Appendix 3 of DOLP.014
Technical protocol of the radiation protection comparison

IAEA-SSDL bilateral comparisons for radiation protection level air kerma measurement standards

1. Introduction

The dissemination of each type of calibration needs to be verified periodically through comparisons organized by the IAEA or a Regional Metrology Organization (RMO). In order to maintain confidence in the traceability chain it is recommended for SSDLs, providing calibration service, to participate in this comparison program at least every 5 years, or whenever their reference standards, irradiation setups and/or the measurement technique have changed. One of the main objectives of the SSDL Network is to ensure traceability of measurements for Member States, by providing the link between the end-users and the international measurement system. In addition, the IAEA Dosimetry laboratory acts as a central laboratory of the IAEA/WHO SSDL Network and provides audits and organizes comparisons for the network members.

2. International measurement system

The Mutual Recognition Arrangement (MRA) provides the formal recognition of national measurement standards and calibration and measurement capabilities (CMCs) among the Member States of the International Committee for Weights and Measures (CIPM) [1]. By linking to its National Metrology Institute (NMI), any SSDL can take part in RMO comparisons. However, their results cannot be included in the Bureau International des Poids et Mesures (BIPM) key comparison database (KCDB) unless their NMI is a signatory to the MRA and the SSDL has a Designated Institute (DI) status for ionizing radiation standards.

3. Purpose of the comparison program

This ongoing radiation protection level comparison program of the IAEA, in line with the objectives of the IAEA/WHO SSDL Network Charter [2], aims to verify that SSDLs can carry out calibrations in terms of dose equivalent operational quantities established by the International Commission on Radiological Units (ICRU) within acceptable limits for photon radiation, and to validate the traceability of the participants` radiation protection level standards.

Since the appropriate operational quantities can be derived from the air kerma free in air by the application of the conversion coefficients published in the ISO 4037 Part 3 [3], the calibration practice of the radiation protection propose dosimeters in terms of operational quantities at the SSDLs is based on the reference air kerma/kerma rate determination. Because the same conversion coefficients and associated uncertainties are applied, this comparison for the air kerma measurement can additionally support the relevant calibration services of SSDLs in terms of dose equivalent operational quantities. The comparison results, if desired by the participant, can be published in open-access literature, for example as an annual summary report on the IAEA/SSDL bilateral comparisons and used as supporting evidence for the eligible SSDLs to publish or maintain their relevant CMCs in the KCDB of the CIPM MRA.

4. Participants

4.1. Pilot laboratory: IAEA

The IAEA signed the MRA under the auspices of the CIPM in 1999. The IAEA maintains a peer reviewed quality management system (QMS) complying with the ISO/IEC 17025:2005 standard [4], and published its revised dosimetry CMC claims in 2016 in the KCDB. The calibration of ionization chambers performed at the IAEA are traceable to the primary standard at the BIPM for ^{137}Cs radiation beam and to the PTB for the ISO Narrow beam series X-ray beam qualities. The charge measurement is traceable to the Federal Office of Metrology in Austria (BEV). The IAEA maintains a secondary standard for the determination of air kerma, ambient dose equivalent and personal dose equivalent at radiation protection level for ^{137}Cs and ^{60}Co gamma radiation beams, and for the ISO Narrow beam series X-ray radiation qualities. It consists of PTW LS-01, PTW HS-01, LS-10, T34035, and RADCAL RC6M type of ionization chambers and Keithley 6517 electrometers. Details of the radiation protection level IAEA calibration service are available in the calibration claims #1006-#1017 in the KCDB under CMCs.

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4.2. Participant

The yearly comparison program is announced for members of the SSDL network in the beginning of each year. A participant laboratory should have a traceable reference standard and a calibration procedure for radiation protection level calibrations. An application should be submitted to the IAEA to participate in the comparison program. The number of accepted participants is limited and dependent on the workload. The laboratory which has not participated in the last 5 years or its last result was not acceptable, has priority in the selection.

The application should include full contact information, a shipment address and the preferred time schedule. If a participant intends to use this bilateral comparison result to support CMC claims it should also be stated in the application.

5. Transfer chamber and radiation qualities

The comparison is conducted through the calibration of one robust reference quality transfer chamber in terms of air kerma according to the participant's laboratory procedure. The comparison parameters are the calibration coefficients of the transfer chamber for the selected beam qualities. The technical details of the chamber are given in Table 1 and its photo in Figure 1. In addition to the 662 keV photon radiation from ^{137}Cs-radionuclide, being recommended as reference radiation for radiation protection dosimeters measuring photon radiation, further X-ray radiation qualities listed in Table 2 are also available for the comparison.

The participants may decide how many radiation qualities are used for the comparison according to the available beam qualities and calibration services in their laboratories. Note that the N-100 beam quality is the reference beam quality when the rated range of the ambient dose equivalent meter ($H^{*}(10)$) is from 20 keV to 150 keV [5]. The N-80 beam quality is the reference beam quality for directional and personal dose equivalent meters measuring at 0.07 mm depth [6, 7], and can also be used for calibration of eye dosimeters in terms of $H_p(3)$. The further X-ray qualities in Table 2 are frequently used for type or performance tests of radiation protection instruments.

