Published JRP Summary Report for ENV57 MetroERM
Metrology for radiological early warning networks in Europe

Background
In the event of a major radiological emergency, the early and reliable knowledge of radioactivity concentrations in air, and subsequently the assessment of contamination levels of farmland and of dose rate levels in urban areas are of key importance for organising sound countermeasures for the protection of the public. Therefore, all European countries operate airborne radioactivity and dose rate early warning networks.

This project is developing 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. 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 totally 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.

Need for the project
The protection of citizens during a nuclear or radiological emergency is a high priority task for radiation protection authorities. The basic safety standards for the health protection of the general public and workers against the dangers arising from ionizing radiation are laid down in the Council Directive 96/29/EURATOM (2013/59/EURATOM is being implemented) and are mandatory for all EU Member States. In addition, as a direct consequence of the Chernobyl accident, the Council Decision 87/600/EURATOM requires information exchange in the event of a nuclear or radiological emergency and this is technically implemented by the European Community Urgent Radiological Information Exchange System (ECURIE).

There are about 5500 dose rate monitoring stations operational in Europe, which provide hourly data transmission to the European Radiological Data Exchange Platform (EURDEP) operated by the European Commission (EC). In case of a major radiological or nuclear accident, the information collected by EURDEP will be used by the ECURIE system to inform the EC, which will initiate responses of national authorities to trans-border radioactive contamination events.

However, only approximately 250 of the existing stations are capable of on-line particulate and/or gaseous airborne monitoring. In most cases, the collected data require further analysis as neither appropriate calibration nor corrections for the variety of detector types have been performed. Moreover, due to the simple detector designs the calibration at a single photon energy is insufficient to derive correct dose rate data, even if the energy and angular dependencies are known.

As the quantity of data submitted to the EURDEP database has increased, network operators and metrology institutes have become more aware of the impact of the current high uncertainties in the area dose rate and airborne radioactivity concentration measurement data. Action on a European scale is required to address the underlying measurement problems and to resolve it.

Scientific and technical objectives
The aim of this project is to improve the metrological foundation of measurements (devices and methods) for monitoring airborne radioactivity and to introduce pan-European harmonisation in data reliability for area dose rate measurements which are input to EURDEP and other monitoring networks. The specific scientific and technological objectives are:
1. To develop novel and improved instrumentation for field station use to enable both the measurement of dose rates and the collection of nuclide-specific information;

2. To undertake comprehensive scientific investigations of detector features and of spectra evaluation and deconvolution methods for new and improved measurement systems based on novel spectrometric detectors, e.g. LaBr₃, CeBr₃, SrI₂ and CdZnTe. In parallel, to develop improved instrumentation for the field of airborne radioactive particulate monitoring;

3. To validate common metrological procedures and to implement traceable calibrations of detector systems used to supply data to central databases, especially EURDEP;

4. To install an underground low-dose (≤100 nSv h⁻¹) calibration facility of IFIN-HH at Slanic-Prahova in Romania and to validate it against PTB’s globally unique UDO II underground facility;

5. To validate new detection principles such as the use of the new spectrometry systems for the calculation of dose rates and contamination levels from in-situ spectra by Monte Carlo simulations and bench mark experiments;

6. To undertake enhanced on-site evaluation of the diverse environmental and radiological conditions and measurement techniques used at monitoring stations (provision of background information on site conditions and scientific development of appropriate correction methods);

7. 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;

8. To develop 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 and dosimetry measurements at field stations;

9. To develop new and more sophisticated data analysis protocols to enable rapid information dissemination.

Expected results and potential impact

1) Novel and improved instrumentation for field station use

Within the project, novel and improved instrumentation and new measurement techniques and analysis methods will be developed for field stations of the radiological early warning networks in Europe.

In order to investigate and document the present state of the art, concerning data acquisition and evaluation, questionnaires were sent to the operators of European early warning networks. The answers to the questionnaires were analysed and the results are an important input for further investigations towards the harmonisation of data collation and evaluation by European radiological early warning networks. Furthermore, existing literature on this topic has been compiled, which can be a reference for the future.

2) New and improved measurement systems based on novel spectrometric detectors

Dose rate and contamination level monitoring:

New spectrometry systems, based on scintillators like LaBr₃, CeBr₃, SrI₂, have been characterised experimentally, as well as by various Monte Carlo (MC) simulations. The aim of using these spectrometry systems (also called “spectro-dosimetry systems”), is to derive nuclide specific information additionally to the determination of area dose rates from gamma ray spectra. Such systems may replace the mainly Geiger Muller based dose rate meters currently operated in the European early warning networks. In addition, spectrometric systems based on CdZnTe semiconductor detectors, have been developed.

