International co-operation, basic principles and on-going developments in radiation protection metrology and measurements

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Abstract

Assessment of external and internal exposure for radiation protection purposes needs reasonable physical, biological and ecological concepts. Reliable instruments and well-established measurement methods are the essential basis for high quality dose and activity measurements.

In this paper, international co-operation, basic principles and recent developments in radiation protection measurement techniques are given. Metrological aspects as traceability chains to assure traceability from national primary standards to end-user measurements are discussed together with the international and European metrological network in radionuclide metrology and dosimetry. Basic metrological standards and practical implementation of uncertainty assessments in activity and dose measurements methods are presented. Finally main aspects and recent research projects in radiation protection metrology and measurements are discussed.

The paper provides a comprehensive evaluation of on-going radionuclide metrology and dosimetry for radiation protection. The results serve as state-of-the-art theoretical foundation and practical information for qualified RP experts and all users of measurement instruments in radiation protection.

Keywords

Metrology, dosimetry, radionuclide metrology, traceability, primary standards, measurement uncertainty

1 Introduction

Because radiation protection is mainly a human health safety issue, ambient and personal dose measurements, radionuclide activity measurements and effective dose assessments have to be carried out on a high quality level. This requirement leads to traceable calibration of measurement instruments used in the different sections of radiation protection. This means that any measurement done for radiation protection purposes have to be carried out by measurement instruments which are traceably calibrated at primary or secondary standards. In practice this technical claim is ensured by institutional authorisation or accreditation or verification of the used measurement instrument. The achievable measurement uncertainties of operational measurement methods are higher than metrological standardisation measurement methods due to uncertainty propagation in the calibration chain.

The future requirements for dose and activity measurements in Europe can be derived from the main part and the technical annexes of the proposal for the Basic Safety Standards for Radiation Protection (EC BSS, 2011).

2 International Co-operation in ionising radiation and radionuclide metrology

2.1 General aspects

Since the late 1950s, an international co-operation in the field of ionising radiation metrology has been established. Today a worldwide metrological infrastructure in ionising radiation dosimetry and radionuclide activity measurement is in operation. Fig. 1 shows the institutions operating the metrological infrastructure from national via regional to international level. National Metrological Institutes (NMIs) and Designated Institutes (DIs) provide the primary and secondary measurement standards for dose and activity units (e.g. J/kg, Bq).

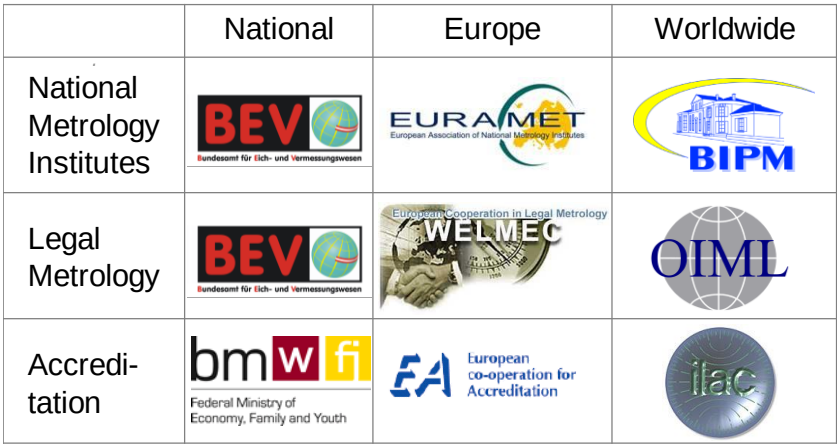

Fig. 1. International Co-operation in metrology – national (e.g. Austria), regional (e.g. Europe) and international infrastructure

The Regional Metrological Organisations (RMOs), responsible for the metrological co-operation on the worldwide regional level are shown in Fig. 2. Additionally the International Atomic Energy Agency IAEA provides co-operation and technical support in radiation protection measurement techniques like the Secondary Standard Dosimetry Laboratory (SSDL) Network. This network is an important co-operation platform for nations not member states in the Metre Convention.

2.2 BIPM – Bureau international des poids et mesures

The Convention of the Metre (Convention du Mètre) is a treaty that created the International Bureau of Weights and Measures (BIPM, www.bipm.org), an intergovernmental organization under the authority of the General Conference on Weights and Measures (CGPM) and the supervision of the International Committee for Weights and Measures (CIPM). The BIPM acts in matters of world metrology, particularly concerning the demand for measurement standards of ever increasing accuracy, range and

diversity, and the need to demonstrate equivalence between national measurement standards. Today The Metre Convention now has fifty-five Member States, including all the major industrialized countries. Austria is one of the 19 founding members since 1875.

