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 will develop reliable instrumentation and methods needed in the field of preparedness, so that correct decisions on countermeasures will be possible. In addition, new measuring devices and methods will be 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. This project will further work on improved methods for long-term monitoring of contaminated areas and will investigate whether non-governmental networks could support official data or undermine it. The results of this project will enable an adequate response to the protection of the public and the environment 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 nuclear 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 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 to decision makers in order to be able 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 need to be developed. Metrologically sound data is needed in this field too because decisions on e.g. decontamination measures or the re-opening of restricted areas are of crucial importance. Passive dosemeters must therefore be studied in terms of their suitability for this purpose.

Objectives

The overall objective of this project is 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 are:

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 will include 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 the state of the art was that 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, without absolute calibration.

In the meantime, sound interpretation of measured data from unmanned aircraft systems has been achieved by several different approaches. Different spectrometric systems were mounted on unmanned airborne monitoring systems so that the detectors could be calibrated, and their performance be tested systematically. These investigations have been performed at dedicated aerial test sites which were prepared for traceable measurements. Hence, procedures to calibrate unmanned aerial monitoring systems for radiation emergency situations have been developed under real field conditions. These procedures are based on performance studies and traceable laboratory calibrations of the detectors and supported by MC simulations. New unmanned aerial detection systems are designed and being 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 have been developed and tested in cooperation with industrial partners. The new transportable air-sampling systems are prepared for industrial production, realising novel concepts, e.g. online measurements using transportable systems in radioactivity in air monitoring for nuclear or radiological emergency preparedness and response.

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

Non-governmental networks

Numerous measurements with non-governmental dosemeters have been performed in reference facilities in order to investigate whether non-governmental networks could serve as a reasonable source of useful information for the support of decision makers or how such data could be rated in the future. Guidance will be elaborated for further metrologically sound developments of non-governmental dosimetry systems.

Passive dosimetry for environmental radiation monitoring

Recommendations and guidelines will be prepared which will serve as a basis for the development of international standards. For nuclear and radiological incidents, the feasibility of follow-up surveillance using passive dosemeters has been investigated. Detailed metrological studies, especially a comprehensive intercomparison exercise was performed for this purpose.

Results

Unmanned aerial vehicles for dose rate and activity concentration measurements

This project will establish traceable calibration procedures so that a sound interpretation of measured data will become possible. Basic technical information has been collected which is needed for UAV based determination of activity concentration. The UAVs have been selected based on their flight capabilities and are ready for test flights. The information needed for data transmission was collected and exchanged between the partners. Investigations started at dedicated aerial test sites using radioactive reference sources. Different spectrometric detectors were adapted to be mounted on drones. First test flights have been performed and further flights are in preparation: i) A HPGe detector for airborne spectrometry to be mounted on a regular helicopter and on a high pay-load UAV, ii) a detection system based on a $CeBr_3$ adapted and mounted on a multi-rotor UAV, iii) a NaI to be mounted on the multirotor UAV, iv) the CZT has been mounted on small drones and tested, v) a Kromek Sigma50 CsI-detector has been attached to a mini PC and the investigation to mount it on a drone is ongoing, and vi) the upgrade of a hotspot localizer to be adapted for installing in a multi-rotor UAV is finished.

A review study has been carried out to identify the most convenient aerial sites for this project. The following sites were selected for the various comparison campaigns: i) Mollerussa Aerial Site (Spain), ii) naturally enhanced radioactivity region in Seelingstädt (Thuringia, Germany), and iii) Vyškov – Military Exercise Area (TPC-3)- NBC Defence Institute (University of Defence, Czech Republic).

Flights with small and medium size spectrometers have been carried out in a comparison campaign using a Cs-137-point source in the Mollerussa Aerial Site (Spain). UPC organized this first exercise campaign with the participation of PTB, BfS and SCK·CEN (observer). Data measured by the participants PTB, BfS and UPC are being analysed. In the Czech Republic, CMI will conduct a final “airshow” with point sources distributed in the Vyškov – Military Exercise Area close to Brno in May 2020. For UAV-measurement campaigns with extended sources, the enhanced natural radioactivity area in Thuringia (Germany) has been selected. The measurements will be carried out at characterized complex areas such as in Sorge-Settendorf (close to Seelingstädt), Thuringia, Germany by April 2020.

