EURAMET Key-Comparison

Luminous Flux EURAMET.PR-K4

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Content

1 Introduction

This report describes the international key comparison "EURAMET.PR-K4" of luminous flux values transferred to the pilot laboratory by about 60 incandescent lamps. The lamps are grouped in batches from the twelve participants. This key comparison was carried out under the auspices of the European Association of National Metrology Institutes (EURAMET), which is the Regional Metrology Organisation (RMO) in Europe. A key comparison is part of an arrangement agreed within the Comité International des Poids et Mesures (CIPM) and supports the Mutual Recognition Arrangement CIPM MRA [1].

Key comparisons deal with a specified quantity – here the luminous flux measured with the unit lumen derived from the SI-base unit, candela - and they determine on different levels (such as CCPR and RMO) the related Reference Values (RV). The relative differences between the value of each participant and the RV are evaluated as the second result, which is denoted as Degree of Equivalence (DOE). Finally, from the DOEs of the participants, their relative mutual differences to the values of all other participants are evaluated and presented as a matrix of DOEs. All results mentioned above are evaluated with associated expanded uncertainties.

More than a decade ago, the CCPR initialised a key comparison for luminous flux denoted as CCPR-K4, which was piloted by the Physikalisch-Technische Bundesanstalt (PTB, Germany). The resulting "… key comparison reference value CCPR-KCRV was calculated as the weighted average of the individual results, weighted by the inverse square of the individual standard uncertainties, with the application of a minimum uncertainty cutoff of 0.30 % " [2]. All results of this CCPR-key-comparison were published [3] in 1999 and the DOEs are listed in the data base [2] of the BIPM. The part of the data base relevant for this key comparison is shown from page 19 ff.

This key comparison "EURAMET.PR-K4" is performed according to the regulations valid within the Comité Consultatif de Photométrie et Radiométrie (CCPR). All participating laboratories are National Metrological Institutes (NMI) and all of them are accredited according to the ISO 17025 [4]. The comparison follows strictly the Technical Protocol specifying procedures for organisation and models for the determination of all results with the associated measurement uncertainties. The latter are evaluated and reported according to the "Guide to the Expression of Uncertainty in Measurement" (GUM) [5]. Before the measurements were started, the Technical Protocol was prepared by the pilot laboratory and agreed in all details by the working group with participants as members.

The reference value CCPR-KCRV for luminous flux is maintained since that time by the participants of that early CCPR comparison and three of them are now acting as link laboratories for this EURAMET-Key-Comparison:

1. Laboratoire Commun de Métrologie (LNE-INM/CNAM, France; former BNM-INM),
2. Instituto Nazionale di Ricerca Metrologica (INRIM, Italy; former IEN),
3. Physikalisch-Technische Bundesanstalt (PTB, Germany).

These laboratories support the comparison with values for luminous flux to restore the CCPR-KCRV as the reference value EURAMET-RV for this EURAMET-Key-Comparison and the PTB agreed to act as pilot laboratory.

The link laboratories transferred their maintained values of luminous flux by batches of incandescent lamps to the pilot laboratory, which measured the lamps and evaluated a weighted average for the luminous flux, i.e. the reference value EURAMET-RV with its associated uncertainty. Averaging the values from three link laboratories reduces the uncertainty contributions originated by maintenance, transfer and by the measurements performed at both sides; i.e. at each of the three link laboratories and the pilot laboratory. This ensures that the EURAMET-RV is as close as possible to the original CCPR-KCRV and the associated uncertainty is only slightly increased.

Finally, the luminous flux values transferred from all other participants are compared with the EURAMET-RV and the DOEs of their values with the reference value and mutually with all other luminous flux values are evaluated with the associated uncertainties. All principle information, the data collection and the evaluation are given in the following chapters and are supplemented with more details in the Annexes.

2 General information

2.1 List of Participants

The acronyms of the participating National Metrological Institutes are listed in the first column of Table 1. The names of the institute and the contact person with the e-mail address are given in the second column. The third column shows the country and the city of each participant. In the last column, the number and types of the lamp-transfer-standards used by the participants are entered. According to the guidelines for CCPR comparisons all link laboratories and participating NMIs are treated as anonymous in this pre-draft A report (coded by a character for each NMI).

In the invitation to this comparison, "hand-carrying" was recommended for the transport of the transfer standards. Thus, for each participant, two trips had to be scheduled. The majority of NMIs followed this recommendation, less than 20 % of the lamps were shipped to PTB using public transport. So, none of the lamps was broken and only one lamp showed a defect.

Table 1 EURAMET KC of Luminous Flux: Participants and their lamp-transfer-standards

Acronym	**Laboratory Name** ***Contact Person / Email***	**Country** ***City***	**Number and lamp type**
BIM	Bulgarian Institute for Metrology *Nikolay Alexandrov, Email: nikal_alex@abv.bg*	Bulgaria *Sofia*	4 OSRAM WI5
SP	Swedish National Testing and Research Institute *Stefan Kallberg, Email: Stefan.Kallberg@sp.se*	Sweden *Boras*	3 GEC 200W
MIKES	Helsinki University of Technology and Centre for Metrology, Metrology Research Institute *Tuomas Poikonen, Email: tuomas.poikonen@aalto.fi*	Finland *Helsinki*	4 OSRAM WI40 Globe
GUM	Central Office of Measures, Optical Radiation Division *Dorota Sobótko, Email: radiation@gum.gov.pl*	Poland *Warsaw*	4 Polaron LF200
BEV	Bundesamt für Eich- und Vermessungswesen, Gruppe Eichwesen (Metrology Service) *Norbert Hörhager-Berl, Email: Norbert.Hoerhager-Berl@bev.gv.at*	Austria *Wien*	4 Mazda
INM	National Institute of Metrology *Mihai Simionescu, Email: mihai.simionescu@inm.ro*	Romania *Bucureşti*	6 OSRAM WI5(1
CMI	Czech Metrology Institute *Marek Šmid, Email: msmid@cmi.cz*	Czech Republic *Praha*	2 OSRAM WI5-E40 2 Philips 100W
VSL	NMi Van Swinden Laboratorium B.V. *Elena Revtova, Email: ERevtova@vsl.nl*	Netherlands *Delft*	2 OSRAM WI40/G 2 Polaron LV60W
DMDM	Directorate of Measures and Precious Metals, *Boban Zarkov, Email: zarkov@dmdm.rs*	Serbia *Beograd*	6 OSRAM WI40/G
INRIM	Istituto Nazionale di Ricerca Metrologica, *Maria Luisa Rastello, Email: rastello@inrim.it or alternative: g.brida@inrim.it*	Italy *Torino*	6 Polaron LF200
LNE-CNAM	Laboratoire Commun de Métrologie *Gael Obein, Email: gael.obein@cnam.fr*	France *La Plaine Saint-Denis*	6 GEC LV200W
PTB	Physikalisch-Technische Bundesanstalt *Matthias Lindemann, Email: matthias.lindemann@ptb.de*	Germany *Braunschweig*	5 Polaron LV200W 1 OSRAM WI40 Globe

Remarks: 1) one lamp defect

2.2 Lamp-Transfer-Standards

Seven different types of lamp-transfer-standards were used by the participants and are stated in the last column of Table 1. Their images are shown in Fig. 1. Obviously, the bulbs, filaments and spatial light distributions of these lamps are significantly different. These properties could affect the light integrating capability of the integrating sphere. Thus, the pilot laboratory spends high effort to calibrate at least one lamp from each participant batch by the PTB goniophotometer. Then these lamp(s) acts as reference lamps to calibrate the integrating sphere to avoid effects due to different spatial light distributions of the different lamps.

a) OSRAM WI5 (E27)	b) OSRAM WI5 (E40)	c) OSRAM WI40/G	d) OSRAM WI40/Globe	e) Mazda N.N.	f) GEC/Polaron LV200 LF200 200W, LV60W	g) GEC LV60W	h) Philips 100W

Fig. 1 Images of the eight different lamp-transfer-standards used by the participants identified by the manufacturers and the lamp types. If necessary the socket size is given in parentheses.

2.3 Time Schedule

At the beginning of the comparison, the measurements were delayed due to missing lamps. The last lamps reached PTB in May 2009. The measurements at PTB started in October 2009 and ended in May 2010. This measurement period was interrupted due to a failure of the air conditioner of the integrating sphere room from December 2009 to February 2010. Because the integrating sphere was real-time calibrated by reference lamps calibrated by the PTB goniophotometer, no effects of ageing or drifts had occured. The lamps measured left PTB from October 2009 to June 2011 depending from the kind of transport (by hand carriage or by commercial transport service).

All data regarding the lamps of a participant, sent from a participant or measured in the PTB, are collected in an individual table. All tables are organised to perform the evaluations for each participant and to get final results for the whole comparison. In spring 2011, a complete overview of the results was distributed to the participants as pdf-sheet. This pdf-sheet shows the results for each participant normalised to its own mean value. This prevented the data of a participant from being compared with the results of the other participants, but allowed for cross-checking all own entries. This process was introduced in the procedure to avoid misinterpretation and typos. The latest responses on these checks and the messages dealing with the measurement uncertainties and their budgets were received in November 2013.

2.4 Influences of the Operational Conditions

The operational conditions for the lamp-transfer-standards affect their geometric, electric, thermodynamic and temporal properties. According to the sensitivity of the lamps with respect to these conditions and regarding the associated uncertainties connected to the transfer of the luminous flux values, the operational conditions can be divided in three groups:

(i) Conditions, which do not change the properties, but modify a measurement result;
(ii) Conditions, which affect the properties in a reversible manner;
(iii) Conditions, which create an irreversible change of the lamp-transfer-standard.

Maximum care and attention were taken at PTB to avoid any irreversible change of the lamp-transfer-standards. All conditions were optimally fulfilled to reduce any modification of measurement results.

2.4.1 Geometric Alignment

The geometrical alignment of the lamps had to be done according to the rules of the participants for their specific lamps. That means in all cases a vertical orientation of the lamps with base up was used. Since the calibration of the integrating sphere was carried out by goniophotometric calibrated lamps of the same type as calibrated, the pilot-laboratory made sure, that the orientation around the vertical axis inside the integrating sphere was always the same for all lamps of same type.

2.4.2 Electric Supply

In this comparison, the incandescent lamp standards for the transfer of the luminous flux values are operated using the lamp current as setting parameter, which is held constant. There is one exception: the standard lamps of VSL had to be operated at constant voltage.
A lamp, seasoned and calibrated with a DC-supply at a fixed polarity, can irreversibly be altered if accidentally operated with reversed polarity. Although all participants within this comparison were using DC power supplies for their transfer-standard-lamps, two possible conditions with respect to polarity were used:

i) Negative polarity at central contact of the lamp cap;
ii) Positive polarity at central contact of the lamp cap;

In general, the lamps were measured using four-pole-technique, directly at the electrically conducting parts of the cap.

2.4.3 Thermodynamic Conditions

It is well known that the properties of incandescent lamps are not very sensitive to the environmental conditions like ambient temperature, air pressure, speed of moving air and humidity. Therefore, it was sufficient that, for the duration of the measurements for this comparison, the stability of these values was high enough to avoid any related effects. The ambient temperature was stabilised at a value of 23.0 °C and the fluctuations were less than ±1.0 °C.

2.4.4 Temporal Conditions

At PTB, all lamp-transfer-standards were operated following the PTB rules for the temporal management of these types of lamp standards. These rules are facilitating the save operation of lamp standards and minimise contribution of Type B uncertainties.

In detail: The lamp current as setting parameter was ramped up within one minute to the value given by the participant. The warm-up time was considered as stated by the participant and was additionally checked by analysing the stability of the readings of the meters. The measurements were started after the thermal equilibrium was achieved (typically after 10 min to 15 min burning time). Finally, after the measurements, the lamp current was ramped down within the time period of about one minute.

The burning time for each individual lamp operation complemented by additional data is shown in the individual breakdown for the measurement results. An example for such an overview is given in Table 3, page 17. PTB did not apply any burning time dependent corrections for lamp aging to the measured values of the luminous flux.

2.5 Operational Conditions used at PTB and by the Participants

2.5.1 Luminous flux standard lamps

There are different types of luminous flux standard lamps which are used and operated according to the conditions stated in Table 2.

Geometrical conditions:

all lamps

- optical axis of the lamp vertical
- cap up
- rotational orientation for a specific lamp type always the same, rotation mark at the base of the lamp points in x-direction (r.m.x.)
- vertical height -> centre of filament

Electrical power supply and measurements:

- the quantity to be set is constant DC current (in case of VSL constant DC voltage)
- polarity depends on the individual lamp standard
- lamp voltage is measured with two separate contacts, using "four-pole-technique".

2.5.2 Operational Conditions at the Participating Laboratories

A reduction of measurement uncertainty associated with the value of the transferred luminous flux can be achieved, if the operational conditions from the participants were duplicated for the measurements of their standards at PTB. The measurement setup at PTB for these variations is documented in Table 2.

Table 2 Geometrical and electric operational conditions used by the participants for the lamp-transfer-standards

symbol	operational conditions (see also Fig. 2)	polarity
Cap up - center	PTB-conditions	negative at center contact
Cap up + center	PTB-conditions	positive at center contact

Fig. 2 shows an example of the mechanical alignment of the lamp-transfer-standards inside the integration sphere. Due to the (small) spatial non uniformity response of the integrating sphere all lamps (including the reference lamps used to calibrate the integrating sphere!) should be mechanically aligned in the same way for all measurements at PTB. This procedure allows nearly the negligence of the non uniformity response of the integrating sphere. This is why at least one individual lamp could be used for the calibration of the integrating sphere for each lamp type group. Only a small remaining part of the non uniformity had to be considered in the uncertainty budget.

First all lamps were marked at its base with a small black point (see fig. 1, also). This mark represents the positive x-direction of the integrating sphere (see fig. 2). To find the correct rotational position (the positive x-direction) of this point a cross line projection laser was used. The vertically x-z plane, represented by the cross line projection laser, must met the black point. The horizontally x-y plane must intersect the filament center of the lamp to align the lamp for the correct height inside the integration sphere. In case of the example lamp (see fig. 2) this not very difficult, because the filament is visible. In case of frosted bulb lamps these lamps were operated with a small current to see the filament glow for a short moment. Then it is very easy to align the height of the lamp inside the integration sphere.

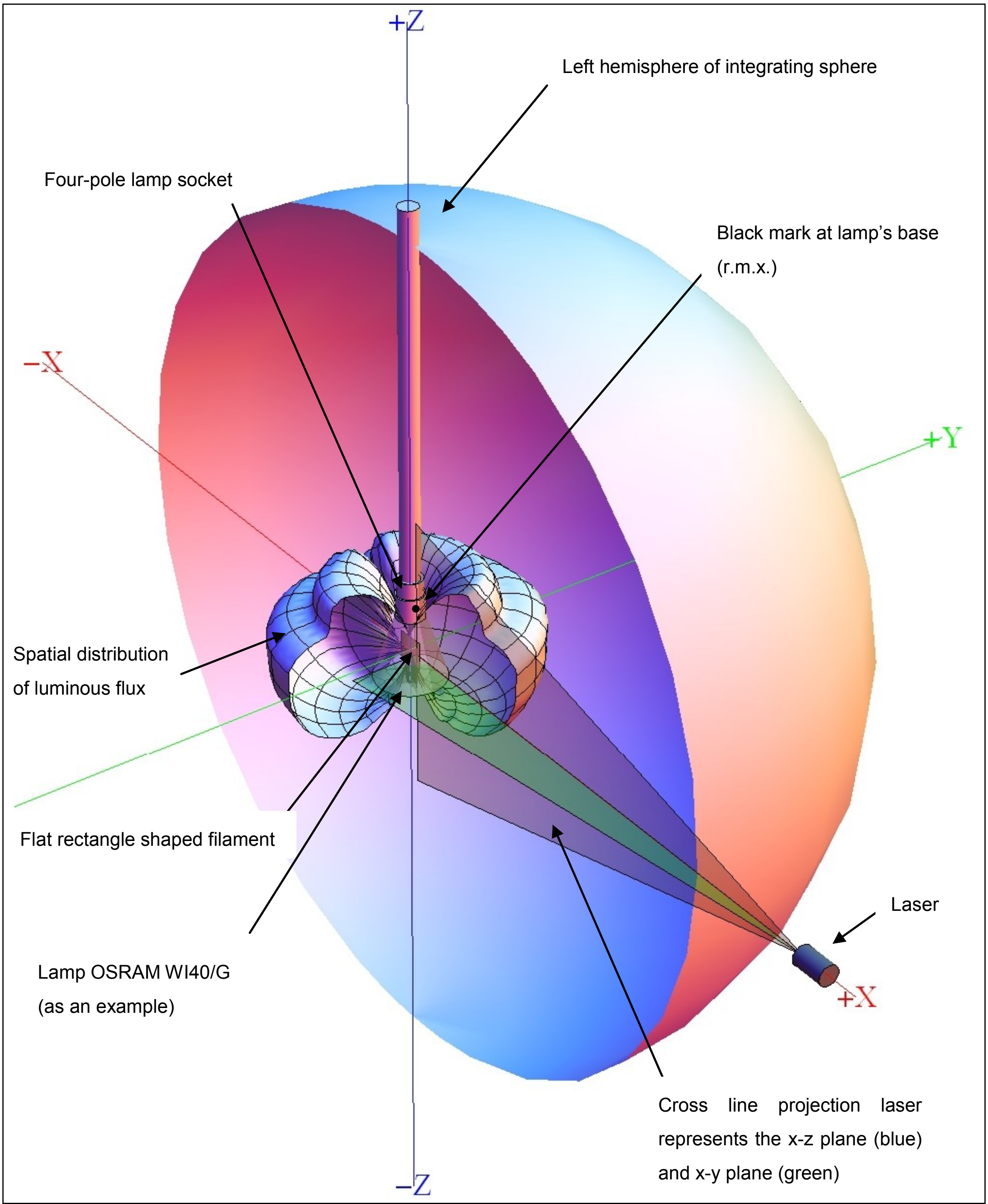

Fig. 2: Example of the mechanical alignment of the lamps for rotation and height inside the integrating sphere.

2.5.3 Influence of Transport

In general, the lamps, when returned from PTB to the participant's laboratory, should have been operated following the same procedure as used for the measurements before shipment. From the "initial" and "return" data sets measured by the participant before and after the transportations and the measurements at the PTB, the lamp data and lamp characteristics shall verify that the values previously assigned to the lamps properties are still valid. Thus, the two sets of lamp data will allow the detection and the magnitude of changes due to a possible small alteration during transport and from the use in PTB. Provided these changes are negligible, the values measured at PTB can be taken as a basis for the dissemination of the EURAMET-RV value of the luminous flux.

In case that a significant change of one lamp has occurred, the weight of that specific transfer standard for the calculation of the average shall be reduced or, in worst case, the specific standard might be excluded from the comparison by the participant.

2.5.4 Influence of Aging

In principle, any operation of the lamp transfer standards - the operations at PTB, too - will irreversibly alter the lamp data and the values transferred by the lamp. These changes depend on the aging rate specific for each lamp-transfer-standard and the total duration of the burning time. This is the reason why the total burning time at PTB is summarised in the tables explained below. Using the lamps aging rate – which is usually known only by the participants laboratory - and the burning time at PTB, an expectation of the possible ageing related change can be calculated and compared with the change found by the return-measurements.

A relative aging rate c_{R} of a few parts in 10^{-4} per hour of the luminous flux value is usually found for these types of lamps. When multiplied with the typical burning time at PTB of less than ≈ two hours, the effect of aging is negligible, otherwise it would be in the liability of a participant to perform the appropriate correction for the values of the “return” measurement results.

3 Results Normalised to EURAMET-RV

3.1 Luminous Flux Values

Each link laboratory was asked to calibrate its luminous flux lamp-transfer-standards such that the luminous flux values represent the magnitude of its luminous flux unit at the former time, when the laboratory participated in the CCPR key comparison. The uncertainty associated with this maintained luminous flux value is combined from the former uncertainty and the contribution for the maintenance over the long period of time. It is important to notice that the maintained luminous flux values of a link laboratory transfer the former values, independent of today’s values, which might be changed due to new realisations of the luminous flux unit or because of improved measurement techniques.

The luminous flux values of all other participants represent the luminous flux values used for their day–to–day calibrations associated with the minimum uncertainties.

The pilot laboratory starts with a constant but arbitrary luminous flux value when collecting the values of the link laboratories. Their weighted contribution is the reference value EURAMET-RV. This value is the best approach to the CCPR-KCRV available during this EURAMET key comparison and it is finally used at the pilot laboratory, to normalise the luminous flux values of all other participants.

Two link laboratories as well as all other participating laboratories measured the relevant quantities of their lamp-transfer-standards before and after the shipments to and from the pilot laboratory. These measurements are denoted as “initial” and “return” measurements. All participating laboratories reported for each lamp-transfer-standard four values with the associated uncertainties, two for luminous flux and two more for lamp voltage (in case of VSL lamp current) embedding the measurements carried out at the pilot laboratory. All these values were corrected by the participating laboratory for an operation under the stated conditions.

The pilot laboratory operated the lamp-transfer-standards of a participant at minimum in two independent runs (at the beginning of the measurement campaign and again at the end). It acquired the values for lamp currents, lamp voltages, distribution temperatures and integrating sphere response. From these raw data, the values for luminous flux and lamp voltages are first corrected for perfect settings of the operational conditions and then evaluated with associated uncertainties as normalised contribution to the comparison. The values of luminous flux are normalised to the EURAMET-RV, while those of the lamp voltages are normalised to the values determined at the PTB.

3.2 Tables Summarising NMI results

For each participant, the submitted data and evaluated results of the measurements carried out at the pilot laboratory are collected in individual tables, see Annex B. Table 3 (page 17) shows an example and explanations in detail of the entries. Title and name of the key comparison are given on top and the acronym of the corresponding NMI is shown in the upper right corner. The characters “A, B, C, …” and numbers “1, 2, 3, …” in the first row and first column, respectively, are for reference to identify the cells with the different entries.

The first framed block in the table includes the cells from A1 to F2 and contains general information, starting from left with “date” and “version of the related draft”. The entries in the two blocks of cells C1 to D2 and E1 to F2 explain that the relative data of voltages (C6-C14) and luminous fluxes (E6-E14) are averaged as arithmetic means and that the latter is normalised to the key comparison reference value EURAMET-RV, which is realised within this key comparison from the luminous flux values transferred by the link laboratories.

The second framed block C4 to F14 collects the averaged and normalised results of all lamp measurements for one NMI (the entries will be explained later). The small block of cells A7 to B11 holds the standard uncertainties indicated by the participating NMI and gives access to these uncertainty contributions.

The largest part of the table deals with the properties and measurements of the individual lamp-transfer-standards. The names of quantities, units and further descriptions for the entries in blocks below row 24 are given in a header block (A16 to F24). The respective values for each lamp are given below row 24 in blocks of eight rows according to the description in the header block. The entry respective to the header cell A18 stands for the lamp number, while the respective entry for A19 states the operational condition at PTB with the identifier defined in the columns of Table 2. During the explanation of the individual cells in a block with lamp data, it is inconvenient to refer individually to the respective cell in the header block. Therefore, a cell with lamp data is referenced to the respective cell in the header by the additional character "r" at the cell identifier. As example, the explanation "lamp number" in cell A18 of the header is referenced as A18r for the corresponding entry in the blocks of lamp data.

The values for the lamp current, the distribution temperature and the warm-up time are taken from the data sheet prepared by the participant and copied in the cells A20r to A22r. In cell A23r, a value for the distribution temperature measured at PTB is shown. It was determined by blue-red-ratio measurements with an uncertainty just sufficient for PTB mismatch correction.

The relative standard uncertainty in cell A24r gives constancy and deviation of the set-value for lamp current during lamp operation at PTB. In columns B16r to C24r, the values of the individual measurements of the lamp voltage are summarised and the cells B17r and B18r show the values for the lamp voltage as given by the participant („initial" and „return" transportation, respectively) and their average in B19r. The stated standard deviations of the participant's voltage measurements are given in the cells C17r and C18r with their average in cell C19r. The ratios of the participant's value of lamp voltage (from B19r) divided by the PTB values of lamp voltage determined during repeated operations (#1,…, #4) are listed in the cells B20r to B23r and the relative standard deviations of these voltage measurements are given in the cells C20r to C23r. Averages of the ratios of values and relative standard deviations are given in the cells B24r and C24r, respectively.

In the columns D16r to D24r and E16r to E24r, the values and associated relative standard deviations (further on taken as relative standard uncertainties) of the luminous flux are summarised similar to the lamp voltages. The cells D17r to D18r show the participant's „initial" (before transportation to the pilot) and „return" (after transportation back to the NMI) values with the average in D19r, while the cells E17r to E19r state their respective related relative standard deviations calculated from the values given by the participants. The cells D20r to D23r show the ratio of the average in the cell D19r divided by the photometric value determined during the repeated operations (#1,…,#4) at PTB and the PTB values are normalised to the EURAMET-RV, which represents a value close to the CCPR-KCRV. Therefore, the listed relative deviations of the participant's values are just the deviations from the CCPR-KCRV. The relative standard deviations are collected in the cells E20r to E23r. The averaged value of a lamp is calculated and placed in the cell D24r together with the relative standard deviation stated in the cell of E24r.

In column "F" of the block for a lamp-transfer-standard, the burning time at PTB is given separately for each power up sequence and the total burning time is stated in F24r, too. In very few cases, the number of measurements per power up sequence at PTB was larger than usually, which can be seen from the reported longer burning time. This tabulation is consecutively repeated for all lamp-transfer-standards of the individual participant.

The averaged results for relative voltages and normalised luminous flux of all lamps for one participant are copied from below and are summarised within the second framed block C6 to F13, which simplifies the overview and the check of consistency. The repeatability of a single lamp as well as the uniformity of the batch can be analysed from these results which forms the basis for an identification of transfer standards, which might be affected by transport, use or operational conditions.

The relative mean values associated with standard deviations for lamp voltage and normalised luminous flux values are shown in cells C14 to F14 and the value in cell E14 subtracted by "1" is just the DOE, which is the relative deviation of the participant's value of luminous flux from the EURAMET-RV, which is close to the CCPR-KCRV.

It should be noted that, in a key comparison, the (single) DOE value of a participant states the relative deviation of its luminous flux value from the related KCRV. This means that, in a CCPR key comparison, the (single) DOE value depends on the values of all other accepted participants and only the mutual DOE values are independent of the RV.

Similarly, in this EURAMET key comparison, the (single) DOE value of a participant is the relative deviation of its luminous flux value from the related EURAMET-RV. However, it depends on the luminous flux values transferred by the link laboratories only, but is totally independent of the values of the other participants. Again the mutual DOE values are independent of the RV.

The CCPR-KCRV and the EURAMET-RV are close to each other, but the uncertainty associated with the value of the latter is increased due to contributions from (i) maintenance at the link laboratories over a long period of time (since the CCPR key comparison), (ii) the uncertainties of the link laboratories originated from the transfer at the time when participating in the former CCPR key comparison, and (iii) the uncertainties from the new transfer in this comparison, which includes additional operations and measurements at the link laboratories and at the pilot laboratory. The relation is given in the next chapter.

Table 3 Table with collected data measured by the participant and at the PTB

	Luminous Flux KC:		***EURAMET.PR-K4***		**NMI:**	**BIM**
	A	B	C	D	E	F
1	date	version of draft	mean-values are calculated as:		reference for normalisation is:	
2	3.12.13	**PreDraftA**	**arithmetic**	**mean**	**norm=**	**mean of NMI**
3						
4			U_L		Φ_L	
5			**NMI / PTB**	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
6			0.99931	1.2E-03	0.9995	5.7E-04
7	Uncertainties of NMI (k =1)		1.00033	2.6E-04	1.0046	3.3E-04
8	$u_{c,rel}(J_L)$	nominal	1.00043	5.0E-04	0.9960	9.1E-04
9	$u_{c,rel}(U_L)$	1.5E-04	1.00019	6.5E-04	0.9999	4.1E-04
10	$u_{c,abs}(T_{NMI})$	8.7				
11	$u_{c,rel}(\Phi_L)$	1.3E-02				
12						
13						
14		**means of participant:**	***1.00007***	***2.6E-04***	***1.0000***	***1.8E-03***
15						
16	**data collection**	***U* / V**	**rel.std.dev.**	***Φ* /lm**	**rel.std.dev.**	**burn.time / min**
17		$U_{L,NMI}$ **#1**		$\Phi_{L,NMI}$ **#1**		
18	**lamp number**	**#2**		**#2**		
19	**operation. cond.**	**mean** $U_{L,NMI}$		**mean** $\Phi_{L,NMI}$		
20	J_L **/ A**	$U_{L,NMI}/U_{L,PTB}$ **#1**		$\Phi_{L,NMI}/\Phi_{L,norm}$ **#1**		
21	T_{NMI} **/ K**	**#2**		**#2**		
22	**warm-up / min**					
23	T_{PTB} **/ K**					**Goniophotometer**
24	$u_{rel}(J_L)$	**mean ratio** U_L	**ave.rel.std.dev.**	**mean ratio** Φ	**ave.rel.std.dev.**	**total at PTB**
25		100.360		1100.09		
26	**1**	100.610		1098.91		
27	**Cap up - center**	***100.485***	1.2E-03	***1099.50***	5.4E-04	
28	**0.8965**	0.99932	8.9E-07	0.9997	1.0E-03	21
29	**2795**	0.99930	3.6E-07	0.9993	1.0E-03	35
30	**12**					
31	**2764**					301
32	**2.00E-04**	***0.99931***	**1.3E-05**	***0.9995***	**1.9E-04**	**357**
33		100.700		1100.08		
34	**2**	100.750		1099.97		
35	**Cap up - center**	***100.725***	2.5E-04	***1100.03***	5.0E-05	
36	**0.8955**	1.00039	9.3E-07	1.0049	1.0E-03	17
37	**2795**	1.00026	1.4E-06	1.0043	1.0E-03	34
38	**12**					
39	**2760**					100
40	**2.00E-04**	***1.00033***	**6.5E-05**	***1.0046***	**3.3E-04**	**151**
41		100.670		1094.69		
42	**3**	100.770		1092.71		
43	**Cap up - center**	***100.720***	5.0E-04	***1093.70***	9.1E-04	
44	**0.8895**	1.00046	5.8E-07	0.9960	1.0E-03	17
45	**2795**	1.00041	5.0E-07	0.9959	1.0E-03	34
46	**12**					
47	**2764**					95
48	**2.00E-04**	***1.00043***	**2.4E-05**	***0.9960***	**3.6E-05**	**146**
49		100.470		1097.36		
50	**4**	100.600		1096.61		
51	**Cap up - center**	***100.535***	6.5E-04	***1096.99***	3.4E-04	
52	**0.8945**	1.00021	8.1E-07	1.0002	1.0E-03	18
53	**2795**	1.00017	4.3E-07	0.9997	1.0E-03	34
54	**12**					
55	**2760**					94
56	**2.00E-04**	***1.00019***	**1.8E-05**	***0.9999***	**2.3E-04**	**146**

4 Calculations in the Comparison

4.1 Stability of the PTB Instrumentation

At the PTB, the stability of the instrumentation was verified with batches of monitor lamps. For the luminous flux measurements over a period of several weeks, but interrupted for approx. 3 months due to a failure of the air conditioner, one integrating sphere photometer was used. The responsivity proved to be stable within the repeatability of the measurements. No corrections had to be applied.

The results of measurements using 3 monitor lamps are shown in the following Fig. 3.

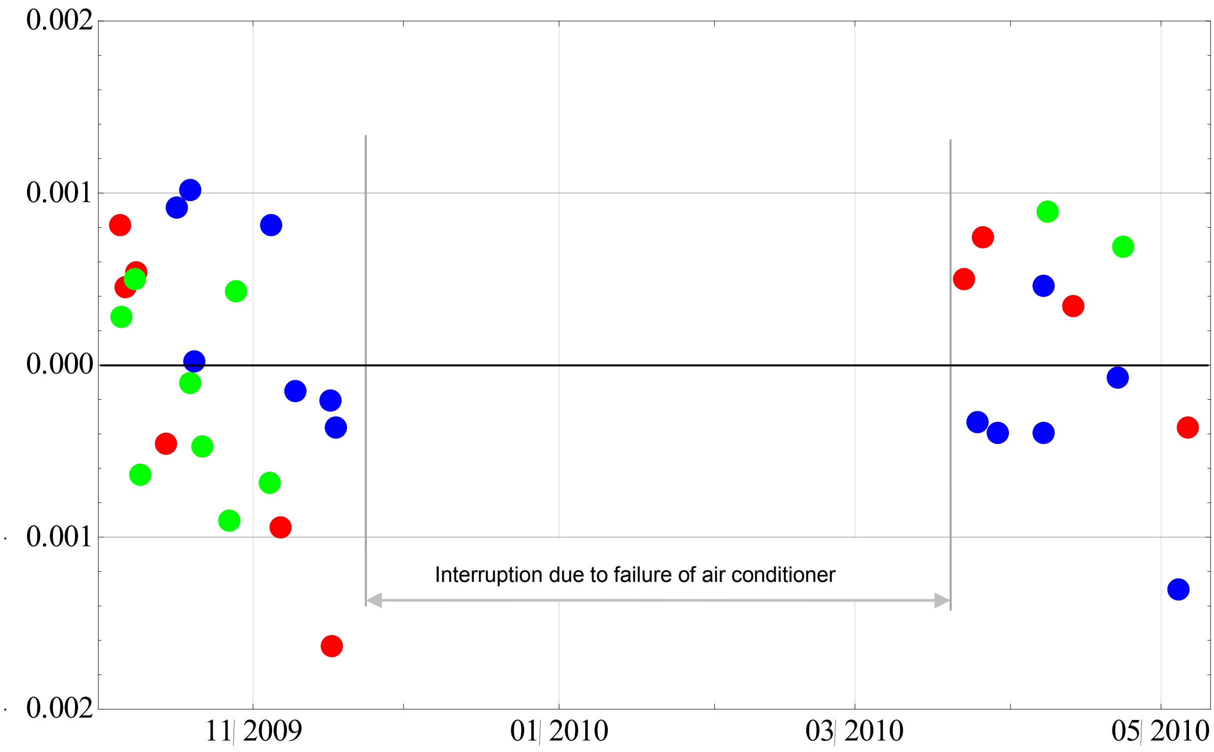

Fig. 3 Long term stability of responsivity of the integrating sphere verified by repeated measurements of three luminous flux monitor lamps (indicated by red, green and blue points) normalized to their mean luminous flux results

4.2 Determination of the EURAMET-RV

The evaluation of the EURAMET-RV is explained in Table 4 and the result is shown in the last row. A graphical presentation of the content of this table is given in Fig. 4. The values of the link laboratories are shown in three groups of two rows: The first column holds the acronym of the link laboratory or a hint to the KCRV, respectively. The upper row of a group shows the DOE for the link laboratory with associated expanded uncertainty as determined in the former CCPR key comparison and published by the BIPM [2]. These values are marked as blue squares in Fig. 4 together with the related reference CCPR-KCRV.

The second row in a group presents the results from this EURAMET key comparison. The results are the normalised and averaged values taken from the tables in Annex B similar to the example shown in Table 3. The second column shows the relative deviation of lamp voltages measured at a link laboratory from the voltages measured at the PTB. The small relative differences prove that neither instability of the lamps nor differences in the operational conditions between link and pilot laboratory influence the luminous flux values significantly.
The normalised averaged luminous flux value from cell E14 in Table 3 is transferred by the batch of lamps from the link laboratory to the pilot laboratory. The value represents the luminous flux of the link laboratory at the time of the CCPR key comparison and the DOE is just the difference to the CCPR-KCRV. Therefore, the DOE was subtracted from the transferred and normalised value of luminous flux placed in column three of Table 4 in the second row of a link laboratory. The associated uncertainties in column five of Table 4 are combined and expanded from the contributions in the four more columns to the right. These four contributions of uncertainties are explained in Annex A.

Table 4 Reference value for the EURAMET key comparison by the link laboratories

Link-Results of Luminous Flux KC: EURAMET.PR-K4								Pilot-Lab.: PTB - Photometry
Link Laboratory	U_{NMI}/U_{PTB} -1	Φ_{NMI}/Φ_{RV} -1	E_N	*U(batch)*	u_{rel}(unit)	u_{rel}(transfer)	u_{rel}(PTB)	u_{rel}(homog.)
CCPR_PTB		-0.0042		5.6E-03				
Link_PTB	0.00001	0.0000	0.00	1.1E-02	5.1E-03	1.7E-03	1.7E-03	2.2E-04
CCPR_LNE_CNAM		0.0069		5.8E-03				
Link_LNE_CNAM	-0.00278	0.0005	0.03	1.3E-02	6.0E-03	1.7E-03	1.7E-03	2.0E-04
CCPR_INRIM		-0.0006		9.6E-03				
Link_INRIM	0.00033	-0.0007	0.04	1.5E-02	6.9E-03	1.7E-03	1.7E-03	3.0E-04
CCPR_KCRV		0.0000		2.0E-03				
EURAMET_RV		0.0000		7.4E-03				

The EURAMET-RV is evaluated as the average of the entries in column three, i.e. the second row, weighted by the associated uncertainties in column five. This EURAMET-RV is used to normalise all luminous fluxes in the example of Table 3 and in the Annex B including those values of the link laboratories, which are entries in Table 4. By definition, the two references CCPR-KCRV and EURAMET-RV have identical values as shown in the presentations of Table 4 and Fig. 4, but the expanded uncertainty associated with the EURAMET-RV is about triply the expanded uncertainty associated with the CCPR-KCRV.

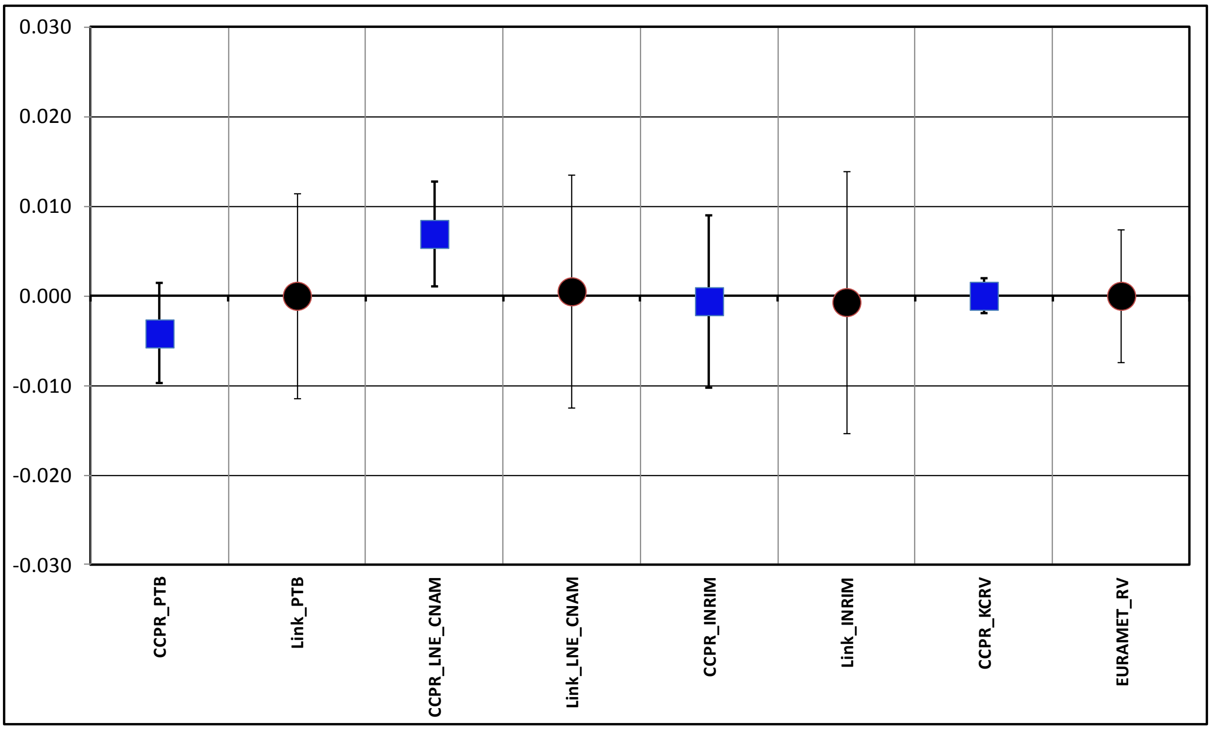

Fig. 4 Degrees of equivalence to EURAMET-RV; Bars represent expanded uncertainties for the link-participants; Blue squares refer to the CCPR key comparison, while black dots show the results in this EURAMET key comparison

In a calculation of weighted averages, it is important to analyse two properties of the contributions: (i) The E_N-criterion has to be fulfilled for each contribution and (ii) the Birge-ratio must be valid for the weighted average (see Annex A). In Table 4, the E_N-values shown in column 4 are small and prove the validity of the E_N-criteria for each link laboratory.

