

CIPM Key Comparison K1.b
Spectral Irradiance 200 nm to 350 nm
Technical protocol

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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 its meeting in March 1997, the Consultative Committee for Photometry and Radiometry, CCPR, identified several key comparisons in the field of optical radiation metrology. In particular, it decided that a key comparison of spectral irradiance in the air-UV spectral range shall be carried out. It was decided that this comparison would be carried out as the second phase of two phases defined by the spectral coverage of the transfer standards likely to be used. The first phase covered the spectral region 250 nm to 2500 nm with the National Physical Laboratory, UK (NPL) acting as the pilot laboratory. The second phase would follow afterwards over the spectral region 200 nm to 350 nm and be piloted by the Physikalisch-Technische Bundesanstalt, Germany (PTB), starting in summer 2003.
- 1.3 This technical protocol has been drawn up by the participants of the K1.b key comparison: Physikalisch-Technische Bundesanstalt, Germany (PTB), National Physical Laboratory, UK (NPL), the National Institute of Standards and Technology, USA (NIST), the Institut National de Métrologie, France (BNM-INM / CNAM) and the National Research Council, Canada (NRC).
- 1.4 The procedures outlined in this document cover the technical procedure to be followed during measurement of the transfer standard lamps. The procedure, which follows the guidelines established by the BIPM¹, is based on current best practise in the use of standard lamps and takes account of the experience gained from the previous CCPR spectral irradiance comparison of 1993/1994² and that of the working group.

¹ T.J. Quinn, "Guidelines for key comparisons carried out by Consultative Committees", BIPM, Paris

² Report of the WG on Air-UV Spectral Radiometry to the CCPR, part II, 1997

2. Organization

2.1. Participants

- 2.1.1 The list of participants which was submitted to the CCPR for approval, was drafted by the pilot laboratory taking account of the RMOs.
- 2.1.2 All participants must be able to demonstrate independent traceability to the realization of the quantity, or make clear the route of traceability to the quantity via another named laboratory.
- 2.1.3 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.
- 2.1.4 Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

2.2. Participants' details

Contact person	Institute	Contact details	Shortcut
Peter Sperfeld	Physikalisch-Technische Bundesanstalt 4.11 Spectroradiometry Bundesallee 100 D 38116 Braunschweig Germany	Tel. +49 531 592 4144 Fax +49 531 592 69 4144 Email: Peter.Sperfeld@ptb.de	PTB
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2.3. Form of comparison

- 2.3.1 The comparison will principally be carried out through the calibration of a group of transfer standard lamps. These lamps have been shown to have reasonable short term stability (during <50 hrs burn time) and with care, robustness, to be used to transfer a spectral irradiance 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. This will also allow the participant to maintain a record of the compared quantity.
- 2.3.2 A full description of the transfer standard lamps selected for use in this comparison is given in section 3 of this protocol. The minimum set of any transfer standards used for this comparison should be a group of three lamps. This minimises the risk of unknown drift and damage.
- 2.3.3 The transfer standard lamps used in this comparison will all be supplied pre-aged and mounted in a suitable holder. PTB as pilot will implement the selection, checking, assembling and ageing of all the lamps. However, it will require participants to purchase the standard lamps that are used. These lamps will then remain the property of that participant on conclusion of their sequence of measurements. For convenience and to obtain some form of discount from lamp manufacturers, PTB organizes the purchase of all the lamps and the participants will purchase the lamps from the company msscscientific Chromatographie-Handel GmbH, Karlsgartenstrasse 16, D-12049 Berlin, Germany (Tel. +49 30 6270 6087, Fax +49 30 6270 6089, Email: info@msscscientific.de, www.msscscientific.de). This transaction will be carried out at cost and no charge will be made for PTB's involvement. Similarly, spare lamps and the cost of pre-ageing and pre-selection of the lamps at PTB will not be charged to participants.
- 2.3.4 The comparison will take the form of a star comparison, carried out in 1 phase. The artefacts (lamp systems) will initially be calibrated by the pilot laboratory. They will then be distributed to participants who will perform a first calibration. They will then be returned to the pilot laboratory to carry out a repeat calibration to monitor drift. The standard lamps will then be finally returned to the participant for a repeat calibration and retention.
- 2.3.6 PTB 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 of the completion of all the measurements by a laboratory.
- 2.3.7 The participating laboratories were asked to specify a preferred timetable slot for their own measurements of the transfer standard lamps - the timetable given below has been drawn up taking these preferences into account.
- 2.3.8 Each laboratory has 8 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.
- 2.3.9 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. It may be possible for the participant to continue to take part by returning the calibrated lamps back to the pilot laboratory at an agreed later date. 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. Exclusion may also occur if the results are not available in time to prepare the draft report.

