Key Comparison EUROMET.PR-K3.b.1

Bilateral Comparison on Illuminance Responsivity
IFA-CSIC/Spain and UME/Turkey

Final Report

21 September 2005

This document was prepared by:

Alicia Pons (1)
Joaquín Campos (1)
Antonio Corróns (1)
Farhad Samedov (2)

(1) Dpto Metrología. Instituto de Física Aplicada. Consejo Superior de Investigaciones Científicas. Spain
(2) National Metrology Institute. Scientific and Technical Research Council. Turkey

Abstract

A bilateral comparison of illuminance responsivity scales between the UME and the IFA-CSIC was carried out, where the IFA-CSIC acted as the pilot and link to the key comparison CCPR-K3.b. The ratio of the measured illuminance responsivities (UME/IFA) was 1,0003 with expanded uncertainty of 0,0084 (k = 2) including the uncertainty of the comparison and the uncertainties of the realization of the scales.

1. Introduction

At its meeting in 1997, the Consultative Committee for Photometry and Radiometry, CCPR, identified several key comparisons in the field of optical radiation metrology. One of those, illuminance responsivity, named CCPR-K3.b, has been carried out and its final report approved. In 2003, the National Metrology Institute of the Scientific and Technical Research Council of Turkey (TÜBITAK- UME) expressed the wish to participate in a bilateral comparison with the Applied Physics Institute of the Spanish Council on Scientific Research (IFA-CSIC). The comparison was carried out according to a technical protocol approved in April 2004, in the framework of the EUROMET Project No 824 and has been identified as EUROMET.PR-K3.b.1. This document reports the final results of the bilateral comparison of illuminance responsivity between the IFA and the UME.

2. Participants

The pilot of the comparison is Applied Physics Institute of the Council on Scientific Research, Spain. The participant of the comparison is National Metrology Institute of the Scientific and Technical Research Council, Turkey.

3. Comparison photometers

The UME supplied four transfer standard photometers for this comparison, 2 photometer heads with a temperature control and photocurrent measurement unit, and 2 filter radiometers. All of them are identified in the table below. Both photometer heads and their control unit are manufactured by PRC. The filter radiometers are V(λ) filtered and thermally stabilized home made Filter-Radiometers. Two home-made temperature control units, identified as SK01, were also supplied by UME to control the filter-radiometers' temperature.

ITEM	Manufacturer	Type	Serial No.
Photometer Head	PRC Krochmann Germany	TH15BA, V(λ)-Si	970133-9704
Photometer Head	PRC Krochmann Germany	TH15BA, V(λ)-Si	941114-V
Filter Radiometer	UME Turkey	FR	25.0-1
Filter Radiometer	UME Turkey	FR	25.0-2

Detector housings are shown in the figure below. Every detector is fitted with a LEMO connector.