From the values and expanded uncertainties, the Birge-ratio $R_B = 0.09 < 1$ is found to be small. Therefore, the uncertainties within the link procedure are consistent and small enough for the stated expanded uncertainty associated with the EURAMET-RV.

4.3 Determination of the Degrees of Equivalence

The results for all participants in this EURAMET key comparison are shown in Table 5 organised quite similar to the entries of the link laboratories in Table 4 and are graphically presented in Fig. 5. The third group in Table 5 repeats the last group from Table 4 with the results of the RVs. The following rows show the results of the 9 participants copied from the individual tables in Annex B. The acronym of a participant in the first column is followed by the relative difference of the lamp voltage averaged for all lamps in the batch. Relative differences below 0.1 % are negligible, while the three entries with higher values are reasoned due to missing comparable 4-pole measurements at the participant's laboratory.

The DOEs of the participants are shown in column 3 with the associated expanded uncertainties in column 5. The latter are combined and expanded by $k = 2$ from the entries in the columns 6 to 9. As before, the values of the E_N-criteria in column 4 prove that the deviations from the RV and the associated expanded uncertainties are well matched for all participants.

Table 5 Results of all participants in the EURAMET key comparison

Results of Luminous Flux KC: EURAMET.PR-K4								Pilot-Lab.: PTB - Photometry
Participant	U_{NMI}/U_{PTB} -1	Φ_{NMI}/Φ_{RV} -1	E_N	U(batch)	u_{rel}(unit)	u_{rel}(transfer)	u_{rel}(PTB)	u_{rel}(homog.)
CCPR_KCRV		0.0000		2.0E-03				
EURAMET_RV		0.0000		7.4E-03				
MIKES	9.0E-05	3.0E-04	0.03	7.6E-03	2.8E-03	1.7E-03	1.7E-03	8.9E-04
CMI	8.1E-04	3.5E-03	0.27	1.0E-02	4.5E-03	1.7E-03	1.7E-03	9.3E-04
DMDM	8.2E-04	4.3E-03	0.30	1.2E-02	5.6E-03	1.7E-03	1.7E-03	2.4E-04
INM	-6.9E-04	-7.1E-03	0.47	1.3E-02	5.9E-03	1.7E-03	1.7E-03	1.4E-03
VSL	-3.9E-04	1.2E-02	0.88	1.1E-02	4.9E-03	1.7E-03	1.7E-03	1.5E-03
GUM	-3.0E-04	-7.3E-03	0.59	1.0E-02	4.4E-03	1.7E-03	1.7E-03	3.3E-04
BIM	7.0E-05	-1.0E-02	0.38	2.6E-02	1.3E-02	1.7E-03	1.7E-03	1.8E-03
BEV	8.7E-04	-8.0E-03	0.50	1.4E-02	6.6E-03	1.7E-03	1.7E-03	7.6E-04
SP	3.5E-04	2.0E-04	0.01	1.4E-02	6.3E-03	1.7E-03	1.7E-03	3.1E-04

The numerical results are summarized in Table 5a and presented in Fig. 5.

Table 5a Unilateral Degrees of Equivalence (DOE) of luminous flux

Participant	D_i	$U(D_i)$
CCPR_KCRV	0.0E+00	2.0E-03
EURAMET_RV	0.0E+00	7.4E-03
MIKES	3.0E-04	7.6E-03
CMI	3.5E-03	1.0E-02
DMDM	4.3E-03	1.2E-02
INM	-7.1E-03	1.3E-02
VSL	1.2E-02	1.1E-02
GUM	-7.3E-03	1.0E-02
BIM	-1.0E-02	2.6E-02
BEV	-8.0E-03	1.4E-02
SP	2.0E-04	1.4E-02

On the left in Fig. 5, the two RV from the CCPR and this EURAMET KC are shown and, to the right, the DOEs of the participants and as bars the expanded associated uncertainties are drawn. Obviously, the DOEs are well localised near the centre-line representing the KCRV and the intervals of the expanded uncertainties includes the KCRV for all participants, which can be seen as the graphical meaning of the E_N-criteria.

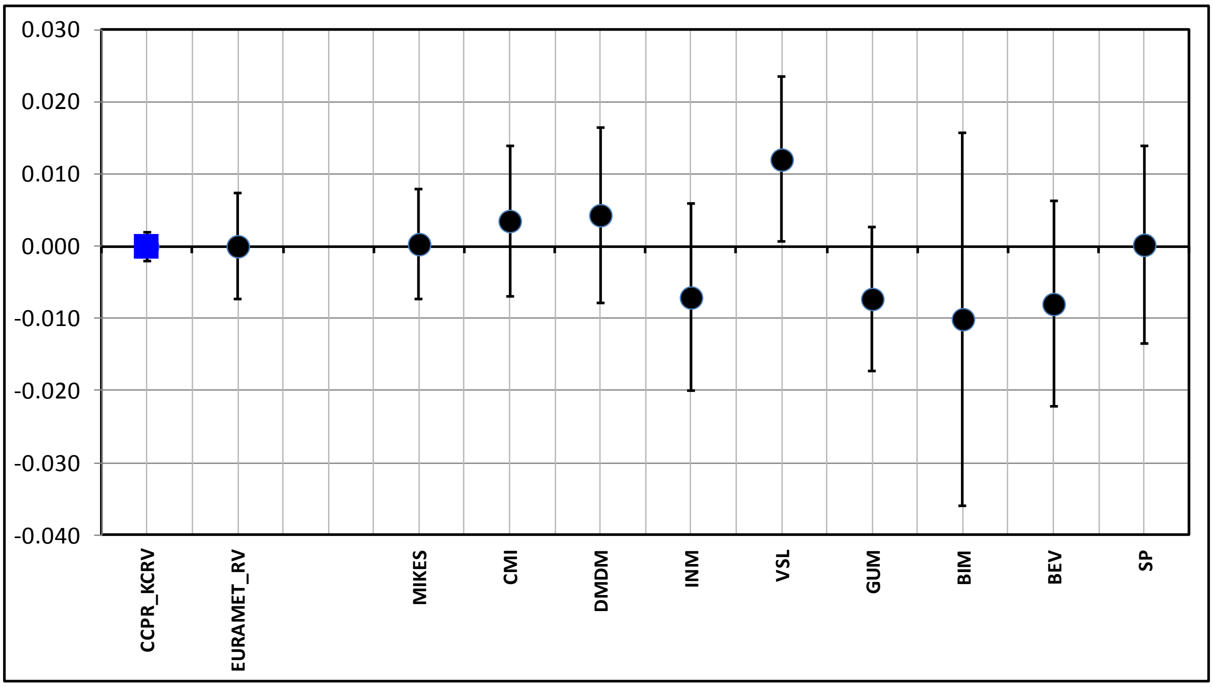

Fig. 5 Degrees of equivalence to EURAMET-RV; Bars represent expanded uncertainties for the participants; Blue square refer to the CCPR-KCRV, while the black dots show the results in this EURAMET key comparison

4.4 Determination of Bilateral DOE

The values of the bilateral equivalences of one participant to another is calculated by $D_{ij} = D_i - D_j = (x_i - x_j)/x_\mathrm{R}$. The normalisation of all luminous fluxes with the RV with a value $x_\mathrm{R} \cong 1$ leads to expanded uncertainties $u(D_{ij}) = \sqrt{u^2(D_i) + u^2(D_j) + (D_i - D_j)^2 \cdot u^2(x_\mathrm{R})}$ associated with the mutual equivalences D_{ij}. The term $(D_i - D_j)^2 \cdot u^2(x_\mathrm{R})$ accounting for the contribution of the uncertainty associated with the RV is negligible, as known from other key comparisons.

Table 6 shows the matrix of the mutual DOEs $D_{ij} = D_i - D_j$ with the associated expanded $k = 2$ uncertainties $U(D_{ij}) = k\,\sqrt{u^2(D_i) + u^2(D_j)}$.

Table 6 Matrix of bilateral DOEs with associated expanded uncertainties

$(D_{ij} \pm U_{ij})/10^{-2}$			j								
			1	2	3	4	5	6	7	8	9
			MIKES	**CMI**	**DMDM**	**INM**	**VSL**	**GUM**	**BIM**	**BEV**	**SP**
i	1	**MIKES**		-0.32 ± 1.3	-0.40 ± 1.4	+0.74 ± 1.5	-1.17 ± 1.4	+0.76 ± 1.3	+1.04 ± 2.7	+0.83 ± 1.6	+0.01 ± 1.6
	2	**CMI**	+0.32 ± 1.3		-0.08 ± 1.6	+1.06 ± 1.7	-0.85 ± 1.5	+1.08 ± 1.4	+1.36 ± 2.8	+1.15 ± 1.8	+0.33 ± 1.7
	3	**DMDM**	+0.40 ± 1.4	+0.08 ± 1.6		+1.14 ± 1.8	-0.77 ± 1.7	+1.16 ± 1.6	+1.44 ± 2.9	+1.23 ± 1.9	+0.41 ± 1.8
	4	**INM**	-0.74 ± 1.5	-1.06 ± 1.7	-1.14 ± 1.8		-1.91 ± 1.7	+0.02 ± 1.6	+0.30 ± 2.9	+0.09 ± 1.9	-0.73 ± 1.9
	5	**VSL**	+1.17 ± 1.4	+0.85 ± 1.5	+0.77 ± 1.7	+1.91 ± 1.7		+1.93 ± 1.5	+2.21 ± 2.8	+2.00 ± 1.8	+1.18 ± 1.8
	6	**GUM**	-0.76 ± 1.3	-1.08 ± 1.4	-1.16 ± 1.6	-0.02 ± 1.6	-1.93 ± 1.5		+0.28 ± 2.8	+0.07 ± 1.7	-0.75 ± 1.7
	7	**BIM**	-1.04 ± 2.7	-1.36 ± 2.8	-1.44 ± 2.9	-0.30 ± 2.9	-2.21 ± 2.8	-0.28 ± 2.8		-0.21 ± 2.9	-1.03 ± 2.9
	8	**BEV**	-0.83 ± 1.6	-1.15 ± 1.8	-1.23 ± 1.9	-0.09 ± 1.9	-2.00 ± 1.8	-0.07 ± 1.7	+0.21 ± 2.9		-0.82 ± 2.0
	9	**SP**	-0.01 ± 1.6	-0.33 ± 1.7	-0.41 ± 1.8	+0.73 ± 1.9	-1.18 ± 1.8	+0.75 ± 1.7	+1.03 ± 2.9	+0.82 ± 2.0	

4.5 Literature

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[2] BIPM database,
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CCPR Key Comparison K3a of Luminous Intensity and K4 of Luminous Flux with Lamps as Transfer Standards, PTB-Opt-62, 1999. - ISBN 3-89701-471-8

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[5] ISO. *Guide to the Expression of Uncertainty in Measurement (GUM)*,
http://www.bipm.org/en/publications/guides/gum.html (accessed Febr. 1 2013)

[6] Combined result and associated uncertainty from
interlaboratory evaluations based on the ISO Guide
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Annex A

A 1 PTB Measurement Equation for Luminous Flux

At the PTB, the luminous flux Φ_i of all lamps was measured by the substitution method. Its value is calculated from a factor f_0 multiplied with the photocurrent y_i of a photometer of the integrating sphere in illuminance mode. Within the relative combined standard uncertainty $u_{\mathrm{rel}}(f_0)$, at a defined distribution temperature of the lamp under test, the factor f_0 is independent of individual lamps.

$$\Phi_i = f_0 \cdot y_i \qquad u_{\mathrm{rel}}(f_0) = 0.17\% \tag{A1}$$

Let $1 \le k \le n$ be the number of the participants and similarly $1 \le j \le n_k$ the number of transfer standards of the participant k. At the PTB, the photocurrent y_i for one measurement is averaged from 20 readings and for each lamp $1 \le i \le r = 2$ measurements are averaged to get the PTB value of luminous flux $\Phi_{k,j}^{(0)}$ having a relative standard uncertainty $u_{\mathrm{rel}}\left(\Phi_{k,j}^{(0)}\right)$ of the mean.

$$\Phi_{k,j}^{(0)} = f_0 \cdot y_{k,j}^{(0)} = f_0 \cdot \frac{\sum_{i=1}^{r} y_i}{r} \qquad u_{\mathrm{rel}}^2\left(\Phi_{k,j}^{(0)}\right) = \frac{\sum_{i=1}^{r}\left(y_i / y_{k,j}^{(0)} - 1\right)^2}{(r-1)\cdot r} \tag{A2}$$

Each participant reported two values $\Phi_{k,j}^{(\mathrm{i})}$ and $\Phi_{k,j}^{(\mathrm{r})}$ from “initial“ and “return” measurements for one lamp. The mean of these two values is divided by the PTB-value and calculated as lamp ratio $v_{k,j}$ for the *j*-th lamp of the *k*-th participant. The related standard uncertainty is calculated as a combination from the reproducibility stated by the participant and the repeatability in Eq. (A2) found at the PTB.

$$v_{k,j} = \frac{\Phi_{k,j}^{(\mathrm{i})} + \Phi_{k,j}^{(\mathrm{r})}}{2 \cdot \Phi_{k,j}^{(0)}} \qquad u_{\mathrm{rel}}^2\left(v_{k,j}\right) = \left(\frac{\Phi_{k,j}^{(\mathrm{i})} - \Phi_{k,j}^{(\mathrm{r})}}{\Phi_{k,j}^{(\mathrm{i})} + \Phi_{k,j}^{(\mathrm{r})}}\right)^2 + u_{\mathrm{rel}}^2\left(\Phi_{k,j}^{(0)}\right) \tag{A3}$$

All lamp ratios determined of one participant are averaged to the batch ratio v_k with a related relative variance taken as squared uncertainty $u_{\mathrm{rel}}^2(v_k)$ of the mean.

$$v_k = \frac{1}{n_k}\sum_{j=1}^{n_k} v_{k,j} \qquad u_{\mathrm{rel}}^2(v_k) = \frac{1}{(n_k - 1)\cdot n_k}\sum_{j=1}^{n_k}\left(v_{k,j} - v_k\right)^2 \tag{A4}$$

A 2 Measurement Uncertainties

The uncertainty statement of the participants was divided into two parts dealing with the uncertainty of:

- the realization, including the maintenance since that time $u_{\mathrm{rel}}(\mathrm{unit})$,
- the transfer of the maintained unit to the pilot laboratory $u_{\mathrm{rel}}(\mathrm{transfer})$.

Similarly, at the pilot laboratory, two sources of uncertainty have to be regarded:

- the homogeneity of a batch of lamps of a participant $u_{\mathrm{rel}}(\mathrm{homog.})$,
- the stability or repeatability of measurements at the laboratory $u_{\mathrm{rel}}(\mathrm{PTB})$.

The homogeneity is calculated individually for each batch of a participant according to Eq. (A4) and the repeatability is found as a type B uncertainty from the results of the photometer used and the stability found with the batches of monitor lamps, it is stated as relative expanded uncertainty in the following equation.

$$U(\text{batch}) \equiv U_{\text{rel}}(\text{batch}) = k \cdot \sqrt{u_{\text{rel}}^2(\text{unit}) + u_{\text{rel}}^2(\text{transfer}) + u_{\text{rel}}^2(\text{homog.}) + u_{\text{rel}}^2(\text{PTB})} \quad \text{with} \quad k = 2 \qquad \text{(A5)}$$

The relative uncertainties mentioned above and $U(\text{batch})$ are listed in the Tables 4 and 5. The expanded uncertainties $U(\text{batch})$ are also used in Fig. 4 and 5.

The integrating spheres indirect illuminance $E(T)$ of a radiation is in principle characterised by $E(T) = \frac{\Phi(T)}{A_K} \cdot \frac{\rho}{1-\rho}$, where $\Phi(T)$ is the luminous flux of the lamp with the distribution temperature T, A_K is the surface of the integrating sphere and ρ is the reflectance of the paint of the integrating sphere.

This illuminance generates a photocurrent y' of a photometer with responsivity $s_v(T,t)$. Generally the exact values of ρ and A_K are unknown, but they are included in the so called spheres responsivity $s_K(T,t)$. To correct for a possible drift of the spheres responsivity, the time t is included in the list of variables, too.

$$\Phi(T) = \frac{y'}{s_v(T,t)\dfrac{\rho}{A_K(1-\rho)}} = \frac{y'}{s_K(T,t)} \qquad \text{(A6)}$$

To avoid any confusion with luminous intensity symbolised by the character "I", in this report, the lamp current is symbolised by the character "J". Luminous flux Φ, distribution temperature T and lamp voltage U of incandescent lamps vary with the lamp current according to the following equations with the exponents m_Φ, m_T, m_U.

$$\Phi' = \Phi(T) \cdot \left(\frac{J'}{J(T)}\right)^{m_\Phi}; \; T' = T \cdot \left(\frac{J'}{J(T)}\right)^{m_T}; \qquad U' = U \cdot \left(\frac{J'}{J(T)}\right)^{m_U} \qquad \text{(A7)}$$

At the PTB, the readings J of the lamp current are adjusted (or corrected) to exactly match the values $J(T)$ given by the participant, but the lamp current may differ by a factor c_J due to measurement errors (shunt resistance, DVM calibration).

$$J' = c_J \cdot J \qquad \text{(A8)}$$

An ideal integrating sphere would response to different spatial distributions of lamps but identically luminous flux values with exact the same response. Due to the non uniformity reflectance of the integrating sphere these responses are not identically. To minimize this effect the integrating sphere is calibrated by reference lamps of the same type as measured later on. Small differences between reference lamp and lamp under test are considered by an uncertainty of c_{NF}.

$$c_{\text{NF}} = 1 \pm u(c_{\text{NF}}) \qquad \text{(A9)}$$

The responsivity $s_{\mathrm{K}}(T,t)$ of a sphere photometer is constant s_{K} with two correction factors: for a possible drift (linear approach) up to the time t and due to mismatch errors depending on the distribution temperature T (exponent m for the ratio of that distribution temperature and CIE Illuminant A, referenced by T_{A}).

$$s_{\mathrm{K}}(T,t) = s_{\mathrm{K}} \cdot (1 + a \cdot t) \cdot \left(\frac{T}{T_{\mathrm{A}}} \right)^{-m} \tag{A10}$$

The luminous flux Φ' is found by combination of the equations stated above.

$$\Phi' = \frac{y}{s_{\mathrm{K}}} \cdot \frac{c_J^{m_\Phi + m_T \cdot m}}{1 + a \cdot t} \cdot \left(\frac{T}{T_{\mathrm{A}}} \right)^{m} \tag{A11}$$

Due to the arbitrary value of the responsivity, the first factor has an arbitrary value, too, but is constant, while the last term - the photocurrent - is strongly dependent on the luminous flux of the individual lamp. The two more factors in between are for correction purposes having values very close to unity. They are discussed below:

Lamp current: The transfer standards are incandescent lamps with values of the exponents $m_T = 0.7$ and $m_\Phi = 7$ varying for individual lamps by less than 10 % and the combination photometer/integrating sphere used at the PTB have a mismatch index of $|m| \le 0.1$. From these values, the product $m \cdot m_T$ in Eq. (A11) is negligible compared to m_Φ. During the comparison, the equipment (DVM, shunt resistor) at the PTB for the measurement of the lamp current was tested to be stable within 0.01 % - an interval with rectangular probability distribution. Due to the final normalization of all ratios, in the first order, the correction factor c_J cancels out and as second order, the variation of m_Φ has to be regarded. The relative uncertainty of the luminous flux due to the lamp current measurement is calculated from:

$$u_{\mathrm{rel}}(\Phi(c_J)) = \sqrt{\frac{(0.1 \cdot m_\Phi \cdot u_{\mathrm{rel}}(c_J))^2}{12}} = 0.004\ \% . \tag{A12}$$

Distribution temperature: At the PTB, the distribution temperature T of each transfer standard lamp was measured and the mismatch correction was applied. Due to the final normalization, neither the uncertainty of the distribution temperature scale nor the uncertainty of the mismatch index have to be regarded. Calculated as a second order effect for a distribution temperature up to an uncertainty of $|\Delta T| \le 20\ \mathrm{K}$ - an interval with rectangular probability distribution - the luminous flux will be minor affected.

$$u_{\mathrm{rel}}(\Phi(\Delta T)) = \sqrt{\frac{(m \cdot \Delta T / 2856)^2}{12}} = 0.002\ \% . \tag{A13}$$

Drift of photometer: The stability of the sphere photometer (i.e. the stability of the measurement setup for luminous flux at PTB, see Fig. 3) was tested periodically by groups of "monitor lamps". The campaign for the measurement of luminous flux lasted two times for six weeks (interrupted due to a failure of the air conditioner) and a possible change of the sphere photometer was considered by periodically re-calibrations of the integrating sphere. Therefore, no correction for a drift of the photometer was applied, but the limited repeatability of the readings for the monitor lamps has to be taken into account. It is found within the limits stated below (rectangular distribution):

$$u_{\mathrm{rel}}(\Phi(a \cdot t)) = 0.003/\sqrt{3} = 0.17\,\% \qquad \text{(A14)}$$

In Eq. (A11), the luminous flux is calculated from the photocurrent multiplied with a constant factor f_0, having a relative combined uncertainty $u_{\mathrm{rel}}(f_0)$ calculated from the contributions stated above.

$$\Phi = f_0 \cdot y \qquad u_{\mathrm{rel}}(f_0) = 0.17\,\% \qquad \text{(A15)}$$

A 3 The E_{N}-Criterion

The E_{N}-criterion is calculated as the ratio of the absolute value of the relative difference $\Delta x = \left|(x_i - x_{\mathrm{R}})/x_{\mathrm{R}}\right|$ of a luminous flux contribution x_i from the average x_{R} divided by the expanded uncertainty $U(\Delta x)$ of this difference.

$$E_{\mathrm{N}} = \left|\frac{\Delta x}{U(\Delta x)}\right| \le 1 \qquad \text{(A16)}$$

A 4 The Birge-Ratio

Assume, a quantity was measured several times $1 \le i \le n$ with values x_i and with associated standard uncertainties u_i then the weighted mean x_{R} is associated with the so called internal uncertainty $u_{\mathrm{int}} = 1\Big/\sqrt{\sum_i (1/u_i)^2}$. The external uncertainty associated with the weighted mean is originated from the individual contributions x_i and their weights and evaluated as $u_{\mathrm{ext}} = \sqrt{\sum_i ((x_i - x_{\mathrm{R}})/u_i)^2 \Big/ \left((n-1)\sum_i (1/u_i)^2\right)}$. The Birge-ratio [6]
$R_{\mathrm{B}} = u_{\mathrm{ext}}/u_{\mathrm{int}} \approx 1$ compares the consistency of internal and external uncertainties.

$$R_{\mathrm{B}} = \frac{u_{\mathrm{ext}}}{u_{\mathrm{int}}} = \sqrt{\frac{\sum_i ((x_i - x_{\mathrm{R}})/u_i)^2}{(n-1)}} \qquad \text{(A18)}$$

Provided the stated uncertainties are too small for the scatter of the weighted contributions, then the Birge-ratio exceeds a value of unity. Thus, the Birge-ratio indicates whether stated uncertainties are realistic.
The Birge-ratio was not applicable for the participants results, their contributions are averaged without weights.
The Birge-ratio was determined for the contributions of the link laboratories as basis for the evaluation of the EURAMET-KRCV. It was found to be less than unity, so the

internal uncertainty multiplied by $k = 2$ is stated as the expanded uncertainty associated with the EURAMET-KRCV.

Annex B

The entries in the highlighted fields of the following tables are thoroughly approved and finally accepted by the participants.

B 1 Data Collected from the Three Link Laboratories

The following 3 Tables document and evaluate all measured data for the lamp-transfer-standards of the three link laboratories. The meaning of the entries is given in chapter 3.2 and the principle equations for the calculations are explained in Annex A.

B 1.1 Link Laboratory PTB

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI:** **PTB**

	A	B	C	D	E	F
1	date	version of draft	mean-values are calculated as:		reference for normalisation is:	
2	**25.2.14**	**DraftA**	**arithmetic**	**mean**		**norm= CCPR-RV**
3						
4			U_L		Φ_L	
5			**NMI / PTB**	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
6			0.99992	1.8E-04	0.9950	5.1E-04
7	Uncertainties of NMI (k=1)		0.99997	9.2E-05	0.9959	7.2E-04
8	$u_{c,rel}(J_L)$	nominal	0.99998	6.1E-05	0.9962	4.4E-04
9	$u_{c,rel}(U_L)$	1.2E-04	0.99996	2.3E-05	0.9956	3.1E-04
10	$u_{c,abs}(T_{NMI})$	20K	0.99992	1.3E-04	0.9966	5.8E-04
11	$u_{c,rel}(\Phi_L)$	5.1E-03	1.00033	5.5E-04	0.9958	2.2E-03
12						
13						
14		**means of participant:**	***1.00001***	***6.4E-05***	***0.9958***	***2.2E-04***
15						
16	**data collection**	***U* / V**	**rel.std.dev.**	**Φ /lm**	**rel.std.dev.**	**burn.time / min**
17		**$U_{L,NMI}$ #1**		**$\Phi_{L,NMI}$ #1**		
18	**lamp number**	**#2**		**#2**		
19	**operation. cond.**	**mean $U_{L,NMI}$**		**mean $I_{L,NMI}$**		
20	**J_L / A**	**$U_{L,NMI}/U_{L,PTB}$ #1**		**$\Phi_{L,NMI}/\Phi_{L,norm}$ #1**		
21	**T_{NMI} / K**	**#2**		**#2**		
22	**warm-up / min**					
23	**T_{PTB} / K**					**Goniophotometer**
24	**$u_{rel}(J_L)$**	**mean ratio U_L**	**ave.rel.std.dev.**	**mean ratio Φ**	**ave.rel.std.dev.**	**total at PTB**
25		105.143		2748.07		
26	**422**	105.143		2748.07		
27	**Cap up - center**	***105.143***	6.1E-08	***2748.07***	0.0E+00	
28	**1.9300**	1.00009	1.2E-06	0.9955	3.6E-04	17
29	**2796**	0.99974	1.1E-06	0.9945	3.6E-04	18
30	**12**					
31	**2800**					212
32	**2.00E-04**	***0.99992***	**1.8E-04**	***0.9950***	**5.1E-04**	**247**
33		106.447		2799.00		
34	**426**	106.447		2799.00		
35	**Cap up - center**	***106.447***	3.8E-07	***2799.00***	0.0E+00	
36	**1.9300**	1.00007	1.7E-06	0.9966	3.6E-04	17
37	**2796**	0.99988	2.5E-06	0.9952	3.6E-04	17
38	**12**					
39	**2804**					169
40	**2.00E-04**	***0.99997***	**9.2E-05**	***0.9959***	**7.2E-04**	**203**
41		105.617		2665.74		
42	**430**	105.617		2665.74		
43	**Cap up - center**	***105.617***	1.3E-07	***2665.74***	0.0E+00	
44	**1.9300**	1.00004	2.4E-06	0.9966	3.6E-04	18
45	**2775**	0.99992	2.7E-06	0.9957	3.6E-04	17
46	**12**					
47	**2780**					187
48	**2.00E-04**	***0.99998***	**6.1E-05**	***0.9962***	**4.4E-04**	**222**
49		107.709		2726.78		
50	**438**	107.709		2726.78		
51	**Cap up - center**	***107.709***	2.0E-07	***2726.78***	0.0E+00	
52	**1.9300**	0.99998	1.5E-06	0.9959	3.6E-04	17
53	**2780**	0.99994	1.0E-06	0.9953	3.6E-04	17
54	**12**					
55	**2784**					94
56	**2.00E-04**	***0.99996***	**2.3E-05**	***0.9956***	**3.1E-04**	**128**
57		106.415		2714.81		
58	**443**	106.415		2714.81		
59	**Cap up - center**	***106.415***	5.5E-08	***2714.81***	0.0E+00	
60	**1.9300**	1.00005	2.7E-07	0.9972	3.6E-04	18
61	**2783**	0.99979	1.6E-07	0.9960	3.6E-04	17
62	**12**					
63	**2784**					84
64	**2.00E-04**	***0.99992***	**1.3E-04**	***0.9966***	**5.8E-04**	**119**
65		27.561		1972.40		
66	**IP2**	27.554		1974.93		
67	**Cap up - center**	***27.558***	1.3E-04	***1973.66***	6.4E-04	
68	**5.5000**	0.99979	1.5E-05	0.9938	1.1E-03	17
69	**2741**	1.00087	1.4E-05	0.9979	1.1E-03	17
70	**12**					
71	**2740**					131
72	**2.00E-04**	***1.00033***	**5.4E-04**	***0.9958***	**2.1E-03**	**165**

B 1.2 Link Laboratory LNE-CNAM

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI: LNE_CNAM**

	A	B	C	D	E	F
1	date	version of draft	mean-values are calculated as:		reference for normalisation is:	
2	**25.2.14**	**DraftA**	**arithmetic mean**		**norm= CCPR-RV**	
3						
4			U_L		Φ_L	
5			NMI / PTB	rel.std.dev.	norm. ratio	rel.std.dev.
6			0.99732	7.0E-04	1.0071	6.5E-04
7	Uncertainties of NMI (k=1)		0.99704	4.2E-04	1.0073	8.8E-04
8	$u_{c,rel}(J_L)$	nominal	0.99678	3.0E-04	1.0075	1.8E-03
9	$u_{c,rel}(U_L)$	2.0E-04	0.99761	3.0E-04	1.0078	2.7E-03
10	$u_{c,abs}(T_{NMI})$	20.0	0.99729	9.9E-05	1.0066	1.1E-03
11	$u_{c,rel}(\Phi_L)$	6.0E-03	0.99724	2.0E-04	1.0078	2.2E-03
12						
13						
14		**means of participant:**	***0.99722***	***1.1E-04***	***1.0074***	***2.0E-04***
15						
16	**data collection**	***U* / V**	**rel.std.dev.**	**Φ /lm**	**rel.std.dev.**	**burn.time / min**
17		$U_{L,NMI}$ #1		$\Phi_{L,NMI}$ #1		
18	**lamp number**	#2		#2		
19	**operation. cond.**	mean $U_{L,NMI}$		mean $I_{L,NMI}$		
20	J_L / A	$U_{L,NMI}/U_{L,PTB}$ #1		$\Phi_{L,NMI}/\Phi_{L,norm}$ #1		
21	T_{NMI} / K	#2		#2		
22	**warm-up / min**					
23	T_{PTB} / K					Goniophotometer
24	$u_{rel}(J_L)$	mean ratio U_L	ave.rel.std.dev.	mean ratio Φ	ave.rel.std.dev.	total at PTB
25		106.850		2872.00		
26	**425**	106.700		2869.00		
27	**Cap up - center**	***106.775***	7.0E-04	***2870.50***	5.2E-04	
28	**1.9200**	0.99733	2.3E-07	1.0075	3.9E-04	17
29	**2819**	0.99731	1.4E-07	1.0067	3.9E-04	17
30	**12**					
31	**2804**					391
32	**2.00E-04**	***0.99732***	**1.4E-05**	***1.0071***	**3.9E-04**	**425**
33		94.980		2400.00		
34	**185**	95.060		2396.00		
35	**Cap up - center**	***95.020***	4.2E-04	***2398.00***	8.3E-04	
36	**1.9994**	0.99704	1.6E-07	1.0075	3.9E-04	17
37	**2788**	0.99704	2.9E-07	1.0070	3.9E-04	17
38	**12**					
39	**2748**					100
40	**2.00E-04**	***0.99704***	**2.6E-06**	***1.0073***	**2.8E-04**	**134**
41		101.720		2566.00		
42	**428**	101.780		2575.00		
43	**Cap up - center**	***101.750***	2.9E-04	***2570.50***	1.8E-03	
44	**1.9200**	0.99680	5.1E-07	1.0081	3.9E-04	17
45	**2782**	0.99677	2.3E-07	1.0070	3.9E-04	17
46	**12**					
47	**2768**					95
48	**2.00E-04**	***0.99678***	**1.5E-05**	***1.0075***	**5.5E-04**	**129**
49		98.640		2394.00		
50	**421**	98.580		2407.00		
51	**Cap up - center**	***98.610***	3.0E-04	***2400.50***	2.7E-03	
52	**1.9200**	0.99762	1.5E-07	1.0081	3.9E-04	17
53	**2774**	0.99761	1.6E-06	1.0076	3.9E-04	17
54	**12**					
55	**2756**					98
56	**2.00E-04**	***0.99761***	**4.0E-06**	***1.0078***	**2.9E-04**	**132**
57		101.860		2550.00		
58	**423**	101.880		2555.00		
59	**Cap up - center**	***101.870***	9.8E-05	***2552.50***	9.8E-04	
60	**1.9200**	0.99730	3.2E-07	1.0071	3.9E-04	17
61	**2783**	0.99728	1.2E-07	1.0060	3.9E-04	17
62	**12**					
63	**2768**					94
64	**2.00E-04**	***0.99729***	**1.2E-05**	***1.0066***	**5.5E-04**	**128**
65		102.170		2539.00		
66	**429**	102.210		2550.00		
67	**Cap up - center**	***102.190***	2.0E-04	***2544.50***	2.2E-03	
68	**1.9200**	0.99725	3.3E-07	1.0084	3.9E-04	18
69	**2779**	0.99723	1.5E-07	1.0072	3.9E-04	17
70	**12**					
71	**2764**					95
72	**2.00E-04**	***0.99724***	**9.8E-06**	***1.0078***	**6.1E-04**	**130**

B 1.3 Link Laboratory INRIM

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI: INRIM**

A	B	C	D	E	F
date	version of draft	mean-values are calculated as:		reference for normalisation is:	
25.2.14	**DraftA**	**arithmetic mean**		**norm= CCPR-RV**	
		U_L		Φ_L	
		NMI / PTB	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
		1.00041	5.3E-05	0.9991	1.0E-03
Uncertainties of NMI (k=1)		0.99990	6.5E-04	0.9993	1.1E-03
$u_{c,rel}(J_L)$	nominal	1.00010	1.8E-04	0.9987	1.4E-03
$u_{c,rel}(U_L)$	1.1E-05	1.00046	7.5E-05	0.9978	1.2E-03
$u_{c,abs}(T_{NMI})$	9.0	1.00044	1.6E-04	0.9980	1.0E-03
$u_{c,rel}(\Phi_L)$	6.9E-03	1.00068	2.2E-04	0.9996	1.5E-03
	means of participant:	***1.00033***	***1.1E-04***	***0.9987***	***3.0E-04***

data collection	U / V	**rel.std.dev.**	Φ /lm	**rel.std.dev.**	**burn.time / min**
	$U_{L,NMI}$ #1		$\Phi_{L,NMI}$ #1		
lamp number	#2		#2		
operation. cond.	mean $U_{L,NMI}$		mean $\Phi_{L,NMI}$		
J_L / A	$U_{L,NMI}/U_{L,PTB}$ #1		$\Phi_{L,NMI}/\Phi_{L,norm}$ #1		
T_{NMI} / K	#2		#2		
warm-up / min					
T_{PTB} / K					Goniophotometer
$u_{rel}(J_L)$	mean ratio U_L	**ave.rel.std.dev.**	mean ratio Φ	**ave.rel.std.dev.**	**total at PTB**
	85.045		1897.00		
P359	85.036		1897.00		
Cap up - center	***85.041***	5.3E-05	***1897.00***	0.0E+00	
1.9060	1.00042	1.4E-06	1.0001	4.7E-04	17
2744	1.00041	7.9E-07	0.9981	4.7E-04	24
20					
2728					266
2.00E-04	***1.00041***	**4.1E-06**	***0.9991***	**1.0E-03**	**307**
	86.634		1959.00		
P361	86.522		1960.00		
Cap up - center	***86.578***	6.5E-04	***1959.50***	2.6E-04	
1.9150	0.99992	7.5E-07	1.0004	4.7E-04	17
2750	0.99989	1.4E-07	0.9982	4.7E-04	17
20					
2736					96
2.00E-04	***0.99990***	**1.3E-05**	***0.9993***	**1.1E-03**	**130**
	88.773		1939.00		
P363	88.741		1937.00		
Cap up - center	***88.757***	1.8E-04	***1938.00***	5.2E-04	
1.8770	1.00014	5.0E-07	1.0000	4.7E-04	17
2740	1.00007	4.7E-07	0.9974	4.7E-04	17
20					
2724					183
2.00E-04	***1.00010***	**3.5E-05**	***0.9987***	**1.3E-03**	**217**
	87.585		1955.00		
P364	87.598		1953.00		
Cap up - center	***87.592***	7.4E-05	***1954.00***	5.1E-04	
1.9070	1.00048	8.5E-07	0.9989	4.7E-04	17
2753	1.00045	2.2E-06	0.9967	4.7E-04	17
20					
2732					169
2.00E-04	***1.00046***	**1.2E-05**	***0.9978***	**1.1E-03**	**203**
	89.779		2027.00		
P368	89.808		2026.00		
Cap up - center	***89.794***	1.6E-04	***2026.50***	2.5E-04	
1.8940	1.00045	3.9E-06	0.9990	4.7E-04	17
2754	1.00044	1.0E-06	0.9970	4.7E-04	17
12					
2736					94
2.00E-04	***1.00044***	**3.9E-06**	***0.9980***	**9.8E-04**	**128**
	88.217		1942.00		
P371	88.255		1940.00		
Cap up - center	***88.236***	2.2E-04	***1941.00***	5.2E-04	
1.8850	1.00068	8.4E-07	1.0010	4.7E-04	17
2747	1.00067	2.7E-07	0.9983	4.7E-04	17
20					
2728					253
2.00E-04	***1.00068***	**1.7E-06**	***0.9996***	**1.4E-03**	**287**

B 2 Data Collected from the Nine Participating NMIs

B 2.1 NMI Laboratory BIM

Luminous Flux KC: *EURAMET.PR-K4* NMI: **BIM**

	A	B	C	D	E	F
1	date	version of draft	mean-values are calculated as:		reference for normalisation is:	
2	**25.2.14**	**DraftA**	**arithmetic mean**		**norm= CCPR-RV**	
3						
4			U_L		Φ_L	
5			**NMI / PTB**	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
6			0.99931	1.2E-03	0.9894	5.7E-04
7	Uncertainties of NMI (k=1)		1.00033	2.6E-04	0.9945	3.3E-04
8	$u_{c,rel}(J_L)$	nominal	1.00043	5.0E-04	0.9859	9.1E-04
9	$u_{c,rel}(U_L)$	1.5E-04	1.00019	6.5E-04	0.9899	4.1E-04
10	$u_{c,abs}(T_{NMI})$	8.7				
11	$u_{c,rel}(\Phi_L)$	1.3E-02				
12						
13						
14		**means of participant:**	***1.00007***	***2.6E-04***	***0.9899***	***1.8E-03***
15						

