CCPR-K6.2010 Key Comparison

Spectral Regular Transmittance

Technical Protocol

1. Introduction

1.1 The metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organised by the Consultative Committees of the CIPM working closely with the Regional Metrology Organisations (RMOs).

1.2 At its meeting in June 2007, the Consultative Committee for Photometry and Radiometry, CCPR, instigated a new series of key comparisons in the field of optical radiation metrology. In particular, it decided that a key comparison of spectral regular transmittance would be carried out, and subsequently appointed MSL (New Zealand) to act as pilot laboratory.

1.3 This technical protocol has been drawn up by a small working group comprising the Measurement Standard Laboratory, New Zealand (MSL); the Physikalisch-Technische Bundesanstalt, Germany (PTB); the Institut National de Metrologie, France (BNM-INM); the National Institute of Standard and Technology, USA (NIST); the National Physical Laboratory, UK (NPL); All Russian Research Institute for Optical and Physical Measurements (VNIIOFI); and the Hungarian Trade Licensing Office (MKEH).

1.4 The procedures outlined in this document cover the technical procedure to be followed during measurement of the transfer standard filters. The procedure, which follows the guidelines established by the BIPM [1], is based on current best practice in the use of standard filters and takes account of the experience gained from the previous comparisons organised in this field [2, 3, 4].

2. Organisation

2.1 Participants

2.1.1 The list of participants was agreed upon at the CCPR WG-KC meeting in September 2009.

2.1.2 In accordance with the guidelines established at the 19th meeting of CCPR, participants must

- be members of CCPR,
- have made an independent realisation of their transmittance scale, and
- have CMC coverage of transmittance at all wavelengths in the range covered by the comparison (380 nm to 1000 nm).

2.1.3 By their declared intention to participate in this key comparison, the laboratories accept the general instructions and the technical protocols written in this document and commit themselves to follow the procedures strictly.

2.1.4 Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

2.2 Participants' details

Korea Research Institute of Standards and Science KRISS	Dr Jisoo Hwang Division of Physical Metrology 1 Doryong-Dong, Yuseong-Gu 305-340 Daejeon, REPUBLIC OF KOREA	Phone : +82-42-868-5294 jhwang@kriss.re.kr
Laboratoire National d'Essai LNE-INM	Dr Gael Obein LNE-INM 61 Rue du Landy 93210 La Plaine St Denis FRANCE	Phone : +33 1 58 80 87 88 gael.obein@cnam.fr
Hungarian Trade Licensing Office MKEH	Péter Gál MKEH 1124. Budapest XII. Németvölgyi út 37-39 HUNGARY	Phone : + 361-4585-852 galpeter@mkeh.hu
Measurement Standards Laboratory MSL	Dr Annette Koo MSL – Callaghan Innovation 69 Gracefield Rd Lower Hutt 5040 NEW ZEALAND	Phone : + 64 4 931 3739 Fax : + 64 4 931 3117 annette.koo@callaghaninnovation.govt.nz
National Institute of Standards and Technology NIST	Dr Catherine Cooksey National Institute of Standards and Technology 100 Bureau Drive Gaithersburg, MD 20899-8441 USA	Phone : + 1 301-975-6208 catherine.cooksey@nist.gov
National Metrology Centre – Agency for Science, Technology and Research NMC/A*STAR	Mr Liu Yuanjie National Metrology Centre 1 Science Park Drive Singapore 118221 REPUBLIC OF SINGAPORE	Phone : +65 62791940 Liu_yuanjie@nmc.a-star.edu.sg
National Metrology Institute of Japan NMIJ, AIST	Dr Hiroshi Shitomi Optical Radiation Section Photometry and Radiometry Division AIST-3, 1-1-1,Umezono, Tsukuba Ibaraki 305-8563 JAPAN	Phone : +81-29-861-5684 h-shitomi@aist.go.jp
National Metrology Institute of South Africa NMISA	Ms Elsie Coetzee Building 5, CSIR Campus Meiring Naude Road, Brummeria Pretoria 0184 SOUTH AFRICA	Phone: +27 12 841 3047 Cell: +27 83 628 4887 emcoetzee@nmisa.org
National Physical Laboratory NPL	Dr Teresa Goodman National Physical Laboratory Hampton Road Teddington Middlesex TW11 0LW UNITED KINGDOM	Phone : +44 20 8943 6863 Teresa.Goodman@npl.co.uk