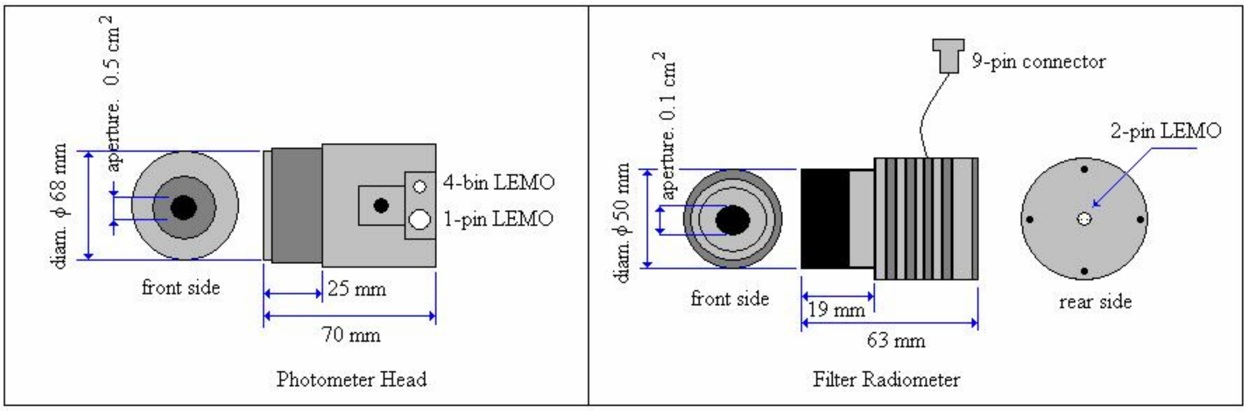

Figure 1. Dimensions of the transfer detectors

4. Protocol of the comparison

The form of the comparison was similar as that of the earlier comparison [1] although the present comparison was arranged as a bilateral comparison resembling closely that of ref [2]. The UME calibrated the photometers first and then sent them to the IFA with calibration results. The IFA calibrated the photometers and returned the devices. Finally, the UME recalibrated the photometers to check the drift during the comparison period and sent the results to the IFA. The IFA prepared the report of the comparison.

At UME the measurement were done over the period 11 May 2004 – 14 May 2004 (first round) and over the period 23 August 2004 – 26 August 2004 (second round). At IFA the measurements were done over the period 29 June 2004 - 13 July 2004.

All but one photometer, identified as PRC 970133-9704, showed sufficient stability between UME calibrations. Furthermore, as was pointed during measurements, this detector presented some problems in the alignment procedure. Then after a consult between the pilot and the participant, it was decided to retire this detector from the comparison completely.

5. Comparison measurements and results

5.1.- IFA Measurements

At the IFA, the transfer standard photometers were measured directly against the IFA reference photometers.

The measurements were done at the illuminance level of approximately 17 lx and at a colour temperature of 2856 K using a luminous intensity standard lamp (Osram Wi/41G). The calibration results of the IFA are given in Table 1.

Table 1. IFA calibration results of the transfer standard photometers

Room temperature: 22,5 ºC

Detector	Serial No:	Illuminance responsivity nA/lx	Num. of Measurements
Photometer Head	941114-V	12,587	5
Filter Radiometer	25.0-1	3,560	5
Filter Radiometer	25.0-2	3,564	5

5.2.- UME Measurements

The illuminance responsivity values of working standard filter radiometers and single Si photodiode based photometer heads used in this comparison were obtained by calibrating against reference filter-radiometers.

The calibration results of the UME are given in Tables 2 (first round) and 3 (second round). The measurements were carried out at the illuminance level of approximately 16 lx and at a color temperature of 2856 K ± 8 K.

Table 2. Initial UME calibration results of the transfer standard photometers

Room temperature: 23ºC

Detector	Serial No:	Illuminance responsivity nA/lx	Num. of Measurements
Photometer Head	941114-V	12,614	4
Filter Radiometer	25.0-1	3,562	4
Filter Radiometer	25.0-2	3,560	4

Table 3.- UME calibration results after return of the transfer standard photometers.

Room temperature: 23ºC

Detector	Serial No:	Illuminance responsivity nA/lx	Num. of Measurements
Photometer Head	941114-V	12,582	4
Filter Radiometer	25.0-1	3,560	4
Filter Radiometer	25.0-2	3,566	4

6.- Measurement uncertainties

The uncertainty components of IFA calibration of the transfer standard photometers to the IFA illuminance responsivity scale are given in Table 4. The repeatability component includes effect due to drift of the intensity of the lamp. The photocurrent measurement uncertainty is caused by different gains of the current-to-voltage converter.

Table 4. IFA uncertainty budget for calibration to the IFA scale

Component	**Standard uncertainty (%)**
Repeatability	0,15
Distance setting	0,02
Photocurrent measurement	0,01
Angular alignment	0,0003
Stray light	0,02
Combined standard uncertainty	0,15

The spectral mismatch of the reference and the distribution temperature contribute only a negligible factor to the uncertainties.

The uncertainty components of UME calibration of the transfer standard photometers to the UME scale of illuminance responsivity are given in Table 5.

Table 5.- UME uncertainty budget for calibration to the UME scale

Component	**Standard uncertainty (%)**
Stability of lamp current	0,013
Color temperature	0,061
Mismatch index	0,012
Photocurrent measurements	0,009
Stray light	0,011
Detector perpendicularity alignments	0,022
Distance measurements	0,026
Repeatability	0,142
Combined standard uncertainty (k=1)	0,16

The uncertainty budget of the comparison is given in Table 6, where the first and third entries are taken from Tables 4 and 5, respectively. As the purpose of the present comparison is to establish a link to CCPR-K3.b, the uncertainty component due to seven-year stability of the IFA scale is taken into account as an uncertainty component of the comparison.