	A	B	C	D	E	F
16	**data collection**	***U* / V**	**rel.std.dev.**	**Φ /lm**	**rel.std.dev.**	**burn.time / min**
17		$U_{L,NMI}$ #1		$\Phi_{L,NMI}$ #1		
18	**lamp number**	#2		#2		
19	**operation. cond.**	mean $U_{L,NMI}$		mean $\Phi_{L,NMI}$		
20	J_L / A	$U_{L,NMI}/U_{L,PTB}$ #1		$\Phi_{L,NMI}/\Phi_{L,norm}$ #1		
21	T_{NMI} / K	#2		#2		
22	**warm-up / min**					
23	T_{PTB} / K					Goniophotometer
24	$u_{rel}(J_L)$	mean ratio U_L	ave.rel.std.dev.	mean ratio Φ	ave.rel.std.dev.	total at PTB
25		100.360		1100.09		
26	**1**	100.610		1098.91		
27	**Cap up - center**	***100.485***	1.2E-03	***1099.50***	5.4E-04	
28	**0.8965**	0.99932	8.9E-07	0.9896	1.0E-03	21
29	**2795**	0.99930	3.6E-07	0.9892	1.0E-03	35
30	**12**					
31	**2764**					301
32	**2.00E-04**	***0.99931***	**1.3E-05**	***0.9894***	**1.9E-04**	**357**
33		100.700		1100.08		
34	**2**	100.750		1099.97		
35	**Cap up - center**	***100.725***	2.5E-04	***1100.03***	5.0E-05	
36	**0.8955**	1.00039	9.3E-07	0.9948	1.0E-03	17
37	**2795**	1.00026	1.4E-06	0.9941	1.0E-03	34
38	**12**					
39	**2760**					100
40	**2.00E-04**	***1.00033***	**6.5E-05**	***0.9945***	**3.3E-04**	**151**
41		100.670		1094.69		
42	**3**	100.770		1092.71		
43	**Cap up - center**	***100.720***	5.0E-04	***1093.70***	9.1E-04	
44	**0.8895**	1.00046	5.8E-07	0.9860	1.0E-03	17
45	**2795**	1.00041	5.0E-07	0.9859	1.0E-03	34
46	**12**					
47	**2764**					95
48	**2.00E-04**	***1.00043***	**2.4E-05**	***0.9859***	**3.6E-05**	**146**
49		100.470		1097.36		
50	**4**	100.600		1096.61		
51	**Cap up - center**	***100.535***	6.5E-04	***1096.99***	3.4E-04	
52	**0.8945**	1.00021	8.1E-07	0.9901	1.0E-03	18
53	**2795**	1.00017	4.3E-07	0.9896	1.0E-03	34
54	**12**					
55	**2760**					94
56	**2.00E-04**	***1.00019***	**1.8E-05**	***0.9899***	**2.3E-04**	**146**

B 2.2 NMI Laboratory SP

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI:** **SP**

	A	B	C	D	E	F
1	date	version of draft	mean-values are calculated as:		reference for normalisation is:	
2	**25.2.14**	**DraftA**	**arithmetic**	**mean**	**norm=**	**CCPR-RV**
3						
4			U_L		Φ_L	
5			**NMI / PTB**	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
6			1.00027	5.6E-04	0.9999	2.3E-03
7	Uncertainties of NMI (k=1)		1.00043	3.7E-04	1.0005	1.8E-03
8	$u_{c,rel}(J_L)$	nominal				
9	$u_{c,rel}(U_L)$	1.0E-03				
10	$u_{c,abs}(T_{NMI})$	100.0				
11	$u_{c,rel}(\Phi_L)$	6.3E-03				
12						
13						
14		**means of participant:**	***1.00035***	***8.0E-05***	***1.0002***	***3.1E-04***
15						
16	**data collection**	**U / V**	**rel.std.dev.**	**Φ /lm**	**rel.std.dev.**	**burn.time / min**
17		**$U_{L,NMI}$ #1**		**$\Phi_{L,NMI}$ #1**		
18	**lamp number**	**#2**		**#2**		
19	**operation. cond.**	**mean $U_{L,NMI}$**		**mean $\Phi_{L,NMI}$**		
20	**J_L / A**	**$U_{L,NMI}/U_{L,PTB}$ #1**		**$\Phi_{L,NMI}/\Phi_{L,norm}$ #1**		
21	**T_{NMI} / K**	**#2**		**#2**		
22	**warm-up / min**					
23	**T_{PTB} / K**					**Goniophotometer**
24	**$u_{rel}(J_L)$**	**mean ratio U_L**	**ave.rel.std.dev.**	**mean ratio Φ**	**ave.rel.std.dev.**	**total at PTB**
25		97.760		3180.40		
26	**88:1**	97.870		3166.60		
27	**Cap up + center**	***97.815***	5.6E-04	***3173.50***	2.2E-03	
28	**2.0400**	1.00031	4.1E-07	1.0006	5.1E-04	17
29	**2870**	1.00023	1.5E-07	0.9992	5.1E-04	17
30	**15**					
31	**2880**					181
32	**2.00E-04**	***1.00027***	**4.0E-05**	***0.9999***	**6.9E-04**	**215**
33		94.630		2996.30		
34	**90:1**	94.700		2986.30		
35	**Cap up + center**	***94.665***	3.7E-04	***2991.30***	1.7E-03	
36	**2.0400**	1.00039	4.0E-07	1.0013	5.1E-04	17
37	**2840**	1.00047	1.8E-07	0.9998	5.1E-04	17
38	**15**					
39	**2868**					139
40	**2.00E-04**	***1.00043***	**4.2E-05**	***1.0005***	**7.5E-04**	**173**

B 2.3 NMI Laboratory BEV

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI:** **BEV**

A	B	C	D	E	F
date	version of draft	mean-values are calculated as:		reference for normalisation is:	
25.2.14	**DraftA**	**arithmetic**	**mean**	**norm=**	**CCPR-RV**

A	B	C	D	E	F
		U_L		Φ_L	
		NMI / PTB	rel.std.dev.	norm. ratio	rel.std.dev.
		1.00215	4.2E-04	0.9938	2.8E-03
Uncertainties of NMI (k=1)		1.00086	7.6E-04	0.9926	1.5E-03
$u_{c,rel}(J_L)$	nominal	1.00007	4.0E-04	0.9912	1.7E-03
$u_{c,rel}(U_L)$	1.0E-03	1.00041	2.5E-04	0.9904	5.0E-04
$u_{c,abs}(T_{NMI})$					
$u_{c,rel}(\Phi_L)$	6.6E-03				
	means of participant:	***1.00087***	***4.5E-04***	***0.9920***	***7.6E-04***

data collection	U / V	rel.std.dev.	Φ /lm	rel.std.dev.	burn.time / min
	$U_{L,NMI}$ #1		$\Phi_{L,NMI}$ #1		
lamp number	#2		#2		
operation. cond.	mean $U_{L,NMI}$		mean $\Phi_{L,NMI}$		
J_L / A	$U_{L,NMI}$ / $U_{L,PTB}$ #1		$\Phi_{L,NMI}$ / $\Phi_{L,norm}$ #1		
T_{NMI} / K	#2		#2		
warm-up / min					
T_{PTB} / K					Goniophotometer
$u_{rel}(J_L)$	mean ratio U_L	ave.rel.std.dev.	mean ratio Φ	ave.rel.std.dev.	total at PTB
	108.476		2630.98		
401	108.420		2637.48		
Cap up + center	***108.448***	2.6E-04	***2634.23***	1.2E-03	
1.7315	1.00248	9.3E-06	0.9963	4.3E-04	27
2800	1.00182	1.5E-05	0.9913	4.3E-04	17
15					
2784					291
2.00E-04	***1.00215***	**3.3E-04**	***0.9938***	**2.5E-03**	**335**
	109.445		2568.23		
404	109.350		2563.28		
Cap up + center	***109.398***	4.4E-04	***2565.75***	9.6E-04	
1.6647	1.00024	7.4E-06	0.9937	4.3E-04	17
2800	1.00148	7.3E-06	0.9915	4.3E-04	17
15					
2784					102
2.00E-04	***1.00086***	**6.2E-04**	***0.9926***	**1.1E-03**	**136**
	109.904		2551.91		
405	109.861		2548.75		
Cap up + center	***109.883***	1.9E-04	***2550.33***	6.2E-04	
1.6672	1.00042	8.1E-06	0.9927	4.3E-04	17
2800	0.99973	5.4E-06	0.9897	4.3E-04	17
15					
2780					187
2.00E-04	***1.00007***	**3.5E-04**	***0.9912***	**1.5E-03**	**221**
	107.552		2602.17		
409	107.536		2599.97		
Cap up + center	***107.544***	7.7E-05	***2601.07***	4.2E-04	
1.7152	1.00017	1.1E-05	0.9901	4.3E-04	17
2800	1.00065	9.3E-06	0.9906	4.3E-04	17
15					
2784					95
2.00E-04	***1.00041***	**2.4E-04**	***0.9904***	**2.7E-04**	**129**

B 2.4 NMI Laboratory VSL

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI:** **VSL**

A	B	C	D	E	F
date	version of draft	mean-values are calculated as:		reference for normalisation is:	
25.2.14	**DraftA**	**arithmetic**	**mean**		**norm= CCPR-RV**
		J_L		Φ_L	
		NMI / PTB	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
		0.99879	9.1E-04	1.0108	1.3E-03
Uncertainties of NMI (k=1)		0.99970	2.6E-05	1.0088	2.3E-03
$u_{c,rel}(U_L)$	nominal	1.00019	2.0E-04	1.0158	4.8E-04
$u_{c,rel}(J_L)$	8.0E-05	0.99976	2.9E-04	1.0128	1.1E-03
$u_{c,abs}(T_{NMI})$					
$u_{c,rel}(\Phi_L)$	4.9E-03				
	means of participant:	***0.99961***	***2.9E-04***	***1.0120***	***1.5E-03***

data collection	J / A	**rel.std.dev.**	Φ /lm	**rel.std.dev.**	**burn.time / min**
	$J_{L,NMI}$ **#1**		$\Phi_{L,NMI}$ **#1**		
lamp number	**#2**		**#2**		
operation. cond.	**mean** $J_{L,NMI}$		**mean** $\Phi_{L,NMI}$		
U_L **/ V**	JL,PTB **#1**		$\Phi_{L,NMI}/\Phi_{L,norm}$ **#1**		
T_{NMI} **/ K**	**#2**		**#2**		
warm-up / min					
T_{PTB} **/ K**					**Goniophotometer**
$u_{rel}(U_L)$	**mean ratio** J_L	**ave.rel.std.dev.**	**mean ratio** Φ	**ave.rel.std.dev.**	**total at PTB**
	5.8914		2923.30		
13	5.9021		2915.50		
Cap up + center	***5.8968***	9.1E-04	***2919.40***	1.3E-03	
30.9800	0.99879	3.9E-06	1.0108	5.3E-04	26
0	0.99879	4.8E-07	1.0107	5.3E-04	17
12					
2840					443
2.00E-04	***0.99879***	**1.7E-06**	***1.0108***	**4.1E-05**	**486**
	5.9197		3064.00		
19	5.9200		3077.70		
Cap up + center	***5.9199***	2.6E-05	***3070.85***	2.2E-03	
30.9720	0.99970	1.0E-05	1.0083	5.3E-04	17
0	0.99970	6.8E-07	1.0093	5.3E-04	17
12					
2868					94
2.00E-04	***0.99970***	**8.4E-07**	***1.0088***	**4.8E-04**	**128**
	0.5123		467.90		
P379	0.5125		467.50		
Cap up + center	***0.5124***	2.0E-04	***467.70***	4.3E-04	
110.0000	1.00018	1.1E-06	1.0156	3.0E-03	18
0	1.00020	1.6E-07	1.0160	3.0E-03	17
12					
2584					473
2.00E-04	***1.00019***	**9.8E-06**	***1.0158***	**2.2E-04**	**508**
	0.5224		588.90		
P485	0.5221		587.60		
Cap up + center	***0.5223***	2.9E-04	***588.25***	1.1E-03	
110.0000	0.99969	6.1E-07	1.0128	3.0E-03	18
0	0.99983	1.3E-07	1.0128	3.0E-03	17
12					
2692					93
2.00E-04	***0.99976***	**6.7E-05**	***1.0128***	**3.1E-05**	**128**

B 2.5 NMI Laboratory CMI

Luminous Flux KC: *EURAMET.PR-K4* **NMI:** **CMI**

A	B	C	D	E	F
date	version of draft	mean-values are calculated as:		reference for normalisation is:	
25.2.14	**DraftA**	**arithmetic mean**		**norm= CCPR-RV**	
		U_L		Φ_L	
		NMI / PTB	rel.std.dev.	norm. ratio	rel.std.dev.
		1.00117	6.1E-04	1.0022	1.7E-03
Uncertainties of NMI (k=1)		0.99979	2.4E-04	1.0017	3.9E-04
$u_{c,rel}(J_L)$	nominal	1.00130	6.3E-04	1.0043	1.0E-03
$u_{c,rel}(U_L)$	1.0E-03	1.00097	4.1E-04	1.0057	7.2E-04
$u_{c,abs}(T_{NMI})$	100.0				
$u_{c,rel}(\Phi_L)$	4.5E-03				
	means of participant:	***1.00081***	***3.5E-04***	***1.0035***	***9.3E-04***

data collection	***U* / V**	**rel.std.dev.**	**Φ /lm**	**rel.std.dev.**	**burn.time / min**
	$U_{L,NMI}$ #1		$\Phi_{L,NMI}$ #1		
lamp number	#2		#2		
operation. cond.	mean $U_{L,NMI}$		mean $\Phi_{L,NMI}$		
J_L / A	$U_{L,NMI}/U_{L,PTB}$ #1		$\Phi_{L,NMI}/\Phi_{L,norm}$ #1		
T_{NMI} / K	#2		#2		
warm-up / min					
T_{PTB} / K					Goniophotometer
$u_{rel}(J_L)$	mean ratio U_L	ave.rel.std.dev.	mean ratio Φ	ave.rel.std.dev.	total at PTB
	108.500		1334.95		
391	108.450		1338.55		
Cap up - center	***108.475***	2.3E-04	***1336.75***	1.3E-03	
0.8822	1.00061	1.2E-05	1.0011	8.1E-04	40
2760	1.00174	1.0E-05	1.0033	8.1E-04	16
10-15					
2792					287
2.00E-04	***1.00117***	**5.6E-04**	***1.0022***	**1.1E-03**	**343**
	108.520		1323.95		
392	108.570		1324.75		
Cap up - center	***108.545***	2.3E-04	***1324.35***	3.0E-04	
0.8821	0.99974	4.9E-06	1.0014	8.1E-04	34
2760	0.99985	1.6E-05	1.0019	8.1E-04	18
10-15					
2788					
2.00E-04	***0.99979***	**5.5E-05**	***1.0017***	**2.4E-04**	**52**
	98.450		3420.55		
E1	98.330		3416.65		
Cap up - center	***98.390***	6.1E-04	***3418.60***	5.7E-04	
2.5290	1.00115	9.7E-06	1.0035	6.5E-04	17
2770	1.00146	1.2E-05	1.0051	6.5E-04	17
12					
2788					346
2.00E-04	***1.00130***	**1.5E-04**	***1.0043***	**8.2E-04**	**380**
	97.680		3395.70		
E2	97.600		3390.90		
Cap up - center	***97.640***	4.1E-04	***3393.30***	7.1E-04	
2.5250	1.00097	1.6E-05	1.0056	6.5E-04	17
2770	1.00096	1.4E-05	1.0058	6.5E-04	17
10-15					
2788					
2.00E-04	***1.00097***	**4.1E-06**	***1.0057***	**1.1E-04**	**34**

B 2.6 NMI Laboratory DMDM

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI:** **DMDM**

Row	A	B	C	D	E	F
1	date	version of draft	mean-values are calculated as:		reference for normalisation is:	
2	**25.2.14**	**DraftA**	**arithmetic mean**		**norm= CCPR-RV**	
3						
4			U_L		Φ_L	
5			**NMI / PTB**	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
6			1.00015	4.0E-04	1.0055	1.3E-03
7	Uncertainties of NMI (k=1)		1.00034	3.0E-04	1.0043	7.6E-04
8	$u_{c,rel}(J_L)$	nominal	1.00072	5.6E-05	1.0044	1.5E-03
9	$u_{c,rel}(U_L)$	1.1E-03	1.00041	2.2E-04	1.0038	7.4E-04
10	$u_{c,abs}(T_{NMI})$	9.0	1.00128	6.8E-04	1.0041	5.5E-04
11	$u_{c,rel}(\Phi_L)$	5.6E-03	1.00201	1.3E-03	1.0040	2.4E-04
12						
13						
14		**means of participant:**	***1.00082***	***2.9E-04***	***1.0043***	***2.4E-04***
15						

Row	A	B	C	D	E	F
16	**data collection**	***U* / V**	**rel.std.dev.**	**Φ /lm**	**rel.std.dev.**	**burn.time / min**
17		$U_{L,NMI}$ #1		$\Phi_{L,NMI}$ #1		
18	**lamp number**	#2		#2		
19	**operation. cond.**	mean $U_{L,NMI}$		mean $\Phi_{L,NMI}$		
20	J_L / A	$U_{L,NMI}/U_{L,PTB}$ #1		$\Phi_{L,NMI}/\Phi_{L,norm}$ #1		
21	T_{NMI} / K	#2		#2		
22	**warm-up / min**					
23	T_{PTB} / K					Goniophotometer
24	$u_{rel}(J_L)$	mean ratio U_L	ave.rel.std.dev.	mean ratio Φ	ave.rel.std.dev.	total at PTB

Row	A	B	C	D	E	F
25		29.499		2426.11		
26	**65**	29.523		2430.20		
27	**Cap up - center**	***29.511***	4.0E-04	***2428.16***	8.4E-04	
28	**5.7700**	1.00016	8.7E-06	1.0064	3.7E-04	17
29	**0**	1.00013	6.1E-06	1.0045	3.7E-04	17
30	**12**					
31	**2784**					453
32	**2.00E-04**	***1.00015***	**1.2E-05**	***1.0055***	**9.5E-04**	**487**
33		29.6105		2443.90		
34	**69**	29.6280		2441.40		
35	**Cap up - center**	***29.6193***	3.0E-04	***2442.65***	5.1E-04	
36	**5.7715**	1.00035	1.2E-05	1.0049	3.7E-04	17
37	**0**	1.00033	1.4E-05	1.0037	3.7E-04	17
38	**12**					
39	**2788**					192
40	**2.00E-04**	***1.00034***	**1.2E-05**	***1.0043***	**5.6E-04**	**226**
41		29.6837		2458.55		
42	**66**	29.6870		2464.50		
43	**Cap up - center**	***29.6854***	5.6E-05	***2461.53***	1.2E-03	
44	**5.7890**	1.00072	1.7E-05	1.0053	3.7E-04	17
45	**0**	1.00073	1.5E-05	1.0035	3.7E-04	17
46	**12**					
47	**2788**					252
48	**2.00E-04**	***1.00072***	**3.4E-06**	***1.0044***	**8.9E-04**	**286**
49		29.3975		2450.86		
50	**29**	29.3850		2450.70		
51	**Cap up - center**	***29.3913***	2.1E-04	***2450.78***	3.3E-05	
52	**5.7750**	1.00044	6.9E-06	1.0046	3.7E-04	20
53	**0**	1.00037	1.3E-05	1.0031	3.7E-04	17
54	**12**					
55	**2788**					230
56	**2.00E-04**	***1.00041***	**3.6E-05**	***1.0038***	**7.4E-04**	**267**
57		29.5640		2424.29		
58	**68**	29.5240		2425.90		
59	**Cap up - center**	***29.5440***	6.8E-04	***2425.10***	3.3E-04	
60	**5.7779**	1.00129	4.1E-06	1.0045	3.7E-04	17
61	**0**	1.00127	3.1E-06	1.0036	3.7E-04	17
62	**12**					
63	**2788**					132
64	**2.00E-04**	***1.00128***	**8.5E-06**	***1.0041***	**4.4E-04**	**166**
65		29.6698		2443.22		
66	**70**	29.5940		2444.40		
67	**Cap up - center**	***29.6319***	1.3E-03	***2443.81***	2.4E-04	
68	**5.7730**	1.00201	1.1E-05	1.0040	3.7E-04	34
69	**0**	1.00201	9.9E-06	1.0040	3.7E-04	35
70	**12**					
71	**2788**					98
72	**2.00E-04**	***1.00201***	**0.0E+00**	***1.0040***	**2.1E-06**	**167**

B 2.7 NMI Laboratory GUM

Luminous Flux KC: *EURAMET.PR-K4* **NMI:** **GUM**

	A	B	C	D	E	F
1	date	version of draft	mean-values are calculated as:		reference for normalisation is:	
2	**25.2.14**	**DraftA**	**arithmetic**	**mean**		**norm= CCPR-RV**
3						
4			U_L		Φ_L	
5			**NMI / PTB**	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
6			0.99989	7.2E-04	0.9928	1.4E-03
7	Uncertainties of NMI (k=1)		0.99978	1.1E-03	0.9925	8.2E-04
8	$u_{c,rel}(J_L)$	nominal	0.99928	1.2E-03	0.9919	2.3E-03
9	$u_{c,rel}(U_L)$	2.5E-05	0.99985	7.9E-04	0.9935	1.8E-03
10	$u_{c,abs}(T_{NMI})$					
11	$u_{c,rel}(\Phi_L)$	4.4E-03				
12						
13						
14		**means of participant:**	***0.99970***	***1.4E-04***	***0.9927***	***3.3E-04***
15						
16	**data collection**	***U* / V**	**rel.std.dev.**	**Φ /lm**	**rel.std.dev.**	**burn.time / min**
17		**$U_{L,NMI}$ #1**		**$\Phi_{L,NMI}$ #1**		
18	**lamp number**	**#2**		**#2**		
19	**operation. cond.**	**mean $U_{L,NMI}$**		**mean $\Phi_{L,NMI}$**		
20	**J_L / A**	**$U_{L,NMI}/U_{L,PTB}$ #1**		**$\Phi_{L,NMI}/\Phi_{L,norm}$ #1**		
21	**T_{NMI} / K**	**#2**		**#2**		
22	**warm-up / min**					
23	**T_{PTB} / K**					**Goniophotometer**
24	**$u_{rel}(J_L)$**	**mean ratio U_L**	**ave.rel.std.dev.**	**mean ratio Φ**	**ave.rel.std.dev.**	**total at PTB**
25		95.150		2744.60		
26	**P373**	95.286		2751.70		
27	**Cap up + center**	***95.218***	7.1E-04	***2748.15***	1.3E-03	
28	**1.9961**	0.99997	2.5E-07	0.9933	4.7E-04	16
29	**0**	0.99981	2.8E-07	0.9922	4.7E-04	17
30	**10**					
31	**2840**					180
32	**2.00E-04**	***0.99989***	**7.9E-05**	***0.9928***	**5.1E-04**	**213**
33		98.389		2934.20		
34	**P376**	98.599		2938.80		
35	**Cap up + center**	***98.494***	1.1E-03	***2936.50***	7.8E-04	
36	**2.0072**	0.99982	2.3E-07	0.9928	4.7E-04	17
37	**0**	0.99975	1.7E-07	0.9923	4.7E-04	20
38	**10**					
39	**2848**					236
40	**2.00E-04**	***0.99978***	**3.5E-05**	***0.9925***	**2.5E-04**	**273**
41		94.467		2745.40		
42	**P378**	94.688		2757.90		
43	**Cap up + center**	***94.578***	1.2E-03	***2751.65***	2.3E-03	
44	**1.9920**	0.99929	1.7E-07	0.9923	4.7E-04	18
45	**0**	0.99927	2.1E-07	0.9915	4.7E-04	17
46	**10**					
47	**2836**					30
48	**2.00E-04**	***0.99928***	**1.2E-05**	***0.9919***	**4.1E-04**	**65**
49		96.010		2765.10		
50	**P469**	96.161		2774.60		
51	**Cap up + center**	***96.086***	7.9E-04	***2769.85***	1.7E-03	
52	**2.0026**	0.99989	6.6E-07	0.9939	4.7E-04	16
53	**0**	0.99980	5.4E-07	0.9931	4.7E-04	16
54	**10**					
55	**2828**					
56	**2.00E-04**	***0.99985***	**4.4E-05**	***0.9935***	**4.0E-04**	**32**

B 2.8 NMI Laboratory INM

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI:** **INM**

	A	B	C	D	E	F
1	date	version of draft	mean-values are calculated as:		reference for normalisation is:	
2	**25.2.14**	**DraftA**	**arithmetic**	**mean**	**norm=**	**CCPR-RV**
3						
4			U_L		Φ_L	
5			NMI / PTB	rel.std.dev.	norm. ratio	rel.std.dev.
6			0.99930	9.4E-05	0.9932	1.2E-03
7	Uncertainties of NMI (k=1)		0.99981	1.9E-04	0.9976	1.4E-03
8	$u_{c,rel}(J_L)$	nominal	0.99735	1.1E-03	0.9896	2.0E-03
9	$u_{c,rel}(U_L)$	1.9E-04	0.99970	4.3E-05	0.9911	1.9E-03
10	$u_{c,abs}(T_{NMI})$	30.0	1.00037	4.0E-04	0.9931	1.2E-03
11	$u_{c,rel}(\Phi_L)$	5.9E-03				
12						
13						
14		**means of participant:**	***0.99931***	***5.2E-04***	***0.9929***	***1.4E-03***
15						

	A	B	C	D	E	F
16	**data collection**	***U* / V**	**rel.std.dev.**	***Φ* /lm**	**rel.std.dev.**	**burn.time / min**
17		$U_{L,NMI}$ #1		$\Phi_{L,NMI}$ #1		
18	**lamp number**	#2		#2		
19	**operation. cond.**	mean $U_{L,NMI}$		mean $\Phi_{L,NMI}$		
20	J_L / A	$U_{L,NMI}/U_{L,PTB}$ #1		$\Phi_{L,NMI}/\Phi_{L,norm}$ #1		
21	T_{NMI} / K	#2		#2		
22	**warm-up / min**					
23	T_{PTB} / K					Goniophotometer
24	$u_{rel}(J_L)$	mean ratio U_L	ave.rel.std.dev.	mean ratio Φ	ave.rel.std.dev.	total at PTB
25		106.840		1293.94		
26	**L105**	106.820		1296.99		
27	**Cap up + center**	***106.830***	9.4E-05	***1295.47***	1.2E-03	
28	**0.9198**	0.99931	1.3E-06	0.9929	1.0E-03	18
29	**2800**	0.99930	5.1E-07	0.9934	1.0E-03	17
30	**12**					
31	**2780**					354
32	**2.00E-04**	***0.99930***	**8.0E-06**	***0.9932***	**2.7E-04**	**389**
33		104.690		1196.67		
34	**L107**	104.730		1199.89		
35	**Cap up + center**	***104.710***	1.9E-04	***1198.28***	1.3E-03	
36	**0.9125**	0.99983	4.2E-07	0.9980	1.0E-03	17
37	**2800**	0.99979	5.4E-07	0.9950	1.0E-03	17
38	**12**					
39	**2752**					123
40	**2.00E-04**	***0.99981***	**2.1E-05**	***0.9976***	**4.5E-04**	**157**
41		113.580		800.06		
42	**3-866**	113.490		802.39		
43	**Cap up + center**	***113.535***	4.0E-04	***801.23***	1.5E-03	
44	**0.5387**	0.99633	1.4E-06	0.9881	1.0E-03	17
45	**2800**	0.99836	9.3E-07	0.9910	1.0E-03	17
46	**12**					
47	**2776**					95
48	**2.00E-04**	***0.99735***	**1.0E-03**	***0.9896***	**1.4E-03**	**129**
49		117.800		540.73		
50	**LP8884**	117.810		542.44		
51	**Cap up + center**	***117.805***	4.2E-05	***541.59***	1.6E-03	
52	**0.3764**	0.99970	9.2E-07	0.9921	1.0E-03	17
53	**2800**	0.99998	5.5E-07	0.9901	1.0E-03	18
54	**12**					
55	**2776**					96
56	**2.00E-04**	***0.99970***	**7.6E-06**	***0.9911***	**9.9E-04**	**131**
57		112.360		808.65		
58	**LP8885**	112.450		810.45		
59	**Cap up + center**	***112.405***	4.0E-04	***809.55***	1.1E-03	
60	**0.5566**	1.00037	1.2E-06	0.9936	1.0E-03	17
61	**2800**	1.00038	7.9E-07	0.9925	1.0E-03	17
62	**12**					
63	**2776**					192
64	**2.00E-04**	***1.00037***	**4.0E-06**	***0.9931***	**5.3E-04**	**226**

B 2.9 NMI Laboratory MIKES

Luminous Flux KC: ***EURAMET.PR-K4*** **NMI: MIKES**

A	B	C	D	E	F
date	version of draft	mean-values are calculated as:		reference for normalisation is:	
25.2.14	**DraftA**	**arithmetic mean**		**norm= CCPR-RV**	
		U_L		Φ_L	
		NMI / PTB	**rel.std.dev.**	**norm. ratio**	**rel.std.dev.**
		1.00008	1.5E-04	1.0005	1.2E-03
Uncertainties of NMI (k=1)		0.99977	4.0E-04	0.9977	2.1E-03
$u_{c,rel}(J_L)$	nominal	1.00024	6.7E-05	1.0014	2.8E-04
$u_{c,rel}(U_L)$	3.5E-05	1.00028	3.8E-05	1.0015	6.9E-04
$u_{c,abs}(T_{NMI})$	10				
$u_{c,rel}(\Phi_L)$	2.8E-03				
	means of participant:	***1.00009***	***1.2E-04***	***1.0003***	***8.9E-04***
data collection	U / V	**rel.std.dev.**	Φ /lm	**rel.std.dev.**	**burn.time / min**
	$U_{L,NMI}$ **#1**		$\Phi_{L,NMI}$ **#1**		
lamp number	**#2**		**#2**		
operation. cond.	**mean** $U_{L,NMI}$		**mean** $\Phi_{L,NMI}$		
J_L **/ A**	$U_{L,NMI}/U_{L,PTB}$ **#1**		$\Phi_{L,NMI}/\Phi_{L,norm}$ **#1**		
T_{NMI} **/ K**	**#2**		**#2**		
warm-up / min					
T_{PTB} **/ K**					**Goniophotometer**
$u_{rel}(J_L)$	**mean ratio** U_L	**ave.rel.std.dev.**	**mean ratio** Φ	**ave.rel.std.dev.**	**total at PTB**
	29.323		2206.80		
LMS005	29.314		2201.47		
Cap up - center	***29.319***	1.5E-04	***2204.14***	1.2E-03	
5.7339	1.00009	1.6E-07	1.0004	1.3E-03	34
2715	1.00006	1.3E-07	1.0007	1.3E-03	17
10					
2728					392
2.00E-04	***1.00008***	**1.7E-05**	***1.0005***	**1.6E-04**	**443**
	28.859		2162.80		
LMS9902	28.882		2171.77		
Cap up - center	***28.871***	4.0E-04	***2167.29***	2.1E-03	
5.6690	0.99978	4.5E-07	0.9980	1.3E-03	18
2729	0.99976	3.4E-07	0.9974	1.3E-03	17
10					
2748					182
2.00E-04	***0.99977***	**8.7E-06**	***0.9977***	**3.2E-04**	**217**
	29.600		2307.20		
LMS0004	29.597		2306.06		
Cap up - center	***29.599***	4.9E-05	***2306.63***	2.5E-04	
5.8228	1.00019	1.8E-06	1.0012	1.3E-03	17
2727	1.00028	1.7E-07	1.0015	1.3E-03	17
10					
2736					176
2.00E-04	***1.00024***	**4.6E-05**	***1.0014***	**1.2E-04**	**210**
	30.133		2374.20		
LMS0003	30.135		2377.46		
Cap up - center	***30.134***	3.8E-05	***2375.83***	6.9E-04	
5.8506	1.00028	2.6E-07	1.0015	1.3E-03	17
2724	1.00028	3.8E-07	1.0014	1.3E-03	17
10					
2732					
2.00E-04	***1.00028***	**3.3E-06**	***1.0015***	**5.5E-05**	**34**

Annex C

Technical specifications of the 12 participants.

Technical Specification

of

BEV (Austria)

EURAMET.PR-K4

EURAMET project No 569:
EURAMET.PR-K4: Luminous Flux
Report
BEV, Austria

1 General Remarks

For this comparison the luminous flux of 4 standard lamps is calibrated two times by the participant. Then the lamps are sent to the pilot laboratory for calibration. After return transportation the lamps are again calibrated two times by the participant.

2 Participant Calibration Principle

The BEV uses four luminous flux standard lamps as national standards. These lamps are regularly calibrated by the PTB in Germany. Thus, for luminous flux BEV is fully traceable to PTB (EURAMET Project 811).
For calibration of other standard lamps (working standards), the sensitivity of a photometer in an Ulbricht sphere is calibrated against the national standards.
Immediately afterwards, the luminous flux of working standards can be calibrated against the sphere photometer. Four of these working standards serve as transfer standards for EURAMET.PR-K4.

3 Instrumentation

3.1. National standard lamps

Four Mazda luminous flux standard lamps serve as national standards:

Lamp	Φ /lm	J_0 /A	U /V	T_d /K
406	2622	1,7353	107,435	2800
407	2559	1,6683	108,865	2800
410	2585	1,7160	106,757	2800
412	2603	1,6792	110,122	2800

Table. 1: National standards data

These lamps were last calibrated on 08. 2005. No correction concerning the CCPR key comparison reference value of the last K4 comparison was done.

3.2. Transfer standard lamps

The four transfer standard lamps are also Mazda lamps. All lamps are connected with the plus pole on the middle contact of the E27 socket. The lamp voltage is measured using 4-pole technique directly at the cap. The lamp number is sanded on bottom side of the glass bulb.

Lamp	J_0 /A	U /V	T_d /K
401	1,7315	108,6	2800
404	1,6647	109,3	2800
405	1,6672	109,8	2800
409	1,7152	107,6	2800

Table. 2: Transfer standard data

3.3. Lamp current source

A Heinzinger PTN 125-10 serves as stable current source.

3.4. Lamp current measurement

3.4.1. Shunt

A Norma 0.1 Ohm resistor in an oil bath is used as shunt resistor. The bath temperature is 20±0.05 °C

3.4.2. Digital voltmeter

A Keithley2002 multimeter at the 2 V DC range measures the voltage at the shunt resistor. This voltage is read via the GPIB-port of the instrument with a Labview programme. The lamp current is calculated from the resistance value of the shunt resistor. The lamp voltage is also measured with this device (range 200 V DC). A relay controlled by the same Labview programme switches between the two circuits.

3.5. Photometer

3.5.1. Photometer head

A LMT P 30 SCT photometer head serves as sphere photometer. The flat diffuser has a diameter of 22 mm. The Si-photoelement is temperature stabilized at 35±0.1°C.

3.5.2. Photo-current meter

A LMT I 1000 SD photo-current meter measures the photocurrent (channel A). The photocurrent is read via the GPIB-port of the instrument with the same Labview programme, which reads also the shunt resistor voltage. Immediately before the first and the third calibration of the transfer lamps, the device is zero balanced with the sphere closed.

3.6. Ulbricht Sphere

For this comparison a 1500 mm diameter Ulbricht sphere is used (former BIPM sphere). A baffle to prevent direct lightning of the photometer (100 mm diameter) is positioned right in front of the photometer at a distance of about 300 mm. An auxiliary lamp with a small baffle for assessment of self absorption is positioned at the bottom of the sphere. The geometrical conditions stated in TP_RMO569_F-revised.pdf subsection 2.6.3 concerning the Mazda lamp type are fulfilled.

3.7. Temperature and Humidity

The temperature of the laboratory is stabilized at 24±1 °C. Temperature and relative humidity are measured with a Lufft Opus 10 close to the position of the sphere.

3.8. Operating conditions

The temperature was 24±1 °C and the relative humidity 35±2 %.
For each measurement the lamp current was increased successively at a rate of 0.01 A/s till it reached approximately its nominal value. After about 15 minutes for stabilisation, lamp current, lamp voltage and photocurrent are measured 20 times.
Each time the lamps were measured in the following sequence:
401->406->407->404->405->410->412->409.

4 Measurement and uncertainty model

4.1. Symbols

s	photometer sensitivity
J	lamp current
J_0	nominal lamp current
m	exponent of the lamp current correction depending on lamp type
Φ	luminous flux
Y	photo current
k_1	correction for selfabsorption of the lamp
k_2	correction for spectral mismatch
k_3	correction for spatial nonuniformity, light loss and dust etc.
U	variance, covariance matrix

4.2. Measurement Model

The model equation for the calculation of the sphere photometer sensitivity is:

$$s = \frac{\Phi_n}{Y_n}\left(\frac{J_n}{J_{n,0}}\right)^{m_n}$$

The model equation for the calculation of the transfer standard luminous flux is:

$$\Phi_t = sY_t\left(\frac{J_{t,0}}{J_t}\right)^{m_t}$$

$m_n = m_t = m$ leads to:

$$\Phi_t = \Phi_n \frac{Y_t}{Y_n}\left(\frac{J_n}{J_t}\right)^m \left(\frac{J_{t,0}}{J_{n,0}}\right)^m$$

This model has to be extended with the correction factors:

$$\Phi_t = \Phi_n \frac{Y_t}{Y_n}\left(\frac{J_n}{J_t}\right)^m \left(\frac{J_{t,0}}{J_{n,0}}\right)^m k_1 k_2 k_3$$

The exponent for the lamp current correction for the Mazda lamps is set to: $m = 7$
The correction coefficients are all set to 1: $k_1 = k_2 = k_3 = 1$
According to the use of four national standards, four values of the luminous flux are obtained for each transfer lamp. The final result of the measurement is the weighted mean of these four values.

$$\Phi_{t,final} = \left(1^t U^{-1} 1\right)^{-1} 1^t U^{-1} \Phi$$

where: $\Phi = \begin{pmatrix} \Phi_t\left(\Phi_{n1}, Y_{n1}, J_{n1}, J_{n1,0}\right) \\ \Phi_t\left(\Phi_{n2}, Y_{n2}, J_{n2}, J_{n2,0}\right) \\ \Phi_t\left(\Phi_{n3}, Y_{n3}, J_{n3}, J_{n3,0}\right) \\ \Phi_t\left(\Phi_{n4}, Y_{n4}, J_{n4}, J_{n4,0}\right) \end{pmatrix}$ and $1 = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$.

4.3. Uncertainties

4.3.1. Luminous flux of national standard lamps Φ_n

According to the calibration certificates the uncertainty is 0.31% for all national standard lamps (gauss distributed). The uncertainty due to the drift of the lamp for a burntime of 2 hours is 0.2% (rectangular distributed):

$$u_{rel}\left(\Phi_n\right) = \sqrt{0.31^2 + 0.2^2} = 0.37\%$$

4.3.2. Photo current ratio Y_t/Y_n

Since this is a ratio of values of almost the same order, many sources of uncertainty concerning the photo current measurement cancel out. The sum of the uncertainties due to temperature stability of the silica photoelement, drift between measurements and standard deviation of the mean is estimated to 0.1 % (gauss distributed). Thus:

$$u_{rel}\left(Y_t / Y_n\right) = 0.1\%$$

4.3.3. Lamp current ratio J_n/J_t

Since this is a ratio of values of almost the same order, many sources of uncertainty concerning the lamp current measurement cancel out. Unfortunately, the shunt resistor recently showed some considerable drift of 150 ppm/y, rectangular distributed. All other possible sources of uncertainty are negligible compared to this drift. For the ratio this means:

$$u_{rel}(J_n / J_t) = \sqrt{2} \cdot 0.015\%$$

4.3.4. Lamp current correction exponent m

The uncertainty of the exponent m is estimated to be rectangular distributed:

$$u_{rel}(m) = 3\%$$

4.3.5. Correction for self-absorption of the lamps k_1

Since the national standard lamps and the transfer lamps are of the same type this correction is negligible (k_1=1). The rectangular distributed uncertainty of this correction is estimated to:

$$u_{rel}(k_1) = 0.05\%$$

4.3.6. Spectral mismatch correction k_2

Since the national standard lamps and the transfer lamps are of the same type and the distribution temperature is nearly the same (2800±50 K (CIE A)) this correction is negligible (k_1=1). The rectangular distributed uncertainty of this correction is estimated to:

$$u_{rel}(k_2) = 0.15\%$$

4.3.7. Correction for spatial nonuniformity, lightloss and dust in the sphere etc. k_3

The uncertainty of the correction is estimated to be rectangular distributed:

$$u_{rel}(k_3) = 0.1\%$$

4.3.8. Luminous Flux of transfer standard lamps I_t

The calculation gives:

$$u_{rel}(\Phi_t) = \sqrt{u_{rel}^2(\Phi_n) + u_{rel}^2\left(\frac{Y_t}{Y_n}\right) + m^2 u_{rel}^2\left(\frac{J_n}{J_t}\right) + \ln^2\left(\left(\frac{J_n}{J_t}\frac{J_{t,0}}{J_{n,0}}\right)^m\right) u_{rel}^2(m) + \sum_{i=1}^{3} u_{rel}^2(k_i)}$$

Thus:

$$u_{rel}(\Phi_t) = \sqrt{0.37^2 + 0.10^2 + 0.15^2 + 0.01^2 + 0.05^2 + 0.15^2 + 0.10^2} = 0.45\%$$

4.3.9. Correlations concerning the 4 values for Φ_t and the uncertainty of $\Phi_{t,final}$

The correlations of the four values for I_t are considerable:
All four national standard lamps were calibrated at the same laboratory.
All measurements were done with the same equipment.
All alignments were done by the same person.
etc., etc.

