

REPORT

COOMET INTERNATIONAL COMPARISON OF RELATIVE REFLECTANCE MEASUREMENTS

Report on NPL Measurements
for PTB, Friedrichshagen, Berlin

Dr P J Clarke

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COOMET INTERNATIONAL COMPARISON OF RELATIVE REFLECTANCE MEASUREMENTS

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SUMMARY

As part of COOMET project "152/DE-a/97 'Photometry and Radiometry' - International comparison of relative reflectance measurements", measurements were made on a number of samples supplied by PTB Berlin-Friedrichshagen.

The samples were 8 matt, neutral and coloured, opal glasses of Russian production and 1 matt opal glass of German production. Relative measurements of 7 of the samples were made in the specular included geometry against one of the supplied white Russian opals. This white Russian opal and the remaining sample, another white Russian opal, were also measured against NPL master matt white standards. Reflectance data for the neutral tiles is presented at 10 nm intervals and that for the coloured tiles at 5 nm intervals.

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Approved on behalf of Managing Director, NPL
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COOMET INTERNATIONAL COMPARISON OF RELATIVE
REFLECTANCE MEASUREMENTS

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COOMET INTERNATIONAL COMPARISON OF RELATIVE REFLECTANCE MEASUREMENTS

1 INTRODUCTION

As part of COOMET project 152/DE-a/97 'Photometry and Radiometry' - International comparison of relative reflectance measurements, measurements were made on a number of samples supplied by PTB Berlin-Friedrichshagen. The relative nature of the measurements to be made was emphasised by PTB. This intercomparison is not a direct comparison of reflectance scales.

The samples were 8 matt neutral and coloured opal glasses of Russian production and 1 matt opal glass of German Production. The Russian opals are 2 whites, light grey, dark grey, red, green, blue and black, and the German opal is a matt white.

Measurements were to be made in specular included geometry, from 380 to 780 nm, with data presented at 10 nm intervals for neutral samples and 5 nm intervals for coloured samples. A patch size of 20 - 30 mm diameter was asked for. This is not achievable on the Lambda 9 spectrophotometer, and a patch size of 3 x 17 mm was used instead. Bandwidth was to be in the range 2 - 5 nm and the temperature was to be $23 \pm 0.5^\circ\text{C}$.

One of the white Russian opals was to be measured against an NPL master white standard. The other white Russian Opal was the reference that the other Russian opals and German opal were to be measured against.

As an addition to the above measurements NPL was also asked to measure the white Russian opal, used for the relative measurements of the other opals, against an NPL master white standard. It was agreed that absolute colour data would be calculated by PTB.

2 MEASUREMENT OF SAMPLES

2.1 SAMPLE IDENTIFICATION

The 9 samples supplied are:-

Russian Opals:-

NM 24-12-68	White opal to be measured on NPL scale.
W1 01-1-85 W	White opal for measurement of other opals. (Also to be measured on NPL scale).
H2 01-2-85 HG	Light grey opal
D3 01-3-85 DG	Dark grey opal
R4 01-4-85 R	Red opal
G5 01-5-85 G	Green opal
B6 01-6-85 B	Blue opal
NS SU-91-S	Black opal

German Opal:-

WOL 708549	White opal
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2.2 SUMMARY OF MEASUREMENT AND INSTRUMENT PARAMETERS

Measurements were made using a Perkin Elmer Lambda 9 spectrophotometer fitted with a 150 mm integrating sphere.

Size of measurement aperture:- 15 x 23 mm

Size of illuminating area - 3 x 17 mm

Measurement geometry - Specular included

Angle of incident light on the sample - 8°

Measurement temperature- 23 ± 0.5°C

Scan speed - 240 nm/min

Spectral bandwidth - 2 nm

Response time - 0.5 s

NPL white standard - WT42 matt white ceramic tile

2.3 MEASUREMENT OF WHITE OPALS AGAINST NPL MASTER STANDARDS

The white Russian opals NM 24-12-68 and W1 01-1-85 W were calibrated against NPL master matt white ceramic tile WT42 in specular included geometry. The calibrations were made over the spectral range 380 to 780 nm at 5 nm intervals using the Lambda 9 spectrophotometer. An area 17 mm x 3 mm in the centre of each opal was used. Each measurement consisted of scans made in the order: master, sample, master. The uncorrected values were calculated and the appropriate dark error and specular beam error corrections were applied to them. Two sets of measurements were made on separate occasions on the opals, one with the label on the back upright and the other with the label inverted. The mean of the two scans was calculated. The 5 nm interval measurements were converted to 10 nm interval measurements using a triangular weighting function over an interval of 20 nm centred on the required wavelength. The weights were 0.5 at the centre, 0.25 at ± 5 nm from the centre, and 0 at ± 10 nm. The absolute reflectances are given in Tables 1 and 2. Table 3 contains the data for the NPL master matt white tile WT42. The reflectances of NM 24-12-68 relative to the NPL master matt white WT42 are given in Table 4.

2.4 MEASUREMENT OF SAMPLES AGAINST RUSSIAN OPAL W1 01-1-85 W

The opals H2 01-2-85 HG - light grey opal, D3 01-3-85 DG - dark grey opal, R4 01-4-85-R - red opal, G5 01-5-85 G - green opal, B6 01-6-85 B - blue opal, NS SU-91-S - black opal and WOL 708549 - white opal, were calibrated against Russian opal W1 01-1-85 W in the specular included geometry. The calibrations were made over the spectral range 380 to 780 nm at 5 nm intervals using the Lambda 9 spectrophotometer. An area 17 mm x 3 mm in the centre of each opal was used. Each measurement consisted of scans made in the order: master, sample, master. The uncorrected values were calculated and the appropriate dark error and specular beam error corrections were applied to them. Two sets of measurements were made on separate occasions on the opals, one with the label on the back upright and the other with the label inverted. The mean of the two scans was calculated. The 5 nm interval measurements for the neutral tiles were converted to 10 nm interval measurements using a triangular function. The reflectances are given in Tables 5 to 11.

3 UNCERTAINTIES OF CALIBRATION

3.1 ABSOLUTE REFLECTANCE UNCERTAINTIES

The uncertainty of calibration in the absolute spectral values for the specular included (8°/t) geometry for the wavelength range 320 to 460 nm had been previously assessed and is given by the formula:

$$\Delta R = \pm (0.05 + 0.0055R) \%$$

and for the wavelength range 465 to 780 nm is:

$$\Delta R = \pm (0.05 + 0.0035R) \%$$

where R is the spectral reflectance.

3.2 RELATIVE REFLECTANCE UNCERTAINTIES

The uncertainty of calibration in the relative spectral values for the specular included (8°/t) geometry for the wavelength range 320 to 460 nm had been previously assessed and is given by the formula:

$$\Delta R = \pm (0.05 + 0.0025) \%$$

and for the wavelength range 465 to 780 nm is:

$$\Delta R = \pm (0.05 + 0.0015R) \%$$

where R is the spectral reflectance.

3.3 WAVELENGTH UNCERTAINTIES

The wavelength uncertainties include uncertainties due to the wavelength scale of the spectrophotometers and also due to thermochromism effects.