Finally, after the comparison campaigns are finished, a training course on the use of the drones together with a demo for the stakeholders in the Barcelona Drone Centre (Spain) will be organized.

Transportable air-sampling systems

In this project, several mobile systems are being developed that can be transferred easily and in a timely manner to areas of interest, especially to contaminated zones. A fully automated, remotely controlled modular high-sensitivity HPGe-based instrument has been successfully operated for several months at the laboratory, monitoring the surroundings of the NPP Dukovany site (Czech Republic). Field evaluation of the system is almost complete.

For another compact air-sampling system, capable of remotely measuring radioactivity in air in real-time based on a $CeBr_3$-detector, a communication protocol has been developed that enables remote operation. The protocol is currently being integrated into the NUVIA-GAMWIN spectral analysis software for in situ analysis. For the measurement of alpha and beta emitters, radiochemical methods are required. Two approaches for the rapid radiochemical separation of U, Pu, Am and Sr are being tested: one method is based in extraction chromatography and the other uses ion-exchange chromatography. Both methods use mineral samples to take matrix effects into account. Both procedures achieve the separation of the elements, although the recoveries in some cases are low. Therefore, the work is focused on increasing the recovery efficiencies while maintaining the short time duration for the analysis achieved so far. A method of analysis using ICP-MS is

being developed in parallel that does not require elemental separation prior to measurement. Early results have suggested that this technique has the potential to provide rapid, high-throughput analysis in emergency scenarios.

Non-governmental networks

The metrological relevance of data from non-governmental networks and the feasibility of including such data into those reported by governmental networks is being investigated. Non-governmental networks having measuring devices in Europe were identified. The systems and methods used by these networks to measure external ionising radiations and to map the data were examined on the basis of a web study and a questionnaire completed by network managers. A number of measuring devices from different suppliers, which are used by the networks to measure radioactivity, were selected and investigated under metrological aspects at the four institutions PTB, ENEA, VINS and NPL. At VINS and at PTB all devices have been tested for linearity and the energy dependence of the response using in-house gamma irradiation facilities. The intercomparison of all devices at unique PTB measurement sites – underground laboratory UDOII, floating platform at a lake and plume simulation irradiation facility – has been organized by PTB and successfully conducted in June 2019. In addition, climatic tests have been carried out. In parallel, the production of a newly developed dose rate detector has started, based on a simplification of Kromek's D3S instrument. Characterisation of different prototypes was performed at PTB reference sites.

Passive dosimetry

This project will establish stable and reproducible procedures to measure ambient dose equivalent rates using passive dosimetry in order to harmonize passive dosimetry for environmental radiation monitoring across Europe. A survey has been carried out to find standards or guideline on passive area dosimetry. However, scarce information was found due to a lack of published recommendations or standards. Furthermore, literature reviews have been carried out on passive dosimetry methods used in the aftermath of a radiological incident and on uncertainties of passive dosimetry systems.

A comprehensive intercomparison was performed to investigate the technical properties and typical precision of about 40 passive area dosimetry systems used by European dosimetry services. Reference values were measured and determined independently by the organiser. The complete data evaluation is finished, and the results are published in a comprehensive paper [2]. Minimum criteria for a successful participation were derived from an IEC standard on dosimetry.

To study the influence of detector holders on measured dosimetric data, a prototype of a new holder for TLD pellets was made and irradiations of this dosemeter type have been prepared. In addition, a literature study on the influence of 'site criteria' when using passive dosemeters in the aftermath of a radiological event has been made. Two measurement campaigns were performed to check whether the surrounding or height may have a significant influence on TLD measurements. Furthermore, the coordinated detailed investigation of 11 passive dosimetry systems in four different European irradiation facilities is ongoing. Several irradiations were carried out, e.g. to study the angular response of the systems.

The ability of radon-tight sealed electret ion chambers (EIC) to measure the ambient dose equivalent was examined by performing laboratory measurements and is currently being verified by environmental benchmark measurements. Electret ion chambers were irradiated at different photon energies and angles to obtain information on their energy response and angular response. Response factors, the electret's voltage drop due to irradiation in terms of H*(10), were deduced as function of the photon energy and angular response.

