CCPR Key Comparison CCPR-K1a.2017

Spectral Irradiance 250 nm to 2500 nm

Technical Protocol

(Final)

Contents

1. Introduction

1.1 The metrological equivalence of national measurement standards is 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 its meeting in March 1997, the Consultative Committee for Photometry and Radiometry, (CCPR) identified several key comparisons (KC) in the field of optical radiation metrology. In particular, it decided that a key comparison of spectral irradiance shall be carried out in two spectral ranges: from 250 nm to 2500 nm (CCPR-K1a) and from 200 nm to 350 nm (CCPR-K1b). The comparison CCPR-K1a was piloted by the National Physical Laboratory, UK (NPL) and was completed in 2006 [1]. In 2013 CCPR announced the second round of key comparison CCPR-K1a. All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI) was chosen to pilot this comparison. VNIIOFI participated in the first round of CCPR-K1a and later served as a link laboratory in the bilateral comparison APMP.PR-K1a.1-2008 with KRISS [2].

1.3 This technical protocol has been drawn up by the seven-member Task Group (TG) of the participants of the CCPR-K1a.2017 key comparison, agreed by all the participants and approved by the CCPR working group on key comparisons (WG-KC).

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 CIPM [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 K1a comparisons carried out by CCPR [1] and RMOs [2, 5, 6, 7] and that of the Task Group.

2. Organization

2.1. Participants

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.

2.1.2 The selection process for the participants was guided by the criteria described in the document CCPR-G4**,** *Guidelines for preparing CCPR Key Comparisons* [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 to select the maximum number of participants in accordance with limits fixed in CCPR-G4 [4], presented in Table 1.

Table 1. RMO participant limits.

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 the WG-KC, no change to the protocol or list of participants may be made without prior agreement of all participants.

2.1.6 The list of participants and their contact information are presented in Table 2.

Table 2. List of participant and contact information.

NMI			NMI Contact	
NMI	**Address**	**RMO**	**Name**	**Address**
VNIIOFI (pilot)	All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI) 46 Ozernaya Str. 119361 Moscow, RUSSIA	COOMET	Boris Khlevnoy	TEL: +7 (495) 437-29-88 EMAIL: khlevnoy-m4@vniiofi.ru

IO-CSIC	Instituto de Optica (IO, CSIC) Serrano, 144. 28006 Madrid, SPAIN	EURAMET	Alicia Pons Aglio	TEL: +34 915618806 EMAIL: apons@io.cfmac.csic.es
KRISS	Korea Research Institute of Standards and Science 267 Gajeong-Ro, Yuseong-Gu, Daejeon 305-340, REPUBLIC OF KOREA	APMP	Dong-Joo Shin	TEL: +82-42-868-5209 EMAIL: djshin@kriss.re.kr
LNE-CNAM	LNE-CNAM Laboratoire Commun de Métrologie (LCM) 61, rue du Landy 93210 La Plaine Saint Denis, FRANCE	EURAMET	Bernard Rougié	TEL: +33 1 40 27 20 22 EMAIL: bernard.rougie@cnam.fr
NIM	National Institute of Metrology, China No. 18, Bei San Huan Dong Lu, Beijing, 100013, P.R.CHINA Room 109, Building 13	APMP	Lin Yandong Dai Caihong	TEL: 86-10-64524805 EMAIL: linyd@nim.ac.cn TEL: 86-10-64524813 EMAIL: daicaihong@nim.ac.cn
NIST	National Institute of Standards and Technology 100 Bureau Drive, MS 8442 Room A313, Bldg. 220, NIST, Gaithersburg, MD 20899 USA	SIM	Howard Yoon Charles Gibson	TEL: +1 301-975-2482 EMAIL: howard.yoon@nist.gov TEL: +1 301-975-2329 EMAIL: charles.gibson@nist.gov
NMC, A*STAR	National Metrology Centre, A*STAR 1 Science Park Drive SINGAPORE 118221	APMP	LIU Yuanjie	TEL: +65 62791940 EMAIL: liu_yuanjie@nmc.a-star.edu.sg
NMIA	National Measurement Institute, Australia Bradfield Rd, West Lindfield, NSW 2070, AUSTRALIA	APMP	Peter Manson	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	Tatsuya Zama	TEL: +81 29 861 5649 EMAIL: zama-t@aist.go.jp
NPL	Optical Measurement Group Engineering Measurement Division National Physical Laboratory Teddington, Middlesex TW11 0LW United Kingdom	EURAMET	Teresa Goodman	TEL: +44 (0)20 8943 6863 EMAIL: teresa.goodman@npl.co.uk
NRC	National Research Council of Canada Measurement Science and Standards 1200 Montreal Road, Building M36 Ottawa, Ontario, Canada K1A 0R6	SIM	Arnold Gaertner Angela Gamouras	TEL: +1 613-993-9344 EMAIL: arnold.gaertner@nrc-cnrc.gc.ca angela.gamouras@nrc-cnrc.gc.ca
PTB	Physikalisch-Technische Bundesanstalt Bundesallee 100 38116 Braunschweig, Germany	EURAMET	Peter Sperfeld Sven Pape	TEL: +49 531 592 4144 EMAIL: Peter.Sperfeld@ptb.de TEL: +49 531 592 4112 EMAIL: Sven.Pape@ptb.de