Thus, the correlation coefficient is estimated to 0.9 and the uncertainty matrix is calculated accordingly for the final result of the luminous flux of the transfer standard lamp.

For the calculation of the uncertainty of the final value the matrix may be simplified to:

$$U\left(\Phi_t\right) \approx \frac{\Phi^2_{t,final}}{10000} \begin{pmatrix} 0.45^2 & 0.9\cdot 0.45^2 & 0.9\cdot 0.45^2 & 0.9\cdot 0.45^2 \\ 0.9\cdot 0.45^2 & 0.45^2 & 0.9\cdot 0.45^2 & 0.9\cdot 0.45^2 \\ 0.9\cdot 0.45^2 & 0.9\cdot 0.45^2 & 0.45^2 & 0.9\cdot 0.45^2 \\ 0.9\cdot 0.45^2 & 0.9\cdot 0.45^2 & 0.9\cdot 0.45^2 & 0.45^2 \end{pmatrix}$$

This leads to the uncertainty of the final result of (not including the drift of the transfer standard lamp):

$$u_{rel}\left(\Phi_{t,final}\right) = \sqrt{\left(1^t U^{-1} 1\right)^{-1}} \approx 0.43 \frac{\Phi_{t,final}}{100} = 0.43\%$$

4.3.10. Drift of the transfer standard lamps during the comparison

The drift of the transfer standard lamps over a period of 2 hours is estimated due to experience to 0.5% (rectangular distributed). The drift is due to the stress during transportation and to the burntime of the lamps at the pilot laboratory as well as at the participant laboratory:

$$u_{rel}\left(\Phi_{t,final}\right) \approx \sqrt{0.43^2 + 0.50^2} = 0.66\%$$

5 Results

5.1. Luminous Flux data of transfer standard lamps

Lamp	1. Calibration		2. Calibration	
	Date: 07. 05. 2009 1. Measurement /lm	Date: 08. 05. 2009 2. Measurement /lm	Date: 30.01.2012 3. Measurement /lm	Date: 31.01.2012 4. Measurement /lm
401	2632	2633	2636	2636
404	2564	2567	2562	2560
405	2548	2550	2548	2547
409	2602	2601	2598	2598

Table. 3: Luminous Flux values

The expanded relative uncertainty (k=2) of these values is:

$$U_{rel}\left(\Phi_{t,\text{final}}\right) \approx 2 \cdot \sqrt{0.43^2 + 0.50^2} = 1.3\%$$

This was also checked with a Monte Carlo simulation.
According to recent BIPM guides concerning the calculation of key comparison reference values, this result must not contribute to the reference value, since BEV is fully traceable to PTB.

6 Appendix

6.1. Measured lamp currents and lamp voltages

Lamp	1. Calibration							
	Date: 07. 05. 2009 1. Measurement				Date: 08. 05. 2009 2. Measurement			
	J /A	s(J) /A	U /V	s(U) /V	J /A	s(J) /A	U /V	s(U) /V
401	1,73200	0,00002	108,5988	0,0018	1,73200	0,00001	108,4781	0,0014
404	1,66381	0,00002	109,2791	0,0091	1,66382	0,00002	109,3789	0,0053
405	1,66626	0,00002	109,7898	0,0015	1,66624	0,00002	109,7680	0,0019
409	1,71499	0,00002	107,5504	0,0012	1,71497	0,00002	107,4987	0,0012

Table 4.: Lamp currents and lamp voltages at the 1. calibration ("s" stands for standard deviation of the mean).

Lamp	2. Calibration							
	Date: 30.01.2012 3. Measurement				Date: 4. Measurement			
	J /A	s(J) /A	U /V	s(U) /V	J /A	s(J) /A	U /V	s(U) /V
401	1,73063	0,00003	108,2412	0,0011	1,73140	0,00002	108,4775	0,0011
404	1,66366	0,00003	109,1428	0,0013	1,66426	0,00005	109,3624	0,0094
405	1,66638	0,00002	109,7404	0,0012	1,66720	0,00002	109,8342	0,0008
409	1,71427	0,00005	107,4089	0,0008	1,71483	0,00002	107,4995	0,0010

Table 5.: Lamp currents and lamp voltages at the 2. calibration ("s" stands for standard deviation of the mean).

6.2. Lamp Drift during Comparison

Lamp	Drift /%
401	0,282
404	0,257
405	0,207
409	0,169

Table 6.: Lamp drifts during comparison

The Lamp drift is calculated due to the following formula:

$$\mathrm{Drift}_{\mathrm{Lamp}} = 200 \frac{\max_i \left(I_{\mathrm{Lamp},i} \right) - \min_i \left(I_{\mathrm{Lamp},i} \right)}{\max_i \left(I_{\mathrm{Lamp},i} \right) + \min_i \left(I_{\mathrm{Lamp},i} \right)}$$

Where the index *i* stands for the four measurements during the comparison.

Operator: Norbert Hörhager-Berl
Laboratory: BEV

Date: 01.02.2012 Signature: N. Hörhager-Berl

Technical Specification

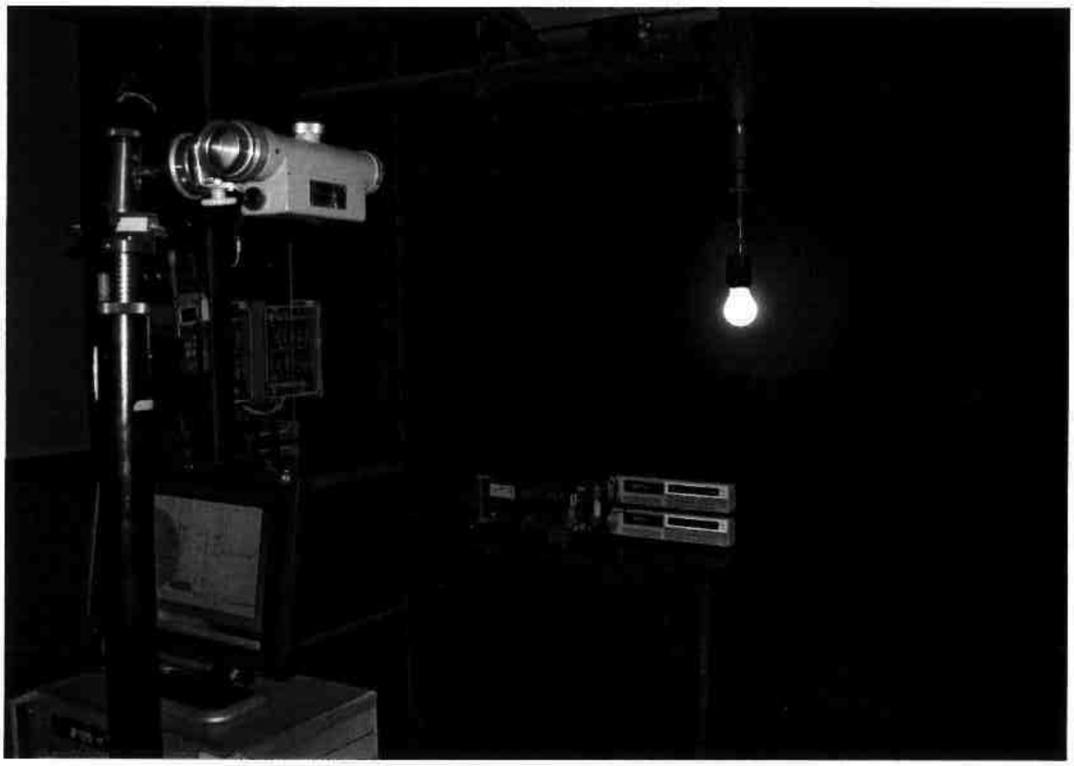
of

BIM (Bulgaria)

EURAMET.PR-K4

BULGARIAN INSTITUTE OF METROLOGY
DIRECTORATE GENERAL
“NATIONAL CENTER OF METROLOGY”
SECTION
"OPTICAL MEASUREMENTS"

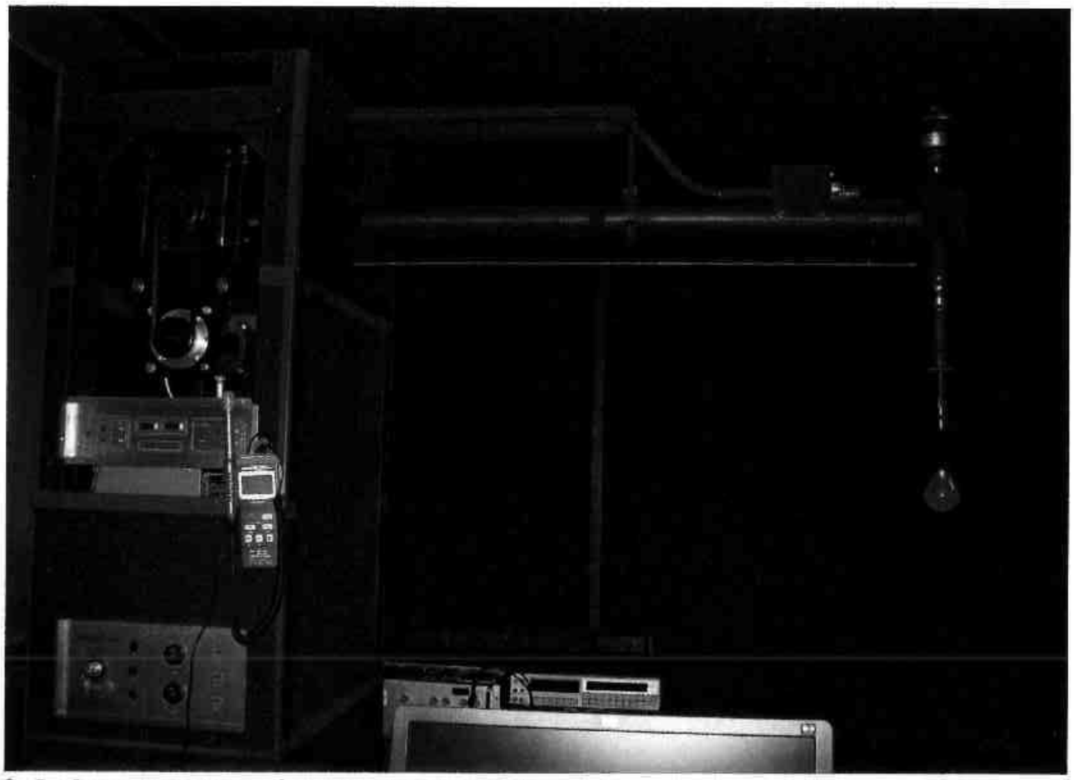
ANNEX G: DESCRIPTION OF THE MEASUREMENT FACILITY



SOFIA, BULGARIA
2008

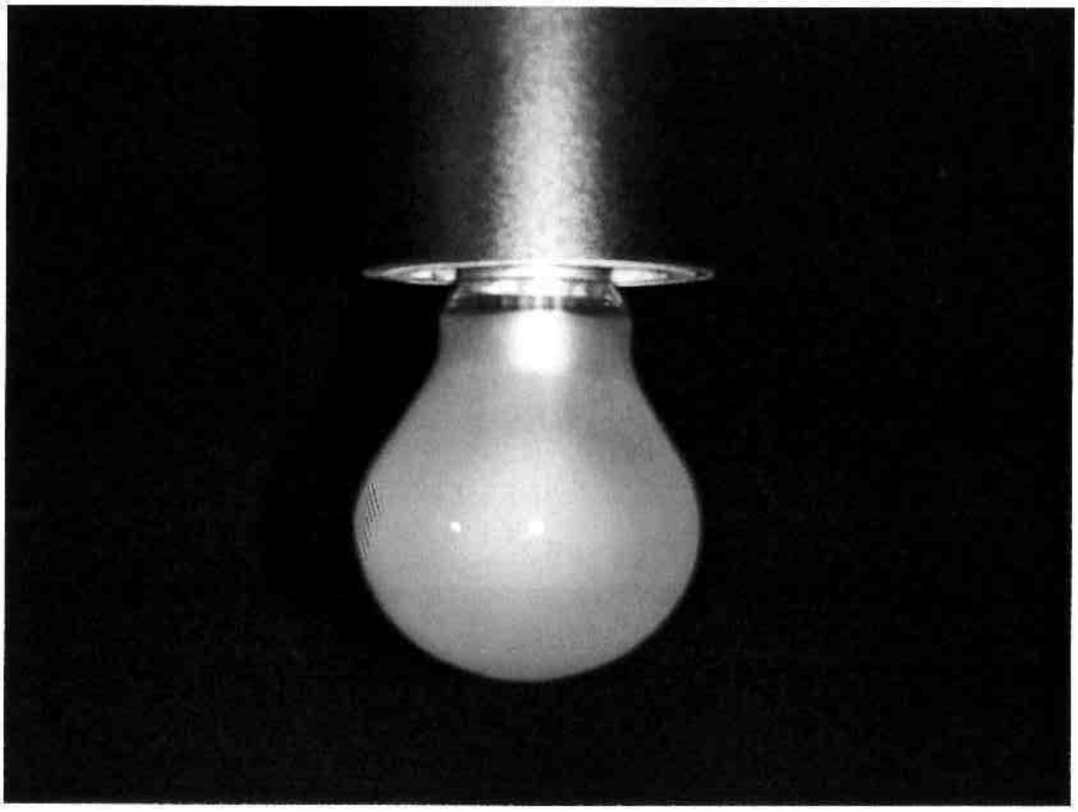
1. Make and type of the photometer:

- **AGP 01** Type standard goniophotometer



2. Laboratory transfer standards used:

Wi5 Type standard incandescent lamps



3. Description of measuring technique

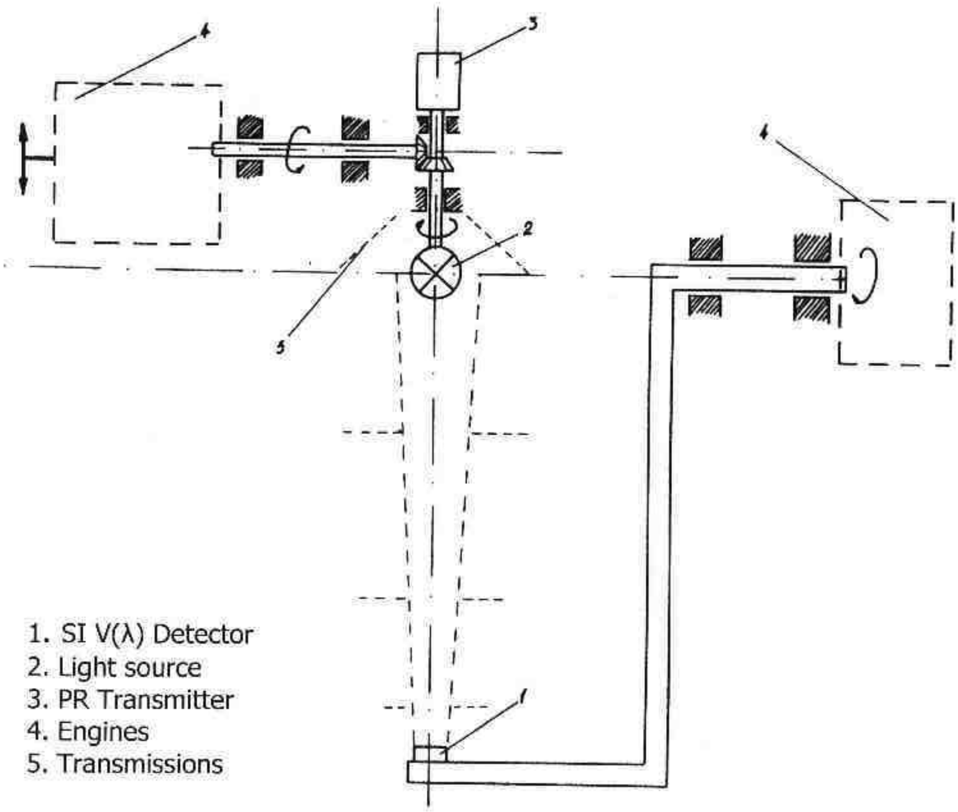
For calibration of standard lamps of luminous flux the following measurement standards and auxiliary equipment are used:

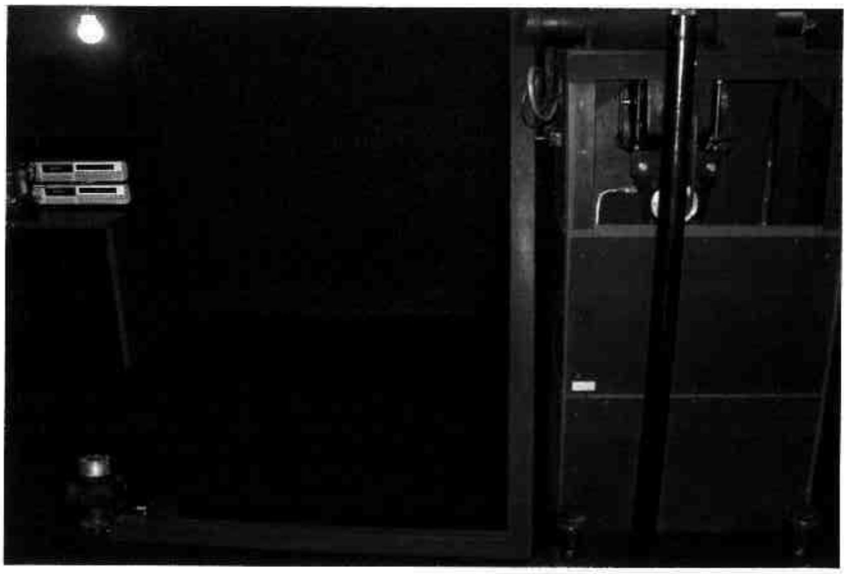
- Standard Goniophotometer with radius R = 1375 mm;

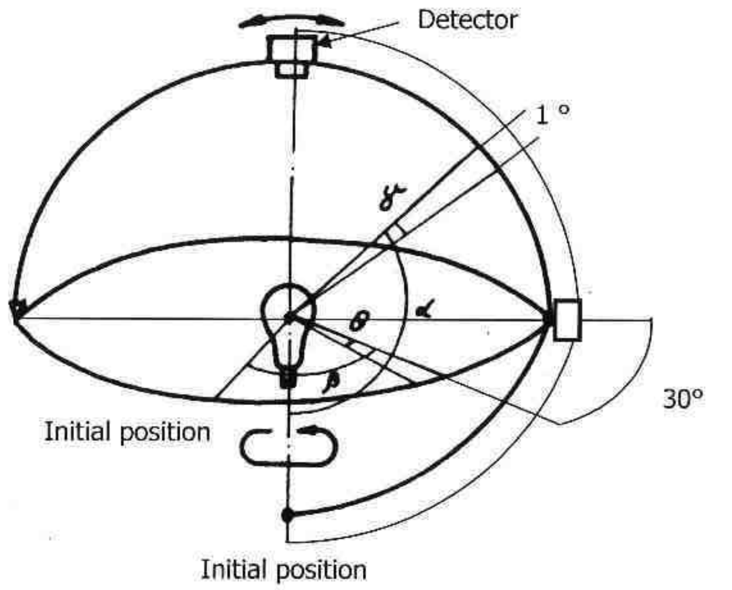
 C plane 2°, 5°, 10°, 20°, 30°, 45°, 90°;

 γ plane 1°, 2°, 5°, 10°;

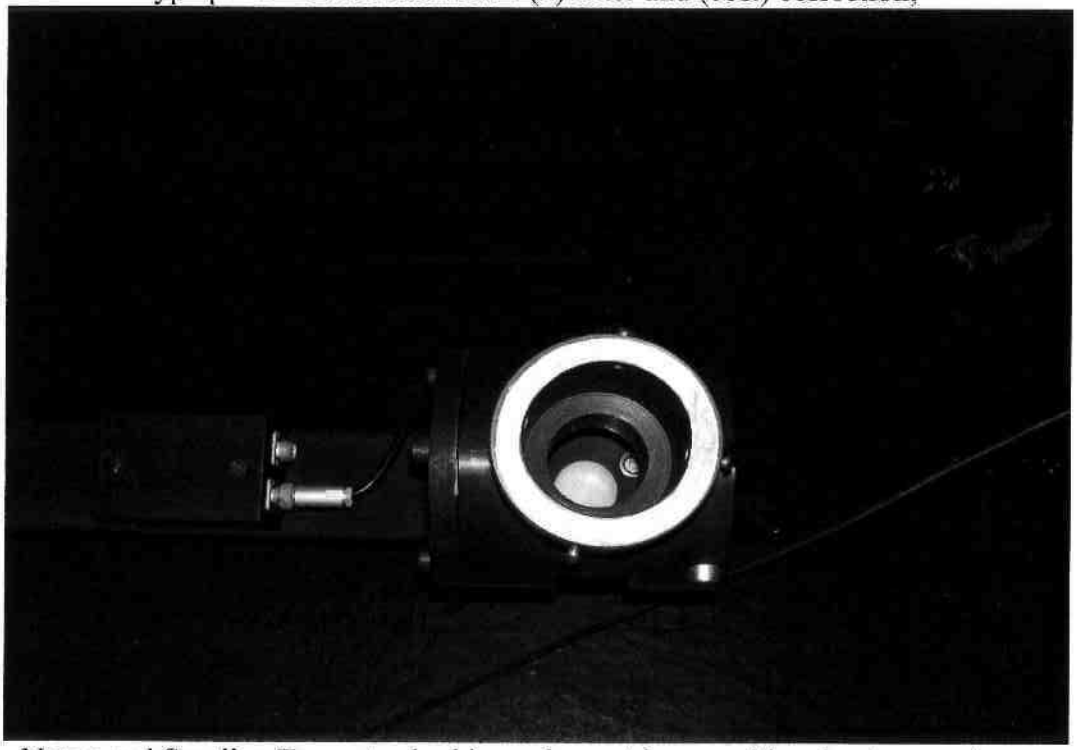
 During measurement process: the speed of arm is 2°/s





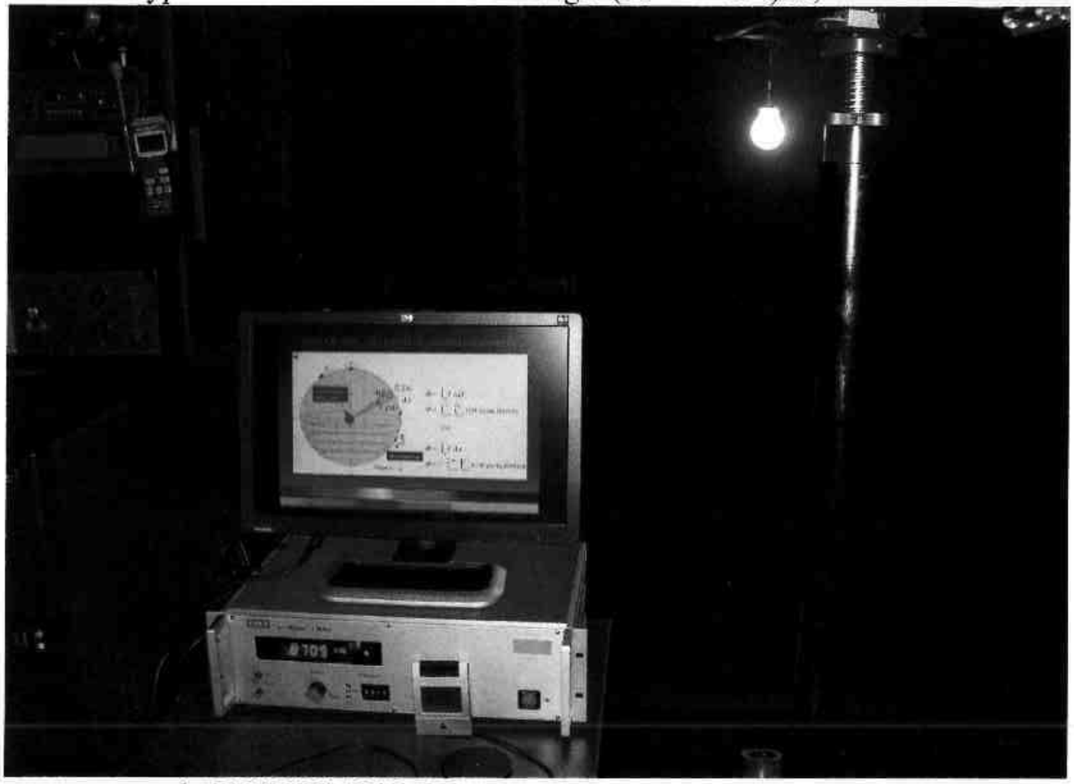


- STC 30 Type photometric head with V(λ) filter and (cos.) correction;

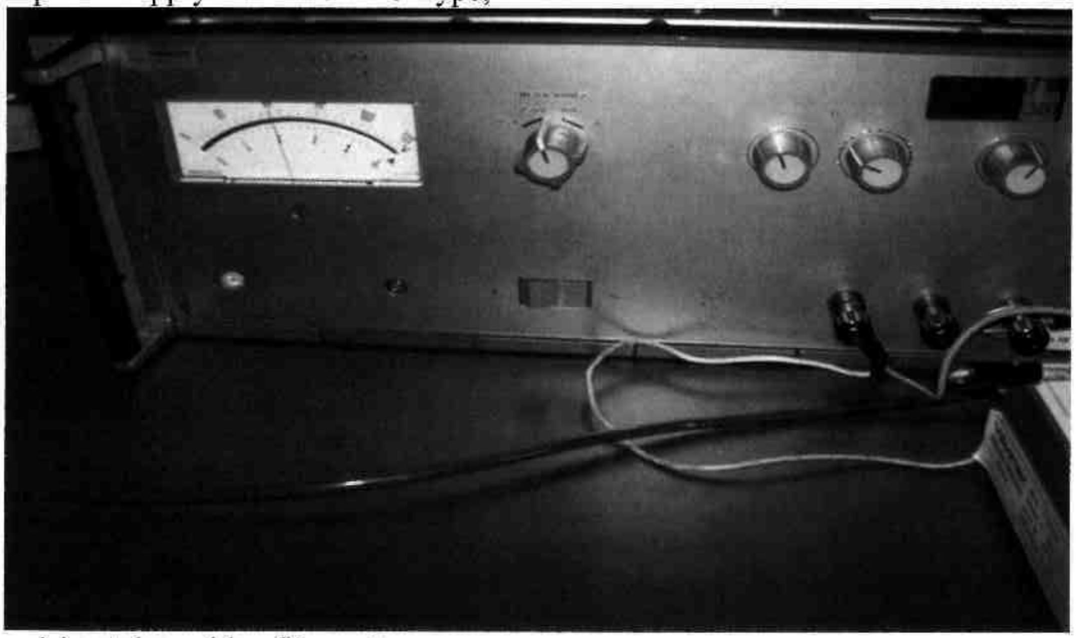


- Narva and Svetlina Type standard incandescent lamps with color temperature 2795 ± 15 K;
- standard resistor "Wavetek 4953" Type, nominal value R = 0,01 Ω and accuracy class 0,01;
- digital voltmeter "Wavetek 1281" Type used for measurement of direct voltage of the lamps into the range - 100 V with a resolution ability of 0,0001 V;
- digital voltmeter "Wavetek 1281" Type used for measurement of direct voltage on the resistor into the range 100 mV with a resolution ability of 0,0001 mV;

- I 1000 Type Photocurrent meter with range: $(10^{-12} \div 10^{-2})$ A;



- power supply PHILIPS 1213 Type;



- vision tubes with a filament cross;
- He-Ne laser for determination of optical center;
- digital thermometer with a measuring range from 0 ℃ to 50 ℃ and 0,5°C accuracy;
- standard length measure – 1 m with a scale resolution - 0.001 m;
- Computer system for ménage of all measurement process. (Motors and all data from all measurement device).

4. Establishment or traceability route of primary scale including date of last realization and breakdown of uncertainty:

Last calibration certificates:

- AGF Type goniophotometer - calibration certificate N 048-OM/BIM – December 2007;
- I 1000 Type Photocurrent meter - calibration certificate - BIM – August 2006;
- Narva ALN N88/4 and Svetlina N23/87 Type standard lamps - calibration certificates N 4562/PTB 07 - March 2007 and N 4563/PTB 07 – March 2007;
- standard resistor "Wavetek 4953" - calibration certificate - BIM – December 2004;
- digital voltmeter "Wavetek 1281" - calibration certificate - BIM – December 2004;
- digital voltmeter "Wavetek 1281" - calibration certificate - BIM – November 2004;
- digital thermometer - calibration certificate - BIM – March 2008;

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

Calibration of the standard lamps for luminous flux is carried out in a photometric laboratory equipped with a photometric bench and standard luminous sources and receivers, where the following conditions shall be observed:

- temperature range during measurement (24 ± 1)° C;
- relative air humidity – (30 ÷ 80) %;
- before switching on the flasks of the standard incandescent lamps shall be cleaned with pure alcohol;
- ceiling and walls are painted with matte black paint, without any access of external light.

6. Operating conditions of the lamps: e.g. geometrical alignment, polarity, stray-light reduction etc.

Lamp position:	- plane, containing optical axis and lamp axis (cap above) is vertical;
Measuring direction:	- angle of rotation of lamp in the horizontal plane from 0° to 360° thru 30°; - angle of rotation of detector in every one vertical plane from 0° to 180°; - angle of scanning of the detector thru 1°; - during of the scanning the speed of arm is 2°/s;
Distance:	- the distance between the surface of the detector and the centre of the filament lamp is 1375 mm;
Power supply:	- constant lamp current, negative polarity at central contact of lamp cap; lamp current as the quantity to be set measurement with 4-pol-socket;
Environment:	- object to be measured freely operated in draught-free air, ambient temperature in the interval (24 ± 1) °C;
Time period:	- warm-up-time > 12 min.

Measurement results of the lamps in section "Optical Measurements"

Lamp type	Lamp No	Lamp current	Lamp voltage	Burning time	Temper. aver.	Distrebution temperature	Measurement results	Uncertu rel.
OSRAM WI5 with Edison cap "E27"	01	0.89646 A	100.36 V	163 min	24.2°C	2795 K	1100.09 lm	1.25 %
	02	0.89546 A	100.70 V	162 min	24.1°C	2795 K	1100.08 lm	1.25 %
	03	0.88947 A	100.67 V	168 min	23.9°C	2795 K	1094.69 lm	1.25 %
	04	0.89446 A	100.47 V	169 min	23.8°C	2795 K	1097.36 lm	1.25 %

Measurements carried out by:

1. Nikolay Alexandrov: ....

2. Natalia Terzieva: ....

Lamp N 01

Imeas. = 0.89700 A **Resistant cor. factor Rf = 1.0006 -True value I = Im/Rf = 0.89646 A**

Average measurement values

I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
0,897	**100,36**	**24,2**	**1,375**	**30**	**1**	**1100,09**

Date: 28/07/2008 Time: 10:15 - 11:10 Tc = 2795 K Burning time = 55 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
1	0,89703	100,368	24,5	1,375	30	1	1100,21

Date: 29/07/2008 Time: 09:42 - 10:35 Tc = 2795 K Burning time = 53 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
2	0,89696	100,352	24,3	1,375	30	1	1099,9

Date: 30/07/2008 Time: 10:11 - 11:06 Tc = 2795 K Burning time = 55 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
3	0,89701	100,36	23,8	1,375	30	1	1100,16

Lamp N 02

Imeas. = 0.89600 A **Resistant cor. factor Rf = 1.0006 -True value I = Im/Rf = 0.89546 A**

Average measurement values

I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
0,896	**100,7**	**24,1**	**1,375**	**30**	**1**	**1100,08**

Date: 28/07/2008 Time: 12:00 - 12:55 Tc = 2795 K Burning time = 55 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
1	0,89601	100,7	24,2	1,375	30	1	1100,04

Date: 29/07/2008 Time: 11:40 - 12:36 Tc = 2795 K Burning time = 56 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
2	0,89597	100,699	24,3	1,375	30	1	1099.8

Date: 30/07/2008 Time: 12:35 - 13:26 Tc = 2795 K Burning time = 51 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
3	0,89602	100,701	23,8	1,375	30	1	1100,12

Lamp N 03

Imeas. = 0.89000 A **Resistant cor. factor Rf = 1.0006** -True value I = Im/Rf = 0.88947 A

Average measurement values

I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
0,89	**100,67**	**23,9**	**1,375**	**30**	**1**	**1094,69**

Date: 28/07/2008 Time: 14:14 - 15:12 Tc = 2795 K Burning time = 58 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
1	0,88998	100,66	24,3	1,375	30	1	1094,59

Date: 29/07/2008 Time: 13:23 - 14:18 Tc = 2795 K Burning time = 55 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
2	0,89006	100,68	23,6	1,375	30	1	1095,01

Date: 30/07/2008 Time: 14:50 - 15:45 Tc = 2795 K Burning time = 55 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
3	0,88996	100,67	23,8	1,375	30	1	1094,47

Lamp N 04

Imeas. = 0.89500 A **Resistant cor. factor Rf = 1.0006 -True value I = Im/Rf = 0.89446 A**

Average measurement values

I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
0,895	**100,47**	**23,8**	**1,375**	**30**	**1**	**1097,36**

Date: 28/07/2008 Time: 16:18 - 17:15 Tc = 2795 K Burning time = 57 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
1	0,895	100,47	24,1	1,375	30	1	1097,74

Date: 29/07/2008 Time: 15:06 - 16:03 Tc = 2795 K Burning time = 57 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
2	0,89503	100,48	23,8	1,375	30	1	1097,36

Date: 30/07/2008 Time: 16:50 - 17:45 Tc = 2795 K Burning time = 55 min

Measurement values

	I(A)	U(V)	T(C)	r(m)	< θ°	< γ°	Φ(lm)
3	0,89497	100,46	23,5	1,375	30	1	1096,98

Annex H: Record of lamp operating time

Lamp: N 01

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
21.07.08	14.50	Current determination, 2795 K	15.40	0.83	N/A, N/T
22.07.08	15.30	Current determination, 2795 K	15.50	0.33	N/A, N/T
28.07.08	10.15	Measure - Luminous Flux	11.10	0.94	N/A, NT
29.07.08	09.42	Measure - Luminous Flux	10.35	0.93	N/A, N/T
30.07.08	10.11	Measure - Luminous Flux	11.06	0.94	N/A, NT

Operator: Nikolay Alexandrov / Natalia Terzieva

Laboratory: BIM

Date: Signature: ……………………………………..

30.07.08

Annex H: Record of lamp operating time

Lamp: N 02

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
21.07.08	15.55	Current determination, 2795 K	16.15	0.33	N/A, N/T
22.07.08	15.57	Current determination, 2795 K	16.12	0.30	N/A, N/T
28.07.08	12.00	Measure - Luminous Flux	12.55	0.94	N/A, NT
29.07.08	11.40	Measure - Luminous Flux	12.32	0.92	N/A, N/T
30.07.08	12.35	Measure - Luminous Flux	13.26	0.93	N/A, NT

Operator: Nikolay Alexandrov / Natalia Terzieva

Laboratory: BIM

Date: Signature: ……………………………………..

30.07.08

Annex H: Record of lamp operating time

Lamp: N 03

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
21.07.08	16.25	Current determination, 2795 K	17.05	0.67	N/A, N/T
22.07.08	16.20	Current determination, 2795 K	16.45	0.42	N/A, N/T
28.07.08	14.14	Measure - Luminous Flux	15.12	0.93	N/A, NT
29.07.08	13.23	Measure - Luminous Flux	14.18	0.94	N/A, N/T
30.07.08	14.50	Measure - Luminous Flux	15.45	0.94	N/A, NT

Operator: Nikolay Alexandrov / Natalia Terzieva

Laboratory: BIM

Date: Signature: ....

30.07.08

Annex H: Record of lamp operating time

Lamp: N 04

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
21.07.08	17.20	Current determination, 2795 K	17.40	0.33	N/A, N/T
22.07.08	16.50	Current determination, 2795 K	17.16	0.43	N/A, N/T
28.07.08	16.18	Measure - Luminous Flux	17.15	0.95	N/A, NT
29.07.08	15.16	Measure - Luminous Flux	16.13	0.95	N/A, N/T
30.07.08	16.50	Measure - Luminous Flux	17.45	0.94	N/A, NT

Operator: Nikolay Alexandrov / Natalia Terzieva

Laboratory: BIM

Date: Signature: ....

30.07.08

PROTOCOL

№ 2.1 / 08.08.2008 г.

Comparison: I N 569 lamp
ser. No 01
Type: Wi5
I = 0,89646 A
U= 100,36 V

Burning time: total 163 min
T = 24,0 ± 1,0 C
H = 45 ± 5 %
Goniophotometer
Type AGP 01, ser. No 01
Tcol. = 2795 K

No	Quantity	Symb.	Value	I(nA) aver.	u(xi)	destibution	Ci	u(xi)c%	u(y)rel %
1	Photometer	V(nA)	1142,2	1143,3	0,857321	normal	0,96313	0,0750587	0,0750587
2	respnsivity	SnA/lx	20,1	1140,9	10,45086	normal	1	0,95	0,95
3	distr.temp..	Tr(K)	2795	1142,4	8,660508	rectangular.	0,03	0,0472353	0,0472353
4	devision amp	Idiv	0,1	1142,2	0,577367	rectangular.	1	0,0505001	0,0505001
5	currentmeter	Vi (V)	0,089646		0,00046	normal	11001	0,4421942	0,453394
6	DVM calibr.	Ci	99,99991		1E-04	normal	11001	0,1000008	
7	shunt-resist.	Ri(Ω)	0,0100059		5,5E-06	normal	11001	0,0055	
8	expon.destr.	mT	0,71		0,081986	rectangular.	0,00896	0,0819861	0,1226034
9	mismatch	m	-0,023		0,026559	rectangular.	0,41312	0,0009974	
10	expon.inten.	mi	7		1,002765	rectangular.	0,24812	0,091153	
11	distance	r (m)	1,375		0,003	rectangular.	1100,1	0,3464235	0,6000231
12	locus lamp	dlc (m)			0,003	rectangular.	1100,1	0,3464235	
13	locus photom	dp (m)		Φ (lm)	0,003	rectangular.	1100,1	0,3464235	
14	amb.temper.	αΔT	0,0007	1100,21	0,000808	rectangular.	1100,1	0,0808298	0,2666314
15	rel.straylight	γstr.	0,05	1099,9	0,057735	rectangular.	1100,1	0,0050499	
16	aging effect	βΔt	0,0022	1100,16	0,00254	rectangular.	1100,1	0,2540341	
Luminous flux		Φ(lm)=	1100,09	1100,09				u rel (%) =	1,2508529

DIM
13.10.08

P R O T O C O L
№ 2.2 / 08.08.2008 г.

Comparison: I N 569 lamp
ser. No 02
Type: Wi5
I = 0,89546 A
U= 100,70 V

Burning time: total 162 min
T = 24,0 ± 1,0 C
H = 45 ± 5 %
Goniophotometer
Type AGP 01, ser. No 01
Tcol. = 2795 K

No	Quantity	Symb.	Value		I(nA)aver.	u(xi)	destibution	Ci	u(xi)c%	u(y)rel %
1	Photometer	V(nA)	1142,2		1142,1	0,815475	normal	0,96312	0,0713952	0,0713952
2	respnsivity	SnA/lx	20,1		1141,1	10,45076	normal	1	0,95	0,95
3	distr.temp..	Tr(K)	2795		1143,4	8,660508	rectangular.	0,03	0,0472357	0,0472357
4	devision amp	Idiv	0,1		1142,2	0,577367	rectangular.	1	0,0505531	0,0505531
5	currentmeter	Vi (V)	0,089546			0,00046	normal	11001	0,4426588	0,4538474
6	DVM calibr.	Ci	99,99991			1E-04	normal	11001	0,1000017	
7	shunt-resist.	Ri(Ω)	0,0100059			5,5E-06	normal	11001	0,0055001	
8	expon.destr.	mT	0,71			0,081986	rectangular.	0,00896	0,0819861	0,122604
9	mismatch	m	-0,023			0,026559	rectangular.	0,41312	0,0009974	
10	expon.inten.	mi	7			1,002765	rectangular.	0,24812	0,0911538	
11	distance	r (m)	1,375			0,003	rectangular.	1100,08	0,3464203	0,6000176
12	locus lamp	dlc (m)				0,003	rectangular.	1100,08	0,3464203	
13	locus photom	dp (m)			Φ (lm)	0,003	rectangular.	1100,08	0,3464203	
14	amb.temper.	αΔT	0,0007		1100,04	0,000808	rectangular.	1100,08	0,080829	0,2666312
15	rel.straylight	γstr.	0,05		1099,8	0,057735	rectangular.	1100,08	0,0050552	
16	aging effect	βΔt	0,0022		1100,4	0,00254	rectangular.	1100,08	0,2540341	
Luminous flux		Φ(lm)=	1100,08		1100,08				u rel (%) =	1,2508024

PROTOCOL

№ 2.3 / 08.08.2008 г.

