Development of a Dual Alpha-Gamma Camera for Radiological Characterization Applications

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DE LA RECHERCHE À L’INDUSTRIE

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Development of a Dual Alpha-Gamma Camera for Radiological Characterization Applications

(NSS) Nuclear instrumentation and Measurement for reactors and related Applications

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www.cea.fr

HISTORICAL FEEDBACK

In Situ measurement laboratory in Marcoule : ~40 years

R&D on Nuclear Instrumentation for decommissioning projects

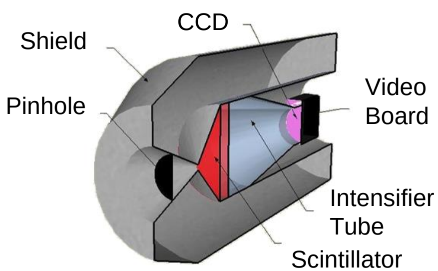
Technical Support and particular operations for CEA, AREVA, EDF, IAEA, CSK-CEN, …

- **CEA Centers :** Saclay, Fontenay-Aux-Roses, Marcoule, Cadarache, Grenoble, Valduc, La Hague
- **AREVA Centers :** Marcoule, Cadarache, La Hague
- **EDF Powerplant :** Tricastin, Cruas, Saint-Laurent, Gravelines, Le Blayais, Dampierre, Chinon, Chooz, Cattenom, Flamanville, …

Part of a laboratory including : virtual reality, robotics (teleoperation) & laser cutting developments

New gamma cameras under development and/or qualification at CEA

1980

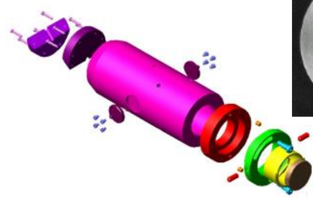


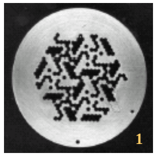
Aladin

Scintillator

Gamma camera

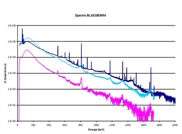
2000





Coded aperture

Additionnal shutter



CZT Spectrometry

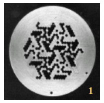
Dose rate

2012

IPix™ (CEA/CANBERRA)

Medipix technology, USB

Coded aperture

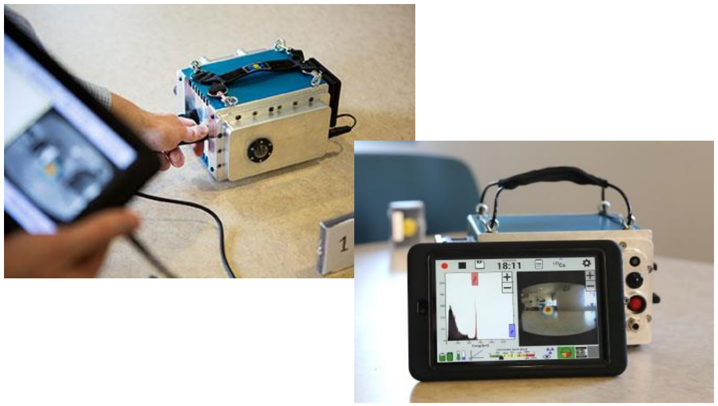


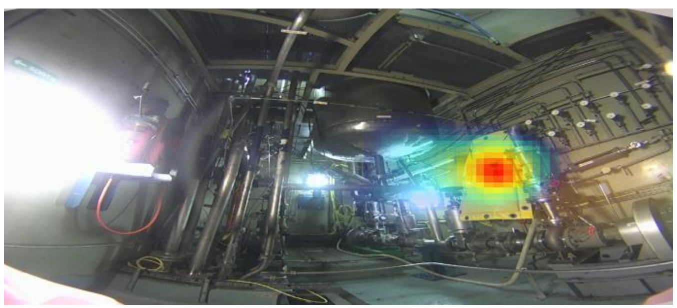
Better performances

Lower price

More compact & portable device

New gamma cameras under development and/or qualification at CEA





POLARIS (H3D)

CZT Compton camera

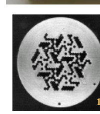
Wireless

Gamma spectrum + gamma image (>250 keV in Compton Mode)

IPix^{TM} (CEA/MIRION)

Medipix technology, USB

Coded aperture



Better performances

Lower price

More compact & portable device

Next generation

?

