

# Scientific and technical aspects of alpha radioluminescence detection

Remote Alpha Demo Day 5.7.2023 Johan Sand Alfa Rift Oy, Finland

#### 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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- 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 radiolumines center of the Spectrum (July 17, Configuration of the Spectrum of the Spe

1903	The first observation of alpha radioluminescence in air by Sir W. Huggins and Lady Huggins (UK)
2001	Patent: "Remote $\alpha$ source location device and method" by JF. 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

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SYSTEM

#### 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





- 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

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- 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







1,

(b)

(f)











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#### Camera: MOX pellets in a glovebox



(d)





- 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.



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#### Radioluminescence mapping: Calibration at 1 m distance



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- 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</li>

- 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

 $\cdot 10^{4}$ 





### Radioluminescence mapping: fluorescent vs LED lighting



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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!

# Alfa Rift Team

Sand thesis topic: "Alpha Radiation Detection via Radioluminescence of Air"

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Ihantola thesis topic: "Novel approaches to the analysis of nuclear and other radioactive materials - Improving detection capability through alpha-gamma coincidence, alphainduced optical fluorescence and advanced spectrum analysis"

# 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

(a)



- 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 (<u>ASTM G-173-03</u>) 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



1300

#### Cs-137 is not visible in RL image



Cs-137 emitter ~11 MBq







1050 1100 1150 1200 1250