APMP.L-K8

International Comparison of Surface Roughness

Final report
January 2013

Measurements
July 2008 to June 2010

Prepared by

Mr Andrew Baker
National Measurement Insitute
Australia
(NMIA)

Co-authored by

S.L.Tan, National Metrology Centre (NMC, A*STAR), Singapore
R.Leach, National Physical Laboratory (NPL), UK
L.Jung, Physikalisch-Technische Bundesanstalt (PTB), Germany
S.Y.Wong, Standards and Calibration Laboratory (SCL), Hong Kong
A. Tonmueanwai, National Institute of Metrology, Thailand (NIMT), Thailand
K. Naoi, National Metrology Institute of Japan (NMIJ), Japan
J. Kim, Korea Research Institute of Standards and Science (KRISS), South Korea
T.B.Renegar, National Institute of Standards and Technology (NIST), USA
K P Chaudhary, National Physical Laboratory India (NPLI), India
O. Kruger, National Metrology Institute of South Africa (NMISA), South Africa
M. Amer, National Institute of Standards (NIS), Egypt
S. Gao, National Institute of Metrology (NIM), China
C. L. Tsai, National Measurement Laboratory (CMS), Chinese Taipei
N. Anh, Vietnam Metrology Institute (VMI), Vietnam
A. Drijarkara, Kalibrasi Instrumentasi dan Metrologi Lembaga Ilmu Pengetahuan Indonesia (KIM-LIPI), Indonesia

TABLE OF CONTENTS

Abstract:

Surface roughness calibration services of sixteen countries from four metrology regions are compared through measurements of roughness and step height standards. The artefacts circulated include three steps of nominal depths 0.4 μm, 2.4 μm and 10 μm, whereas the roughness sections of both type C and type D profiles have nominal *Ra* values of 0.2 μm, 0.95 μm, 1.5 μm and 3.1 μm. Two softgauges were also circulated for comparison of software independent of hardware. For the steps, parameter *d* is reported, while for the type C and type D standards and softgauges, fourteen different roughness parameters are reported between them. Concluding measurements from the pilot in general show good standard stability, however, for some parameters on the artefacts of larger roughness, stability may be considered less certain and this may be an issue in additional outliers in results from the last few laboratories in the schedule. For each parameter, a key comparison reference value (KCRV) is determined using a weighted mean with outliers excluded based on the Birge ratio method until all accepted values form a statistically consistent population. For the five artefacts, out of thirty-five separate parameters, only ten have good agreement of all submitted results. Where some parameters had to be excluded from the KCRV, some laboratories had consistent problems with particular types of parameter over the different artefacts, while for other laboratories the types of parameters excluded seemed to be random. Comparison of softgauge results and artefact results has proven to be inconclusive.

1. Introduction

The broad objective of the Asia Pacific Metrology Program (APMP) is to improve the measurement capabilities in the Asia Pacific region by sharing facilities and experience in metrology. Comparison of calibrations by different laboratories on given artefacts adds confidence in the measurement of standards and leads to international acceptance of the measurements carried out by these laboratories. This intercomparison concerns the calibration of surface roughness standards by both contact and non-contact methods. Standards and data files are circulated for groove and parameter measurement with each laboratory to decide which method is appropriate for each standard. The comparison was expanded to include laboratories from the EURAMET, SIM and SADCMET with measurements spanning two years as shown in Table 3.

2. Description of the standards

The artefacts circulated for assessment of surface texture are listed in Table 1 and Figures 1 to 6.

Table 1. Nominal sizes of standards and softgauges. All sizes in micrometres.

Type [4]	Model	Serial Number	Nominal Depth	Nominal *Ra*	Nominal *RSm*
A1	112/331	**A277**	(A) 0.4	-	-
			(B) 2.7	-	-
A1	45/13222	**7462**	10	-	-
D1	4058/01A1	**5276**	-	0.2	-
C1	112/331	**A277**	-	0.95	80
D1	4058/01A3	**5256**	-	1.5	-
C1	2073a	**1286**	-	3.1	100
F1	Cos4		-	0.5	
F1	Sin_2_16		-	0.4	