CZT/Coded Aperture

+

Compton Camera

+

Spectrometric function at any Energy range

Partnership under progress

CEA/DRT, CEA/IRFU, CEA/DEN

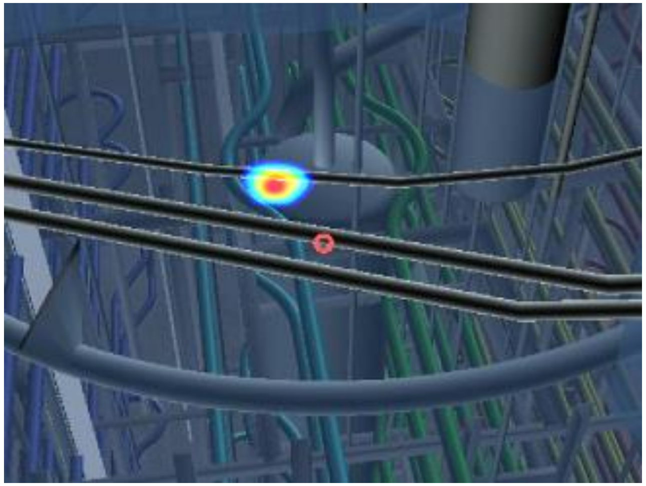
MIRION, GIE INTRA, IRSN, 3D PLUS

GAMMA CAMERA FEEDBACK

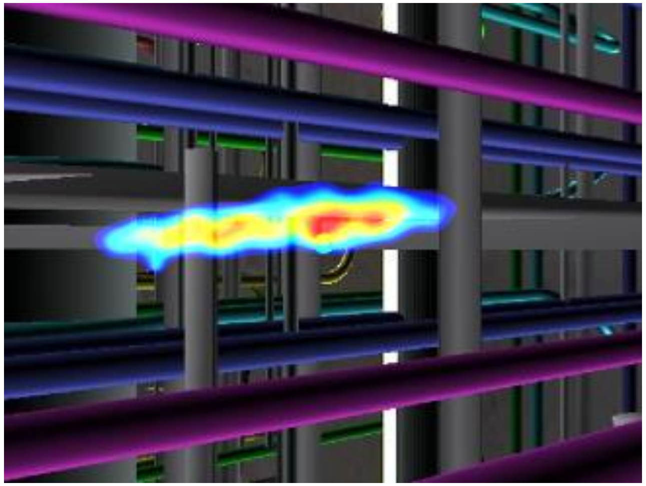
Used with *3D* view

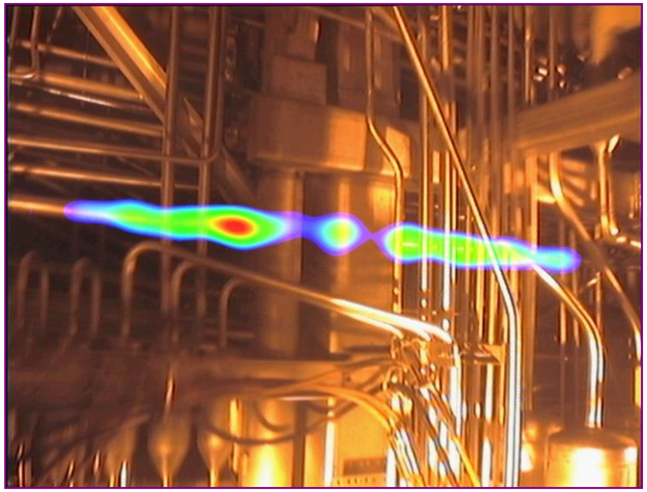
Used with *real* view

Hot spots localization



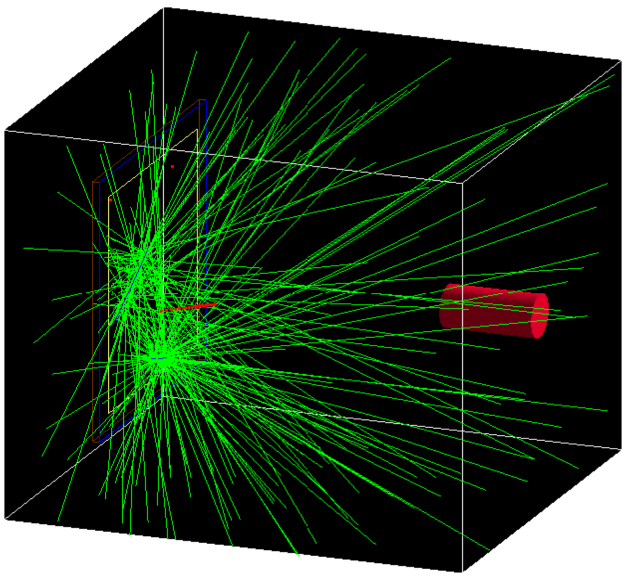
Extended spots localization



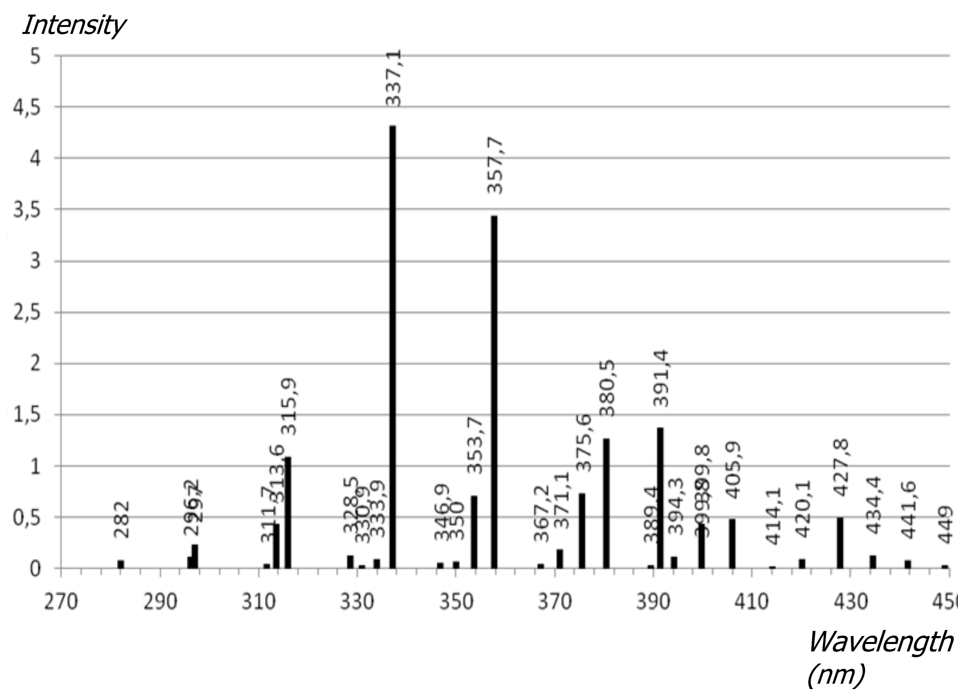


ALPHA CAMERA : A RECENT CAMERA TO LOCALIZE ALPHA CONTAMINATION

Detection of the UV produced by nitrogen molecules under an alpha particle desintegration

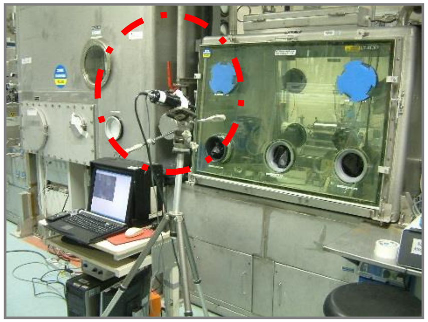


GEANT4 Model of a ^{241}Am source



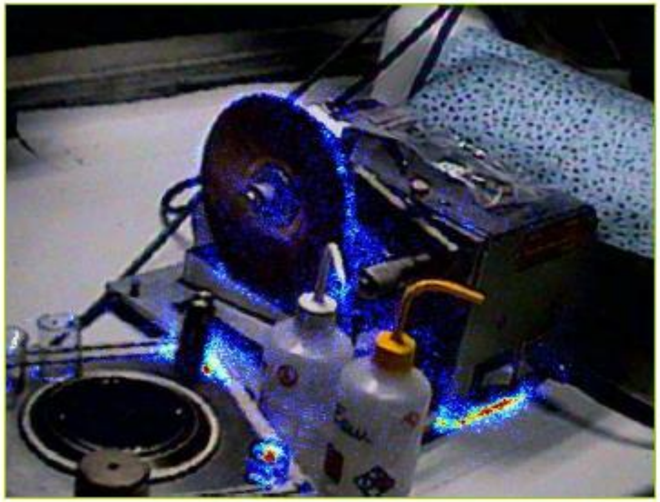
Radio-luminescence of Nitrogen phenomena

ALPHA CAMERA : A RECENT CAMERA TO LOCALIZE ALPHA CONTAMINATION



Raw α image

Atalante plant (2009)



Results after processing (threshold, colour rendering, superimposition)

- Localisation of α hot spots
- Radionucléides : U / ^{241}Am / Pu
- Quick acquisition times (< 15 minutes)

- Measurements at distance, trought Triplex (1,3 cm) & Leaded glass (1,5 cm à 6 cm)

