CCPR Key Comparison CCPR-K3.2014

Luminous Intensity

Technical Protocol

Contents

1. Introduction 2
2. Organization 3
2.1. Participants, selection 3
2.2. Participants, contact information 3
2.3. Task Group, selection 5
2.4. Task Group, members 5
2.5. Comparison artifacts, selection 5
2.6. Traveling Standards, handling 5
2.7. Traveling Standards, transportation 6
2.8. Comparison, general procedures or measurement sequence 7
2.9. Comparison, timetable 8
3. Description of the Traveling Standards 9
4. Measurement Instructions 10
4.1. Traceability 10
4.2. Measurand 10
4.3. Measurement procedures 11
4.4. Pilot laboratory measurement procedures 12
5. Reporting of Results 18
6. Measurement Uncertainty 19
6.1. Uncertainty Components 19
6.2. Measurement influence parameters 20
7. Determination of Key Comparison Reference Value (KCRV) 20
8. Acronyms 21
9. References 21
10. Appendices 22
Appendix A.1 Receipt Confirmation 23
Appendix A.2 Inspection of the Traveling Standards 24
Appendix A.3 Description of the measurement facility 25
Appendix A.4 Record of lamp operating time 26
Appendix A.5 Sample Measurement Uncertainty Budget 27
Appendix A.6 Measurement Results 28

1. Introduction

1.1 The metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs).

1.2 At the 14^{th} meeting of the Consultative Committee for Photometry and Radiometry (CCPR) held on 1997-June-10 and 11, several key comparisons in the field of optical radiation metrology were identified. In particular, it decided that luminous intensity/responsivity be considered a Key Comparison (KC) and that the comparisons being piloted by PTB (K3.a Luminous Intensity of lamps) and the BIPM (K3.b Luminous Responsivity of photometers) at that time be treated as Key Comparisons. These first KCs of luminous intensity/responsivity were completed in 1998 [1]. At the 20^{th} meeting of the CCPR (2009-September-17, 18), it was decided that a second round of key comparison CCPR-K3 be commenced [2]. The CCPR approved "that for this next round there will be only one CCPR-K3 comparison, called luminous intensity, and the details of the comparison (use of lamps or photometers) should be decided by the task group carrying out the comparison. The task group will be established by the WG-KC and its proposal of comparison artifacts shall be submitted to CCPR for approval."[1] The National Research Council of Canada (NRC) was chosen to pilot this comparison, with the intention that measurements would start in 2012.

1.3 This technical protocol has been drawn up by the eight-member Task Group (TG) of the participants of the CCPR-K3.2014 key comparison (see Section 2.4.), and approved by all the participants.

1.4 The procedures outlined in this document cover the technical procedure to be followed during measurement of the traveling standard lamps. The procedure, which follows the guidelines established by the BIPM [3] and the CCPR [4], is based on current best practice in the use of standard lamps and takes account of the experience gained from the previous CCPR luminous intensity comparison of 1998 [1] and that of the Task Group.

1 WG-KC = CCPR Working Group on Key Comparisons

2. Organization

2.1. Participants, selection

2.1.1 The invitation to participate in this comparison was prepared by the pilot laboratory and the WG-KC, and then sent to all CCPR members by Michael Stock, Executive Secretary of the CCPR.

2.1.2 The selection process for the participants was guided by the following criteria [4]:

1. The participant must be a member of CCPR.
2. The participant must be willing to serve as a link laboratory to their RMO.
3. The participant must have an independent realization of the unit or scale of the comparison quantity.
4. The participant's measurement capability of the comparison quantity, over the full range of the comparison (e.g., full spectral range), must be listed in the CMC table published at the time of the call for participants.

2.1.3 Since the number of applications exceeded the maximum of 12, the RMO Groups were requested by the pilot to select the maximum number of participants in accordance with the following table [4]:

RMO Group	RMO Group Members	Maximum Number of Participants
Group 1	EURAMET+COOMET	6
Group 2	APMP+AFRIMETS	4
Group 3	SIM	2

2.1.4 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 follow the procedures strictly.

2.1.5 After the list of participants and this protocol have been approved by all the participants and the WG-KC, no change to the protocol or list of participants may be made without prior agreement of all participants.

2.2. Participants, contact information

NMI			NMI Contact	
NMI	**Address**	**RMO**	**Name**	**Address**
NMISA	National Metrology Institute of South Africa Room 248, Building 5, CSIR Campus Meiring Naudé Road, Brummeria, 0184 Pretoria, South Africa	AFRIMETS	Sieberhagen, Dr. Rheinhardt	TEL: +27 12 841 3618 EMAIL: rsieberhagen@nmisa.org
NIM	National Institute of Metrology, China No. 18, Bei San Huan Dong Lu Chaoyang Dist Beijing, P.R.China 100013	APMP	Hui, Mrs. Liu	TEL: 86-10-64524830 EMAIL: liuhui@nim.ac.cn

NMIA	National Measurement Institute, Australia Bradfield Rd, West Lindfield, NSW 2070, AUSTRALIA	APMP	Manson, Dr. Peter	TEL: +61 2 8467 3858 EMAIL: peter.manson@measurement.gov.au
NMIJ	Optical Radiation Section Photometry and Radiometry Division National Metrology Institute of Japan (NMIJ) National Institute of Advanced Industrial Science and Technology (AIST) Tsukuba Central 3-1, 1-1-1 Umezono, Tsukuba, Ibaraki, 305-8563 Japan	APMP	Kinoshita, Dr. Kenichi	TEL: +81 29 861 4082 EMAIL: kenichi.kinoshita@aist.go.jp
IO-CSIC	Instituto de Optica (IO, CSIC) Serrano, 144. 28006 Madrid, Spain	EURAMET	Pons, Dr. Alicia	TEL: +34 915618806 EMAIL: apons@io.cfmac.csic.es
LNE-CNAM	LNE-CNAM Laboratoire Commun de Métrologie (LCM) 61, rue du Landy 93210 La Plaine Saint Denis, France	EURAMET	Obein, Dr. Gaël	TEL: +33 1 58 80 87 88 EMAIL: gael.obein@cnam.fr
METAS	Federal Office of Metrology METAS Lindenweg 50 CH-3084 Wabern, Switzerland	EURAMET	Blattner, Dr. Peter	TEL: +41 58 387 03 40 EMAIL: peter.blattner@metas.ch
NPL	Optical Measurement Group Engineering Measurement Division National Physical Laboratory Teddington, Middlesex TW11 0LW United Kingdom	EURAMET	Goodman, Ms Teresa	TEL: +44 (0)20 8943 6813 EMAIL: teresa.goodman@npl.co.uk
PTB	Physikalisch-Technische Bundesanstalt Bundesallee 100 38116 Braunschweig, Germany	EURAMET	Sperling, Dr. Armin	TEL: +49 531 592 4120 EMAIL: armin.sperling@ptb.de
VNIIOFI	All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI) 46 Ozernaya Str. 119361 Moscow, RUSSIA	COOMET	Khlevnoy, Dr. Boris	TEL: +7 (495) 437-29-88 EMAIL: Khlevnoy-m4@vniiofi.ru
NIST	National Institute of Standards and Technology 100 Bureau Drive, MS 8442 Room A313, Bldg. 220, NIST, Gaithersburg, MD 20899 USA	SIM	Miller, Dr. Cameron	TEL: +1 301-975-4713 EMAIL: c.miller@nist.gov
NRC	National Research Council of Canada Measurement Science and Standards 1200 Montreal Road, Building M36 Ottawa, Ontario, Canada K1A 0R6	SIM	Gaertner, Dr. Arnold	TEL: +1 613-993-9344 EMAIL: arnold.gaertner@nrc-cnrc.gc.ca

