SIM Key Comparison SIM.PR-K3.2023

Luminous Intensity

Technical Protocol

Version: 1.2 (final approved)

Version History

V0.1: Initial draft based on TP of CCPR-K3.2014 and EURAMET.PR-K3.2020

V0.2: The following items were added or modified:

- 1.3 and 2.3 proviso for activities shared – still being defined.
- 1.5 and 2.7.2 FEL type lamps were included in addition to WI 41/G. A proviso was added indicating the possibility of other lamp types being used under specific circumstance.
- 3.2.1 and 4.3.6 Description of FEL lamps added with basic description of alignment procedure.
- 4.3.3 Clause allowing laboratories that are not able to measure CCT to participate.
- 2.6.1 Proposed timetable updated.

V0.3: INTI comments inserted.

V0.5: Changes:

- 2.2 List of participants updated – inclusion of NIMT and KRISS.
- 2.2 Inclusion of contact name and address (please check if this is correct).

V0.6:

- 2.2 List of participants updated – inclusion of CMS/ITRI.
- 2.2 Update in contact name from CENAM.
- 2.9.5 and Appendix G Added shipping instructions.
- 4.5 updated with CENAM measurement procedure.

V0.7:

- 2.2 List of participants updated – address of CMS/ITRI modified.
- 3.4.2 Inclusion of list of lamps used by each participant – please review.
- 5.6 Added as proposal for data reporting and analysis.
- Changes from previous version accepted.

V0.8:

- 2.1.3 inserted to describe inclusion of participants from other RMOs.
- 2.2 List of participants updated – added new contact for NIMT; Added interim participant UzNIM (participation is being checked with WG-KC).
- 2.5.5 Added comment to extend measurement period in the pilot from three to five months. This is to be done in the review of the timetable during next meeting.
- 3.3.2 Added lamp types and quantities for CENAM, NIMT and UzNIM.
- 5.6 Edited proposal on data analysis.
- Changes from previous version accepted.

V0.9:

- 2.5.5 Timetable updated to take into account current situation.
- 3.3.2 Number of lamp types for NRC updated.
- 4.2.2 Added description of luminous intensity that includes source-based and detector-based method.
- Changes from previous version accepted.

V1.0:

- A number of editorial corrections were accepted from comments received after comments from NIST and NRC.
- 2.9.5 and 5.8 were reworded after comment from NRC.
- 6.2 was reworded and text from previous 6.10 added to it.
- 3.3.2 Number of lamp types for NIST updated.

V1.1:

- A number of editorial corrections were accepted from comments from CCPR WG-KC.
- 2.5.5 Timetable updated to take into account current situation.

V1.2:

- One editorial correction was accepted from Yuqin Zong from NIST.
- 2.5.5 Timetable updated to take into account current situation.
- 3.4.2 NIST total lamp number change from 5 to 4.

Table of contents

1. Introduction

1.1. This Technical Protocol (TP) describes the SIM key comparison of luminous intensity of incandescent lamps.
1.2. The comparison was initially agreed by MWG2 for PR of SIM in 2016. The first call of participants was done in 2018 and the development of the comparison was halted due to the pandemic period. It was agreed in the MWG2 annual meeting of 2022 to resume the comparison with a new call for participants, which was done in May 2023.
1.3. CENAM agreed to pilot the comparison with support of other NMIs to draft the protocol, data analysis and report preparation.
1.4. The technical protocol is based on the technical protocol of CCPR.K3.2014 and EURAMET.PR-K3.2020 [1,2]. 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. Osram WI 41/G lamps or FEL type lamps are used in the comparison. In addition, one of the labs will be using lower power halogen lamps.

   b. The electrical current of the lamps shall result in a CCT between 2800 K and 2900 K for the photometric output of the lamp, following CCPR.K3.2014 [1]. If the participant cannot measure the CCT (i.e., when it can only perform recalibration of lamps), it shall still inform the pilot about the CCT for which the lamps were set and the source of this information.

   c. The data analysis will be performed following the approach recommended in CCPR-G6 [3].

