Final Publishable Summary for 14RPT04 Absorb
Absorbed dose in water and air

Overview

Due to both the number of cases of cancer increasing and the ageing of the population, current high levels of demand for diagnostic and interventional radiosurgery, radiology and cardiology procedures will grow. The goal of radiotherapy is to kill tumour cells, while minimising damage to the surrounding healthy tissue; however, small percentage changes in a radiotherapy dose can significantly increase the risk of complications. Uncertainty requirements for radiotherapy and radiosurgery doses are difficult to achieve due to the disparity between calibration and treatment conditions.

This project developed improved calibration practices, better primary dosimeter standards and decreased calibration uncertainties, enabling participating NMIs and DIs to build their own primary dosimeter standards and launch new calibration services. Measurement laboratories accessing these improved calibrations and working with the hundreds of thousands of facilities across Europe, will ultimately bring improved treatment outcomes for patients.

Need

The very large number of facilities for radiotherapy, interventional radiology/cardiology and radio diagnostic exams requires proximity to calibration services traceable to national primary standards.

There are four million new cases of cancer per year and subsequently the number of treatments per year is increasing so there is a need for diagnostic radiotherapy. In addition, the number of interventional radiology/cardiology procedures in developed countries is already very high and will only increase in future due to the global ageing of the population.

The goal of radiotherapy is to kill the tumour cells and simultaneously achieve a high survival rate of the surrounding healthy tissue. A change in the dose of 5 % can result in a normal tissue complication probability of 20 % - 30 %. However, prior to this project, the standard uncertainty requirement for the dose to the tumour (2.5 %) is very difficult to achieve due the gap between the calibration and treatment conditions. In order to overcome this problem, there was a need for improved traceability of measurement devices, known as dosemeters.

There was a need for leading national metrology laboratories to launch their own calibration services to answer the needs of end users. For diagnostic and interventional radiology/cardiology, the large number of facilities to be calibrated and/or controlled requires the development of a network of primary laboratories that is able to transfer the primary reference to calibration laboratories and end users in their own countries. The primary standards used are either cavity or free air ionisation chambers, used for high and low/medium photon radiation energies respectively, or calorimeters used to measure absorbed dose.

In addition to these requirements, there was also the need to evaluate the future end user needs for standards for radiotherapy and for diagnostics.

Objectives

The key aims of the project were to:

- **Study the design of water calorimeter primary standards**, so that participating NMIs and DIs seeking to establish a research capability in measuring adsorbed dose to water for high energy beams are able to build and operate the primary standards with a harmonised target uncertainty budget of 2.0 % and harmonised calibration procedures.
- **Study the design of free air chamber primary standards**, so that participating NMIs and DIs seeking to establish a research capability in measuring the air kerma (kinetic energy released per

unit mass) for low or medium X-ray energies used in radiation protection and diagnostic (i.e. mammography, short pulse) are able to build and operate the primary standards with a harmonised target uncertainty budget of 0.5 % for continuous beam and 1.0 % for pulsed beams and harmonised calibration procedures.
- **Study the design of cavity chamber primary standards**, so that participating NMIs and DIs seeking to establish a research capability in measuring the air kerma for photon energies such as those of Cs-137 used in radiotherapy are able to build and operate the primary standards with a harmonised target uncertainty budget of 0.5 % and harmonised calibration procedures.
- **Develop for each participant an individual strategy for the long-term development of their research capability in radiation dosimetry** including priorities for collaborations with the research and end users community in their country, the establishment of appropriate quality schemes and accreditation (e.g. participation in key comparisons, the entry of CMCs into the BIPM database, accreditation to ISO/IEC 17025), and a strategy for offering calibration services from the established facilities to their own country and neighbouring countries.

Progress beyond the state of the art

The project was focused on capacity-building activities on different technological levels to achieve a balanced and integrated measurement system in the participating states. Knowledge transfer between partners was the main goal of the project in the field of photon dosimetry primary standards development and construction based on the water calorimeter, free air ionisation chamber and cavity chamber. The main project developments are available to other stakeholders, mainly metrology institutes not participating in the project. NMIs and DIs previously relying on secondary standards now have all the information needed to be able to design, build and operate primary dosimeters based on water calorimeters, cavity ionisation chambers and free air ionisation chambers. Partners harmonised uncertainty budgets to achieve 0.5 % and 2.0 % for air kerma and absorbed dose to water respectively, calibration procedures and calibration certificates for a better comparison of the capabilities of the laboratories according to the requirements of ISO/IEC 17025.

Results and conclusions

Water calorimeters

The principle, design and construction of water calorimeters were studies and developed to enable participating laboratories to build and operate primary standards. This included the regulation system of temperature, the characteristics of the temperature probe, water vessels, the water purification system and the positioning of the probes. Correction factors to be applied to the raw measurements due to the thermal conduction, perturbation of the radiation field, the chemical defect and the density of the water were evaluated and reported. Dosimetric software that enables automatic measurements, correction factors and associated uncertainties for the water calorimeter primary standard was reviewed.