2.3.10 Timetable

Activity	Date
Order for lamps received by msscientific	July 2002
Lamps collected	October 2002
Lamps assembled by PTB	December 2002
Lamps pre-aged and characterized by PTB	February – May 2003
Lamp calibration at the PTB	June / July 2003
Lamp calibration at the participants	August - December 2003
Repeated lamp calibration at the PTB	January / February 2004
Repeated lamp calibration at the participants	March / April 2004
Draft comparison report circulated	June 2004
Final comparison report submitted to CCPR	September 2004

2.4. *Handling of artefacts*

- 2.4.1 The standard lamps should be examined immediately upon receipt at final destination. However, care should be taken to ensure that the lamps and packaging have sufficient time to acclimatise to the rooms environment thus preventing any condensation etc. The condition of the lamps and associated packaging should be noted and communicated to the pilot laboratory. Please use the fax form in appendix A.7.
- 2.4.2 The standard lamps should only be handled by authorized persons and stored in such a way as to prevent damage.
- 2.4.3 No cleaning of any lamp windows, jigs or envelopes should be attempted. No parts should be removed, the housing of the lamp systems must not be opened. If a standard lamp appears damaged a replacement will be only available from the pilot laboratory. However, appropriate insurance should be taken out by participating laboratories to cover the cost of such a replacement if the damage occurred in transit.
- 2.4.4 During operation of the standard lamps if there is any unusual occurrence, e.g. change of voltage, change in output etc the pilot laboratory should be notified immediately before proceeding.
- 2.4.5 Please inform the pilot laboratory via fax or e-mail when the measurement on the standard lamps are completed to arrange a suitable date for dispatch.

- 2.4.6 After the measurements, the lamps should be re-packaged in their original transit cases. Ensure that the content of the package is complete before shipment. Always use the original packaging.

2.5. Transport of artefacts

- 2.5.1 It is of utmost importance that the artefacts be transported in a manner in which they will not be lost, damaged or handled by un-authorised persons.
- 2.5.2 Packaging for the artefacts has been made which should be suitably robust to protect the artefacts from being deformed or damaged during transit.
- 2.5.3 Artefacts (Deuterium Lamp System see 3.1) should as a preference be carried by hand between participating laboratories, either by personal road transport, sea, or in an aircraft cabin. However, recognising that this may result in high financial costs to some participants and recognising that the lamp systems are fragile and may be subject to change in their characteristics from transportation, it should be noted that there is as yet no conclusive evidence indicating whether lamps are less likely to change when hand carried as opposed to a careful postal service. They should under all circumstances be marked as 'Fragile'.
- 2.5.4 The artefacts should be accompanied by a suitable customs carnet (where appropriate) or documentation identifying the items uniquely. The packaging will be lockable e.g. by clasp, but is easy to open with minimum delay to allow customs inspections to take place.
- 2.5.5 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 have occurred within its country. 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 standards during transportation.

3. Description of the standards

3.1. Artefacts: The Deuterium Lamp System (DLS)

- 3.1.1 The measurement artefacts will be specially developed transfer standard lamp systems, consisting of a set of deuterium lamps in special housings, an associated power supply and a monitor detector. This deuterium lamp system (DLS) is a result of extended investigations on several deuterium lamp types from different manufacturers¹. The participants have agreed to use this DLS for the intercomparison.
- 3.1.2 Each deuterium lamp system consists of a lamp power supply (PS), a monitor detector (MD, with its own power supply unit MP) and a set of three or four lamps mounted in a housing (L#01, L#02 etc) with an accompanying alignment jig (J#01, J#02 etc). Each DLS has its own notation marking their correlation. The nomenclature is of the type "DLS-*nnn*-*ttt*" where "*nnn*" is the system notation (typically the institute name) and "*ttt*" is the name for the part of the system. For example the full name of one lamp of the PTB system would then be "DLS-PTB-L#01" with its alignment jig "DLS-PTB-J#01".
- 3.1.2.1 **Power supply:** The deuterium lamp power supply used is a DLV300 type from Leistungselektronik Jena GmbH, Germany, especially designed for the 30 W deuterium lamp type. The nominal output current after the ignition lamp is (300 ± 3) mA. The relative reproducibility and stability of the power supplies have been found to be better

¹ Sperfeld P., Stock K.D., Raatz K.-H., Nawo B. and Metzdorf J., "Characterization and use of deuterium lamps as transfer standards of spectral irradiance", Metrologia, 40 (2003) S111–S114

than 10^{-4} under normal laboratory conditions. Each power supply has its own assigned operating current which is independent of the lamp operated. However, each lamp is equipped with its own resistor to measure the lamp current. The corresponding current values for each lamp-power-supply combination will be given in the accompanying technical documents. Each power supply also includes a (pre-)heater for the deuterium lamp cathode. A pre-heating time of 20 s and a heating value of 10 V for pre-heating and 6 V for heating under operation has to be selected (see Figure 1). A power supply should only be used with the set of lamps that is assigned to it by the system notation. The power supplies can be set to 115 V where necessary. The accompanying settings will be carried out by the pilot laboratory before the lamp systems are prepared for transportation to the participants.