The wavelength uncertainties, which had been previously assessed, are given in the table below:-

Type of opal	Specular included geometry $\pm$ nm
Neutral	0.15
Coloured	0.20

4 REFLECTANCE DATA TABLES

- Table 1 - White Russian opal NM 24-12-68, absolute reflectance data, NPL scale, specular included geometry.
- Table 2 - White Russian opal W1 01-1-85 W, absolute reflectance data, NPL scale, specular included geometry.
- Table 3 - NPL absolute reflectance data for matt white tile WT42.
- Table 4 - White Russian opal NM 24-12-68, reflectance data relative to NPL matt white tile WT42, specular included geometry.
- Table 5 - White German opal WOL 708549, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.
- Table 6 - Light Grey Russian opal H2 01-2-85 HG, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.
- Table 7 - Dark Grey Russian opal D3 01-3-85 DG, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.
- Table 8 - Red Russian opal R4 01-4-85 R, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.
- Table 9 - Green Russian opal G5 01-5-85 G, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.
- Table 10 - Blue Russian opal B6 01-6-85 B, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.
- Table 11 - Black Russian opal NS SU-91-S, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Table 1 - White Russian opal NM 24-12-68, absolute reflectance data, NPL scale, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Absolute Reflectance %	Meas. 2 Absolute Reflectance %	Mean Absolute Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Absolute Reflectance %
380	94.12	93.96	94.04	0.08	-0.08	380	94.04
385	94.62	94.57	94.60	0.03	-0.03		
390	94.98	94.98	94.98	0.00	0.00	390	94.93
395	95.19	95.16	95.18	0.02	-0.02		
400	95.50	95.44	95.47	0.03	-0.03	400	95.45
405	95.72	95.65	95.69	0.03	-0.03		
410	95.87	95.82	95.85	0.03	-0.03	410	95.84
415	95.99	96.00	96.00	-0.01	0.00		
420	96.17	96.12	96.15	0.02	-0.03	420	96.13
425	96.25	96.24	96.25	0.00	-0.01		
430	96.37	96.31	96.34	0.03	-0.03	430	96.34
435	96.44	96.39	96.42	0.03	-0.02		
440	96.48	96.52	96.50	-0.02	0.02	440	96.50
445	96.59	96.60	96.60	0.00	0.00		
450	96.68	96.62	96.65	0.03	-0.03	450	96.63
455	96.64	96.63	96.64	0.01	0.00		
460	96.64	96.63	96.64	0.01	0.00	460	96.65
465	96.70	96.72	96.71	-0.01	0.01		
470	96.75	96.73	96.74	0.01	-0.01	470	96.75
475	96.82	96.79	96.81	0.01	-0.02		
480	96.87	96.85	96.86	0.01	-0.01	480	96.86
485	96.94	96.91	96.93	0.02	-0.02		
490	97.02	96.99	97.01	0.02	-0.02	490	96.99
495	97.05	97.03	97.04	0.01	-0.01		
500	97.08	97.09	97.09	-0.01	0.00	500	97.08
505	97.11	97.10	97.11	0.01	0.00		
510	97.14	97.10	97.12	0.02	-0.02	510	97.13
515	97.18	97.15	97.17	0.02	-0.02		
520	97.22	97.21	97.22	0.00	-0.01	520	97.21
525	97.24	97.22	97.23	0.01	-0.01		
530	97.22	97.20	97.21	0.01	-0.01	530	97.22
535	97.24	97.23	97.24	0.00	0.00		
540	97.29	97.25	97.27	0.02	-0.02	540	97.26
545	97.27	97.28	97.28	-0.01	0.00		
550	97.28	97.24	97.26	0.02	-0.02	550	97.26
555	97.25	97.27	97.26	-0.01	0.01		
560	97.25	97.22	97.24	0.02	-0.02	560	97.24
565	97.21	97.21	97.21	0.00	0.00		
570	97.16	97.21	97.19	-0.03	0.02	570	97.18
575	97.18	97.11	97.15	0.03	-0.04		
580	97.16	97.14	97.15	0.01	-0.01	580	97.15
585	97.20	97.10	97.15	0.05	-0.05		
590	97.15	97.12	97.14	0.02	-0.02	590	97.15
595	97.16	97.18	97.17	-0.01	0.01		

Table 1 - White Russian opal NM 24-12-68, absolute reflectance data, NPL scale, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Absolute Reflectance %	Meas. 2 Absolute Reflectance %	Mean Absolute Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Absolute Reflectance %
600	97.20	97.16	97.18	0.02	-0.02	600	97.18
605	97.17	97.18	97.18	-0.01	0.00		
610	97.20	97.10	97.15	0.05	-0.05	610	97.15
615	97.17	97.11	97.14	0.03	-0.03		
620	97.09	97.08	97.09	0.00	-0.01	620	97.10
625	97.10	97.06	97.08	0.02	-0.02		
630	97.10	97.11	97.11	0.00	0.01	630	97.09
635	97.08	97.03	97.06	0.02	-0.03		
640	97.11	97.04	97.08	0.03	-0.03	640	97.07
645	97.09	97.04	97.07	0.03	-0.02		
650	97.16	97.19	97.18	-0.02	0.02	650	97.15
655	97.18	97.22	97.20	-0.02	0.02		
660	97.12	97.12	97.12	0.00	0.00	660	97.12
665	97.01	97.06	97.04	-0.02	0.03		
670	97.10	97.12	97.11	-0.01	0.01	670	97.08
675	97.01	97.10	97.06	-0.05	0.04		
680	97.09	97.13	97.11	-0.02	0.02	680	97.09
685	97.14	97.06	97.10	0.04	-0.04		
690	97.09	97.14	97.12	-0.03	0.02	690	97.09
695	97.02	97.00	97.01	0.01	-0.01		
700	96.98	96.99	96.99	0.00	0.00	700	97.01
705	97.06	97.05	97.06	0.00	-0.01		
710	97.03	97.02	97.03	0.00	-0.01	710	97.03
715	96.95	97.08	97.02	-0.06	0.06		
720	96.84	97.01	96.93	-0.09	0.08	720	96.95
725	97.05	96.81	96.93	0.12	-0.12		
730	97.00	96.86	96.93	0.07	-0.07	730	96.92
735	96.83	96.93	96.88	-0.05	0.05		
740	96.96	96.74	96.85	0.11	-0.11	740	96.90
745	97.05	97.00	97.03	0.02	-0.03		
750	96.80	96.82	96.81	-0.01	0.01	750	96.84
755	96.78	96.63	96.71	0.08	-0.08		
760	96.65	96.64	96.65	0.00	-0.01	760	96.66
765	96.62	96.63	96.63	0.00	0.00		
770	96.73	96.74	96.74	0.00	0.00	770	96.64
775	96.34	96.57	96.46	-0.11	0.11		
780	96.87	97.25	97.06	-0.19	0.19	780	97.06

Table 2 - White Russian opal W1 01-1-85 W, absolute reflectance data, NPL scale, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Absolute Reflectance %	Meas. 2 Absolute Reflectance %	Mean Absolute Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Absolute Reflectance %
380	93.73	93.56	93.65	0.08	-0.09	380	93.65
385	94.23	94.14	94.19	0.05	-0.05		
390	94.67	94.54	94.61	0.06	-0.06	390	94.58
395	95.02	94.83	94.93	0.09	-0.09		
400	95.33	95.14	95.24	0.09	-0.09	400	95.22
405	95.57	95.42	95.50	0.07	-0.08		
410	95.73	95.62	95.68	0.05	-0.06	410	95.68
415	95.96	95.80	95.88	0.08	-0.08		
420	96.14	95.98	96.06	0.08	-0.08	420	96.04
425	96.20	96.15	96.18	0.02	-0.03		
430	96.36	96.26	96.31	0.05	-0.05	430	96.29
435	96.42	96.33	96.38	0.05	-0.05		
440	96.53	96.43	96.48	0.05	-0.05	440	96.48
445	96.64	96.49	96.57	0.08	-0.08		
450	96.71	96.60	96.66	0.05	-0.06	450	96.64
455	96.72	96.63	96.68	0.05	-0.05		
460	96.73	96.62	96.68	0.05	-0.06	460	96.69
465	96.77	96.69	96.73	0.04	-0.04		
470	96.86	96.71	96.79	0.08	-0.08	470	96.79
475	96.93	96.78	96.86	0.08	-0.08		
480	96.97	96.84	96.91	0.06	-0.06	480	96.91
485	97.03	96.93	96.98	0.05	-0.05		
490	97.09	96.98	97.04	0.06	-0.05	490	97.03
495	97.13	97.01	97.07	0.06	-0.06		
500	97.18	97.04	97.11	0.07	-0.07	500	97.10
505	97.17	97.07	97.12	0.05	-0.05		
510	97.19	97.06	97.13	0.06	-0.06	510	97.13
515	97.20	97.10	97.15	0.05	-0.05		
520	97.24	97.15	97.20	0.05	-0.04	520	97.19
525	97.28	97.16	97.22	0.06	-0.06		
530	97.29	97.17	97.23	0.06	-0.06	530	97.23
535	97.30	97.15	97.23	0.08	-0.07		
540	97.32	97.21	97.27	0.06	-0.05	540	97.25
545	97.27	97.18	97.23	0.05	-0.04		
550	97.27	97.23	97.25	0.02	-0.02	550	97.23
555	97.24	97.16	97.20	0.04	-0.04		
560	97.22	97.13	97.18	0.05	-0.05	560	97.17
565	97.16	97.06	97.11	0.05	-0.05		
570	97.12	97.09	97.11	0.02	-0.02	570	97.11
575	97.15	97.08	97.12	0.03	-0.04		
580	97.12	97.06	97.09	0.03	-0.03	580	97.10
585	97.16	97.08	97.12	0.04	-0.04		
590	97.13	97.02	97.08	0.06	-0.05	590	97.09
595	97.10	97.09	97.10	0.00	0.00		

