Mt. Baker Research LLC

Measurement Services

& Calibration Certificates

Mt. Baker Research LLC
2921 Sylvan Street / P.O. Box 28370
Bellingham, Washington 98228-0370
360-650-0771

Certificate of Traceable Calibration

Customer:	SICPA SA		
Contact:	Maarten Krupers	Tel:	+41 21 627 5555
P.O. No.:	20091110-02	Date:	09.12.14
CAL No.:	MBR-(45/0)-091214-01		

Laboratory Conditions

Mean T:	23.0 ± 0.2 °C
Humidity:	40%
Certified by:	John W. Root, Ph.D.

Measurement Parameters

Instrument:	Konica-Minolta CM-2500c NUV-VIS spectrophotometer; S/N D4001408
Geometry:	(45°/0°) Bi-directional (ring illumination & vertical viewing)
Sample Port:	Circular w/ 11 mm (illuminated) & 7 mm (viewed) diameters
Wavelength Pitch:	10 nm
Wavelength Range:	360 - 740 nm
No. Spectra per Measurement:	30 (3 repeated measurements w/ each averaging 10 consecutive spectra)
Delay between Spectra:	6 seconds
No. Averaged Measurements:	4 independent measurements per tile w/ replacement & re-calibration
Traceable Reference Standard:	CERAM White tile (NRC Calibration Report No. PAR-2008-2594)
Data Media:	16 Excel charts (attached) & CD Disk (certified data)
Samples Measured:	Diagnostic Tile Set; 16 ceramic transfer standards

Procedure

Spectral radiance factors ("SRF") were measured at ambient temperature and humidity with a Konica-Minolta CM2500c ("CM2500c") NUV-VIS spectrophotometer. The instrument was operated in the (45°/0°) bi-directional geometry. SRF data were measured from 360 - 740 nm in 10 nm intervals. CyberChrome OnColor QC Premium® software was used to control the spectrophotometer, to average the replicate spectra obtained during each measurement series, and to perform colorimetric analysis. The statistical analysis was based on proprietary algorithms developed at Mt. Baker Research L.L.C.

SRF values were measured relative to the calibrated NRC/NIST traceable CERAM white reference tile. The metrological SRF scaling procedure monitored and corrected for instrument drift and optimized the statistical quality of the results. This was accomplished by bracketing 3 consecutive measurements of each tile with 2 measurements of the calibrated white reference tile. [REF: NRC Calibration Report No. PAR-2008-2594.]

Each data series consisted of 12 measurements performed using the following sequence: **C R R T1 T1 T1 R R T2 T2 T2 R R**. Here, **C**, **R**, **T1** and **T2** denote re-calibration followed by measurements of the white reference tile, the 1st test tile, and the 2nd test tile. For each pair of test tiles this sequence was repeated 4 times with sample replacement and re-calibration of the instrument between each series. [REF: Diagnostic Tile Set Instruction Manual.]

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Procedure -- Continued

Synopsis: The present study consisted of 4 parts, as follows: Part A: Traceable SRF calibrations were measured for 16 diagnostic test tiles. [REF: Charts #1 to #4.] Part B: Additional traceable SRF calibrations were performed for the #D01 UltraWhite tile. [REF: Charts #8 to #11.] Part C: A new procedure was developed to characterize the statistical noise levels of the CM2500c instrument during parts A and B. [REF: Charts #12 and #13.] Part D: Additional tests were performed to determine the increases in statistical noise that resulted from decreasing the number of consecutive spectra averaged during each measurement. [REF: Charts #14 to #16. NOTE: The error bars shown on the charts in this report represent 2σ standard errors of estimate (95% confidence level).]

During Parts A to C each measurement averaged the data from 10 consecutive spectra measured at a 6 second delay interval. During Part D each measurement averaged the data from 3 or 5 consecutive spectra measured at an interval of 6 or 11 seconds. As described below, independent repeatability measurements were performed during each set of tests.

Accuracy Studies: The absolute accuracy of the Konica-Minolta CM2500c instrument was measured independently using 9 ceramic transfer standards calibrated at NRC. [REF: NRC Calibration Report No. PAR-2008-2594.] Charts #5 to #7 show the SRF comparisons based on our standard metrological scaling procedure with the calibrated CERAM white tile used as reference.

From Charts #5 to #7 the average 2σ relative error for the 8 tested transfer standards was 0.0077 ± 0.0079, and the averaged wavelength-dependent relative errors ranged from 0.026 at 370 nm to 0.008 at 740 nm. Based on traceability to NRC/NIST and the procedures described herein, the 2σ absolute accuracy of the CM2500c instrument was 99.2% ± 1.6%. Although Konica-Minolta does not certify the absolute accuracy of the CM2500c, the average inter-instrument agreement is specified to be within ΔE*ab = 0.25. [NOTE: For this test the average inter-instrument agreement is measured for 12 CERAM BCRA Series II tiles.]

For the #D01 UltraWhite tile the measured average 2σ standard error of estimate was 0.72, and the corresponding relative standard error was 0.0079. For the #D09 Light Grey 60% tile the corresponding errors were 0.41 and 0.0075. For tiles #D20 Deep Green and #D21 Mid-Green the respective errors were 0.15, 0.011, 0.23, and 0.0087.

For the 13 usable diagnostic tiles the grand average 2σ relative standard error of estimate was 0.0090 ± 0.0018. On this basis, with traceability to NRC/NIST the estimated 2σ absolute accuracy of the certified SRF values was 99.1% ± 0.4%. This result is statistically equivalent to the 99.2% ± 1.6% accuracy result obtained from the analysis of NRC calibration data. [NOTE: For the #D02, #D27 and #D28 tiles the (45°/0°) SRF values were vanishingly small over much of the wavelength range. As a result the calculated relative errors exhibited erratic behavior, so these 3 tiles were omitted from the analysis of absolute accuracy.]

Repeatability Studies: For the CM2500c instrument Konica-Minolta specifies a repeatabity within ΔE*ab = 0.05. [NOTE: This specification is based on 30 replicate measurements of the Konica-Minolta white reference tile at 10 second intervals without replacement or re-calibration.]

In the present study repeatability measurements were based on the CERAM white reference tile and the #D01 UltraWhite tile. During Part A, based on 63 measurements of the CERAM white tile without replacement or re-calibration, the repeatability of the spectrophotometer was ΔE*ab = 0.014 ± 0.007. Based on 100 measurements with replacement but without re-calibration, the repeatability was ΔE*ab = 0.014 ± 0.009. [NOTE: The cited measurement uncertainties are standard deviations.]

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Procedure -- Continued

During Part B, based on 80 measurements with replacement but without re-calibration, the repeatability was ΔE*ab = 0.014 ± 0.007. The Part B study included 40 measurements each of the CERAM white tile and the #D01 UltraWhite tile.

During Part D 3 series of measurements were performed, again using 40 measurements each of the CERAM white reference tile and the #D01 UltraWhite tile with replacement but without re-calibration. With 5 spectra per measurement and a 6 second delay between spectra, the repeatability was ΔE*ab = 0.014 ± 0.007. When the same measurements were performed with an 11 second delay between the consecutive spectra, the repeatability was ΔE*ab = 0.017 ± 0.015. Finally, with 3 spectra per measurement and a 6 second delay, the repeatability was ΔE*ab = 0.016 ± 0.010.

Noise Studies: The wavelength-dependent noise data shown in Charts #12 to #16 represent the precision-based random error contributions to the average relative standard error of estimate values.

In Charts #12 and #13 (Part C) the statistical noise levels are compared for the SRF measurements performed during Parts A and B. As shown in Chart #13, the noise level was significantly reduced during Part B. In Part B the standard measurement sequence was modified as follows: **C R R T1 T1 T1 R R T1 T1 T1 R R**. Here, **C**, **R** and **T1** denote re-calibration followed by measurements of the CERAM white reference tile and the #D01 UltraWhite tile.

In Charts #14 to #16 (Part D) the noise level progressively increases. Based on these results, the main consequence of decreasing the number of averaged spectra below 10 per measurement was to significantly increase the statistical noise. This difference is reflected in the smaller error bars shown on SRF Charts #1 to #4 and #8 vis-a-vis those shown on Charts #9 to #11. More dramatic corroboration is shown in statistical noise charts #12 to #16.

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Notes – Certified Data

1. The attached graphs of SRF data are provided for informational purposes only. The accompanying CD-R disk contains the certified SRF & colorimetric data for the calibrated tiles.

Notes – Basis for Traceability

1. NRC Calibration Report No. PAR-2007-2528, 2007, "0°:45° Radiance Factors of Two Ceramic Tiles, S/N: P-6-Light-Green, B-5-White," National Research Council Canada, Institute for National Measurement Standards, Ottawa, Canada, www.nrc-cnrc.gc.ca.
2. ASTM E1349-06, 2006, "Standard Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional (45:0 or 0:45) Geometry," ASTM International, West Conshohocken, PA, www.astm.org.
3. ASTM E1345-98, 1998 (2003), "Standard Practice for Reducing the Effect of Variability of Color Measurement by Use of Multiple Measurements," ASTM International, West Conshohocken, PA, www.astm.org.