2.2. Task Group

2.2.1 A subset of the 12 participants was discussed and selected by participants to serve as the Task Group (TG). The following seven selected TG members were then approved by the WG-KC:

VNIIOFI All-Russian Research Institute for Optical and Physical Measurements, Russia
KRISS Korea Research Institute of Standards and Science, Republic of Korea
NIST National Institute of Standards and Technology, USA
NMIA National Measurement Institute, Australia
NMIJ National Metrology Institute of Japan
NPL National Physical Laboratory, UK
PTB Physikalisch-Technische Bundesanstalt, Germany

2.3. Comparison artifacts and form of comparison

2.3.1 The comparison will principally be carried out through the calibration of a group of traveling standard lamps (traveling standards). These lamps have been shown to have reasonable stability and robustness, to be used to transfer a spectral irradiance scale maintained in a participating laboratory to that of the pilot laboratory.

2.3.2 Each participant will use a separate set of lamps to minimise the effects of ageing. This will also allow the participant to maintain a record of the compared quantity.

2.3.3 The comparison will take the form of a star comparison. The sequence of measurements will be the following:

Participant – Pilot – Participant.

The artifacts (lamps) will initially be calibrated by participants. They will then be transported to the pilot for pilot calibration. They will then be returned to participants to carry out repeat calibrations to monitor drift.

2.3.4 Each participant will provide its own set of three traveling standard lamps.

2.3.5 Traveling standard lamps will be tungsten halogen lamps of FEL type with nominal voltage and electrical power of 110 V and 1000 W, respectively. The lamps will be operated at constant DC current. Each lamp set will be equipped with an alignment jig that allows precise alignment. According to a WG-KC decision, participants will not use lamps that were used for any previous spectral irradiance international comparison; all lamps will be new lamps of the same type selected by the TG. A full description of the traveling standard lamps is given in section 3 of this protocol.

2.3.6 VNIIOFI will act as the pilot laboratory. All results are to be communicated directly to the pilot laboratory as soon as possible and certainly within 6 weeks after the completion of all the measurements by a laboratory.

2.3.7 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.

2.3.8 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.

2.3.9 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.

2.4 Timetable

2.4.1 Table 3 presents the timetable of the comparison. Please note that many of the completion dates given in this table are the maximum suggested by the CCPR guidelines [4, 8]. 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.

Table 3. Comparison Timetable

Activity (responsibility)	**Completion Date**
Call for participants (CCPR)	August 2013
Finalise participants (CCPR)	September 2014
Develop draft Protocol (TG)	February 2016
Approval of draft Protocol by all participants (pilot, participants)	April 2017
Protocol approved by CCPR WG-KC (WG-KC)	May 2017
Registration in KCDB (pilot)	May 2017
First measurements of traveling standards: VNIIOFI, IO-CSIC, KRISS, NIST, NMC, NMIA, NMIJ, PTB LNE-CNAM, NIM, NRC, NPL	 September 2017 October 2017
Receipt of calibrated traveling standards by pilot: IO-CSIC, KRISS, NIST, NMC, NMIA, NMIJ, PTB LNE-CNAM, NIM, NRC, NPL	 October 2017 November 2017
Measurement of participants' traveling standards (pilot)	February 2018
Return of traveling standards to participants (participants)	March 2018
Repeat measurements of traveling standards (participants)	May 2018
Participant data received by pilot (participants)	July 2018
Pre-Draft A Process 1: Verification of reported results (pilot, participants)	August 2018
Pre-Draft A Process 2: Review of uncertainty budgets (pilot, participants)	September 2018

Pre-Draft A Process 3: preparation of "Relative Data" (pilot)	August 2018
Pre-Draft A Process 3: response to "Relative Data" (participants)	September 2018
Pre-Draft A Process 4: Identification of outliers and consistency check (pilot)	October 2018
Comments, responses and revisions to uncertainty budgets	November 2018
Distribution of Draft A (pilot)	December 2018
Review of Draft A (participants)	February 2019
Submit Draft B to CCPR WG-KC for approval (pilot)	April 2019
Approval of Draft B (WG-KC)	June 2019
Approval of Draft B (CCPR)	August 2019
Publication of final report	September 2019

2.5. Traveling Standards, handling

2.5.1 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. Prior to the comparison the participants might fill out a pro forma version to record the lamp conditions at the beginning of the comparison. It is helpful to provide photos of the lamp bulbs and filaments to document any visible changes during the comparison.

