RemoteALPHA

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EMPIR Project 19ENV02 RemoteALPHA: An introduction

Alpha particles represent the biggest risk to soft biological tissues compared to all nuclear decay products due to their high energy, large mass and high linear energy transfer. The amount of deposited energy is about 2 000 000 to 6 000 000 times higher than that of an ordinary chemical reaction (ordinary chemical energy used by the cells in the body), which means that a single alpha particle has the ability to severely or lethally damage all the cells within its range. Therefore, the release of alpha-emitting radionuclides in the environment, such as by nuclear terroristic attacks or transportation accidents, as well as by severe emergencies in nuclear installations, represent a major radiological threat to human beings if they enter the human body.

Following a possible radiological emergency involving an accidental or deliberate dispersion of alpha emitting radionuclides in the environment, tinny fallout particles could be easily deposited in common environmental surfaces (e.g, in soil, sand, vegetation, concrete, etc.) and ingested or inhaled by living beings. This scenario represents a very a complex situation which can cause significant damage to humans and could affect many aspects of peoples live, including their local economies. Alpha contamination could also be a serious concern during the decommissioning of nuclear fuel fabrication and reprocessing facilities.

The efficiency of responding to such radiological scenarios depends strongly on the available instrumentation for detection alpha emitting radionuclides. Due to the short range of alpha particles in air of only a few centimeters, this cannot be achieved by conventional detectors for alpha contamination such as detectors based on the scintillation technology (e.g., silver activated ZnS thin films) and detectors based on the semiconductor devices (e.g., passivated implanted planar silicon and silicon gold surface-barrier detectors). These detectors must be positioned within few centimeters of the source (typically, within 4 cm) in order for the alpha radiation to be detected and thus have major drawbacks such as, for example, personnel will be exposed to other hazards and risks such as other types of radiation, fire, etc. and detectors may become contaminated if they touch the source.

The EMPIR project 19ENV02 RemoteALPHA has developed several radioluminescence detection systems capable of efficiently detecting the weak radioluminescence of air in the UV-A and UV-C spectral regions, while being as insensitive as possible to ambient light. To facilitate the deployment of these systems for the management of radiological emergencies, nuclear safety, security and safeguards, SI traceable calibration schemes and standards have also been developed. To extend the optical detection system to an imaging functionality for mapping of alpha contaminations in the environment, an Unmanned Aerial Monitoring System (UAMS) was developed for the first time to enable real-time radiological data collection and faster, more reliable information for decision-making authorities. In addition, feasibility studies were conducted to investigate the advantages of laser-induced fluorescence spectroscopy over radioluminescence for the detection of alpha emitters.

The 19ENV02 RemoteALPHA consortium includes 8 leading European institutions (see

Fig. 1) contributing their expertise, knowledge and experience in the fields of environmental monitoring, radioecology, optical detection of ionizing radiation and radiation protection.

Fig. 1 *Institutions participating in the RemoteALPHA consortium*.

Additional information about the consortium, project goals, work packages, list of publications, and events can be found on the project website at https://remotealpha.drmr.nipne.ro/.

New instrumentation for the optical detection of alpha particle emitters in the environment

Radioluminescence mapping using well-characterized and optimized optical systems is an effective method for localizing contamination with alpha-emitting radionuclides. In the framework of RemoteALPHA, PTB with the help of IFIN-HH, LUH, UPC, TAU, ALFA RIFT, MATE and BFKH has developed and optimized two radioluminescence detection systems to establish the metrological basis for the optical detection of alpha-emitting radionuclides. One detection system is based on a high-quality UV fused silica lens (UVFS), while the other uses a PMMA Fresnel lens (Fig. 2). Both systems operate as mapping systems by generating the radioluminescence image of alpha radiation sources by remotely scanning a narrow field of view over the user-defined region of interest while recording the photon count rate. While the UVFS system was optimized for use as a scanning telescope on a tripod due to limitations in its weight and mechanical stability, the Fresnel lens-based lens system was optimized for use as an unmanned airborne monitoring system for mapping alpha contamination in the environment. These optical detection systems are aimed to facilitate a rapid, coordinated, and effective response in emergency situations involving the release of alpha-emitting radionuclides, nuclear safeguards, nuclear decommissioning and nuclear forensics.

