EURAMET Project 1676

Pilot study of air kerma and tube voltage for new radiation qualities in x-ray imaging using XMMs

Proposed identifier in Appendix B of the BIPM key comparison database (BIPM KCDB):

EURAMET Project 1677

Supplementary comparison of air kerma standards for x-ray imaging

Proposed identifier in Appendix B of the BIPM key comparison database (BIPM KCDB):

EURAMET.RI(I)-S21

EURAMET Project 1678

Supplementary comparison of tube voltage for x-ray imaging

Proposed identifier in Appendix B of the BIPM key comparison database (BIPM KCDB):

EURAMET.RI(I)-S20

Start of the project:

1 November 2024

Technical Protocol

Pilot laboratories: STUK (reporting) and VSL (coordinating)

Paula Toroi

STUK – Radiation and Nuclear Safety Authority

Jokiniemenkuja 1, 01370 Vantaa, Finland

Tel. +358 40 152 0165

e-mail: paula.toroi@stuk.fi

Leon de Prez

VSL – National Metrology Institute

Thijsseweg 11

2629 JA DELFT, The Netherlands

Tel. +31 6 3111 9903

e-mail: ldprez@vsl.nl

1 Introduction

Within the scope of EURAMET EPM project 22NRM01 Traceability in Medical X-ray Imaging dosimetry (TraMeXI) it was agreed to organize two EURAMET supplementary comparisons (SC) and a pilot study (PS). These are carried out in existing RQR and RQT radiation qualities [1] and 3 newly proposed radiation qualities, so-called CCPRQ-qualities in accordance with the TraMeXI-project terminology. In line with the objectives of the TraMeXI-project, the measurements are performed with ionization chambers and x-ray multimeters (XMMs). The new CCPRQ radiation qualities were developed within TraMeXI to extend the range of well-defined RQR and RQT radiation qualities to better cover the clinical usage of added copper filtration ranging from 0.1 mm to 0.9 mm copper (Cu). The new radiation qualities also provide additional points for interpolation of calibration coefficients for radiation qualities with HVLs exceeding the current range covered by RQR and RQT. The radiation qualities selected for this comparison represent the range of HVLs which cannot be covered by the current reference radiation qualities but are relevant for the traceability of measurements performed by then end-users of these services.

For the supplementary comparisons, the quantities of interest are air kerma (K_a) for all radiation qualities, and the (maximum) peak tube voltage (kVp) for RQR radiation qualities, respectively in the unit gray (Gy) and kilovolt (kV). The pilot study investigates the quantities air kerma and peak tube voltage with additional XMMs compared to the supplementary comparison, and in all radiation qualities for all XMMs. In the pilot study, additional quantities provided by XMMs are also recorded and compared for quality control purposes. Special focus is given to measurements of HVL values to study if this could be included in future comparisons.

The aim of the comparisons is to verify that the participants can carry out calibrations in terms the comparison quantities by comparing the calibration coefficients and calibration factors of transfer instruments measured by the participants. These are established using participants' own methods and measurement procedures and reported as valid under given reference conditions. The comparison results, including the participants' names, will be published open-access. The SCs can be used as supporting evidence for the eligible participants to publish or maintain CMCs in the KCDB of the CIPM MRA.

The shape of the comparison consists of rounds, i.e. the transfer instruments will be circulated among participants in a single transport case. All measurements take place in the same time-window and reporting is restricted to the same time schedule.

The comparisons and pilot study are organized by the partners in the TraMeXI-consortium, under EURAMET TC-IR. This technical protocol is prepared according to the EURAMET guides on comparisons [2].

2 Comparisons and pilot study

2.1 Overview

This protocol describes three independent comparisons:

- **EUR-1676: a pilot study (PS) as a comparison of air kerma and peak tube voltage (kVp)** in four RQR, two RQT [1] and three new CCPRQ radiation qualities with XMMs. Additional measurement registrations and comparisons will be done for half value layer (HVL) and other parameters. This PS can be used as an additional information to support CMC claims if the results and uncertainties enable it. Special focus is given to measurements of HVL to study if this quantity could be included in future comparisons.

- **EUR-1677: a supplementary comparison (SC) of air kerma, K_a, or air kerma rate, $\dot{K}_a$,** respectively in the unit Gy or Gy/s in four RQR, two RQT [1] and three new CCPRQ radiation qualities with two ionization chambers as transfer instruments. This SC can be used as supporting evidence to publish or maintain CMCs in the KCDB of the CIPM MRA for the quantity air kerma for x-ray radiation qualities between 50 kV and 120 kV.
- **EUR-1678: a supplementary comparison (SC) of peak tube voltage (*kVp*)** in the unit kV in four RQR radiation qualities [1] using two x-ray multimeters (XMMs) as transfer instruments. This SC can be used as supporting evidence to publish or maintain CMCs in the KCDB of the CIPM MRA for the quantity tube voltage for x-ray radiation qualities between 50 kV and 120 kV.

For all measurements environmental conditions will be recorded and reported.