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

2.5.3 No cleaning of any lamp 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.1 should be used to communicate this information between the two laboratories.

2.5.4 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.

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

2.6. Traveling Standards, transportation

2.6.1 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.

2.6.2 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.

2.6.3 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, the shipping of carefully-packaged lamps via a postal service is accepted for this comparison. They should under all circumstances be marked as 'Fragile'.

2.6.4 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.

2.6.5 The traveling standards should be accompanied by an **ATA CARNET** document when shipped to VNIIOFI. Each **participant is responsible** for preparing this document for their lamps.

2.6.8 Transportation is each laboratory's responsibility and cost. **Each participating laboratory covers the costs for its own measurements, transportation (both ways) and any customs charges** (both its own country customs and Russian customs) as well as for any damages that may occur during transportation. Please be aware that the ATA CARNET document helps to avoid the Russian customs charges and saves time significantly. 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.

2.6.9 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.

3. Description of the Traveling Standards

3.1. Type of the Traveling Standards

3.1.1 The traveling standards (artifacts) will be tungsten halogen lamps of the **FEL** type with nominal power of **1000 W** and nominal voltage of **120 V**. This lamp consists of a double-coiled tungsten filament, supported at the top and bottom of the filament and operated in a bromine-filled quartz envelope. Each lamp will be mounted in a special mount and equipped with an alignment jig. The lamps are produced by **OSRAM-Sylvania** and mounted and pre-aged by **Gigahertz-Optik GmbH** (Germany). The Gigahertz-Optik product number is BN-9101-02. The lamp and the alignment jig are shown in Fig.1. The same type of lamps was used as the traveling standards for the previous CCPR-K1a comparison [1].

3.1.2 Each participant shall supply **three** aged and calibrated traveling standards.

3.2. Electrical Parameters

3.2.1 The traveling standards will operate with DC electrical power, with the positive (+) and negative (-) polarity terminals clearly marked for each lamp.

3.2.2 All lamps will be operated at the same fixed electrical current of **8.100 A**. The value of the related voltage at this current is approximately 105 V.

Fig.1. Measurement artifact – tungsten halogen lamp of FEL 120V-1000W type mounted by Gigahertz-Optik with alignment jig (right).

3.3. Seasoning and selection of lamps

3.3.1 Generally each participant is responsible for preparing its lamps including seasoning to insure suitable stability.

3.3.2 The following seasoning and selection procedure developed and approved by the TG is recommended:

1. <u>Visual inspection.</u>

   Quartz envelope must not display striations (variations in thickness), must be clear and free of bubbles and white markings. Lamp must be mounted straight without visible tilts in any direction.

2. <u>Initial seasoning.</u>

   Season a lamp at the defined working current for 24-48 hours (for OSRAM Sylvania FEL-type lamps the working current is 8.1A). If, during the initial or further seasoning, obvious dark and white depositions appear on the lamp envelope in front of the filament, the lamp is not selected.

3. <u>Monitoring stability.</u>

   Then burn the lamp at the working current and continuously measure lamp voltage and the photosignal of a monitor-detector (any visible or UV photo-detector). Turn the lamp off after every 2 h of burning time and allow it to cool down for at least 30 minutes. Then turn the lamp back on and continue measuring. Perform this cycle three times for a total of six hours of burn time. So, the working sequence for each time this step 3 is performed should be the following: ON 2h – OFF 0.5h – ON 2h – OFF 0.5h – ON 2h.

4. <u>Analysis of stability.</u>

Then analyze the voltage and monitor signal when the lamp was ON (excluding the time for lamp heating (ca. 15 min.) of each ON period). If, for the total time (6 hours) of the last time step 2 was performed no significant voltage jumps (> 0.05 V) are observed, the relative change of the voltage is less than $1.5\cdot 10^{-4}\cdot h^{-1}$ and the relative change of the signal is less than $2\cdot 10^{-4}\cdot h^{-1}\cdot(550\ nm/\lambda)$, respectively ($\lambda$ is the effective wavelength of the detector in nm), then the lamp is selected. If not, repeat the steps 3 and 4.

5. If the test is still failed after 72 h of seasoning, the lamp is not selected.

3.3.3 Gigahertz-Optic will perform seasoning and selection of the CCPR-K1a.2017 lamps following the procedure described in 3.3.2 and provide an appropriate certificate.

