Final Publishable JRP Summary for ENV57 MetroERM
Metrology for radiological early warning networks in Europe

Background

All European countries operate radiological early warning networks, and there are approximately 5500 monitoring stations currently active across Europe. Each monitoring station has a detector that is designed to detect radioactivity, and is linked to other stations, giving a live picture of the radioactivity level across large areas. This network of monitoring stations also provides information to enable European authorities to take appropriate action in the event of an adverse radiological event such as a nuclear accident.

However, many of these stations are based on simple detector designs which do not give the required level of radiological accuracy or detail, and thus further time-consuming data analysis is needed before any decisive action can be taken. To address this, this project will develop devices, new measurement techniques and methods to coordinate the radiological data collected from monitoring stations and to improve comparisons between different stations and networks. This will result in the faster and more coordinated response of European authorities in the event of a nuclear emergency.

Need for the project

During an airborne spread of nuclear contamination there is an urgent need for authorities to advise the population on the necessary precautions to stay safe. Recommendations from the European authorities could affect millions of people and may have severe economic and sociological consequences. Therefore, metrologically sound monitoring data of ambient dose rate and airborne radionuclide activity concentrations are a prerequisite for sound governmental decisions.

Safety standards for the health protection of the general public and workers against the dangers arising from ionising radiation are laid down in the Council Directive 2013/59/EURATOM and are mandatory for all EU Member States. In addition, as a direct consequence of the Chernobyl accident, information exchange in the event of a radiological emergency is implemented by the European Community Urgent Radiological Information Exchange System (ECURIE) operated by the European Commission. The 5500 dose rate monitoring stations operating in Europe provide hourly data transmission to the European Radiological Data Exchange Platform (EURDEP). In the case of a major radiological or nuclear accident, the information collected by EURDEP is used by the ECURIE system to initiate the responses of national authorities to radioactive contamination.

Networked radioactive contamination monitoring stations use two main types of detectors to determine if levels of airborne contamination are increasing as a result of a nuclear incident:

- Dose stations use passive devices to monitor for changes in the levels of radioactivity in the environment. Current dose meters are not capable of providing data on specific radionuclides, but recent developments in detector materials mean that modern instruments have the potential to provide this information.
- Airborne particulate samplers use a pump operating at high flow rates to suck air through a filter and trap airborne particles and often augment dose monitoring. After many hours of operation filters are removed for offsite analysis using chemical extraction techniques. The analysis methods used provide

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very accurate determinations of radioactive contamination but there is a significant delay in generating contamination level results.

All monitoring systems are affected by background effects such as radon, a naturally occurring radioactive gas, and cosmic interferences. New detector materials are becoming available but these need to be performance evaluated for dose and determination of radionuclides before they can be used in instruments and devices for active radioactive monitoring. The most accurate gamma radiation detectors HPGe (High Purity Germanium) have previously been restricted to laboratory conditions because they need to be cooled to liquid nitrogen temperatures. However, new refrigeration techniques can now be used which means the HPGe detectors can be deployed at monitoring stations.

Evaluation of these technologies is needed to provide cost effective recommendations for monitoring networks. Prior to this project, it was common to see uncertainties in radiological data of a factor of 2 or more. Therefore, automation, an upgrade to newer detector types, accurate characterisation and standardised operation procedures to ensure trans-boundary events are accurately recorded across the EU are needed in order to ensure that the best possible data is available to ECURIE.

Scientific and technical objectives

The aim of this project was to improve the metrological foundation of measurements for monitoring airborne radioactivity and to introduce pan-European harmonisation of data for input to monitoring networks, in particular EURDEP. The specific scientific and technological objectives were:

