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

C. Mahe, F. Lafont, S. Mitra, J. Venara

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DE LA RECHERCHE À L'INDUSTRIE



2017 IEEE Nuclear Science Symposium & Medical Imaging Conference

21-28 October 2017, Hyatt Regency, Atlanta, Georgia, USA

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

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



MAHE Charly, LAFONT Fabien, MITRA Saptarshi, VENARA Julien

www.cea.fr



In Situ measurement laboratory in Marcoule : ~40 years

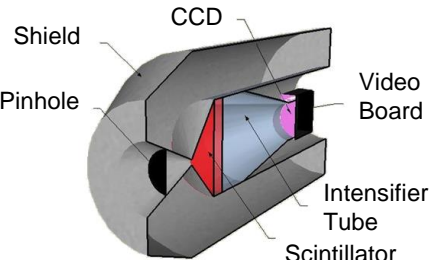

R&D on Nuclear Instrumentation for decommissioning projects

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, ...

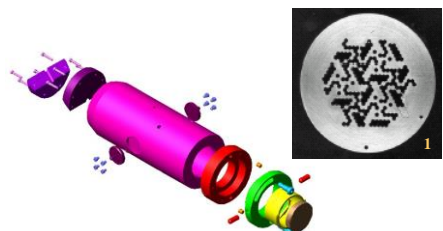
Part of a laboratory including : virtual reality, robotics (teleoperation) & laser cutting developments

New gamma cameras under development and/or qualification at CEA





1980

Aladin
Scintillator
Gamma camera

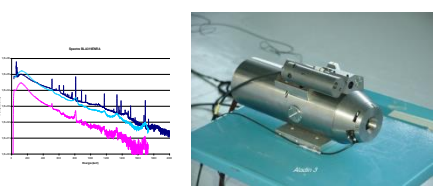


Coded aperture



Additional shutter

2000



CZT Spectrometry
Dose rate



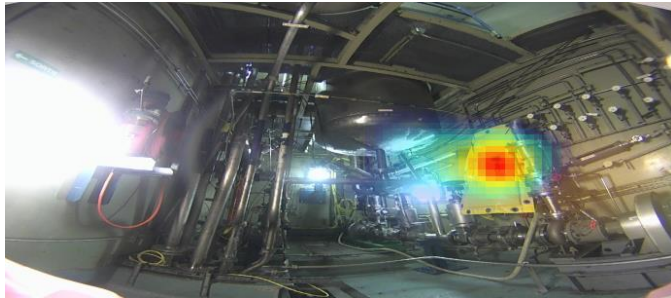
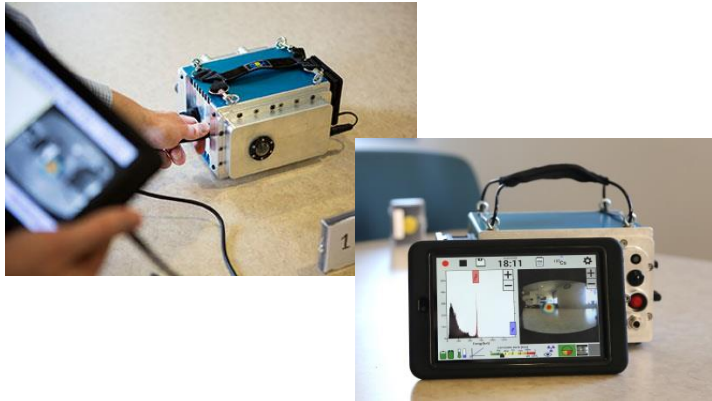
2012

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)

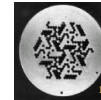


IPIX™ (CEA/MIRION)

Medipix
technology, USB



Coded aperture



Better performances

Lower price

More compact & portable device

**Next
generation**

?

CZT/Coded Aperture

+

Compton Camera

+

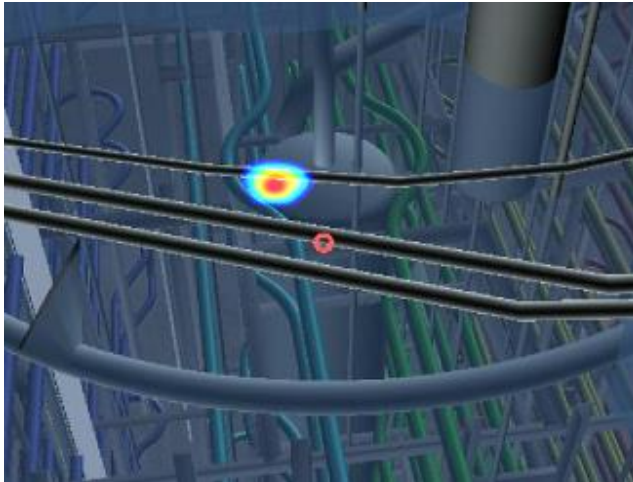
Spectrometric function
at any Energy range

Partnership under progress

CEA/DRT, CEA/IRFU, CEA/DEN

MIRION, GIE INTRA, IRSN, 3D
PLUS

Used with 3D view

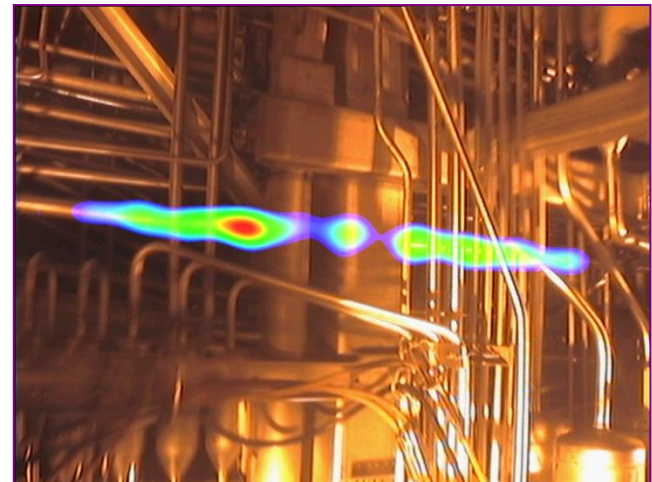
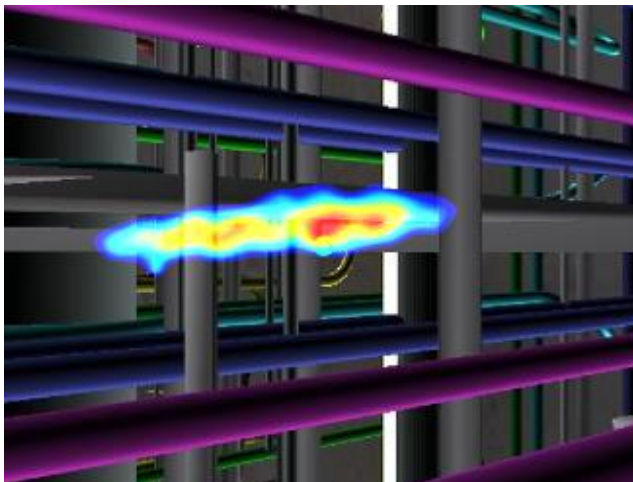