3.4. Aligning the lamps

3.4.1 Position an alignment laser to define the optical axis of the spectral irradiance facility. It is assumed that the laser points towards the facility entrance optics and the lamp will be placed between the laser and the facility.

3.4.2 Carefully remove the protective cover while lying on a table. Make sure that the fixing screw is untightened and the cover is not tilted while being removed.

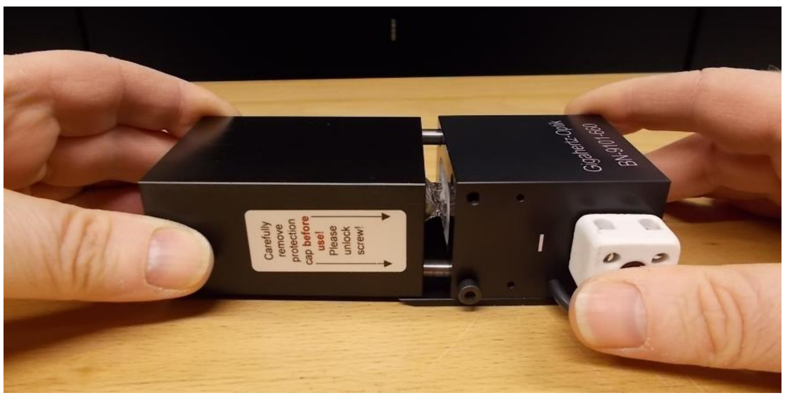

Fig.2. Removing the lamp cover.

3.4.3 The lamp envelope should never be touched. ***It is recommended that gloves are worn when handling the lamp***, since any finger marks will be burnt into the lamp envelope when it is run and will result in changes in output or possibly even lamp failure.

3.4.4 Place the lamp in a mount that provides 6 degrees of freedom (3 rotational and 3 positional).

3.4.5 Connect the four electrical terminals, observing the proper polarity, to a power supply and to the measuring devices for lamp current and lamp voltage. Fig.3. ***Do not switch on***.

3.4.6 Position the alignment jig in the rear holes of the lamp holder. The side with the engraved crosslines on the alignment jig should face towards the laser (away from the measurement facility). The position of the warning sticker at the bottom of the alignment jig is thereby not taken into account (it may vary between different jigs).

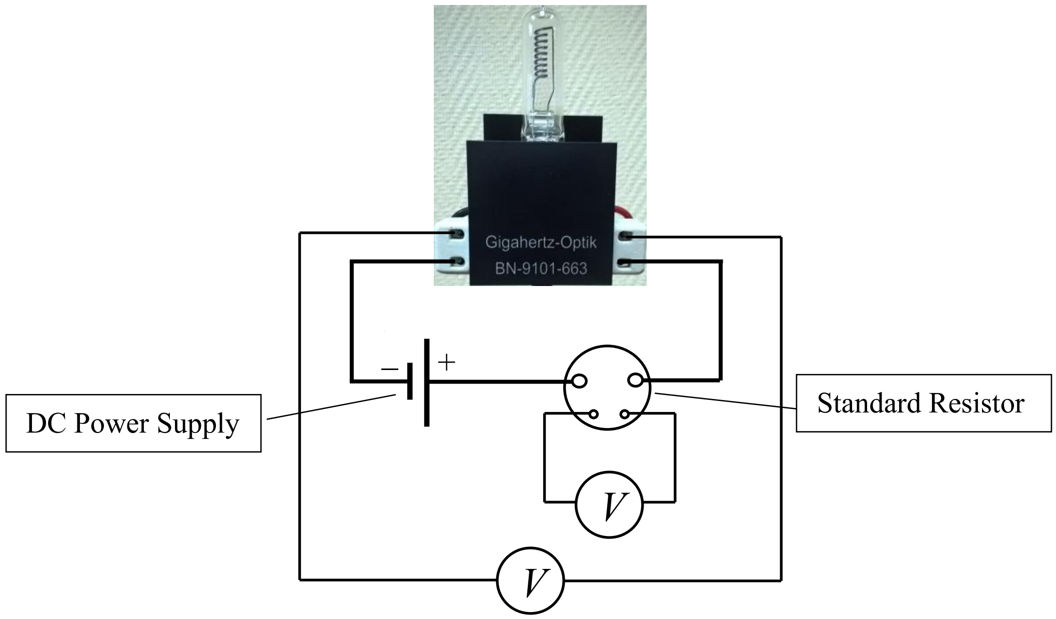

Fig.3. Electrical connections

3.4.7 Rest a spirit level on the top of the alignment jig (taking care not to touch the lamp envelope) and rotate the lamp such that the top of the jig is leveled. Fig.4.