Comparison: I N 569
lamp
ser. No 03
Type: Wi5
I = 0,88947 A
U= 100,67 V

Burning time: total 168 min
T = 24,0 ± 1,0 C
H = 45 ± 5 %
Goniophotometer
Type AGP 01, ser. No 01
Tcol. = 2795 K

No	Quantity	Symb.	Value	I(nA)aver.	u(xi)	destibution	Ci	u(xi)c%	u(y)rel %
1	Photometer	V(nA)	1136,6	1136,4	0,648074	normal	0,96313	0,0570189	0,0570189
2	respnsivity	SnA/lx	20,1	1137,6	10,39956	normal	1	0,95	0,95
3	distr.temp..	Tr(K)	2795	1135,8	8,660508	rectangular.	0,03	0,0474683	0,0474683
4	devision amp	Idiv	0,1	1136,6	0,577367	rectangular.	1	0,0507977	0,0507977
5	currentmeter	Vi (V)	0,088947		0,00046	normal	10947	0,4426175	0,4538069
6	DVM calibr.	Ci	99,99991		1E-04	normal	10947	0,1000008	
7	shunt-resist.	Ri(Ω)	0,0100059		5,5E-06	normal	10947	0,0055001	
8	expon.destr.	mT	0,71		0,081986	rectangular.	0,00896	0,0819861	0,1229381
9	mismatch	m	-0,023		0,026559	rectangular.	0,41312	0,0010023	
10	expon.inten.	mI	7		1,002765	rectangular.	0,24812	0,0916026	
11	distance	r (m)	1,375		0,003	rectangular.	1094,7	0,3464235	0,6000231
12	locus lamp	dlc (m)			0,003	rectangular.	1094,7	0,3464235	
13	locus photom	dp (m)		Φ (lm)	0,003	rectangular.	1094,7	0,3464235	
14	amb.temper.	αΔT	0,0007	1094,59	0,000808	rectangular.	1094,7	0,0808298	0,2666319
15	rel.straylight	γstr.	0,05	1095,01	0,057735	rectangular.	1094,7	0,0050796	
16	aging effect	βΔt	0,0022	1094,47	0,00254	rectangular.	1094,7	0,2540341	
Luminous flux		Φ (lm)=	1094,69	1094,69				u rel (%) =	1,2501038

PROTOCOL

№ 2.4 / 08.08.2008 г.

Comparison: I N 569
lamp
ser. No 04
Type: Wi5
I = 0,89446 A
U= 100,47 V

Burning time: total 169 min
T = 24,0 ± 1,0 C
H = 45 ± 5 %
Goniophotometer
Type AGP 01, ser. No 01
Tcol. = 2795 K

No	Quantity	Symb.	Value	I(nA)aver.	u(xi)	destibution	Ci	u(xi)c%	u(y)rel %
1	Photometer	$V(nA)$	1139,4	1140,3	0,674537	normal	0,9631	0,0592011	0,0592011
2	respnsivity	SnA/lx	20,1	1139,5	10,42492	normal	1	0,95	0,95
3	distr.temp..	$Tr(K)$	2795	1138,4	8,660508	rectangular.	0,03	0,0473528	0,0473528
4	devision amp	$Idiv$	0,1	1139,4	0,577367	rectangular.	1	0,0506329	0,0506329
5	currentmeter	$Vi\ (V)$	0,089446		0,00046	normal	10974	0,4422694	0,453468
6	DVM calibr.	Ci	99,99991		1E-04	normal	10974	0,1000036	
7	shunt-resist.	$Ri(\Omega)$	0,0100059		5,5E-06	normal	10974	0,0055002	
8	expon.destr.	mT	0,71		0,081986	rectangular.	0,00896	0,0819861	0,1227721
9	mismatch	m	-0,023		0,026559	rectangular.	0,41312	0,0009999	
10	expon.inten.	mi	7		1,002765	rectangular.	0,24812	0,0913798	
11	distance	$r\ (m)$	1,375		0,003	rectangular.	1097,4	0,346433	0,6000395
12	locus lamp	$dlc\ (m)$			0,003	rectangular.	1097,4	0,346433	
13	locus photom	$dp\ (m)$		Φ (lm)	0,003	rectangular.	1097,4	0,346433	
14	amb.temper.	$\alpha\Delta T$	0,0007	1097,74	0,000808	rectangular.	1097,4	0,080832	0,2666323
15	rel.straylight	$\gamma str.$	0,05	1097,36	0,057735	rectangular.	1097,4	0,0050631	
16	aging effect	$\beta\Delta t$	0,0022	1096,98	0,00254	rectangular.	1097,4	0,2540341	
Luminous flux		$\Phi(lm)=$	1097,36	1097,36				u rel (%) =	1,2500628

Technical Specification

of

CMI (Czech Republic)

EURAMET.PR-K4

CMI

EURAMET Key Comparison
Luminous Intensity EURAMET.PR-K4

Finally results I. run

Lamp Number	391	392	E1	E2
1. independent measurement luminous flux [lm]	1335.9	1326.3	3419.1	3398.7
2. independent measurement luminous flux [lm]	1334.0	1321.6	3422.0	3392.7
Uncertainty (k=1) [%]	0.45	0.45	0.45	0.45
Number of measurements	10	10	10	10
current [A]	0.8822	0.8821	2.529	2.525
voltage [V]	108.50	108.52	98.45	97.68
corr. colour temperature [K]	2760	2760	2770	2770

Ambient temperature = 23,6 ± 2 °C

Laboratory: CMI Prague, CZE
Date: 6. 4. 2009

Dr.Ing. Marek Šmíd

Annex G: Description of the measurement facility – Luminous Flux

Make and type of the integrating sphere:

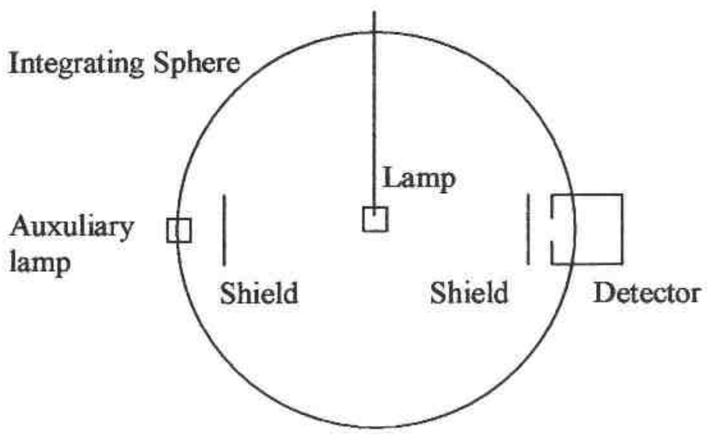
Schmidt Haensch integrating sphere
Diameter: 1,5 m
Photometer Head LMT 60 mm diameter

Laboratory reference standards used:

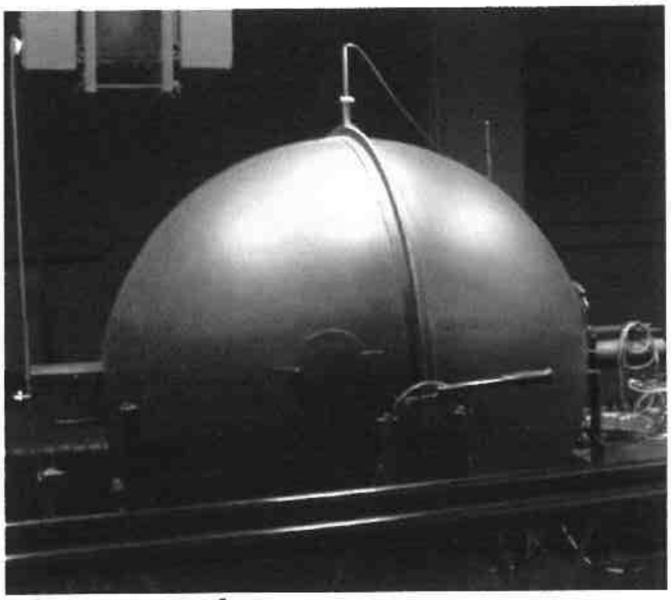
Set of standard lamps.

Description of measuring technique (please include a diagram):

The test and reference lamps are consecutively placed in the center of an integrating sphere photometer. A lamp is operated and two photocurrents for indirect illuminances are measured and corrected for dark-current-offset: one photocurrent when the lamp is operated in thermal equilibrium, and a second photocurrent after the lamp was ramped down and still in place for the light of an auxiliary lamp to correct for self-absorption.
The standard lamps are operated with stabilized current. The two lamp currents are measured with the same shunt resistor and DVM.
The output voltage from photometer is measured by a Keithley 2000 digital multimeter (20 ppm total uncertainty)



Picture 1.: Scheme of measuring setup



Picture 2.: photo of integrating sphere

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

The Standard lamps are traceable directly to the NPL standard lamps with standard uncertainty 0,4% (k=1). Last calibration 2008.

Description of calibration laboratory conditions: e.g. temperature, humidity etc.
Laboratory temperature: 23,6°C ±2°C
Humidity: 45 ± 5 % rsh

Operating conditions of the lamps: e.g. geometrical alignment, polarity, stray-light reduction
Current set to the lamp nominal values, voltage was monitored. The lamp current is monitored through a calibrated shunt resistor. The centre contact of the cap was connected to the negative side of the supply. The lamp orientation was vertical, cap up. Warm up time 10 - 15 min. Four pole wiring - two poles socked.

Operator: M. Smid
Laboratory: Czech Metrology Institute

Date: 6.4.2009 Signature: ……………………………………

EURAMET Key Comparison
Luminous Intensity EURAMET.PR-K4

Finally results II. run

Lamp Number	391	392	E1	E2
1. independent measurement luminous flux [lm]	1336.1	1325.2	3416.6	3386.6
2. independent measurement luminous flux [lm]	1341.0	1324.3	3416.7	3395.2
Uncertainty (k=1) [%]	0.45	0.45	0.45	0.45
Number of measurements	10	10	10	10
current [A]	0.8822	0.8821	2.529	2.525
voltage [V]	108.45	108.57	98.33	97.60
corr. colour temperature [K]	2760	2760	2770	2770

Ambient temperature = 23.5 ± 2 °C

Laboratory: CMI Prague, CZE
Date: 16. 4. 2010

Dr. Marek Šmíd

Annex H: Record of lamp operating time

Lamp: 391

Date	Activity (Test, Alignment, Measure)	Burn Hrs	Operator initials
30.3.09	Measure I. run	0,33	PK
31.3.09	Measure I. run	0,23	PK
8.12.09	Measure II. run	0,33	PK
9.12.09	Measure II. run	0,58	PK

Operator: Kliment

Laboratory: CMI Prague

Date: 10.12.2009 Signature: ....

Annex H: Record of lamp operating time

Lamp: 392

Date	Activity (Test, Alignment, Measure)	Burn Hrs	Operator initials
30.3.09	Measure I. run	0,42	PK
31.3.09	Measure I. run	0,58	PK
8.12.09	Measure II. run	0,32	PK
9.12.09	Measure II. run	0,48	PK

Operator: Kliment

Laboratory: CMI Prague

Date: 10.12.2009 Signature: ....

Annex H: Record of lamp operating time

Lamp: E1

Date	Activity (Test, Alignment, Measure)	Burn Hrs	Operator initials
30.3.09	Measure I. run	0,25	PK
31.3.09	Measure I. run	0,25	PK
8.12.09	Measure II. run	0,57	PK
9.12.09	Measure II. run	0,28	PK

Operator: Kliment

Laboratory: CMI Prague

Date: 10.12.2009 Signature: ....Kliment........

Annex H: Record of lamp operating time

Lamp: E2

Date	Activity (Test, Alignment, Measure)	Burn Hrs	Operator initials
30.3.09	Measure I. run	0,42	PK
31.3.09	Measure I. run	0,33	PK
8.12.09	Measure II. run	0,37	PK
9.12.09	Measure II. run	0,27	PK

Operator: Kliment

Laboratory: CMI Prague

Date: 10.12.2009 Signature: ....

EURAMET.PR-K4, Luminous Flux, Czech Metrology Institute Prague

Lamp E2, 1. independent measurement Uncertainty budget

Model

$$corS1 = \left(1 - \Delta sf_{S1} + \alpha_{S1}\,\Delta T_{aS1} - \gamma_{S1}\,\Delta t_{S1}\right)$$

$$corSR = \left(1 - \Delta sf_{SR} + \alpha_{SR}\,\Delta T_{aSR} - \gamma_{SR}\,\Delta t_{SR}\right)$$

$$\Phi_{CS1} = \Phi_{CSR}\,\frac{y_{KS1}}{y_{KSR}}\,\frac{y_{ASR}}{y_{AS1}}\left(\frac{T_{dC1}}{T_{dCR}}\right)^{m_S}\left(\frac{c_J \cdot U_{JS1}}{R_J \cdot J_{C1}}\right)^{m_S \cdot mT_{S1} - mI_{S1}}\left(\frac{c_J \cdot U_{JSR}}{R_J \cdot J_{CR}}\right)^{-m_S \cdot mT_R + mI_R}\frac{corSR}{corS1}$$

No	Quantity X_i	Symbol	Value x_i	Abs. stand. uncertainty $u(x_i)$	Type	DOF ν_i	Absolute sensitivity c_i	Absolute contribution $u_i(y)$	Relative contribution $u_{rel,i}(y)$
1	amb.temp. difference [°C]	ΔT_{aS1}	0.0	1.0	B	29	0.0007	0.000700	0.000700
2	rel.temp.coeff. [1/K]	α_{S1}	0.0007	0.0004	B	∞	0.0100	0.000004	0.000004
3	sphere response factor	Δsf_{S1}	0.0	0.001200	B	∞	-1.0000	-0.001200	-0.001200
6	rel.aging coeff. [1/h]	γ_{S1}	0.0005	0.0003	B	∞	-0.1700	-0.000051	-0.000051
7	burning time [h]	Δt_{S1}	0.17	0	B	∞			
6	**correction factor source**	$corS1$	**0.9999**			**451**		**0.001390**	**0.0014**
7	amb.temp. difference REF [°C]	ΔT_{aSR}	0.0	1.0	B	29	0.00015	0.0001500	0.000150
8	rel.temp.coeff. REF [1/K]	α_{SR}	0.00015	0.00002	B	∞	0.00000	0.0000000	0.000000
9	sphere response factor REF	Δsf_{SR}	0.0	0.00050	B	∞	-1.00000	-0.0005000	-0.000500
14	rel.aging coeff. REF [1/h]	γ_{SR}	0.0005	0.0003	B	∞	-0.87000	-0.0002610	-0.000261
15	burning time REF [h]	Δt_{SR}	0.87	0	B	∞			
12	**correction factor source REF**	$corSR$	**0.9996**			**6646**		**0.000584**	**0.000584**
13	correction factor source	$corSR$	0.9996	0.000584	A	6646	3388.0984	1.977387	0.000584
14	correction factor photometer	$corS1$	0.9999	0.001390	A	451	-3386.9220	-4.708451	-0.001390
15	luminous flux REF [lm]	Φ_{CSR}	3680.0	14.7	B	∞	0.92028	13.546498	0.004000
16	photometer signal [V]	y_{KS1}	-0.66342	0.00011	A	9	-5104.784	-0.546462	-0.000161
17	photometer signal REF [V]	y_{KSR}	-0.723268	0.000090	A	9	4682.393	0.422565	0.000125
18	photometer auxiliary [V]	y_{AS1}	-1.512430	0.000016	A	9	2239.195	0.035642	0.000011
19	photometer auxiliary REF [V]	y_{ASR}	-1.51691	0.00015	A	9	-2232.581	-0.338880	-0.000100
20	mean value current [V]	U_{JS1}	0.02525718	0.00000041	A	9	-875198.2	-0.355223	-0.000105
21	mean value current REF [V]	U_{JSR}	0.02570999	0.00000054	A	9	859813.3	0.462805	0.000137
22	current intensity exponent	$m\Phi_{S1}$	6.59	0.37	B	∞	-0.96303	-0.356320	-0.000105
23	current intensity exponent REF	$m\Phi_R$	6.58	0.25	B	∞	1.31628	0.329070	0.000097
24	current distrib. temp exponent	mT_{S1}	0.71	0.2	B	∞	0.18184	0.036369	0.000011
25	current distrib. temp exp. REF	mT_R	0.69	0.1	B	∞	-0.10925	-0.010925	-0.000003
26	distrib. temperature source [K]	T_{dC1}	2770	30	B	∞	0.10148	3.044399	0.000899
27	distrib. temperature REF [K]	T_{dCR}	2770	30	B	∞	-0.10148	-3.044429	-0.000899
28	shunt resistor current [ohm]	R_J	0.01	0.0000008	B	∞	-75.39	-0.000060	0.000000
29	cal. factor current DVM	c_J	1	0.00005	B	∞	0.75	0.000038	0.000000
30	sphere mismatch index	m_S	0.083	0.012	B	∞	-0.2245	-0.002694	-0.000001
31	nominal current of source [A]	J_{C1}	2.5250	0					
32	nominal current source REF [A]	J_{CR}	2.5700	0					0.001670
35	**luminous flux, nom. current [lm]**	Φ_{CS1}	**3386.6**			**47202**		**15.14**	**0.0045**

found from approximation formula: k =	2.00	30.3	0.0089

variance $u_{dev}(y)$ = 0.17%

variance $u_{inst}(y)$ = 0.41%

Technical Specification

of

CNAM (France)

EURAMET.PR-K4

RMO 569 – Luminous flux

Please, find below the « after » values for LNE-CNAM

Adopted values (sent to PTB on 26 june 2012)
(After)

Lamp	Tc (K)	Current (A)	Voltage (V)	Flux (lm)
D185	2788	1,9994	95,06	2396
421	2774	1,9200	98,58	2407
423	2783	1,9200	101,88	2555
425	2819	1,9200	106,70	2869
428	2782	1,9200	101,78	2575
429	2779	1,9200	102,21	2550

Best regards

Gaël Obein

Annex G: Description of the measurement facility

Laboratory transfer standards used:

6 pieces Polaron LF4 200W (serial # D185, 421, 423, 425, 428 and 429)

Description of measuring technique (please include a diagram):

The measurements are carried out on our reference facility which is 7 meters diameter "home-made" goniophotometer (figure 1).

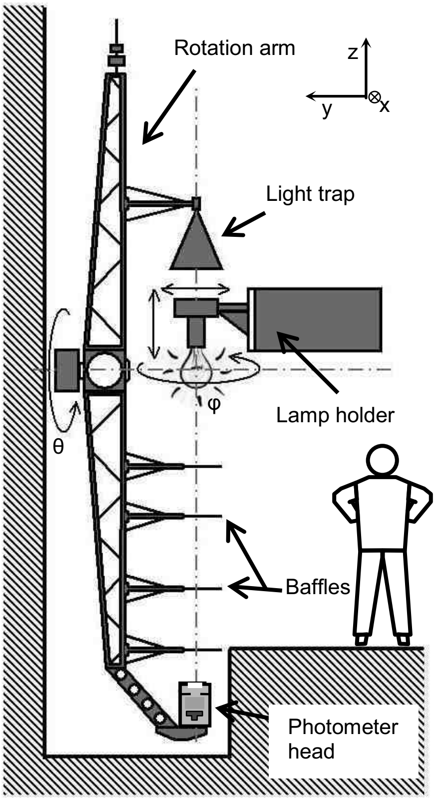


Figure 1: general view of the goniophotometer.: the lamp holder allows the alignment and the rotation of the lamp. The photometer rotates thanks to the rotation arm. 4 baffles and a light trap are used to reduce the stray light. The man is 1.80m.

The lamp is operated vertical, cap up. The goniophotometer realises the spatial measurement of the luminous intensity according to the following method : the lamp is rotated around its vertical axis over a full circle (360°). The photometer rotates in a vertical plane containing the axis of the lamp. Its rotation is only a half of a circle (180°). The lamp is put at the centre of the circle described by the photometer. These two rotations allow measuring the luminous intensity distribution of the lamp all over the space around it.

The main characteristics of the facility are :

- Distance between source and detector : 3 400 mm
- Photometer cosine corrected, diameter : 60 mm (angular measurement 1°)
- Mosaic V(λ) filter temperature controlled within ± 0.1°C
- Speed of motion of the detector : 4°/s
- Standard uncertainty on the angular setting : 0.02°

For the measurement, the lamp is set at an azimuth angle and the photometer is moved on half a circle, taking a measurement every 3°. Then the lamp is rotated by an angle of 6° and the motion of the photometer starts again in the reverse direction. The measurement continues until all the sphere has been described giving a total number of 3 600 luminous intensity data and the same number of angle data.

In order to keep the time of measurement at a reasonable level (about 2 hours) the measurements are taken "on the fly".

The luminous flux emitted by the lamp is calculated by integrating the luminous intensity distribution over the complete sphere.

The photoelectric current is measured using a high quality current to voltage converter with a gain of 10^6 and a high precision voltmeter. The DC current in the lamps is adjusted and controlled thanks to a standard resistor and a high precision voltmeter. It is provided by a power supply with a relative stability on one hour better than 10 ppm.

The motorization of the rotation of the lamp and of the photometer is done by stepping motors connected with step down gears free from play. With stepping motors it is possible to have, with the same electronic device, the motor rotation and the angular positioning by pulse counting measurements. The data regarding the luminous intensity and the angle are taken at the same time.

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

The photometer is calibrated using a set of three luminous intensity transfer standard lamps of the laboratory. The photometer is calibrated just before and after each measurement campaign. The luminous intensity lamps are mounted on the goniophotometer allowing an "in situ" calibration of the photometer. The sensitivity of the photometer is expressed in $V \cdot cd^{-1}$ and takes into account the current to voltage converter.

The set of transfer standard lamps is periodically compared with another set of transfer standard lamps that has participated to CCPR-K3a key comparison and has a traceability to the realization of the candela carried out in 1984 (see CCPR-K3a report for details).

Measurement model:

We integrates the luminous intensity of the lamp on the full sphere to compute the luminous flux of the lamps.

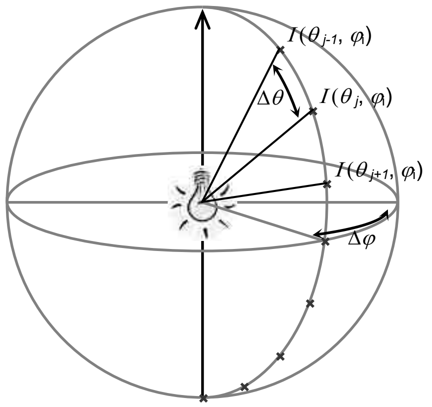


Figure 2: Angular notations. θ is the elevation angle and varies between 90° and -90°. φ is the azimuth angle. $I(\theta_j\ \varphi_i)$ is the luminous intensity at the position ($\theta_j\ \varphi_i$). For a luminous flux measurement, the steps are $\Delta\theta$ = 3° and $\Delta\varphi$ = 6° which given 3600 luminous intensity measurements

According to the notations described on figure 2, the measurement model is given by:

$$\phi = \frac{1}{S} \cdot \sum_i \sum_j y_{ij} \cdot \cos\theta_j \cdot \Delta\varphi \cdot \Delta\theta \cdot corr \quad (1)$$

$$corr = \left(1 + \varepsilon - \frac{y_0}{y_{ij}} - mI \cdot \Delta J - \gamma \cdot \Delta t\right) \quad (2)$$

Were Φ is the luminous flux of the lamp
corr is a correction factor with about unity value.
S is sensitivity of the photometer
y_{ij} is the voltage at the photometer at the angular position (θ_j ; φ_i) and corrected for straylight and offset y_0.
ε is the misalignment of the lamp.
mI =6.75 is the coefficient for corrections of relative lamp current differences
ΔJ is the relative difference in the lamp current setting.
γ is the ageing coefficient of the lamp.
Δt is the burning time

The lamps run at a colour temperature of (2800 ± 15) K, the same colour temperature as the luminous intensity transfer standards lamps. The photometer head of the photometer is very well

$V(\lambda)$ corrected. No correction and no uncertainty are applied for the spectral matching factor of the photometer head.
The other contributions to the combined uncertainty are summarised in the following table.

Table – Uncertainty budget of LNE-CNAM for luminous flux lamp comparison.

Source	Symbol	Probability distribution.	Divisor	100 × Rel. Standard uncertainty
Sensitivity of the photometer	S	Normal	1	0.45
Voltage measurement for 1 position	y_{ij}	Normal	1	0.001
Voltage measurement for straylight	y_0	Normal	1	0.001
Azimuth step	Δφ	Rectangular	√3	0.002
Elevation step	Δθ	Rectangular	√3	0.003
Misalignment lamp	ε			
x		Rectangular	√3	0.001
y		Rectangular	√3	0.001
z		Rectangular	√3	0.001
Current in the lamp	ΔJ	Normal	1	0.006
Aging of the standard lamp	$\gamma \cdot \Delta t$	Rectangular	√3	0.01
Standard deviation		Normal	1	0.10
Combined uncertainty		Normal		0.53
Expanded uncertainty		Normal (k=2)		1.06

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

The measurements are performed at a temperature of 23 ± 1°C and a relative humidity of 50 ± 10%.

Operating conditions of the lamps: e.g. geometrical alignment, polarity, stray-light reduction etc.

These points have been discussed at the PTB, when we delivered the lamps.

Operator: Catherine Martin, Gaël Obein

Laboratory: LNE-CNAM

Technical Specification

of

DMDM (Serbia)

EURAMET.PR-K4

Annex G: Description of the measurement facility

Make and type of the photometer (or equivalent):

Photodetector LMT-P30SCT with digital electrical current measuring instrument (nanoampermeter) LMT- I 1000, with measuring range from $1\cdot10^{-13}$ A to $1\cdot10^{-3}$ A, and with accuracy of 0,1 %, was used for photocurrent measurement. Calibration of nanoampermeter performed in DMDM Electricity Division. Detectors spectral responsivity within $f_1' \leq 0,5$.

Laboratory transfer standards used:

DMDM primary group of luminous flux standard lamps, calibrated in LNE/INM:

1. LNE-INM Certificate, No 1154-Ra-06, for Polaron, type LFS, No P 134, issued 2006-02-10
2. LNE-INM Certificate, No 1155-Ra-06, for Polaron, type LFS, No P 135, issued 2006-02-10
3. LNE-INM Certificate, No 1156-Ra-06, for Polaron, type LFS, No P 137, issued 2006-02-10
4. LNE-INM Certificate, No 1157-Ra-06, for Polaron, type LFS, No P 142, issued 2006-02-10
5. LNE-INM Certificate, No 1158-Ra-06, for Polaron, type LFS, No P 143, issued 2006-02-10
6. LNE-INM Certificate, No 1159-Ra-06, for Polaron, type LFS, No P 144, issued 2006-02-10

Description of measuring technique (please include a diagram):

After the operating current of all of the transfer lamps is assigned for the 2800 K colour temperature (B/R method), the luminous flux of the lamp is determined. The method used is comparison with luminous flux standard in an integrating sphere (substitution method).

Characterics of the sphere are following:

- inner diameter is 1,25 m;
- shelter distance from the measuring aperture in the sphere wall is 1/6 of the diameter;
- auxiliary lamp and its shelter is in the sphere wall opposite to the measuring aperture;
- moveable lamp holder enables possitioning of the lamp;
- four-contact measuring socket enables measuring lamp voltage directly on the lamp;
- inner paint of the sphere has constant spectral characteristic $\phi(\lambda)=[\rho(\lambda)/(1-\rho(\lambda))]$ with integral spectral reflection of $\rho \sim 0.8$

Simplified diagram of the sphere is shown on the Figure1.

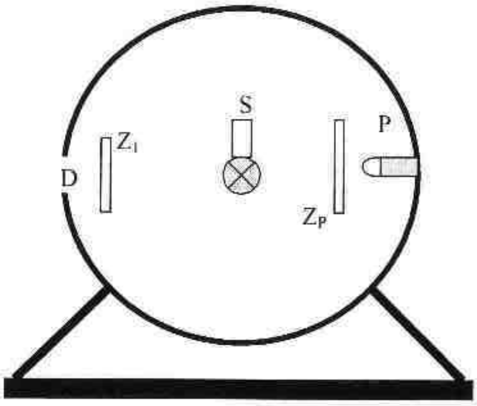


Fig.1 DMDM integrating sphere

-D- detector (measuring aperture)
-Z_1-shelter in front of the detector
-S-luminous flux lamp
-Z_2-shelter in front of the auxiliary lamp
-P- auxiliary lamp

Photo of integrating sphere is shown on Figure2.

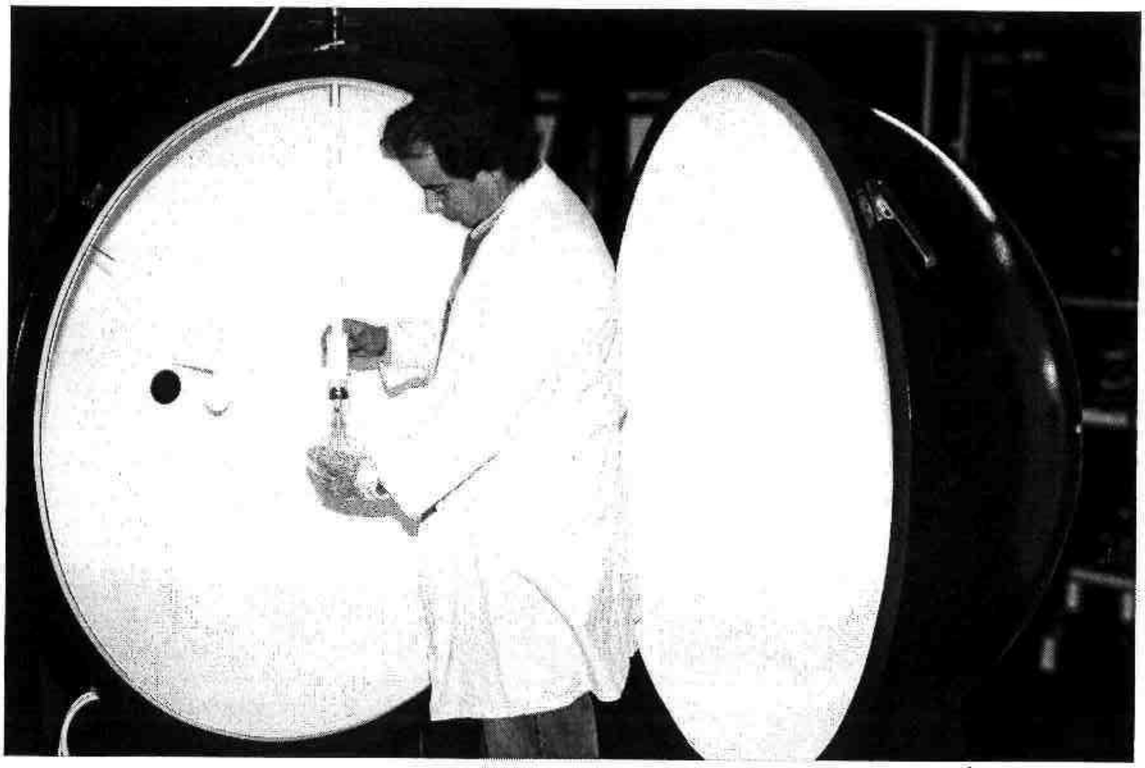
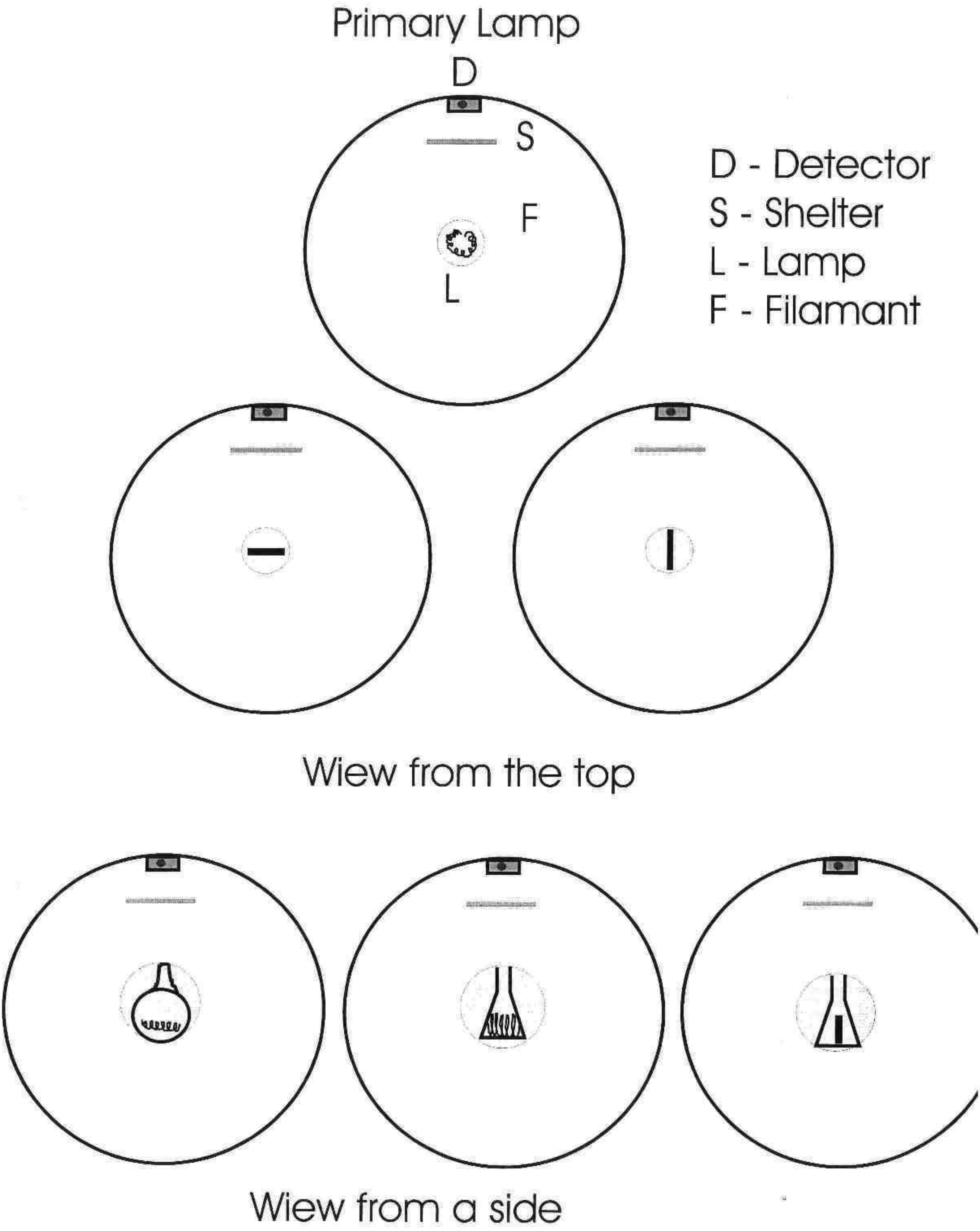


Fig.2 Photo of DMDM integrating sphere


Primary Lamp
D
S
F
L
D - Detector
S - Shelter
L - Lamp
F - Filamant
Wiew from the top
Wiew from a side

These measurements are made with six primary standard lamps. Calibration coefficients are calculated according to formulas:

$$K_i = \frac{\Phi_{oi}}{I_{phoi}} \cdot I_{phpoi}, \quad K = \frac{\sum_{i=1}^{6} K_i}{6}$$

where Φ_{0i} is luminous influx of **i** lamp standard from the calibration certificate, I_{phoi} is recorded photocurrent of the detector when illuminated with **i** lamp standard and I_{phpoi} is recorded photocurrent when detector is illuminated with auxiliary lamp and **i** lamp standard is in sphere, but not turned on. Dark current signal is subtracted from each I_{phoi} and I_{phpoi} reading.

Lamp under calibration is then positioned at the place of standard lamp with the detector in the same place. Photocourent I_{phx} of the detector is then recorded. After lamp under calibration is turned off and left in the same possition, auxiliary lamp is turned on and photocurrent I_{phpxi}. The luminous flux of tested lamp is calculated as:

$$\Phi_x = K \cdot I_{phxi}/I_{phpxi}.$$

Organization of comparison was such that every lamp was switched on two times, i.e. two measuring series where executed. These two series actually make four measurements of the comparison, where the photocurrents from the lamps under calibration were recorded in two positions regarding its filament. These two positions are taken as representatives of the difference between the shape of the filament of the primary lamps (Polaron) and transfer lamps (Osram).

These positions are presented on a separate page enclosed to this report.

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

Measuring uncertainty of the Serbian (primary) standard of luminous flux is obtained from the data about uncertainty with which the values of each of the lamps from primary group are determined in LNE/INM and estimation of the influence of the environment, uncertainty of measuring electrical parameters and instability of power supplies, and from the results of mutual comparison.

B component of uncertainty includes sources of uncertainty (estimated on 1 σ basis) that are given in table 1.

Table1.- B component of the measuring uncertainty of the DMDM primary standard of luminous flux (i.e. calibration factor K)

Source of the uncertainty	Estimated influence on photometric measurements
Instability of the current power supply ($3\cdot10^{-5}$)	0,02 %

Measurement of the voltage drop on resistance standard ($1\cdot10^{-5}$)	0,01 %
Resistance standard uncertainty ($5\cdot10^{-5}$)	0,04 %
Selfapsorption	0,02 %
Uniformity of sphere coating	0,01 %
Uncertainty of measuring detectors signal	0,01 %
Estimated total influence - S_Θ	0,05 %

Table2. – A component of the primary standard of luminous flux, uncertainty of reproducing the value of the luminous flux and total uncertainty of primary group

Formula	Explanation	Value
$\lvert\bar{\delta}\rvert = \sum_1^6 \frac{\lvert\delta_i\rvert}{6}$	Average deviation from the LNE assigned value to each of the lamps	0,05 %
$\sigma(x) = \sqrt{\frac{\delta_i^2}{5}}$	Mean standard deviation for the each of the lamps from the primary group	0,06 %
$\sigma(\bar{x}) = \frac{\sigma(x)}{\sqrt{6}}$	Mean standard deviation for the whole primary group of luminous flux lamps	0,025 %
$u_{\varphi} = \sqrt{\sigma(x)^2 + S_\Theta^2}$	Uncertainty of reproducing the value of luminous flux when calibration is done with one lamp from the primary group	0,08 %
$u_{\varepsilon\sigma} = \sqrt{\sigma(\bar{x})^2 + \frac{S_\Theta^2}{6}}$	Uncertainty of reproducing the value of luminous flux when calibration is done with all six lamps from the primary group	0,03 %
u_{LNE}	LNE uncertainty for each of the lamps from the certificate of calibration	0,5 %
$u = \sqrt{\sigma(\bar{x})^2 + \frac{S_\Theta^2}{6} + u_{LNE}^2}$	Total uncertainty of the primary group of luminous flux lamps	0,51 %

Measurement results for first round of K4 EURAMET luminous flux comparison from DMDM

The summary of the results is given in Table 1.
Lamp voltages are mean values from four burnings of the lamps, and each voltage reading is the mean value of the voltage after stabilization period and at the end of measurement.
The luminous fluxes of the lamp transfer standards were determined with a value and associated relative expanded uncertainty for a coverage factor k=1 for an interval containing a 68,27 % fraction of probability and reads as given in fourth column of the Table 1. below:

Table 1. Summary of measurement results

Lamp	I [A]	U [V]	Φ [lm]
043-07-29	5.7750	29,3975	2450.86 (1±0,54)
043-07-65	5.7700	29.4990	2426.11 (1±0,57)
043-07-66	5.7890	29.6837	2458.55 (1±0,58)
043-07-68	5.7779	29.5640	2424.29 (1±0,53)
043-07-69	5,7715	29.6105	2443.90 (1± 0,56)
043-07-70	5,738	29.6698	2443,22 (1± 0,56)

The detailed measurement results of luminous intensity and voltage for each of the calibrated lamps is given below:

Operators: Predrag Vukadin and Veljko Zarubica
Laboratory: Laboratory for photometry and radiometry

Date: 19.05.2008 Signature: ....