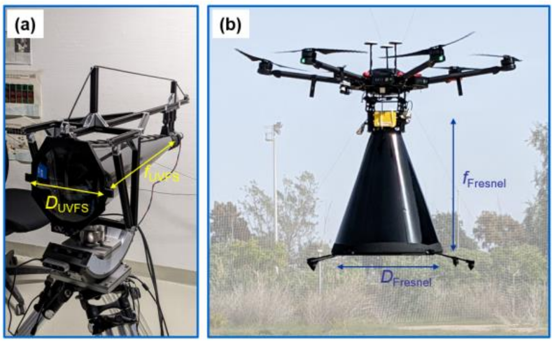

Fig. 2 *Lens-based radioluminescence detection systems developed within the RemoteALPHA. By using the appropriate interference filters and PMTs, they can operate in both the UV-A and UV-C spectral regions. (a)The UVFS system was optimized for use as a tripod telescope due to weight and mechanical stability constraints, while (b) the Fresnel lens-based system was optimized as an unmanned airborne mapping system due to its light weight (less than 5 kg) and mounted on the DJI Matrice 600 Pro UAV*.

These detection systems have been successfully used in a number of experiments to quantify total surface activity and to image various distributions of alpha-emitting radionuclides.

Technical information on the optical detection systems and UAMS can be found in

[1] M. Luchkov, V. Dangendorf, U. Giesen, F. Langner, C. Olaru, M. Zadehrafi, A. Klose, K. Kalmankoski, J. Sand, S. Ihantola, H. Toivonen, C. Walther, S. Röttger, M.-R. Ioan, J. Toivonen, F. S. Krasniqi, *Novel optical technologies for emergency preparedness and response: Mapping contaminations with alpha-emitting radionuclides*, Nuclear Inst. and Methods in Physics Research, A 1047 (2023) 167895, https://doi.org/10.1016/j.nima.2022.167895

[2] Royo, P.; Vargas, A.; Colls, T.G.; Saiz, D.; Pichel Carrera, J.; Rabago, D.; Duch, M.A.; Grossi, C.; Luchkov, M.; Dangendorf, V.; Krasniqi, F. Mapping of Alpha-Emitting Radionuclides in the Environment Using an Unmanned Aircraft System. Submitted to Remote Sensing. Preprints 2023, 2023101698. https://doi.org/10.20944/preprints202310.1698.v1

Calibration system for the novel-type radioluminescence detector systems

To facilitate the deployment of radioluminescence systems developed in the framework of RemoteALPHA, SI traceable calibration schemes and standards have been developed. The developed calibration schemes are source-based and rely on two complementary approaches. The first calibration method comprises the application of a dedicated activity standard and environmental samples with deposited alpha emitting radionuclides (see Figs. 3-6), whereas the second method uses two purely optical radiation-based devices (Fig. 7) which simulate the radioluminescence in air induced by an alpha emitting source.

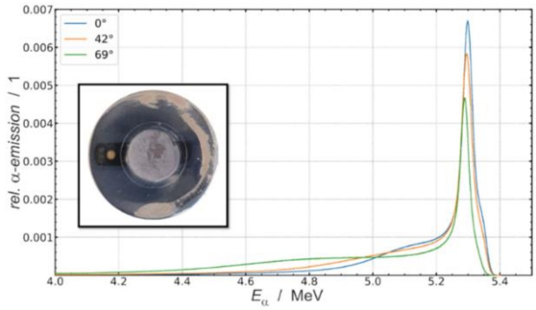

Fig. 3 *Relative alpha emission of ^{210}Po activity standard measured with a 25 mm^2 silicon surface barrier detector behind a 3.2 mm aperture and a distance from the source surface of 15 mm. The spectra have been measured at 0°, 42° and 69° relative to the surface normal. The inset shows the ^{210}Po sample with a diameter of 12 mm (central part) deposited on the silver substrate*.

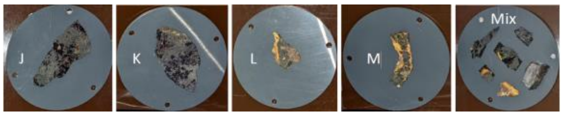

Fig. 4 *Pitchblende mineral samples prepared and characterized by LUH. Stones from Puy de Dôme in France, Uranium City in Canada and Wölsendorf in Germany with an estimated high uranium content were characterized with a grid ionization chamber and alpha trace detection*.