Technical References

1. ASTM E275-01, 2001, "Standard Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near-Infrared Spectrophotometers," ASTM International, West Conshohocken, PA, www.astm.org.
2. ASTM E2214-02, 2002, "Standard Practice for Specifying and Verifying the Performance of Color-Measuring Instruments," ASTM International, West Conshohocken, PA, www.astm.org.
3. ASTM E1164-07, 2007, "Standard Practice for Obtaining Spectrometric Data for Object-Color Evaluation," ASTM International, West Conshohocken, PA, www.astm.org.
4. ASTM E308-06, 2006, "Standard Practice for Computing the Colors of Objects by Using the CIE System," ASTM International, West Conshohocken, PA, www.astm.org.
5. CIE 15:2004, "CIE Technical Report: Colorimetry," 3rd edition, International Commission on Illumination (Commission Internationale de l'Eclairage), Vienna, Austria, ISBN: 3-901-906-33-9, www.cie-usnc.org.
6. D.R. Wyble, D.C. Rich, "Evaluation of Methods for Verifying the Performance of Color-Measuring Instruments. Part I: Repeatability," Color Research and Application, 32(3), 166(10), 2007.
7. D.R. Wyble, D.C. Rich, "Evaluation of Methods for Verifying the Performance of Color-Measuring Instruments. Part II: Inter-Instrument Reproducibility," Color Research and Application, 32(3), 176(19), 2007.
8. J.W. Root, "Diagnostic Tile Set Instruction Manual," v. 2.1, Mt. Baker Research L.L.C., Bellingham, Washington, October 1, 2009.

General References

1. ISCC Technical Report 2003-1, 2003, J. Ladson, A.W. Springsteen, J. Sefl, H.S. Fairman, M.H. Brill, and J. Zwinkels, "Guide to Material Standards and Their Use in Color Measurement," Inter-Society Color Council, Reston, VA, www.iscc.org.
2. R.S. Berns, "Billmeyer and Saltzman's Principles of Color Technology," 3rd edition, John Wiley & Sons, Inc., New York, 2000, ISBN: 978-0-471-19459-0, www.wiley.com.
3. M.D. Fairchild, "Color Appearance Models," 2nd edition, John Wiley & Sons, Ltd., Chichester, England, 2005, ISBN: 0-470-01216-1, www.wiley.com.
4. "Spectrophotometer CM-2500c Instruction Manual," Konica-Minolta Sensing Americas, Inc., Ramsey, NJ, www.se.konicaminolta.

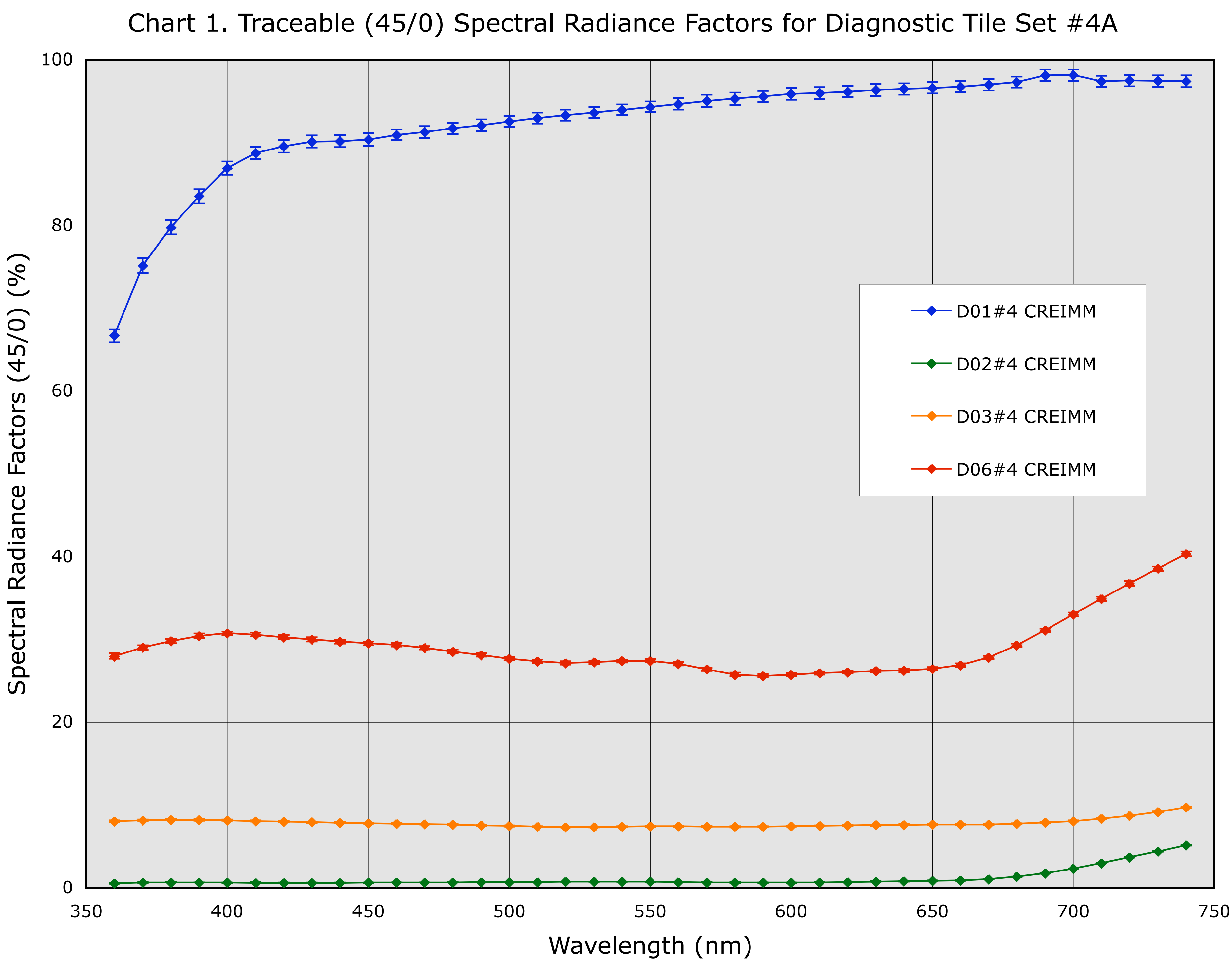
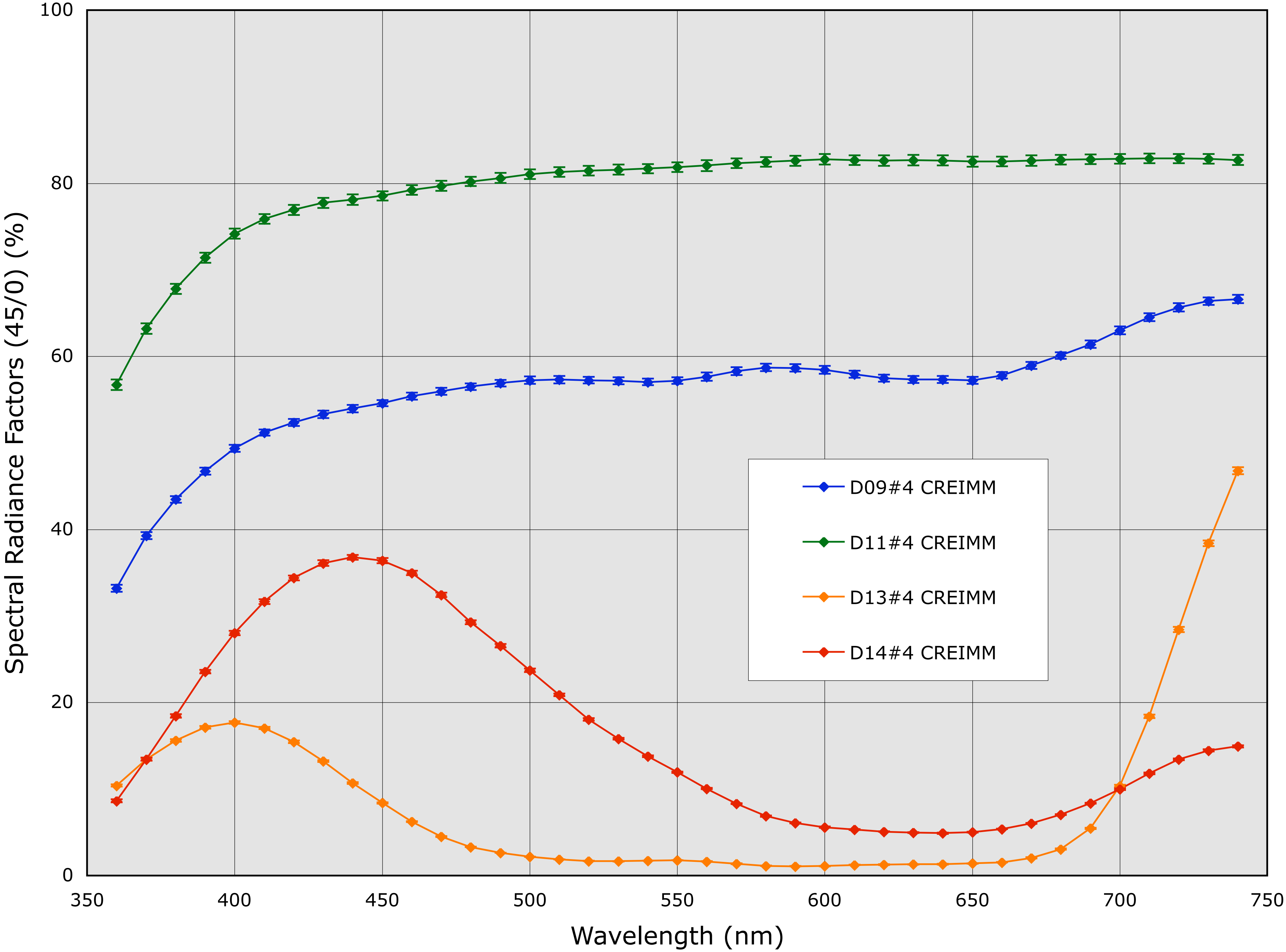