	First calibration of OSRAM 043-07-29					
	$Iph \cdot 10^{-5}$ [A] ⊗	$Iph \cdot 10^{-5}$ [A] ↑	$Iphpi \cdot 10^{-5}$ [A] ⊗	$Iphpi \cdot 10^{-5}$ [A] ↑	Φ ↑	Φ ⊗
	3.7958	3.8068	1.3667	1.3667		
	3.7952	3.8063	1.3667	1.3667		
	3.7945	3.8062	1.3668	1.3668		
	3.7943	3.8062	1.3667	1.3667		
	3.7936	3.8059	1.3668	1.3668		
	3.7921	3.8058	1.3667	1.3667		
	3.7912	3.8058	1.3667	1.3667		
	3.7909	3.8054	1.3667	1.3667		
	3.7902	3.8055	1.3667	1.3667		
	3.7899	3.8054	1.3668	1.3668		
Mean values	3.79277	3.80593	1.36674	1.36674	2446.54	2455.03
Mean value of the first round	3.79935		1.36674		2450.78	
Standard deviation	0.00217	0.00045				

	Second calibration of OSRAM 043-07-29					
	$Iph \cdot 10^{-5}$ [A] ⊗	$Iph \cdot 10^{-5}$ [A] ↑	$Iphpi \cdot 10^{-5}$ [A] ⊗	$Iphpi \cdot 10^{-5}$ [A] ↑	Φ ~~⊗~~ ↑	Φ ~~↑~~ ⊗
	3.7842	3.806	1.3667	1.3667		
	3.7841	3.8057	1.3667	1.3667		
	3.7839	3.8056	1.3668	1.3668		
	3.7839	3.8054	1.3667	1.3667		
	3.7838	3.8052	1.3668	1.3668		
	3.7839	3.8052	1.3667	1.3667		
	3.7836	3.8056	1.3667	1.3667		
	3.7839	3.8052	1.3667	1.3667		
	3.7838	3.8043	1.3667	1.3667		
	3.7838	3.8046	1.3668	1.3668		
Mean values	3.78389	3.80528	1.36674	1.36674	2447.26	2454.61
Mean value of the second round	3.763815		1.36674		2450.94	
Standard deviation	0.000166	0.000512				

	First calibration of OSRAM 043-07-65					
	Iph · 10^{-5} [A] ⊗	Iph · 10^{-5} [A] ↑	Iphpi · 10^{-5} [A] ⊗	Iphpi · 10^{-5} [A] ↑	Φ ↑	Φ ⊗
	3.7566	3.7747	1.3675	1.3675		
	3.7556	3.7741	1.3676	1.3676		
	3.7552	3.7736	1.3675	1.3675		
	3.7549	3.7731	1.3676	1.3676		
	3.7547	3.7729	1.3674	1.3674		
	3.7544	3.7727	1.3676	1.3676		
	3.7541	3.7723	1.3674	1.3674		
	3.7539	3.7721	1.3675	1.3675		
	3.754	3.7719	1.3675	1.3675		
	3.7537	3.7718	1.3674	1.3674		
Mean values	3.75471	3.77292	1.3675	1.3675	2420.57	2432.31
Mean value of the first round	3.763815		1.36754		2426.44	
Standard deviation	0.0009	0.000969				

	Second calibration of OSRAM 043-07-65					
	Iph · 10^{-5} [A] ⊗	Iph · 10^{-5} [A] ↑	Iphpi · 10^{-5} [A] ⊗	Iphpi · 10^{-5} [A] ↑	Φ ~~⊗~~ ↑	Φ ~~↑~~ ⊗
	3.755	3.7736	1.3675	1.3675		
	3.7547	3.7731	1.3676	1.3676		
	3.7543	3.7726	1.3675	1.3675		
	3.7539	3.7723	1.3676	1.3676		
	3.7536	3.772	1.3674	1.3674		
	3.7534	3.7717	1.3676	1.3676		
	3.7531	3.7713	1.3674	1.3674		
	3.7529	3.7713	1.3675	1.3675		
	3.7528	3.771	1.3675	1.3675		
	3.7526	3.7708	1.3674	1.3674		
Mean values	3.75363	3.77197	1.3675	1.3675	2.419.87	2431.70
Mean value of the second round	3.763815		1.3675		2425.78	
Standard deviation	0.000827	0.000926				

	First calibration of OSRAM 043-07-66					
	Iph · 10^{-5} [A] ⊗	Iph · 10^{-5} [A] ↑	Iphpi · 10^{-9} [A] ⊗	Iphpi · 10^{-9} [A] ↑	Φ ↑	Φ ⊗
	3.8195	3.8321	1.3667	1.3667		
	3.8177	3.8318	1.3667	1.3667		
	3.8164	3.8315	1.3668	1.3668		
	3.8148	3.8311	1.3667	1.3667		
	3.815	3.8308	1.3668	1.3668		
	3.8143	3.8303	1.3667	1.3667		
	3.8131	3.8302	1.3667	1.3667		
	3.8126	3.8298	1.3667	1.3667		
	3.8121	3.8294	1.3667	1.3667		
	3.8106	3.8291	1.3668	1.3668		
Mean values	3.81461	3.83061	1.36674	1.36674	2460.63	2470.95
Mean value of the first round	3.82261		1.36674		2465.79	
Standard deviation	0.002701	0.00102				

	Second calibration of OSRAM 043-07-66					
	Iph · 10^{-5} [A] ⊗	Iph · 10^{-5} [A] ↑	Iphpi · 10^{-5} [A] ⊗	Iphpi · 10^{-5} [A] ↑	Φ ~~⊗~~ ↑	Φ ~~↑~~ ⊗
	3.8008	3.8318	1.3667	1.3667		
	3.801	3.8313	1.3667	1.3667		
	3.8011	3.8311	1.3668	1.3668		
	3.801	3.8282	1.3667	1.3667		
	3.8013	3.8287	1.3668	1.3668		
	3.8017	3.8285	1.3667	1.3667		
	3.8019	3.8282	1.3667	1.3667		
	3.8018	3.8276	1.3667	1.3667		
	3.8018	3.8267	1.3667	1.3667		
	3.8016	3.8275	1.3668	1.3668		
Mean values	3.8014	3.82896	1.36674	1.36674	2452.11	2469.88
Mean value of the second round	3.81518		1.36674		2461.00	
Standard deviation	0.000406	0.001784				

	First calibration of OSRAM 043-07-68					
	$Iph \cdot 10^{-5}$ [A] ⊗	$Iph \cdot 10^{-5}$ [A] ↑	$Iphpi \cdot 10^{-9}$ [A] ⊗	$Iphpi \cdot 10^{-9}$ [A] ↑	Φ ↑	Φ ⊗
	3.7661	3.7646	1.3673	1.3673		
	3.7642	3.7644	1.3673	1.3673		
	3.7627	3.7644	1.3675	1.3675		
	3.7608	3.7642	1.3674	1.3674		
	3.7592	3.7641	1.3674	1.3674		
	3.7577	3.7639	1.3674	1.3674		
	3.7568	3.7639	1.3674	1.3674		
	3.7555	3.7636	1.3674	1.3674		
	3.754	3.7635	1.3675	1.3675		
	3.7527	3.7634	1.3675	1.3675		
Mean values	3.75897	3.764	1.36736	1.36736	2423.64	2426.87
Mean value of the first round	3.82261		1.36736		2425.26	
Standard deviation	0.004446	0.000411				

	Second calibration of OSRAM 043-07-66					
	$Iph \cdot 10^{-5}$ [A] ⊗	$Iph \cdot 10^{-5}$ [A] ↑	$Iphpi \cdot 10^{-5}$ [A] ⊗	$Iphpi \cdot 10^{-5}$ [A] ↑	Φ ~~⊗~~ ↑	Φ ~~↑~~ ⊗
	3.753	3.7696	1.3673	1.3673		
	3.7525	3.7686	1.3673	1.3673		
	3.7521	3.7663	1.3675	1.3675		
	3.7519	3.7662	1.3674	1.3674		
	3.7515	3.7654	1.3674	1.3674		
	3.7511	3.765	1.3674	1.3674		
	3.7508	3.7641	1.3674	1.3674		
	3.7508	3.763	1.3674	1.3674		
	3.7505	3.7623	1.3675	1.3675		
	3.7502	3.7617	1.3675	1.3675		
Mean values	3.75144	3.76522	1.36736	1.36736	2418.78	2427.85
Mean value of the second round	3.75833		1.36736		2423.32	
Standard deviation	0.000917	0.00258				

	First calibration of OSRAM 043-07-69					
	$Iph \cdot 10^{-5}$ [A] ⊗	$Iph \cdot 10^{-5}$ [A] ↑	$Iphpi \cdot 10^{-9}$ [A] ⊗	$Iphpi \cdot 10^{-9}$ [A] ↑	Φ ↑	Φ ⊗
	3.7842	3.7974	1.3667	1.3667		
	3.7838	3.7971	1.3667	1.3667		
	3.7833	3.7969	1.3667	1.3667		
	3.7833	3.7965	1.3667	1.3667		
	3.7827	3.7965	1.3667	1.3667		
	3.7819	3.7963	1.3667	1.3667		
	3.7808	3.7961	1.3667	1.3667		
	3.7807	3.7958	1.3667	1.3667		
	3.7796	3.7957	1.3667	1.3667		
	3.7785	3.7956	1.3667	1.3667		
Mean values	3.78188	3.79639	1.3667	1.3667	2439.58	2448.95
Mean value of the first round	3.789135		1.3667		2444.26	
Standard deviation	0.001914	0.00061				

	Second calibration of OSRAM 043-07-66					
	$Iph \cdot 10^{-5}$ [A] ⊗	$Iph \cdot 10^{-5}$ [A] ↑	$Iphpi \cdot 10^{-5}$ [A] ⊗	$Iphpi \cdot 10^{-5}$ [A] ↑	Φ ⊗ ↑	Φ ↑ ⊙
	3.7773	3.7987	1.3667	1.3667		
	3.7776	3.7987	1.3667	1.3667		
	3.7774	3.7981	1.3667	1.3667		
	3.7773	3.7983	1.3667	1.3667		
	3.7775	3.7985	1.3667	1.3667		
	3.7772	3.799	1.3667	1.3667		
	3.7773	3.7989	1.3667	1.3667		
	3.7772	3.7991	1.3667	1.3667		
	3.7771	3.7986	1.3667	1.3667		
	3.7773	3.7987	1.3667	1.3667		
Mean values	3.77732	3.79866	1.3667	1.3667	2436.64	2450.46
Mean value of the second round	3.78799		1.3667		2443.55	
Standard deviation	0.000148	0.000306				

	First calibration of OSRAM 043-07-70					
	$Iph \cdot 10^{-5}$ [A] ⊗	$Iph \cdot 10^{-5}$ [A] ↑	$Iphpi \cdot 10^{-9}$ [A] ⊗	$Iphpi \cdot 10^{-9}$ [A] ↑	Φ ↑	Φ ⊗
	3.7802	3.7981	1.3666	1.3666		
	3.7804	3.7974	1.3667	1.3667		
	3.7802	3.7969	1.3667	1.3667		
	3.7799	3.7966	1.3667	1.3667		
	3.7802	3.7966	1.3666	1.3666		
	3.7799	3.7957	1.3667	1.3667		
	3.7792	3.7952	1.3667	1.3667		
	3.7793	3.7952	1.3666	1.3666		
	3.7791	3.7949	1.3667	1.3667		
	3.7792	3.7947	1.3667	1.3667		
Mean values	3.77976	3.79613	1.3667	1.3667	2438.27	2448.83
Mean value of the first round	3.787945		1.36667		2443.55	
Standard deviation	0.000506	0.001155				

	Second calibration of OSRAM 043-07-66					
	$Iph \cdot 10^{-5}$ [A] ⊗	$Iph \cdot 10^{-5}$ [A] ↑	$Iphpi \cdot 10^{-5}$ [A] ⊗	$Iphpi \cdot 10^{-5}$ [A] ↑	Φ ~~⊗~~ ↑	Φ ~~↑~~ ⊗
	3.7773	3.7987	1.3666	1.3666		
	3.7776	3.7987	1.3667	1.3667		
	3.7774	3.7981	1.3667	1.3667		
	3.7773	3.7983	1.3667	1.3667		
	3.7775	3.7985	1.3666	1.3666		
	3.7772	3.799	1.3667	1.3667		
	3.7773	3.7989	1.3667	1.3667		
	3.7772	3.7991	1.3666	1.3666		
	3.7771	3.7986	1.3667	1.3667		
	3.7773	3.7987	1.3667	1.3667		
Mean values	3.77732	3.79866	1.3667	1.3667	2436.77	2449.02
Mean value of the second round	3.78693		1.36667		2442.90	
Standard deviation	0.000237	0.00122				

	Calibration of OSRAM 043-07-29 (Voltage)			
	First round		Second round	
* U_0 [V]	29.3830	29.3930	29.3840	29.4040
* U_1 [V]	29.3740	29.3900	29.3830	29.4050
U_a [V]	29.3785	29.3915	29.3835	29.4045
Mean value of the first and second round [V]	29.3850		29.3940	

* U_0 - Voltage after 10 min. stabilization; U_1 - Voltage at the end measurement; U_a - Mean values $U_a = \frac{U_0 + U_1}{2}$.

	Calibration of OSRAM 043-07-65 (Voltage)			
	First round		Second round	
* U_0 [V]	29.5000	29.5000	29.5000	29.5000
* U_1 [V]	29.4950	29.5000	29.4990	29.5000
U_a [V]	29.4975	29.5000	29.4995	29.5000
Mean value of the first and second round [V]	29.4987		29.4997	

* U_0 - Voltage after 10 min. stabilization; U_1 - Voltage at the end measurement; U_a - Mean values $U_a = \frac{U_0 + U_1}{2}$.

	Calibration of OSRAM 043-07-66 (Voltage)			
	First round		Second round	
* U_0 [V]	29.7000	29.6800	29.6750	29.6950
* U_1 [V]	29.6840	29.6700	29.6710	29.6950
U_a [V]	29.6920	29.6750	29.6730	29.6950
Mean value of the first and second round [V]	29.6835		29.6840	

* U_0 - Voltage after 10 min. stabilization; U_1 - Voltage at the end measurement; U_a - Mean values $U_a = \frac{U_0 + U_1}{2}$.

	Calibration of OSRAM 043-07-68 (Voltage)			
	First round		Second round	
* U_0 [V]	29.5300	29.5590	29.5390	29.6600
* U_1 [V]	29.5000	29.5570	29.5200	29.6470
U_a [V]	29.5150	29.5580	29.5295	29.6535
Mean value of the first and second round [V]	29.5365		29.5915	

* U_0 - Voltage after 10 min. stabilization; U_1 - Voltage at the end measurement; U_a - Mean values $U_a = \frac{U_0 + U_1}{2}$.

	Calibration of OSRAM 043-07-69 (Voltage)			
	First round		Second round	
* U_o [V]	29.6100	29.6100	29.6180	29.6080
* U_1 [V]	29.6000	29.6100	29.6200	29.6080
U_a [V]	29.6050	29.6100	29.6190	29.6080
Mean value of the first and second round [V]	29.6075		29.6135	

* U_o - Voltage after 10 min. stabilization; U_1 - Voltage at the end measurement; U_a - Mean values $U_a = \frac{U_0 + U_1}{2}$.

	Calibration of OSRAM 043-07-70 (Voltage)			
	First round		Second round	
* U_o [V]	29.5650	29.5630	29.9170	29.6700
* U_1 [V]	29.5630	29.5640	29.8590	29.6580
U_a [V]	29.5640	29.5635	29.8880	29.6640
Mean value of the first and second round [V]	29.5637		29.7760	

Annex H: Record of lamp operating time

Lamp: OSRAM 043-07-70

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
31.07.2008	11^{35}	20 min.	12^{05}	1/2	V.S &V.Z.
05.08.2008	10^{40}	20 min.	11^{10}	1/2	V.S &V.Z.
07.08.2008	13^{50}	20 min.	14^{20}	1/2	V.S &V.Z.
08.08.2008	10^{50}	20 min.	11^{20}	1	V.S &V.Z.

Operator: Vladan Skerovic and Veljko Zarubica

Laboratory: Laboratory for photometry and radiometry of DMDM

Date: 2008-10-27 Signature: ....

Annex H: Record of lamp operating time

Lamp: OSRAM 043-07-69

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
31.07.2008	12^{45}	20 min.	13^{15}	1/2	V.S &V.Z.
04.08.2008	11^{40}	20 min.	12^{10}	1/2	V.S &V.Z.
07.08.2008	14^{25}	20 min.	14^{55}	1/2	V.S &V.Z.
08.08.2008	09^{40}	20 min.	10^{40}	1	V.S &V.Z.

Operator: Vladan Skerovic and Veljko Zarubica

Laboratory: Laboratory for photometry and radiometry of DMDM

Date: 2008-10-27 Signature: ....

Annex H: Record of lamp operating time

Lamp: OSRAM 043-07-68

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
31.07.2008	09^{15}	20 min.	09^{45}	1/2	V.S &V.Z.
05.08.2008	13^{15}	20 min.	13^{45}	1/2	V.S &V.Z.
07.08.2008	11^{40}	20 min.	12^{10}	1/2	V.S &V.Z.
08.08.2008	13^{45}	20 min.	14^{15}	1/2	V.S &V.Z.

Operator: Vladan Skerovic and Veljko Zarubica

Laboratory: Laboratory for photometry and radiometry of DMDM

Date: 2008-10-27 Signature: ....

Annex H: Record of lamp operating time

Lamp: OSRAM 043-07-65

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
31.07.2008	09^{55}	20 min.	10^{25}	1/2	V.S &V.Z.
05.08.2008	12^{05}	20 min.	12^{35}	1/2	V.S &V.Z.
07.08.2008	12^{20}	20 min.	11^{50}	1/2	V.S &V.Z.
08.08.2008	12^{55}	20 min.	13^{25}	1/2	V.S &V.Z.

Operator: Vladan Skerovic and Veljko Zarubica

Laboratory: Laboratory for photometry and radiometry of DMDM

Date: 2008-10-27 Signature: ....

Annex H: Record of lamp operating time

Lamp: OSRAM 043-07-65

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
30.07.2008	12^{30}	20 min.	13^{00}	1/2	V.S &V.Z.
05.08.2008	14^{05}	20 min.	14^{35}	1/2	V.S &V.Z.
07.08.2008	11^{05}	20 min.	11^{35}	1/2	V.S &V.Z.
08.08.2008	14^{20}	20 min.	14^{50}	1/2	V.S &V.Z.

Operator: Vladan Skerovic and Veljko Zarubica

Laboratory: Laboratory for photometry and radiometry of DMDM

Date: 2008-10-27 Signature: ....

Annex H: Record of lamp operating time

Lamp: OSRAM 043-07-29

Date	Switch-on Local Time	Activity (Test, Alignment, Measure)	Switch-off Local Time	Burn Hrs	Operator initials
31.07.2008	10^{35}	20 min.	11^{35}	1	V.S &V.Z.
05.08.2008	11^{25}	20 min.	11^{55}	1/2	V.S &V.Z.
07.08.2008	13^{00}	20 min.	13^{30}	1/2	V.S &V.Z.
08.08.2008	11^{35}	20 min.	12^{35}	1/2	V.S &V.Z.

Operator: Vladan Skerovic and Veljko Zarubica

Laboratory: Laboratory for photometry and radiometry of DMDM

Date: 2008-10-27 Signature: ....

Annex E: Uncertainty Budget

Measurement uncertainty analysis

Mathematical model of measurement

Mathematical model of luminous flux calibration is defined with following equation:

$$\Phi_x = K \cdot I_{phxi}/I_{phpxi},$$

where: K is defined in annex G,

I_{phxi} is photocurrent from the detector when the sphere is illuminated with transfer standard flux,

I_{phpxi} is photocurrent from the detector when the sphere is illuminated with auxiliry lamp flux and transfer standard in a measuring position but not operated.

In this short analysis only the main uncertainty contributions are discussed.

Uncertainty of K is defined in Annex G, and it is 0,51 %.

Uncertainty of measuring I_{phxi} and I_{phpxi} are almost negligable, since only their standard deviations are to be taken into account. Their contributions to total uncertainty of calibration is rounded to 0,05 % for each of the lamps.

Uncertainty component which is here disscused and presented is the one which arrises from the averaging mesurement positions of the transfer lamps -two critical cases which should be the extremes of difference between the shape of the filaments of primary flux lamps (Polaron) and transfer lamps (Osram). This component is calculated for every of the trasfer lamps, as the mean value of the two rounds. For one round it is calculated as:

$u_d = (\Phi\oplus - \Phi\uparrow)/2(\Phi\oplus + \Phi\uparrow)$

In Table 1. these uncertainties are presented for each of the transfer standard lamps. as well as total calibration uncertainties:

Table 1. Calibration uncertainties for transfer standard lamps

Lamp Number	u_K(%)	u_I(%)	u_D(%)	u(%)
043-07-29	0,51	0,05	0,16	0,537
043-07-65	0,51	0,05	0,24	0,567
043-07-66	0,51	0,05	0,28	0,584
043-07-68	0,51	0,05	0,15	0,534
043-07-69	0,51	0,05	0.23	0,562
043-07-70	0,51	0,05	0,23	0,562

Responsible: Predrag Vukadin

Laboratory: Laboratory for Photometry and Radiometry of DMDM

Date: 2008-05-19 Signature: ....

Technical Specification

of

GUM (Poland)

EURAMET.PR-K4

Luminous Flux EURAMET.PR-K4
Questionnaire

lamp number	lamp current A	voltage V	lum. flux lm
P 373 initial return (*k* = 1) uncert	1,9961 nominal	95,150 95,286 0.0025 %	2744,6 2751,7 0,36 % 0,52 %
P 376 initial return (*k* = 1) uncert	2.0072 nominal	98,389 98,599 0.0025 %	2934,2 2938,8 0,36 % 0,52 %
P 378 initial return (*k* = 1) uncert	1,992 nominal	94,467 94,688 0.0025 %	2745,4 2757,9 0,36 % 0,52 %
P 469 initial return (*k* = 1) uncert	2,0026 nominal	96,010 96,161 0.0025 %	2765,1 2774,6 0,36 % 0,52 %

Operator: Grzegorz Szajna
Central Office of Measures (GUM)
Photometry and Radiometry Lab.
Elektoralna 2; 00-950 Warsaw
Poland

Date: 05.07.2010
Signature:

EURAMET Key Comparison: Luminous Intensity (EURAMET.PR-K3a) and Luminous Flux (EURAMET.PR-K4)

Annex G: Description of the measurement facility

Make and type of the photometer (or equivalent)

Luminous flux national standard consisting of five tungsten lamps type PS 95 100V 200W produced by Toshiba.

Laboratory transfer standards used:

Luminous flux transfer standard consisting of four tungsten lamp type LF 200 produced by Engel & Gibbs, calibrated with the reference to luminous flux national standard.

Description of measuring technique (please include a diagram):

Source based calibration using reference (national) standard.

The luminous flux standard calibration facility is based on Ulbricht sphere, photometric reference standards and LMT photocurrent meter. Standard lamps are supplied with Heinzinger power supply for stable current, their electrical parameters are controlled by means multimeters Hewlett-Packard

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

The national standard (reference) calibrated at MIKES (FINLAND) in October 2009, expanded uncertainty 1,0 % (at 95% confidence level).

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

ambient temperature – (21,7 ÷ 22,6) ^{o}C,

relative air humidity – (26,4 ÷ 27,6) %

Operating conditions of the lamps: e.g. geometrical alignment, polarity, stray-light reduction etc.

- used photocurrent meter – LMT type I 1000 , head firm Osram
- diameter of head (and window of sphere) – 60 mm,
- the lamps were mounted base-up, in a vertical position,
- positive polarity at the center of the cap (weren't changed between the measurements),
- the quantity to be set is the lamp current
- the measurement results were determined within 2 min after a burning-in time of 10 min

Operator: Grzegorz Szajna

Laboratory: Central Office of Measures (GUM), Radiation and Influence Quantities Department, Photometry and Radiometry Lab

Date: 27.04.2010

Signature:

Luminous Flux EURAMET.PR-K4

Central Office of Measures
Photometry and Radiometry Lab. Page of pages 1z 8
The return measurements (26-27.04.2010).

Part I

Determination of calibration factor of LMT photocurrent meter by luminous flux national standard calibrated at MIKES (Finland).
Calibration factor of LMT photocurrent meter is calculated according to the formula:

$$c = \frac{1}{5}\sum_{i=1}^{5} c_i \cdot 10^5 \left[\frac{\mathrm{lm}}{\mathrm{A}}\right], \text{ where } c_i = \frac{\Phi_w}{\alpha_w}\left(\frac{V}{J_R \cdot R}\right)^{m_\Phi} \cdot (1 - \alpha \cdot \Delta t)\left[\frac{\mathrm{lm}}{\mathrm{A}\cdot 10^{-5}}\right]$$

c_i – calibration factor of photocurrent meter illuminated by i-th reference lamp,
Φ_w – luminous flux of i-th reference lamp, given in calibration certificate,
α_w – mean value photocurrent of meter illuminated by i-th reference lamp,
V – value set on multimeter ,
R – resistance stated in the certificate of the normal resistor,
J_R – reference lamp current, no uncertainty,
m_Φ – exponent for changes of lamp current affecting the luminous flux,
$\alpha \cdot \Delta t$ – relative correction for ageing.

No lamp **TA 21531 C**

Symbol	Estymata	Standard uncertainty	Distribution	Sensitivity coefficient	Uncertainty contribution
xi	Xi	u(xi)		ci	u(y)
					10^5 [lm/A]
Φ_w	2596 lm	12,98 lm	normal	$0,602367 \cdot 10^5$ A^{-1}	7,818723
α_w	$1,6613 \cdot 10^{-5}$ A	$0,001073 \cdot 10^{-5}$A	normal	$-941,2682 \cdot 10^{10}$ lm/A^2	-1,00952
		$0,000289 \cdot 10^{-5}$A	rectang.	$-941,2682 \cdot 10^{10}$ lm/A^2	-0,271721
V	19,527 mV	0,00035 mV	normal	$277,0808 \cdot 10^5$ lm/mVA	0,096978
R	0,009998 Ω	4,5E-10 Ω	normal	$-541168,6 \cdot 10^5$ lm/ΩA	-0,000244
m_Φ	3,46	0,046303	rectang.	$0,326308 \cdot 10^5$ lm/A	0,015109
$\alpha \cdot \Delta t$	0	0	rectang.	$1563,745 \cdot 10^5$ lm/A	0
c_i	**$1563,745 \cdot 10^5$ lm/A**				4,96003

U(c)= 15,77784 · 10^5 lm/A U(c) = 1,01 %

Approved: Dorota Sobótko
Date:27.04.2010
Signature:

No lamp **TA 21533 C**

Symbol	Estymata	Standard uncertainty	Distribution	Sensitivity coefficient	Uncertainty contribution
xi	Xi	u(xi)		ci	u(y)
					10^5 [lm/A]
Φ_w	2630 lm	13,15 lm	normal	$0,596301 \cdot 10^5$ A^{-1}	7,841358
α_w	$1,6782 \cdot 10^{-5}$ A	$0,000647 \cdot 10^{-5}$A	normal	$-934,487 \cdot 10^{10}$ lm/A^2	-0,604615
		$0,000289 \cdot 10^{-5}$A	rectang.	$-934,487 \cdot 10^{10}$ lm/A^2	-0,269763
V	19,679 mV	0,006888 mV	normal	$275,7366 \cdot 10^5$ lm/mVA	1,899177
R	0,009998 Ω	4,5E-10 Ω	normal	$-542735,2 \cdot 10^5$ lm/ΩA	-0,000244
m_Φ	3,46	0,046303	rectang.	$0,327252 \cdot 10^5$ lm/A	0,015153
$\alpha \cdot \Delta t$	0	0	rectang.	$1568,272 \cdot 10^5$ lm/A	0
c_i	**1568,272 10^5lm/A**				5,261273

U(c)= 16,19041 · 10^5 lm/A U(c) = 1,03 %

No lamp **TA 21535 C**

Symbol	Estymata	Standard uncertainty	Distribution	Sensitivity coefficient	Uncertainty contribution
xi	Xi	u(xi)		ci	u(y)
					10^5 [lm/A]
Φ_w	2606 lm	13,03 lm	normal	$0,599172 \cdot 10^5$ A^{-1}	7,807212
α_w	$1,6702 \cdot 10^{-5}$ A	$0,000712 \cdot 10^{-5}$A	normal	$-934,8975 \cdot 10^{10}$ lm/A^2	-0,665975
		$0,000289 \cdot 10^{-5}$A	rectang.	$-934,8975 \cdot 10^{10}$ lm/A^2	-0,269882
V	19,623 mV	0,006868 mV	normal	$275,3193 \cdot 10^5$ lm/mVA	1,890907
R	0,009998 Ω	4,5E-10 Ω	normal	$-540371,9 \cdot 10^5$ lm/ΩA	-0,000243
m_Φ	3,46	0,046303	rectang.	$0,325827 \cdot 10^5$ lm/A	0,015087
$\alpha \cdot \Delta t$	0	0	rectang.	$1561,442 \cdot 10^5$ lm/A	0
c_i	**1561,442 · 10^5lm/A**				5,246168

U(c)= 16,13006 · 10^5 lm/A U(c) = 1,03 %

No lamp **TA 21537 C**

Symbol	Estymata	Standard uncertainty	Distribution	Sensitivity coefficient	Uncertainty contribution
xi	Xi	u(xi)		ci	u(y)
					10^5 [lm/A]
Φ_w	2557 lm	12,785 lm	normal	$0,608354 \cdot 10^5$ A^{-1}	7,777808
α_w	$1,6450 \cdot 10^{-5}$ A	$0,000575 \cdot 10^{-5}$A	normal	$-945,6493 \cdot 10^{10}$ lm/A^2	-0,543774
		$0,000289 \cdot 10^{-5}$A	rectang.	$-945,6493 \cdot 10^{10}$ lm/A^2	-0,272985

V	19,445 mV	0,006806 mV	normal	$276,7932 \cdot 10^5$ lm/mVA	1,883785
R	0,009998 Ω	4,5E-10 Ω	normal	$-538336,6 \cdot 10^5$ lm/ΩA	-0,000242
m_Φ	3,46	0,046303	rectang.	$0,3246 \cdot 10^5$ lm/A	0,01503
$\alpha \cdot \Delta t$	0	0	rectang.	$1555,562 \cdot 10^5$ lm/A	0
c_i	**$1555,562 \cdot 10^5$lm/A**				5,212781

U(c)= 16,05159 $\cdot$ 10^5 lm/A U(c) = 1,03 %

No lamp **TA 21539 C**

Symbol	Estymata	Standard uncertainty	Distribution	Sensitivity coefficient	Uncertainty contribution
xi	Xi	u(xi)		ci	u(y)
					10^5 [lm/A]
Φ_w	2568 lm	12,84 lm	normal	$0,60898 \cdot 10^5$ A^{-1}	7,819308
α_w	$1,6433 \cdot 10^{-5}$ A	$0,000454 \cdot 10^{-5}$A	normal	$-951,6737 \cdot 10^{10}$ lm/A^2	-0,431863
		$0,000289 \cdot 10^{-5}$A	rectang.	$-951,6737 \cdot 10^{10}$ lm/A^2	-0,274725
V	19,537 mV	0,006838 mV	normal	$276,9597 \cdot 10^5$ lm/mVA	1,893836
R	0,009998 Ω	4,5E-10 Ω	normal	$-541209,1 \cdot 10^5$ lm/ΩA	-0,000244
m_Φ	3,46	0,046303	rectang.	$0,326332.10^5$ lm/A	0,01511
$\alpha \cdot \Delta t$	0	0	rectang.	$1563,862 \cdot 10^5$ lm/A	0
c_i	**$1563,862 \cdot 10^5$lm/A**				5,22988

U(c)= 16,12333 $\cdot$ 10^5 lm/A U(c) = 1,03 %

Date:	**26-27.04.2010**		
N° lamp	c 10^5 lm/A	U(c) %	calibration factor LMT nr o8A6161 + head Osram nr 7550
TA21531C TA21533C TA21535C TA21537C TA21539C	1563,745 1568,272 1561,442 1555,562 1563,862 **1562,5766**	1,01% 1,03% 1,03% 1,03% 1,03%	**c = 1562,5766** $\cdot 10^5$ lm/A **U_{max}(c) =1,03%**

Part II
The evaluation of measurement uncertainty of the calibration of the luminous flux transfer standard

Measurement model:

$$\Phi_{\mathrm{b}} = \frac{\cdot \overline{\alpha}_{\mathrm{b}}}{\left(\dfrac{V}{J_{\mathrm{R}} \cdot R}\right)^{m_\phi} \cdot (1-\alpha \cdot \Delta t)} \cdot \frac{1}{5}\sum_{i=1}^{5}\frac{\Phi_w}{\alpha_w}\text{, because } \frac{1}{5}\sum_{\mathrm{i}=1}^{5}\frac{\Phi_{\mathrm{w_i}}}{\alpha_{\mathrm{w_i}}} = c$$

then

$$\Phi_{\mathrm{b}} = \frac{c \cdot \overline{\alpha}_{\mathrm{b}}}{\left(\dfrac{V}{J_{\mathrm{R}} \cdot R}\right)^{m_\phi} \cdot (1-\alpha \cdot \Delta t)} \text{ [lm]}$$

$\overline{\alpha}_{\mathrm{b}}$ – mean value photocurrent of meter illuminated by calibrated lamp;
the standard deviation $s(\overline{\alpha}_{\mathrm{b}})$ is taken as experimental of mean standard uncertainty (type A evaluation) $u_{\mathrm{A}}(\overline{\alpha}_{\mathrm{b}})$; the resolution of photocurrent meter $\delta = 0{,}001 \cdot 10^{-5}$ A (stated with rectangular probability distribution) and taken as uncertainty (type B evaluation) $u_{\mathrm{B}}(\overline{\alpha}_{\mathrm{b}}) = (0{,}001/2\sqrt{3}) \cdot 10^{-5}$ A $= 0{,}000289 \cdot 10^{-5}$ A

V – value set on multimeter, standard uncertainty $u(V)$ stated in the certificate of the potentiometer

R – resistance R = 0,00999791351 Ω stated in the certificate of the resistor with an expanded uncertainty $k = 2$ of $9 \cdot 10^{-9}$ Ω, $u(R) = 0{,}00000000045$ Ω,

J_{R} – transfer (calibrated) lamp current, no uncertainty.

c – calibration factor of LMT photocurrent meter calculated according to **Part I** "Determination of calibration factor of LMT photocurrent meter, at confidence level $k = 2$ with value $c = 1562{,}5766 \cdot 10^5$ lm/A and standard uncertainty $u(c) = 1562{,}5766 \cdot 0{,}0067/2 \cdot 10^5$ lm/A $= 5{,}23463161 \cdot 10^5$ lm/A.

m_Φ – exponent for changes of lamp current affecting the luminous flux,

$\alpha \cdot \Delta t$ – relative correction for ageing

Equation of uncertainty of measurement

$$u^2(\Phi_b) = c_1^2 \cdot u^2(c) + c_2^2 \cdot \left[u_A^2(\overline{\alpha}_b) + u_B^2(\overline{\alpha}_b)\right] + c_3^2 \cdot u^2(R) + c_4^2 \cdot u^2(V)$$
$$+ c_5^2 \cdot u^2(J_R) + c_6^2 \cdot u^2(m_\Phi) + c_7^2 \cdot u^2(\alpha \cdot \Delta t)$$

$$c_1 = \frac{\partial \Phi_b}{\partial c} = \frac{\Phi_b}{c} \quad [10^{-5}\mathrm{A}], \qquad c_2 = \frac{\partial \Phi_b}{\partial \overline{\alpha}_b} = \frac{\Phi_b}{\overline{\alpha}_b} \quad [\mathrm{lm/A \cdot 10^{-5}}], \qquad c_3 = \frac{\partial \Phi_b}{\partial R} = m_\Phi \frac{\Phi_b}{R} \quad \mathbf{[lm/\Omega]}$$

$$c_4 = \frac{\partial \Phi_b}{\partial V} = -m_\Phi \frac{\Phi_b}{V} \quad [\mathrm{lm/mV}], \qquad c_5 = \frac{\partial \Phi_b}{\partial J_R} = m_\Phi \frac{\Phi_b}{J_R} \quad [\mathrm{lm/A}]$$

$$c_6 = \frac{\partial \Phi_b}{\partial m_\Phi} = \Phi_b \cdot \ln\left(\frac{J_R \cdot R}{V}\right) \quad \mathrm{lm}, \qquad c_7 = \frac{\partial \Phi_b}{\partial \alpha \cdot \Delta t} = \frac{\Phi_b}{1 - \alpha \cdot \Delta t} \quad \mathrm{lm}$$

Uncertainty budget

Nr lampy	**P 373**						
$\alpha \cdot 10^{-5}\,A$	$\alpha_{śr} \cdot 10^{-5}\,A$		$s(\alpha_{śr}) \cdot 10^{-5}\,A$		$c_{kal} \cdot 10^5\,[\mathrm{lm/A}]$	$u_B(\alpha_{śr}) 10^{-5}\,\mathrm{A}$	
				Φ[lm]			
1,7629	1,7635	0,00033303	0,00009614	2751,7	1562,5766		0,000289
1,7630							
1,7631							
1,7636							
1,7637							
1,7638							
1,7634							
1,7635							
1,7636							
1,7637							
1,7638		Jr	R	V		m_Φ	$\alpha \cdot \Delta t$
1,7639		1,9961	0,00999791	19,961	mV	6,875	0
1,7635				0,00005		0,267	
		1,00020869	1,00143564	1,001436			
Symbol	Estymata	standard uncertainty		distribution	sensitivity coefficient		uncertainty contribution
							[lm]

α	$1,7635 \cdot 10^{-5}$	9,6138E-05	10^{-5} A	normal	1560,337	10^{5} lm/A	0,150007
		0,00028868	10^{-5} A	rectangular	1560,337	10^{5} lm/A	0,45043
c	$1562,5766 \cdot 10^{5}$lm/A	8,04726949	10^{5} lm/A	normal	1,7610	10^{-5} A	14,17102
R	0,00999791 Ω	4,5E-10	Ω	normal	1892157	lm/Ω	0,000851
m_{Φ}	6,875	0,15415252		rectangular	-0,57419	lm	-0,088513
$\alpha \cdot \Delta t$	0	0		rectangular	2751,653	lm	0
V	19,961 mV	0,00049903	mV	normal	-947,7289	lm/mV	-0,47294
Φ	2751,7 lm						9,242789
U(Φ) =	**28,3742539**	lm	**1,03**	%			

Lamp N^o^ P 373 Φ = (2751,7 ± 28,4) lm

Nr lampy	**P 376**						
$\alpha \cdot 10^{-5} A$	$\alpha_{śr} \cdot 10^{-5} A$		$s(\alpha_{śr}) \cdot 10^{-5} A$		$c_{kal} \cdot 10^{5} [lm/A]$	$u_B(\alpha_{śr}) 10^{-5} A$	
				Φ[lm]			
1,8823	1,8835	0,00077753	0,00022445	2938,8	1562,5766		0,000289
1,8824							
1,8825							
1,8831							
1,8832							
1,8833							
1,8837							
1,8838							
1,8839							
1,8843							
1,8844		Jr	R	V		m_{Φ}	$\alpha \cdot \Delta t$
1,8845		2,0072	0,009999791	20,072	mV	6,875	0
1,8835				0,00005		0,267	
		1,0002087	1,001435641	1,001436			
Symbol	Estymata	standard uncertainty		distribution	sensitivity coefficient		uncertainty contribution
							[lm]
α	$1,8835 \cdot 10^{-5}$ A	0,000224452	10^{-5} A	normal	1560,337	10^{5}lm/A	0,350221
		0,000288675	10^{-5} A	rectangular	1560,337	10^{5}lm/A	0,45043
c	$1562,5766 \cdot 10^{5}$lm/A	8,04726949	10^{5} lm/A	normal	1,8807	10^{-5} A	15,1349
R	0,00999791 Ω	4,5E-10	Ω	normal	2020858	lm/Ω	0,000909
m_{Φ}	6,875	0,154152522		rectangular	-0,613245	lm	-0,094533
$\alpha \cdot \Delta t$	0	0		rectangular	2938,816	lm	0
V	20,072 mV	0,0005018	mV	normal	-1006,594	lm/mV	-0,505109
Φ	2938,8 lm						**9,874932**
U(Φ) =	**30,308735**	lm	**1,03**	%			

Lamp N^o^ P 376 Φ = (2938,8 ± 30,3) lm

Nr lampy	**P 378**						
$\alpha \cdot 10^{-5} A$	$\alpha_{śr} \cdot 10^{-5} A$		$s(\alpha_{śr}) \cdot 10^{-5} A$		$c_{kal} \cdot 10^{5} [lm/A]$		$u_B(\alpha_{śr}) 10^{-5} A$
				Φ[lm]			
1,7673	1,7675	0,00021794	0,00006292	2757,9	1562,5766		0,000289
1,7674							
1,7675							
1,7675							
1,7676							
1,7677							
1,7671							
1,7672							
1,7673							
1,7676							
1,7677		Jr	R	V		m_Φ	$\alpha \cdot \Delta t$
1,7678		1,992	0,00999791	19,92	mV	6,875	0
1,7675				0,00005		0,267	
		1,0002087	1,00143564	1,001436			
Symbol	Estymata	standard uncertainty		distribution	sensitivity coefficient		uncertainty contribution
							[lm]
α	$1,7675 \cdot 10^{-5}$ A	6,2915	10^{-5} A	normal	1560,337	10^{5}lm/A	0,098169
		0,00028868	10^{-5} A	rectangular	1560,337	10^{5}lm/A	0,45043
c	$1562,5766 \cdot 10^{5}$lm/A	8,0472695	10^{5} lm/A	normal	1,7649	10^{-5} A	14,20296
R	0,00999791 Ω	4,5E-10	Ω	normal	1896422	lm/Ω	0,000853
m_Φ	6,875	0,15415252		rectangular	-0,575484	lm	-0,0887712
$\alpha \cdot \Delta t$	0	0		rectangular	2757,856	lm	0
V	19,92 mV	0,000498	mV	normal	-951,8202	lm/mV	-0,474006
Φ	2757,9 lm						**9,262873**
U(Φ) =	**28,437234**	lm	**1,03**	**%**			

Lamp N° P 378 Φ = (2757,9 ± 28,4) lm

Nr lampy	**P 469**						
$\alpha \cdot 10^{-5} A$	$\alpha_{śr} \cdot 10^{-5} A$		$s(\alpha_{śr}) \cdot 10^{-5} A$		$c_{kal} \cdot 10^{5} [lm/A]$		$u_B(\alpha_{śr}) 10^{-5} A$
				Φ[lm]			
1,7775	1,7782	0,00049175	0,00014196	2774,6	1562,5766		0,000289
1,7776							
1,7777							
1,7779							
1,7780							
1,7778							
1,7785							
1,7786							
1,7787							
1,7786							
1,7787		Jr	R	V		m_{Φ}	$\alpha \cdot \Delta t$
1,7788		2,0026	0,00999791	20,026	mV	6,875	0
1,7782				0,00005		0,267	
		1,00020869	1,00143564	1,001436			
Symbol	Estymata	standard uncertainty		distribution	sensitivity coefficient		uncertainty contribution
							[lm]
α	$1,7782 \cdot 10^{-5}$ A	0,00014196	10^{-5} A	normal	1560,337	10^{5}lm/A	0,221499
		0,000028868	10^{-5} A	rectangular	1560,337	10^{5}lm/A	0,45043
c	$1562,5766 \cdot 10^{5}$ lm/A	8,0472695	10^{5} lm/A	normal	1,7757	10^{-5} A	14,28914
R	0,00999791 Ω	4,5E-10	Ω	normal	1907929	lm/Ω	0,000859
m_{Φ}	6,875	0,15415252		rectangular	-0,578976	lm	-0,089251
$\alpha \cdot \Delta t$	0	0		rectangular	2774,59	lm	0
V	20,026 mV	0,00050065	mV	normal	-952,5272	lm/mV	-0,476883
Φ	2774,6 lm						**9,321056**
U(Φ) =	**28,612366**	lm	**1,03**	%			

Lamp N^{o} P 469 Φ = (2774,6 ± 28,6) lm

Technical Specification

of

INM (Romania)

EURAMET.PR-K4

II. EURAMET. PR-K4 (Luminous flux)

1. Make and type of the photometer: INM comparator is based on a 3 m dia. Schmidt Haensch sperical integrator and on a home made photometric head (**Fig. 1**).