2. Organization

2.1. Participations, Selection

2.1.1. According to CCPR-G6 [3] the pilot laboratory sends out a call for participants to all member NMIs of the Group of RMOs as defined in the G4-Guidelines [4] for preparing CCPR Key comparisons (plus any other invited NMIs) with the information of the comparison quantity.
2.1.2. A call for participants was first sent out in 2018. At the time, five laboratories signed into the comparison – CENAM (pilot), INTI, INMETRO, NIST (link) and NRC (link). Due to the long delay in the start of protocol preparation and measurements, a new call for participants was done in middle 2023. During the call, IBMETRO and INACAL joined the group of participants.
2.1.3. In December 2023, the call for participants was extended to other RMOs, considering CCPR-G6 guidelines. During this call, CMS/ITRI, KRISS, NIMT and UzNIM joined the group of NMIs.

2.2. Participants, Contact Information

Institute	Address	Contact Person	Email
CENAM	km 4.5 Carretera a los Cués Municipio El Marqués 76246 – Querétaro, México	Carlos Matamoros / Laura González	cmatamor@cenam.mx lgonzale@cenam.mx TEL: +52 4422110552
CMS/ITRI	Bldg. 16, 321, Sec. 2, Kuang Fu Rd., Hsinchu 30011, Taiwan	Dr. Yi-Chen Chuang	ycchuang@itri.org.tw
KRISS	267 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea	Dr. Seongchong Park	seongchong.park@kriss.re.kr
IBMETRO	Av. Camacho 1488, La Paz, Bolivia	Juan Jose Mendoza Aguirre	jjmendoza@ibmetro.gob.bo
INACAL	Calle Las Camelias 815, San Isidro, Lima, Perú	José Samuel Ramirez Herrera	jramirez@inacal.gob.pe
INTI	Colectora Avenida Gral Paz 5445, Parque Tecnológico Miguelete San Martín, Provincia de Buenos Aires, Argentina	Juan Pablo Babaro	jbabaro@inti.gob.ar
INMETRO	Av. Nossa Senhora das Graças 50 - Xerém Duque de Caxias – Rio de Janeiro 25250-020 Brazil	Dr. Hakima Belaïdi	hbelaidi@inmetro.gov.br
NIMT	3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand	Dr. Rattana Chuenchom	rattana_p@nimt.or.th
NIST	100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070 USA	Yuqin Zong	yuqin.zong@nist.gov
NRC	1200 Montreal Road Ottawa, Ontario K1A 0R6 Canada	Dr. Arnold Gaertner	arnold.gaertner@nrc-cnrc.gc.ca
UzNIM	333 A, 333 B, Farobiy street, Almazar district, 100174, Tashkent city, Republic of Uzbekistan	Jamol Rustamov	rustamov@nim.uz

2.3. Task Group

2.3.1. The following NMIs accepted to support the pilot laboratory (CENAM) with drafting the technical protocol and thus form the task group (TG): INTI, INMETRO and NRC.

2.3.2. The following NMIs accept supporting the pilot with data analysis and drafting the comparison report: INTI, INMETRO and NRC. Data analysis is considered to start during the preparation of Draft-A report as described in Section 7 of CCPR-G6, which includes linking the results of the RMO KC to the CCPR KC and calculation of unilateral Degree of Equivalence. Pre-Draft-A processes, including verification of reported results, review of uncertainty budgets and review of relative data are conducted exclusively by CENAM.

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 note 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 realizations of the luminous intensity unit or because of improved measurement techniques.

2.4.2. The following laboratories will act as link laboratory to CCPR-K3.2014 [1]: NIST and NRC.

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.

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 minimize 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 [3, 4]. 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 to reach the final dates.