2.3. Task Group, selection

The Chair of the WG-KC requested that a subset of the 12 participants be appointed to serve on the Task Group (TG). The following eight NMIs requested to serve on the TG and were appointed by the Chair of the WG-KC.

2.4. Task Group, members

METAS	Federal Office of Metrology, Switzerland
NIM	National Institute of Metrology, China
NIST	National Institute of Standards and Technology, USA
NMIA	National Measurement Institute, Australia
NMIJ	National Metrology Institute of Japan
NPL	National Physical Laboratory, UK
NRC	National Research Council of Canada, pilot
PTB	Physikalisch-Technische Bundesanstalt, Germany

2.5. Comparison artifacts, selection

2.5.1 Type of artifact: In response to the Call for Participants, eight of the participants had indicated a preference for standard lamps as the comparison artifact, two of the participants had indicated a preference for photometers as the comparison artifact, and two of the participants had indicated that they had no preference. The TG discussed the suitability of photometers and lamps to represent a key comparison of luminous intensity. After some (email) discussions, the TG selected standard lamps to be the comparison artifact. This decision, together with a summary report of the discussions, was submitted to the full CCPR for their approval, which was subsequently received.

2.5.2 Type of lamp and measurement start dates: The pilot undertook a survey of all twelve participants in the comparison to determine the number and type of lamps that the participants wished to use for the comparison. Eleven of the twelve NMIs replied, with three of the participants indicating that they would like to use both Osram and Polaron lamps. The survey also requested that the twelve participants indicate, given a choice of August 2013 to January 2014, approximately when they would be ready to ship the lamps to the pilot. The replies included all the choices (including April 2014), with a majority indicating the December(2013)/January(2014) time period. Based upon the responses to this survey of the CCPR-K3.2014 participants, the comparison will include both the Osram Wi41/G lamp and the NPL/Polaron Heavy Current LIS incandescent lamp, with the participants expected to ship their lamps to the pilot in the December(2013)/January(2014) time period.

2.6. Traveling Standards, handling

2.6.1 The traveling standard lamps should be examined immediately upon receipt at their final destination. However, care should be taken to ensure that the lamps and packaging have sufficient time to acclimatise to the room environment, thus preventing any condensation, etc. The condition of the lamps and associated packaging should be noted and communicated to the laboratory that has shipped the lamps (participant or pilot). Please use the forms in Appendix A.1 and Appendix A.2. The pilot will use similar forms to report to the participants.

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

2.6.3 No cleaning of any lamp windows or envelopes should normally be attempted. 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 A.2 should be used to communicate this information between the two laboratories.

2.6.4 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.

2.6.5 Please inform the pilot laboratory via fax or e-mail when the measurements on the traveling standard lamps are completed to arrange a suitable date for dispatch.

2.7. Traveling Standards, transportation

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

2.7.2 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 labeled to allow unambiguous identification.

2.7.3 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’.

2.7.4 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.

2.7.5 The traveling standards should be accompanied by a suitable Customs Carnet (where necessary, see Sections 2.7.6, 2.7.7) or documentation identifying the items uniquely. The packaging may be lockable e.g. by clasp, but should be easy to open with minimum delay to allow Customs inspections to take place.

2.7.6 The NRC has a temporary importation code that allows importation, for a time period of less than one year, of equipment or material sent to NRC for testing/calibration purposes only. To enable this procedure, the participant shipper documentation (commercial invoice) MUST CLEARLY INDICATE that the equipment is being sent for testing/calibration purposes only and will be returned. This should be indicated both on the commercial invoice and on the packaging itself. Suitable wording would be:

“Temporary entry/not for resale” Material sent for testing purpose only / will be returned after testing/.

2.7.7 Consideration must also be given for the Customs requirements of the participant’s county when the lamps are returned to the participant. Although NRC does not require a Carnet, if a Customs Carnet is necessary for the return to the participant, the traveling standards should be accompanied by a suitable Customs Carnet when shipped to NRC.

2.7.8 Transportation is each laboratory’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 that may occur during transportation. 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.

2.7.9 If the traveling standards are to be 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.

2.8. Comparison, general procedures or measurement sequence

2.8.1 The comparison will be carried out through the calibration of a group of transfer standard traveling lamps. These lamps have been shown in previous CCPR comparisons to have good short-term stability and, with care, robustness, to be used to transfer a luminous intensity scale maintained in a participating laboratory to that of the pilot laboratory. 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 record of the compared quantity.

2.8.2 A full description of the traveling standard lamps selected for use in this comparison is given in Section 3 of this protocol. The minimum set of any traveling standards used for this comparison is a group of four lamps, with a set of six lamps recommended. This minimizes the risk of unknown drift and damage.

2.8.3 The traveling standard lamps used by each participant for this comparison will all be supplied pre-aged and calibrated by the participant. They will be returned to the participant at the end of the comparison and will remain the property of the participant.

2.8.4 The comparison will take the form of a star comparison carried out in a single phase. The initial calibration (round #1) of the traveling standards will be performed by the participant laboratory. They will then be sent to the pilot laboratory for the comparison measurements with the traveling standards from all the participants. They will then be returned to the participant laboratory to carry out a repeat calibration (round #2) to monitor drift and for their final retention. (Participant–Pilot–Participant)

2.8.5 NRC will act as the pilot laboratory. All results are to be communicated directly to the pilot laboratory as soon as possible and certainly within 4 weeks of the completion of all the measurements by a laboratory.

2.8.6 The participating laboratories were asked to specify a preferred timetable for their measurements of their traveling standard lamps. The timetable, with anticipated completion dates, given below in Section 2.9 has been drawn up taking these preferences into account, in addition to the recommendations of the CCPR [2] and the WG-KC [5]. The pilot may need to set earlier specific deadlines in order for the completion dates to be achieved.

