PREPAREDNESS

Metrology for mobile detection of ionising radiation following a nuclear or radiological incident.

EURAMET

Publishable Summary for 16ENV04 Preparedness Metrology for mobile detection of ionising radiation following a nuclear or radiological incident

Overview

The protection of the public against ionising radiation and radioactive contaminations caused by nuclear or other radiologically relevant incidents or accidents (i.e. events), including terrorist attacks, is of major importance and may affect thousands of people. Following a radiological event, radiation protection authorities and other decision makers need quick and credible information on affected areas. Therefore, this project has developed reliable instrumentation and methods needed in the field of preparedness, so that correct decisions on countermeasures will be possible. New measuring devices and methods have been developed to quickly gather quantitative data on contaminated areas and dose rate levels by aerial measurements, and to analyse contamination of the air by flexible transportable systems. In addition, improved methods for long-term monitoring of contaminated areas using passive dosimetry systems were investigated. Finally, the feasibility to use dose rate values provided by non-governmental dosimetry networks has been studied. The results of this project are relevant for the protection of the public against dangers arising from ionising radiation during and in the aftermath of a nuclear or radiological event.

Need

Following a nuclear or radiological event, fast and appropriate radiation protection measures, based on reliable radiological data, are of high priority for decision makers worldwide. The nuclear accidents in Chernobyl (1986) and Fukushima (2011) are major examples where such protection measures were crucial. But also, several minor accidents and incidents caused severe problems, e.g. the Tokaimura accident (1999). According to the IAEA Safety Standard No. GSR Part 7 'Preparedness and Response for a Nuclear or Radiological Emergency', all safety and security measures have one common aim: to protect human life and health, and the environment. It also emphasises the importance of adequate protective measures in the aftermath of nuclear and radiological emergencies. Reliable radiological data, available at the earliest possible stage, are a prerequisite for protecting people effectively from such unexpected but potentially highly dangerous events.

In the immediate vicinity of a nuclear or radiological accident, as well as in case of large-area ground contaminations, monitoring by unmanned airborne monitoring systems, consisting of unmanned aerial vehicles (UAVs) with spectrometric detectors, are the best solution to protect operators and early responders against contaminations and irradiation. However, advanced calibration procedures based on reference materials and standard radionuclide sources must be elaborated for these systems and verified by Monte Carlo simulations. For airborne radioactivity monitoring, transportable field stations equipped with high-resolution spectrometric detectors and appropriate shielding are needed to allow the measurement of radioactivity concentration levels in affected areas.

During a large-scale nuclear or radiological emergency with the release of a radioactive plume to the atmosphere, the levels of ambient dose equivalent rate and activity concentrations provide essential information about the progression of the radioactive cloud. This information is important for decision makers to take timely and adequate countermeasures to protect the members of the public against the dangers of ionising radiation.

After a major release of radionuclides, a short-term decontamination may not be possible. Hence, concepts for long-term measurements needed to be developed. Metrologically sound data was needed in this field too because decisions on e.g. decontamination measures or the re-opening of restricted areas are of crucial importance. Therefore, passive dosemeters were studied in terms of their suitability for this purpose.

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Objectives

The overall objective of this project was the establishment of a metrological basis to support adequate protective measures in the aftermath of nuclear and radiological emergencies. To achieve this, the specific objectives of this project were:

1. To develop unmanned aerial detection systems installed on aerial vehicles[1] and helicopters for the remote measurement of dose rates and radioactivity concentrations. In addition, to establish novel methods applicable to core and remote areas of a nuclear or radiological incident for air-based radiological measurements including dose rates, radioactivity concentrations, traceable calibrations for the determination of ground surface activities and interpretation methodologies for rotary-wing unmanned airborne monitoring system or helicopter based radiological measurements.
2. To develop transportable air-sampling systems for immediate information on radioactive contamination levels in air. This included generating industry appropriate pre-production models of modular and portable air-sampling systems based on gamma spectrometric detectors that can be quickly transported to places of interest.
3. To investigate the metrological relevance of 'crowd sourced monitoring' data on dose rates and provide recommendations on the usability of such data. In addition, to develop handy detector systems with the potential to be used as dose rate measuring instruments in governmental and non-governmental applications.
4. To establish stable and reproducible procedures to measure ambient dose equivalent rates using passive dosimetry in order to harmonise passive dosimetry for environmental radiation monitoring across Europe.
5. To facilitate the take-up of the technology and measurement infrastructure developed in the project by the measurement supply chain (instrument manufacturers, accredited laboratories), standards developing organisations (ISO, IEC) and end users (national nuclear regulatory bodies, decision/policy makers e.g. IAEA, European Community Urgent Radiological Information Exchange (ECURIE), OECD/NEA, EURADOS, UNEP, WHO, WMO).

