EURAMET Key Comparison EURAMET.PR-K3.2020

Luminous Intensity

Technical Protocol

Version: 1.3

Version History

V0.1: Initial draft based on TP of CCPR-K3, EURAMET.PR-K3 and COOMET.PR-K3

V0.2: Discussion at TG meeting (2020-06-02)

V0.3: Include comments from PTB and VSL, description of Wi 41/G added (chapter 3), Appendices added, crosslinks added

V0.4: Includes comments MIKES-Aalto, discussion at TG meeting (2020-06-09) and some cleaning up

V0.5: Appendix B and D transformed into Excel Workbooks, Appendix C (measurement uncertainties) rewritten, Paragraph 4.5, Chapter 6 (measurement uncertainty) cleaned up, Chapter 7 (Data analysis) and references added. Chapter 1 (Introduction) completed.

V0.6: Discussion at TG meeting (2020-06-18) and some cleaning up

V0.7: Input from PTB, and CSiC and some editorial changes and discussions the TG meeting (2020-06-26)

V0.8: cleaned version of V0.7

V0.9: Input from VSL.

V1.0: cleaned version of V0.9, distributed to participants and CCPR-WG-KC on 2020-08-02 for commenting and approval.

V1.1: Feedback from CCPR WG KC, discussions in the TG on 2020-11-10, updating of time schedule due to COVID19 pandemic

V1.2: TG proposal of updating the time schedule due to COVID19 pandemic

V1.3: new participant added (UzNIM/Uzbekistan)

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1. Introduction

1.1. This Technical Protocol (TP) describes the "second round" EURAMET key comparison of luminous intensity of incandescent lamps.

1.2. The comparison was agreed by EURAMET.TC-PR on its annual meeting on 2020-01-29 at INM-MD, Chisinau, Moldova.

1.3. The selection of the pilot follows the guidelines of EURAMET.TC-PR. METAS's offer to pilot the comparison was accepted by EURAMET.TC-PR on 2020-01-29.

1.4. The technical protocol is based on the technical protocol of CCPR.K3.2014, EURAMET.PR-K3 and COOMET.PR-3. It has been drafted by the comparison task group and agreed by all the participants and the CCPR WG KC.

1.5. In respect to the earlier key comparisons on luminous intensity the following adaptations are made:

a. Only one type of lamps is used (i.e. WI 41/G) allowing efficient processing of the comparison with the large number of participants.

b. All the lamps shall be at the pilot lab at the specific date. The date was chosen to coincide with the next annual meeting of the EURAMET-TCPR at pilot's laboratory allowing hand carried the lamps by the participants.

c. The minimum number of lamps per participants is three. It is however recommended to provide four lamps; the maximum are six lamps.

d. The electrical current of the lamps has to be adjusted to have a correlated colour temperature in a range of 2750 K to 2950 K. The tolerance interval is larger than required by CCPR.K3 however the expanded measurement uncertainty shall be considered when defining the acceptance interval. The expanded measurement uncertainty of the correlated colour temperature has to be reported.

e. The data analysis will be performed using the matrix formulation according the recent CCPR-G6 draft.

2. Organization

2.1. Participations, Selection

2.1.1. According to CCPR-G6 [1] the pilot laboratory sends out a call for participants to all member NMIs of the Group of RMOs as defined in the G4-Guidelines [2] for preparing CCPR Key comparisons (plus any other invited NMIs) with the information of the comparison quantity.

2.1.2. A call of participants went out to the technical committees on photometry and radiometry of EURAMET and CCPR on 2020-02-03. 20 laboratories signed into the comparison, two of them from outside EURAMET (i.e. VNIIOFI, SASO).

2.2. **Participants, Contact Information**

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2.3. Task Group

2.3.1. The following NMIs accepted to support the pilot laboratory (METAS) with drafting the technical protocol and thus form the task group (TG): CMI, IO-CSIC, LNE-CNAM, MIKES-Aalto, PTB, VSL, DMDM.

2.4. Link laboratories

2.4.1. Each link laboratory is asked to calibrate its luminous intensity lamp-transfer standards such that the luminous intensity values represent the magnitude of its luminous intensity unit at the former time, when the laboratory participated in the CCPR key comparison. It is important to notice that the maintained luminous intensity values of a link laboratory transfer the former values, independent of today's values, which might be changed due to new realisations of the luminous intensity unit or because of improved measurement techniques.

2.4.2. The following laboratories will act as link laboratory to CCPR-K6.2014: METAS, PTB, and IO-CSIC

2.5. Comparison, General Procedure and Measurement Sequence

2.5.1. By their declared intention to participate in this key comparison, the laboratories accept the general instructions and the technical protocols written down in this document and commit themselves to strictly follow the procedures. This is demonstrated by signing EURAMET Form G-OPS-FRM-012 (Participation in EURAMET comparison) by a representative[1] of the participating NMIs.

2.5.2. Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants and the CCPR-WG-KC.

2.5.3. The comparison will be carried out by the measurement of a group of transfer standard lamps.

2.5.4. The comparison will take the form of a star-type comparison. The artefacts (lamps) will initially be measured by the participant laboratory. They will then be transported to the pilot laboratory for the measurements by the pilot. The standard lamps will then be returned to the participant laboratory to carry out a repeated measurement to monitor drift (Participant–Pilot–Participant).

2.5.5. Each participant will use a separate set of lamps to minimise the effects of ageing and travel. This will also allow the participant to maintain a post-comparison record of the compared quantity.

2.6. Comparison, Timetable

2.6.1. Please note that many of the completion dates given in this table are based on the maximum lead time suggested by the CCPR guidelines [4, 6]. If any activities can be completed at an earlier date, the completion dates for the subsequent activities may also be moved to an earlier date. The pilot may have to set earlier specific deadlines in order to reach the final dates.