2.2 EUR-1676: Pilot study

The quantities of interest for the pilot study are air kerma and tube voltage as described for the supplementary comparisons. Determination of the calibration coefficients and calibration factors takes place according to the same procedures described for these comparisons. The exceptions are the applied correction factors for influence quantities and the unit of the instrument reading for the air kerma measurement, which are dependent on the type of instrument. Additional XMMs are included in the pilot study. Reference values obtained in the supplementary comparisons for air kerma and tube voltage will, where applicable, be also used as reference values for the pilot study.

For the remaining registrations such as the HVL the comparison, the reference value will be determined by the laboratory using their own method described in their quality system. The comparison reference value for the calibration coefficient is calculated as an average of the results from all participants and this is defined during the analysis phase of the pilot study.

2.3 EUR-1677: Supplementary comparison in terms of air kerma (-rate)

The quantity of interest is air kerma K_a in the unit gray (Gy) and air kerma rate, K_a-rate ($\dot{K}_a$) in the unit gray per second (Gy/s). The comparison is based on the determination of the ionization chamber calibration coefficient for air kerma, N_K in the units mGy/nC, which is numerically equivalent to (mGy/s)/nA for air kerma rate.

Participants establish a reference value for air kerma, K_a, or air kerma rate, $\dot{K}_a$, at their facilities in accordance with their own procedures. This can be done either with primary or calibrated secondary standards. A transfer ionization chamber is calibrated with the participant's calibration set-up such that the calibration coefficient for the instrument N_K is established as:

$$N_K = \frac{K_a}{M_{participant}}$$

or (1)

$$N_K = \frac{\dot{K}_a}{I_{participant}}$$

Here $M_{participant}$ and $I_{participant}$ are respectively collected electrical charge, in nC, and measured electrical current, in nA, in the ionization chamber, corrected for influence quantities. These corrections are based on the reference conditions given in section 3.4. The participants should apply all these corrections according to their own procedure and report them with their uncertainties. This means that when the measurement condition is the same as the reference condition, the correction is unity, and an uncertainty contribution can be reported. The participants are responsible for correct transfer and traceability of the electrical units applicable for the electrometer system, such as charge, current and bias voltage and, if applicable, the time measurements.

2.4 EUR-1678: Supplementary comparison in terms of tube voltage

In practice the quantities used for the measurement of x-ray tube potential are the maximum peak tube voltage, *kVp* hereafter noted as V_{peak}, and practical peak voltage, *PPV*, both expressed in the unit kilovolt, kV. The values of these quantities are considered numerically identical for an ideal constant potential x-ray generator, i.e. no ripple. For this comparison, the quantity to be reported is the peak tube voltage, V_{peak}, in the unit kilovolt (kV). The comparison is based on the determination of a calibration factor in terms of peak tube voltage, N_{TV}, per XMM for the indicated value of the XMM. The transfer instrument must be run in *kVp* mode.

Participants are asked to establish a reference value for peak tube voltage, V_{peak}. In case that the participant performs a measurement of *PPV* or the mean tube voltage instead, the conversion to the V_{peak} can be assumed unity, as long as the reference conditions on the generator ripple have been met (see section 3.4). An additional Type B uncertainty will be added for this scenario, to be determined by the participant. If the reference conditions on the generator ripple are not met at the participant's laboratory, the participant shall apply a conversion factor with the related uncertainty.

In the scope of the comparison, V_{peak} can also be derived from the maximum photon energy E_{max} (in keV), e.g. determined by a spectrometric measurement, by the equation:

$$V_{\mathrm{peak}} = \frac{E_{\mathrm{max}}}{e} \tag{2}$$

where e is the elementary charge.

A transfer XMM is calibrated with the participant's calibration set-up such that the calibration factor for the instrument N_{TV} is established as:

$$N_{TV} = \frac{V_{\mathrm{peak}}}{M} \tag{3}$$

Here M is the XMM reading with respect to the given quantity, if applicable, corrected for influence quantities. These corrections are based on the reference conditions given in section 3.4. The participants should apply all these corrections according to their own procedure and report them with given uncertainties.

3 Design

3.1 General requirements

Prior to participation each laboratory needs to ensure and confirm that their reference standard and calibration set-up is in good working condition to provide the claimed measurement capabilities for the quantity of interest at the subjected radiation qualities. The participants are expected to perform the measurements according to the time schedule. It is essential that all participants respond directly to all communication of the coordinating pilot lab. If for some reasons, an institute cannot perform the measurements within the required time window and it still wishes to participate, the institute needs to contact the coordinating pilot lab immediately. If the participant fails to communicate swiftly it can be excluded from the comparison.

3.2 Radiation qualities

The radiation qualities used in the comparisons and pilot study are provided in Table 1. RQR and RQT radiation qualities are established in accordance with IEC 61267: 2005 [1]. The new CCPRQ-qualities, introduced for the purpose of this comparison are established based on the procedures described for RQC radiation qualities, but with the deviating copper filtration as described in Table 1.