Chart 1. Traceable (45/0) Spectral Radiance Factors for Diagnostic Tile Set #4A
Spectral Radiance Factors (45/0) (%)
Wavelength (nm)
0
20
40
60
80
100
350
400
450
500
550
600
650
700
750
D01#4 CREIMM
D02#4 CREIMM
D03#4 CREIMM
D06#4 CREIMM

Chart 2. Traceable (45/0) Spectral Radiance Factors for Diagnostic Tile Set #4A



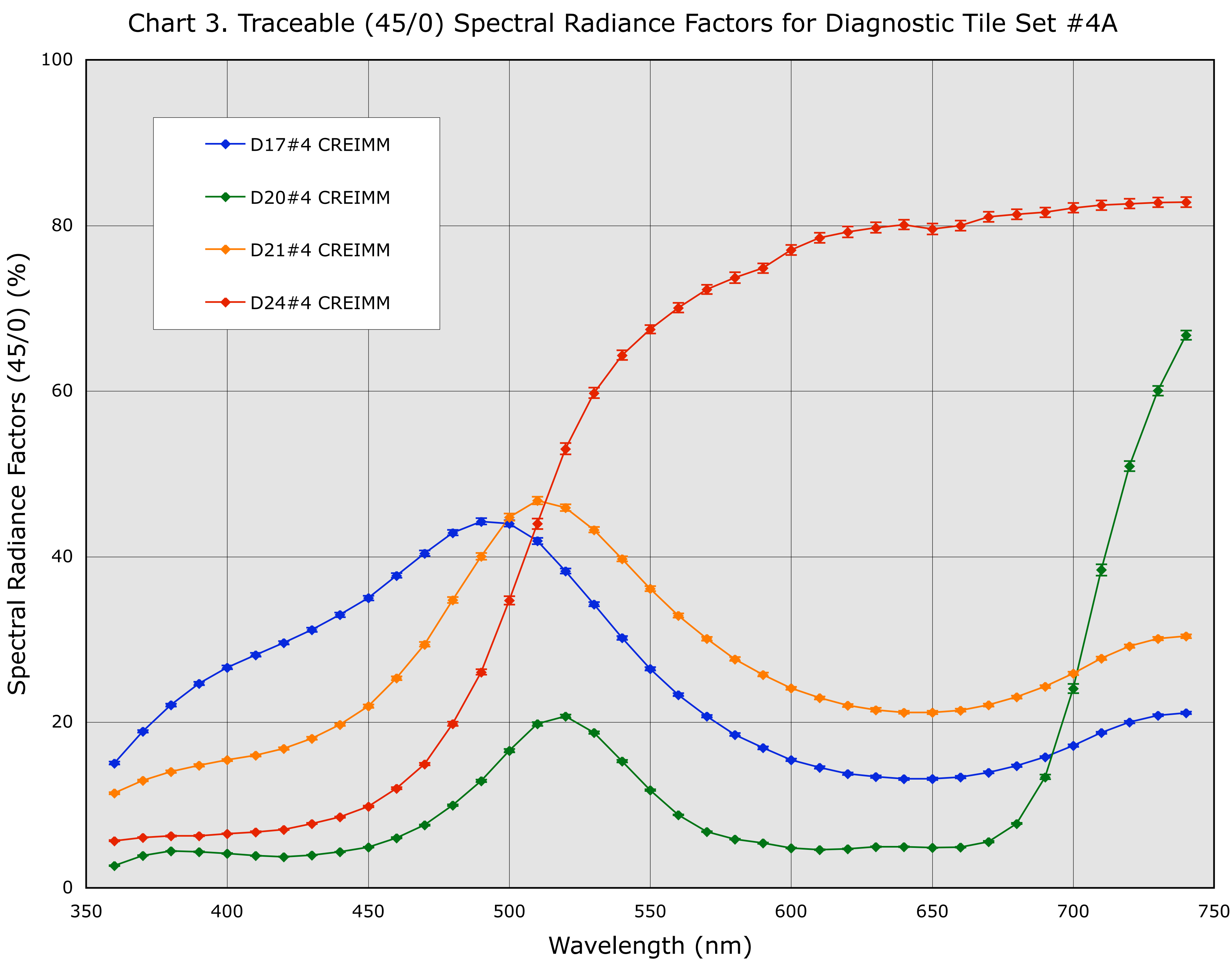


Chart 3. Traceable (45/0) Spectral Radiance Factors for Diagnostic Tile Set #4A
D17#4 CREIMM
D20#4 CREIMM
D21#4 CREIMM
D24#4 CREIMM
Spectral Radiance Factors (45/0) (%)
Wavelength (nm)
0
20
40
60
80
100
350
400
450
500
550
600
650
700
750

Chart 4. Traceable (45/0) Spectral Radiance Factors for Diagnostic Tile Set #4A

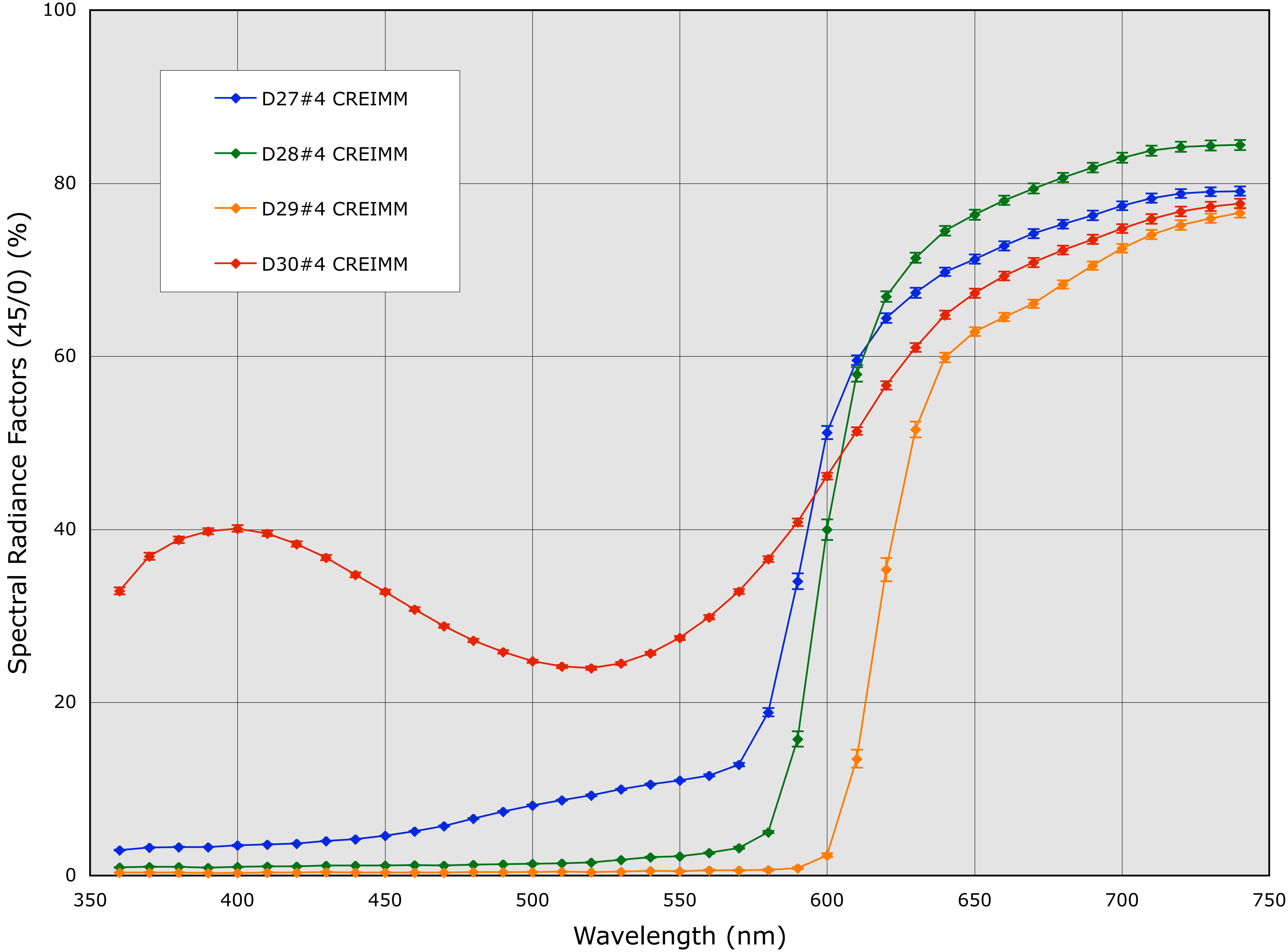
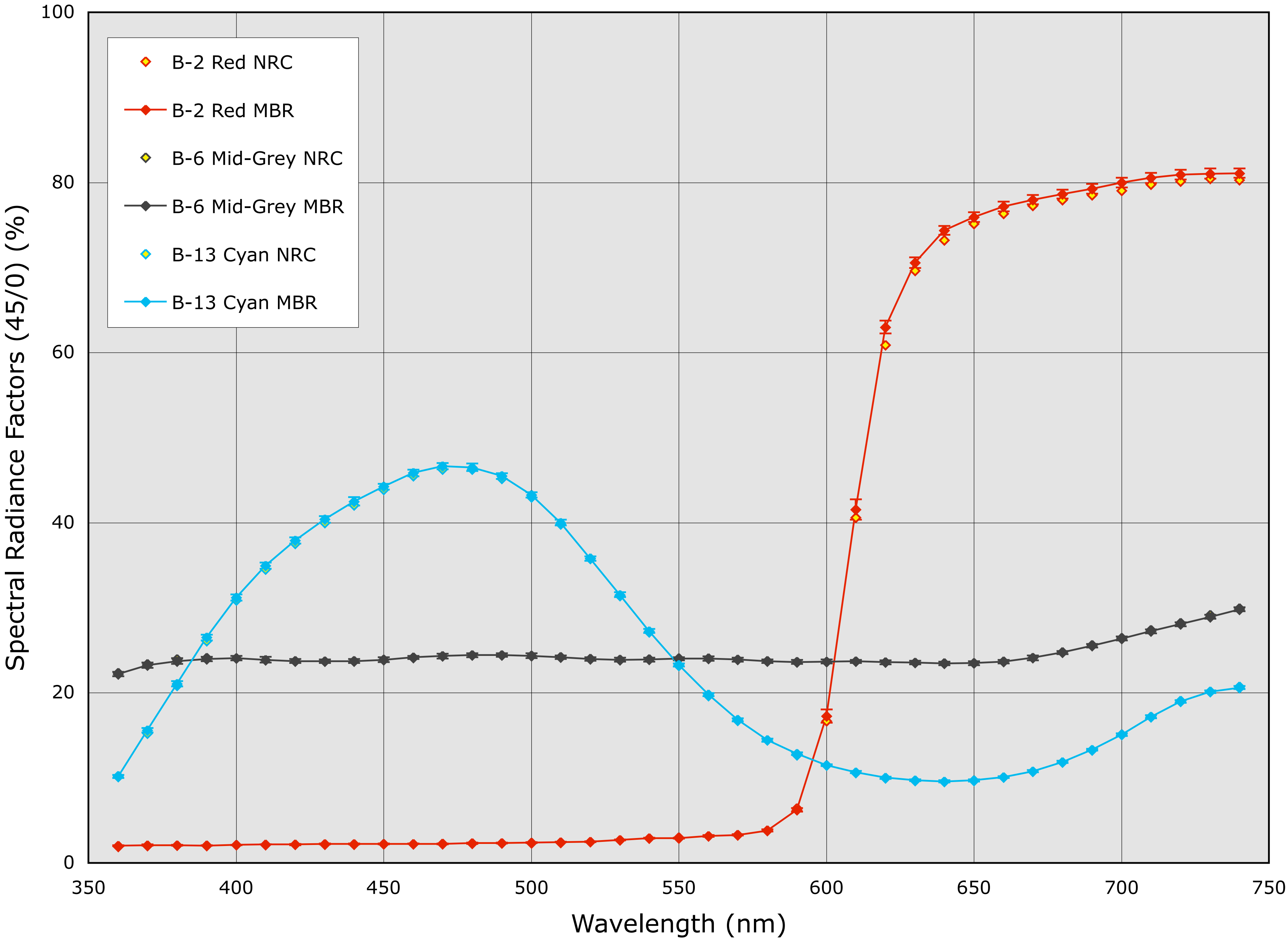