A very important co-operation tool of the BIPM is the organisation of so called key comparisons to provide and maintain the comparability of the BIPM member state standards. The results of these key comparisons support the entry of the Calibration and Measurement Capabilities of the member states' National Metrology Institutes (or Designated Institutes) in the BIPM-CMC-Database.

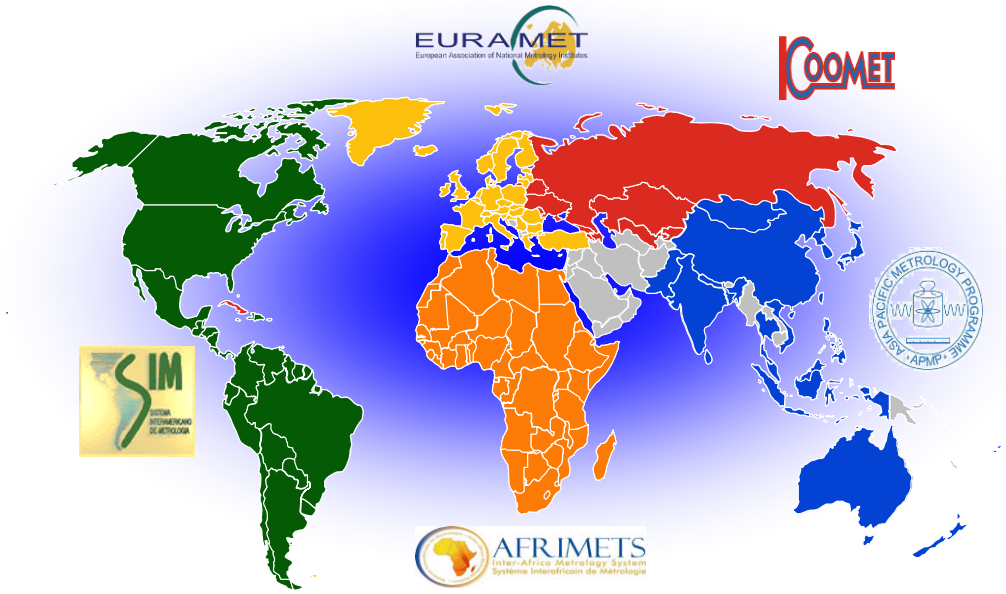

Fig. 2. Worldwide Regional Metrology Organisations

2.3 ICRM – International Committee for Radionuclide Metrology

The International Committee for Radionuclide Metrology (ICRM, http://physics.nist.gov/ICRM) is an association of radionuclide metrology laboratories whose membership is composed of delegates of these laboratories together with other scientists actively engaged in the study and applications of radioactivity. It explicitly aims at being an international forum for the dissemination of information on techniques, applications and data in the field of radionuclide metrology. This discipline provides a range of tools for tackling a wide variety of problems in numerous other fields, for both basic research and industrial applications.

Plenary meetings of the ICRM are held biennially and have developed into a successful instrument of communication among various specialists, thus encouraging international co-operation. The most recent in the series of ICRM meetings, the "18th International Conference on Radionuclide Metrology and its Applications," September 19-23, 2011, was hosted by the NMIJ/AIST (National Metrology Institute of Japan, Advanced Industrial Science and Technology) in Tsukuba, Japan.

The next biennial conference of the ICRM, the "19th International Conference on Radionuclide Metrology and its Applications," will be organized by the IRMM (Institute for Reference Materials and Measurements) in June 2013 in Antwerp, Belgium.

The Low-Level Measurement Techniques working group will hold its next conference (4 years after the last conference) in September 2012 in Jeju, Korea (http://icrm-llrmt.kriss.re.kr).

2.4 EURAMET – European Association of National Metrology Institutes

The European Association of National Metrology Institutes (EURAMET; www.euramet.eu) is a Regional Metrology Organisation (RMO) of Europe. It coordinates the cooperation of National Metrology Institutes (NMI) of Europe in fields like research in metrology, traceability of measurements to the SI units, international recognition of national measurement standards and related Calibration and Measurement Capabilities (CMC) of its members. Through Knowledge Transfer and cooperation among its members EURAMET facilitates the development of the national metrology infrastructures.