CEA provided all of the information for the calculation and measurement of correction factors for water calorimetry; this information will be used once the calorimeter is built. The design allows the user to achieve a relative uncertainty of 0.39 % in a radiotherapy photon beam emitted by a Co-60 (cobalt-60) source. In addition, the BEV-PTP design of the graphite calorimeter was also discussed. CEA has both a graphite and water calorimeter to enable a comparison between these two independent calorimetric measurements. BEV-PTP plans to build a water calorimeter in addition to its graphite one. GUM and SCK-CEN have started building their own primary standards based on water calorimeters. Other partners plan to build primary standards in the future.

Free air chambers

The principle, design and construction of free air chambers were studied and developed to enable participating laboratories seeking to establish a research capability in measuring the air kerma for low or medium X-ray energies used in radiation protection and diagnostic (i.e. mammography, short pulse) to build and operate the primary standards.

Aspects reviewed included aperture diameters, the dimensions needed to reach electronic equilibrium, positioning of the guard and collecting electrodes, determination of the collecting volume and cleaning of the pieces. Several designs were compared using information published in international comparison reports. Correction factors to be applied to the raw measurements due to the saturation, polarisation, scatter on the aperture, florescence, distortion of the field lines, transmission of walls, humidity and air density, and also the ratios of mass attenuation coefficients and the values of the fraction of the initial electron energy lost through the radiative process in air according to the energy of the photons were studied. Examples of dosimetric software were developed by CMI enabling automatic measurement, correction factors and associated uncertainties for the free air ionisation chamber primary standard. Using the example of the BEV-PTP free air ionisation chamber design the partners were trained in the calculation and measurement of correction factors. The adopted design enables an uncertainty between 0.58 % and 0.30 % for photons of low and medium energies. Based on this review and evaluation, IST began to build a free air ionisation chamber for low and medium energies for use in radiation protection and diagnostics fields, starting from a previous prototype which needed to be improved. SCK-CEN also plans to develop a primary dosimeter, starting from an old prototype.

Cavity chambers

The principle, design and construction of cavity chambers were reviewed by the partners, to enable participating laboratories seeking to establish a research capability in measuring the air kerma for photon energies, such as those of ^{60}Co and ^{137}Cs (Caesium-137) used in radiotherapy, to build and operate the primary standards. This included the collection volume definition and determination, wall thickness for electronic equilibrium, establishment, guard and collecting electrode positioning and the cleaning of the pieces.

Two designs were studied, one cylindrical and one mixed between cylindrical and spherical, and the electric field behaviour inside the collecting volume was analysed. Correction factors were studied (to be applied to the raw measurements) due to the saturation and polarisation as well as the scattered radiation from the stem, the wall transmission, humidity and density of the air, the ratios of the stopping power and mass energy absorption coefficients and the values of the fraction of the initial electron energy lost through radiative processes in air according to the photon energy. Examples of dosimetric software were developed by CMI enabling automatic measurement and calculation of correction factors and associated uncertainties for the cavity ionisation chamber primary standard.

Using the CEA cylindro-spherical design the partners were trained in the calculation and measurement of correction factors for the cavity ionisation chamber. This design enables an uncertainty of 0.39% for Co-60 photons. Based on this review and evaluation, IST built, tested and compared its cavity chamber with the CEA ones and after a key comparison registered in the BIPM database it is now the national primary standard. IFIN-HH in cooperation with CEA has started building its primary standard based on a cavity ionisation chamber. CMI has already started to build its own primary standard. Other partners plan to build a primary standard in the future within the framework of a bilateral collaboration. For example, the CEA LNHB built and delivered two primary cavity ionization chambers to CIEMAT by the end of 2017.

Individual strategy for the long-term development

The long term strategy of all the partners is to develop new services, or update existing ones, to meet the needs expressed by their stakeholders. The steps needed to reach this goal are as follows:

- obtain reference values from primary or secondary standards
- participate in an intercomparison
- obtain ISO 17025 accreditation (peer audit mandatory)
- publish Calibration and Measurement Capabilities (CMCs)
- launch service

Finding manufacturers able to machine the pieces required for the primary standards confirms that finding workshops able to machine them is difficult when taking into account the required tolerances. Nevertheless, some manufacturers were identified in different European countries and information was shared between the partners. CEA organised and reported a trial comparison between the partners for air kerma to train those having little experience in such work. The results will be published as a CEA report freely available on the CEA-LNHB website (http://www.lnhb.fr). To check the compliance of the quality system of the partners to ISO 17025 requirements, IST gathered and analysed a set of calibration methods and calibration certificate templates. This showed that all partners follow the requirements of the standard.

Impact

Dissemination

Papers were published in the proceedings for the project Absorb workshop and in the Metrologia journal.

Research results were presented at national and international conferences including the Czech Association of Medical Physicists, American Association of Physicists in Medicine and Radiological Protection in Health.

A training course on primary standards for absorbed dose in water and air was run for external delegates from the scientific community. Partners were trained on primary standards building for absorbed dose in water and air, and performed ISO 17025 audits.

