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Intercomparison of transmittance measurements on V(λ) filter

EUROMET project 353

SP Swedish National Testing and Research Institute

SP Measurement Technology
SP REPORT 2004:19

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Abstract

Five National Metrology Institutes participated in the EUROMET project No. 353, Intercomparison of transmittance measurements on V(λ) filter.

The V(λ) filter which was used in this project is made for usage together with a silicon detector or preferably with a silicon trap detector to approximate the CIE photometric standard observer for photopic vision.

The spectral transmittance of the filter was compared at a reference temperature of 25 °C.

The visual (spectrally integrated) transmittance for CIE standard source A, weighted with the spectral responsivity of the silicon trap detector, shows an agreement within 1.3 % including all five participants but when excluding one of the participants the agreement was within 0.1 %

Key words: Intercomparison, V-lambda, filter, photometry, trap detector.

SP Sveriges Provnings- och Forskningsinstitut
SP Rapport 2004:19
ISBN 91-7848-992-X
ISSN 0284-5172
Borås 2004

SP Swedish National Testing and Research Institute
SP Report 2004:19

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Acknowledgement

We are particularly grateful to the Metrology Research Institute at Helsinki University of Technology for supplying the V(λ) filter used in this project.

Preface

This report on EUROMET project 353, Intercomparison of transmittance measurements on V(λ) filter. Measurement instrumentations are described. Measurement results on filter spatial uniformity, temperature dependency, and especially spectral transmittance are presented.

Summary

Five National Metrology Institutes participated in the EUROMET project No. 353, Intercomparison of transmittance measurements on V(λ) filter.

The V(λ) filter which was used in this project is made for usage together with a silicon detector or preferably with a silicon trap detector to approximate the CIE photometric standard observer for photopic vision.

The spectral transmittance of the filter was compared at a reference temperature of 25 °C.

The visual (spectrally integrated) transmittance for CIE standard source A, weighted with the spectral responsivity of the silicon trap detector, shows an agreement within 1.3 % including all five participants but when excluding one of the participants the agreement was within 0.1 %.

Sammanfattning

Fem nationella metrologiinstitut deltog I EUROMET projekt nummer 353, Intercomparison of transmittance measurements on V(λ) filter.

V(λ)-filtret som användes i detta projekt är tillverkat för att tillsammans med en kiseldetector eller helst en s k trapdetektor innehållande kiseldetektorer, som ger en spektral responsivitet som efterliknar CIE fotometriska standardobservatör för fotopiskt seende.

Filtrets spektrala transmittans jämfördes vid en referenstemperatur på 25 °C.

Visuell (spektralt integrerad) tranmittans för CIE standardljus A, viktad med spektral responsivitet hos kisel-trapdetektor, visar en överesstämmelse inom 1,3 % om man inkluderar samtliga fem deltagare men om man exkluderar en av deltagarna blir överensstämmelsen 0,1 %.

1 Introduction

In the framework of EUROMET project No. 353 "Transmittance of V(λ) intercomparison", a filter with a transmittance close to the V(λ) function of the CIE photometric standard observer has been circulated between five participating laboratories. The spectral transmittance of the central part of the filter was measured at filter temperature 25 ±1 °C. The objective of the intercomparison was to confirm the estimated uncertainty (filter part) for each participating laboratory when using a calibrated V(λ) filter together with a precision aperture and a silicon trap detector for realization of photometric scales [1,2].

2 Participants

Five national laboratories participated in the intercomparison:
- Bureau National de Métrologie, Institute National de Métrologie (BNM-INM), Paris, France
- Helsinki University of Technology (HUT), Metrology Research Institute, Espoo, Finland
- National Metrology Institute / Van Swinden Laboratory (Nmi/VSL), Delft, the Netherlands
- Swedish National Testing and Research Institute (SP), Borås, Sweden
- Ulusal Metroloji Enstitüsü (UME), Kocaeli, Turkey

In the results presented below, these laboratories are given the numbers 1-5 in random order.

3 Instrumentation

HUT used a precision transmittance spectrophotometer set-up. SP used a commercial Perkin-Elmer UV-VIS-NIR Lambda 9 (replaced with Perkin-Elmer Lambda 900 in 1998). These two instruments have been described in [3].