Table 2 - White Russian opal W1 01-1-85 W, absolute reflectance data, NPL scale, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Absolute Reflectance %	Meas. 2 Absolute Reflectance %	Mean Absolute Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Absolute Reflectance %
600	97.15	97.04	97.10	0.06	-0.05	600	97.09
605	97.13	97.05	97.09	0.04	-0.04		
610	97.09	97.02	97.06	0.03	-0.04	610	97.07
615	97.11	97.02	97.07	0.05	-0.05		
620	97.09	97.00	97.05	0.05	-0.05	620	97.05
625	97.06	97.01	97.04	0.03	-0.02		
630	97.08	97.07	97.08	0.01	0.00	630	97.06
635	97.11	96.98	97.05	0.06	-0.06		
640	97.13	97.00	97.07	0.06	-0.06	640	97.05
645	97.09	96.98	97.04	0.06	-0.05		
650	97.18	97.16	97.17	0.01	-0.01	650	97.13
655	97.20	97.12	97.16	0.04	-0.04		
660	97.16	97.10	97.13	0.03	-0.03	660	97.12
665	97.10	97.03	97.07	0.03	-0.03		
670	97.15	97.12	97.14	0.02	-0.02	670	97.09
675	97.01	97.05	97.03	-0.02	0.02		
680	97.08	97.08	97.08	0.00	0.00	680	97.07
685	97.13	97.03	97.08	0.05	-0.05		
690	97.06	97.03	97.05	0.02	-0.02	690	97.03
695	96.97	96.90	96.94	0.03	-0.03		
700	96.95	96.95	96.95	0.00	0.00	700	96.95
705	96.93	97.03	96.98	-0.05	0.05		
710	96.89	96.96	96.93	-0.03	0.03	710	96.94
715	96.95	96.89	96.92	0.03	-0.03		
720	96.81	96.82	96.82	0.00	0.00	720	96.84
725	96.84	96.75	96.80	0.05	-0.05		
730	96.68	96.86	96.77	-0.09	0.09	730	96.78
735	96.93	96.64	96.79	0.15	-0.14		
740	96.93	96.89	96.91	0.02	-0.02	740	96.87
745	96.71	97.01	96.86	-0.15	0.15		
750	96.65	96.77	96.71	-0.06	0.06	750	96.72
755	96.67	96.49	96.58	0.09	-0.09		
760	96.73	96.68	96.71	0.02	-0.03	760	96.67
765	96.48	96.87	96.68	-0.20	0.19		
770	96.19	96.63	96.41	-0.22	0.22	770	96.50
775	96.44	96.56	96.50	-0.06	0.06		
780	97.09	96.49	96.79	0.30	-0.30	780	96.79

Table 3 - NPL absolute reflectance data for matt white tile WT42.

Wavelength nm	Reflectance (%)	Wavelength nm	Reflectance (%)
380	73.99	580	89.58
385	76.28	585	89.64
390	78.37	590	89.69
395	80.23	595	89.82
400	81.81	600	89.91
405	83.12	605	89.93
410	84.13	610	89.96
415	84.93	615	89.96
420	85.57	620	89.98
425	86.05	625	89.99
430	86.44	630	90.02
435	86.68	635	90.02
440	86.90	640	90.07
445	87.08	645	90.08
450	87.27	650	90.09
455	87.47	655	90.13
460	87.67	660	90.18
465	87.90	665	90.24
470	88.08	670	90.28
475	88.25	675	90.30
480	88.41	680	90.33
485	88.56	685	90.33
490	88.72	690	90.32
495	88.86	695	90.35
500	88.96	700	90.34
505	89.04	705	90.37
510	89.10	710	90.42
515	89.19	715	90.41
520	89.26	720	90.43
525	89.34	725	90.42
530	89.41	730	90.45
535	89.47	735	90.43
540	89.53	740	90.39
545	89.57	745	90.40
550	89.59	750	90.34
555	89.61	755	90.35
560	89.63	760	90.42
565	89.62	765	90.37
570	89.59	770	90.35
575	89.57	775	90.35
		780	90.20

Table 4 - White Russian opal NM 24-12-68, reflectance data relative to NPL master matt white standard WT42, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements relative to NPL white tile WT42, column 4 is the mean of the measurements, column 5 is the wavelength at 10 nm intervals, and column 6 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Wavelength nm	10 nm Relative Reflectance %
380	127.21	126.99	127.10	380	127.10
385	124.04	123.98	124.01		
390	121.19	121.19	121.19	390	121.26
395	118.65	118.61	118.63		
400	116.73	116.66	116.70	400	116.78
405	115.16	115.07	115.12		
410	113.95	113.90	113.92	410	114.00
415	113.02	113.03	113.03		
420	112.39	112.33	112.36	420	112.40
425	111.85	111.84	111.85		
430	111.49	111.42	111.45	430	111.50
435	111.26	111.20	111.23		
440	111.02	111.07	111.05	440	111.06
445	110.92	110.93	110.93		
450	110.78	110.71	110.75	450	110.73
455	110.48	110.47	110.48		
460	110.23	110.22	110.23	460	110.24
465	110.01	110.03	110.02		
470	109.84	109.82	109.83	470	109.85
475	109.71	109.68	109.69		
480	109.57	109.55	109.56	480	109.56
485	109.46	109.43	109.45		
490	109.36	109.32	109.34	490	109.33
495	109.22	109.19	109.21		
500	109.13	109.14	109.13	500	109.13
505	109.06	109.05	109.06		
510	109.02	108.98	109.00	510	109.00
515	108.96	108.92	108.94		
520	108.92	108.91	108.91	520	108.90
525	108.84	108.82	108.83		
530	108.74	108.71	108.72	530	108.74
535	108.68	108.67	108.68		
540	108.67	108.62	108.65	540	108.64
545	108.60	108.61	108.60		
550	108.58	108.54	108.56	550	108.57
555	108.53	108.55	108.54		
560	108.50	108.47	108.48	560	108.49
565	108.47	108.47	108.47		
570	108.45	108.51	108.48	570	108.47
575	108.50	108.42	108.46		
580	108.46	108.44	108.45	580	108.43
585	108.43	108.32	108.38		
590	108.32	108.28	108.30	590	108.29
595	108.17	108.19	108.18		