ALPHA CAMERA FEEDBACK

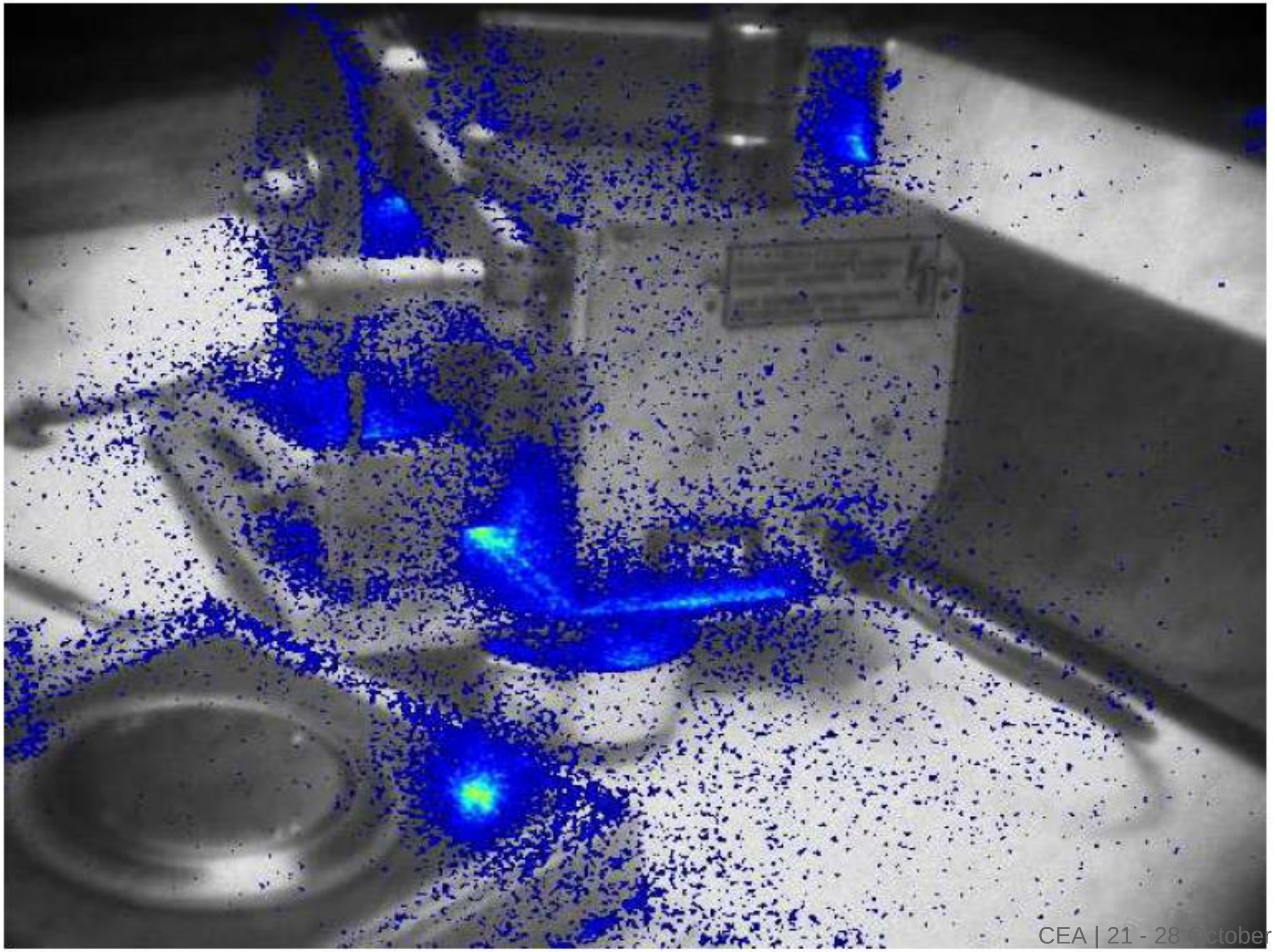
Raw image (without light)

ALPHA CAMERA FEEDBACK

Visible B&W image (with light)