Action (responsible)	**Deadline**	**Date of completion**
Preparation		
Call for Participants (EURAMET.TC-PR chair)	2020-02-03	2020-02-03
Deadline to reply to Call (EURAMET/COOMET)	2020-04-15	2020-04-15
Formation of the task group (EURAMET.TC-PR)	2020-05-15	2020-05-15
Preparation of technical protocol (TG)	2020-07-15	2020-08-02
Approval of technical protocol (Participants)	2020-08-30	2020-08-31

[1] Please note that it is up to the institute, based on its regulations, who is authorised to sign this form.

Approval of comparison by authorized representative of the institute (Form G-OPS-FRM-012)	2020-09-30	2020-10-15
Approval of technical protocol by CCPR-WG-KC	2020-09-30	2020-09-30
Measurements		
Next decision on maintaining/updating the time schedule	2021-04-30	2021-05-04
Next decision on maintaining/updating the time schedule	2021-09-30	2021-11-01
1st round measurement by participants	2021-12-31	
Deadline for the participants lamps to be at pilot laboratory (participants), Participants are invited to carry the lamps earlier at the time of their convenience.	2022-01-27 (TC-PR Meeting)	
Reporting of the draft first round results to pilot using Appendix D	2022-01-27	
Appendix A (description of measurement setup) and Appendix B (record of operation time) to be sent to the pilot	2022-01-27	
Lamps measured by pilot (pilot)	2022-04-30	
Transport of lamps back to participants (participants), updated Appendix B sent to the participant	2022-05-31	
2nd measurement by the participants (participants)	2022-09-30	
Reporting of the final measurement data to pilot (participants) using Appendix D	2022-10-31	
Appendix C (uncertainty budget) and updated Appendix B to be sent to the pilot	2022-10-31	
Evaluation & Report		
PreDraft A.1 (Verification of reported results) & replies by participants	2022-11-30	
PreDraft A.2 (Review of uncertainty budgets) & replies by participants	2023-02-28	
PreDraft A.3 (Review of Relative Data) & replies by participants	2023-04-30	
Draft A & replies by participants	2023-08-31	
Draft B & replies by participants	2023-10-31	
Approval by CCPR WG KC	2023-11-30	
Final report	2023-12-31	

2.6.2. In view of the large amount of work for the pilot laboratory and the need for a strict timetable to allow the comparison to take place, strict deadlines will be applied. If the deadlines can't be met the participant and their results may have to be excluded from the final report. Exclusion may also occur if the results are not available in time to prepare the draft report.

2.6.3. The decision of exclusion is made by all participants (simple majority ballot) upon proposal by the pilot after consultation with the Task Group.

2.6.4. In case of force majeure (i.e. pandemic, etc.) participants shall decide on updating the timetable upon proposal by the pilot after consultation with the Task Group.

2.7. Comparison Artefacts, Selection

2.7.1. In response to the Call for Participants one type of incandescent lamp will be used.

2.7.2. The measurement artefacts will be lamps of type Osram WI41/G.

2.7.3. Each participant shall supply a minimum of three, and maximum of six, four being the recommended number, aged and calibrated travelling standards.

2.8. Comparison Artefacts, Handling

2.8.1. The standard lamps should only be handled by authorized persons and stored and packed in such a way as to prevent damage.

2.8.2. No cleaning of any lamp windows or envelopes should normally be attempted.

2.8.3. If a traveling standard lamp appears to have been mishandled and either the pilot laboratory or the participant laboratory consider that cleaning appears to be required, the form in Appendix E should be used to communicate this information between the two laboratories.

2.8.4. If there is any unusual occurrence during operation of the traveling standard lamps, e.g. change of voltage, change in output, etc., the participant laboratory and the pilot laboratory should notify each other.

2.8.5. The pilot laboratory will inform the participants via e-mail when the measurements on the traveling standard lamps are completed to arrange a suitable date for dispatch.

2.9. Comparison Artefacts, Transportation

2.9.1. It is of utmost importance that the traveling standards be transported in a way they will not be lost, damaged or handled by un-authorised persons.

2.9.2. Packaging for the traveling standards should be suitably robust to protect the traveling standards from being deformed or damaged during transit. Each lamp must be clearly labelled to allow unambiguous identification.

2.9.3. Preferably, the traveling standards should be carried by hand between each participating laboratory and the pilot laboratory, either by personal road transport, sea, or in an aircraft cabin. However, recognising that this may result in high financial costs to participants and recognising that the lamps are fragile and may be subject to change in their characteristics from transportation, even if hand-carried, the shipping of carefully-packaged lamps via a postal service is accepted for this comparison. They should under all circumstances be marked as ‘Fragile’.

2.9.4. The shipping package should include a warning note that the package should only be opened by laboratory personnel, or under the guidance of laboratory personnel.

2.9.5. Detailed instruction for transporting/sending to the pilot and customs clearance can be found at METAS webpage (https://www.metas.ch/metas/en/home/dl/geraete-ans-metas-senden.html). It is strongly recommended to use an ATA carnet for the custom declaration.

2.9.6. Transportation is each participant’s responsibility and cost. Each participating laboratory covers the costs for its own measurements, transportation and any customs charges as well as for any damages to their lamps that may occur during transportation or at pilot's laboratory. The overall costs for the organisation of the comparison are covered by the pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the traveling standards during transportation. Appropriate insurance should be taken out by participating laboratories to cover the cost of replacement if any loss or damage occurs in transit.

2.9.7. If the traveling standards are shipped between the participant and the pilot, the participant should inform the pilot of the shipment date and the air waybill number as soon as possible after shipment.

The participant shall also inform the pilot concerning the shipping company and account number that are to be used to return the traveling standards to the participant.