The performance of the novel spectro-dosimetry systems has been tested under metrologically well-defined irradiation conditions, like e.g. in PTB’s underground calibration facility UDO II and in quasi isotropic irradiation fields in radon-progeny atmospheres at PTB’s former radon chamber. In addition, long term measurements of several month, under real weather conditions, were performed to study the feasibility to replace conventional dose rate meters by spectro-dosimetry systems. The measurement results were compared with data derived...
from well characterised reference instruments (e.g. high pressure ionisation chambers, particle detectors for secondary cosmic radiation and others) and the results and the achieved uncertainties have been compared.

The results achieved, impressively demonstrate the ability of the novel spectrometric detectors to replace conventional dose rate meters used in early warning networks. Such a modernization would be accompanied by a considerable increase of the accuracy of the data and its information content (nuclide specific data).

Airborne activity monitoring:

Similar to dose rate monitoring (see above), novel spectrometric detectors with medium energy resolution like LaBr₃, CeBr₃ and SrI₂ have been investigated experimentally as well as by various 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, CdZnTe and CsI detectors was performed by NPL. The range of spectrometers chosen represents the full breadth of the price-performance matrix. The results achieved allow national networks to decide which technology is suitable for their individual needs and how best to apply it. A second comparison study is under way to compare the performance of commercially available continuous air monitors that may be suitable for permanent or rapid deployment. In addition, methods for a quick "quasi-online" data analysis have been investigated.

As technical developments, three novel prototypes of portable aerosol monitoring systems have been established by the following MetroERM partners:

Institute Jožef Stefan (IJS): A compact portable on-line aerosol sampling gamma spectrometry was developed. The system incorporates a CeBr₃ scintillation detector positioned centrally within a concertinaed filter assembly and an improved high flow rate air pump. It provides continuous on-line low level airborne radioactive particulate monitoring for field station use via 3G network communications. The calibration of the device and performance tests (using spiked filters as well as exposure to environments with elevated natural radon level) were performed at the National Physical Laboratory (NPL).

CMI in cooperation with NUVIA: A new modular air sampling system for in-field airborne radioactivity measurements has been designed and an experimental device has been produced. The system consists of a fully automated sample changer for filters, and a shielded mechanically cooled HPGe detector. Special software is being developed for the subtraction of contributions of natural radionuclides to gamma-ray spectra for each measured filter. Control and operational software for CMI’s existing HPGe system was developed and tested including associated algorithms for the analysis of the results. The system can be equipped with a transportable shielding consisting of low-activity building materials.

CIEMAT: A continuous on-line air sampler, based on a continuous glass fibre filter and an electro-mechanically cooled HPGe detector, was implemented at CIEMAT’s free field reference site for radiological measurements.

3) Common metrological procedures and implementation of traceable calibrations

The metrological foundation and particularly the traceability of calibrations at low dose rates as well as of measurements of activity concentrations in air will be improved by this project. Traceable calibrations and measurements are a prerequisite for the harmonisation of the European early warning networks. The implementation of these 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 (at least 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.

For the stationary measurement of both environmental dose rates and alpha and beta particle emitting radionuclides in air dust, relevant standards, guidelines and operational recommendations were identified and collected. Procedures for dose rate and airborne radioactivity sampling and monitoring were documented. In addition, the evaluation of the response to the questionnaires concerning calibration and verification methods is used to support the development of common metrological procedures for the harmonization of radiological early warning networks in Europe.

PTB evaluated the results of the intercomparison of dosemeters used within dosimetry network systems in European Member States, after the intercomparison has been performed at PTB in June 2016. From this intercomparison, the basic metrological parameters of the dosemeters including information on the calibration
could be derived. In addition, the sensitivity of the dosimetry systems was examined so that conclusions can be drawn regarding the ability of the instruments to detect small changes of the dose rate.

In order to achieve traceability of IFIN-HH’s underground photon calibration facility (see subsection 4) to CEA’s primary standards, in a first step a commercial scintillation dose rate meter, with a very low (but positive) inherent background value was selected as a secondary standard. The inherent background was determined at the underground laboratory UDO II of PTB.

4) Underground low-dose calibration facility

The installation of a second low dose rate gamma-ray underground calibration facility in Europe will considerably increase the capacity for the investigation and calibration of dosimetry systems at low dose rates. The infrastructure of this facility at IFIN-HH’s underground laboratory in the salt mine of Slanic Prahova has been established. By using radioactive sources of different radionuclides, collimated photon radiation fields will be available for calibration purposes. A first set of such radionuclide sources has been produced by CEA and CMI and is now available at IFIN-HH.

5) Validation of new detection principles

There has been considerable progress in the field of Monte Carlo simulations: Detection forcing methods have been implemented in the Penelope software, and a new version of the DETEFF code, which is able to calculate the basic parameters for dose rate calculation from spectra, has been created and verified with very promising results. The enhanced Monte Carlo codes PENNELOPE and DEFF were used for various benchmark experiments. Both computer codes were compared regarding their ability to calculate the area dose (more precisely, the ambient dose-equivalent $H'(10)$) from spectra recorded with a LaBr₃ based detector. Reference values were derived from irradiations in different photon fields at the INTE-UPC secondary standard calibration laboratory. Different methodologies were used for the calculation of $H'(10)$: The stripping method and the conversion factor method (using PENNELOPE/ penEasy after subtracting the internal contamination) as well as MC procedures combined with a maximum entropy method (implemented in the code DET-H10), for the calculation of the detector response matrices and the deconvolution of the measured energy loss spectra.