Table 1. Radiation qualities relevant for the comparisons. The RQR- and RQT-qualities, including the tolerances, are defined in [1]. The RQT and CCPRQ are referred to as the corresponding RQR radiation qualities with additional copper (mm Cu) filtration. The pilot study comprises measuring with an XMM the quantities air kerma, tube voltage and, additionally, the formal registration of other quantities (indicated with +).

quantities **PS**	quantity **SC: K_a**	quantity **SC: *TV***	RQ series	RQR ID	tube voltage /kV	RQR add. mmCu	1^{st} HVL /mm[1]
K_a, *TV*, +	K_a	*TV*	RQR	3	50	0	1.78
K_a, *TV*, +	K_a	*TV*		5	70	0	2.58
K_a, *TV*, +	K_a	*TV*		8	100	0	3.97
K_a, *TV*, +	K_a	*TV*		9	120	0	5.00
K_a, *TV*, +	K_a	-	RQT	8	100	0.20	6.9
K_a, *TV*, +	K_a	-		9	120	0.25	8.4
K_a, *TV*, +	K_a	-	CCPRQ	5	70	0.90	-[2]
K_a, *TV*, +	K_a	-		8	100	0.90	-[2]
K_a, *TV*, +	K_a	-		9	120	0.90	-[2]

[1] values from IEC 61267: 2005 [1]

[2] not given because these will be collected and compared within the scope of the SCs and PS.

3.3 Transfer instruments

The instruments used in the SC comparison are considered to perform as reference class instruments for their type. The additional XMMs in the PS comparison are not necessarily type tested but all transfer instruments used for these three comparisons were shown to be stable and linear by experience. Any established calibration coefficients of the transfer instruments have previously not been made publicly available outside the calibration laboratory.

Stability of the transfer instruments is evaluated based on the stability measurements at several times during the course the comparison at the measuring pilot laboratory (see section 3.6). The performance of the transfer instruments is evaluated based on stability measurements. This will be evaluated as part of the uncertainty in the comparison results.

The manufacturer, type, serial number and owner, including technical (operating) details of the instruments are presented in Appendix 2 and in the Annex.

3.4 Reference conditions

The calibration coefficients and factors for the transfer instruments must be corrected to reference conditions. The reference conditions depend on the type of transfer instrument, ion chamber or XMM, and their sensitivity to influence quantities. The reference conditions are valid for the calibration coefficients and factors as reported for the comparison measurements and given in Table 2.

Table 2. Reference conditions for air kerma (K_a) and peak tube voltage (V_{peak}).

quantity	symbol	reference value	allowed range[1]
kerma rate /(mGy/min)	K_a-*rate*	-	1 – 200
source detector distance /cm	*SDD*	100	80 – 150
Generator voltage ripple[2]	*r*	constant potential	0.1 %[2]
field size diameter /cm	*F*	10	8 – 15
temperature (detector) /°C	*T*	20	15 – 26
pressure (detector) /kPa	*p*	101.325	80 – 110
relative humidity /%RH	*RH*	50	20 – 80
bias voltage[1] /V	V_{bias}	300	-
collecting electrode polarity[1]	*pol*	negative	-

[1] correction factors to be applied if necessary
[2] for *kVp* comparison only, the uncertainty contribution due to ripple depends on the tube current
[3] ion chamber only (K_a), relative to chamber wall

The source detector distance, *SDD*, is defined as the distance between the x-ray focus and the detector reference point according to the manual. The field size, *F*, is defined as the distance between the 50 % penumbra fall-off. For measurements carried out between 20 %RH and 80 %RH, no additional correction for relative humidity is needed. For ion chambers and kerma rates smaller than 200 mGy/min, no correction for recombination loss needs to be applied. For the measurements at the participants, if the ion chamber is supplied with a bias voltage and the polarity of the collecting electrode (compared to that of the thimble) is set as stated in Table 2, no additional corrections for ion recombination loss and polarity effects need to be applied. Any deviations or additional corrections used, should be reported.

3.5 Reference value

One participating primary standards laboratory, here referred to as linking laboratory, provides the reference value for the comparisons (see Table 3). The linking laboratory has CMCs for the low- and medium energy x-ray CCRI-radiation qualities. Their primary standards, traceability and applied methods are validated in comparisons, BIPM.RI(I)-K2 and -K3. For the radiation qualities used in this comparison, the linking laboratory performs their measurements according to the same procedures as for the most recent key-comparisons. All radiation qualities in the comparisons study are within the range covered by the CCRI radiation qualities based on *HVL* and tube voltage.

For peak tube voltage, the traceability of the linking laboratory is based on internal traceability to their electrical department which has CMCs for electrical potential in the unit kilovoltage, kV, supported by key comparisons, EURAMET.EM-S36. Traceability is established by calibrated x-ray generators via a calibrated high-voltage divider that provide the x-ray tube voltage.

Traceability is based on the available CMCs for the respective physical quantities and on proven (internal) traceability to relevant (inter)nationally accepted primary standards on which their units are based. With respect to the radiation qualities, as far as they are not mentioned in the respective KCDB, the same internal standards and methods are used to obtain the calibration coefficient.

The reference values will be established separately for each transfer instrument and the values reported by the participants will be compared to the reference value by the ratio of average calibration coefficients of the linking lab and the participant, e.g. $N_{link}/N_{participant}$.

