Final Report of the APMP Comparison of Luminous Responsivity (APMP.PR-K3.b)

April 2004

J.L. Gardner, E. Atkinson
CSIRO National Measurement Laboratory
PO Box 218, Lindfield NSW 2070
Australia

M. Stock (paragraph on link only)
BIPM
Pavillon de Breteuil
F-92312 Sèvres CEDEX

Introduction

Luminous responsivity is a Key Comparison quantity for the Consultative Committee on Photometry and Radiometry (CCPR) of the International Bureau of Weights and Measures (BIPM), linked to the SI unit for luminous intensity, the candela. The CCPR completed a comparison of luminous responsivity in 1998, subsequently designated CCPR-K3.b. This document reports the method and results of an international intercomparison of luminous responsivity within the Asia Pacific Metrology Program (APMP), following the protocols as laid down for the Mutual Recognition Arrangement of the General Conference of Weights and Measures (CIPM). In Appendix B the results of the CCPR and the APMP comparisons are linked together.

	Institute	Country
Coordinator:		
CSIRO	CSIRO National Measurement Laboratory	Australia
Participants:		
ITRI	CMS/ITRI	Chinese Taipei
KIM-LIPI	KIM-LIPI	Indonesia
KRISS	Korean Research Institute of Standards & Science	Korea
MSL	Measurement Standards Laboratory	New Zealand
NPLI	National Physical Laboratory	India
PSB[1]	Productivity and Standards Board	Singapore
SIRIM	SIRIM National Metrology Centre	Malaysia

SIRIM received the photometers, but did not present results, citing staffing problems.

Comparison photometers

Two photometers were circulated. These were two of those used in the CCPR luminous responsivity comparison by CSIRO, the coordinating laboratory for this comparison. The third had shown problems with changes in transmittance of the cemented window or filter, with interference fringes appearing in the aperture . Both were temperature stabilised and with Vλ filters uniform over the full aperture. The first was a LMT type P15FOT Serial Number 39638, with a nominal aperture diameter of 15 mm and approximate response 50 nA/lx. The second was an Inphora Serial Number 0696PO112 with a nominal aperture of 9 mm and approximate response 16 nA/lx.

[1] Now re-named as SPRING Singapore - Standards, Productivity and Innovation Board

Spectral characterisation, linearity measurements, effect of apertures close to the photometers, sensitivity to alignment and thermal loading of the mount were all determined for these photometer types as part of the CCPR comparison by BIPM. Details can be found in the report of that comparison [1]. Spectral characterisation of the photometers had been undertaken on the photometers at CSIRO; the participant laboratories were not required to make these measurements.

Spectral matching to V(λ) was such that the Inphora photometer response varied by < 0.01% for lamps whose distribution temperature varied from 2000-3000 K. The LMT photometer showed a variation of order 0.2% for the same range. The different variation for these photometers was thought to be useful as a secondary check on setting of distribution temperature – not all of the APMP participant laboratories have the capability of measuring this directly.

The LMT photometer was irreparably damaged by incorrect connections at one of the participant laboratories. The silicon photodiode and filter package in this device are cemented together. CSIRO had to hand a window-less silicon photodiode of the correct dimensions, and the facilities to cut and re-cement this to the filter. The detector type did not match that of the original device and so the spectral responsivity of the repaired detector (renamed 39638A to distinguish it from the original) was altered. Figure 1 shows the spectral responsivity of both modes. The f_1' value of the photometer was changed from 2.3% to 13%. The sensitivity of the detector to variations in distribution temperature was also changed, now being 0.7% over the range 2000-3000 K.

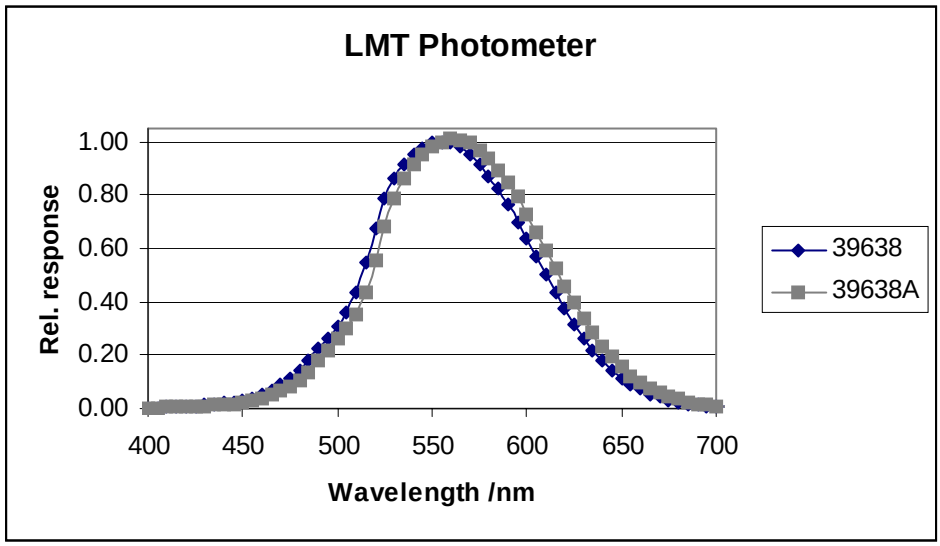


Figure 1. Change in relative spectral responsivity for the LMT photometer with the replaced silicon photodetector

Protocol for the comparison

The comparison was carried out in a star fashion, with CSIRO making measurements before and after each of the participating laboratories. While extending the overall time for a comparison, such a procedure offers the best checking for drift and protection against loss in a region where transportation of goods between countries is not always reliable.
Participants were advised that the responses of the photometers to a field of illuminance, with a distribution of CIE illuminant A, approximately in the range 10-50 lx, were required, to be reported in units of nA/lx. Mounting details were provided in advance, so that the laboratory

could minimise the time for required for measurement by preparing before receiving the photometers. Details of power supplies required were also provided in advance.

