**2024-07-08**

**EURAMET Project 1668**

**Key comparisons of air kerma standards in 137Cs radiation beams for radiation protection**

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

**EURAMET.RI(I)-K5.X**

**Technical Protocol**

*(accepted by EURAMET TC-IR and CCRI(I)*)

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# Objective and participants

The national metrology laboratories for dosimetry quantities of Spain (CIEMAT, the Spanish National Metrology Institute for Ionising Radiation), United Kingdom (NPL, The National Physical Laboratory UK), Sweden (SSM, Swedish Radiation Safety Authority), Norway (DSA, Norwegian Radiation and Nuclear Safety Authority), and Finland (STUK, Radiation and Nuclear Safety Authority have agreed to perform a comparison in terms of air kerma in 137Cs radiation protection beams. CIEMAT and NPL are Primary Standards Dosimetry Laboratories (PSDL) and the Nordic laboratories are Secondary Standard Dosimetry Laboratories (SSDLs).

In the project two transfers chambers will be circulated among participants and each laboratory will report calibration coefficients and their expanded uncertainties for those chambers in terms of air kerma. CIEMAT as a primary dosimetry laboratory will provide a link to the BIPM.RI(I)-K5 comparison throughout this comparison.

This technical protocol prepared by the laboratories specifies the procedure to be followed in this particular dosimetry comparison. The technical protocol is prepared according to the BIPM technical protocol for the BIPM ongoing key comparison BIPM.RI(I)-K5. The purpose of a comparison is to establish the degrees of equivalence by comparing the calibration results of the participating laboratories, without requiring each participant to adopt precisely the same conditions of measurement. The protocol, therefore, specifies the procedures necessary for the comparison, e.g. reference conditions, but not the procedures used in the calibration of the laboratories being compared.

The comparison is performed simultaneously with a supplementary comparison of air kerma standards for 241Am and 60Co beam qualities.

## Objective of the comparison

The objective of the comparison is to support the ionising radiation CMCs of SSM, DSA and STUK in the dosimetry branch for the quantities of air kerma/rate from a 137Cs source at radiation protection levels. For NPL the objective of the comparison is to support the scope at the national accreditation organisation which requires validation of methods by means of interlaboratory comparisons.

## Participants

Table 1 lists the participants. In Appendix I, the complete contact details for the participants are presented. Table 2 presents the traceability of participating laboratories in terms of *Kair* in 137Cs radiation protection beams.

Table 1. Participants of the project.

|  |  |  |  |
| --- | --- | --- | --- |
| **Institute** | **Country** | **Contact person** | **e-mail** |
| CIEMAT | Spain | Néstor Armando Cornejo Díaz | nestorarmando.cornejo@ciemat.es |
| NPL | United Kingdom | Martin Kelly | martin.kelly@npl.co.uk |
| SSM (pilot, reporting) | Sweden | Linda Persson | [linda.persson@ssm.se](mailto:linda.persson@ssm.se) |
| DSA | Norway | Per Otto Hetland | per.otto.hetland@dsa.no |
| STUK (pilot, measuring) | Finland | Jussi Huikari | jussi.huikari@stuk.fi |

Table 2. Traceability of calibrations at the participating laboratories in terms of *Kair* in 137Cs radiation protection beams.

|  |  |  |
| --- | --- | --- |
| **Traceability** | | |
| **Institute** | **137Cs** | **Type of standard** |
| CIEMAT | CIEMAT | Primary |
| NPL | NPL | Primary |
| SSM | VSL | Secondary |
| DSA | IAEA | Secondary |
| STUK | PTB | Secondary |

# Transfer instruments

Two reference ionisation chambers will be used as transfer instruments for this comparison. Two chambers will be used to minimize the risk of potential transfer instrument breakage during the comparison. If a chamber suffers a failure during the comparison, the comparison will be continued with the other chamber, which is listed in this protocol. If there are results from a half of the participating laboratories (before chamber failure), results will be reported in the final publication. The chambers are the property of STUK and SSM. The chamber stability will be evaluated over the period of the comparison from the measurements carried out by STUK in the framework of the comparison. These chambers have not been calibrated outside the laboratory before this comparison. No electrometer is circulated, and laboratories shall use their own electrometers and cables for performing the measurements during the comparison and ensure traceability for their ionisation current measurements and high-voltage setting applied to the ion chamber. The details of the electrical measurement equipment (e.g. measurement mode) shall be specified when reporting results.