EURAMET is responsible for the elaboration and execution of the European Metrology Research Programme, known as the EMRP, which is designed to encourage collaboration between European National Metrology Institutes (NMIs) and partners in industry or academia. The programme funds joint research projects in specific fields of metrology with over 50 projects selected for funding so far and many more expected over the coming years.

2.5 EMRP – European Metrology Research Programme

2.5.1 General aspects

The European Metrology Research Programme (EMRP) is a metrology-focused European programme of coordinated R&D that facilitates closer integration of national research programmes. The EMRP enables European metrology institutes, industrial organisations and academia to collaborate on joint research projects within specified fields. These collaborative efforts will accelerate innovation in areas where shared resources and decision-making processes are desirable due to economic factors and the distribution of expertise across different countries and sectors.

The EMRP is jointly supported by the European Commission and the participating countries within the European Association of National Metrology Institutes (EURAMET). The EMRP will ensure collaboration between National Measurement Institutes, reducing duplication and increasing impact. The overall goal of the EMRP is to accelerate innovation and competitiveness in Europe whilst continuing to provide essential support to underpin the quality of our lives.

2.5.2 EMRP Joint Research Projects in ionising radiation dosimetry

Recent dosimetry projects (EMRP/iMERA Call 2007) were "Increasing cancer treatment efficacy using 3D brachytherapy" (project number T2.J06) and "External beam cancer therapy" (project number T2.J07). Both projects started in 2008 and finished in 2011.

The BEV was project partner of the brachytherapy project. The aim of the project was to establish a more accurate metrological basis for the dosimetry of radioactive sources used in clinics for brachytherapy (BT) treatment in Europe. There was a necessity to create a suitable metrology chain for traceability of absorbed dose measurements of BT radiation sources to absorbed dose to water primary and secondary standards. The absorbed dose to water is the quantity of interest for dosimetry in radiotherapy. In the frame of the project the BEV has developed its absorbed dose to water secondary standard on a base of well type ionizing chamber. Using this secondary standard the first calibration for BT source ^{192}Ir was realized at the PTB primary laboratory in 2010.

A new European joint dosimetry research project will start in June 2012 (EMRP Call 2011). It is called "Metrology for radiotherapy using complex radiation fields" (project number HLT09). It will be finished in 2015.

2.5.3 EMRP joint research projects in radionuclide metrology

The three years European joint research project ‘MetroFission’ Metrology for New Generation Nuclear Power Plants (ENG08, co-ordinated by NPL, Lena Johansson) finished in 2011. Two new JRPs started in 2011 for a three years period: ‘MetroMetal’ Ionizing Radiation Metrology for Metallurgical Industry (IND04, co-ordinator CIEMAT, Spain, José M Los Arcos and ‘MetroRWM’ Metrology for Radioactive Waste Management Petr (ENV09, co-ordinator Czech Metrological Insitute, Petr Kovář).

3 Ionising radiation and radionuclide metrology in Austria

3.1 Legal metrology

The Austrian Metrology Act "MEG - Maß- und Eichgesetz" (MEG 2011) requires the verification ("Eichung") of photon dosemeters, dose calibrators, contamination monitors, and other activity measurement instruments like gamma-ray spectrometers or radon detectors when they are used for radiation protection purpose, legal measurements or for measurements in medicine or environment. That means a type approval of the instrument for legal use in Austria (similar to the German PTB type approval) and verification ("Eichung" similar to Germany) every two years. Type approval is done in Austria by the BEV (Federal Office of Metrology and Surveying) only, verification could be done also by a verification laboratory authorised by the BEV. The BEV is the National Metrology Institute (NMI) and National Authority on Legal Metrology of Austria.

Verification of an measuring instrument is not a calibration. The verification includes the examination (and verification marking) of measuring instruments by a competent body. The examination ascertains, whether the measuring instrument complies with the verification regulations (issued by BEV), in particular whether the measurement errors are not larger than the maximum permissible errors of verification ("Eichfehlergrenzen"). Measuring instruments are only acceptable for verification, if their type is approved by BEV or if the conformity is approved by a European notified body (CE mark) and the national safety conformity of the instrument has been ascertained by BEV.