Participants were asked to identify the following uncertainty components:
Required uncertainty components:

- Uncertainty of the base unit
- Uncertainty of the transfer measurement
- Uncertainty due to position of detector
- Other relevant components

In all cases, uncertainty of the base unit was the dominant component.

An approximate schedule was arranged in consultation with the laboratories, but delays in customs and damage to one of the photometers meant that the schedule was delayed, and laboratories were contacted prior to shipping from CSIRO to confirm that they were in a position to receive and measure the photometers in a timely manner.

CSIRO results

Special mounting jigs for the photometers were used at CSIRO to minimise effects of re-positioning. The photometers were mounted with their measurement planes at a fixed distance from a lamp operated as an illuminance standard, calibrated against the CSIRO primary photometer. Tables 1 and 2 show repeat measurements of the photometers at CSIRO between the participant measurements, with the results plotted in Figures 2-4. The results also show the effect of cleaning. The photometer was always measured at CSIRO as received, but in a number of cases required cleaning of the windows to remove dust or marks. The window was subjected to warm, moist air and wiped with a fresh soft tissue. After a period of some hours the response was then remeasured before sending the photometers to the next participant. All measurements are shown in the table.

Table 1. CSIRO repeat measurements of the Inphora responsivity.

Index	Date	Notes	Sensitivity (nA/lx)	Standard Uncertainty (nA/lx)
1	October 13, 1998		16.447	0.037
2	December 9, 1998		16.404	0.028
3	March 17, 1999		16.442	0.028
4	March 18, 1999	Cleaned at NML	16.438	0.028
5	May 6, 1999		16.439	0.028
6	June 18, 1999		16.447	0.028
7	June 18 - 22, 1999	Blew dust from window	16.441	0.028
8	August 26,1999		16.474	0.028
9	August 30, 1999	Repeat	16.467	0.028
10	January 17, 2000		16.469	0.028
11	January 19, 2000	Cleaned at NML	16.468	0.028
12	May 18, 2000		16.425	0.028
13	July 25, 2000		16.438	0.028

Table 2. CSIRO repeat measurements of the LMT responsivity.

Index	Date		Sensitivity (nA/lx)	Standard Uncertainty (nA/lx)
1	October 13, 1998		50.161	0.097
2	December 9, 1998		50.055	0.085
3	March 17, 1999		50.183	0.086
4	March 18, 1999	Cleaned	50.126	0.085
5	May 6, 1999		50.080	0.085
6	June 18, 1999		50.054	0.085
7	June 18 - 22, 1999	Dust removed	50.080	0.085
		Photodiode replaced		
8	August 30, 1999		38.595	0.066
9	January 17, 2000		38.601	0.066
10	January 19, 2000	Repeat	38.597	0.066
11	May 18, 2000		38.594	0.067
12	July 25, 2000		38.582	0.066

Figure 2.
Inphora – CSIRO measurements

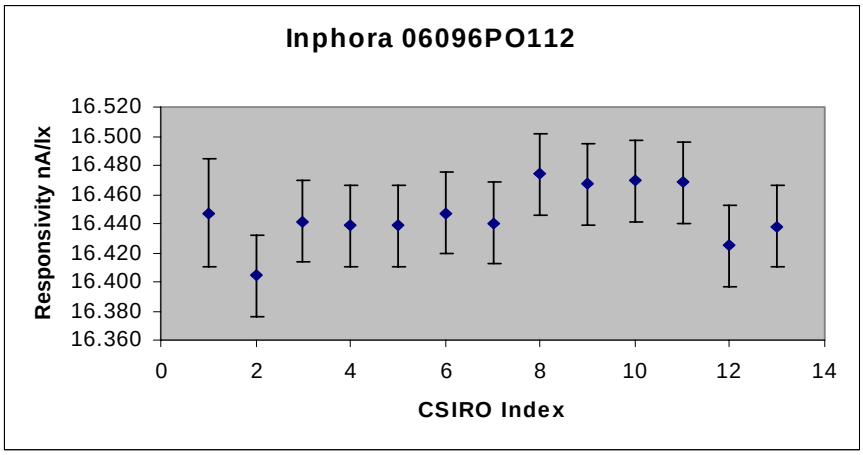


Figure 3.
Original LMT – CSIRO measurements.