The technical details of the chambers are listed in table 3.

Table 3. Technical data of the transfer chambers.

|  |  |  |
| --- | --- | --- |
| **Chamber type** | **EXRADIN A6**  **Ref. 92716** | **EXRADIN A6**  **Ref.92716** |
| Serial number | XQ200282 | XQ152602 |
| Geometry | spherical | spherical |
| Wall material | C552 | C552 |
| Wall thickness  [g cm-2] | 3,0 | 3,0 |
| External diameter / mm | 120 | 120 |
| Nominal volume / cm3 | 800 | 800 |
| Reference point for the air kerma measurements | Geometric center of the chamber | Geometric center of the chamber |
| Polarising voltage of a chamber | +400 V on collector (central) electrode, 0 V on chamber wall (collecting negative charge)  (if +400 V on collector is not available: -400 V on chamber wall, 0 V on collector electrode) | +400 V on collector (central) electrode, 0 V on chamber wall (collecting negative charge)  (if +400 V on collector is not available: -400 V on chamber wall, 0 V on collector electrode) |
| Connector type | Triax BNC (male) (2 lug) | Triax BNC (male) (2 lug) |

# Measurement Procedure

The dosimetry laboratories are expected to ensure that their reference standard is in perfect working order prior to the comparison. When the participant receives the transfer chambers, they shall perform a visual check for any damage and verify correct functioning prior to any additional measurements. If it seems that the chambers are broken, the participant should contact the piloting laboratories SSM and STUK to discuss further actions.

Each participant will proceed following their own calibration procedure(s) according to their quality management system to determine the calibration coefficients of the transfer chambers in terms of air kerma. Furthermore, each laboratory may add needed correction factors for calibrations and these correction factors shall be reported when reporting results.

## Radiation qualities and quantities

The radiation quality used in the comparison is 137Cs (see point 3.2). The quantity used for the comparison is the air kerma defined according to ICRU85a. The relevant data from ICRU90 should be used for the primary standards from participants in the comparison and for primary standards against which the secondary standards have been calibrated.

## Reference conditions

Radiation fields for 137Cs radiation protection fields should fulfil ISO 4037-1:2019 and ISO4037-2:2019. The reference points for chambers are described in table 3. For the chamber setup, the marking on the stem shall be oriented facing the radiation source and placed free in air. In order to reduce the uncertainty due to the beam radial non-homogeneity, the diameter of the useful beam cross-section should be at least twice the chamber diameter. To minimize the contribution of scattered radiation, the presence of scattering objects in the useful beam (except required holders of light materials and small sections, the chamber stem and the temperature probe) should be reduced as far as possible.

The calibration coefficients for the transfer chambers should be given in terms of air kerma per charge in units of Gy/C and corrected to standard conditions of air temperature and pressure; *T* = 293.15 K and *p* = 101.325 kPa. The reference conditions for relative humidity (RH = 50%) will not be corrected for the measurements performed between 20 and 80% RH. Each laboratory will use their own equipment to measure environmental conditions and ensure traceability for those measurements.

## Reference value

CIEMAT as linking laboratory to BIPM.RI(I)-K5 comparison will provide the reference value for this comparison. All other results will be compared to this value. None of the participating laboratories are traceable to CIEMAT for the comparison quantity. The reference values will be determined separately for each chamber and the values reported by other laboratories will be compared to the reference value by calculating a ratio between calibration coefficients, e.g. *NK,LabX/NK,CIEMAT.*

## Determination of the calibration coefficient

Each laboratory details their own procedure or refers to international practices/ guidance followed when performing the calibration.