3. Description of the Traveling Standards

3.1.1. The measurement artefact is a specially developed transfer standard lamp for luminous intensity: It is a commercially available gas-filled incandescent lamp of type OSRAM Wi 41/G (see Figure 1).

3.1.2. The design current according the manufacturers is 6 A and the design voltage 31.0 V. For the comparison a constant current supply at the value rated by the participant will be used.

3.1.3. The standard product has a E27 base.

3.1.4. The original manufacturer packaging of the lamp has a size of 310 mm x 160 mm x 165 mm (l x w x h) and a weight of about 390 g.

3.1.5. The lamp is designed with a filament arranged in one plane in a form of a meander. It is constructed so that the detector cannot see reflections from the envelope behind the filament or from any other part of the lamp. On one side, the conical glass bulb is provided with a light-tight mask with window in order to reduce the stray light from parts of the lamp that are not the filament.

Figure 1 : WI 41/ G (photograph © OSRAM)

3.1.6. On the first occasion that a new tungsten lamp is lit, its characteristics change quite rapidly over the first few hours of burning. After an initial period of operation (ageing), however, they tend to become more settled.

3.1.7. For the aging process the direct electrical current shall be similar than for the intended operation, and the polarity of the supply, once established, must not be changed. The aging process shall be monitored.

3.1.8. For the comparison, only sufficiently aged lamps shall be used.

4. Measurement Instructions

4.1. Traceability

4.1.1. All participants must be able to demonstrate independent traceability to the realization of the luminous intensity or make clear the route of traceability to the quantity via another named laboratory.

4.1.2. Auxiliary quantities shall be traceable to an international agreed realization of the corresponding SI-units.

4.2. Measurand

4.2.1. The measurand is the luminous intensity of an incandescent lamp in a specified direction from a defined point on a reference plane defined by the plane of the lamp filament. The luminous intensity shall be measured for the specified mechanical and electrical operating conditions for each lamp.

4.2.2. The luminous intensity of the traveling standards is typically determined by the measurement of the illuminance at a given distance. This distance shall be large enough with respect of the sizes of the source and the detector to minimize the uncertainty distribution in respect to averaging of both finite solid angles, respectively.

4.3. Measurement conditions

4.3.1. The measurements should be performed in suitable laboratory environment maintained at a temperature of 20 °C to 27 °C. The temperature and humidity of the laboratory during the time of the measurements shall be reported.

4.3.2. The traveling standards will operate with DC electrical power, with the positive (+) and negative (-) polarity terminals clearly marked for each lamp. If marking the lamp is difficult, this information shall be clearly indicated in the measurement report.

4.3.3. The correlated colour temperature (CCT) of the luminous intensity of the lamp at the given nominal electrical current shall be between 2750 K and 2950 K, and shall be determined by the participant and reported for each lamp. If the participant wishes instead to report the distribution temperature, it may do so. However, the pilot will consider both temperature descriptions equivalent for any spectral mismatch corrections.

4.3.4. The value of the related voltage shall also be indicated. This will enable initial evaluation of the lamp condition during operation, especially after travel.

4.3.5. The pilot laboratory is capable of mounting and aligning plain Osram WI41/G with E27 base.

4.3.6. The electrical and optical/geometrical conditions of their measurements must be specified (Appendix A), particularly with reference to Section 4.5, which describes the procedures to be used at the pilot laboratory. Any differences between the participant and the pilot procedures shall be discussed with the pilot prior to shipping of the lamps.

4.3.7. Basic geometric conditions:
- The lamp is mounted base down.
- The optical axis is horizontal and passes through the centre of the filament.
- The optical axis is perpendicular to the plane of the filament (Osram WI41/G)
- Distance from the lamp is measured from the centre of the filament.
- The photometric measurements shall take into account only the light passing through the rectangular opening in the black mask on the face of the Osram WI41/G lamp.

4.3.8. Basic electrical conditions:
- The nominal electrical DC current for operation which has been determined by the participant to

result in a CCT between in the tolerance interval of 2750 K and 2950 K for the photometric output of the lamp. The acceptance interval of the CCT shall be set considering the expanded measurement uncertainty of the CCT determination (k = 2). The actual CCT value and its standard uncertainty (k = 1) must be reported to the pilot.
- Defined electrical polarity at lamp contacts
- The warm-up time for each lamp as used by the participant and reported to the pilot.

4.4. Measurement procedures

4.4.1. Participants shall perform the measurements using the facilities and procedures that are normally used in their laboratories for their calibration services, while meeting the conditions of measurement specified by this technical protocol.

4.4.2. Care shall be taken to ensure that the lamps and packaging have sufficient time to acclimatise to the actual environment thus preventing any condensation.

4.4.3. Before use, the lamps shall be inspected for any damage or contamination to the lamp window, lamp base, or lamp mount. Any damage should be documented with photos and, if relevant, a drawing and the pilot and participant should immediately exchange this information using the form in Appendix E.

4.4.4. No parts other than noted within operating conditions belonging to specific lamps shall be removed from or connected to this lamp.

4.4.5. The nominal operational conditions and alignment procedures for each lamp as determined by the participants shall be followed and recorded. The details of the procedure should be described and reported to the pilot (Appendix A). A photograph of the experimental setup may be taken and added to the report.

4.4.6. After connecting the electrical power to the lamp, the prescribed warm-up procedure (Section 4.5.8) for each lamp shall be followed. The operational parameters for each lamp (specified in the lamp operating procedure) shall be recorded and compared with those supplied with the lamp. If these values are outside expected values for the lamp, the lamp shall be turned off and this information exchanged between the participant and the pilot laboratory.