3.2 Measurement instruments calibration

The BEV is not accredited because it is the National Metrology Institute (NMI) of Austria. As the NMI the metrology service of the BEV maintains the national standards for the realisation of the legal units of measurement and ensures their international equivalence and recognition. Thus it is at the top of the national metrology system. Within the scope of the BEV Physical-Technical Testing Service (PTP) the legal units of measurement are disseminated through calibration by comparing measuring instruments with the national standards.

The mutual recognition of national measurement standards and of calibration, test and measurement certificates of national metrology institutes is arranged by an international arrangement in the frame of the Metre Convention (CIPM MRA = International Committee for Weights and Measures Mutual Recognition Arrangement). Basis for the recognition is the demonstration of competence by participating in international key comparisons of the measurement standards. A precondition is in addition the implementation of a quality management (QM) system according to EN ISO 17025. According to the CIPM MRA accreditation is not required, self-declaration is sufficient. But the QM system has to be presented to a group of international experts of the regional metrology organization of Europe EURAMET, which evaluates the QM system.

The BEV signed the CIPM MRA and implemented a QM system according to EN ISO 17025 and put it into force by self-declaration. The competent EURAMET body stated, that this QM system fulfils the requirements of the CIPM MRA. Respective international comparison measurements (key comparisons) are performed by CIPM, BIPM and the regional metrology organisations (RMO). Results of key comparisons and also calibration and measurement capabilities (CMCs) recognised within the CIPM MRA are published on the BIPM website under the Key Comparison Database (KCDB) of the BIPM (kcdb.bipm.org/).
Therefore the calibration and test certificates of the BEV issued within this frame are internationally recognized and are proof of traceability to the International system of units SI.

For dosimetric quantities the BEV is a primary standard laboratory and member of the CCRI(I) (Consultative Committee for Ionizing Radiation Section 1, X- and gamma-rays, charged particles) under the authority of the CIPM at the BIPM. The BEV CMCs for dosimetric quantities are given at the KCDB. For activity quantities the BEV is member of the CCRI(II) (radionuclide metrology).

3.3 Ionising radiation metrology at BEV

Recognizing the importance of the measurement of ionising radiation, the “Bundesamt für Eich- und Vermessungswesen (BEV)” considered the construction of a dosimetry laboratory already many years ago. In 1977 the dosimetry laboratory, which is situated in the Research Center Seibersdorf near Vienna, was put into operation. It is jointly operated by the BEV and Seibersdorf Laboratories (SL).

The dosimetry laboratory contains the following irradiation facilities, which are set up in two irradiation rooms:

- Three X-ray facilities with adjustable tube voltage from 5 kV to 320 kV for dosimetry in radiation protection, diagnostic radiology (including several mammographic radiation qualities) and radiation therapy
- A ^{60}Co teletherapy unit with adjustable collimator and preset of the irradiation time for therapy dosimetry (Fig. 3)

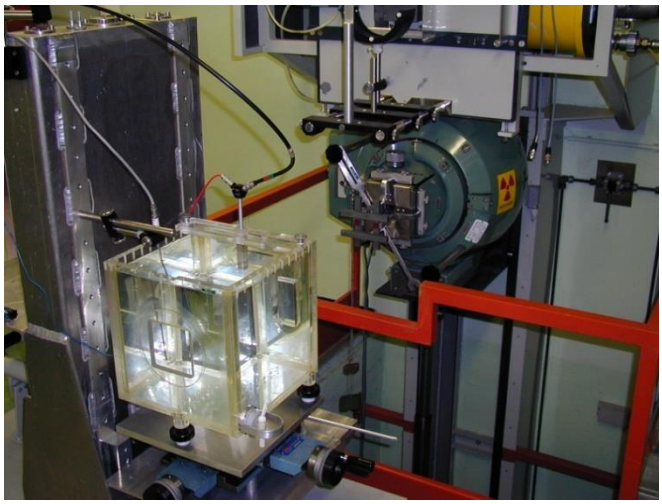

Fig. 3. ^{60}Co teletherapy unit with water phantom for calibration of therapy dosimeters in terms of absorbed dose to water

- A panoramic irradiation facility containing four selectable ^{137}Cs sources with pneumatic transport system and preset of the irradiation time for radiation protection dosimetry
- A reference beam facility containing three ^{137}Cs and three ^{60}Co sources with conical ring collimator, pneumatic shutter and preset of the irradiation time for radiation protection dosimetry

For the realization of units of the various dosimetric quantities BEV is equipped with the following measurement standards, which were partly developed in co-operation with foreign National Metrology Institutes:

