Scientific and technical aspects of alpha radioluminescence detection

Remote Alpha Demo Day

5.7.2023

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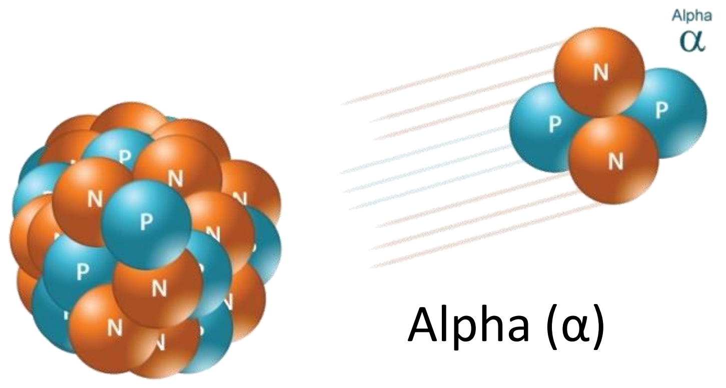
Outline

Basics of alpha radiation and radioluminescence

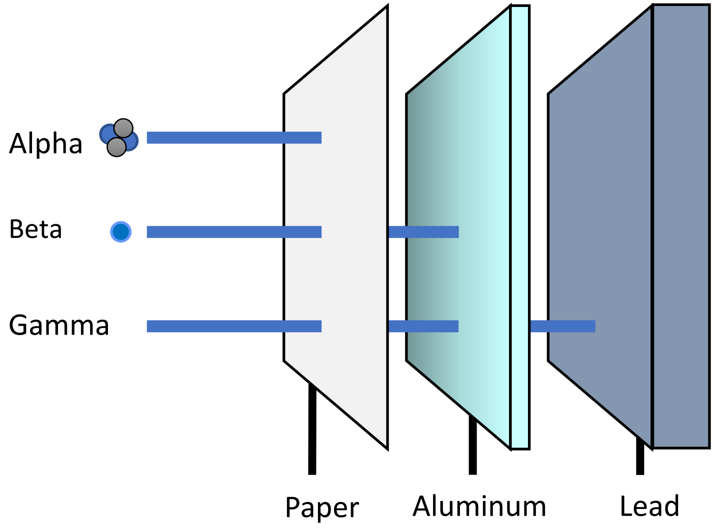
Tools and technology for radioluminescence detection

Application examples

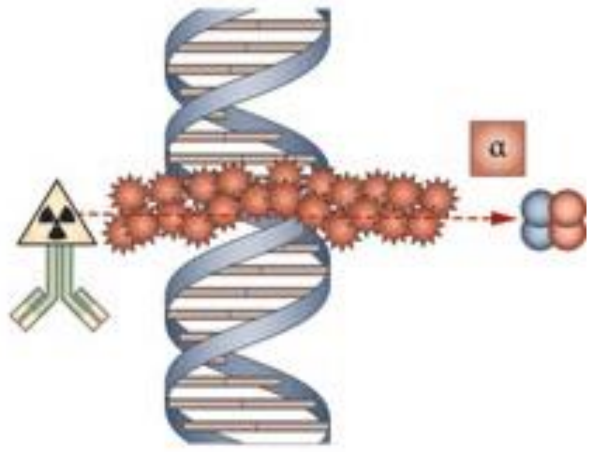
Alpha decay



- Alpha particle is a helium nucleus
- Alpha decay is typical for heavy elements which are often also chemically toxic

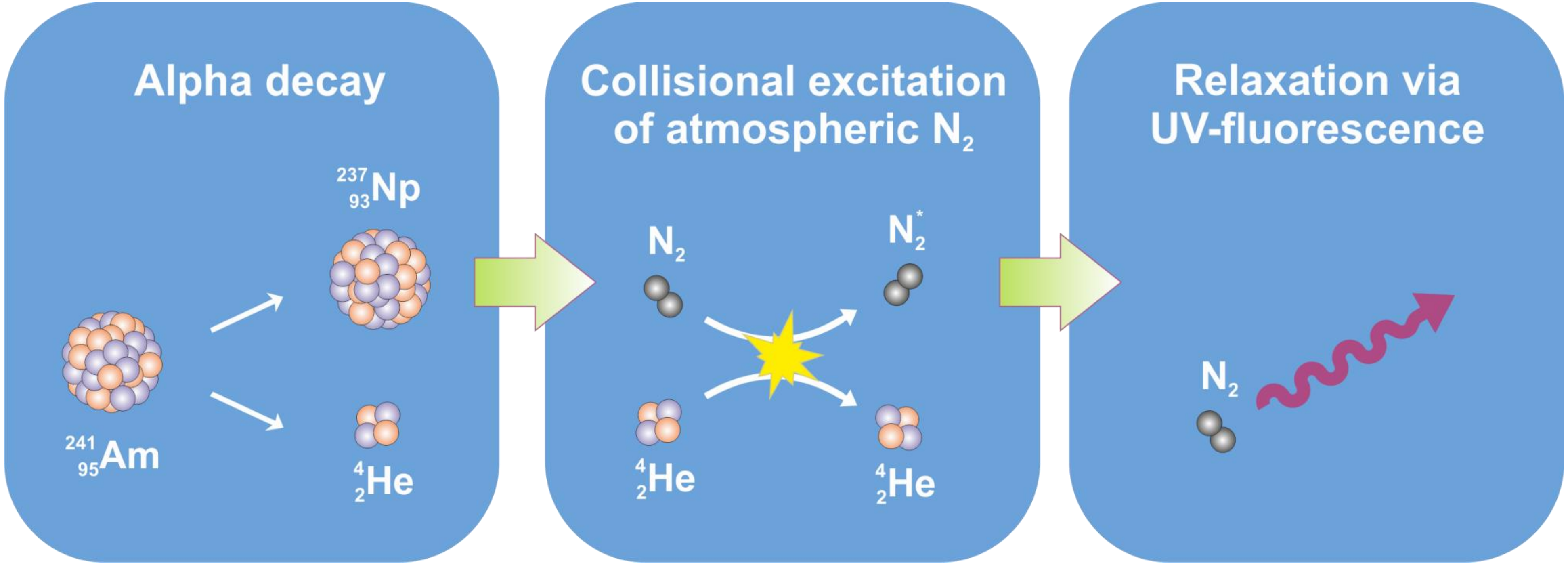


- Alpha particles have a low penetrating power
- Alpha particles carry a lot of energy (a few MeVs)



- Due to their high ionization potential, alpha particles are harmful when ingested or inhaled

Alpha particles induce radioluminescence in air



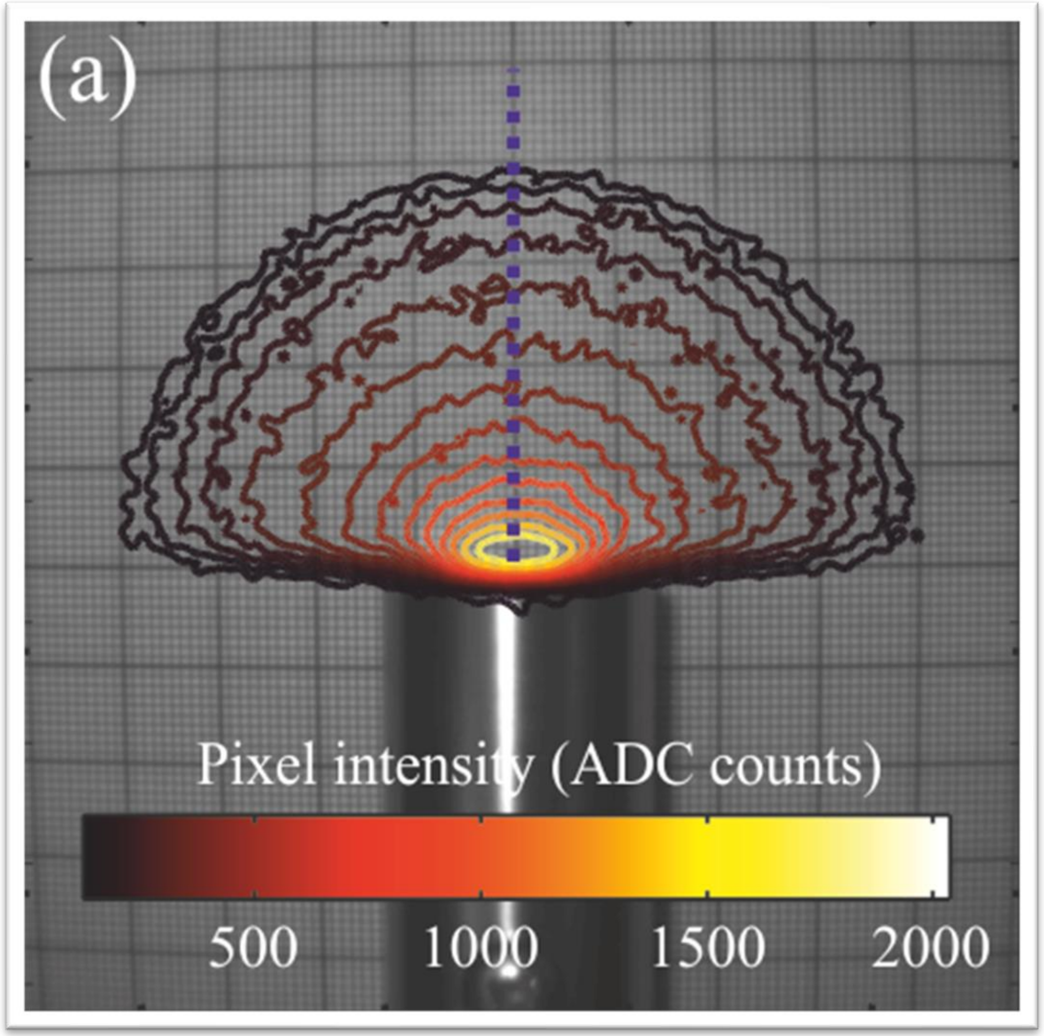
- When absorbed in air, alpha particles transfer energy to air molecules (N2, O2)
- Non-radiative (thermal) relaxation dominates but approximately 100 photons are created by one 5 MeV alpha particle