Hot spots
localization

Used with *real* view

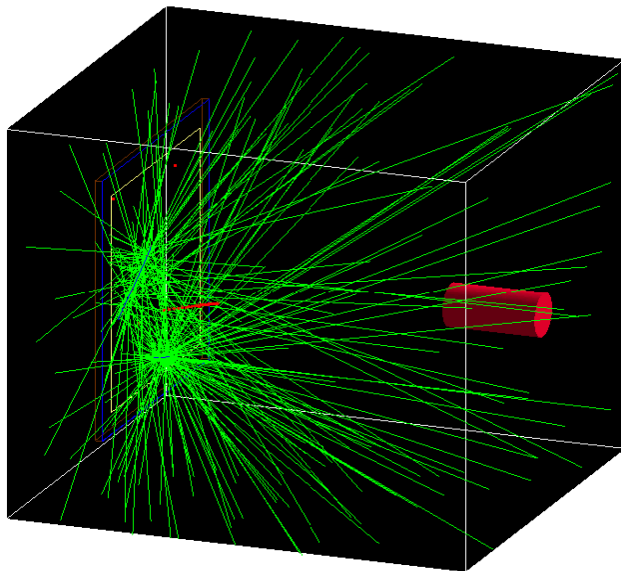


Extended
spots
localization

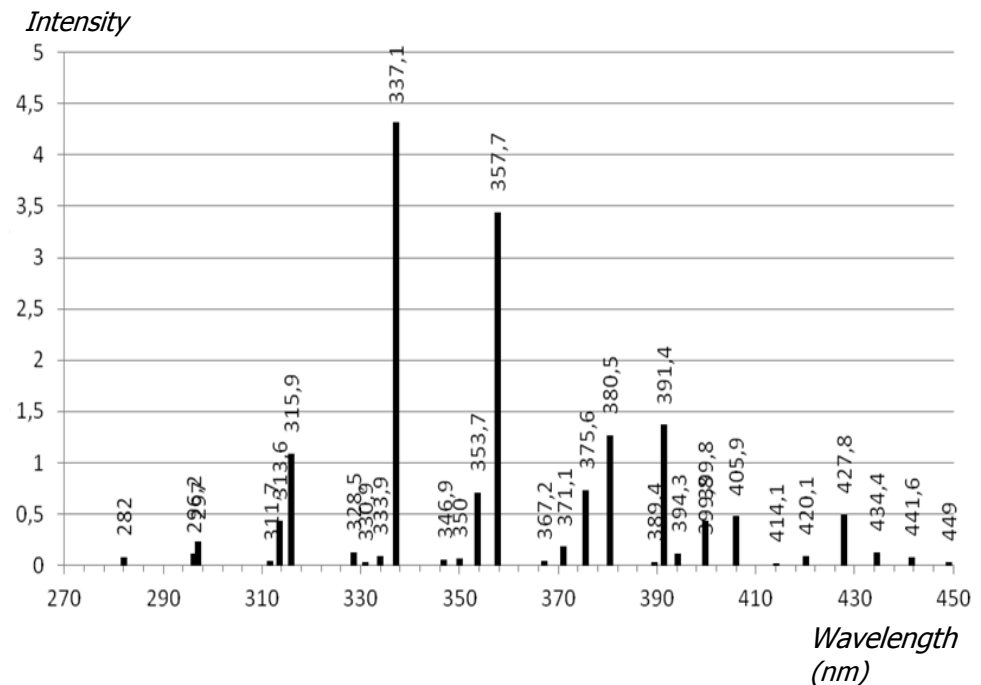


ALPHA CAMERA : A RECENT CAMERA TO LOCALIZE ALPHA CONTAMINATION

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

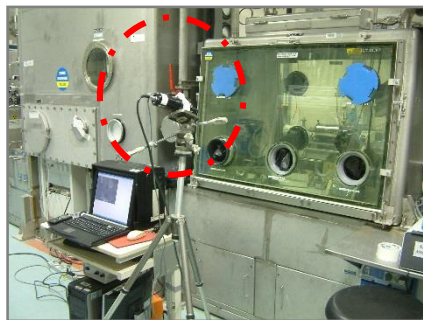


GEANT4 Model of a ^{241}Am source

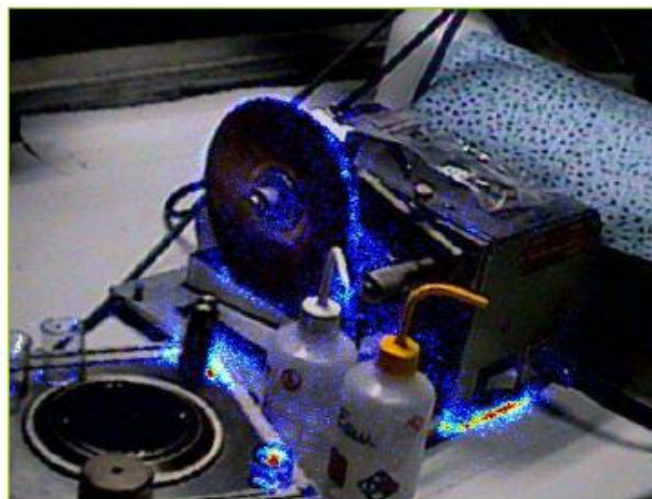


Radio-luminescence of Nitrogen phenomena

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,
trough Triplex (1,3 cm)
& Leaded glass (1,5 cm à 6 cm)