4.4.7. The operating time (i.e. including the ramp-up and ramp-down time) for each lamp shall be recorded each time the lamp is used during this comparison. The summary form given in Appendix B has to be provided for each lamp by the participant to the pilot after the first measurement round. The pilot will send back the updated reporting form to each participant for each of their lamps after completion of the measurements at the pilot laboratory. After the second measurement round by the participants the final version of the form is transmitted to the pilot.

4.4.8. A 4-wire configuration shall be used to power the lamps and measure the voltage drop across the lamp.

4.4.9. The luminous intensity of each lamp should be measured independently at least two times. Each independent measurement shall consist of the lamp being realigned in the measurement configuration and being switched off for at least 1 h between measurements. Each independent measurement should be reported.

4.4.10. Note that each independent measurement may consist of a set of more than one measurement; the actual number should be that normally used by the laboratory to obtain the appropriate accuracy as limited by the noise characteristics of their specific measurement facility. The exact number of measurements used should be stated in the measurement report, but only the mean of the set and the standard deviation of the mean are required to be reported.

4.4.11. Participants are reminded that the luminous intensity of the traveling standard lamps will change as a function of the operational burning time and so it is recommended to keep burning time to a minimum.

4.4.12. The luminous intensity of the traveling standard lamps should be measured together (at the same time if possible) with the electrical values. The results of the measurements, together with the operating conditions and the standard uncertainties ($k = 1$) shall be submitted to the pilot laboratory following the procedure outlined in chapter 5 .

4.4.13. No other measurements are to be made with the traveling standards by the participants or the pilot, nor any modification to the operating conditions, during the course of this comparison. The traveling standards used for this comparison should not be used for any purpose other than described in this document, nor given to any party other than the predetermined participants in this comparison.

4.4.14. Participants should confirm that their procedures to set up the measurement and environmental conditions do not give rise to additional correlated or systematic contributions to uncertainty that are not included in the model of evaluation for the comparison.

4.4.15. Any information obtained relating to the use or any results obtained by a participant during the course of the comparison shall be sent only to the pilot laboratory, who will be responsible for coordinating how the information should be disseminated to other participants. No communication whatsoever regarding any details of the comparison other than the general conditions described in this protocol shall occur between any of the participants or any party external to the comparison without the written consent of the pilot laboratory. The pilot laboratory will in turn seek permission of all the participants. This is to ensure that no bias from whatever accidental means can occur.

4.5. Pilots Measurement Procedure

4.5.1. This section describes the measurement procedures the pilot (METAS) uses for this comparison. Participants should compare these with their own procedures to verify that the pilot and the participant will be measuring the same radiation.

4.5.2. The lamps will be operated at the pilot laboratory as close as possible to the nominal operating conditions stated by the participant. If possible, the results of the measurements by the pilot laboratory will be corrected to result in values that would have been obtained if the nominal conditions were met exactly. However, it is the intent of the pilot to measure all the lamps from all the participants under as identical conditions as possible.

4.5.3. Each lamp will be operated at least twice to produce two measurements at the specified operating conditions. Between the measurements the lamp will be switched off for at least 1 h and realigned.

4.5.4. The stability of the METAS facility will be monitored through the measurement of a group of monitor lamps throughout the comparison measurements.

4.5.5. The quantity compared will the luminous intensity assessed by three independent photometers produced by the output radiation of the lamp when operating at the specified electrical parameters.

4.5.6. In addition, a tri-stimulus colorimeter will be used to measure the correlated colour temperature of the lamps.

4.5.7. The electrical operating parameters of the lamps will be measured using the standard four-terminal measurement to permit an accurate measurement of the lamp operating current and voltage.

4.5.8. The lamp current will be ramped up slowly to the value indicated by the participant using a computer-controlled system. The ramp rate can be adjusted to the participant's specification. Without indication by the participant the pilot will use a ramp rate of about 2.4 A/min.

4.5.9. The pilot will use approximately the same length of warm-up time that the participant has indicated and was used for the measurements in the participant laboratory. Without indication by the participant, the pilot will use 15 min stabilization time.

4.5.10. The measurement time at pilot laboratory is typically 10 min, 4.5.11. After measurements, the lamp current will be ramped down slowly. The ramp rate can be adjusted to the participant's specification. Without indication by the participant the pilot will use a ramp rate of about -2.4 A/min.

4.5.12. After switching off, the lamp will be cooled down for at least 10 min prior handling.

4.5.13. The lamp current and voltage will be recorded during the full lamp operation time at a reading interval of 30 s.

4.5.14. The maximum operation time of the lamp (including ramps) is 40 min for each measurement.

4.5.15. METAS optical configuration

The measurements at METAS are performed on a photometric bench of 3.8 m length, equipped with different stray light apertures and light traps. The detectors are mounted on a computer-controlled rotation table. An outline of the photometric bench is shown in Figure 2.