2.8.7 Each laboratory has approximately 10 weeks for calibration and transportation. With its confirmation to participate, each laboratory has confirmed that it is capable to perform the measurements in the time allocated to it. It ensures that the relatively short timetable to complete the comparison is met.

2.8.8 If for some reasons, the measurement facility is not ready or Customs clearance takes too much time in a country, the participating laboratory must contact the pilot laboratory immediately to discuss further details and changes of the measurement timetable. However, 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, this may not be possible. If this is the case the participant and their results may have to be excluded from the final report.

2.8.9 Participants will be given a deadline date for the submission of results. If a participant fails to submit the results by the deadline (except for special reasons such as failure of artifacts), the participant will be disqualified.

2.9. Comparison, timetable

Please note that many of the completion dates given in this table are the maximum 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 need to set earlier specific deadlines in order for the completion dates to be achieved. The dates for the shipment of participant artifacts to the pilot were discussed in Section 2.5.2.

Activity (responsibility)	Completion Date
Call for participants (CCPR)	Start 2010-September-06
	End 2010-October-31
Finalise participants (pilot)	2011-March-10
Finalise and appoint Task Group (chair of WG-KC)	2011-April-15
Choice of comparison artifact (TG)	2011-August-23
CCPR approval of comparison artifact (CCPR)	2011-September-17
Develop draft Protocol (TG)	2013-July-31
Approval of draft Protocol by all participants (pilot, participants)	2013-October-25
Protocol approved by CCPR WG-KC (WG-KC)	2014-January-15
Submit KCDB entry form and technical protocol to CCPR Executive Secretary for Registration of CCPR-K3.2014 with KCDB office (pilot)	2014-January-17
Receipt of calibrated traveling standards by pilot (participants)	2014-March-20
Measurement of participants' traveling standards (pilot)	Start 2014-March-24
	End 2014-July-25
Return of traveling standards to participants (pilot)	2014-August-15
Repeat measurements of traveling standards (participants)	2014-October-13
Participant data received by pilot (participants)	2014-November-07
Pre-Draft A Process 1: Verification of reported results (pilot)	2015-January-07
Pre-Draft A Process 1: Response to 'Verification' (participants)	2015-January-30
Pre-Draft A Process 2: Review of uncertainty budgets (pilot)	2015-January-07
Pre-Draft A Process 2: Response to Review of uncertainty budgets (participants)	2015-February-20

Pre-Draft A Process 3: preparation of "Relative Data" (pilot)	2015-January-08
Pre-Draft A Process 3: response to "Relative Data" (participants)	2015-February-08
Pre-Draft A Process 4: Identification of outliers and consistency check (pilot)	2015-March-20
Comments, responses and revisions to uncertainty budgets	2015-March-11
Distribution of Draft A (pilot)	2015-May-08
Review of Draft A (participants)	2015-July-09
Approval of final Draft A (participants)	2015-August-10
Submit Draft B to CCPR WG-KC for approval (pilot)	2015-September-10
Approval of Draft B (WG-KC)	2015-October-20
Approval of Draft B (CCPR)	2015-December-01
Publication of final report	2015-December-21

3. Description of the Traveling Standards

3.1 The measurement artifacts will be standard Osram Wi41/G and NPL/Polaron Heavy Current LIS incandescent lamps.

3.2 Each participant shall supply a minimum of four, and maximum of six (recommended number), aged and calibrated traveling standards.

3.3 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.

3.4 The fixed electrical current operating point shall be indicated for each lamp in the measurement report. The value of the related voltage shall also be indicated. This will enable initial evaluation of the lamp condition during operation, especially after travel.

3.5 The correlated colour temperature (CCT) of the luminous intensity of the lamp at the given electrical operating conditions shall be between approximately 2800 K and 2900 K, and shall be determined by the participant and reported for each lamp. 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. The pilot has compared the CCT and Distribution Temperature calculations for several Osram Wi41/G lamps in the NRC laboratory and found that the temperature values differ by less than 5 K.

3.6 The pilot laboratory is capable of mounting and aligning plain Osram Wi41/G and Polaron lamps. If any special holders are permanently mounted to the participant's lamps, the participant shall discuss with the pilot laboratory any necessary mounting holders or alignment jigs that may be needed for the measurements at the pilot laboratory. This should be done before shipment of the lamps to ensure that the pilot is able to measure the lamps.

4. Measurement Instructions

4.1. Traceability

4.1.1 Length measurements should be independently traceable to the latest realisation of the metre.

4.1.2 Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

4.1.3 Electrical measurements should be independently traceable to the latest realisations of the ampere and volt.

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 should be measured for the specified mechanical and electrical operating conditions for each lamp.

4.2.2 The luminous intensity of the traveling standards may depend, to a small amount, upon the total solid angle over which the luminous intensity is measured. The solid angle, or photometer input aperture diameter and distance from lamp filament, used to calibrate the lamp should be reported. Note Section 4.4.10 for the configuration and approximate solid angle that will be used at NRC to compare the lamps. If there is a significant difference between the solid angle used by the participant and that at NRC, the participant should report any expected difference in measured luminous intensity.

4.2.3 The electrical operating conditions of each lamp shall be such that the correlated colour temperature (CCT) of the luminous intensity is between 2800 K and 2900 K. This temperature shall be determined by the participant and reported to the pilot laboratory. (See also Section 3.5.)

4.2.4 The lamps are to be operated with DC power at a fixed electrical polarity and stabilised current, which must be specified by the participant for each lamp.

4.2.5 The measurements should be performed in suitable laboratory accommodation maintained at a temperature of 20 to 27 °C. The temperature of the laboratory during the time of the measurements should be reported.

4.2.6 The luminous intensity of each lamp should be measured independently at least two times. Each independent measurement should 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. 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 or final declared value of the set and the standard deviation of the mean are required to be reported. 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 that this be kept to a minimum.

4.3. Measurement procedures

4.3.1 Participants should 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. 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. The electrical and optical/geometrical parameters for their measurements must be specified (Appendix A.3), particularly with reference to Section 4.4, which describes the procedures to be used at the pilot laboratory. Any differences between the participant and the pilot procedures should be indicated to the pilot.

4.3.2 Basic geometric conditions:

- The lamp is mounted base down.
- The optical axis is horizontal and passes through the center of the filament.
- The optical axis is perpendicular to the plane of the filament (Osram Wi41/G), or to the rear surface of the front window of the lamp envelope (Polaron).
- Distance from the lamp is measured from the center of the filament.
- The photometric measurements accept only the light passing through the rectangular opening in the black mask on the face of the Osram Wi41/G lamp or the black lamp mask of the Polaron lamp.

See Sections 4.4.8 to 4.4.10 for further information related to the geometry of the lamps.

