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**Report on Project QR9816B1
Gloss Measurements at NPL**

**A R Hanson, J A F Taylor, M A Basu, D C Williams
Centre for Optical and Environmental Metrology**

**J Zwinkels
National Research Council**

**W Czepluch
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National Physical Laboratory
Teddington, Middlesex, UK, TW11 0LW

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by D H Nettleton, Head of Centre for Optical and Environmental Metrology.

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Report on Project QR9816B1 Gloss Measurements at NPL

1 ABSTRACT

The work at NPL was carried out as part of the Optical Radiation Measurement Programme. The development of a calibration facility for gloss measurements includes adapting the optics of the NPL Reference Reflectometer to comply with published gloss standards; investigating the sources of uncertainty in commercial gloss-meters; investigating the effects of cleaning gloss transfer standards and comparing measurement results of the Reference Reflectometer and a high quality commercial gloss meter with those of other international workers in the field.

2 SCOPE

The principle objectives of the project, which are reported in this document are:

- 1 To survey gloss paper standards currently available;
- 1.2 To investigate the variation in the measurement of several material standards using a range of commercial instruments;
- 1.3 To develop facilities and procedures for gloss measurement at NPL;
- 1.4 To compare results of prospective gloss transfer standards measured on two NPL instruments to establish if results are consistently comparable.
- 5 To compare NPL gloss measurements with those of other national laboratories (NRC and BAM) including:

An investigation of the measurement of semi-gloss and high gloss;

A study of the effects of cleaning;

An examination of the stability of gloss transfer standards.

3 CURRENT GLOSS PAPER STANDARDS

A survey of gloss measurement standards was carried out by NPL. Details of the findings are given in Section 9.1. About 150 titles of standards contained the word 'gloss'. One of the reasons why there are so many standards is that gloss forms an important part in test methods for a wide range of industries. There is also a wide range of gloss specification systems - Hunter [Ref 1] describes no less than six different types of gloss. However, the angles of incidence and reflectance of 20°, 60° and 85° feature in the most popular standards. The majority of standards use a common system of units (described in Section 9.2), abbreviated in this document as GU.

4 DIVERSITY IN RESULTS OF COMMERCIAL GLOSS METERS

4.1 METERS AND SAMPLES USED

Five gloss meters were purchased. For these systems - each costing no more than £2000 - the main causes of inter-instrument disagreement are:

- 1) calibration of scale;
- 2) geometric differences, particularly detector and illuminator numerical aperture and angles;
- 3) electronic instability and detector noise;
- 4) detector and source spectral characteristics.

The instruments are identified in this report as Meter A to Meter E

The 53 measured samples were a combination of currently used gloss transfer standards and samples from typical industrial applications. They included aluminised glass, black glass, white glass backed with black paint, ceramics, matt and gloss paint mixtures, fabric and paper.

4.2 RESULTS

A summary of results in graphical format is given in Figures 1 to 3. These graphs plot the difference in reading for each instrument from the mean reading from all instruments.

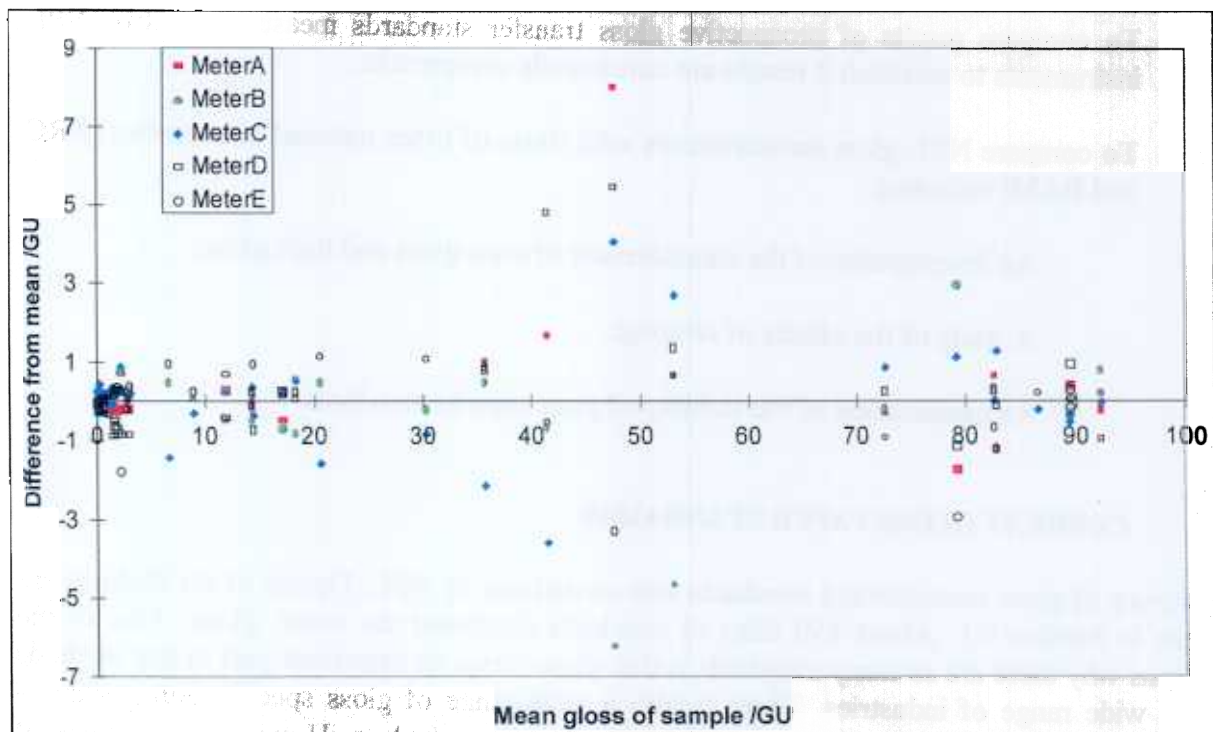


Figure 1: Results from 5 gloss-meters, 20° geometry

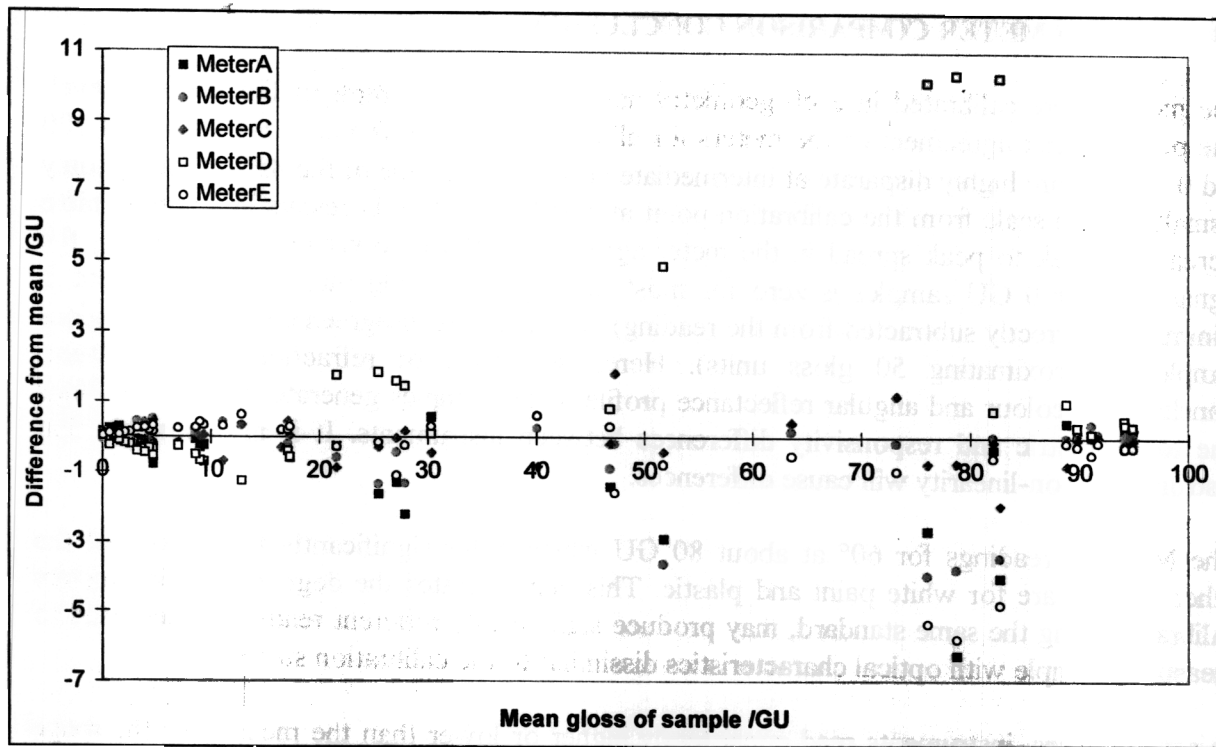


Figure 2: Results from 5 gloss-meters, 60° geometry

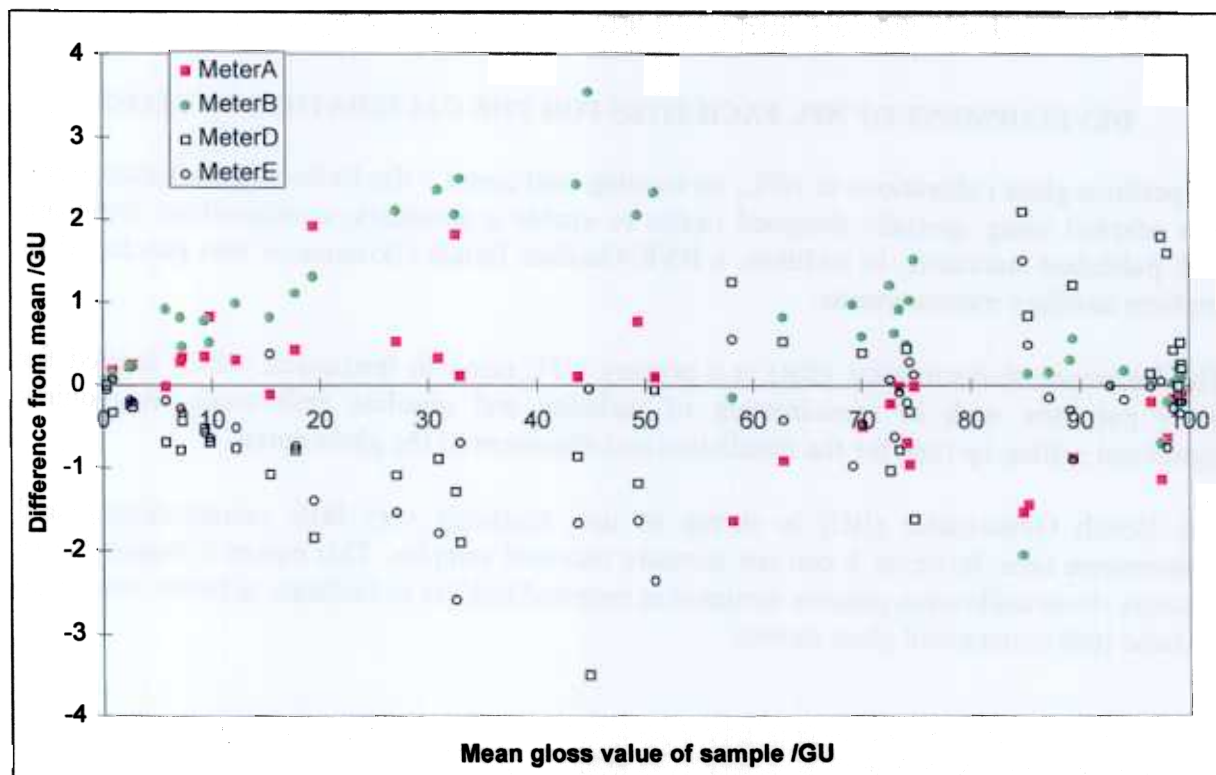


Figure 3: Results from 4 gloss-meters, 85° geometry

4.3 GLOSS METER COMPARISON CONCLUSIONS

The meters were calibrated in each geometry using a common sample at the 100 GU level. The peak to peak agreement of the meters for all geometries is approximately 0.6 GU at 100 and 0 GU but are highly disparate at intermediate values. In the case of the 85° geometry, only a small drop in scale from the calibration point at 100 GU to 97 GU results in a considerable increase in peak to peak spread in the meter agreement. At the lower end of the scale, the signal read for 0 GU samples is zero for most meters (suggesting that any dark current is minimal or correctly subtracted from the reading). The greatest disagreement is for semi-gloss samples (approximating 50 gloss units). Here, the range of refractive index, texture, translucency, colour and angular reflectance profile of the samples generate different readings due to geometric and responsivity differences between instruments. It is also possible that instrumental non-linearity will cause differences.

The Meter D readings for 60° at about 80 GU which differ significantly from those of the other meters, are for white paint and plastic. This demonstrates the degree to which meters calibrated using the same standard, may produce significantly different readings when used to measure a sample with optical characteristics dissimilar to the calibration standard.

In several cases, instruments read consistently higher or lower than the mean over the range 0 and 100 GU.

This study suggests that it is possible to anchor the scales of gloss meters at the 100 GU level, and measure a limited range (close to 100 GU) of different samples with an uncertainty of ± 1 GU. However, instruments need to be calibrated using standards similar to test samples to achieve a similar uncertainty for semi-gloss samples.

5 DEVELOPMENT OF NPL FACILITIES FOR THE CALIBRATION OF GLOSS

To perform gloss calibrations at NPL, an existing instrument - the Reference Reflectometer - was adapted using specially designed optics to enable a geometric configuration compliant with published standards. In addition, a BYK-Gardner Bench Gloss-meter was purchased to perform auxiliary measurements.

The Reference Reflectometer (RR) is a primary NPL research instrument which is used for many purposes such as measurement of turbidity and absolute reflectance. It requires significant setting up time for the installation and alignment of the gloss optics.

The Bench Gloss-meter (BG) is simple to use, requiring very little commissioning and maintenance time, however it can not measure recessed samples. This makes it impossible to measure those calibration plaques mounted in recessed holders to facilitate accurate relocation on hand held commercial gloss meters.