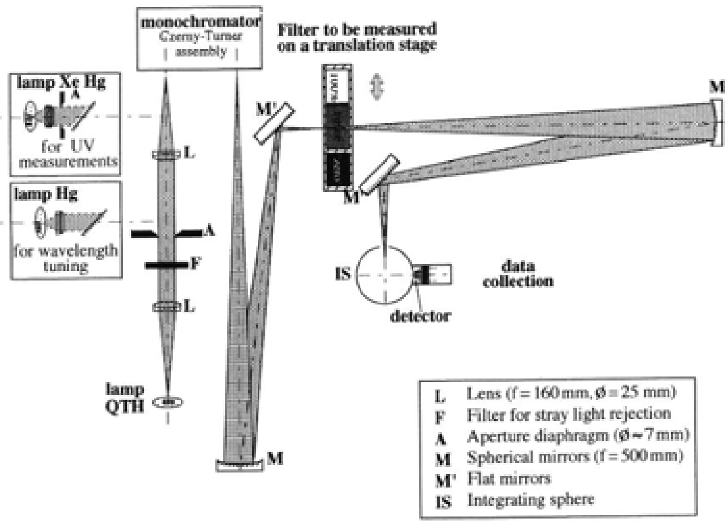

Figure 1. Precision transmittance measurement set-up at BNM-INM

Figure 1 illustrates the precision transmittance measurement set-up at BNM-INM using a very high resolution single grating Jobin-Yvon. For the spectral range 200 nm - 800 nm this monochromator is equipped with a 2000 groves per mm holographic grating.

UME used a spectrophotometer based on the monochromator Bentham Instruments, model
DTM 300V, using 1.3 nm bandwidth in the wavelength range 200 nm - 900 nm.

Nmi/VSL used a Jobin-Yvon. model HR1000, single grating monochromator (f=1000 mm) in which the transmittance measurement set-up gives 0,6 µW - 2,6 µW output for 1.2 nm bandwidth. Straylight blocking is better than 10^{-6} at 650 nm. Wavelength calibration was made using Cs and Ne spectral lamps with an uncertainty <0,1 nm.

The major differences between the instruments and measurements are summarised in Table 1.

Table 1. Instrumentation

Feature	**BNM-INM**	**HUT**	**Nmi/VSL**	**SP**	**UME**
Gratings	single	single	single	double	double
Beams	single	single	single	double	single
Optimized for transmittance	yes	yes	yes	no	n.a.
Bandwidth used	0,5 nm	1,5 nm	1.2 nm	2 nm	1,3
Spot size	2x6 mm	5 mm diam		2x5 mm in four directions	
Temperature	24,8 °C	25,0±0,5 °C	25,0±0,5 °C	25,0±0,5 °C	23,0±0,2 °C *)

*) UME transmittance data below is corrected to 25 °C

4 The V(λ) filter and measurement procedures

The V(λ) filter used for the intercomparision has a diameter of 15 mm (13 mm open diameter), is about 4 mm thick, and manufacturered by PRC Krochmann, Berlin. It was supplied by HUT with their designation 95_1. The task was to measure its transmittance in an 5 mm diameter spot in the centre of the filter. This was achieved exactly only by HUT. The BNM and SP instruments gave a 2x6 and 2x5 rectangular spot respectively. To reduce the effect of this deviation, SP measured the average value of the transmittance with the filter in four rotational positions. Two laboratories, HUT and BNM-INM measured the spatial uniformity of the filter.

In general, 5 nm wavelength intervals were used, but in the ranges 380 nm - 490 nm and 610 nm - 780 the data was reduced to 10 nm intervals in order to achieve conformity for all laboratories.

The filter was circulated in a star configuration and generally the filter was measured at SP before and after circulation to each single laboratory. The results for the laboratory was compared with SPs result (average of measurements before and after circulation).

5 Filter characterization

5.1 Spatial uniformity

The non-uniformity of the transmittance was measured by BNM, HUT and NMI-VSL. (See Figure 2.). BNM measured in only one point 0,5 mm on each side of the centre but at several wavelengths in range 490 nm - 570 nm and found a transmittance change less than 0,1 % from the centre value. Each BNM point in Figure 1 represents an average of transmittances at three different wavelengths near 555 nm.