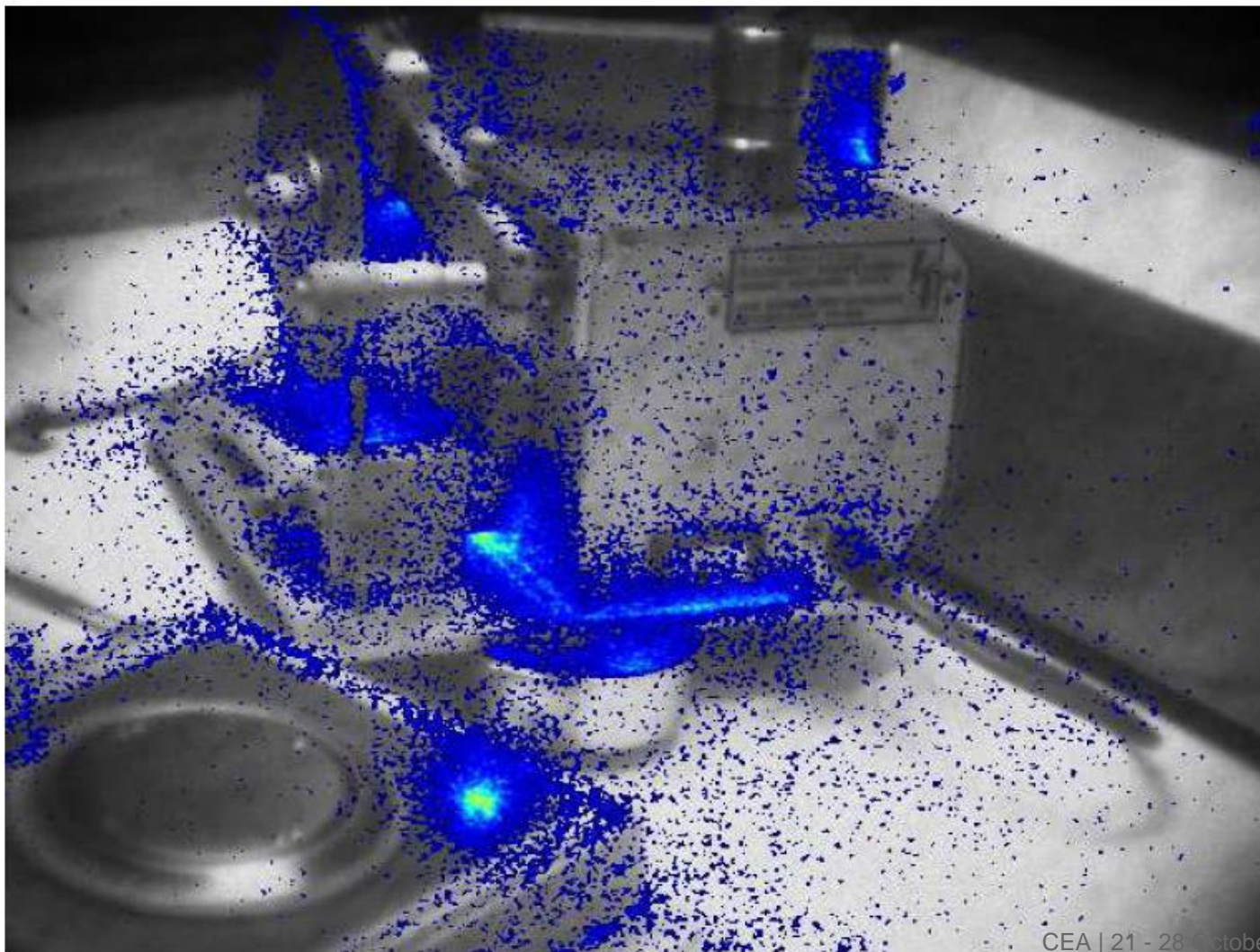
Raw image (without light)



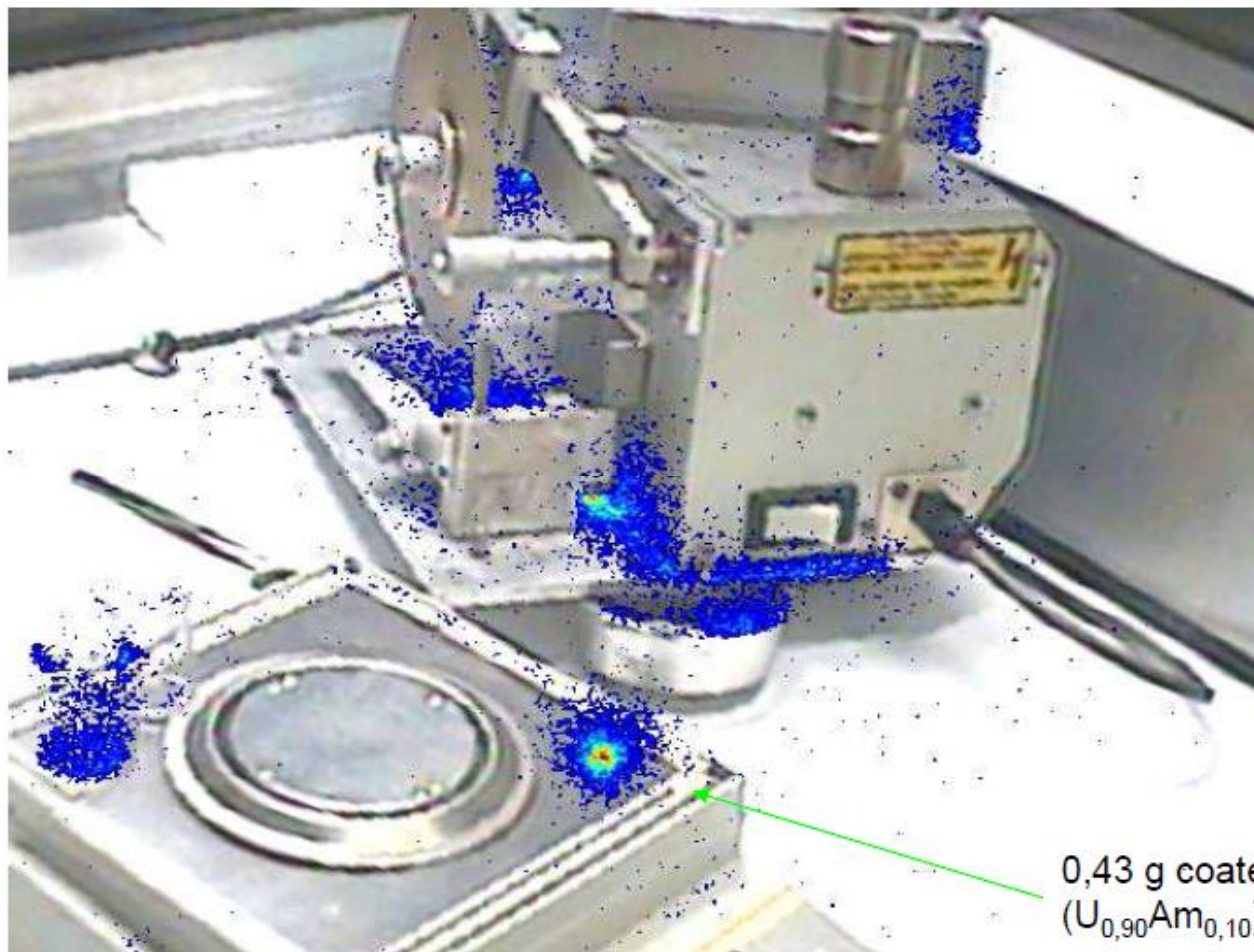
Visible B&W image (with light)



