Publishable Summary for 17RPT01 DOSEtrace
Research capabilities for radiation protection dosimeters

Overview

Traceable dosimetry measurements are necessary for meeting the legal requirements of the EU Council Directive 2013/59/EURATOM. This project aimed to develop procedures for calibrating radiation protection dosimeters in various types of radiation protection beams, with a measurement uncertainty of ≤ 5 % (k=2). This was accomplished through further research on operational quantities for external radiation exposure and the development of secondary standards for eye lens dosimetry. In addition, all participating NMIs have prepared individual strategies for radiation protection metrology which were reviewed within the EURAMET community, in order to ensure a coordinated and optimised approach.

Need

Controlling the level of exposure to ionizing radiation for patients and individuals working in science, medicine or industry has been widely recognized as the most urgent need. Therefore, there was a demand for new and improved calibration services for operational radiation protection quantities, to ensure that the services provided fulfil the requirements of regulatory authorities.
The International Commission on Radiation Units and Measurements (ICRU) has defined four operational dose quantities for use in radiation measurements for external exposure that can assess the protection quantities. The operational quantities related to area monitoring are: ambient dose equivalent H*(10) and directional dose equivalent H'(0.07, Ω), and in terms of individual monitoring, the quantities are defined as: personal dose equivalent $H_p(10)$ for control of effective dose and personal dose equivalent $H_p(0.07)$ for control of skin dose. For the special case of controlling the dose to the lens of the eye the directional dose equivalent, H´(3,Ω), and personal dose equivalent $H_p(3)$ have been defined. Since protection quantities cannot be measured directly, operational quantities are used for monitoring external exposures instead.
Both theoretical and practical training courses were required to extend the capabilities of participating NMIs on calibrating radiation protection equipment at a secondary level, in order to ensure the stakeholders needs for traceable measurements of radiation protection quantities can be met. In addition, the obligations to legal metrology and the dissemination of the standards obtained, should lead to improved radiation protection.

Objectives

The overall aim of this project was to improve the capabilities of participating NMIs from emerging countries so that operational radiation protection quantities are traceable to the SI. The specific objectives of the project were:

1. To develop traceable measurement capabilities for operational radiation protection quantities, including the full characterisation of a measurement setup conversion procedure from air kerma (K_{air} kinetic energy released per unit mass) to ($H_p(0.07)$, $H_p(3)$, H_p (10), $H'(0.07)$, $H'(3)$, $H^*(10)$ operational quantities with an uncertainty of 5 % (k=2) or less. The applicable photon energy range and dose rate range are 5 keV to 7 MeV and 0.05 µSv/h to 100 Sv/h respectively.
2. To validate the developed measurement capabilities for operational radiation protection quantities, to ensure that within an applicable energy range, from 5 keV to 7 MeV and dose rates, 0.05 µSv/h to 100 Sv/h, the accuracy of the dose measurement under well-defined calibration conditions has to be at least 5 % (k=2), by organising and undertaking a intercomparison in dosimetry, including activities related to travelling standards, technical protocols, logistical provisions, and the evaluation of intercomparison results.
3. To develop and submit draft CMCs for the traceable calibration of dosimeters, thus proving the international equivalence of their measurement standards and the calibration and certificates that they issue.

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4. For each partner, to develop an individual strategy for the long-term operation of the capacity developed, including possible regulatory support, research collaborations, quality control, the quality management system and accreditation. They should also develop a strategy for offering calibration services from the established facilities to their own country and neighbouring countries. The individual strategies should be discussed within the consortium and with other EURAMET NMIs/DIs, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

Progress beyond the state of the art

Prior to the start of the project, there was limited accessibility to calibration services across Europe, and two partners (IMBiH and TAEK) were not able to provide such services. Both TAEK and IMBiH have now developed these services for calibrations in terms of radiation protection operational quantities. IMBiH validated those through bilateral intercomparison with IAEA. The quality management procedures used by other partners were reviewed by IRB, IMBiH, TAEK, EEAE, GUM, SMU and INM and recommendations on improvement and correction of specific components of calibration procedures, uncertainty budgets and calibration certificates have been given to participating laboratories to update and improve these procedures where it seemed necessary. The calibration service's needs of stakeholders have been identified and calibration procedures were revised accordingly, to include a full characterisation of measurement setup for the conversion from air kerma to the operational radiation protection quantities, which were integrated by all partners.

