COOMET.PR-S1 Comparison of Whiteness and Brightness

Final Report

(COOMET project 366/RU/06)

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ABSTRACT

This report gives the results of the COOMET supplementary comparison COOMET.PR-S1 of Whiteness and Brightness, defined as CIE whiteness value W_{10} and ISO brightness R_{457} by the documents ISO 11475-2007 and ISO 2469, respectively.

Three NIMs took part in the comparison: All-Russian Research Institute for Optical and Physical measurement (VNIIOFI. Russia), Belarusian State Institute of Metrology (BelGIM. Belarus) and National Scientific Centre “Institute of Metrology” (NSC IM. Ukraine). VNIIOFI was a pilot of the comparison.

One more laboratory performed measurements of the traveling artefacts: All-Ukrainian state research and production centre for standardization, metrology, certification and consumers' rights protection (Ukrmetrteststandard, Ukraine). However, the designated institute from Ukraine in this area of the Photometry and Radiometry field is NSC IM, but not Ukrmetrteststandard. Therefore, the Ukrmetrteststandard measurement data were not used for evaluating the comparison Reference Values (RV) and Differences from RV, and are not included in the main part of this report, but only presented in the Annex.

The comparison artefact was a set of six opal glass samples with different values of whiteness/ brightness. The artefacts were measured by the participants in series. The pilot measured twice, in the beginning and at the end.

The all measurement results of all three participants (excluding only one sample measurement of one participant) agree with the Reference Values within the expanded uncertainties (k=2).

Content

1. INTRODUCTION

This report describes an international Supplementary Comparison COOMET.PR-S1 of whiteness (CIE whiteness value W_{10}) and brightness (ISO brightness R_{457}), conducted by the Euro-Asian Cooperation of National Metrological Institutions (COOMET) as the Regional Metrology Organization (RMO) in accordance with the COOMET project 366/RU/06.

The Mutual Recognition Arrangement (MRA) was signed in 1999 with the objectives of establishing the degree of equivalence of national measurement standards and providing for the mutual recognition of calibration and measurement certificates issued by National Metrology Institutes (NMIs) [1]. Under the MRA the equivalence of national measurement standards maintained by the NMIs is determined by a set of Key Comparisons which are chosen and organised by the Consultative Committees of the International Committee for Weights and Measures (CIPM), and a set of Supplementary Comparisons, organised by RMOs.

COOMET organised the supplementary comparison COOMET.PR-S1 – the first comparison of whiteness and brightness, defined as CIE whiteness value W_{10} and ISO brightness R_{457} by the documents ISO 11475-2007 and ISO 2469, respectively. COOMET.PR-S1 supplementary comparison was carried out to evaluate the equivalence between the following participating laboratories: the All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI, Russia), the Belarusian State Institute of Metrology (BelGIM, Belarus) and the National Scientific Centre “Institute of Metrology” (NSC IM, Ukraine). COOMET.PR-S1 was piloted by VNIIOFI.

COOMET.PR-S1 used as artefacts a set of six samples made of opal glass with different values of whiteness/ brightness. The artefacts were measured by the participants in series. The pilot performed its measurement twice, in the beginning and at the end, to check stability of the samples.

There was one more participant of the comparison: All-Ukrainian state research and production centre for standardization, metrology, certification and consumers' rights protection (Ukrmetrtest-standard, Ukraine). It was the second participant from Ukraine. However, the designated institute from Ukraine in this area of the Photometry and Radiometry field is NSC IM, but not Ukrmetrteststandard. Therefore, the Ukrmetrteststandard measurement results were not compared with the results of other participants: they were not used for evaluating the comparison Reference Values (RV) and Differences from RV. The Ukrmetrteststandard’s measurement data are not included in the main part of this report, but only presented in the Annex B.

COOMET.PR-S1 was registered in the BIPM key comparison database (KCDB) in 2009 and followed the Technical Protocol approved by the COOMET technical committee for photometry and radiometry (COOMET TCPR also known as COOMET TC 1.7) and published in KCDB in 2012. Measurements within COOMET.PR-S1 were performed in the period from 2012 to 2013. Data analysis and the report preparation were done in accordance with the “Guidelines for RMO PR Supplementary Comparisons" (CCPR-G7) [2] and the “Guidelines for CCPR Key Comparison Report Preparation" [3].

2. ORGANISATION

2.1 PARTICIPANTS

Table 1. List of participants

	NMI	NMI acronym	Contact person	Contact details
Pilot	All-Russian Research Institute for Optical and Physical Measurements	VNIIOFI	Stanislav Shirokov	Ozernaya str. 46. 119361 Moscow. **Russia** Tel: +7 (495) 437-33-11 Fax: +7 (495) 437-33-11 Email: gortb@vniiofi.ru
Participant 1	Belarussian State Institute of Metrology	BelGIM	Olga Tarasova	93. Starovilensky trakt. Minsk. 220053. **Republic of Belarus** Tel.: +375 17-234-98-20 Fax: +375 17-288-09-38 E-mail: optic@belgim.belpak.minsk.by
Participant 2	National Scientific Centre "Institute of metrology"	NSC IM	Alexandr Kupko	42 Mironositskaya str.. Kharkiv 61002 **Ukraine** Tel.: +38 057 700-34-09 Fax: +38 057 700-34-47 E-mail: kupkoad@metrology.kharkov.ua
Participant 3	*All-Ukrainian state research and production centre for standardization. metrology. certification and consumers' rights protection	*Ukrmetrtest-standard	Natalya Parhomenko	Kiev. Metrologicheskaya st. 4 (invited as a guest) **Ukraine** Tel/fax: +38 (044) 526 36 98 E-mail: parkhomenko@ukrcsm.kiev.ua

* Note, that Ukrmetrteststandard was the second participant from Ukraine. Ukrmetrteststandard is not the designated institute from Ukraine in this area of the Photometry and Radiometry field. NSC IM is the designated institute from Ukraine. Therefore, Ukrmetrteststandard was not a competent participant. It's measurement results were not compared with the results of other participants: they were not used for evaluating the comparison Reference Values (RV) and Differences from RV. The Ukrmetrteststandard's measurement data are not included in the main part of this report, but only presented in the Annex B.