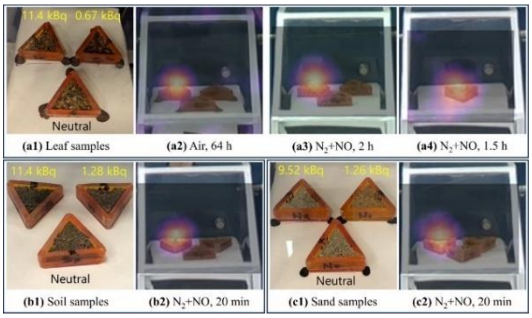

Fig. 5 *^{241}Am-spiked leaves, soil and sand environmental samples prepared and characterized by IFIN-HH, and processed radioluminescence images measured by the UVFS lens system in an airtight chamber*.

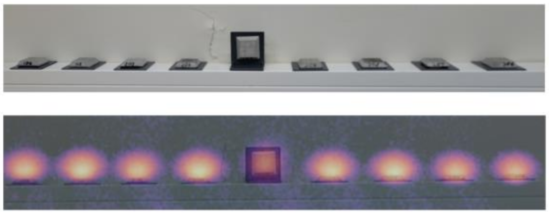

Fig. 6 (a) *Photos of nine 241Am-spiked concrete samples prepared and characterized by LUH.* **(b)** *Processed radioluminescence images obtained by the UVFS lens system.*

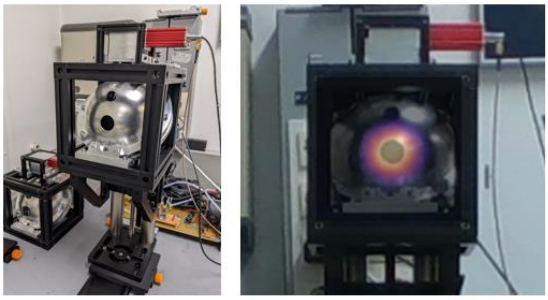

Fig. 7 *(Left) Radiance standards based on integrating spheres, designed and developed by PTB with the help of BFKH. (Right) Mapping of simulated radioluminescence by the low-photon flux radiance standard at 260 nm measured by the UVFS detection system.*

Technical information on the standards preparation and characterization can be found in:

[3] A. Klose, M. Luchkov, V. Dangendorf, F. Krasniqi, A. Lehnert, C. Walther, *On the way to remote sensing of alpha radiation: radioluminescence of pitchblende samples*, Journal of Radioanalytical and Nuclear Chemistry 2022, https://doi.org/10.1007/s10967-022-08540-6

[4] M. Luchkov, C. Olaru, I. Lalau, M. Zadehrafi, I. R. Nikolényi, Z. Gémesi, M.-R. Ioan, F. Krasniqi, *Radioluminescence mapping of ^{241}Am-doped environmental samples and nuclear materials*, Journal of Radioanalytical and Nuclear Chemistry (2023), Accepted.

[5] F. S. Krasniqi, R. D. Taubert, S. Röttger, M. Luchkov, F. Mertes, A. Honig, C. Baltruschat, V. Dangendorf, U. Giesen, *A calibration methodology for the novel radioluminescence detector systems*, submitted to Nuclear Instruments and Methods in Physics Research Section A, https://doi.org/10.7795/EMPIR.19ENV02.PA.20231027

Mapping of alpha contaminations in the environment using UAVs

UPC with the help of PTB has developed an UAMS which integrates an unmanned aircraft system (UAS) from the UPC fleet (DJI Matrice 600 Pro) with a Fresnel lens-based detection system to scan and obtain a map of the contaminated area. The UAMS hardware uses the RIMASpec software architecture developed by the UPC, which allows the real-time viewing of alpha contaminations.

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a)
b)

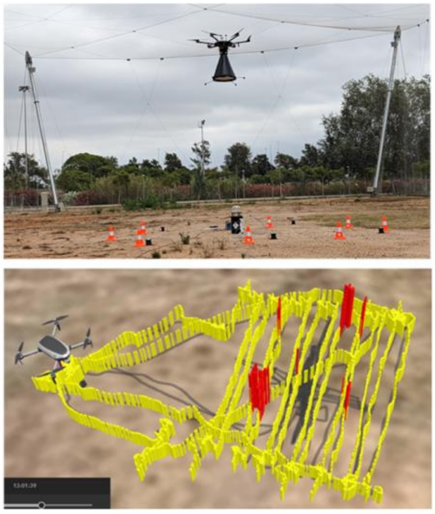

Fig. 8 *Flight performed with 5 LEDs and an americium source.* ***(a)*** *UAMS during the flight at the Drone Research Laboratory (DroneLab) of the Technical University of Catalonia (UPC).* ***(b)*** *Radioluminescence mapping via RIMASpec. The colour map is set such as the yellow colour (background) is set to 20 s^{-1} and the red colour shows the count rate of 50 s^{-1} or more, with intermediate count rate values having a colour between yellow and red*.