Chart 5. Traceable Scaled Reflectance Data Measured for Calibrated Tiles

Konica-Minolta CM-2500C (45/0) Bi-directional Geometry



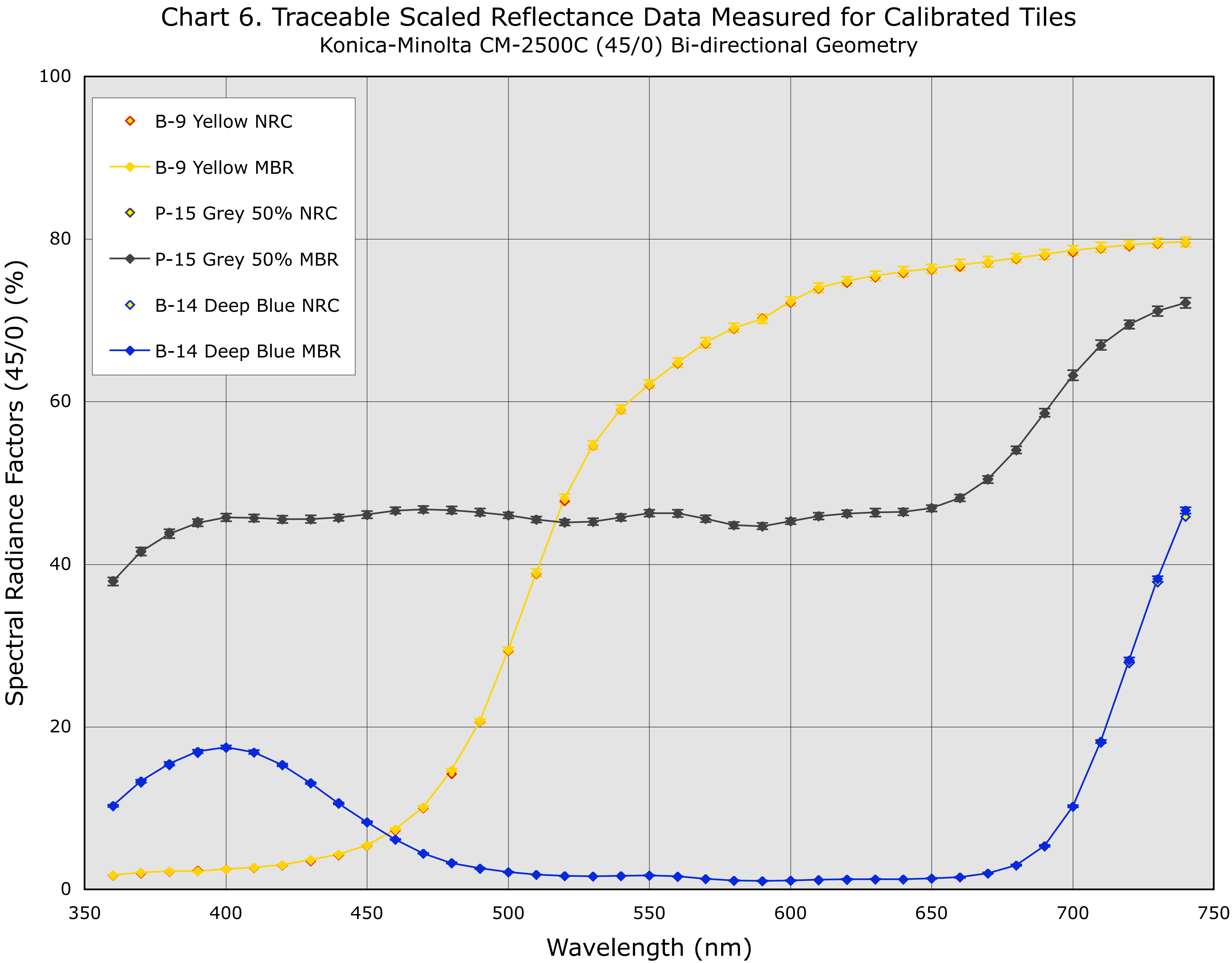


Chart 6. Traceable Scaled Reflectance Data Measured for Calibrated Tiles
Konica-Minolta CM-2500C (45/0) Bi-directional Geometry
B-9 Yellow NRC
B-9 Yellow MBR
P-15 Grey 50% NRC
P-15 Grey 50% MBR
B-14 Deep Blue NRC
B-14 Deep Blue MBR
Spectral Radiance Factors (45/0) (%)
Wavelength (nm)
0
20
40
60
80
100
350
400
450
500
550
600
650
700
750