VNIIOFI acted as a pilot.

2.2 FORM OF COMPARISON

The comparison was carried out by means of measuring a group of six traveling samples prepared at the pilot laboratory.

The measurements were performed in the following sequence:

Pilot → Participant 1 → Participant 2 → Participant 3 → Pilot

The pilot measured the sample twice: in the beginning and at the end. These data were used to estimate stability of the samples.

3. COMPARISON TRAVELING ARTEFACT

The comparison traveling artefact was a set of six samples with different nominal values of whiteness / brightness, presented in Table 2. Samples had the following identification numbers: 01, 02, 03, 04, 05 and 06.

The samples were made of opal glass and had a shape of disk with diameter of 60 mm and thickness of 6 to 8 mm. One side of a sample is polished and the another is matt. Only the matt side was measured within this comparison. The samples in the case are shown in Figure 1. The samples used in the comparison are the first six samples starting from the left.

Figure 1. Comparison traveling artefacts in the case

Table 2. Nominal values of whiteness and brightness of the comparison traveling samples

Sample No	Nominal values	
	CIE whiteness value W_{10}. (dimensionless)	ISO brightness R_{457}. %
01	84	88
02	76	82
03	94	95
04	53	65
05	51	62
06	28	46

4. MEASUREMENT RESULTS

Measurement results of the participants are presented in Tables 3 – 5.

Table 3. VNIIOFI measurement results

Sample No	CIE whiteness W_{10}				ISO brightness R_{457}			
	W_{10}	u_A	u_B	u_c	R_{457},%	u_A	u_B	u_c
01	85.61	0.03	0.31	0.31	89.85	0.01	0.30	0.30
02	77.49	0.03	0.31	0.31	83.28	0.02	0.30	0.30
03	94.60	0.03	0.31	0.31	96.30	0.02	0.30	0.30
04	71.18	0.02	0.31	0.31	75.16	0.01	0.30	0.30
05	59.28	0.06	0.30	0.31	68.81	0.01	0.30	0.30
06	53.14	0.12	0.31	0.33	64.59	0.05	0.31	0.31

Table 4. BelGIM measurement results

Sample No	CIE whiteness W_{10}				ISO brightness R_{457}			
	W_{10}	u_A	u_B	u_c	R_{457},%	u_A	u_B	u_c
01	85.38	0.014	0.340	0.34	89.44	0.005	0.300	0.30
02	78.03	0.009	0.340	0.34	83.14	0.025	0.299	0.30
03	94.38	0.013	0.340	0.34	95.97	0.029	0.299	0.30
04	71.18	0.012	0.340	0.34	74.90	0.017	0.300	0.30
05	58.92	0.042	0.337	0.34	68.15	0.035	0.298	0.30
06	53.28	0.007	0.340	0.34	64.38	0.023	0.299	0.30

Table 5. NSC IM measurement results

Sample No	CIE whiteness W_{10}				ISO brightness R_{457}			
	W_{10}	u_A	u_B	u_c	R_{457},%	u_A	u_B	u_c
01	85.81	0.04	0.44	0.44	89.55	0.03	0.20	0.20
02	78.60	0.02	0.45	0.45	83.50	0.02	0.19	0.19
03	94.83	0.11	0.42	0.43	96.12	0.05	0.20	0.21
04	72.07	0.05	0.47	0.47	75.21	0.02	0.17	0.17
05	59.36	0.05	0.47	0.47	68.42	0.03	0.15	0.15
06	52.28	0.02	0.48	0.48	63.80	0.02	0.14	0.14

5. COMPARISON REFERENCE VALUES

Comparison Reference Values (RV) were calculated independently for each sample.

The method of RV determination was weighted mean with cut-off. The cut-off $u_{\text{cut-off}}$ was calculated as:

$$u_{\text{cut-off}} = \text{average}\{u_i\} \text{ for } u_i \leq \text{median}\{u_i\}; \quad i = 1 \text{ to } 3 \tag{1}$$

where u_i are standard uncertainties reported by participants, and *i* indicates the participants: VNIIOFI, BelGIM and NSC IM.

Then the reported uncertainty u_i of each participant *i* was adjusted by the cut-off:

$$\begin{aligned} u_{i,\text{adj}} &= u_i \quad \text{for } u_i \geq u_{\text{cut-off}} \\ u_{i,\text{adj}} &= u_{\text{cut-off}} \quad \text{for } u_i < u_{\text{cut-off}} \end{aligned} \tag{2}$$

The weights w_i for participant *i* was determined by

$$w_i = u_{\text{adj}}^{-2} / \sum_{i=1}^{3} u_{\text{adj}}^{-2} \tag{3}$$

The RV (W_{RV} for CIE whiteness W_{10}, and B_{RV} for ISO brightness R_{457}) were determined by

$$W_{\text{RV}} = \sum_{i=1}^{3} w_i W_i \quad \text{and} \quad B_{\text{RV}} = \sum_{i=1}^{3} w_i B_i \tag{4}$$

where W_i and B_i are values of CIE whiteness W_{10} and ISO brightness R_{457}, respectively, reported by the participants.

The uncertainty of RV, u_{RV} ($u(W_{\text{RV}})$ or $u(B_{\text{RV}})$) is given by

$$u_{\text{RV}} = \sqrt{\sum_{i=1}^{3} \frac{u_i^2}{u_{i,\text{adj}}^4}} \Big/ \sum_{i=1}^{3} u_{i,\text{adj}}^{-2} \tag{5}$$

Tables 6 and 7 present calculated RVs with uncertainties, as well as values of CIE whiteness and ISO brightness and their uncertainties reported by the participants, the values of cut-off, adjustment uncertainties and weights.