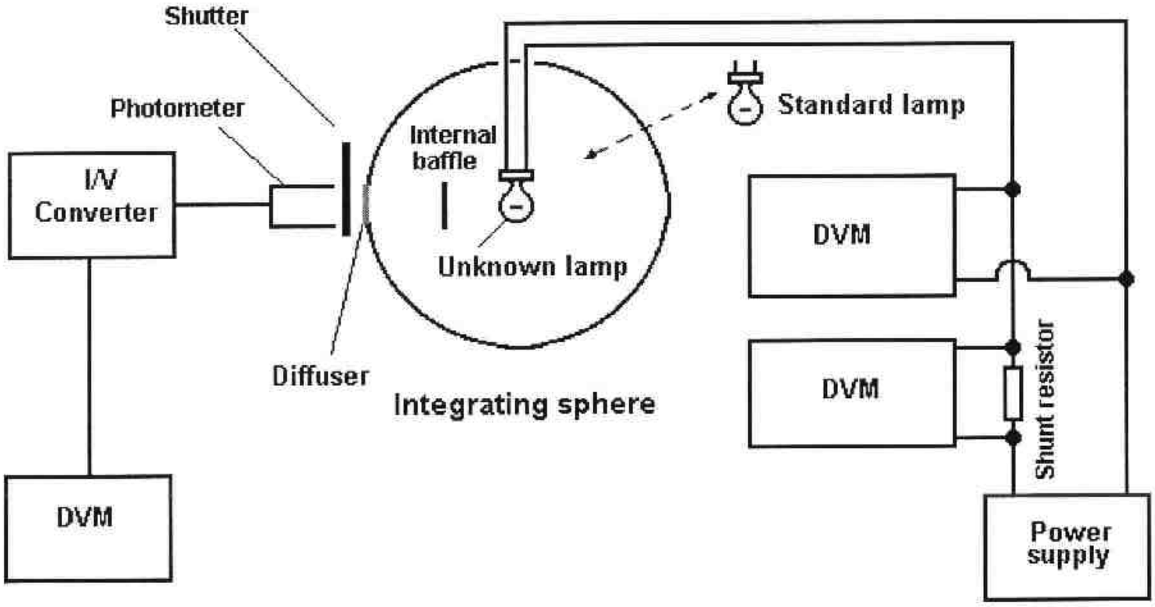


Fig. 1 Luminous flux transfer installation at INM

2. Laboratory transfer standard used: OSRAM Wi5 type lamps of 40 W…150 W

3. Description of measuring technique: Comparison by substitution with references of similar construction, in a sphere integrating comparator.

4. Establishment or traceability route of primary scale, last realisation date and uncertainty breakdown.

4.1 Reference standard last calibration and uncertainty breakdown

The reference standard used for the EURAMET PR K4 comparison measurements is a group of standard lamps traceable to the BIPM reference group (2002).

The reference lamps are very similar to the transfer standards used in the comparison (same make, same construction, same flux range, same color temperature.)

According to the BIPM calibration certificate no. 35 of 24 June 2002, for the reference group lamps the components of the estimated uncertainty are as follows:

KCRV and transfer to the BIPM reference group:	*0,25 %*
25Stability of the BIPM reference group:	*0,3 %*
Stability of the working standards:	*0,1 %*
Nonuniformity of sphere	*0,1 %*
Absorption correction	*0,1 %*
Dependence on lamp type:	*0,1 %*
Repeatability:	*0,15%*
Measurement of lamp current:	*0,01 %*
Colour temperature correction:	*0,01 %*
Combined uncertainty:	*0,5 %*

4.2 Unit transfer at INM

The measurand expression is:

$$\Phi_x = k \cdot V_x \cdot C_I \cdot C_T \cdot C_S. \qquad (3)$$

where: Φ_x is the luminous flux of the lamp under calibration;

V_x is the output voltage of the Current to Voltage converter (**Fig. 1**);

C_I is the correcting factor for the dc current in the lamp filament **.**

It`s associated uncertainty is: $u_{CI} = m \cdot u_I / I$ where m is the exponent in the eq. $I_v = kI^m$; m was experimentally estimated to be: $m \approx$ **6,6** so for $I \approx$ 0,37…1,0 A,: $u_{CI} \approx$ 0,0011

$$k = \frac{1}{N} \cdot \frac{C_A}{C_I} \cdot \sum_{i=1}^{N} \frac{\Phi_{e,i}}{V_{e,i}}$$

with: C_A = correction factor for the standard lamps ageing. Its estimated value is 0,996 with an associated standard uncertainty: $u_{CA} = 0{,}002$

$\Phi_{e,i}$ = certified flux values for the reference group lamps;

$V_{e,i}$ = output voltages of the Current to Voltage converter (for the reference lamps).

Lamp calibration uncertainty budget

Std. uncert. comp.	Type	Source of uncertainty	$u(x_i)$ (%)	c_i	Probability distribution	$c_i \cdot u(x_i)$ (%)
k	B	Lumenmeter calibration factor	0.56	1.00	normal	0.56
u_{V_x}	B	Measured voltage output of the Current to Voltage converter	0.015	1.00	normal	0.015
u_{C_I}	B	Correction factor for the current in the lamp filamant	0.11	1.00	normal	0.11
u_{C_T}	B	Correction factor for the color temperature of the lamp under test	0.07	1.00	normal	0.07
u_{C_S}	B	Sphere non-uniformity	0.10	1.00	normal	0.10
B type component						**0.58**
s	A	Measurement repeatability	0.10	1.00	normal	0.10
Combined standard uncertainty						**0.59**

5. Description of calibration laboratory conditions:

Temperature and humidity: T = 24+/-1 C; Rh = (50+/-10)%

Other conditions: calibration room relatively isolated from dust and electro-magnetic perturbations.

Integrating sphere diameter: 3 m

6. Operating conditions for the lamps.

Color Temperature: Tc= (2800+/-30) K established according the Blue-Red method, with traceability to the BIPM maintained references (2002).

6.1 Electrical parameters

Date *(dd/mm/yyy)*	Lamp serial	dc curent for Tc = (2800+/-30) K (A)	dc voltage (lamp in sphere) (V)	Luminous flux (lm)
30.06.2011	**LP8884**	**0.37639**	117.81+/-0.02	542.44
			117.80+/-0.02	542.05
			117.82+/-0.02	542.82
Mean:			**117.81+/-0.02**	**542.44**
30.06.2011	**3/866**	**0.53867**	113.47+/-0.02	801.95
01.07.2011			113.49+/-0.02	802.37
02.07.2011			113.50+/-0.02	802.85
Mean:			**113.49+/-0.02**	**802.39**
30.06.2011	**LP8885**	**0.55659**	112.45+/-0.02	810.32
01.07.2011			112.45+/-0.02	810.41
02.07.2011			112.46+/-0.02	810.62
Mean:			**112.45+/-0.002**	**810.45**
30.06.2011	**L105**	**0.91976**	106.81+/-0.02	1296.15
01.07.2011			106.82+/-0.02	1296.95
02.07.2011			106.83+/-0.02	1297.87
Mean:			**106.82+/-0.02**	**1296.99**
30.06.2011	**L107**	**0.91250**	104.73+/-0.02	1199.30
01.07.2011			104.73+/-0.02	1199.35
02.07.2011			104.75+/-0.02	1201.02
Mean:			**104.73+/-0.02**	**1199.89**

6.2 Geometrical alignment: All lamps were operated vertically, cap down, in controlled dc (**Fig. 1**)

6.3 Polarity: All lamps are supplied with positive voltage at the central contact of the socket.

6.4 Stay light reduction: NA

Operator: Amadeu Seucan and Mihai Simionescu
Laboratory: INM-Romania, Optical Quantities lab.

Date: July 10, 2011 Signature:

Technical Specification

of

INRIM (Italy)

EURAMET.PR-K4

UNCERTAINTY BUDGET

The luminous flux estimation from the reading of the detector at different position over the sphere is done using the following equation:

$$\Phi = 4\pi \cdot (R + k(\vartheta,\varphi))^2 \cdot \frac{1}{m} \cdot \sin\left(\frac{\Delta\vartheta}{2}\right) \cdot A + c$$

$$A = \sum_{i=1}^{n} \sin(\vartheta_i) \cdot \sum_{j=1}^{m} \left(s_v \cdot \frac{(S_l - S_{ldark}) - (S_s - S_{sdark})}{\cos(\varepsilon)} \right)_{i,j} \cdot \left(\frac{T_{source}}{T_{ref}}\right)_{i,j}^{p} \left(\frac{T_{source}}{T_{ref}}\right)_{i,j}^{q} \left(\frac{T_{source}}{T_{ref}}\right)_{i,j}^{r} \cdot \left(\frac{1}{\frac{\alpha}{100}\Delta T + 1} \right) \cdot \Gamma_{i,j}$$

$$\Gamma_{i,j} = (k_{\dim} \cdot k_{dir} \cdot k_{pol} \cdot k_{dis} \cdot k_{curr} \cdot k_{term})_{i,j}$$

$$k_{curr} = \left[\frac{c_l \cdot V_l}{R_s \cdot (1 + \beta \cdot \Delta T_s) \cdot I_{nom}} \right]^{m_\phi}$$

where:

- *Φ* luminous flux of the source;
- *R* distance of the photocell from the rotation center of the goniometer;
- *k(θ,φ)* correction coefficient that considers the possible deformations of the structure as a function of the angular position of the arm port detector;
- *φ* azimuthal coordinate of the reference system;
- *θ* polar coordinate of the reference system;
- *Δθ* *angular step in the polar coordinate*
- S_l value read by the detector, in the position i, j, when illuminated by the source;
- S_s value read by the detector, at the position i, j, during the measurement of the straylight;
- S_{ldark} value of the dark current of the detector, when illuminated by the source, at the position i, j;
- S_{sdark} value of the dark current of the detector, during the measurement of the straylight, at position i, j,;
- s_v sensitivity of the detector, expressed as readings over lux;
- *ε* angle accounting for the mismatch between source and detector;
- T_{source} color temperature of the source under measurement;
- T_{ref} reference color temperature 2856 K;
- *α* coefficient accounting for the variation of the sensitivity of the sensor with temperature;
- *ΔT* difference between the temperature of the photometric detector during the calibration and the temperature of the same during the measurement;
- *p* coefficient accounting for the photometric response of the detector to infrared radiation;
- *q* coefficient accounting for the imperfect adaptation of the spectral sensitivity of the sensor to V(λ);
- *r* coefficient accounting for the photometric detector response to ultraviolet radiation;
- k_{dim} coefficient accounting for the size and anisotropy of the source;
- k_{dir} coefficient accounting for the directional response of the photometric detector;
- k_{pol} coefficient accounting for the sensitivity to the polarization of the light of the photometric detector;
- k_{dis} coefficient accounting for the spatial non-uniformity of response of the photometric detector;
- k_{curr} coefficient accounting for the variation of the luminous flux (at the measurement position i, j) due to the change of the lamp current with respect to the nominal current;
- k_{tem} coefficient accounting for the variation of the luminous flux emitted by the lamp considering variations in laboratory temperature than the nominal measuring range;
- C_l calibration coefficient of the voltmeter to measure the supply current of the lamp;
- V_l reading of the voltmeter for measuring the supply current of the lamp (voltage across the resistor Rs) when the detector is in the position i, j,
- R_s value of the resistor used for measuring the supply current of the lamp;

β temperature coefficient of the resistor Rs;

ΔT_s difference between the temperature of the resistor Rs in the operating condition and temperature during the resistor calibration;

I_{nom} nominal supply current of the lamp;

m_ϕ exponent which considers the variation of the luminous flux emitted towards the variation of supply current of the lamp;

c numerical integration contribution;

m number of parallel measured;

n number of meridians measured.

The contribution of the coefficient $k(\theta,\varphi)$ was experimentally evaluated for different values of the angles(θ,φ). Since $k(\theta,\varphi)$ variations is of the same order of magnitude of the uncertainty on R, $k(\theta,\varphi)$ = 1 incorporating its uncertainty in the radius R.

The equation does not define the position of the source within the virtual sphere of radius R. Therefore, at least theoretically, an isotropic source may be positioned at any point, provided inside the sphere. To reduce the contribution of stray light and the uncertainty due to variations of the sensitivity of the cell with the direction of incidence of light, compared to the condition of calibration (normal incidence), the lamp is positioned at the center of the sphere, using a pointing system with two laser beams. The uncertainty of this alignment is estimated to be 10 mm and its contribution incorporated in the evaluation of the parameter k_{dir}.

From tests carried out with lamps of different types, the uncertainty associated with the size and anisotropy of the lamp is negligible. Therefore k_{dim} =1 and its uncertainty is incorporated in k_{dir}..

From the mechanical realization of the goniometer, the angular misalignment is extremely low (ε <0.1 °) and then it should be approximated with cos ε = 1. The contribution of this parameter to the uncertainty of the final measurement is included in the contribution associated with the directional sensitivity of the sensor, which is the dominant parameter.

Concerning the parameter k_{curr} the feedback system of the lamp current ensures the maintenance of the average value over the total duration of the measurement within the uncertainty of electrical parameters. Furthermore, the integration time used for the measurement of the illuminance and supply current of the lamp differs for 3 orders of magnitude and therefore the variations of the power supply current can not be related to a specific position illuminance measurement. The k_{curr} factor contributes only for purposes of calculating the final uncertainty.

Given the type of lamp and requirements of air conditioning of the laboratory parameter, k_{tem}=1 and the influence on the luminous flux of the ambient temperature negligible.

The contribution terms related to the influence of ultraviolet and infrared radiation are considered consistent with the position of the sensor. The sensor is designed to have low sensitivity in these two spectral regions, therefore, possible variations of T_{source} with the direction of measurement are second order corrections with respect to the other corrections. This consideration is not valid for the visible radiation. Unfortunately, the actual set-up does not allow the evaluation of the spectrum emitted in the directions of measurement. The term is therefore considered constant. For the calculation of the contribution to the uncertainty related to this parameter, as a precaution, it is considered an uncertainty twice as declared by the calibration of the lamp color temperature T_{source}.

The measurement is performed with a continuous motion of the goniometer along the meridians. The exact values of the parameters S_l and S_s refer to a single reading. Their uncertainties must consider both the characteristics of the instrument is the instability in the short term (noise) of the lamp. For this reason, two sets of measurements are performed with the goniometer initial stop. The uncertainty evaluated in these conditions is extended to all acquisitions.

To reduce the measurement duration the dark current of the photocell is not measured in all the position i, j but evaluated previously, in the heating phase and the stabilization of the lamp. Therefore we consider the contribution of the dark current constant during the measurement of the luminous flux either during the evaluation of the straylight, η (Sdark); only the contribution u (η (Sdark)) in the uncertainty budget should be .considered

From assessments obtained through computational simulations and measurements performed at different steps $\Delta\theta$ and $\Delta\varphi$ it has been determined that for the condition $\Delta\theta \leq 1°$ and $\Delta\varphi \leq 5°$ the contribution due to numerical integration c is negligible. These conditions are met by the measurement procedure.

With these considerations, the model can then be simplified as follows:

$$\Phi = 4\pi \cdot R^2 \cdot \frac{1}{m} \cdot \sin\left(\frac{\Delta\vartheta}{2}\right) \cdot \left(\frac{T_{source}}{T_{ref}}\right)^{p+q+r} \cdot \left(\frac{1}{\frac{\alpha}{100}\Delta T + 1}\right) \cdot K \cdot s_v \cdot \sum_{i=1}^{n} \sin(\vartheta_i) \cdot \sum_{j=1}^{m} \left(S_l - S_s + \eta(S_{dark})\right)_{i,j}$$

$$K = \left[\frac{c_l \cdot V_l}{R_s \cdot (1 + \beta \cdot \Delta T_s) \cdot I_{nom}}\right]^{m_\phi} \cdot k_{dir} \cdot k_{pol} \cdot k_{dis}$$

The uncertainty estimation of measurements is evaluated according to Table A where:

- The parameter d is the number of readings of the dark current carried out during the period of stabilization of the lamp (usually d = 1000) and the readings taken for the estimation of the uncertainties of S_l and S_s;
- the parameter e is the number of measurements of the supply current of the lamp performed during the period of measurement of the flow (usually between 50 and 70).

Table A - INRIM uncertainty budget

x_i	value			Distribution	Degree of freedom	Relative uncertainty contribution
	x_i	$u(x_i)$	unit		ν_i	
R	2,7949E+00	3,4641E-04	m	rect.	∞	1,43E-04
$\Delta\theta$	1,7453E-02	3,4907E-05	rad	rect.	∞	1,15E-03
θ		1,7453E-03	rad	rect.	∞	1,81E-06
S_l	3,8675E-01	3,0172E-04	au	rect.	d-1	4,55E-04
S_s	3,9066E-03	1,2220E05	au	rect.	d-1	1,84E-05
$\eta(S_{dark})$	3,8675E-04	1,5886E-05	au	normal	d-1	2,07E-05
s_v	5,2680E+01	4,7412E-01	lx / au^{-1}	rect.	∞	4,50E-03
T_{source}	2,7500E+03	4,0000E+01	K	rect.	∞	1,09E-03
p	4,0000E-02	6,9282E-04		rect.	∞	6,21E-06
q	5,0000E-02	8,6603E-04		rect.	∞	7,76E-06
r	4,0000E-02	6,9282E-04		rect.	∞	6,21E-06
α	1,0000E-02	1,7321E-04	% / K	rect.	∞	1,00E-06
ΔT	1,0000E+00	1,7321E-01	K	rect.	∞	9,90E-06
k_{dir}	1,0000E+00	1,7321E-03		rect.	∞	1,00E-03
k_{pol}	1,0000E+00	1,7321E-03		rect.	∞	1,00E-03
k_{dis}	1,0000E+00	1,7321E-03		rect.	∞	1,00E-03
V_l	9,9999E-01	8,0000E-06	V	rect.	∞	3,24E-08
C_l	1,0000E+00	5,5426E-06		normal	e-1	2,59E-08
R_s	5,0000E-01	1,7321E-05	Ω	rect.	∞	1,62E-07
β	5,0000E-06	5,0000E-08	Ω / K	rect.	∞	1,17E-15
ΔT_s	3,5000E+00	1,0000E-01	K	normal	e-1	2,02E-09
m_ϕ	8,0988E-03	8,0988E-05		rect.	∞	1,78E-10
Uncertainty u = Σ ($c_i \cdot u_i$)^2						5,10E-03
Extended uncertainty (k=2), U = k·u =						1,02E-02

Technical Specification

of

MIKES (Finland)

KALIBROINTITODISTUS
KALIBRERINGSBEVIS
CERTIFICATE OF CALIBRATION

Nro nr • no.	T-R 614
Tilaaja Uppdragsgivare • Customer	PTB / EURAMET.PR-K4 Key Comparison Bundesallee 100 D 38116 Braunschweig, Germany
Kalibroitu laite Kalibrerat instrument • Calibrated Instrument	4 photometric standard lamps. Calibrated for luminous flux.
Valmistaja Tillverkare • Manufactured by	Osram GmbH Hellabrunner Strasse 1 D-81543 München, Germany
Tyyppi Typ • Model	Osram Wi40/G Globe
Sarjanumero Serienummer • Serial number	lms9902, lms0003, lms0004, lms0005
Kalibrointipäivä Kalibreringsdatum • Date of calibration	29.10.2009
Päiväys Datum • Date	03.02.2010
Allekirjoitukset Underskrifter • Signatures	
	Pasi Manninen Branch Manager — Tuomas Poikonen Scientist
Sivu Sida • Page	1/4
Jakelu Utdelning • Distribution	Metrology Research Institute / Archive Metrology Research Institute / T.P.

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METHOD OF CALIBRATION

Calibration was based on the absolute integrating sphere method [1,2]. Lamp to be calibrated was mounted inside a large integrating sphere. External light source (Osram FEL operated at 2856 K) outside the sphere generated a reference luminous flux which was determined according to the following procedure: The illuminance produced by the external source was measured with a standard photometer at the aperture plane of a precision aperture, approximately 70 cm from the light source. The diameter of the aperture was 40 mm. The reference luminous flux passing through the aperture was obtained by multiplying the measured illuminance with the aperture area. The standard photometer was removed and the reference luminous flux entered the sphere through an opening on the sphere wall. A signal relative to this reference flux was measured with a photometer attached to the sphere. Another sphere photometer signal was recorded when the lamp under calibration was operated inside the sphere. The ratio of these signals and the known reference luminous flux were used to derive the luminous flux of the lamp under calibration.

Results were fine-tuned by correction factors obtained from the measurement system characterization, which included measurements of several spatial and spectral properties. More detailed information about these corrections can be found in [1].

TRACEABILITY

The reference luminous flux is traceable to the unit of luminous intensity of Metrology Research Institute and the national standards of length [Certificate of calibration T-R 582 and M-07L302]. The calibrations of the digital multimeters HP3458A (HP-1, HP-6) and the current-to-voltage converters Vinculum SP042 (Vinculum-2, Vinculum-3) are traceable to the national standards of electricity [Certificates of calibration INT 040, INT 054, INT 038 and INT 047]. The resistance of a precision shunt resistor (SR-00) used for measuring the lamp current is traceable to the resistance measurements of MIKES [Certificate of calibration M-07E043].

UNCERTAINTY

Expanded uncertainty of the calibration is 0.57 % ($k = 2$). Detailed uncertainty budget is presented in Table 1. The uncertainty estimations are based on the published papers [1,2].

CALIBRATED ARTIFACTS

The lamps under calibration were incandescent lamps with E27 screw bases and frosted spherical bulbs. Each lamp was operated for 15 minutes during the calibrations. The lamps worked fine during the calibration.

Table 1. Uncertainty budget of luminous flux at MIKES.

Source of uncertainty	Relative standard uncertainty [%]
System characterization and calibration	
Spatial correction factor scf_e	0.07
Spatial correction factor scf_i	0.05
Colour correction factors ccf_e / ccf_i	0.04
Correction for incident angle dependence β	0.10
Correction for illuminance non-uniformity k_a	0.03
Unit of illuminance	0.15
Transfer to standard photometer	0.10
Drift of the standard photometer	0.04
Photometer distance	0.10
Aperture area	0.01
Stray light	0.01
Drift of the reference lamp	0.01
Noise (illuminance)	0.01
Noise (reference flux)	0.02
Current measurement (illuminance)	0.01
Current measurement (reference flux)	0.05
Luminous flux measurement	
Non-linearity of the sphere photometer	0.01
Temperature increase	0.01
Noise	0.01
Current measurement	0.01
Other	
Sphere opening / closing	0.01
Repeatability (typical)	0.05
Lamp holder	0.10
Combined standard uncertainty	0.28
Expanded uncertainty (k = 2)	0.57

MEASUREMENTS

The measurements were carried out 29.10.2009 in the integrating sphere laboratory of Metrology Research Institute. During the measurements the ambient temperature of the laboratory was T_a = (24.4 ± 1.5)°C and the relative humidity of air was *R.H.* = (22 ± 5) %.

The lamps under calibration were mounted base up to a 4-pole lamp socket with negative polarity at the center of the lamp cap. The lamps were allowed to stabilize for 10 minutes before the calibration measurements started. Lamp voltages, lamp currents and photocurrents from the photometers were recorded during the calibration by taking 20 measurement samples with 2 second integration times. In addition, the dark currents from the photometers were measured and subtracted from the photocurrents.

RESULTS

The results of the return measurements are presented in Table 2. The revised results of the initial measurements with the updated uncertainties, are shown in Table 3. The uncertainty components of spatial correction factor scf_e, incidence angle correction factor β and unit of illuminance are re-evaluated.

Table 2. Results of the return measurements.

Lamp	Current [A]	Voltage [V]	CCT / K	Luminous flux [lm]
lms9902	5.6686 ± 0.0015	28.878 ± 0.002	2728 ± 20	2170.7 ± 13
lms0003	5.8497 ± 0.0015	30.126 ± 0.001	2712 ± 20	2374.9 ± 14
lms0004	5.8222 ± 0.0015	29.591 ± 0.001	2717 ± 20	2304.4 ± 14
lms0005	5.7335 ± 0.0014	29.310 ± 0.001	2709 ± 20	2200.4 ± 13

Table 3. Revised results of the initial measurements.

Lamp	Luminous flux / lm	CCT / K
lms9902	2162.8 ± 13	2729 ± 20
lms0003	2374.2 ± 14	2724 ± 20
lms0004	2307.2 ± 14	2727 ± 20
lms0005	2206.8 ± 13	2716 ± 20

[1] J. Hovila, P. Toivanen, E. Ikonen, "Realization of the unit of luminous flux at the HUT using the absolute integrating-sphere method," *Metrologia* **41**, 407–413 (2004).

[2] J. Hovila, P. Toivanen, E. Ikonen, Y. Ohno, "International comparison of the illuminance responsivity scales and units of luminous flux maintained at the HUT (Finland) and the NIST (USA)," *Metrologia* **39**, 219–223 (2002).

Technical Specification

of

PTB (Germany)

EURAMET.PR-K4

Annex G: Description of the measurement facility

M. Lindemann, PTB, 08/2013

Make and type of the integrating sphere:

For this comparison an aluminum integrating sphere with a diameter of 2.5 m was used (see fig. 1). The integrating sphere (1) consists of two separable hemispheres, each with a white diffuse reflecting barium sulphate coating, $BaSO_4$ (2).

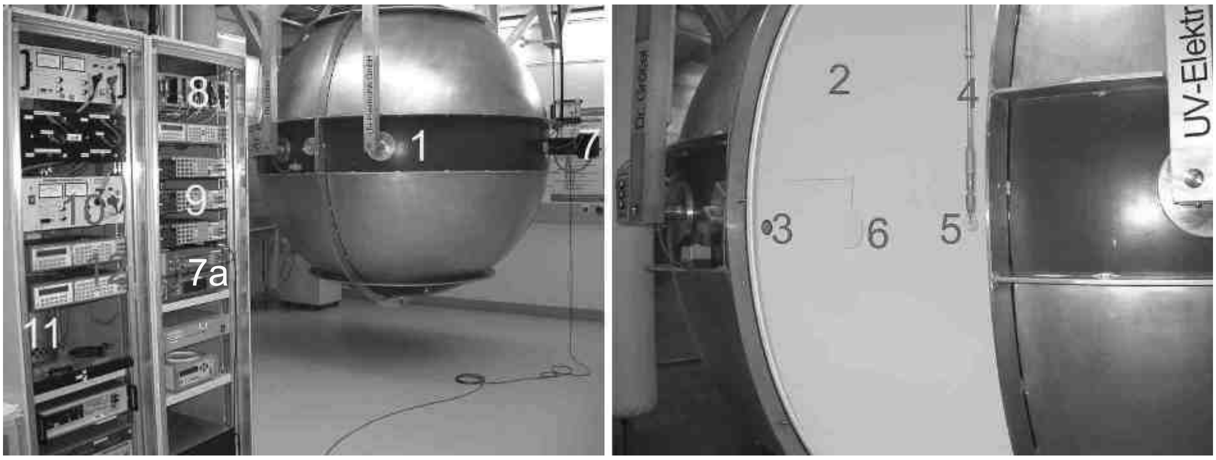
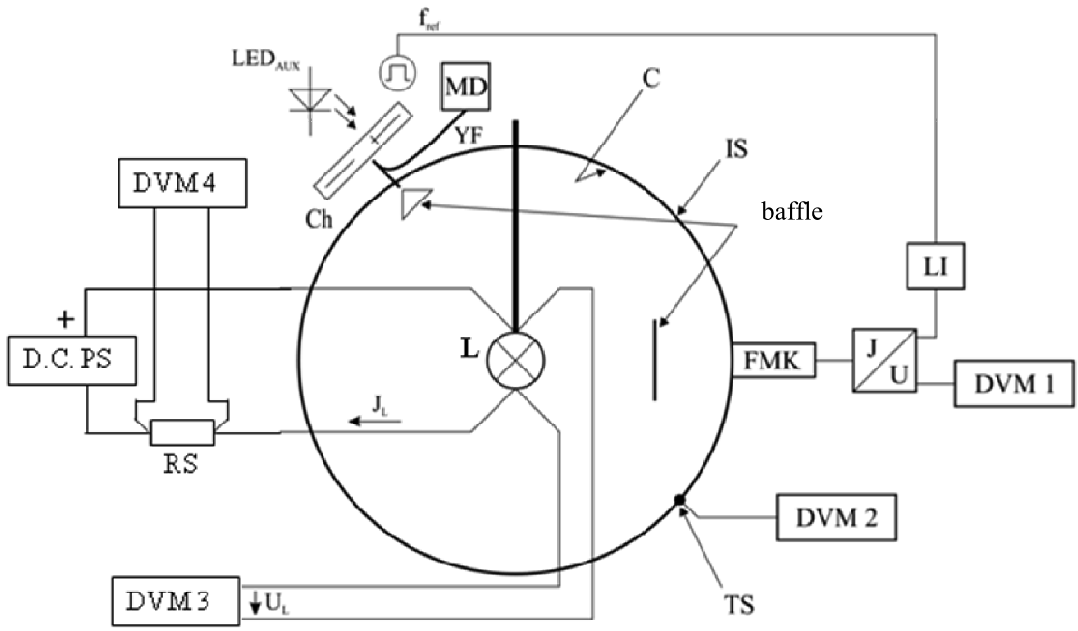


Fig. 1, integrating sphere, 2.5 m diameter

A cosine corrected photometer head (3) is installed in one hemisphere. A lamp holder (4) with quadruple lamp socket placed the lamp under test (5) or the reference lamp in the center of the integrating sphere. A baffle (6) between lamp and photometer entrance window avoids the direct illumination of the photometer. An auxiliary white LED (7) allows the self-absorption correction for the different lamps. The auxiliary lamp does not illuminate photometer or lamp directly. The auxiliary light is chopped by a chopper wheel and only a part of it reaches the integrating sphere via a y-fiber. The remaining light illuminates a monitor detector. A Lock-In amplifier (7a) is used to recover the chopped auxiliary signal. The photocurrent of the photometer is amplified by means of a photocurrent-amplifier (current to voltage converter, 8) and digitized by a digital voltmeter (9). The temperature of the integrating sphere is measured at different points distributed over the sphere. The lamps are operated with a D.C. power supply (10). The current of the lamp is measured via a shunt resistor (11). The voltage of the lamp is measured by means of further digital voltmeters (12). A more detailed schematic diagram of the integrating sphere is shown in fig. 2.



D.C. PS:	D.C. Power supply
RS:	Shunt resistor
LED_{AUX}:	Auxiliary lamp (LED)
Ch:	Light chopper (AC signal)
f_{ref}:	Reference frequency by chopper control unit
MD:	Monitor detector
YF:	Y-fiber
C:	Coating $BaSO_4$ with a reflectance $\rho \approx 0{,}95$
IS:	Integrating sphere ∅ = 2,5 m, material: aluminum (Al)
FMK:	Tristimulus head/photometer type LMT
$^{J}/_{U}$:	Current-to-voltage converter type 9710 (developed by PTB)
LI:	Lock-In-Amplifier, Signal Recovery Model 7270 DSP
DVM 1:	Digital volt meter HP 3456A (photocurrent)
DVM 2:	Digital volt meter HP 3457A (temperature of IS)
DVM 3:	Digital volt meter HP 3457A (lamp voltage)
DVM 4:	Digital volt meter HP 3457A (lamp current)
TS:	Integrating Sphere, NTC temperature sensor

Fig. 2 Schematic diagram of the integrating sphere

Description of calibration laboratory conditions: e.g. temperature, humidity etc.
- ambient temperature: 23°C (± 1°C)
- relative humidity: 45% (± 10%)
- clean room class: “100 000”

Uncertainty budget

The uncertainty budget of PTB takes into account all uncertainty contributions partially from the realisation and totally from maintenance of KCRV and dissemination in this comparison.

Model for Luminous Flux: The values of individual transfer standards of a batch are depending on the same (set) of reference standards, which creates correlated uncertainties. This correlation is avoided, if the contributions in the evaluation are separated into two factors A and B, for individual or common effects, respectively.

$$\Phi_X = A \cdot B \tag{1}$$

with

$$A = \left(\frac{273 + T_{KX}/°C}{273 + 23}\right)^{-m_K} \left[\frac{T_{DX}}{2856\ K}\right]^{-m_D} c_{NF} \frac{Y_{VMonLEDX}}{Y_{LIX}} \quad .. \\ .. \left[\frac{U_{SX}}{R_{SX0}(1 + \alpha_{SX}(T_{SX} - T_{SX0}) + \beta_{SX}(T_{SX} - T_{SX0})^2} \Big/ J_{X0}\right]^{-m_J} \frac{Y_{PX} - Y_{P0X}}{R_{gX}} \tag{2}$$

and

$$B = \Phi_R \left(1 + c_R \cdot \Delta t\right) \left(\frac{273 + T_{KR}/°C}{273 + 23}\right)^{m_K} \left[\frac{T_{DR}}{2856\ K}\right]^{m_D} \frac{Y_{LIR}}{Y_{VMonLEDR}} \quad .. \\ .. \left[\frac{U_{SR}}{R_{SR0}(1 + \alpha_{SR}(T_{SR} - T_{SR0}) + \beta_{SR}(T_{SR} - T_{SR0})^2} \Big/ J_{R0}\right]^{m_J} \frac{R_{gR}}{Y_{PR} - Y_{P0R}} \tag{3}$$

Values and explanations for the quantities and associated uncertainties are given below. Numbers are stated as typical for the PTB.

Φ_X	Luminous flux value corrected for nominal DC-lamp current J_{X0} and a related distribution temperature T_{DX}. The value of this quantity is the result of the calibration procedure and the associated relative expanded uncertainties has to be determined.
Φ_R	Luminous flux value corrected for nominal DC-lamp current J_{R0} and a related distribution temperature T_{DR}. The value of this quantity is the result of the calibration procedure and the associated relative expanded uncertainties has to be determined.
A	The factor contains all individual contributions, and the associated uncertainty can be reduced by averaging of the results from the members of a batch.
B	The factor is constant to all members of a batch of transfer standards and contains all common contributions. The associated uncertainty cannot be reduced by averaging processes.
T_{KX}, T_{KR}	Temperature in °C of the integrating sphere during the measurements.
T_{DX}, T_{DR}	Distribution temperatures in K of the lamps.
c_{NF}	Correction factor for the non uniformity response of the integrating sphere. This factor equals 1, but has an uncertainty.
Y_{LIX}, Y_{LIR}	Signal of Lock-In Amplifier represents self-absorption of the lamp and possible changing of the reflectivity properties of the integrating sphere. Must be corrected by $Y_{VMonLEDX}, Y_{VMonLEDR}$.
$Y_{VMonLEDX}, Y_{VMonLEDR}$	Corrects Y_{LIX}, Y_{LIR} for a possible changing of the auxiliary LED.
U_{SX}, U_{SR}	Mean values of n readings of the voltage drop across the shunt resistor. The empirical standard deviation of the means are taken as associated uncertainties (the resolution of the DVM was never limiting the standard deviation).
T_{SX}, T_{SR}	Temperatures of shunt resistors.
T_{SX0}, T_{SR0}	Nominal temperatures of shunt resistors.
R_{SX0}, R_{SR0}	Value of resistance of the shunt resistor at nominal temperature T_{SX0}, T_{SR0}.
α_{SX}, α_{SR}	Linear coefficients to calculate the shunt resistor value at temperature T_{SX}, T_{SR}.
β_{SX}, β_{SR}	Quadratic coefficients to calculate the shunt resistor value at temperature T_{SX}, T_{SR}.
J_{X0}, J_{R0}	The values of the lamp currents are fixed to achieve specified values of luminous flux and of distribution temperature. The values are stated as nominal values with neither an uncertainty nor a tolerance interval.
Y_{PX}, Y_{P0X}	Mean values of n readings of the current-to-voltage converter output, when measuring the light of the transfer standard. The values depend on the range setting and are given for light and dark measurements together with the empirical standard deviations of the mean taken as standard uncertainty (the resolution of the DVM was sufficiently high and never limiting the standard deviation).