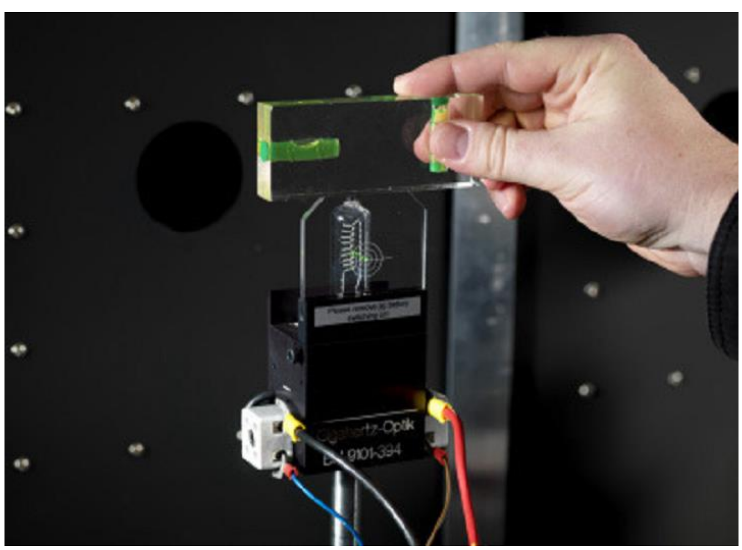

Fig.4. Aligning the lamp: using a level

3.4.8 Turn on the laser and move/rotate the lamp such that the laser hits the centre of the target and the laser beam is back-reflected back to the laser. Fig.5.

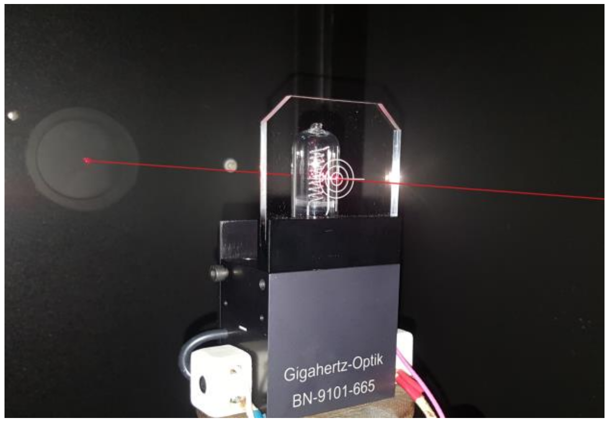

Fig.5. Aligning the lamp: using the laser

3.4.9 Move the lamp towards to the facility until the front plate of the lamp is **500 mm** from the entrance reference plane of the spectral irradiance measurement facility. The area of the front plate to measure the distance from is above the upper central screw, as shown in Fig.6.

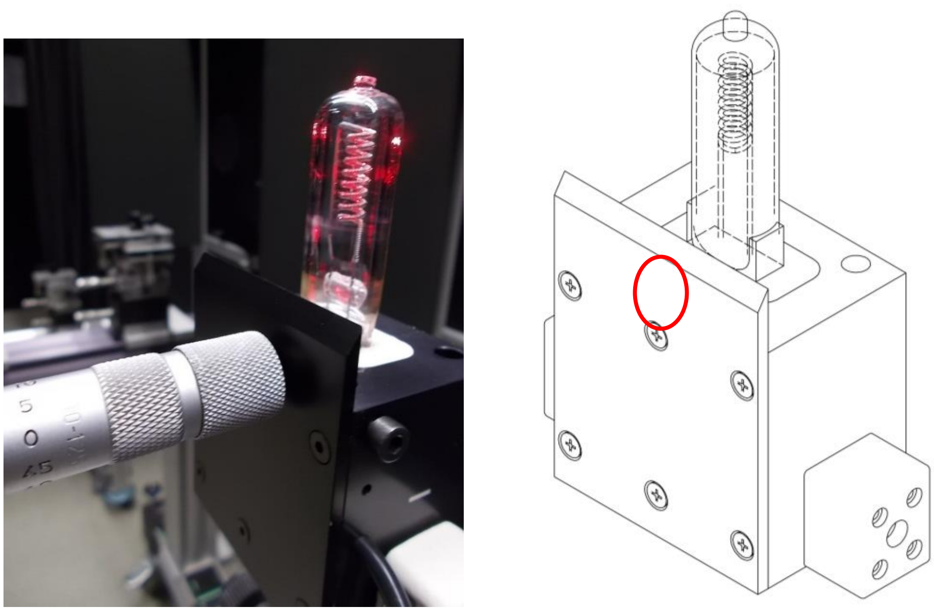

Fig.6. Measuring distance: The area of the front plate of the lamp to measure the distance from is marked by a red a circle.