Figure 1 Power supply DLV300 – The settings for preheating time (20 s) and heating level (10V/6V) have to be as shown on the picture. These settings and the notation of the power supply are printed on a label on top of the power supply.

3.1.2.2 **Lamps:** The deuterium lamp type Cathodeon J64 has been thoroughly investigated by PTB and an optimum selection, characterisation and operational procedure have been determined. In selecting these lamps PTB will carry out the mounting, initial ageing and characterisation of the lamps.

Each lamp will be operated at a current of (300.0 ± 3) mA. The lamps are working at a nominal DC voltage of 72 - 80 volts and are operated in constant current mode. Each lamp will be assigned to its own special power supply and must only be operated with this power supply and must be aligned using its correlated jig.

The lamps must be allowed to warm up at least 45 min before starting spectral measurements.



Figure 2. The lamp housing includes a connector for electrical measurements at the back (not shown), a base plate to be placed on a flat surface and a specially designed opening that allows the lamp jig and the monitor detector to be connected reproducibly to the housing.

- 3.1.2.3 **Lamp housing:** Each deuterium lamp is set up in its own housing, which protects the lamps from environmental conditions. The housing together with the alignment jig is defining the optical measurement axis which is perpendicular to the centre of the jig marked with a target. The base plate of the housing allows it to be placed on a table or to be mounted on a measurement system.

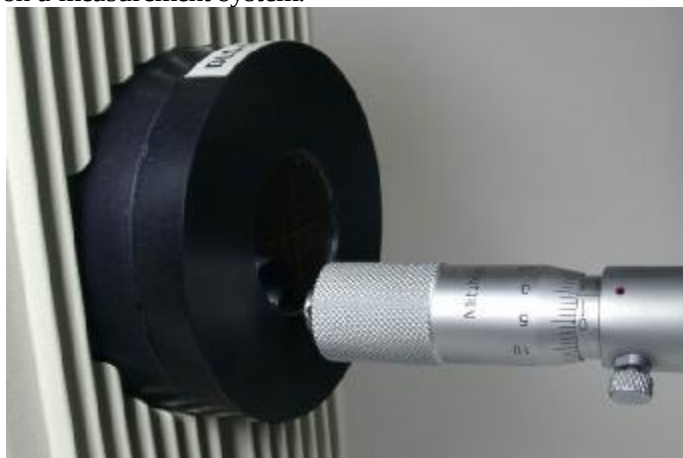


Figure 3. The alignment jig in front of the lamp. Each jig is assigned to one lamp and has to be connected so that the sign on it shows upwards. The reference point for distance measurements is below the window.

- 3.1.2.4 **Alignment jig:** Each lamp has its own alignment jig with a glass window and a target in its centre. The jig has to be connected to the lamp housing in that way that the sign on it shows upwards. It is safe to leave the jig at the housing during the lamp is operating but it is necessary to remove it for spectral calibrations. The front of the jig below the glass target is used as the reference plane for the distance measurement.

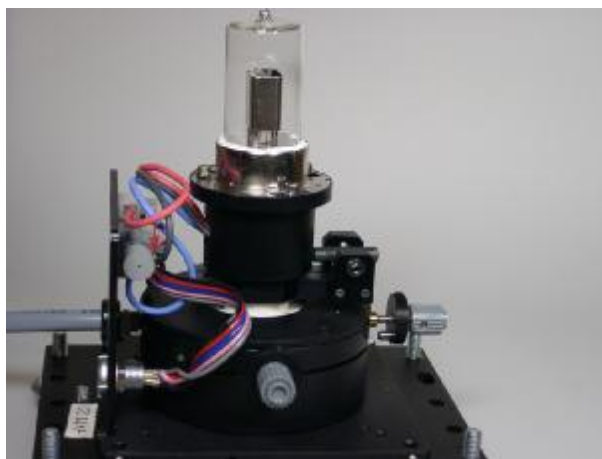


Figure 4. Lamp pre-alignment: The UV-irradiance distribution of the lamps are aligned to the centre of the optical axis using the lamp housing alignment capabilities. A SiC-detector is used to scan the lateral irradiance distribution at a distance of 300 mm to the lamp jig front.