Optical emission of a point alpha source

Alpha radioluminescence hemisphere imaged

- The contour image shows the extent and intensity of the radioluminescence (RL) emission of a point source
- The RL image is captured in darkness
- The background image is captured under visible light
- The two images are combined in post-processing

Most RL photons originate from a volume of few cubic cm close to the point source



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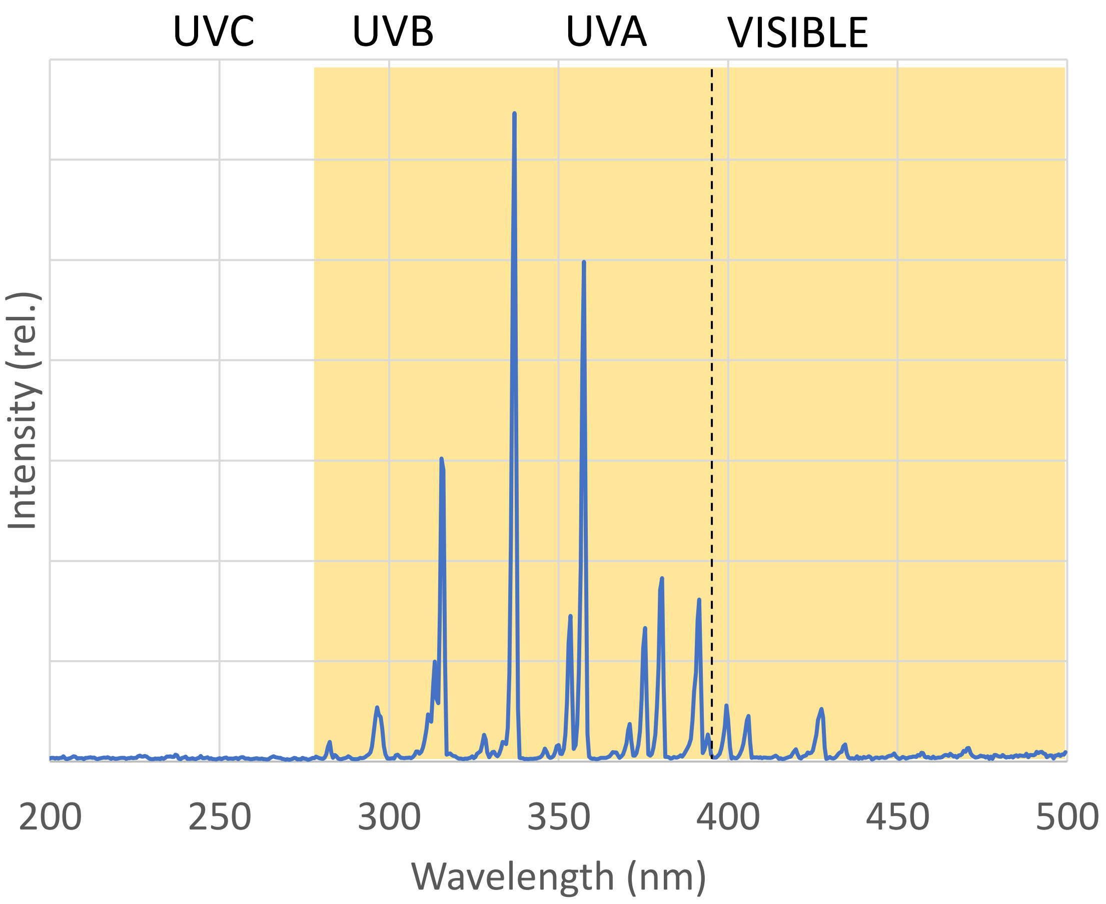
Radioluminescence emission spectrum in air

- Strongest emissions are observed at 300-420 nm wavelengths
  - 315 nm, 337 nm, 357 nm
- Normal lighting and sunlight are orders of magnitude brighter than RL emission
- Due to the low light yield of alpha particles, optical detection requires a wavelength band with close to zero background



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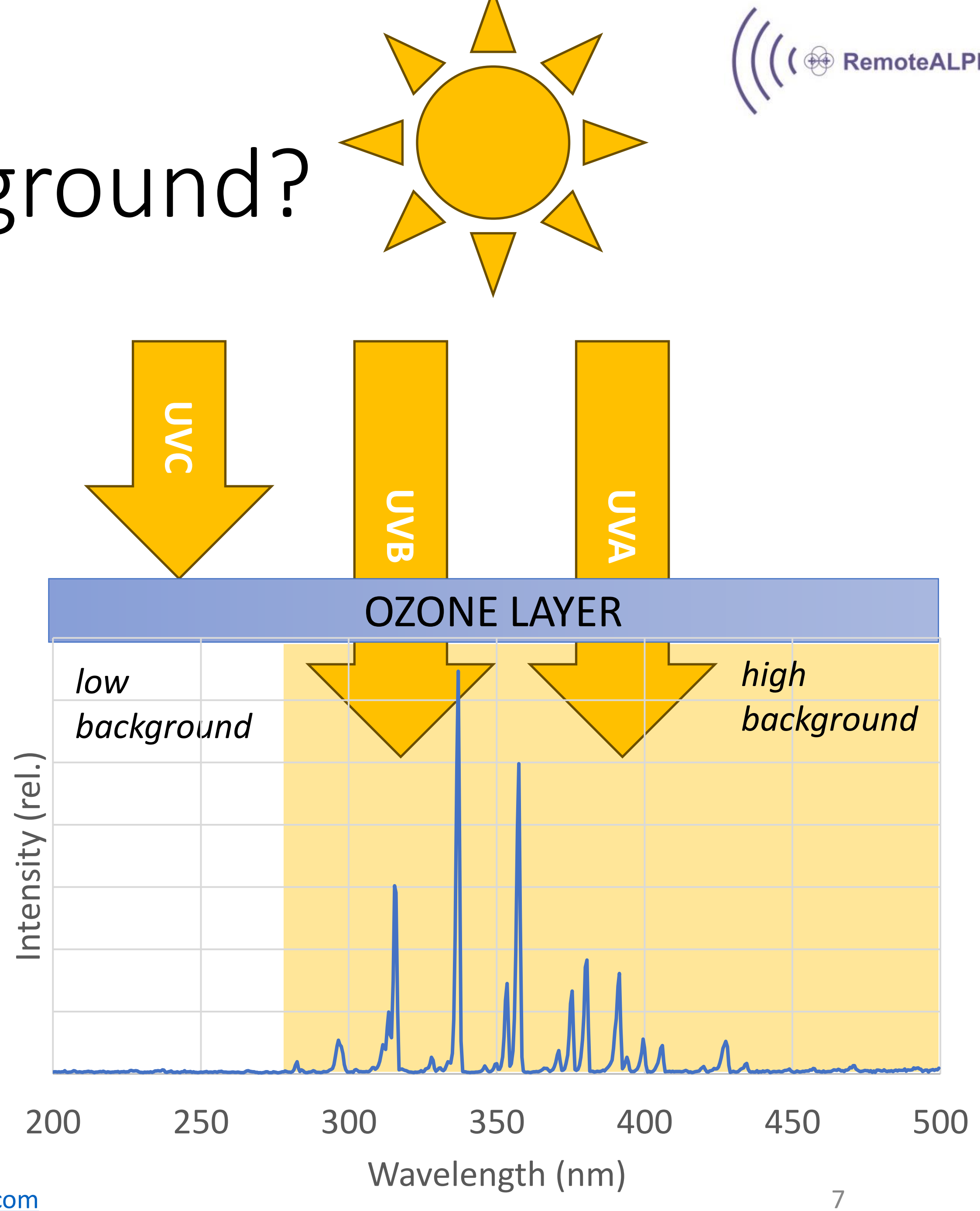
How to achieve low background?