National Research Council of Canada NRC	Dr Joanne Zwinkels National Research Council of Canada Institute for National Measurement Standards 1200 Montreal Road Ottawa, Ontario K1A 0R6 CANADA Attention: Joanne Zwinkels, Bldg. M-36, Room 1401C	Phone : +1 (613) 993-9363 Joanne.zwinkels@nrc-cnrc.gc.ca
Physikalisch-Technische Bundesanstalt PTB	Dr Alfred Schirmacher PTB Braunschweig AG 4.24, Reflexion und Transmission Bundesallee 100 38116 Braunschweig GERMANY	Phone : + 49 531 592 4240 alfred.schirmacher@ptb.de
All-Russian Research Institute for Optical and Physical Measurements VNIIOFI	Dr Svetlana P. Morozova VNIIOFI 46 Ozernaya Str. 119361 Moscow RUSSIA	Phone : +7 (495) 437-3700 Morozova-m4@vniiofi.ru

2.3 Form of comparison

2.3.1 The comparison will be carried out through the calibration group of transfer standard filters. Each participant will use a separate set of filters to minimise the time needed for the completion of the comparison.

2.3.2 A full description of the transfer standard filters is given in section 3 of this protocol.

2.3.3 The comparison will take the form of a star comparison comprising 4 steps:
Step 1. The artefacts (filters) will initially be calibrated by the pilot laboratory.
Step 2. They will then be distributed to participants who will perform a calibration.
Step 3. They will be returned to the pilot laboratory to carry out a repeat calibration.
Step 4. They will then be redistributed to participants to make a second calibration.
Step 5. They will then be returned to the pilot laboratory to carry out a final calibration.

2.3.4 Each laboratory has 3 months for calibration and transportation. With its confirmed application to participate, each laboratory has confirmed that it will undertake to complete the measurements in the time allocated to it. In steps 2 and 4, the deadline for returning the artefacts will be notified when the filters are shipped to participants.

2.3.5 Final results must be submitted directly to the pilot laboratory within six weeks of completion of each round of measurements by each participating laboratory. The deadline for submitting results will also be notified when the filters are shipped to participants.

2.3.6 If for some reason, the measurement facility is not ready or customs clearance takes too much time in a country, the participant laboratory must contact the pilot laboratory immediately. For such a situation it may be possible for the participant to continue to take part by returning the calibrated filters back to the pilot laboratory at an agreed later date. However, in view of the large amount of work for the pilot laboratory this may not be possible. If this is the case or if results are not reported to the pilot in accordance with the deadlines, then the participant may be disqualified and their results will be excluded from the final report.

2.3.7 Draft Timetable

Activity	Date
Invitation to participate	August 2009
Receipt of request to participate	September 2009
First measurement by Pilot Laboratory (Step 1)	June 2013
Filters sent to participants (Step 2)	September 2013
First measurement by participants	
Filters returned to Pilot Laboratory (Step 3)	December 2013
Results of first measurement submitted to Pilot	6 weeks from above
Second measurement by Pilot laboratory	
Filters sent to participants (Step 4)	March 2014
Second measurement by participants	
Filters returned to Pilot laboratory (Step5)	June 2014
Final results and other data submitted to Pilot Laboratory	6 weeks from above
Third measurement by Pilot laboratory	
Pre-Draft A process starts	September 2014
Draft A comparison report circulated	March 2015
Draft B comparison report submitted to CCPR	

The commencement of the first measurement by Pilot Laboratory (Step 1) is subject to establishing the temporal stability of the filters (see section 7.4). The dates listed above would be correspondingly amended if those first measurements are delayed.

2.4 Handling the artefacts

2.4.1 During steps 2, 3, 4 and 5 of section 2.3.3 the standard filters should be examined immediately upon receipt at final destination. The condition of the filters and associated packaging should be noted and communicated to the pilot laboratory. The form in appendix B.1 should be filled in and sent to the pilot laboratory for each of these steps.

2.4.2 The standard filters should only be handled by authorised persons wearing powder-free gloves and stored in such a way as to prevent damage.

2.4.3 Cleaning should not be carried out unless there is clear evidence of filter contamination. Dust could be removed with a stream of dry gas (avoid cans with liquid propellants). Should further cleaning be required, the laboratory should consult with the pilot laboratory and if cleaning is approved

- make a measurement before cleaning
- use their own standard cleaning method, which must be described in their calibration report.
- make a measurement after cleaning

Cleaning must be indicated in the measurement report and documented using the form in appendix B.2. If a filter appears damaged a replacement may be available from the pilot laboratory.