Raw image processed and superimposed on the B&W image



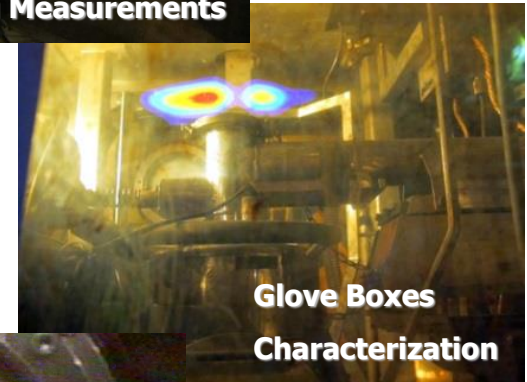
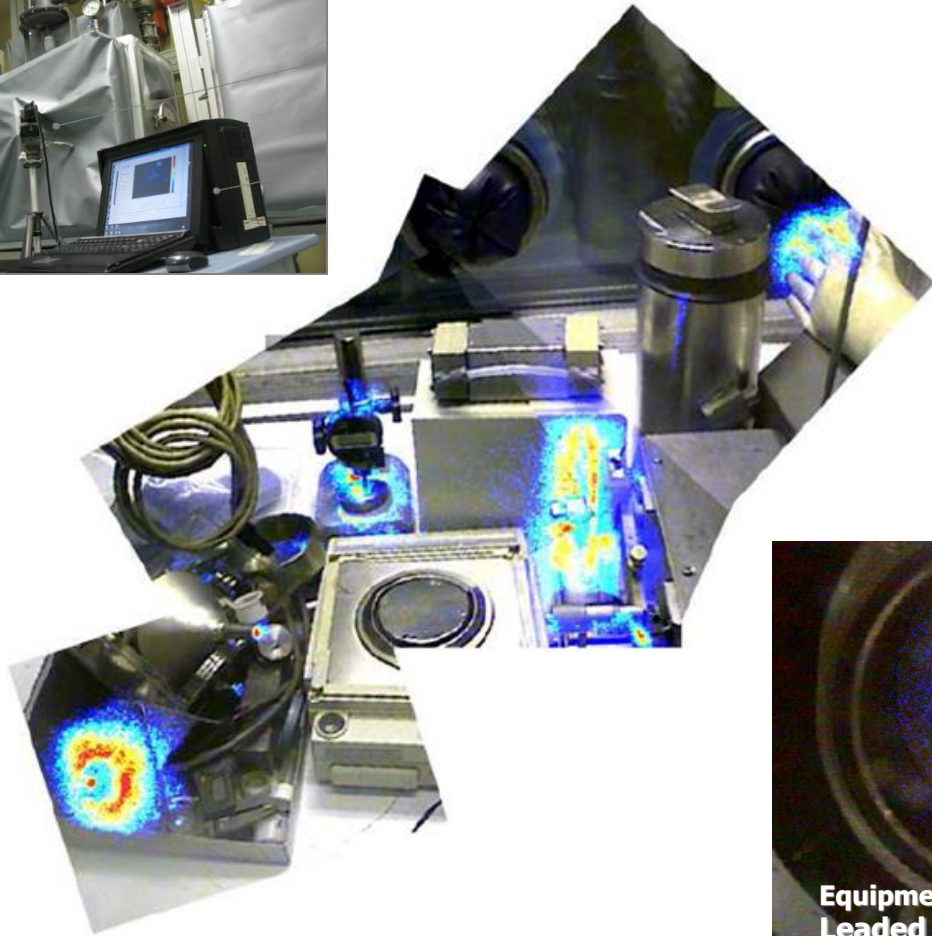
Raw image processed and superimposed on the colour image



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

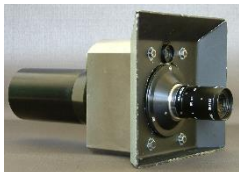
ALPHA CAMERA : A RECENT CAMERA TO LOCALIZE ALPHA CONTAMINATION

Surface Alpha Contamination Mapping in Darkness Conditions

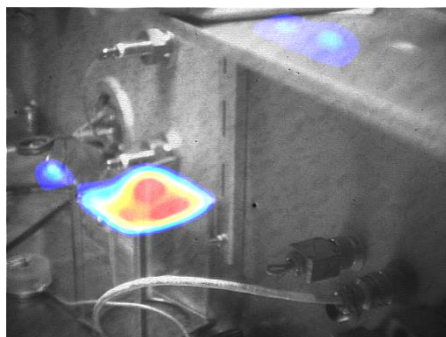
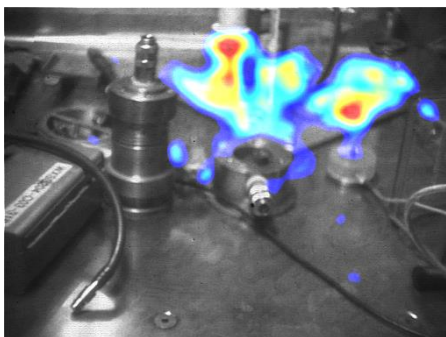
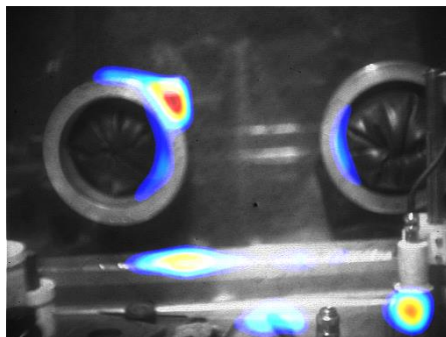
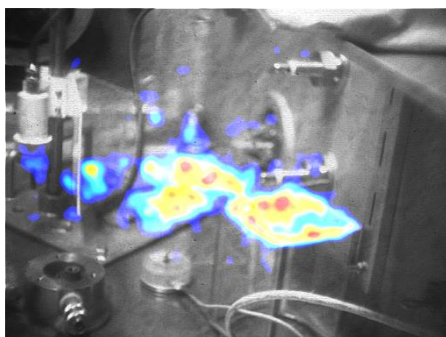