Action (responsible)	Deadline	Date of completion
Preparation		
Call for Participants (SIM.MWG2-PR chair)	-	2023-06-01
Deadline to reply to Call (SIM)	-	2023-06-12
Formation of the task group (SIM.MWG2-PR)	-	2023-06-28
Deadline call for participants outside SIM		2023-12-08
Preparation of technical protocol (TG)	2023-12-10	2024-02-29

Approval of technical protocol (Participants)	2024-03-31	2024-04-05
Approval of technical protocol by CCPR-WG-KC	2024-05-31	2024-09-15
Registration of the comparison at KCDB by the pilot	2024-10-31	
Measurements		
Next decision on maintaining/updating the time schedule	2024-10-15	
1st round measurement by participants	2025-03-31	
Deadline for the participants' lamps to be at pilot laboratory (participants)	2025-04-30	
Reporting of the draft first round results to pilot using Appendix D	2025-05-31	
Appendix A (description of measurement setup) and Appendix B (record of operation time) to be sent to the pilot	2025-05-31	
Lamps measured by pilot (pilot)	2025-08-31	
Transport of lamps back to participants (participants), updated Appendix B sent to the participant	2025-09-30	
2nd measurement by the participants (participants)	2025-12-31	
Reporting of the final measurement data to pilot (participants) using Appendix D	2026-02-28	
Appendix C (uncertainty budget) and updated Appendix B to be sent to the pilot	2026-02-28	
Evaluation & Report		
PreDraft A.1 (Verification of reported results) & replies by participants	2026-03-31	
PreDraft A.2 (Review of uncertainty budgets) & replies by participants	2026-05-31	
PreDraft A.3 (Review of Relative Data) & replies by participants	2026-07-31	
Draft A & replies by participants	2026-09-30	
Draft B & replies by participants	2026-11-30	
Approval by CCPR WG KC	2026-12-31	
Final report	2027-02-28	

2.7. Comparison Artefacts, Selection

2.7.1. The measurement artefacts will preferably be standard Osram Wi41/G or FEL type lamps with nominal power of 1000 W. Considering issues raised during the call for participants, other lamp types might be admitted, subject to previous approval by the pilot and consent of other participants.

2.7.2. 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 considers that cleaning appears to be required, the form in Appendix E should be used to communicate this 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. 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 in Appendix G. If possible, 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. Description of Osram Wi41/G lamps

3.1.1. Osram Wi41/G are gas-filled incandescent lamps with nominal DC electrical current and voltage of 6 A and 31 V, respectively. For the comparison, a constant DC current will be supplied at the value rated by the participant.

3.1.2. 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.

3.1.3. The base of the lamp is E27.

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

3.2. Description of FEL type lamps

3.2.1. FEL lamps are tungsten halogen lamps with nominal DC electrical power and voltage of 1000 W and 120 V, respectively. For the comparison, a constant DC current will be supplied at the value rated by the participant.

3.2.2. This type of lamp consists of a double-coiled tungsten filament, supported at the top and bottom of the filament and operated in an inert gas-filled quartz envelope.

3.2.3. After being prepared for use, each lamp is mounted in a special bi-post base and equipped with an alignment jig. The jig shall be provided to the pilot for the alignment.

3.3. Other types of lamps

3.3.1. The laboratory wishing to use a different type of lamp shall contact the pilot informing details about the lamp type, such as nominal operating parameters and alignment procedure. The laboratory should also inform the reason for not using Wi41/G lamps or FEL type lamps. This could be, for example, that the facilities of the laboratory are prepared to calibrate only other type of commercially available luminous intensity standard lamps, and this supports the needs of the economy.

3.3.2. After the pilot confirms the feasibility of measuring the specific lamp type, all other participants of the comparison shall be notified to agree on the participation of the laboratory.

3.4. General

3.4.1. Independently of the lamp type selected by the participant laboratory, only sufficiently aged and stable lamps shall be used.

3.4.2. The list of lamps each lab intends to use during the measurements is shown in Table below.

NMI	Number of lamps		
	WI41/G	FEL	Other
CENAM	3	3	Halogen lamps: 2 (10 W) 2 (100 W) 2 (150 W)
CMS/ITRI	3	-	-
KRISS	-	3	-
IBMETRO	-	3	-
INACAL	-	-	3 halogen lamps (10 W and 100 W)