- 3.1.2.5 **Lamp pre-alignment:** The lamp mounting inside the lamp housing allows the lamp to be aligned to the optical measurement axis which is defined by the housing and the jig. The operating Lamp has been aligned so that its UV-irradiance is maximum on the optical axis. Therefore the irradiance distribution of the lamp at a distance of 300 mm from the front jig has been measured by the pilot laboratory using a SiC photodiode. The lamp has been turned and tilted until the centre of the irradiance distribution is on the optical axis. For this alignment the lamp may be tilted and turned up to 2°. The irradiance uniformity on a 32 mm diameter area around the optical axis will be documented in the accompanying

technical documents. The centre of the UV irradiance is dependent on the electrode ignition. It is shown that its position is reproducible even after several re-ignitions of the lamps. But it may not be coinciding to the distribution of the visible light. Therefore, it is possible that the visible light spot is not centred to the optical axis. This should be ignored. The lamp pre-alignment must not be changed and the accompanying screws are secured (!) to avoid accidental misalignment during transportation or use of the lamp systems.

- 3.1.2.6 **Lamp holder:** The lamp housing can directly be placed on an optical table. To allow the lamp system to be mounted on a mechanical alignment facility, an adapter will be delivered with the system. The dimensions of that adapter are 165 mm x 48 mm x 12 mm. It has a 6 mm tapped hole in the centre and the optical axis is at app. 139 mm above the bottom of the adapter (127 mm + 12 mm). The participants can modify this adapter to fit into their system. It will stay at the participants lab and needs not to be sent back to the pilot laboratory. The participants can also temporarily remove the rubber feet from the lamp housing and replace it with adjusting screws if necessary.



Figure 5. Holder for the lamp systems. The lamps can easily be replaced and fixed on that adapter.

- 3.1.2.7 **Measuring connector:** The lamps are equipped with a connector to measure the electrical parameters of the lamps. The pin occupancy of the connector is shown in Figure 6 and on the back of each lamp housing. The lamp current is determined measuring the voltage drop over a 1 Ω resistor inside each lamp. The lamp voltage and the voltage of the heater are measured to monitor sudden changes of the lamps. The ignition voltage pulse of the lamps can be up to 600 V so that the measuring instruments should be capable to stand such voltage pulses. The participants will be equipped with a corresponding plug with BNC connectors. This connector will stay at the participants lab and needs not to be sent back to the pilot laboratory.



Figure 6 Connector at the lamps back to measure the electrical parameters of the lamp: Pin 1-2, ...

- 3.1.2.8 **Lamp characterisation:** The initial ageing of the lamps will take 100 h at minimum. During that time the lamps will be switched on and off several times and their re-ignition reproducibility and the temporal (spectral) irradiance drift will be monitored. The characteristic drift of each lamp can be used to correct for changes during the calibration process.
- 3.1.2.9 **Monitor detector:** Each set of lamp systems comes with a monitor detector equipped with a SiC photodiode. This detector can be connected to the front of the lamp housing before and after each spectral measurement to monitor the drift of the lamps during calibration. Each monitor detector is assigned to the set of lamps of each participants and will also be circulated during the intercomparison. A power supply for each detector is also part of the circulating equipment. The photocurrent-equivalent voltage ($< 0,2$ V) can be measured at a LEMOSA connector. The accompanying plug will be added as accessories as well as a plug to measure the ambient temperature of the monitor detector with a Pt100 resistor. A data sheet of the SiC photodiode will be part of the technical documents of the lamp systems. Due to the low temperature coefficient of the photodiode temperature stabilization of the monitor detector is not necessary as long as the ambient temperature is between 20°C and 25°C.

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 amp and volt.

4.2. Measurand

- 4.2.1 The measurand is the spectral irradiance of a lamp in a plane at a specified distance from a reference plane defined by a jig aligned to the optical axis of the lamp system. The spectral irradiance should be measured for the defined operating conditions for each lamp, defined by the associated power supply. The measurements should be performed in suitable laboratory

accommodation maintained at a temperature of 20 to 25 °C. The temperature of the laboratory during the time of the measurements should be reported.

