Appendix 1 of DOLP.014
Technical protocol of the diagnostic radiology comparison
IAEA-SSDL bilateral comparisons for diagnostic radiology level air kerma measurement standards in X-ray radiation qualities

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. The main objective 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 diagnostic radiology 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 air kerma within acceptable limits, and to validate the traceability of the participants` diagnostic radiology standards. The comparison results, if desired by the SSDL, can be published in open-access literature for example as an annual summary report on the IAEA/SSDL bilateral comparisons. The published report can be 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 [3], and published its revised dosimetry CMC claims in the KCDB in 2016. The calibration of ionization chambers and the charge measurements performed at the IAEA are traceable to the appropriate primary standards at the BIPM, Physikalisch-Technische Bundesanstalt (PTB) and Federal Office of Metrology in Austria (BEV), respectively. The IAEA maintains a secondary standard for the determination of air kerma for the X-ray radiation qualities used in diagnostic radiology. It consists of Exradin A3, A4 and Radcal 10X5-6M type ionization chambers

and Keithley 6517 electrometers for the conventional and mammography radiation qualities.

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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 diagnostic radiology level calibration. 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, the preferred type of transfer chamber connection (TNC, BNC or M type) 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 chambers and radiation qualities

Each comparison is conducted through the calibration of one or two transfer chambers in terms of air kerma according to the laboratory procedure of the participant. The comparison parameters are the calibration coefficients of the transfer chambers. The technical details of the chambers are given in Table 1 and their photos in Figures 1 and 2. The X-ray radiation qualities to be used are listed in Table 2.

The participant may decide how many radiation qualities are used for the comparison, noting that to support conventional diagnostic radiology, computed tomography and mammographic CMC claims the relevant RQR, RQT, RQR-M and RQA-M radiation qualities, listed in Table 2, need to be involved. The W-Mo and W-Al mammography radiation qualities are established by an X-ray tube having tungsten anode with 0.066 mm Mo and 0.500 mm Al added filtration respectively, corresponding to the radiation qualities WMV and WAV qualities at the PTB, where the IAEA is traceable.

Table 1. Technical data for the transfer chambers

Type*	**Reference point**	**Nominal volume (cm^3)**	**Polarizing voltage**** **(V)**	**Wall thickness**	**Outer diameter (mm)**
Exradin A3, spherical chamber	chamber centre	3.6	+300	0.25 mm	19.5
Radcal RC6M, parallel plate chamber	Red line on the chamber side***	6	+300	0.7 mg/cm^2	43 (collector 30)

* Both chamber types comply with the IEC 61674 Standard [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.
*** This line can be taken to be 8.5 mm from the front of the plastic casing.

Table 2. Radiation qualities available for the comparison

Radiation quality*	**Tube voltage** (kV)	**Air kerma rate IAEA** (mGy/min)	**1st HVL IAEA** (mm Al)	**1st HVL IEC 61267** (mm Al)	**IAEA standard traceability**
Conventional diagnostic radiology qualities					
RQR-2	40	50	1.42	1.42	PTB
RQR-5	70	50	2.59	2.58	PTB
RQR-10	150	50	6.74	6.57	PTB
RQT-9	120	50	8.49	8.40	PTB
Mammography qualities					
RQR-M1	25	50	0.289	0.28	BIPM
RQR-M2	28	50	0.324	0.31	BIPM
RQR-M4	35	50	0.381	0.36	BIPM
RQA-M2	28	3	0.625	0.60	PTB
W-Mo	30	50	0.367	--	BIPM
W-Al	28	50	0.354	--	PTB

* see IEC 61267 [5]

Figure 1. Transfer chamber type Exradin A3

Figure 2. Transfer chamber type Radcal RC6M

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 focus to chamber distance and beam diameter are 100 cm and 10 cm, respectively, to ensure the uniform irradiation of the transfer chambers.
- The mark on the stem of the Exradin A3 chamber is to face the X-ray tube.
- No correction for polarity should be applied and no correction for saturation if the air kerma rate is less than 200 mGy/min.
- If any additional correction factors are applied they are to be stated in the Excel worksheets for data record and evaluation of comparison measurements (DOLF. 1401).

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 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 [6].

7.2. Shipment

The IAEA schedules each comparison and informs the participating SSDL by email of 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 2000 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 its country. Participants shall confirm the receipt of the transfer instruments 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, (use the attached triax-BNC adapter if required), 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 20 fA, report it to the IAEA.
- The sensitivities of the transfer chambers can be checked in a radiation beam before a full calibration is made. The nominal sensitivity values for the Exradin A3 and Radcal RC6M chambers are 0.13 and 0.21 nC/mGy, respectively.

7.4. Calibration in the participant laboratory

The transfer chambers shall be calibrated by the participant in its respective X-ray radiation qualities selected from Table 2, using the routine calibration procedure. The calibration should be repeated twice. Between these repeated calibrations, the chambers 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.1401. 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 chambers 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 to 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 [7], 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 radiology calibration uncertainty budgets (Appendix of the IAEA Calibration Certificate) [6].

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.

Differences 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 (i.e. the expanded uncertainty of the R covers the unit value), and if $0.975 \leq R \leq 1.025$. This acceptance limit ensures the SSDL to maintain reliable and accurate calibration services for diagnostic radiology level dosimeters.

The ±2.5% acceptance limit for R is established taking into account: (i) the available calibration uncertainties from the PSDLs; (ii) the reference quality of the transfer chamber; (iii) the good calibration practice at the participant SSDL, (see Table 6.8 of IAEA TRS 457 [8]); and (iv) the uncertainties of the N_{ref} determinations. Details of the IAEA uncertainties are available in the Appendix of the IAEA Calibration Certificate [6].

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 0.2%. 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 request.

8. References

[1] Measurement comparisons in the context of the CIPM MRA CIPM MRA-D-05 http://www.bipm.org/utils/common/CIPM_MRA/CIPM_MRA-D-05.pdf

[2] IAEA/WHO Network of Secondary Standard Dosimetry Laboratories, SSDL Network Charter IAEA, Vienna (1999).

[3] ISO/IEC 17025:2005 General requirements for the competence of testing and calibration laboratories, 2005

[4] IEC 61674 ed.2.0 Medical electrical equipment - Dosimeters with ionization chambers and/or semiconductor detectors as used in X-ray diagnostic imaging, (2012)

[5] IEC 61267:2005 Medical diagnostic X-ray equipment - Radiation conditions for use in the determination of characteristics, (2005)
[6] Appendix to IAEA Calibration Certificate: Calibration of reference dosimeters for diagnostic radiology at the IAEA Dosimetry Laboratory
[7] ISO/IEC Guide 98-3:2008, JCGM 100:2008, Evaluation of measurement data- Guide to the Expression of Uncertainty of Measurement, 2008
[8] IAEA Technical Report Series no. 457, Dosimetry in Diagnostic Radiology: An International code of Practice, (2007)