- Natural low background is available in UVC region (absorption in ozone layer)
  - Challenge: extremely low light yield of alpha particles in this wavelength region
- LED lights can be used to create low background in UVA/UVB
  - Challenge: light leaks



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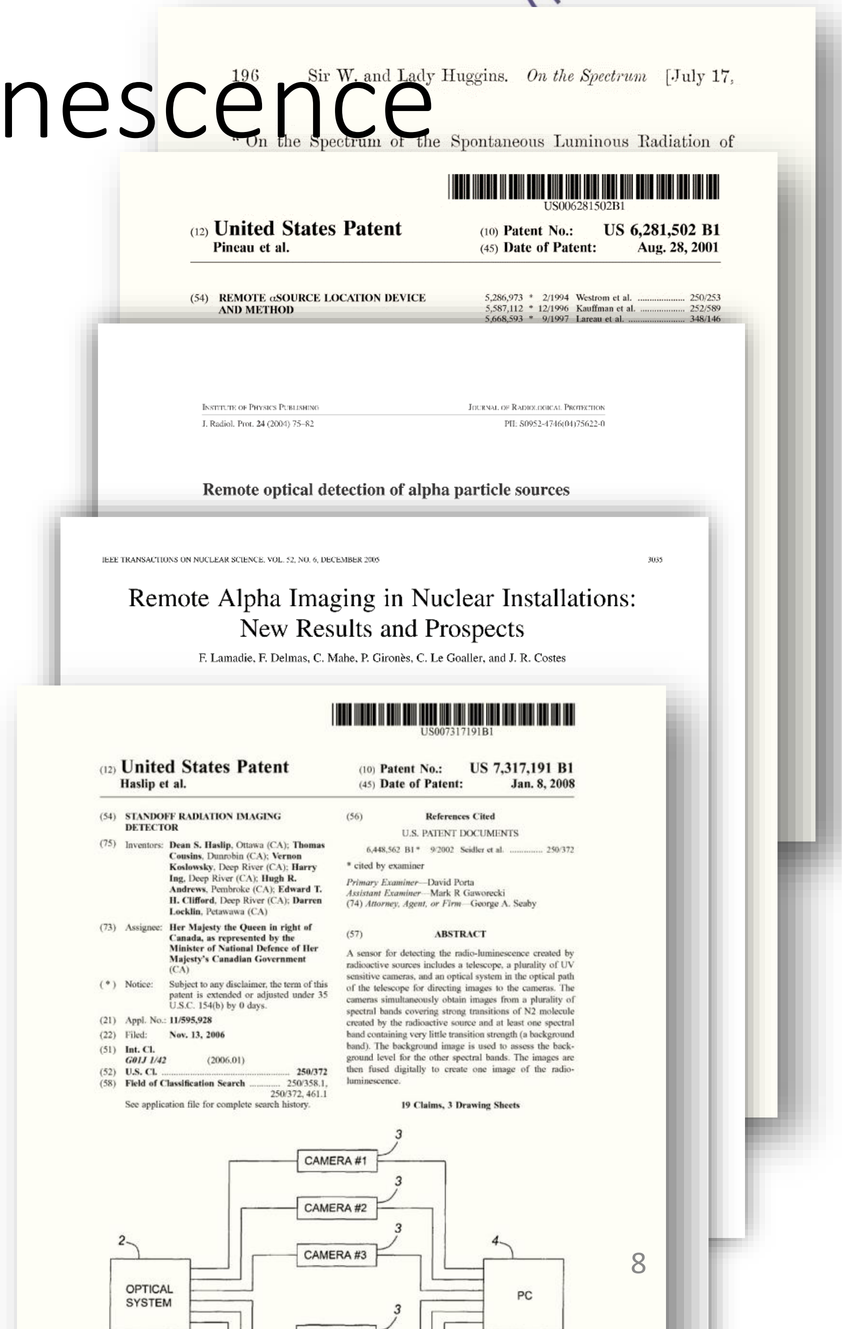
Key activities on alpha radioluminescence

1903	The first observation of alpha radioluminescence in air by Sir W. Huggins and Lady Huggins (UK)
2001	Patent: “Remote α source location device and method” by J.-F. Pineau (France)
2004	”Remote optical detection of alpha particle sources” by S. Baschenko (Ukraine)
2005	”Remote alpha imaging in nuclear installations: new results and prospects” by F. Lamadie (France)
2006-	Developments by Bubbletech Inc. (Canada)
2008-	Research at Tampere University (Finland)
2020-	Remote Alpha (EMPIR)

Alpha radioluminescence has been know for more than 100 years but most application-oriented research originates from the last 20 years



Tools for radioluminescence detection

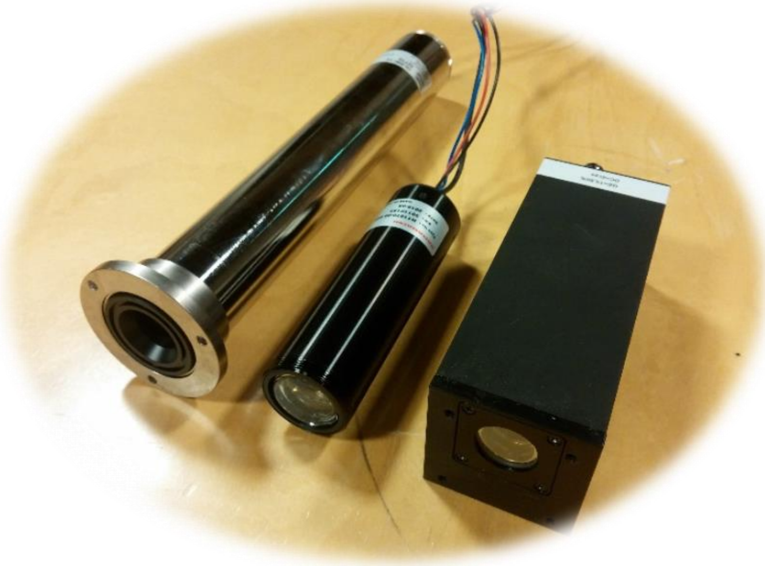
Photomultiplier tubes

Cameras

Optics & Filters

Photomultiplier tubes for counting photons

- Photons can be counted with photomultiplier tubes (PMTs)
  - High sensitivity & low background are essential
  - Pulse shape analysis/energy measurement not possible
- PMTs are moderately priced and widely used in the industry
  - PMTs rely on glass vacuum systems which make them somewhat fragile
- Semiconductor detectors still struggle to provide large active area and low background needed for the job



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Cameras for low light imaging

- Scientific-grade cameras can capture images of alpha radioluminescence
  - CCD, EMCCD, ICCD sensor technologies have been demonstrated
  - CMOS perhaps soon
- Cameras can be significant cost driver but provide user-friendly image output
- Cameras excel at characterization of contamination distribution after detection

https://andor.oxinst.com/products/ixon-emccd-camera-series/ixon-ultra-897

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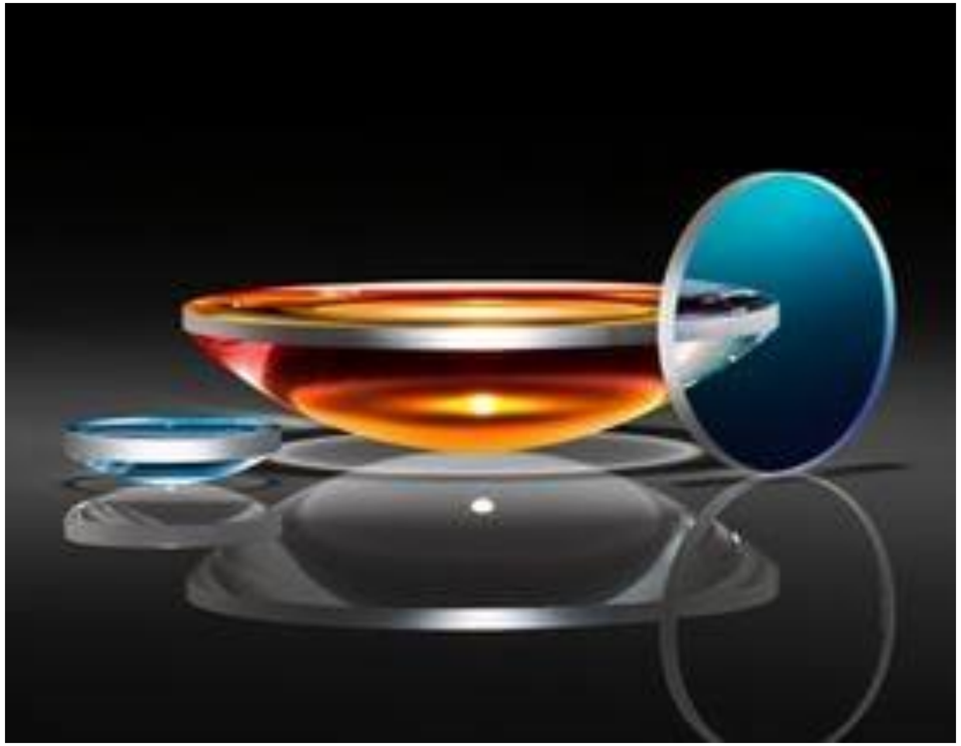
Optics for collecting photons

- Large optics collect more photons and allow measurements from a greater distance
  - Need to consider size, weight and price
- Telescopes are often employed for alpha detection
  - Narrow field of view, large entrance pupil
- Limited number of materials available for deep UV applications



https://www.edmundoptics.eu/f/uv-fused-silica-plano-convex-pcx-lenses/12410/

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Filters for increasing signal to background