Services provided by most of the partners have been accredited/peer-reviewed according to new EN ISO/IEC 17025:2017. To validate the measurement capabilities developed during the project, an inter-comparison exercise was conducted. The results of the inter-comparison compared and validated the measurement capabilities of the participating laboratories, for radiation protection dosimeter calibrations, which led to improved radiation safety of workers and public, in particular the health protection of medical staff and of patients involved in diagnostic procedures thus improving the quality of life for these patients.

The procedure for submitting new or revised CMCs (Calibration and Measurement Capabilities) for the traceable calibration of dosimeters, have been documented and will be implemented by all. The approval process for an institute's CMCs, in the context of the Mutual Recognition Arrangement of the International Committee of Weights and Measures (CIPM MRA), is based on three criteria: participation in review and approved key and supplementary comparisons; operation of an appropriate and approved quality management system; and an international peer review (regional and inter regional) of claimed calibration and measurement capabilities. Within this framework, partners are now able to establish the degrees of equivalence of their national measurement standards as well as the mutual recognition of their calibration and measurement certificates. The new or revised CMC claims on radiation protection operational quantities will be submitted to BIPM CIPM MRA database, as agreed by the partners. Moreover, the knowledge gained led to improved measurement capabilities at the calibration laboratories and this, in turn, enabled improvements to be made in radiation safety and in the health protection of workers exposed to ionizing radiation as well as members of the public.

A strategy for offering calibration services from the established facilities did not exist. Some partners identified national strategies for providing calibration services for radiation protection, so during the project, individual strategies have been developed by each project partner and reviewed by other EURAMET NMIs/DIs as this will ensure a coordinated and optimised approach to the development of traceability in this field. These strategies will support the long-term operation of the CMCs developed in the project.

Results

Objective 1 - To develop traceable measurement capabilities for operational radiation protection quantities

The measurement capabilities and a unified code of practice were set up on the procedures for the measurement and secondary realisation of the operational radiation protection quantities.
This enabled harmonisation in the field, so the services provided are now comparable across Europe. To ensure a unified code of practice, a theoretical training course as well as the practical training course were successfully organised and held, so that all participating laboratories were familiarised with the common code of practice in accordance with ISO 4037:2019 and other relevant standards.
The lessons learned from the training actions have been shared with EURADOS and the new European Metrology Network for Radiation Protection to optimise their future training actions. One of the partners gave

a talk on ISO 4037 in the CCRI webinar. This webinar will become content of the IAEA training material and was included in an IAEA SSDL Newsletter 74 in 2021.
Additionally, a methodology for the design of an $H_p(3)$ secondary standard ionization chamber was developed in the project, with a focus on measurements at the radiology and nuclear medicine departments.

Three different prototypes of the $H_p(3)$ secondary standard ionization chamber were built and tested in laboratory conditions and two were tested also in work place fields. The advantage of a $H_p(3)$ secondary standard is that such ionization chamber will be calibrated in one reference beam quality and then used for all other energies, therefore no spectrometric measurements will be necessary. Since its design fulfils the ISO 4037-2 requirements for a secondary standard in respect to the energy dependence of the response, conversion coefficients from air kerma will also not be needed, as the measurement provides directly the $H_p(3)$ dose value. By using these new transfer instrument in laboratory, X-ray units can be calibrated in terms of $H_p(3)$ and these used for the calibration of eye lens dosimeters. For measurements in unknown radiation fields at workplaces in radiology and nuclear medicine departments, this new secondary standard chamber represent an easier and direct measurement method.