1. To develop novel and improved dosimetry systems for field station use to enable both the measurement of dose rates and the collection of nuclide-specific information. This includes comprehensive investigations of detector features and of spectra evaluation and deconvolution methods for new and improved measurement systems based on novel spectrometric detectors, for example those made from materials Lanthanum Bromide ($LaBr_3$), Cerium Bromide ($CeBr_3$), Strontium iodide (SrI_2) and Cadmium zinc telluride (CdZnTe);
2. To validate the new techniques for the calculation of dose rates and contamination levels from in-situ gamma spectra by Monte Carlo simulations;
3. To undertake enhanced on-site evaluation of the diverse environmental and radiological conditions and measurement techniques used at dosimetry monitoring stations;
4. To develop improved detection methods and data analyses techniques to enable accurate measurements of low activity concentrations of radon (in the range from 300 Bq m^{-3} and below). To develop and cross-check procedures for determining the blank indication of active radon monitors;
5. To develop novel and improved instrumentation for airborne radioactive particulate monitoring, for field deployment focused on mobile systems with real-time capability. This includes the development of novel traceable reference materials and standard sources (especially for large-area aerosol filters) and to perform proficiency tests and other comparison exercises to quantify airborne radioactivity measurements at field stations;
6. To validate the new techniques for use in the field with airborne radioactive particulate monitoring;
7. To validate common metrological procedures and to implement traceable calibrations of the detector systems used to supply data to central databases, especially EURDEP;
8. To develop new and more sophisticated data analysis protocols to enable rapid radiological information dissemination;
9. To install an underground low-dose (≤100 nSv h^{-1}) calibration facility at IFIN-HH at Slanic-Prahova in Romania and to validate it against PTB's globally unique UDO II underground facility.

Results

1) Novel and improved dosimetry systems for field station use, based on novel spectrometric detectors

The project developed novel and improved instrumentation and new measurement techniques and analysis methods for dosimetric field stations that are part of the radiological early warning networks in Europe. New

spectrometry systems which give nuclide specific data in addition to dose, based on scintillators (luminesces when excited by ionising radiation) such as $LaBr_3$, $CeBr_3$, SrI_2, and the semiconductor CdZnTe, were characterised experimentally, as well as by Monte Carlo theoretical simulations, to investigate their suitability as dosimeters. The performance of these novel systems was also tested under metrologically well-defined irradiation conditions, such as PTB's underground calibration facility. In addition, long term measurements of several months, under real weather conditions, were undertaken to study the feasibility of replacing conventional dose rate meters with spectro-dosimetry systems. The measurement results were compared with data derived from well characterised reference instruments.

The results demonstrate that the newly developed spectrometric (able to detect which radionuclide is present) detectors are suitable replacements for conventional dose rate meters, such as the Geiger Muller based dose rate meters presently used in most early warning networks. A change to these novel spectrometric detectors will bring a considerable increase in accuracy (from deviations of up to a factor of 2, improved to about 20 % or even less) of the data and will provide nuclide specific data. The properties of these newly developed spectro-dosemeters were described in publications (Radiation Physics and Chemistry, Journal of Environmental Radioactivity) which include recommendations how the novel instruments should be integrated into the existing infrastructure.

2) Validation of new spectrometric dose rate monitoring and contamination level estimation

Computer codes were compared to assess their ability to calculate H*(10) from spectra recorded with a $LaBr_3$ detector, where H*(10) represents the ambient dose equivalent, which is the absorbed dose equivalent at a depth of 10 mm in a virtual phantom (30 cm in diameter) of tissue equivalent material. Different methodologies were used for the calculation of H*(10). For the calculation of the detector response matrixes and the deconvolution of the measured energy loss spectra; a) the stripping method, b) the conversion factor method and c) a maximum entropy method were tested. Intercomparison exercises with 15 spectrometers of 5 project partners (PTB, UPC, BfS, EHU, CIEMAT) were performed to validate the newly developed equipment and procedures for dose rate monitoring and contamination level estimation.

3) On-site evaluation of conditions and techniques used at dosimetric monitoring stations

Correction for the influence of on-site characteristics on dose rate and nuclide specific data were developed and tested at monitoring stations. Recommendations for the selection of appropriate sites will soon be published and included improved site characteristics that will help to reduce the uncertainty of radiological data and hence contribute to the harmonisation of early warning networks. The contributions of the different background sources to measured dose rate values of spectrometric detectors were also determined, and background correction methods were developed. In addition, the results achieved were used to provide guidance for future developments of spectro-dosimetry systems and data treatment.

As a new approach in dose rate data analysis, signal processing methods were used to perform the time series (i.e. a set of data points in time order) analysis of long-term measurements. The results showed the typical fluctuations and their frequency, which can be used to calculate the typical uncertainties that occur during long-term dosimetric monitoring.