IFA-CSIC took part in two CCPR key comparisons in 1997-98 relevant to this bilateral comparison: the K3.a comparison of luminous intensity [3] and the K3.b comparison of luminous responsivity. In both cases, the reference was a set of three standard photometers, traceables to a cryogenic radiometer. Since 1997 supplementary checks were done regularly comparing the standards photometers and the transfer standard lamps. As a conclusion the seven-years stability of the IFA scale was estimated as 0,09%.

Table 6. Uncertainty budget for the illuminance responsivity comparison

Component	Standard uncertainty (%)
IFA calibration of transfer photometers (to IFA scale)	0,15
Long-term stability of the IFA illuminance responsivity scale	0,09
UME calibration of transfer photometers (to UME scale)	0,16
Instability of transfer photometers during the comparison	0,08
Combined Standard uncertainty	0,25

In Table 6, the uncertainty estimate due to instability of the transfer standard photometers during the comparison is based on the results of UME measurements (Tables 2 and 3).

The uncertainty budget of the realization of illuminance responsivity scales is given in Table 7. This uncertainty budget is useful for assessing the agreement of the scale realizations through the uncertainty of the mutual degree of equivalence. The detailed uncertainty budgets of the realizations of the IFA, refs [4] and [5], and the UME, refs [6] , [7] and [8], are given in Appendix 1.

At the IFA, luminous intensity unit of candela has been realized using partial filtering photometers. The reference photometers relative spectral responsivity was measured and then the absolute responsivity value was determined at two Kr laser wavelengths against a Si detector, whose responsivity is traceable to a cryogenic radiometer.

At UME, luminous intensity unit has been realized using reference filter-radiometers. The spectral responsivity of each trap detector based filter-radiometer was obtained by calibrating it against helium cooled electrical substitution cryogenic radiometer system of the UME at discrete laser wavelengths [6]. The spectral responsivity then was expanded in the visible region using the reflectance and internal quantum efficiency models. The spectral transmittances of $V(\lambda)$ filter and effective area of precise aperture were characterized separately. Then the illuminance responsivity was obtained by characterizing spectral responsivity fitted with a $V(\lambda)$ filter and a precision aperture.

Table 7. Uncertainties of the realization of the illuminance responsivity scales

Component	Standard uncertainty (%)
Uncertainty of the IFA illuminance responsivity scale	0,30
Uncertainty of the UME illuminance responsivity scale	0,16
Combined standard uncertainty of realization of the scales	0,34

7. Ratios of the UME data to the IFA data

Ratios of the illuminance responsivities measured by the UME and the IFA are given in Table 8. Average values of the UME data of Tables 2 and 3 are used.

Table 8. Ratios of the illuminance responsivities measured by the UME and the IFA

Detector serial number	Ratio (average UME)/IFA	Standard uncertainty
941114-V	1,0009	0,0025
25.0-1	1,0002	0,0025
25.0-2	0,9998	0,0025
Average	1,0003	0,0025

The standard uncertainty of the ratios is the combined standard uncertainty of the comparison from Table 6. The discrepancy of the illuminance responsivity scales realized by the IFA and the UME is well within the combined standard uncertainty of 0,0042 calculated as the quadratic sum of the combined standard uncertainties of Tables 6 and 7.

References

[1]. R. Köhler, M. Stock, and C. Garreau, Final Report on the International Comparison of Luminous Responsivity CCPR-K3.b (2004).

[2] E. Ikonen, J. Hovila, Final Report of CCPR-K3.b.2-2004: Bilateral comparison of illuminance responsivity scales between the KRISS and the HUT, *Metrologia* **41**, *Tech. Suppl*. 02003 (2004).

[3]. G. Sauter, D. Lindner and M. Lindemann, Final Report on the CIPM Key Comparisons K3a of Luminous Intensity and K4 of Luminous Flux with Lamps as Transfer Standards. PTB Report, PTB-Opt-62, 1999, 29 pages

[4]. J. Campos, A. Corróns, A. Pons and P. Corredera. Realization of the Candela from a partial filtering V(λ) detector traceable to a cryogenic radiometer. *Metrologia* **32**, 675-679 (1995/96).