INTEREST OF COUPLING ALPHA AND GAMMA MEASUREMENTS

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



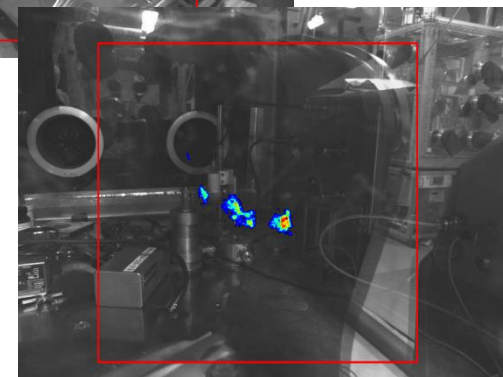
Surface Alpha Contamination



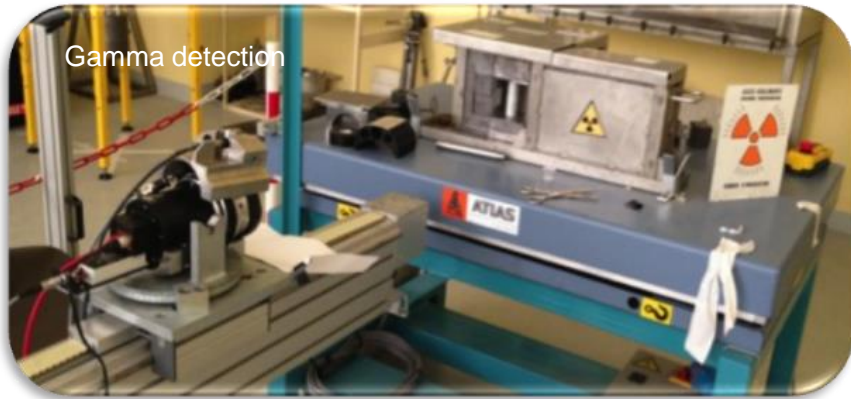
Gamma Main Hot Spot localization
(Dose <math>< 10 \mu\text{Gy}\cdot\text{h}^{-1}</math>)



IPIX™
(CEA/MIRION)



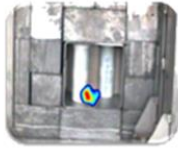
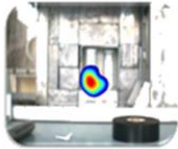
DEVELOPMENT OF A DUAL ALPHA / GAMMA CAMERA



Dual Alpha/Gamma Camera (3rd prototype)

2017

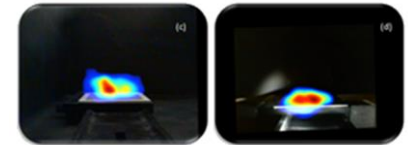
- Still under development and qualification
- Patented still 2015
- Detection of main gamma hot spots



2015

Solar Blind Alpha Camera (2nd prototype)

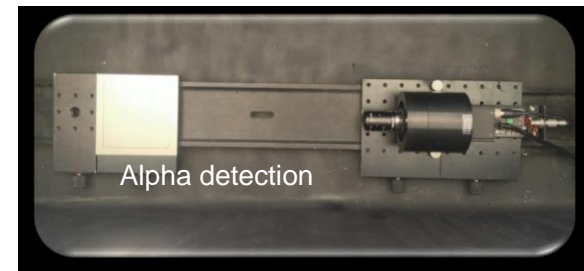
- Reduced influence of the light
- Good sensitivity to UV for high contaminated area
- Enhanced Connectivity (ethernet)



Standard Alpha Camera (1st prototype)

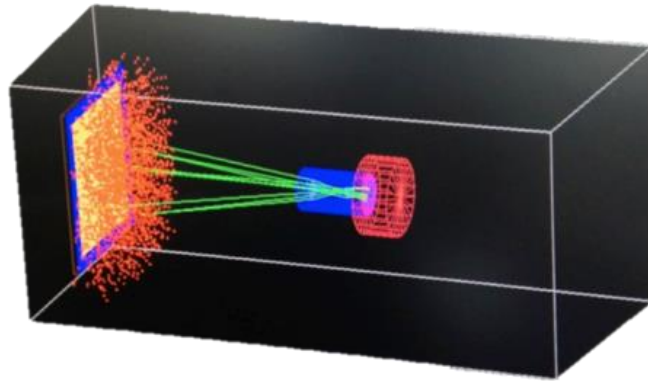
- Darkness condition
- Very good sensitivity to UV

Detection Limit : Act > 100 Bq.cm⁻² (5 min)

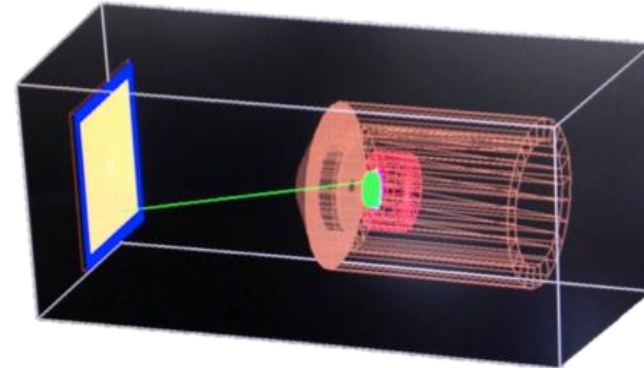


2010

DEVELOPMENT OF A DUAL ALPHA / GAMMA CAMERA

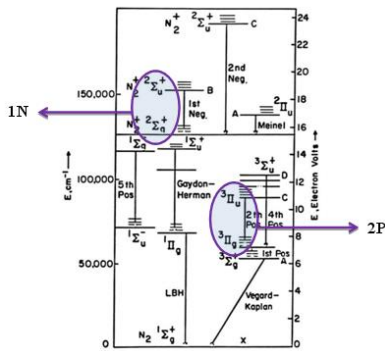


Alpha Camera mode



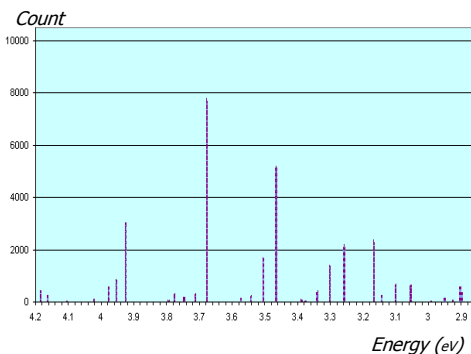
Gamma Camera mode

GEANT 4 Modeling of collection of Scintillation Photons from radio-luminescence through 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 _γ
CdWO ₄	7,9	475	12 – 15
Bi ₄ Ge ₃ O ₁₂	7,13	480	8 – 10
Lu _{1,8} Y _{0,2} SiO ₅ :Ce	7,1	420	32
CsI : TI	4,51	550	54
BaF ₂	4,88	310	10