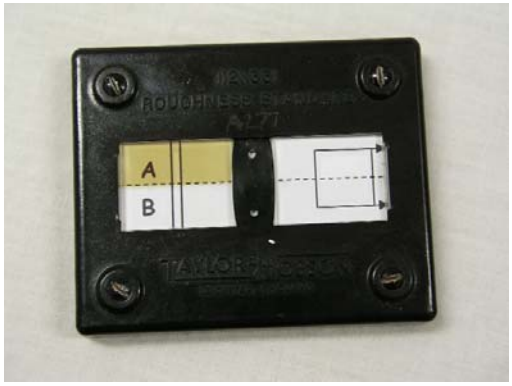


Figure 1. s/n A277: two grooves and roughness

Figure 2. s/n 7462: 10 µm groove

Figure 3. type D1 s/n 5276 and 5256 roughness

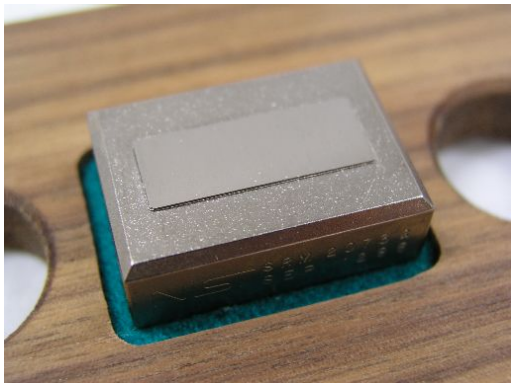


Figure 4. type C1 s/n 1286

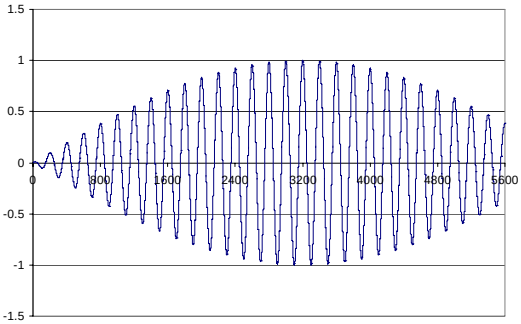


Figure 5. Softgauge profile Cos4

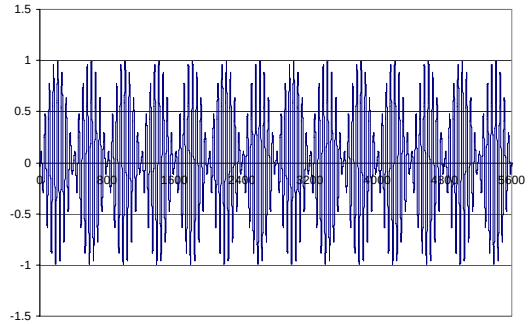


Figure 6. Softgauge profile Sin_2_16

3. Participating laboratories and measurement schedule

Participants were required to offer step height and surface roughness as a calibration service. By accepting the offer to participate, they accept and agree to follow the measurement procedures described in the protocol "APMP-L-K8 surface roughness intercomparison protocol v2.pdf". Malaysia are listed in the protocol but withdrew due to equipment difficulty.

Table 2. Participants

Country	Laboratory / Address	Contact
Australia [PILOT]	**National Measurement Institute Australia (NMIA)** 1/153 Bertie St, Port Melbourne, 3207, Australia	**Mr Andrew Baker** andrew.baker@measurement.gov.au
Singapore	**National Metrology Centre (NMC, A*STAR)** 1 Science Park Drive, #02-27, Singapore 118221	**Ms Siew Leng Tan** tan_siew_leng@nmc.a-star.edu.sg
United Kingdom	**National Physical Laboratory (NPL)** Hampton Road, Teddington, Middlesex, TW11 0LW, United Kingdom	**Prof Richard Leach** richard.leach@npl.co.uk
Germany	**Physikalisch-Technische Bundesanstalt (PTB)** Bundesallee 100, D-38116 Braunschweig, Deutschland, Germany	**Dr Lena Jung** lena.jung@ptb.de
Hong Kong	**Standards and Calibration Laboratory (SCL)** 36/F Immigration Tower, 7 Gloucester Road, Wan Chai, Hong Kong	**Dr Seung Yin Wong** sywong@itc.gov.hk
Thailand	**National Institute of Metrology, Thailand (NIMT)** 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani, 12120 Thailand	**Mr Anusorn Tonmueanwai** anusorn@nimt.or.th
Japan	**National Metrology Institute of Japan (NMIJ)** AIST Tsukuba Central 3, Umezono 1-1-1, Tsukuba, Ibaraki 305-8536, Japan	**Dr Kazuya Naoi** naoi.k@aist.go.jp
South Korea	**Korea Research Institute of Standards and Science (KRISS)** 1 Doryong-dong, Yuseong-gu, Daejeon, 305-340, South Korea	**Dr Jaewan Kim** jaewan@kriss.re.kr
United States of America	**National Institute of Standards and Technology (NIST)** 100 Bureau Drive, Stop 8212, Gaithersburg, MD 20899-8212, USA	**Dr Thomas Brian Renegar** brenegar@nist.gov
India	**National Physical Laboratory India (NPLI)** Dr.K.S Krishnan Marg, New Delhi 110012, India	**Dr K P Chaudhary** kpc@mail.nplindia.ernet.in
South Africa	**National Metrology Institute of South Africa (NMISA)** PO Box 395, Brummeria, Pretoria, Republic Of South Africa	**Mr Oelof Kruger** oakruger@nmisa.org
Egypt	**National Institute of Standards (NIS)** Tersa St., El-Haram, El-Giza, Egypt, Box136 Giza Code No 1221, Egypt	**Dr. Mohamed A. Amer** amer@nis.sci.eg
China	**National Institute of Metrology (NIM)** Beisanhuandonglu 18, 100013 Beijing, China	**Prof Sitian Gao** gaost@nim.ac.cn
Chinese Taipei	**National Measurement Laboratory (CMS)** Bldg. 16, 321 Kuang Fu Rd, Sec. 2, Hsinchu, Taiwan	**Mr Chin-Lung Tsai** Walter_Tsai@itri.org.tw
Vietnam	**Vietnam Metrology Institute (VMI)** 08 HoangQuocViet Road, CauGiay Dist, Hanoi, Vietnam	**Mr Ngo Ngoc Anh** anhnn@vmi.gov.vn
Indonesia	**Kalibrasi Instrumentasi dan Metrologi Lembaga Ilmu Pengetahuan Indonesia (KIM-LIPI)** Kompleks Puspiptek, Tangerang, Banten 15314, Indonesia	**Mr Augustinus Drijarkara** probo@kim.lipi.go.id