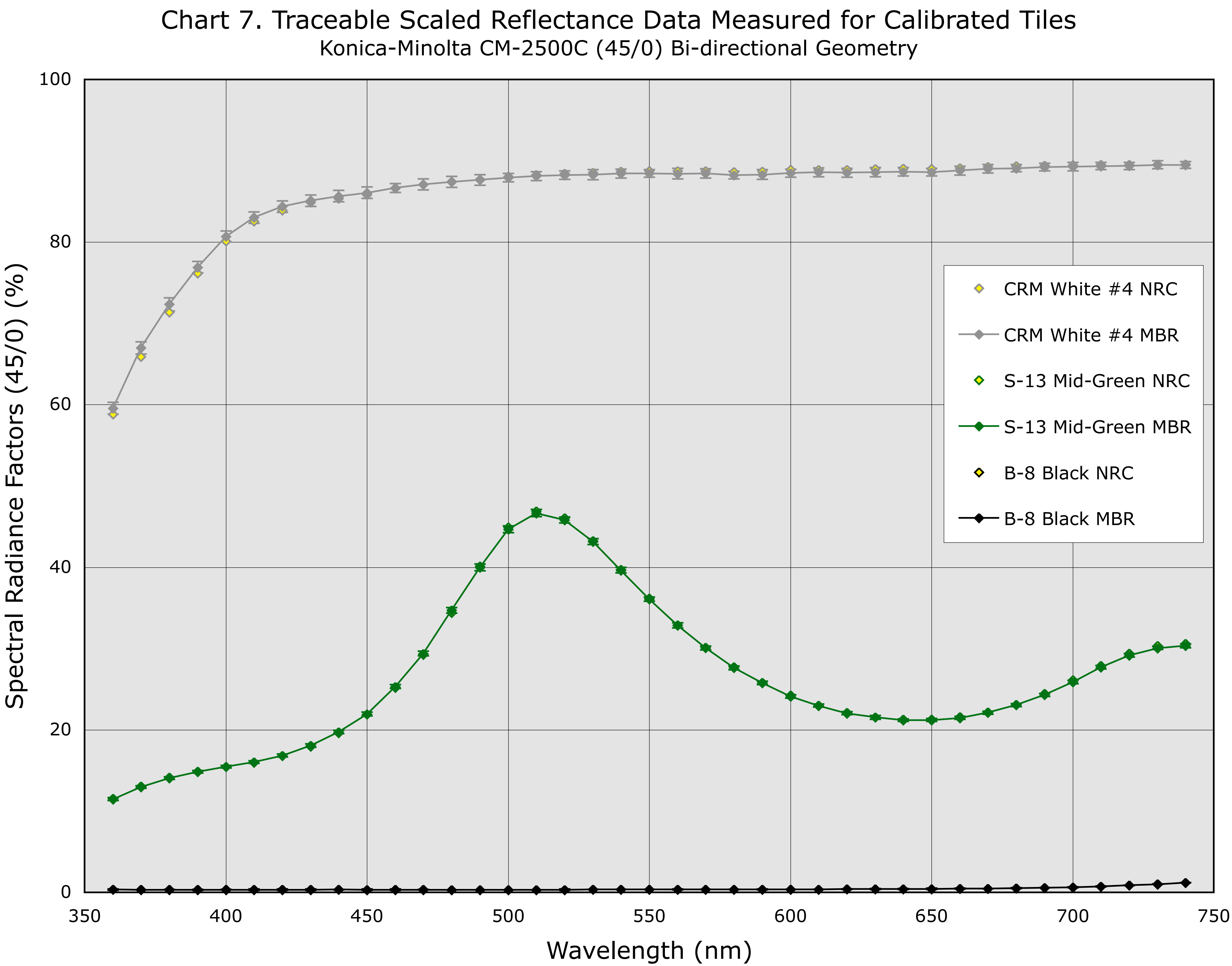


Chart 7. Traceable Scaled Reflectance Data Measured for Calibrated Tiles
Konica-Minolta CM-2500C (45/0) Bi-directional Geometry
Spectral Radiance Factors (45/0) (%)
Wavelength (nm)
0
20
40
60
80
100
350
400
450
500
550
600
650
700
750
CRM White #4 NRC
CRM White #4 MBR
S-13 Mid-Green NRC
S-13 Mid-Green MBR
B-8 Black NRC
B-8 Black MBR

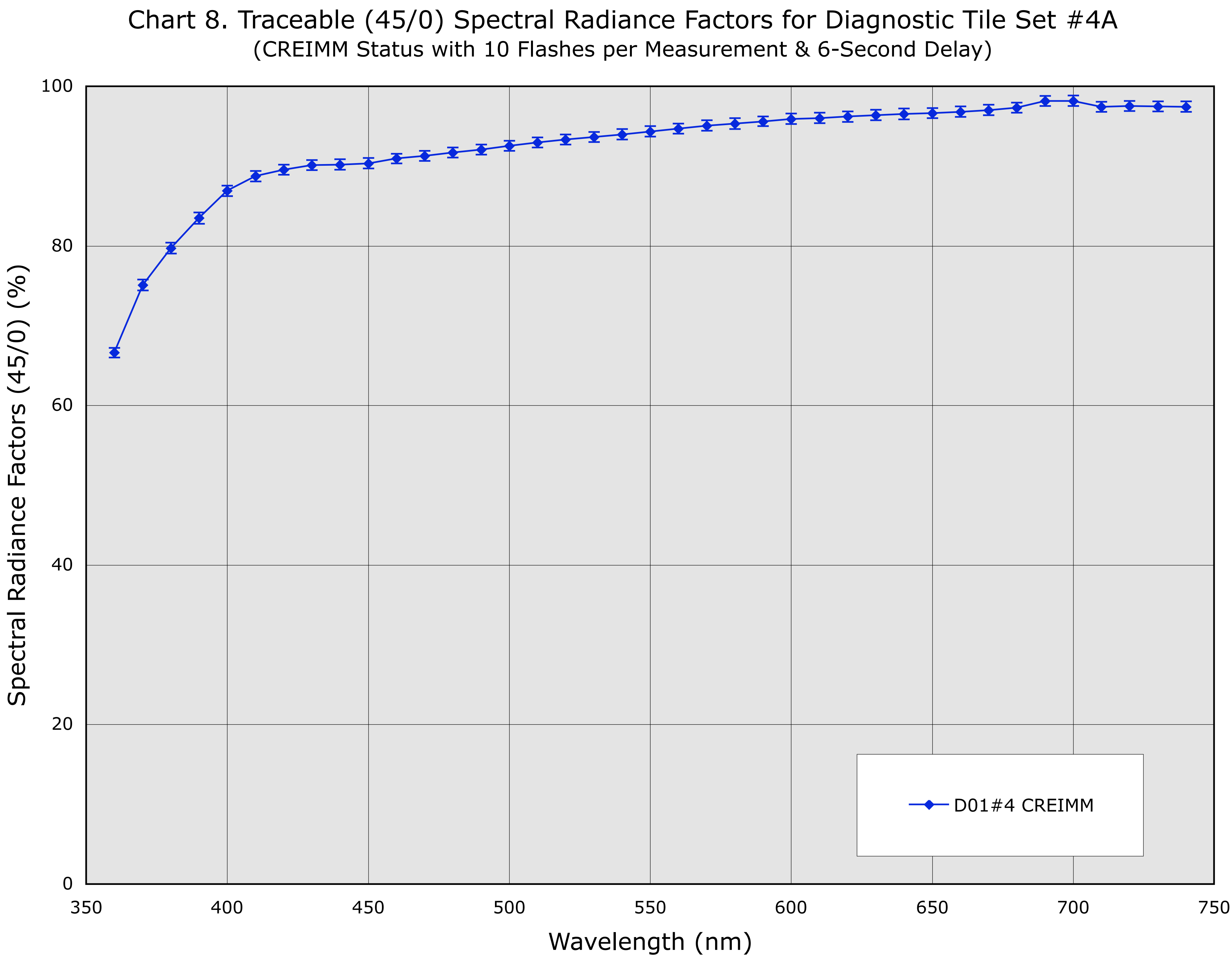


Chart 8. Traceable (45/0) Spectral Radiance Factors for Diagnostic Tile Set #4A
(CREIMM Status with 10 Flashes per Measurement & 6-Second Delay)
Spectral Radiance Factors (45/0) (%)
100
80
60
40
20
0
350
400
450
500
550
600
650
700
750
Wavelength (nm)
D01#4 CREIMM

Chart 9. Traceable (45/0) Spectral Radiance Factors for Diagnostic Tile Set #4A
(CREIMM Status with 5 Flashes per Measurement & 6-Second Delay)