4.3.3 Basic electrical conditions:

- DC electrical power
- Defined fixed electrical current for operation
- Defined electrical polarity at lamp contacts
- The defined electrical current has been determined by the participant to result in a CCT between 2800 K and 2900 K for the photometric output of the lamp. The actual CCT value must be reported to the pilot. (See also Section 3.5.)
- The warm-up time for each lamp as used by the participant and reported to the pilot.

4.3.4 Before use, the lamps should be inspected for any damage or contamination to the lamp window, lamp base, or lamp mount. Any damage should be documented with photos and a drawing and the pilot and participant should immediately exchange this information using the form in Appendix A.2.

4.3.5 The defined operational conditions and alignment procedures for each lamp should be followed and recorded. The details of the procedure should be described and reported to the pilot (Appendix A.3). A photograph of the experimental setup may be taken and a copy sent with the report.

4.3.6 After connecting the electrical power to the lamp, the prescribed warm-up procedure (Section 4.4.5) for each lamp should be followed. The operational parameters for each lamp (specified in the lamp operating procedure) should be recorded and compared with those supplied with the lamp. If these values are outside expected values for the lamp, the lamp should be turned off and this information exchanged between the participant and the pilot laboratory. The operating time for each lamp should be recorded each time the lamp is used during this comparison and a summary form, such as given in Appendix A.4, returned to the pilot laboratory as part of the final report. The pilot will send each participant a summary form such as Appendix A.5 for each of their lamps after completion of the measurements at the pilot laboratory.

4.3.7 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. Email, signed and scanned PDF, signed and FAXed, or signed paper versions are all acceptable.

4.3.8 No other measurements with the traveling standards are to be attempted by the participants, 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.

4.3.9 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.

4.4. Pilot laboratory measurement procedures

4.4.1 This section describes the measurement procedures the pilot (NRC) proposes to use 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. Participant procedures and any potential problems should be reported as indicated in Section 3.6 and/or Section 4.3.1 above. 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. See also Section 4.4.10.

4.4.2 Each lamp will be operated at least twice to produce two measurements at the specified operating conditions. The stability of the NRC facility will be monitored through the measurement of a group of monitor lamps throughout the comparison measurements.

4.4.3 The quantity compared will be the photometer signal produced by the output radiation of the lamp when operating at the specified electrical parameters under the following conditions:

4.4.4 The lamps will be operated with base-down.

4.4.5 NRC electrical controls:

All lamps will be operated with DC power at the fixed polarity and fixed current indicated by the participant. 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. The voltage will be measured at the lamp socket, rather than the lamp base.

The lamp current will be ramped up slowly over approximately one minute to the value indicated by the participant. The pilot will use approximately the same length of warm-up time that the participant has indicated was used for the measurements in the participant laboratory. The lamp current and voltage will be recorded immediately after the photometric measurements. After measurements, the lamp voltage will be ramped down slowly over approximately one minute.

4.4.6 NRC photometers:

The NRC photometers used for this comparison will be commercial, temperature-controlled, full-filtered $V(\lambda)$-corrected photometers, with aperture mode input. The relative spectral responsivity of the photometers will be measured to enable a spectral mismatch correction to be made for any difference in CCTs between the participants' lamps. The CCTs reported by the participants will be used for this correction. (See also Section 3.5.)

The NRC photometers have an input aperture diameter of approximately 8 mm.

4.4.7 NRC optical coordinate system:

The optical axis for the measurements is the straight line between the center 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 centered on this beam line, and aligned to be perpendicular to this beam-line. The defined point on the reference plane of the lamp will be centered on this beam-line, and the reference plane will be aligned to be perpendicular to this beam-line. See Figure One for the coordinate axis system, shown with the Osram Wi41/G lamp filament. The same coordinate system is used for the Polaron lamp filament. In Figure One 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 center of the filament.

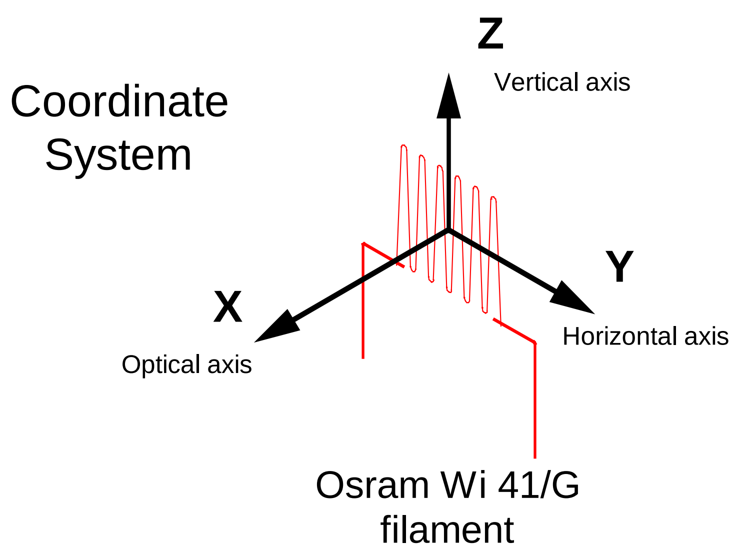


Figure One
Lamp filament and coordinate system, shown with the Osram Wi41/G filament.

The origin of the coordinate system is established in the laboratory at NRC using an alignment telescope. The alignment telescope is positioned such that its optical axis is horizontal and perpendicular to the laser beam-line. This is done using a 90° beam-splitting cube inserted into the laser beam-line. The telescope mounts are adjusted such that the secondary laser beam produced by the cube is centered on the telescope crosshairs, and the horizontal motion of the telescope is along this secondary beam. The rotation of the crosshairs is adjusted such that the vertical crosshair is parallel to a plumb line. With this alignment, the point of crossing of the primary beam-line and the secondary beam-line, which becomes the position of reference for the distance of the lamp filament along the optical axis, can be obtained using the telescope. If the telescope is initially positioned at the desired lamp distance from the photometer, this final aligned position of the telescope can be used to set and align all the lamps at the same distance from, and orientation to, the photometer.

4.4.8 NRC alignment of Osram Wi41/G incandescent lamps

The Osram Wi41/G lamps are aligned to this laser beam-line and coordinate system by aligning the filament to the coordinate system. There are two types of Osram Wi41/G filament mounts (Figure Two), which results in two slightly different alignment procedures. Photographs (courtesy of PTB) of a typical filament alignment for the two filament types are shown in Figure Three.