[5]. J. Campos, A. Corróns, A. Pons and P. Corredera. Luminous Intensity Standard Based on a Cryogenic Radiometer. *Pub. CIE Nº 119*. pag. 102-105. CIE Central Bureau. Viena (1995).

[6]. F.Samedov, M.Durak and Ö.Bazkır. Filter-radiometer based realization of Candela and establishment of photometric scale at UME. *Optics and Lasers in Engineering* **43 (11),** 1252-1266 (2005).

[7]. F.Samedov and Ö.Bazkır. Realization of photometric base unit of candela traceable to cryogenic radiometer at UME. *European Physical Journal of Applied Physics* **30,** 205-213 (2005).

[8] M Durak and F Samedov. Realization of a filter radiometer based irradiance scale with high accuracy in the region from 286 nm to 901 nm. *Metrologia* **41**, 401-406 (2004).

Appendix 1 – Detailed uncertainty budgets

The detailed updated uncertainty budget of the IFA illuminance responsivity scale is given below.

Component (IFA)	**Standard uncertainty (%)**
Relative responsivity	0,24
Absolute responsivity	0,10
Linearity	0,04
Standard radiometer area	0,13
Illuminant correction factor f	0,03
Repeatability	0,04
Illuminance uniformity	0,01
Combined standard uncertainty	0,30

The detailed uncertainty budget of the UME illuminance responsivity scale is given below.

Component (UME)	**Standard uncertainty (%)**
Absolute responsivity of trap detector	0,025
Nonlinearity of trap detector	0,010
Spatial nonuniformity of trap detector	0,010
Polarization sensitivity of trap detector	0,010
Peak transmittance of V(λ) filter	0,051
Spatial nonuniformity	0,047
Temperature setting	0,014
IR leakage	0,020
Aperture area	0,016
Spectral responsivity of trap detector	0,090
Spectral transmittance of V(λ) filter	0,091
Spectrum of lamp	0,012
Current stability of the monochromator lamp	0,025
Photocurrent measurements	0,035
Straylight	0,013
Repeatability	0,025
Combined standard uncertainty	0,161

Appendix 2 - Link to the key comparison CCPR-K3.b

The link of the comparison result to the key comparison CCPR-K3.b is considered in this Appendix. The deviation of the IFA result from the key comparison reference value is [1].

$$d(\text{IFA}) = 0{,}0038 \pm 0{,}0011 \quad (1)$$

where the standard uncertainty of 0,0011 includes only the uncertainty of the comparison and the uncertainty of the key comparison reference value. The calibration uncertainty of IFA is not included at this point.

Combining the results of Eq. (1) and of Tables 7 and 8, the degree of equivalence of the UME in CCPR-K3.b is given by

$$D(\text{UME}) = 0{,}0041 \pm 0{,}0063 \quad (2)$$

where the expanded uncertainty of 0,0063 (k = 2) is calculated as twice the quadratic sum of the uncertainties of the UME illuminance responsivity scale (Table 7), of Table 8, and of Eq. (1).

With the values of Eq. (2) and those reported in Ref. [1], the mutual degrees of equivalence between the UME and participants of CCPR-K3.b can be calculated in a straightforward way. For example, the mutual degree of equivalence between the UME and the IFA is:

$$\text{D(UME, IFA)} = 0{,}0003 \pm 0{,}0087 \quad (3)$$

where the expanded uncertainty of 0,0087 (k = 2) is calculated as the quadratic sum of the uncertainty of Eq. (2) and the calibration uncertainty of the IFA result in CCPR-K3.b.

The mutual degrees of equivalence between the UME and the participants of CCPR-K3.b are given below:

NMI	***D*(UME,NMI)**	***U*(UME,NMI) k=2**
BNM	0,0121	0,0085
CSIC	0,0003	0,0087
CSIRO	0,0032	0,0073
HUT	0,0076	0,0087
IRL	0,0122	0,0081
NIM	0,0028	0,0068
NIST	0,0056	0,0075
NPL	0,0044	0,0073
NRC	0,0041	0,0118
OFMET	-0,0061	0,0081
OMH	0,0078	0,0085
PTB	0,0006	0,0072
SMU	0,0065	0,0167
VNIIOFI	0,0011	0,0080
BIPM	0,0057	0,0081