If for some reason, during the course of the comparison, the linking lab is not able to participate or perform measurements, then one of the other primary standards labs will be appointed to provide the reference value for comparison.

3.6 Stability checks

For each comparison round, the transfer instruments will start at and return to the laboratory performing the repeat measurements, i.e. the coordinating pilot lab (see Table 3). Variation in the repeat measurements will be used to evaluate the stability of transfer instruments and the associated uncertainty during the comparison. In case where the transfer instruments are property of any of the participating laboratories and stability data for these instruments are available, these data can be used. During the course of the comparison, the coordinating pilot lab will perform their quality assurance methods for stability checks of the calibrations in their facilities. If for some reason the coordinating pilot lab is not able to perform the calibrations or only part of the calibrations, another lab will receive the equipment for a second time and will become the laboratory performing the repeat measurements for this purpose.

3.7 Measurement procedure

Each participant will proceed following their own calibration procedure(s) and in agreement with their quality management system to determine the calibration coefficients of the transfer instruments. A short description of the calibration set up and procedures will be part of the comparison report as provided by the participants. At least the following procedures have to be followed:

- The transfer instruments shall be placed in the laboratory at least 12 hours before the measurements start to let them adjust to the climatic conditions. A complete measurement should consist of at least 5 repeated single measurements and the mean value should be taken as the result.

- If time allows, the measurement should be repeated at least once during the course of the participant's measurement window.

3.8 Traceability

It is required that the participants achieve the best uncertainty that is regularly available for their calibration service regarding the performance of the transfer instrument. It is the responsibility of each participant to assure the shortest traceability route to calibrated reference standards in accordance with their stated uncertainty budget. A description of the traceability route for each participant as provided by the participant will be part of the comparison report.

3.9 Uncertainty budgets

An uncertainty budget shall be provided in accordance with the Guide to the Expression of Uncertainties in measurements [3], with its final uncertainty expressed as an expanded combined uncertainty, $k = 2$. Components of the uncertainty budget shall be provided as relative values. A spreadsheet is provided for the uncertainty budget, into which each laboratory is recommended to add components according to their procedures. This spreadsheet will form the basis for a generalised uncertainty budget in the comparison report for comparability of the claimed measurement capabilities for the participants.

4 Implementation

4.1 Pilot laboratories

The comparison is run by two pilot laboratories, given in Table 3, a reporting pilot lab and a coordinating pilot lab. The pilot labs are also participating in the comparison.

The reporting pilot laboratory is responsible for the overall execution of the comparisons and pilot study. However, all of its tasks are delegated to the coordinating pilot lab with the exception of reception and collection of the measurement results from the participants and submission of the final comparison report to the EURAMET TC-IR chair.

The coordinating pilot laboratory is responsible for the coordination of the comparison, the preparation of the transfer instruments for initial transport and the repeating of the measurements. The coordinating pilot lab will communicate (any changes to) the comparison schedule and monitor the actual location of the equipment and progress of the comparison measurements. The coordinating pilot laboratory will also prepare the draft of the comparison report.

4.2 Requirements

The participants in the supplementary comparisons and pilot study have provided proof of their capabilities to realize the beam qualities by submitting their beam characteristics for each radiation quality tube voltage and HVL shown in Table 1 before the start of this project.

4.3 Linking laboratory

The linking laboratory for this comparison is given in Table 3. If for any unfortunate reason the linking laboratory is not able to perform the comparison measurement, e.g. due to failure of the calibration equipment, another PSDL with the appropriate metrological traceability, within the participants will be assigned this task.

4.4 Coordinating pilot laboratory

The coordinating pilot laboratory for this comparison is given in Table 3. If for any unfortunate reason the measurement laboratory cannot repeat the measurement, e.g. due to failure of the calibration equipment during the course of the comparison period, another participant will be assigned this task.

4.5 Participants

Among the participants' laboratories, national metrology institutes and designated institutes are primary standards dosimetry laboratories (PSDLs) and secondary standards dosimetry laboratories (SSDLs). Table 4 lists the participants and their contact emails. In the Appendix, the complete contact details for the participants are presented. Table 4 presents the traceability of participating laboratories.

Table 3. Participants of the comparison.

Institute	Country	Contact person	Email
STUK[1]	Finland	Paula Toroi	paula.toroi@stuk.fi
VSL[2]	Netherlands	Leon de Prez	ldprez@vsl.nl
PTB[3]	Germany	Stefan Pojtinger	stefan.pojtinger@ptb.de
CMI	Czechia	Vladimír Sochor	vsochor@cmi.cz
EEAE	Greece	Argiro Boziari	rgiro.boziari@eeae.gr
ENEA	Italy	Alessia Ciccotelli	alessia.ciccotelli@enea.it
IMBiH	Bosnia and Herzegovina	Amra Sabeta	amra.sabeta@met.gov.ba
INM	Moldova	Siarhei Saroka	Siarhei.Saroka@inm.gov.md
IST	Portugal	Ana Fernandes	anafer@ctn.tecnico.ulisboa.pt
TENMAK	Turkey	Erinç Reyhanioğlu	erinc.reyhanioglu@tenmak.gov.tr
VINS	Serbia	Miloš Živanović	milosz@vin.bg.ac.rs

1. reporting pilot laboratory
2. coordinating pilot laboratory, responsible for performing the repeat measurements
3. linking laboratory, providing the reference values

Table 4. Traceability of calibrations at the participating laboratories in terms of air kerma and peak tube voltage for medical x-ray imaging.