Typically for air kerma free in air, SSDLs establish the reference air kerma rate at their facilities in accordance with their own procedure following an equation such as:

(1)

where *NK*,PSDL is the calibration coefficient used by the given SSDL in order to reach traceability to a primary standards laboratory for air kerma in a 137Cs radiation protection field, and where *I*SSDL is the ionisation current measured by the SSDL with an electrometer system with traceability to electrical standards. In accordance with ISO 4037-2:2019, *I*SSDL is corrected to standard conditions of air temperature and pressure (T=20 °C and p=101.325 kPa), and if needed for relative humidity, chosen for the comparison. For the other corrections to *I*SSDL a laboratory shall proceed according to their own procedure and may include e.g. the electrometer correction factor, correction for leakage, correction for distance, correction for volume etc. All corrections used shall be reported in addition to the final results.

CIEMAT and NPL will determine calibration coefficients in the same way as the SSDLs, except that realization of the quantity at CIEMAT and NPL is based on their primary air kerma standards, based on graphite-walled cavity ionisation chambers as described in: Kessler C. et al., 2024 and Bass GA. et.al. 2019.

Each laboratory positions a transfer chamber at the reference set-up such that the calibration coefficient for the transfer chamber *N*K,lab is computed as:

(2)

where is the air kermarate under reference conditions at the laboratory, and where *IM,lab* is the signal from the tr ansfer chamber measured by the laboratory at the specific reference polarity stated in table 3 using their own electrometer systems with traceability to electrical standards. *IM,lab* is corrected to standard conditions of air temperature and pressure, and if needed for relative humidity, chosen for the comparison.

## Uncertainty budgets

In addition to calibration coefficients each participant shall provide the related detailed measurement uncertainty budget. Each participant shall describe the main components of the uncertainty in the budget at the level of one standard uncertainty and provide the final expanded combined uncertainty, *k*=2. The detailed uncertainty budget shall be provided in accordance with the Guide to the Expression of Uncertainties in measurements (JCGM, 2008) with corresponding level of confidence. Components of the uncertainty budget shall be provided as relative values [%]. It is expected that in these measurements, participants achieve the best uncertainty that is regularly available. The report Excel sheet includes an example form for the uncertainty budget, into which each laboratory is recommended to add components according to their procedures.

## Reporting the results

The measuring pilot laboratory (STUK) will send their results to the CCRI Executive Secretary Vincent Gressier (vincent.gressier@bipm.org) within 6 weeks of completing their measurements. Other participants will send their results (calibration coefficients and uncertainty budgets) to STUK ([jussi.huikari@stuk.fi](mailto:jussi.huikari@stuk.fi)) within 6 weeks of completing their measurements. The last measurement set by STUK is used only to check stability of the transfer chambers and it will not be published as a separate result. STUK will deliver data for chamber stability within 2 weeks of completing their last measurement set, after which SSM will begin data analysis. All results shall be received by SSM by the beginning of February 2025. If a participant has not sent their results (calibration coefficients and uncertainty budgets) by the due date, the laboratory will be excluded from the comparison.

A common Excel template for reporting the results will be provided to each participant in addition to the technical protocol.

Before the draft A is delivered to participants, the pilot laboratory (SSM) will confirm with all participants that they will participate using the given results. If there is not enough information available, e.g., uncertainty budgets don’t include all needed components to estimate/calculate degrees of equivalence for the comparison, the pilot laboratory (SSM) reserves the right to contact the participant to obtain the particular details. In this case a participant is expected to answer quickly (i.e. within two weeks) to the pilot laboratory in order to keep the comparison on track.

## Evaluation of the results

After the reporting pilot laboratory (SSM) has received all results, i.e., at beginning of February 2025, the results of the participating laboratories will be evaluated in comparison to CIEMAT’s results and link the result to the BIPM reference value BIPM.RI(I)-K5.

CIEMAT provides a reference value for this comparison with a link to BIPM.RI(I)-K5. The results will be analysed for single chambers. Degrees of equivalence will be calculated in terms of comparison results (calibration coefficients and uncertainties) according to CCRI(I)/17-09 instructions. In general, and for the specific case of the quantity air kerma, the degree of equivalence of each laboratory, with respect to the key comparison reference value, is evaluated as follows separately for each transfer chamber:

(3)

in which *RCIEMAT,BIPM*represents the results of CIEMAT in BIPM comparison (Kessler C et al, 2024).