Progress beyond the state of the art

Unmanned aerial detection systems

Prior to the start of this project, gamma-ray pulse height spectra were collected in flight using NaI-scintillation detectors and HPGe detectors carried mainly by manned helicopters and aircrafts. The results reported were typically qualitative which means that radionuclide concentrations on the ground were investigated but without absolute calibration. The same was true for airborne dose rate measurements.

In this project, however, a sound interpretation of radiological data measured from unmanned aircraft systems has been achieved based on several different approaches. Various spectrometric systems were mounted on unmanned aerial vehicles so that the spectrometric detectors could be calibrated in flight, and their performance could be tested systematically under real field conditions [1], [2], [3]. The flights were made at dedicated aerial test sites (aerodromes for drones), which were prepared with artificial radioactive sources for traceable measurements. Hence, procedures for calibrating unmanned aerial monitoring systems for radiation emergency situations have been developed. These procedures are based on performance studies and traceable laboratory calibrations of the detectors and are supported by MC simulations. New unmanned aerial detection systems were designed and are prepared for serial production, realizing novel concepts in ground radioactivity monitoring for nuclear or radiological emergency preparedness and response.

Transportable air-sampling systems

Mobile systems with on-line measurement capability have been developed that can be easily and timely transferred to areas of interest, especially contaminated zones or other places where an incident happened. Consequently, in this project three industrial pre-production transportable air sampling systems were produced and tested in cooperation with industrial partners. The new transportable air-sampling systems have been prepared for industrial production, realising novel concepts, e.g. online measurements using transportable systems for radioactivity monitoring in air under harsh emergency situations.

[1] In the public, multi-rotor aerial vehicles are often called 'drones'.

Non-governmental networks

Numerous investigations into a variety of dose “Measuring Instruments used in Non-governmental Networks” (MINNs), which appeared on the market after the Fukushima Daiichi Nuclear Power Plant (NPP) accidents and which are intended to be used by laypersons in citizen science initiatives, were conducted in reference facilities in order to investigate whether such non-governmental networks could serve as a reliable source of dose rate information for the support of decision makers and how such data could be rated in the future in case of nuclear or radiological emergencies. The metrological properties of 16 different MINN systems (4 detectors each) were investigated. The publication of the results of these investigations can also give guidance to MINN-manufacturers on how to develop metrologically sound non-governmental dosimetry systems [4], [5].

Passive dosimetry for environmental radiation monitoring

The drawn-up recommendations and guidelines will serve as a basis for the development of international standards. For nuclear and radiological incidents, the feasibility of a follow-up surveillance using passive dosemeters was investigated. Detailed metrological studies and a comprehensive intercomparison exercise were performed for this purpose [6], [7], [8].

Results

Unmanned aerial vehicles for dose rate and activity concentration measurements

This project established traceable calibration procedures, which allow a quantitative interpretation of measured data. Basic technical information and experiences were collected which are needed for the UAV based determination of dose rates (at flight altitudes and on ground) as well as ground level activity concentrations [1], [2], [3]. The UAVs were selected based on their flight capabilities. Different spectrometric detectors were adapted and mounted on drones and tested in various flight campaigns at dedicated aerial test sites using artificial radioactive reference sources placed on the ground: i) a HPGe detector for airborne spectrometry was mounted on an unmanned petrol helicopter with a high pay-load, ii) a detection system based on a $CeBr_3$ medium size scintillator crystal was adapted and mounted on a multi-rotor UAV, iii) a NaI medium size scintillator crystal was mounted on a multirotor UAV, iv) a small CZT semiconductor detector was mounted on a small multirotor UAV, v) a Kromek Sigma50 CsI-detector was mounted on a multi-rotor UAV, and vi) a hotspot localizer was upgraded for installing in a multi-rotor UAV by using a gimbal system.