5.1 REFERENCE REFLECTOMETER SET UP

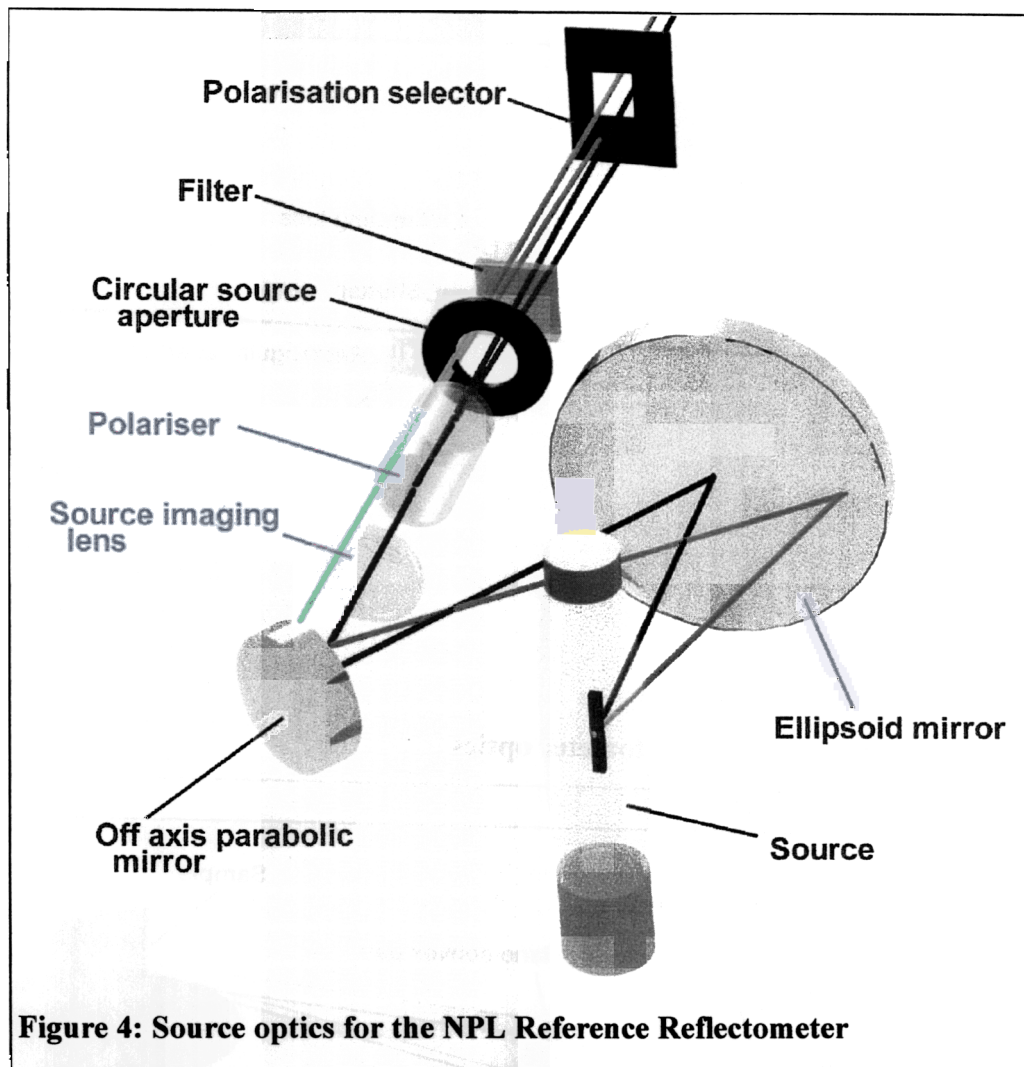


Figure 4 shows the Reference Reflectometer source optics. The source is an inverted tungsten ribbon lamp imaged to the focal plane of the paraboloidal mirror by an ellipsoidal mirror. The off axis paraboloidal mirror produces a collimated beam. This beam passes through a magnesium fluoride Rochon polarising prism which is rotated to provide the two planes of polarisation. A circular aperture placed after the polariser defines the sample spot size. A filter converts the combination of the spectral power distribution of the tungsten source with the response of the silicon detector to the combination of CIE Standard Illuminant C with the photopic response. The main beam from the prism is separated from the second (orthogonally polarised) beam by the rectangular aperture before it enters the sample compartment.

The instrument uses two rotary tables driven by stepper motors with a common vertical rotation axis. The upper table carries the sample, mounted vertically in a holder which is itself mounted on linear horizontal and vertical stepper motor slides. The lower table carries the detector, at a distance of about 500 mm from the rotation axis. This enables the sample to be positioned at any angle to the incident light beam and the light reflected in any direction in the horizontal plane to be measured. The angular positions of both tables are read with an uncertainty of 0.04° using radial gratings.

To achieve the standard illumination geometries for gloss, a rectangular aperture is positioned outside the sample compartment, in the focal plane of an achromatic doublet collimating lens (located just inside the compartment). This is shown in Figure 5. This lens also images a

circular aperture close to the filter onto the sample. A lens inserted near to the polarising prism images the lamp ribbon onto the rectangular aperture so that it is overfilled.

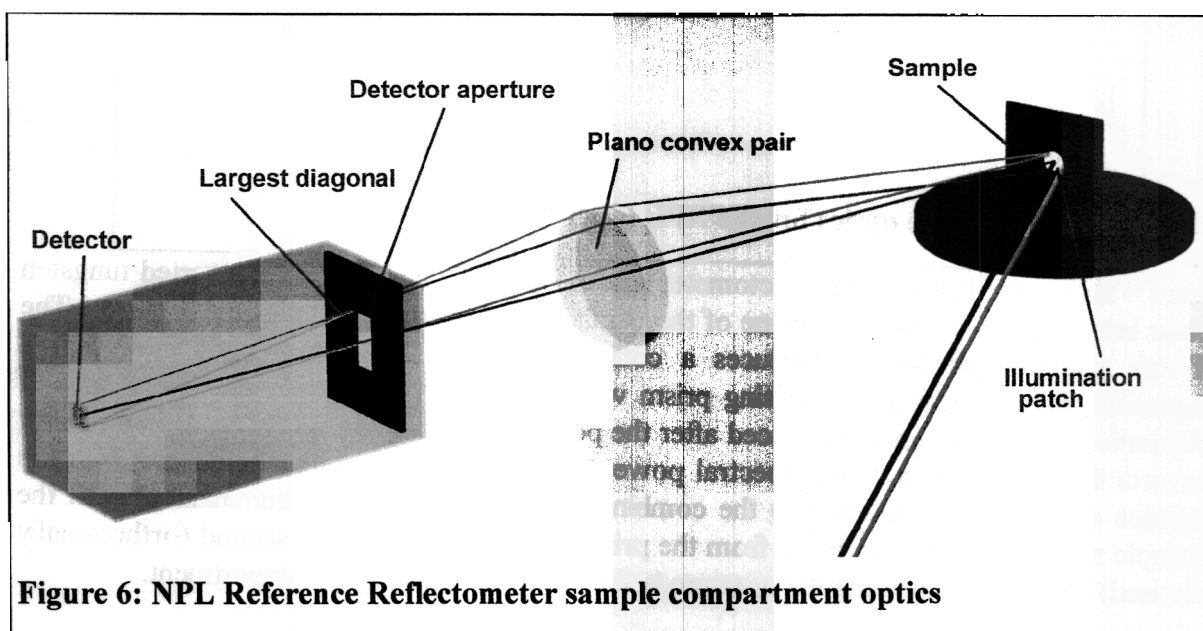
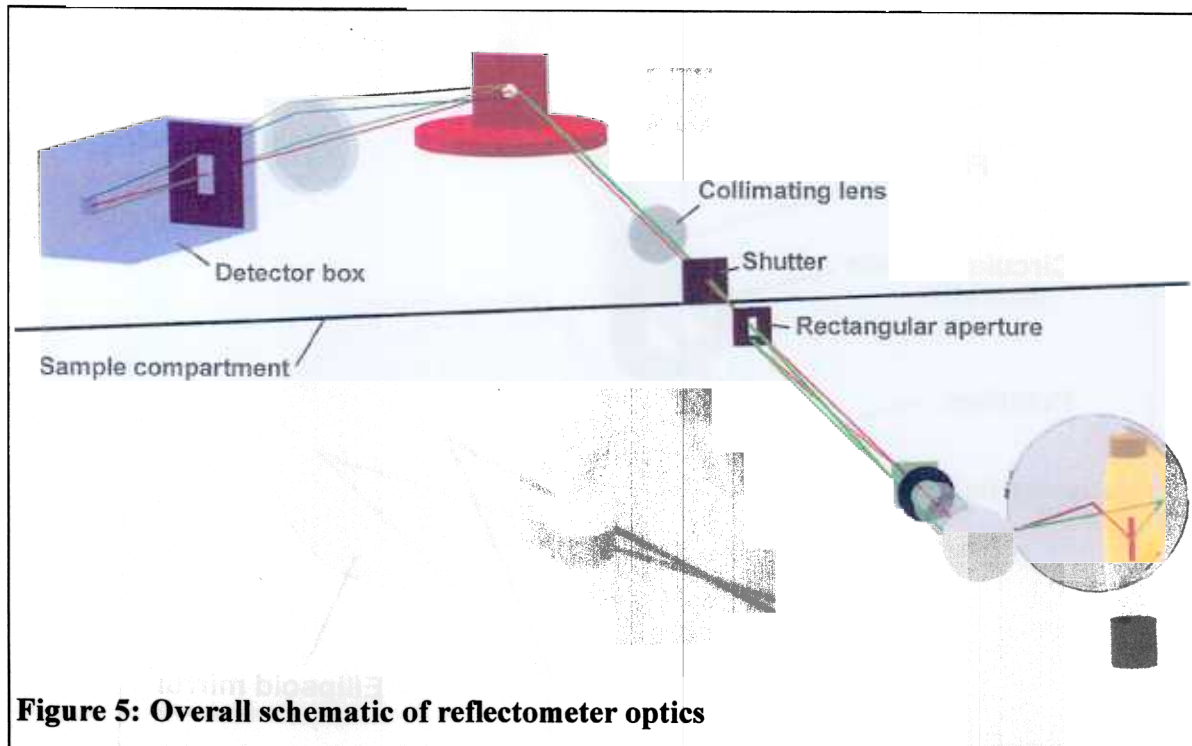


Figure 6 shows the sample compartment optics. A plano convex lens pair is attached to the front of the detector box and a holder for a second rectangular aperture is fitted in the box in the back focal plane of the lens. In a similar manner to the source lens, this lens also images the patch of light on the sample onto the detector. To reduce aberrations to an acceptable level, the lens is constructed as a plano-convex pair with the convex surfaces facing each other.

The detector is an 18 mm square windowless silicon photodiode (Hamamatsu type S6337). To reduce the effects of stray light this is mounted at the rear of a black perspex box which contains several baffles. The size of the image ensures that the detector is not overfilled.

Sample gloss is calculated from the ratio of detector response to the incident and reflected beams with dark responses subtracted. This ratio is the absolute regular reflectance. The results are then multiplied by conversion factor derived using the gloss standard definitions and Fresnel's equations outlined in Section 9.2.

Final results are the mean of eight measurements - with the detector on each side of the sample normal, with incident light in each of the two planes of polarisation, on two separate occasions.

As part of the instrument validation, regular reflectance of clear and black polished fused silica at several angles was measured and gave good agreement with published [Ref. 2] theoretical values calculated using Fresnel equations.

5.2 UNCERTAINTIES IN REFERENCE REFLECTOMETER GLOSS VALUES

Several factors are considered in determining the NPL measurement uncertainty. A summary of uncertainty sources is given in Table 1. (These results are repeated in Appendix 9.3 in the determination of the overall uncertainty for the intercomparison).

Uncertainty source	20° GU	60° GU	85° GU
Linearity = 0.038 (peak to peak)	0.28	0.14	0.02
Beam/detector Uniformity	0.05	0.02	0.00
Repeatability	X	X	X
Uniformity of sample	0.20	0.20	0.20
Spectral illuminator and Response	0.10	0.10	0.10
Temperature (over range 20-26 °C)	0.00	0.00	0.00
Humidity (when non condensing over range 50-75 %RH)	0.00	0.00	0.00

Table 1: Summary of uncertainties (at k=1 level) for NPL Reference Reflectometer.
(For values of X, see Table 2.)

Notes on uncertainty

The relationship between gloss and angle is very non linear and a small deviation in angle and cone angle may have a significant bearing on results.

- The linearity was tested using a series of calibrated neutral filters. The expected value was compared with the measured signal. Incorporated into this investigation is the switching of amplifier ranges. The difference between signal levels for incident and reflected radiation will typically be in the order of 100:1.
- The angular uncertainty of the instrument is 0.02°. As the reflected specular beam considerably under-fills detector, there is substantial headroom angle. Measurements are made on both sides which significantly reduces the effects of geometric error.
- The magnitude of the incident beam is monitored throughout the measurements and changes are less than 0.001%. The source is sufficiently stable therefore, not to have any contribution to the total uncertainty.
- Sample uniformity of mirrors has been measured and found to be in the order of 0.05%, that of ground ceramic was found to be 0.6%.

- 6 The agreement between the required Illuminant C/Photopic response combination and the achieved source/filter/detector combination is 94% as shown in Figure 7. Regular spectral reflectance is a function of effective refractive index. As the refractive index of the gloss standards changes slightly with wavelength (ie they exhibit dispersion), there will be a small error in the integrated regular reflectance (and therefore gloss) value as the illuminant+detector response is not that required by the paper standards. However, the magnitude of this error will be negligible, particularly as the mismatch is limited over a small spectral range.
- 7 Values of repeatability, X , vary with sample and are given Table 3. The repeatability value is the change in value between the two RR measurements. The samples were removed from the instrument and measured on the BG in-between the two measurements which were performed on separate days. This value incorporates errors in sample placement and uniformity. Values of X are given in the 'RR Abs Diff' columns in Tables 7 and 11.

The factors detailed above are combined and summed in quadrature.