Table 4 - White Russian opal NM 24-12-68, reflectance data relative to NPL master matt white standard WT42, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements relative to NPL white tile WT42, column 4 is the mean of the measurements, column 5 is the wavelength at 10 nm intervals, and column 6 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Wavelength nm	10 nm Relative Reflectance %
600	108.11	108.06	108.09	600	108.10
605	108.05	108.06	108.06		
610	108.05	107.94	107.99	610	108.01
615	108.01	107.95	107.98		
620	107.90	107.89	107.90	620	107.91
625	107.90	107.86	107.88		
630	107.86	107.88	107.87	630	107.86
635	107.84	107.79	107.81		
640	107.82	107.74	107.78	640	107.78
645	107.78	107.73	107.75		
650	107.85	107.88	107.86	650	107.83
655	107.82	107.87	107.84		
660	107.70	107.70	107.70	660	107.69
665	107.50	107.56	107.53		
670	107.55	107.58	107.57	670	107.54
675	107.43	107.53	107.48		
680	107.48	107.53	107.51	680	107.50
685	107.54	107.45	107.49		
690	107.50	107.55	107.52	690	107.48
695	107.38	107.36	107.37		
700	107.35	107.36	107.36	700	107.37
705	107.40	107.39	107.40		
710	107.31	107.30	107.30	710	107.33
715	107.23	107.38	107.31		
720	107.09	107.28	107.18	720	107.22
725	107.33	107.07	107.20		
730	107.24	107.09	107.16	730	107.17
735	107.08	107.19	107.13		
740	107.27	107.03	107.15	740	107.19
745	107.36	107.30	107.33		
750	107.15	107.17	107.16	750	107.17
755	107.12	106.95	107.03		
760	106.89	106.88	106.88	760	106.93
765	106.92	106.93	106.92		
770	107.06	107.07	107.07	770	106.95
775	106.63	106.88	106.76		
780	107.39	107.82	107.61	780	107.61

Table 5 - White German opal WOL 708549, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Relative Reflectance %
380	94.11	94.01	94.06	0.05	-0.05	380	94.06
385	94.77	94.70	94.74	0.04	-0.04		
390	95.34	95.20	95.27	0.07	-0.07	390	95.27
395	95.86	95.75	95.81	0.06	-0.06		
400	96.33	96.36	96.35	-0.02	0.02	400	96.32
405	96.81	96.79	96.80	0.01	-0.01		
410	97.23	97.15	97.19	0.04	-0.04	410	97.18
415	97.56	97.51	97.54	0.03	-0.03		
420	97.87	97.76	97.82	0.06	-0.06	420	97.79
425	98.05	97.95	98.00	0.05	-0.05		
430	98.18	98.08	98.13	0.05	-0.05	430	98.11
435	98.22	98.17	98.20	0.03	-0.03		
440	98.32	98.17	98.25	0.08	-0.08	440	98.24
445	98.33	98.25	98.29	0.04	-0.04		
450	98.35	98.32	98.34	0.02	-0.02	450	98.36
455	98.51	98.46	98.49	0.03	-0.03		
460	98.63	98.57	98.60	0.03	-0.03	460	98.59
465	98.71	98.62	98.67	0.05	-0.05		
470	98.81	98.76	98.79	0.03	-0.03	470	98.77
475	98.87	98.82	98.85	0.03	-0.03		
480	98.92	98.85	98.89	0.04	-0.04	480	98.89
485	98.99	98.89	98.94	0.05	-0.05		
490	99.02	98.96	98.99	0.03	-0.03	490	98.99
495	99.09	98.99	99.04	0.05	-0.05		
500	99.12	99.04	99.08	0.04	-0.04	500	99.07
505	99.13	99.05	99.09	0.04	-0.04		
510	99.16	99.09	99.13	0.04	-0.04	510	99.12
515	99.18	99.08	99.13	0.05	-0.05		
520	99.18	99.12	99.15	0.03	-0.03	520	99.15
525	99.21	99.15	99.18	0.03	-0.03		
530	99.22	99.13	99.18	0.05	-0.05	530	99.19
535	99.29	99.16	99.23	0.07	-0.07		
540	99.25	99.13	99.19	0.06	-0.06	540	99.21
545	99.28	99.18	99.23	0.05	-0.05		
550	99.26	99.19	99.23	0.04	-0.04	550	99.22
555	99.23	99.15	99.19	0.04	-0.04		
560	99.26	99.15	99.21	0.06	-0.06	560	99.21
565	99.26	99.20	99.23	0.03	-0.03		
570	99.23	99.16	99.20	0.04	-0.04	570	99.21
575	99.25	99.15	99.20	0.05	-0.05		
580	99.25	99.18	99.22	0.04	-0.04	580	99.21
585	99.24	99.14	99.19	0.05	-0.05		
590	99.20	99.15	99.18	0.03	-0.03	590	99.18
595	99.21	99.16	99.19	0.03	-0.03		

Table 5 - White German opal WOL 708549, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Relative Reflectance %
600	99.24	99.12	99.18	0.06	-0.06	600	99.19
605	99.24	99.17	99.21	0.04	-0.04		
610	99.23	99.13	99.18	0.05	-0.05	610	99.19
615	99.20	99.22	99.21	-0.01	0.01		
620	99.23	99.21	99.22	0.01	-0.01	620	99.22
625	99.27	99.17	99.22	0.05	-0.05		
630	99.28	99.24	99.26	0.02	-0.02	630	99.25
635	99.29	99.19	99.24	0.05	-0.05		
640	99.34	99.22	99.28	0.06	-0.06	640	99.27
645	99.34	99.23	99.29	0.06	-0.06		
650	99.33	99.23	99.28	0.05	-0.05	650	99.29
655	99.37	99.27	99.32	0.05	-0.05		
660	99.39	99.31	99.35	0.04	-0.04	660	99.35
665	99.39	99.36	99.38	0.02	-0.02		
670	99.42	99.38	99.40	0.02	-0.02	670	99.39
675	99.39	99.37	99.38	0.01	-0.01		
680	99.43	99.36	99.40	0.04	-0.04	680	99.41
685	99.53	99.44	99.49	0.05	-0.05		
690	99.48	99.43	99.46	0.03	-0.03	690	99.46
695	99.54	99.37	99.46	0.09	-0.09		
700	99.52	99.45	99.49	0.04	-0.04	700	99.50
705	99.60	99.56	99.58	0.02	-0.02		
710	99.68	99.63	99.66	0.03	-0.03	710	99.66
715	99.80	99.68	99.74	0.06	-0.06		
720	99.75	99.65	99.70	0.05	-0.05	720	99.70
725	99.69	99.59	99.64	0.05	-0.05		
730	99.64	99.63	99.64	0.01	-0.01	730	99.61
735	99.52	99.54	99.53	-0.01	0.01		
740	99.78	99.66	99.72	0.06	-0.06	740	99.71
745	99.90	99.83	99.87	0.04	-0.04		
750	99.96	99.90	99.93	0.03	-0.03	750	99.93
755	100.14	99.85	100.00	0.15	-0.15		
760	99.75	99.52	99.64	0.12	-0.12	760	99.79
765	100.07	99.72	99.90	0.18	-0.18		
770	99.69	99.64	99.67	0.03	-0.03	770	99.81
775	100.35	99.69	100.02	0.33	-0.33		
780	100.12	100.46	100.29	-0.17	0.17	780	100.29