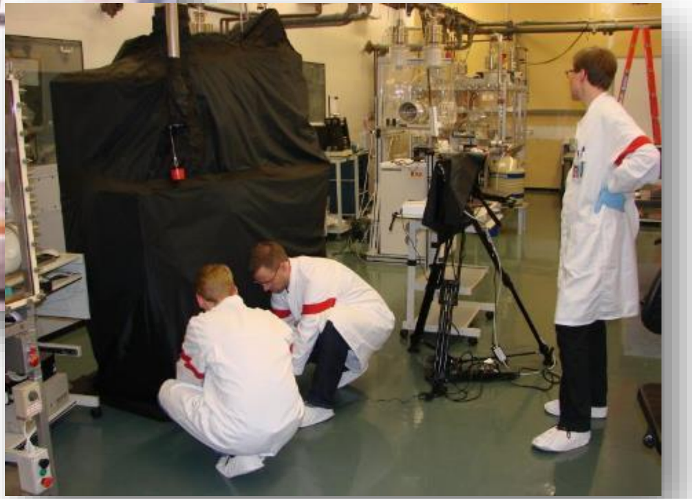
- Optical filters limit the spectral bandwidth that arrives on camera or PMT sensor
- Filters are essential for alpha detection in every scenario and application
- Only a limited number of filters are good enough for the purpose
  - Very difficult to simulate, experimental verification work needed

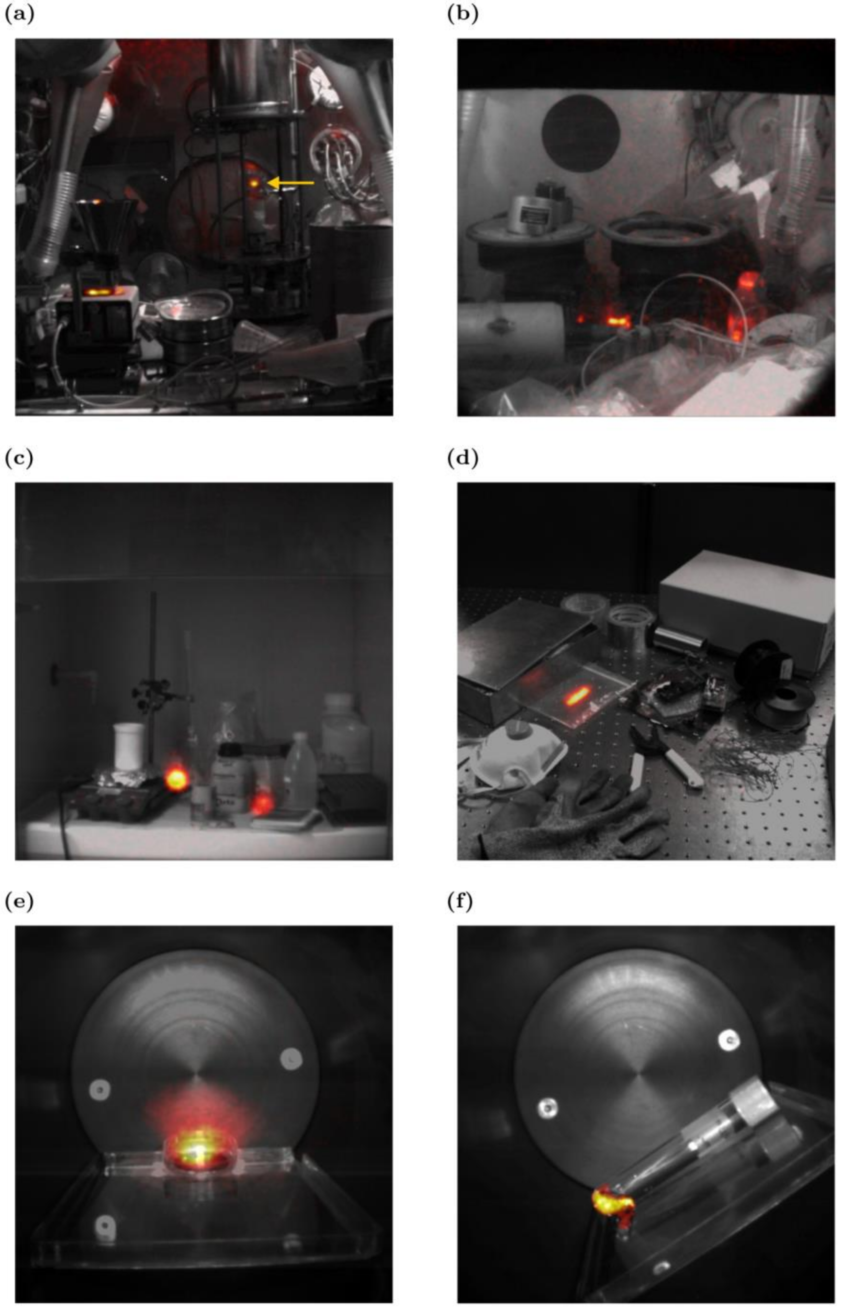
Application Examples

Imaging with camera

Radioluminescence mapping

Imaging with EMCCD camera





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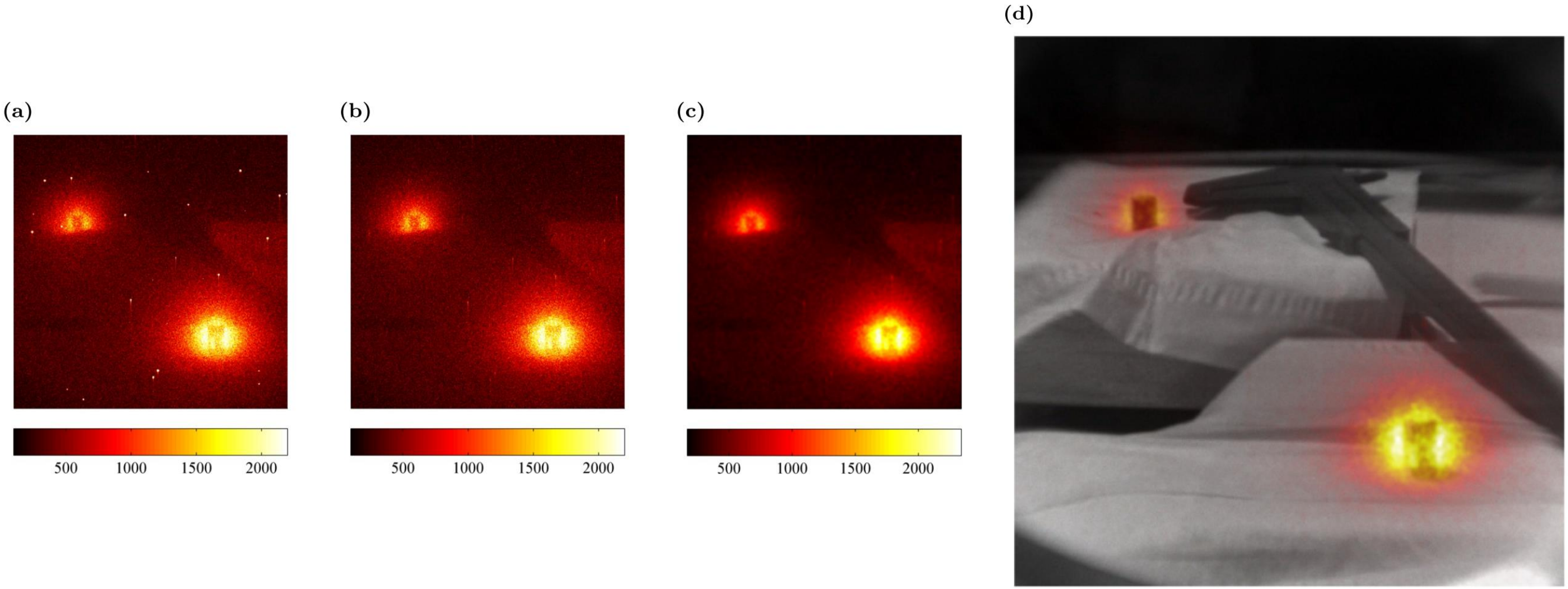
Camera: MOX pellets in a glovebox