Table 6. Reference values W_{RV} and $u(W_{\text{RV}})$ for CIE whiteness W_{10}

Participant	W_i	u_i	$u_{\text{cut-off}}$	$u_{i,\text{adj}}$	w_i	W_{RV}	$u(W_{\text{RV}})$
	Sample 01						
VNIIOFI	85.61	0.31	0.325	0.325	0.41	85.57	0.20
BelGIM	85.38	0.34		0.34	0.37		
NSC IM	85.81	0.44		0.44	0.22		
	Sample 02						
VNIIOFI	77.49	0.31	0.325	0.325	0.41	77.93	0.20
BelGIM	78.03	0.34		0.34	0.38		
NSC IM	78.60	0.45		0.45	0.21		

	Sample 03						
VNIIOFI	94.60	0.31	0.325	0.325	0.40	94.57	0.20
BelGIM	94.38	0.34		0.34	0.37		
NSC IM	94.83	0.43		0.43	0.23		
	Sample 04						
VNIIOFI	71.18	0.31	0.325	0.325	0.42	71.36	0.21
BelGIM	71.18	0.34		0.34	0.38		
NSC IM	72.07	0.47		0.47	0.20		
	Sample 05						
VNIIOFI	59.28	0.31	0.325	0.325	0.42	59.16	0.21
BelGIM	58.92	0.34		0.34	0.38		
NSC IM	58.86	0.47		0.47	0.20		
	Sample 06						
VNIIOFI	53.14	0.33	0.335	0.335	0.40	53.02	0.21
BelGIM	53.28	0.34		0.34	0.40		
NSC IM	52.28	0.48		0.48	0.20		

Table 7. Reference values B_{RV} and $u(B_{\mathrm{RV}})$ for ISO brightness R_{457}. All values are in %

Participant	B_i	u_i	$u_{\mathrm{cut-off}}$	$u_{i,\mathrm{adj}}$	w_i	B_{RV}	$u(B_{\mathrm{RV}})$
	Sample 01						
VNIIOFI	89.85	0.30	0.25	0.30	0.29	89.61	0.15
BelGIM	89.44	0.30		0.30	0.29		
NSC IM	89.55	0.20		0.25	0.42		
	Sample 02						
VNIIOFI	83.28	0.30	0.25	0.30	0.29	83.33	0.15
BelGIM	83.14	0.30		0.30	0.29		
NSC IM	83.50	0.19		0.25	0.42		
	Sample 03						
VNIIOFI	96.30	0.30	0.26	0.30	0.30	96.13	0.15
BelGIM	95.97	0.30		0.30	0.30		
NSC IM	96.12	0.21		0.26	0.40		
	Sample 04						
VNIIOFI	75.16	0.30	0.24	0.30	0.28	75.11	0.14
BelGIM	74.90	0.30		0.30	0.28		
NSC IM	75.25	0.17		0.24	0.44		
	Sample 05						
VNIIOFI	68.81	0.30	0.23	0.30	0.26	68.45	0.13
BelGIM	68.15	0.30		0.30	0.26		
NSC IM	68.42	0.15		0.23	0.48		
	Sample 06						
VNIIOFI	64.59	0.31	0.22	0.31	0.25	64.15	0.13
BelGIM	64.38	0.30		0.30	0.26		
NSC IM	63.80	0.14		0.22	0.49		

6. CONSISTANCY CHECK (χ^2 TEST)

The Chi-square χ^2 value for consistency check was calculated by

$$\chi^2 = \sum_{i=1}^{3} \frac{(W_i - W_{\mathrm{RV}})^2}{u_{i,\mathrm{adj}}^2} \quad \text{or} \quad \chi^2 = \sum_{i=1}^{3} \frac{(B_i - B_{\mathrm{RV}})^2}{u_{i,\mathrm{adj}}^2} \tag{6}$$

The consistency check is satisfied if $\chi^2 \leq \chi^2_{0.05}(v)$, where v = N-1 = 2 (N is the number of participants), and $\chi^2_{0.05}(2) = 5.991$.

The calculated square χ^2 values are presented in Table 8. As one can see, the consistency check is satisfied for all samples for both CIE whiteness W_{10} and ISO brightness R_{457}.

Table 8. Results of the χ^2 test

Sample No	χ^2 for W_{10}	χ^2 for R_{457}	$\chi^2_{0.05}(2)$
01	0.62	1.02	5.991
02	4.14	0.91	
03	0.69	0.61	
04	2.87	0.70	
05	0.82	2.46	
06	3.09	5.13	

7. DIFFERENCES FROM THE REFERENCE VALUES

The differences from RV, $D_{W,i}$ and $D_{B,i}$, for participant *i* were determined independently for each sample by

$$D_{W,i} = W_i - W_{\mathrm{RV}} \quad \text{and} \quad D_{B,i} = B_i - B_{\mathrm{RV}} \tag{7}$$

The standard uncertainty of the differences from RV, $u(D_i)$ (where $u(D_i)$ is $u(D_{W,i})$ or $u(D_{W,i})$), were calculated as

$$u(D_i) = \sqrt{u_i^2 + u_{RV}^2 - 2\left(\frac{u_i^2}{u_{i,\mathrm{adj}}^2} \Big/ \sum_{i=1}^{3} u_{i,\mathrm{adj}}^{-2}\right)} \tag{8}$$

The expanded uncertainties of the differences from RV were determined by

$$U(D_i) = k \cdot u(D_i), \quad k = 2 \tag{9}$$

The values of differences from RV and corresponding expanded uncertainties for all participants excluding Ukrmetrteststandard, $D_{W,i}$ for CIE whiteness W_{10} and $D_{B,i}$ for ISO brightness R_{457} are presented in Tables 7 and 8, respectively, as well as in Figures 2 and 3. The results of Ukrmetrteststandard are presented in Annex B.

Table 7. Differences from RV, $D_{W,i}$, and their expanded uncertainties $U(D_{W,i})$ for CIE whiteness W_{10}.