4) Improved detection methods and data analyses techniques for radon at low concentrations

Measurements with dose rate meters and spectrometers in known reference atmospheres of radon and its progeny (i.e. decay products of radon) in the radon-chamber of PTB revealed that low concentrations of radon in air (in the range from 300 Bq m^{-3} and below) may influence dose rate measurements, but only slightly. However, it was found that a part of the radon progeny may attach to the surface of detectors and, because of the close geometry, therefore influence measurement results. The potential influence of radon progeny on outdoor dose rate measurements was estimated and found to be small (in maximum a few nSv/h) for typical outdoor radon concentrations The influence of radon progeny on activity concentrations measured by air-samplers was also investigated and found to reduce the detection limits of some relevant radionuclides.

The time dependency of, radon progeny concentrations in air and of gamma dose rates as a function of the radon exhalation rates, were measured at CIEMAT´s free field reference site for radiological measurements (ESMERALDA) for continuous monitoring of airborne particulate radioactivity.

There is a memory effect of radon monitors which have been exposed to high levels of radon activity concentrations, called “blank indication”; i.e. the reading of the instrument, remaining even in the absence of any radon. This inherent background of the instrument, which has to be corrected for, especially when low radon concentrations have to be measured, is caused by internal contaminations of the instrument with long-lived radon progeny from former exposures to radon atmospheres. The blank indication of a radon monitor was investigated at radon chambers of ENEA and BfS. The results achieved by both institutes perfectly agree within the reported measurement uncertainties.

5) Novel and improved instrumentation for airborne radioactivity monitoring

This objective looked at improved airborne radioactivity monitoring. Novel spectrometric detectors with medium energy resolution, such as $LaBr_3$, $CeBr_3$ and SrI_2, were investigated experimentally as well as with Monte Carlo simulations for their capability to analyse activity concentrations of radioactive particulates collected at the filters of air samplers. A comprehensive comparison study of these novel spectrometers with HPGe (traditional lab based detectors), CdZnTe and CsI (both new types of scintillation detector) detectors was performed at NPL. The range of spectrometers selected represents new and emerging technologies for radionuclide detection.

The results allow national networks to decide which technology is most suitable for their individual needs, and how best to apply it. In addition, methods for a quick "quasi-online" data analysis were investigated.

Three novel prototypes of portable aerosol monitoring systems were set up by the following project partners:

- IJS developed a compact portable on-line aerosol sampling gamma spectrometry system based on a $CeBr_3$ detector. It is capable of providing continuous on-line low level airborne radioactive particulate monitoring for field station use via 3G communications network. The calibration of the device and successful performance tests (using filters of air samplers, artificially contaminated with radionuclides, called “spiked filters” as well as exposure to environments with elevated natural radon level) were performed at NPL. Further tests performed in a controlled radon environment at ENEA confirmed the suitability of the device as a portable on-line aerosol sampling gamma spectrometry system.
- CMI and a Researcher Excellence Grant (REG) at NUVIA designed and built a new modular air sampling system for in-field airborne radioactivity measurements. The system consists of a fully automated sample changer for filters, and a shielded mechanically cooled HPGe detector. Special software algorithms were successfully developed and tested for the subtraction of natural radionuclide contributions from the measured gamma-ray spectra and for the analysis of the results. The system can also be equipped with a transportable shielding against external radiation (which would affect measurements and reduce sensitivity).
- CIEMAT developed a continuous on-line air sampler, based on a continuous glass fibre filter and an electro-mechanically cooled HPGe detector. The system has been successfully running for six months at the CIEMAT field site, with periods of unattended operation. This extended dataset proved that the system was capable of reliably measuring key radionuclides with an improved detection limit.

In order to perform proficiency tests and other comparison exercises to quantify airborne radioactivity measurements at field stations, novel traceable reference materials and standard sources for airborne radioactive particulate monitoring were developed and tested. JRC organised a laboratory comparison exercise of air-sampling systems aimed at the operators of European national monitoring networks for the detection of airborne radioactive contamination both for routine and emergency response. JRC prepared spiked filter sources for the comparison and despatched them to the participants. 66 laboratories from 29 countries participated in this intercomparison in spring 2016. All 66 participants reported valid results and in the majority of the cases these results were reliable (i.e. the differences from the reference values were within the ±20% range). Only the evaluation of the performance of the laboratories on ^{131}I showed unexpected issues (systematic underestimations of the ^{131}I-activity) which requires further investigations and appropriate precautions in case of a real emergency.