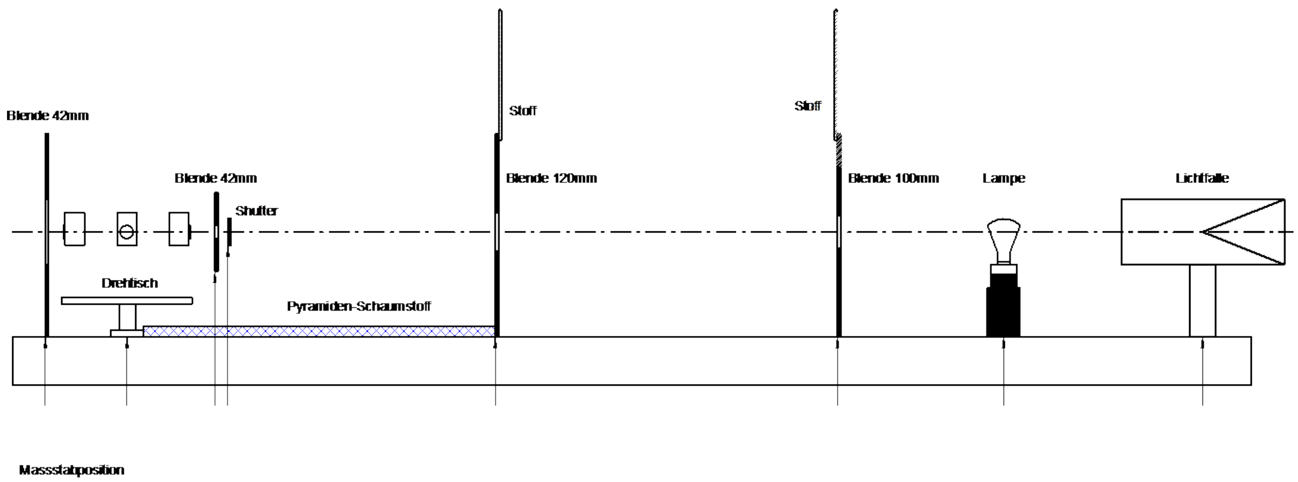


Figure 2: Sketch of the photometric bench at METAS

4.5.16. The distance between the photometer input aperture and the lamp filament plane on the METAS photometric bench is approximately 2.5 m.

4.5.17. The optical axis for the measurements is the straight line between the centre of the photometer input aperture and the defined point on the reference plane defined by the plane of the lamp filament. A laser beam-line will be set up horizontally along the length of the photometric bench at the height required to allow the mounting and alignment of the photometers and the lamps to this beam-line, such that the optical axis will coincide with the laser beam-line. The photometer input aperture will be centred on this beamline and aligned to be perpendicular to this beamline. A first alignment telescope with a crosshair reticule is adjusted to be collinear with the laser beam and used for alignment in the plane orthogonal to the optical axis (height, lateral position, rotation). A second telescope orthogonal to the optical axis, positioned on the negative Y side of the lamp coordinate system, looking into the positive direction of the Y coordinate, is used to define the location and orientation of the reference plane .

4.5.18. The coordinate system is outlined in Figure 3, shown with the Osram WI 41/G lamp filament. The reference plane is shown as the YZ plane, which is the plane of the filament. The defined point on the reference plane is the origin of the coordinate axis system, shown at the centre of the filament

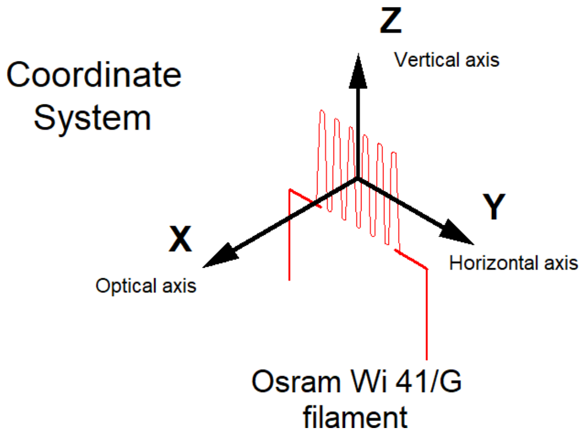


Figure 3: Coordinate system in respect to the WI 41/G filament

4.5.19. METAS alignment procedure: The Osram WI 41/G lamps are aligned to the crosshair of the first alignment telescope. There are two types of Osram WI 41/G filament mounts (Figure 4), which results in two slightly different alignment procedures.

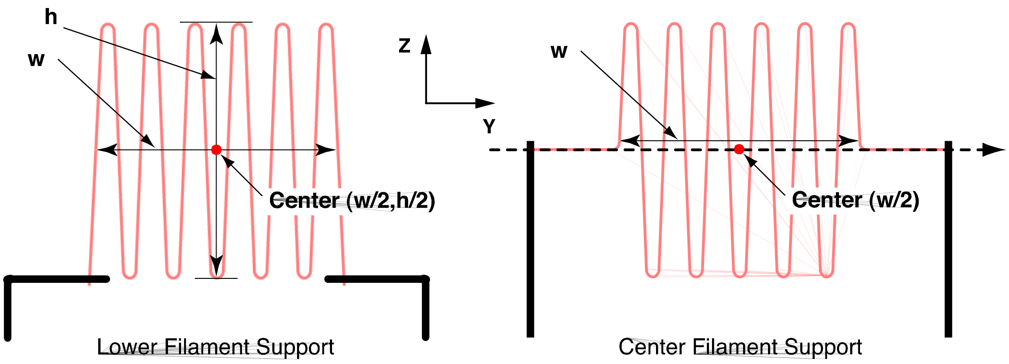


Figure 4: Alignment conditions for two types of WI 41/G luminous intensity standard lamps with different filament support.

4.5.20. The lamp may be aligned with either a cold (room temperature) filament, or a small electrical current, just enough to cause the filament to glow, may be applied to the lamp to assist in alignment. The participant should inform the pilot which method is used for their lamps. Without indication METAS will use the cold filament for alignment.