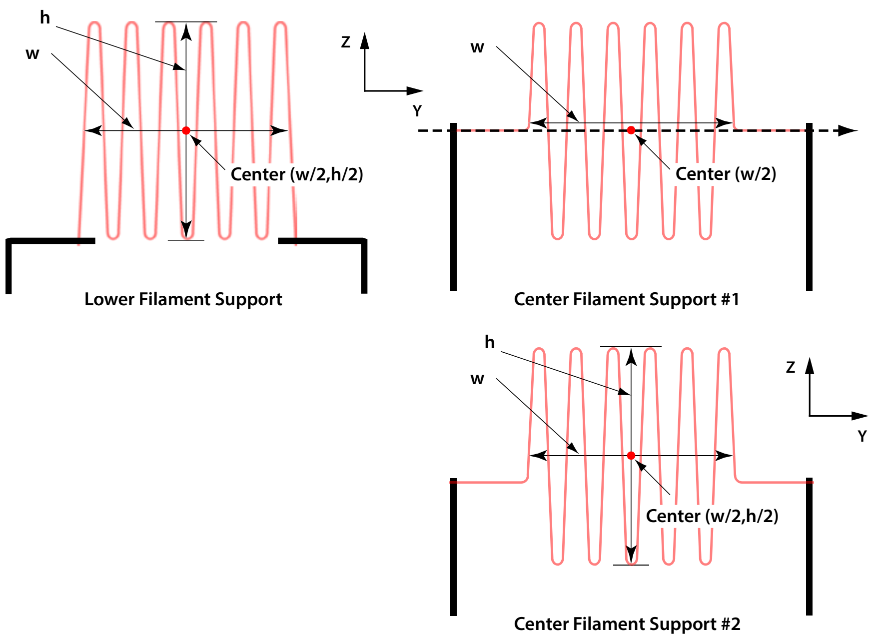
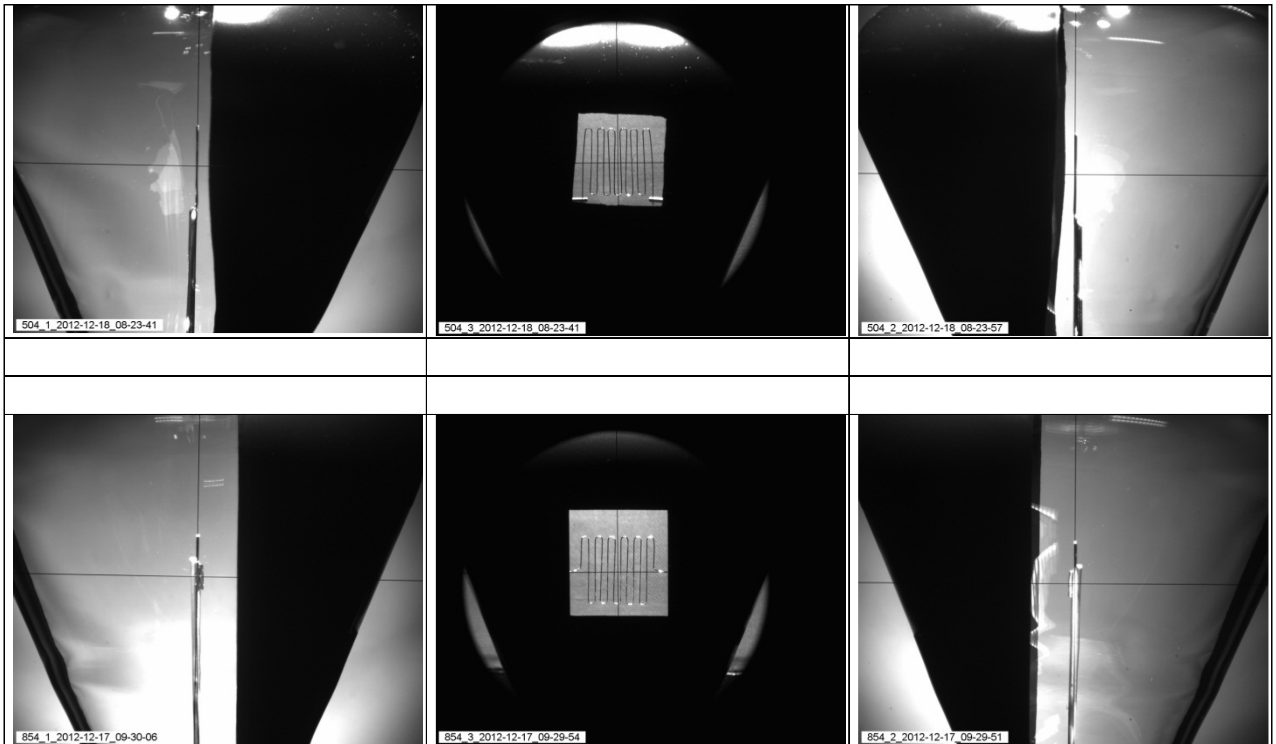


Figure Two
Osram Wi41/G filament defined point: Center.

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 and to take account of any possible motion of the filament due to the thermal changes in the filament and its mount when the lamp is operating. The participant should inform the pilot which method is used for their lamps (Appendix A.3).



Left view	Front view	Right view

Figure Three
Osram Wi41/G filament alignment.

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 telescope is minimized. In the case of the filament with the center 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 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 the 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 the filament with the center 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 laser beam passes through the defined point of the filament plane. 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. As indicated in Figure Two, there are two possibilities for the alignment of lamps with the center filament support: 1.) For Center Filament Support #1, 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. 2.) For Center Filament Support #2, the defined Z-point is the same as for the lamps with the Lower Filament

Support. The participants with Center Filament Support lamps should inform the pilot which method of alignment is used for their lamps (Appendix A.3).

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 telescope, which was minimized in the rotation about the Z-axis in step i. above.

4.4.9 NRC alignment of NPL/Polaron Heavy Current LIS incandescent lamps

The Polaron lamps are aligned to this laser beam-line and coordinate system by aligning both the filament and the lamp envelope to the coordinate system. The lamp envelope is used for the three angular alignments and the lamp filament is used for the three spatial positionings. The black lamp mask is also aligned when the filament is centered on the laser beam (step iii below). Only light from the area inside this lamp mask should be measured. A schematic of one type of the Polaron lamps is shown in Figure Four. Photographs (courtesy of NPL) of typical alignment steps are shown in Figure Five. Figure Five also shows another type of the Polaron lamp.

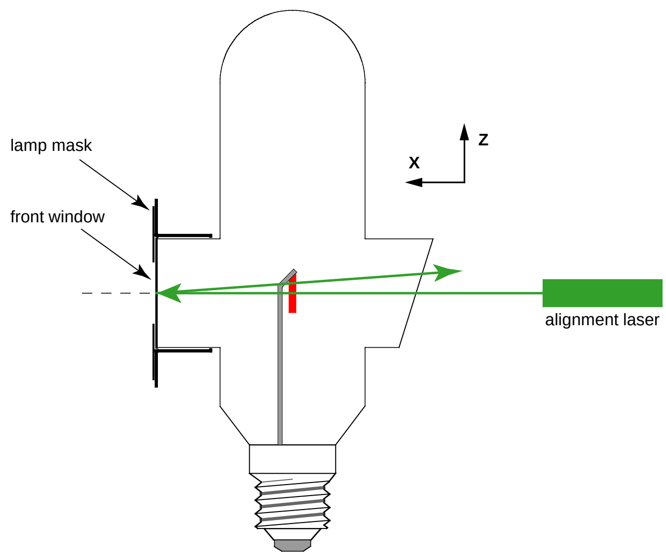


Figure Four

Alignment Schematic for NPL/Polaron Heavy Current LIS incandescent lamps

i. Rotation about the X-axis: A spirit level or plumb-line is used along the side of the lamp envelope to set the lamp envelope vertical.

ii. Rotations about the Y-axis and Z-axis are adjusted until the reflection of the alignment laser from the rear of the front window (Figure Four) is directly returned to the laser.

iii. The spatial position of the lamp is adjusted in the Y and Z direction until the laser beam passes through the defined point of the filament plane, which is the center of the filament. As shown in Figure Five: Hold a piece of lens cleaning tissue between the laser and the lamp and turn off the room lights. Hold a piece of paper in front of the lamp and you will see a shadow of the filament and the lamp mask aperture. The lamp should be moved so that the main laser spot goes through the centre of the filament. The black mask on the front window of the lamp should be made central and vertical.

iv. The distance along the X-axis is measured to the center along the X-axis of the image of the lamp filament in the telescope.

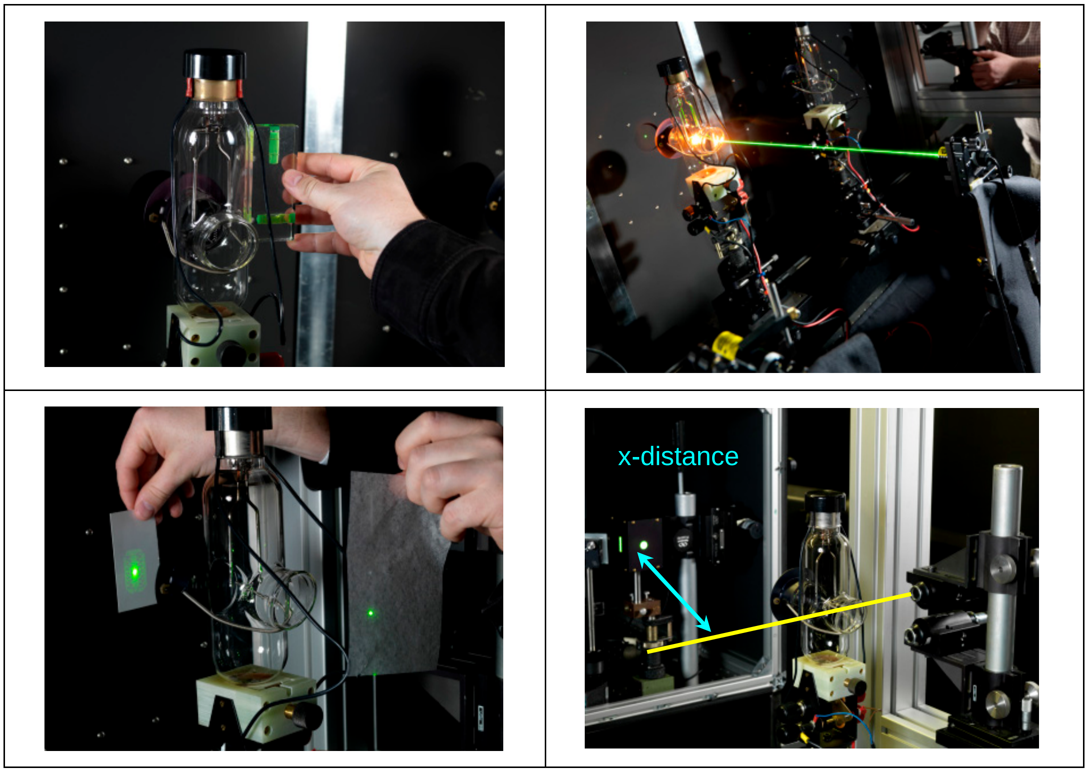


Figure Five
Polaron lamp alignment

4.4.10 NRC optical configuration:

The experimental configuration for the luminous intensity measurements to be used at NRC is shown schematically in Figure Six.

In this configuration the laser is placed behind the lamp to enable alignment of the photometer as well as the lamp in the same setup. If any participant requires the use of an alignment jig to set up their lamps, this configuration may need to be modified.

The distance between the photometer input aperture and the lamp filament plane on the NRC photometric bench is approximately 3.2 m. The NRC 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 5 μsr.

The limiting aperture is sized and placed to restrict the field of view of the photometer to accept only the light passing through the rectangular opening in the black mask on the face of the Osram Wi41/G lamp or the black lamp mask of the Polaron lamp. Since the lamps used for the comparison are similar, it is intended that the setup in Figure Six will remain constant for all the lamps of one type (Osram or Polaron), with only minor changes, such as the limiting aperture, between the two different lamp types. For example, to minimize distance uncertainties, it is planned to measure, as much as possible, all the lamps from all the participants at the same distance between the photometer and the lamp filament.

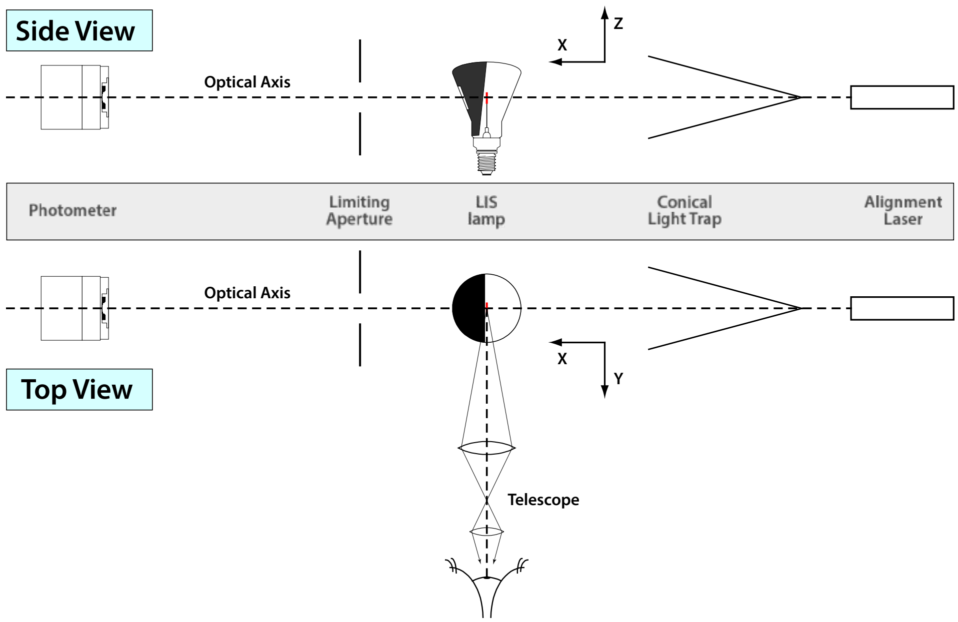


Figure Six
Schematic of NRC Measurement Configuration
LIS = Luminous Intensity Standard (Osram lamp shown)

5. Reporting of 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 A.6, should be sent to the pilot laboratory along with the traveling standard lamps to be used for the comparison. This report should also include the measurement geometry, measurement procedures and the operating conditions of the traveling standard lamps, such as indicated in Appendix A.3.

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 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 forms in Appendices A.4 to A.6. The results of both rounds of measurements must be reported.

5.4 The following information must be submitted before, or at the latest with, the submission of the final measurement results indicated in Section 5.3 above:

- 5.4.1 A description of the laboratory facility for luminous intensity measurements, such as indicated in Appendix A.3.
- 5.4.2 Information on the traceability of the laboratory luminous intensity scale (listed in Appendix A.3).
- 5.4.3 A detailed uncertainty budget, including the list of uncertainty contributions identifying uncertainty components related to correlated and uncorrelated effects

between measurements rounds, for the laboratory's measurement of luminous intensity (general one for the quantity, not for each individual transfer artifact).

5.5 Email, signed and scanned PDF, signed and FAXed, or signed paper versions are all acceptable versions of the reports.

5.6 The four Pre-Draft-A Processes as described in *CCPR G2 Guidelines for CCPR Comparison Report Preparation* [6] will be followed at this point:
- Pre-Draft-A Process 1: Verification of reported results,
- Pre-Draft-A Process 2: Review of uncertainty budgets,
- Pre-Draft-A Process 3: Review of relative data, and
- Pre-Draft-A Process 4: Identification of outliers and consistency check.

6. Measurement Uncertainty

6.1. Uncertainty Components

6.1.1 The uncertainty of measurement shall be estimated according to the *Guide to the expression of uncertainty in measurement (GUM)* [7].

6.1.2 In order to achieve optimum comparability, both for this CCPR KC and the RMO linking KCs, a list containing the principal influence parameters for calibration of luminous intensity standard lamps is given below. An example uncertainty budget that should be completed by participants is included as Appendix A.5. The participating laboratories are encouraged to follow this breakdown 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 should be added with an appropriate explanation and/or reference. The CIE has published document CIE 198:2011 [8] that includes a measurement model that may also be used for presenting the uncertainties. As well as the value associated with the standard uncertainty, participants should give an indication as to the basis of their estimate. All values should be given for a coverage factor of k=1. Participants are asked to make at least 2 independent (after full realignment) sets of measurements of luminous intensity on each lamp and record the results of each set in a table such as given in Appendix A.6.

6.1.3 It is important that the uncertainties given in the uncertainty budget be separated into uncertainty components that are related to systematic (correlated) and random (uncorrelated) effects. Such data are needed for data analysis not only for this comparison but also for linking the results to RMO comparisons in the future. The classification of these effects may be different between the first round calibration of the individual traveling lamps and the second round calibration of the lamps performed upon the return of the lamps to the participant.

6.1.4 In general, systematic effects produce their (unknown) values from one measurement to the next, so that the uncertainty associated with these effects cannot be reduced through multiple measurements. Hence these uncertainty components are generally evaluated using Type B methods. These constant 'errors' 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 some time later in the second round. Such changes should be reported.

6.1.5 The random effects usually produce values that vary randomly from measurement to measurement and are usually evaluated using Type A methods.

6.1.6 The following list of influence parameters is separated into probable systematic/random parameters. This is given as a guide and individual participant laboratory procedures may require modifications.

6.2. Measurement influence parameters

The factors contributing to the uncertainty budget are primarily related to the calibration and use of the working standards used to calibrate the traveling standard lamps, the various lamp parameters, electrical parameters, photometer parameters and environmental effects.

6.2.1 Systematic effects:

1. Calibration of the working standards used to calibrate the traveling standard lamps. These working standards could be either reference photometers or reference lamps. This is the total uncertainty of the working standards for the participant's underpinning scale as disseminated by them. This should include the uncertainty in the primary SI realisation. All uncertainties contributing to this parameter should be itemised as part of the report, or if published a copy of this publication attached. This must include a complete compilation of all uncertainties contributing to the establishment of the primary quantity together with those associated with the measurement facility used for this comparison e.g. linearity, stray light, positioning of reference standard etc. Since there may also be a time factor between the establishment of the primary quantity and its use in this comparison, an appropriate uncertainty should be included to represent the maintenance of the primary scale.
2. Electrical parameters, such as the calibration of the standard resistor used to determine the lamp current and the calibration of the voltmeter used to measure the lamp voltage and the voltage across the standard resistor.
3. Photometer parameters, such as spectral mismatch errors, linearity, and distance (lamp-to-photometer) errors.
4. Environmental effects such as stray light, especially if the same setup is used for all lamps. The temperature and/or humidity in the laboratory may have some effects.

6.2.2 Random effects:

1. Most lamp parameters are characteristic of the individual lamp and vary from use to use. These include lamp alignment, lamp ageing, lamp fluctuations during operation and lamp reproducibility due to thermal effects (on/off thermal cycling) and mechanical effects (removal/ replacement in socket, etc.).
2. Electrical parameters, such as the fluctuations on the current or voltage output of the electrical power supply used to operate the lamp.
3. Photometer parameters, such as the electrical noise in the photometer signal.
4. As indicated in Section 4.2.6, each reported independent measurement is the mean of a set of measurements with a standard deviation of the mean dependent upon the number of measurements. This standard deviation of the mean may include the fluctuations indicated in the three items above.

A summary of each of the two uncertainties is to be given with each lamp measurement as indicated in Appendix A.6. The detailed itemization of the uncertainties should be given in a table, such as that indicated in Appendix A.5.

7. Determination of Key Comparison Reference Value (KCRV)

The KCRV will be determined using the methods and data analysis given in *CCPR G2 Guidelines for CCPR Comparison Report Preparation* [6].

8. Acronyms

BIPM	Bureau International des Poids et Mesures
CCPR	Consultative Committee for Photometry and Radiometry
CCT	Correlated Colour Temperature
CIPM	Comité international des poids et measures
KC	Key Comparison
KCDB	Key Comparison Data Base
KCRV	Key Comparison Reference Value
LIS	Luminous Intensity Standard
RMO	Regional Metrology Organization
TG	Task Group for CCPR-K3.2014
WG-KC	CCPR Working Group on Key Comparisons

9. References

[1] **K3.a**: Georg Sauter, Detlef Lindner, Matthias Lindemann, *CCPR Key Comparisons K3a of Luminous Intensity and K4 of Luminous Flux with Lamps as Transfer Standards*, PTB Bericht, PTB-Opt-62, 1999.