The comparison was carried out in circular form with repeat measurements by the pilot, Australia. Only the first measurements by the pilot are included in determination of the key comparison reference values. Superficial checks were made by the coordinator, Andrew Baker, while on secondment to NPL in May 2009. The actual schedule is listed in Table 3. Significant customs delays occurred due to a lost Carnet between Germany and Hong Kong and also a customs clearance difficulty between the NMIA mid-cycle check at NPL in the UK and the USA. Overall the delays did not affect the intercomparison.

Table 3. Measurement schedule

Country	Laboratory	Region	Planned Schedule	Actual Schedule (approximate)	Carnet
Australia	NMIA	APMP	July 2008	July 2008	-
Singapore	NMC, A*STAR	APMP	August 2008	August 2008	Yes
United Kingdom	NPL	EURAMET	September 2008	September 2008	Yes
Germany	PTB	EURAMET	October 2008	October 2008	Yes
Hong Kong	SCL	APMP	November 2008	December 2008	Yes
Thailand	NIMT	APMP	December 2008 / January 2009	January 2009	Yes
Japan	NMIJ	APMP	January / February 2009	January / February 2009	Yes
Malaysia	SIRIM	APMP	March 2009	Withdrawn	Yes
South Korea	KRISS	APMP	April 2009	April 2009	Yes
Australia (check)	NMIA	APMP	May 2009	May 2009 (in UK)	Yes
USA	NIST	SIM	June 2009	June / July 2009	Yes
India	NPLI	APMP	July 2009	August 2009	Yes
South Africa	NMISA	AFRIMET	August 2009	October 2009	Yes
Egypt	NIS	AFRIMET	September 2009	November 2009	No
China	NIM	APMP	October 2009	December 2009 / January 2010	No
Chinese Taipei	CMS	APMP	November 2009	February 2010	No
Vietnam	VMI	APMP	December 2009 / January 2010	March / April 2010	No
Indonesia	KIM-LIPI	APMP	January 2010 / February 2010	April / May 2010	No
Australia (repeat)	NMIA	APMP	March 2010	June 2010	Yes

4. Measuring equipment

The equipment and software (where reported) used by each laboratory for measurement is listed in Table 4. Where a laboratory does not calibrate their own reference grooves and uses another laboratory's services, the traceability path is listed.