A review study was carried out and the most convenient aerial sites were selected: i) Mollerussa Aerial Site (Spain), ii) Barcelona Drone Center (Spain) iii) naturally enhanced radioactivity region in Seelingstädt (Thuringia, Germany) and iv) Vyškov – Military Exercise Area (TPC-3)- (University of Defence, Czech Republic). Unfortunately, due to the Covid-19 pandemic, the latter comparison campaign had to be cancelled.

Flights with small and medium size airborne spectrometers were carried out in a comparison campaign using a calibrated Cs-137-point source at the Mollerussa Aerial Site (Spain). UPC organized this first exercise campaign in September 2019 with the participation of PTB, BfS, UPC and SCK·CEN (observer). Data measured by the participants were analysed and the results were submitted for publication [2].

The second campaign was carried out in Seelingstädt (Thuringia, Germany), at a former uranium mine area in March 2020 with the participation of BfS, PTB, SCK·CEN, UPC and the German federal Police as invited team. Flights over already covered and uncovered areas with enhanced uranium content in the soil and hidden point sources of Cs-137 and Co-60 were carried out during the campaign. The results achieved under flight conditions showed the complexity of the data that needs to be analysed in a real emergency situation. The information needed for data transmission during the flights was collected and exchanged between the partners.

The measurement campaigns in the Barcelona Drone Centre (Spain) were focused on the characterization of a source locator airborne detector. In addition, the locator system and the spectrometric system commonly used was presented and compared in a video that can be accessed via the link https://www.youtube.com/watch?v=IV45uvionKI&t=46s.

Finally, measurement campaigns to map the air concentration of special radionuclides were carried out by SCK·CEN: i) on November 20th 2018, a nuclear emergency exercise took place at the IRE (Institut National des Radioélements) in Fleurus. During this day, at IRE, normal isotope production was going on, which involves a routine release of Xe–isotopes through the 25 m high chimney, and ii) On the SCK premises, the BR1 reactor, when working, produces a rather constant Ar-41 source term during its operation time. The equipment for measuring the gamma radiation of Ar-41 from a UAS, in this case was a medium size CsIscintillation detector (Kromek Sigma50) further developed by SCK·CEN. It was noted that mapping the plume of an ongoing release with a source term that changes quickly in time was challenging.

Transportable air-sampling systems

Three transportable systems for the monitoring of gamma-ray emitting radioactivity in the air have been developed, calibrated and tested. Each system comprises of an air sampler and integrated gamma-ray spectrometer. These systems were designed to be rapidly deployed / re-deployed during the immediate and long-term response to a nuclear or radiological accident in order to obtain accurate information on activity concentrations in air, vital for the health of first responders, recovery operatives and the local public community. The first system, developed by Kromek and tested by NPL, is the QuantAir; a compact, hand-carriable device based on a coplanar grid CdZnTe radiation detector. The second system, developed and tested by JSI, is the MARE; a ruggedized system built into a flight case and based on a $LaBr_3$ radiation detector. The third system, a segmented, fully automatic air-sampler with remote access, has been developed and tested by Nuvia and CMI. This system is transportable by lorry or by helicopter and is based on a portable, electro-mechanically cooled high resolution HPGe radiation detector.

The Kromek QuantAir detector has been calibrated for measurement and quantification of ^{137}Cs. It was found that the QuantAir can measure an activity concentration of ^{137}Cs below its minimal derivable activity concentration (DAC)-value of 2000 Bq/m^3 within 1 min following a sampling period of 10 min, or within 10 min following a sampling period of 1 min. This result provides confidence that the QuantAir instrument is suitable for use by recovery workers operating in a contaminated environment following a nuclear or radiological incident.