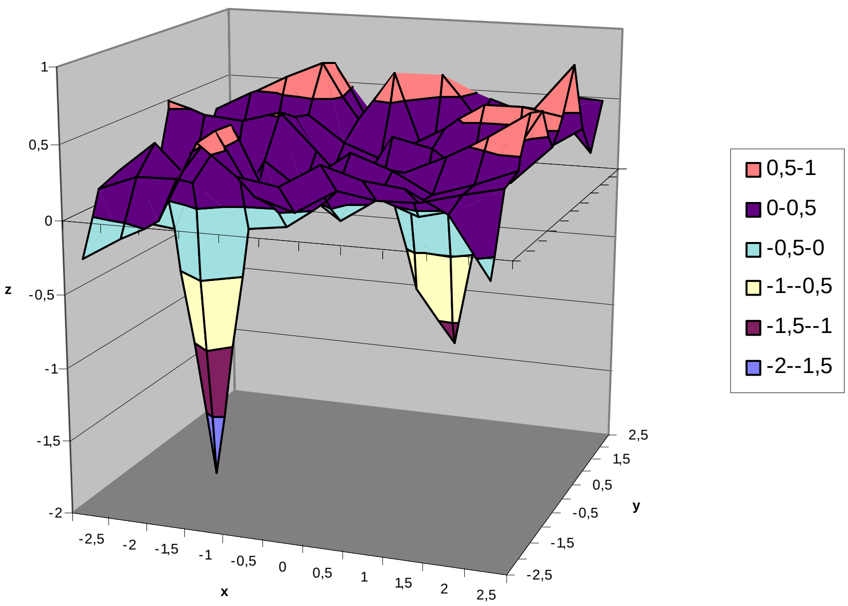

Figure 2. Non-uniformity (T%-T%$_{centre}$) with 1,5 mm spot size, ±3 mm from centre point.

HUT measured in august 1995 this parameter, with 0.5 mm intervals, in a 3x3 mm matrix around the centre using 1,5 mm diameter spot size from a green helium-neon laser. Figure 2 shows the result reduced to a 2.5x2.5 mm matrix where variations up to almost 2 % could be seen. However, if the average is taken of the 25 points ±1 mm around each point in a 2x2 mm matrix the result will be more equivalent to the desired 5 mm spot size and the non-uniformity be within about ±0,1 %T. (See Table 2.)

Table 2. Non-uniformity (T%-T%$_{centre}$) with about 5 mm spot size ±2 mm from centre point

y\x	-2	-1,5	-1	-0,5	0	0,5	1	1,5	2
-2	-0,42	-0,02	0,03	0,09	0,18	0,14	0,16	0,18	0,16
-1,5	-0,06	-0,04	-0,01	0,04	0,15	0,13	0,18	0,23	0,28
-1	0,05	0,02	0,01	0,03	0,13	0,10	0,14	0,24	0,30
-0,5	0,02	-0,01	-0,02	0,01	0,12	0,11	0,18	0,28	0,33
0	-0,03	-0,03	-0,04	-0,05	0,00	0,00	0,07	0,20	0,29
0,5	0,19	0,17	0,16	0,12	0,03	-0,01	0,02	0,11	0,19
1	0,22	0,22	0,24	0,22	0,12	0,07	0,11	0,15	0,16
1,5	0,12	0,14	0,20	0,20	0,11	0,07	0,12	0,17	0,18
2	0,15	0,19	0,26	0,24	0,12	0,05	0,08	0,11	0,15

In Figure 3 are transmittances with 5 mm spot, along two orthogonal diameters, randomly chosen from each HUT and Nmi-VSL, and presented as difference from the transmittance at centre position.