The development of the $H_p(3)$ chamber addressed and closed the gap of missing secondary standards for the operational quantities ($H_p(0.07)$, $H'(0.07)$, $H_p(3)$, $H'(3)$, $H_p(10)$, $H^*(10)$).

Calibration measurements with an uncertainty better than 5 % (k=2) were achieved and the results were validated through an intercomparison carried out in the project. The objective was fully achieved.

Objective 2 - To validate the developed measurement capabilities for operational radiation protection quantities within an applicable energy range

An extensive intercomparison exercise was organised, so the partners were able to compare and validate their measurement capabilities for the operational quantities identified, with the target uncertainty of 5% (k=2). The comparison included 5 radiation qualities: i) N-40 (mandatory), ii) N-100 (mandatory), iii) N-200 (additional), iv) S-Cs (mandatory), and v) S-Co (additional). In order to minimise the influence of dose rate, it was agreed for each laboratory to select a dose rate within the range between 0.5 mSv/h and 10 mSv/h (the recommended value was 6 mSv/h). The comparison was delayed due to the COVID-19 pandemic; however, the work was completed and Draft B report written before the end of the project.

One project partner was not able to participate in the official comparison, because of their status (not an NMI/DI and missing approval from their NMI). Due to technical problems, three laboratories didn't complete the measurements in all planned radiation qualities. Four values of dose rate were outside of the agreed range, but the comparison results for all of the measurements were acceptable. The target uncertainty was achieved by most laboratories in the comparison. Exceptions are the following: NSC IM for X-ray radiation qualities, TENMAK-NÜKEN for N-40, HMI/IRB-SSDL for S-Cs and S-Co, SMU for S-Co. In most cases the reason for higher uncertainty was calibration coefficient of the reference chamber, and the solution would be to reduce the traceability chain or to calibrate the chamber in a primary laboratory, which can provide lower uncertainty. Based on the new concept for CMC entries, a validation for the most challenging measurement condition, in this case lowest possible photon energy, is sufficient to cover the whole possible parameter range (from 5 keV to 7 MeV). Additionally, the used primary standard or method must be validated. This was fulfilled by the intercomparison in the selected measurement conditions.

Objective 3 - To develop and submit draft CMCs for the traceable calibration of dosimeters

A workshop was organised, and a procedure written to explain the approval process for CMCs to the consortium. The laboratories gained more information on three fundamental elements, required to the approval of CMCs such as: i) participation in reviewed and approved scientific comparisons, ii) operation of an appropriate and approved quality management system; iii) international peer-review (regional and inter-regional) of claimed calibration and measurement capabilities. This will lead to the approval of the institutes' CMCs, who will be able to request the BIPM to publish those CMCs in their database, after the end of the project.
Currently, several CMCs are in various stages of the publication process. In June 2020, project partner VINS published 18 CMC lines in the KCDB - 16 of which are in the field of radiation protection. Therefore, the objective to develop and submit draft CMCs for traceable calibration of radiation protection dosimeters has been fully met.

Objective 4 - Development of an individual strategy for the long-term operation of the capacity developed

All participating countries (Bosnia and Herzegovina, Poland, Croatia, Slovakia, Turkey, Serbia, Greece Republic of Moldova and Ukraine) prepared their individual strategies. Each one of the partners from these countries formulated a document with their long-term strategies for the development and operation of the calibration capacities in the field of radiation in terms of the operational quantities developed within the project. The strategies described the priorities of each country. National strategies are the first step towards national infrastructure strategy documents describing the existing national infrastructure in the metrology field. The individual strategies, for the long-term operation of the developed capacities, that were developed in the project will lead to the provision of calibration services from the established facilities and this will ensure the sustainability of the activities undertaken. The partners with less developed laboratories increased their research activities and established standards, methods and uncertainty budgets for the calibration of radiation protection dosimeters at an acceptable international level. The general structure of the strategy document was adopted by the project partners and individual national strategies have been developed. The strategy documents took into account developed and improved capacities, which completely meets the set objective to develop of individual strategies for the long-term operation of capacities developed.