INTI	-	3	-
INMETRO	3	-	-
NIMT	3	-	-
NIST	-	4	-
NRC	4	-	-
UzNIM	3	-	-

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 for Wi41/G lamps or by the corresponding reference plane defined by the jig for FEL type lamps. 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 lamp is measured either against luminous intensity reference standard lamps (source-based method) or by using reference photometers (detector-based method). In the source-based method, the photometer is only used to compare one lamp to another. In the detector-based method, the luminous intensity is 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 2800 K and 2900 K. Typically the CCT of each lamp should be determined by the participant and reported to the pilot. If the participant wishes instead to report the Distribution Temperature or the Colour Temperature of the luminous intensity of the lamp, it may do so. However, the pilot will consider all three temperature descriptions equivalent for any spectral mismatch corrections. For information on differences of temperature description, see [5]. The participant shall report to the pilot if it cannot measure the CCT (or the Distribution Temperature or the Colour Temperature), i.e., when the laboratory provides only recalibration of previously adjusted lamps. If this is the case, the laboratory should still inform the CCT for which the lamps were set and the source of this information.

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 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.

4.3.6. Basic geometric conditions:

a) Lamps are mounted base down.

b) For Wi41/G lamps:

- the optical axis is horizontal and passes through the centre of the filament, perpendicular to its plane;
- the participant shall describe the method for defining the centre of the filament;
- the 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 lamp., i.e., this opening is oriented in the direction of the photometer.

c) For FEL lamps:

- the lamp is aligned using an alignment jig.
- **the distance from the lamps is measured from the centre of the bi-post of the jig.** If another reference plane is used, this shall be reported by the participant.
- the height of the lamps is adjusted so that the optical axis passes through the centre mark of the jig. If another reference mark is used, then this shall be reported by the participant.
- the identifier number of the lamp is facing the direction opposite to the photometer. If another orientation is used, this shall be reported by the participant.

4.3.7. Basic electrical conditions:

- DC electrical power
- Defined fixed electrical current for operation
- Defined electrical polarity at lamp contacts
- The defined electrical current results in a CCT between 2800 K and 2900 K for the photometric output of the lamp, which should be reported as described in 4.3.3
- 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 sent 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 Section 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.

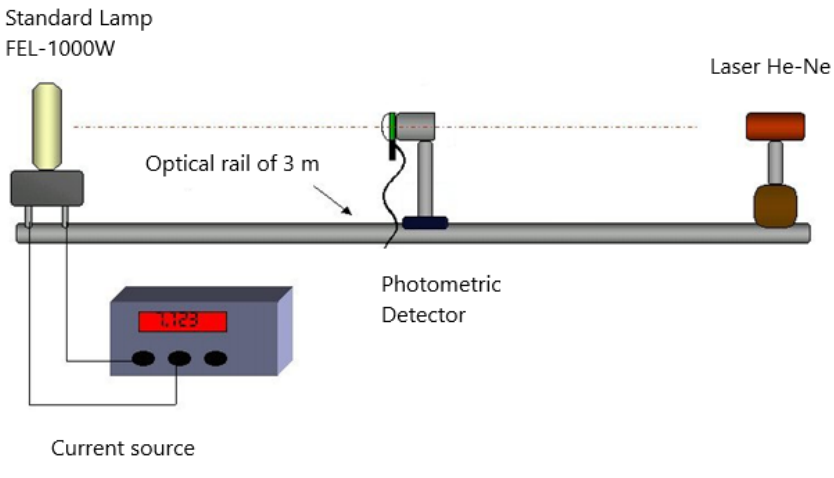
4.5. Pilots Measurement Procedure

4.5.1. This section describes the measurement procedures the pilot (CENAM) 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 measurand.