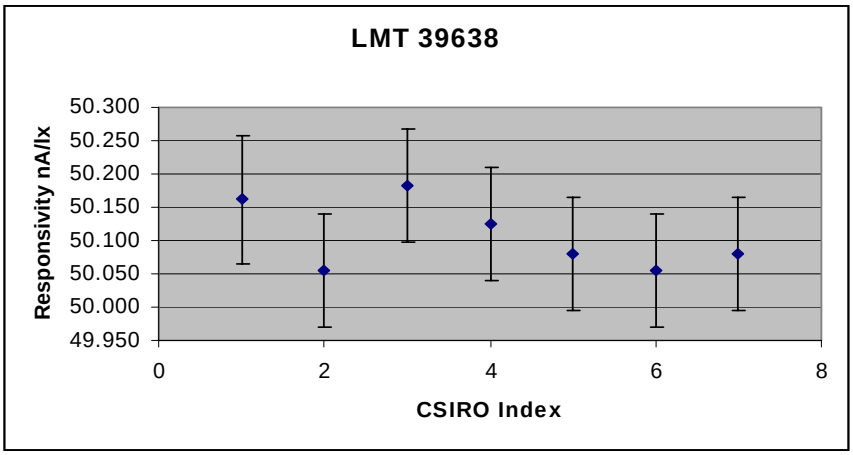
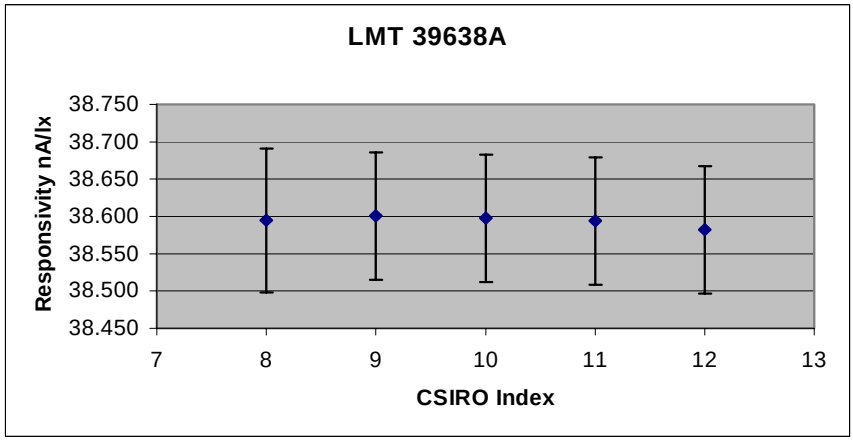


Figure 4. Repaired LMT – CSIRO measurements.



Laboratory results

The results reported by the laboratories are shown in Table 3. The uncertainties indicated are those of the laboratory only. The uncertainty of the laboratory primary standard is also shown. In most cases, this base uncertainty dominates the uncertainty as the transfer to the comparison artefact adds only a small amount. The PSB result for the LMT-A photometer has been corrected for a source of distribution temperature 2856K. The responsivity measured at PSB for a 2800 K source was 38.494 nA/lx. The MSL stated its standard uncertainty as 0.18 % with two degrees of freedom. This was multiplied with a coverage factor of 1.32 (for 2 d.o.f. , 68.3 %) to obtain the uncertainty for 68.3 % confidence, which is 0.24 %.
Appendix A contains a brief summary of the derivation of each laboratory's photometric standards.

Table 3. Measurements reported by the participants. Relative standard uncertainties (%) shown here are for the participant laboratory only. Laboratories marked * measured the LMT detector after replacement of the photodiode.

Laboratory.	LMT nA/lx	LMT-A nA/lx	Inphora nA/lx	Base uncertainty
KIM-LIPI *	-	50.47 ± 0.33%	21.89 ± 0.33%	0.30%
KRISS	49.47 ± 0.27%	-	16.22 ± 0.27%	0.25%
PSB *	-	38.41 ± 0.54%	16.42 ± 0.54%	
ITRI	50.60 ± 0.7%	-	16.67 ± 0.7%	0.7%
MSL	50.20 ± 0.24%	-	16.44 ± 0.24%	0.24%
NPLI *	-	39.10 ± 1.30%	16.70 ± 1.32%	1.2%
CSIRO	-		-	0.17%

Ratios to CSIRO

No significant difference was found between each participant's measurements on the Inphora and LMT photometers. The mean ratio and standard uncertainty for each laboratory relative to the CSIRO results is shown in Table 4. The measurements on the Inphora and LMT photometers made by each laboratory are correlated through the laboratory base standards. Standard uncertainties (relative) in the mean ratio are calculated as follows:

The transfer uncertainty of each measurement is obtained by quadrature subtraction of the base uncertainty from the reported standard uncertainty. For each photometer, the uncorrelated transfer uncertainties of the before and after CSIRO results are averaged in quadrature and the uncertainty in the ratio [laboratory:CSIRO] formed by quadrature addition. The two detector ratios are then averaged, with the propagated uncertainty in this average representing the transfer uncertainty between the laboratory and CSIRO. The final uncertainty is then found by adding in quadrature this transfer uncertainty with the base uncertainties of the laboratory and CSIRO.

Table 4. Mean ratios and standard uncertainties between the participants and CSIRO.

Laboratory	Ratio to CSIRO	Standard uncertainty
ITRI	1.0123	0.0072
MSL	1.0013	0.0029
KRISS	0.9868	0.0031
NPLI	1.0135	0.0127
KIM-LIPI	1.3192	0.0036
PSB	0.9973	0.0055

Linking to the CCPR Key Comparison

Two CCPR Key Comparisons are relevant to the APMP comparison. These are the direct equivalent, that of luminous responsivity CCPR-K3.b, and luminous intensity CCPR-K3.a. Both trace to the determination of the candela. Three of the participating laboratories – CSIRO, KRISS and MSL – are members of CCPR. Only CSIRO participated in the CCPR luminous intensity comparison. All three participated in the CCPR luminous responsivity comparison, but KRISS identified a problem with their reference photometer and the values obtained were not reliable. Values for CSIRO and MSL relative to the key comparison reference values are shown in Table 5. The uncertainties are the combined standard uncertainties of the deviations from the reference value. Subsequent to the CCPR and prior to this comparison, MSL re-established their primary reference, finding a relative change in value of +0.0096 with a standard uncertainty of 0.0004. The effect of this change is shown in Table 5.