2.4.4 After the measurements of each step of section 2.3.3 the form in appendix B.2 must be filled in and sent to the pilot laboratory before the filters are packaged in their original transit cases for transportation (steps 1, 2, 3 and 4). Ensure that the content of the package is complete and that the container has been flushed with dry nitrogen before sealing and shipment. Flush by inserting a tube into the open container; there are no flushing ports.

2.5 Transport of artefacts

2.5.1 It is of the utmost importance that the artefacts be transported in a manner in which they will not be lost, damaged or handled by unauthorised persons.

2.5.2 Artefacts should be marked as "fragile".

2.5.3 If required participants may request that the pilot laboratory arrange for a customs carnet to accompany the artefacts on the first round of measurements. If a carnet is not used the artefacts should be accompanied by documentation identifying the items uniquely.

2.5.4 The pilot laboratory covers the costs for transportation to the participant laboratory. Transportation back to the pilot laboratory is each participant laboratory's responsibility and cost. Each participating laboratory covers the costs for its own measurements, transportation and any customs charges as well as for any damage that may have occurred within its country. The pilot laboratory has limited insurance for any loss of or damage to the standards during transportation. If damage occurs in New Zealand or in transit from the pilot laboratory to the participant then the pilot laboratory will replace the set of artefacts at its own cost.

3. Description of the standards

3.1 The filter set to check the photometric scale consists of 5 neutral coloured glass filter plates 50 mm x 50 mm with nominal transmittance, at the wavelength of 546 nm, of 92%, 50%, 10%, 1% and 0.1%.

3.2 Each filter is identified by a reference engraved in the top left corner outside the area used for measurement. This reference has two parts. One is a number indicating the set to which the filter belongs, the other is a letter indicating the filter type (see table below).

3.3 The main characteristics of the filters are summarised in the following table:

Nominal transmittance %	Type of glass	Nominal thickness mm	Filter Type Identifier
92	BK 7	4.0	A
50	NG 11	2.0	B
10	NG 5	3.9	C
1.0	NG 4	3.9	D
0.1	NG 3	3.1	E

4. Measurement instructions

4.1 Traceability

Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90)

4.2 Measurand

4.2.1 The measurand is the average spectral transmittance of each filter

- over a circular area of 17 mm diameter centred on the middle of the filter
- over a bandwidth of 1 nm centred on the wavelengths (380, 400, 500, 600, 700, 800, 900 and 1000) nm
- for a parallel beam with normal angle of incidence
- at a temperature of 23 °C
- and at a relative humidity not exceeding 60 %.

4.3 Measurement instructions

4.3.1 Before measurement each filter should be inspected for damage or contamination. Any initial or subsequent damage or cleaning should be documented using the appropriate form in appendix B.1 or B.2.

4.3.2 The measurement should be performed in suitable laboratory accommodation maintained at a temperature as close as possible to 23 °C and at a relative humidity not exceeding 60 %. The temperature and relative humidity of the laboratory during the time of the measurements should be reported. It is the responsibility of the individual laboratory to correct the measurement for the deviation of the temperature from 23 °C. The pilot laboratory will provide the participants with temperature coefficients and their uncertainties for the filters.

4.3.3 The filter transmittance must be measured independently several times. The number of measurements should be that normally used by the participating laboratory to obtain the appropriate accuracy of their specific measurement facility. The number of measurements used should be stated in the measurement report but only the mean or final declared value of each filter of the set is required to be included.

4.3.4 The transmittance measurement of the filters should be made at wavelengths of (380, 400, 500, 600, 700, 800, 900 and 1000) nm.

4.3.5 The measurement of interest in this comparison is the average transmittance of each filter over a circular area of 17 mm diameter centred on the middle of the filter as determined from the edges of the filter. The ideal beam is therefore a circular beam of 17 mm diameter. Should the measurement beam be different to this then the participant laboratory should incorporate an uncertainty to account for this when estimating the average transmittance over the area of interest for this comparison.

4.3.6 The beam geometry shall be as close as possible to a parallel beam with normal angle of incidence. Any deviation from these conditions should be reported. Any influence on transmittance as defined by 4.2.1 caused such by deviations should be handled as either a correction with associated uncertainty or solely as an uncertainty, whichever is the participant laboratory's regular practice.