Scintillation photons integration

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

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

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

Simulation of fluorescence photons spectrum

Geometrical Efficiency

Calibration Factors

Y : Champ de scintillation

I : Intensité relative

p₀ : Pression de référence (1 bar)

T₀ : Température de référence (273°K)

p : Pression de l'environnement

T : Température de l'environnement

p_h : Pression partielle en eau

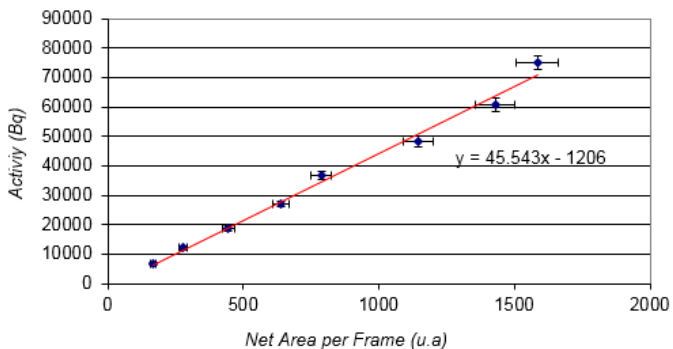
λ : Longueur d'onde de la raie d'émission

p'_{air} (λ) : paramètre de pression lié à la raie λ

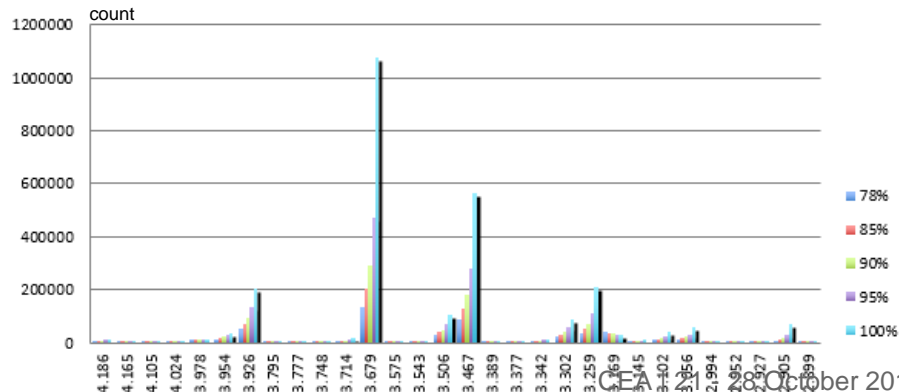
p'_{H₂O} (λ) : paramètre de pression en eau lié à la raie λ

α(λ) : paramètre de température lié à la raie λ

Surface Activity Calibration with S20 photocathode

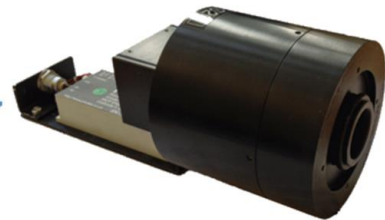


Impact of N₂ Proportion in Air on the fluorescence



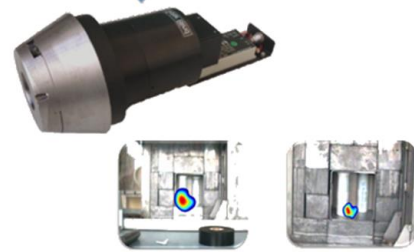
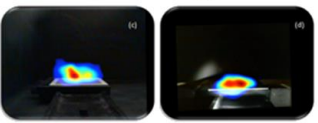
DEVELOPMENT OF A DUAL ALPHA / GAMMA CAMERA

S20

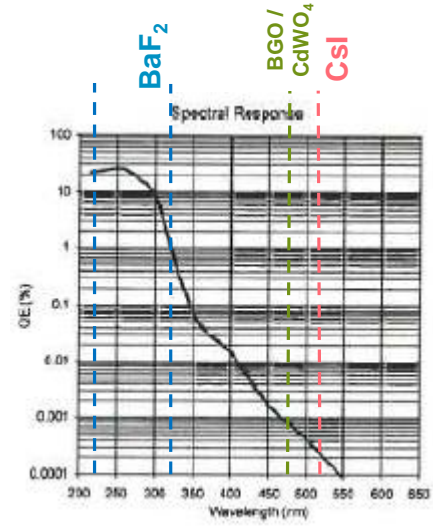
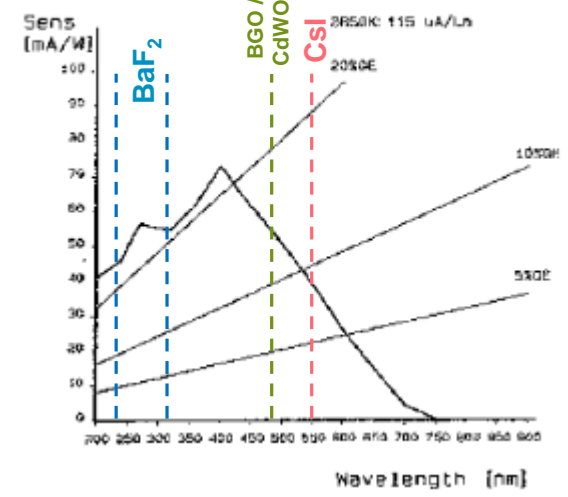