Table 6 - Light Grey Russian opal H2 01-2-85 HG, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Relative Reflectance %
380	58.22	58.45	58.34	-0.12	0.12	380	58.34
385	58.63	58.87	58.75	-0.12	0.12		
390	58.87	59.09	58.98	-0.11	0.11	390	58.97
395	59.07	59.28	59.18	-0.10	0.11		
400	59.19	59.54	59.37	-0.17	0.18	400	59.35
405	59.34	59.66	59.50	-0.16	0.16		
410	59.48	59.76	59.62	-0.14	0.14	410	59.63
415	59.62	59.92	59.77	-0.15	0.15		
420	59.68	60.03	59.86	-0.18	0.17	420	59.86
425	59.79	60.09	59.94	-0.15	0.15		
430	59.86	60.16	60.01	-0.15	0.15	430	60.01
435	59.93	60.26	60.10	-0.16	0.16		
440	59.95	60.30	60.13	-0.17	0.17	440	60.13
445	60.02	60.34	60.18	-0.16	0.16		
450	59.99	60.34	60.17	-0.18	0.17	450	60.17
455	60.01	60.36	60.19	-0.18	0.17		
460	60.00	60.37	60.19	-0.19	0.18	460	60.20
465	60.04	60.41	60.23	-0.18	0.19		
470	60.05	60.43	60.24	-0.19	0.19	470	60.25
475	60.09	60.48	60.29	-0.19	0.20		
480	60.11	60.51	60.31	-0.20	0.20	480	60.31
485	60.12	60.55	60.34	-0.21	0.22		
490	60.16	60.59	60.38	-0.22	0.22	490	60.38
495	60.23	60.64	60.44	-0.21	0.20		
500	60.25	60.67	60.46	-0.21	0.21	500	60.47
505	60.28	60.73	60.51	-0.22	0.23		
510	60.33	60.73	60.53	-0.20	0.20	510	60.53
515	60.35	60.77	60.56	-0.21	0.21		
520	60.37	60.81	60.59	-0.22	0.22	520	60.58
525	60.35	60.82	60.59	-0.23	0.23		
530	60.38	60.84	60.61	-0.23	0.23	530	60.60
535	60.35	60.85	60.60	-0.25	0.25		
540	60.36	60.85	60.61	-0.25	0.24	540	60.60
545	60.35	60.84	60.60	-0.24	0.25		
550	60.36	60.84	60.60	-0.24	0.24	550	60.60
555	60.34	60.86	60.60	-0.26	0.26		
560	60.35	60.89	60.62	-0.27	0.27	560	60.61
565	60.35	60.85	60.60	-0.25	0.25		
570	60.32	60.82	60.57	-0.25	0.25	570	60.57
575	60.27	60.81	60.54	-0.27	0.27		
580	60.21	60.79	60.50	-0.29	0.29	580	60.50
585	60.17	60.72	60.45	-0.27	0.27		
590	60.11	60.69	60.40	-0.29	0.29	590	60.40
595	60.05	60.64	60.35	-0.30	0.30		

Table 6 - Light Grey Russian opal H2 01-2-85 HG, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Relative Reflectance %
600	59.99	60.53	60.26	-0.27	0.27	600	60.26
605	59.87	60.50	60.19	-0.32	0.31		
610	59.81	60.42	60.12	-0.31	0.31	610	60.11
615	59.73	60.33	60.03	-0.30	0.30		
620	59.64	60.26	59.95	-0.31	0.31	620	59.95
625	59.54	60.21	59.88	-0.34	0.34		
630	59.44	60.09	59.77	-0.33	0.33	630	59.77
635	59.39	59.96	59.68	-0.28	0.29		
640	59.26	59.94	59.60	-0.34	0.34	640	59.60
645	59.18	59.86	59.52	-0.34	0.34		
650	59.11	59.75	59.43	-0.32	0.32	650	59.44
655	59.05	59.69	59.37	-0.32	0.32		
660	58.93	59.59	59.26	-0.33	0.33	660	59.27
665	58.84	59.51	59.18	-0.33	0.34		
670	58.71	59.38	59.05	-0.34	0.34	670	59.06
675	58.64	59.30	58.97	-0.33	0.33		
680	58.52	59.19	58.86	-0.34	0.33	680	58.85
685	58.38	59.06	58.72	-0.34	0.34		
690	58.28	58.88	58.58	-0.30	0.30	690	58.58
695	58.13	58.78	58.46	-0.32	0.33		
700	57.99	58.70	58.35	-0.35	0.36	700	58.33
705	57.80	58.55	58.18	-0.38	0.38		
710	57.70	58.37	58.04	-0.33	0.34	710	58.03
715	57.55	58.23	57.89	-0.34	0.34		
720	57.45	58.06	57.76	-0.31	0.31	720	57.75
725	57.27	57.91	57.59	-0.32	0.32		
730	57.02	57.84	57.43	-0.41	0.41	730	57.43
735	56.94	57.56	57.25	-0.31	0.31		
740	56.82	57.38	57.10	-0.28	0.28	740	57.11
745	56.72	57.25	56.99	-0.27	0.27		
750	56.45	57.09	56.77	-0.32	0.32	750	56.82
755	56.23	57.24	56.74	-0.51	0.51		
760	56.28	56.69	56.49	-0.20	0.20	760	56.54
765	55.93	56.98	56.46	-0.52	0.52		
770	55.97	56.41	56.19	-0.22	0.22	770	56.20
775	56.00	55.94	55.97	0.03	-0.03		
780	55.47	56.08	55.78	-0.31	0.31	780	55.78

Table 7 - Dark Grey Russian opal D3 01-3-85 DG, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Relative Reflectance %
380	20.52	20.67	20.60	-0.08	0.08	380	20.60
385	20.71	20.82	20.77	-0.06	0.06		
390	20.90	21.01	20.96	-0.06	0.06	390	20.95
395	21.07	21.17	21.12	-0.05	0.05		
400	21.25	21.35	21.30	-0.05	0.05	400	21.30
405	21.45	21.54	21.50	-0.05	0.05		
410	21.65	21.74	21.70	-0.05	0.05	410	21.69
415	21.83	21.94	21.89	-0.06	0.06		
420	22.03	22.10	22.07	-0.04	0.04	420	22.07
425	22.19	22.30	22.25	-0.06	0.06		
430	22.36	22.46	22.41	-0.05	0.05	430	22.41
435	22.53	22.63	22.58	-0.05	0.05		
440	22.69	22.80	22.75	-0.06	0.06	440	22.74
445	22.85	22.95	22.90	-0.05	0.05		
450	22.98	23.07	23.03	-0.05	0.05	450	23.03
455	23.12	23.21	23.17	-0.05	0.05		
460	23.24	23.33	23.29	-0.05	0.05	460	23.29
465	23.36	23.45	23.41	-0.05	0.05		
470	23.48	23.58	23.53	-0.05	0.05	470	23.53
475	23.62	23.71	23.67	-0.05	0.05		
480	23.74	23.82	23.78	-0.04	0.04	480	23.78
485	23.84	23.93	23.89	-0.05	0.05		
490	23.91	24.01	23.96	-0.05	0.05	490	23.96
495	24.00	24.07	24.04	-0.04	0.04		
500	24.05	24.13	24.09	-0.04	0.04	500	24.09
505	24.10	24.19	24.15	-0.05	0.05		
510	24.13	24.21	24.17	-0.04	0.04	510	24.17
515	24.16	24.23	24.20	-0.04	0.04		
520	24.17	24.23	24.20	-0.03	0.03	520	24.20
525	24.19	24.25	24.22	-0.03	0.03		
530	24.19	24.26	24.23	-0.04	0.04	530	24.23
535	24.19	24.27	24.23	-0.04	0.04		
540	24.20	24.27	24.24	-0.04	0.04	540	24.24
545	24.20	24.28	24.24	-0.04	0.04		
550	24.21	24.28	24.25	-0.04	0.04	550	24.24
555	24.20	24.29	24.25	-0.05	0.05		
560	24.19	24.29	24.24	-0.05	0.05	560	24.24
565	24.20	24.27	24.24	-0.04	0.04		
570	24.19	24.25	24.22	-0.03	0.03	570	24.22
575	24.19	24.25	24.22	-0.03	0.03		
580	24.19	24.25	24.22	-0.03	0.03	580	24.22
585	24.20	24.25	24.23	-0.03	0.03		
590	24.20	24.28	24.24	-0.04	0.04	590	24.24
595	24.23	24.29	24.26	-0.03	0.03		