4.3.7 The preferred bandwidth for the measurements is 1 nm; the bandwidth used should be stated in the report. Should the participant laboratory make measurements using some different bandwidth then any bandwidth effects should be accounted for by the participant in their uncertainty budget.

4.3.8 No information relating to the comparison, such as measurement results, obtained by a participant during the course of the comparison shall be communicated to any party other than the pilot laboratory. The pilot laboratory will be responsible for disseminating information to other participants and any other release of information. In the latter case the pilot laboratory will seek permission of all the participants before releasing information.

5. Measurement uncertainty

5.1 Measurement uncertainty shall be estimated according to the ISO Guide to the Expression of Uncertainty in Measurement [5]. In order to achieve optimum comparability, a list containing the principal influence parameters for calibration of spectral transmittance is given below. The participating laboratories are encouraged to follow this breakdown as closely as possible, and adapt it to their instruments and procedures if necessary. Other additional parameters that it may be felt appropriate can be added to the list; these include dependence on specific measurement facilities and should be added with an appropriate explanation and or reference. As well as the value associated with the uncertainty, participants should give an indication of the basis for their estimate. All values should be given as absolute uncertainties for a coverage factor of k=1.

5.2 The reproducibility of measurements can be determined by calculating the standard deviation of a set of measurements with realignment and repositioning of the filter between each individual measurement. It characterises the whole process of the measurement. It is this value which has to be taken into account for the uncertainty evaluated according the type A method.

5.3 Type B uncertainty components may include the following:

- temperature of the filter during measurement,
- non-linearity of the detector over the dynamic range of the detector used for the measurements,
- that due to the uncertainty in the wavelength setting of the monochromator,
- stray light,
- beam size and position ,
- inter-reflection between the filter and the various optical and mechanical components of the experimental set-up,
- obliquity effects (changes to path length and Fresnel reflection) due to a non-parallel beam or the imperfect alignment of the filter,
- polarisation of the light,
- drift of the sources during the measurements,
- bandwidth,
- any other uncertainty components specific to the apparatus used for the measurements as explained in § 5.1.

5.4 Some components of type B uncertainty will be partially or wholly correlated between the measurements of steps 2 and 4. The degree of correlation and the total correlated and uncorrelated type B components must be reported at the completion of step 4 using the table A-3ii in appendix A.3.

6. Reporting of results

6.1 The final results should be submitted to the pilot laboratory at the latest within six weeks from completion of measurements in steps 2 and 4. The tables in appendices A.1 and A.2 should be completed after step 2 and the tables in appendices A.1 and A.3 should be completed after step 4.

6.2 The measurement report tables (appendices A.1, A.2 and A.3) of this document will be sent by e-mail (as a Microsoft word document) to all participants to be filled in. It would be appreciated if the completed form could be sent back electronically to the co-ordinator. **In any case, the signed report including the results must also be sent in paper form by mail, or in PDF or JPG format of the signed report scanned and sent by email.** In case of any differences, the paper versions are considered to be the definitive version.

6.3 In completing the description of the participant's measurement facility, Appendix A.1, a schematic diagram of the facility should be included.

6.4 Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will follow the procedure outlined in the Guidelines for CCPR Comparison Report Preparation [6].

7. Analysis of Comparison Results

7.1 Introduction

In the Technical Supplement to the Mutual Recognition Arrangement (MRA) [7], key comparisons are identified as the technical basis for the arrangement. The technical deliverables of a key comparison are outlined as:

(a) reference values, known as key comparison reference values (KCRV) and

(b) the unilateral degree of equivalence (DOE) of each national measurement standard, both its deviation from the KCRV and the uncertainty of that deviation at the 95 % level of confidence.

The bilateral degrees of equivalence between pairs of national measurement standards are also defined in the Technical Supplement; it has, however, been decided by CCPR that these are no longer required to be reported in CCPR key comparison reports [8].

As the key comparisons are the technical basis for the MRA, the results reported should be the basis upon which CMCs are validated and subsequently evaluated. The CCPR Guidelines state that all participants should be able to "check the consistency of their CMCs with the KC results" ([6], §8.1). This means that the comparison should determine the value of each participant's bias (DOE) and the uncertainty associated with that value in order to give some indication as to whether a participant has adequately estimated the likely magnitude of that bias.