- 4.2.2 The spectral irradiance 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 and being switched off and on after a break of at least 2 h for each lamp. Each independent measurement set should be reported. 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. The exact number of measurements used should be stated in the measurement report but only the mean or final declared value of the set is required to be included. Participants are reminded that the spectral irradiance of the transfer standard lamps will change as a function of the operational burn time and so it is recommended that this is kept to a minimum.
- 4.2.3 The measurements should be taken at the defined distance of 300 mm described in Appendix A.5.7. If measurements are made at another than at the defined distance the results should be corrected by the participant to those expected at that distance by an appropriate means. The method employed should be described by the participant in his final report. It should be noted that due to the limited uniformity of the irradiance of deuterium-lamps, measurements at other distances might be unfeasible to be corrected.

4.3. Measurement instructions

- 4.3.1 Before connecting to any electrical power supply, the standard lamps should be inspected for damage or contamination of either the window of the lamp (viewed through the front aperture), its housing or its supporting mount. The housing of a lamp system must not be removed by the participants at any time. Any damage should be documented by photos and a drawing using the appropriate form in appendix A.2 and the pilot laboratory should be informed immediately.
- 4.3.2 Before switching the current to any lamp, an appropriate time recording device and notebook should be established to allow the burn time for each lamp to be recorded. An example form which could be used has been attached as appendix A.6. A summary sheet such as this should be completed for and kept with each lamp and returned to the pilot laboratory as part of the final report.
- 4.3.3 After connecting the electrical power to the lamps, the prescribed warm-up procedure for each lamp should be followed. After the ignition of the lamp, the additional operational parameters for each lamp (specified in the lamp operating procedure appendix A.5.) should be recorded and compared to those supplied with the lamp. If these values are outside of the nominal range indicated, the lamp should be switched off and the information reported to the pilot laboratory.
- 4.3.4 The operational conditions and alignment procedure for each lamp should be noted and followed according to the details described in the notes supplied with each lamp. The check list presented in appendix A.5 should be followed, filled out and signed for each measurement. The check list should be kept by the participants for documentation and quality insurance.
- 4.3.4 The spectral irradiance of the transfer standards should then be measured over the spectral range from 200 nm to 350 nm. Measurements should be performed at a wavelength interval of 10 nm. If the participating laboratory cannot cover the complete spectral range it should declare this before the start of the comparison.

- 4.3.5 The bandwidth used to measure the spectral irradiance should be less than 5 nm (Full Width at Half Maximum) and ideally less than 3 nm. The exact bandwidth used for each spectral point should be reported, together with the centre wavelength uncertainty.
- 4.3.6 No other measurements are to be attempted by the participants nor any modification to the operating conditions during the course of this comparison. The transfer 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.
- 4.3.7 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 co-ordinating 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. Measurement uncertainty

- 5.1 The uncertainty of measurement shall be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement*. 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 is included as appendix A.4. 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. All values should be given for a coverage factor of $k=1$. Participants are asked to make 3 independent (after full realignment) measurements of spectral irradiance on each lamp and record the results in separate versions of Appendix A1, this will allow the reproducibility for each lamp to be calculated and, therefore, this does not need to be calculated separately by the participants.

5.2 Type A

Repeatability of reference standard - reproducibility (run to run) without re-alignment of the participants reference standard. This component should be largely caused by the measurement set-up related to the output from the reference standard. In effect the standard deviation of a single set of measurements made on the reference standard. This should be presented as a relative quantity.

Repeatability of transfer standard - reproducibility (run to run) without re-alignment of the measurements of the comparison transfer standard. This should be, largely caused by the measurement set-up related to the output from the transfer standard. The standard deviation of a single set of measurements made on the transfer standard. This should be presented in terms of percentage of the assigned spectral irradiance.

Type B

Participants disseminated scale - This is the total uncertainty of the participants underpinning scale as disseminated by them. This should include the uncertainty in the primary SI realisation, or in the case of a scale originating from another laboratory, the uncertainty of the scale disseminated to it by that laboratory. It should of course reference the originating laboratory. 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, especially for those using a scale originating from another laboratory an appropriate uncertainty should be included to represent the maintenance of the primary scale.

Distance to transfer standard - This is the uncertainty in setting the distance between the reference plane on the transfer standard and the measurement plane as specified in the comparison, or where different, to include correction to the specified distance.

Absolute value of current passed through transfer standard - This is the uncertainty in reading the specified current-equivalent voltage for each lamp and should include both the uncertainty in absolute value, noise and resolution available from the reading electronics.

Wavelength - This is the uncertainty in the absolute value of the wavelength used for the comparison. This should only be taken account of in terms of the transfer standard, any similar error which occurs in establishing the primary scale should be separated including finite bandwidth effects.