Impact

Five presentations have been given at European and International conferences, such as the CROLAB international conference on laboratories competencies, held on October 2018, in Croatia. Also, 2 posters on the research capabilities of radiation protection dosimeters have been presented at relevant events (such as the 3rd International Conference on Dosimetry and its Application, held in May 2019, in Portugal). In addition, the partners have presented the project results to 4 key standardization bodies that are involved in the ionizing radiation field: EURAMET TC-IR, EURADOS, ISO TC/85 and IEC SC/45B. The project has successfully organized 3 workshops for various target audiences. Simulations of the secondary standard for eye lens dosimetry were demonstrated during the training course on *Metrology and Calibration in Radiation Protection*, in September 2018. In addition, the project partners have implemented three main approaches of the Monte Carlo simulations in order to design prototypes for a $H_p(3)$ standard ionization chamber. Three prototypes of $H_p(3)$ standard ionization chamber were constructed and tested in laboratory and workplace fields. This work is beneficial for calibration laboratories and will have a clear impact on industry. As such, the progress on the design of the prototypes was presented at each technical meeting, as well as, on the annual EURAMET Technical Committee meetings for ionizing radiation.

A supplementary "hands-on" training course on the practical aspects of calibrations was held in March-April 2019, opened new research possibilities that were conducted through Research Mobility Grants (RMGs) in the laboratories of PTB and IST. Two RMGs were performed during the lifetime of the project. One studied the type test requirements and methods valid for area workplace and environmental dosimeters and another studied the requirements of the new standard ISO 4037-1 with special attention to personal dose equivalent $H_p(10)$. Both RMGs' results are of importance for the international standardization in ISO and IEC. Also, the project website was updated regularly with progress overviews and highlights.

As a result of the work, 3 papers were prepared for submission to open-access peer-reviewed journals. One paper on the influence of photon spectra and long-term stability on calibration of field-class dosimeters, other on the interlaboratory comparison, and a third on the harmonisation of IEC type testing requirements and test methods for active area dosimeters in environmental monitoring.

Impact on industrial and other user communities

The knowledge transfer amongst the participating calibration laboratories, created impact by enabling greater confidence in the measurements of radiation protection quantities, through an improved accuracy of national reference standards for operational radiation protection quantities with an uncertainty of 5 % (k=2) or less. Partners are able to use the calibration techniques validated in the project, as well as, the measurement uncertainty which is a vital parameter in assessing the operation and quality of a measuring instrument, to provide traceable measurements. Therefore, the calibration laboratories have an increased capability (calibration, measurement, training, consultancy, etc.) and the metrology services provided are now more widely available, which will benefit the end-users.

Furthermore, the research on the secondary standard for eye lens dosimetry will provide industry with more information on the design of the standard ionization chamber based on measurements in standard laboratory radiation fields and in workplace radiation fields such as the ones found in radiology departments at hospitals. The uptake of the new measurement capabilities developed by the partners in this project is expected after the end of the project, after CMCs are published. Early uptake will also be important for the accredited laboratories and manufacturers of radiation protection devices as it will enable them to confidently demonstrate the performance of their products which will ensure that they remain internationally competitive. In addition, the project will contribute to improving the quality of the information available on the performance of different types of dosimeters. This information will be valuable for the manufacturers of these devices, in light of the improvements to the dosimeters characteristics thus ensuring their clients requirements are met.

IMBIH and TAEK started providing services for the calibration of radiation protection dosimeters using techniques developed in this project. TAEK completed the quality management system and was subject to an external audit. IMBiH also prepared a quality management system and will have this peer reviewed after the end of the project. Both partners made important improvement in terms of developing capacities and providing calibration services to end-users such as: industry, clinical centres, radiation protection centres, regulators, etc.