7.2 Data Analysis Model

The analysis technique to be used in CCPR-K6.2010 is generalised least squares (GLS) regression. The least-squares model approach is a general method suited to all forms of comparison. Effects such as artefact fluctuation and correlations between measurements are easily accommodated. Consistency checking of the data and reported variances is inherent in the method. Most importantly, this method gives the best linear unbiased estimator as a solution and avoids the averaging often required to apply the so called 'step-by-step' method [8, Appendix B].

Each of the 40 measurements (5 filters x 8 wavelengths) is considered an independent comparison of standards, with its own DOEs.Within each comparison each measurement of the filters will be modelled with the following measurement equation (after [9, 11]):

$$y_{i,f,r} = T_f + \Delta_i + \varepsilon_{i,f,r} \tag{1}$$

where $y_{i,f,r}$ is a single measurement of filter *f* by participant i in round *r*, T_f is the transmittance of the filter *f*, Δ_i is the systematic bias of laboratory i and $\varepsilon_{i,f,r}$ is the error associated with the participant's measurement and with the intrinsic variability of the filter itself (e.g. drift or contamination with time).

For this comparison, only a single measurement of a single artefact is reported in a given round, so there will be no correlations between the errors in measurements within a round except for the pilot. As the transmittance standard is realised independently by every participant, there are no correlations between participants. The only correlations to be taken into account are those between the measurements of a particular participant over the two rounds and those of the pilot within a round.

The solution for the T_f and Δ_i in equation (1) is obtained by using least squares fitting to minimise the weighted sum of squared residuals (differences between estimates and reported measurements). This can be written as

$$z^2 = (\mathbf{y} - X\hat{\boldsymbol{\beta}})^T V_{\mathbf{y}}^{-1} (\mathbf{y} - X\hat{\boldsymbol{\beta}}) \tag{2}$$

where $\mathbf{y}$ is the column vector of all measurement results $y_{i,f,r}$, X is the design matrix with each row representing a single measurement, $\hat{\boldsymbol{\beta}}$ is the estimate of $\boldsymbol{\beta}$, the column vector of the unknown T_f and Δ_i, and $V_{\mathbf{y}}$ is the covariance matrix of the errors associated with the measurements. The function is minimised by differentiating expression (2) with respect to $\hat{\boldsymbol{\beta}}$, setting the derivative equal to zero and solving the resulting equation. For a unique solution however, an additional constraint must be imposed. The constraint chosen to be compatible with the CCPR Guidelines [6, §5.3] is

$$\sum w_i \Delta_i = 0 \tag{3}$$

where

$$w_i = \frac{u_c^{-2}(t_i)}{\sum_j u_c^{-2}(t_j)} \tag{4}$$

are the weights assigned to each participant and the $u_c(t_i)$ are the averages of the total uncertainties given by each participant for all measurements after applying a cut-off. The cut-off is the average of the uncertainty values of those participants that reported uncertainties smaller than or equal to the median of all the participants.

This constraint is added as a final row in $\mathbf{y}$ and X. This formulation then has the unique solution

$$\hat{\boldsymbol{\beta}} = (X^T V_{\mathbf{y}}^{-1} X)^{-1} X^T V_{\mathbf{y}}^{-1} \mathbf{y}\,. \tag{4}$$

The elements Δ_i of $\hat{\boldsymbol{\beta}}$ are the values of the DOEs; their uncertainties will be estimated in accordance with the GUM [5].

7.3 Treatment of Pilot

As the pilot is making considerably more measurements per comparison (22) than any other participant (2), the uncertainty on their DOE due to random components will be lower than that of other participants. This comparison will be analyzed so that the final DOE and its uncertainty represent a single measurement of a single artefact as is ‘ordinarily available to the customers of an institute through its calibration and measurement services’ [7]. Therefore the components of uncertainty on the DOE will need to be divided into random and systematic components, and the random component determined by the least squares method will be replaced by a simple average of the random uncertainties associated with each of a participant’s measurements.

7.4 Model for drift

In the previous comparison, it was found necessary to incorporate a model for drift or fluctuation in artefact transmittance. For this comparison several months of monitoring will be carried out before the comparison begins in the hope that good stability will be established. However the presence of drift due to filter instability or contamination may still be significant.