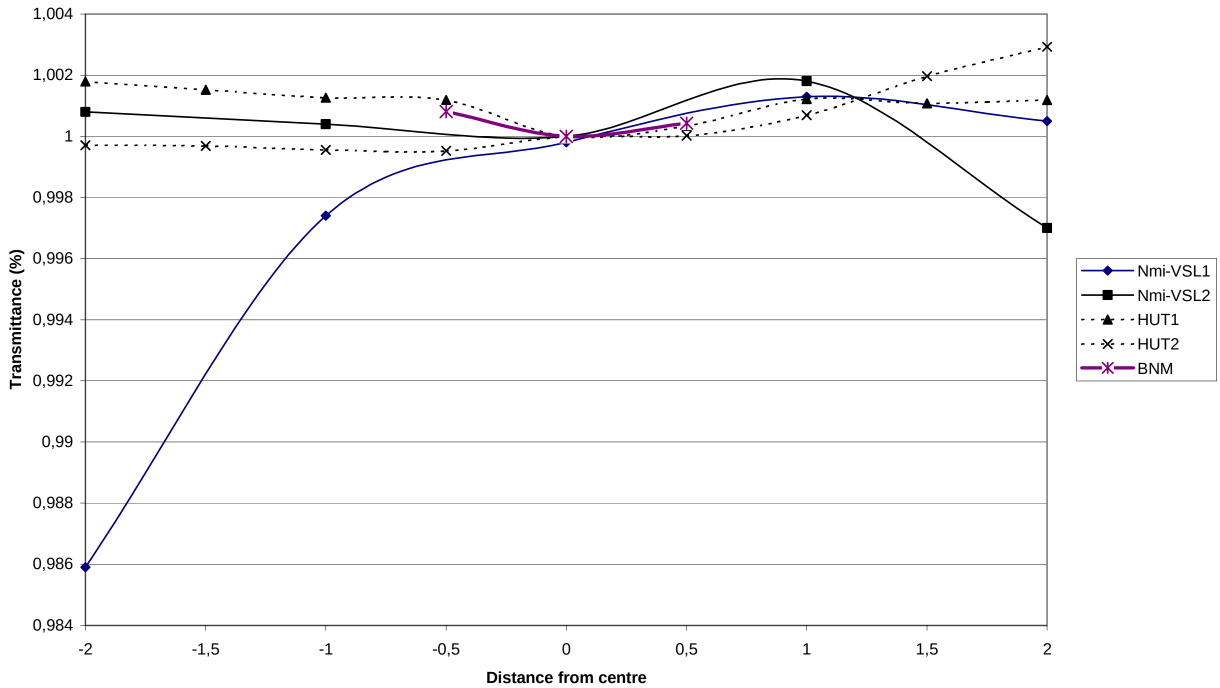

Figure 3. Non-uniformity of the transmittance with 5 mm spot size which is measured in two orthogonal diameters by BNM, HUT and NMI-VSL.

5.2 Out of band transmittance

BNM-INM measured the transmittance of the filter outside its transmission band. The measured transmittance in the 280 nm - 370 nm range and 780 - 790 nm range was less than 0,001 %T.

5.3 Temperature dependence

The transmittance was measured by HUT in 5 nm steps in the range 380 nm - 750 nm at three different temperatures: 20 °C, 25 °C and 30 °C. The differences of transmittance at 20 °C and the transmittance at 25 °C is plotted in Figure 4 together with the corresponding difference between 30 °C and 25 °C. This result was used to correct the transmittance data of UME from 23 °C to 25 °C.