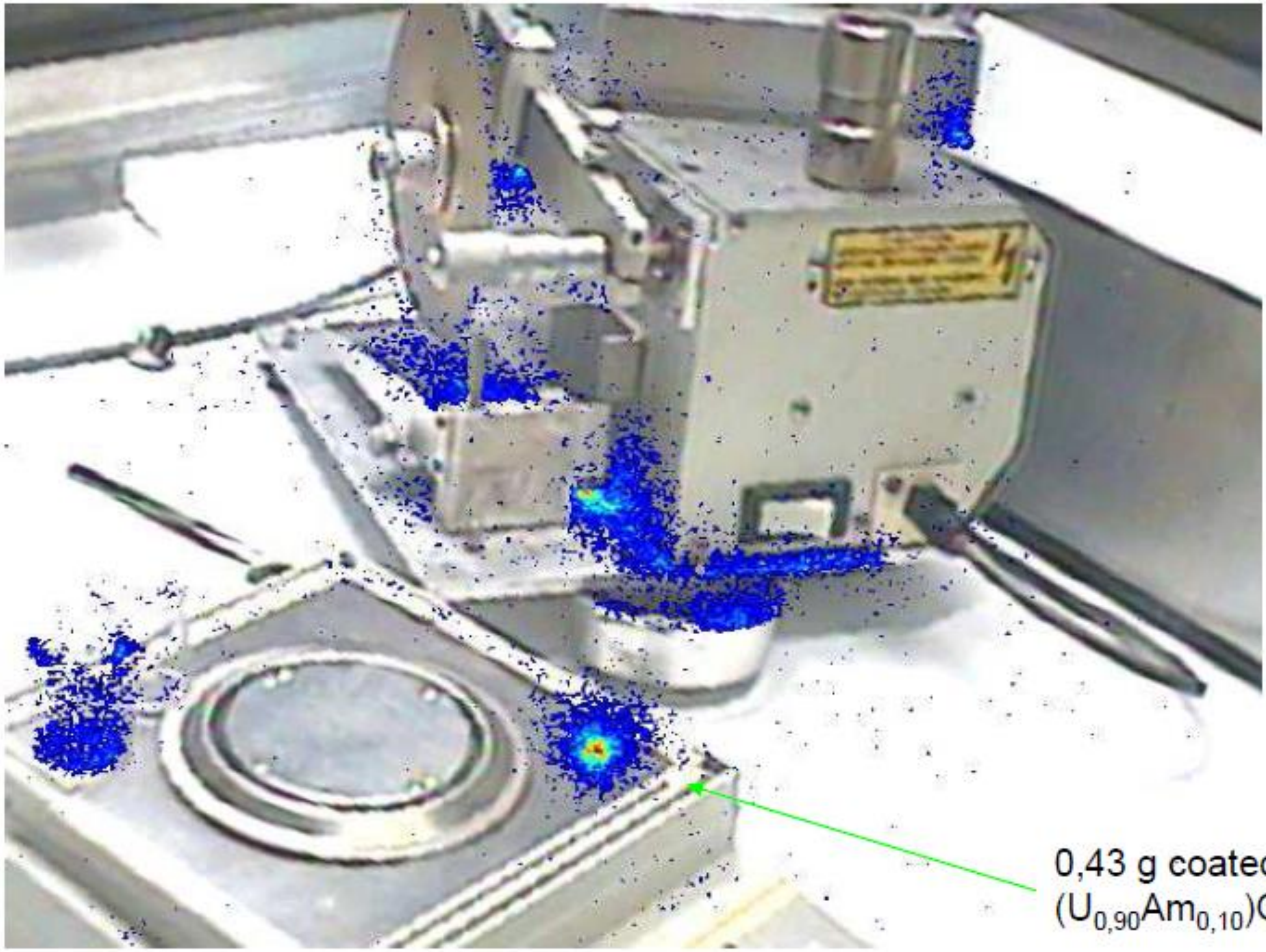
ALPHA CAMERA FEEDBACK

Raw image processed and superimposed on the B&W image



ALPHA CAMERA FEEDBACK

*Raw image processed and superimposed on the **colour** image*

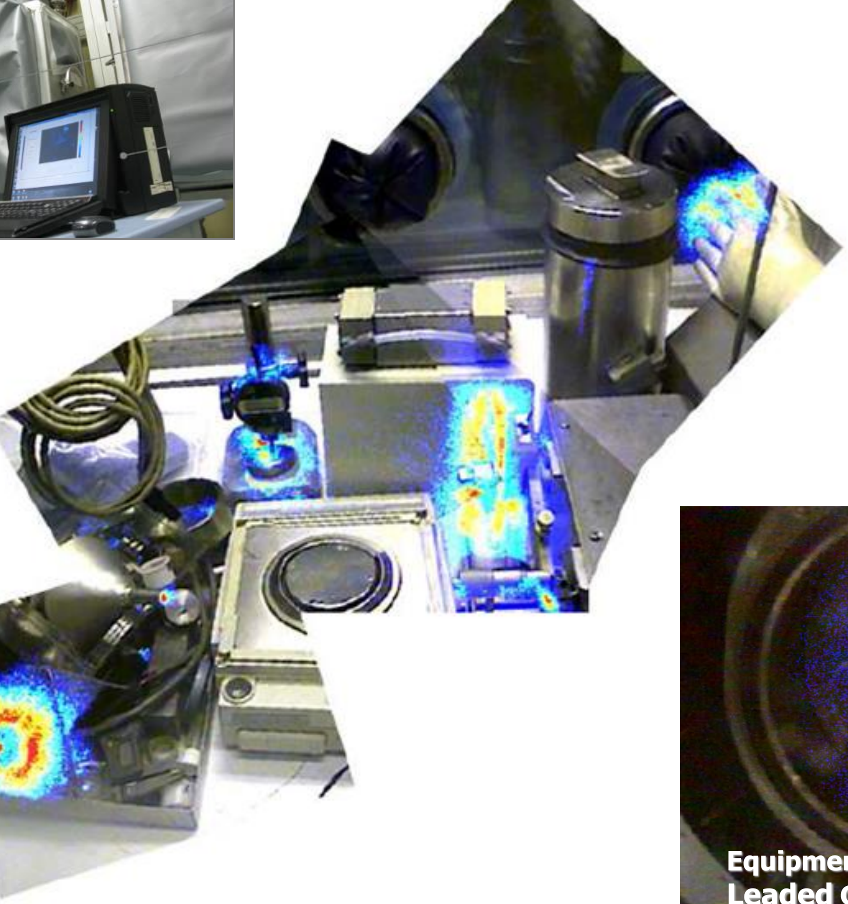


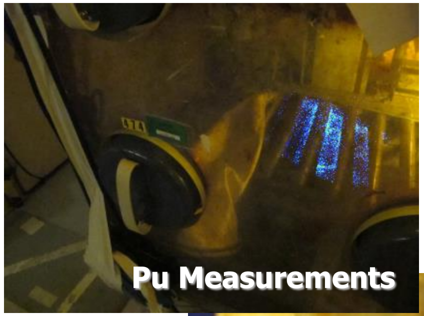
0,43 g coated tablet
$(U_{0,90}Am_{0,10})O_{2-x}$