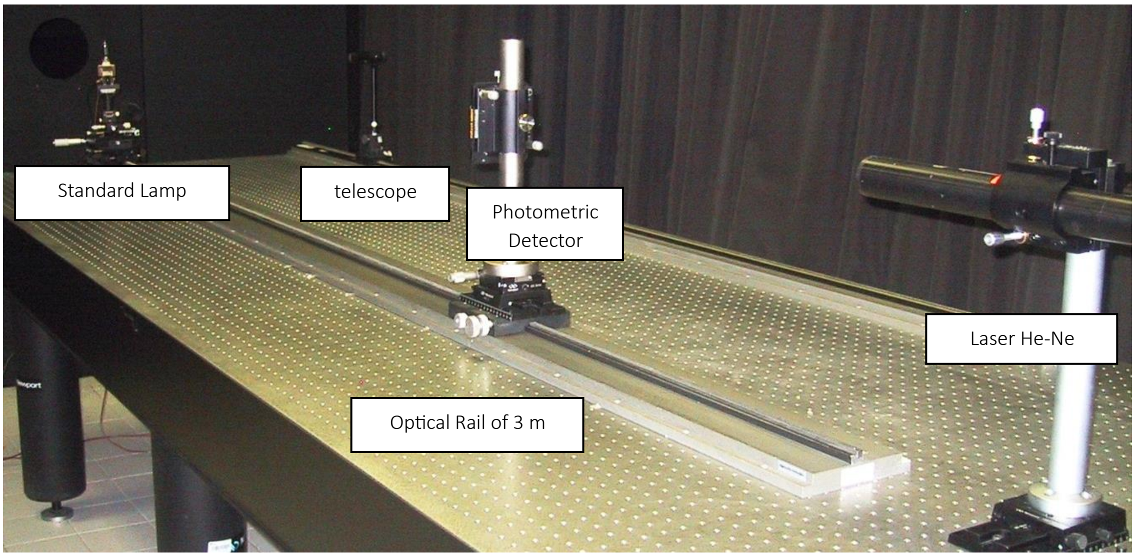
4.5.2. The lamps will be operated at the pilot laboratory as close as possible to the nominal operating conditions stated by the participant. If possible, the results of the measurements by the pilot laboratory will be corrected to result in values that would have been obtained if the nominal conditions 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 quantity compared will be the luminous intensity assessed by three independent photometers produced by the output radiation of the lamp when operating at the specified electrical parameters.
4.5.5. In addition, a portable spectroradiometer will be used to measure the correlated colour temperature of the lamps.
4.5.6. 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.
4.5.7. The lamp current will be ramped up slowly over approximately one minute to the value indicated by the participant.
4.5.8. 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 minutes stabilization time for lamps with nominal power less than 300 W and 30 minutes for higher power lamps.
4.5.9. The measurement time at pilot laboratory is typically 10 min.
4.5.10. After measurements, the lamp current will be ramped down slowly over approximately one minute.
4.5.11. After switching off, the lamp will be cooled down for at least 20 min prior handling.
4.5.12. The lamp current and voltage will be recorded during the full lamp operation time.
4.5.13. The maximum operation time of the lamp (including ramps) is 40 minutes for each measurement for lamps with nominal power of 300 W or less, and 60 minutes for higher power lamps.
4.5.14. CENAM optical configuration

The measurements at CENAM are performed on a photometric bench of 3.0 m length, equipped with different stray light apertures. A sketch and photograph of the photometric bench is shown in Figure 1.



(a)



(b)

Figure 1. (a) Sketch and (b) photograph of the Photometric Bench at CENAM without the screening shields.

4.5.15. The distance between the lamp filament plane aperture and photometric detector on the CENAM photometric bench is approximately 2.5 m.

4.5.16. The optical axis for the measurements is the straight line between the centre of the photometric detector input aperture and the defined point on the reference plane defined by the plane of the lamp filament or lamp jig, depending on lamp type (see Section 4.3.6). 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 photometric detectors and the lamps to this beam-line, such that the optical axis will coincide with the laser beam-line. We use a telescope with crosshair reticule for alignment height, lateral position and rotation of the lamp filament or jig and to determine the distance between it and the plane of reference of the photometric detectors.

4.5.17. CENAM photometric detector description: Three temperature-controlled photometric detectors from LMT. These detectors have an input aperture diameter of 10 mm and a quality index for spectral $V(\lambda)$-match f_1' of 2.5 % and they are calibrated traceable to a cryogenic radiometer as primary standard of Mexico.

4.5.18. The portable spectroradiometer of CENAM is a compact spectrometer UPRTek, model MK350D in the range of 380 nm to 780 nm with the capacity to measure illuminance, correlated color temperature and spectral power distribution, among other quantities. It is calibrated against spectral irradiance lamps (calibrated also for correlated color temperature), traceable to PTB.