Table 5. Performance of link laboratories in CCPR key comparisons shown as (laboratory-reference value) and its standard uncertainty.

Laboratory	Luminous responsivity	Luminous intensity
CSIRO	0.0009 ± 0.0019	-0.0007 ± 0.0030
MSL	-0.0081 ± 0.0026	
MSL amended	0.0015 ± 0.0026	

The two CSIRO results in the two CCPR comparisons are correlated through the common base standard with its uncertainty 0.0017. Averaging the two results and taking the partial correlation into account leads to a factor of (1.0001 ± 0.0022) by which the ratios of Table 4 must be multiplied to obtain the degrees of equivalence when using only the CSIRO as the link laboratory.

If the link is made by using the MSL, the corresponding factor is 1.0015/1.0013 ± 0.0026, that is (1.0002 ± 0.0026). The division by 1.0013 takes into account that the data in Table 4 are referenced to CSIRO. To apply the correction factor of 1.0015 obtained with the MSL results from Table 5, the data of Table 4 have to be normalised to the MSL result, that means to be divided by 1.0013.

Taking the average of both link factors and treating their uncertainties as uncorrelated[2] gives (1.0002 ± 0.0017), factor by which the ratios of Table 4 must be multiplied to obtain the degrees of equivalence based on the two link laboratories. These are shown in Table 6. Results for MSL are not included in this table as their equivalence was used in the derivation of the values shown.

Table 6. Degrees of equivalence of APMP laboratories for measurements of luminous responsivity, relative to the CCPR Key Comparison reference value.

Laboratory	Ratio to CCPR reference value	Standard uncertainty
ITRI	1.013	0.007
KRISS	0.987	0.004
NPLI	1.014	0.013
KIM-LIPI	1.320	0.004
PSB	0.997	0.006

[2] A small correlation exists due to the use of the same reference value of CCPR-K3.b used to calculate the CSIRO and MSL results in Table 5. Since the uncertainty of the reference value is very small (0.0006), the same is true for the correlation, which can therefore be neglected.

Reference

[1] Final Report on the International Comparison of Luminous Responsivity CCPR-K3.b, *Metrologia Techn. Suppl. xxx*

Appendix A - Participant's realisations of the candela.

The information provided for the derivation of the participant's primary standards is as follows:

KIM-LIPI – Wi 41/G luminous intensity standards calibrated by PTB. Last calibrated 1992.

PSB – luminous intensity standards traceable to BIPM. Last calibrated 1998.

KRISS – reference photometer traceable to the KRISS cryogenic radiometer.

CMS/ITRI – independent realisation of illuminance using an electrically-calibrated radiometer and photopic filters.

MSL – independent realisation of luminous responsivity in 1998, based on silicon-trap photometers referenced to a cryogenic radiometer.

NPLI - Wi 41/G luminous intensity standards calibrated by BIPM at 2 yearly intervals.

CSIRO - independent realisation of illuminance using commercial photometers calibrated against silicon trap responsivity standards referenced to a cryogenic radiometer.

Appendix B - Link with CCPR-K3.b

Calculation of degrees of equivalence for APMP.PR-K3.b

M. Stock, BIPM

The degrees of equivalence for the participants of APMP.PR-K3.b are shown in Table 6 of this comparison report. The results for those of them which are signatories of the MRA but not link laboratories are shown in Table B.1 below. For the link laboratories, CSIRO and MSL, no new degrees of equivalence are generated from their participation in the APMP comparison. Their role as link laboratory assumes that their standards did not change. Nevertheless, a new entry will be created in the database for the MSL showing their results of the CCPR comparison recalculated to their amended primary reference. Although KRISS participated in the CCPR comparison, a new entry is generated, because it was not used as a link laboratory since it identified a problem with its reference photometer after the CCPR comparison.

Laboratory	**Degrees of equivalence**	
	Relative deviation from KCRV of CCPR-K3.b	**Standard uncertainty of deviation**
ITRI	0.013	0.007
KRISS	-0.013	0.004
NPLI	0.014	0.013
PSB	-0.003	0.006

Table B.1: Degrees of equivalence for the participants of APMP.PR-K3.b which are signatories of the MRA but not link laboratories.

The mutual degrees of equivalence between participants of the APMP comparison only are calculated directly from their results in the APMP comparison (Table B.2). The deviations between two participants are calculated as the difference of their deviations from the pilot laboratory (CSIRO). These deviations do not depend on the results of CSIRO. The uncertainties of the bilateral differences are calculated as the square root of the quadratic sum of the uncertainties of the deviations from the pilot laboratory, taken from Table 4 of the Final Report. The contribution of a possible systematic[3] uncertainty of the CSIRO measurements during the APMP comparison should be removed from the uncertainty of the bilateral deviations. This contribution is at the moment unknown, but certainly smaller than 0.0017, which is the CSIRO uncertainty related to their standards.

j →

i ↓

$D_{ij} = x_i - x_j$	**ITRI**		**KRISS**		**NPLI**		**PSB**	
	D_{ij}	u_{ij}	D_{ij}	u_{ij}	D_{ij}	u_{ij}	D_{ij}	u_{ij}
ITRI			0.026	0.008	-0.001	0.015	0.015	0.009
KRISS	-0.026	0.008			-0.027	0.013	-0.011	0.006
NPLI	0.001	0.015	0.027	0.013			0.016	0.014
PSB	-0.015	0.009	0.011	0.006	-0.016	0.014		

Table B.2: Bilateral deviations D_{ij} between pairs of participants of the APMP comparison and related uncertainties u_{ij}.