6. Reporting of results

- 6.1 On completion of the first set of measurements by the participating laboratory the provisional results of these measurements should be sent to the pilot laboratory with the standard lamps.
- 6.2 As soon as possible after the second set of measurements have been made, the results should be communicated to the pilot laboratory and at the latest within six weeks.
- 6.3 In completing the description of the participants measurement facility, appendix A.3, it would be useful for a schematic diagram of the facility to be included.
- 6.4 The measurement report forms in appendix A.1, A3, A4 of this document will be sent by e-mail (Word95 (V7.0) document) to all participating laboratories. It would be appreciated if the report forms (in particular the results sheet) could be completed by computer and sent back electronically to the co-ordinator. **In any case, the signed report must also be sent in paper form by mail.** In case of any differences, the paper forms are considered to be the definitive version.
- 6.5 If, on examination of the complete set of provisional results, the pilot institute finds results that appear to be anomalous, the corresponding institute are invited to check their results for numerical errors without being informed as to the magnitude or sign of the apparent anomaly. If no numerical error is found the result stands and the complete set of final results is sent to all participants. Note that once all participants have been informed of the results, individual values and uncertainties may be changed or removed, or the complete comparison abandoned, only with the agreement of all participants and on the basis of a clear failure of the travelling standard or some other phenomenon that renders the comparison or part of it invalid.
- 6.6 Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare a first draft report on the comparison. This will be circulated to the participants for comments, additions and corrections. Subsequently, the procedure outlined in the BIPM Guidelines will be followed.

7. Determination of the reference value

The pilot laboratory will determine and compare the respective reference values with its assigned uncertainties in accordance with different procedures (weighted mean without and with cut-off, median) including statistical tests.

To be completed following discussion by Key comparison working group.

A.1 Measurement results

The attached measurement summary should be completed for each lamp and each completed set of measurements. A complete set being one which may include multiple measurements on the same lamp but does not include any realignment of the lamp. For each realignment a separate measurement sheet should be completed. Therefore, for each lamp be 3 complete measurements sheets are needed.

For clarity and consistency the following list describes what should be entered under the appropriate heading in the table.

Wavelength	The assigned centre wavelength of the measured spectral irradiance.
Spectral Irradiance	The value of the spectral irradiance of the lamp as measured by the participating laboratory.
Bandwidth	The spectral bandwidth of the instrument used for the comparison defined as the Full Width at Half the Maximum.
Std Deviation	The standard deviation of the number of measurements made to obtain the assigned spectral irradiance without realignment.
Number of Runs	The number of independent measurements made to obtain the specified std deviation.
Uncertainty	The total uncertainty of the measurement of spectral irradiance separating this into Type A and B for a coverage factor of $k=1$.
Burn Hrs	The estimated number of operational burn hours made on the lamp taken from a start time of 0 hrs on receipt of the lamp from the pilot.

Additionally the mean of the electrical parameters of each lamp system as well as the measured readings of the monitor detector before and after each measurement set should be reported:

Ambient temperature	The mean of the ambient temperature at the measurement facility during the spectral measurements measured in °C.
Lamp Current	The mean of the lamp current equivalent voltage recorded during the spectral measurement and its standard deviation.
Lamp Voltage	The mean of the lamp voltage recorded during the spectral measurement and its standard deviation.
Heater Voltage	The mean of the lamps heater voltage recorded during the spectral measurement and its standard deviation.
Burning Time	The burning time of the lamp for this set of spectral measurements including the time for warming up the lamp system.
Monitor Detector	The mean of the monitor detector photo signal measurements (at least

4 readings) and its standard deviations recorded separately before and after each set of spectral measurements. Additionally the dark readings of the monitor detector photo signal is needed.

Measurement results

Lamp system: DLS- -L#

Measurement Number:

Ambient temperature: °C

Lamp Current: ± mA

Lamp Voltage: ± V

Heater Voltage: ± V

Burning Time: : h

Monitor Detector:

Before spectral measurement: ± V

After spectral measurement: ± V

Number of readings:

Dark reading: V

Wavelength Nm	Spectral Irradiance $\text{W m}^{-2} \text{nm}^{-1}$	Bandwidth nm	Std Dev.	Num of Runs	Uncertainty A % B		Burn hrs h
200							
210							
220							
230							
240							
250							
260							
270							
280							
290							
300							
310							
320							
330							
340							
350							

Remarks:

Operator:

Laboratory:

Date: Signature:

A.2 Inspection of the transfer standards

Has the lamp transportation package been opened during transit ? e.g. Customs... ☐ Y / ☐ N

If Yes please give details:

Is there any damage to the transportation package?..... ☐ Y / ☐ N.