3.4.10 Repeat step 3.4.8 to check the alignment.

3.4.11 Carefully remove the alignment jig with a smooth upward lift. It should be easy to remove. If it is not easy to remove, then the alignment process should be repeated.

3.4.12 Repeat step 3.4.9 to check the distance.

3.4.13 Double check that the alignment jig has been removed before turning on a power supply.

3.5. Lamp warm-up and cool-down

3.5.1 Check again that the alignment jig has been removed and that the power supply and the measurement devices for lamp current and voltage are connected with proper polarity before turning on.

3.5.2 The lamps should be turned on slowly by increasing the electrical current (voltage) over a 2 minute period to prevent sudden thermal shock.

3.5.3 Each lamp must be warmed up at the operational current (8.100 A) for at least 20 minutes prior to the measurements being taken. Check lamp current setting again after the warm-up time and write down the lamp voltage at that time.

3.5.4 After operation the lamp should be cooled down slowly by decreasing the electrical current (voltage) over a 2 minute period to prevent sudden thermal shock. The lamp should not be moved after switching off until the lamp base is cool enough to be touched (for approximately 20 to 30 minutes).

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

4.2. Measurement Wavelength set points

4.2.1 The comparison will be analysed as a set of separate comparisons for each wavelength. The wavelength set points for this comparison are as in Table 4. All together there are 28 wavelength set points in the range from 250 nm to 2500 nm.

Table 4. Wavelengths of the comparison

Wavelength range	Wavelength step	Wavelength, nm
250 nm - 300 nm	10 nm	250, 260, 270, 280, 290, 300
300 nm – 400 nm	20 nm	320, 340, 360, 380, 400
400 nm – 1100 nm	100 nm + 450 nm + 555 nm	450, 500, 555, 600, 700, 800, 900, 1000, 1100
1100 nm – 1700 nm +2000 nm	200 nm + 2000 nm	1300, 1500, 1700, 2000
2200 nm – 2500 nm	100 nm	2200, 2300, 2400, 2500

4.3. Measurand

4.3.1 The measurand is the spectral irradiance of a lamp in a plane at 500 mm from the reference plane defined by the front plane of the lamp base (see section 3.4.9) aligned to the optical axis of the lamp system (see alignment procedures in section 3.4). The spectral irradiance of each lamp must be measured for the defined operating current of 8.100 A. The measurements should be performed in suitable laboratory accommodation maintained at a temperature of 20 to 25 °C. The ambient temperature of the laboratory during the time of the measurements should be reported.

4.3.2 The spectral irradiances of each lamp should be measured independently at least 3 times. Each independent measurement should consist of the lamp being realigned in the measurement facility. But only the mean or final spectral irradiance value for each lamp should be reported by the participant as a combination of the results of these independent measurements. It should be noted that each independent measurement may consist of more than one set of measurements, the exact number should be that normally used by the participating laboratory to obtain the appropriate accuracy as limited by the noise characteristics of their specific measurement facility.

4.4. Measurement instruction

4.4.1 Before use, the lamps should be inspected for any damage or contamination to the lamp envelope, lamp filament or lamp mount. Any damage should be documented with photos or a drawing and the pilot and participant should immediately exchange this information using the form in Appendix A.1.

4.4.2 Before using any lamp, an appropriate time recording device and notebook should be established to allow recording the lamp burn time. 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.2, returned to the pilot laboratory with the lamps, as well as a part of the final report.

4.4.3 The power supply should be connected observing proper polarity with the positive (+) and negative (-) terminals clearly marked on the base of the lamp.

4.4.4 Before switching on the current to any lamp, the lamp should be aligned (see the section 3.4) and then all ***alignment jigs removed***.

4.4.5 After connecting the electrical power to the lamps the prescribed warm-up procedure (see section 3.5) for each lamp should be followed. At the end of the warm-up time the lamp current should be adjusted to the exact value of 8.100 A, and the lamp voltage should be measured and recorded and compared with those supplied with the lamp. If the voltage is outside expected values for the lamp, the lamp should be turned off and this information exchanged between the participant and the pilot laboratory. The lamp voltage should be also measured and recorded after the spectral measurements before ramping down the lamp voltage.

4.4.6 The spectral irradiance of the traveling standards should then be measured at the specified wavelengths. If the participating laboratory cannot cover the complete spectral range it should declare this before the start of the comparison.

4.4.7 The bandwidth used to measure the spectral irradiance should be less than 10 nm (Full Width at Half Maximum) and ideally less than 5 nm in the visible and UV spectral regions. The exact bandwidth used for each spectral point should be reported, together with the wavelength uncertainty. If the data is corrected for bandwidth, then the correction should be as though for negligible bandwidth.