	Sample 01	***Sample 02***	***Sample 03***	***Sample 04***	***Sample 05***	***Sample 06***
Reference value (RV) W_{RV}	85.57	77.93	94.57	71.36	59.16	53.02
Uncertainty of RV $u(W_{\mathrm{RV}})$	*0.20*	*0.20*	*0.20*	*0.21*	*0.21*	*0.21*
VNIIOF Differences from RV $D_{W,\mathrm{VNIIOFI}}$	0.04	- 0.44	0.03	-0.18	0.12	0.12
$U(D_{W,\mathrm{VNIIOFI}})$, k=2	*0.49*	*0.49*	*0.49*	*0.48*	*0.48*	*0.51*
BelGIM Differences from RV $D_{W,\mathrm{BelGIM}}$	-0.19	0.10	-0.19	-0.18	-0.24	0.26
$U(D_{W,\mathrm{BelGIM}})$, k=2	*0.53*	*0.53*	*0.53*	*0.53*	*0.53*	*0.53*
NSC IM Differences from RV $D_{W,\mathrm{NSC\ IM}}$	0.24	0.67	0.26	0.71	0.20	-0.75
$U(D_{W,\mathrm{NSC\ IM}})$, k=2	*0.77*	*0.79*	*0.75*	*0.84*	*0.84*	*0.86*

Table 8. Differences from RV, $D_{B,i}$, and their expanded uncertainties $U(D_{B,i})$ for ISO brightness R_{457}. All values are in %. The uncertainties are not relative.

	Sample 01	***Sample 02***	***Sample 03***	***Sample 04***	***Sample 05***	***Sample 06***
Reference value (RV) B_{RV}	89.61	83.33	96.13	75.11	68.45	64.15
Uncertainty of RV $u(B_{\mathrm{RV}})$	*0.15*	*0.15*	*0.15*	*0.14*	*0.13*	*0.13*
VNIIOF Differences from RV $D_{B,\mathrm{VNIIOFI}}$	0.24	- 0.05	0.17	0.05	0.36	0.44
$U(D_{B,\mathrm{VNIIOFI}})$, k=2	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*	*0.51*
BelGIM Differences from RV $D_{B,\mathrm{BelGIM}}$	-0.17	-0.19	-0.16	-0.21	-0.30	0.23
$U(D_{B,\mathrm{BelGIM}})$, k=2	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*
NSC IM Differences from RV $D_{B,\mathrm{NSC\ IM}}$	-0.06	0.17	-0.01	0.10	-0.03	-0.35
$U(D_{B,\mathrm{NSC\ IM}})$, k=2	*0.34*	*0.33*	*0.35*	*0.30*	*0.28*	*0.26*