- Graphite cavity ionisation chambers for absolute realization of the units of air kerma and derived dose equivalent quantities for gamma radiation from ^{137}Cs and ^{60}Co radionuclides
- Three free air parallel plate ionisation chambers for absolute realization of the units of air kerma and derived dose equivalent quantities for X-radiation with energies from 5 keV to 320 keV
- A graphite calorimeter for absolute realization of the units of absorbed dose to water, which is derived from absorbed dose to graphite

- Several transfer ionisation chambers with volumes from 0,03 cm^3 to 10 000 cm^3 for realization of the dosimetric units for the entire dose rate range from environmental levels up to dose rates, which are used in radiation therapy
- A digital current- and charge measurement systems for the measurement of ionisation currents from ionisation chambers in the range from 0,1 pA to 100 nA

The Austrian Metrology Act stipulates which tasks of public interest are assigned to the BEV. Concerning dosimetry the tasks are as follows:

- Maintenance of the national standards for dosimetry in radiation protection, diagnostic radiology and radiation therapy
- Verification and calibration of dosimeters used in radiation protection, diagnostic radiology and radiation therapy (Fig. 4)
- Metrological control of personal dosimeters

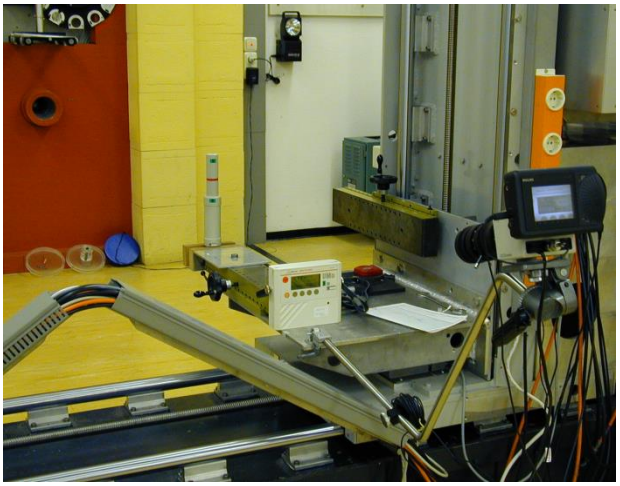

Fig. 4. Verification of a radiation protection dosimeter with a video camera in the foreground, in the background the opening of the ring collimator of the reference beam facility

The dosimetry laboratory regularly participates in international comparisons especially key comparisons co-ordinated by the BIPM (Fig. 5).

Furthermore the dosimetry laboratory regularly irradiates reference thermoluminescence dosimeters for the postal dose comparison measurement program of the International Atomic Energy Agency (IAEA). In this irradiation program the dosimetry laboratory of the BEV serves among other national metrology institutes and the Bureau International des Poids et Mesures (BIPM) in Paris as a reference laboratory, i. e. the irradiations performed by the BEV provide a quality control for the IAEA.

The dosimetry laboratory of the BEV met with special international approval by its membership in the „Consultative Committee for Ionising Radiation (CCRI)“. This committee advises the „Comité International des Poids et Mesures (CIPM)“ in metrological affairs, in the planning and running of international comparison measurements and the scientific work in the laboratories of the BIPM for ionising radiation.