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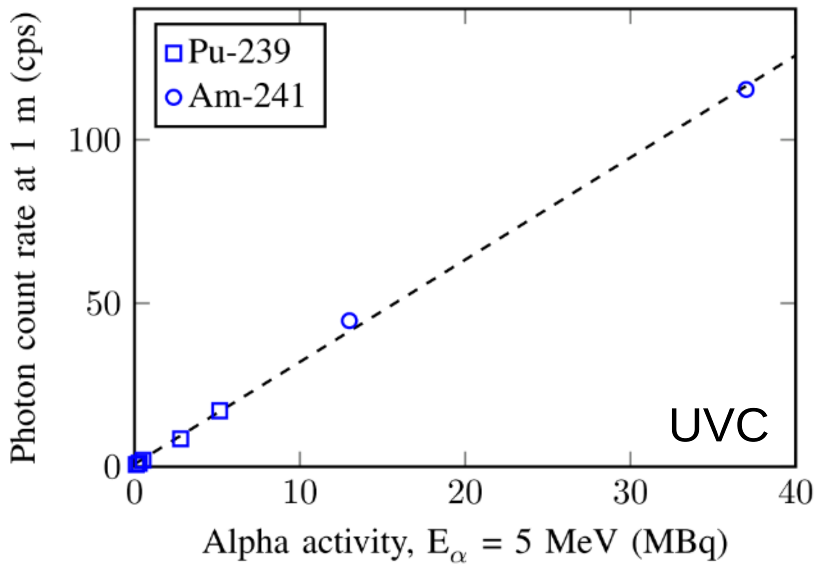
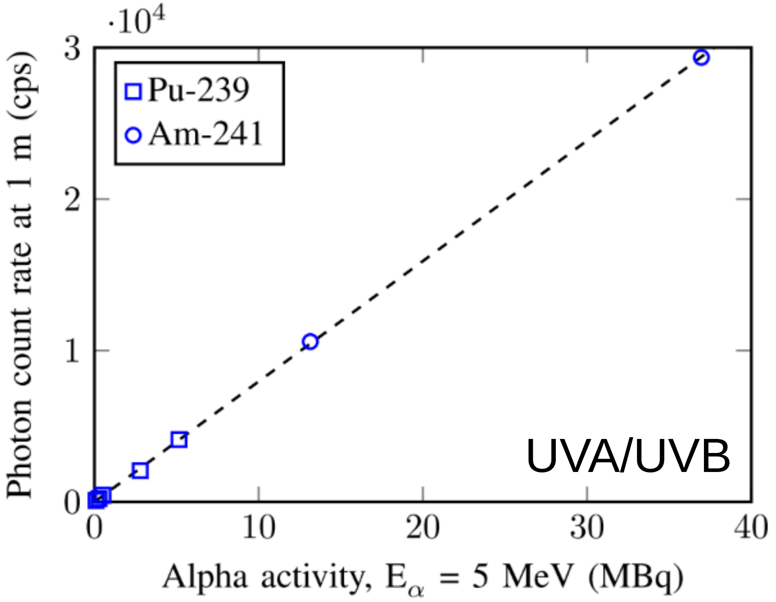
Radioluminescence mapping telescope

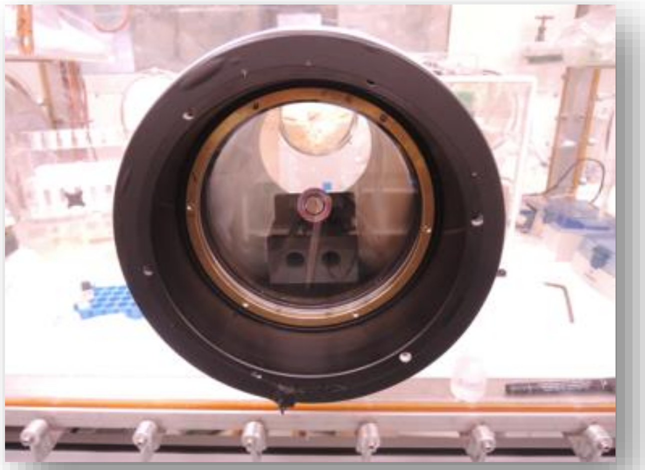
- Telescope + filter + PMT = tailored solution for different illumination environments – can be operated without light shield!
- Sensitivity for alpha particles and tolerance for ambient light is defined by the selection of detection wavelength
- Automated scanning is implemented with a motorized panorama head
- System could be directly applied for surface contamination inspection or integrated to a robotic system

J. Sand, A. Nicholl, E. Hrnecek, H. Toivonen, J. Toivonen, and K. Peräjärvi, "Radioluminescence mapping of alpha emitters under bright lighting," IEEE Transactions on Nuclear Science , vol. 63, no. 3, pp. 1777-1783, 2016.

Radioluminescence mapping: Calibration at 1 m distance







- Alpha detection is possible under full fluorescent lighting with a solar blind PMT and carefully selected filters
- Sensitivity 3 c/s/MBq @ 1m distance, background <4 cps under fluorescent lights

- Bi-alkali PMT provides higher signal level if white fluorescent light and sunlight can be avoided
- Sensitivity 800 c/s/MBq @ 1m distance, background <10 cps under yellow fluorescent light or LED light

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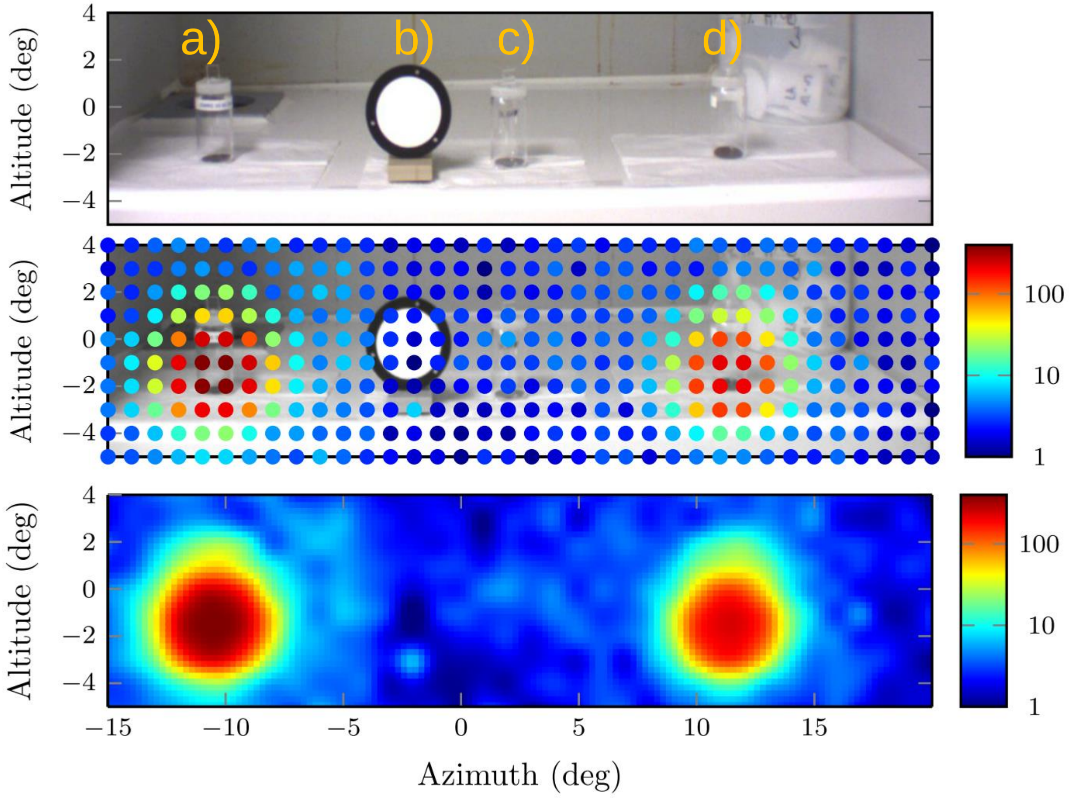
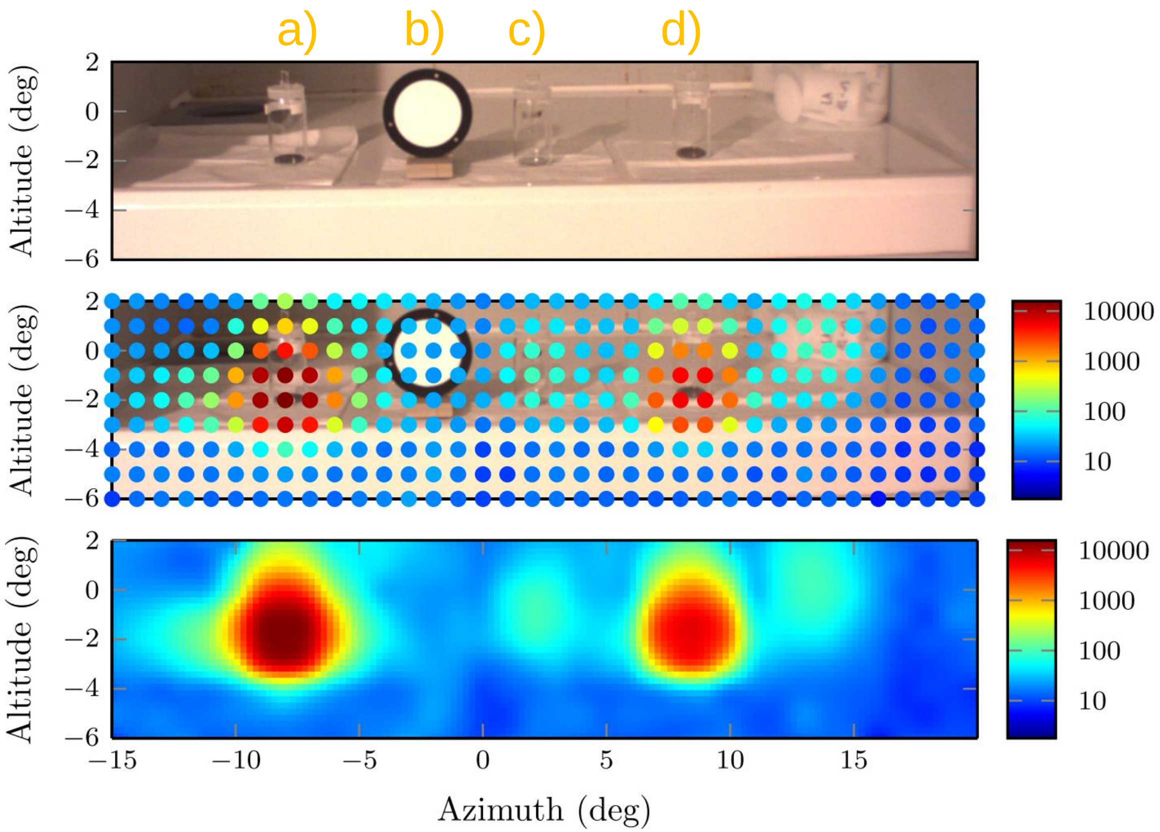
Radioluminescence mapping: fluorescent vs LED lighting