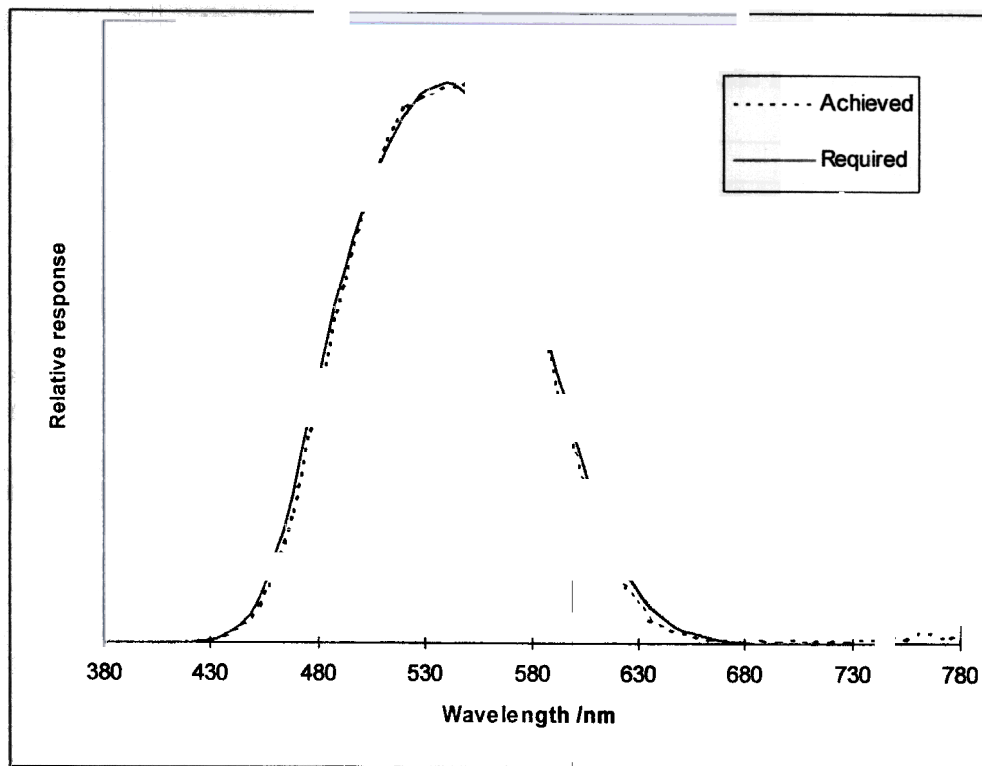


Figure 7: Achieved response of system compared with CIE Illuminant C x photopic response curve

In an independent check of measurements of RR values, the theoretical regular reflectance at 500 nm of a fused silica block at several angles was calculated by using the published [Ref. 2] refractive index of 1.462326 and the equations for regular reflectance given in Section 9.2.

A fused-silica wedge was then measured on the RR and the differences between measured and calculated values scaled to gloss unit values by multiplying the differences by $100/(\text{reflectance value for a sample with refractive index } 1.567)$. (The sample used in gloss standard definitions has the refractive index 1.567). The results are shown in Table 2.

unit polarisation Angle	Theoretical values			Measured values			Differences (Meas-Theory)			Values for	Differences
	/% s	/% p	/% s+p	/% s	/% p	/% s+p	/% s	/% p	/% s+p	ri=1.567 /% s+p	/GU s+p
6	3.5787	3.4725	3.5256	3.5850	3.4800	3.5325	0.0063	0.0075	0.0069	4.8789	0.14
45	8.3120	0.6909	4.5014	8.3070	0.6950	4.5010	-0.0050	0.0041	-0.0004	5.9708	-0.01
60	16.3345	0.2357	8.2851	16.2940	0.2370	8.2655	-0.0405	0.0013	-0.0196	10.0056	-0.20
85	72.1529	49.4822	60.8175	72.0590	49.4250	60.7420	-0.0939	-0.0572	-0.0755	61.9148	-0.12

Table 2: Comparison of theoretical with measured values of regular reflectance of fused silica sample at 500 nm.

The results show agreement to approximately ± 0.1 GU.

A summary of uncertainties for the RR by sample /geometry is given in Table 3. X is the repeatability of measurements, while U is the total uncertainty which includes X, and other contributions outlined in Table 1.

Sample/type	Geometry	X (k=1)	U (k=2)
EW97	20	0.02	0.77
Black Silica	60	0.03	0.58
	85	0.22	0.89
KC97	20	0.09	0.91
NPL Black Glass	60	0.01	0.56
	85	0.04	0.53
KD97	20	0.05	0.83
Float Glass	60	0.02	0.57
	85	0.03	0.52
KE97	20	0.01	0.76
Float Glass	60	0.07	0.67
	85	0.03	0.51
KH97	20	0.67	2.07
Mirror	60	0.12	0.77
	85	0.03	0.51
S941935	20	0.05	0.83
White Glass	60	0.03	0.60
	85	0.08	0.60
S941936	20	0.03	0.79
White Glass	60	0.14	0.81
	85	0.09	0.63
24525	20	0.08	0.90
Ceramic	60	0.01	0.56

Table 3: Summary of uncertainties for samples measured at NPL

6 COMPARISON OF RESULTS BETWEEN TWO NPL INSTRUMENTS

It is important to know how the results of samples measured using the two NPL instruments differ. Driving this work is the anticipation that - to some degree - the bench gloss meter may be used as a device to calibrate samples by the direct substitution method - ie measurement of known standard (calibrated on the more complicated RR) against similar sample.

The standards used for this investigation (which are the same as those used in the intercomparison) are a selection of different materials which are possible candidates as gloss transfer standards. The materials used are identified in Table 4.

Material Type	Description	Identifier
a	Black silica	EW97
b	NPL black glass	KC97
c	Black float glass	KD97, KE97
d	Mirror	KH97
e	White glass with back and sides painted black	S941935, S941936
f	Off-white 'pot' ceramic	024525

Table 4: Types of standard used in the intercomparison

Figure 8 presents the differences between results from the two NPL instruments.

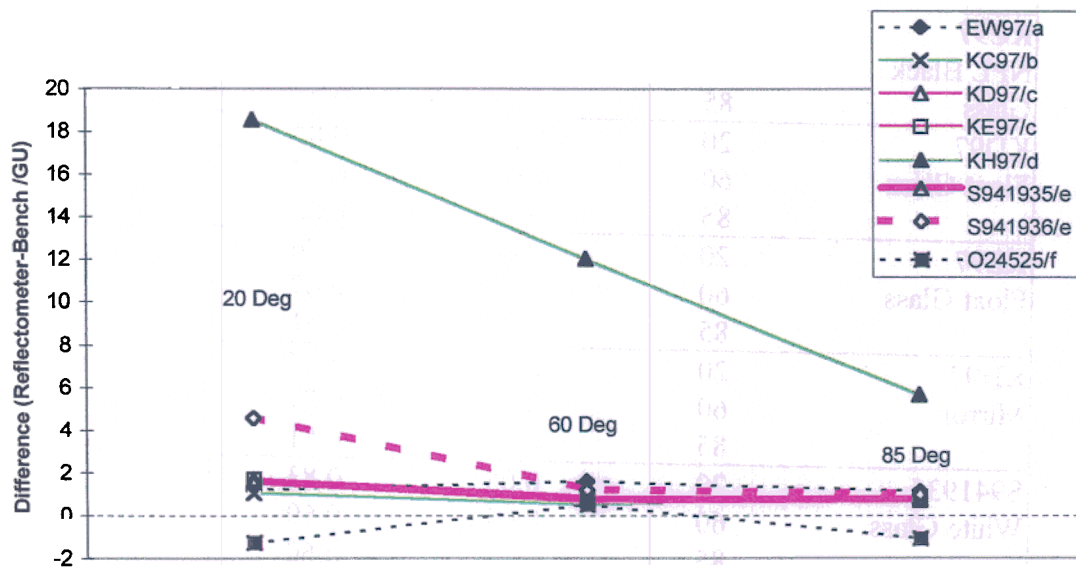


Figure 8: Comparison of first set of results from two NPL instruments

The main points to note are:

- The RR tends to read higher than the BG.
- 2 There is no overall systematic conversion factor which can be used to transform RR readings to BG readings for all materials.
 - 3 The relationship between RR and BG values varies considerably with geometry. This is because the different geometries will incur different systematic errors in each instrument. The BG uses a different set of illuminator and detector for each geometry.
 - 4 KH97 is a high gloss mirror. Measurements of two similar mirrors (KF97 and KG97) at the same time gave essentially identical results. The same set of three factors (one for each geometry) can be used to convert RR to BG values for this type of mirror.
 - 5 The factors converting values for class e samples (white glass with a black backing) vary with geometry and sample. S941936/e has more roughly ground surface than S941935/e giving it a lower gloss at low angles.
 - 6 The method of calibration by direct substitution may be applied under limited circumstances - ie when standard and sample are of identical material and finish (and therefore giving similar values).

7 **INTERNATIONAL INTERCOMPARISON**

The intercomparison of gloss measurements was organised by NPL who are extremely grateful for the help from its partners NRC and BAM, not only for measuring samples in a timely manner, but also for advice.

The timetable of measurements was as follows:

- Sep-96 Two NPL standards measured by NRC
- Jan-98 Standards measured by NPL on both their instruments
- Mar-98 Standards re-measured using NPL bench gloss-meter
- Mar-98 Standards divided into two sets and shipped to NRC and BAM
- Mar-98 Standards measured by BAM
- Apr-98 Standards returned to NPL from BAM. Measured at NPL with bench gloss-meter
- Jun-98 Standards measured by NRC
- Standards returned to NPL from NRC. Measured at NPL with bench gloss-meter
- Aug-98 Cleaning investigations completed.

7.1 **MEASUREMENTS AT NPL**

The measurements at NPL for the intercomparison were performed primarily on the RR using specially designed gloss optics compliant with published standards, with additional measurements made in parallel using a BYK-Gardner Bench Gloss-meter.

7.1.1 **REFERENCE REFLECTOMETER SET UP**

The RR configuration is described in Section 5.1 of this document.

EXPERIMENTAL CONDITIONS

Gloss measurements of the samples were made for angles of incidence and reflectance of 20°, 60° and 85°. The illumination spot onto the sample was circular with a 10 mm diameter. Ambient temperature was 24 ± 2 °C.

Measuring Geometries	20°, 60°, 85°
Illuminated areas	20°: 10 mm diameter
	60°: 14 x 10 mm
	85°: 115 x 10 mm
Light source	filtered tungsten ribbon lamp
Detector	photopic filtered 18 mm square silicon cell
Illuminator/detector response	Illuminant C, 2° photopic observer

7.1.3 BENCH GLOSSMETER SET UP

The bench gloss meter is a BYK Gardner haze-gloss measuring instrument model 4600. The instrument was uncalibrated as it was felt that calibration might change instrumental scale resulting in an effective systematic drift. This instrument is always to be used to compare samples with standards calibrated using the Reference Reflectometer.

The bench gloss-meter technical details are as follows.

Measuring Geometries	20°, 60°, 85°
Illuminated areas	20°: 15 mm diameter 60°: 27 x 15 mm 85°: 60 x 8 mm
Precision	0.1 unit (range 0-100 units), 1 unit (range >100 units)
Repeatability	± 0.3 units
Temperature drift	0.2 units / °C
Light sources	1 W tungsten lamps
Detectors	photopic filters over silicon photocells
Illuminator/detector response	Illuminant C, 2° photopic observer

The instrument uses a 1 W tungsten source for each measurement geometry. Light from each source is collimated onto the sample and monitored via a beam-splitter detector combination. Three detectors are mounted at corresponding angles. Their field of view is aperture limited.

The instrument conforms with ISO 2813, and ASTM D523. In addition, its model type has been tested by BAM and was found to fulfil the requirements set by the DIN 67 530.

A detailed assessment of uncertainty in gloss-meter measurements was not undertaken. The instrument scale was not adjusted during the intercomparison and no calibration routine was employed. The readings taken are based on an internally generated instrumental scale which was calibrated by the manufacturer prior to shipment. The instrument has very good repeatability. The readings change only by one in the final of the four digits given during measurements over an hour. An indication of systematic error is the spread in agreement with the results of the Reference Reflectometer. This is shown in Section 6 of this report and for full and semi-gloss measurements are in the order of between -2 and +4 GU for 20° measurements, -0 and +2 for 60° measurements and -1 and +2 for 85° measurements. The high gloss sample measured high on the bench gloss-meter by 18, 12 and 6 GU for 20°, 60°, and 85° respectively. With the exception of the high gloss measurements, these results are reasonably compliant with the accuracy information provided in the instrument handbook (were the instrument first to be recalibrated to the NPL scale). The handbook states the following values for a 'high gloss' standard (taken to mean a full gloss standard in the vernacular of this report):

Repeatability:	± 0.05 GU
Reproducibility:	± 0.3 GU
Absolute Accuracy:	± 1 GU
Long term stability (>10000 measurements)	± 0.2 GU
Temperature drift	0.02 GU/° C.

7.1.4 NPL MEASUREMENT RESULTS

The sequence of measurements and events for the initial NPL measurements performed in January 1998 was as follows:

- 1 bench gloss-meter;
- 2 samples cleaned;
- 3 bench gloss-meter;
- 4 Reference Reflectometer;
- 5 bench gloss-meter;
- 6 Reference Reflectometer;
- 7 bench gloss-meter.

The Reference Reflectometer results quoted are the mean of measurement results 4 and 6. Results 3, 5 and 7 showed no significant drift and were averaged to provide a result for the bench gloss meter after cleaning. The means of all measurement results are given in Table 5. The Reference Reflectometer values in bold are those used in the intercomparison.

The temperature during all the measurements was 24 ± 2 °C.

Sample /type	Prior to cleaning			After cleaning and prior to shipment					
	Bench Gloss-meter			Bench Gloss-meter			Reference Reflectometer		
	20°	60°	85°	20°	60°	85°	20°	60°	85°
EW97/a	71.1	80.9	96.3	71.4	81.2	96.8	72.6	82.8	98.0
KC97/b	88.3	93.7	97.7	88.0	93.6	98.6	89.0	94.1	99.4
KD97/c	87.9	92.8	97.7	89.1	93.5	98.4	90.8	94.4	99.3
KE97/c	84.6	88.2	96.2	89.2	93.5	98.4	90.9	94.4	99.2
KH97/d	-	-	-	1721	871	151	1739	883	157
S941935/e	-	-	-	94.2	96.3	98.6	95.8	97.0	99.3
S941936/e	-	-	-	73.8	81.3	94.7	78.4	82.5	95.6
024525/f	-	-	-	37.9	48.7	72.6	36.6	49.2	71.5

Table 5: NPL gloss measurement results prior to standard shipment

The standards were measured again using the bench gloss-meter on return from NRC and BAM. These results are given in Sections 7.2.4 and 7.3.5.