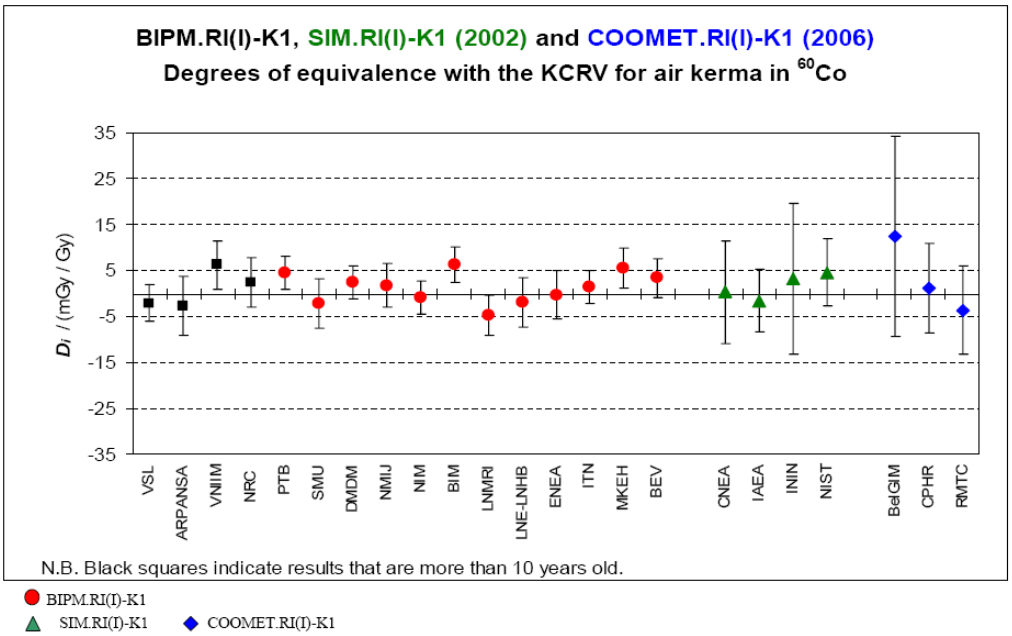

Fig. 5. Result of the key comparison for air kerma in ^{60}Co radiation flied (Kessler et al., 2010)

3.4 Radionuclide metrology at BEV

3.4.1 Verification and calibration of dose calibrators and contamination monitors

Periodically (2 years) verified dose calibrators ("activity meters") are used to determine the activity of ampoules and syringes applied for diagnostic or therapeutic therapy in nuclear medicine. Verified contamination monitors are used to check laboratory areas (Fig. 6) where open radioactive sources are handled as well as the measurement of palms, soles and clothing (hand-foot-clothing-monitor) of the personnel handling radioactive substances with regard to contamination by spilt substances.

Fig. 6. Verification of contamination monitors at BEV

Measuring instruments for the clearance of waste containers from such laboratories or laundry of nuclear medicine wards in hospitals must also be verified at regular intervals (2 years) to protect population and environment.

3.4.2 Metrological examination of gamma-ray spectrometer

Examples for the use of periodically (2 years) examined gamma-ray spectrometer are the clearance of radioactive waste water in nuclear medicine wards, the measurement of the activity concentration of aerosols in air as well as the inspection of foodstuff and environmental samples (Fig. 7).

Fig. 7. Metrological control of a gamma-ray spectrometer

3.4.3 Verification and calibration of radon monitors

The verification of measuring systems for the determination of the activity concentration of ^{222}Rn in ambient air can be executed either in the emanation- and calibration container or in the radon chamber (Fig. 8). The activity concentration in a closed volume is determined by the reference measuring system of the BEV. The mean values over 24 hours of the activity concentration of the secondary standard and the test specimen are compared at a reference point in time.

Fig. 8: Radon monitors in the BEV radon chamber

3.4.4 Radionuclide metrology laboratory infrastructure at BEV

- Portable well type ionisation chambers with current/charge measuring devices calibrated (traceable to NPL and PTB) for over 50 radionuclides for the international comparison of standards and for the determination the activity concentration of radioactive substances likewise

- Fixed and transportable high-purity germanium detectors (planar and coaxial) with signal processing and PC's with analysis software
- Radon monitors with emanation source and emanation- and calibration container as well as radon chamber for simultaneous measurements of several test specimen
- Radioactive point sources and volume sources of different geometries and densities with defined activity for calibration and quality assurance of measuring instruments and area sources with defined activity and surface emission rate

4 Measurement uncertainty and practical implementation

4.1 General

Traceability and uncertainty are important aspects of the calibration chain. The calibration chain starts with the calibration by a National Metrology Institute or Designated Institute and ends at the end-user measurements instruments (Fig. 9).

The uncertainties of calibration provided by National Metrology Institutes are given in the CMC-Database of the BIPM. The BEV-CMCs in the field of ionizing radiation dosimetry can find online (http://kcdb.bipm.org/appendixC/RI/AT/RI_AT.pdf).

