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 performance of laboratories providing calibrations, needs to be validated periodically and one method is to participate in an intercomparisons. In order to maintain confidence in the measurement capability it is recommended for SSDLs, providing this calibration service, to participate in this comparison programme at least once 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 measurement traceability by providing a link between the end users and the International measurement System (SI). The IAEA Dosimetry Laboratory acts as a central laboratory of the IAEA/WHO SSDL Network and provides calibration, audit, and comparison services for the Network members.

2. International measurement system

In 1999, the International Committee for Weights and Measures (CIPM) established a mutual recognition arrangement (CIPM MRA) [1] for Member States of the Metre Convention and Associate States of the General Conference of Weights and Measures. The CIPM MRA provides a possibility for the eligible SSDLs to get an international approval for their calibration and measurement capabilities (CMCs). To achieve international recognition within the CIPM MRA, a laboratory has to take part in a relevant measurement comparison and demonstrate the quality of their measurements through a quality management system (QMS) in line with the ISO/IEC 17025.

3. Purpose of the comparison programme

This ongoing diagnostic radiology comparison programme of the IAEA, in line with the objectives of the IAEA/WHO SSDL Network Charter [2], aims to validate the measurement capabilities of SSDLs for calibrations performed in terms of air kerma for diagnostic radiology level, is within acceptable limits and within the uncertainty claims of the SSDL. Based on the request, the exercise can be organized as a bilateral comparison (the results are restricted) or the participant may request to use the result to support their CMCs (the results are published).

The comparison results, if agreed by the participating SSDL, can be published in open-access literature for example as a biannual 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 17025:2017 standard [3] and has some of their dosimetry measurement capabilities published in the KCDB.

The calibration of ionization chambers and the charge measurements performed at the IAEA are traceable to the appropriate primary standards at the BIPM and Physikalisch-Technische Bundesanstalt (PTB). The charge measurements are traceable to the primary standards at the Federal Office of Metrology in Austria (BEV). The IAEA maintains secondary standards 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 model ionization chambers and Keithley 6517 electrometers.

IAEA contact information:
Email: ssdl@iaea.org
mailto:**Subject:** IAEA/SSDL Bilateral Comparisons for Diagnostic Radiology Dosimetry

Postal address:
IAEA laboratories Seibersdorf
Dosimetry Laboratory
Mr. Joao Cardoso
Friedenstraβe 1
A-2444 Seibersdorf
AUSTRIA

4.2. Participant

The IAEA comparison programme is an ongoing service for members of the SSDL Network. A participant laboratory should have a traceable reference standard and a calibration procedure for diagnostic radiology level calibrations. A comparison request form should be submitted to the IAEA to participate in the comparison programme. The number of accepted participants is limited and dependent on the workload and source availability. The laboratory which has not participated in the last 5 years, or its last result was not acceptable, has priority in the selection.

The request should include full contact information, a shipment address, the preferred type of transfer chamber connection (TNC, BNC or M type), the preferred time schedule and technical details of the comparison requested. If a participant intends to use this bilateral comparison result to support CMC claims it should also be stated in the request.

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 standard calibration procedure of the participant. The comparison parameters are the calibration coefficients of the transfer chambers and its associated uncertainty. The technical details of the chambers are given in Table 1 and their photos in Figures 1, 2 and 3. The X-ray radiation qualities to be used are listed in Table 2.

The participant decides on how many radiation qualities to request for the comparison according to the available radiation qualities and calibration services in their laboratories. 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 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)**	**Outer diameter (mm)**
Exradin A3, spherical chamber	chamber centre	3.6	+300	19.5
Radcal RC6M, parallel plate chamber	Red line on the chamber side***	6	+300	43 (collector 30)
PTW 34069!	chamber center	6	+300	42

* All 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.
! Used only for those with M type connectors.

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	2.57	2.58	PTB
RQR-10	150	50	6.71	6.57	PTB
RQT-9	120	50	8.47	8.4	PTB
Mammography qualities					
RQR-M1 (Mo+Mo 25)	25	50	0.28	0.28	BIPM
RQR-M2 (Mo+Mo 28)	28	50	0.32	0.31	BIPM
RQR-M4 (Mo+Mo 35)	35	50	0.37	0.36	BIPM
W+Mo 30	30	50	0.363	--	BIPM
W+Al 28	28	50	0.36	--	PTB

* see IEC 61267 [5]
**Actual HVL is defined in the final report.

Figure 1. Transfer chamber type Exradin A3

Figure 2. Transfer chamber type Radcal RC6M

Figure 3. Transfer chamber type PTW 34069

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, corrected 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 selected focus to chamber distance and beam diameter should ensure a uniform irradiation of the transfer chambers.
- The mark on the stem and the window of the RC6M chamber shall face the X ray tube.
- 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 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 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 of its country. Participants shall confirm the receipt of the transfer instruments and their correct functioning by email using the IAEA contact. The participants are responsible for the shipment costs related to the return of the transfer instruments back to the IAEA.

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 covered 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 chambers are Exradin A3: 0.13 nC/mGy, Radcal RC6M: 0.21 nC/mGy and PTW 34069: 230 nC/Gy.

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 their own 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 sent to the IAEA before the chamber is sent back.

After the preliminary comparison results are received and reviewed, the IAEA will inform the participant and request for the transfer chamber to be shipped back to the IAEA. The participant confirms the shipment by sending an email with a tracking number of the package to the IAEA contact.

If the 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.

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

environmental conditions 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 from the uncertainty budgets of the IAEA calibrations (Appendix of the IAEA Calibration Certificate) [6] or from the IAEA TRS 457 [8].

7.6. Data evaluation and analysis

The IAEA calibration coefficients, N_K, (IAEA), are the comparison reference values. The result of the comparison is $R = N_K(\text{SSDL}) / N_K(\text{IAEA})$, where N_K(SSDL) is the calibration coefficient determined by the participant. The IAEA secondary standard is traceable to the PTB.

If the traceability chain is the same as that of the IAEA, some uncertainty components are correlated but this is not taken into account in the uncertainty calculation of R. The expanded uncertainty of the comparison result, U_R, is calculated as a square sum of the uncertainties of the calibration coefficients and this is included in the standard comparison report. However, it is analysed and considered separately if the participant wants to use the comparison to support their CMCs. The degree of equivalence, as determined for the key comparison, is not calculated.

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 enables 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 at 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 not within the acceptance limits, 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 the participant wants to use their result to support their CMCs, the participant needs to provide a short

procedure of their measurement process to be used for issuing an appendix to the report. The comparison data may be published with the consent of the participants.

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 2nd edition, IAEA, Vienna (2018). https://ssdl.iaea.org/Home/SSDLNetworkCharter

[3] ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories, Geneva (2017)

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

[5] IEC 61267:2005 Medical diagnostic X-ray equipment - Radiation conditions for use in the determination of characteristics, Geneva (2005)

[6] Appendix to IAEA Calibration Certificate: Calibration of reference dosimeters for diagnostic radiology at the IAEA Dosimetry Laboratory https://ssdl.iaea.org/Content/DOLP_013_Appendix_2.pdf

[7] 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

[8] IAEA Technical Report Series no. 457, Dosimetry in Diagnostic Radiology: An International code of Practice, IAEA, Vienna (2007) https://www-pub.iaea.org/MTCD/publications/PDF/TRS457_web.pdf