6) Validation of new techniques in airborne radioactivity monitoring

A method was developed for the subtraction of Monte Carlo simulated detector spectra of the natural background radioactivity from measured detector spectra. The aim of the method was to decrease the Minimum Detectable Activity of artificial radionuclides. After subtracting simulated spectra for all relevant

naturally occurring nuclides and an estimation of the background caused by cosmic rays, the final spectrum included only the contribution of un-subtracted radionuclides resulting in significantly reduced Minimum Detectable Activity values. Newly developed equipment and procedures in the field of airborne radioactivity measurements were tested at reference installations of the project partners. All three novel portable aerosol monitoring systems, described in objective 5, showed their capability to detect low activity concentrations of artificial radionuclides in air.

7) Common metrological procedures and implementation of traceable calibrations

Existing relevant standards, guidelines, operational recommendations and end-user responses to questionnaires developed by the project were used to develop common metrological procedures to be used for the harmonisation of radiological early warning networks in Europe. These were published in scientific journals and as online e-learning modules. In particular end-users such as BfS in Germany and PAA in Poland, spent significant efforts to improve the quality of their data by asking NMI's for traceable calibrations.

PTB evaluated the results of two intercomparisons of existing dosimeters used within current dosimetry network systems in European Member States, and novel spectrometers. Information on the traceability, calibration and sensitivity of the dosimetry systems to small dose rate changes has been used by the project to feed into harmonisation procedures.

The implementation of harmonised methods developed in this project will significantly reduce uncertainties in radiological data from typically a factor of 2 or more to a level of 30 % to 40 % for dosimetric data (under reference conditions) and to uncertainties of less than 20 % to 50 % for off-line air-sampling measurements of radioactivity for the most relevant radionuclides released during a nuclear power plant accident.

The traceability of calibrations of activity concentration measurements in air was also improved by this project, especially, by the interlaboratory comparison in objective 5. This is important as traceable calibrations and measurements are a prerequisite for the harmonisation of European early warning networks.

8) New and more sophisticated data analysis protocols

A time series of gamma dose rates, originally measured in the period 1988 to 2015 on the premises of the University of Thessaloniki in Greece (AUTH), and the different time variations found were attributed by a Researcher Excellence Grant REG(AUTH)) and the project to a variety of physical effects such as solar activity and soil humidity. This knowledge can be used by operators of dosimetric early warning networks to reduce uncertainties of dose rate measurements caused by such time variations of the natural background radiation.

In addition, a number of different databases were created which are able to store a large number of spectra provided by early warning network systems. This is especially important for the use of spectro-dosimetry systems and these databases have been tested in routine operation by several network operators, including BfS in Germany and IRSN in France. There is no final agreement of the best suited database and, hence, several different databases are presently in operation in Europe.

9) Underground low-dose calibration facility

A new low dose rate gamma-ray underground calibration facility was developed by the project. This facility is only the second in Europe, and considerably increases Europe's capacity for the calibration of dosimetry systems at low dose rates. This new calibration facility is at IFIN-HH's underground laboratory in the salt mine of Slanic Prahova, where the first measurements of dosimeters in a collimated beam at dose rates typical of that in the natural environment were performed.

Impact

This project has developed methods for the harmonisation of values of both dose rate and airborne radioactivity concentrations reported by early warning networks so that data related to the same transboundary event, measured by different networks using different detectors, are directly comparable. In future, this will allow consistent data collation and evaluation, which will enable reliable conclusions to be drawn by the responsible authorities. In addition, this project has developed new measurement techniques which allow both the calculation of dose rates and of contamination levels (i.e. nuclide specific information) at the same time. These systems will considerably increase the information content provided by early warning networks, in real-time.

Dissemination

A stakeholder committee was established with 29 members from early warning networks operators, radiation protection bodies, national nuclear authorities and standardisation bodies. Three stakeholder workshops were organised:

- PENELOPE/penEasy variance reduction techniques applied to environmental dosimetry, May 2016, Spain
- Measurement on simulated airbone particulates - 137 Cs in air filters: Workshop for the participants of the 2014 EC and the 2016 ENV57/MetroERM measurement comparisons, April 2016, Belgium
- Basics of gamma-ray spectrometry and analysis of air filters, April 2016, Belgium

The partners presented the work of the project with 35 presentations at international conferences such as EURADOS (European Radiation Dosimetry Group), Science and Technology, ENVIRA (International Conference on Environmental Radioactivity), IAEA (International Atomic Energy Agency), ICRM (International Committee for Radionuclide Metrology), and NRC9 (9th International Conference on Nuclear and Radiochemistry).