Table 7 - Dark Grey Russian opal D3 01-3-85 DG, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Relative Reflectance %
600	24.26	24.29	24.28	-0.02	0.02	600	24.28
605	24.29	24.35	24.32	-0.03	0.03		
610	24.33	24.40	24.37	-0.04	0.04	610	24.37
615	24.41	24.46	24.44	-0.03	0.03		
620	24.48	24.53	24.51	-0.03	0.03	620	24.51
625	24.55	24.62	24.59	-0.04	0.04		
630	24.68	24.72	24.70	-0.02	0.02	630	24.70
635	24.76	24.84	24.80	-0.04	0.04		
640	24.91	24.99	24.95	-0.04	0.04	640	24.95
645	25.05	25.11	25.08	-0.03	0.03		
650	25.22	25.28	25.25	-0.03	0.03	650	25.24
655	25.37	25.42	25.40	-0.03	0.03		
660	25.55	25.60	25.58	-0.03	0.03	660	25.57
665	25.69	25.75	25.72	-0.03	0.03		
670	25.89	25.93	25.91	-0.02	0.02	670	25.90
675	25.99	26.09	26.04	-0.05	0.05		
680	26.18	26.23	26.21	-0.03	0.03	680	26.20
685	26.33	26.38	26.36	-0.03	0.03		
690	26.45	26.46	26.46	-0.01	0.01	690	26.47
695	26.58	26.64	26.61	-0.03	0.03		
700	26.66	26.79	26.73	-0.07	0.07	700	26.73
705	26.84	26.88	26.86	-0.02	0.02		
710	26.96	27.02	26.99	-0.03	0.03	710	26.98
715	27.03	27.13	27.08	-0.05	0.05		
720	27.13	27.18	27.16	-0.03	0.03	720	27.17
725	27.26	27.32	27.29	-0.03	0.03		
730	27.34	27.49	27.42	-0.08	0.08	730	27.41
735	27.47	27.57	27.52	-0.05	0.05		
740	27.51	27.61	27.56	-0.05	0.05	740	27.56
745	27.55	27.63	27.59	-0.04	0.04		
750	27.69	27.76	27.73	-0.04	0.04	750	27.74
755	27.93	27.93	27.93	0.00	0.00		
760	27.93	27.89	27.91	0.02	-0.02	760	27.95
765	28.01	28.10	28.06	-0.05	0.05		
770	28.08	28.10	28.09	-0.01	0.01	770	28.11
775	28.18	28.23	28.21	-0.03	0.03		
780	28.09	28.10	28.10	-0.01	0.01	780	28.10

Table 8 - Red Russian opal R4 01-4-85 R, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, and columns 5 and 6 show the difference between the mean and the individual reflectance measurements.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %
380	8.43	8.41	8.42	0.01	-0.01
385	8.33	8.33	8.33	0.00	0.00
390	8.23	8.22	8.23	0.00	-0.01
395	8.13	8.13	8.13	0.00	0.00
400	8.06	8.05	8.06	0.01	0.00
405	8.00	7.99	8.00	0.00	0.00
410	7.93	7.93	7.93	0.00	0.00
415	7.90	7.88	7.89	0.01	-0.01
420	7.84	7.82	7.83	0.01	-0.01
425	7.78	7.78	7.78	0.00	0.00
430	7.73	7.72	7.73	0.01	0.00
435	7.69	7.68	7.69	0.00	-0.01
440	7.65	7.64	7.65	0.01	0.00
445	7.61	7.59	7.60	0.01	-0.01
450	7.56	7.54	7.55	0.01	-0.01
455	7.52	7.50	7.51	0.01	-0.01
460	7.47	7.45	7.46	0.01	-0.01
465	7.43	7.42	7.43	0.00	0.00
470	7.39	7.37	7.38	0.01	-0.01
475	7.36	7.35	7.36	0.00	-0.01
480	7.33	7.32	7.33	0.00	0.00
485	7.30	7.29	7.30	0.00	0.00
490	7.28	7.27	7.28	0.00	-0.01
495	7.25	7.24	7.25	0.00	0.00
500	7.22	7.21	7.22	0.00	0.00
505	7.21	7.19	7.20	0.01	-0.01
510	7.19	7.18	7.19	0.00	-0.01
515	7.18	7.17	7.18	0.00	0.00
520	7.16	7.15	7.16	0.00	0.00
525	7.19	7.17	7.18	0.01	-0.01
530	7.22	7.21	7.22	0.00	0.00
535	7.26	7.25	7.26	0.00	0.00
540	7.30	7.30	7.30	0.00	0.00
545	7.35	7.33	7.34	0.01	-0.01
550	7.36	7.35	7.36	0.00	-0.01
555	7.39	7.37	7.38	0.01	-0.01
560	7.40	7.39	7.40	0.01	0.00
565	7.41	7.40	7.41	0.00	0.00
570	7.42	7.40	7.41	0.01	-0.01
575	7.44	7.42	7.43	0.01	-0.01
580	7.47	7.46	7.47	0.00	0.00
585	7.58	7.56	7.57	0.01	-0.01
590	7.93	7.91	7.92	0.01	-0.01
595	8.96	8.93	8.95	0.02	-0.02

Table 8 - Red Russian opal R4 01-4-85 R, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, and columns 5 and 6 show the difference between the mean and the individual reflectance measurements.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %
600	11.88	11.83	11.86	0.03	-0.03
605	19.27	19.12	19.20	0.07	-0.07
610	32.26	32.06	32.16	0.10	-0.10
615	47.73	47.51	47.62	0.11	-0.11
620	60.97	60.85	60.91	0.06	-0.06
625	70.17	70.14	70.16	0.02	-0.02
630	76.26	76.21	76.24	0.03	-0.03
635	80.39	80.40	80.40	-0.01	0.00
640	83.38	83.39	83.39	0.00	0.01
645	85.46	85.47	85.47	-0.01	0.00
650	86.94	87.03	86.99	-0.05	0.05
655	88.09	88.12	88.11	-0.02	0.02
660	88.87	89.00	88.94	-0.06	0.06
665	89.38	89.51	89.45	-0.06	0.07
670	89.96	89.89	89.93	0.03	-0.03
675	90.13	90.25	90.19	-0.06	0.06
680	90.42	90.41	90.42	0.01	0.00
685	90.53	90.50	90.52	0.02	-0.02
690	90.59	90.56	90.58	0.02	-0.02
695	90.63	90.67	90.65	-0.02	0.02
700	90.63	90.63	90.63	0.00	0.00
705	90.60	90.70	90.65	-0.05	0.05
710	90.68	90.62	90.65	0.03	-0.03
715	90.52	90.60	90.56	-0.04	0.04
720	90.56	90.54	90.55	0.01	-0.01
725	90.45	90.47	90.46	-0.01	0.01
730	90.40	90.38	90.39	0.01	-0.01
735	90.31	90.40	90.36	-0.05	0.05
740	90.06	90.20	90.13	-0.07	0.07
745	89.89	90.13	90.01	-0.12	0.12
750	89.93	89.93	89.93	0.00	0.00
755	89.96	90.08	90.02	-0.06	0.06
760	89.69	89.86	89.78	-0.09	0.08
765	89.74	89.89	89.82	-0.08	0.08
770	89.95	89.69	89.82	0.13	-0.13
775	89.53	89.36	89.45	0.09	-0.08
780	89.48	89.11	89.30	0.19	-0.19