The JSI MARE device has been upgraded to allow for easy control from a remote location to perform real-time analyses of the measured data and determine the absolute activity concentrations for the radioisotopes in air at the sampled locations. The device firmware has been upgraded with a radionuclide identification algorithm so that the device will be able to perform analyses of the data on its own and report results to a remote location/laboratory for further and more precise analyses. The pre-production model has been tested and validated in the laboratory by JSI with spiked filters provided by NPL.

The NUVIA/CMI instrument has been upgraded with regards to its usability and communication capability to allow operation as a remote station. This new system was tested to ensure the instrument is ready for deployment in an emergency situation. Special software was developed for the fully automatic operation, calibration and spectral evaluation, including the subtraction of natural radionuclide contributions from the measured gamma spectra. The system was tested in-situ at a site in the surroundings of the NPP Dukovany (CZ) and detection limits and uncertainties were determined. The system will be offered to the Preparedness end-user community (e.g. radiation protection institutes, nuclear facilities, waste repository agencies) as the NUVIA's catalogue product CEGAM (Continuous Environmental Gas Aerosol Monitor).

Based on the collective experience of developing and operating gamma-ray spectrometers integrated into air-monitoring systems, a guide to the laboratory and in-field calibration, validation and operation in routine and emergency scenarios has been produced. In addition, off-line laboratory measurements of alpha and beta emitters collected on filters is required to verify the on-line in-field results. For this purpose, new, rapid radiochemical methods were investigated and developed. EHU developed a method based on microwave acid digestion of the mineral residue and a radiochemical separation scheme which combines ion exchange chromatography for U and Pu and extraction chromatography for Am and Sr. The analytical method was validated with spiked samples and various reference mineral samples. PTB developed a method based on a fusion treatment of the mineral residue and a radiochemical separation scheme based entirely on extraction chromatography. NPL investigated the feasibility of ICP-MS as an alternative to the radiometric measurement techniques traditionally used for measuring alpha and beta emitters collected on air-filters. Additionally, the potential of the QQQ-ICP-MS system to perform elemental separations within its collision cell using O_2 as a collision gas was tested as an alternative to the time-consuming radiochemical separations.

Non-governmental networks

A comprehensive study was conducted on relatively simple, light-weighted and cheap dose rate Measurement Instruments used in Non-governmental dosimetry Networks (MINNs). A total amount of 64 detectors (16 different systems with 4 detectors, respectively) were tested by PTB, NPL, ENEA and VINCA. These laboratories provided irradiation facilities with dose rate values traceable to primary standards which allow testing at low dose rates and assessing the most relevant performance parameters (detector's inherent background, energy dependence and linearity of the response, the response to secondary cosmic radiation, the sensitivity to small changes of the dose rate, the stability of the detector's readings at various climatic conditions).

None of the tested MINNs fully conformed with the relevant dosimetric standards, and they all showed inferior performance when compared with dedicated dosimeters used by governmental networks [4]. Nevertheless, in case of a nuclear or radiological emergency, the large amount of data obtainable by non-governmental networks using MINNs could presumably be used to track radioactive plumes and to detect radioactive contaminations. However, such information based on non-governmental measurements using MINNs should be used with great precautions, considering the possibility of faked data or of malfunctioning MINNs. In addition, non-governmental networks are sometimes not able to keep the data up to date due to manual data up-load. Therefore, comparison with other nearby MINNs and with data from stationary or mobile governmental detector systems should be a prerequisite for an appropriate quality assurance.

Two new dose rate detectors were developed within the project: one based on a simplification of Kromek's D3S instrument, and one developed from scratch by BfS being medium cost, based on a PIN diode and using a Raspberry Pi like circuit board. Such detectors were tested at NPL and PTB reference sites respectively. Kromek, with support of NPL, determined the response of its CsI(Tl)-SiPM based detector allowing spectral dose to be calculated following the same fluence algorithms employed in the Kromek RayMon10 hand-held detector. Kromek and NPL assessed the validity of crowd sourced data produced by the dose rate detectors. Kromek developed a concept website (an HTML server software) for real-time sharing of dose rate readings. Kromek's final product will be offered for use in non-governmental radiological networks.