27 papers were published or have been approved for publication in peer-reviewed journals, such as the Journal of Instrumentation, Radiation Protection Dosimetry, Health Physics, Applied Radiation and Isotopes and Journal of Environmental Radioactivity.

The project also provided input to the UK Parliament Science and Technology Select Committee expert evidence session on UK's future preparedness efforts, focussing on the replacement of the conventional Geiger Mueller based dosemeters of UK's early warning network by spectro-dosemeters.

Presentations from the stakeholder workshops and links to conferences and publications can be found on the project webpage http://www.earlywarning-emrp.eu

Early impact

- Discussions are underway between project partner CMI and the physics department of the Czech Technical University in Prague regarding a collaboration in the development of the procedure for the dose rate calculation from the HPGe amplitude spectra (objective 5).
- REG(NUVIA) at Nuvia a.s. (an engineering and supply company providing devices and services in the field of nuclear power engineering, laboratory technology, software development, industrial automation and systems for ionising radiation detection) are manufacturing and intend to sell the modular portable system for monitoring airborne radioactivity based on the improved HPGe detector (objective 5).
- The continuous on-line particulate airborne monitoring system based on mechanically-cooled HPGe detector will be installed at CIEMAT'sreference station ESPERALDA as a part of the Spanish early warning network (objective 5).
- SCK-CEN (the Belgian nuclear research centre) is intending to use the aerosol monitoring system developed by IJS (objective 5).
- The German Federal Office for Radiation Protection (operator of the biggest dosimetric network in the world, with almost 2000 stations) are working with PTB and the Polish National Atomic Energy Agency (PAA) to implement the novel spectro-dosemeters developed within this project.
- A new low dose rate gamma-ray underground calibration facility at IFIN-HH's underground laboratory in the salt mine of Slanic Prahova has been developed and is already operational.

Contribution to Standards

Results from the project have been used to provide input to working group SC45B Radiation Protection Instrumentation of technical committee IEC TC45 Nuclear Instrumentation. The input was used for a draft documentary standard on radiation protection instrumentation: transportable, mobile or installed equipment to measure photon radiation for environmental monitoring.

The project partners also presented the project results or gave input to standards to CENELEC/TC45B Radiation protection instrumentation and EURAMET TC-IR Ionising radiation.

Potential future impact

Novel and improved instrumentation and new measurement techniques and analysis methods were developed by this project for the field stations in the radiological early warning networks in Europe. The project contributed to the improvement of the quality of dose rate and air borne radioactivity data derived from measurements, of some 5500 radiological early network stations in Europe. The metrological foundation and particularly, the traceability of measurements carried out at these stations was significantly improved, thus addressing the current and future harmonisation of European early warning networks.

After a radiological incident, improved accuracy in the determination of the extent of land contamination will help to reduce the area designated for exclusion and evacuation zones and will considerably reduce follow-up costs. The early estimation of the contamination of agricultural products will lead to swifter decisions on whether these goods need to be banned from markets. Reliable radiological data from routine measurements will also be vital for achieving credibility and acceptance of the use of nuclear installations in Europe.

List of Publications

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JRP-Coordinator: Dr. Stefan Neumaier, PTB, Germany Tel: +49 531 5926150, E-mail: stefan.neumaier@ptb.de JRP website address: http://www.earlywarning-emrp.eu	
JRP-Partners: JRP-Partner 1 PTB, Germany JRP-Partner 2 CEA, France JRP-Partner 3 CIEMAT, Spain JRP-Partner 4 CMI, Czech Republic JRP-Partner 5 ENEA, Italy JRP-Partner 6 IFIN-HH, Romania JRP-Partner 7 IJS, Slovenia	JRP-Partner 8 JRC, European Commission JRP-Partner 9 NPL, United Kingdom JRP-Partner 10 SCK•CEN, Belgium JRP-Partner 11 TAEK, Turkey JRP-Partner 12 BfS, Germany JRP-Partner 13 IRSN, France
REG-Researcher (associated Home Organisation):	Alexandros Clouvas AUTH, Greece
REG-Researcher (associated Home Organisation):	Arturo Vargas UPC, Spain
REG-Researcher (associated Home Organisation):	Ján Kubančák NUVIA, Czech Republic

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