gamma image** of a radioactive hot spot measured with **Nanopix camera** on a **contextual scene** recorded with a **LIDAR** system.



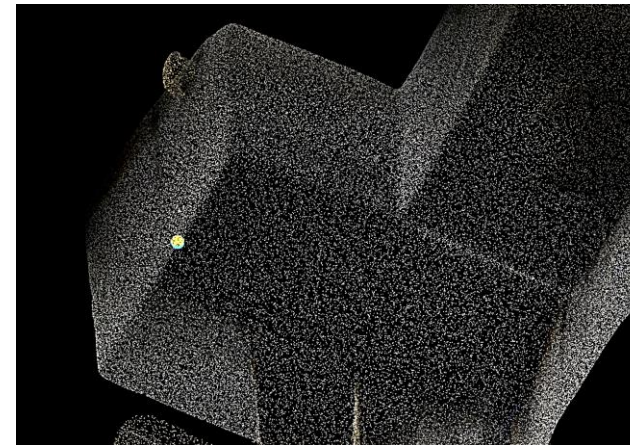
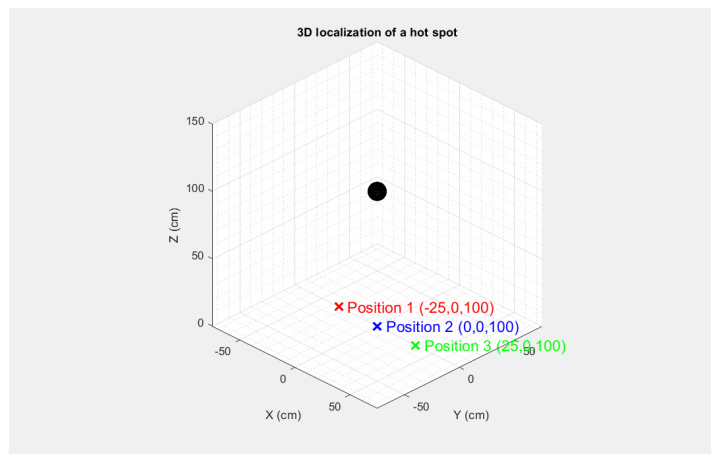


**V.**

# **Conclusion and outlooks**

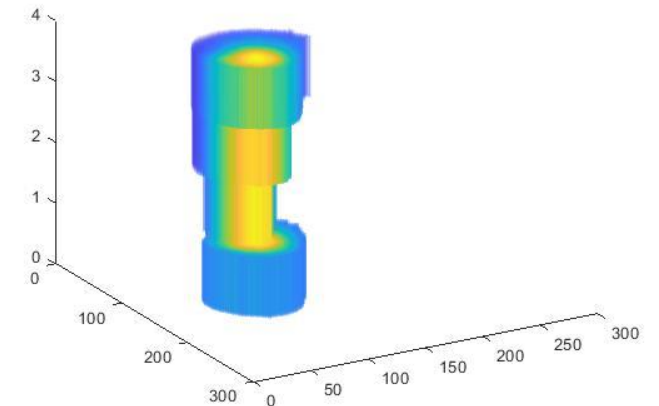
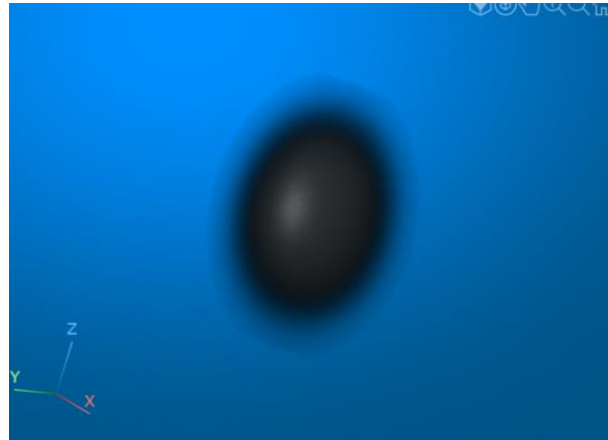
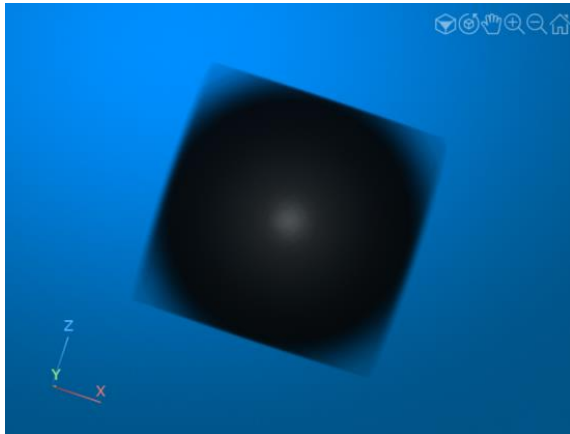
# Conclusion & outlooks

- 3D gamma imaging system
  - ✓ Use of a **single detector**
  - ✓ Adaptation of **triangulation** method for **3D localization** of radioactive hot spot
  - ✓ **Volumetric 3D** reconstruction of the hot spot
  - ✓ Radiological mapping in **3D**: superimposition of the **3D point source** on a **3D contextual scene**



# Conclusion & outlooks

- Implementation of **volumetric** reconstruction to extended radioactive sources
- **3D** localization using gamma Compton imaging technique





**Thank you for your attention**

[Kamel.benmahi@cea.fr](mailto:Kamel.benmahi@cea.fr)