***a)** 37 MBq Am-241* ***b)** Reflector* ***c)** Blank* ***d)** 13 MBq Am-241*

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Conclusions

Optical alpha detection is motivated by

- Long range detection capability and potential for automated screening
- Detection through translucent materials
- Complementing gamma cameras

The unique benefits come with a tradeoff

- Sensitivity is limited by low light yield of alpha particles
- It is challenging to reach typical free release limits for alpha contamination
- Ambient optical background can prevent optical measurements in some environments

Close collaboration with end-users is needed to identify application areas where optical alpha technology can facilitate operations!

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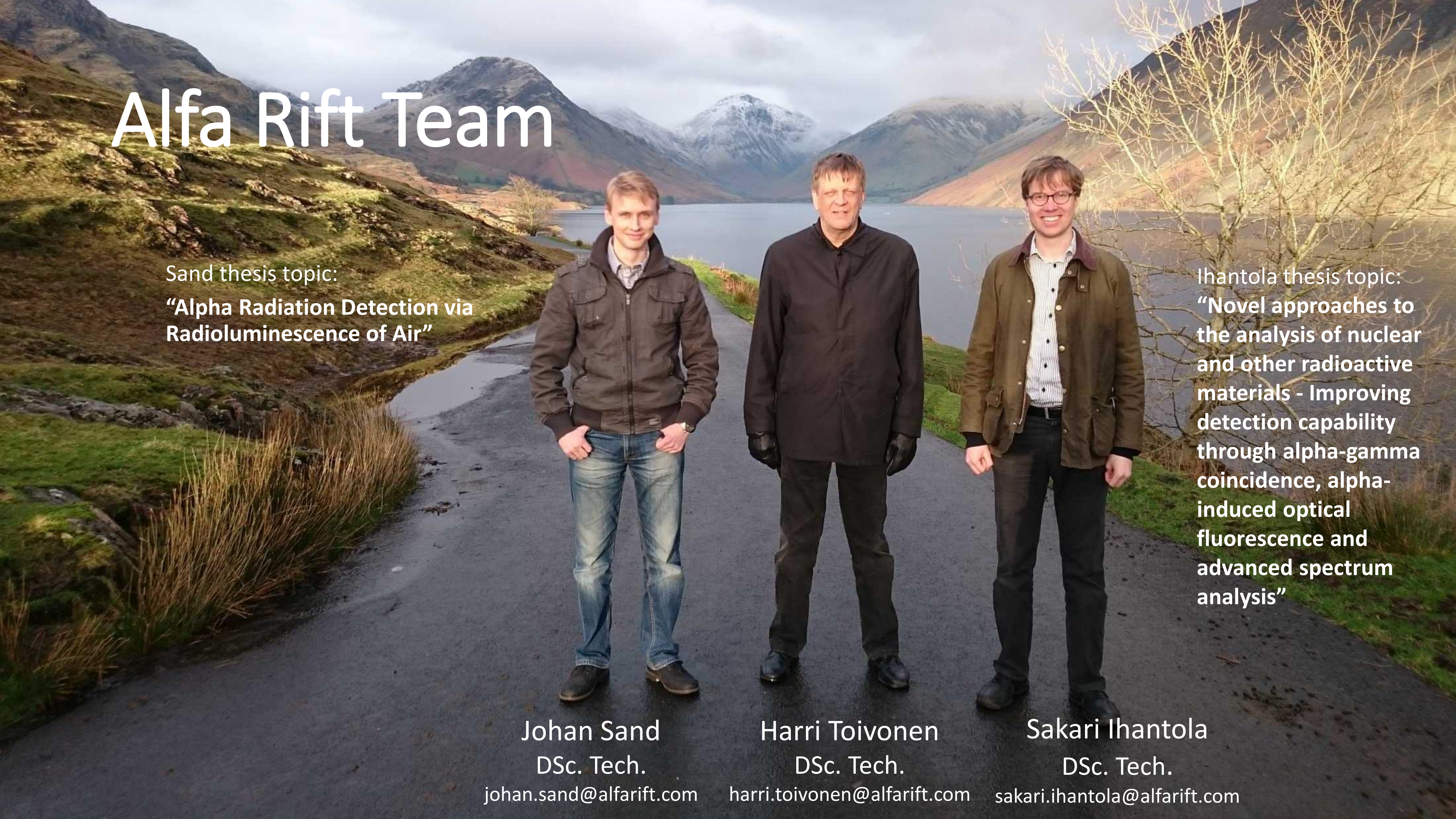
Alfa Rift Team



Sand thesis topic:

“Alpha Radiation Detection via Radioluminescence of Air”

Ihantola thesis topic:

“Novel approaches to the analysis of nuclear and other radioactive materials - Improving detection capability through alpha-gamma coincidence, alpha-induced optical fluorescence and advanced spectrum analysis”

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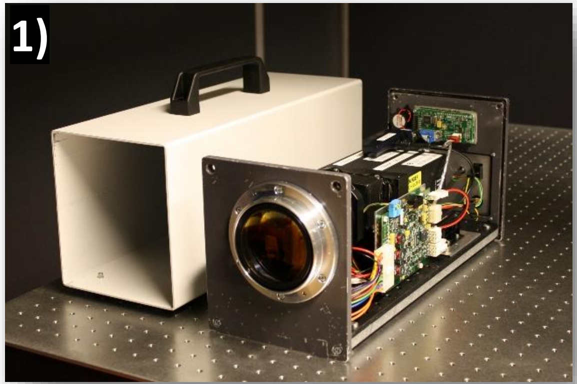
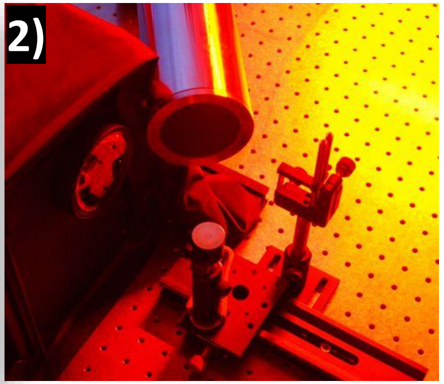
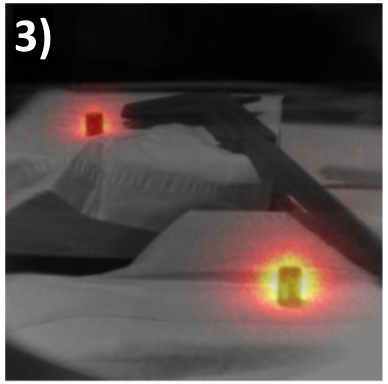
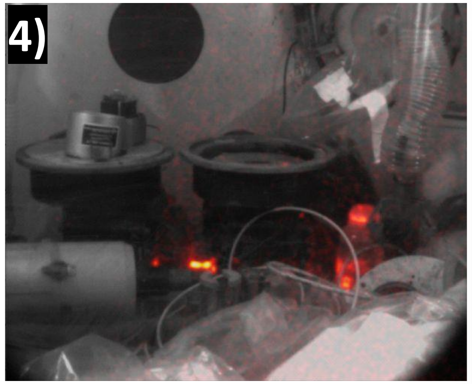
Alfa Rift – Unique expertise in optical remote detection of alpha radiation

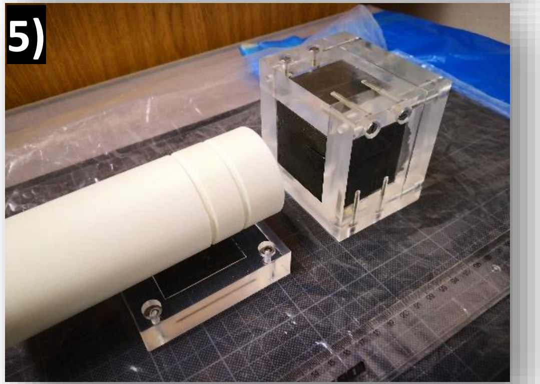
1) **Portable alpha contamination detection system**
2) **Nuclide identification** via alpha-gamma coincidence
3) **Detection and imaging of alpha emitters in gloveboxes**
4) **Imaging of high-level contamination through lead glass**
5) **Alpha counter concept for gloveboxes**
6) **Automated mapping of alpha contamination** under bright lighting