Table 4. Expected measurement instruments

Country	Laboratory	Measurement Equipment and Software	Traceability Path
Australia	NMIA	Zeiss Jena Epival Interference Microscope with He-Ne laser, Hommelwerke T8000, software Turbo Wave v7.20	Self
Singapore	NMC, A*STAR	Form Talysurf Series S3C	Self, NPL
United Kingdom	NPL	NanoSurf IV Softgauges 1.01	Self
Germany	PTB	Taylor Hobson Nanostep QZM Zeiss Interference Microscope, Mahr Perthometer Concept, Software RPTB v1.46	Self
Hong Kong	SCL	Talysurf 120, ø25 mm steel ball	NPL
Thailand	NIMT	Surfcarder ET4000AK	NMIA
Japan	NMIJ	Surfmaster Software NMIJ v1.1	Self
South Korea	KRISS	Form Talysurf 2, software Ultra v4.3.14	Self
USA	NIST	Taylor Hobson Talystep, Taylor Hobson Form Talysurf PGI 1240 NIST software web-based	Self
India	NPLI	Mahr Perthometer S6P	PTB
South Africa	NMISA	Talysurf Series 2 Software: Ultra 5.11.6.17	Self
Egypt	NIS	Taylor Hobson Form Talysurf i60 Software Taylor Hobson Ultra 5.16.2.0	KRISS, NPL
China	NIM	Form Talysurf series 2, Software Taylor Hobson Ultra v4.6.8, Talymap v3.1.9	Self
Chinese Taipei	CMS	Kosaka ET-4100 Software not specified	Self
Vietnam	VMI	Surftest Extreme SV3000 – CNC Software: Form Tracepak 3000	NMIJ
Indonesia	KIM-LIPI	Form Talysurf i120	NPL

Disclaimer. Certain commercial equipment, instruments, or materials are identified in this report in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the participants or their institutes, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

5a. Measurement conditions for grooves

For the three grooves of the intercomparison, the centre groove was to be measured with a minimum of five measurements spanning the groove by either non-contact or contact method. The required spacing between profile lines (for the three grooves) is given in Figure 7. For stylus instruments, direction of measurement was from left to right on standard A277 and in the same direction as the arrow label on standard 7462. The speed of traverse was recommended to be slower than 0.5 mm/s. For stylus instruments, the parameter *d* described in ISO 5436-1 [4] was to be determined. If this cannot be measured, *Pt (*ISO 4287 [2]) could be used for an approximation, minimising unnecessary profile length and ensuring acceptable levelling or line fitting. For non-contact optical instruments, an approximation of *d* was to be given.

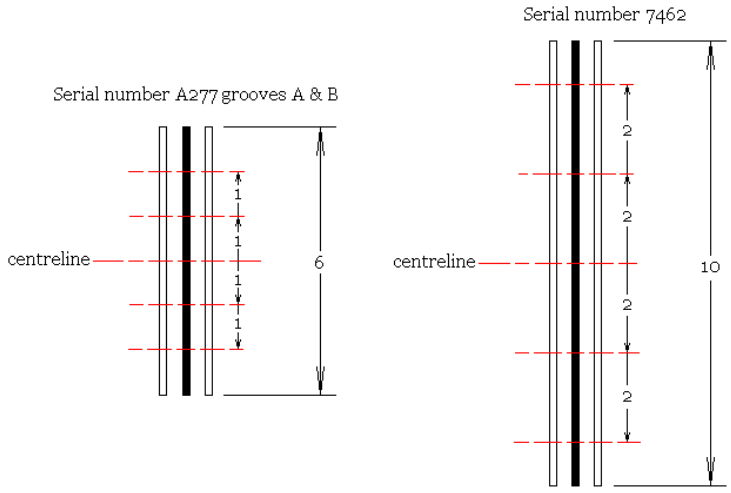


Figure 7. Measurement profile locations in red for the serial numbers A277 and 7462 grooves. Dimensions in mm.

5b. Measurement conditions for roughness section

Parameters were to be calculated according to ISO 4287 [2] with measurement conditions listed in Table 5, with a Gaussian filter (ISO 11562 [6]) in preference to an RC filter. A traverse speed slower than 0.2 mm/s and a sample spacing less than 0.5 µm with a tip radius of 2 µm were recommended with any conditions variation to be noted. Skids were not recommended. Laboratories were required to report any of the listed parameters, noting that the definition *Rz* had changed from ISO 4287:1984 and that *RSm* could vary if software used different methods of counting peaks. Profiles displaying obvious surface flaws were to be discarded from the results.

Table 5. Measurement conditions for roughness standards

Type	Serial Number	Nominal *Ra* (µm)	Nominal *RSm* (µm)	ln (mm)	λc (mm)	Filter λc/λs	Parameters ISO 4287 [2] ISO 13565-2 [8]
D1 non periodic	5276	0.2	-	4.0	0.8	300:1	***Ra, Rq, Rz, Rv, Rp, Rt, Rsk, Rku Rk, Rpk, Rvk, Mr1, Mr2***
	5256	1.5	-				
C1 periodic	A277	0.95	80	1.25	0.25	100:1	***Ra, Rz, RSm***
	1286	3.1	100	4.0	0.8	300:1	

The recommended profile locations on each roughness standard are shown in figures 8, 9 and 10 with either twelve, fifteen or twenty measurements to be made.