Table 1. Technical data for the transfer chambers

Type	**Reference point**	**Nominal volume (cm^3)**	**Polarizing voltage* (V)**	**Wall thickness material** (mm)	**Outer diameter (mm)**
Exradin A6, spherical chamber	chamber centre	800	+400	3.0 C552**	120.4

* This positive polarity is applied to the collector. If an arrangement is used in which the collector is at virtual ground potential, then a negative polarity should be applied.
**Shonka air-equivalent plastic

Table 2. Radiation qualities available for the comparison

Radiation quality*	**Tube voltage** (kV)	**Mean energy E (keV)**	**Air kerma rate IAEA (2m distance)** (mGy/h)	**1st HVL IAEA** (mm Cu)	**1st HVL ISO 4037** (mm Cu)	**IAEA standard traceability**
N-40	40	33	20	0.088	0.084	PTB
N-80	80	65	20	0.59	0.58	PTB
N-100	100	83	20	1.13	1.11	PTB
N-200	200	164	20	3.92	3.99	PTB
N-300	300	250	20	6.20	6.12	PTB
Gamma ray qualities						
Radiocuclide	**Photon energy** (keV)		**Air kerma rate** IAEA **(3m distance)** (mGy/h)			**IAEA standard traceability**
^{137}Cs	661.6		3.6			BIPM

* ISO 4037 Narrow-spectrum X-ray beam qualities [8]

Figure 1. Transfer chamber type Exradin A6

6. Reference conditions

- The calibration coefficients for the transfer chambers should be given in terms of air kerma per charge in units of mGy/nC, normalized to standard conditions of air temperature and pressure of T = 293.15 K, P = 101.325 kPa.
- The relative air humidity should be between 30% and 70% during the calibrations.
- The recommended focuses to chamber distances are 200 cm and 300 cm, in X-ray and ^{137}Cs beams respectively. The minimum beam diameter is 20 cm to ensure the uniform irradiation of the transfer chambers.

- The mark on the stem of the Extradin A6 chamber shall face to the radiation source.
- No correction for polarity should be applied and no correction for saturation is needed if the air kerma rate is less than 200 mGy/min.
- If any additional correction factors are applied they shall be stated in the Excel worksheets for data record and evaluation of comparison measurements (DOLF. 1403).

7. Work flow of the comparison

7.1. Calibrations at the IAEA

For the purpose of a constancy check, the IAEA repeats the calibrations before and after the return of the transfer chamber and uses the average of the two calibrations. Details of the IAEA calibration procedure are available in the Appendix of the IAEA Calibration Certificate [9].

7.2. Shipment

The IAEA schedules each comparison and informs the participating SSDL by email on the shipment of the package. The IAEA covers the shipment costs from the IAEA to the participants, including insurance (the insurance value of a transfer chamber is 3000 euro). All other potential costs associated with transportation (customs procedures, deposition fee etc.) shall be paid by the participant. Each participating SSDL is responsible for any damage that may occur within the borders of its country. Participants shall confirm the receipt of the transfer instrument and their correct functioning by email using the IAEA contact.

7.3. Preliminary tests

The procedure to verify the correct functioning of each transfer chamber is as follows.

- Measure your electrometer leakage together with the connected extension cable on the most sensitive range. Please note that the cable should be terminated with the protective cap when it is not used.
- Connect the cable of the transfer chamber to your extension cable, switch on the polarizing potential, wait at least 10 minutes and measure the leakage again.
- If the difference between the two leakages is more than 50 fA, report it to the IAEA.
- The sensitivities of the transfer chambers can also be checked in a radiation beam before a full calibration is made. The nominal sensitivity value of the Exradin A6 transfer chamber is $2.6 \cdot 10^{-5}$ C/Gy.

7.4. Calibration in the participant laboratory

The A6 type of transfer chamber shall be calibrated by the participant in the selected beam qualities from Table 2, using the routine calibration procedure. For each beam quality the calibration should be repeated twice. Between these repeated calibrations, the chamber shall be removed from the beam and repositioned.

The laboratory details and calibration data shall be reported to the IAEA using the data sheet DOLF.1403. The participating SSDL has four weeks to complete the calibrations and send the preliminary result by email using the data sheet. This data sheet should be send to IAEA before the chamber is send back.

If the preliminary comparison results are acceptable, the IAEA will inform the participant and asks to send back the transfer chamber together with the signed hard copy of the data sheet. The participant confirms the shipment by sending an email with an enclosed tracking number of the package to the IAEA contact.