Y_{PR}, Y_{P0R} Mean values of n readings of the current-to-voltage converter output, when measuring the light of the reference transfer standard. The values depend on the range setting and are given for light and dark measurements together with the empirical standard deviations of the mean taken as standard uncertainty (the resolution of the DVM was sufficiently high and never limiting the standard deviation).

m_K Exponent to correct the temperature of the integrating sphere.

m_D, m_J The mismatch index m_D of a photometer/sphere combination can have a positive or a negative value and the associated uncertainty may be even larger than the value. The second exponent m_J is describing the variation of luminous flux with a change of lamp current, is common to all incandescent lamps. The variation between different types of lamps may be included in the associated uncertainty interval.

R_{gX}, R_{gR} Gain of current-to-voltage converter

c_R Corrects for aging of the luminous flux reference lamp

At the pilot laboratory, the uncertainty budget is calculated using the software "Mathematica" and the three equations (1)..(3) are given first. The symbols, values with the associated standard uncertainties and degrees of freedom (DOF) for the contributions are listed below.
The calculation starts with the individual contribution, herein denoted as "uncorrelated". The budget is valid for all individual lamps, even if in this example representative values are taken instead of those for an individual lamp.

In the uncertainty budget below, the entries are sorted with the more important contributions at the bottom, which clearly shows, that a non uniformity response of the integrating sphere gives the highest contribution. The value of the effective DOF for the combined uncertainty was calculated from the Welch-Satterthwaite-equation. The last line shows these results for the factor A including uncertainty and relative contribution.

SYMBOL	VALUE	UNIT	UNCERTAINTY (IN)	DOF	SENSITIVITY	UNCERTAINTY	REL. UNCERTAINTY
J_{X0}	4.	A	0.	∞	0.000121942	0.	0.
T_{SX0}	23.	°C	0.	∞	-5.27917×10^{-9}	0.	0.
β_{SX}	-5.3702×10^{-7}	1	5.3702×10^{-8}	47.	0.000107747	5.78623×10^{-12}	8.3039×10^{-8}
Y_{P0X}	0.0102	V	0.0000102	19.	-0.0000112938	-1.15197×10^{-10}	-1.6532×10^{-6}
mK	0.0146	1	0.002	5.	1.17804×10^{-7}	2.35608×10^{-10}	3.38123×10^{-6}
α_{SX}	0.000011328	1	1.1328×10^{-6}	47.	0.000229249	2.59693×10^{-10}	3.72689×10^{-6}
R_{gX}	999759.	Ω	7.	∞	-6.96977×10^{-11}	-4.87884×10^{-10}	-7.00169×10^{-6}
mJ	7.	1	1.	∞	9.06206×10^{-10}	9.06206×10^{-10}	0.0000130051
T_{SX}	23.47	°C	0.2	9.	5.27917×10^{-9}	1.05583×10^{-9}	0.0000151524
T_{KX}	22.5	°C	0.7	19.	-3.44278×10^{-9}	-2.40995×10^{-9}	-0.0000345854
mD	-0.0804	1	0.008	78.	3.914×10^{-6}	3.1312×10^{-8}	0.000449362
U_{SX}	0.400021	V	0.0000400021	9.	-0.00121935	-4.87766×10^{-8}	-0.0007
R_{SX0}	0.100006	Ω	0.0000100006	47.	0.00487737	4.87766×10^{-8}	0.0007
T_{DX}	2700.	K	30.	5.	2.07494×10^{-9}	6.22483×10^{-8}	0.000893333
c_{NF}	1.	1	0.001	∞	0.0000696809	6.96809×10^{-8}	0.001
Y_{PX}	6.18005	V	0.00618005	19.	0.0000112938	6.97961×10^{-8}	0.00100165
$Y_{VMonLEDX}$	0.905	V	0.0012	9.	0.0000769955	9.23946×10^{-8}	0.00132597
Y_{LIX}	0.0798	V	0.00015	9.	-0.000873195	-1.30979×10^{-7}	-0.0018797
A	0.0000696809	1	-	53.	-	2.12229×10^{-7}	0.00304572

The second factor for the determination of the luminous flux as output quantity is the common contribution, also denoted as "correlated" factor. In the list all entries are sorted again with increasing contribution. In this budget, the realisation of the units and the transfer by the reference lamp(s) gives the dominant contribution, a result just as expected for a high level transfer.

SYMBOL	VALUE	UNIT	UNCERTAINTY (IN)	DOF	SENSITIVITY	UNCERTAINTY	REL. UNCERTAINTY
J_{R0}	3.8	A	0.	∞	-3.67281×10^{7}	0.	0.
T_{SR0}	23.	°C	0.	∞	1540.54	0.	0.
β_{SR}	-5.3702×10^{-7}	1	5.3702×10^{-8}	47.	-1.01744×10^{7}	−0.546385	-2.7404×10^{-8}
mJ	7.	1	1.	∞	−3.22376	−3.22376	-1.61688×10^{-7}
Y_{P0R}	0.0102	V	0.0000102	19.	3.44471×10^{6}	35.1361	1.76225×10^{-6}
mK	0.0146	1	0.002	5.	20197.3	40.3947	2.026×10^{-6}
α_{SR}	0.000011328	1	1.1328×10^{-6}	47.	-3.76829×10^{7}	−42.6872	-2.14099×10^{-6}
R_{gR}	999759.	Ω	7.	∞	19.9429	139.601	7.00169×10^{-6}
T_{SR}	23.27	°C	0.2	9.	−1540.54	−308.107	−0.0000154532
Δt	0.5	h	0.1	1.	−3988.02	−398.802	−0.000020002
c_R	−0.0002	1	0.00005	∞	9.97006×10^{6}	498.503	0.0000250025
T_{KR}	23.3	°C	0.7	19.	982.439	687.707	0.0000344921
mD	−0.0804	1	0.008	78.	−112012.	−896.098	−0.0000449439
U_{SR}	0.380024	V	0.0000380024	9.	3.67258×10^{8}	13956.7	0.0007
R_{SR0}	0.100006	Ω	0.0000100006	47.	-1.39558×10^{9}	−13956.7	−0.0007
T_{DR}	2840.	K	30.	5.	−564.446	−16933.4	−0.000849296
Y_{PR}	5.79824	V	0.00579824	19.	-3.44471×10^{6}	−19973.3	−0.00100176
$Y_{VMonLEDR}$	0.904	V	0.0012	9.	-2.20555×10^{7}	−26466.5	−0.00132743
Y_{LIR}	0.0801	V	0.00015	9.	2.48915×10^{8}	37337.3	0.00187266
Φ_R	1302.26	lm	3.906	21.	15310.4	59802.4	0.0029994
B	1.99381×10^{7}	lm	-	50.	-	82145.8	0.00412004

Finally the combination of the two factors gives the value and associated uncertainty of the luminous intensity.

$$\Phi_X = A \cdot B = 0.0000696809 \cdot 1.99381 \cdot 10^7 \text{ lm} = 1389.31 \text{ lm}$$

The luminous flux of the lamp transfer standard was determined with a value and associated relative expanded uncertainty for a coverage factor of k = 2 for an interval containing a 95.45% fraction of probability and reads:

$$u_{rel}(\Phi_X) = \sqrt{u_{rel}^2(A) + u_{rel}^2(B)} = \sqrt{0.00304572^2 + 0.00412004^2} = 0.0051$$

$$\Phi_{X,Print} = 1389.31 \text{ lm} \cdot (1 \pm k \cdot u_{rel}(\Phi_X)) = 1389.31 \text{ lm} \cdot (1 \pm 0.010)$$

Technical Specification

of

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Date
2012-03-01

Reference
PR-K4 (RMO569)

Page
1 (1)

Your reference
Armin Sperling

Physikalisch-Technische Bundesanstalt
4.12 Photometry

SP Sweden Luminous Flux results, second measurements

The measurements were performed in Jan-Feb 2012, at SP Borås, Sweden.
Room temperature: (23 ± 1) °C
Lamp type: GEC-Hirst 200W
Lamp orientation: Vertical, cap up
Polarity: + cap bottom, - cap side
Lamp stabilization time: 15 min

The lamps' identities are written on the lamp caps. Lamp 90:2 was broken prior to any measurements were taken.

Table 1. Lamp data

Lamp no.	Operating current (A)	Lamp voltage (V)	CCT (K)
88:1	2,0400	97,87	2869
90:1	2,0400	94,70	2854
90:2	*Broken*	*Broken*	*Broken*

Table 2. Measured luminous flux (mean of 3 different measurements):

Lamp no.	Luminous flux (lm)	Uncertainty (k=1)
88:1	**3166,6**	±0,63 %
90:1	**2986,3**	±0,63 %
90:2	-	-

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Page
1 (1)

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Physikalisch-Technische Bundesanstalt
4.12 Photometry

SP Sweden Luminous Flux results, completed

The measurements were performed 29-30 April, 2008, at SP Borås, Sweden.
Room temperature: (23 ± 1) °C
Lamp type: GEC-Hirst 200W
Lamp orientation: Vertical, cap up
Polarity: + cap bottom, - cap side
Lamp stabilization time: 15 min

Prior to the first measurements the lamps were cleaned with a soft cloth. The lamps' identities are written on the lamp caps.

Table 1. Lamp data

Lamp no.	Operating current (A)	Lamp voltage (V)	CCT (K)
88:1	2,0400	97,76	2870
90:1	2,0400	94,63	2840
90:2	2,0200	100,76	2720

Table 2. Measured luminous flux:

Lamp no.	Luminous flux (lm)			Uncertainty (k=1)
	29/4-08	30/4-08	**Mean**	
88:1	3182,0	3178,7	**3180,4**	±0,63 %
90:1	2998,0	2994,5	**2996,3**	±0,63 %
90:2	2481,9	2485,1	**2483,5**	±0,63 %

SP Technical Research Institute of Sweden
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16/5-08

Stefan Källberg

Annex G: Description of the measurement facility

Make and type of the photometer (or equivalent)
Photometric detector OSRAM CENTRA, V(lambda), fitted at the exit port of a 1,5 m integrating sphere.

Laboratory transfer standards used:
Several G.E.C Hirst 200 W (G.E.C Hirst was later aquired by Polaron, thus the similarity with LF200W)

Description of measuring technique (please include a diagram)
Direct comparison with primary standards of the same type, and with only small differences in total flux and CCTs.
Each lamp is measured the following way (vertical, cap up): After a 15 minutes stabilization time the measurement starts. A total of 9 separate measurements are taken automatically , with the lamp rotated 45° degrees around its vertical axis between each measurement (pos 1 and 9 is the same and only used for stabilization check). Also, the lamp current (measured over a precision resistor) and voltage is recorded.

Establishment or traceability route of primary scale including date of last realisation and breakdown of uncertainty:
A group of primary standards is calibrated on a regular basis, earlier at the BIPM, the last times at HUT Finland. Immediately after calibrating the primary standards, several working standards of different types are calibrated at SP. All lamps are closely followed up concerning their stability.

The latest calibration of the primary standards was performed by HUT in May, 2005. Typically the primary standards are burned less than 1 h/year, and no significant drift have been detected over the last 10 years.

In the

Source of uncertainty	Standard uncertainty u (k=1)
Calibration primary standards	0,50 %
Drift primary standards	0,20 %
Overall repeatability	0,10 %
Lamp current	0,18 %
Spectral mismatch (sphere+detector)	0,17 %
Straylight	0,06 %
Temperature effect sphere	0,12 %
Flux distribution	0,12 %
System linearity	0,06 %
Combined standard uncertainty (k=1)	0,63 %

Description of calibration laboratory conditions: e.g. temperature, humidity etc.
Laboratory temperature: (23 ±2) °C
Humidity: (40 ±10) % RH

Operating conditions of the lamps: e.g. geometrical alignment, polarity, stray-light reduc-tion etc.

Positive polarity (+ cap bottom, – cap side)
Stray-light: Closed sphere
Alignment: The position of the lamp is by visual means adjusted so that the lamp is centred around the baffle covering the exit port from direct radiation.

Operator: Stefan Källberg

Laboratory: SP

Date: Signature: 16/5-08 [signature]

Technical Specification

of

VSL (Netherlands)

EURAMET.PR-K4

VSL

EURAMET. PR-K4

Final report

Version	Date	Name	Description
V1.0	28 June 2012	Daniël H.C.D. Bos	Creation
V1.2	11 July-10 Aug 2012	Elena Revtova	Review, Editing
V2.0	06 Feb - 20 Feb 2013	E. Revtova, D. Bos, J. Snoeij	Review, Revision
V3.0	6 May 2013	E. Revtova	Approval

1 Introduction

This document describes the VSL (Dutch Metrology Institute) calibration procedure of a light source in terms of the total luminous flux used in the Key Comparison project No 569 "Euramet.PR-K4: Luminous flux".

Measurement of the total luminous flux of a lamp using an integrating sphere can be done in several different ways. At VSL a comparison (relative) method is used.

The traceability route of the facility, the uncertainty of the measurement as well as the analysis of the measurement results will be discussed below.

2 Artefacts

In this Key Comparison four artefacts have been used. According to the protocol [1] the star-type comparison has been organized in such a way that the artefacts owned by VSL have been initially measured by VSL ("direct measurements"), then distributed to the pilot to perform calibration according to KCRV (PTB, Germany) and after that returned back to VSL for the repeating set of measurements to monitor drift ("return measurements").

The following set of lamps has been used as artefacts at VSL:

Type	Polaron		Osram	
Specification	60 W	60W	Wi40G_SN13-B-DO	Wi40G_SN18-B-UP
ID	P379	P485	13	18
Typical Voltage	~110 V	~110 V	~31 V	~31 V
Typical current	~0.5 A	~0.5 A	~5.9 A	~5.9 A

3 Transfer standards and photometer

The following set of transfer lamp standards have been used for the measurements:

Type	Philips		Philips	
Specification	60 W	60W	180 W	180 W
ID	601560	601561	12000116	12000143
Typical Voltage	~110 V	~110 V	~220 V	~220 V
Typical current	~0.5 A	~0.5 A	~0.87 A	~0.87 A

The standard photometer used is given below:

Photometer	LMT head type P30SOT, s/n SN129520

The flat diffuser of the photometer has the diameter of 30±0.1 mm. The standard photometer is traceable to Absolute Cryogenic Radiometer at VSL.

4 Measurement method

The total luminous flux of a lamp is determined by comparing the measurement result (amount of illuminance in voltage) with a reference standard lamp which luminous flux value has been predetermined and taken to be known within a specified uncertainty.

The method as described in [2] is applied at VSL. A calibrated illuminance meter (luxmeter) is used as a detector to measure the indirect illuminance on the sphere wall. This illuminance is proportional to the total luminous flux of the light source. The luxmeter is connected to a trans-impedance amplifier (AMP) which is then connected to a digital multimeter (DMM). The amount of illuminance detected is calculated by converting the voltage obtained from the DMM to illuminance.

An auxiliary lamp is used to correct for the influence of the artefacts (e.g. . lamp itself, baffles, lamp holder etc.) on the measurement result.

The temperature at one position on the inside wall is measured during a measurement to keep track of the temperature fluctuations during the calibration.

4.1 Measurement range and best measurement uncertainty

The calibration method under consideration is only applicable when the following list of criteria is adhered to:

- A homogenous radiating lamp operated at a correlated color temperature (CCT) within 2650K to 3100K.
- The size, shape and electrical power of the lamp to be measured don't differ from the reference standard lamp.
- The lamp to be measured is a plancking radiator.

At VSL the direct and return measurements have been fulfilled on different facilities. The direct measurement has been done with the use of 1 m integrating sphere and return measurement with the use of the new 3 m integrating sphere which has been installed and validated in 2011. Therefore, two different measurement ranges and uncertainty estimations are given in tables 1 and 2.

The measurement method used in both cases is the same.

The tables 1 and 2 state the minimum and maximum total luminous flux values which can be measured with VSL facilities as well as the relative Uncertainty.

Column 1 gives the minimum luminous flux measurable with the facility, column 2 the maximal luminous flux measurable the facility, and column 3 an example of the best attainable uncertainty. The minimum value is a result of the fact that the detector has a certain minimum light needed to function properly. The maximum value is due to the temperature rise of the sphere and its influence on the CCT inside the sphere, and the detector sensitivity to that.

Table 1: Total luminous flux level attainable with 1 m integrating sphere and the relative Uncertainty (k=2)

$\Phi_{v\,min.}$ (lm)	$\Phi_{v\,max.}$ (lm)	$u(\Phi_v)$ (%)
30	3500	0.56

Table 2: Total luminous flux level attainable with 3 m integrating sphere and the relative Uncertainty (k=2)

$\Phi_{v\ min.}$ (lm)	$\Phi_{v\ max.}$ (lm)	$u(\Phi_v)$ (%)
30	30000	0.44

Note: the best measurement capability (Uncertainty) is documented in [3].

4.2 Measurement setup

The measurement setup (3 m sphere as an example) consists of several components which are depicted in Figure 1. It consists of two lamps, namely a lamp that should be measured (L_{Std}), which is placed in the middle of the sphere, and an auxiliary lamp (L_{Aux}) which is fixed at the side of the sphere. There are two baffles inside the sphere, one in front of the auxiliary lamp (B_{Aux}) and another in front of the detector (B_{Std}). Two alignment lasers (L1 and L2) are used to define the middle of the sphere. An illuminance detector (S) is attached at the side of the sphere to measure the light reflected from the inner wall of the sphere. The baffle in front of the detector is translatable in the horizontal direction to change the distance between baffle and detector. The distance between baffle and detector should be A = D/6 or A = D/4 according to [4], where D is the diameter of the sphere (which are 1 meter and 3 meters in our case). The two distances are dependent on the lamp diameter (see table 3 for more details). The temperature is monitored at one position in the sphere using a thermistor (1 m sphere) or a Climate System sensor (3 m sphere).

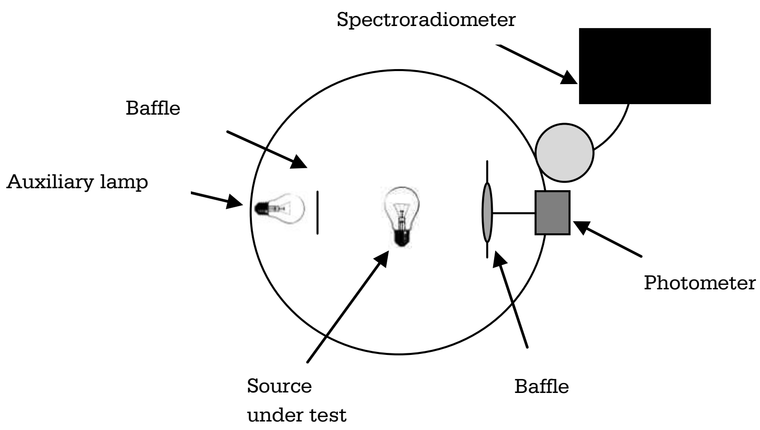

Figure 1: Top view schematic depiction of the 3 m sphere setup.

5 Traceability:

5.1 Traceability chain

The reference standards are traceable to the spectral irradiance responsivity which is traceable to the spectral responsivity scale (Absolute Cryogenic Radiometer) of Optics group at VSL. The electrical measurement instrumentation (digital multimeter, zeroflux and amplifiers) are traceable to the group of Electricity at VSL. The color temperature of the illumination standard is traceable through the calibration with SIRF (Spectral IrRadiance Facility) of Optics group at VSL.

Figure 2 shows the traceability scheme for the luminous intensity as it is derived at VSL.

The primary scale realizations for the periods of both runs are given in the following list.

- Spectral responsivity scale on the Absolute Cryogenic Radiometer (ACR) in 2007 en validation in 2010;
- Spectral irradiance responsivity in 2007 and 2010;
- Illuminance responsivity in 2008.

The VSL luminous flux realization is based on a goniometer facility named RAD3D. This goniometer has a detector platform with a tristimulus meter and an array-spectroradiometer on it. The platform scans the illuminance distribution over a virtual sphere surface around the measured lamp. The diameter of the virtual sphere is 3 meter.

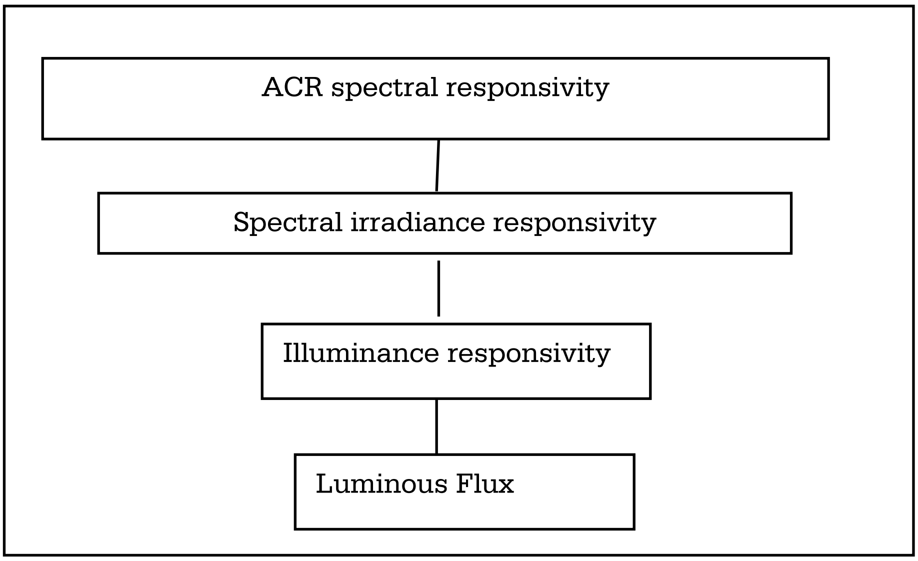

Figure 2. Traceability chain

The uncertainty budget for luminous flux defined with the goniometer is mainly based on the uncertainty of the tristimulus meter, the radius of the virtual sphere, stray light of the room, step size illuminance distribution and the stability (including drift) of the source to be measured. This leads to an overall uncertainty of the RAD3D facility to ($k=1$) of 0.28% (see table 3).

Table 3: Uncertainty budget for luminous flux based on the RAD3D goniometer.

Quantity	estimate	unit	standard	probability	sensitivity	uncertainty	uncertainty
Xi	Xi	xi	uncertainty	distribution	coefficient		%
			u(xi)			u(yi)	u(yi)
Detector	1.00E+00	lm	2.00000E-03	normal	1.00000E+02	2.00000E-03	0.20
Drift	1.00E+00	lm	5.00000E-04	normal	1.00000E+02	5.00000E-04	0.05
Source	1.00E+00	lm	1.00000E-03	normal	1.00000E+02	1.00000E-03	0.10
Stray light	1.00E+00	lm	1.40000E-03	normal	1.00000E+02	1.40000E-03	0.14
Radius	1.00E+00	lm	8.00000E-04	normal	1.00000E+02	8.00000E-04	0.08
Steps	1.00E+00	lm	5.00000E-04	normal	1.00000E+02	5.00000E-04	0.05
Φ_m	1.0000				*k=1*	2.84605E-03	0.28

The goniometer facility is designed to measure lamps in the base-down position. In order to participate to the Euramet K4 key comparison it was needed to perform the measurements in base-up position. This was performed by using two integrating sphere facilities. The direct measurement of the Key Comparison was based on a 1 meter sphere and the return measurement was based on a 3 meter sphere. In both cases the spheres were at first calibrated using standard lamps calibrated on the RAD3D goniometer in base-down position. Secondly, the base up/down ratio was investigated for correction which was then applied.

5.2 Uncertainty breakdown

The luminous flux (based on a integrating sphere) of the lamp is calculated as follows,

$$\Phi_v = \Phi_{ref} \cdot \frac{E_{v,m}}{E_{v,ref}} \cdot \frac{E_{v,aux1}}{E_{v,aux2}} = \Phi_{ref} \cdot \left(\frac{U_{v,m}}{A_{v,m}} \cdot \frac{1}{S_v} \right) \cdot \left(\frac{U_{v,aux1}}{A_{v,aux1}} \cdot \frac{1}{S_v} \right) \cdot \left(\frac{U_{v,ref}}{A_{v,ref}} \cdot \frac{1}{S_v} \right)^{-1} \cdot \left(\frac{U_{v,aux2}}{A_{v,aux2}} \cdot \frac{1}{S_{v,}} \right)^{-1}$$

(1)

where: $E_{v,ref}$ is the measured illuminance of the reference lamp

$E_{v,m}$ is the measured illuminance of the lamp to be measured

Ev,aux1 is the measured illuminance of the auxiliary lamp with reference lamp present in the sphere

Ev,aux2 is the measured illuminance of the auxiliary lamp with lamp to be measured present in sphere

Φref is luminous flux of reference lamp

Φv is luminous flux of the lamp to be measured.

Sv is the responsivity of the reference standard luxmeter including sphere

Uv is the measured voltage

Av is the amplification factor

The uncertainty budget for the integrating sphere facilities is based on the following components.

The total uncertainty in the measured lumen value is given by

$$u^2(\Phi_m) = u^2(\Phi_v) + u^2(\varsigma_v) + u^2(\Phi_{ref}) + u^2(\Theta) + u^2(\Gamma) \qquad (2)$$

where Φ_m : is the calculated luminous flux of the customer lamp

Φ_v : is the calculated luminous flux of a lamp

ζ_v	:	is the detector system
Φ_{ref}	:	is the lumen value of the reference standard lamp.
Θ	:	is the integrating sphere
Γ	:	is the lamp to be measured

The uncertainty of the lumen value Φ_{ref} of the reference standard lamp is traceable to the RAD3D.

The uncertainty of the luminous flux of a lamp is analytically calculated using equation (1). The procedure is summarized by the following.

$$u^2(\Phi_v) = \left[\sum_{i=1}^{n} \left[c_i \cdot \frac{\partial \Phi_v}{\partial x_i} \right]^2 \right] \qquad (3)$$

where c_i is the uncertainty of component *i* previously determined.

x_i is component (factor) *i* on which Φ_v is dependent on.

The uncertainty in ζ_v (given in equation 2) is calculated with the uncertainty in the current measurement and the relative uncertainty in the luxmeter dependence on CCT.

$$u^2(\varsigma_v) = \left[\Phi_m \cdot \frac{u(I_{st})}{I_{st}} \right]^2 + \left[\sigma_{T_v} \cdot \Phi_m \right]^2 \qquad (4)$$

where $u(I_{st})$ is the uncertainty in the calculated current

σ_{Tv} is the relative uncertainty in the luxmeter dependence on CCT.

With

$$u^2(I_{st}) = \left[I_{st} \cdot \frac{u(U)}{\bar{U}} \right]^2 + \left[I_{st} \cdot \frac{u(A)}{A} \right]^2 \qquad (5)$$

where $\bar{U}$ is the average voltage measurement

A is the amplification factor of the amplifier

u(U) is the uncertainty of the average voltage measurement also includes uncertainty in digital multimeter (DMM).

u(A) is the uncertainty of the amplification factor of the amplifier.

The uncertainty in the average voltage measurement is given by,

$$u^2(\bar{U}) = \left[\frac{\sum_{i=1}^{n} \left(\bar{U} - U_i \right)^2}{n \cdot (n-1)} \right] + \left[\sigma_{DMM}(U) \cdot \bar{U} \right]^2 \qquad (6)$$

where U_i is one voltage measurement of a sample of n measurements

$\bar{U}$ is the average voltage of a sample of n measurements

σ_{DMM} is the relative uncertainty of the digital multimeter (DMM)

The relative uncertainty in the luxmeter responsivity is traceable to the ACR.

The relative uncertainty in the detector dependence on CCT was investigated in a specified range of CCT for the LMT P30SOT in [3].

The total uncertainty of the integrating sphere u(Θ) is given by

$$u^2(\Theta) = \left[\Phi_v \cdot \frac{u(T_\Theta)}{T_\Theta}\right]^2 + \left[\Phi_v \cdot \delta_{CCT}\right]^2 \quad (7)$$

where T_Θ is the temperature of the sphere measured at one point

δ_T is the relative uncertainty concerning the effects related to the influence which temperature has on the sphere on the inside

There is no term for the uncertainty in the baffle positioning. The effect of mispositioning was investigated and seen to be nihil, and thus not included in the uncertainty budget.

The uncertainty in the temperature is given by:

$$u^2(T_\Theta) = \left[\frac{\sum_{i=1}^{n}\left(\bar{T} - T_{\Theta,i}\right)^2}{(n-1)}\right] + u^2(T_{sensor}) \quad (8)$$

where $T_{\Theta,i}$ is a single temperature measurement

T_Θ is the average temperature taken over n measurements

T_{sensor} is the uncertainty in the sensor used to measure the temperature

The relative uncertainty concerning the temperature dependence of the sphere was investigated in [3].

The temperature sensor is traceable to temperature the department.

The total uncertainty with respect to the lamp to be measured u(Γ) is given by

$$u^2(\Gamma) = \left[\Phi_v \cdot \frac{u(U_\Gamma)}{U_\Gamma}\right]^2 + \left[\Phi_v \cdot \delta_\Delta\right]^2 + \left[\Phi_v \cdot \delta_\alpha\right]^2 + \left[\Phi_m \cdot \delta_i\right]^2 \quad (9)$$

where $u(U_\Gamma)$ is the uncertainty in the stability of the light output of the lamp in

term of voltage

δ_Δ is the relative uncertainty in alignment of the lamp

δ_α is the uncertainty in the difference of the radiation pattern between the reference lamp and the customer lamp to be measured (i.e. the non-uniformity of the sphere wall)

δ_i is the relative uncertainty in the lamp current.

The uncertainty in the stability of the lamp in terms of light output is given in equation 10.

$$u^2\left(\bar{U}_\Gamma\right) = \left[\frac{\sum_{i=1}^{n}\left(\bar{U}_\Gamma - U_{\Gamma,i}\right)^2}{n\cdot(n-1)} + \left[\sigma_{DMM}\left(U_\Gamma\right)\cdot\bar{U}_\Gamma\right]^2 \right] \qquad (10)$$

where $\bar{U}_\Gamma$ is the average voltage of a sample of n measurements

σ_{DMM} is the relative uncertainty of the digital multimeter (DMM)

The relative uncertainty in alignment of the lamp in both the vertical and horizontal direction was investigated for both integrating sphere facilities. In both cases the uncertainty contribution is negligible. This also counts for the influence of the non-uniformity in reflection of the sphere wall as the reference lamp has an equal illuminance distribution compared to the lamps used in this Key Comparison.

6 Uncertainty budget (typical)

The typical uncertainty budget of luminous flux of a 60W Polaron lamp obtained with the use of 3 m integrating sphere is shown in table 4.

7 Description of calibration laboratory conditions

Temperature and humidity data in the laboratory space (outside the sphere facility) have been obtained in multiple places through the use of temperature sensors of the internal climate system at VSL. The sensors are traceable to Temperature department standards.

Additionally, during each optical run the temperature and humidity was measured inside the sphere facility (at one point behind the detector baffle) with the use of one of the sensors of the same internal climate system.

The nominal condition of the laboratory space is the temperature of 25 ± 0.5 °C and humidity of 45 ± 10 %.

These data are not used for the standard photometer values corrections as it is temperature stabilized.

Table 4: The typical uncertainty budget for luminous flux of the Euramet K4 lamps (3 m sphere).

Quantity	Symbol	estimate	unit	standard	probability	sencetivity	uncertainty	uncertainty
Xi	Xi	Xi	xi	uncertainty	distribution	coefficient		%
				u(xi)			u(yi)	u(yi)
Stability of light output	$u(U_\Gamma)/U_\Gamma$	1.0000		9.42894E-05	normal	4.42201E+02	4.16948E-02	0.01
alignment	δ_Δ	1.0000		1.41421E-03	normal	4.42201E+02	6.25367E-01	0.14
non-uniformity reflection of sphere wall	δ_α	1.0000		5.77350E-04	rectangular	4.42201E+02	2.55305E-01	0.06
uncertainty in lamp current	δ_i	1.5000	A	8.00000E-05	normal	4.42201E+02	3.53761E-02	0.01
Lamp under test	Γ						**6.76399E-01**	**0.15**
calculated lamp current	$u(I_{st})/I_{st}$	1.0000		9.67762E-05	normal	4.42201E+02	4.27945E-02	0.01
spectral mismatch dependence	σ_{Tv}	1.0000		1.00000E-03	normal	4.42201E+02	4.42201E-01	0.10
spectral mismatch	ζ_v						**4.44267E-01**	**0.10**
temperature influence of sphere	δ_T	1.0000		1.00000E-03	normal	4.42201E+02	4.42201E-01	0.10
temperature measurement	T_Θ	1.0000		2.23607E-03	normal	4.42201E+02	9.88791E-01	0.22
Temperature of sphere	Θ						**1.08317E+00**	**0.24**
Luminous flux reference lamp	Φ_{ref}	498.67	lm	1.39628E+00	normal	8.86761E-01	1.23816E+00	0.28
Detector voltage of lamp under test	$U_{v,m}$	0.7951	V	7.52858E-05	normal	5.56158E+02	4.18708E-02	0.01
Detector current of lamp under test	$A_{v,m}$	10000.5	Ohm	2.00000E-01	normal	-4.42179E-02	-8.84358E-03	0.00
respons of sphere	$S_{v,m}$	2.10E-08	A/lx	3.15675E-11	normal	-2.10122E+10	-6.63301E-01	-0.15
Detector voltage of aux measurement lamp under test	$U_{v,aux1}$	0.0589	V	1.65085E-05	normal	7.50766E+03	1.23940E-01	0.03
Detector current of aux measurement lamp under test	$A_{v,aux1}$	10000.5	Ohm	2.00000E-01	normal	-4.42179E-02	-8.84358E-03	0.00
respons of sphere	$S_{v,aux1}$	2.10E-08	A/lx	0.00000E+00	normal	-2.10122E+10	0.00000E+00	0.00
Detector voltage of ref lamp	$U_{v,ref}$	0.8936	V	7.53078E-05	normal	-4.94853E+02	-3.72663E-02	-0.01
Detector current of ref lamp	$A_{v,ref}$	10000.5	Ohm	2.00000E-01	normal	4.42179E-02	8.84358E-03	0.00
respons of sphere	$S_{v,ref}$	2.10E-08	A/lx	0.00000E+00	normal	2.10122E+10	0.00000E+00	0.00
Detector voltage of aux measurement ref lamp	$U_{v,aux2}$	0.0591	V	1.65085E-05	normal	-7.48225E+03	-1.23521E-01	-0.03
Detector current of aux measurement ref lamp	$A_{v,aux2}$	10000.5	Ohm	2.00000E-01	normal	4.42179E-02	8.84358E-03	0.00
respons of sphere	$S_{v,aux2}$	2.10E-08	A/lx	0.00000E+00	normal	2.10122E+10	0.00000E+00	0.00
	Φ_v						**1.41672E+00**	**0.32**
	Φ_m	442.20				***k=1***	**1.95837E+00**	**0.44**

8 Operations conditions of the lamps

The artefacts were voltage stabilized during the measurements. The lamp stabilization has been performed following IESNA (Illuminating Engineering Society of North America) LM-79-08 norm "Approved Method for Electrical and Photometric Measurement of SSL Products" [5]:

"…Stability is reached when the variation (maximum – minimum) of at least 3 readings of the light output and electrical power over a period of 30 min, taken 15 minutes apart, is less than 0.5%…"

For the current measurement a zeroflux meter is used in combination with a digital voltmeter and an amplifier. For power measurements a Yokogawa WT210 power meter traceable to Electrical department of VSL is used.

The lamp was operated with the negative wire connected to the outside of the lamp fitting and the positive wire to the center contact point of the lamp. Alignment of the artefacts inside the sphere facilities has been done with the use of alignment lasers.

9 Results

The direct measurement has been conducted in September 2009. It was performed with the use of the integrating sphere facility with a diameter of 1 meter. The return measurement was based on the measurements performed on the newly developed integrating sphere facility with a diameter of 3 meter in summer 2012.

Some corrections to the measurements and associated uncertainties have been included and are described below.

Correction due to voltage

As the measurements of the direct and return measurements have been done with the slightly different voltage level a correction has been estimated and applied to the results of the return run. In such a way both measurements have been brought to the nominal voltage which is equal to the voltage of the direct run. The nominal voltage is given in Table 5 in red.

The voltage dependency of the Osram lamps of type Wi40G was found to be negligible and no correction has been applied.

At the same time for Polaron lamps SN13 and SN18 some additional tests have been fulfilled to estimate the voltage dependence of both current and luminous flux. The following relations have been found for current and luminous flux correction:

$$\mathrm{I}_m{}' = \left(\frac{V_m}{V_{nom}}\right)^M \cdot \mathrm{I}_{m,2012}$$

$$\Phi_m{}' = \left(\frac{V_m}{V_{nom}}\right)^N \cdot \Phi_{m,2012}$$

where the power factors are estimated to be M = -0.55 and N = -3.1.

The results of the return measurement (conducted in June 2012) corrected for voltage are given in Table 6.

Correction due to 1 m sphere facility

The results of the direct measurement (conducted in September 2009) include correction related to the error found in the period 2011-2012 due to the fact that the 1 m sphere facility was not as thoroughly investigated as new 3 m sphere facility. This correction concerns such effects as spectral response of the sphere coating and homogeneity of the sphere. The uncertainty of the direct measurement was also corrected due to mentioned above effects.

The correction for 1 m sphere was estimated to be **-0.30%** with the contributing uncertainty $u(\Phi_{corr})$ = **0.35%.**

The results of the direct measurement corrected for 1 m sphere effect are given in table 5.

Table 5: The results of VSL Euramet K4 luminous flux, direct measurement (Sep 2009).

Value	Polaron Lv 60W	Polaron Lv 60W2	Osaram Wi 40/G	Osaram Wi 40/G3
serial number	P379	P485	13	18
current	0.5123	0.5224	5.8914	5.9197
Voltage, nom	**110.000**	**110.000**	**30.980**	**30.972**
luminous flux	**467.9**	**588.9**	**2923.3**	**3064.0**

Table 6: The results of VSL Euramet K4 luminous flux, return measurement (June 2012).

Value	Polaron Lv 60W	Polaron Lv 60W2	Osaram Wi 40/G	Osaram Wi 40/G3
serial number	P379	P485	13	18
current	0.5125	0.5221	5.9021	5.9200
Voltage, nom	**110.000**	**110.000**	**30.980**	**30.972**
luminous flux	**467.5**	**587.6**	**2919.5**	**3077.7**

The associated uncertainties per each measurement are given in table 7.

Table 7. Associated uncertainties of the direct and return measurements.

Direct, Sep 2009

Quantity	Uncertainty (k=1) %
current	0.008
voltage	0.009
luminous flux	0.56

Return, June 2012

Quantity	Uncertainty (k=1) %
current	0.008
voltage	0.009
luminous flux	0.44

The final uncertainty $\mathbf{u(\Phi_{m,final})}$ was estimated by weighing the uncertainties of the direct and return measurements according to the contribution of the uncertainty due to 1 m sphere effect mentioned above into the direct measurement.

The weights have been estimated to be w1 = **0.38** and w2 = **0.62** for direct (2009) and return (2012) measurements respectively using the following expressions:

$$w1 = 1 - u(\Phi_{corr})/\, u(\Phi_{m,2009}),\ w2 = 1 - w1 \qquad (11)$$

Then, the final uncertainty has been estimated using this expression:

$$u(\Phi_{m,final}) = \sqrt{w1 \cdot u(\Phi_{m,2009})^2 + w2 \cdot u(\Phi_{m,2012})^2} \qquad (12)$$

Final uncertainty of this Key Comparison in such a way has been estimated to be :

$$\mathbf{u(\Phi_{m,final}) = 0.49\ \%,\ k=1}$$

10 Reference

[1] Technical protocol “EURAMET Key Comparison: Luminous Intensity EURAMET.PR-K3.a and Luminous Flux EURAMET.PR-K4”,PTB, 2008;

[2] Calibration Instruction “*Ennov_026_Total luminous flux calibration of lamps utilizing a 1m sphere*”, VSL, 2009

[3] Optics “Best Measurement Capability” for “Integrating Sphere” facilities; K:\Quality\BMC\BMC IntSphere EA tables.xls, VSL 2009

[4] Commission Internationale de l'Eclairage, "*The Measurement of luminous flux, Publication CIE-84*", 1989.

[5] IESNA *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*, http://www.iesna.org/

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