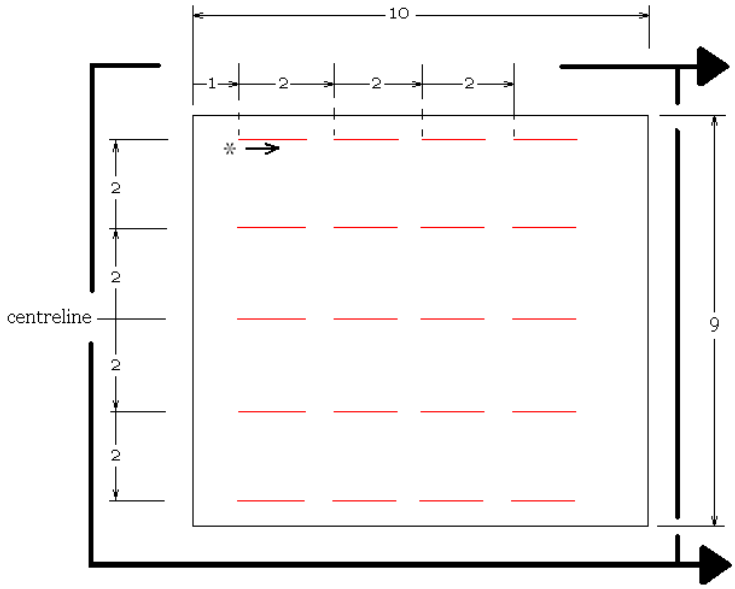


Figure 8. Profile locations for serial number A277 roughness section. 20 profiles, ln = 1.25 mm. Dimensions in mm.

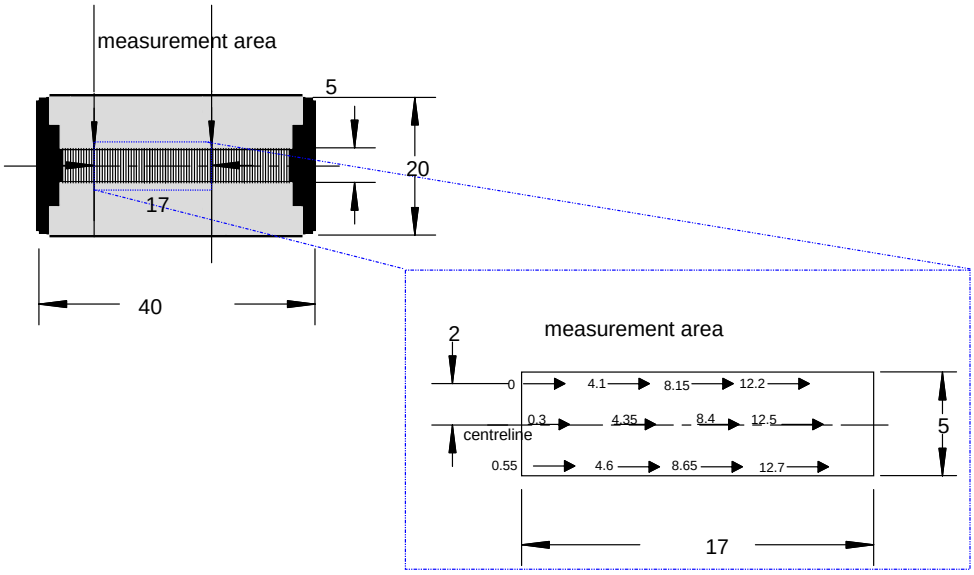


Figure 9. Profile locations for both type D standards, 12 profiles, ln = 4.0 mm. Dimensions in mm.

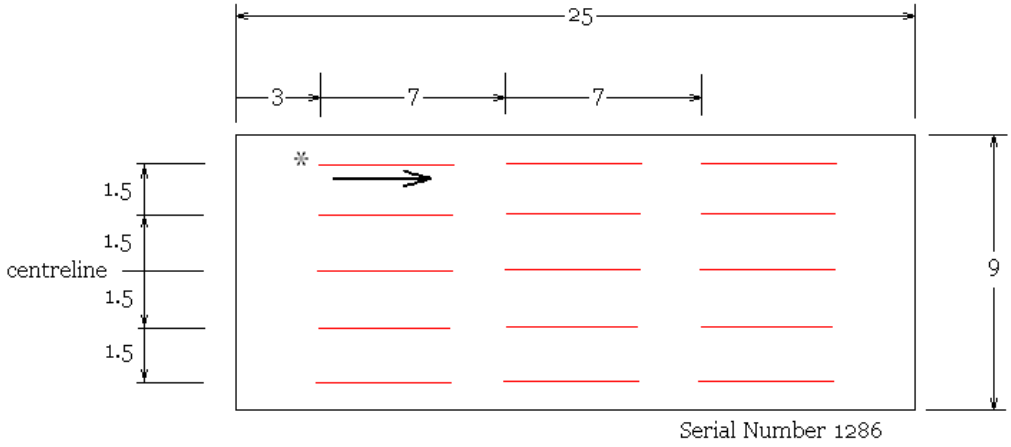


Figure 10. Profile locations for the type C serial number 1286 standard. 15 profiles, ln = 4.0 mm. Dimensions in mm.