4.4.8 No other measurements are to be attempted by the participants, nor any modification to the operating conditions during the course of this comparison. The traveling standards used in this comparison should not be used for any purpose other than described in this document nor given to any party other than the participants in the comparison during or following the comparison. Any test measurements or modifications on the traveling standards should be carried out prior to the beginning of the comparison.

4.4.9 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.

5. Reporting of Results

5.1 On completion of the first round of measurements by the participating laboratory the provisional results of these measurements should be sent to the pilot laboratory together with the standard lamps. The results should include the lamp measurement conditions and operating time (Appendix A.2). The first round results may be revised, if necessary, when the second round of measurements is submitted.

5.2 As soon as possible, and within six weeks, after the completion of the second round of measurements the participant should provide a full measurement report. This should include the measurement results of both rounds, description of the scale realization, description of the measurement facility and procedure, a schematic diagram of the facility and full uncertainty analysis.

5.3 The four Pre-Draft-A Processes will be carried out following the *CCPR-G2 Guidelines for CCPR Comparison Report Preparation,* [8]:
- 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.

5.4 Draft A report, Draft B report and a Final report will be prepared, agreed and approved following the requirements of CCPR-G2 [8].

6. Measurement Uncertainty

6.1 General requirements

6.1.1 The uncertainty of measurement shall be estimated according to the *Guide to the expression of uncertainty in measurement* (GUM) [9]. A full breakdown of uncertainties must be provided by the participants with the measurement report and results.

6.1.2 Each wavelength is considered entirely independently for this comparison.

6.1.3 In order to achieve optimum comparability, a list containing the principal influence parameters for calibration of spectral irradiance standard lamps is given below. An example table, which should be completed by participants, will be included in the results templates. 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. As well as the value associated with the uncertainty, participants should give an indication as to the basis of their estimate.

6.1.4 All values should be given as standard uncertainties, in other words, for a coverage factor of $k = 1$.

6.1.5 Participants are asked to make at least **three** independent (after full realignment) measurements of spectral irradiance on each comparison traveling standard lamp. The overall spectral irradiance and its associated uncertainty for the lamp should be supplied by the participant as a combination of the results of these independent measurements.

6.1.6 It is important that the uncertainty components will be separated into parts that are related to systematic (correlated) and random (uncorrelated) effects. Such data are needed for linking the results to RMO comparisons in the future.

6.2 Scale realisation

6.2.1 Participants must give an uncertainty budget of the primary Spectral Irradiance scale realization. If the scale is based on a blackbody, the budget should include components associated with emissivity, air refractive index, blackbody temperature measurement, blackbody uniformity, blackbody stability, aperture area and distance measurement.

6.3 Working standard

6.3.1 If a working standard lamp is used to calibrate the traveling standard lamps, the participant must give an uncertainty budget of the working standard lamp calibration, which should include the uncertainty of the scale realization and components associated with the working standard lamp and the process of its calibration. Generally, they are similar to that described in Section 6.4.

6.4 Uncertainty budget of traveling standard lamp

Type B:

6.4.1 Uncertainty of the ***scale***. This is the uncertainty of the scale realization if the traveling standard lamps are calibrated directly against the primary standard (a blackbody); OR the uncertainty of the working standard lamp if that is used to calibrate the traveling standard.

6.4.2 Uncertainty associated with the ***distance from the working standard lamp*** (or the blackbody if this uncertainty was not taken into account at the stage of realisation) to the reference plane. Correlation between this measurement and the measurement at the stage of calibration of the working standard lamp has to be taken into account, if necessary.

6.4.3 Uncertainty associated with the ***distance from the traveling standard lamp*** to the reference plane.

6.4.4 Uncertainty associated with the operating ***current of the working standard lamp*** (if it is used). Correlation between this measurement and the measurement at the stage of calibration of the working standard lamp has to be taken into account, if necessary.

6.4.5 Uncertainty associated with the operating ***current of the traveling standard lamp***.

6.4.6 Uncertainty associated with ***wavelength*** setting.

6.4.7 Uncertainty associated with lamp alignment generally will be taken into account as a Type A via reproducibility, i.e. standard deviation of the independent measurements carried out after total re-alignment of traveling and working standard lamps. However, if a participant feels that this way underestimates the alignment effect, an additional uncertainty component associated with the alignment estimated as Type B might be added. In this case the value of the component should be $1/\sqrt{n}$ part (n – number of independent measurements) of the value estimated for only one independent measurement.

6.4.8 Other components such as non-linearity, stability, stray light etc. might be included in the budget if necessary.

Type A:

6.4.9 ***Reproducibility*** – Standard deviation of the mean calculated from the results of independent measurements, where each independent measurement is carried out after realignment of the traveling standard lamp and (if necessary) the working standard.