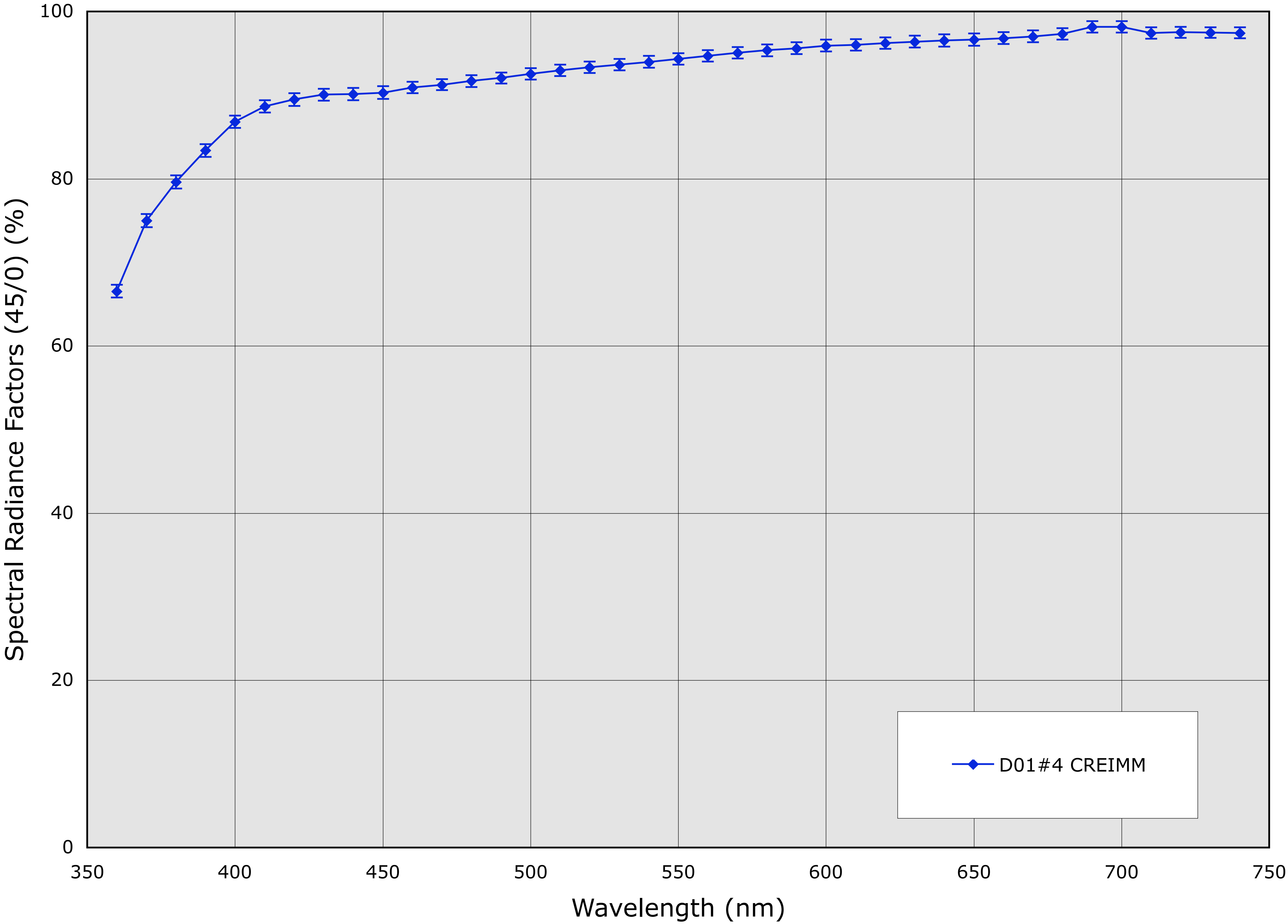
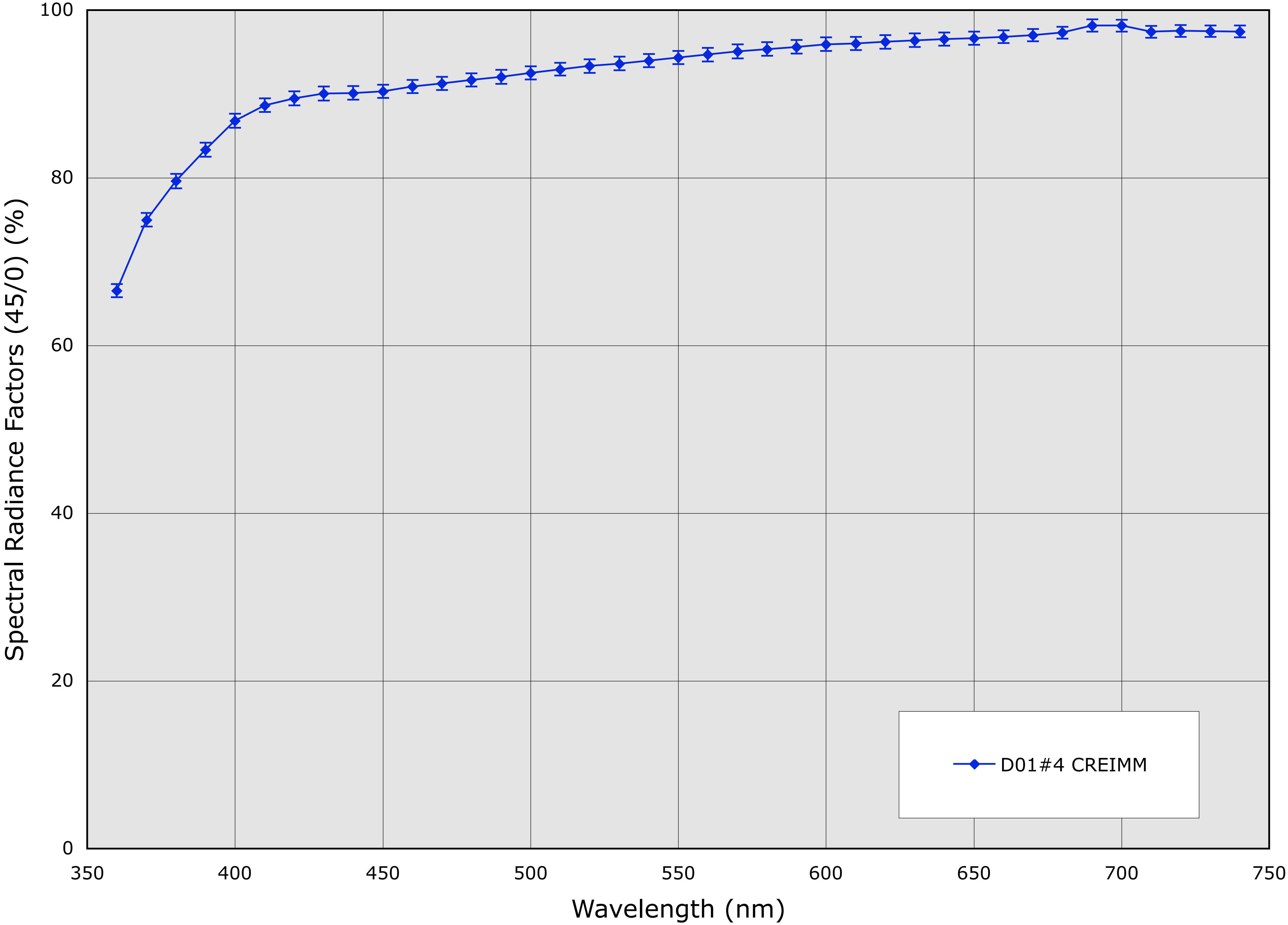


Chart 10. Traceable (45/0) Spectral Radiance Factors for Diagnostic Tile Set #4A
(CREIMM Status with 5 Flashes per Measurement & 11-Second Delay)



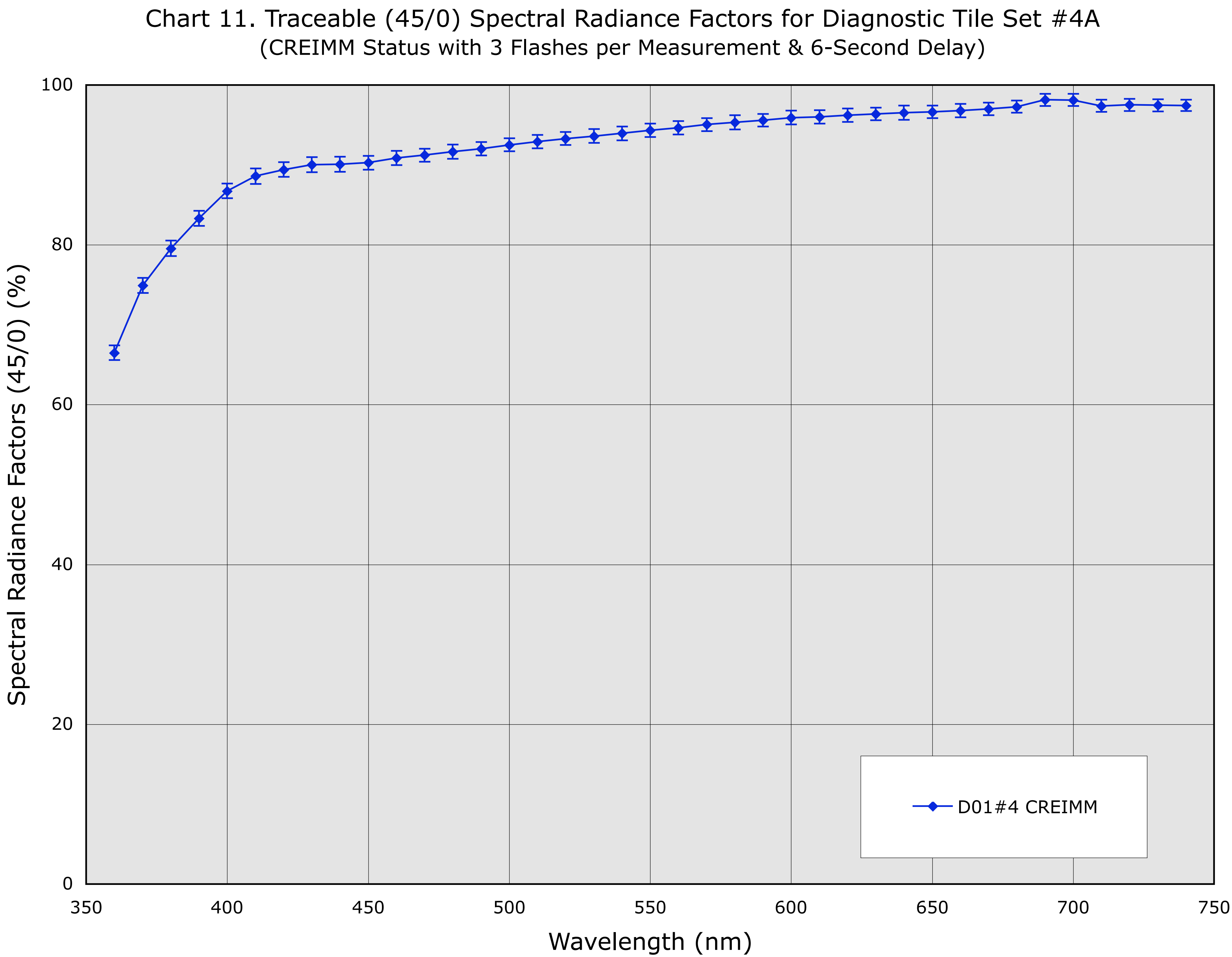


Chart 11. Traceable (45/0) Spectral Radiance Factors for Diagnostic Tile Set #4A
(CREIMM Status with 3 Flashes per Measurement & 6-Second Delay)
Spectral Radiance Factors (45/0) (%)
Wavelength (nm)
0
20
40
60
80
100
350
400
450
500
550
600
650
700
750
D01#4 CREIMM