Data to inform a model of the time-dependent component of the drift will be available from the stability monitoring to be carried out by the pilot before the comparison begins. After this period of testing, but before the commencement of measurements contributing to the comparison itself, a model for drift, which takes account of both temporal drift and possible contamination during the comparison, will be developed and agreed upon by the task group.

7.5 Consistency Check

The result for $\hat{\beta}$ can be inserted back into equation (2) to carry out a consistency check on the data via a chi-square test. The result from equation (2) should be distributed as χ^2 with v degrees of freedom ($v = m - n$, m is the number of observations and n the number of model parameters). If there is a less than 0.05 probability of obtaining a value of $\chi^2 > z^2$ then the model and the data will be considered inconsistent.

The choice of a model for drift may be amended to reduce or eliminate any inconsistency. Otherwise the next step would be to discuss the removal of outliers from the constraint equation (3) with all participants as directed by the CCPR Guidelines §4.1 [6].

7.6 Analysis Software

The CCPR Guidelines [6] require that the "data analysis program and intermediate results should be made available for all participants". The model approach outlined here is not straightforward to implement in the commonly used software package Microsoft Excel. Python (http://www.python.org/), an open source programming language, or Mathcad (http://www.ptc.com/products/mathcad/) will be used to carry out the calculations required.

References

[1] T.J. Quinn, "Guidelines for CIPM key comparisons" BIPM, Paris, (1999, modified 2003).

[2] K.L. Eckerle, J. Bastie, J. Zwinkels, V. Sapritsky and A. Ulyanov, "Comparison of regular transmittance scales of four national standardizing laboratories," Col. Res.Appl. 18 35(1993).

[3] J.F. Verrill, "Intercomparison of spectrophotometric measurements of regular transmittance," Report contract N°. MAT1-CT940021, (1996).

[4] Obein G and Bastie J 2008 *Report on the CCPR Key Comparison K6 Spectral regular transmittance,* available at http://kcdb.bipm.org/AppendixB/appbresults/ccpr-k6/ccpr-k6_final_report.pdf

Obein, J. Bastie "Report on the CCPR Key Comparison K6: Spectral Regular Transmittance," Metrologia 46, Tech. Suppl., 02002 (2009).

[5] BIPM IEC IFCC ILAC ISO IUPAC IUPAP and OIML 2008 *Guide to the Expression of Uncertainty in Measurement* (Geneva: International Organization for Standardization) available at http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

[6] Consultative Committee on Photometry and Radiometry Key Comparison Working Group, Guidelines for CCPR Comparison Report Preparation, 2009 available at http://www.bipm.org/utils/common/pdf/Guidelines_for_CCPR_KC_Reports.pdf

[7] International Committee for Weights and Measures, 2003, Mutual Recognition of National Measurement Standards and of Calibration and Measurement Certificates Issued by National Measurement Institutes (Paris: Comité International des Poids et Mesures), available at http://www.bipm.org/utils/en/pdf/mra_2003.pdf

[8] CCPR 2009 *20th CCPR Meeting, Draft Report* Decision D8

[9] White D R 2004 On the analysis of measurement comparisons Metrologia 41 122–131

[10] Parr A 2005 *CCPR/05-04* Comments on the use of weighted mean in data analysis.

[11] Appendix B "A Guide to the Analysis Approach", CCPR K1.a Report (2005).

Appendix **A.1 Description of measurement facility and measurement method**

Laboratory:

Indicate whether this table relates to Step 2 [ ] or Step 4 [ ]

If the measurement setup has not changed from Step 2, check here [ ] and the following table does not need to be completed. Otherwise, please fill out the whole table.

Table A-1 Details of Measurement Setup

Make and Type of Spectrophotometer	
Additional Stray Light Rejection	
Source Drift Monitoring	
Source	
Detector	
Temperature[(a)]	
Humidity	
Beam Size	
Beam Collimation	
Measurement Sequence[(b)]	
Bandwidth	

[(a)] i.e. describe method of temperature monitoring of filters and range of temperatures [(b)] i.e. describe number of measurements and whether filter orientation with respect to beam changes between measurements

Description of measuring technique (please include a diagram)

If any damage, contamination or cleaning of the filters was carried out, please give details

Signature : **Date :**

Appendix **A.2 Measurement Results**

Please reproduce the following tables for each of the five filters measured at the completion of step 2 of the comparison. All uncertainties should be reported as absolute uncertainties.