The variance of *Rlab* is:

(4)

where *u*lab is the combined standard uncertainty of the calibration coefficient reported by the i-th participating laboratory; *u*BIPM is the combined standard uncertainty of the BIPM’s air kerma rate standard (*K*BIPM) as described in the BIPM.RI(I)-K5; *u*tr is the uncertainty arising from the transfer chamber; *u*CIEMAT represents the uncertainty arising from the linking mechanism (the components to be considered in *u*CIEMAT are indicated in Table 1 of the report CCRI(I)/17-09 for the case of a direct BIPM comparison) and

*fj* are weighting factors related to correlating components (i.e. the W/e and the stopping power ratio graphite to air) , which will be evaluated during the analysis.

In equation (4) *utr* combines the stability of the transfer chambers over the period of the comparison and the variation in the ratios for a specific chamber. *utr* will be calculated based on standard uncertainties *Rlab* for each laboratory according to CCRI(I)/17-09. Additionally, the pilot laboratory (STUK) will perform several measurements for each transfer chamber and *utr* may also be calculated and adjusted based on these (e.g. if STUK repeatability data is significantly higher than *utr*, more than two standard deviations). If *utr* is significantly higher (more than two standard deviations of repeatability data ) for a specific chamber, that chamber will be excluded from the comparison.

In equation (4) *uCIEMAT* includes the uncertainty of non-statistical components, which are not cancelled out via the linking mechanism. To ease estimation of the *u*CIEMAT, the CIEMAT’s measurements conditions in this comparison are as close as possible to those used in the CIEMAT-BIPM comparison, BIPM.RI(I)-K5.

For the case of the 2 transfer chambers (*j* = 1 to 2) which will be circulated in this comparison, equation (3) for the quantity air kerma becomes:

(5)

The degree of equivalence for the participating laboratory is:

(6)

and its expanded relative uncertainty is *Ulab*=2*uR,lab*.

Further details for data analysis may be discussed among the participants on the basis of the Draft A report.

In the reporting of the results, document “CIPM MRA-G-11: Measurement comparisons in the CIPM MRA, Guidelines for organizing, participating and reporting” will be applied.

# Course of comparison

## Transport and time schedule

The laboratory should make all the arrangements for safe transport of the transfer standards once measurements have been completed. Each participating institute is responsible for its own costs regarding the measurements. The standards won’t be insured by the pilot, and each participant is responsible for the good care of the chambers in their facilities and good packing of the chambers for the subsequent shipment. Each participant is responsible for the chambers within their country and onward shipment until the receiving laboratory has received the equipment. Shipping outside/back to EU, i.e., to Norway and NPL is done by STUK and DSA and they will agree on the cost allocation. SSM will cover the shipping and cost to/back to CIEMAT. Shipment shall be made using a courier. It is recommended to take photographs of the chambers before the shipment.

The transfer standards are packed in a Pelican protection box together with a complete information of the devices (i.e. technical protocol) including information about the manufacturer, type, serial number, size, weight and technical data needed for their operation. The information also includes weight and size of the whole package as well as value of the equipment for customs purposes.

The measurements will start in summer 2024 at STUK and the last measurements are scheduled to be performed in December 2024 at CIEMAT. Table 4 summarises the proposed schedule of the comparison measurements and table 5 summarises the course of the comparison events. Due to two participants outside EU/EEC the course will have two loops. STUK will perform a stability check of the chamber after the first and second loop i.e STUK will perform three sets of measurements (in the beginning, in the middle between loops and in the end of the comparison).