5c. Measurement conditions for softgauges

Softgauges are computer data files that typify a digital representation of a surface. Two profiles were supplied on a memory stick in SMD format according to ISO 5436-2 [5], however, other non-standard formats were also supplied. Each laboratory was to determine which format was suitable for their software and determine the parameters listed in Table 6 using the conditions listed. There was some confusion during the intercomparison about what filtering to apply. The instruction listed in the protocol was intended to have a long wave filter of 0.8 mm applied but no short wave filter (λs) applied. For ***Rz*** and ***RSm*** see notes in previous section.

Table 6. Measurement conditions

Type F1	Filename	ln (mm)	λc (mm)	Filter λc/λs	Parameters ISO 4287
1	Cos4	5.6	0.8	OFF	***Ra, Rq, Rz, Rp, Rv, Rt, RSm***
2	Sin_2_16				

6. Comments on documents submitted

Each laboratory was requested to submit results using the protocol Appendix C template, full reports (as would be given to any calibration client) and full uncertainty calculations.

All laboratories submitted results from the protocol forms. Many laboratories did not measure all parameters. Not all laboratories submitted evidence of the surface condition of each standard before and after measurement. Not all laboratories submitted full calibration reports. Not all laboratories submitted uncertainty calculations. Refer to Appendix A for a table of which documents each laboratory submitted.

7. Analysis methods

When all results had been submitted, the reference value for each measured quantity was determined from the weighted mean of the values x_i from each individual laboratory, as shown in equation 1.

$$\bar{x}_w = \left[\sum_{i=1}^{N} x_i / u^2(x_i)\right] \Big/ \left[\sum_{i=1}^{N} 1/u^2(x_i)\right] \quad (1)$$

To avoid bias, only the first set of measurements from the pilot laboratory was included in reference value determination.

The standard uncertainty of the reference value was taken as the standard deviation of the mean of the set of reported x_i values. The calculation for the standard uncertainty of the weighted mean, including correlation terms, is shown in equation 2.

$$u^2(\bar{x}_w) = \left[\sum_{i=1}^{N} 1/u^2(x_i)\right]^{-1} + 2\left[\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} r(x_i, x_j)\frac{1}{u(x_i)}\frac{1}{u(x_j)}\right] \Big/ \left[\sum_{i=1}^{N} 1/u^2(x_i)\right]^2 \quad (2)$$

Assessment of each laboratory's result was made with the degree of equivalence ratio, E_n, with respect to the reference value. The calculation for the determination of E_n is:

$$E_n = \frac{x_i - \bar{x}}{2\sqrt{u^2(x_i) - u^2(\bar{x})}} \tag{3}$$

where $u(x_i)$ is the standard uncertainty of the individual laboratory and $u(\bar{x})$ is the standard uncertainty of the weighted mean. The largest value of E_n which exceeded unity is excluded and the reference value and E_n ratio are recalculated. Only one result is excluded at a time.

The Birge ratio is a value that can be used to test of the consistency of a set of data and its uncertainties. If the measurements being compared come from the same population, then the propagated (internal) uncertainty, $u_I(\bar{x}_w)$, should agree with that calculated from the standard deviation of the weighted mean (external uncertainty), $u_E(\bar{x}_w)$, as given in equations 4 and 5.

$$u_I^2(\bar{x}_w) = \left[\sum_{i=1}^{N} 1/u^2(x_i)\right]^{-1} \tag{4}$$

$$u_E^2(\bar{x}_w) = \left[\sum_{i=1}^{N} (x_i - \bar{x}_w)^2 / u^2(x_i)\right] \Big/ \left[(N-1)\sum_{i=1}^{N} 1/u^2(x_i)\right] \tag{5}$$

For an infinite population size, the ratio should approximate a value of 1. For a limited population size, the Birge criterion is given by:

$$R_B = \sqrt{1 + \sqrt{\frac{8}{N-1}}} \tag{6}$$

where N is the number of accepted measurements. For sixteen laboratories, R_B is equal to 1.32. The criterion is recalculated if any results are excluded. A Birge ratio much larger than the criterion implies that some data contain systematic offsets or alternately that some uncertainties have been underestimated. A ratio much less than the criterion implies that uncertainties have been overestimated. The results will point to calculations that may need further investigation and possibly reassessment. The reference value will be selected that best reflects the population.