A method has been developed for the subtraction of Monte Carlo simulated detector spectra of the natural background from measured detector spectra with the aim to decrease the minimum detectable activity (MDA) of artificial radionuclides. After subtracting simulated spectra for all relevant natural nuclides and an estimate of the background caused by cosmic rays, the final spectrum only includes the contribution of not subtracted radionuclides resulting in significantly reduced MDA values. Measurements have been made of very low level $^{137}$Cs contamination in order to test the new background correction method and work is ongoing to analyse the results.

A first intercomparison exercise of spectro-dosimetry systems was performed at the reference facilities for dosimetry at low dose rates at PTB. Important detector parameters derived from traceable measurements at different PTB facilities, especially at the underground calibration facility and at the secondary cosmic radiation field station available at a floating platform on a lake. Several partners and some stakeholders participated in this exercise. The results achieved will help to optimise the use of these new systems and to validate the methods of data evaluation developed.

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

It is an important aim of this project to develop scientific concepts to account for the influence of the various site-characteristics on dose rate and nuclide specific data. Methods for an appropriate correction of such data have been developed and tested at some representative locations of monitoring stations. Recommendations for the selection of appropriate sites for new monitoring stations (“site criteria”) shall be given to the network operators. Improved site characteristics will reduce uncertainties 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 have been determined and correction methods (to subtract the background) have been developed. The results achieved have been used to provide guidance values for an intercomparison exercise (section 5) and for future benchmark experiments.
In addition, signal processing methods were used to perform the time series analysis of long-term dose rate measurements. The results reveal the typical fluctuations and their frequency, which may serve to calculate typical uncertainties that occur during long-term dosimetric monitoring. A paper was published on the findings.

7) 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 in the radon-chamber of PTB revealed that low concentrations of radon in air may influence dose rate measurements only marginally. Nevertheless, it was found that a considerable part of the radon progeny may be attached to the surface of detectors and thereby, due to the close geometry, influenced measurement results. The potential influence of radon progeny on outdoor dose rate measurements was estimated and published in a peer reviewed paper. The influence of radon progeny on activity concentrations measured by air-samplers was also investigated.

The time dependency of soil radon concentrations, radon progeny concentration in air, gamma dose rates and radon exhalation rates, were measured at a dedicated installation. In addition to these measurements, MC simulations have been performed and the results compared with the experimental results.

A study was conducted to identify the influence of radon (gas and progeny) on the ambient dose equivalent rate measured at a reference station, where continuous measurements of the ambient dose equivalent rate combined with activity concentration measurements of radon gas and radon progeny as well as meteorological parameters have been collected. One result was that $H^*(10)$ and Rn progeny concentrations are correlated in rainless days. Highest correlations have been obtained when the atmospheric parameters vary smoothly due to the atmospheric stability. Furthermore, no seasonal variations have been found.

8) Novel traceable reference materials and standard sources

The responses to the questionnaire on requirements for reference materials were the basis to organise 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. About 60 institutions participated in this intercomparison in spring 2016. The results achieved will help to quantify airborne radioactive field station performance.

9) New and more sophisticated data analysis protocols

A time series of gamma dose rates, measured in the period 1988 - 2015, was analysed. Different periodicities were found and attributed to various physical effects. This knowledge shall be used to reduce uncertainties of dose rate measurements caused by time variations of the natural background radiation.

A database has been created which is 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. This database has been tested in routine operation by several network operators. The feedback of the operators will be used to optimize the database performance. A software tools shall be offered to the stakeholder community for data conversion and data exchange.

A Stakeholder Committee (SC) has been established with 29 members from early warning networks operators, radiation protection bodies, national nuclear authorities and standardisation bodies. The first stakeholder workshop was organised and held at the JRC Ispra in April 2017.

The partners have been disseminating the project’s results at international conferences such as EURADOS, Science and Technology, ENVIRA, IAEA, ICRM, and NRC9, which has resulted in 30 presentations, thus far. In addition, 10 papers have already been accepted or approved for publication in peer-reviewed journals, such as Journal of Instrumentation, Radiation Protection Dosimetry and Journal of Environmental Radioactivity. The workshop presentations and links to conferences and publications can be found on the project webpage http://www.earlywarning-emrp.eu.

The partners presented the project results or gave input to standards prepared by the IEC/TC45, CLC/TC45B technical committees, and EURAMET TC-IR.
This project is contributing to the improvement of the quality of dose rate and air borne radioactivity data derived from the measurements of some 5500 radiological early network stations in Europe. 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 the market. Reliable radiological data from routine measurements are also required for achieving credibility and acceptance of the use of nuclear installations by the public in Europe.

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