Laboratory: Filter Identifier:

Table A-2i Measurement Results

Wavelength (nm)	380	400	500	600	700	800	900	1000
Spectral Transmittance[(a)]								
Number of Measurements								
Temperature								
Type A Uncertainty[(b)]								
Type B Uncertainty[(c)]								
Total Uncertainty[(d)]								
Degrees of Freedom								

[(a)]**Spectral transmittance.** The value of the spectral transmittance of the central 17 mm diameter of the filter as measured by the participant laboratory. [(b)]**Type A Uncertainty.** The uncertainties associated with the spectral transmittance values attributed to reproducibility of the measurement. [(c)]**Type B Uncertainty.** The uncertainties associated with the spectral transmittance values attributed to all type B sources. [(d)]**Total Uncertainty.** The total uncertainty of the measurement of spectral transmittance for a coverage factor of k=1.

Table A-2ii Type B Uncertainty Budget[(a)]

Fill out the table below for the uncertainty contributions in measurement at Step 2. All uncertainties should be reported as absolute uncertainties.

Wavelength (nm)	380	400	500	600	700	800	900	1000
Nonlinearity								
Temperature								
Wavelength								
Stray Light								
Beam Size & Position								
Inter-reflection								
Obliquity								
Polarization								
Source Drift & Fluctuation								
Bandwidth								
Other[(b)]								
Total Type B Uncertainty								
Degrees of Freedom								

[(a)] Please record any uncertainties considered negligible as zero (rather than e.g. < some value) [(b)]Add lines to the table as necessary, itemising other components of uncertainty considered

Signature : **Date :**

A.3 Measurement Results

Please reproduce the following two tables for each of the five filters measured at the completion of step 4 of the comparison. All uncertainties should be reported as absolute uncertainties.

Laboratory: Filter Identifier:

Table A-3i Measurement Results

Wavelength (nm)	380	400	500	600	700	800	900	1000
Spectral Transmittance[(a)]								
Number of Measurements								
Temperature								
Type A Uncertainty[(b)]								
Type B Uncertainty[(c)]								
Total Uncertainty[(d)]								
Degrees of Freedom								

[(a)]**Spectral transmittance.** The value of the spectral transmittance of the central 17 mm diameter of the filter as measured by the participant laboratory. [(b)]**Type A Uncertainty.** The uncertainties associated with the spectral transmittance values attributed to reproducibility of the measurement. [(c)]**Type B Uncertainty.** The uncertainties associated with the spectral transmittance values attributed to all type B sources. [(d)]**Total Uncertainty.** The total uncertainty of the measurement of spectral transmittance for a coverage factor of k=1.

Table A-3ii Type B Uncertainty Budget[a]

Fill out the table below for the uncertainty contributions in measurement at Step 4. All uncertainties should be reported as absolute uncertainties.

If the uncertainty budget has not changed from Step 2 (Table A-2ii), check here [   ] and only the Correlated Component column of the following table needs to be filled out. Otherwise, please fill out the whole table.

Wavelength (nm)	380	400	500	600	700	800	900	1000	Correlated Component[b]
Nonlinearity									
Temperature									
Wavelength									
Stray Light									
Beam Size & Position									
Inter-reflection									
Obliquity									
Polarization									
Source Drift & Fluctuation									
Bandwidth									
Other[c]									
Total Correlated[b]									
Total Type B Uncertainty									
Degrees of Freedom									

[a]Please record any uncertainties considered negligible as zero (rather than e.g. < some value) [b]Component of uncertainty correlated with measurements made during step 2, expressed in absolute terms [c]Add lines to the table as necessary, itemising other components of uncertainty considered

Signature : **Date :**

Appendix B.1 Receipt of Standards

To Laboratory :

From Laboratory:

Has the filter transportation package been opened during transit ? e.g; Customs…..Y / N

If yes please give details:

Is there any damage to the packaging ?…….Y / N

If yes please give details:

Are there any visible signs of damage or contamination on the filters ?……Y / N

If yes please give details:

We confirm receipt of the standards of the BIPM Key comparison K6.2010 "Regular Spectral Transmittance".

Signature : **Date :**

Appendix B.2 Condition of the transfer standards on departure

Laboratory:

Were the filters contaminated or damaged in any way while at your laboratory? Y / N

If yes please give details:

Was any cleaning of filters undertaken while at your laboratory? Y / N

If yes please give details:

Has the filter container been flushed with dry nitrogen and sealed? Y / N

Signature : **Date :**