Common Architecture
Intensifier tube (optimized)
Optical fiber
CCD

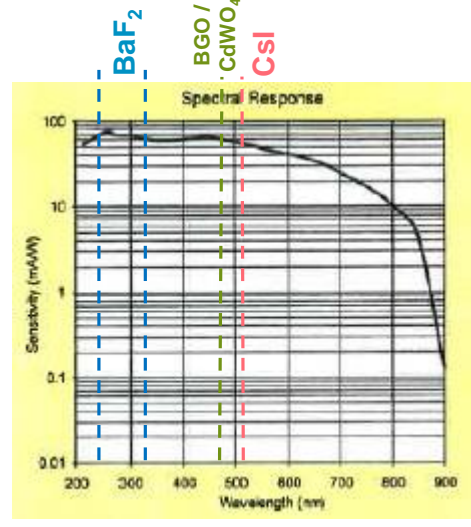
Dual α/γ Detection Head
Scintillator + pinhole
Or
Scintillator + coded mask
UV lens



CATHODE SENSITIVITY err : 5d19238 03/05/2003
part. no: 144-8298A



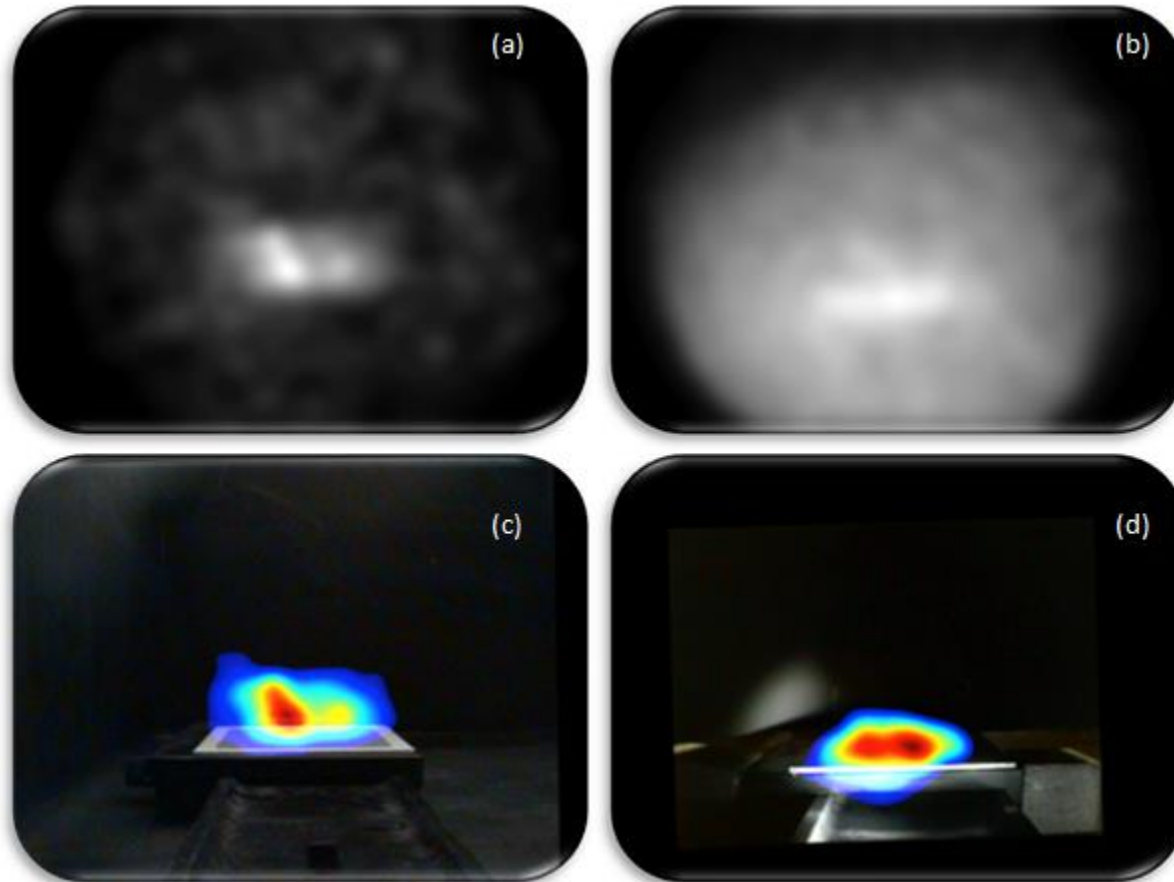
Solar Blind



S20 « Low-Noise »