5. Reporting of Measurement Results

5.1. 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.

5.2. 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.

5.3. Each measurement results shall have a unique identifier composed of "NMI-LampNo-#Round". As an example, the second round, first measurement set, of Lamp A123 of laboratory ABC shall be denominated with "ABC-A123-#2-1", see also Appendix D.

5.4. 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.

5.5. 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.
5.6. Data analysis will be done using data from the Excel Workbooks.
5.7. 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.
5.8. The correlation between the first-round and the second-round measurements for each lamp and between lamps by the participants shall be explicitly stated (see also Appendix C).

6. Measurement Uncertainty

6.1. The measurement uncertainty shall be estimated according to the Guide to the Expression of Uncertainty in Measurement (GUM) [6].
6.2. The measurement equation shall be reported. An example of a measurement equation and a list of the parameters influencing the final result is given in Appendix C of [2].
6.3. For reporting the uncertainty contributions, participants shall use the measurement equation that represents the procedure normally applied by the laboratory for calibration services. 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.
6.4. The CIE has published documents CIE 198:2011 [7] and CIE 198-SP1:2011 [8] that includes a measurement model that may also be used for presenting the uncertainties.
6.5. 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 $k = 1$.
6.6. It is important that the uncertainties given in the uncertainty budget be separated into uncertainty components that are related to correlated (i.e., those components that are common to the measurement of each artifact) and uncorrelated effects (i.e., random components that change from artifact to artifact, such as noise). Correlated means the correlated contribution between all measurements by a participant (during one round).
6.7. 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 C).
6.8. 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.
6.9. The uncorrelated effects usually produce values that vary randomly from measurement to measurement.

7. Data analysis

7.1. 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 5.6.
- Pre-Draft-A Process 2: Review of uncertainty budgets
- Pre-Draft-A Process 3: Review of Relative Data

7.2. 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.

7.3. 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 approach recommended in CCPR-G6 [3]. The matrix formulation approach presented in CCPR-WG-KC19_19 might also be used for checking.

7.4. 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.

7.5. Bilateral DoEs will not be reported.

8. References

[1] CCPR-K3.2014, "CCPR Key Comparison Luminous Intensity, Technical Protocol", 2014.

[2] EURAMET.PR-K3.2020, "EURAMET Key Comparison Luminous Intensity – Technical Protocol", 2020.

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

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

[5] CIE TN 013:2022, "Terms Related to Planckian Radiation Temperature for Light Sources," CIE, Vienna, 2022.

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

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

[8] 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
- limiting 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?
    - alignment jig? If so, how is it used?
    - size and position of limiting aperture
- 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
- CCT (or Distribution Temperature or Colour Temperature) of the lamps (see 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 of luminous intensity including date of last realization 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. An example of measurement equation based on CIE 198 is provided in protocol of comparison EURAMET.PR-K3.2020 for detector-based calibration of a luminous intensity lamp. It is important that the measurement equation represents the procedure of the laboratory normally used for the calibration service.

In addition to the reporting of the correlated and uncorrelated uncertainty, as described in 6.6, the correlation coefficient r between the first round and second round measurements for each lamp shall be reported. This is calculated as

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

where:

u_{cor} is the total systematic uncertainty related to the correlated contributions of both measurement rounds

$u_{\mathrm{uncor},1}$ and $u_{\mathrm{uncor},2}$ the total uncorrelated uncertainties of each round.

The correlated contribution might be different in each measurement round. If this is the case, u_{cor} is calculated as an average of the correlated contribution of each round.

Additionally, 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

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

   ☐ No;

   ☐ Yes. Please give details:

2) Is there any damage to the transportation package?

   ☐ No;

   ☐ Yes. Please give details:

3) Are there any indications of damage to the lamps?

   ☐ No;

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

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

   ☐ No;

   ☐ Yes. Please give details:

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

   ☐ No;

   ☐ Yes. Please give details:

   Lamp ID numbers:

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

   V =

   I =

6) Do you believe the lamps are functioning correctly?