Table 9 - Green Russian opal G5 01-5-85 G, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, and columns 5 and 6 show the difference between the mean and the individual reflectance measurements.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %
380	4.92	4.92	4.92	0.00	0.00
385	4.99	4.99	4.99	0.00	0.00
390	5.04	5.06	5.05	-0.01	0.01
395	5.25	5.27	5.26	-0.01	0.01
400	5.59	5.61	5.60	-0.01	0.01
405	5.79	5.80	5.80	0.00	0.00
410	5.95	5.96	5.96	0.00	0.00
415	6.13	6.15	6.14	-0.01	0.01
420	6.34	6.36	6.35	-0.01	0.01
425	6.67	6.69	6.68	-0.01	0.01
430	7.14	7.16	7.15	-0.01	0.01
435	7.81	7.82	7.82	0.00	0.01
440	8.77	8.77	8.77	0.00	0.00
445	10.09	10.11	10.10	-0.01	0.01
450	11.78	11.79	11.79	-0.01	0.00
455	13.74	13.75	13.75	-0.01	0.00
460	15.90	15.91	15.91	-0.01	0.00
465	18.07	18.10	18.09	-0.02	0.02
470	20.04	20.04	20.04	0.00	0.00
475	21.70	21.72	21.71	-0.01	0.01
480	23.20	23.22	23.21	-0.01	0.01
485	24.71	24.74	24.73	-0.02	0.01
490	26.28	26.30	26.29	-0.01	0.01
495	27.96	27.99	27.98	-0.02	0.01
500	29.83	29.87	29.85	-0.02	0.02
505	31.92	31.95	31.94	-0.02	0.01
510	34.24	34.28	34.26	-0.02	0.02
515	36.79	36.80	36.80	-0.01	0.00
520	39.45	39.47	39.46	-0.01	0.01
525	42.14	42.17	42.16	-0.02	0.02
530	44.69	44.72	44.71	-0.02	0.02
535	46.89	46.91	46.90	-0.01	0.01
540	48.46	48.51	48.49	-0.02	0.02
545	49.23	49.27	49.25	-0.02	0.02
550	49.03	49.04	49.04	0.00	0.01
555	47.90	47.92	47.91	-0.01	0.01
560	46.01	46.01	46.01	0.00	0.00
565	43.53	43.53	43.53	0.00	0.00
570	40.69	40.73	40.71	-0.02	0.02
575	37.77	37.80	37.79	-0.01	0.02
580	34.86	34.89	34.88	-0.02	0.02
585	32.08	32.08	32.08	0.00	0.00
590	29.43	29.44	29.44	-0.01	0.00
595	27.03	27.03	27.03	0.00	0.00

Table 9 - Green Russian opal G5 01-5-85 G, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, and columns 5 and 6 show the difference between the mean and the individual reflectance measurements.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %
600	24.81	24.81	24.81	0.00	0.00
605	22.91	22.91	22.91	0.00	0.00
610	21.21	21.20	21.21	0.01	0.00
615	19.66	19.67	19.67	0.00	0.01
620	18.33	18.34	18.34	-0.01	0.00
625	17.25	17.27	17.26	-0.01	0.01
630	16.53	16.52	16.53	0.01	0.00
635	16.09	16.11	16.10	-0.01	0.01
640	15.76	15.76	15.76	0.00	0.00
645	15.15	15.13	15.14	0.01	-0.01
650	14.60	14.60	14.60	0.00	0.00
655	14.37	14.37	14.37	0.00	0.00
660	14.39	14.40	14.40	0.00	0.01
665	14.72	14.73	14.73	-0.01	0.00
670	15.30	15.30	15.30	0.00	0.00
675	15.14	15.12	15.13	0.01	-0.01
680	14.44	14.44	14.44	0.00	0.00
685	14.33	14.33	14.33	0.00	0.00
690	14.64	14.62	14.63	0.01	-0.01
695	15.07	15.05	15.06	0.01	-0.01
700	15.63	15.65	15.64	-0.01	0.01
705	16.29	16.28	16.29	0.00	0.00
710	17.08	17.05	17.07	0.02	-0.01
715	17.97	17.91	17.94	0.03	-0.03
720	19.01	18.95	18.98	0.03	-0.03
725	20.15	20.11	20.13	0.02	-0.02
730	21.46	21.40	21.43	0.03	-0.03
735	22.87	22.81	22.84	0.03	-0.03
740	24.40	24.36	24.38	0.02	-0.02
745	26.17	26.09	26.13	0.04	-0.04
750	27.99	27.95	27.97	0.02	-0.02
755	29.94	30.00	29.97	-0.03	0.03
760	32.23	32.15	32.19	0.04	-0.04
765	34.34	34.26	34.30	0.04	-0.04
770	37.02	36.61	36.82	0.21	-0.20
775	39.28	39.01	39.15	0.14	-0.13
780	41.97	41.75	41.86	0.11	-0.11

Table 10 - Blue Russian opal B6 01-6-85 B, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, and columns 5 and 6 show the difference between the mean and the individual reflectance measurements.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %
380	54.77	54.65	54.71	0.06	-0.06
385	54.46	54.28	54.37	0.09	-0.09
390	53.29	53.17	53.23	0.06	-0.06
395	48.69	48.63	48.66	0.03	-0.03
400	42.08	41.97	42.03	0.06	-0.06
405	36.04	35.99	36.02	0.03	-0.03
410	31.45	31.38	31.42	0.04	-0.04
415	27.61	27.59	27.60	0.01	-0.01
420	25.47	25.47	25.47	0.00	0.00
425	22.90	22.89	22.90	0.01	-0.01
430	20.44	20.45	20.45	-0.01	0.01
435	18.28	18.29	18.29	-0.01	0.01
440	16.48	16.50	16.49	-0.01	0.01
445	14.86	14.89	14.88	-0.02	0.02
450	13.26	13.32	13.29	-0.03	0.03
455	12.02	12.07	12.05	-0.03	0.03
460	10.86	10.92	10.89	-0.03	0.03
465	9.63	9.71	9.67	-0.04	0.04
470	8.36	8.44	8.40	-0.04	0.04
475	7.34	7.43	7.39	-0.05	0.05
480	6.57	6.66	6.62	-0.05	0.05
485	6.00	6.09	6.05	-0.05	0.05
490	5.62	5.71	5.67	-0.05	0.05
495	5.37	5.46	5.42	-0.05	0.05
500	5.19	5.29	5.24	-0.05	0.05
505	5.02	5.12	5.07	-0.05	0.05
510	4.89	4.98	4.94	-0.05	0.05
515	4.78	4.87	4.83	-0.05	0.05
520	4.68	4.77	4.73	-0.05	0.05
525	4.59	4.68	4.64	-0.05	0.05
530	4.54	4.62	4.58	-0.04	0.04
535	4.48	4.58	4.53	-0.05	0.05
540	4.45	4.54	4.50	-0.05	0.05
545	4.44	4.53	4.49	-0.05	0.05
550	4.44	4.52	4.48	-0.04	0.04
555	4.45	4.54	4.50	-0.05	0.05
560	4.44	4.53	4.49	-0.05	0.05
565	4.44	4.52	4.48	-0.04	0.04
570	4.40	4.48	4.44	-0.04	0.04
575	4.36	4.44	4.40	-0.04	0.04
580	4.32	4.40	4.36	-0.04	0.04
585	4.28	4.35	4.32	-0.04	0.04
590	4.24	4.32	4.28	-0.04	0.04
595	4.23	4.31	4.27	-0.04	0.04