7.1.5 CLEANING PROCEDURES AT NPL

The cleaning procedure adopted at NPL for the standards prior to shipment was as follows:

- 1 immerse standard in fluorophor-free detergent;
- 2 gently rub standard with wet lint free cloth;
- 3 rinse with de-ionised water until it 'beads';
- 4 blow dry with filtered air;
- 5 inspect surface for marks, and if present, re-start process at step 2.

On their return to NPL after measurement by participating laboratories, the standards were measured, and the following advanced cleaning technique was used:

Make up a solution of fluorophor free detergent in de-ionised water. Totally immerse the standard in this solution for 15 minutes.

- 2 Gently rub the surface of the sample with the solution using a lint free cloth, removing any dirt marks.
- 3 From now on handle the sample ensuring that fingers do not touch the working face. It is preferable to wear (rubber) gloves.
- 4 Rinse the sample under running de-ionised water for at least two minutes to remove any detergent residue. The water should 'bead up' on the sample surface.
- 5 Blow dry the sample with filtered air.
- 6 Squirt pure ethanol over the working face. Blow dry with clean air so that the alcohol drying 'front' carries any dirt along with it away from the centre.
- 7 Closely examine the working face under a single tungsten source obliquely illuminating the sample. Take care not to mistake any internal structure of the sample for surface blemishes. Any dust particles remaining can be gently brushed away with a fine art paintbrush. If surface blemishes remain which may jeopardise measurements, it is unfortunately necessary to return to the beginning of the cleaning procedure.
- 8 Now dry the sample. Carefully place it about 50 mm under a 100 W infrared lamp for 10 minutes. Then place in a dessicator or humidity cabinet for at least 24 hours prior to measurement.

7.2 MEASUREMENTS AT NRC

Standards S941935/c and S941936/c were measured by NRC in 1996 prior to the intercomparison. The instrumentation and methods leading to those results are identical to those for this intercomparison. Results from both the 1996 and 1998 exercises summarised in the following section, though only those of the 1998 intercomparison are used in later analyses.

7.2.1 NRC INSTRUMENTAL SET UP

The NRC Reference Gloss-meter, shown in Figure 9, was developed in 1970 by Budde [Ref. 3] to conform with ISO 2813 and ASTM D523 specifications. The design incorporates a diffuser placed in front of the detector to limit the degree of polarisation to about 0.1%.

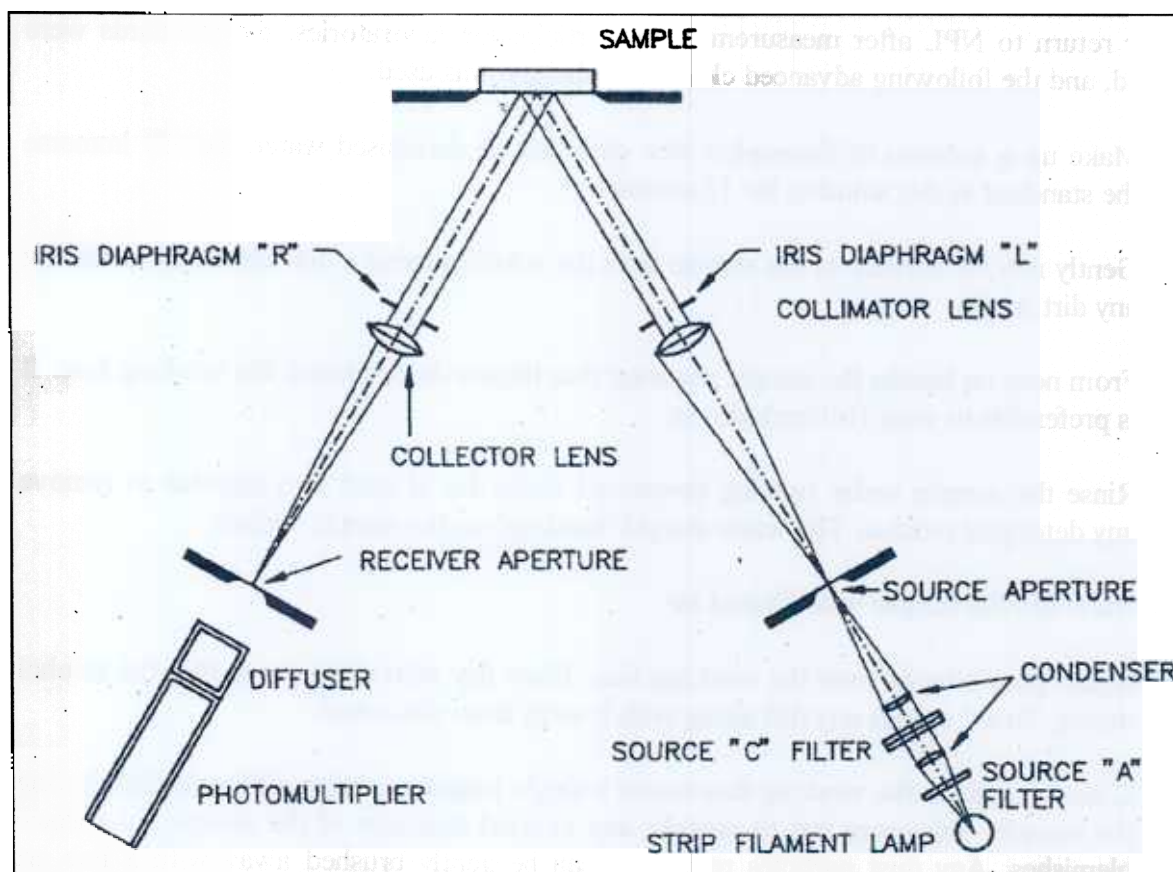


Figure 9: Schematic diagram of the optical layout of the NRC Reference Gloss-meter

The NRC method is to use their instrument to compare readings of samples with those of a quartz wedge standard (Suprasil 311) of known refractive index. The back surface of the wedge is at an angle of 5.7° to that of the front face to deflect any back surface reflection. Front surface flatness is to 2 fringes (633 nm) and the roughness is about 0.1 nm. The back and side surfaces are coated with black felt to eliminate reflections from surfaces behind the transparent material. The standard is calibrated for refractive index using an Abbe refractometer at several wavelengths to determine a dispersion curve. The Fresnel reflectance is calculated for each geometry over the wavelength range 380-760 nm at 5 nm intervals and integrated with CIE Standard Illuminant C and the 2° Standard Observer. A corresponding Fresnel reflectance is calculated for the theoretical primary gloss standard of refractive index 1.567 (with no dispersion). The ratio of the luminous reflectance factors of the quartz wedge to the theoretical standard is multiplied by 100 GU to provide the wedge's gloss value.

NRC EXPERIMENTAL CONDITIONS

Samples were cleaned prior to measurement (refer to Section 7.2.5 for details on the cleaning method). Measurements are made in the sequence standard, sample, standard to compensate for linear source drift. Sample gloss is calculated from the sample to mean standard ratio after correction for a dark current. Typically ten readings are taken of both sample and standard to give a measurement precision of better than ± 0.1 GU.

Performance characteristics of the NRC instrument are:

Measuring Geometries	20°, 60°, 85°
Measurement areas	20°: 7 x 12 mm 60°: 13 x 10 mm 85°: 70 x 10 mm
Reproducibility	± 0.1 GU
Accuracy	± 0.3 GU
Light source	filtered tungsten strip filament lamp
Detector	photopic filter over photomultiplier
Illuminator/detector response	Illuminant C, 2 degree photopic observer

NRC UNCERTAINTIES

The following uncertainties are quoted at the 95% confidence level.

The systematic uncertainty ΔG_s of the NRC calibrations is estimated to be ± 0.3 GU (over the 0-100 GU range).

Total uncertainty is a combination in quadrature of ΔG_s with twice the statistical uncertainty in sample measurement $2\Delta G_R$. The total uncertainty for each sample and geometry are quoted in the results Table 6.

7.2.4 NRC MEASUREMENT RESULTS

Two samples were measured by both NPL and NRC in an exercise pre-dating this intercomparison. The results of this project is summarised in Table 6 and Figure 10. At NPL the Reference Reflectometer was used. Two high gloss samples of different materials were included. The results agree to within the quoted uncertainties in two thirds of the measurement results. It is noted that the relationship between geometry and gloss value appears linear for both NPL results, and exponential for both NRC results. This may be a coincidence.

	Result $\pm$ total uncertainty (at $k=2$) /GU					
Geometry	20		60		85	
Sample/type	NRC	NPL	NRC	NPL	NRC	NPL
S941935/e	96.9 ± 0.3	96.7 ± 0.3	98.1 ± 0.3	98.9 ± 0.3	100.1 ± 0.3	98.8 ± 0.3
NPL Black Glass	90.9 ± 0.3	90.4 ± 0.3	94.4 ± 0.3	95.2 ± 0.3	99.8 ± 0.3	99.5 ± 0.3

Table 6: NRC 1996 calibration values compared with NPL RR measurements

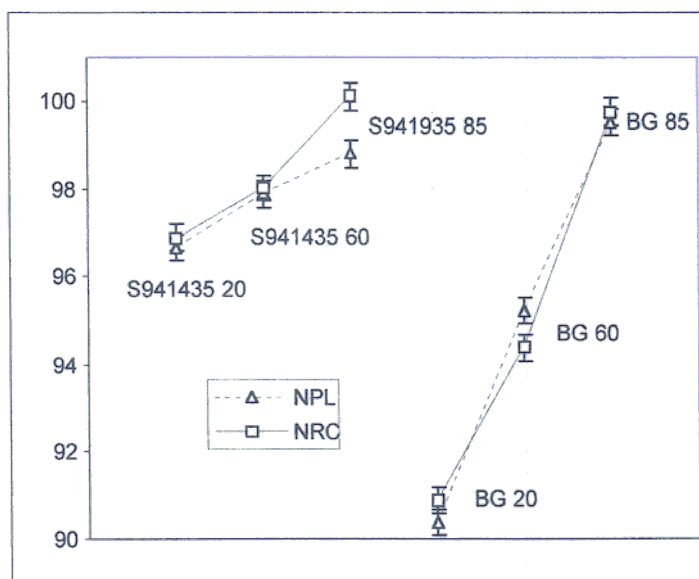


Figure10: Agreement between NPL and NRC in 1996 /GU

	Sample	Geometry /°	RR Mean /GU	Abs Diff /GU	BG Mean /GU	Stdevmean /GU
Black Silica	EW97	20	72.6	0.03	71.4	0.03
		60	82.8	0.04	81.2	0.10
		85	98.0	0.32	96.8	0.27
Float Glass	KE97	20	90.9	0.02	89.2	0.03
		60	94.4	0.10	93.5	0.03
		85	99.2	0.04	98.4	0.09
Mirror	KH97	20	1739	0.97	1721	0.67
		60	883.4	0.17	871.3	0.33
		85	156.6	0.04	151.0	0.00
White Glass	S941935	20	95.7	0.07	94.2	0.07
		60	97.0	0.05	96.3	0.00
		85	99.3	0.11	98.6	0.03
Ceram	024525	20	36.6	0.12	37.9	0.00
		60	49.2	0.02	48.7	0.00

Table 7: NPL values of standards prior to shipment to NRC

Table 7 shows NPL measurement results for the five standards sent to NRC before shipment to Canada. The measurements were made in the sequence: BG, RR, BG, RR, BG, where BG and RR refer to the bench gloss-meter and Reference Reflectometer respectively. The RR values (shown in bold) are those used in the intercomparison. The BG values are used to assess the stability of samples throughout the intercomparison.

The NRC measurement results are given in Table 8. These values are described as being the adjusted Mean NRC-BAM Specular Gloss Values.

Table 9 gives the NPL results after the samples had returned from Canada. These results were obtained from the NPL bench gloss-meter. The first column gives values measured on the day the standards arrived back. Samples were then cleaned and re-measured. The

difference between the BG values before and after the samples were sent to Canada (denoted 'Change') was used in the evaluation of the overall intercomparison uncertainty.

Sample	Geometry /°	NRC Val /GU	NRC Unc /GU
EW97	20	72.37	0.34
	60	82.83	0.34
	85	98.42	0.36
KE97	20	90.5	0.34
	60	94.54	0.45
	85	99.66	0.34
KH97	20	1743	8
	60	897	4
	85	156.6	0.5
S941935	20	97.1	0.34
	60	98.21	0.45
	85	100.04	0.34
024525	20	36.67	0.34
	60	46.83	0.41

Table 8: Values of standards from NRC

Table 10 gives the differences between NPL and NRC results, along with the total combined uncertainty of NPL measurement, NRC measurement, and changes in the samples monitored using the NPL bench gloss-meter.

Sample	Geometry /°	BG 6/7/98 /GU	Change Pre clean /GU	BG 10/7/98 post clean. /GU	Effect of clean after return /GU	Change post clean /GU
EW97	20	71.10	-0.3	71.3	0.2	-0.1
	60	80.70	-0.5	81.0	0.3	-0.2
	85	94.70	-2.1	96.9	2.2	0.1
KE97	20	88.10	-1.1	89.1	1.0	-0.1
	60	92.30	-1.2	93.3	1.0	-0.2
	85	97.60	-0.8	98.3	0.7	-0.1
KH97	20	1718	-2.7	1717	-1.0	-3.7
	60	869	-2.3	869	0.0	-2.3
	85	150	-1.0	150	0.0	-1.0
S941935	20	95.40	1.2	95.4	0.0	1.2
	60	96.90	0.6	96.9	0.0	0.6
	85	98.10	-0.5	98.6	0.5	0.0
024525	20	36.90	-1.0	37.2	0.3	-0.7
	60	47.80	-0.9	48.1	0.3	-0.6

Table 9: Measurement at NPL of samples on return from NRC

Sample	Geometry /°	NPL Val /GU	NPL-NRC /GU	Uncertainty /GU
EW97	20	72.6	0.2	0.82
	60	82.8	-0.0	0.67
	85	98.0	-0.5	1.46
KE97	20	90.9	0.4	0.99
	60	94.4	-0.2	0.92
	85	99.2	-0.5	0.70
KH97	20	1739	-3.8	8.44
	60	883.4	-13.6	4.26
	85	156.6	0.0	0.89
S941935	20	95.7	-1.4	1.08
	60	97.0	-1.2	0.78
	85	99.3	-0.8	0.65
024525	20	36.6	-0.1	0.93
	60	49.2	2.4	0.77

Table 10: Difference between NPL and NRC

Figure 11 shows the absolute differences between NRC and NPL results. The values of the high gloss samples, EW97 and KE97 agree reasonably well, however the mirror KH97 and ground surface white glass sample 024525 do not agree so well for all geometries. However, the 3 GU difference at 20°, and 14 GU difference at 60° (not shown in the figure for reasons of scale) for KH97 constitute only 0.2 and 1.5 % of the value.