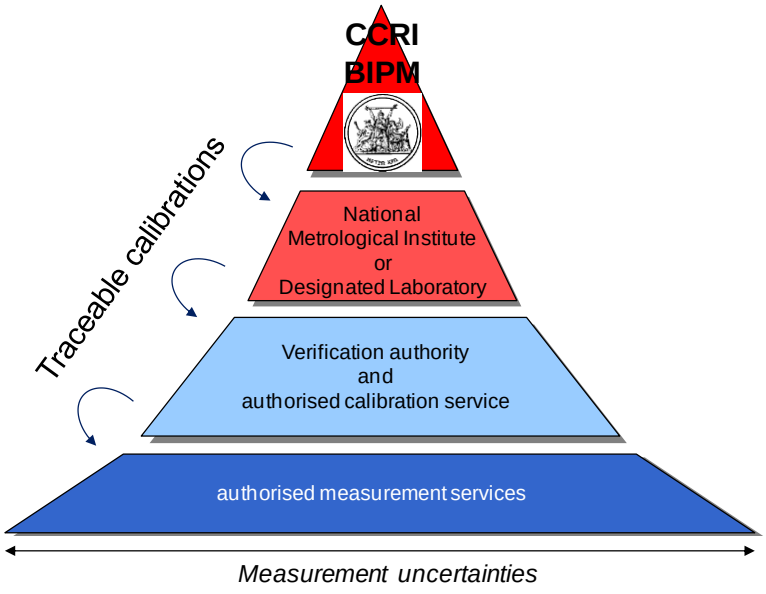

Fig. 9: Tracebility and uncertainty pyramid

4.2 Dosimetry

Supported by key comparisons, the dosimetry laboratory of the BEV are in the uncertainty range between 0,8 % and 2,0 % for air kerma and absorbed dose to water (coverage factor k = 2). For radiation protection quantities (e.g. ambient dose equivalent, personal dose equivalent the typical uncertainties are between 3 % and 7 % (k = 2), depending on the doserate, the radiation quality and the used conversion coefficients.

The measurement uncertainty of radiation protection dosemeters used in practice is quite higher. Typical radiation protection dosemeter are used for low and high dose rates, for a very large photon energy range (keV up to MeV) in very different environmental conditions (air pressure, temperature, humidity). A radiation protection dosemeter is a compromise between broad rate range for these influence quantities und reasonable variation of the response within these ranges. Requirements for radiation protections dosemeters are given in international standards (e.g. OVE/ÖNORM EN 60846, 2005). Using these requirements one will understand the high uncertainties of radiation protection dosimeters in a range of often more than 40 % or 50 %.

Austria has established national standards to calculate uncertainties for practical radiation protection measurements (ÖNORM S 5255-1, 2001; ÖNORM S 5250-1, 2002; Steurer et al., 2003).

4.3 Radionuclide metrology

In radionuclide metrology about 150 different radionuclides (out of about 2000 in total) are of interest for medical, technical and environmental applications. These radionuclides of interest have to be standardised with about 20 different primary standardisation methods. The achievable measurement uncertainty for these primary standardisation methods for radionulide activites ranges from 0,4 % to 5,0 % (k = 2). NMI's and DI's achieve by using primary or secondary activity standards uncertainties between 0,4 % and about 10 %. The end-user activity measurement instruments come up to measurement uncertainties (k = 2) between 3 % (e.g. dose calibrators for medical treatment) to 30 % (e.g. contamination monitors, nuclear waste monitors). In general, traceable measurements in radionuclide metrology provides total measurement uncertainties (k = 2) from 0,4 % from the metrological top (key comparisons at BIPM of NMI / DI primary standards laboratories) to maximum 30 % for end-user measurements in radiation protection practise.

5 References

EC BSS (2011). Proposal for a Council Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. Draft presented under Article 31 Euratom Treaty for the opinion of the European Economic and Social Committee, COM(2011) 593 final, 2011/0254 (NLE). Brussels, 29 Sept. 2011

MEG (2010). Maß- und Eichgesetz. Bundesgesetzblatt BGBl. I 115/2010

Kessler C, Allisy-Roberts P J, Steurer A, Tiefenböck W, Gabris F (2010). Comparison of the standards for air kerma of the BEV and the BIPM for ^{60}Co gamma radiation. BIPM, Paris

ÖNORM S 5250-1 (2002). Counting statistics in radioactivity measurements – Part 1: Uncertainties of measurements, decision threshold and detection limit. Austrian Standards Institute, Vienna (in German)

ÖNORM S 5255-1 (2001). Uncertainties of measurements and limiting values in radiation protection - Part 1: Basics (in German)

OVE/ÖNORM EN 60846 (2005). Radiation protection instrumentation - Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation (IEC 60846:2002, modified) (in German)

Steurer A, Schmitzer C, Gruen K (2003). Uncertainties of measurements in radiation protection. Kerntechnik Vol. 68, 168-171