To the best of authors' knowledge (see Ref. 2), the results presented in Fig. 8 demonstrate for the first time remote detection of alpha particles from an UAS. The described prototype system, with certain operational improvements, can be used to assess contaminated areas without the need to put first responders at risk.

Details on the UAMS can be found in

[2] Royo, P.; Vargas, A.; Colls, T.G.; Saiz, D.; Pichel Carrera, J.; Rabago, D.; Duch, M.A.; Grossi, C.; Luchkov, M.; Dangendorf, V.; Krasniqi, F. Mapping of Alpha-Emitting Radionuclides in the Environment Using an Unmanned Aircraft System. Submitted to Remote Sensing. Preprints 2023, 2023101698. https://doi.org/10.20944/preprints202310.1698.v1

Feasibility study for a laser-induced fluorescence spectroscopic method for the detection of alpha emitters

TAU identified and ranked the most suitable transitions in N_2 molecules and N_2^+ ions for laser-induced fluorescence (A, B, C, D, and X denote molecular states). Optical re-excitation of some transitions may be possible and would enhance the radioluminescence intensity to overcome daylight measurement challenges. To determine possible transition for re-excitation TAU has developed a rate-equation model for N_2 molecules and N_2^+ ions. Laboratory experiments indicate that laser-induced emission of nitrogen ions is not detectable at the nitrogen ion concentration of 10^8 ions/cm^3. The re-excitation and detection efficiency would be increased by one to two orders of magnitude by choosing a laser with a narrower linewidth and higher pulse energy. Narrower linewidth laser is absorbed more efficiently by the narrow spectral lines of nitrogen ions, and more pulse energy directly increases the amount of signal.

Website

More information on RemoteALPHA can be found at the website: https://remotealpha.drmr.nipne.ro/

The tab *Information* contains details on

- Events,
- Dissemination activities (conference presentation in pdf),
- Reports,
- Published papers (including articles in popular press), and
- Datasets (few will become active during the 1st week of November 2023).

Publications (peer-reviewed)

[1] M. Luchkov, V. Dangendorf, U. Giesen, F. Langner, C. Olaru, M. Zadehrafi, A. Klose, K. Kalmankoski, J. Sand, S. Ihantola, H. Toivonen, C. Walther, S. Röttger, M.-R. Ioan, J. Toivonen, F. S. Krasniqi, *Novel optical technologies for emergency preparedness and response: Mapping contaminations with alpha-emitting radionuclides*, Nuclear Inst. and Methods in Physics Research, A 1047 (2023) 167895, https://doi.org/10.1016/j.nima.2022.167895

[2] Royo, P.; Vargas, A.; Colls, T.G.; Saiz, D.; Pichel Carrera, J.; Rabago, D.; Duch, M.A.; Grossi, C.; Luchkov, M.; Dangendorf, V.; Krasniqi, F. Mapping of Alpha-Emitting Radionuclides in the Environment Using an Unmanned Aircraft System. Submitted to Remote Sensing. Preprints 2023, 2023101698. https://doi.org/10.20944/preprints202310.1698.v1

[3] A. Klose, M. Luchkov, V. Dangendorf, F. Krasniqi, A. Lehnert, C. Walther, *On the way to remote sensing of alpha radiation: radioluminescence of pitchblende samples*, Journal of Radioanalytical and Nuclear Chemistry 2022, https://doi.org/10.1007/s10967-022-08540-6

[4] M. Luchkov, C. Olaru, I. Lalau, M. Zadehrafi, I. R. Nikolényi, Z. Gémesi, M.-R.