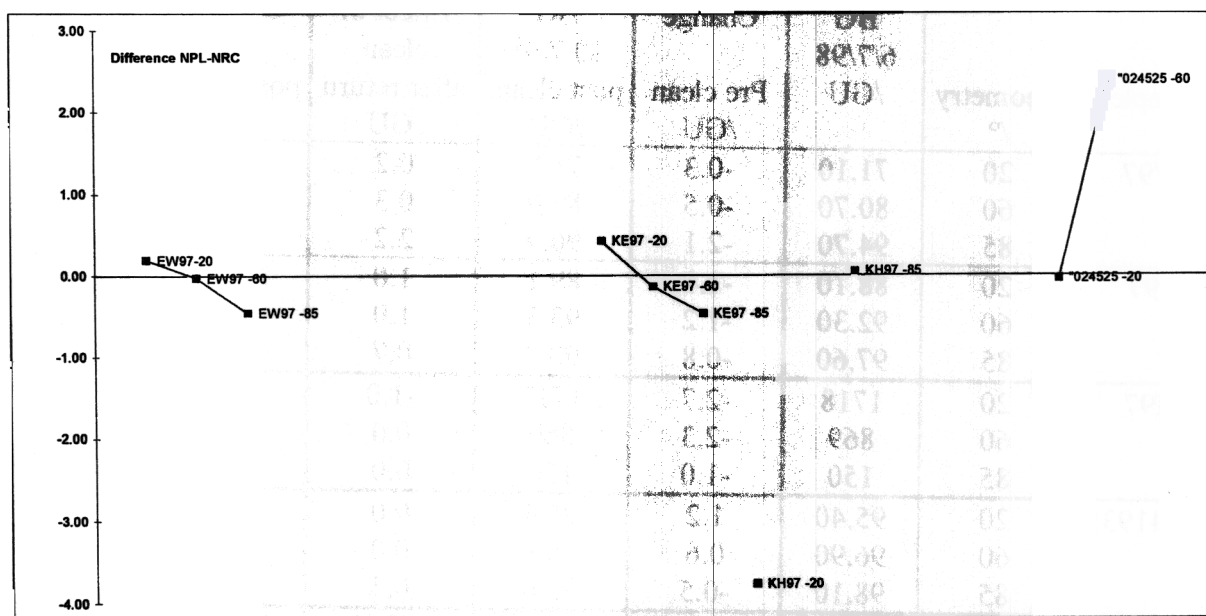


Figure11: Differences between NPL and NRC

7.2.5 CLEANING PROCEDURES AT NRC

One of the standards, EW97, was significantly damaged on its front side with several broken fragments shattering from one corner during transport from the UK to Canada. Two other standards in the box were not damaged, but all three standards were very dirty with several fingerprints. With agreement from NPL, NRC applied its standard cleaning procedure to all samples, with the exception of the mirror standard, prior to the gloss measurements at NRC. No measurements were carried out in the "as received" state.

The cleaning procedure adopted at NRC is as follows. The standards are cleaned using a soft nylon brush and a mild non-fluorescent detergent solution, such as Fisher Sparkleen, one tablespoon per gallon of water; or Flow Laboratories 7X cleaning solution, 1% solution in water. The latter is a mixture of anionic surface active agents and special solvents, with alkaline salts, such as complex phosphates, added as builders. The standards are then rinsed for several minutes under running distilled water, until there is no beading on their surface. They are dried under a jet of dry nitrogen gas, starting at one edge of the surface and slowly working towards the opposite edge, using a back-and-forth motion. Final drying is done under an infrared lamp for about 10 minutes. The standards are stored in a desiccator for a minimum of 24 hours, prior to their measurement.

MEASUREMENTS AT BAM

BAM INSTRUMENTAL SET UP

The instrument used at BAM is described as their Reference Reflectometer. At the time of writing this report, papers describing the construction detail remain in draft form only.

The basis for the construction is the geometric specification denoted in DIN 67530/ISO2813. Construction is largely based on the Spindler and Hoyer ‘microbank’ system and fixed on an aluminium table stabilised by a honeycomb system. The illumination and collection construction is symmetric with the light source (or detector) imaged onto a corresponding aperture. Using a Maxwellian view approach, additional diaphragms reduce the field of view permitting selection of the area viewed on the sample surface. A 6 V, 10 W halogen and an LMT detector with a photopic response connected to an LMT operational amplifier system was used.

The photometer/source combination was found to be within a 10% match to the $V(\lambda) \cdot \text{Illuminant A}$ combination. As the change in refractive index with wavelength of samples is of second order magnitude, BAM reasoned that errors resulting from this 10% difference were acceptable, and added that they would be common for both sample and standard, the system would be valid in the measurements for a Standard Illuminants C or D65.

The degree of polarisation $\left[(p_{\max} - p_{\min}) / (p_{\max} + p_{\min}) \right]$ was found to be in the order of 10%.

7.3.2 BAM EXPERIMENTAL CONDITIONS

Performance characteristics of the BAM instrument are:

Measuring Geometries	20°, 60°, 85°
Measurement areas	20°: 8.5 x 8 mm
	60°: 16 x 8 mm
	85°: 91.8 x 8 mm
Light source	filtered tungsten halogen lamp
Detector	photopic filter over photomultiplier
Illuminator/detector response	Illuminant A, 2° photopic observer

7.3.3 BAM UNCERTAINTIES

Uncertainties vary with sample and are given in Section 7.4.

7.3.4 CLEANING PROCEDURES AT BAM

Samples were cleaned at BAM upon receipt prior to measurement using water and Kernseife, a mild laundry soap.

7.3.5 BAM MEASUREMENT RESULTS

Table 11 shows NPL measurement results for the three standards sent to BAM before shipment to Germany. The measurements were made in the sequence: BG, RR, BG, RR, BG, where BG and RR refer to the bench gloss-meter and Reference Reflectometer respectively. Indications of repeatability are the difference between the two RR measurements and the Standard Error of the Mean of the three BG measurements. (These values are also given in the table.) The RR values (shown in bold) are those used in the intercomparison. The BG values are used to assess the stability of samples throughout the intercomparison.

Type	Sample	Geom /°	Reference Reflectometer mean /GU		Bench Glossmeter /GU	
			Mean	Abs Diff	Mean	StDevP
NPL Black Glass	KC97	20	89.0	0.13	88.0	0.22
		60	94.1	0.02	93.6	0.13
		85	99.4	0.06	98.6	0.03
Float Glass	KD97	20	90.8	0.07	89.1	0.03
		60	94.4	0.03	93.5	0.03
		85	99.3	0.05	98.4	0.07
	S941936	20	78.4	0.04	73.8	0.10
		60	82.5	0.20	81.3	0.10
		85	95.6	0.13	94.7	0.07

Table 11: NPL Measurements of standards prior to shipment to BAM

The BAM measurement results are given in Table 12. All values are in GU.

Sample	Geom	1	2	3	4	5	6	7	uncert
KC97	20	88.5	85.6	88.4	88.7	88.4	88.6		1.0
	60	93.5	92.0	93.6	93.7	93.6	93.7		1.0
	85	99.5	99.7	99.7	100.3	100.0	100.1		1.0
KD97	20	90.1	90.2	90.3				89.2	0.3
	60	93.8	94.0	94.1				93.6	0.3
	85	99.7	100.0	99.9				99.4	0.3
S941936	20	77.8	78.4	78.4					1.0
	60	85.2	85.6	85.6					1.0
	85	97.5	97.9	97.9					1.0

Table 12: Values of standards from BAM

Notes:

1. Measurement 1: sample as received, before cleaning
2. Measurement 2: after cleaning
3. Measurement 3: repeat measurement, (given in bold). Values used in intercomparison
4. Measurement 4: repeat measurement.
5. Measurement 5: after cleaning
6. Measurement 6: repeat measurement.
7. Column 7 gives specular gloss value calculated according to the Fresnel equations based on a refractive index of 1.527 measured at 589.3 nm.

Sample	Geom	BG 8/4/98 /GU	BG10/7/98 /GU	Change /GU	Effect of clean /GU	Change /GU
		before	after clean.	pre clean	after return	post clean
KC97	20	87.4	86.3	-0.6	-1.1	-1.7
	60	93.2	92.5	-0.4	-0.7	-1.1
	85	98.6	98.3	0.0	-0.3	-0.3
KD97	20	89.2	89.2	0.1	0.0	0.1
	60	93.5	93.4	-0.0	-0.1	-0.1
	85	98.6	98.4	0.2	-0.2	-0.3
S941936	20	77.4	77.2	3.6	-0.2	3.4
	60	85.0	84.6	3.7	-0.4	3.3
	85	96.6	96.3	1.93	-0.3	1.6

Table 13: Measurements of BAM Samples on return to NPL

Table 13 gives the NPL measurement results after the samples had returned from Germany. All these measurements were performed using the bench gloss-meter. The first column gives values measured on the day the standards arrived back. After a period of storage in a clean environment, samples were then cleaned and re-measured. The difference between the BG values before and after the samples were sent to Germany (denoted 'Change') was used in the evaluation of NPL uncertainty.

A summary of results is shown in Figure 12.

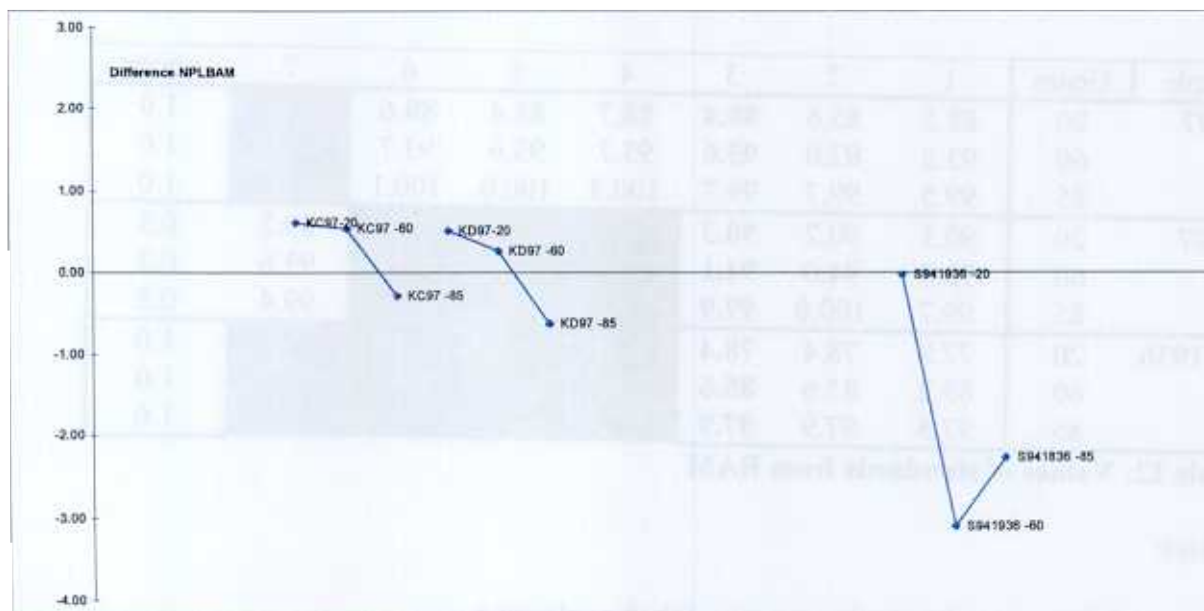


Figure 10 Summary of agreements between BAM and NPL

Table 14 gives the differences between NPL and BAM results, along with the total combined uncertainty of NPL measurement, BAM measurement, and changes in the samples monitored using the NPL bench gloss-meter.

Sample	Geometry	NPL-BAM /GU	Uncertainty /GU
KC97	20	0.6	1.70
	60	0.5	1.37
	85	-0.3	1.12
KD97	20	0.5	0.80
	60	0.3	0.62
	85	-0.6	0.56
S941936	20	-0.0	2.32
	60	-3.1	2.25
	85	-2.3	1.47

Table 14: Differences between NPL and BAM results

7.4 QUALITY OF STANDARDS

7.4.1 EFFECTS OF STORAGE

It should be noted that one of the standards, EW97 (black silica) sustained damage during transit from the UK to Canada. This is more a reflection of the quality of packing and treatment in carriage than of the mechanical strength of the standard. Packing is an important aspect of the use of gloss standards. Ideally the working face should not come in to contact with anything, yet the standard should be enclosed by an airtight clean container. Some black float glass prospective gloss standards were previously stored at NPL wrapped in tissue paper. This paper appeared to have absorbed atmospheric pollutants and deposited them onto the working surface. The resultant patchy dull dirty sheen dramatically reduced gloss readings and rendered the standards unusable unless cleaned.

7.4.2 EFFECTS OF CLEANING

Investigations into cleaning have shown that not all types of standards 'clean back' to the same gloss values. This may be due to the adhesion of dirt to the working face which is hard to remove unless resorting to a cleaning process which threatens to affect surface quality itself. In the case of white glass with a black painted edge and back surface, cleaning has sometimes removed some of the backing paint which is likely to affect results. Of all the standards examined, the black silica seems to clean back best to provide an acceptably repeatable set of gloss values.

7.5 MID AND HIGH GLOSS MEASUREMENTS

7.5.1 THE REQUIREMENT FOR MID AND HIGH GLOSS MEASUREMENTS

While the majority of published gloss standards refer to realisation of the scale at the 100 GU level, industries using these standards perform measurements on items with considerably higher or lower gloss. An example of this is the computer hardware industry who are required by BS7179 part 4: 1990 to ensure that the keyboard housing and key-tops have surfaces whose specular reflectance should be no greater than 45 GU (when measured by the method described in BS 3900: Part D5).