For a population with a number of results of E_n greater than 1 and the Birge ratio greater than the Birge criterion, the result with the largest E_n was removed and the weighted mean, the uncertainty of the mean, all E_n values, the Birge ratio and Birge criterion were recalculated. This iteration process was repeated until the Birge ratio became less than the Birge criterion and the exclusion process was stopped. If the population still contained a laboratory with an E_n greater than 1, this laboratory was retained in the calculation of the KCRV.

8. Condition and stability of standards

Many laboratories reported the surface condition of the standards before and after measurement. Only minor damage was reported in the form of minor scratches or corrosion spots. Graphs of results in Appendix B suggest that any damage during the two year period of the intercomparison is not significant. Few laboratories reported any results affected by flaws observed in profiles.

The pilot completed full measurements on the standards as the first laboratory and the last laboratory. Some intermediate measurements were made in the middle of the schedule; however, these were simple condition tests and cannot be used for quantative comparison. The E_n ratios for each parameter of the last measurements of NMIA and the first measurements of NMIA are listed in Table 7. Note that this equivalence number is not the same as that calculated for the initial and final NMIA results in the tables in Appendix C which are relative to the KCRV.

The majority of parameters gave a very good reproducibility and therefore the standards in general can be considered stable for the period of the project. However, for the two coarse standards, 1286 and 5256, the E_n values of many parameters do not repeat as well as for the smaller standards. This could be a significant issue in interpreting outliers from laboratories at the end of the schedule. It can be seen from individual parameter results that where the NMIA final result is significantly different to the initial result, the previous laboratory results are often in the opposing direction from the KCRV suggesting no real trend.

As shown in Figure 11, only one parameter, *Rk* for standard 5256, gave an E_n larger than 1. Observation of the individual laboratory results show that the three results prior to the last NMIA results were lower than the KCRV while the last NMIA result was higher. Overall this suggests that the 5256 standard for *Rk* can be considered stable for the period of the intercomparison.

Table 7. NMIA E_n first and last measurements

	GrA	GrB	Gr	*Ra*	*Rz*	*RSm*	*Rq*	*Rp*	*Rv*	*Rt*	*Rsk*	*Rku*	*Rk*	*Rpk*	*Rvk*	*Mr1*	*Mr2*
A277	0.04	0.33	-	0.15	0.4	0	-	-	-	-	-	-	-	-	-	-	-
7462	-	-	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1286	-	-	-	0.54	0.8	0	-	-	-	-	-	-	-	-	-	-	-
5276	-	-	-	0.16	0.09	-	0.17	0.02	0.06	0.26	0.03	0.53	0.39	0.12	0.03	0.15	*
5256	-	-	-	0.62	0.72	-	0.6	0.36	0.7	0.86	0.1	0.19	1.18	0.04	0.92	0.02	0.03

* Note: The parameter *Mr2* was not remeasured at the end of the intercomparison due to a parameter selection error.

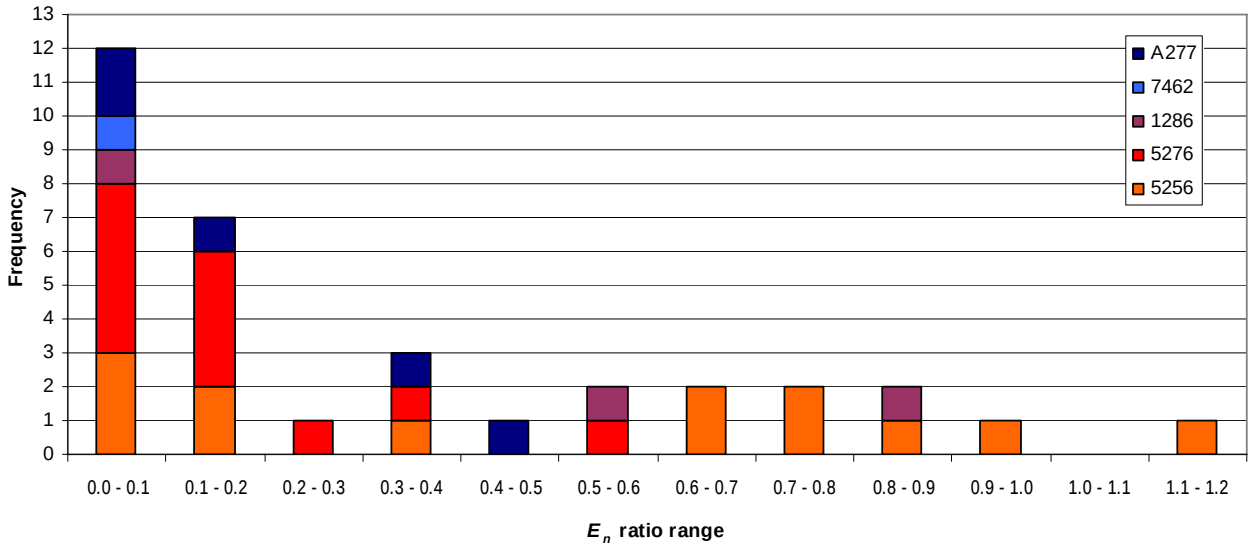


Figure 11. Frequency of E_n ratio range for NMIA first and last measurements.