4.5.21. There are three angular alignments and three spatial alignments required:

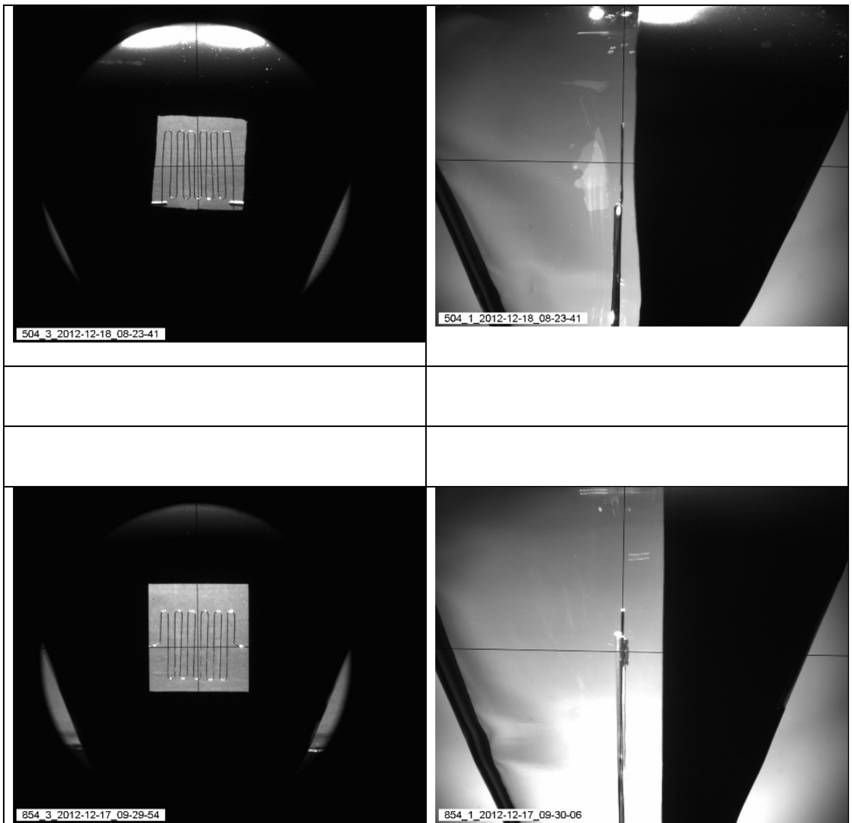
i. Rotation about the Z-axis is adjusted until the width (in the X direction) of the image of the filament in the second telescope is minimized. In the case of the filament with the centre support, only the top half of the filament will be visible for this alignment.

ii. Rotation about the Y-axis is adjusted until the image of the filament in the first telescope is parallel to the vertical crosshair, or to a plumb line. In the case of the filament with the center support, only the top half of the filament will be visible for this alignment.

iii. Rotation about the X-axis: In the case of lamps with the lower filament support, rotation about the X-axis is adjusted until a plumb line is visually equidistant from the two filament wires at the center of the filament. In the case of lamps with the center filament support, the horizontal sections on each side of the filament are aligned along the Y-axis (horizontal).

iv. The spatial position of the lamp is adjusted in the Y and Z direction until the defined point of the filament plane is in the center of the first telescope. In the case of the lamps with the lower filament support, the defined point along the Z-axis is defined as the center of the distance between the top and bottom of the filament at the two filament wires at the center of the filament for the filament with the lower supports. The defined Z-point for the filament with the center support is that of the horizontal line passing through the two horizontal sections on each side of the filament as set up in step iii. above.
For both filament types, the defined point along the Y-axis is the center of the distance between the two side filament wires as measured at the Z-axis center.

v. The distance along the X-axis is measured to the center along the X-axis of the image of the lamp filament in the second telescope, which was minimized in the rotation about the Z-axis in step i. above.



Front view (first telescope)	Right view (second telescope)

Figure 5: Photos of different views on two luminous intensity standard lamps of type WI 41/G with different filament support documenting their alignment (photographs provided by PTB)

4.5.22. METAS photometer description: Three Si-trap based photometers will be used for the calibration consisting of precis apertures and temperature stabilized transmittance filters for $V(\lambda)$ match. The quality index for spectral $V(\lambda)$-match f_1' is in the order of 1.8 %.

4.5.23. The illuminance responsivity of the photometer is traceable to the spectral responsivity scale and the length scale (for the determination of the aperture area), both realized at METAS.

4.5.24. The METAS photometers have an input aperture diameter of approximately 8 mm. Thus, the solid angle for the light emitted from the lamp that is measured by the photometer is approximately 8 µsr.

4.5.25. METAS colorimeter description: A tri-stimulus colorimeter is used for the determination of the correlated colour temperature of the lamps. The colorimeter has an aperture of 30 mm and quality indices for the spectral match as following: $f_{1,x}$'= 1.2 %, $f_{1,y}$' = 0.9 %, and $f_{1,z}$'= 1.3 %.

5. Reporting of Measurement Results

5.1.1. Upon completion of the first round of measurements by the participating laboratory, the results of these measurements, including their uncertainties, using the table in Appendix D, should be sent to the pilot laboratory along with the traveling standard lamps to be used for the comparison.

5.1.2. The results of the first round of measurements can be treated as preliminary, and these may be revised, if necessary, when the second round of measurements is submitted.

5.1.3. Each measurement results shall have a unique identifier composed of "NMI-LampNo-#Round-MeasurementNo". As an example, the first measurement in the second round of Lamp A121 of laboratory METAS shall be denominated with "METAS-A121-#2-1", see also Appendix D.

5.1.4. In addition the record of the lamp operating time (Appendix B) and the report including the measurement geometry measurement procedures and the operating conditions of the traveling standard lamps (i.e. Appendix A), shall be sent to the pilot upon completion of the first round of measurements by the participants laboratory.

5.1.5. As soon as possible, and within four weeks, after the completion of the second round of measurements by the participant, the final measurement results, including any revision of the first round of measurements should be communicated to the pilot laboratory using the Excel Workbook given in Appendix D. The results of both rounds of measurements must be reported. Appendix C for more details.

5.1.6. The pilot will embed the Excel Workbook into a PDF form and resend the PDF form to the participant asking for confirmation. The data evaluation will be done by the pilot using the data embedded to the PDFs.