Mid gloss standards are not easy to realise. They rely on surface roughness to reduce effective refractive index. This surface quality is prone to erosion by cleaning and in some cases the increased porosity will actively increase hydrocarbon absorption.

Several types of semi-gloss standards are manufactured, and several of these were used in this intercomparison.

Table 15 demonstrates the fabrication techniques used to manufacture semi-gloss and high-gloss standards and gives the effective refractive index. Note that effective refractive index varies considerably with angle, values at 60° are given.

Standard	Type	Gloss value at 60° /GU	Method used	Approximate effective refractive index at 60°
KH97	polished metal on silica mirror	883	metallic	26.7
S941935	white glass with back and sides painted black	97.0	rough surface finish	1.55
EW97	black silica	82.8	reduced refractive index	1.46
024525	off-white 'pot' ceramic	49.2	glaze has rough finish	1.28
SF17ARC	matt ceramic	19.0	surface made matt by bombardment with steel balls	1.13

Table 15: High and Semi-gloss standards

7.5.2 INTERCOMPARISON AGREEMENT FOR MID AND HIGH GLOSS LEVELS

The first four of the five samples listed in Table 15 were included within the intercomparison and their results are reported in previous sections. The agreement between labs was generally poorer for gloss standards with low values than for those closer to the 100 GU level. Agreement was better (about 0.3% of value) for the higher gloss mirror samples.

8 SUMMARY AND CONCLUSIONS

8.1 PAPER STANDARDS

Gloss paper surveys cover a wide range of industries and generally use the same measurement unit and method. The three geometries used for the intercomparison are common to many paper standards. There are some inherent problems in system used to specify the unit. By definition, a sample with refractive index of 1.567 has a gloss value of 100 when illuminated by monochromatic radiation at 587.6 nm. However, most measurements are made using Illuminant C and a photopic detector. Dispersion in the material is not accounted for. This, and other shortfalls in the unit definition are detailed in Section 9.2 of this report. Samples of mid and low gloss samples (which unfortunately constitute a significant proportion of industrial applications) will often rely on scattering properties and non-flat surfaces to achieve their finish. This means that the angles, and cones of illumination and collection in the instrument become significantly critical.

8.2 COMMERCIAL GLOSSMETERS

The results from commercial instruments span a relatively wide range, particularly when calibrated at the 100 GU level and used to measure mid gloss samples. This seems to confirm concerns raised in Section 8.1 on the applicability of such instrumentation to provide absolute results for medium and low values when calibrated at the 100 GU level. The measurement of mid gloss samples is an issue which deserves further investigation. To a degree, this is an intractable problem since the change of reflectance with angle of any mid-gloss standard will not necessarily match that of a sample leading to errors. The stability (over hours) of commercial gloss-meters seems good (<0.1 GU). These instruments would be suitable for maintaining a production process within tolerance, though are likely to disagree with other different instruments. It is quite possible for two instruments calibrated using one plaque to yield different results when used to measure another samples, even if the second sample has an identical gloss value to that standard according to one instrument.

8.3 NPL GLOSS CALIBRATION FACILITY

An NPL gloss calibration service would use one of two methods.

In the first method, the sample is measured using the Reference Reflectometer fitted with the gloss optics, and regular reflectance values are converted to GU using the factors detailed in Section 9.2 of this document. Supplementary measurements are also made at the same time using the bench gloss-meter.

The second (cheaper) method can be used for recalibration or calibration of samples whose type has previously been characterised by the Reference Reflectometer. Since the ratio between readings for both instruments is known, results from the bench gloss-meter can be scaled accordingly to provide equivalent theoretical Reference Reflectometer values.

This system would require the stability of the bench gloss-meter to be monitored. This could be achieved by the periodic measurement of a standard on both instruments.

The uncertainty would be based on those methods and results derived within the intercomparison reported in this document.

8.4 INTERCOMPARISON OF GLOSS MEASUREMENT

NPL gloss measurements performed on the Reference Reflectometer were compared with BAM (Germany) and NRC (Canada). A tabular summary of the results is provided in Table 16 and graphically illustrated in Figure 13. For clarity, NRC and BAM values are given in blue and green respectively. The results of the mirror KH97 have been omitted from Figure 13 as the differences are about a decade greater than for the other samples (as are the gloss values).

The evaluation of uncertainties given in Table 16 and Figure 13 is given in Appendix 3. This includes the uncertainties in the measurement of laboratories, along with sample cleanliness and stability.

Sample/geom	NPL Value	Lab Val	NPL-Lab	Total Uncert at k=2
EW97_20	72.55	72.37	0.18	0.82
EW97_60	82.80	82.83	-0.03	0.67
EW97_85	97.96	98.42	-0.46	1.46
KC97_20	89.00	88.40	0.60	1.70
KC97_60	94.10	93.60	0.50	1.37
KC97_85	99.40	99.70	-0.30	1.12
KD97_20	90.80	90.30	0.50	0.80
KD97_60	94.40	94.10	0.30	0.62
KD97_85	99.30	99.90	-0.60	0.56
KE97_20	90.92	90.50	0.42	0.99
KE97_60	94.39	94.54	-0.15	0.92
KE97_85	99.18	99.66	-0.48	0.70
S941935_20	95.73	97.10	-1.37	1.08
S941935_60	97.00	98.21	-1.21	0.78
S941935_85	99.27	100.04	-0.77	0.65
S941936_20	78.40	78.40	0.00	2.32
S941936_60	82.50	85.60	-3.10	2.25
S941936_85	95.60	97.90	-2.30	1.47
24525_20	36.62	36.67	-0.05	0.93
24525_60	49.20	46.83	2.37	0.77
KH97_20	1739.22	1743.00	-3.78	8.44
KH97_60	883.36	897.00	-13.64	4.26
KH97_85	156.64	156.60	0.04	0.89

Table 16: Summary of intercomparison data for all labs. Blue and green denote NRC and BAM respectively.

Table 16 and Figure 13 show that the black silica and (black) float glass results agree well between all three laboratories. The differences between values measured by laboratories are either within, or close to quoted uncertainties. For the S941 'finished' surface white glass samples, agreement is not so good. This may be because these samples use a non-optically flat surface to reduce the effective refractive index. The resulting light scatter phenomena may not be measured similarly by the three laboratory instruments. Values for the mirror KH97 agree well at 20° and 85°, but not so well at 60° where the difference amounts to 1.5% of value and the estimated uncertainty is 0.5% of value.

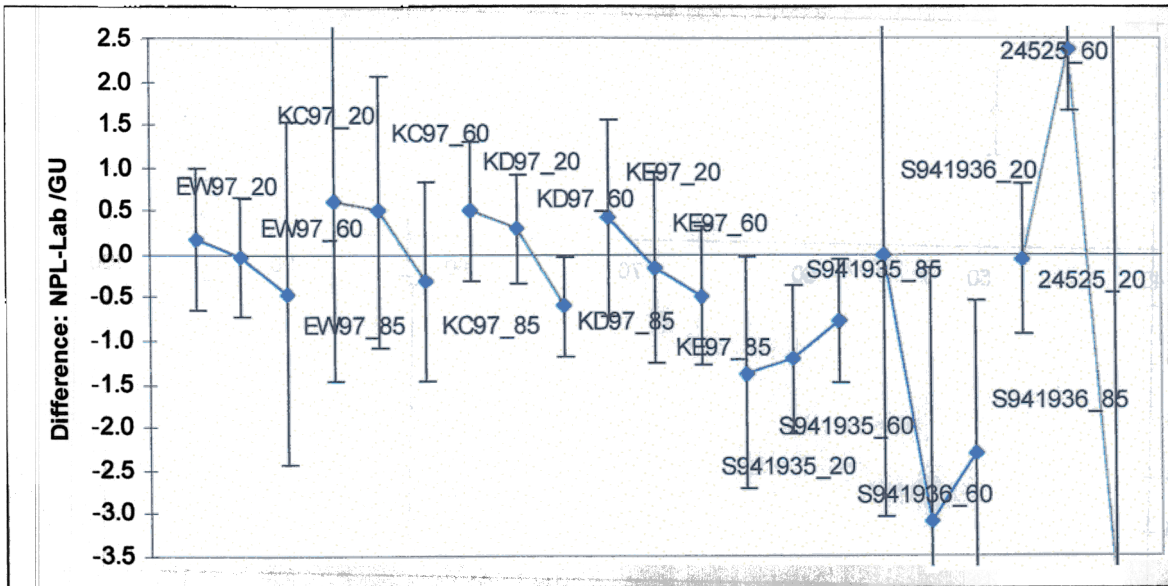


Figure 12: Summary of intercomparison data for all labs

There does not appear to be any trend of any laboratory reading consistently higher or lower at any angle.

The following Figures (14-16) give the results of the intercomparison by geometry as a function of gloss value. The error bars are the uncertainties of the intercomparison at the k=2 level.

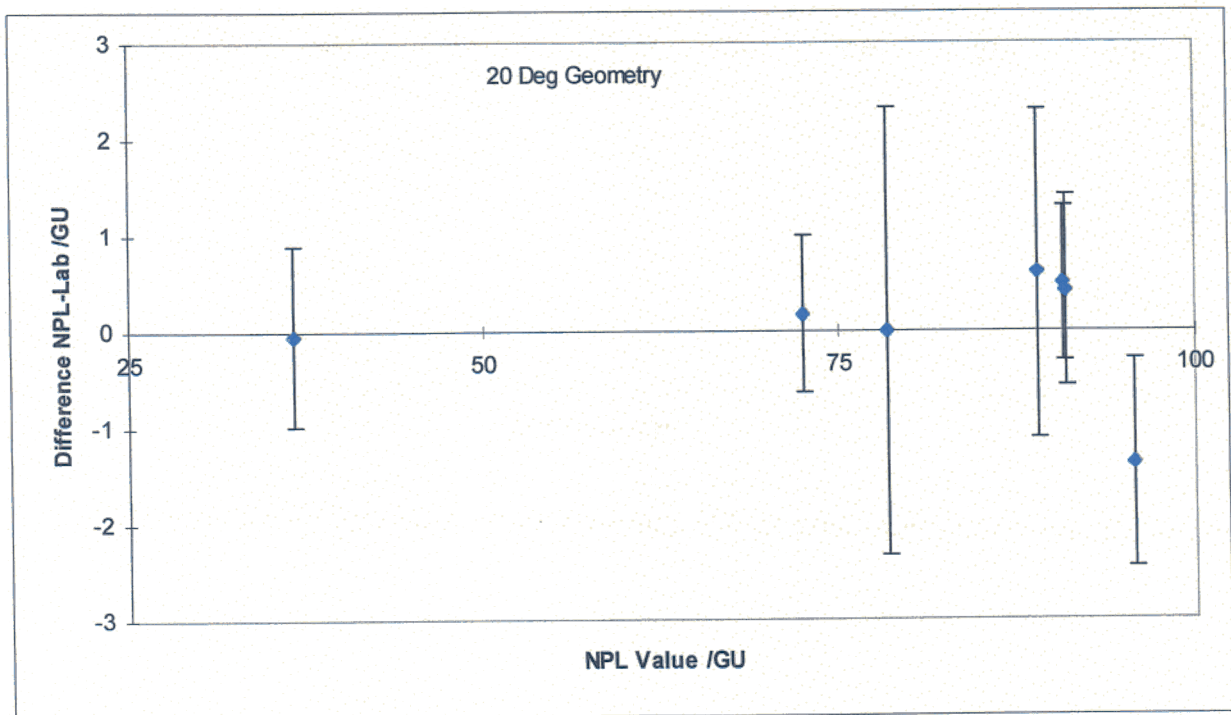


Figure 13: Intercomparison data for 20° geometry. Error bars give uncertainty at k=2.

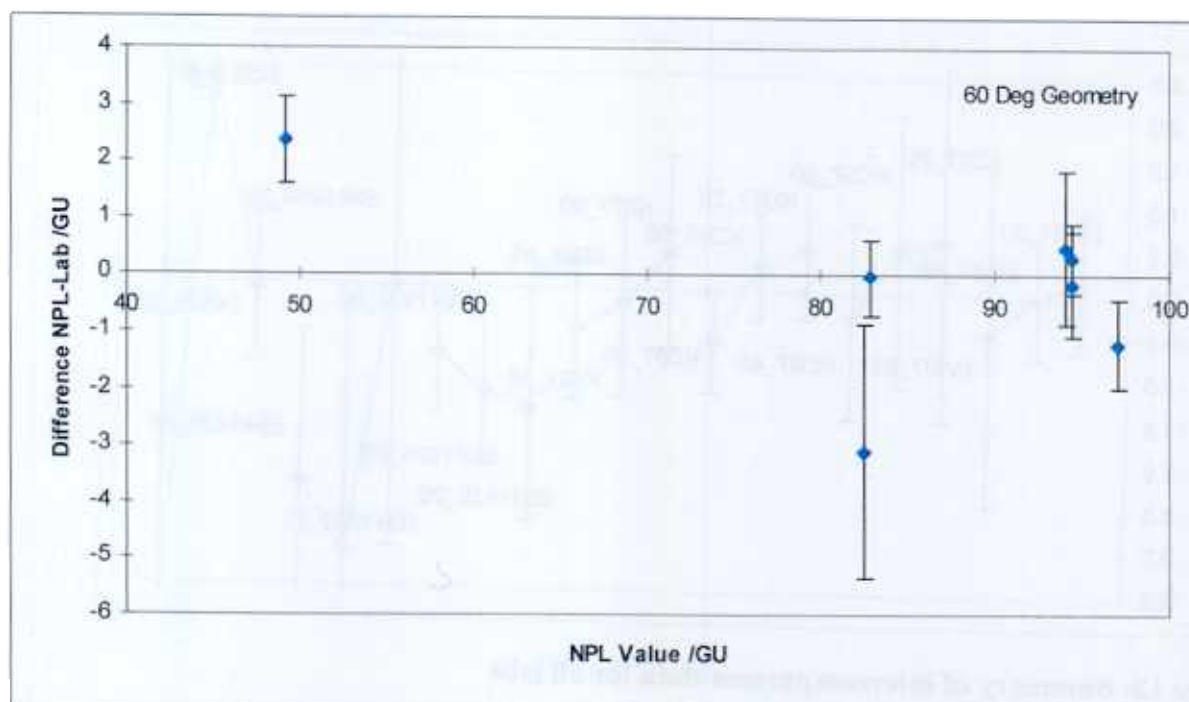


Figure 14: Intercomparison data for 60° geometry. Error bars give uncertainty at $k=2$.