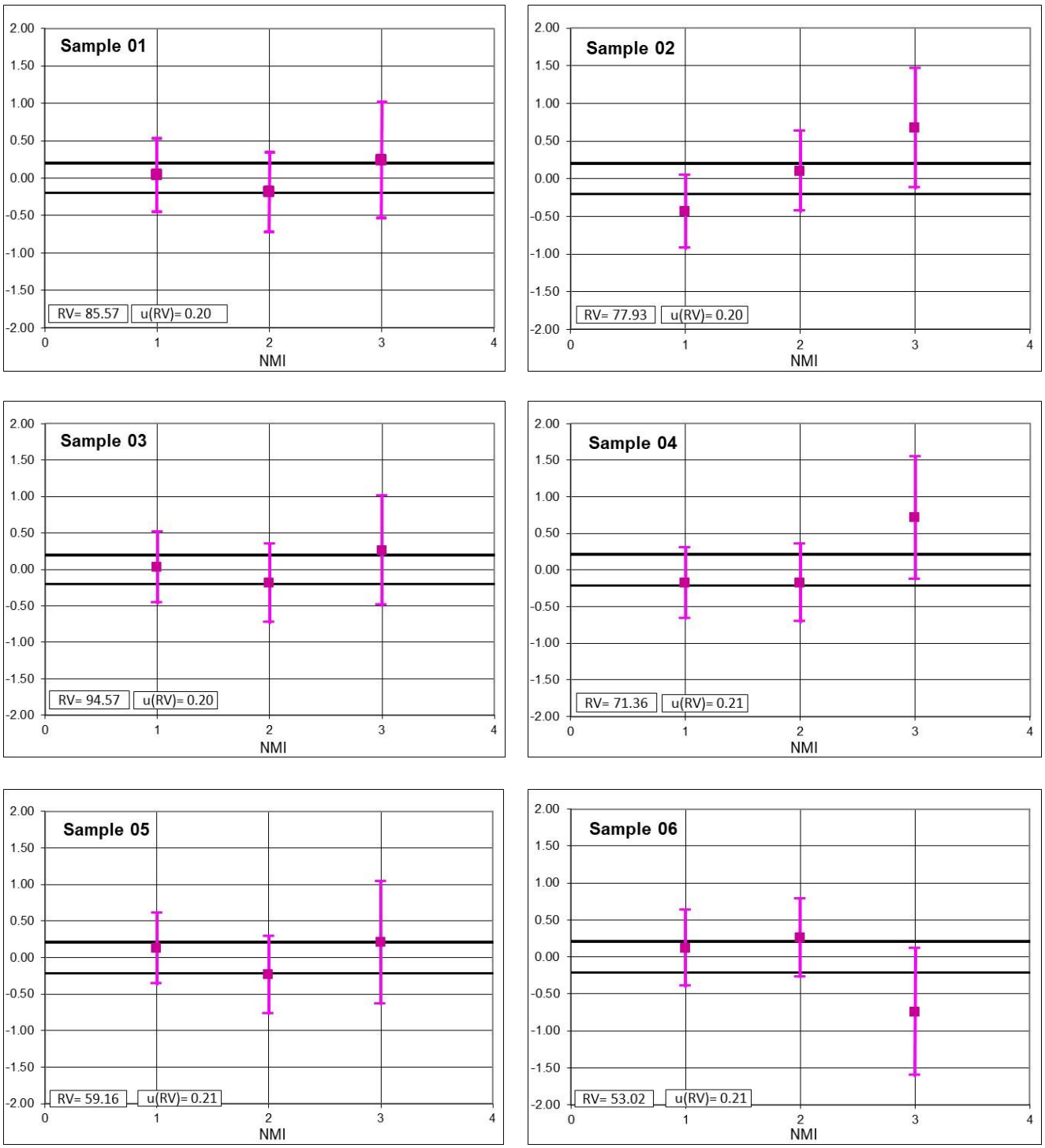

Figure 2. Results of comparison for CIE whiteness W_{10} : dots - Differences from RV, $D_{W,i}$; bars - expanded uncertainties $U(D_{W,i})$ for participating NMIs: 1 – VNIIOFI, 2 – BelGIM, 3 – NSC IM. Black lines present standard uncertainty of RV.

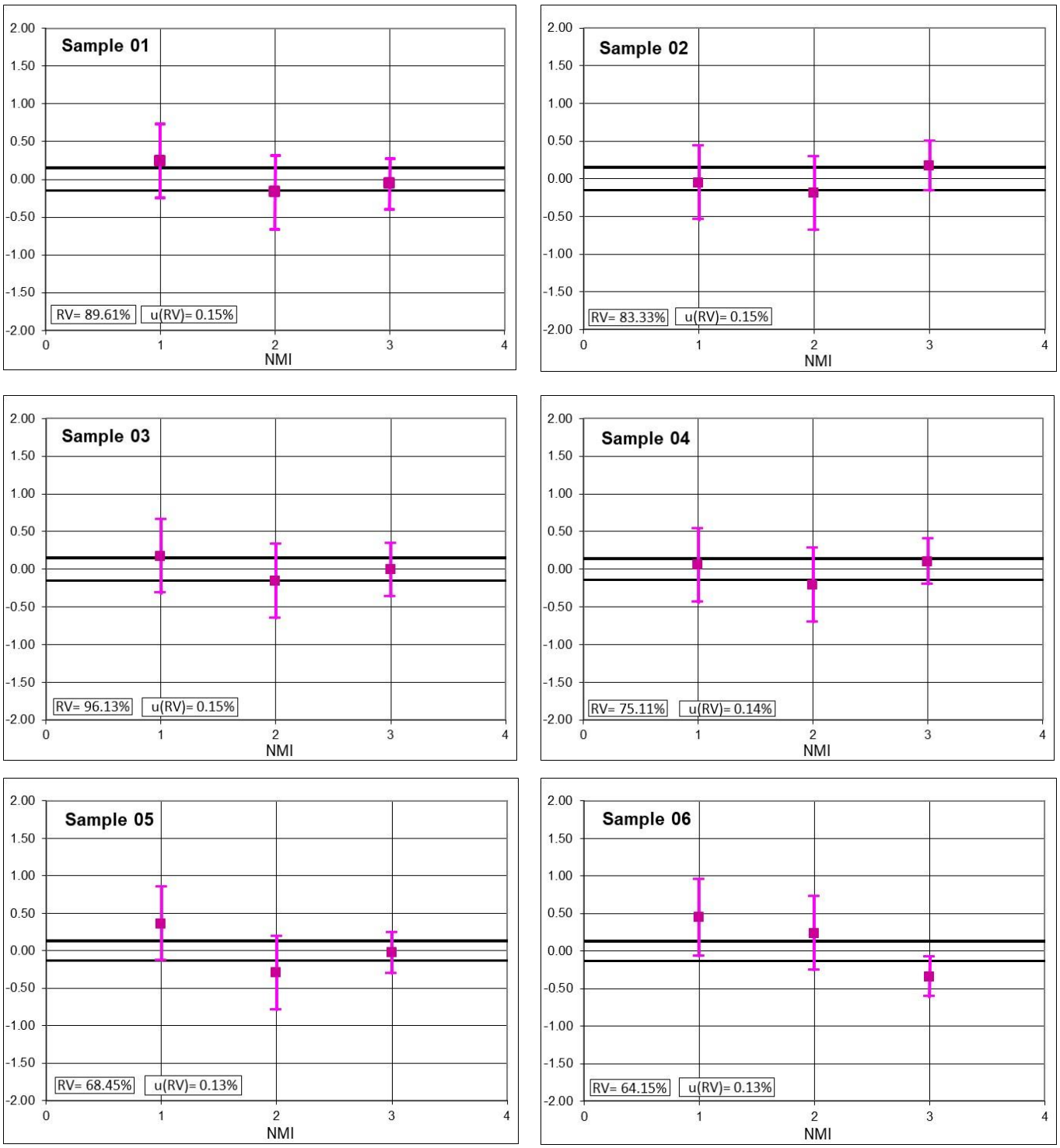

Figure 3. Results of comparison for ISO brightness R_{457} in % (not relative): dots - Differences from RV, $D_{B,i}$; bars - expanded uncertainties $U(D_{B,i})$ for participating NMIs: 1 – VNIIOFI, 2 – BelGIM, 3 – NSC IM. Black lines present standard uncertainty of RV.

8. REFERENCES

[1] CIPM MRA

[2] *CCPR-G7* Guidelines for RMO PR Supplementary Comparisons. 14 December 2018

[3] *CCPR-G2* Guidelines for CCPR Key Comparison Report Preparation. Rev-4. January 8. 2019

Annex A. PARTICIPANTS MEASUREMENT FACILITIES

A1. VNIIOFI

The measurements of CIE whiteness and ISO brightness at VNIIOFI were measured using a spectrophotometer Lambda850 manufactured by «PerkinElmer Inc.». The spectrophotometer is a part of National primary standard facility of colorimetry. The appearance of the spectrophotometer is shown in Fig. A1.1.