[3] A systematic uncertainty is understood as an uncertainty related to an effect leading to a systematic bias or error in the measurements.

The degrees of equivalence between one of the laboratories KRISS, NPLI, PSB and ITRI and one of the link laboratories CSIRO and MSL is also determined directly from the APMP comparison. The degree of equivalence between CSIRO and MSL remains the one already found in the CCPR comparison, but is re-calculated to the new MSL reference.

	CSIRO		**MSL, amended**		**MSL, old**	
	D_{ij}	u_{ij}	D_{ij}	u_{ij}	D_{ij}	u_{ij}
ITRI	0.012	0.007	0.011	0.008	0.021	0.008
KRISS	-0.013	0.003	-0.015	0.004	-0.005	0.004
NPLI	0.014	0.013	0.012	0.013	0.022	0.013
PSB	-0.003	0.006	-0.004	0.006	0.006	0.006

Table B.3: Degrees of equivalence between the participants of the APMP comparison only and the link laboratories.

The deviations between a CCPR participant (i) and an APMP participant (j), who did not participate in the CCPR comparison, are calculated via the KCRV:

$$D_{ij} = D_{i,CCPR} - D_{j,APMP} = (x_{i,CCPR} - KCRV) - (x_{j,APMP} - KCRV)$$

The $D_{i,CCPR}$ are taken from Table 4 of the Final Report of the CCPR comparison [1]. The $D_{j,APMP}$ are taken from Table B.1.
The corresponding uncertainty is calculated as the square root of the quadratic sum of the individual uncertainties. A correlation exist from the use of the key comparison reference value in both comparisons, but this is negligible in comparison to the relatively large uncertainties of the APMP participants. The KRISS result of the CCPR comparison is not linked to the results of the APMP comparison because it is considered as erroneous. Only the KRISS result of the APMP round is used for this purpose.