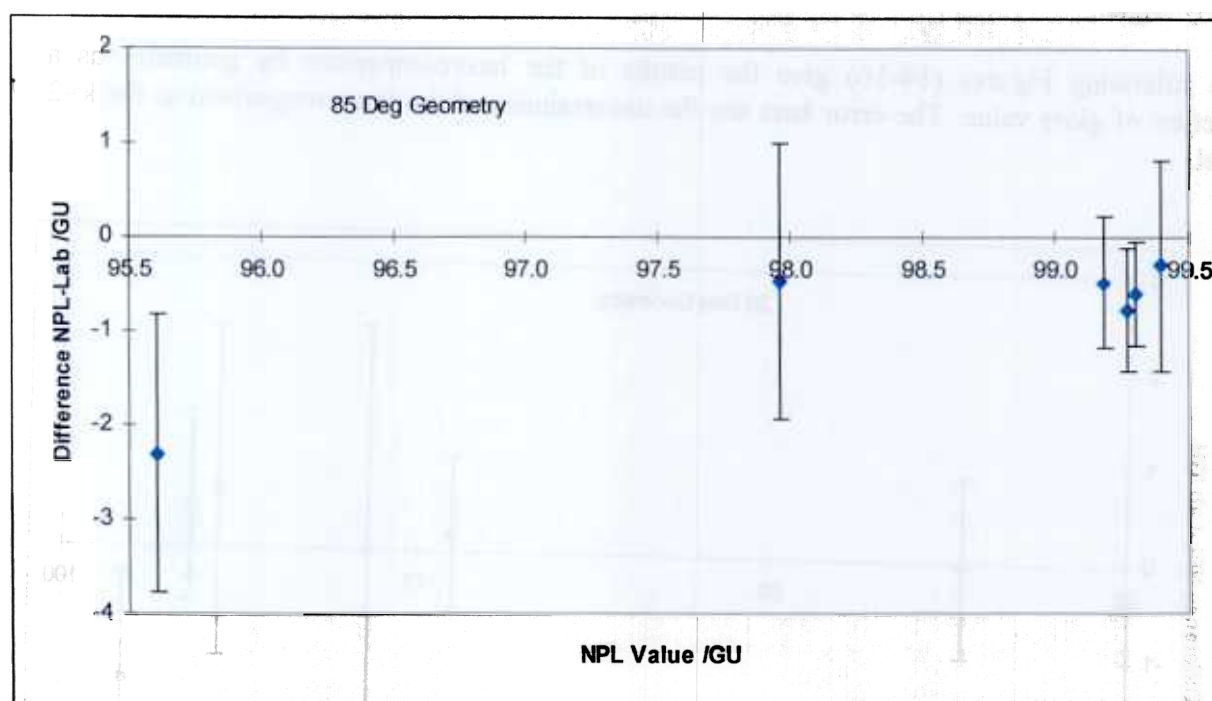


Figure 15: Intercomparison data for 85° geometry. Error bars give uncertainty at $k=2$.

Figures 14-16 may be compared with Figures 1-3 (diversity of results in commercial gloss-meters) with some qualifications:

Figures 1-3	Figures 14-16
Samples are a combination of practical standards and typical measured surfaces such as paper and paint.	Samples are a range of calibration standards.
Instrumental scales are all calibrated using a common standard at the 100 GU level.	Instrumental scales are independently evaluated by National Laboratories.
Measurements were all made in the same room at approximately the same time.	Measurements were made in different countries, in some cases months apart.
Instruments used were commercial gloss-meters	Instruments used were specially developed.

There are several possible explanations as to why the three labs obtained different results.

Although the cone angles are within tolerance, the patch sizes are not identical. These are compared in Table 17. Any sample non uniformity may compound with these different sizes to provide different results.

Lab	20°	60°	85°
NRC	7 x 12	13 x 10	70 x 10
NPL	10 x 10	14 x 10	115 x 10
BAM	8.5 x 8	16 x 8	91.8 x 8

Table 17: Comparison of illumination patch sizes

As sample cleanliness has a large bearing on result, it is likely that the three labs, employing different cleaning techniques may have 'cleaned back' to different degrees.

The effects of dispersion (change of refractive index with wavelength) may have a slight bearing on results at lower angles - particularly those at 20°, and to a lesser extent those at 60°.

None of the labs were able to obtain a source and detector combination equivalent to Illuminant C + 2° photopic observer. There was some variance in their exact realisations.

8.5 SUITABILITY OF TRANSFER STANDARDS

Cleaning was a major contributor to measurement uncertainty. It was very difficult to obtain repeatable results for some samples. Results at 20° and 60° for KC97 (black glass) and KE97 (float glass) changed significantly after cleaning, as did the 85° value for EW97 (black silica). However, the latter two did clean back to original values.

EW97 (black silica), KD97, KE97 (float glass) 24525 (matted ceramic) behaved well over the period of the intercomparison. On return to NPL, these samples cleaned back to <0.5 GU of the value originally measured prior to shipment abroad. Not so well behaved were the black backed white glass samples S941935 and S941936, or the NPL black glass sample KC97.

8.6 UNCERTAINTY IN GLOSS MEASUREMENTS THROUGHOUT THE WORLD

The world of calibrated gloss measurement can be represented by a flow chart of the type given in Figure 17. The degree of international agreement (a) is given in Figures 14-16, while the degree of instrumental variation (b) would be in the order of the values of Figures 1-3. The total measurement uncertainty (c) of shop floor instruments directly traceable through calibration to National Laboratories would approximate the sum of (a) and (b).

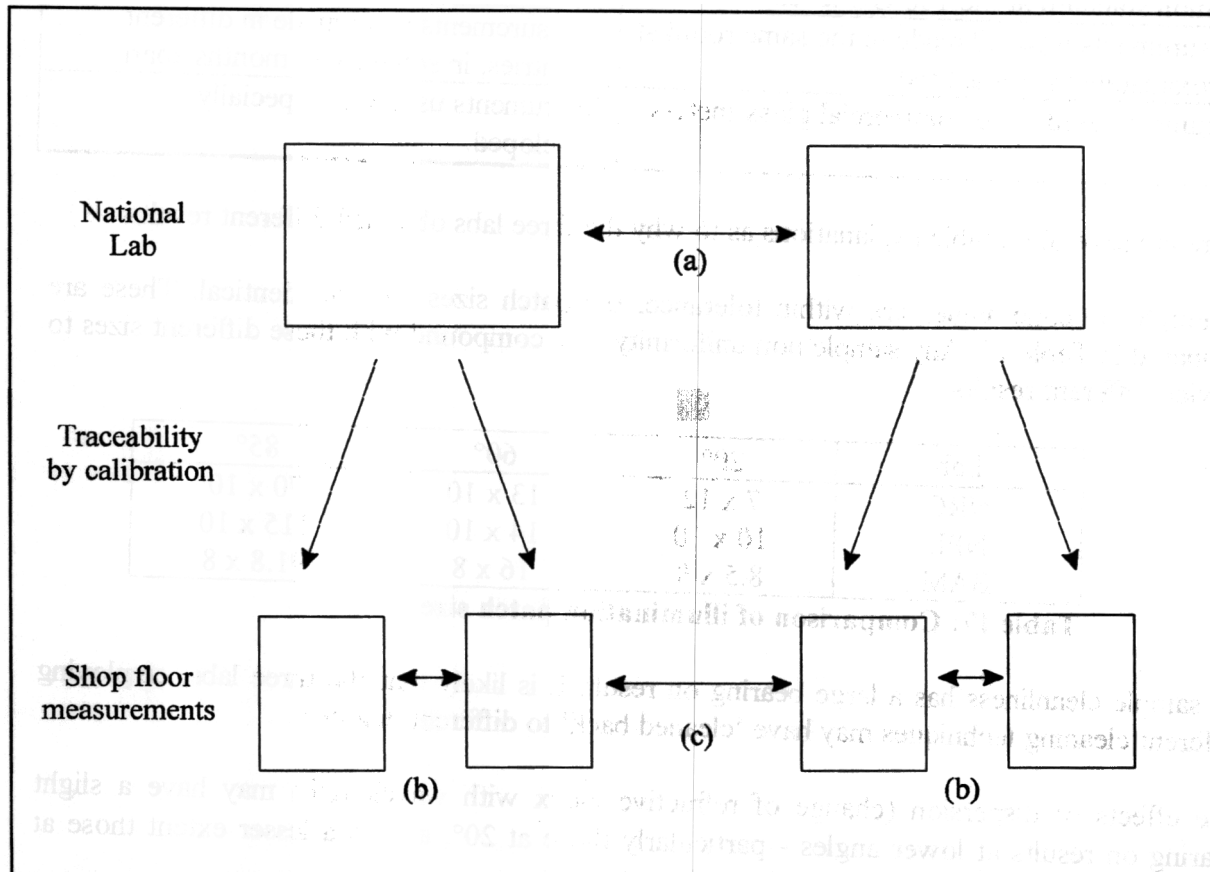


Figure 16: Measurements of gloss traceability schematic

9 REFERENCES

- HUNTER, R. S., The Measurement of Appearance, John Wiley & Sons, New York, 1975
- 2 MALTISON, I.H. Interspecimen Comparison of the Refractive Index of Fused Silica. *J. Opt. Soc. Am.*, 1965, **55**, 1205-1209
- 3 BUDDE, W., *Metrologia*, 1980, **16**, 1.

APPENDICES

APPENDIX 1 GLOSS STANDARD SPECIFICATIONS

The following list of standards has been abstracted from about 150 titles containing the word 'gloss', taken from the CD ROM Standards Infodisk held by NPL Main Library. Where the number of a standard is underlined, a copy of the standard has been obtained - Main Library has a selection of British Standards and a series of bound volumes containing all ASTM standards, while UKAS has all British Standards on CD ROM. The qualification [Infodisk] indicates that the preceding information comes from the disk; {Sheen, Rhopoint} indicates that these suppliers quote the standard in their literature.

GENERAL

ASTM D523 1994 (USA)

TEST METHOD FOR SPECULAR GLOSS

Nominally the same as ISO 2813, although differently drafted. {Sheen, Rhopoint}

PAINT

BS 3900: Part D 5 1995 (UK)

METHODS OF TEST FOR PAINTS - OPTICAL TESTS ON PAINT FILMS - MEASUREMENT OF SPECULAR GLOSS OF NON-METALLIC PAINT FILMS AT 20°, 60° AND 85°

Identical to ISO 2813; supersedes 1980 version. Angle tolerances are now all 0.1°; formerly they were 0.1°, 0.2°, 0.5°. Source image dimension in perpendicular plane is now $2.5^\circ \pm 0.5^\circ$; formerly it was 3° maximum with no minimum. Primary standard is now black glass only, formerly it was black or clear. {Sheen, Rhopoint}

ISO2813 1994

PAINTS AND VARNISHES - DETERMINATION OF SPECULAR GLOSS OF NON-METALLIC PAINT FILMS AT 20°, 60° AND 85°

The principal standard; supersedes 1978 version. {Sheen, Rhopoint}

DIN 67 530 1982 (Germany)

REFLECTOMETER AS A MEANS FOR GLOSS ASSESSMENT OF PLANE SURFACES OF

PAINTS AND PLASTICS

REFLEKTOMETER ALS HILFSMITTEL ZUR GLANZBEURTEILUNG AN EBENENANSTRICH-UND KUNSTSTOFF-OBERFLACHEN

Similar to ISO 2813: 1978 version; English BSI translation [Infodisk] {Sheen, Rhopoint}

NFT 30-064 1977 (France)

PAINTS - MEASUREMENT OF THE SPECULAR GLOSS OF NON-METALLIC PAINT FILMS AT 20,60 AND 85°

PEINTURES - MESURAGE DE LA REFLEXION SPECULAIRE DES FEUILS DE PEINTURE NON METALLISE A 20, 60 ET 85°

Technically equivalent to ISO 2813: 1978 [Infodisk]

SS 18 41 84 1982 (Sweden)

PAINTS AND VARNISHES - MEASUREMENT OF SPECULAR GLOSS OF NON-METALLIC PAINT FILMS AT 20, 60 & 85°

Identical to ISO 2813: 1978 [Infodisk]

AS 1580: MTD 602.2 1974 (Australia)

METHODS OF TEST FOR PAINTS AND RELATED MATERIALS - SPECULAR GLOSS

Technically equivalent to ISO 2813: 1978 [Infodisk] (Sheen)

BS AU148: Part 5 1969

METHODS OF TEST FOR MOTOR VEHICLE PAINTS - GLOSS MEASUREMENT

Test to be carried out in accordance with BS 3900, Part D2, Gloss (specular reflection value), which specifies 45° incidence angle; this appears to be withdrawn [not in 1995/6 BSI Cat.].

PLASTICS

BS 2782: Pt 5, Method 520A 1992

METHODS OF TESTING PLASTICS - OPTICAL AND COLOUR PROPERTIES, WEATHERING - DETERMINATION OF SPECULAR GLOSS

Similar to ISO 2813

ASTM D 2457 1990

TEST METHOD FOR SPECULAR GLOSS OF PLASTIC FILMS

Ref. Std ASTM D 523 [Infodisk]. Specifies the primary standard as a perfect mirror with a defined gloss value of 1000 [Zwinkels]. 20°, 60° and 45°; the 45° method is as ASTM C346 for ceramics. {Sheen, Rhopoint}

METALS

BS 6161: Part 12 1987

METHODS OF TEST FOR ANODIC OXIDATION COATINGS ON ALUMINIUM AND ITS ALLOYS - MEASUREMENT OF SPECULAR REFLECTANCE AND SPECULAR GLOSS AT ANGLES OF 20°, 45°, 60° OR 85°

Ref. Std BS 3900: Part D5 (1980); technically equivalent to ISO 7668; replaces BS 1615:1972 Infodisk BSI Cat.]. At 45°, dimensions of source image and receptor aperture are as for 60°. Squares with sides equal to the shorter sides of the rectangles are also recommended. Alternatively, total reflection in a 45° prism is used as a reference; source image and receptor aperture are then circular, both with angular diameter $3.44^\circ \pm 0.23^\circ$ (1.5 mm $\pm$ 0.1 mm at 25.4 mm focal length) {Sheen Rhopoint}

ISO 7668 1986

ANODIZED ALUMINIUM AND ALUMINIUM ALLOYS - MEASUREMENT OF SPECULAR REFLECTANCE AND SPECULAR GLOSS AT ANGLES OF 20°, 45°, 60° OR 85°.