Passive dosimetry for environmental radiation monitoring

The basic properties of different passive area dosimetry systems were investigated [6]. The studies comprised the energy and angular dependency of the response of the detectors, their linearity in a wide range of doses, the accuracy of the calibration and the quantification of the overresponse to secondary cosmic radiation.

The performance of existing equipment and procedures used by European measuring bodies and services for environmental dose monitoring was investigated also using results from questionnaires and from former investigations by EURADOS. The results served as input for the development of recommendations which are based on the experimental investigations and on literature studies. In particular, conclusions were drawn with respect to the applicability of passive dosimetry systems for environmental radiation monitoring and especially for their use in the aftermath of a nuclear or radiological event. The uncertainties of ambient dose equivalent measurements using passive dosimetry systems at low dose levels, i.e. close to the natural radiation background, could be fairly high. A systemic study on these uncertainties and their main influencing parameters was performed and the results have been published in [7]. On the other hand, a very comprehensive intercomparison exercise with passive dose meters used for environmental radiation monitoring showed, that most of the 38 participating dosimetry services in Europe were able to provide results for exposure times of at least 6 months, that were within a range of +- 20 % relative to the reference dose value [8]. In addition, the feasibility of using radon-tight electret ion chambers for radiation monitoring of external gamma radiation in the natural environment was systematically investigated. Procedures were developed to measure mean ambient dose equivalent rates with such simple detectors. Especially at significantly enhanced dose rate levels the results achieved are promising. However, it is recommended to expose at least three to five detectors in parallel, as such a redundant measurement allows to identify and to exclude outliers that can happen, when using such simple devices [9].

Impact

To promote the uptake of the project's outputs, this was disseminated to a network of stakeholders and end-users, formally organised with the assistance of a Stakeholder Committee. Finally, the project had 11 collaborators and 29 other stakeholders from industry, universities, public research organisations, public bodies and NMIs/DIs. The results of this project have been disseminated to the interested community via presentations and open-access peer-reviewed publications. 56 presentations and posters were presented at international workshops and conferences on ionizing radiation monitoring, preparedness issues and related topics. The project's results are available on the project website. In addition, communities such as EURADOS and NERIS served as a platform to share results of this project with experts in related fields. Partners of the project are working in different advisory boards of various national radiation protection authorities, including ministries and other governmental institutions. Thereby, input has also been given directly to national governments in partnering countries.

Impact on industrial and other user communities

Reliable radiological data is of key importance for the European Data Exchange Platform (EURDEP). The feasibility to use non-governmental data, in addition to the data provided by the 5500 governmental stations, has been comprehensively investigated for the first time. Reliable radiological data will also strengthen the confidence and credibility of the public in the decisions of the legal authorities.

The development and test of radiation detection systems, together with good practice guides on the measurement of dose rates and radioactivity concentrations using measurement systems that have been developed in the project, are useful both for the metrological community working in this field and for end users (e.g. regulatory authorities, supervisory authorities, civil protection or official measuring bodies) and for manufacturers of dosemeters, contamination monitors or other radiation meters.

The two industrial partners of the project, Kromek and NUVIA, have developed UAV based spectrometry systems for the measurement of ground contaminations. In line with that, the company SwissDrones developing and producing UAVs has been adopting a method for monitoring radioactivity after a nuclear accident using HPGe detectors. Joint tests with CMI were performed in Switzerland and a joint product will be presented in the Czech Republic during an air-show, which will be organized by NUVIA and CMI as soon as reduced pandemic restrictions will allow it; presently envisaged for May 2022.

In collaboration with the Jozef Stefan Institute in Ljubljana, a real time detector for the localization of hotspots of gamma radiation (brand name “Gamma 4“) has been adapted to be operated on a Matrice 600 drone. Specific software was developed for this use and preliminarily tested. The final product should have been presented during a course and demo performance at the Barcelona drone Centre in June 2020 to stakeholders like the Spanish Nuclear Safety Council, Catalan Nuclear Safety Authority, Catalan Police, operators of NPPs, fire-fighters and military services. This course had to be replaced by an online-video presentation because of the corona pandemic.