In order to ensure that the calibration capabilities are harmonized and recognized by external bodies and at the same level as in developed European countries, information on the performance of radiation protection devices will be included in a calibration certificate from a laboratory accredited in compliance with EN ISO/IEC 17025 [9] or in a certificate with a CIPM MRA logo representing published CMCs. As a result, the end users of these services will benefit most from the improved performance characteristics in light of increased quality of life due to better dose assessment in the workplace.

Impact on the metrology and scientific communities

The project improved collaborations between European NMIs which will decrease the gap between emerging NMIs and more experienced NMIs. To ensure the sustainability of the project's results, most of these countries developed long term strategies for the operation of the developed capacities and they drafted a report on their long term strategy for radiation protection dosimetry that responds to future challenges, for presentation to the metrology community.

The knowledge transfer between more experienced NMIs and emerging NMIs on developing and validating radiation protection operational quantities was beneficial for the metrological community on the whole. In particular, it had impact on laboratories that have either not established or needed to improve their traceability chain for radiation protection operational quantities.

Impact on relevant standards

This project has contributed towards the implementation of EU Council Directive 2013/59/EURATOM, by developing procedures for measuring and assessing human exposure and radioactive contamination of the environment as well as establishing methods for the regular calibration of measuring equipment. The project's outputs will directly influence the following international standards: ISO 29661, ISO 4037, ICRU51 and could help to revise CMCs according to the latest version of ICRU90. Research on the secondary standard for eye lens dosimetry, in both dosimetry laboratories and clinical environments, will provide new input to relevant standards (e.g. ISO 15382), on the correction factors for the discrepancies between laboratories and clinical environments. The research activities within both RMG will have impact on ISO 4037 and on the IEC type test standards for area and environmental dosemeters.

Longer-term economic, social and environmental impacts

The results of the project will have an indirect impact on environmental safety as environmental radiation monitoring measurements will be traceable and more reliable, and the road transport and import/export of radioactive materials at border crossings will be safer. The results of the project will also improve safety and the radiation protection of the general population via more reliable and traceable radiation/contamination measurements of the environment (soil, water, air).

Lower measurement uncertainty and unified calibration procedures will improve the performance of radiation protection monitoring equipment. This will result in a better quality of life for the general public and workers.

By improving radiation protection calibration services among the project partners' countries, this project will provide adequate dissemination of radiation protection operational quantities. Moreover, calibration laboratories will be able to introduce new/improved calibration services and in doing so, will meet industry's need for higher accuracy calibration services across Europe. Thus, making calibrations more efficient, economical and readily available.

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 June 2018, 42 months</td></tr>
<tr><td colspan="3">Coordinator: Amra Šabeta, IMBiH, Tel: +387 33 568 928 E-mail: amra.sabeta@met.gov.ba
Project website address: http://dosetrace-empir.eu/</td></tr>
<tr><td>Internal Funded Partners:
1. IMBiH, Bosnia and Herzegovina
2. GUM, Poland
3. IRB, Croatia
4. IST, Portugal
5. PTB, Germany
6. SCK•CEN, Belgium
7. SMU, Slovakia
8. TAEK, Turkey
9. VINS, Serbia</td><td>External Funded Partners:
10. EEAE, Greece
11. INM, Republic of Moldova
12. NSC-IM, Ukraine
13. USC, Spain</td><td>Unfunded Partners:</td></tr>
<tr><td colspan="3">RMG1: INM, Republic of Moldova (Employing organisation); PTB, Germany (Guestworking organisation) – terminated due to COVID-19
RMG2: VINS, Serbia (Employing organisation); PTB, Germany (Guestworking organisation)
RMG3: IMBiH, Bosnia and Herzegovina (Employing organisation); IST, Portugal (Guestworking organisation)</td></tr>
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