6.4.10 ***Repeatability of traveling standard lamp*** – Standard deviation of the mean calculated from a set of readings when measuring the traveling standard lamp.

6.4.11 ***Repeatability of working standard lamp*** – Standard deviation of the mean calculated from a set of readings when measuring the working standard.

6.4.12 Reproducibility already partly includes repeatability. Therefore, when combining all components, the repeatability components should be divided by a factor of $1/\sqrt{n}$ part where n is the number of independent measurements.

7. Determination of Key Comparison Reference Value (KCRV) and Degrees of Equivalence (DoE)

The KCRV and DoE of the participants will be determined using the methods and data analysis given in *CCPR G2 Guidelines for CCPR Comparison Report Preparation* [8].

8. References

[1] Emma R Woolliams, Nigel P Fox, Maurice G Cox, Peter M Harris and Neil J Harrison, Final report on CCPR K1-a: Spectral irradiance from 250 nm to 2500 nm, *Metrologia*, 2006, **43**, Tech. Suppl., 02003.

[2] Dong-Joo Shin, Chul-Woung Park, Svetlana S Kolesnikova and Boris B Khlevnoy , Final report on bilateral comparison APMP.PR-K1.a.1-2008 between KRISS (Korea) and

VNIIOFI (Russia): Spectral irradiance from 250 nm to 2500 nm, *Metrologia*, 2010, **47**, Tech. Suppl., 02005.

[3] Measurement Comparisons in the CIPM MRA, ***CIPM MRA-D-05***, Version 1.6, March 2016, available from www.bipm.org.

[4] Guidelines for preparing CCPR Key Comparisons, ***CCPR-G4***, July 2013, available from www.bipm.org.

[5] Frank Wilkinson, Gan Xu and Yuanjie Liu, Final report on CCPR-K1.a.1: Bilateral comparison of spectral irradiance between NMIA (Australia) and SPRING (Singapore), *Metrologia*, 2006, **43**, Tech. Suppl., 02002.

[6] Teresa Goodman, William Servantes, Emma Woolliams, Peter Sperfeld, Mihai Simionescu, Peter Blattner, Stefan Källberg, Boris Khlevnoy and Paul Dekker, Final report on the EURAMET.PR-K1.a-2009 comparison of spectral irradiance 250 nm—2500 nm, *Metrologia*, 2015, **52**, Tech. Suppl., 02003.

[7] M Ojanen, M Shpak, P Kärhä, R Leecharoen and E Ikonen, Report of the spectral irradiance comparison EURAMET.PR-K1.a.1 between MIKES (Finland) and NIMT (Thailand), *Metrologia*, 2009, **46**, Tech. Suppl., 02001.

[8] Guidelines for CCPR Comparison Report Preparation, ***CCPR-G2***, Rev.3, July 2013 available from www.bipm.org.

[9] 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 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.*

9. Appendices

Appendix A.1 Receipt Confirmation / Inspection of the Traveling Standards
Appendix A.2 Record of lamp operating time
Appendix A.3 Measurement Results

Appendix A.1 Receipt Confirmation / Inspection of the Traveling Standards

We confirm having received the traveling standards for the CIPM key comparison CCPR-K1a.2017 *Spectral Irradiance 250 nm to 2500 nm* on: (date of receipt)

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 at the defined current are the lamp voltages within their specified ranges?

- [ ] Yes
- [ ] No. Please give details:

  Lamp ID number: ……………
  I = 8,100 A
  U = ………..

Do you believe the lamps are functioning correctly?

- [ ] Yes
- [ ] No. Please indicate your concerns:

Participant/Pilot (NMI): ……………………………..

Date: ……………………………………

Contact person: ………………………………

Appendix A.2 Record of lamp operating time

Supply this record with the lamp to the pilot. The pilot will continue the record during its measurements.

Lamp reference number:
Operating current: 8.1 A

NMI	Date	Time ON	After Warm up		Before switch-off		Time OFF	Burn Time	Cumulative Burn Time
			Current	Voltage	Current	Voltage			

Appendix A.3 Measurement Results

Lamp reference number:
Operating current: 8.1 A
Round #

All uncertainties are standard (*k*=1)

Wavelength, nm	Spectral Irradiance, W m^{-2} nm^{-1}	Uncertainties associated with, %		Combined uncertainty
		Uncorrelated effects	Correlated effects	
250				
260				
270				
280				
290				
300				
320				
340				
360				
380				
400				
450				
500				
555				
600				
700				
800				
900				
1000				
1100				
1300				
1500				
1700				
2000				
2200				
2300				
2400				
2500				