If Yes please give details:

Are any of the enclosed strain gauges indicating any damage?..... ☐ Y / ☐ N

If Yes give details:

Are there any visible signs of damage to the lamp or housing?..... ☐ Y / ☐ N

If Yes please give details (e.g. scratches, dust, broken coil, alignment mask moved etc):

After warm-up is the lamp voltage and current within its specified range?.... ☐ Y/ ☐ N

If not what is the voltage and the current ? V, mA

Do you believe the standard is functioning correctly ?... ☐ Y/ ☐ N

If not please indicate your concerns

Operator:

Laboratory:

Date: Signature:

A.3 Description of the measurement facility and primary scale

This form should be used as a guide. It is anticipated that many of the questions will require more information than the space allocated, please use separate sheets of paper as appropriate.

Make and type of spectroradiometer (or equivalent)

Laboratory transfer standards used:

Description of measuring technique (please include a diagram):

Establishment or traceability route of primary scale including date of last realisation and breakdown of uncertainty:

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

Operator:

Laboratory:

Date: Signature:

A.4 Uncertainty of measurement

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Spectral Irradiance %
Repeatability of Ref.	u_{Ref}		u_{Ref}
Repeatability of Trans	u_{Trans}		u_{trans}
Scale		u_{scale}	u_{scale}
Distance		u_d	$(u_d)^2$
Current		u_I	$(u_I)^2$
Wavelength		u_λ	$(d_{\text{irad}}/d_\lambda) u_\lambda$
RMS total	$((u_{\text{ref}})^2 + (u_{\text{Trans}})^2)^{1/2}$		

The above table is a suggested layout for the presentation of uncertainties for the calibration of each lamp. However, it should be noted that since the wavelength uncertainty in particular has a strong dependency on wavelength this table can only present a range for that parameter. It would therefore be helpful for the participants to provide an appropriate breakdown for such uncertainties to match this sensitivity. The summary table associated with the results (appendix A.1.) will of course need to take full account of this wavelength dependent parameter for each wavelength point.

The RMS total refers to the usual expression i.e. square root of the sum of the squares of all the individual uncertainty terms as shown in the example for Type A uncertainties.

Operator:
Laboratory:

Date: Signature:

A.5 Checklist for the alignment and operation procedure for deuterium lamps

1. Position a laser beam so that is aligned along the optical axis of the measurement system, with the laser pointing towards the lamp front.
2. This lamp is very fragile and great care should be taken in its handling. Do not open the lamp housing or move any screws of the lamp pre-alignment.
3. Attach the lamp and holder to a suitable mount which allows: vertical and horizontal translation of the lamp perpendicular to the optical axis; has two axis tilt to enable the lamp to be tilted in the plane of the optical axis and in a horizontal plane perpendicular to the optical axis; rotation in the horizontal plane about the lamp filament. The lamp should be positioned so that the distance measurement reference plane is pointing towards the measuring instrument and at approximately the correct distance from the facility measurement plane (300 mm). The alignment jig, should be attached to the lamp housing. The jig should be mounted in that way that the sign on it shows upward. This jig is a precision fitting item and as such may appear to be a tight fit. This is normal and when in the correct orientation will fit perfectly to the lamp housing.
4. Attach the current leads to the power supply assigned to the lamp system and make sure that the plug is fixed. Attach the measuring connector at the back of the lamp housing. Connect the three measurement channels to a suitable DVM. Note the lamp voltage can be up to 600 V during ignition of the lamp.
5. Position the lamp so that it is aligned vertical and perpendicular to the measurement axis. This should be carried out by using the alignment target and the back reflection of the alignment laser from the alignment jig window. Additionally the target might produce a diffraction pattern when it is well aligned to the measurement axis (depending on the laser spot size). The pattern appears symmetrically to the back reflection. The horizontal pattern indicates exact horizontal alignment (pattern of the vertical target line) whereas the vertical pattern belongs to the vertical alignment. The vertical axis of the lamp (degree of freedom around the optical axis) can be adjusted by putting a water-level at one side of the lamp housing.
6. Adjust the horizontal and vertical position of the lamp so that the alignment laser beam passes through the centre of the target on the alignment jig.
7. Finally, accurately position the lamp the correct distance from the measurement plane. For this type of standard 0.300 m. This distance should be measured to the distance reference plane at the front of the lamp jig below the target window (see Figure 3).
8. Check that the power supply is at the right settings. The operating voltage should be in accordance to your electrical power system (set by the pilot laboratory). The warm up time should be set to 20 s and the filament heating should be set to 10 V / 6 V (middle position).
9. Switch on the power supply. After the warm up time the lamp will be ignited automatically. After the ignition allow the lamp to stabilise for forty-five minutes before starting measurements. Record the lamp current, voltage and heating voltage of the lamp at least every five minutes during the whole operating time of the lamp.
10. Before starting the spectral measurements remove the lamp jig and carefully connect the monitor detector to the lamp housing so that its sign shows upwards.¹ Record the photocurrent-equivalent voltage at least four times and determine its mean and standard deviation. Carefully remove the monitor detector from the lamp housing and start the spectral measurements.