Institute	Traceability air kerma	Type of ionisation chamber	Traceability peak tube voltage	Type of standard
STUK	PTB	Exradin A3	FGH, Eng. & Test GmbH, Ge STUK	HV divider DCV-meter spectrometry (HP-Ge)
VSL	VSL	free air chamber	VSL	spectrometer (HP-Ge)
PTB	PTB	free air chamber	PTB	HV divider DCV-meter
CMI	PTB	Radcal RC60	CMI	spectrometer (CdTe)
EEAE	PTB	Exradin A3	PTB	HV divider DCV-meter
ENEA	ENEA	free air chamber	FGH, Eng. & Test GmbH, Ge	HV divider DCV-meter
IMBiH	PTB via IAEA	Exradin A3	Parker Medical GiCi, US	HV divider DCV-meter
INM	PTB via IAEA	Exradin A3	-	-
IST	PTB via IAEA	PTW 34069	-	-
TENMAK	PTB	PTW 34069-2,5	FGH Eng. & Test GmbH, Ge	HV divider DCV-meter
VINS	PTB via IAEA	Exradin A3	PTB; VINS	HV divider DCV-meter; spectrometer (CdTe)

4.6 Time schedule

The time schedule of the comparison is shown in Table 5. The comparison starts on the 1st of November 2024. The Draft B comparison report, as an official project deliverable, must be available before the end of the TraMeXI-project, i.e. May 2026. The measurements are planned to be finished in December 2025.

In case of any delay of the comparison, the reporting pilot lab will start drafting the comparison report with the participants' results available on 1st January 2026 and after informing all participants.

The result of the comparison will be initially communicated through a Draft A report, to be finished before March 2026, to be followed by a Draft B report before May 2026.

Each participant is responsible for responding in time to comparison related correspondence. In case of any delay in shipment, the coordinating pilot labs must be informed immediately. Due to the strict time schedule, if a participant fails to respond in time, they can be excluded from the comparison. This could mean that they will not receive the instruments to be calibrated. Also, if a participant fails to respond in time (i.e. within two weeks) to the coordinating or reporting pilot laboratory during the drafting period for the comparison, the participant can be excluded from the comparison where the final decision rests with the pilot laboratories.

Table 5. Proposed comparison events.

Event	Due date (2025 - 2026)
transfer standards to measuring pilot laboratory, VSL	01 August 2024
Comparison measurements (Table 6)	01 November 2024 – 31 December 2025
Reporting deadline	31 December 2025
Chamber stability measurement reported	31 December 2025
Draft A delivered to participants	28 February 2026
Comments by the participants to draft A	20 March 2026
Draft B available	31 May 2026
Final report available	Depending upon comments by evaluators

4.7 Comparison schedule

The detailed comparison schedule is shown in Table 6 and Figure 1. It consists of two rounds. The first round will start in November 2024 at the coordinating pilot lab and the last measurements of the second round are scheduled to be finished in December 2025 at the coordinating pilot lab. The transfer instruments are calibrated once at each participant. The arrival of the equipment is before the first calendar-day of the month. The equipment should be shipped at the latest on the 21st of the month (non-EU) or the 25th of the month (EU). This means that measurements take place between the 1st and 20th calendar-day of the month. Measurements that cannot be performed in time should be skipped. Table 7 shows the detailed schedule for the measurement time window at each participant. If the laboratory can perform the measurements in a shorter time, they can send the package earlier. If a laboratory is not able to use their slot, the order can be changed, or they can be excluded from the comparison. In these cases, the time schedule can be modified and the total time can be decreased.

Table 6. Schedule for the comparison measurements. The coordinating pilot lab is indicated in **bold**, the linking lab is indicated in *italics*.

Institute	Measuring time window
VSL	**November 2024**
STUK	December 2024
PTB	January 2025
CMI	February 2025
ENEA	March 2025
EEAE	April 2025
IST	May 2025
VSL	**June 2025**
VINS	July 2025
IMBiH	August 2025
INM	September 2025
TENMAK	October 2025
VINS[1]	November 2025
VSL	**December 2025**

[1] At the end of Round 2, VINS only serves as a stopover for transfer back to VSL.

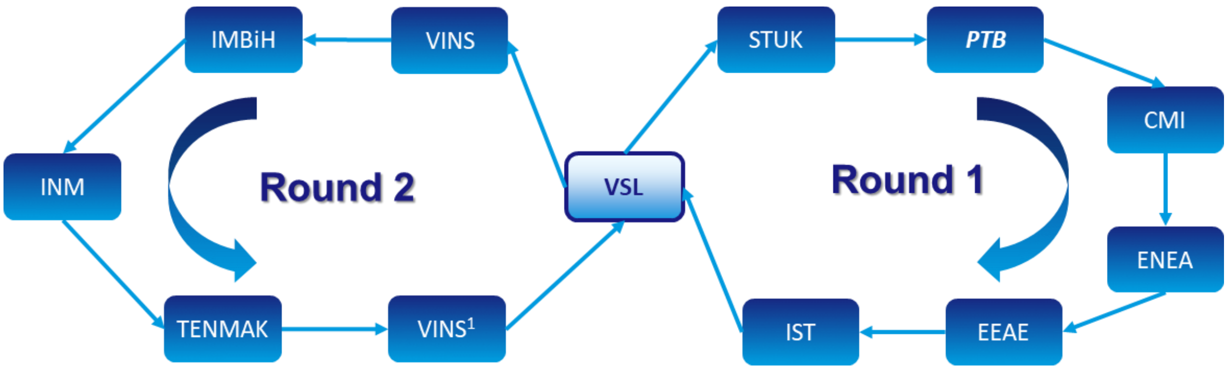

Figure 1. Schematic illustration of the comparison course. [1]At the end of Round 2, VINS only serves as a stopover for transfer back into the EU, i.e. VSL. [1] At the end of Round 2, VINS only serves as a stopover for transfer back to VSL.

Table 6. Schedule for the comparison measurements at the participant.

By calendar day	Activity
-15	Contacted by coordinating pilot lab to confirm readiness
-7	Deadline to confirm readiness
< 1	Arrival of equipment
1	Start of measurements
15	Contact coordinating pilot lab on progress of the measurements
20	Finishing of measurements
22	Finishing shipment preparation
23	Shipment pick-up by transport company
+ 4 w	Reporting of results to reporting pilot lab within 4 weeks

4.8 Transport

Each participant is responsible for the delivery of the equipment to the next participant on time. The coordinating laboratory will communicate pick-up and arrival of the equipment at the respective participant.

4.8.1 Shipment

Two weeks before the shipment, by the 15th calendar day of the month, i.e. during the period that the measurements are taking place, the coordination pilot lab is informed by the participant on the progress of the measurements. At this moment the participant needs to prepare the shipment to the next participant. After positive response, the coordinating laboratory will inform the next participant on the arrival of the equipment, who will need to confirm to be ready for the planned measurement period. If the next participant does not respond swiftly to the emails of the coordinating pilot lab, it is assumed that they are not ready to receive the equipment and another participant will be contacted to perform their measurements. If it cannot be guaranteed that the shipment will be sent to the participant at a later time and the participant can therefore be excluded from the comparison at this point.

If the participant, responsible for sending the equipment has not finished in time (despite having received the equipment on time), and fails to communicate this to the coordinating pilot lab, their results can be excluded from the comparison report.

Once the measurements are completed, the participant must pack the equipment in its transport case according to the instructions (the Annex) and make all the arrangements for shipment and customs. Shipment shall be arranged using a courier agreed on with the coordinating pilot lab. The shipment method should have a maximum shipment time of 5 working days. It is required to take photographs of the chambers before and during packing and shipment. These photos must be sent to the coordinating pilot laboratory who must also be informed when the equipment has been picked up for delivery by the transportation company. This must include an estimated time of arrival and track-trace code. If, for any reason, shipment is delayed or other complications arise, the measuring pilot labs shall be notified immediately. The measuring pilot lab will inform the receiving participant on the status of the comparison schedule and their role in this.

The deadline for shipment for each participant is 7 working days before the end of the month. This is to ensure that the equipment will arrive in time at the next participant. If the participant fails to ship the equipment in time, they can be excluded from the comparison.

4.8.2 Receiving the instruments

Two weeks (15th calendar day of the month) before receiving the instruments, the participant will receive an email with the details of shipment and reception of the instruments. The participant must reply to this email immediately for the shipment to proceed. If the participant fails to reply swiftly to a reminder, the shipment will not take place and the instruments will be shipped to another participant that is ready for their measurements.

The transfer standards are packed in a transport case as described in Appendix 2 and the Annex. After receiving the transport case the coordinating pilot lab needs to be informed and a visual check for any damage needs to be performed. Photos must be taken prior to opening and during the process of unpacking the instrument up-until the instrument condition and serial number are visible. These photos must be sent, together with a confirmation of receipt, to the coordinating pilot lab. If there is any indication of damage or broken instruments, the participant should contact the coordinating pilot laboratory to discuss further actions.

4.9 Insurance and liability

The participant is responsible for good care of the instruments during their stay at the participant’s facilities. Prior to any measurement verification of correct functioning needs to be performed. The participants are expected to handle the instruments with the care. When an instrument if defective or damaged the coordinating pilot laboratory must be contacted immediately in order to find appropriate solutions. The damage or failure of the instruments because of transport is the liability of the laboratory which sends the instruments and should be covered by an insurance by the sender.

5 Evaluation of results

After all measurement results are available, they will be shared with the coordinating pilot lab, which will conduct the final analysis together with the reporting pilot laboratory. The results will be analyzed for single instruments. The comparison results will be based on the agreement of the participant with the linking laboratory:

$$\Delta_{participant} = \left(\frac{N_{participant}}{N_{linking}} - 1\right) \times 100\ \% \tag{3}$$

This will be evaluated with an E_n-score [4] defined as:

$$E_n = \frac{\Delta_{participant}}{U} \tag{4}$$

where U is the combined expanded uncertainty (k = 2) of the participant result ($U_{participant}$) and that of the linking result ($U_{linking}$) in %. An absolute value of the E_n-score smaller or equal to 1 is generally considered to give a satisfactory comparison result.

Further details for data analysis may be discussed among the participants based on the Draft A report. In the reporting of the results, document “CIPM MRA-G-11 [5]: Measurement comparisons in the CIPM MRA, Guidelines for organizing, participating and reporting” will be followed.

6 Reporting

6.1 Reporting to pilot lab

Each laboratory will report calibration coefficients and their uncertainties accompanied with an uncertainty budget for those calibrations according to the Guide to the Expression of Uncertainties in measurements [3]. One primary standards dosimetry laboratory (PSDL) with a related CMC-entry in the KCDB will be acting as linking lab to the international system of standards via the BIPM. The linking lab will provide the comparison reference values.

All participants, including the coordinating pilot laboratory, VSL, will send their results to the reporting pilot laboratory within 4 weeks after the measurements. The reporting pilot laboratory will send their own results to the CCRI Executive Secretary within 4 weeks of completing the measurements before receiving any of the participants' results. I.e. the report on measurements of the reporting pilot laboratory will be sent to the EURAMET TC-IR chair and to the Executive Secretary of CCRI before the first participant has submitted his report to the pilot laboratory. A common spreadsheet template for reporting the results will be provided to each participant in addition to the technical protocol.

For each transfer instrument a comparison result will be determined. If these agree within their uncertainty, the final comparison result is evaluated as the mean of the individual comparison results obtained with the transfer standards. Depending on the stability of the transfer instruments during the course of the project (see section 3.6), a transfer instrument can be excluded if needed. The first measurement of the coordinating pilot lab will be their submitted value for the comparison.

6.2 Reporting deadlines

All results shall be received by STUK by 31 December 2025. If a participant has not sent their results (calibration coefficients and uncertainty budgets) by the due date, the participant will be excluded from the comparison.

If, at the time of the reporting deadline, there are results from at least one third (i.e. 4 out of 11) of the participating laboratories, these available results will be reported. The result of participants, that have not reported their results at this moment, can be excluded from the comparison report. If less than 4 institutes have reported their results at the reporting deadline, the reporting pilot laboratory is responsible for finding an appropriate solution or to cancel the comparison.

The participants are requested to describe their irradiation facilities including manufacturer and type of the x-ray equipment, including information about its specifications such as voltage ripple, anode angle, inherent filtration, and age.

Before the draft A report is finished and communicated to the participants, the reporting pilot laboratory will confirm from all participants that they will participate using the provided measurement results. If sufficient information is not provided by the participant, e.g. on measurement results or uncertainty budgets, the reporting pilot laboratory will contact the participant to obtain the required details. In this case a participant is expected to answer within one week. Failing to report or answer in time can result in exclusion from the comparison.

6.3 Publication of results

If no objection against the publication was raised before the finalization of draft A, the results established in the final report of this comparison can be published without further agreement from or notification to the participants. By taking part in this project, the participants agree that their results can be made publicly available. If a participant objects against publication of its results, it should indicate this prior to publication so that their results should be removed from the report.

The final comparison report will be published as an online EURAMET comparison report and submitted as a publication in Metrologia as joint authorship. The order of authors will be alphabetically with the main contributors as the first and last authors.

7 Extension of the comparison

Any participants that have been excluded from the comparison during the course of the comparison, or any eligible laboratories that were not able to join the current comparison, are free to organize a new comparison, based on the current project or parts of it. Support from the current participants cannot be guaranteed.

8 References

[1] IEC 61267:2005, Medical diagnostic X-ray equipment - Radiation conditions for use in the determination of characteristics, International Electrotechnical Commission, 2005 https://webstore.iec.ch/publication/5079

[2] EURAMET Guide on Comparisons, EURAMET Guide No. 4, Version 2.0 (04/2021) https://www.euramet.org/Media/news/G-GNP-GUI-004_Guide_on_Comparisons_web.pdf

[3] JCGM (Joint Committee for Guides in Metrology). Evaluation of measurement data – Guide to the expression of uncertainty in measurement. JCGM 100:2008, GUM 1995 with minor corrections. First edition, September 2008.

[4] ISO 13528: 2022, Statistical methods for use in proficiency testing by interlaboratory comparison, International Standards Organization, 2022 https://www.iso.org/standard/78879.html

[5] CIPM MRA-G-11, Measurement comparisons in the CIPM MRA -Guidelines for organizing, participating and reporting, version 1.1, 18/01/2021 https://www.bipm.org/documents/20126/43742162/CIPM-MRA-G-11.pdf/9fe6fb9a-500c-9995-2911-342f8126226c

9 Appendix 1: Participants' contact and shipment details

9.1 STUK/Finland

STUK – Säteilyturvakeskus, Dosimetrialaboratorio
Jokiniemenkuja 1
01370 Vantaa
Finland
Contact: Paula Toroi
Tel: +358 40 152 0165
e-mail: paula.toroi@stuk.fi

9.2 VSL/Netherlands

VSL, National Metrology Institute
Thijsseweg 11
2629 JA DELFT
The Netherlands
Contact: Leon de Prez
Tel: +31 631119903
e-mail: ldprez@vsl.nl

9.3 PTB/Germany

Physikalisch-Technische Bundesanstalt (PTB)
Bundesallee 100
38116 Braunschweig
Germany
Contact: Stefan Pojtinger
Tel: +49 531 592-6250
e-mail: stefan.pojtinger@ptb.de

9.4 CMI/Czechia

Czech Metrology Institute, Regional Branch Prague
Department of Ionizing Radiation
Radiova 1288/1a
10200 Praha
Czech Republic
Contact: Vladimír Sochor
Tel: +420 266020285; +420 607853049
e-mail: vsochor@cmi.cz

9.5 EEAE/Greece

Greek Atomic Energy Commission, Ionizing Radiation Calibration Laboratory
Patriarxou Grigoriou and Neapoleos
15341 Agia Paraskevi
Attika Greece
Tel:+302106506765
Email: argiro.boziari@eeae.gr

9.6 ENEA/Italy

ENEA-INMRI Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti
C.R. Casaccia
Via Anguillarese, 301,
00123 Roma RM
Italy
Contact:Alessia Ciccotelli
Tel:+39 0630483357
E-Mail:alessia.ciccotelli@enea.it

9.7 IMBiH/Bosnia and Herzegovina

IMBiH– Institute of Metrology of Bosnia and Herzegovina
Branilaca Sarajeva 25
71000 Sarajevo
Bosnia and Herzegovina
Contact: Vedrana Makaric/Amra Sabeta
Tel: +38766141909 or +38762576628
e-mail: vedrana.makaric@met.gov.ba

9.8 INM/Republic of Moldova

National Metrology Institute of the Republic of Moldova (INM-MD)
28, Eugen Coca str.
MD 2064 Chisinau
Republic of Moldova
Contact: Siarhei Saroka
Tel: +37322238446
e-mail: Siarhei.Saroka@inm.gov.md

9.9 IST/Portugal

Instituto Superior Técnico - Loures
Campus Tecnológico e Nuclear, E.N. 10, km 139.7
2695-066 Bobadela
Portugal
Contact: Ana Fernandes
Tel: +351 219946338
e-mail: anafer@ctn.tecnico.ulisboa.pt

9.10 TENMAK/Turkey

Türkiye Energy, Nuclear And Mineral Research Agency
Nuclear Energy Research Institute
Saray Mahallesi Atom Caddesi No 27, 06980
Kahramankazan – Ankara
Türkiye
Contact: Erinç Reyhanioğlu
Tel: +90 5327866272
e-mail: erinc.reyhanioglu@tenmak.gov.tr

9.11 VINS/Serbia

Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia (VINS)
Department for Radiation and Environmental Protection
Mike Petrovića Alasa 12-14
11351 Vinča, Belgrade
Serbia
Contact: Miloš Živanović
Tel: +381 63 467 561
e-mail: milosz@vin.bg.ac.rs

10 Appendix 2: Transfer instruments

10.1 X-ray multimeters, XMMs (EUR-1676 and EUR-1678)

PTW NOMEX Multimeter T11049, sn. 101929	(owner: PTW)
RaySafe X2 R/F, sn. 322710	(owner: RaySafe)
RTI Mako R with F probe, sn. 9765011-00	(owner: RTI Group)
Radcal AGMS-D+, sn. 43-2512	(owner: IBA Dosimetry)

10.2 Ionization chambers (EUR-1677)

Exradin A3 sn. XR240813	(owner: Standard Imaging)
Exradin A3 sn. XR240814	(owner: PTB)
Exradin A3 sn. XR240810	(owner: VSL), stays at VSL

Table 7. Transfer instruments used for the pilot study and supplementary comparisons.

<table>
<tr><th>pilot study</th><th colspan="2">supplementary comparisons</th></tr>
<tr><th>EUR-1676</th><th>EUR-1678</th><th>EUR-1677</th></tr>
<tr><td>V_{peak} & K_a</td><td>V_{peak}</td><td>K_a</td></tr>
<tr><td colspan="2">RTI Mako R, F-probe, 9765011-00</td><td>Exradin A3, XR240813</td></tr>
<tr><td colspan="2">PTW Nomex, 101929</td><td>Exradin A3, XR240814</td></tr>
<tr><td colspan="2">Radcal AGMS-D+, 43-2512</td><td></td></tr>
<tr><td>RaySafe X2, 322710</td><td></td><td></td></tr>
</table>

Instructions for packaging, transport and operation of the instruments is given in the addendum (Addendum_to_EUR-TraMeXI_SC.Ka_Sc.TV_PS_version_##).