Figure A1.1. Lambda 850 spectrophotometer appearance

The spectrophotometer was calibrated using a white surface sample. which was calibrated in term of spectral coefficient of diffuse reflection against the National primary standard facility of the units of spectral coefficient of diffuse and specular reflection. The mail parameters of the spectrophotometer are presented in Table A1.1.

Table A1.1. The mail parameters of the spectrophotometer Lambda 850

Measurement geometry (lighting / observation)	8/D
Additional compensation for scattered light	No
two-beam scheme (separate reference beam channel and measuring channel)	Yes
Type of detector	PMT
Temperature stabilization	No
Measuring spot size	4 mm horizontal x 10 mm vertical
Spectral bandwidth	0.5 nm

The average value of the ambient temperature was 23 °C. while the minimum temperature was not lower than 21 °C. and the maximum temperature was not higher than 24 °C.

The relative air humidity during the measurements varied from 28 % to 47 %. The average value was 39 %.

The measurements of CIE whiteness and ISO brightness were carried out with the following spectral parameters of the spectrophotometer: the spectral slit width was 0.5 nm. and the spectral scanning step was 1 nm.

For each sample. 10 independent measurements of the CIE whiteness and ISO brightness were performed. The arithmetic mean values of independent measurement were taken as the final measurement result.

A2. BelGIM

Measurements at BelGIM were carried out using a spectrophotometer ELREPHO 071 No. 1227. calibrated in the department of physical. chemical and optical measurements of BelGIM.

The spectrophotometer was calibrated against a non-fluorescent reference standard that met the ISO requirements for reference standards of level 3 specified in ISO 2470-1. and a set of samples made of pressed polytetrafluoroethylene (PTFE) powder. The values of radiance factors assigned to the samples were in the range from 5.0% to 99.0%.

Adjustment of the ultraviolet part of the spectrum (UV content) was carried out using a fluorescent reference standard. corresponding to the ISO requirements for reference standards of level 3. specified in ISO 2470-1

The appearance of the spectrophotometer and the standard samples are shown in Fig.A2.1 and Fig.A2.2. respectively.

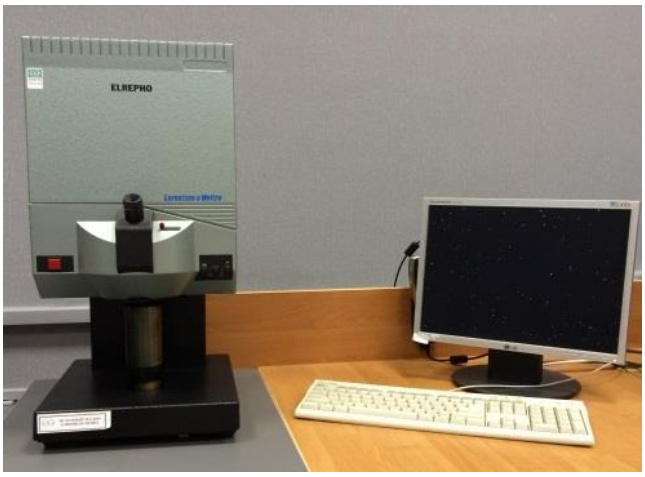

Figure A2.1. ELREPHO 071 spectrophotometer appearance

Figure A2.2. Standard samples used an BelGIM to calibrate the spectrophotometer

The results of measurements performed at BelGIM are traceable to the Belarus national standard of colorimetric units. spectral coefficients of regular transmittance and diffuse reflectance NS RB 3-00, as well as to the initial standards of IR3 level issued by the authorized laboratory ISO "INNVENTIA" (Sweden).

Measurement conditions:

— Ambient temperature. °C	20.4
— Air pressure. kPa	99.1
— Relative humidity. %	58
— AC mains voltage. V	220.4
— Mains frequency. Hz	50.4

— ISO Brightness was determined for the standard CIE source C and the CIE standard colorimetric observer of 2°.
— CIE Whiteness Index was determined for the standard CIE source D65 and the CIE standard colorimetric observer of 10°.

Figure A2.3 shows the structural diagram of the spectrophotometer ELREPHO 071. The measured was sample was illuminated diffusely using a built-in integrating sphere with diameter of 150 mm. The viewing angle was 0°.

The diameter of the exit opening of the sphere was 34 mm. The size of the measuring part of the sample was 28 mm.

Measurements were carried out in the spectral range from 360 nm to 700 nm. The spectral bandwidth was 5 nm.

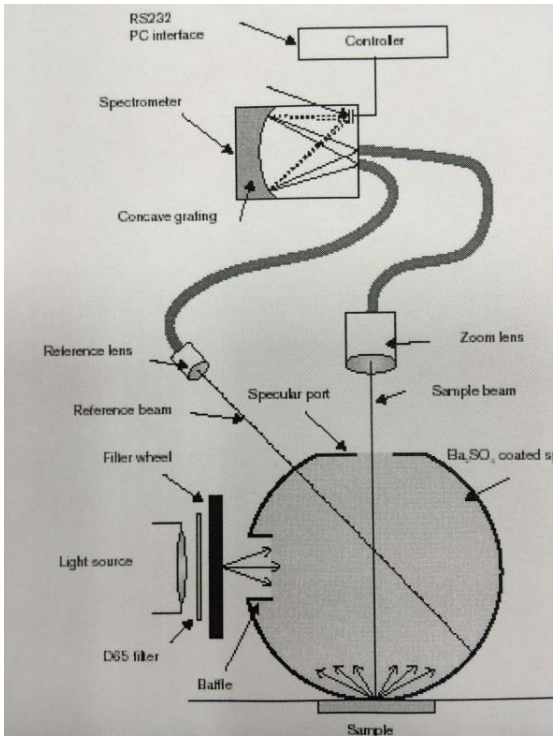

Figure A2.3. Structural diagram of the spectrophotometer ELREPHO 071

A3. NSC IM

The artefacts were received in suitable packaging without any damages. According to the clause 2.5 of the Protocol the surfaces of the artefacts had not cleaned.

Measurements and processing of the results. in accordance with clause 4 of the Protocol. were carried out on a standard spectrophotometer Lambda 950. A photograph of the spectrophotometer is shown in Figure A3.1.

Figure A3.1. Spectrophotometer Lambda 950

The spectrophotometer measures reflection coefficients by the method of comparison with a reference plate - a standard sample of diffuse reflection No.5 made of MC-20 milk glass. A photograph of the internal structure of the spectrophotometer is shown in Figure A3.2.

Figure A3.2. Internal structure of the Spectrophotometer Lambda 950

The standard sample of diffuse reflection No. 5 was calibrated at the National primary standard of Ukraine for units of spectral coefficients of regular transmission. specular and diffuse reflection in the wavelength range from 0.2 μm to 25 μm. Table A3.1 shows the values of the spectral coefficients of diffuse reflectance of the sample No. 5. obtained by the Taylor method.

Table A3.1. Values of spectral diffuse reflectance of the standard sample No. 5

λ. нм	№5	λ. нм	№5	λ. нм	№5
360	0.9151	510	0.9395	660	0.9383
370	0.9222	520	0.9387	670	0.9388
380	0.9267	530	0.9386	680	0.9382
390	0.9296	540	0.9389	690	0.9380
400	0.9318	550	0.9374	700	0.9374
410	0.9342	560	0.9366	710	0.9366
420	0.9367	570	0.9378	720	0.9360
430	0.9381	580	0.9380	730	0.9353
440	0.9427	590	0.9383	740	0.9330
450	0.9406	600	0.9385	750	0.9309
460	0.9432	610	0.9368	760	0.9302
470	0.9431	620	0.9364	770	0.9263
480	0.9435	630	0.9356	780	0.9285
490	0.9438	640	0.9366	790	0.9271
500	0.9422	650	0.9361	800	0.9264

The scheme for measuring the spectral coefficients of diffuse reflection applied in the National primary standard facility is shown in Figure A3.3. The appearance of the National primary standard is shown in Figure A3.4.

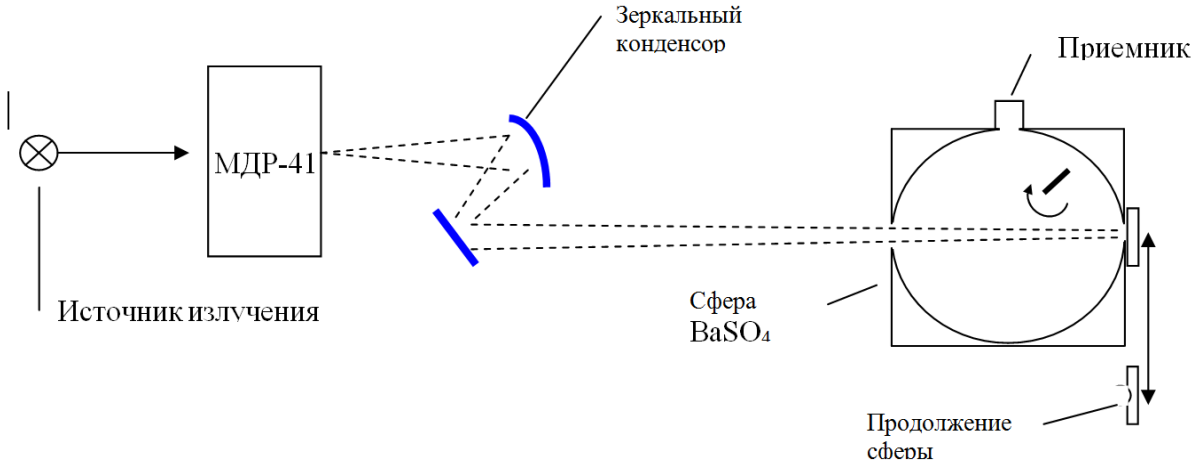

Figure A3.3. Scheme for measuring the spectral coefficients of diffuse reflection applied in the National primary standard facility of Ukraine

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Figure A3.4. Appearance of the National primary standard facility of Ukraine

A quartz halogen lamp was used in the primary standard facility as the light source. The lamp was powered from a stabilized power supply. The lamp was warmed up for about 30 minutes to achieve good stability. A monochromator of the MDR 41 model was used as a spectral device. In accordance with Standard Practice for Computing the Colors of Objects by Using CIE System ASTM E 308-01. the spectral slit width was about 10 nm. the wavelength step was also10 nm. The radiation was recorded with a Hamamatsu S1337-1010BQ photodiode in the unbiased mode; the photodiode current was recorded using a Keithley 6458 picoammeter. The geometry of measurements was 0 / D. A central area of 15 × 5 mm was selected for measurements. The measurements were carried out in an automatic mode, 5 measurements at each wavelength.

The relative measurement uncertainty of the Lambda 950 spectrophotometer in the visible range was U = 0.3 % (k = 2). Since the contribution of the uncertainty at different wavelengths to the resulting uncertainty is not the same, the calculation was performed in the following way. The measured values of spectral defuse reflectance were multiplied by correcting coefficients that smoothly vary with wavelengths. The coefficients used were constantly linear increasing. constantly linear decreasing. with a maximum or minimum in the middle of the wavelength range. The coefficients are shown in Figure A3.5. In addition, a constant wavelength coefficient of 1.003 was used.