Table 4. Proposed schedule for the comparison measurements.

|  |  |  |
| --- | --- | --- |
| **Institute** | **Measuring period** | **Date of chamber leaving to next participant** |
| STUK | June-August 2024 | August 16th, 2024 |
| DSA | August-September 2024 | Sept 13th, 2024 |
| NPL | October 2024 | October 11th, 2024 |
| STUK, stability check | October2024 | October 25th, 2024 |
| SSM | October 2024 | November 22th, 2024 |
| CIEMAT | December2024 | December 20th, 2024 |
| STUK, stability check | 13-17 January 2025 |  |

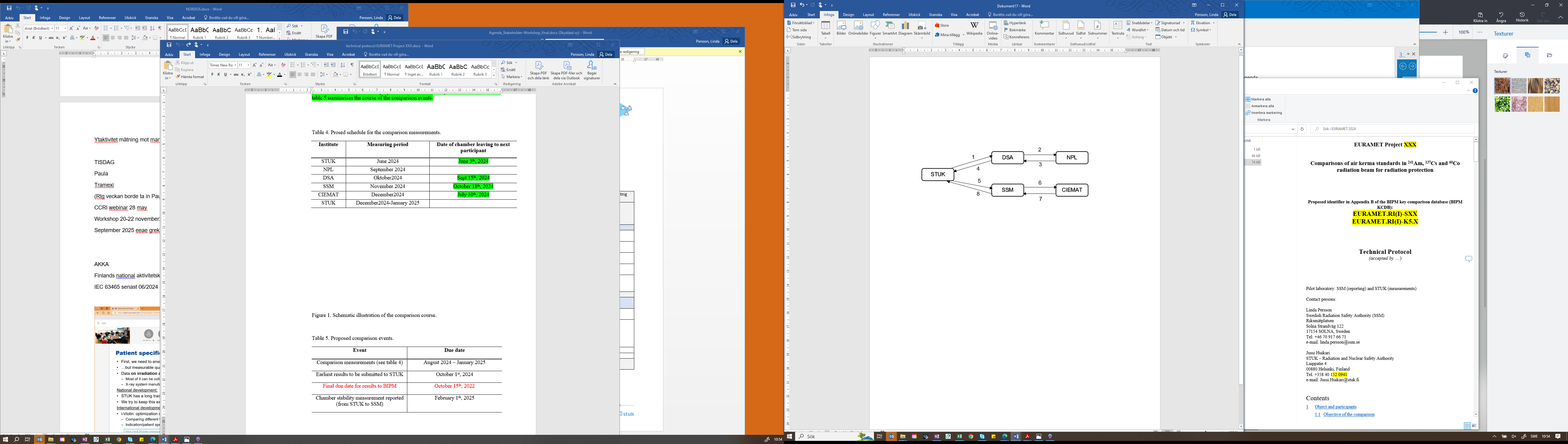


Figure 1. Schematic illustration of the comparison course.

Table 5. Proposed comparison events.

|  |  |
| --- | --- |
| **Event** | **Due date** |
| Comparison measurements (see table 4) | June 2024 – January 2025 |
| Final due date for STUK results to BIPM | October 1st, 2024 |
| Earliest results to be submitted to STUK | October 3st, 2024 |
| Chamber stability measurement reported (from STUK to SSM) | February 1th, 2025 |
| Draft A delivered to participants | March 31st, 2025 |
| Comments by the participants to draft A | April 31st, 2025 |
| Draft B available | June 30th, 2025 |
| Final report available | Depending upon comments by evaluators |

# References

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ISO 4037-2:2019 X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy

Part 2: Dosimetry for radiation protection over the energy ranges from 8 keV to 1,3 MeV and 4 MeV to 9 MeV

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.

Kessler C., Roger P. and Cornejo Díaz N., Key comparison BIPM.RI(I)-K5 of the air-kerma standards of the CIEMAT, Spain and the BIPM in 137Cs gamma radiation. Metrologia 61 2024.

# Appendix I: Complete addresses of the participants (used for shipment)

**CIEMAT/Spain**

Postal address:

Laboratorio de Metrología de Radiaciones Ionizantes (LMRI)

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)

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**DSA / Norway**

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Norwegian Radiation Protection Authority (DSA)

Department of Emergency Preparedness and Response

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**NPL/United Kingdom**

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# Appendix II. Pictures of transfer chambers.

Figure of Exradin A6 XQ152602. The white dot is showing the reference direction of the chamber.



Figure of connector Exradin A6 XQ152602



Figure of Exradin A6, sno XQ200282. The red dot is showing the reference direction of the chamber.