The following Good Practice Guides about how to build primary standards were published on the project website:

- Guide on how to build a free air ionisation chamber
- Guide on how to build a cavity chamber
- Guide on how to build a calorimeter

Impact on industrial and other user communities

Over twenty stakeholders mainly from hospitals joined the project and were informed about the results concerning uncertainty reduction and calibration methods harmonisation, with the aim of establishing a direct calibration service.

National reference values are being transferred to clinics through the calibration of dosemeters, leading to better diagnosis and treatment in radiotherapy.

Companies able to machine special materials such as graphite, an insulator, with a high level of precision, were checked and/or identified and cooperation started in some partnering countries.

Impact on metrology and scientific communities

Metrology institutes participating in the project were trained in building primary standards and they were provided with the software for automatic measurement, correction factors and the associated uncertainty calculations for standards based on water calorimetry, the cavity ionisation chamber and the free air ionisation chamber.

IST built and tested their cavity chamber, now the national primary standard, after a key comparison registered in the BIPM database.

IFIN-HH has started building their primary standard based on a cavity ionisation chamber.

CEA are working with the Spanish metrology institute CIEMAT in order to establish a new primary standard for air kerma based on a cavity ionisation chamber.

The partners were provided with the information needed to build primary standards. BEV-PTP, SCK-CEN and GUM have plans to build their own primary standard in the future.

Impact on relevant standards

Presentations of the project’s results were made to the following standards committees:

- ISO TC85 SC2 WG2, responsible for standard ISO 4037 dealing with reference radiation quality

- EURAMET TC-IR, the technical committee for ionising radiation, where project workshop proceedings were presented with the link to CEA's official website, and also partners' plans to update or set new CMC lines
- BIPM CCRI(I) consultative committee, with the emphasis on planned participation of the partners in key comparisons organised by BIPM
- IEC WG45 working group, and will be taken into account in the preparation of new or updated standards.

Future potential impact

Collaborations will continue between many of the partners, in particular aimed at measurements using water calorimeters, free air ionisation chambers and cavity ionisation chambers. Results will be presented at future conferences, and partners will participate in international comparisons organised by IAEA, EURAMET and BIPM.

The longer term impact will be to share the knowledge on primary standards and harmonise the calibration procedure according to ISO 17025. This will allow shorter traceability chains, thus improving the traceability and accuracy of the ionising radiation doses delivered to the patients.

List of publications

V. Sochor: Free air chamber – principle of operation, basic design, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

A. Steurer: Free air chamber at BEV, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

MI. Camacho Caldeira: Cavity chamber, method Principle form collected charges to air kerma, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

MI. Camacho Caldeira: Cavity chamber manufacturing, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

S. Bercea et al: Development of a cavity ionization chamber at IFIN-HH – primary standard for air kerma, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

A. Steurer: Measuring system (current measurement) and evaluation software, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

MI. Camacho Caldeira: Electronic associated to IC, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

S. Bercea et al: Electronic associated to IC and IC characteristics, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

MI. Camacho Caldeira: Cavity chamber, correction factors measurement, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

MI. Camacho Caldeira: Cavity chamber, correction factors calculation, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

A. Steurer: Cavity chamber at BEV, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

A. Steurer: Measurement calibration method at BEV, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

B. Rapp: Calorimetry – water and graphite calorimeter pro and con, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

A. Steurer: Graphite calorimeter at BEV, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

J.-M. Bordy: Introduction to uncertainty budget GUM method, Rapport CEA-R-6467, ISSN 0429-3460 (http://www.lnhb.fr/pdf/Rapport-CEA-R-6467.pdf)

C. Kessler, L.C. Mihailescu et al.: Key comparison BIPM.RI(I)-K1 of the air-kerma standards of the SCK•CEN, Belgium and the BIPM in Co-60 gamma radiation, Metrologia 54 (2017) Tech. Supl. 06004

J.-M. Bordy et al.: Trial comparison of air kerma for Cs-137, submitted as a CEA report

<table>
<tr><td colspan="2">Project start date and duration:</td><td>1st June 2015; 30 months</td></tr>
<tr><td colspan="3">Coordinator:
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Project website address: http://absorb-empir.eu/</td></tr>
<tr><td>Internal Funded Partners:
1 CEA, France
2 BEV-PTP, Austria
3 CMI, Czech Republic
4 GUM, Poland
5 IFIN-HH, Romania
6 IMBiH, Bosnia and Herzegovina
7 IRB, Croatia
8 IST, Portugal
9 SCK-CEN, Belgium
10 VINCA, Serbia</td><td>External Funded Partners:</td><td>Unfunded Partners:</td></tr>
<tr><td colspan="3">RMG1: IMBiH, Bosnia and Herzegovina (Employing organisation); CEA, France (Guestworking organisation)
RMG2: IFIN-HH, Romania (Employing organisation); CEA, France (Guestworking organisation)
RMG3: VINS, Serbia (Employing organisation); SCK•CEN, Belgium (Guestworking organisation)</td></tr>
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