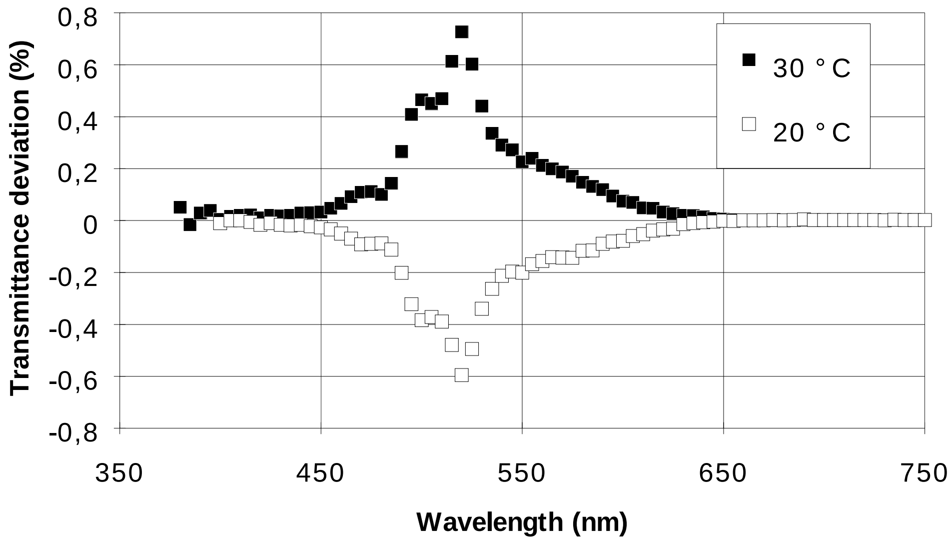

Figure 4. Temperature dependence of the V(λ)-filter. Deviation (%) from transmittance at 25 °C temperature

6 Measurement uncertainty

The uncertainties (standard uncertainties) of the transmittance measurements, stated by each participant, are given in Table 3. The number given below to the laboratories are different to the order in the list above.

Table 3. Uncertainties (1σ) near 555 nm

Laboratory No.	Uncertainty, %T
1	0,087
2	0,083
3	0,153
4	0,113
5	0,094

7 Results

The transmittance of the filter was measured by SP before and after circulation to each participant. The difference of the transmittance measured by each other lab and the average transmittance measured by SP is plotted in Figure 5.

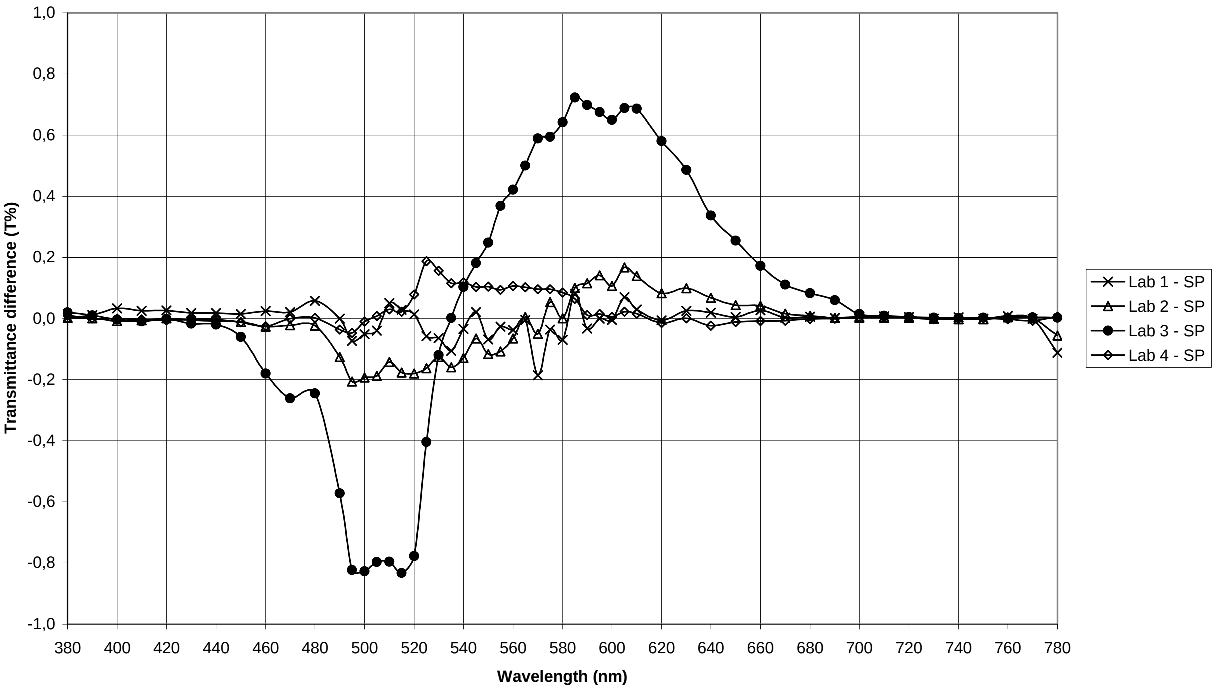

Figure 5. Measured transmittance $T\%_{Lab}$ - $T\%_{SP}$

The shape of No. 2 and No. 3 indicates a systematic wavelength deviation compared to SP. A wavelength shift of 0,2 nm improves the No. 2 result considerably. Corrected transmittance $\tau_c(\lambda)$ is then calculated according to

$$\tau_c(\lambda) = \tau(\lambda) + \Delta\lambda \cdot \frac{\partial \tau}{\partial \lambda}$$

where $\Delta\lambda$ is the wavelength shift.