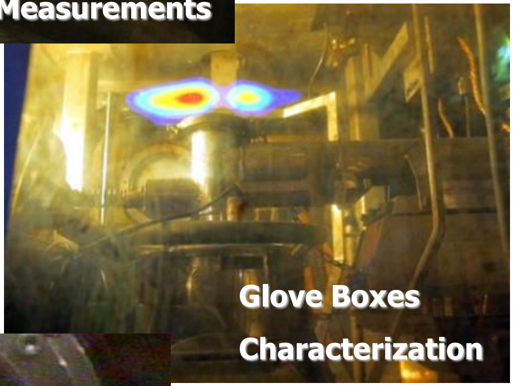
Atalante, 2009, december : Glove box

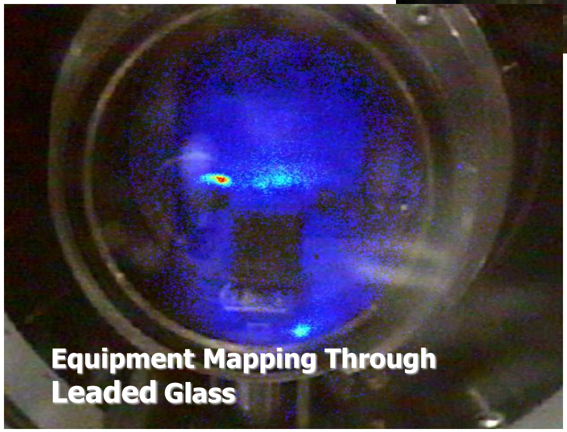
ALPHA CAMERA : A RECENT CAMERA TO LOCALIZE ALPHA CONTAMINATION

Surface Alpha Contamination Mapping in Darkness Conditions



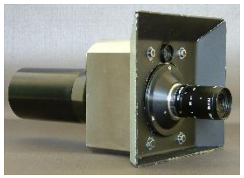




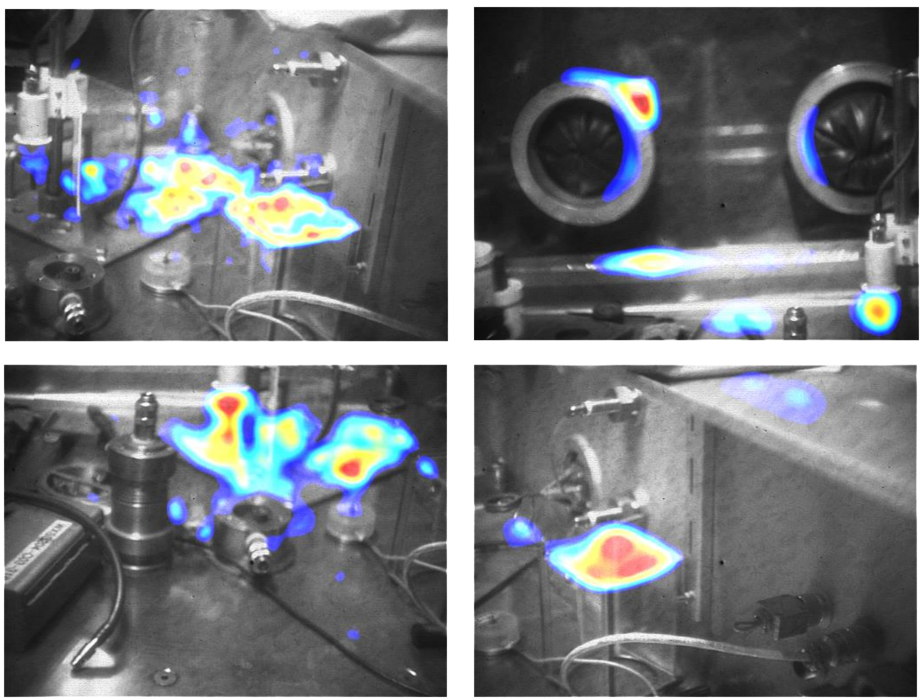


INTEREST OF COUPLING ALPHA AND GAMMA MEASUREMENTS

Example Of A Glove Box Characterization using Alpha Camera and IPIX Gamma Camera, 2016



Surface Alpha Contamination

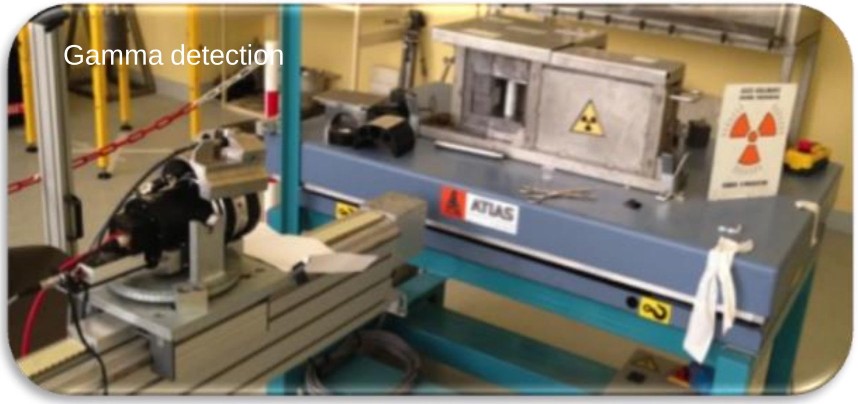


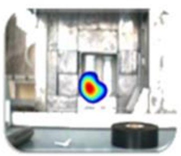
Gamma Main Hot Spot localization (Dose<10μGy.h^{-1})

IPix™

(CEA/MIRION)

DEVELOPMENT OF A DUAL ALPHA / GAMMA CAMERA





2017

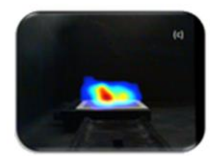
Dual Alpha/Gamma Camera (3rd prototype)

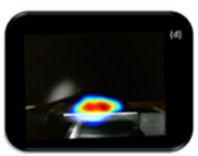
- Still under development and qualification
- Patented still 2015
- Detection of main gamma hot spots

2015

Solar Blind Alpha Camera (2nd prototype)

- Reduced influence of the light
- Good sensitivity to UV for high contaminated area
- Enhanced Connectivity (ethernet)

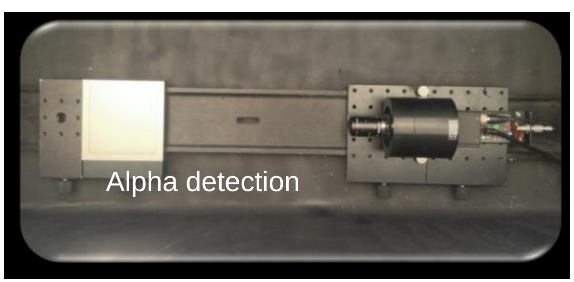




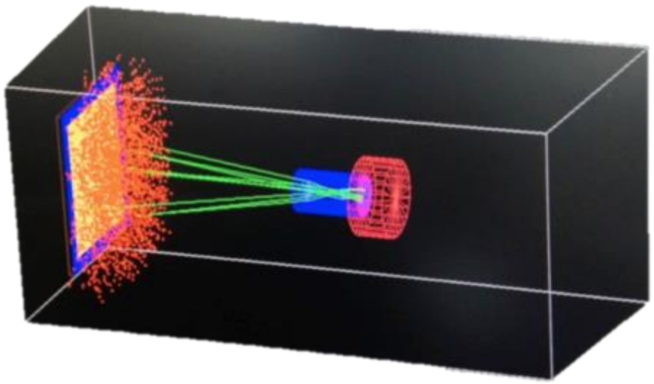
Standard Alpha Camera (1st prototype)

- Darkness condition
- Very good sensitivity to UV
- **Detection Limit : Act > 100 $Bq.cm^{-2}$ (5 min)**

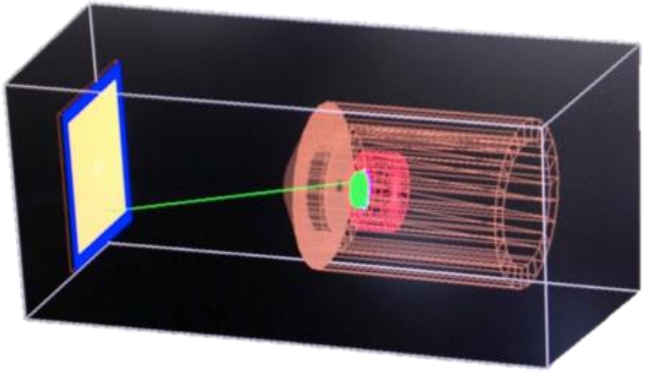
2010



DEVELOPMENT OF A DUAL ALPHA / GAMMA CAMERA

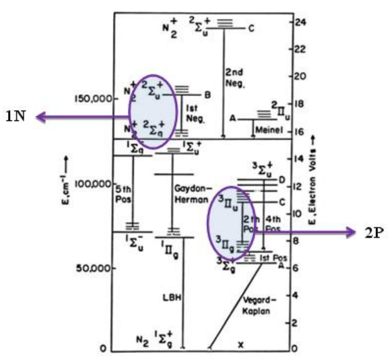


Alpha Camera mode



Gamma Camera mode

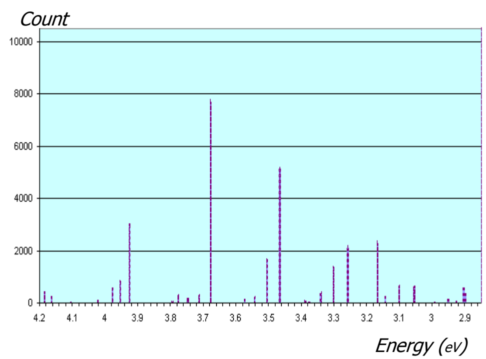
GEANT 4 Modeling of collection of Scintillation Photons from radio-luminescence trhough a UV objectif (left) and scintillations photons from gamma->photons conversion using a CsI scintillator and a pinhole collimator (right)