Impact

To promote the uptake of the project's outputs, the latter will be disseminated to a network of stakeholders and end-users, formally organised with the assistance of a Stakeholder Committee that has been established. The project has presently 7 collaborators and 27 other stakeholders from industry, universities, public research organisations, public bodies and NMIs/DIs.

The results of this project are being disseminated to the interested community via presentations and open-access peer-reviewed publications. Up to now, about 60 presentations and posters have been presented at international workshops and conferences. on ionizing radiation monitoring, preparedness issues and related topics. The project's results will be 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 this field.

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 been given to some national governments, e.g. in UK and Germany.

Impact on industrial and other user communities

Reliable radiological data is of key importance for the protection of the public against dangers arising from ionising radiation. In line with that, the relevance of dose rate data provided by non-governmental networks and the feasibility of using such data for the European Data Exchange Platform (EURDEP) has been comprehensively investigated for the first time. Reliable radiological data will allow appropriate countermeasures and reduce the risk of exaggerated actions and preventable follow-up costs. Appropriate and accurate radiological data on radiation levels and environmental damage will strengthen the confidence and credibility of the public in the decisions of the legal authorities.

Environmental damages will be minimised as a result of early and correct decisions of national nuclear regulators based on quick accurate data about ground surface contamination and airborne radioactivity levels. Timely data transfer between national regulators, in case of the release of radioactive material with trans-boundary implications, will be possible.

The development and test of radiation detection systems, together with a good practice guide on the measurement of dose rates and radioactivity concentrations using measurement systems that have been developed in the project, will be 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 have been performed in Switzerland and a joint product will be presented in May 2020 in the Czech Republic during an air-show.

In collaboration with the Jozef Stefan Institute in Ljubljana, a real time detector for the localization of hotspots of gamma radiation, developed by the Slovenian company AlSense (brand name „Gamma 4“) has been adapted to be operated on a Matrice 600 drone. Specific software is being developed for this use and will be preliminarily tested in March 2020. The final product will be presented during a course+demo 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.

Kromek Limited will produce at least 10 units of a newly developed version of a dose rate detector based on a simplification of the existing D3S instrument by Kromek. Kromek with support of NPL will determine 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 will assess the validity of crowd sourced data produced by the dose rate detectors. Kromek will develop a concept website (an HTML server software) for real-time sharing of dose rate readings. NPL and Kromek, with support of JRC, will complete an area-wide trial of the dose rate detector. 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 metrological and scientific communities

The progress in measurement technologies to be achieved in this project will improve 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. Such 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 will be 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 will be a major step forward in quality assurance. In addition, 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 will 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, was performed at various free field 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 Cs-137 as well as to pure secondary cosmic radiation in order to determine the various response factors and the sensitivity of the systems for low doses. The information gained from the systems is of key importance for the quality assurance of various dosimetry services. The published results [2] show that most dosimetry services are able to measure typical free field annual dose values with reasonably small uncertainties (about 10 %). In a few cases, however, the measurements based on thermoluminescence detectors 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 aims 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 ensures that the harmonised procedures and methods developed in this project will input directly into European and international standardisation.

So far, the project has been presented to ISO/TC 147 (Water quality, radioactivity), ISO/TC 85 (Nuclear energy, nuclear technologies and radiological protection), IEC/TC 45 (Nuclear instrumentation) and CENELEC/TC 45B (Radiation protection instrumentation).

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 will be 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, will be 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 a considerable cost saving.

Additionally, environmental damages will be minimised by early and correct governmental decisions. This project will enable national regulators to judge emergency situations more effectively. Therefore, the affected population will be protected more effectively against dangers arising from ionising radiation caused by a nuclear or radiological incident and the public 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] Royo, P., 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] Dombrowski, H.: 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.

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Internal Funded Partners: 1 PTB, Germany 2 CMI, Czech Republic 3 IRB, Croatia 4 JSI, Slovenia 5 NPL, United Kingdom 6 VINS, Serbia	External Funded Partners: 7 AUTH, Greece 8 BfS, Germany 9 CLOR, Poland 10 UPV/EHU, Spain 11 ENEA, Italy 12 JRC, European Commission 13 Kromek, United Kingdom 14 MTI, Czech Republic 15 NUVIA, Czech Republic 16 UPC, Spain	Unfunded Partners: 17 SCK•CEN, Belgium
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