Kromek Limited produced 10 units of a newly developed version of a dose rate detector based on a simplification of the existing D3S instrument. Kromek with support of NPL determined the response of the CsI(Tl)-SiPM based detector allowing spectral dose to be calculated following the same fluence algorithms employed in the Kromek RayMon10 hand-held detector. Kromek and NPL assessed the validity of crowd sourced data produced by the dose rate detectors. Kromek has developed a concept website (an HTML server software) for real-time sharing of dose rate readings. The final product will be offered for use in non-governmental radiological networks.

The NPP Dukovany (CZ) will use the data and experiences from the long-term monitoring of radioactivity in air by a modular and transportable air-sampling system developed in this project. The Slovenian NPP Krsko showed interest in the rapidly deployable spectrometric air-sampling system upgraded by JSI and NPL. The system was also presented to the US company F&J Specialty Products Inc. as a potential distributor.

Impact on the metrology and scientific communities

The progress in measurement technologies achieved in this project improved the early identification of affected areas, including identification of radionuclides, e.g. Cs-137, I-131, Ba-140, Ce-141, Ru-103 and Np-239 as well as the determination of contamination levels. The novel instrumentation is essential for a quick and adequate response from nuclear regulatory bodies and other decision makers, e.g. from local authorities or aid organisations, during and in the aftermath of a nuclear or radiological accident.

After establishing aerial calibration and test sites for airborne dosimetric and spectrometric instruments, standardised procedures became available for European measuring services and governmental bodies. In this scope of application, the verification of methods to measure absolute dose rates and activity concentrations on a metrological basis are a major step forward in quality assurance. In addition, the proposed harmonised procedures will result in a mutual recognition of calibrations, with transparency and significant cost saving for the customers. As a further direct impact of this project, more reliable dose values in routine monitoring using passive dosimetry systems should become available on a European scale. This and other goals of the project are in line with the policy of the EC DG ENER.

An intercomparison exercise with 760 passive dosemeters from 38 different dosimetry services in Europe was performed at various reference sites of PTB. Passive dose meters were exposed for six months to natural radiation and some of these systems also to artificial radiation fields of Cs-137 as well as to pure secondary cosmic radiation in order to determine the various response factors and the sensitivity of the systems to low doses and to small dose rates variations. The information gained from the systems is of key importance for the quality assurance of various dosimetry services. The published results [8] show that most dosimetry services are able to measure typical free field annual dose values with reasonably small uncertainties (less than 20 %). In a few cases, however, the measurements based on thermoluminescence dosimetry detectors (TLDs) failed. The intercomparison gave the operators of such TLD systems the chance of an improved understanding of their methods and thereby helped to improve their performance.

Impact on relevant standards

The project also aimed at an international harmonisation by providing guidance for stakeholders and by providing input to international standardisation bodies (ISO, IEC), as far as nuclear and radiological emergency preparedness is concerned. The project will help to fulfil the IAEA requirements listed in the Convention on *Early Notification of a Nuclear Accident and in the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency* of the European Commission.

Members of the consortium are involved in the following committees: ISO/TC 85 (Nuclear Energy), IEC/TC 45 (Nuclear Instrumentation), EURAMET TC-IR (Technical Committee for Ionizing Radiation), ICRM (Gamma and Beta Spectrometry WG, Alpha Spectrometry WG and Low Level WG) and BIPM CCRI I and II. This enabled the direct dissemination of the harmonised procedures and methods developed in this project to European and international standardisation committees and working groups.

The project was presented to ISO/TC 147 (Water quality, radioactivity), ISO/TC 85 (Nuclear energy, nuclear technologies and radiological protection), IEC/TC 45 (Nuclear instrumentation), CENELEC/TC 45B (Radiation protection instrumentation), ICRM WG Gamma Spectrometry and EURAMET TC-IR.