Direct UV integration

Simulated spectrum of photons

(0.913 bars, T= 20°C)



Scintillator	Density ($g.cm^{-3}$)	λ_{max} (nm)	Ph/keV$_\gamma$
$CdWO_4$	7,9	475	12 – 15
$Bi_4Ge_3O_{12}$	7,13	480	8 – 10
$Lu_{1.8}Y_{0,2}SiO_5$:Ce	7,1	420	32
CsI : Tl	4,51	550	54
BaF_2	4,88	310	10

Scintillation photons integration

DEVELOPMENT OF A DUAL ALPHA / GAMMA CAMERA

Use of the AIRFLY (AIR FLuorescence Yield) collaboration [1]

$$Y_{air}(\lambda,p,T,p_h) = Y_{air}(337nm,p_0,T_0,0).I(\lambda,p_0,T_0) * \frac{1+p_0*\left(\frac{1}{p'_{air}(\lambda,T_0)}*\left(1-\frac{p_h}{p}\right)+\frac{1}{p'_{H_2O}(\lambda)}*\frac{p_h}{p}\right)}{1+\frac{p}{\left(\frac{T}{T_0}\right)^{\alpha(\lambda)+0,5}}*\left(\frac{1}{p'_{air}(\lambda,T_0)}*\left(1-\frac{p_h}{p}\right)+\frac{1}{p'_{H_2O}(\lambda)}*\frac{p_h}{p}\right)}$$

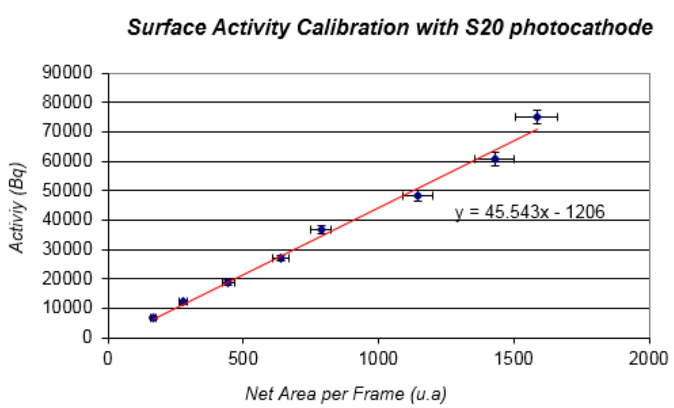
Parametric study (température, pression, humidity in air, …)

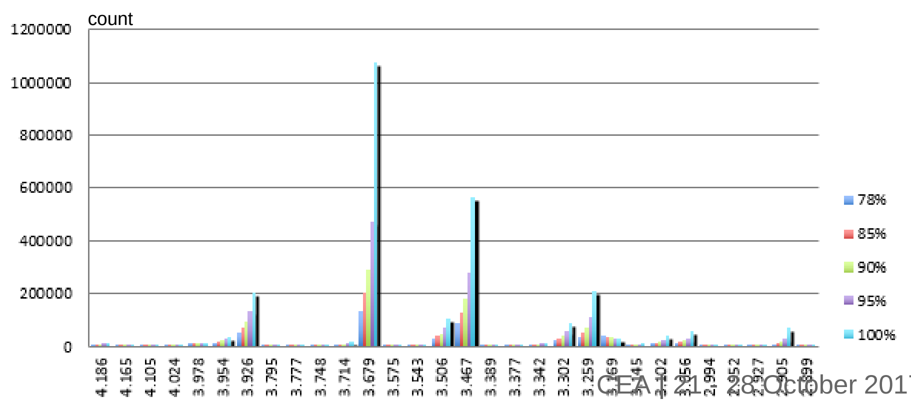
Simulation of fluorescence photons spectrum

Geometrical Efficiency

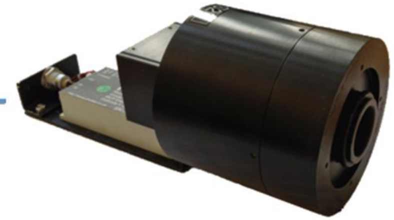
Calibration Factors

Y : Champ de scintillation
I : Intensité relative
p_0 : Pression de référence (1 bar)
T_0 : Température de référence (273°K)
p : Pression de l'environnement
T : Température de l'environnement
p_h : Pression partielle en eau
λ : Longueur d'onde de la raie d'émission
p'_{air} (λ) : paramètre de pression lié à la raie λ
p'_{H20} (λ) : paramètre de pression en eau lié à la raie λ
α(λ) : paramètre de température lié à la raie λ





DEVELOPMENT OF A DUAL ALPHA / GAMMA CAMERA

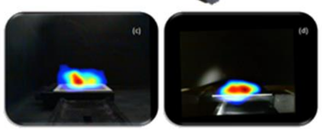


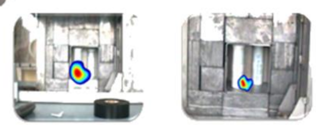
Common Architecture

- Intensifier tube (optimized)
- Optical fiber
- CCD

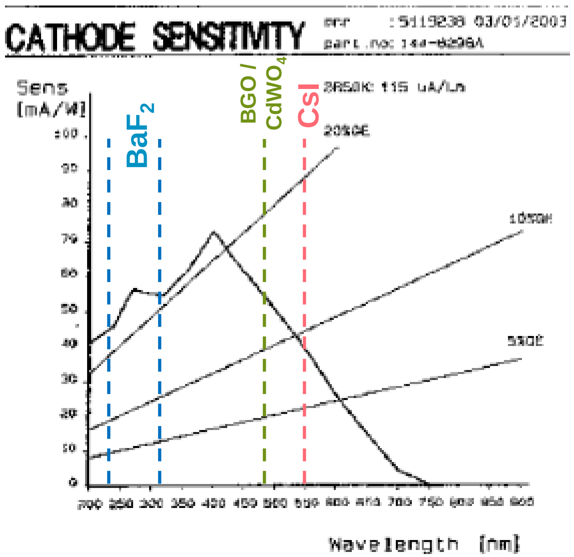
Dual α/γ Detection Head

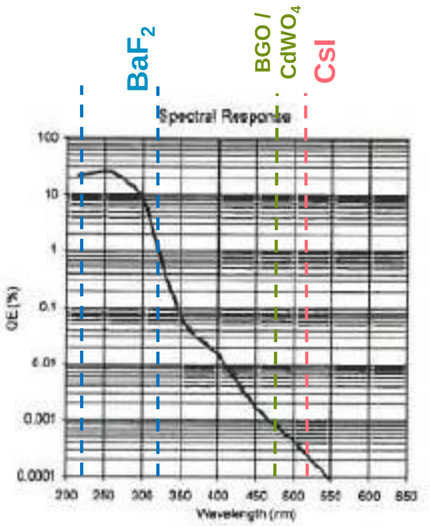
- Scintillator + pinhole
- *Or*
- Scintillator + coded mask
- UV lens