5.1.7. In addition the detailed uncertainty budget including the information about the type of uncertainty (According to GUM: Type A “statistical” of Type B “determined by other means”) and the measurement equation for a single measurement of luminous intensity shall be provided by the participant to the pilot (see also Appendix C), as soon as possible, and within four weeks, after the completion of the second round of measurements. To assess the uncertainty of the group of lamps sent to the pilot from a participant, and hence the DoE correctly, the list of uncertainty contributions shall identify also correlated and uncorrelated components.

5.1.8. The correlation between the first round and the second round measurements by the participants shall be explicitly stated (see also Appendix C).

6. Measurement Uncertainty

6.1.1. The measurement uncertainty shall be estimated according to the Guide to the Expression of Uncertainty in Measurement (GUM) [3].

6.1.2. The measurement equation shall be reported. An example of a measurement equation is given in Appendix C.

6.1.3. For reporting the uncertainty contributions, the participating laboratories are encouraged to follow the breakdown given in Appendix C as closely as possible, and adapt it to their instruments and procedures. Other additional parameters may be felt appropriate to include dependent on specific measurement facilities and these shall be added with an appropriate explanation and/or reference.

6.1.4. The CIE has published documents CIE 198:2011 [4] and CIE 198-SP1:2011 [5] that includes a measurement model that may also be used for presenting the uncertainties.

6.1.5. As well as the value associated with the standard uncertainty, participants should give an indication as to the basis of their estimate. All values shall be given for a coverage factor of $k = 1$.

6.1.6. It is important that the uncertainties given in the uncertainty budget be separated into uncertainty components that are related to correlated and uncorrelated effects. Correlated means the correlated contribution between all measurements by a participant (during one round).

6.1.7. The classification of these effects into correlated and uncorrelated may be different between the first round measurement of the individual traveling lamps and the second round measurement of the lamps performed upon the return of the lamps to the participant. Therefore, correlation between the first and second round have to be specified (see Appendix D).

6.1.8. In general, correlated effects produce their (unknown) uncertainty contributions from one measurement to the next always in the same form, so that the uncertainty associated with these effects cannot be reduced through multiple measurements. These 'constant' contributions will probably be the same for a complete round of measurements performed within a short period of time but may change when the lamps are re-measured sometimes later in the second round. Such changes should be reported.

6.1.9. The uncorrelated effects usually produce values that vary randomly from measurement to measurement.

6.1.10. A list of influence parameters separated into probable correlated/uncorrelated parameters is given in Appendix C. This is given as a guide and individual participant laboratory procedures may require modifications.

7. Data analysis

7.1.1. The data analysis will follow CCPR-G6 and CCPR-G2. In particular, it will include the following Pre-Draft A Processes:
- Pre-Draft-A Process 1: Verification of reported results using the procedure outlined in 5.1.6.
- Pre-Draft-A Process 2: Review of uncertainty budgets
- Pre-Draft-A Process 3: Review of Relative Data

7.1.2. The Pre-Draft-A Process 4 (Identification of outliers and consistency check) outlined in CCPR-G2 will not be applied as no Key Comparison Reference Value is calculated.

7.1.3. The unilateral Degree of Equivalence (DoE) of the participating laboratories will be calculated using all appropriate information available from the CCPR KC and the RMO KC following the matrix formulation presented in CCPR-WG-KC19_19.

7.1.4. The Draft A report, and subsequently the Draft B and final reports, will contain unilateral DoEs for the participating laboratories but not for the link laboratories, including the deviation and associated expanded uncertainty of each participant to the KCRV of the CCPR comparison.

7.1.5. Bilateral DoEs will not be reported.

8. References

[1] CCPR-G6, *Guidelines for RMO PR Key Comparisons (CCPR-G6),* 2014.

[2] CCPR-G4, *Guidelines for preparing CCPR key comparisons (CCPR-G4),* 2013.

[3] JCGM, "JCGM 100 - Evaluation of measurement data – Guide to the expression of uncertainty in measurement," BIPM, Sèvre / FR, 2008.

[4] CIE-198, "Determination of Measurement Uncertainties in Photometry," CIE, Vienna/AT, 2011.

[5] CIE-198-SP1, "CIE 198-SP1 Determination of Measurement Uncertainties in Photometry - Supplement 1: Modules and Examples for the Determination of Measurement Uncertainties (4 Parts)," CIE, Vienna, 2011.

Appendix A. Description of the measurement facility

The items listed on this form should be used as a guide. It is anticipated that many of the questions will require more information than the space allocated on this page. Please expand your reply document as necessary and return it as a Microsoft Word document to the pilot together with the first round draft results. These reports will be added to the annex of the final report of the comparison.

A.1. Description of measurement geometry (please include a diagram):

- positions of lamp, detector, bench, shielding, baffles (number, distances and sizes)
- alignment tools
- solid angle of luminous intensity measurements:
    - distance of photometer from lamp
    - size of photometer input aperture

A.2. Description of measurement procedures.

A.3. Brand and type of the photometer (or equivalent) and the lamp power supply.

A.4. Operating conditions of the lamps:

- geometrical alignment
    - definitions of defined point and reference plane at the lamp
    - alignment procedure
        - is the filament at room temperature or glowing for the alignment?

- electrical polarity, nominal current as defined by the participant, voltage for each traveling standard
- length of warm-up time for each lamp before measurements are taken
- measured CCT (or Distribution Temperature see Section 4.3.3).
- stray-light reduction

A.5. Description of calibration laboratory conditions: e.g. temperature, humidity etc.

A.6. Laboratory transfer standards used:

- type of transfer standards and traceability to primary scale

A.7. Establishment or traceability route to and of the primary realization of luminous intensity including date of last realisation and uncertainty budget.