   ☐ Yes;

   ☐ No. Please indicate your concerns:

Laboratory:

Responsible person:

Date:

Appendix F. **Receipt Confirmation**

Email

TO: Carlos Matamoros and Laura González

Email: cmatamor@cenam.mx; lgonzale@cenam.mx

We confirm having received the traveling standards for the SIM key comparison SIM.PR-K3.2023 *Luminous Intensity* on:

date-of-receipt:

After visual inspection, we report:

☐ No damage has been noticed

☐ The following damage must be reported:

Laboratory:

Responsible Person:

Date:

Signature:

Appendix G. Recommendations for temporary shipping to CENAM

Participant must notify CENAM in advance of the intention to embark the equipment, indicating the date on which it will embark and, tentatively, the date of arrival in Mexico.

Whether the customer chooses the best shipping option knowing how sensitive the equipment is to handle.
• There is equipment that can be sent by parcel. **IT IS SUGGESTED TO USE DHL. THE PACKAGE ARRIVES DIRECTLY AT THE CUSTOMS OF QUERETARO**, (please do not use Fedex, UPS, Post Office, their policies are not compatible with those of CENAM and they generate other expenses, also don't know the appropriate management of measurement standards).
• There is other extremely delicate equipment that requires special handling, so it is suggested to hire the service of a consolidator or logistics company in your country that oversees temporary shipping.

Shipment either by parcel or with the consolidator, the client must pay all shipping and return costs for his equipment.

Option 1. Shipping by parcel
The participant must generate a shipping bill with incoterm **DDP (door to door)** all expenses paid.
For the return you generate another guide for collection with **incoterm (EXW).**
If DHL is used, they are responsible for collecting, clearing customs and delivering of the equipment. All expenses appear on the invoice that DHL will issue, and you will pay in your country.

Option 2. Shipping through a consolidator.
The participant must hire a Logistics company in their country that oversees DDP shipping (door to door, all expenses paid from origin)
The Forwarder or contracted logistics company will oversee the collection, customs clearance in your country and Mexico, and delivery to CENAM.
For customs clearance in Mexico, it will be carried out through the CENAM customs agent, but the payment for the release will be paid by the consolidator, which in turn will charge it to the participant (or the participant will directly pay the customs agent).
For the return, the consolidator collects at CENAM, will pay the export clearance to the CENAM customs agent and will take care of the air freight and release in your country.

Option 3. Shipping by passenger.
Please send an email to lgonzale@cenam.mx and to trafico@cenam.mx mentioning your interest in shipping per passenger, attaching the proforma invoice and being able to review the issue regarding the value of the equipment and determine if Mexican Customs will let it pass or you could If your equipment is retained until the corresponding temporary import clearance is carried out, to avoid setbacks and release costs, it is best to contact trafico@cenam.mx to suggest the best option.

Considerations
Packaging and risks are the responsibility of the participant. It is suggested to check that they guarantee the proper transportation of the equipment during the trip, and/or take out insurance to cover it.
In the customs clearance of the shipped equipment, the costs of storage, custody, taxes, customs agent fees, etc., are the responsibility and risk of the participant.

Customs Agents

Below, we provide you with the details of the customs agents that CENAM currently works with, which we suggest you to use to manage your customs clearance process.

For Customs at the Querétaro Intercontinental Airport:

1. Customs Organization Siglo XXI S.C.
Customs Agent: Carlos Alejandro Torres Frías
Patent: 3010
Address: Cerro del Mesontepec N° 81-a-, 81-B., Colinas del Cimatario, Querétaro.
Contacts: Oscar Garcia Palacios.
Telephone: 01(442) 2235704 ext. 106
Email: oscarg_qro@carlos-torres.com.mx

For Customs at Mexico City International Airport:

1. Customs Organization of Mexico, S.C.
Customs Agent: Carlos Alejandro Torres Frías
Patent: 3010
Address: Aguascalientes N° 8, int. 201, Col. Peñón de los Baños, México, D.F.
Contacts: Juan Carlos Balderrama Agis
Telephone: 01(555) 7629493 ext. 111
Email: jbalderrama_mx@carlos-torres.com.mx

For more information you can contact:

CENAM Traffic Area
Email: trafico@cenam.mx
Telephone Number: +52 (442) 211 05 00 Extension 3039