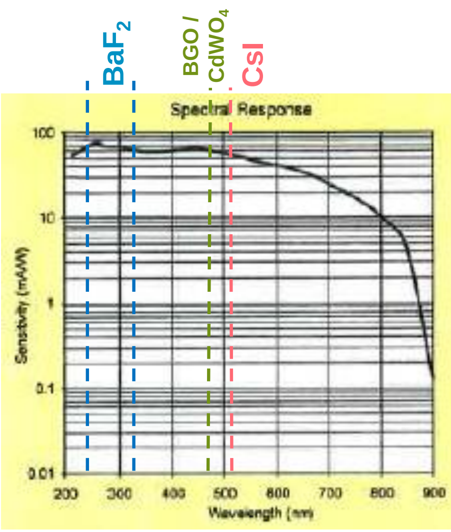


S20





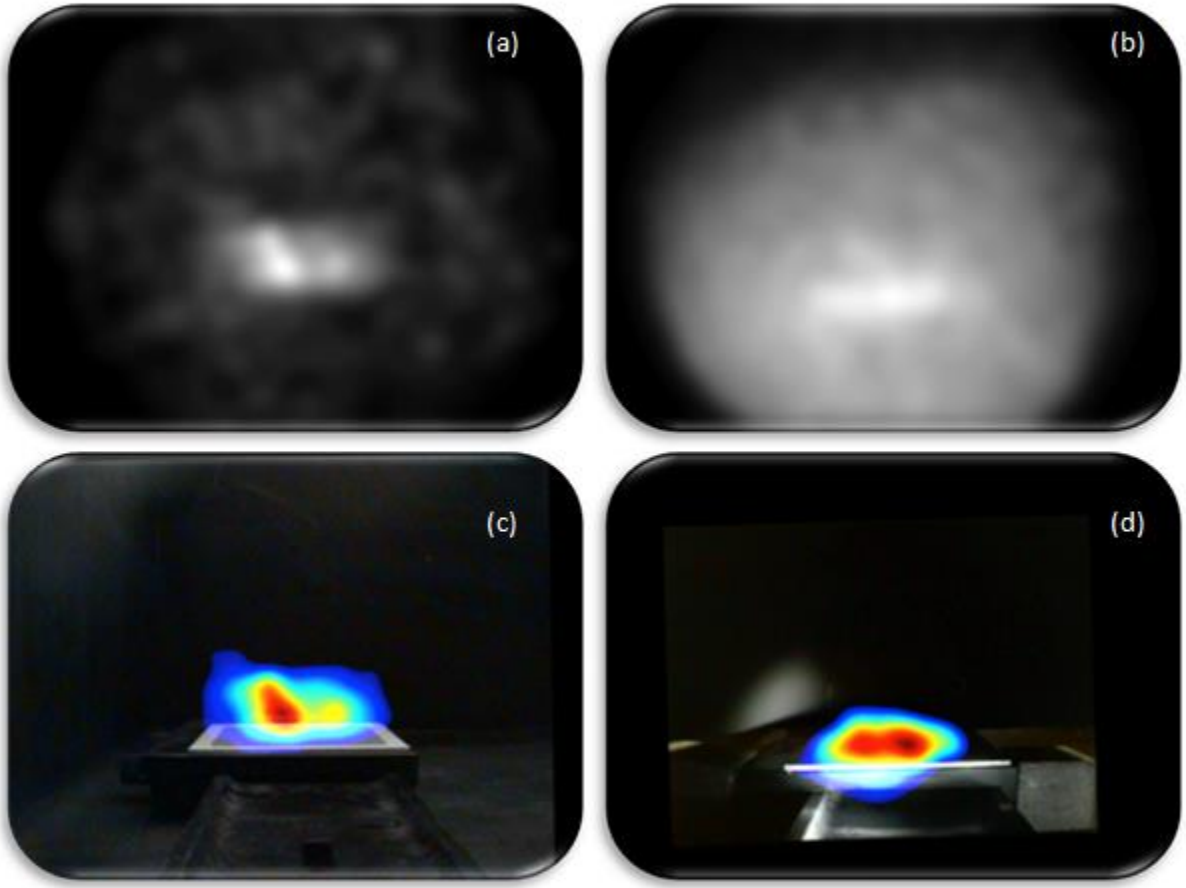
Solar Blind



S20 « Low-Noise »