j →

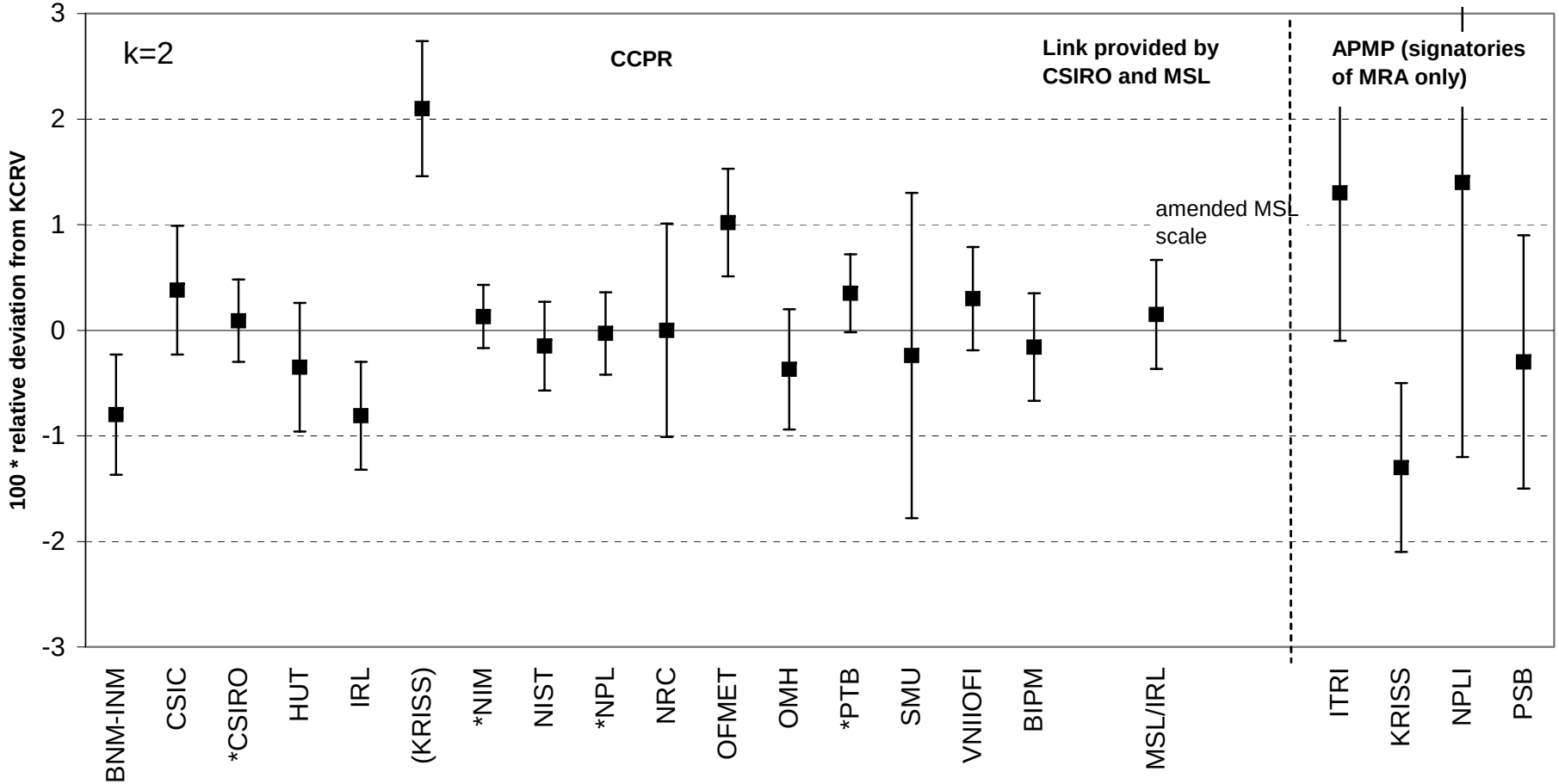
i ↓

Participants of	**Participants of APMP comparison**							
CCPR comparison	**ITRI**		**KRISS**		**NPLI**		**PSB**	
	D_{ij}	u_{ij}	D_{ij}	u_{ij}	D_{ij}	u_{ij}	D_{ij}	u_{ij}
BNM-INM	-0.021	0.008	0.005	0.005	-0.022	0.013	-0.005	0.007
CSIC	-0.009	0.008	0.017	0.005	-0.010	0.013	0.007	0.007
CSIRO	*-0.012*	*0.007*	*0.013*	*0.003*	*-0.014*	*0.013*	*0.003*	*0.006*
HUT	-0.017	0.008	0.010	0.005	-0.018	0.013	-0.001	0.007
KRISS	*-0.026*	*0.008*			*-0.027*	*0.013*	*-0.011*	*0.006*
MSL (amended)	*-0.011*	*0.008*	*0.015*	*0.004*	*-0.012*	*0.013*	*0.004*	*0.006*
NIM	-0.012	0.007	0.014	0.004	-0.013	0.013	0.004	0.006
NIST	-0.015	0.007	0.012	0.004	-0.016	0.013	0.002	0.006
NPL	-0.013	0.007	0.013	0.004	-0.014	0.013	0.003	0.006
NRC	-0.013	0.009	0.013	0.006	-0.014	0.014	0.003	0.008
OFMET	-0.003	0.007	0.023	0.005	-0.004	0.013	0.013	0.007
OMH	-0.017	0.008	0.009	0.005	-0.018	0.013	-0.001	0.007
PTB	-0.010	0.007	0.017	0.004	-0.011	0.013	0.007	0.006
SMU	-0.015	0.010	0.011	0.009	-0.016	0.015	0.001	0.010
VNIIOFI	-0.010	0.007	0.016	0.005	-0.011	0.013	0.006	0.006
BIPM	-0.015	0.007	0.011	0.005	-0.016	0.013	0.001	0.007

Table B.4: Degrees of equivalence between the participants of the APMP comparison and those of the CCPR comparison. Results in *italics* are directly calculated from the results of APMP.PR-K3.b.

The degrees of equivalence for the CCPR and APMP participants are shown in the following graph. The bilateral degrees of equivalence are shown in the table.

Link between CCPR and APMP comparison K3.b



Key comparison CCPR-K3.b and APMP.PR-K3.b

CCPR-K3.b

MEASURAND: Luminous responsivity of photometers

The individual measurements, x_i, of the participating laboratories correspond to the results of a virtual calibration of the luminous responsivity of the same photometer.

Key comparison reference value: the KCRV is calculated as the weighted mean of the participants results, weighted by the inverse square of the uncertainties with the application of a minimum uncertainty cutoff of 0.2 %. The KRISS is excluded from the calculation of the KCRV

The degree of equivalence of each laboratory with respect to the reference value is given by a pair of numbers:
$D_i = (x_i - x_{KCRV})$ and U_i, its expanded uncertainty ($k = 2$), both expressed in relative units
$U_i^2 = 2^2(u_i^2 + u_{KCRV}^2 - u_{corr}^2 + u_{transfer}^2)$, where u_{corr} is the correlation between u_i and u_{KCRV}

The degree of equivalence between two laboratories is given by a pair of numbers:
$D_{ij} = D_i - D_j = (x_i - x_{KCRV}) - (x_j - x_{KCRV})$ and U_{ij}, its expanded uncertainty ($k = 2$), both expressed in relative units
$U_{ij}^2 = 2^2(u_i^2 + u_j^2 + 2u_{transfer}^2)$

APMP-PR-K3.b

If more than one possibility exists to calculate the degree of equivalence between two laboratories, the most direct way is chosen.

For the two link laboratores (CSIRO and MSL) no new results are generated by the APMP comparison.
For the KRISS a new result is produced by the APMP comparison, because it did not participate as a link laboratory due to its measurement problems in the CCPR comparison

A new entry is generated for MSL showing the results of the CCPR comparison recalculated to their amended reference which was used for the APMP comparison.

Between the participants of the APMP comparison only, the degrees of equivalence are calculated directly from the results of the APMP comparison.
Between the participants of the APMP comparison only, and one of the two link laboratories (CSIRO and MSL) the degrees of equivalence are taken directly from the APMP comparison.
Between the participants of the APMP comparison only, and those of the CCPR comparison (except CSIRO and MSL), the degrees of equivalence are calculated via the KCRV.