K3.b: R. Köhler, M. Stock, C. Garreau, *Final Report on the International Comparison of Luminous Responsivity CCPR-K3.b*, Metrologia **41**, 2004, Tech. Suppl., 02001.

Summary results are available at the BIPM Key Comparison Database (KCDB) at www.bipm.org.

[2] *Consultative Committee for Photometry and Radiometry (CCPR), Report of the 20th meeting (17-18 September 2009) to the International Committee for Weights and Measures, Version 2: amended 13 April 2011*, BIPM, Paris, file CCPR20.pdf available from www.bipm.org.

[3] CIPM MRA-D-05, *Measurement Comparisons in the CIPM MRA*, Version 1.3 October 2012, BIPM, Paris, file CIPM_MRA-D-05.pdf available from www.bipm.org.

[4] CCPR-G4, July 01, 2013 *Guidelines for preparing CCPR Key Comparisons*, CCPR WG-KC, BIPM, Paris.

[5] *Minutes of CCPR WG-KC meeting 9 July 2010, NPL, Teddington, UK*, file WGKC-10-Minutes.pdf, available from www.bipm.org.

[6] CCPR-G2 Rev.3, July 01, 2013 *Guidelines for CCPR Comparison Report Preparation*, CCPR WG-KC, BIPM, Paris.

[7] JCGM 100:2008, Joint Committee for Guides in Metrology (September 2008), Evaluation of Measurement Data — *Guide to the expression of uncertainty in measurement (GUM).* Available from http://www.bipm.org . See also JCGM 104:2009, *Evaluation of measurement Data — An introduction to the "Guide to the expression of uncertainty in measurement" and related documents.*

[8] CIE Publication 198:2011, *Determination of Measurement Uncertainties in Photometry*, Commission Internationale de l'Eclairage, Vienna, Austria.

10. Appendices

Appendix A.1 Receipt Confirmation 23
Appendix A.2 Inspection of the Traveling Standards 24
Appendix A.3 Description of the measurement facility 25
Appendix A.4 Record of lamp operating time 26
Appendix A.5 Sample Measurement Uncertainty Budget 27
Appendix A.6 Measurement Results 28

Appendix A.1 Receipt Confirmation

FAX or Email

TO: Dr. Arnold A. Gaertner
Measurement Science and Standards
Building M-36, Room 115
National Research Council of Canada
1200 Montreal Road
Ottawa, Ontario, Canada K1A 0R6

FAX: 613-952-1394
Email: Arnold.Gaertner@nrc-cnrc.gc.ca

FROM: participating laboratory

We confirm having received the traveling standards for the CIPM key comparison CCPR-K3.2014 *Luminous Intensity* on:

date-of-receipt: ....

After visual inspection, we report:

☐ No damage has been noticed

☐ The following damage must be reported:

....
....
....
....

Participant: ……………………………..

NMI: ……………………………………

Date: ……………………………………

Signature: ………………………………

Appendix A.2 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 visible signs 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 number: ………………

  What are the voltage and the current?

  V = ………..

  I = ………..

Do you believe the lamps are functioning correctly?

- ☐ Yes
- ☐ No. Please indicate your concerns:

Participant: ……………………………..

NMI: ……………………………………

Date: ……………………………………

Signature: ………………………………

Appendix A.3 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.

Description of measurement geometry (please include a diagram):
- positions of lamp, detector, bench, shielding, baffles (number, distances and sizes)
- alignment devices
- solid angle of luminous intensity measurements:
    - distance of photometer from lamp
    - size of photometer input aperture
- limiting aperture?

Description of measurement procedures.

Make and type of the photometer (or equivalent).

Operating conditions of the lamps:
- geometrical alignment
    - definitions of defined point and reference plane at the lamp
        - for Osram lamps with center filament supports, which center filament support type is used for the alignment (see Figure Two and Section 4.4.8.)
    - 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, current, voltage for each traveling standard
- length of warm-up time for each lamp before measurements are taken
- measured CCT (or Distribution Temperature or Colour Temperature, see Section 3.5).
- stray-light reduction

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

Laboratory transfer standards used:
- type of transfer standards and traceability to primary scale

Establishment or traceability route of primary scale including date of last realisation and uncertainty budget.

Participant: ……………………………..

NMI: ……………………………………

Date: ……………………………………

Signature: ………………………………

Appendix A.4 Record of lamp operating time

Lamp number: …………..

Date	Lamp ON time	Activity/Comments (test, alignment, measurement)	Lamp OFF time	Burn time (hrs)	Lamp Current (amperes)	Lamp Voltage (volts)	Operator initials

Participant: ……………………………..

NMI: ……………………………………

Date: ……………………………………

Signature: ………………………………

Appendix A.5 Sample Measurement Uncertainty Budget

Measurement Parameter	**Uncertainty Type (A or B)**	**Standard Uncertainty in luminous intensity (%)**
Systematic effects:		
Calibration of working standards		
- *itemize as per laboratory*		
Electrical		
- standard resistor		
- voltmeter		
Photometer		
- spectral mismatch		
- linearity		
- distance		
Environment		
- stray light		
- temperature / humidity ?		
RMS total systematic effects:		
Random effects:		
Lamp parameters:		
- lamp ageing		
- lamp alignment		
- lamp reproducibility		
- lamp output fluctuations		
Electrical parameters:		
- power supply fluctuations		
Photometer noise		
(Measurement Set standard deviation of mean)		
RMS total random effects:		
RMS total standard uncertainty:		

Measurement parameters given in this table are suggested. Please modify and itemize according to your particular situation. See Section 6.2 for explanation of the various items.

Note that if lamps are used as the laboratory working standards, a group of uncertainties would need to be included in the above table to account for their behaviour.

The RMS total refers to the usual square root of the sum of the squares of all the individual uncertainty terms.

Participant: ……………………………..

NMI: ……………………………………

Date: ……………………………………

Signature: ………………………………

Appendix A.6 Measurement Results

Lamp Number: ____________

Measurement Round #1:

Measurement Set Number	Number of measurements per set	Date/time	Lamp current	Lamp voltage	Luminous Intensity	Standard Uncertainty in Luminous Intensity (%)	
						Random	Systematic

Measurement Round #2:

Measurement Set Number	Number of measurements per set	Date/time	Lamp current	Lamp voltage	Luminous Intensity	Standard Uncertainty in Luminous Intensity (%)	
						Random	Systematic

The random/systematic labels in this table are those related to the measurements within the particular round of the measurements. If the systematic factors change between the measurement rounds, this information should be indicated separately.

Participant: ……………………………..

NMI: ……………………………………

Date: ……………………………………

Signature: ………………………………