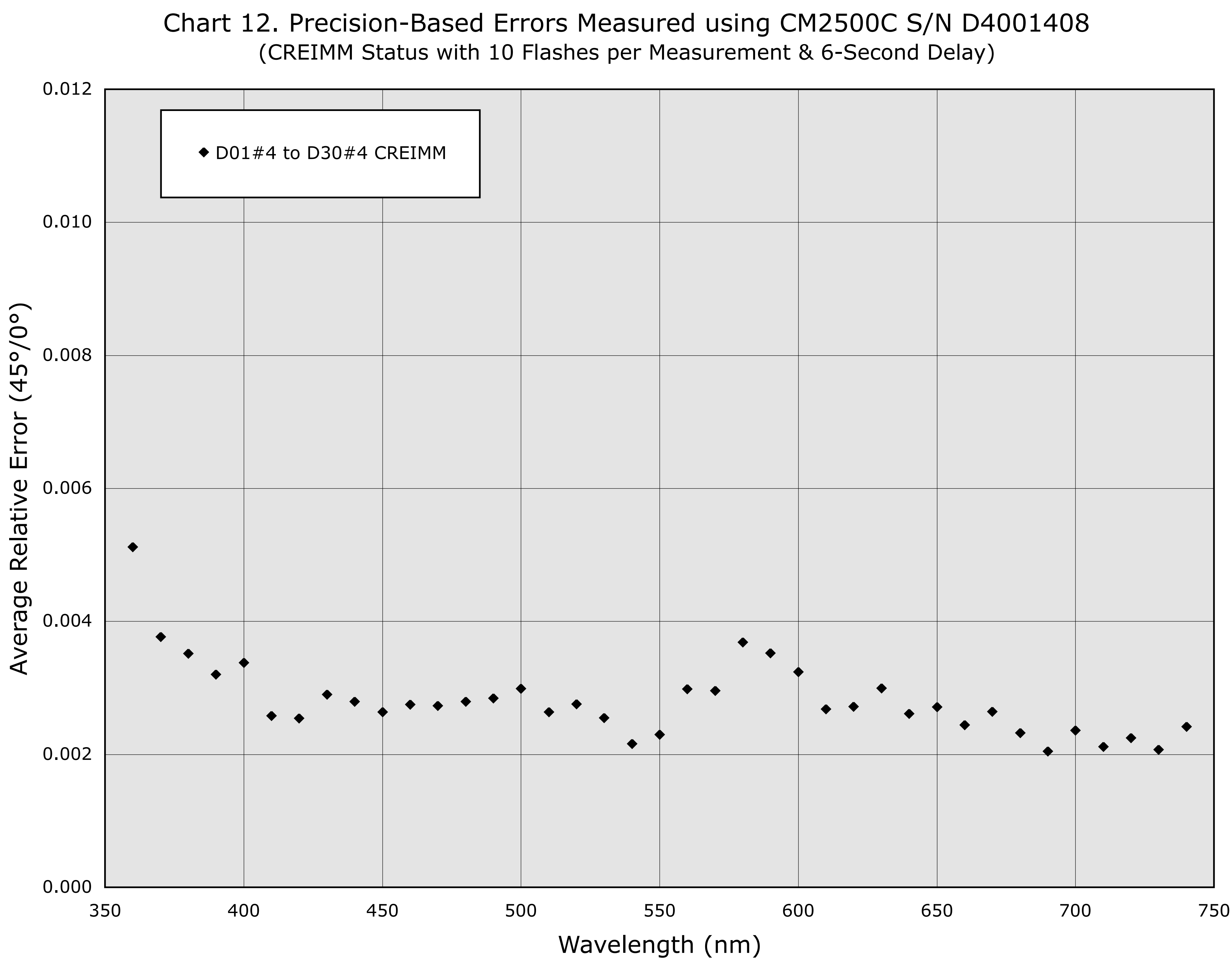


Chart 12. Precision-Based Errors Measured using CM2500C S/N D4001408
(CREIMM Status with 10 Flashes per Measurement & 6-Second Delay)
D01#4 to D30#4 CREIMM
Average Relative Error (45°/0°)
0.012
0.010
0.008
0.006
0.004
0.002
0.000
350
400
450
500
550
600
650
700
750
Wavelength (nm)

Chart 13. Precision-Based Errors Measured using CM2500C S/N D4001408
(CREIMM Status with 10 Flashes per Measurement & 6-Second Delay)

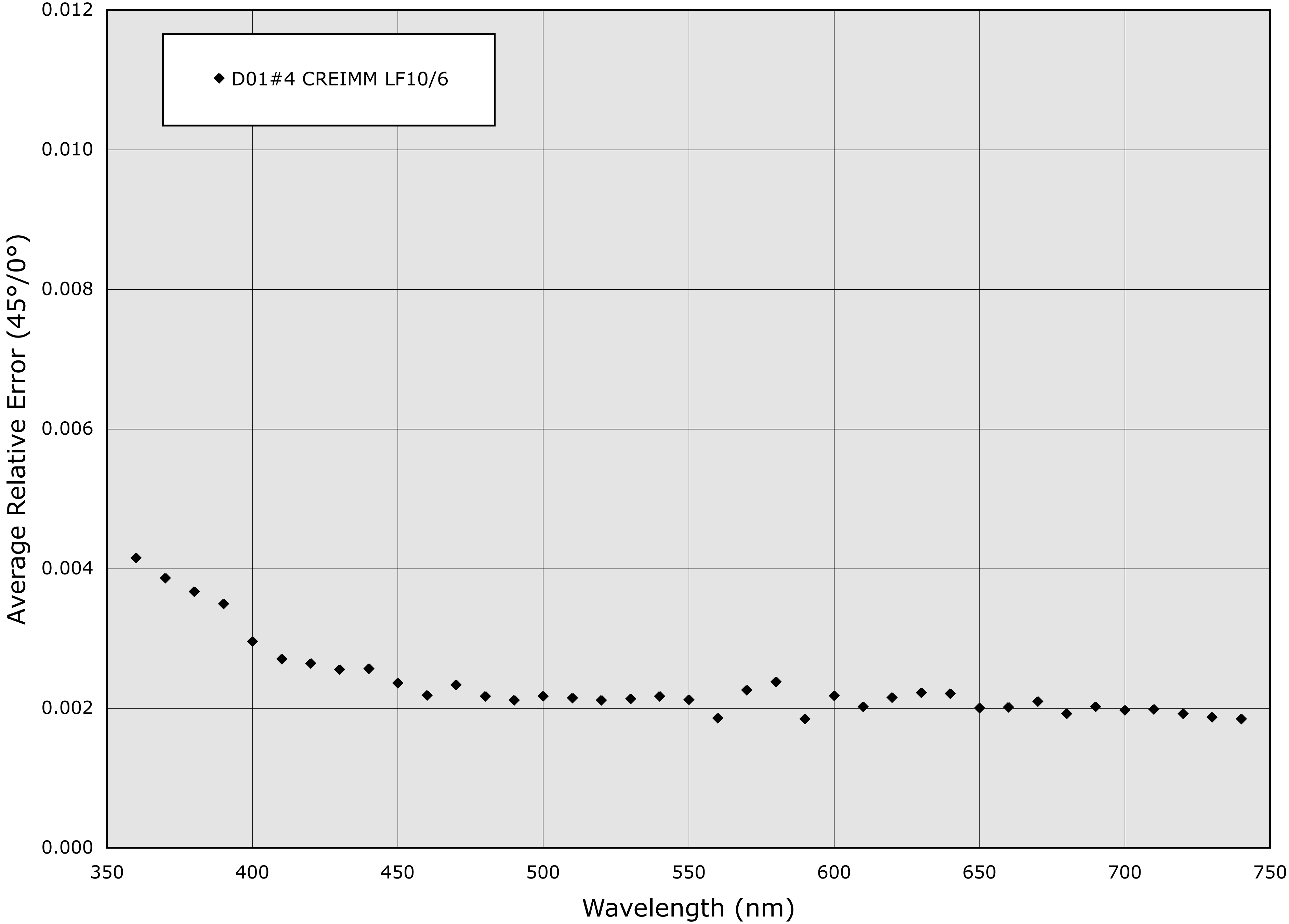


Chart 14. Precision-Based Errors Measured using CM2500C S/N D4001408
(CREIMM Status with 5 Flashes per Measurement & 6-Second Delay)