Longer-term economic, social and environmental impacts

The development of radiation detection systems operated on drones and other unmanned aerial vehicles, together with good practice guides on remote measurement of dose rates and radioactivity concentrations, will be very useful for end-users and manufacturers. After establishing aerial calibration and test sites for airborne dosimetric and spectrometric instruments, standardised procedures have become available for European measuring services and governmental bodies. Metrologically sound, i.e. accurate and traceable accidental and post-accidental measurements of area contaminations, airborne radioactivity concentrations and ambient dose equivalent rates, are a major step forward in quality assurance. This will contribute to increase the competitiveness of European manufacturers. In addition, harmonised procedures will result in a mutual recognition of calibrations, with transparency and significant cost saving for the customers.

After an event, all follow-up and countermeasures, especially on the prompt determination of exclusion zones and off-site emergency zones, will depend significantly on the metrological quality of data. The total economic costs of both the Chernobyl and the Fukushima accident are estimated at hundreds of billions of euros. The adoption of the project results and recommendations by national nuclear regulators and international standard bodies will contribute to considerable cost savings in case of future nuclear or radiological emergencies.

Additionally, environmental damages will be minimised by early and correct governmental decisions. This project will enable national regulators to judge emergency situations more appropriately. Therefore, the affected population will be protected more effectively against dangers arising from ionising radiation caused by a nuclear or radiological event and the public’s confidence in governmental decisions will be increased. For the latter, the investigation of non-governmental dose rate monitoring networks and the feasibility study of the potential use of non-governmental dose rate data provided by such networks, is of key importance for the credibility of governmental authorities and their decision and hence has a considerable social impact.

List of publications

[1] P. Royo, et al.: An Unmanned Aircraft System to Detect a Radiological Point Source Using RIMA Software Architecture. Remote Sensing 10(11), 1712, (2018). https://doi.org/10.3390/rs10111712

[2] A. Vargas et al.: Comparison of airborne radiation detectors carried by rotary-wing unmanned aerial systems. Radiation Measurements 145, 106595, (2021). https://doi.org/10.1016/j.radmeas.2021.106595 .

[3] M. Luchkov et al.: Unmanned aircraft-based gamma spectrometry system for radiological surveillance. SMSI 2020 peer-reviewed proceedings. https://doi:/10.5162/smsi.2020/E6.2

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[7] G. Iurlaro et al.: Study on the uncertainty of passive area dosimetry systems for environmental radiation monitoring in the framework of the EMPIR "Preparedness" project. Radiation Measurements. https://doi.org/10.1016/j.radmeas.2021.106543

[8] H. Dombrowski: Preparedness intercomparison of passive H*(10) area photon dosemeters in 2017/2018 (IC2017prep). Journal of Instrumentation. https://doi:10.1088/1748-0221/14/10/P10008

[9] F. Leontaris et al.: Procedures to measure mean ambient dose equivalent rates using electret ion chambers, Radiation Protection Dosimetry 190 (1), 6–21, (2020). https://doi.org/10.1093/rpd/ncaa061

The published papers are also available here: https://www.euramet.org/repository/research-publications-repository-link/

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 August 2017, 42 months</td></tr>
<tr><td colspan="3">Coordinator: Stefan Neumaier, PTB Tel: +49 – 531 592 6160 E-mail: stefan.neumaier@ptb.de
Project website address: www.preparedness-empir.eu</td></tr>
<tr><td>Internal Funded Partners:
1. PTB, Germany
2. CMI, Czech Republic
3. IRB, Croatia
4. JSI, Slovenia
5. NPL, United Kingdom
6. VINS, Serbia</td><td>External Funded Partners:
7. AUTH, Greece
8. BfS, Germany
9. CLOR, Poland
10. EHU, Spain
11. ENEA, Italy
12. JRC, European Commission
13. Kromek, United Kingdom
14. MTI, Czech Republic
15. NUVIA, Czech Republic
16. UPC, Spain</td><td>Unfunded Partners:
17.SCK•CEN, Belgium</td></tr>
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