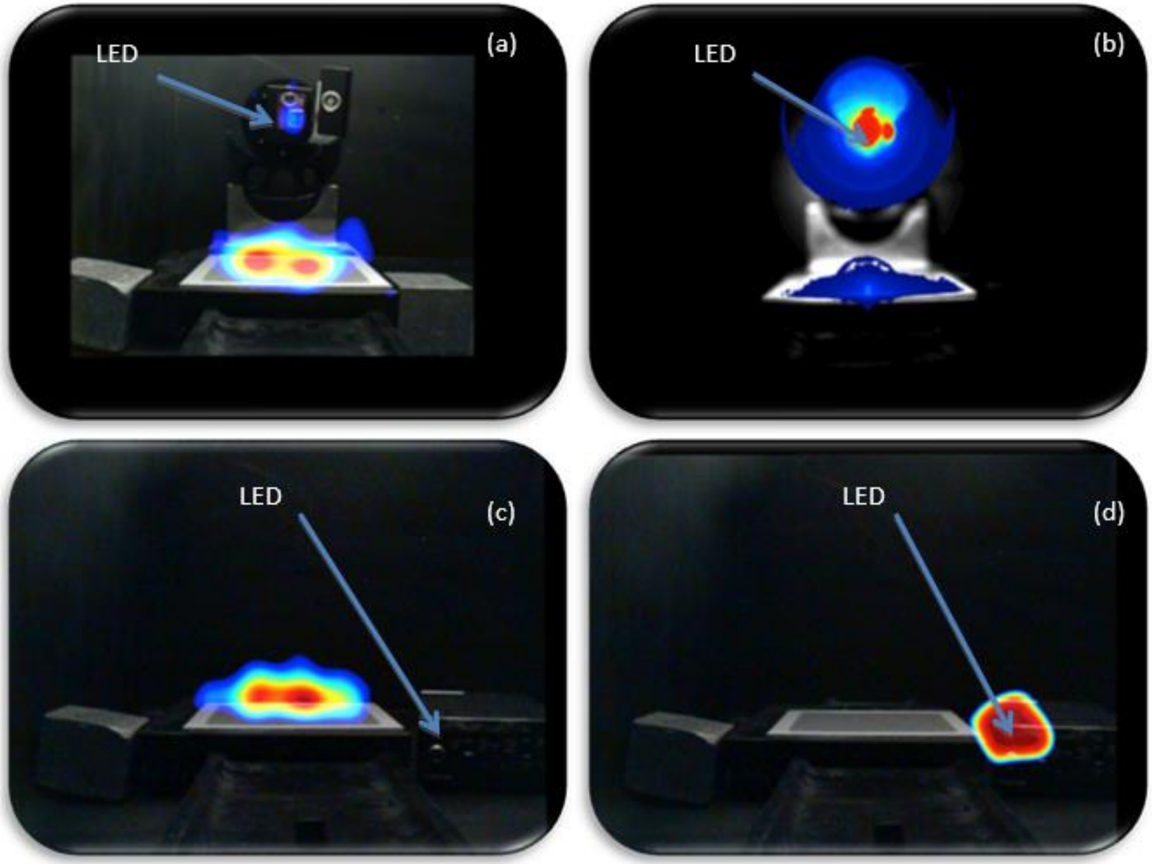
Image Intensifier Tubes Comparison

Alpha / UV Mode



(a, b) Raw Alpha/UV Images with FFT filtering (a : Solar Blind, b : Low-Noise S20)
(c, d) Final superimposition on visble image (c : Solar Blind, d : Low-Noise S20)

Alpha / UV Mode with 550 nm LED-Light Pollution



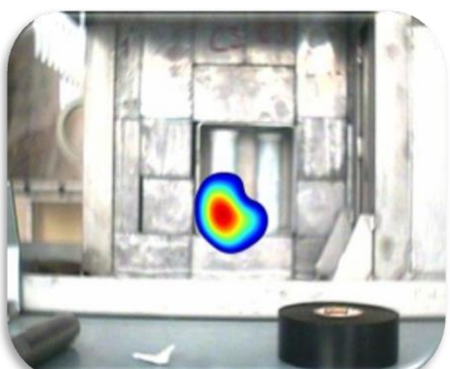
(a, b) Raw Alpha/UV Images with FFT filtering (a : Solar Blind, b : Low-Noise S20)
(c, d) Final superimposition on visible image (c : Solar Blind, d : Low-Noise S20)

DEVELOPMENT OF A DUAL ALPHA / GAMMA CAMERA

Gamma Mode with ^{137}Cs and ^{60}Co sources

Distance between cameras and gamma sources : 1 meter

Several configurations tested with S20/SB intensifier tubes, scintillators and existing pinholes in DENAL®



Low-Noise S20 + BGO
1000 frames

Solar Blind + BaF2 (λ=220 nm & 310 nm)
1000 frames

View of tubes equiped with ALADIN pinhole and 25 mm diameter scintillator

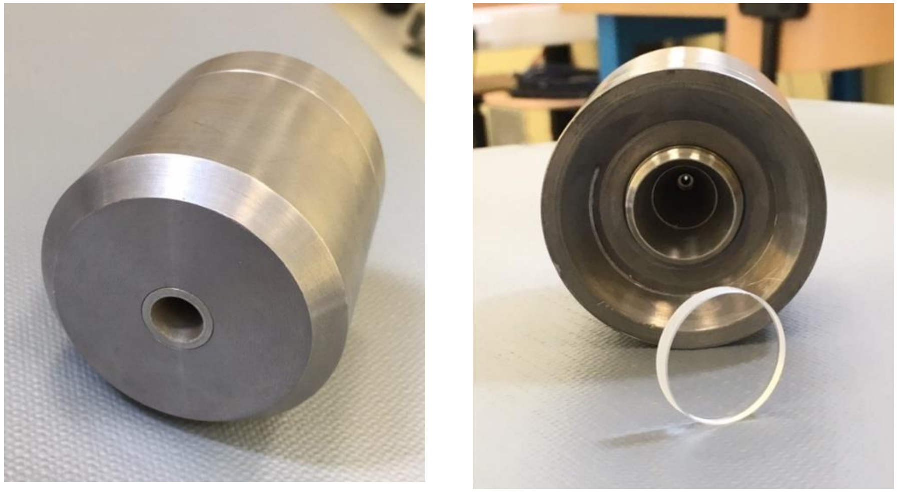
Scintillators : summary of results

Gamma Detection and localization				
Scintillator	**Density ($g.cm^{-3}$)**	**Scintillation Wavelenght (nm)**	**LNS20**	**SB**
$CdWO_4$	7,9	475	✔	✘
BGO	7,13	480	✔	✘
LYSO	7,1	420	✘	✘
CsI : TI	4,51	550	✔	✘
BaF_2	4,88	220, 310	✔	✔

Gamma Sensitivity	
Scintillator & tube	**Relative Sensitivity (%)**
LNS20+$CdWO_4$	100
SB+BaF_2	72
LNS20+BaF_2	38
BGO+LNS20	32
CsI+LNS20	8,5

CONCLUSION

- **Alpha Camera** based on a S20 photocathode (25 mm) is under industrialization process
- A new pinhole has been designed to fit with the S20 (25 mm) tube
- Scintillators (d=25 mm, e=4mm) of $CdWO_4$, BGO and BaF_2 are considered
- The design of the peripheral shielding is under progress



View of the scintillator and the new pinhole design

AirFly / Geant4 References :

1. Bohacova, M. (2011). *Absolute Fluorescence Yield Measurement.* Airfly Collaboration.
2. Fraga, M. (2011). *Temperature Dependence of the UV Fluorescence Yield in Nitrogen and in Dry Air.*
3. GEANT4 Collaboration. (2012). *GEANT4 user's guide for application developpers.*
4. Rodriguez, G. (2008). *Air fluorescence yield dependence on atmospheric parameters.* Airfly Collaboration.
5. Ave, M. (2007). *Spectrally resolved pressure dependence measurements of Air Fluorescence Emission with AIRFLY.* AirFly Collaboration.
6. Ave, M. (2008). *Measurement of the pressure dependence of air fluorecence emission induced by electrons.* Airfly Collaboration.
7. Arqueros, F. (2008). *The yield of air fluorescence induced by electrons.* AirFly Collaboration.

Thanks for your attention

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