If a preliminary comparison result is not within the acceptance limits, the IAEA informs the participant about it, without disclosing the details of the deviations. In this case, additional two weeks are available for the participant to investigate the measurements (setup, calculations, uncertainties etc. or repeat some measurements). However, after that, the transfer chamber should be sent back to the IAEA together with the signed hard copy of the data sheet.

7.5. Uncertainty estimation of the calibration coefficient

The participant should provide a full uncertainty budget of the calibration coefficient including all the components related to the applied calibration method and the environment at the SSDL. Uncertainty estimations for the comparison measurements performed by the participants should follow the GUM: Guide to the Expression of Uncertainty in Measurement [10], and include an estimation of those uncertainty components and values which are used for the relevant routine calibration. Participants can find help for preparing their individual uncertainty budgets in the IAEA diagnostic calibration uncertainty budgets in the Appendix of the IAEA Calibration Certificate.

7.6. Data evaluation and analysis

The IAEA calibration coefficients, N_{ref} , are the comparison reference values. The result of the comparison is $R = N_{part}/N_{ref}$, where N_{part} is the calibration coefficient determined by the participant. If the traceability of the participant differs from that of the IAEA (see Table 2), it has to be taken into account during the data analysis at the IAEA. Difference in the traceability chain will be taken into account by using the published data available about the differences between the relevant primary standards. If the traceability chain is the same as that of the IAEA, some uncertainty components are correlated and this is taken into account in the uncertainty calculation of R.

7.7. Acceptance limit

The comparison result R is considered to be acceptable if it is consistent (the expanded uncertainty of the R covers the unit value), and if $0.97 \leq R \leq 1.03$. This acceptance limit in terms of air kerma enables the participant SSDL to determine the conventional true values of operational quantities with less than 5% standard uncertainty for radiation protection level dosimeter calibrations including the additional typical 2% additional uncertainty of the conversion coefficients [3].

The ±3.0% acceptance limit for R is established taking into account (i) the available calibration uncertainties from the PSDLs; (ii) the reference quality of the Exradin type of transfer chambers; (iii) the good calibration practice at participant SSDL [11], and (iv) the uncertainty of the N_{ref} determination. Details of the IAEA uncertainties are available in the Appendix of the IAEA Calibration Certificate [9].

7.8. Acceptance of results

The final results are analysed after the re-calibration of the transfer chamber in the IAEA. The stability of the transfer chamber during the comparison is acceptable if the difference in the IAEA values before and after the transportation is less than 0.5%. If the stability of the transfer chamber is questionable after further analysis of the measurement data, a repetition of the comparison with another transfer chamber is offered by the IAEA.

If the comparison result is outside of the acceptance limit, the discrepancies require comprehensive investigation of the details before the IAEA issue the report of the comparison results. The process of reconciliation is a collaborative effort with the IAEA attempting to help the SSDL understand the cause of the deviation.

7.9. Report on the comparison

If the stability of the transfer chamber and the comparison results are acceptable, the IAEA prepares the comparison report for the participant. This report is provided only to the participant and the results are not disclosed to any third party. If a participant wants to publish the comparison as a separate publication, the IAEA will assist, upon on request.

8. References

[1] Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes http://www.bipm.org/en/cipm-mra/cipm-mra-text/

[2] IAEA/WHO Network of Secondary Standard Dosimetry Laboratories, SSDL Network Charter IAEA, Vienna (1999). http://www-naweb.iaea.org/nahu/dmrp/SSDL/charter.asp

[3] ISO 4037 Part 3 Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence, Geneva (1998)

[4] ISO/IEC 17025:2005 General requirements for the competence of testing and calibration laboratories, Geneva (2005)

[5] IEC 60846-1 2009 Radiation protection instrumentation – Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation –Part 1: Portable workplace and environmental meters and monitors, Geneva (2009)

[6] IEC 62387:2012 Radiation protection instrumentation - Passive integrating dosimetry systems for personal and environmental monitoring of photon and beta radiation, Geneva (2012).

[7] IEC 61526:2010 Radiation protection instrumentation – Measurement of personal dose equivalents Hp(10) and Hp(0,07) for X, gamma, neutron and beta radiations – Direc reading personal dose equivalent meters, Geneva (2010)

[8] ISO 4037 Part 1 Medical diagnostic X-ray equipment - Radiation conditions for use in the determination of characteristics, Geneva (2005)

[9] Appendix of the IAEA Calibration Certificate: Calibration of reference dosimeters for diagnostic radiology at the IAEA Dosimetry Laboratory http://www-naweb.iaea.org/nahu/dmrp/documents/DOLP_011_Appendix_3B.pdf

[10] ISO/IEC Guide 98-3:2008, JCGM 100:2008, Evaluation of measurement data- Guide to the Expression of Uncertainty of Measurement, Geneva (2008). http://www.bipm.org/en/publications/guides/gum.html

[11] IAEA Safety Report Series No. 16, Vienna (2000) Calibration of radiation protection monitoring instruments. http://www-pub.iaea.org/MTCD/Publications/PDF/P074_scr.pdf