Also the No. 3 result is improved. A 0,8 nm wavelength shift will give a max 0,4 %T deviation instead of max 0,6 %T.

The $V(\lambda)$ filter chosen in this comparison is intended to be used for accurate illuminance measurement together with a silicon trap detector. Therefore the most important quantity for this intercomparison is the integrated value E, of the spectral transmittance $\tau(\lambda)$ over the visible spectra range weighted with the spectral responsivity of the trap detector, i.e. a linear dependency with the wavelength λ, and with the relative spectral irradiance, $S_\lambda(\lambda)$ of a luminous intensity source which is close to the CIE standard source A, 2856 K.

$$E = a \cdot \int \tau(\lambda) \cdot \lambda \cdot S_{\lambda}(\lambda) \cdot d\lambda$$

where a is a constant. In Table 4 this equation is applied on $\tau(\lambda)$ measured at the different institutes and the results are divided by the corresponding SP value. For two labs also the effect of wavelength corrections above are applied.

Table 4. Spectrally weighted transmittances relative SP (E_{Lab}/E_{SP})

Wavelength correction	**Lab 1**	**Lab 2**	**Lab 3**	**Lab 4**
Excluded.	0,9994	1,0004	1.0134	1,0010
Included		0,9984	1,0084	

8 Conclusion

The result in Table 4 shows good agreement, within 0,1 %, between four of the participating laboratories. The disagreement with the fifth institute was quite large. To some extent this could be explained by the fact that the transmittance of the filter decreased, about 1 %, after the year 2002.

Wavelengths corrections, visually improving the spectral differences in transmittance for two of the participators, improved also the spectrally weighted transmittance for one of them but not for the other. The reason for this is that wavelengths near the maximum of the V(λ)-function are more important than others.

With exception for the transmittance drop 2002, the filter transmittance showed a very good stability during the comparison period 1995-2003. During this period the filter was not cleaned.

References

1. Ikonen, E., Kärhä, P. Lassila, A., Manoochehri, F., Fagerlund, H. and Liedquist, L. ”Radiometric realization of the candela with a trap detector”, Metrologia, 1995/96, 32, 689-692
2. Liedquist, L., Ikonen, E., Kärhaä, P. And Fagerlund, H. ”Comparison of luminous-intensity scales based on trap detectors and incandescent lamps”, Metrologia, 1995/96, 32, 681-684
3. Manoochehri, F., Ikonen, E. and Liedquist, L. ”Comparison of Measurements on Regular Spectral Transmittance”, COLOR research and application, Volume 21, Number 6, December 1996

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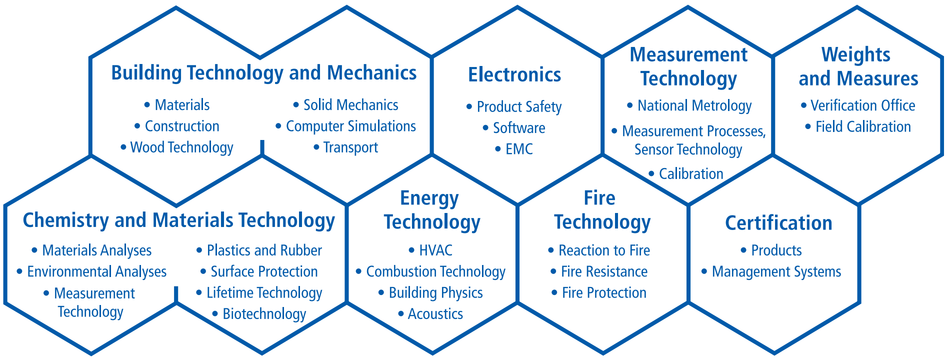

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