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Ionizing particles in upper atmosphere
Oxygen atoms and molecules emit light primarily in green and red wavelengths
Nitrogen molecules emit light in blue and purple wavelengths

Backup

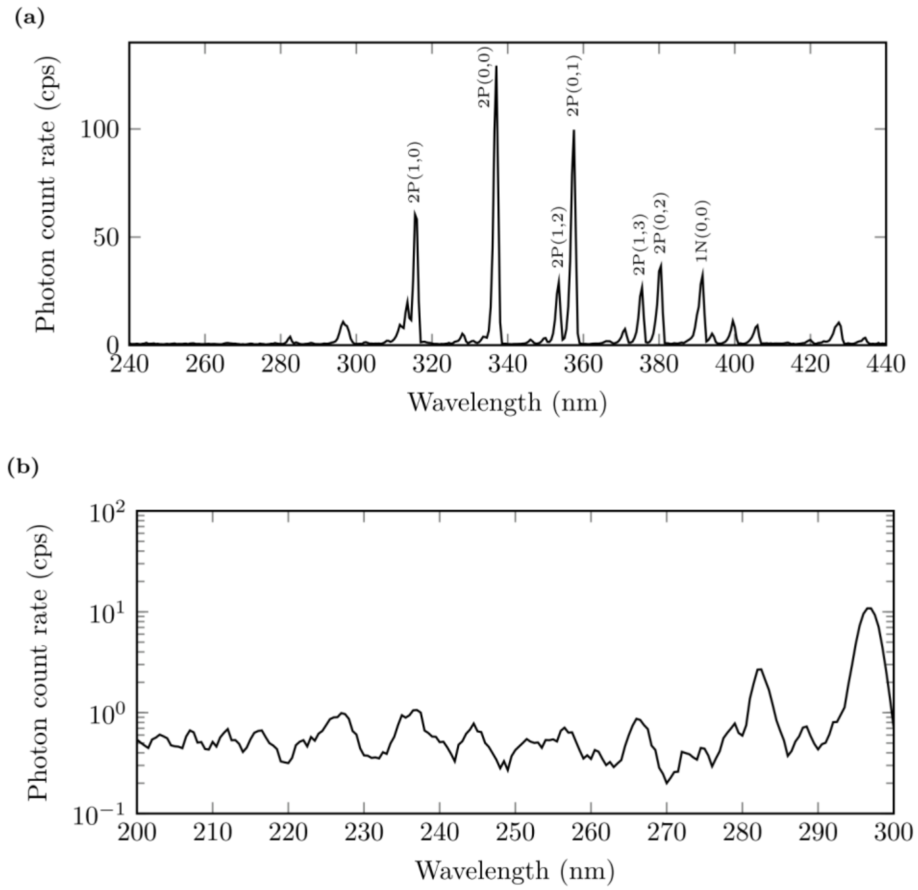
Radioluminescence spectrum

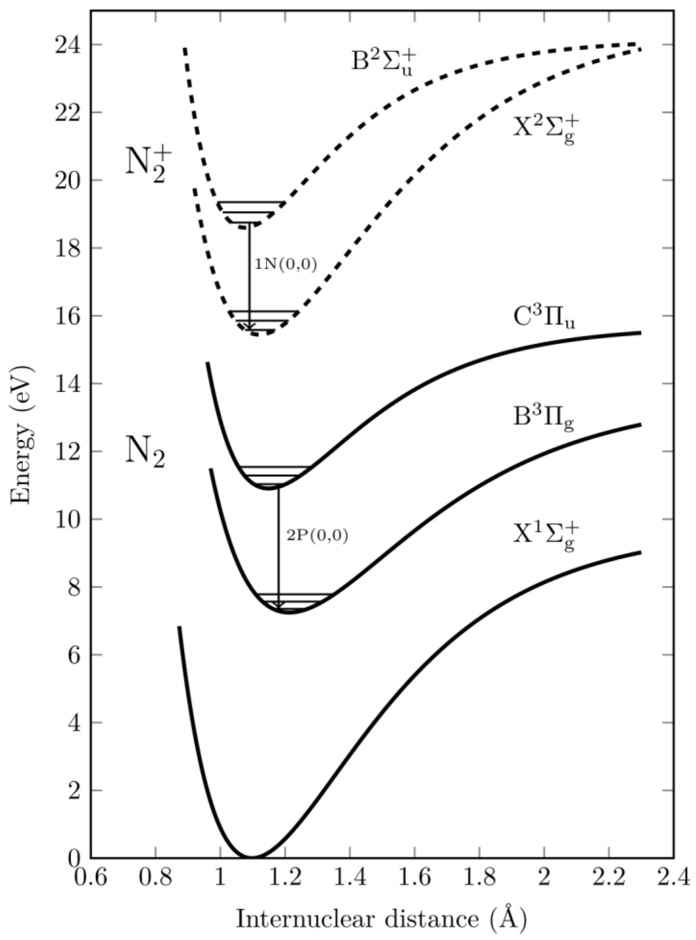
UVA/UVB

- Abundant radioluminescence
- Significant background

UVC

- Scarce radioluminescence
- Low background

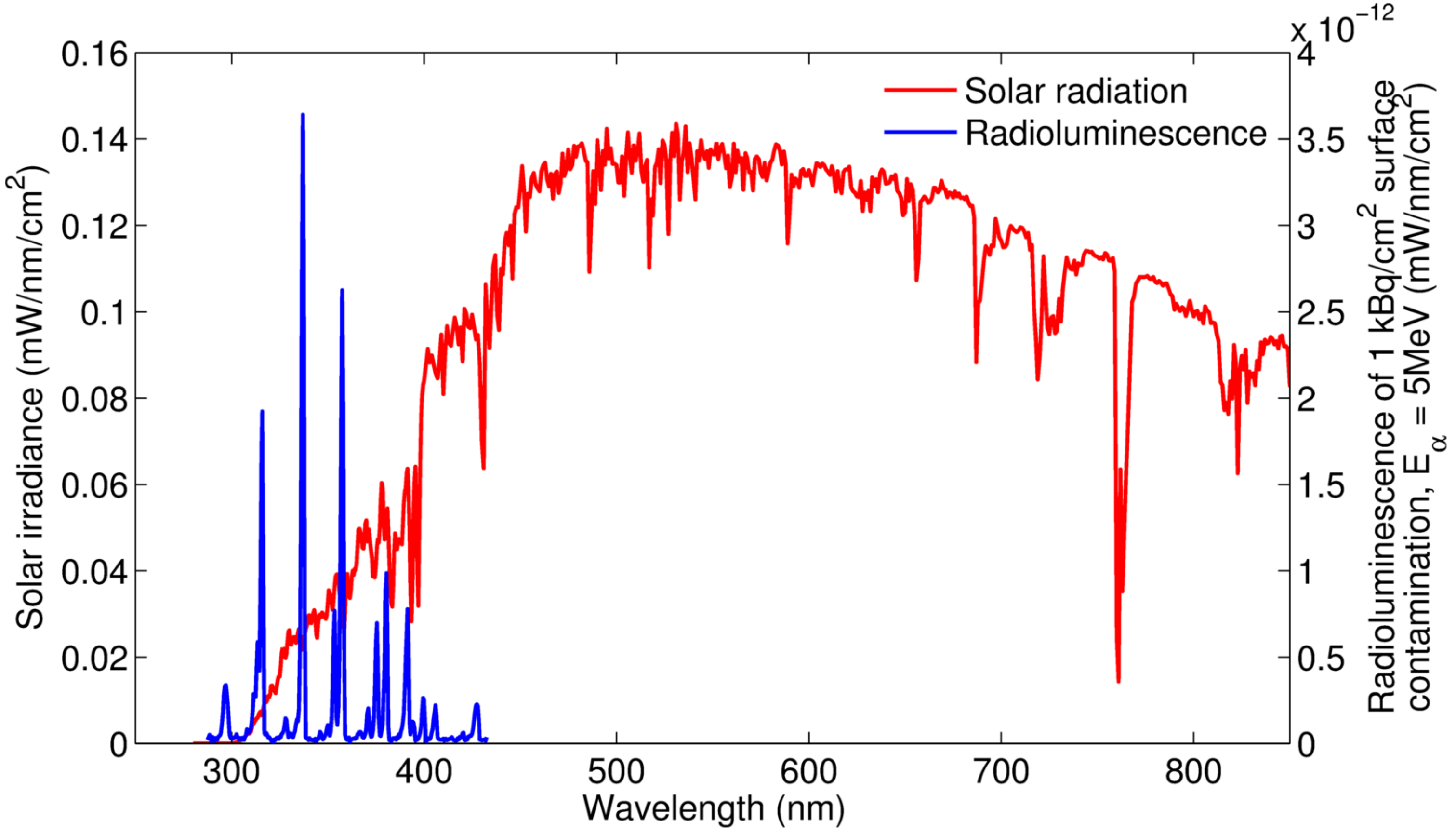




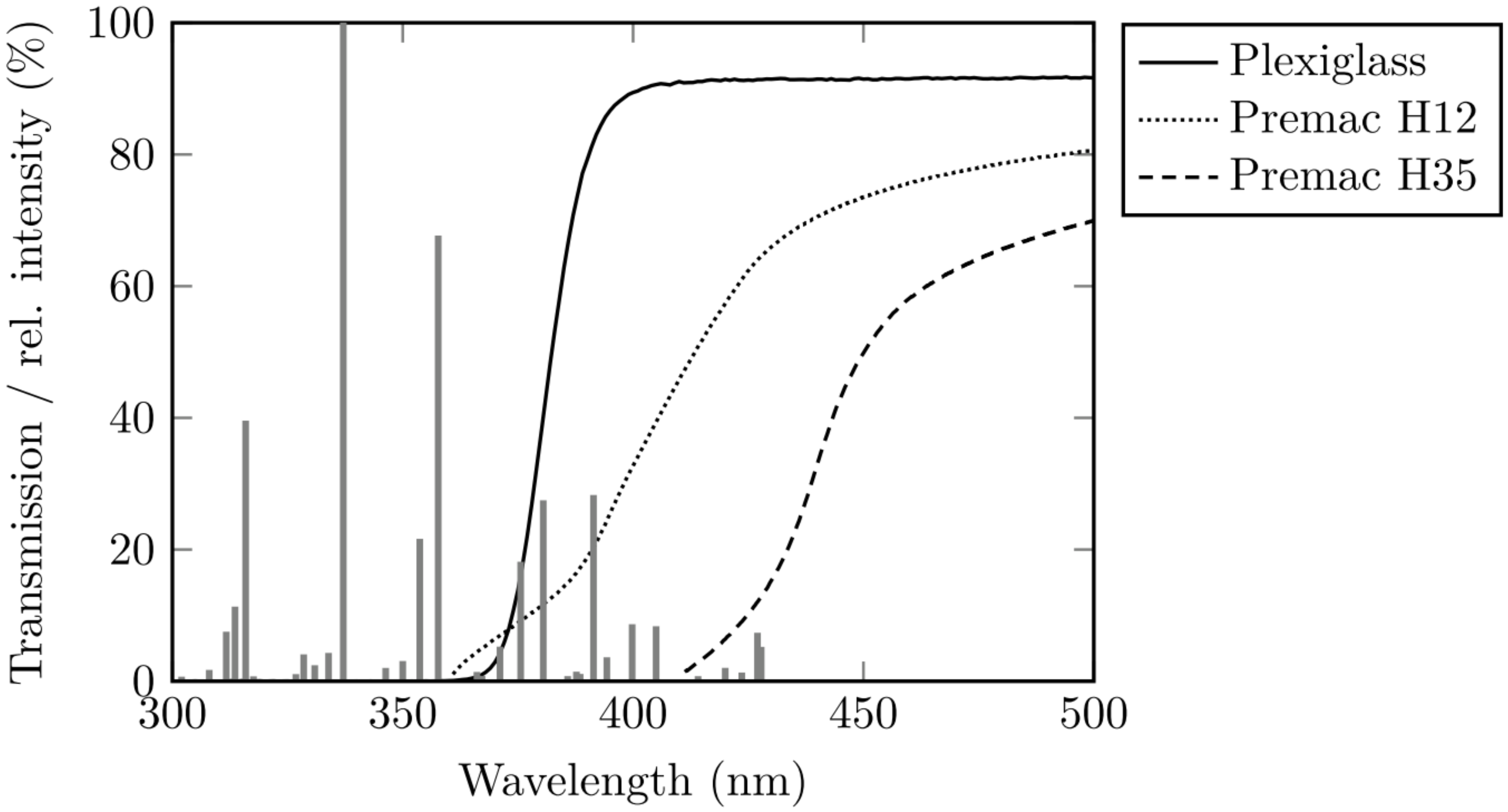
Alpha Radioluminescence vs daylight