Appendix B. Record of Lamp Operating Time

This appendix is provided as Excel Workbook only. Please use one sheet per lamp. Send the Workbook (in Excel format) to the pilot after the first round measurements. The pilot will update the sheet during his measurements and send it back to the participant. After the second round measurement, please return it to the pilot.

Appendix C. Reporting the Measurement Uncertainty

The measurement uncertainty budget shall include the measurement equation stating all parameters influencing the measurement results. As an example, the following equation describes the detector-based calibration of a luminous intensity standard at pilot's laboratory. It is derived from the recommendations of CIE 198. The luminous intensity of a standard lamps I_{CS1} at standard condition can be expressed as

$$I_{CS1} = \frac{d_{PS}^2\left(y_{PS1} - y_{PS10}\right)}{s_{CP1}}\left(\frac{c_P}{G_{PS1}}\right)\left(\frac{T_{dC1}}{T_A}\right)^{m_{P1}}\left(\frac{c_J \cdot U_{JS1}}{J_{C1} \cdot R_J}\right)^{m_{P1}m_{TS1} - m_{IS1}} \cdot \frac{\left(1 + 2\,\Delta d_P/d_{PS} + a_P\Delta T_P + g_P(\varepsilon_P)\right)}{\left(1 + 2\,\Delta d_{S1}/d_{PS} + a_{S1}\Delta T_{S1} + k_{S1}(\varphi_{S1}) + h_{S1}(\vartheta_{S1})\right)}$$

where

y_{PS1}: Digital voltmeter signal of the photometer (when illuminated)

y_{PS10}: Digital voltmeter dark offset signal of the photometer

U_{JS1}: digital voltmeter reading (over a shunt resistance) of the lamp current measurement

ΔT_{S1}: deviation to nominal ambient temperature

ΔT_{P}: deviation to nominal temperature of the photometer calibration

d_{PS}: distance between filament and photometric reference plane of the photometer

s_{CP1}: luminous responsivity of the photometer.

c_{P}: calibration factor of the digital voltmeter

G_{PS1}: gain setting of the current to voltage amplifier for the photocurrent measurement

T_{dC1}: distribution temperature, determined for the lamp current J_{C1}

T_{A}: nominal distribution temperature for CIE illuminant A (no uncertainty)

m_{P1}: exponent for spectral mismatch correction of the photometer

c_{J}: calibration factor of the digital voltmeter used for the lamp current measurement

J_{C1}: nominal current for the lamp used for the calibration (no uncertainty)

R_{J}: shunt resistance used for the lamp current measurement

m_{TS1}: exponent factor for lamp current sensitivity of distribution temperature

m_{IS1}: exponent for lamp current sensitivity of luminous intensity

$\Delta d_{\mathrm{P}}/d_{\mathrm{PS}}$: relative distance misalignment of photometer

α_P: estimated relative temperature coefficient of the photometer

$g_P(\varepsilon_P)$: angular misalignment of photometer

$\Delta d_{\mathrm{S1}}/d_{\mathrm{PS}}$: relative distance misalignment of lamp filament

α_{S1} : estimated relative temperature coefficient of the lamp

$k_{S1}(\varphi_{S1})$, $h_{S1}(\vartheta_{S1})$: correction factor for angular misalignment of the lamp, assigned with the uncertainty angular misalignment

Additional parameters could be:

- straylight effects
- ageing of the reference photometer
- linearity of the photometer/photocurrent transimpedance-amplification

In addition to the reporting of the correlated and uncorrelated uncertainty, the correlation coefficient r between the first round and second round measurements for each lamp shall be reported. This is calculated as

$$r = \frac{u_{\mathrm{cor}}^2}{\sqrt{(u_{\mathrm{cor}}^2 + u_{\mathrm{uncor,1}}^2)(u_{\mathrm{cor}}^2 + u_{\mathrm{uncor,2}}^2)}}, \qquad (1)$$

where u_{cor} is the total systematic uncertainty related to the correlated contributions of both measurement rounds (this might be different that within each round) and $u_{\mathrm{uncor,1}}$ and $u_{\mathrm{uncor,2}}$ the total uncorrelated uncertainties of each round. If the systematic uncertainties are different in each round the correlation coefficient of the affected uncertainty components shall be stated explicitly in the uncertainty budget.

Appendix D. Measurement Results

This appendix is provided as Excel Workbook only. Send the Workbook (in Excel format) as draft to the pilot after the first round measurements. Send the final version after the second round measurement to the pilot.

Appendix E. Inspection of the Traveling Standards

Has the lamp transportation package been opened during transit? e.g. Customs, etc.

☐ No

☐ Yes. Please give details:

Is there any damage to the transportation package?

☐ No

☐ Yes. Please give details:

Are there any indications of damage to the lamps?

☐ No

☐ Yes. Please give details (e.g. scratches, dust, oil, finger prints, broken coil, etc):

Have you cleaned the lamps at any time after your initial measurements?

☐ No

☐ Yes. Please give details:

After warm-up are the lamp voltage and current within their specified ranges?

☐ Yes

☐ No. Please give details:

Lamp ID numbers: ………………

What is the voltage and the nominal current for each of the lamps?

V = ………..

I = ………..

Do you believe the lamps are functioning correctly?

☐ Yes

☐ No. Please indicate your concerns:

Laboratory: ……………………………..

Responsible person: ……………………………………

Date: ……………………………………

Appendix F. Receipt Confirmation

Email

TO: Dr. Peter Blattner

Email: peter.blattner@metas.ch

We confirm having received the traveling standards for the CIPM key comparison EURAMET.PR-K3.2020 *Luminous Intensity* on:

date-of-receipt: ....

After visual inspection, we report:

☐ No damage has been noticed

☐ The following damage must be reported:

....

Laboratory: ……………………………..

Responsable Person: …………………………………..

Date: …………………………………..

Signature: ……………………………..