CCPR-K3.b

Lab j ⇨

Lab i ⇩

Lab i	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM D_{ij} / 10^{-2}	BNM-INM U_{ij} / 10^{-2}	CSIC D_{ij} / 10^{-2}	CSIC U_{ij} / 10^{-2}	*CSIRO D_{ij} / 10^{-2}	*CSIRO U_{ij} / 10^{-2}	HUT D_{ij} / 10^{-2}	HUT U_{ij} / 10^{-2}	IRL D_{ij} / 10^{-2}	IRL U_{ij} / 10^{-2}	(KRISS) D_{ij} / 10^{-2}	(KRISS) U_{ij} / 10^{-2}	*NIM D_{ij} / 10^{-2}	*NIM U_{ij} / 10^{-2}	NIST D_{ij} / 10^{-2}	NIST U_{ij} / 10^{-2}	*NPL D_{ij} / 10^{-2}	*NPL U_{ij} / 10^{-2}	NRC D_{ij} / 10^{-2}	NRC U_{ij} / 10^{-2}	OFMET D_{ij} / 10^{-2}	OFMET U_{ij} / 10^{-2}	OMH D_{ij} / 10^{-2}	OMH U_{ij} / 10^{-2}	*PTB D_{ij} / 10^{-2}	*PTB U_{ij} / 10^{-2}	SMU D_{ij} / 10^{-2}	SMU U_{ij} / 10^{-2}	VNIIOFI D_{ij} / 10^{-2}	VNIIOFI U_{ij} / 10^{-2}	BIPM D_{ij} / 10^{-2}	BIPM U_{ij} / 10^{-2}	MSL/IRL D_{ij} / 10^{-2}	MSL/IRL U_{ij} / 10^{-2}	ITRI D_{ij} / 10^{-2}	ITRI U_{ij} / 10^{-2}	KRISS D_{ij} / 10^{-2}	KRISS U_{ij} / 10^{-2}	NPLI D_{ij} / 10^{-2}	NPLI U_{ij} / 10^{-2}	PSB D_{ij} / 10^{-2}	PSB U_{ij} / 10^{-2}
BNM-INM	-0,80	0,57			-1,18	0,86	-0,89	0,71	-0,45	0,86	0,01	0,79	-2,90	0,86	-0,93	0,66	-0,65	0,73	-0,77	0,71	-0,80	1,17	-1,82	0,79	-0,43	0,83	-1,15	0,70	-0,56	1,66	-1,10	0,78	-0,64	0,79	-0,95	0,80	-2,1	1,6	0,5	1,0	-2,2	2,7	-0,5	1,3
CSIC	0,38	0,61	1,18	0,86			0,29	0,74	0,73	0,89	1,19	0,82	-1,72	0,89	0,25	0,69	0,53	0,76	0,41	0,74	0,38	1,19	-0,64	0,82	0,75	0,86	0,03	0,74	0,62	1,67	0,08	0,81	0,54	0,82	0,23	0,83	-0,9	1,5	1,7	1,0	-1,0	2,7	0,7	1,3
*CSIRO	0,09	0,39	0,89	0,71	-0,29	0,74			0,44	0,74	0,90	0,67	-2,01	0,74	-0,04	0,50	0,24	0,60	0,12	0,57	0,09	1,09	-0,93	0,67	0,46	0,71	-0,26	0,56	0,33	1,60	-0,21	0,65	0,25	0,67	-0,06	0,67	-1,2	1,4	1,3	0,6	-1,4	2,5	0,3	1,1
HUT	-0,35	0,61	0,45	0,86	-0,73	0,89	-0,44	0,74			0,46	0,82	-2,45	0,89	-0,48	0,69	-0,20	0,76	-0,32	0,74	-0,35	1,19	-1,37	0,82	0,02	0,86	-0,70	0,74	-0,11	1,67	-0,65	0,81	-0,19	0,82	-0,50	0,83	-1,7	1,5	1,0	1,0	-1,8	2,7	-0,1	1,3
IRL	-0,81	0,51	-0,01	0,79	-1,19	0,82	-0,90	0,67	-0,46	0,82			-2,91	0,82	-0,94	0,61	-0,66	0,69	-0,78	0,67	-0,81	1,15	-1,83	0,75	-0,44	0,79	-1,16	0,66	-0,57	1,64	-1,11	0,74	-0,65	0,75	-0,96	0,08	-2,1	1,6	0,5	0,8	-2,2	2,6	-0,6	1,2
(KRISS)	2,10	0,64	2,90	0,86	1,72	0,89	2,01	0,74	2,45	0,89	2,91	0,82			1,97	0,69	2,25	0,76	2,13	0,74	2,10	1,19	1,08	0,82	2,47	0,86	1,75	0,74	2,34	1,67	1,80	0,81	2,26	0,82	1,95	0,83								
*NIM	0,13	0,30	0,93	0,66	-0,25	0,69	0,04	0,50	0,48	0,69	0,94	0,61	-1,97	0,69			0,28	0,53	0,16	0,50	0,13	1,06	-0,89	0,61	0,50	0,66	-0,22	0,49	0,37	1,58	-0,17	0,59	0,29	0,61	-0,02	0,62	-1,2	1,4	1,4	0,9	-1,3	2,6	0,4	1,2
NIST	-0,15	0,42	0,65	0,73	-0,53	0,76	-0,24	0,60	0,20	0,76	0,66	0,69	-2,25	0,76	-0,28	0,53			-0,12	0,60	-0,15	1,11	-1,17	0,69	0,22	0,73	-0,50	0,58	0,09	1,61	-0,45	0,67	0,01	0,69	-0,30	0,69	-1,5	1,5	1,2	0,9	-1,6	2,6	0,2	1,3
*NPL	-0,03	0,39	0,77	0,71	-0,41	0,74	-0,12	0,57	0,32	0,74	0,78	0,67	-2,13	0,74	-0,16	0,50	0,12	0,60			-0,03	1,09	-1,05	0,67	0,34	0,71	-0,38	0,56	0,21	1,60	-0,33	0,65	0,13	0,67	-0,18	0,67	-1,3	1,4	1,3	0,9	-1,4	2,6	0,3	1,3
NRC	0,00	1,01	0,80	1,17	-0,38	1,19	-0,09	1,09	0,35	1,19	0,81	1,15	-2,10	1,19	-0,13	1,06	0,15	1,11	0,03	1,09			-1,02	1,15	0,37	1,17	-0,35	1,09	0,24	1,85	-0,30	1,14	0,16	1,15	-0,15	1,15	-1,3	1,7	1,3	1,3	-1,4	2,8	0,3	1,6
OFMET	1,02	0,51	1,82	0,79	0,64	0,82	0,93	0,67	1,37	0,82	1,83	0,75	-1,08	0,82	0,89	0,61	1,17	0,69	1,05	0,67	1,02	1,15			1,39	0,79	0,67	0,66	1,26	1,64	0,72	0,74	1,18	0,75	0,87	0,76	-0,3	1,5	2,3	1,0	-0,4	2,7	1,3	1,3
OMH	-0,37	0,57	0,43	0,83	-0,75	0,86	-0,46	0,71	-0,02	0,86	0,44	0,79	-2,47	0,86	-0,50	0,66	-0,22	0,73	-0,34	0,71	-0,37	1,17	-1,39	0,79			-0,72	0,70	-0,13	1,66	-0,67	0,78	-0,21	0,79	-0,52	0,80	-1,7	1,5	0,9	1,0	-1,8	2,7	-0,1	1,3
*PTB	0,35	0,37	1,15	0,7	-0,03	0,74	0,26	0,56	0,70	0,74	1,16	0,66	-1,75	0,74	0,22	0,49	0,50	0,58	0,38	0,56	0,35	1,09	-0,67	0,66	0,72	0,70			0,59	1,60	0,05	0,64	0,51	0,66	0,20	0,66	-1,0	1,4	1,7	0,9	-1,1	2,6	0,7	1,3
SMU	-0,24	1,54	0,56	1,66	-0,62	1,67	-0,33	1,60	0,11	1,67	0,57	1,64	-2,34	1,67	-0,37	1,58	-0,09	1,61	-0,21	1,60	-0,24	1,85	-1,26	1,64	0,13	1,66	-0,59	1,60			-0,54	1,63	-0,08	1,64	-0,39	1,64	-1,5	2,1	1,1	1,7	-1,6	3,0	0,1	2,0
VNIIOFI	0,30	0,49	1,10	0,78	-0,08	0,81	0,21	0,65	0,65	0,81	1,11	0,74	-1,80	0,81	0,17	0,59	0,45	0,67	0,33	0,65	0,30	1,14	-0,72	0,74	0,67	0,78	-0,05	0,64	0,54	1,63			0,46	0,74	0,15	0,74	-1,0	1,5	1,6	0,9	-1,1	2,6	0,6	1,3
BIPM	-0,16	0,51	0,64	0,79	-0,54	0,82	-0,25	0,67	0,19	0,82	0,65	0,75	-2,26	0,82	-0,29	0,61	-0,01	0,69	-0,13	0,67	-0,16	1,15	-1,18	0,75	0,21	0,79	-0,51	0,66	0,08	1,64	-0,46	0,74			-0,31	0,76	-1,5	1,5	1,1	1,0	-1,6	2,7	0,1	1,3
MSL/IRL	0,15	0,52	0,95	0,80	-0,23	0,83	0,06	0,67	0,50	0,83	0,96	0,08	-1,95	0,83	0,02	0,62	0,30	0,69	0,18	0,67	0,15	1,15	-0,87	0,76	0,52	0,80	-0,20	0,66	0,39	1,64	-0,15	0,74	0,31	0,76			-1,1	1,6	1,5	0,8	-1,2	2,6	0,4	1,2