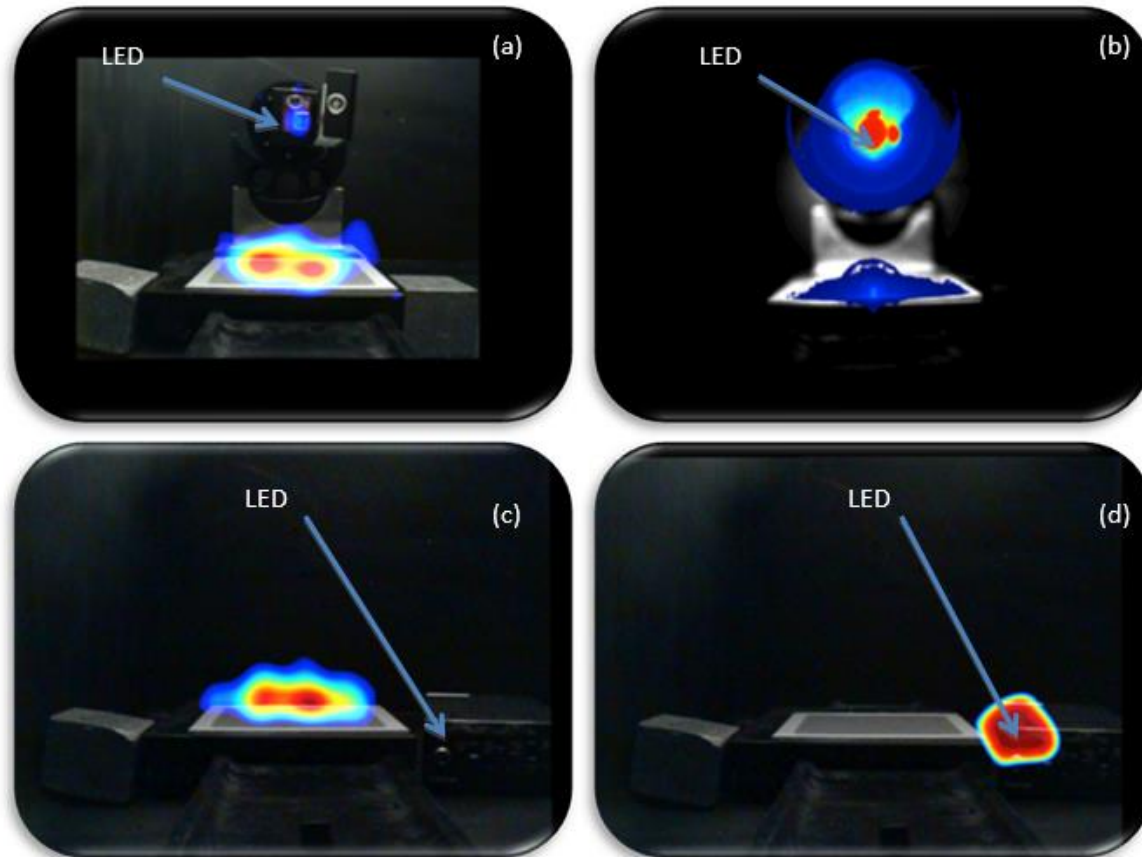
Image Intensifier Tubes Comparison

Alpha / UV Mode



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

Alpha / UV Mode with 550 nm LED-Light Pollution

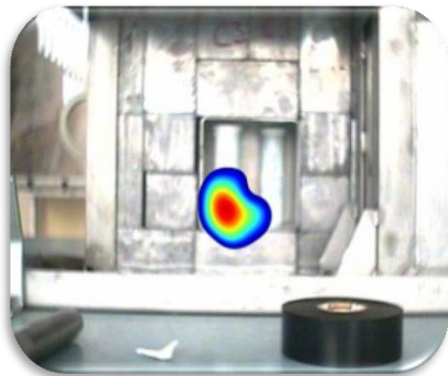
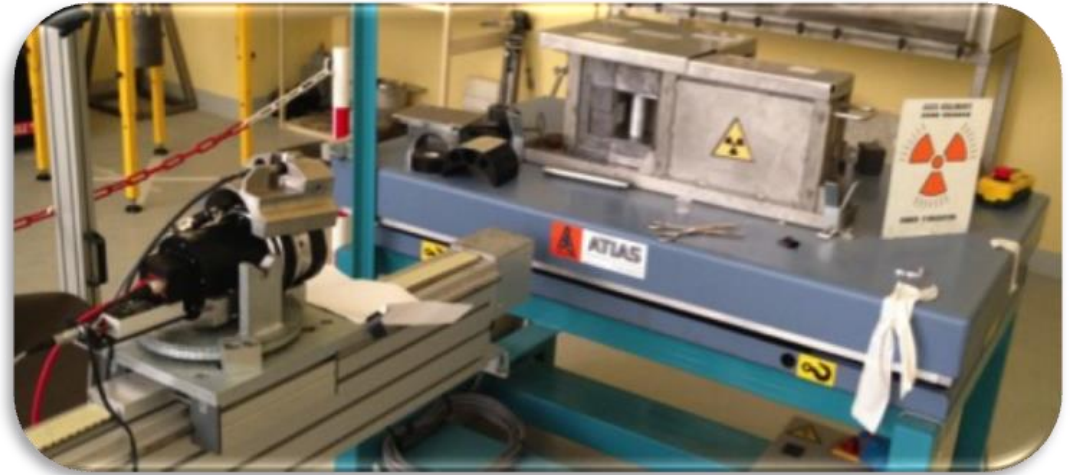


(a, b) Raw Alpha/UV Images with FFT filtering (a : Solar Blind, b : Low-Noise S20)
(c, d) Final superimposition on visible image (c : Solar Blind, d : Low-Noise S20)

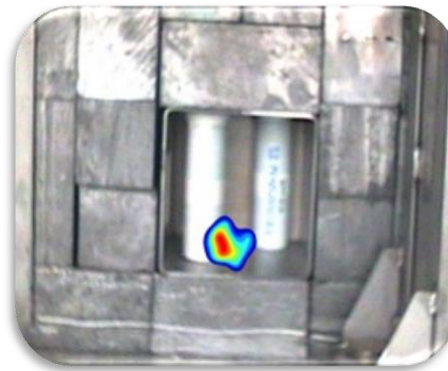
Gamma Mode with ^{137}Cs and ^{60}Co sources

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 ($\lambda=220$ nm & 310 nm)
1000 frames



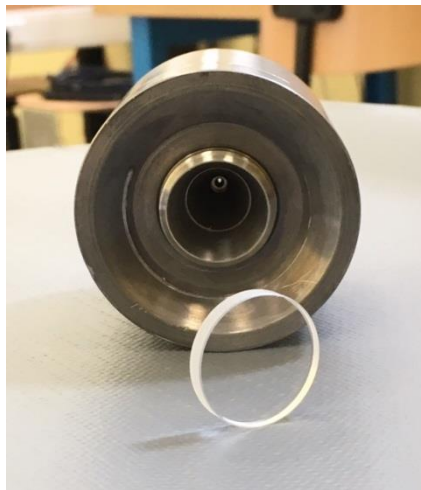
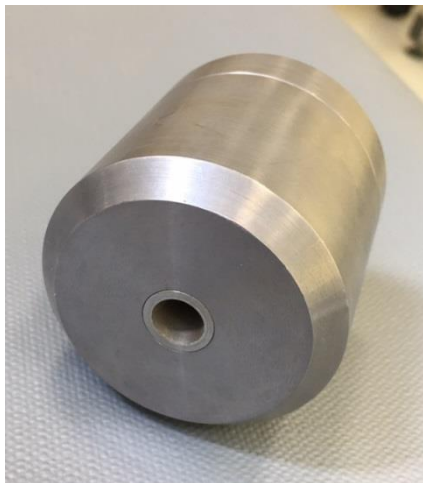
View of tubes equipped with ALADIN pinhole and 25 mm diameter scintillator

Scintillators : summary of results

Gamma Detection and localization				
Scintillator	Density (g.cm ⁻³)	Scintillation Wavelength (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

- **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

Thanks for your attention

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 fluorescence emission induced by electrons*. Airfly Collaboration.
7. Arqueros, F. (2008). *The yield of air fluorescence induced by electrons*. AirFly Collaboration.

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Marcoule | DE2D/SEAD/LSTD | Bt 51
BP 17171 | 30207 Bagnols-sur-Cèze cedex
T. +33 (0)4 66 39 79 51 | F. +33 (0)4 66 79 66 25

Etablissement public à caractère industriel et commercial | RCS Paris B 775 685 019

Direction de l'Energie Nucléaire
Département de recherche sur les technologies pour
l'Enrichissement, le Démantèlement et les Déchets
Service d'Etudes des technologies pour
l'Assainissement-Démantèlement et l'étanchéité
Laboratoire de la Simulation et des Techniques de
Démantèlement