ISO 5190

ANODIZING OF ALUMINIUM AND ITS ALLOYS - EVALUATION OF UNIFORMITY OF APPEARANCE OF ARCHITECTURAL ANODIC FINISHES - DETERMINATION OF DIFFUSE REFLECTANCE AND SPECULAR GLOSS

PAPER

DIN 54502 1992
 TESTING OF PAPER AND BOARD; REFLECTOMETER AS MEANS FOR GLOSS
 ASSESSMENT OF PAPER AND BOARD
*PRÜFUNG VON PAPIER UND PAPPE; GLANZBEURTEILUNG EBENER PAPIER- UND
 PAPPE-OBERFLÄCHEN MIT HILFE VON REFLEKTOMETERWERTEN*

ASTM D 1223 1993
 TEST METHOD FOR SPECULAR GLOSS OF PAPER AND PAPERBOARD AT 75°.
 Has an unusual converging beam geometry. Specifies the primary standard as black glass of
 refractive index 1.540, not 1.567, at the sodium D-line having a defined gloss value of 100
 [Zwinkels]

ASTM D 1834 1990
 TEST METHOD FOR 20° SPECULAR GLOSS OF WAXED PAPER
 Another unusual converging beam geometry, different to the previous one

TAPPI T480 OM-90 1990 (USA)
 SPECULAR GLOSS OF PAPER AND PAPERBOARD AT 75
 Same text as ASTM D 1223 (Sheen, Rhopoint)

TAPPI 653 1990
 SPECULAR GLOSS OF WAXED PAPER (20°)
 Probably the same text as ASTM D 1834 {Rhopoint}

JIS - P8142 1993 (Japan)
 TESTING METHOD FOR 75 0 SPECULAR GLOSS OF PAPER AND PAPERBOARD
 (Sheen, Rhopoint)

FURNITURE

BS 3962: Part 1 1980
 METHODS OF TEST FOR FINISHES FOR WOODEN FURNITURE - ASSESSMENT OF
 LOW ANGLE GLARE BY MEASUREMENT OF SPECULAR GLOSS AT 85°
 Similar to ISO 2813: 1978 [Infodisk]

FLOOR POLISH

ASTM D 1455 1987
 TEST METHOD FOR 60° SPECULAR GLOSS OF EMULSION FLOOR POLISH
 Ref. std ASTM D 523 [Infodisk] {Sheen}

CERAMICS

ASTM C 346 1987

TEST METHOD FOR 45° SPECULAR GLOSS OF CERAMIC MATERIALS

Ref. std ASTM D 523 [Infodisk]

ASTM C 584 1981

TEST METHOD FOR 60° SPECULAR GLOSS OF GLAZED CERAMIC WHITEWARES
AND RELATED PRODUCTS

Ref. std ASTM D 523 [Infodisk] {Sheen}

FABRICS

BS 3424: Method 31: Part 28 1993

TESTING COATED FABRICS - DETERMINATION OF SPECULAR GLOSS

Draft [Infodisk. Not on NAMAS CD ROMs; not in 1995/6 BSI Cat.]

Standard geometric conditions

ISO 2813, BS 3900, ASTM D523 (paints)

		In plane	Out of plane
Source image		$0.75^\circ \pm 0.25^\circ$	$2.5^\circ \pm 0.5^\circ$
Receptor	20°	$1.8^\circ \pm 0.05^\circ$	$3.6^\circ \pm 0.1^\circ$
Receptor	60°	$4.4^\circ \pm 0.1^\circ$	$11.7^\circ \pm 0.2^\circ$
Receptor	85°	$4.0^\circ \pm 0.3^\circ$	$6.0^\circ \pm 0.3^\circ$

ASTM D2457, C346 (plastics, ceramics)

Source image	45°	$1.4^\circ \pm 0.4^\circ$	$3.0^\circ \pm 1.0^\circ$
Receptor		$8.0^\circ \pm 0.1^\circ$	$10.0^\circ \pm 0.2^\circ$

BS 6161 (anodized aluminium)

Source image		$3.44^\circ \pm 0.23^\circ$	
Receptor	45°	$3.44^\circ \pm 0.23^\circ$ (circular)	

DIN 54 502 (paper)

Source image		$1.0^\circ \pm 0.1^\circ$	$2.5^\circ \pm 0.1^\circ$
Receptor			

APPENDIX 2 GLOSS UNIT DEFINITION

Gloss units are defined so that a glass of refractive index $n = 1.567$ gives 100 for any angle of incidence. Using Fresnel's equations, the theoretical reflectance R for a glass of this refractive index can be calculated.

$$R_s = \left(\frac{\cos\theta - (n^2 - \sin^2\theta)^{1/2}}{\cos\theta + (n^2 - \sin^2\theta)^{1/2}} \right)^2 \quad \text{----- Equation 1}$$

$$R_p = \left(\frac{n^2 \cos\theta - (n^2 - \sin^2\theta)^{1/2}}{n^2 \cos\theta + (n^2 - \sin^2\theta)^{1/2}} \right)^2 \quad \text{----- Equation 2}$$

$$R = (R_s + R_p)/2 \quad \text{----- Equation 3}$$

Substituting $n=1.567$ we obtain:

Angle	Reflectance (%) giving 100 gloss units	Factor
20	4.908	20.376
60	10.006	9.994
85	61.915	1.6151

These factors were those used by NPL in this work.

The 'Factor' column gives us a value which is multiplied by the measured reflectance to provide a result in gloss units. ($=100/\text{reflectance}$)

The intention of the unit system is for the value of reflectance at 60° to be exactly 10, however this means that the definition requires the refractive index to be stated at four decimal places (1.5666). Published standards state a refractive index of 1.567. Unfortunately this definition is not precise enough to provide results of required precision.

There are further complications in that the paper standard defines the glass refractive index for the sodium D wavelength of 587.6 nm, yet calls for measurements to be made using Illuminant C and a photopic detector. For a typical glass, the effective refractive index is then about 0.0018 higher due to dispersion. This decreases the above factors:

Angle	Factor for Ill C, photopic response
20	20.276
60	9.966
85	1.6147

APPENDIX3: DETERMINATION OF INTERNATIONAL UNTERCOMPARISON UNCERTAINTIES

The estimation of uncertainty for the intercomparison takes several factors into account. In order to avoid over-accounting, not all uncertainty contributions are included fully in the final sum. Instead, weighting factors are used in the evaluation, so that the final overall uncertainty (U) at the k=2 level is:

$$U = 2 * \sqrt{\sum_i (w_i * u_i)^2}$$

Where w_i is the weighting for uncertainty contribution u_i .

The different uncertainty contributions are given in Table A.3.1:

Table A.3.1 Weighting factors given to each uncertainty contribution.

Uncertainty contribution			Weighting factor
1	Reference Reflectometer	Measurements on NPL instrument (described in detail in Section 5.2)	1
2	Repeatability 1	Difference between two NPL RR measurements	1
3	Repeatability 2	Mean standard deviation of the population of NPL BG results	0
4	Lab uncertainty	Uncertainty quoted by BAM or NRC	1
5	Cleanliness	Effect of cleaning measured using BG on return of samples to NPL	0.5
6	Stability	Change in BG reading before dispatch to BAM or NRC and on return after cleaning.	0.5

Determination of Reference Reflectometer Uncertainties

Table A.3.2: RR Uncertainty source at k=1 level	%R	20° GU	60° GU	85° GU
<i>Factor:</i>		20.276	9.966	1.6147
Linearity = 0.038 (peak to peak)	0.0140	0.28	0.14	0.02
Beam/detector Uniformity	0.0025	0.05	0.02	0.00
Uniformity of sample		0.20	0.20	0.20
Spectral illuminator and Response		0.10	0.10	0.10
Temperature (over range 20-26 °C)	0.00	0.00	0.00	0.00
Humidity (non condensing over range 50-75 %RH)	0.00	0.00	0.00	0.00

Sum at k=1

20° GU	60° GU	85° GU
0.36	0.26	0.22

Notes.

The uncertainty values given in %R column of the Table A.3.2 are converted to GU uncertainties in subsequent columns using the given (italicized) factors)

- The RR uncertainties are summed in quadrature at the k=1 level
- Repeatability (Table A.3.3) varies with sample and is converted from a square coverage factor to one at the k=1 level.
- The RR uncertainties are summed (in quadrature) with the repeatability. The sum is finally multiplied by 2 to give the k=2 value.

Table A.3.3: Repeatability (diff between 2 RR results)						
	square coverage			at k=1		
	20° GU	60° GU	85° GU	20° GU	60° GU	85° GU
EW97	0.03	0.04	0.32	0.02	0.03	0.22
KC97	0.13	0.02	0.06	0.09	0.01	0.04
KD97	0.07	0.03	0.05	0.05	0.02	0.03
KE97	0.02	0.10	0.04	0.01	0.07	0.03
KH97	0.97	0.17	0.04	0.67	0.12	0.03
S941935	0.07	0.05	0.11	0.05	0.03	0.08
S941936	0.04	0.20	0.13	0.03	0.14	0.09
24525	0.12	0.02		0.08	0.01	

Table A.3.4: NPL RR Total uncertainties (Above two summed in quadrature)

k=2	20° GU	60° GU	85° GU
EW97	0.77	0.58	0.89
KC97	0.91	0.56	0.53
KD97	0.83	0.57	0.52
KE97	0.76	0.67	0.51
KH97	2.07	0.77	0.51
S941935	0.83	0.60	0.60
S941936	0.79	0.81	0.63
24525	0.90	0.56	

Table A.3.5: Repeatability (mean stdevp in BG results)

	k=2			k=1		
	20° GU	60° GU	85° GU	20° GU	60° GU	85° GU
EW97	0.03	0.10	0.27	0.02	0.05	0.14
KC97	0.22	0.13	0.03	0.11	0.07	0.02
KD97	0.03	0.03	0.07	0.02	0.02	0.04
KE97	0.03	0.03	0.09	0.02	0.02	0.05
KH97	0.67	0.33	0.00	0.34	0.17	0.00
S941935	0.07	0.00	0.03	0.04	0.00	0.02
S941936	0.10	0.10	0.07	0.05	0.05	0.04
24525	0.00	0.00		0.00	0.00	

Table A.3.6: Lab uncertainty

	k=2			k=1		
	20° GU	60° GU	85° GU	20° GU	60° GU	85° GU
EW97	0.34	0.34	0.36	0.17	0.17	0.18
KC97	1.00	1.00	1.00	0.50	0.50	0.50
KD97	0.30	0.30	0.30	0.15	0.15	0.15
KE97	0.34	0.45	0.34	0.17	0.23	0.17
KH97	8.00	4.00	0.50	4.00	2.00	0.25
S941935	0.34	0.45	0.34	0.17	0.23	0.17
S941936	1.00	1.00	1.00	0.50	0.50	0.50
24525	0.34	0.41		0.17	0.21	

Table A.3.7: Standard Cleanliness (Diff in BG readings before and after cleaning)

	square coverage			k=1		
	20° GU	60° GU	85° GU	20° GU	60° GU	85° GU
EW97	0.20	0.30	2.20	0.12	0.17	1.27
KC97	-1.10	-0.70	-0.30	-0.64	-0.40	-0.17
KD97	0.00	-0.10	-0.20	0.00	-0.06	-0.12
KE97	1.00	1.00	0.70	0.58	0.58	0.40
KH97	-1.00	0.00	0.00	-0.58	0.00	0.00
S941935	0.00	0.00	0.50	0.00	0.00	0.29
S941936	-0.20	-0.40	-0.30	-0.12	-0.23	-0.17
24525	0.30	0.30		0.17	0.17	

Table A.3.8: Stability**difference between BG results (1) before dispatch; (2) on receipt after cleaning**

	square coverage			k=1		
	20° GU	60° GU	85° GU	20° GU	60° GU	85° GU
EW97	-0.07	-0.20	0.07	-0.04	-0.12	0.04
KC97	-1.67	-1.13	-0.27	-0.96	-0.65	-0.15
KD97	0.07	-0.13	-0.03	0.04	-0.08	-0.02
KE97	-0.13	-0.23	-0.07	-0.08	-0.13	-0.04
KH97	-3.67	-2.33	-1.00	-2.12	-1.35	-0.58
S941935	1.23	0.60	0.03	0.71	0.35	0.02
S941936	3.40	3.30	1.63	1.96	1.91	0.94
24525	-0.70	-0.60		-0.40	-0.35	

Table A.3.9: Total summed uncertainties using weightings given in A.3.1.

	k=1			k=2		
	20° GU	60° GU	85° GU	20° GU	60° GU	85° GU
EW97	0.41	0.33	0.73	0.82	0.67	1.46
KC97	0.85	0.68	0.56	1.70	1.37	1.12
KD97	0.40	0.31	0.28	0.80	0.62	0.56
KE97	0.50	0.46	0.35	0.99	0.92	0.70
KH97	4.22	2.13	0.44	8.44	4.26	0.89
S941935	0.54	0.39	0.33	1.08	0.78	0.65
S941936	1.16	1.12	0.73	2.32	2.25	1.47
24525	0.47	0.39		0.93	0.77	

The values given in Table A.3.9 are in terms of GU. Table A.3.10 gives uncertainties in terms of percentage of the value. As KH97 is a mirror with a very high reading, the percentage value is possibly a better way of representing the result.

Table A.3.10: Uncertainties of Table A.3.9 expressed as percentage of value.

	k=1			k=2		
	20° % of val	60° % of val	85° % of val	20° % of val	60° % of val	85° % of val
EW97	0.56	0.40	0.75	1.12	0.80	1.49
KC97	0.96	0.73	0.57	1.91	1.45	1.13
KD97	0.44	0.33	0.28	0.88	0.65	0.56
KE97	0.55	0.49	0.35	1.09	0.98	0.70
KH97	0.24	0.24	0.28	0.49	0.48	0.57
S941935	0.56	0.40	0.33	1.13	0.80	0.66
S941936	1.48	1.36	0.77	2.96	2.72	1.54
24525	1.27	0.79		2.55	1.57	