Table 10 - Blue Russian opal B6 01-6-85 B, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, and columns 5 and 6 show the difference between the mean and the individual reflectance measurements.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %
600	4.23	4.30	4.27	-0.04	0.04
605	4.22	4.30	4.26	-0.04	0.04
610	4.21	4.29	4.25	-0.04	0.04
615	4.20	4.29	4.25	-0.05	0.05
620	4.19	4.26	4.23	-0.04	0.04
625	4.18	4.26	4.22	-0.04	0.04
630	4.17	4.25	4.21	-0.04	0.04
635	4.15	4.22	4.19	-0.04	0.04
640	4.14	4.21	4.18	-0.04	0.04
645	4.14	4.21	4.18	-0.04	0.04
650	4.13	4.21	4.17	-0.04	0.04
655	4.14	4.21	4.18	-0.04	0.04
660	4.15	4.22	4.19	-0.04	0.04
665	4.16	4.25	4.21	-0.05	0.05
670	4.20	4.28	4.24	-0.04	0.04
675	4.27	4.35	4.31	-0.04	0.04
680	4.35	4.43	4.39	-0.04	0.04
685	4.48	4.56	4.52	-0.04	0.04
690	4.72	4.80	4.76	-0.04	0.04
695	5.18	5.24	5.21	-0.03	0.03
700	5.94	5.99	5.97	-0.03	0.03
705	7.27	7.31	7.29	-0.02	0.02
710	9.41	9.42	9.42	-0.01	0.01
715	12.53	12.54	12.54	-0.01	0.01
720	16.67	16.66	16.67	0.01	-0.01
725	21.68	21.63	21.66	0.03	-0.03
730	27.08	27.07	27.08	0.01	-0.01
735	32.52	32.49	32.51	0.02	-0.02
740	37.51	37.33	37.42	0.09	-0.09
745	41.52	41.39	41.46	0.07	-0.07
750	44.54	44.44	44.49	0.05	-0.05
755	46.49	46.39	46.44	0.05	-0.05
760	47.71	47.58	47.65	0.07	-0.07
765	48.67	48.42	48.55	0.13	-0.13
770	48.84	48.66	48.75	0.09	-0.09
775	48.98	48.89	48.94	0.05	-0.05
780	48.65	49.11	48.88	-0.23	0.23

Table 11 - Black Russian opal NS SU-91-S, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Relative Reflectance %
380	6.77	6.86	6.82	-0.05	0.05	380	6.82
385	6.72	6.82	6.77	-0.05	0.05		
390	6.68	6.78	6.73	-0.05	0.05	390	6.73
395	6.64	6.73	6.69	-0.05	0.05		
400	6.61	6.69	6.65	-0.04	0.04	400	6.65
405	6.58	6.66	6.62	-0.04	0.04		
410	6.54	6.62	6.58	-0.04	0.04	410	6.58
415	6.49	6.58	6.54	-0.05	0.05		
420	6.46	6.53	6.50	-0.04	0.04	420	6.49
425	6.41	6.48	6.45	-0.04	0.04		
430	6.37	6.44	6.41	-0.04	0.04	430	6.41
435	6.33	6.40	6.37	-0.04	0.04		
440	6.29	6.36	6.33	-0.04	0.04	440	6.33
445	6.26	6.31	6.29	-0.03	0.03		
450	6.21	6.26	6.24	-0.03	0.03	450	6.24
455	6.17	6.23	6.20	-0.03	0.03		
460	6.13	6.19	6.16	-0.03	0.03	460	6.16
465	6.10	6.15	6.13	-0.03	0.03		
470	6.06	6.12	6.09	-0.03	0.03	470	6.09
475	6.03	6.09	6.06	-0.03	0.03		
480	6.01	6.07	6.04	-0.03	0.03	480	6.04
485	5.98	6.04	6.01	-0.03	0.03		
490	5.95	6.00	5.98	-0.03	0.03	490	5.98
495	5.92	5.98	5.95	-0.03	0.03		
500	5.90	5.95	5.93	-0.03	0.03	500	5.93
505	5.88	5.93	5.91	-0.03	0.03		
510	5.86	5.91	5.89	-0.03	0.03	510	5.89
515	5.84	5.89	5.87	-0.03	0.03		
520	5.81	5.86	5.84	-0.03	0.03	520	5.84
525	5.79	5.84	5.82	-0.03	0.03		
530	5.78	5.82	5.80	-0.02	0.02	530	5.80
535	5.76	5.80	5.78	-0.02	0.02		
540	5.74	5.78	5.76	-0.02	0.02	540	5.76
545	5.73	5.77	5.75	-0.02	0.02		
550	5.72	5.75	5.74	-0.02	0.02	550	5.74
555	5.70	5.74	5.72	-0.02	0.02		
560	5.68	5.72	5.70	-0.02	0.02	560	5.70
565	5.66	5.70	5.68	-0.02	0.02		
570	5.64	5.67	5.66	-0.02	0.02	570	5.66
575	5.62	5.65	5.64	-0.02	0.02		
580	5.61	5.64	5.63	-0.02	0.02	580	5.62
585	5.59	5.62	5.61	-0.02	0.02		
590	5.57	5.61	5.59	-0.02	0.02	590	5.59
595	5.55	5.59	5.57	-0.02	0.02		

Table 11 - Black Russian opal NS SU-91-S, reflectance data relative to white Russian Opal W1 01-1-85 W, specular included geometry.

Column 1 is the wavelength at 5 nm intervals, columns 2 and 3 are the individual reflectance measurements, column 4 is the mean of the measurements, columns 5 and 6 show the difference between the mean and the individual reflectance measurements, column 7 is the wavelength at 10 nm intervals, and column 8 is the 10 nm reflectance data calculated from the 5 nm data using a triangular weighting function.

Wavelength nm	Meas. 1 Relative Reflectance %	Meas. 2 Relative Reflectance %	Mean Relative Reflectance %	Diff. 1 %	Diff. 2 %	Wavelength nm	10 nm Relative Reflectance %
600	5.54	5.57	5.56	-0.02	0.02	600	5.55
605	5.52	5.54	5.53	-0.01	0.01		
610	5.51	5.53	5.52	-0.01	0.01	610	5.52
615	5.49	5.52	5.51	-0.02	0.02		
620	5.47	5.50	5.49	-0.02	0.02	620	5.49
625	5.46	5.48	5.47	-0.01	0.01		
630	5.44	5.47	5.46	-0.02	0.02	630	5.45
635	5.42	5.44	5.43	-0.01	0.01		
640	5.40	5.43	5.42	-0.02	0.02	640	5.42
645	5.39	5.41	5.40	-0.01	0.01		
650	5.37	5.40	5.39	-0.02	0.02	650	5.39
655	5.36	5.38	5.37	-0.01	0.01		
660	5.35	5.36	5.36	-0.01	0.01	660	5.36
665	5.34	5.35	5.35	-0.01	0.01		
670	5.32	5.34	5.33	-0.01	0.01	670	5.33
675	5.31	5.32	5.32	-0.01	0.01		
680	5.28	5.31	5.30	-0.02	0.02	680	5.30
685	5.26	5.29	5.28	-0.02	0.02		
690	5.26	5.28	5.27	-0.01	0.01	690	5.27
695	5.24	5.27	5.26	-0.02	0.02		
700	5.24	5.25	5.25	-0.01	0.01	700	5.25
705	5.23	5.24	5.24	-0.01	0.01		
710	5.21	5.23	5.22	-0.01	0.01	710	5.22
715	5.21	5.20	5.21	0.01	-0.01		
720	5.19	5.20	5.20	-0.01	0.01	720	5.20
725	5.19	5.19	5.19	0.00	0.00		
730	5.17	5.17	5.17	0.00	0.00	730	5.17
735	5.16	5.17	5.17	-0.01	0.01		
740	5.16	5.15	5.16	0.01	-0.01	740	5.15
745	5.15	5.13	5.14	0.01	-0.01		
750	5.12	5.15	5.14	-0.02	0.02	750	5.15
755	5.19	5.18	5.19	0.01	-0.01		
760	5.10	5.16	5.13	-0.03	0.03	760	5.13
765	5.09	5.09	5.09	0.00	0.00		
770	5.15	5.29	5.22	-0.07	0.07	770	5.18
775	5.10	5.27	5.19	-0.09	0.09		
780	5.16	5.12	5.14	0.02	-0.02	780	5.14