APMP.PR-K3.b

ITRI	1,3	1,4	2,1	1,6	0,9	1,5	1,2	1,4	1,7	1,5	2,1	1,6			1,2	1,4	1,5	1,5	1,3	1,4	1,3	1,7	0,3	1,5	1,7	1,5	1,0	1,4	1,5	2,1	1,0	1,5	1,5	1,5	1,1	1,6			2,6	1,6	-0,1	3,0	1,5	1,8
KRISS	-1,3	0,8	-0,5	1,0	-1,7	1,0	-1,3	0,6	-1,0	1,0	-0,5	0,8			-1,4	0,9	-1,2	0,9	-1,3	0,9	-1,3	1,3	-2,3	1,0	-0,9	1,0	-1,7	0,9	-1,1	1,7	-1,6	0,9	-1,1	1,0	-1,5	0,8	-2,6	1,6			-2,7	2,6	-1,1	1,3
NPLI	1,4	2,6	2,2	2,7	1,0	2,7	1,4	2,5	1,8	2,7	2,2	2,6			1,3	2,6	1,6	2,6	1,4	2,6	1,4	2,8	0,4	2,7	1,8	2,7	1,1	2,6	1,6	3,0	1,1	2,6	1,6	2,7	1,2	2,6	0,1	3,0	2,7	2,6			1,6	2,8
PSB	-0,3	1,2	0,5	1,3	-0,7	1,3	-0,3	1,1	0,1	1,3	0,6	1,2			-0,4	1,2	-0,2	1,3	-0,3	1,3	-0,3	1,6	-1,3	1,3	0,1	1,3	-0,7	1,3	-0,1	2,0	-0,6	1,3	-0,1	1,3	-0,4	1,2	-1,5	1,8	1,1	1,3	-1,6	2,8		

* Lab	the weight applied to the laboratory measurement in the calculation of the KCRV corresponds to the cutoff uncertainty
(Lab)	the result of the KRISS is not used in the calculation of the KCRV due to a problem with its reference standard
MSL/IRL	amended scale of MSL, recalculated from CCPR-K3.b