Ioan, F. Krasniqi, *Radioluminescence mapping of ^{241}Am-doped environmental samples and nuclear materials*, Journal of Radioanalytical and Nuclear Chemistry (2023), DOI: 10.1007/s10967-023-09235-2

[5] F. S. Krasniqi, R. D. Taubert, S. Röttger, M. Luchkov, F. Mertes, A. Honig, C. Baltruschat, V. Dangendorf, U. Giesen, *A calibration methodology for the novel radioluminescence detector systems*, submitted to Nuclear Instruments and Methods in Physics Research Section A, https://doi.org/10.7795/EMPIR.19ENV02.PA.20231027

[6] I. Lalau and M.-R. Ioan, *Simulation of radioluminescence induced by alpha particles in the air by Monte Carlo method*, Ninth International Conference on Radiation in Various Fields of Research, June 2021. DOI:10.21175/RadProc.2021.07

[7] I. Lalau and M.-R. Ioan, *Modelling the radioluminescence of alpha particles in the air by the Monte Carlo method*, Ninth International Conference on Radiation in Various Fileds of Research, June 2021. https://doi.org/10.21175/rad.abstr.book.2021.30.6

[8] M. -R. Ioan, I. Radulescu, M. Zadehrafi, L. Tugulan and C. Barna, *Proiecte naționale și europene de metrologia radiațiilor, suport pentru implementarea Directivei 2013/59, în sănătate și protecția mediului*, SOCIETATEA ROMÂNĂ DE RADIOPROTECŢIE, CONFERINȚA NAȚIONALĂ ANIVERSARĂ A SOCIETĂȚII ROMÂNE DE RADIOPROTECȚIE – „SRRp-30", ISBN: 978-973-1985-64-0

[9] K. Manninen, Optical *Detection of Alpha Radiation in Daylight / Alfasäteilyn optinen havainnointi normaalivalaistuksessa*, Thesis (Tampere University, 2022), https://urn.fi/URN:NBN:fi:tuni-202206295906

[10] C. Olaru, M.-R. Ioan, M. Zadehrafi, *Modeling alpha particle-induced radioluminescence using GEANT4, Modeling alpha particle-induced radioluminescence using GEANT4*, Romanian Journal of Physics (2023), Accepted; https://doi.org/10.48550/arXiv.2310.14601

[11] D. Taubert, R. D. Taubert, M. Luchkov, P. Gál, M.-R. Ioan, and F. Krasniqi. *Design and Characterisation of a Low-Photon Flux UV-Radiance Standard for the Calibration of Radioluminescence Detection Systems*. Submitted to: Journal of Physics: Conference Series, 15th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2023).

Open Access Datasets

Description/title of dataset	D.O.I. of dataset (if available) or other identifier	Name of repository used	D.O.I. of linked publication (if applicable)
Mapping contaminations with alpha emitting radionuclides	https://oar.ptb.de/resources/show/10.7795/720.20231026A (DOI: 10.7795/720.20231026A)	PTB Repositoy	https://doi.org/10.1016/j.nima.2022.167895
Radioluminescence mapping of environmental samples and nuclear materials	https://oar.ptb.de/resources/show/10.7795/720.20231026B (DOI: 10.7795/720.20231026B)	PTB Repositoy	DOI: 10.1007/s10967-023-09235-2
New calibration methodologies for radioluminescence detectors	https://oar.ptb.de/resources/show/10.7795/720.20231026C (DOI: 10.7795/720.20231026C)	PTB Repositoy	https://doi.org/10.7795/EMPIR.19ENV02.PA.20231027

Radioluminescence mapping of pitchblende samples	https://oar.ptb.de/resources/show/10.7795/720.20231026D (DOI: 10.7795/720.20231026D)	PTB Repositoy	https://doi.org/10.1007/s10967-022-08540-6
Studying americium spiked concrete samples recovery with GIC	https://oar.ptb.de/resources/show/10.7795/720.20231026E (DOI: 10.7795/720.20231026E)	PTB Repositoy	
Studying soil plant activity DroneLab Spain	https://oar.ptb.de/resources/show/10.7795/720.20231026F (DOI: 10.7795/720.20231026F)	PTB Repositoy	
Determination of the self-absorption of the Mylar cover foil at the Radiation Physics Laboratory of BFKH	DOI: 10.5281/zenodo.10021253	Zenodo	
Stability Measurement of a 340 nm UV Source at the Optical Laboratory of BFKH	DOI: 10.5281/zenodo.10021149	Zenodo	
19ENV02 RemoteALPHA: Development of a 3 UV-PMT coincidence system and experiments with environmental samples	https://doi.org/10.5281/zenodo.10033261	Zenodo	
19ENV02 RemoteALPHA: The GEANT4 files for modeling alpha particle-induced radioluminescence	https://doi.org/10.5281/zenodo.10032686	Zenodo	https://doi.org/10.48550/arXiv.2310.14601

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