¹ It is recommended that this procedure is practiced several times before the first lamp alignment is processed to get experiences in how to attach and detach the monitor detector.

11. When the spectral measurements are complete, attach the monitor detector to the lamp housing. Record the photocurrent-equivalent voltage at least four times and determine its mean and standard deviation.
12. Switch off the power supply. Record the dark current-equivalent voltage of the monitor detector. Remove the monitor detector from the lamp housing and connect the jig to the lamp housing for dust protection. Allow the lamp to cool down for several minutes.
13. Complete the checklist form A.5.b below and sign it. Keep it for documentation of your calibration processes. Use a new checklist for every measurement and follow it closely. Fill out the measurement summary which will be part of the measurement documentation sent back to the pilot laboratory.

Checklist for Lamp measurement

Lamp system: DLS- -L# Measurement Number:

1. ☐ Position a laser beam so that it is aligned along the optical axis of the measurement system.
2. ☐ Attach the lamp and holder to a suitable mount.
3. ☐ Attach the alignment jig to the lamp housing.
4. ☐ Attach the current leads to the power supply assigned to the lamp system.
5. ☐ Attach the measuring connector at the back of the lamp housing.
6. ☐ Position the lamp using the back reflection of the jig target so that the lamp is aligned vertical and perpendicular to the measurement axis.
7. ☐ Accurately position the lamp at the correct distance of 0.300 m from the measurement plane to the distance reference plane at the front of the lamp jig below the target window.
8. ☐ Check that the power supply is at the right settings (20 s warm up, 10 V/6 V heating).
9. ☐ Switch on the power supply and start recording of the lamp current, voltage and heating voltage.

Time of lamp ignition:

10. ☐ Allow the lamp to stabilise for forty-five minutes before starting measurements.
11. ☐ Connect the monitor detector to the lamp housing so that its sign shows upwards.
12. ☐ Record the photocurrent-equivalent voltage of the monitor detector.

Readings (V): 1. 2. 3. 4.
(5. 6. 7. 8.)

13. ☐ Carefully remove the monitor detector from the lamp housing and start the spectral measurements.

Time of measurement start: Time of measurement end:

14. ☐ When the spectral measurements are complete, attach the monitor detector to the lamp housing.
15. ☐ Record the photocurrent-equivalent voltage of the monitor detector.

Readings (V): 1. 2. 3. 4.
(5. 6. 7. 8.)

16. ☐ Switch off the power supply.

Time when lamp turned off: Burning hours of lamp:

17. ☐ Record the dark current-equivalent voltage of the monitor detector.

Dark signal (V):

18. ☐ Remove the monitor detector from the lamp housing and connect the jig to the lamp housing for dust protection.
19. ☐ Allow the lamp to cool down for several minutes.
20. ☐ Fill out the summary for this measurement as shown below. Insert the values of the electrical and environmental parameters measured at the end of the spectral measurements.
21. ☐ Carefully remove the lamp and store it in a dry and safe place.

Measurement summary:

Lamp system: DLS- -L# Measurement Number:

Date of measurement: Time of spectral measurement end:

Operator:

Ambient temperature: °C

Lamp Current: ± mA

Lamp Voltage: ± V

Heater Voltage: ± V

Burning Time: : h

Monitor Detector:

Before spectral measurement: ± V

After spectral measurement: ± V

Number of readings:

Dark reading: V

Remarks:

Operator:

Laboratory:

Date: Signature:

A.6 Record of lamp burn hours

Lamp system: DLS- -L#

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials

Operator:
Laboratory:

Date: Signature:

A.7 Receipt confirmation

FAX

To: Dr. Peter Sperfeld
Physikalisch-Technische Bundesanstalt
4.11 Spectroradiometry
Bundesallee 100
D 38116 Braunschweig
Germany

Fax +49 531 592 69 4144
Email: Peter.Sperfeld@ptb.de

From: Participating Laboratory

We confirm having received the standards of the BIPM *Key Comparison of Spectral Irradiance* on .

After visual inspection

- ☐ No damage has been noticed;
☐ The following damage must be reported:

Operator:
Laboratory:

Date: Signature: