

Study of Improved Methods for Absolute Colorimetry

Fifth Report

Study of Colorimetric Errors in Industrial Instruments

J F Verrill, P J Clarke and J O'Halloran
Centre for Optical and Environmental Metrology
National Physical Laboratory
Queens Road, Teddington, Middlesex, TW11 0LW

© Crown Copyright 1997

Reproduced by permission of the Controller of HMSO

National Physical Laboratory
Queens Road, Teddington, Middlesex, TW11 0LW

ISSN 1369-6807

Extracts from this report may be reproduced provided the source is acknowledged
and the extract is not taken out of context.

Approved on behalf of the Managing Director, NPL
by D H Nettleton, Head, Centre for Optical and Environmental Metrology

CONTENTS

INTRODUCTION.....	1
1. BACKGROUND TO TECHNICALLY BASED STUDIES.....	
2. WORK PROGRAMME.....	2
3. RECALCULATION OF COLOUR DATA USING ASTM WEIGHTING FUNCTIONS.....	3
4. RECALCULATION OF COLOUR DATA USING NPL CALIBRATED WHITE TILES AS THE REFERENCE STANDARDS.....	4
5. GLOSS TRAP ERRORS.....	5
6. SPECULAR BEAM ERRORS.....	6
7. PHOTOMETRIC SCALE ERRORS	7
8. WAVELENGTH ERRORS.....	8
9. CONCLUSIONS.....	11
10. ACKNOWLEDGEMENTS	11
11. REFERENCES	12
12. TABLES	13
APPENDIX	40

Study of Improved Methods for Absolute Colorimetry

Fifth Report

Study of Colorimetric Errors on Industrial Instruments

**J F Verrill, P J Clarke, J O'Halloran
National Physical Laboratory
Teddington, Middlesex, TW11 0LW**

INTRODUCTION

This report covers the third workpackage in the study of Improved Methods for Absolute Colorimetry.

The first workpackage determined the needs, particularly within industry, for absolute colour measurements, assessed how adequately the needs are currently being met and formulated well supported recommendations to direct the future implementation of improved methods where gaps were identified.

The technical studies which form Workpackages 2 and 3 aim to identify why, in many cases, the levels of accuracy obtainable in principle through calibration services and artefacts are not achieved in practice. The intercomparison of colour measurements carried out by 24 members of the NPL Spectrophotometry and Colorimetry Club showed considerable variations in the accuracy achieved in industry.

The objectives of the technically based studies are:

- to identify how current industrial practice can be improved.
- to identify and quantify the sources of measurement errors in industry.
- to further identify and quantify the least understood sources of error in national measurement instruments.

This report is an analysis of the spectral data collected during the Spectrophotometry and Colorimetry Club intercomparison, with the aim of identifying the causes of the inadequate agreement between colour measurements made by UK industry.

1. BACKGROUND TO TECHNICALLY BASED STUDIES

A recent intercomparison of surface colour measurements between four European countries and coordinated by NPL gave spreads of differences in measured values of greater than 0.5 CIELAB units for about half the measurements (Ref 1). Maximum spreads were up to 2.2 CIELAB units, which was considered unsatisfactory by all the participants as the human eye can distinguish between colours which differ by 0.5 CIELAB units. An appropriate long term objective for national laboratories is for 95% of measurements to agree to within 0.2 CIELAB units.

The intercomparison of surface colour measurements between 24 companies organised as a working group of the NPL Spectrophotometry and Colorimetry Club, gave a roughly similar level of agreement as the international intercomparison above for those companies using the best available commercial equipment and having traceability to NPL (Ref 2). Companies with lower quality equipment and companies not having traceability to NPL showed much larger divergences. An appropriate long term objective for industrial laboratories would be 95% of measurements to agree to within 0.5 CIELAB units.

2. WORK PROGRAMME

This investigation was carried out in 3 steps.

- Step 1 Recalculation of colour data from all participants using ASTM weighting functions (Ref 3). This minimises the effect of differences in spectral interval and bandwidth. The improvements in agreement between NPL and participants are quantified.
- Step 2. Recalculation of colour data using NPL white tiles as reference standards. This converts all participants' data to the scales of absolute diffuse reflectance and radiance factor used by NPL. The improvements in agreement with NPL are again quantified.
- Step 3. Analysis of the following spectral reflectance errors:
 - Gloss trap error
 - Specular beam error
 - Photometric scale error
 - Wavelength error

The investigation was carried out by a working group of the participants in the NPL Spectrophotometry and Colorimetry intercomparison of colour measurements under the supervision of NPL. The members of the working group are all from the academic world. The other participants in the intercomparison are mainly from industry. The formation of the working group from academic members was in order to maintain confidentiality and impartiality. Only NPL know the identifications of all the sources of data, individual participants only knowing the results of their measurements.

3. RECALCULATION OF COLOUR DATA USING ASTM WEIGHTING FUNCTIONS

The spectral reflectance data returned by participants is at intervals of 5 nm, 10 nm or 20 nm. The method used for computing colorimetric data from spectral data varies between participants. In Step 1, the colour data have been recalculated from the spectral data using a method from ASTM. The colour data have then been re-compared with NPL data and improvements in agreement quantified.

In Table 1, at the end of this report, the original colour differences in CIELAB ΔE units from NPL are in the rows "Initial". The differences after recalculation are in the rows "ASTM". The improvements in agreement are in the rows "Initial-ASTM". The mean values for all participants for the same tile and measurement geometry are given to the right of the table. By definition, values of ΔE are always positive. Thus figures in rows "Initial" and "ASTM" are always positive. However, differences in agreement with NPL can be positive or negative. Positive numbers in "Initial-ASTM" indicate closer agreement with NPL, negative numbers a lower agreement with NPL.

The improvement in agreement with NPL is greatest for the yellow tiles. The means for all participants are, from Table 1 pages 2, 3, 7, 8, 12, 13:

	Specular excluded	Specular included	0°/45°
glossy yellow	0.60	0.25	0.23
matt yellow	0.37	0.32	-0.08

Data are in CIELAB units ΔE for CIE Standard Illuminant D65 and the CIE 10° Standard Observer.

By comparison, corresponding figures for the white tiles are, from Table 1 pages 1, 2, 6, 7, 11, 12

	Specular excluded	Specular included	0°/45°
glossy white	0.00	0.05	0.03
matt white	0.01	0.05	-0.03

Thus, the improvements in agreement due to use of a common method of calculating colour data vary from tile to tile but can be as much as several tenths of a CIELAB unit.

4. RECALCULATION OF COLOUR DATA USING NPL CALIBRATED WHITE TILES AS THE REFERENCE STANDARDS

For the measurements, each participant used their own reference white standard. The sample tiles supplied by NPL for measurement included glossy white and matt white standards.

In Step 2 all the participants' measurements have been re-normalised using the NPL white tiles and the corresponding NPL reflectance data as the references for diffuse reflectance and $0^\circ/45^\circ$ radiance factor. The results are also presented in Table 1. The colour differences between NPL and participants after re-normalisation are in the rows "Normalise". The improvements in agreement with NPL are in the rows "ASTM-normalise".

The biggest improvements in agreement with NPL are for the white tiles. The mean improvements for these tiles for all participants are from Table 1 pages 1, 2, 6, 7, 11, 12

	Specular excluded	Specular included	$0^\circ/45^\circ$
glossy white	0.40	0.29	0.33
matt white	0.48	0.29	0.74

For tiles of lower reflectance the improvement is smaller, for example from Table 1 pages 1, 3, 6, 8, 11, 13

	Specular excluded	Specular included	$0^\circ/45^\circ$
glossy red	0.06	0.02	0.07
matt red	0.09	0.06	0.20

Data are in CIELAB units ΔE for CIE Standard Illuminant D65 and the CIE 10° Standard Observer.

The improvements to be gained from using the same scales of diffuse reflectance and spectral radiance factor are several tenths of a CIELAB unit for some tiles, in particular white tiles or other tiles of high reflectance.

5. GLOSS TRAP ERRORS

In the specular excluded geometry, the specular beam is absorbed in the gloss trap. Incomplete absorption gives an error. This may be due to an imperfect design of gloss trap or to some of the specular beam falling on the integrating sphere wall outside the area of the gloss trap. The error can be determined using a calibrated mirror and a matt white reflectance standard. The error measured must then be scaled to correspond to the lower specular reflectance from a glossy tile. The method used for the scaling is given in the Appendix.

Table 2 gives the value of the reflectance error, K_2 , when a glossy material is measured against a matt white standard. The maximum possible value of K_2 , corresponding to complete reflection from the gloss trap is 4.0%. The values returned by participants range from about 0.4% to 0.004%. The reflectance of a glossy white sample in the specular excluded geometry can be about 90% and for a glossy black sample in the same geometry about 0.1%. Thus the effect of gloss trap error is much larger for dark glossy samples than for light glossy samples. For dark glossy samples on some instruments the gloss trap error is bigger than the reflectance value for the specular excluded geometry.

The gloss trap error can be determined with a mirror and a matt white reflectance standard and the error can be removed by applying a correction to the spectral reflectance data as described in the Appendix.

6. SPECULAR BEAM ERRORS

In the specular included geometry, the specular component of reflection may not be collected with the same efficiency as the diffuse component, due to non uniformity of the integrating sphere. The error associated with the specular beam can again be determined using a calibrated mirror and a matt white reflectance standard. The method for determining this error is given in the Appendix. The specular beam reflectance error coefficient is denoted K_s . Values of K_s for all participants are listed in Table 3. These range between about 0.4% and 0.04%. For a glossy sample the specular reflectance is usually around 4%. Thus for glossy samples the total reflectance is never less than 4%, even for a black glossy sample. Thus the reflectance is always at least 10 times the specular beam error for results from participants.

The specular beam errors can be measured using a mirror and a matt white reflectance standard and a correction applied to the spectral reflectance data as described in the Appendix.

7. PHOTOMETRIC SCALE ERRORS

Photometric scale errors are defined as being errors due to non linearity of the detector and errors due to offsets other than gloss trap errors and specular beam errors.

The spectral reflectance differences between participants and NPL are listed in Table 4 for the white, mid-grey and black tiles. For the 0°/45° geometry these differences are given for both the matt and glossy tiles. For the specular included and specular excluded geometries, the differences are only given for the matt tiles because of the difficulty of separating gloss trap and specular beam errors.

For white tiles, part of the difference is due to different scales of diffuse reflectance used by participants. The data therefore must be analysed with the results of section 5 in mind. The anomalously large differences for some participants at 400 nm and 440 nm are associated with the use of a uv exclusion filter.

For the black tiles the differences are likely to be caused by dark level errors. They may be due to an electronic offset or by stray light scattered from imperfections in the optics. For a few participants these errors are in excess of 1%. This explains some of the gross errors in colour data in the first report for this intercomparison (Ref 2). It is possible to correct dark errors by using a black glass wedge at the sample port to obtain an optical zero.

8. WAVELENGTH ERRORS

NPL carried out a study to look for a correlation between colour data errors and wavelength errors measured using a holmium tile. No such simple correlation has been found.

An alternative method, using the cyan tile as a wavelength standard has also been investigated (Ref 4). Wavelength errors give rise to differences in spectral reflectance values in regions of rapid change of reflectance with wavelength. These can be seen for typical results in figures 1 and 2. The wavelength error can be calculated from the formula

$$\Delta\lambda = \frac{\Delta R}{\frac{dR}{d\lambda}}$$

where ΔR is the difference between NPL and participants reflectance values and $dR/d\lambda$ is the slope of the spectral reflectance curve.

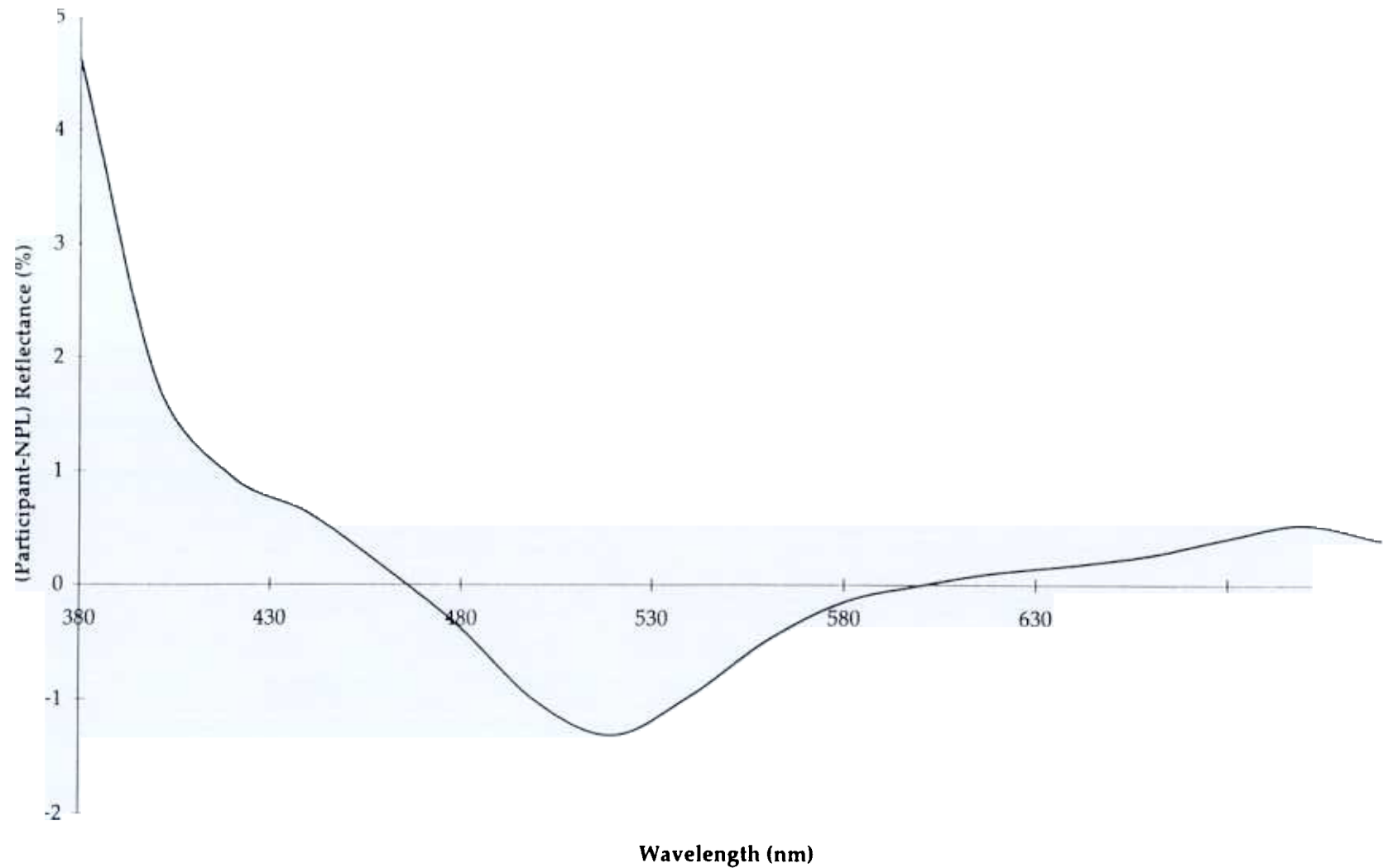
From the data for figure 1 it can be deduced that there is a wavelength error of about 2.8 nm.

Results from another participant in figure 2 show a cyclic error superposed on a similar wavelength error. The cause of this is not clear and requires further study.

It has not yet been possible to carry out a complete analysis of wavelength error because for many participants it is often difficult to separate wavelength errors from other sources of error.

A new method for readily isolating wavelength errors is required. As the majority of colour measuring spectrophotometers now use diode array detectors the method needs to be easy to use with these instruments.

Difference in Spectral Reflectance for Glossy Cyan Tile
Participant 1, 0/45 Geometry



Figure

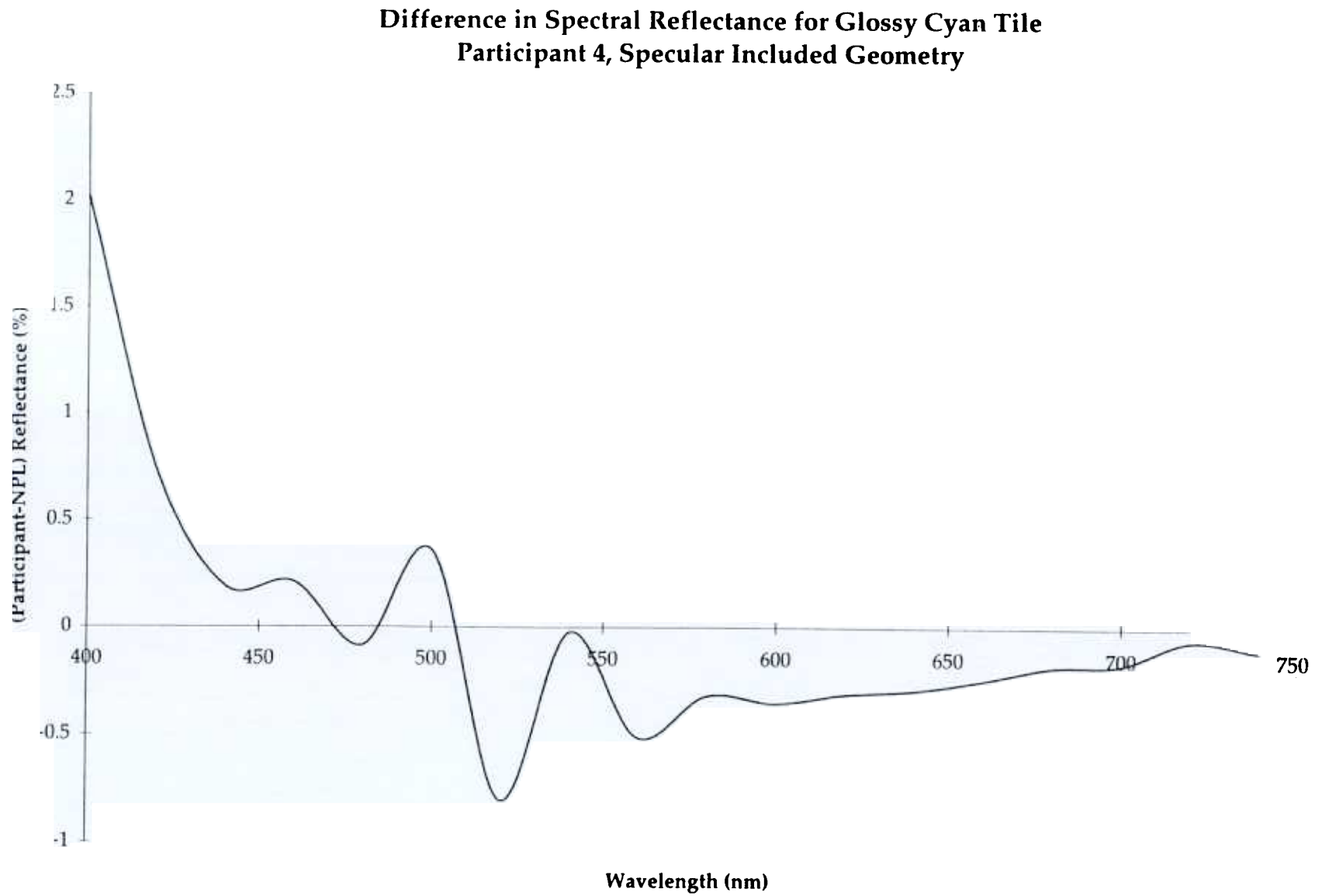


Figure 2

9. CONCLUSIONS

A comprehensive summary of the sources of error in the NPL Spectrophotometry and Colorimetry Club intercomparison of colour measurements has been presented. (Error has been used here to mean the difference between NPL and participants data values. However, some degree of caution is needed in the interpretation of the word "error" because for the most accurate colour measurements made in industry, levels of uncertainties are similar to NPL levels of uncertainty). The results give an analysis of a typical cross section of instruments in industry and academia.

For participants with the most accurate instruments where errors are a few tenths of a CIELAB unit no single source of error can be considered dominant. Therefore most of the errors need to be reduced to achieve an overall improvement in accuracy. The scales of diffuse reflectance and $0^\circ/45^\circ$ radiance factor underpin all industrial surface colour measurements and uncertainties need to be reduced to achieve an overall improvement. A common method of calculating colour data from spectral data needs to be agreed for international use. The leading candidate, at present, is the ASTM method.

The first report on the intercomparison (Ref 2) showed that some participants had gross errors in colour data. Analysis of the spectral data indicates significant gloss trap errors (Table 2) and large offset errors (Table 4, matt black tile data) for these participants. These errors could have been revealed by simple tests using a mirror in the first case and a black glass wedge light trap in the second case. There is a need for routine maintenance using simple tests which could easily be carried out by the instrument owners.

Further research is required into the determination of wavelength errors in diode array spectrophotometry.

This study was concerned primarily with the analysis of spectral data. Further work is required on the correction of spectral data and the transfer of the methodology to industry.

10. ACKNOWLEDGEMENTS

NPL wishes to thank the following members of the working group who analysed the data.

Dr J H Nobbs, Colour Chemistry Department, Leeds University.

Dr B W Moss, Dept of Food Science, The Queen's University of Belfast.

Prof M R Luo and Dr Hong Xu, Design Research Centre, University of Derby.

11. REFERENCES

- 1 Intercomparison of Colour Measurements Synthesis Report, J F Verrill, Report EUR 14982 EN, European Commission, Brussels, 1993.
- 2 NPL Spectrophotometry and Colorimetry Club, Intercomparison of Colour Measurements, J F Verrill, P J Clarke, J O'Halloran and P C Knee, NPL Report QU 113, 1995.
- 3 ASTM E 308-95, Standard practice for computing the colors of objects by the CIE system, 1995.
- 4 Berns R S and Peterson K H, Empirical modelling of systematic spectrophotometric errors, Col.Res.Appl., Vol. 13, pp. 243-256, 1988.

12. TABLES

Table 1

Recalculation and Renormalisation of Colour Data

All units are CIELAB differences ΔE^* from NPL for CIE Standard Illuminant D65 and the CIE 10° Standard Observer.

First row "Initial"	These are the colour differences between data as supplied by participants and NPL.
Second row "ASTM"	These are the colour differences between participants and NPL after recalculation of the colour data by the ASTM method.
Third row "Normalise"	These are the colour differences between participants and NPL after renormalisation of the reflectance data using the NPL white tiles as reflectance standards and recalculation of the colour data by the ASTM method.
Fourth row "Initial - ASTM"	This is the arithmetic difference between data in the first row and data in the second row. It represents the improvement in agreement between participants and NPL due to the use of the ASTM method of calculating colour data.
Fifth row "ASTM - Norm"	This is the arithmetic difference between data in the second row and data in the third row. It represents the improvement in agreement between participants and NPL due to renormalisation of the reflectance data using the NPL white tiles as reflectance standards.

Note: In a few cases there are gaps in the tables. This is because of gaps or errors in the data received from participants which it was not possible to remedy.

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE LAB ΔE^* Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	Specular Excluded geometry 10° Observer, Illuminant D65												3	Mean		
		8	20	6	3	5b	9	4	18	12	19	21					
Glossy White	Initial	0.21	0.18	0.16	0.30	0.12	0.20	0.31	0.17	0.26	0.33	0.11	1.05	0.38	0.82	1.52	0.55
	ASTM	0.21	0.21	0.16	0.30	0.07	0.21	0.26	0.16	0.27	0.33	0.11	1.04	0.37	0.82	1.53	0.55
	Normalized	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01
Glossy Mid Grey	Initial-ASTM	0.00	0.03	0.00	0.00	0.05	-0.01	0.05	0.01	0.01	0.00	0.00	0.01	0.01	0.00	-0.01	0.00
	ASTM-Norm	0.21	0.20	0.15	0.29	0.06	0.20	0.25	0.15	0.26	0.32	0.11	1.03	0.37	0.81	1.52	0.54
	Normalized	0.29	0.22	0.06	0.25	0.13	0.25	2.14	0.18	0.15	0.25	0.25	0.85	0.40	3.81	1.11	1.12
Glossy Black	Initial	0.29	0.24	0.08	0.25	0.11	0.27	2.11	0.17	0.15	0.29	0.26	0.85	0.42	3.86	1.15	1.12
	ASTM	0.16	0.14	0.07	0.08	0.11	0.14	2.10	0.13	0.15	0.11	0.32	0.16	0.22	4.12	0.18	1.38
	Normalized	0.00	-0.02	-0.02	0.00	0.02	-0.02	0.03	0.01	0.00	-0.04	-0.01	0.00	-0.02	-0.05	-0.04	0.00
Glossy Red	Initial-ASTM	0.00	-0.02	0.01	0.17	0.00	0.13	0.01	0.04	0.00	0.18	-0.06	0.69	0.20	-0.26	0.97	-0.26
	ASTM-Norm.	0.13	0.10	0.01	0.03	0.00	0.01	0.01	0.01	0.00	0.01	-0.02	0.18	0.00	0.17	0.18	-0.19
	Normalized	0.58	0.55	0.62	0.61	0.64	0.57	0.64	1.19	0.57	0.28	2.75	1.78	0.69	2.76	4.46	19.77
Glossy Green	Initial	0.59	0.56	0.62	0.61	0.65	0.59	0.62	1.18	0.60	0.27	2.76	1.77	0.72	2.78	4.47	19.77
	ASTM	0.57	0.57	0.61	0.58	0.65	0.60	0.64	1.18	0.61	0.26	2.78	1.59	0.72	2.95	4.29	19.96
	Normalized	0.01	-0.01	0.00	0.00	-0.01	-0.02	0.02	0.01	-0.03	0.01	-0.01	0.01	-0.03	0.02	-0.01	0.00
Glossy Black	Initial-ASTM	0.02	-0.01	0.01	0.03	0.00	-0.01	-0.02	0.00	-0.01	0.01	-0.02	0.18	0.00	0.17	0.18	-0.19
	ASTM-Norm.	0.02	-0.01	0.01	0.03	0.00	-0.01	-0.02	0.00	-0.01	0.01	-0.02	0.18	0.00	0.17	0.18	-0.19
	Normalized	0.45	0.33	0.22	0.37	0.94	0.86	0.59	0.58	1.39	0.90	2.87	3.27	2.31	4.55	11.71	21.74
Glossy Red	Initial	0.31	0.30	0.20	0.19	0.15	0.08	0.75	0.61	0.69	0.86	3.16	3.28	2.71	4.55	12.03	21.73
	ASTM	0.32	0.34	0.22	0.21	0.10	0.16	0.64	0.63	0.68	0.72	3.12	3.38	2.45	4.24	11.89	21.53
	Normalized	0.14	0.03	0.02	0.18	0.79	0.78	-0.16	-0.03	0.70	0.04	-0.29	-0.01	-0.40	0.00	-0.32	0.01
Glossy Green	Initial-ASTM	-0.01	-0.04	-0.02	0.02	0.05	0.08	0.11	-0.02	0.01	0.14	0.04	-0.10	0.26	0.31	0.14	0.20
	ASTM-Norm.	-0.01	-0.04	-0.02	0.02	0.05	0.08	0.11	-0.02	0.01	0.14	0.04	-0.10	0.26	0.31	0.14	0.20
	Normalized	0.10	0.15	0.39	0.53	0.66	0.74	0.51	0.46	0.95	1.22	1.14	0.83	0.62	2.47	1.83	6.19
Glossy Black	Initial	0.38	0.39	0.65	0.31	0.64	0.51	0.45	0.53	0.56	0.30	0.43	0.83	0.92	2.77	1.15	6.20
	ASTM	0.36	0.46	0.70	0.10	0.64	0.50	0.43	0.56	0.42	0.29	0.51	0.48	0.98	3.12	0.96	6.09
	Normalized	-0.28	0.24	0.26	0.22	0.02	0.23	0.06	-0.07	0.39	0.92	0.71	0.00	0.30	-0.30	0.68	-0.01
Glossy White	Initial-ASTM	0.02	0.07	0.05	0.21	0.00	0.01	0.02	-0.03	0.14	0.01	-0.08	0.35	0.06	-0.35	0.19	0.11
	ASTM-Norm.	0.02	0.07	0.05	0.21	0.00	0.01	0.02	-0.03	0.14	0.01	-0.08	0.35	0.06	-0.35	0.19	0.11
	Normalized	0.02	0.07	0.05	0.21	0.00	0.01	0.02	-0.03	0.14	0.01	-0.08	0.35	0.06	-0.35	0.19	0.11

Table 1 Page 1 of 15

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE LAB ΔE* Differences from NPL values for Steps 1 and 2

Specular Excluded geometry
10° Observer, Illuminant D65

File	Value/Lab	15	8	20	6	3	5b	9	4	5a	18	12	19	21	3	Mean
Glossy Yellow	Initial	0.36	0.46	0.38	1.00	1.67	1.38	0.72	1.06	1.55	2.00	2.33	0.72	2.78	1.44	4.39
	ASTM	0.15	0.13	0.71	0.66	0.30	0.14	0.62	0.83	1.02	0.62	1.00	0.72	1.41	1.17	3.13
	Normalized	0.09	0.10	0.82	0.41	0.33	0.09	0.60	0.82	0.83	0.34	0.91	0.69	1.04	0.72	3.30
Glossy Cyan	Initial-ASTM	0.21	0.33	0.13	0.34	1.37	1.24	0.10	0.23	0.53	1.38	1.33	0.00	1.37	0.27	1.26
	ASTM-Norm.	0.06	0.03	0.11	0.25	0.03	0.05	0.02	0.01	0.19	0.28	0.09	0.03	0.37	0.45	-0.17
	Mean	0.13	0.18	0.42	0.50	0.95	0.66	0.42	0.42	0.86	1.08	1.16	0.01	0.87	0.81	0.54
Matt White	Initial	0.25	0.28	0.11	0.36	0.74	0.57	0.66	0.22	0.53	0.29	0.87	0.91	0.75	2.68	1.95
	ASTM	0.24	0.24	0.13	0.31	0.39	0.31	0.70	0.23	0.76	0.18	0.51	0.90	0.48	2.68	1.71
	Normalized	0.16	0.27	0.10	0.09	0.36	0.27	0.69	0.21	0.73	0.11	0.55	0.44	0.43	2.81	2.13
Matt Mid Grey	Initial-ASTM	0.01	0.04	-0.02	0.05	0.35	0.26	-0.04	-0.01	-0.23	0.11	0.36	0.01	0.27	0.00	0.24
	ASTM-Norm.	0.08	-0.03	0.03	0.22	0.03	0.04	0.01	0.02	0.03	0.07	-0.04	0.46	0.05	-0.13	-0.42
	Mean	0.04	0.00	0.00	0.17	0.35	0.15	0.33	0.00	0.10	0.24	0.16	0.23	0.16	0.44	0.10
Matt White	Initial	0.12	0.12	0.15	0.23	0.21	0.07	0.24	0.23	0.24	0.69	0.42	1.07	0.34	1.10	1.19
	ASTM	0.12	0.14	0.14	0.23	0.16	0.09	0.15	0.21	0.26	0.70	0.42	1.07	0.34	1.10	1.20
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.00
Matt Mid Grey	Initial-ASTM	0.00	-0.02	0.01	0.00	0.05	-0.02	0.09	0.02	-0.02	-0.01	0.00	0.00	0.00	-0.01	0.00
	ASTM-Norm.	0.11	0.13	0.13	0.22	0.15	0.08	0.14	0.20	0.26	0.70	0.41	1.06	0.33	1.09	1.20
	Mean	0.05	0.05	0.07	0.12	0.08	0.04	0.10	0.11	0.12	0.34	0.20	0.53	0.17	0.60	0.10
Matt Mid Grey	Initial	0.24	0.13	0.13	0.22	0.12	0.15	0.20	0.18	0.03	0.58	0.04	0.86	0.65	2.31	1.18
	ASTM	0.25	0.15	0.12	0.22	0.05	0.18	0.16	0.17	0.02	0.59	0.08	0.85	0.66	2.34	1.20
	Normalized	0.17	0.16	0.21	0.13	0.08	0.13	0.08	0.07	0.19	0.14	0.29	0.12	0.43	2.70	0.74
Matt Mid Grey	Initial-ASTM	-0.01	-0.02	0.01	0.00	0.07	-0.03	0.04	0.01	0.01	-0.01	-0.04	0.01	-0.01	-0.03	0.01
	ASTM-Norm.	0.08	-0.01	-0.09	0.09	-0.03	0.05	0.08	0.10	-0.17	0.45	-0.21	0.73	0.23	-0.36	0.46
	Mean	0.03	0.03	0.01	0.03	0.02	0.06	0.06	0.06	0.04	0.28	0.12	0.40	0.10	0.16	0.10

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE LAB ΔE^* Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	Specular Excluded geometry 10° Observer, Illuminant D65												13 Mean
		20	3	5b	9	4	18	12	19	21				
Matt Black	Initial	0.10	0.18	0.13	0.22	0.26	0.41	0.27	0.85	0.74	0.42	2.12	0.83	5.74
	ASTM	0.10	0.18	0.14	0.19	0.26	0.42	0.25	0.84	0.75	0.43	2.19	0.82	5.74
	Normalized	0.13	0.24	0.11	0.13	0.26	0.49	0.52	1.02	0.30	0.32	2.26	0.62	6.46
Matt Red	Initial-ASTM	0.00	0.01	0.01	0.03	0.00	-0.01	0.02	0.01	0.01	-0.01	0.07	0.01	0.00
	ASTM-Norm	-0.03	0.04	0.06	0.09	0.06	0.03	0.06	-0.18	0.45	0.11	0.07	0.20	-0.72 -0.03
	Initial	0.49	0.65	0.24	0.96	0.45	0.41	0.40	0.55	0.49	0.75	2.53	1.72	6.62
Matt Green	ASTM	0.50	0.67	0.24	0.94	0.26	0.31	0.56	0.25	0.65	0.75	2.53	2.07	6.62
	Normalized	0.54	0.65	0.18	0.92	0.19	0.33	0.59	0.17	0.40	0.23	2.67	1.69	6.32
	Initial-ASTM	-0.01	-0.02	0.00	0.02	0.19	0.10	-0.16	0.03	0.44	-0.10	0.00	0.35	0.00 -0.01
Matt Green	ASTM-Norm.	-0.04	0.02	0.06	0.02	0.07	-0.02	-0.03	0.08	0.15	0.42	-0.14	0.38	0.30 0.09
	Initial	0.44	0.43	0.30	0.28	0.51	0.60	0.34	0.49	0.66	1.11	0.87	0.57	3.48
	ASTM	0.57	0.54	0.47	0.37	0.73	0.56	0.29	0.70	0.29	0.46	0.66	0.83	3.48
Matt Yellow	Normalized	0.56	0.63	0.52	0.42	0.76	0.58	0.16	0.58	0.29	0.34	0.85	1.44	3.24
	Initial-ASTM	-0.13	-0.11	-0.17	-0.09	-0.22	0.04	0.05	-0.21	0.37	0.65	-0.25	-0.26	0.00 -0.03
	ASTM-Norm.	0.01	-0.09	-0.05	-0.05	-0.03	-0.02	0.13	0.12	0.00	0.12	-0.47	-0.61	-0.03
Matt Yellow	Initial	0.29	0.46	0.23	0.71	1.29	1.28	0.42	0.62	1.09	2.10	1.57	2.22	8.14
	ASTM	0.26	0.32	0.30	0.51	0.42	0.39	0.31	0.71	0.44	1.26	1.74	1.39	8.14
	Normalized	0.27	0.28	0.32	0.34	0.31	0.38	0.27	0.66	0.24	0.52	2.32	1.10	6.90
Matt Yellow	Initial-ASTM	0.03	0.14	-0.07	0.20	0.87	0.89	0.11	-0.09	0.65	0.84	-0.17	0.83	0.00 0.37
	ASTM-Norm.	0.01	0.04	-0.02	0.17	0.11	0.01	0.04	0.05	0.20	0.74	-0.58	0.29	1.24 0.20

Table 1 Page 3 of 15

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE L^{*}AB ΔE^{*} Differences from NPL values for Steps 1 and 2

Specular Excluded geometry
10° Observer, Illuminant D65

Tile	Value/Lab	14	15	8	20	3	5b	9	4	18	12	19	21	13	Mean
Matt Cyan	Initial	0.74	0.76	0.76	0.66	1.24	1.04	0.31	0.98	0.69	0.90	1.28	1.03	1.12	0.85
	ASTM	0.71	0.69	0.69	0.60	0.94	0.81	0.30	0.96	0.43	0.59	1.03	1.03	0.96	0.76
	Normalized	0.72	0.80	0.71	0.62	0.92	0.84	0.23	0.82	0.54	0.65	1.11	0.67	0.97	0.89
Grey Metamer	Initial-ASTM	0.03	0.05	0.07	0.06	0.30	0.23	0.01	0.02	0.26	0.31	0.25	0.00	0.16	0.09
	ASTM-Norm.	-0.01	0.09	0.02	-0.02	0.02	-0.03	0.07	0.14	-0.11	-0.06	-0.08	0.36	-0.01	-0.07
	Mean														0.11
Grey Metamer 2	Initial	0.24	0.16	0.09	0.22	0.15	0.24	0.28	0.21	0.16	0.31	0.29	0.84	0.40	0.86
	ASTM	0.24	0.17	0.10	0.22	0.12	0.27	0.28	0.20	0.16	0.34	0.30	0.84	0.41	0.85
	Normalized	0.12	0.10	0.11	0.04	0.12	0.14	0.12	0.15	0.16	0.15	0.36	0.16	0.19	0.87
Grey Metamer 2	Initial-ASTM	0.00	-0.01	-0.01	0.00	0.03	0.03	0.00	0.01	0.00	-0.03	-0.01	0.00	-0.01	-0.01
	ASTM-Norm.	0.12	0.07	-0.01	0.18	0.00	0.13	0.16	0.05	0.00	0.19	-0.06	0.68	0.22	0.14
	Mean														0.08
Green Metamer 1	Initial	0.31	0.27	0.36	0.24	0.31	0.22	0.29	0.17	0.28	0.15	0.35	0.80	0.76	1.01
	ASTM	0.32	0.28	0.35	0.24	0.28	0.27	0.28	0.17	0.22	0.24	0.38	0.80	0.87	1.01
	Normalized	0.27	0.29	0.38	0.15	0.29	0.25	0.12	0.15	0.19	0.18	0.44	0.22	0.75	0.97
Green Metamer 1	Initial-ASTM	-0.01	0.01	0.01	0.00	0.03	-0.05	0.01	0.00	0.06	-0.09	0.03	0.00	-0.11	-0.02
	ASTM-Norm.	0.05	0.01	0.03	0.09	0.01	0.02	0.16	0.02	0.03	0.06	0.06	0.58	0.12	0.08
	Mean														0.04
Green Metamer 1	Initial	0.36	0.33	0.10	0.30	0.49	0.64	0.43	0.10	0.24	0.49	0.36	0.89	0.74	1.62
	ASTM	0.32	0.28	0.03	0.24	0.23	0.35	0.43	0.19	0.52	0.18	0.44	0.89	0.44	1.61
	Normalized	0.20	0.21	0.09	0.11	0.22	0.23	0.26	0.20	0.45	0.13	0.52	0.29	0.20	1.59
Green Metamer 1	Initial-ASTM	0.04	0.05	0.07	0.06	0.26	0.29	0.00	-0.09	-0.28	0.31	-0.08	0.00	0.30	0.07
	ASTM-Norm.	0.12	0.07	-0.06	0.13	0.01	0.12	0.17	-0.01	0.07	0.05	-0.08	0.60	0.24	0.13
	Mean														0.02

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE LAB ΔE^* Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	Specular Excluded geometry 10° Observer, Illuminant D65												13	Mean		
		14	15	8	20	6	3	5b	9	4	5a	18	12			19	21
Green Metamer 2	Initial	0.30	0.23	0.16	0.23	0.20	0.23	0.33	0.18	0.16	0.25	0.29	0.79	0.40	3.84	1.43	1.16
	ASTM	0.33	0.25	0.18	0.23	0.31	0.30	0.31	0.22	0.20	0.24	0.36	0.80	0.59	3.95	1.41	1.15
	Normalized	0.30	0.32	0.13	0.12	0.31	0.27	0.14	0.21	0.13	0.22	0.43	0.27	0.56	4.23	0.95	1.13
Holmium	Initial-ASTM	-0.03	-0.02	0.02	0.00	0.11	0.07	0.02	-0.04	-0.04	0.01	-0.07	-0.01	-0.19	-0.11	0.02	-0.04
	ASTM-Norm	0.03	-0.07	0.05	0.11	0.00	0.03	0.17	0.01	0.07	0.02	-0.07	0.53	0.03	-0.28	0.46	0.02
	Normalized	0.74	0.59	0.67	0.84	1.50	1.81	0.45	0.79	0.41	1.14	0.98	0.89	3.07	1.43	3.09	3.04
Crossover 1	Initial	0.50	0.39	0.52	0.64	0.39	0.65	0.41	0.58	0.52	0.79	0.81	0.89	2.54	1.33	2.46	
	ASTM	0.47	0.28	0.41	0.50	0.44	0.57	0.41	0.61	0.68	0.70	0.78	0.40	2.32	0.86	1.71	
	Normalized	0.24	0.20	0.15	0.20	1.11	1.16	0.04	0.21	-0.11	0.35	0.17	0.00	0.53	0.10	0.63	0.33
Crossover 2	Initial-ASTM	0.03	0.11	0.11	0.14	-0.05	0.08	0.00	-0.03	-0.16	0.09	0.03	0.49	0.22	0.47	0.75	0.15
	ASTM-Norm.	0.26	0.19	0.08	0.22	0.20	0.32	0.35	0.20	0.25	0.20	0.21	0.86	0.50	1.72	1.21	1.26
	Normalized	0.27	0.21	0.07	0.21	0.17	0.33	0.33	0.19	0.25	0.23	0.21	0.86	0.50	1.74	1.22	1.25
Crossover 3	Initial	0.13	0.14	0.07	0.05	0.15	0.20	0.14	0.19	0.17	0.08	0.28	0.05	0.22	2.05	0.17	0.87
	Initial-ASTM	-0.01	-0.02	0.01	0.01	0.03	-0.01	0.02	0.01	0.00	-0.03	0.00	0.00	0.00	-0.02	-0.01	0.01
	ASTM-Norm.	0.14	0.07	0.00	0.16	0.02	0.13	0.19	0.00	0.08	0.15	-0.07	0.81	0.28	-0.31	1.05	0.38
Crossover 4	Initial	0.25	0.20	0.15	0.28	0.16	0.22	0.51	0.12	0.24	0.30	0.19	0.82	0.63	2.06	1.25	1.78
	ASTM	0.25	0.22	0.15	0.28	0.14	0.25	0.51	0.11	0.25	0.32	0.20	0.82	0.63	2.10	1.28	1.78
	Normalized	0.11	0.12	0.07	0.10	0.12	0.12	0.32	0.05	0.17	0.12	0.27	0.06	0.34	2.40	0.20	1.43
Mean	Initial-ASTM	0.00	-0.02	0.00	0.00	0.02	-0.03	0.00	0.01	-0.01	-0.02	-0.01	0.00	0.00	-0.04	-0.03	0.00
	ASTM-Norm.	0.14	0.10	0.08	0.18	0.02	0.13	0.19	0.06	0.08	0.20	-0.07	0.76	0.29	-0.30	1.08	0.35
	Normalized	0.01	0.01	-0.03	0.06	0.25	0.23	0.02	0.00	0.13	0.22	0.16	0.00	0.08	0.05	0.14	0.00
Grand Mean	Initial-ASTM	0.06	0.03	0.01	0.13	0.02	0.05	0.09	0.05	0.04	0.18	0.01	0.50	0.18	0.06	0.42	0.22
	ASTM-Norm.	0.01	0.01	-0.03	0.06	0.25	0.23	0.02	0.00	0.13	0.22	0.16	0.00	0.08	0.05	0.14	0.00
	Normalized	0.01	0.01	-0.03	0.06	0.25	0.23	0.02	0.00	0.13	0.22	0.16	0.00	0.08	0.05	0.14	0.00

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE LAB ΔE^* Differences from NPL values for Steps 1 and 2

Specular Included geometry
10° Observer, Illuminant D65

Tile	Value/Lab	20	14	15	5b	6	3	19	9	18	5a	4	21	10	12	13	Mean
Glossy White	Initial	0.10	0.17	0.15	0.33	0.18	0.95	0.47	0.27	0.15	0.16	0.22	0.47	0.10	1.44	.15	17
	ASTM	0.10	0.17	0.18	0.30	0.13	0.16	0.47		0.15	0.17	0.22	0.48	0.10	1.44	.14	16
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.00		0.00	0.00	0.00	0.01	0.01	0.00	.00	00
Glossy Mid Grey	Initial-ASTM	0.00	0.00	0.03	0.03	0.05	0.79	0.00		0.00	-0.01	0.00	-0.01	0.00	0.00	0.01	0.05
	ASTM Norm.	0.09	0.16	0.17	0.29	0.12	0.15	0.47		0.15	0.17	0.22	0.47	0.09	1.44	0.14	0.29
	Initial	0.15	0.24	0.15	0.15	0.15	0.54	0.39	0.18	0.16	0.23	0.12	0.49	0.49	1.03	0.61	1.13
Glossy Black	ASTM	0.17	0.25	0.15	0.14	0.09	0.17	0.40	0.18	0.16	0.26	0.14	0.49	0.50	1.07	0.61	1.13
	Normalized	0.16	0.13	0.08	0.07	0.10	0.05	0.14	0.12	0.10	0.17	0.18	0.72	0.57	0.71	0.54	1.11
	Initial-ASTM	0.02	0.01	0.00	0.01	0.06	0.37	-0.01	0.00	0.00	-0.03	-0.02	0.00	-0.01	-0.04	0.00	0.02
Glossy Red	ASTM Norm.	0.01	0.12	0.07	0.10	0.04	0.03	0.28		0.06	0.09	-0.04	-0.23	-0.07	0.36	0.07	0.07
	Initial	0.30	0.50	0.81	0.75	0.85	0.75	0.68	0.95	0.55	0.40	1.12	2.00	2.45	1.10	0.90	7.79
	ASTM	0.31	0.50	0.81	0.75	0.83	0.74	0.71	0.68	0.56	0.41	1.12	2.00	2.45	1.08	0.91	7.79
Glossy Green	Normalized	0.29	0.44	0.86	0.78	0.94	0.73	0.76	0.51	0.51	0.45	1.15	2.14	2.48	1.20	0.86	7.74
	Initial-ASTM	-0.01	0.00	0.00	0.02	0.01	0.04	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.02	-0.01	0.00
	ASTM Norm.	0.02	0.06	0.05	-0.03	-0.11	0.01	-0.05	0.17	0.05	-0.04	-0.03	-0.14	-0.03	-0.12	0.05	0.00
Glossy Black	Initial	0.38	0.89	0.93	0.96	1.48	1.50	1.38	1.11	1.76	1.49	1.06	2.08	2.79	1.47	0.81	8.71
	ASTM	0.42	0.85	0.91	0.94	1.65	1.20	0.87	1.13	1.71	1.32	0.65	2.05	2.83	1.90	0.83	8.70
	Normalized	0.39	0.87	0.94	0.98	1.63	1.12	0.89	1.17	1.32	0.71	2.17	1.69	2.86	1.80	0.82	8.69
Glossy Red	Initial-ASTM	-0.04	0.04	0.02	-0.17	0.30	0.51	-0.02	0.05	0.17	0.41	0.17	0.03	-0.04	-0.43	-0.02	0.01
	ASTM Norm.	0.03	0.02	-0.03	0.02	0.08	-0.02	-0.04		0.00	-0.06	-0.10	0.36	-0.03	0.10	0.01	0.02
	Initial	0.24	0.62	0.18	0.14	0.50	0.68	1.14	0.44	0.56	0.60	1.21	0.95	0.86	0.47	0.70	4.67
Glossy Green	ASTM	0.10	0.42	0.17	0.13	0.45	0.40	0.25	0.92	0.58	0.53	0.17	0.61	1.08	0.64	0.69	4.67
	Normalized	0.13	0.33	0.10	0.15	0.42	0.37	0.18	1.06	0.60	0.08	0.51	2.38	1.08	1.03	0.62	4.73
	Initial-ASTM	0.14	0.20	0.01	0.01	0.05	0.28	0.89	-0.48	-0.02	0.07	1.04	0.34	0.17	-0.22	-0.17	1.13
Glossy Black	ASTM Norm.	0.03	0.09	0.07	-0.02	0.03	0.03	0.07	-0.14	0.07	0.09	0.10	-0.26	0.00	-0.39	0.07	1.02
	Initial	0.30	0.50	0.81	0.75	0.85	0.75	0.68	0.95	0.55	0.40	1.12	2.00	2.45	1.10	0.90	7.79
	ASTM	0.31	0.50	0.81	0.75	0.83	0.74	0.71	0.68	0.56	0.41	1.12	2.00	2.45	1.08	0.91	7.79
Glossy Red	Normalized	0.29	0.44	0.86	0.78	0.94	0.73	0.76	0.51	0.51	0.45	1.15	2.14	2.48	1.20	0.86	7.74
	Initial-ASTM	-0.01	0.00	0.00	0.02	0.01	0.04	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.02	-0.01	0.00
	ASTM Norm.	0.02	0.06	0.05	-0.03	-0.11	0.01	-0.05	0.17	0.05	-0.04	-0.03	-0.14	-0.03	-0.12	0.05	0.00
Glossy Green	Initial	0.38	0.89	0.93	0.96	1.48	1.50	1.38	1.11	1.76	1.49	1.06	2.08	2.79	1.47	0.81	8.71
	ASTM	0.42	0.85	0.91	0.94	1.65	1.20	0.87	1.13	1.71	1.32	0.65	2.05	2.83	1.90	0.83	8.70
	Normalized	0.39	0.87	0.94	0.98	1.63	1.12	0.89	1.17	1.32	0.71	2.17	1.69	2.86	1.80	0.82	8.69
Glossy Black	Initial-ASTM	-0.04	0.04	0.02	-0.17	0.30	0.51	-0.02	0.05	0.17	0.41	0.17	0.03	-0.04	-0.43	-0.02	0.01
	ASTM Norm.	0.03	0.02	-0.03	0.02	0.08	-0.02	-0.04		0.00	-0.06	-0.10	0.36	-0.03	0.10	0.01	0.02
	Initial	0.24	0.62	0.18	0.14	0.50	0.68	1.14	0.44	0.56	0.60	1.21	0.95	0.86	0.47	0.70	4.67
Glossy Red	ASTM	0.10	0.42	0.17	0.13	0.45	0.40	0.25	0.92	0.58	0.53	0.17	0.61	1.08	0.64	0.69	4.67
	Normalized	0.13	0.33	0.10	0.15	0.42	0.37	0.18	1.06	0.60	0.08	0.51	2.38	1.08	1.03	0.62	4.73
	Initial-ASTM	0.14	0.20	0.01	0.01	0.05	0.28	0.89	-0.48	-0.02	0.07	1.04	0.34	0.17	-0.22	-0.17	1.13
Glossy Green	ASTM Norm.	0.03	0.09	0.07	-0.02	0.03	0.03	0.07	-0.14	0.07	0.09	0.10	-0.26	0.00	-0.39	0.07	1.02
	Initial	0.30	0.50	0.81	0.75	0.85	0.75	0.68	0.95	0.55	0.40	1.12	2.00	2.45	1.10	0.90	7.79
	ASTM	0.31	0.50	0.81	0.75	0.83	0.74	0.71	0.68	0.56	0.41	1.12	2.00	2.45	1.08	0.91	7.79
Glossy Black	Normalized	0.29	0.44	0.86	0.78	0.94	0.73	0.76	0.51	0.51	0.45	1.15	2.14	2.48	1.20	0.86	7.74
	Initial-ASTM	-0.01	0.00	0.00	0.02	0.01	0.04	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.02	-0.01	0.00
	ASTM Norm.	0.02	0.06	0.05	-0.03	-0.11	0.01	-0.05	0.17	0.05	-0.04	-0.03	-0.14	-0.03	-0.12	0.05	0.00
Glossy Red	Initial	0.38	0.89	0.93	0.96	1.48	1.50	1.38	1.11	1.76	1.49	1.06	2.08	2.79	1.47	0.81	8.71
	ASTM	0.42	0.85	0.91	0.94	1.65	1.20	0.87	1.13	1.71	1.32	0.65	2.05	2.83	1.90	0.83	8.70
	Normalized	0.39	0.87	0.94	0.98	1.63	1.12	0.89	1.17	1.32	0.71	2.17	1.69	2.86	1.80	0.82	8.69
Glossy Green	Initial-ASTM	-0.04	0.04	0.02	-0.17	0.30	0.51	-0.02	0.05	0.17	0.41	0.17	0.03	-0.04	-0.43	-0.02	0.01
	ASTM Norm.	0.03	0.02	-0.03	0.02	0.08	-0.02	-0.04		0.00	-0.06	-0.10	0.36	-0.03	0.10	0.01	0.02
	Initial	0.24	0.62	0.18	0.14	0.50	0.68	1.14	0.44	0.56	0.60	1.21	0.95	0.86	0.47	0.70	4.67
Glossy Black	ASTM	0.10	0.42	0.17	0.13	0.45	0.40	0.25	0.92	0.58	0.53	0.17	0.61	1.08	0.64	0.69	4.67
	Normalized	0.13	0.33	0.10	0.15	0.42	0.37	0.18	1.06	0.60	0.08	0.51	2.38	1.08	1.03	0.62	4.73
	Initial-ASTM	0.14	0.20	0.01	0.01	0.05	0.28	0.89	-0.48	-0.02	0.07	1.04	0.34	0.17	-0.22	-0.17	1.13
Glossy Red	ASTM Norm.	0.03	0.09	0.07	-0.02	0.03	0.03	0.07	-0.14	0.07	0.09	0.10	-0.26	0.00	-0.39	0.07	1.02
	Initial	0.30	0.50	0.81	0.75	0.85	0.75	0.68	0.95	0.55	0.40	1.12	2.00	2.45	1.10	0.90	7.79
	ASTM	0.31	0.50	0.81	0.75	0.83	0.74	0.71	0.68	0.56	0.41	1.12	2.00	2.45	1.08	0.91	7.79
Glossy Green	Normalized	0.29	0.44	0.86	0.78	0.94	0.73	0.76	0.51	0.51	0.45	1.15	2.14	2.48	1.20	0.86	7.74
	Initial-ASTM	-0.01	0.00	0.00	0.02	0.01	0.04	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.02	-0.01	0.00
	ASTM Norm.	0.02	0.06	0.05	-0.03	-0.11	0.01	-0.05	0.17	0.05	-0.04	-0.03	-0.14	-0.03	-0.12	0.05	0.00

Table 1 Page 6 of 15

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE:LAB ΔE^* Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	Specular Included geometry 10° Observer, Illuminant D65										
		20	14	15	5b	3	19	9	18	5a	4	21
Glossy Yellow	Initial	0.16	0.13	0.15	0.61	1.19	0.95	0.66	0.57	0.95	1.46	1.84
	ASTM	0.10	0.28	0.22	0.51	0.14	0.14	0.62	0.54	0.35	0.37	1.60
	Normalized	0.16	0.29	0.23	0.25	0.34	0.22	0.10	0.90	0.38	0.25	2.05
Glossy Cyan	Initial-ASTM	0.06	0.24	-0.15	-0.07	0.10	1.05	0.81	0.04	0.03	0.60	1.09
	ASTM-Norm.	0.06	0.17	0.05	-0.03	0.17	0.08	0.04	-0.28	-0.03	0.12	-0.45
	Initial	0.11	0.15	0.36	0.58	0.83	1.07	0.41	0.29	0.57	0.36	1.56
Matt White	ASTM	0.03	0.10	0.37	0.60	0.58	0.34	0.44	0.29	0.41	0.08	0.83
	Normalized	0.10	0.07	0.32	0.39	0.52	0.27	0.55	0.44	0.18	0.72	1.83
	Initial-ASTM	0.08	0.05	0.01	-0.02	0.25	0.73	-0.03	0.00	0.16	0.28	-0.34
Matt Mid Grey	ASTM-Norm.	-0.07	0.03	0.05	0.04	0.06	0.07	-0.11	-0.03	-0.10	0.11	-0.23
	Initial	0.18	0.16	0.10	0.12	0.29	0.32	0.94	0.35	0.39	0.63	0.22
	ASTM	0.16	0.17	0.10	0.15	0.25	0.28	0.07	0.35	0.39	0.63	0.22
Matt White	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
	Initial-ASTM	0.02	-0.01	-0.03	0.04	0.04	0.87	0.00	0.01	0.00	0.00	0.00
	ASTM-Norm.	0.15	0.09	0.14	0.24	0.27	0.06	0.34	0.23	0.38	0.22	0.34
Matt Mid Grey	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
Matt White	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
Matt Mid Grey	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
Matt White	Initial	0.18	0.16	0.10	0.12	0.29	0.32	0.94	0.35	0.39	0.63	0.22
	ASTM	0.16	0.17	0.10	0.15	0.25	0.28	0.07	0.35	0.39	0.63	0.22
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Matt Mid Grey	Initial-ASTM	0.02	-0.01	-0.03	0.04	0.04	0.87	0.00	0.01	0.00	0.00	0.00
	ASTM-Norm.	0.15	0.09	0.14	0.24	0.27	0.06	0.34	0.23	0.38	0.22	0.34
	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
Matt White	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
Matt Mid Grey	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
Matt White	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
	Initial	0.18	0.16	0.10	0.12	0.29	0.32	0.94	0.35	0.39	0.63	0.22
Matt Mid Grey	ASTM	0.16	0.17	0.10	0.15	0.25	0.28	0.07	0.35	0.39	0.63	0.22
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
	Initial-ASTM	0.02	-0.01	-0.03	0.04	0.04	0.87	0.00	0.01	0.00	0.00	0.00
	ASTM-Norm.	0.15	0.09	0.14	0.24	0.27	0.06	0.34	0.23	0.38	0.22	0.34
Matt White	Initial	0.18	0.16	0.10	0.12	0.29	0.32	0.94	0.35	0.39	0.63	0.22
	ASTM	0.16	0.17	0.10	0.15	0.25	0.28	0.07	0.35	0.39	0.63	0.22
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Matt Mid Grey	Initial-ASTM	0.02	-0.01	-0.03	0.04	0.04	0.87	0.00	0.01	0.00	0.00	0.00
	ASTM-Norm.	0.15	0.09	0.14	0.24	0.27	0.06	0.34	0.23	0.38	0.22	0.34
	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
Matt White	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
Matt Mid Grey	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
Matt White	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
	Initial	0.18	0.16	0.10	0.12	0.29	0.32	0.94	0.35	0.39	0.63	0.22
Matt Mid Grey	ASTM	0.16	0.17	0.10	0.15	0.25	0.28	0.07	0.35	0.39	0.63	0.22
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
	Initial-ASTM	0.02	-0.01	-0.03	0.04	0.04	0.87	0.00	0.01	0.00	0.00	0.00
	ASTM-Norm.	0.15	0.09	0.14	0.24	0.27	0.06	0.34	0.23	0.38	0.22	0.34
Matt White	Initial	0.18	0.16	0.10	0.12	0.29	0.32	0.94	0.35	0.39	0.63	0.22
	ASTM	0.16	0.17	0.10	0.15	0.25	0.28	0.07	0.35	0.39	0.63	0.22
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Matt Mid Grey	Initial-ASTM	0.02	-0.01	-0.03	0.04	0.04	0.87	0.00	0.01	0.00	0.00	0.00
	ASTM-Norm.	0.15	0.09	0.14	0.24	0.27	0.06	0.34	0.23	0.38	0.22	0.34
	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
Matt White	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
Matt Mid Grey	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
Matt White	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
	Initial	0.18	0.16	0.10	0.12	0.29	0.32	0.94	0.35	0.39	0.63	0.22
Matt Mid Grey	ASTM	0.16	0.17	0.10	0.15	0.25	0.28	0.07	0.35	0.39	0.63	0.22
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
	Initial-ASTM	0.02	-0.01	-0.03	0.04	0.04	0.87	0.00	0.01	0.00	0.00	0.00
	ASTM-Norm.	0.15	0.09	0.14	0.24	0.27	0.06	0.34	0.23	0.38	0.22	0.34
Matt White	Initial	0.18	0.16	0.10	0.12	0.29	0.32	0.94	0.35	0.39	0.63	0.22
	ASTM	0.16	0.17	0.10	0.15	0.25	0.28	0.07	0.35	0.39	0.63	0.22
	Normalized	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Matt Mid Grey	Initial-ASTM	0.02	-0.01	-0.03	0.04	0.04	0.87	0.00	0.01	0.00	0.00	0.00
	ASTM-Norm.	0.15	0.09	0.14	0.24	0.27	0.06	0.34	0.23	0.38	0.22	0.34
	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
Matt White	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02
	Normalized	0.20	0.16	0.17	0.08	0.08	0.13	0.12	0.08	0.29	0.13	0.18
	Initial-ASTM	0.01	-0.01	0.01	0.02	0.05	0.53	-0.01	0.02	-0.04	-0.01	0.01
	ASTM-Norm.	-0.09	0.07	0.01	0.16	0.05	0.04	0.24	0.11	-0.21	0.41	-0.15
Matt Mid Grey	Initial	0.12	0.22	0.15	0.26	0.18	0.70	0.35	0.21	0.04	0.53	1.03
	ASTM	0.11	0.23	0.16	0.24	0.13	0.17	0.36	0.19	0.08	0.54	1.02

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE LAB ΔE^* Differences from NPL values for Steps 1 and 2

Specular Included geometry
10° Observer, Illuminant D65

Tile	Value/Lab	20	14	15	5b	6	3	19	9	18	5a	4	21	10	12	13	Mean		
Matt Black	Initial	127	04	004	036	024	051	020	027	090	031	044	223	015	080	095	189	587	
	ASTM	126	05	004	036	023	024	019	026	090	031	044	223	018	078	095	189	587	
	Normalized	132	09	007	026	034	021	006	029	106	054	052	223	019	062	086	173	590	
Matt Red	Initial-ASTM	001	01	000	000	001	027	001	001	000	000	000	000	-003	002	000	000	002	
	ASTM-Norm	006	04	003	010	-011	003	013	-003	-016	-023	-008	000	-001	016	009	016	-003	000
	Initial	019	40	054	034	044	088	073	118	048	053	065	276	069	168	123	232	599	
Matt Red	ASTM	021	40	055	052	025	021	077	114	044	064	021	275	072	202	119	231	599	
	Normalized	013	45	054	050	012	025	075	106	036	030	036	254	072	165	114	230	602	
	Initial-ASTM	-002	000	-001	-018	019	067	-004	004	004	-011	044	001	-003	-034	004	001	000	004
Matt Green	ASTM-Norm.	008	-005	001	002	013	-004	002	008	008	034	-015	021	000	037	005	001	-003	006
	Initial	031	028	044	039	059	056	031	042	086	107	072	148	112	050	089	079	321	
	ASTM	044	052	050	035	063	055	118	063	069	040	023	139	130	080	086	079	321	
Matt Green	Normalized	049	051	058	017	069	052	132	048	087	033	028	151	125	142	082	073	325	
	Initial-ASTM	-013	-008	007	004	-004	001	-087	-021	017	067	049	009	-018	-030	003	000	000	-002
	ASTM-Norm.	-005	001	008	018	-006	003	-014	015	-018	007	-005	-012	005	-062	004	006	004	-005
Matt Yellow	Initial	030	073	036	057	141	108	080	063	189	208	112	061	054	220	094	174	618	
	ASTM	036	053	024	050	053	048	037	067	100	122	041	054	051	134	097	173	619	
	Normalized	036	040	025	031	051	034	050	049	065	065	056	024	070	052	101	105	185	622
Matt Yellow	Initial-ASTM	-006	020	012	017	007	088	043	-004	089	086	71	007	003	086	-003	001	-001	032
	ASTM-Norm.	000	013	-001	009	-001	019	-002	-012	002	035	066	17	-016	-001	033	-008	-012	-003

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE_{LAB} ΔE* Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	Specular Included geometry 10° Observer, Illuminant D65												Mean
		20	14	15	5b	6	3	19	9	18	5a	4	12	13
Matt Cyan	Initial	0.76	0.65	0.76	0.44	1.27	1.70	0.83	0.98	1.29	0.86	0.67	0.74	2.97
	ASTM	0.68	0.58	0.71	0.44	0.96	0.84	0.67	0.95	1.04	0.55	0.44	0.76	2.98
	Normalized	0.70	0.62	0.80	0.29	0.95	0.82	0.77	0.79	1.14	0.66	0.53	0.67	2.95
Grey Metamer	Initial-ASTM	0.08	0.07	0.04	0.00	0.31	0.86	0.16	0.03	0.25	0.31	0.23	-0.02	-0.01
	ASTM-Norm.	-0.02	-0.04	0.01	0.15	0.01	0.02	-0.10	0.16	-0.10	-0.11	-0.09	0.09	0.03
													-0.06	-0.06
Grey Metamer	Initial	0.15	0.10	0.20	0.13	0.26	0.23	0.70	0.24	0.18	0.06	0.04	0.39	1.53
	ASTM	0.15	0.10	0.20	0.15	0.24	0.15	0.21	0.24	0.16	0.11	0.07	0.34	1.53
	Normalized	0.20	0.04	0.10	0.07	0.09	0.07	0.10	0.11	0.15	0.11	0.16	0.57	1.47
Grey Metamer 2	Initial-ASTM	0.00	0.00	-0.02	0.02	0.08	0.49	0.00	0.02	0.03	-0.01	0.03	-0.04	0.00
	ASTM-Norm.	-0.05	0.06	0.10	0.15	0.08	0.11	0.13		-0.04	-0.04	-0.15	0.07	0.06
													0.34	0.10
Green Metamer 1	Initial	0.35	0.17	0.29	0.24	0.25	0.36	0.69	0.31	0.18	0.13	0.06	0.59	1.49
	ASTM	0.33	0.17	0.29	0.24	0.21	0.31	0.23	0.41	0.17	0.17	0.15	0.66	1.49
	Normalized	0.37	0.14	0.26	0.27	0.02	0.29	0.19	0.29	0.35	0.22	0.12	0.85	1.41
Green Metamer 1	Initial-ASTM	0.02	0.00	0.00	0.04	0.05	0.46	-0.10	0.01	-0.02	-0.04	-0.09	0.00	0.01
	ASTM-Norm.	-0.04	0.03	-0.03	0.19	0.02	0.04	0.12		-0.03	-0.05	0.03	0.07	0.08
													0.28	0.04
Green Metamer 1	Initial	0.16	0.23	0.25	0.22	0.36	0.31	0.57	0.27	0.21	0.12	0.09	0.35	1.78
	ASTM	0.15	0.17	0.24	0.20	0.33	0.20	0.27	0.33	0.28	0.42	0.13	0.34	1.78
	Normalized	0.20	0.11	0.16	0.20	0.17	0.12	0.19	0.34	0.46	0.24	0.51	0.56	1.76
Green Metamer 1	Initial-ASTM	0.01	0.06	0.01	0.02	0.03	0.11	0.30	-0.06	-0.07	0.15	-0.39	0.01	0.00
	ASTM-Norm.	-0.05	0.06	0.08	0.16	0.08	0.08	0.08	-0.01	-0.04	-0.11	-0.03	0.02	0.02
													0.32	0.08

Table 1 Page 9 of 15

NPL Spectrophotometry and Colorimetry Club Colorimetry Comparison

Summary of CIELAB ΔE^* Differences from NPL values for Steps 1 and 2Specular Included geometry
10° Observer, Illuminant D65

Title	Value/Lab	20	14	15	5b	6	3	19	9	18	5a	4	21	10	12	13	Mean
Green Metamer 2	Initial	0.13	0.30	0.25	0.31	0.29	0.63	0.21	0.17	0.27	0.10	0.05	0.84	0.69	0.73	0.52	0.73
	ASTM	0.11	0.33	0.27	0.27	0.39	0.33	0.33	0.21	0.42	0.23	0.21	0.80	0.77	0.73	0.49	0.73
	Normalized	0.17	0.30	0.31	0.07	0.35	0.27	0.34		0.45	0.33	0.22	1.05	0.78	0.61	0.43	1.58
Holmium	Initial-ASTM	0.02	0.01	-0.03	0.04	-0.10	0.30	-0.12	0.04	-0.15	-0.13	-0.16	0.04	-0.08	0.00	0.03	-0.02
	ASTM-Norm.	0.06	0.01	-0.04	0.20	0.04	0.06	-0.01		-0.03	0.10	-0.01	-0.25	-0.01	0.12	0.06	0.04
	Normalized	0.65	0.81	0.68	0.49	0.38	1.39	0.64	2.88	0.61	0.93	0.42	0.85	0.67	2.88	0.52	1.02
Crossover 1	Initial	0.49	0.62	0.45	0.31	0.33	0.38	0.43	2.44	0.43	0.67	0.52	0.74	0.51	2.28	0.52	1.02
	ASTM	0.44	0.51	0.44	0.24	0.30	0.48	0.40	2.26		0.76	0.64	1.21	0.55	1.54	0.46	1.09
	Normalized	0.16	0.19	0.23	0.18	0.05	1.01	0.21	0.44	0.18	0.07	0.26	0.11	0.16	0.60	0.00	0.21
Crossover 2	Initial-ASTM	0.05	0.11	0.01	0.07	0.03	-0.10	0.03	0.18	0.04	0.03	-0.19	-0.47	-0.04	0.74	0.06	0.03
	ASTM-Norm.	0.10	0.18	0.18	0.12	0.29	0.22	0.82	0.27	0.12	0.13	0.12	0.26	0.23	1.07	0.44	0.82
	Normalized	0.10	0.18	0.14	0.27	0.15	0.24	0.27	0.11	0.09	0.15	0.13	0.26	0.21	1.08	0.44	0.81
Mean	Initial	0.14	0.06	0.06	0.04	0.05	0.12	0.09		0.12	0.10	0.08	0.47	0.25	0.31	0.36	0.76
	ASTM	0.00	0.00	-0.02	0.02	0.07	0.58	0.00	0.01	0.02	0.02	-0.01	0.00	0.02	-0.01	0.00	0.04
	Normalized	-0.04	0.12	0.08	0.23	0.10	0.12	0.18		-0.03	0.05	0.05	-0.21	-0.04	0.77	0.08	0.12
Crossover 2	Initial	0.04	0.16	0.17	0.11	0.35	0.18	0.69	0.25	0.20	0.13	0.15	0.17	0.25	0.95	0.46	1.20
	ASTM	0.04	0.16	0.17	0.12	0.33	0.11	0.20	0.25	0.18	0.11	0.09	0.16	0.26	0.97	0.47	1.20
	Normalized	0.09	0.05	0.07	0.09	0.10	0.02	0.08	0.14		0.17	0.08	0.18	0.32	0.27	0.40	1.19
Mean	Initial-ASTM	0.00	0.00	-0.01	0.02	0.07	0.49	0.00	0.02	0.02	-0.01	-0.01	0.00	-0.01	-0.02	-0.01	0.03
	ASTM-Norm.	-0.05	0.11	0.10	0.03	0.09	0.12	0.11		-0.06	0.01	-0.02	-0.17	-0.06	0.70	0.07	0.09
	Normalized	0.02	0.05	0.01	0.01	0.23	0.51	0.03	0.00	0.09	0.22	0.04	0.03	-0.04	0.08	0.00	0.00
Mean	Initial-ASTM	-0.01	0.07	0.04	0.02	0.05	0.05	0.07	0.10	0.00	0.09	-0.01	-0.10	0.00	0.29	0.07	0.01
	ASTM-Norm.																
	Normalized																

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE LAB ΔE^* Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	0°/45° geometry 10° Observer, Illuminant D65									
		14	13	20	17	4	9	19	12	11	Mean
Glossy White	Initial	0.54	0.50	0.32	0.40	0.20	0.18	0.54	0.29	0.57	0.15
	ASTM	0.22	0.50	0.32	0.46	0.18	0.16	0.54	0.28	0.57	0.15
	Normalized	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.00
Glossy Mid Grey	Initial-ASTM	0.32	0.00	0.00	0.06	0.02	0.02	0.00	0.01	0.00	0.03
	ASTM-Norm.	0.22	0.49	0.31	0.45	0.18	0.15	0.54	0.27	0.57	0.33
	Initial	0.14	0.16	0.25	0.37	0.11	0.11	0.30	0.68	0.86	0.14
Glossy Black	ASTM	0.19	0.17	0.25	0.80	0.28	0.11	0.33	0.66	0.86	0.13
	Normalized	0.08	0.17	0.11	0.51	0.27	0.08	0.24	0.73	1.19	0.11
	Initial-ASTM	-0.05	-0.01	0.00	-0.43	-0.17	0.00	-0.03	0.02	0.00	-0.07
Glossy Red	ASTM-Norm.	0.11	0.00	0.14	0.29	0.01	0.03	0.09	-0.07	-0.33	0.03
	Initial	0.32	1.81	0.46	1.65	0.26	0.33	0.67	0.05	0.56	0.72
	ASTM	0.61	1.82	0.46	1.41	0.27	0.35	0.67	0.09	0.56	0.72
Glossy Green	Normalized	0.58	1.82	0.43	1.34	0.28	0.34	0.61	0.10	0.49	0.71
	Initial-ASTM	-0.29	0.01	0.00	0.24	-0.01	-0.02	0.00	-0.04	0.00	-0.01
	ASTM-Norm.	0.03	0.00	0.03	0.07	-0.01	0.01	0.06	-0.01	0.07	0.03
Glossy Black	Initial	1.60	2.38	1.00	0.97	0.57	1.76	2.74	3.50	1.52	2.62
	ASTM	1.05	2.38	0.88	0.79	0.59	1.25	2.44	3.09	1.50	2.66
	Normalized	1.14	2.14	0.63	0.91	0.48	1.11	1.98	3.11	1.85	2.55
Glossy Red	Initial-ASTM	0.55	0.00	0.12	0.18	-0.02	0.51	0.30	0.41	0.02	-0.04
	ASTM-Norm.	-0.09	0.24	0.25	-0.12	0.11	0.14	0.46	-0.02	-0.35	0.11
	Initial	0.65	1.28	0.19	0.41	0.60	0.85	1.23	2.70	0.76	1.75
Glossy Green	ASTM	0.69	1.28	0.37	0.35	0.40	1.81	1.39	2.11	1.06	2.01
	Normalized	0.63	1.29	0.39	0.29	0.49	1.86	1.41	2.16	0.98	1.99
	Initial-ASTM	-0.04	0.00	-0.18	0.06	0.20	-0.96	-0.16	0.59	-0.30	-0.26
	ASTM-Norm.	0.06	0.01	-0.02	0.06	-0.09	-0.05	-0.02	-0.05	0.08	0.02
	Initial	-0.04	0.00	-0.18	0.06	0.20	-0.96	-0.16	0.59	-0.30	-0.26
	ASTM-Norm.	0.06	0.01	-0.02	0.06	-0.09	-0.05	-0.02	-0.05	0.08	0.02
	Initial	-0.04	0.00	-0.18	0.06	0.20	-0.96	-0.16	0.59	-0.30	-0.26
	ASTM-Norm.	0.06	0.01	-0.02	0.06	-0.09	-0.05	-0.02	-0.05	0.08	0.02

Table 1 Page 11 of 15

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIELAB ΔE^* Differences from NPL values for Steps 1 and 2

Sample	Value/Lab	0°/45° geometry 10° Observer, Illuminant D65									
		20	17	4	9	19	12	11	Mean		
Glossy Yellow	Initial	0.49	1.29	1.40	2.61	0.48	09	53	4.84	5.25	6.31
	ASTM	0.14	1.29	1.08	2.50	0.17	38	56	3.79	5.00	6.05
	Normalized	0.22	0.86	1.37	2.88	0.15	37	27	3.87	5.52	5.96
Glossy Cyan	Initial-ASTM	0.35	0.00	0.32	0.11	0.31	-0.29	-0.03	1.05	0.25	0.26
	ASTM-Norm.	0.08	0.43	0.29	-0.38	0.02	0.01	0.29	-0.08	0.52	0.09
	Normalized	0.18	0.45	0.35	0.28	0.17	0.17	0.88	2.46	0.74	1.58
Matt White	Initial	0.22	0.45	0.27	0.26	0.13	0.52	1.26	2.76	0.68	1.54
	ASTM	0.13	0.48	0.19	0.53	0.12	0.54	1.34	2.74	0.87	1.54
	Normalized	-0.04	0.00	0.08	0.02	0.04	-0.35	-0.38	0.30	0.06	0.04
Matt Mid Grey	Initial-ASTM	0.09	-0.03	0.08	0.27	0.01	-0.02	-0.08	0.02	-0.19	0.00
	ASTM-Norm.	0.54	0.84	0.93	0.52	0.77	0.90	1.00	0.59	0.68	0.45
	Normalized	0.94	0.84	0.92	0.43	0.76	0.91	1.00	0.58	0.68	0.45
Matt White	Initial	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
	ASTM	0.40	0.00	0.01	0.09	0.01	-0.01	0.00	0.01	0.00	0.00
	Normalized	0.93	0.83	0.91	0.42	0.75	0.91	0.99	0.57	0.67	0.44
Matt Mid Grey	Initial-ASTM	0.35	0.30	0.64	0.60	0.36	0.55	0.47	0.77	0.53	0.47
	ASTM	0.57	0.31	0.64	0.51	0.46	0.54	0.47	0.75	0.53	0.46
	Normalized	0.09	0.33	0.10	0.35	0.14	0.09	0.23	0.48	0.28	0.25
Matt White	Initial-ASTM	-0.22									
	ASTM-Norm.	0.48	0.00	0.09	-0.10	0.01	0.01	0.00	0.02	0.00	0.01
	Normalized	0.54	0.54	0.16	0.32	0.45	0.24	0.24	0.27	0.25	0.21

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIELAB ΔE^* Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	0°/45° geometry 10° Observer, Illuminant D65									
		14	13	20	17	4	9	19	12	11	Mean
Matt Black	Initial	0.62	0.58	0.35	0.38	0.35	0.18	0.26	0.42	0.34	0.43
	ASTM	0.27	0.58	0.35	0.39	0.51	0.16	0.25	0.43	0.34	0.43
	Normalized	0.28	0.86	0.22	0.56	0.27	0.43	0.39	0.46	0.46	0.42
Matt Red	Initial-ASTM	0.35	0.00	0.00	-0.01	-0.16	0.02	0.01	-0.01	0.00	0.02
	ASTM-Norm.	0.01	-0.28	0.13	-0.17	0.24	-0.27	-0.14	-0.03	-0.12	-0.06
	Initial	1.02	1.73	2.39	0.92	1.40	2.90	3.56	4.47	0.69	1.09
Matt Green	ASTM	0.91	1.73	2.33	1.24	1.31	2.68	3.36	4.30	0.60	1.06
	Normalized	0.74	1.42	1.78	1.35	0.96	2.37	2.79	4.03	0.86	1.18
	Initial-ASTM	0.11	0.00	0.06	-0.32	0.09	0.22	0.20	0.17	0.09	0.03
Matt Yellow	ASTM-Norm.	0.17	0.31	0.55	-0.11	0.35	0.31	0.57	0.27	-0.26	-0.12
	Initial	0.55	0.53	0.68	0.59	0.84	0.92	1.39	2.58	0.47	0.94
	ASTM	0.59	0.53	0.57	0.52	0.77	1.29	1.16	2.03	0.48	1.15
Matt Yellow	Normalized	0.38	0.70	0.67	0.48	0.97	1.02	1.25	2.19	0.13	0.87
	Initial-ASTM	-0.04	0.00	0.11	0.07	0.07	-0.37	0.23	0.55	-0.01	-0.21
	ASTM-Norm.	0.21	-0.17	-0.10	0.04	-0.20	0.27	-0.09	-0.16	0.35	0.28
Matt Yellow	Initial	0.59	1.12	1.24	2.54	0.78	1.58	1.76	3.35	5.85	3.75
	ASTM	1.15	1.12	1.16	2.76	0.70	2.07	2.12	3.02	5.68	3.58
	Normalized	0.76	0.68	1.35	2.82	0.60	1.48	1.56	3.07	6.33	3.91
Matt Yellow	Initial-ASTM	-0.56	0.00	0.08	-0.22	0.08	-0.49	-0.36	0.33	0.17	-0.08
	ASTM-Norm.	0.39	0.44	-0.19	-0.06	0.10	0.59	0.56	-0.05	-0.65	-0.33
	Normalized										0.08

Table 1 Page 13 of 15

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE L_aB_aA_a Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	0°/45° geometry 10° Observer, Illuminant D65									
		14	13	20	17	4	9	19	12	11	Mean
Matt Cyan	Initial	0.64	0.55	53	0.89	0.79	0.81	1.38	2.67	0.22	0.89
	ASTM	0.75	0.54	56	1.00	0.79	0.99	1.66	2.92	0.23	0.84
	Normalized	0.59	0.77	64	1.02	0.80	0.96	1.73	3.10	0.36	0.83
Grey Metamer	Initial-ASTM	-0.11	0.01	0.03	-0.11	0.00	-0.18	-0.28	-0.25	-0.01	0.05
	ASTM-Norm.	0.16	0.23	0.08	0.02	-0.01	0.03	-0.07	-0.18	-0.13	-0.05
	Initial	0.07	0.20	0.38	0.45	0.09	0.35	0.34	0.54	0.34	0.18
Grey Metamer 2	ASTM	0.20	0.21	0.38	0.22	0.19	0.34	0.35	0.51	0.34	0.17
	Normalized	0.09	0.41	0.19	0.50	0.12	0.26	0.11	0.52	0.28	0.22
	Initial-ASTM	-0.13	0.01	0.00	0.23	-0.10	0.01	-0.01	0.03	0.00	0.01
Green Metamer	ASTM-Norm.	0.11	0.20	0.19	-0.28	0.07	0.08	0.24	-0.01	0.06	-0.05
	Initial	0.42	0.45	0.61	0.42	0.43	0.66	1.01	1.53	0.75	0.15
	ASTM	0.35	0.45	0.59	0.59	1.06	0.61	0.97	1.52	0.76	0.17
Green Metamer	Normalized	0.33	0.65	0.49	0.77	1.01	0.60	0.93	1.49	1.10	0.16
	Initial-ASTM	0.07	0.00	0.02	-0.17	-0.63	0.05	0.04	0.01	-0.01	-0.02
	ASTM-Norm.	0.02	-0.20	0.10	-0.18	0.05	0.01	0.04	0.03	-0.34	0.01
Green Metamer	Initial	0.10	0.37	0.17	0.38	0.29	0.41	0.33	0.55	0.42	0.54
	ASTM	0.25	0.37	0.21	0.41	0.15	0.74	0.75	0.86	0.47	0.57
	Normalized	0.17	0.51	0.09	0.70	0.07	0.76	0.69	0.94	0.29	0.58
Green Metamer	Initial-ASTM	-0.15	0.00	-0.04	-0.03	0.14	-0.33	-0.42	-0.31	-0.05	-0.12
	ASTM-Norm.	0.08	-0.14	0.12	-0.29	0.08	-0.02	0.06	-0.08	0.18	-0.01
	Normalized	0.08	-0.14	0.12	-0.29	0.08	-0.02	0.06	-0.08	0.18	-0.01

NPL Spectrophotometry and Colorimetry Club Colour Intercomparison

Summary of CIE L_aB_aG_a ΔE* Differences from NPL values for Steps 1 and 2

Tile	Value/Lab	0°/45° geometry 10° Observer, Illuminant D65									
		14	13	20	17	4	9	19	12	11	Mean
Green Metamer 2	Initial	0.43	0.25	0.47	0.90	0.38	0.66	1.01	1.39	0.37	0.43
	ASTM	0.42	0.25	0.43	0.52	0.56	0.52	0.83	1.23	0.33	0.48
	Normalized	0.38	0.53	0.48	0.61	0.58	0.54	0.90	1.25	0.24	0.46
Holmium	Initial-ASTM	0.01	0.00	0.04	0.38	-0.18	0.14	0.18	0.16	0.04	-0.05
	ASTM-Norm.	0.04	0.28	0.05	-0.09	-0.02	-0.02	-0.07	-0.02	0.09	0.02
	Normalized	0.25	0.26	0.42	2.12	2.76	2.02	0.69	0.99	4.06	4.26
Crossover 1	Initial	0.42	0.27	0.29	2.31	2.68	1.42	1.28	1.01	3.96	4.15
	ASTM	0.39	0.45	0.50	2.59	2.71	1.45	0.90	1.16	4.32	4.08
	Normalized	-0.17	-0.01	0.13	-0.19	0.08	0.60	-0.59	-0.02	0.10	0.11
Crossover 2	Initial-ASTM	0.03	-0.18	-0.21	-0.28	-0.03	-0.03	0.38	-0.15	-0.36	0.07
	ASTM-Norm.	0.69	0.23	0.41	0.68	0.13	0.39	0.42	0.68	0.60	0.50
	Normalized	0.27	0.24	0.41	0.12	0.11	0.40	0.43	0.65	0.60	0.49
Crossover 2	Initial	0.14	0.43	0.18	0.40	0.10	0.33	0.11	0.67	0.32	0.53
	ASTM	0.42	-0.01	0.00	0.56	0.02	-0.01	-0.01	0.03	0.00	0.01
	Normalized	0.13	-0.19	0.23	-0.28	0.01	0.07	0.32	-0.02	0.28	-0.04
Crossover 2	Initial-ASTM	0.32	0.31	0.39	0.39	0.16	0.34	0.43	0.51	0.37	0.35
	ASTM	0.19	0.30	0.39	0.81	0.19	0.36	0.44	0.51	0.37	0.35
	Normalized	0.09	0.52	0.18	0.52	0.14	0.29	0.15	0.61	0.20	0.43
Mean	Initial-ASTM	0.13	0.01	0.00	-0.42	-0.03	-0.02	-0.01	0.00	0.00	-0.03
	ASTM-Norm.	0.10	0.22	0.21	0.29	0.05	0.07	0.29	-0.10	0.17	-0.08
	Normalized	0.01	0.00	0.03	0.00	-0.02	-0.07	-0.06	0.12	0.02	0.00
Mean	Initial-ASTM	0.15	0.03	0.14	-0.04	0.09	0.13	0.22	0.02	-0.02	0.04
	ASTM-Norm.	0.01	0.00	0.03	0.00	-0.02	-0.07	-0.06	0.12	0.02	0.00

Table 1 Page 15 of 15

Table 2**Gloss Trap Errors**

K_2 is the error in the measurement of a glossy sample using a matt white standard in the specular excluded geometry.

All data are in % reflectance.

Note that wavelength range and spectral intervals vary considerably between participants.

Values for K_2 could not be calculated for participant 2 as spectral data for the mirror were not returned.

Gloss Trap Error Coefficients K2

Participant No. Wavelength	14	15	8	20	6	3	5B	9	4	5A	18	12	19	21	2	13
360	0.0085					0.1097										
365																
370	0.0095					0.1247										
375																
380	0.0067					0.1379										
385																
390	0.0072					0.1489										
395																
400	0.0053	0.0047	0.0148	0.0207	0.0929	0.1573	0.0514	0.0000	0.0926	0.0822	0.0524	0.0436	0.0717	0.4144		0.0824
405												0.0444				0.1280
410	0.0072	0.0040	0.0143	0.0210	0.0951	0.1631	0.0539	0.0000				0.0442				0.1488
415												0.0438				
420	0.0067	0.0051	0.0141	0.0201	0.0963	0.1661	0.0567	0.0000	0.1011	0.0904	0.0516	0.0434	0.0707			0.1702
425												0.0434				0.1837
430	0.0072	0.0047	0.0140	0.0208	0.0954	0.1668	0.0578	0.0000				0.0430				0.2008
435												0.0429				0.2089
440	0.0063	0.0049	0.0139	0.0186	0.0935	0.1650	0.0596	0.0000	0.1078	0.0873	0.0503	0.0430	0.0709	0.4387		0.2141
445												0.0429				0.2102
450	0.0063	0.0050	0.0137	0.0176	0.0909	0.1618	0.0609	0.0000				0.0437				0.2132
455												0.0437				0.2131
460	0.0058	0.0046	0.0136	0.0173	0.0871	0.1565	0.0615	0.0000	0.1113	0.1007	0.0508	0.0434				0.2106
465												0.0429	0.0699	0.4519		0.2114
470	0.0058	0.0043	0.0134	0.0162	0.0837	0.1511	0.0618	0.0164				0.0409				0.2109
475												0.0409		0.4471		0.2160
480	0.0053	0.0043	0.0132	0.0158	0.0793	0.1434	0.0619	0.0549	0.1128	0.1010	0.0503	0.0410	0.0686			0.2118
485												0.0419				0.2110
490	0.0048	0.0041	0.0128	0.0148	0.0748	0.1362	0.0614	0.0336				0.0419				0.2125
495												0.0424		0.4444		0.2128
500	0.0048	0.0039	0.0132	0.0140	0.0703	0.1281	0.0610	0.0000	0.1116	0.1011	0.0488	0.0417	0.0680	0.4298		0.2152
505												0.0407				0.2157
510	0.0048	0.0039	0.0130	0.0134	0.0656	0.1199	0.0602	0.0014				0.0408		0.4447		0.2103
515												0.0407				0.2117
520	0.0048	0.0038	0.0129	0.0127	0.0611	0.1117	0.0593	0.0329	0.1091	0.0980	0.0463	0.0407	0.0669	0.4492		0.2127
525												0.0406				0.2134
530	0.0043	0.0036	0.0126	0.0123	0.0568	0.1031	0.0581	0.0181				0.0403		0.4391		0.2106
535												0.0401				0.2097
540	0.0043	0.0034	0.0126	0.0116	0.0527	0.0959	0.0570	0.0195	0.1052	0.0955	0.0453	0.0402	0.0653	0.4448		0.2120
545												0.0398				0.2089
550	0.0038	0.0031	0.0123	0.0112	0.0485	0.0884	0.0557	0.0409				0.0399		0.4400		0.2078
555												0.0396				0.2094
560	0.0033	0.0032	0.0123	0.0108	0.0449	0.0817	0.0546	0.0802	0.0995	0.0914	0.0433	0.0395	0.0639	0.4419		0.2079
565												0.0388				0.2076
570	0.0033	0.0029	0.0122	0.0103	0.0415	0.0746	0.0532	0.0968				0.0386		0.4353		0.2069
575												0.0386				0.2079
580	0.0033	0.0030	0.0122	0.0106	0.0381	0.0684	0.0518	0.0863	0.0930	0.0875	0.0408	0.0385	0.0629	0.4432		0.2069
585												0.0385				0.2066
590	0.0033	0.0029	0.0121	0.0098	0.0352	0.0627	0.0505	0.0407				0.0383		0.4280		0.2052
595												0.0384				0.2067

Gloss Trap Error Coefficients K2															
Participant No. Wavelength	14	15	8	20	6	3	5B	9	4	5A	18	12	19	21	2
600	0.0028	0.0027	0.0119	0.0094	0.0320	0.0575	0.0487	0.0180	0.0854	0.0821	0.0408	0.0383	0.0613	0.4367	0.2030
605												0.0383			0.2044
610	0.0028	0.0029	0.0122	0.0092	0.0295	0.0523	0.0471	0.0000				0.0379		0.4233	0.2073
615	0.0028	0.0021	0.0122	0.0094	0.0268	0.0481	0.0459	0.0161	0.0783	0.0778	0.0394	0.0382	0.0585	0.4448	0.2035
625												0.0381			0.2058
630	0.0028	0.0019	0.0118	0.0087	0.0248	0.0438	0.0443	0.1084				0.0382		0.4310	0.2047
635	0.0024	0.0019	0.0118	0.0084	0.0228	0.0401	0.0430	0.0586	0.0712	0.0740	0.0375	0.0379	0.0542	0.4395	0.2052
645												0.0382			0.2036
650	0.0028	0.0021	0.0119	0.0088	0.0208	0.0363	0.0416	0.0732				0.0378			0.2052
655												0.0380		0.4179	0.2038
660	0.0019	0.0023	0.0117	0.0079	0.0193	0.0335	0.0402	0.0000	0.0647	0.0712	0.0356	0.0378	0.0509	0.4235	0.2043
665												0.0378			0.2055
670	0.0019	0.0019	0.0118	0.0081	0.0176	0.0303	0.0387	0.0000				0.0379		0.4151	0.2074
675												0.0378			0.2052
680	0.0019	0.0018	0.0118	0.0078	0.0163	0.0275	0.0372	0.0000	0.0586	0.0679	0.0337	0.0377	0.0475	0.4186	0.2077
685												0.0379			0.2072
690	0.0019	0.0019	0.0118	0.0079	0.0150	0.0256	0.0361	0.0862				0.0378		0.4196	0.2097
695												0.0384			0.2085
700	0.0019	0.0017	0.0116	0.0076	0.0138	0.0238	0.0350	0.0375	0.0530	0.0667	0.0324	0.0385	0.0449	0.4523	0.2122
705												0.0381			0.2134
710	0.0019	0.0015	0.0114	0.0076	0.0126	0.0214						0.0381		0.4434	0.2151
715												0.0381			0.2219
720	0.0014	0.0009	0.0113	0.0072	0.0115	0.0201			0.0478			0.0382			0.2246
725												0.0382			0.2310
730	0.0019	0.0008	0.0114	0.0073	0.0108	0.0182						0.0386			0.2380
735												0.0379			0.2479
740	0.0005	0.0006	0.0118	0.0068	0.0097	0.0182			0.0426			0.0385			0.2544
745												0.0382			0.2642
750	0.0005	0.0001		0.0068	0.0089	0.0169						0.0388			0.2724
755												0.0388			0.2809
760												0.0376			0.2871
765												0.0395			0.2965
770												0.0379			0.3004
775												0.0374			0.3089
780												0.0384			0.3118
												0.0389			0.3207

Table 3**Specular Beam Errors**

K_s is the error in the measurement of a glossy sample against a matt white reflectance standard in the specular included geometry.

All data are in % reflectance.

Note that wavelength range and spectral intervals vary considerably between participants.

Values for K_s could not be calculated for participant 2 as spectral data for the mirror were not returned.

Specular Beam Error Coefficients K3																		
Participant No. Wavelength	8	20	14	15	5B	6	3	19	9	18	5A	4	7	21	2	10	12	13
360			-0.392															
365																		
370			-0.333															
375																		
380			-0.287										0.483			0.149	0.156	0.322
385																0.129	0.152	0.282
390			-0.230			-0.359							0.583			0.145	0.152	0.241
395																0.137	0.154	0.286
400	0.028	-0.116	-0.168	-0.188	0.317	-0.256		-0.137	-0.185	-0.482	-0.099	-0.335	0.599	-0.388		0.154	0.161	0.272
405																0.142	0.157	0.237
410	0.079	-0.081	-0.123	-0.146	0.284	-0.205	-0.156		-0.141				0.568	-0.407		0.145	0.158	0.319
415																0.152	0.161	0.315
420	0.078	-0.068	-0.095	-0.122	0.258	-0.172	-0.133	-0.075	-0.255	-0.411	-0.049	-0.278	0.545	-0.412		0.136	0.161	0.293
425																0.149	0.163	0.268
430	0.078	-0.062	-0.074	-0.101	0.234	-0.145	-0.121		-0.224				0.535	-0.411		0.143	0.169	0.257
435																0.143	0.163	0.272
440	0.069	-0.060	-0.064	-0.091	0.220	-0.129	-0.119	-0.061	-0.182	-0.387	0.000	-0.254	0.512	-0.431		0.141	0.164	0.268
445																0.145	0.162	0.275
450	0.066	-0.057	-0.053	-0.079	0.204	-0.112	-0.113		-0.193				0.497	-0.408		0.147	0.163	0.275
455																0.149	0.167	0.250
460	0.065	-0.054	-0.045	-0.068	0.192	-0.099	-0.110	-0.058	-0.207	-0.374	0.043	-0.241	0.494	-0.427		0.144	0.165	0.307
465																0.141	0.160	0.292
470	0.059	-0.056	-0.044	-0.065	0.185	-0.093	-0.108		-0.162				0.483	-0.413		0.138	0.156	0.286
475																0.136	0.157	0.255
480	0.060	-0.052	-0.039	-0.059	0.176	-0.082	-0.104	-0.055	-0.133	-0.354	0.074	-0.243	0.477	-0.431		0.136	0.157	0.282
485																0.130	0.153	0.279
490	0.061	-0.050	-0.036	-0.053	0.165	-0.076	-0.099		-0.158				0.470	-0.406		0.131	0.157	0.247
495																0.128	0.157	0.270
500	0.062	-0.048	-0.034	-0.049	0.157	-0.069	-0.096	-0.054	-0.204	-0.351	0.102	-0.233	0.469	-0.434		0.122	0.155	0.260
505																0.127	0.151	0.263
510	0.061	-0.047	-0.033	-0.047	-0.151	-0.065	-0.094		-0.210				0.464	-0.416		0.118	0.150	0.261
515																0.124	0.148	0.231
520	0.061	-0.047	-0.035	-0.047	-0.149	-0.061	-0.095	-0.052	-0.185	-0.333	0.122	-0.237	0.459	-0.411		0.115	0.143	0.219
525																0.109	0.140	0.239
530	0.060	-0.046	-0.036	-0.046	-0.144	-0.060	-0.095		-0.203				0.454	-0.414		0.109	0.139	0.232
535																0.109	0.137	0.210
540	0.061	-0.044	-0.037	-0.045	-0.141	-0.057	-0.094	-0.052	-0.206	-0.333	0.133	-0.239	0.450	-0.410		0.107	0.132	0.224
545																0.105	0.138	0.214
550	0.065	-0.040	-0.035	-0.042	-0.134	-0.051	-0.090		-0.186				0.451	-0.415		0.118	0.137	0.204
555																0.106	0.133	0.192
560	0.067	-0.039	-0.035	-0.041	-0.131	-0.048	-0.089	-0.049	-0.156	-0.324	0.149	-0.235	0.451	-0.408		0.102	0.132	0.180
565																0.095	0.130	0.206
570	0.071	-0.037	-0.036	-0.040	-0.127	-0.045	-0.087		-0.143				0.449	-0.420		0.106	0.128	0.185
575																0.101	0.126	0.178
580	0.070	-0.038	-0.039	-0.042	-0.126	-0.044	-0.087	-0.046	-0.180	-0.322	0.152	-0.236	0.442	-0.424		0.098	0.122	0.176
585																0.098	0.117	0.185
590	0.075	-0.036	-0.039	-0.042	-0.123	-0.040	-0.084		-0.211				0.444	-0.441		0.091	0.118	0.155
595																0.099	0.117	0.160

Table 3 Page 1 of 2

Specular Beam Error Coefficients K3																	
Participant No. Wavelength	8	20	14	15	5B	6	3	19	9	18	5A	4	7	21	10	12	13
600	0.078	-0.033	-0.039	0.041	0.120	0.038	-0.082	-0.045	-0.235	-0.318	0.154	-0.242	0.445	-0.433	0.090	0.117	0.146
605	0.078	-0.033	-0.040	-0.041	0.120	0.039	-0.081		-0.269				0.442	-0.441	0.095	0.114	0.135
615	0.080	-0.032	-0.042	-0.044	0.119	-0.037	-0.079	-0.046	-0.241	-0.319	0.156	-0.242	0.440	-0.430	0.096	0.114	0.133
625	0.083	-0.033	-0.043	-0.043	0.118	-0.036	-0.078		-0.139				0.439	-0.424	0.084	0.110	0.112
635	0.086	-0.031	-0.045	0.045	0.116	0.034	-0.074	-0.044	-0.195	-0.325	0.157	-0.244	0.440	-0.422	0.088	0.106	0.104
645	0.089	-0.031	-0.045	0.046	0.116	0.033	-0.072		-0.184				0.439	-0.429	0.091	0.106	0.094
655	0.090	-0.030	-0.046	0.045	0.116	0.034	-0.070	-0.040	-0.258	-0.330	0.150	-0.246	0.440	-0.458	0.080	0.102	0.093
660	0.091	-0.030	-0.048	0.047	0.114	0.034	-0.069		-0.295				0.439	-0.452	0.081	0.107	0.116
675	0.092	-0.028	-0.053	0.051	0.114	0.035	-0.068	-0.039	-0.332	-0.341	0.140	-0.246	0.440	-0.455	0.086	0.102	0.079
685	0.095	-0.028	-0.055	-0.056	0.114		-0.066		-0.159				0.441	-0.473	0.079	0.101	0.079
695	0.100	-0.023	-0.057	-0.059	0.111		-0.064	-0.036	-0.197	-0.348	0.137	-0.247	0.445		0.072	0.101	0.071
705	0.097	-0.027	-0.062	-0.066			-0.067								0.073	0.102	0.073
715	0.102	-0.024	-0.062	-0.065			-0.062								0.085	0.101	0.077
725	0.101	-0.024	-0.059	0.061			-0.062								0.083	0.100	0.072
735				-0.062			-0.060								0.078	0.104	0.092
745				-0.057			-0.060								0.080	0.103	0.079
750		-0.030					-0.060								0.081	0.102	0.076
755															0.078	0.096	0.059
760															0.075	0.100	0.074
765															0.091	0.094	0.065
770															0.075	0.092	0.051
775															0.078	0.101	0.098
780															0.070	0.093	0.066
															0.070	0.093	0.053
															0.078	0.091	0.084
															0.065	0.087	0.105
															0.068	0.092	0.067
															0.085	0.092	0.082
															0.074	0.088	0.072
															0.065	0.088	0.091
															0.068	0.094	0.144
															0.064	0.090	0.129

Table 3 Page 2 of 2

Table 4

Photometric Errors

Data are the differences in reflectance between participants and NPL for white, mid grey and black tiles for the wavelengths indicated.

All data are in % reflectance.

Note: In a few cases there are gaps in the tables. This is because of gaps or errors in the data received from participants which it was not possible to remedy.

NPL Spectrophotometry and Colorimetry Club

Reflectance Errors, $R - R(NPL)$

Matt Tiles

Specular Included Geometry

	Type	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b	c	c	e
	Tile Set	EH93	EJ93	EK93	EK93	EH93	EH93	EH93	EJ93	EK93	EJ93	EH93	EH93	EH93	EJ93	EH93	EK93	EK93	EK93
Tile	Lab No	8	20	14	15	5B	6	3	19	9	18	5A	4	7	21	2	10	12	13
400 nm	Mt. Whl	0.48	-0.55	0.28	-0.30	0.60	-5.51		0.26	-0.85	-1.72	-0.81	1.62	-0.22	0.41	5.51	-0.53	1.54	-0.76
	Mt. Gry	0.22	-0.31	0.25	0.02	0.25	-2.07		-0.24	-0.39	-0.37	-0.26	0.52	-1.26	0.28	1.44	-0.75	0.97	1.33
	Mt. Blk	0.12	-0.17	-0.07	-0.12	0.15	-0.41		-0.12	-0.24	0.16	0.18	0.24	-1.11	0.03	0.24	-0.39	1.15	3.03
440 nm	Mt. Whl	-0.40	-0.35	0.28	0.03	0.61	-0.68	0.22	-0.79	0.10	-0.89	-1.24	-0.41	-0.50	0.08	2.31	-0.52	1.18	-0.28
	Mt. Gry	0.08	-0.10	0.30	0.20	0.31	-0.16	0.22	-0.33	-0.07	0.05	-0.48	-0.09	-1.39	0.18	0.08	-0.81	0.63	0.98
	Mt. Blk	0.10	-0.07	-0.03	-0.02	0.16	0.08	0.10	-0.08	-0.15	0.31	0.11	0.08	-1.04	-0.08	-0.11	-0.43	0.98	3.07
480 nm	Mt. Whl	-0.42	-0.41	0.26	0.01	0.73	-0.63	0.24	-0.87	0.31	-0.92	-1.29	-0.11	-0.26	0.16	0.83	-0.61	0.93	-0.23
	Mt. Gry	0.12	-0.11	0.30	0.21	0.34	-0.09	0.26	-0.40	0.03	0.02	-0.60	-0.07	-1.26	0.23	-0.41	-0.83	0.51	0.80
	Mt. Blk	0.11	-0.06	-0.01	-0.02	0.16	0.09	0.12	-0.09	-0.12	0.34	0.06	0.08	-0.95	-0.07	-0.20	-0.40	0.91	3.01
520 nm	Mt. Whl	-0.33	-0.44	0.19	-0.18	0.60	-0.68	0.14	-0.89	0.50	-0.93	-1.53	-0.14	0.10	0.18	0.25	-0.47	0.86	0.23
	Mt. Gry	0.10	-0.17	0.23	0.12	0.29	-0.14	0.19	-0.44	0.10	0.02	-0.62	0.00	-1.06	0.22	-0.71	-0.85	0.42	0.73
	Mt. Blk	0.11	-0.05	0.00	-0.02	0.16	0.09	0.10	-0.09	-0.09	0.35	0.08	0.14	-0.88	-0.08	-0.27	-0.42	0.86	2.81
560 nm	Mt. Whl	-0.37	-0.42	0.15	-0.23	0.52	-0.64	0.10	-0.87	0.40	-0.99	-1.51	-0.36	0.02	0.15	-0.03	-0.58	0.78	0.09
	Mt. Gry	0.13	-0.21	0.24	0.12	0.27	-0.11	0.18	-0.38	0.10	-0.01	-0.59	0.03	-1.18	0.25	-0.71	-0.84	0.39	0.31
	Mt. Blk	0.12	-0.04	0.01	-0.01	0.15	0.09	0.09	-0.05	-0.08	0.39	0.10	0.17	-0.95	0.01	-0.24	-0.38	0.82	2.73
600 nm	Mt. Whl	-0.36	-0.37	0.18	-0.14	0.45	-0.57	0.13	-0.83	0.45	-0.93	-1.41	-0.44	0.22	0.19	0.00	-0.62	0.78	-0.26
	Mt. Gry	0.11	-0.19	0.22	0.13	0.25	-0.11	0.19	-0.41	0.08	0.01	-0.56	0.02	-1.00	0.13	-0.76	-0.88	0.28	0.07
	Mt. Blk	0.11	-0.03	0.00	0.00	0.14	0.09	0.10	-0.06	-0.07	0.40	0.15	0.18	-0.86	-0.08	-0.25	-0.37	0.70	2.65
640 nm	Mt. Whl	-0.28	-0.34	0.19	-0.16	0.41	-0.55	0.12	-0.77	0.38	-0.88	-1.44	-0.49	0.48	0.12	-0.01	-0.49	0.77	0.11
	Mt. Gry	0.15	-0.19	0.26	0.14	0.23	-0.07	0.20	-0.36	0.11	0.03	-0.49	0.01	-0.92	0.17	-0.68	-0.84	0.22	0.09
	Mt. Blk	0.11	-0.03	-0.01	0.00	0.13	0.08	0.08	-0.05	-0.05	0.37	0.15	0.17	-0.83	-0.02	-0.26	-0.38	0.61	2.63
680 nm	Mt. Whl	-0.19	-0.29	0.24	-0.10	0.46	-0.51	0.15	-0.73	0.60	-0.72	-1.38	-0.48	0.71	0.21	-0.17	-0.63	0.75	-0.20
	Mt. Gry	0.16	-0.15	0.25	0.14	0.27	-0.08	0.20	-0.37	0.19	0.01	-0.47	0.12	-0.88	0.04	-0.81	-0.86	0.14	-0.14
	Mt. Blk	0.10	-0.02	0.00	-0.01	0.14	0.07	0.09	-0.08	-0.03	0.33	0.14	0.20	-0.84	-0.10	-0.38	-0.43	0.52	2.52
720 nm	Mt. Whl	-0.17	-0.28	0.18	-0.21		-0.60	0.12					-0.33	0.94			-1.02	0.78	-0.43
	Mt. Gry	0.18	-0.16	0.22	0.09		-0.09	0.19					0.14	-0.90			-1.01	0.08	0.00
	Mt. Blk	0.08	-0.04	-0.05	-0.10		0.01	0.04					0.21	-0.85			-0.52	0.36	2.38
Average	Mt. Whl	-0.23	-0.38	0.22	-0.14	0.55	-1.15	0.15	-0.69	0.24	-1.00	-1.33	-0.13	0.17	0.19	1.08	-0.61	0.93	-0.19
	Mt. Gry	0.14	-0.18	0.25	0.13	0.28	-0.32	0.20	-0.37	0.02	-0.03	-0.51	0.08	-1.10	0.19	-0.32	-0.85	0.40	0.46
	Mt. Blk	0.11	-0.06	-0.02	-0.03	0.15	0.02	0.09	-0.08	-0.10	0.33	0.12	0.16	-0.92	-0.05	-0.19	-0.41	0.77	2.76

Table 4 Page 1 of 4

NPL Spectrophotometry and Colorimetry Club

Reflectance Errors, R - R(NPL)

Matt tiles

Specular Excluded Geometry

	Type	a	a	a	a	a	a	a	b	b	b	b	c	d	e	e	e
	Tile Set	EK93	EK93	EH93	EJ93	EH93	EH93	EH93	EK93	EH93	EH93	EJ93	EK93	EJ93	EJ93	EH93	EK93
Tile	Lab No	14	15	8	20	6	3	5B	9	4	5A	18	12	19	21	2	13
400 nm	Mt Whl	0.33	-0.40	0.49	-0.75	-5.32	0.19	0.02	-1.05	1.63	-1.00	-1.90	3.97	-0.17	-1.09	5.41	-3.27
	Mt Gry	0.31	-0.02	0.23	-0.41	-2.03	0.22	0.03	-0.45	0.53	-0.30	-0.43	1.61	-0.25	-2.82	1.24	-0.16
	Mt Blk	-0.07	-0.15	0.10	-0.23	-0.38	0.07	0.04	-0.24	0.21	0.14	0.15	0.53	-0.06	-0.83	0.20	2.50
440 nm	Mt Whl	0.33	-0.03	-0.33	-0.57	-0.31	0.22	0.26	-0.11	-0.45	-1.32	-1.01	3.05	-0.76	-1.88	2.22	-3.17
	Mt Gry	0.31	0.17	0.13	-0.20	-0.04	0.23	0.17	-0.15	-0.08	-0.55	0.00	1.19	-0.60	-1.43	-0.04	-0.18
	Mt Blk	-0.04	-0.06	0.08	-0.12	0.08	0.07	0.07	-0.14	0.05	0.08	0.28	0.41	-0.19	-0.97	-0.11	2.80
480 nm	Mt Whl	0.33	-0.05	-0.38	-0.60	-0.28	0.17	0.36	0.12	-0.06	-1.40	-1.01	2.57	-0.84	-0.31	0.68	-3.45
	Mt Gry	0.32	0.18	0.13	-0.18	0.00	0.21	0.22	-0.03	-0.08	-0.66	-0.01	1.03	-0.62	-1.09	-0.57	-0.25
	Mt Blk	-0.04	-0.07	0.08	-0.10	0.07	0.06	0.08	-0.12	0.07	0.06	0.31	0.34	-0.17	-0.73	-0.23	2.76
520 nm	Mt Whl	0.22	-0.24	-0.30	-0.60	-0.35	0.10	0.28	0.30	-0.10	-1.64	-1.03	2.25	-0.72	-2.41	0.12	-3.42
	Mt Gry	0.27	0.10	0.12	-0.22	-0.04	0.15	0.19	0.05	0.01	-0.67	-0.02	0.92	-0.66	0.34	-0.85	-0.33
	Mt Blk	-0.03	-0.08	0.10	-0.09	0.08	0.05	0.08	-0.08	0.13	0.06	0.32	0.30	-0.13	-0.19	-0.29	2.77
560 nm	Mt Whl	0.19	-0.28	-0.30	-0.58	-0.33	0.04	0.29	0.22	-0.30	-1.65	-1.08	2.04	-0.85	-2.42	-0.15	-3.57
	Mt Gry	0.25	0.09	0.15	-0.27	-0.03	0.13	0.19	0.03	0.06	-0.65	-0.03	0.84	-0.70	0.18	-0.86	-0.69
	Mt Blk	-0.04	-0.07	0.10	-0.08	0.08	0.05	0.08	-0.09	0.16	0.09	0.36	0.27	-0.13	-0.14	-0.22	2.67
600 nm	Mt Whl	0.20	-0.19	-0.34	-0.51	-0.30	0.02	0.17	0.27	-0.54	-1.59	-1.00	1.94	-0.81	-2.13	-0.15	-3.84
	Mt Gry	0.23	0.10	0.13	-0.26	-0.02	0.14	0.17	0.01	0.01	-0.59	-0.03	0.79	-0.76	-0.18	-0.90	-0.92
	Mt Blk	-0.04	-0.05	0.09	-0.08	0.07	0.02	0.06	-0.07	0.16	0.11	0.37	0.26	-0.15	-0.29	-0.25	2.64
640 nm	Mt Whl	0.21	-0.22	-0.23	-0.56	-0.29	0.00	0.10	0.18	-0.51	-1.59	-0.96	1.85	-0.87	-2.46	-0.13	-3.90
	Mt Gry	0.24	0.12	0.17	-0.26	0.00	0.15	0.14	0.04	0.01	-0.53	-0.01	0.78	-0.86	0.25	-0.81	-1.04
	Mt Blk	-0.04	-0.07	0.09	-0.08	0.06	0.01	0.05	-0.04	0.16	0.15	0.35	0.26	-0.28	-0.15	-0.26	2.69
680 nm	Mt Whl	0.28	-0.13	-0.12	-0.48	-0.20	0.05	0.16	0.43	-0.46	-1.51	-0.80	1.95	-0.63	-0.92	-0.30	-4.36
	Mt Gry	0.22	0.09	0.19	-0.24	0.00	0.15	0.16	0.11	0.15	-0.48	-0.01	0.74	-1.07	-2.98	-0.96	-1.18
	Mt Blk	-0.04	-0.07	0.08	-0.05	0.04	0.03	0.06	-0.02	0.18	0.12	0.32	0.24	-0.52	-0.61	-0.37	2.58
720 nm	Mt Whl	0.16	-0.26	-0.10	-0.57	-0.31	-0.04			-0.22			1.69				-4.93
	Mt Gry	0.20	0.07	0.21	-0.27	0.00	0.16			0.22			0.67				-1.15
	Mt Blk	-0.09	-0.15	0.07	-0.09	-0.01	-0.02			0.21			0.20				2.45
Average	Mt Whl	0.25	-0.20	-0.18	-0.58	-0.85	0.08	0.21	0.04	-0.11	-1.46	-1.10	2.37	-0.71	-1.70	0.96	-3.77
	Mt Gry	0.26	0.10	0.16	-0.26	-0.24	0.17	0.16	-0.05	0.09	-0.55	-0.07	0.95	-0.69	-0.97	-0.47	-0.65
	Mt Blk	-0.05	-0.09	0.09	-0.10	0.01	0.04	0.06	-0.10	0.15	0.10	0.31	0.31	-0.20	-0.49	-0.19	2.65

Table 4 Page 2 of 4

NPL Spectrophotometry and Colorimetry Club

Reflectance Errors, R - R(NPL)

Matt Tiles

0/45 Geometry

	Type	b	b	b	b	b	b	b	b	b	b
	Tile Set	EK93	EK93	EJ93	EJ93	EH93	EK93	EJ93	EH93	EK93	EK93
Tile	Lab No	14	13	20	17	4	9	19	1	12	11
400 nm	Mt Wht	3.45	1.26	2.24	2.29	1.45	2.69	2.78	2.42	1.33	0.46
	Mt Gry	1.07	-0.40	0.74	0.68	0.17					
	Mt Blk	0.20	-0.66	0.00	0.07	0.03					
440 nm	Mt Wht	2.16	1.64	1.78	0.74	1.57					
	Mt Gry	0.69	0.19	0.70	0.59	0.37					
	Mt Blk	0.00									
480 nm	Mt Wht	2.24	1.41	1.95	1.19	1.42	1.98	2.22	1.27	1.71	0.99
	Mt Gry	0.64	0.07	0.67	0.44	0.36	0.51	0.34	0.35	0.38	0.34
	Mt Blk	0.08	-0.19	0.05	-0.14	0.11	-0.03	-0.05	-0.02	-0.01	-0.01
520 nm	Mt Wht	2.35	1.68	2.19	0.18	1.72	2.15	2.26	1.36	1.71	1.14
	Mt Gry	0.70	0.21	0.81	0.46	0.47	0.61	0.53	0.62	0.47	0.42
	Mt Blk	0.09	-0.17	0.09	-0.16	0.17	0.00	0.01	0.03	-0.01	0.02
560 nm	Mt Wht	2.24	1.69	2.32	0.99	1.90	2.24	2.49	1.45	1.38	0.92
	Mt Gry	0.65	0.30	0.80	0.68	0.50	0.66	0.52	0.69	0.47	
	Mt Blk	0.06	-0.13	0.11	-0.19	0.18	0.00	0.02	0.01	-0.03	0.01
600 nm	Mt Wht	2.21	2.15	2.26	0.71	1.86	2.33	2.51	1.47	1.53	0.71
	Mt Gry	0.61	0.28	0.76	0.98	0.53	0.66	0.60	0.79	0.55	0.41
	Mt Blk	0.09	-0.23	0.12	-0.07	0.19	0.03	0.06	0.04	-0.01	0.03
640 nm	Mt Wht	2.06	2.24	2.30	0.18	1.67	2.06	2.37	1.29	1.92	0.84
	Mt Gry	0.59	0.23								
	Mt Blk	0.08	-0.26								
680 nm	Mt Wht	2.00	-0.56	2.31	0.19	2.04	1.75	2.53	0.98	1.86	0.64
	Mt Gry	0.65	-0.53	0.59	0.57	0.58	0.53	0.55	0.72	0.92	0.65
	Mt Blk	0.09	-0.36	0.13	0.11	0.17	0.00	0.14	0.10	0.11	0.07
720 nm	Mt Wht		0.27	2.36	0.40				0.59	0.83	-0.06
	Mt Gry		-0.22	0.82	0.47				0.40	0.52	0.49
	Mt Blk		-0.26	0.38	0.17				0.18	0.18	0.12
Average	Mt Wht	2.34	1.31	2.19	0.77	1.70	2.17	2.41	1.34	1.52	0.72
	Mt Gry	0.70	0.01	0.74	0.60	0.43	0.61	0.54	0.54	0.49	0.40
	Mt Blk	0.09	-0.28	0.12	-0.05	0.13	-0.02	0.03	0.01	0.00	0.00

Table 4 Page 3 of 4

NPL Spectrophotometry and Colorimetry Club

Reflection Errors R R(NPL) Glossy Tiles 0/45 Geometry

	Type	b	b	b	b	b	b	b	b	b	b	b	b
	Tile Set	EK93	EJ93	EJ93	EJ93	EJ93	EJ93	EJ93	EJ93	EJ93	EJ93	EK93	EK93
Tile	Lab No	14	13	20	17	4	9	19	1	12	11		
400 nm	Gl Whl	1.81	0.12	1.03	2.68	-0.42	0.60	1.71	0.33	1.40	-0.14		
	Gl Gry	0.71	-0.21	0.42	1.29	-0.20	0.35	0.75	0.47	-0.58	-0.10		
	Gl Blk	0.17	-0.45	0.08	0.25	-0.03	0.04	0.13	-0.01	0.04	0.10		
440 nm	Gl Whl	0.54	0.68	0.15	1.20	0.06	0.25	1.00	-0.63	1.59	0.13		
	Gl Gry	0.21	0.10	0.15	0.63	-0.08	0.15	0.36	0.32	-0.72	-0.06		
	Gl Blk	0.04	-0.11	0.05	0.17	0.06	0.04	0.09	-0.02	0.07	0.10		
480 nm	Gl Whl	0.44	0.50	0.22	0.83	-0.28	-0.09	0.99	-0.80	1.49	-0.03		
	Gl Gry	0.15	0.05	0.13	0.91	-0.28	0.02	0.11	0.28	-0.79	-0.10		
	Gl Blk	0.08	-0.10	0.03	0.18	0.02	0.03	0.08	0.00	0.07	0.09		
520 nm	Gl Whl	0.57	0.78	0.54	0.27	-0.12	0.13	1.19	-0.58	1.47	0.08		
	Gl Gry	0.16	0.15	0.20	0.84	-0.25	0.07	0.28	0.49	-0.84	-0.11		
	Gl Blk	0.07	-0.10	0.06	0.15	0.02	0.05	0.08	0.01	0.07	0.09		
560 nm	Gl Whl	0.50	0.84	0.70	1.27	0.14	0.23	1.33	-0.39	1.05	-0.12		
	Gl Gry	0.18	0.24	0.34	0.93	-0.22	0.15	0.30	0.59	-0.88	-0.10		
	Gl Blk	0.05	-0.08	0.04	0.17	0.02	0.03	0.06	-0.02	0.06	0.09		
600 nm	Gl Whl	0.43	1.09	0.63	1.09	0.09	0.27	1.33	-0.22	1.14	-0.29		
	Gl Gry	0.09	0.12	0.24	0.75	-0.24	0.07	0.31	0.66	-0.89	-0.20		
	Gl Blk	0.03	-0.24	0.05	0.11	0.00	0.01	0.05	0.00	0.04	0.06		
640 nm	Gl Whl	0.36	1.26	0.72	0.97	0.22	0.43	1.29	-0.26	1.30	-0.27		
	Gl Gry	0.09	0.08	0.27	0.78	-0.08	0.11	0.26	0.55	-0.74	-0.14		
	Gl Blk	0.03	-0.28	0.05	0.10	-0.03	0.04	0.08	0.00	0.06	0.08		
680 nm	Gl Whl	0.39	-0.80	0.67	0.64	0.59	0.13	1.48	-0.29	1.34	-0.43		
	Gl Gry	0.06	-0.47	0.07	0.67	-0.09	-0.03	0.29	0.54	-0.78	-0.25		
	Gl Blk	0.06	-0.15	0.11	0.14	0.06	0.04	0.12	0.07	0.07	0.07		
720 nm	Gl Whl		0.48	0.82	1.16				-0.34	1.52	-0.72		
	Gl Gry		-0.03	0.42	1.05				0.32	-1.21	-0.34		
	Gl Blk		-0.15	0.23	0.15				0.18	0.16	0.09		
Average	Gl Whl	0.63	0.55	0.61	1.12	0.04	0.24	1.29	-0.35	1.37	-0.20		
	Gl Gry	0.21	0.00	0.25	0.87	-0.18	0.11	0.33	0.47	-0.82	-0.15		
	Gl Blk	0.07	-0.18	0.08	0.16	0.01	0.04	0.09	0.03	0.07	0.08		

Table age

APPENDIX

INTEGRATING SPHERE GLOSS TRAP AND SPECULAR BEAM ERRORS

For most dielectric (non metallic) materials such as ceramic tiles, paints or plastics the glossy component of reflection (specular component) is about 4% of the incident light and does not vary strongly with wavelength.

The gloss trap error is due to not all of the specular beam being absorbed by the gloss trap in the specular included geometry. The specular beam error is due to the specular component of reflection being collected with a slightly different efficiency from the diffuse component because of non uniformities of the integrating sphere.

The two errors are best determined by taking readings from a calibrated mirror and a matt white reflectance standard placed at the sample port of the instruments. A mirror has a much higher specular reflectance (typically 80% to 90%) than the 4% for a glossy tile or paint but it has no significant diffuse component of reflection. Because of the high reflection it gives a very sensitive test. However, the mirror readings need to be scaled down to correspond with the specular reflection from a glossy tile or paint. The following equations give the mathematical theory for the determination of gloss trap and specular beam errors. The reflectance R_s of the sample is to be measured. The reflectances R_t of the matt white standard and the mirror M must be known. Instrument readings, ρ_s , ρ_t and ρ_m are taken from the sample, white standard and mirror respectively. To simplify the equations the assumption is made that the error in ρ_t is small compared with the value of ρ_t , which is usually the case.

For matt materials, the gloss trap error and specular beam error are both zero. In industrial instruments either the sample or the standard can be glossy or matt. To allow for any combination of glossy and matt, factors α and β have been introduced which equal 1 for a glossy surface and 0 for a matt surface. α is used to give the factor (1 or 0) for the sample and β is used for the white standard.

In the absence of any error, the equation linking the required value of the reflectance of the sample, R_s to the instrument readings is

$$R_s = \frac{\rho_s}{\rho_t} \bullet R_t$$

In the presence of an error this becomes

$$R_a = \frac{\rho_a - error}{\rho_t - error} \bullet R_t$$

Appendix

Notation

Subscripts	a	sample
	t	standard
	m	mirror
	g	gloss trap
	s	specular beam

sample reading, ρ_t standard reading

absolute diffuse reflectance of sample, %

absolute diffuse reflectance of standard, %

M absolute specular reflectance of reference mirror, %

4 absolute reflectance of specular (glossy) component of reflection from sample or standard (for a glossy tile, plastic or paint the specular reflectance is about 4%)

Note: Readings and absolute reflectances vary with wavelength

Appendix

Gloss Trap Error - Specular Excluded Geometry

A calibrated mirror of reflectance M gives a reading of ρ_{gm} which is an error reading. If there were no gloss trap error ρ_{gm} would be zero. The scaled error corresponding to the glossy component of a tile, paint or plastic is

$$\rho_{g4} = \frac{4}{M} \rho_{gm}$$

Absolute diffuse reflectance of a sample

$$R_a = \frac{\rho_a - \alpha \rho_{g4}}{\rho_t - \beta \rho_{g4}} \cdot R_t$$

Where $\alpha, \beta = 1$ for a glossy surface
 $\alpha, \beta = 0$ for a matt surface

If $\rho_{g4} \ll \rho_t$ this approximates to

$$R_a \approx \frac{\rho_a}{\rho_t} R_t + k_2 \left(\beta \frac{\rho_a}{\rho_t} \right) \alpha$$

where $K_2 = \frac{\rho_{g4}}{\rho_t} R_t$

Note that when a glossy sample is measured against a matt white reference standard, $\beta = 0$ and $\alpha = 1$. In this case the error in reflectance measurement is K_2 .

Appendix

Specular Beam Error - Specular Included Geometry

A calibrated mirror of reflectance M placed at the sample port gives a reading ρ_{sm}

A matt white tile of reflectance R_t placed at the sample port gives a reading ρ_t

If there were no specular beam error, the mirror would give a reading

$$\rho_t \cdot \frac{M}{R_t}$$

thus the error in the mirror reading e_m is given by

$$e_m = \rho_{sm} - \rho_t \frac{M}{R_t}$$

for a specular component of about 4% from a typical glossy sample the scaled error in the specular beam is

$$e_s = \frac{4}{M} \left(\rho_{sm} - \rho_t \frac{M}{R_t} \right)$$

Appendix

Specular Beam Error Continued

The absolute reflectance of a sample, applying a correction is

$$R_a = \frac{\rho_a}{\beta e_s} \cdot R_t \quad \begin{array}{l} \text{where } \alpha, \beta = 1 \text{ for a glossy sample} \\ \text{where } \alpha, \beta = 0 \text{ for a matt sample} \end{array}$$

if $e_s \ll \rho_t$ this approximates to

$$R_a \approx \frac{\rho_a}{\rho_t} \cdot R_t + k_3 \left(\beta \frac{\rho_a}{\rho_t} - \alpha \right)$$

where $k_3 = 4 \left(\frac{\rho_{sm}}{\rho_t} - \frac{R_t}{M} \right)$

Note that when a glossy sample is measured against a matt white reference standard, $\beta = 0$ and $\alpha = 1$. In this case the error in reflectance measurement is K_3 .