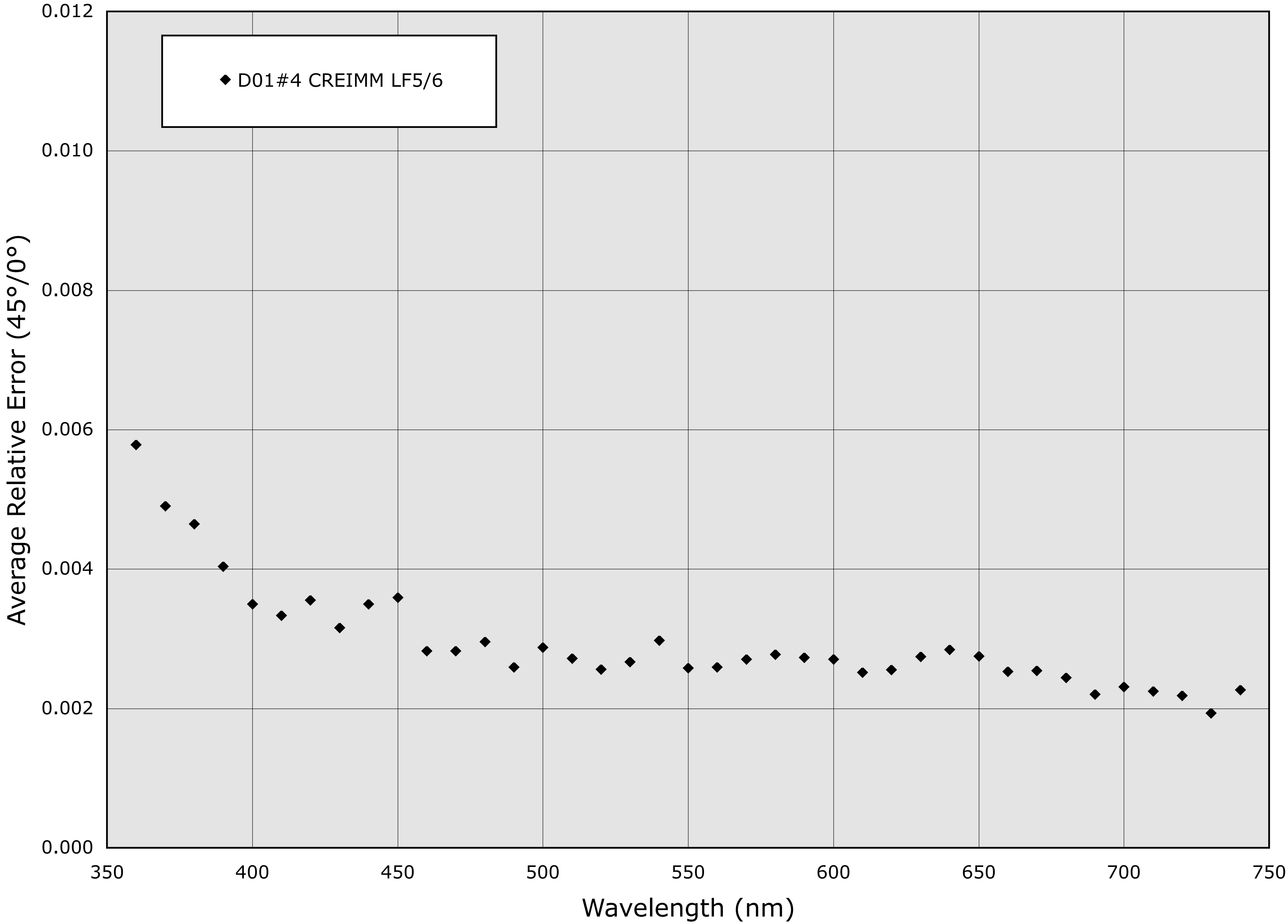


Chart 15. Precision-Based Errors Measured using CM2500C S/N D4001408
(CREIMM Status with 5 Flashes per Measurement & 11-Second Delay)

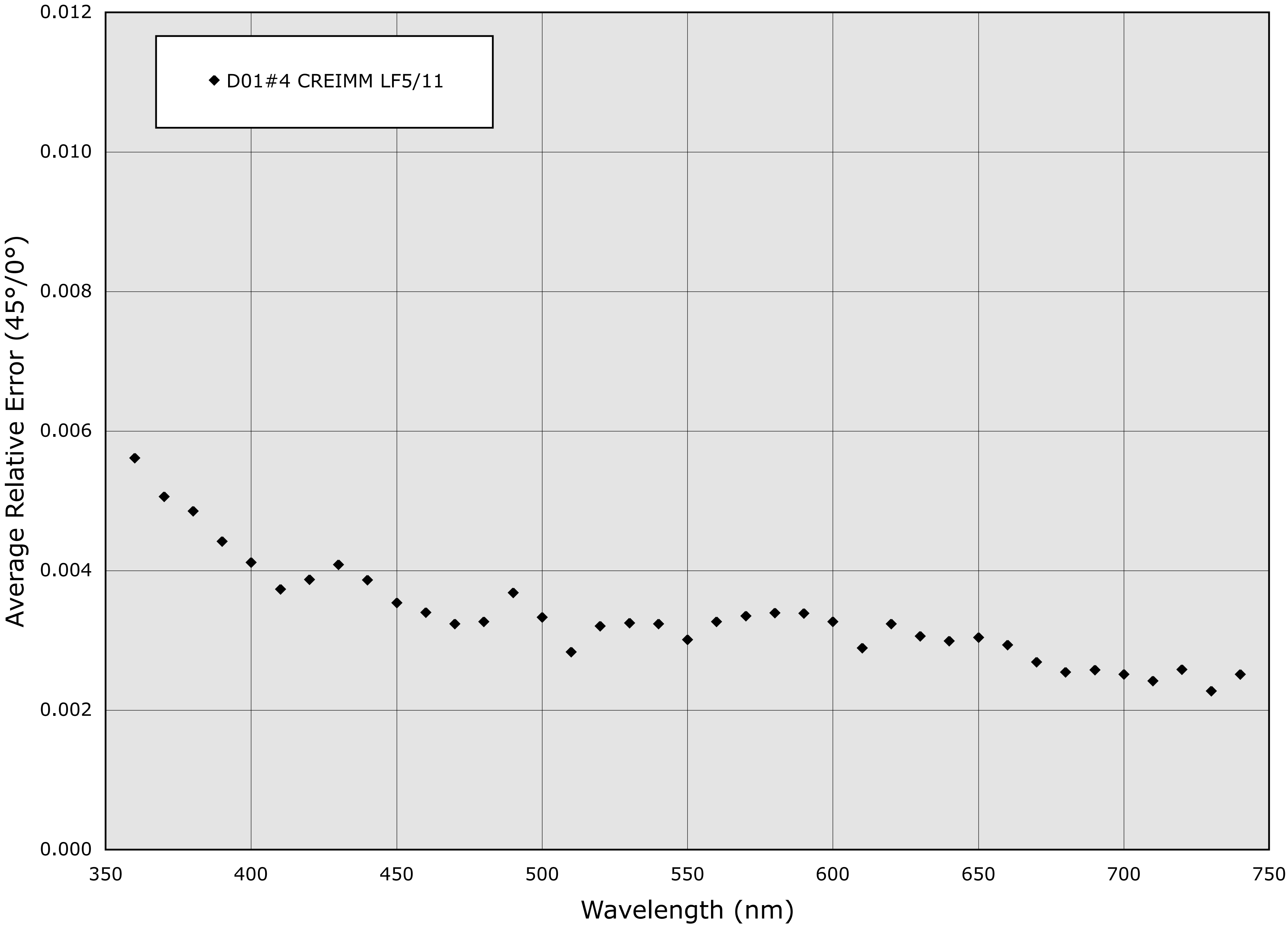
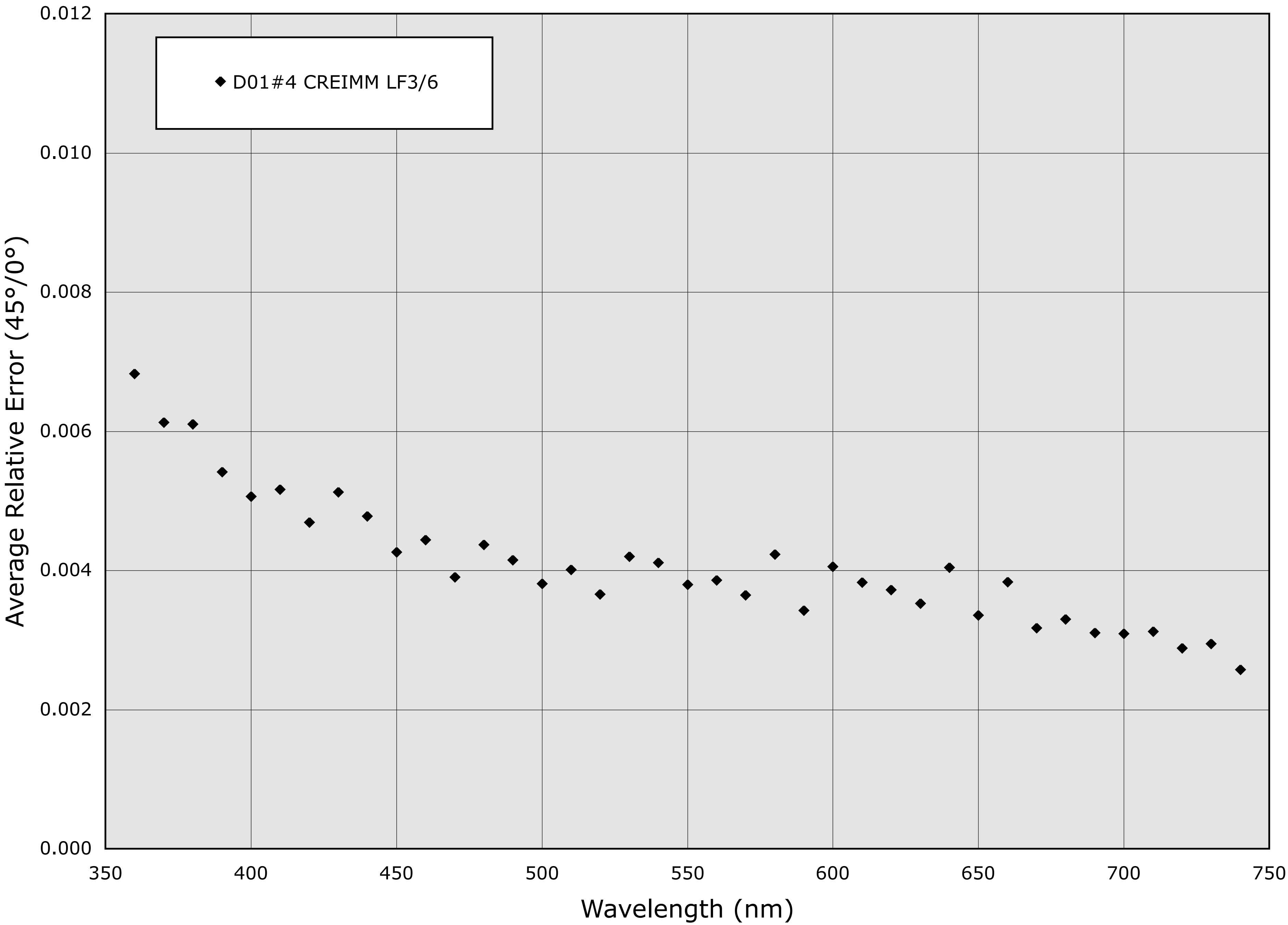


Chart 16. Precision-Based Errors Measured using CM2500C S/N D4001408
(CREIMM Status with 3 Flashes per Measurement & 6-Second Delay)



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