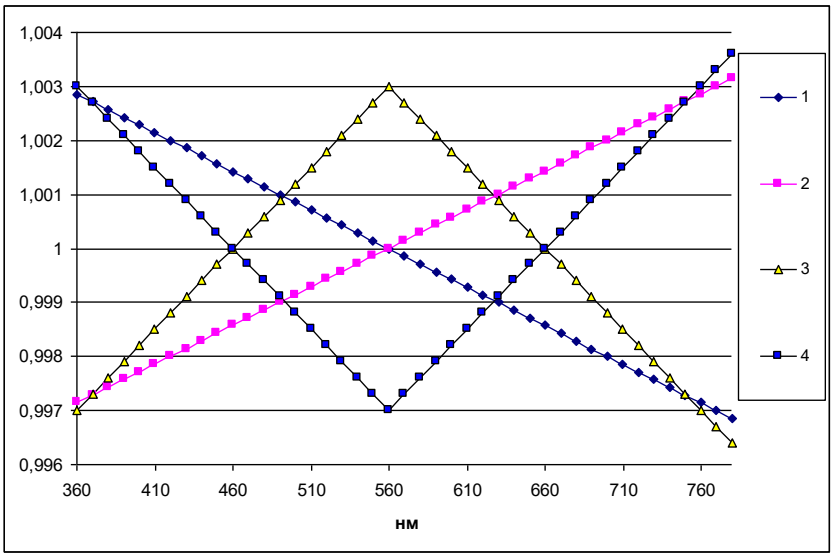

Figure A3.5. Wavelength dependent correction coefficients for estimating uncertainties.

The result was a set of 5 values of R_{457} and W_{10} for each sample. The difference between the maximum and minimum values was considered the corresponding uncertainty for each sample.

Annex B. Ukrmetrteststandard measurement

B1. Ukrmetrteststandard measurement facility and procedure

The reference double-beam spectrophotometer UV-3101PC with integrating sphere for reflection measurements (Fig. B.1) is composed primarily of a source, a monochromator and a detector part. The detector part is composed of a 150 mm integrating sphere and a detector. Possible measurement geometry of irradiation/view can be 7°/diffuse. Size of the light spot on the sample is 4×20 mm.

The measurement room is controlled by an air-conditioning unit. The temperature of the ambient air is 20 ± 1°C. The humidity was between 35 % and 45 %.

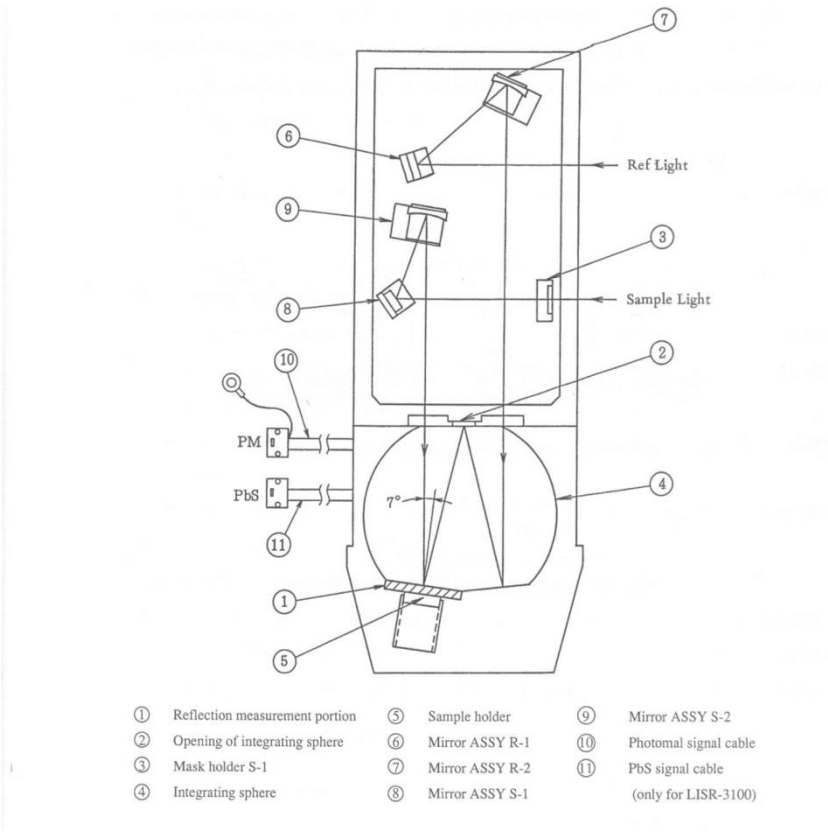

Fig. B.1. Structure of integrating sphere and accessories for reflection measurements

Method applied to measure the whiteness and brightness

Spectral diffuse reflectance of every comparison standard was measured over the wavelength region of 380 – 780 nm with a 10 nm step. a 8 nm bandpass and specular component excluded. Ten series of 10 measurements of spectral reflectance were carried out randomly by shifting pattern around the center of 2-3 mm. For the measurement result of spectral reflectance it takes an average value. ISO brightness R_{457} was calculated according to ISO 2470-2007 and CIE whiteness value W_{10} was calculated according to ISO 11475-2007 using measured spectral diffuse reflectance over the wavelength region of 380 – 780 nm.

Procedures of evaluating uncertainty components

The repeatability of the measurements has been estimated by making 10 measurements in series for every sample.

The reflectance uncertainty caused by the uncertainty in the wavelength setting is sample-dependent. but this is not essential in the case of neutral artifacts over the wavelength region of 400 – 780 nm. Also the uncertainty budget includes components uncertainty type B caused by the following factors: the detector non-linearity (u_B). the dark uncertainty. the reference standard uncertainty.

B2. Ukrmetrteststandard measurement results

The Ukrmetrteststandard measurement results of CIE whiteness W_{10} and ISO brightness R_{457} are presented in Table B.1.

Table B1. Ukrmetrteststandard measurement results

Sample No	CIE whiteness W_{10}				ISO brightness R_{457}			
	W_{10}	u_A	u_B	u_c	R_{457},%	u_A	u_B	u_c
01	85.61	0.02	0.37	0.37	89.90	0.01	0.34	0.34
02	78.01	0.02	0.36	0.36	83.67	0.01	0.33	0.33
03	94.92	0.02	0.37	0.37	96.53	0.00	0.35	0.35
04	71.50	0.02	0.33	0.33	75.25	0.00	0.30	0.30
05	58.86	0.02	0.31	0.31	68.64	0.00	0.27	0.27
06	53.37	0.02	0.32	0.32	64.59	0.00	0.21	0.21