Spectrum of solar irradiation at sea level is reproduced from Standard Reference Spectra ([ASTM G-173-03]) of American Society for Testing and Materials (ASTM) (US)

Radioluminescence spectrum of alpha particles in air is measured at Tampere University of Technology (Finland).



Glovebox window



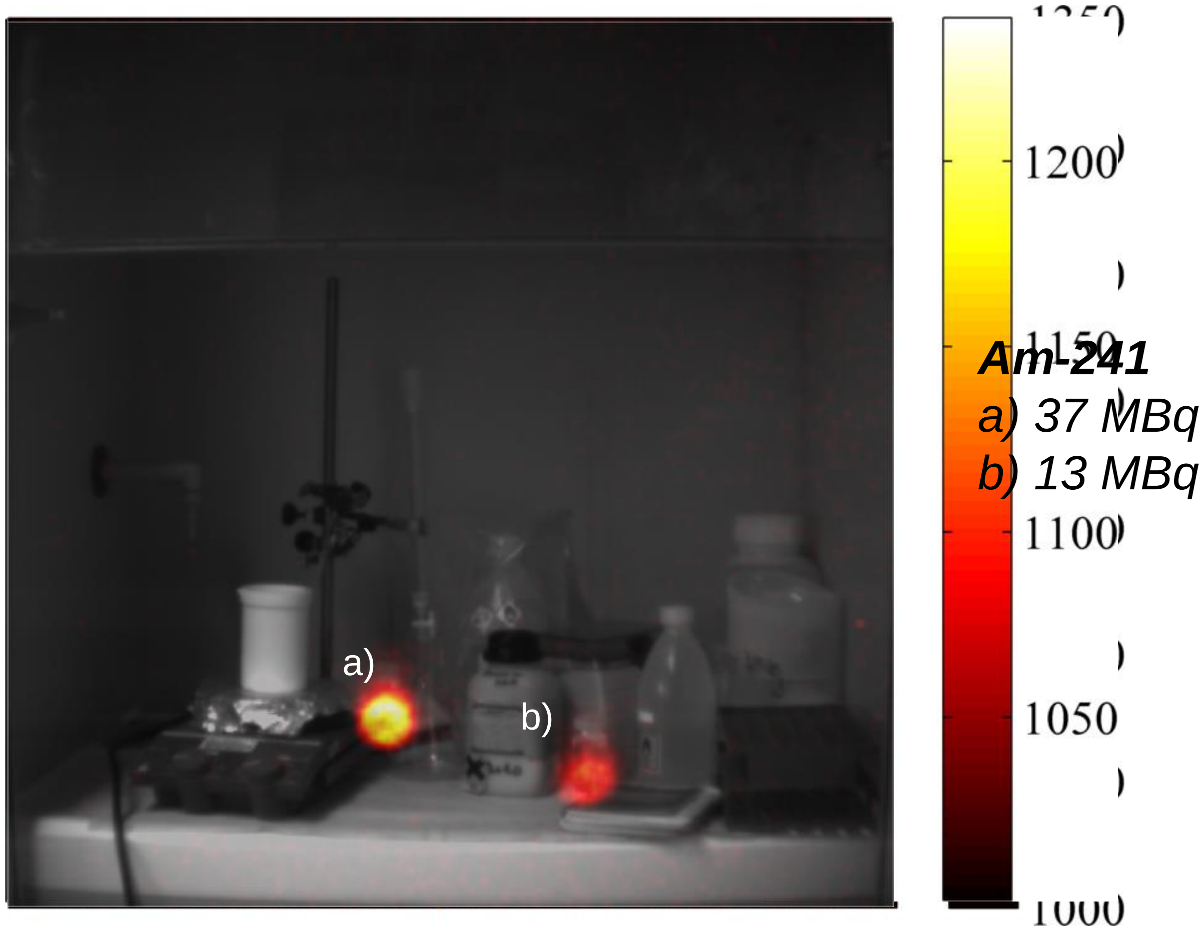
Camera: Crime scene demonstration

1) Daylight image

2) UV image 10 x 60 s exposure

3) Low pass filter

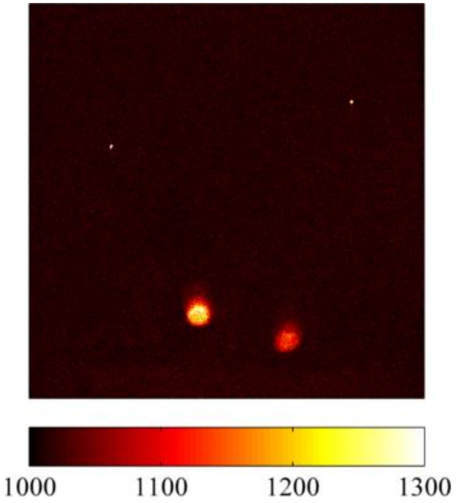
4) Superimposition

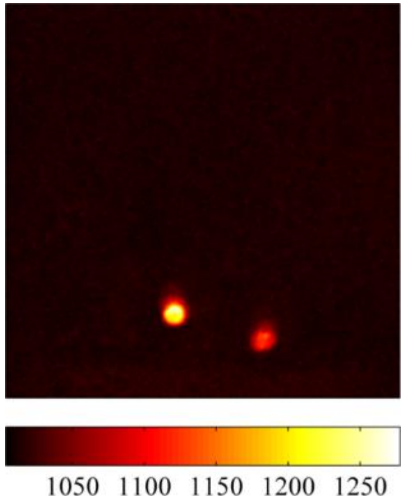


ITU, September 2015

Cs-137 is not visible in RL image

Cs-137
emitter
~11 MBq





Generic Integrated Forensic Toolbox