9. Results and observations for physical standards

A total of thirty-five parameters, including three groove depths, were measured across the five artefacts. Using the E_n and Birge ratio method described in section 7, for each parameter, outliers were excluded from the KCRV. This process is shown in Appendices B and C and a summary of the final results are shown in Table 8. The uncertainty of the KCRV for each parameter has a coverage factor of k = 2.0, resulting in a confidence level of approximately 95%.

Table 8. Results of outlier exclusion and key comparison reference value calculation

S/N	Param	Initial		Outliers removed					Final			Change
		n	KCRV µm	First	Second	Third	Fourth	Fifth	n	KCRV µm	U95% µm	µm
A277	***Gr A***	14	0.383	VMI					13	**0.383**	0.001	-
	Gr B	15	2.834	NPLI	VMI				13	**2.834**	0.003	-
	Ra	16	0.931	KRISS	NPLI	NIST			13	**0.931**	0.003	-
	Rz	16	2.482	NMISA	NPLI	KIM-LIPI			13	**2.486**	0.005	0.005
	RSm	15	76.235	KIM-LIPI	KRISS	NIS			12	**76.284**	0.076	0.049
7462	***Groove***	15	10.043	VMI	NPLI				13	**10.037**	0.011	-0.006
1286	***Ra***	16	3.106	KIM-LIPI					15	**3.106**	0.003	-
	Rz	16	9.815	KIM-LIPI					15	**9.817**	0.010	0.003
	RSm	15	99.158	KIM-LIPI	KRISS				13	**99.160**	0.016	0.002
5276	***Ra***	15	0.223						15	**0.223**	0.001	-
	Rq	15	0.271						15	**0.271**	0.001	-
	Rz	15	1.464	VMI	NMC				13	**1.452**	0.013	-0.012
	Rp	15	0.707	NPLI	NMC	VMI			12	**0.700**	0.008	-0.007
	Rv	14	0.758	NMC	VMI	CMS			11	**0.764**	0.011	0.006
	Rt	15	1.673						15	**1.673**	0.018	-
	Rsk	13	-0.071	NPLI					12	**-0.062**	0.010	0.009
	Rku	12	2.594						12	**2.594**	0.018	-
	Rk	10	0.771						10	**0.771**	0.009	-
	Rpk	10	0.203						10	**0.203**	0.006	-
	Rvk	10	0.231						10	**0.231**	0.005	-
	Mr1	10	6.761						10	**6.761**	0.131	-
	Mr2	10	90.895	KRISS					9	**90.539**	0.240	-0.355
5256	***Ra***	15	1.653	KIM-LIPI	NIS				13	**1.656**	0.006	0.003
	Rq	15	2.013	KIM-LIPI	NIS				13	**2.018**	0.006	0.005
	Rz	15	8.523	VMI	NMC	KIM-LIPI	NIS		11	**8.055**	0.042	-0.468
	Rp	15	2.870	NPLI	VMI	KIM-LIPI			12	**2.871**	0.018	-
	Rv	14	5.292	VMI	NMC	NIS	KIM-LIPI		10	**5.186**	0.031	-0.106
	Rt	15	10.375	NIS	CMS	KIM-LIPI			12	**10.434**	0.043	0.059
	Rsk	13	-0.718	NPLI	NPL	CMS			10	**-0.813**	0.018	-0.095
	Rku	12	2.831	NMC	NIM	VMI	NMIA	KRISS	7	**2.724**	0.028	-0.108
	Rk	10	4.199	NIM	VMI				8	**4.151**	0.038	-0.048
	Rpk	10	0.266						10	**0.266**	0.017	-
	Rvk	10	3.331	CMS	VMI	KIM-LIPI			7	**3.386**	0.031	0.055
	Mr1	8	2.565						8	**2.565**	0.221	-
	Mr2	10	78.035	NIM					9	**77.765**	0.436	-0.270
Totals	**35**	**464**							**404**			
Removed									**60**			

For the thirty five parameters listed, 466 results were submitted; however, two results were rejected from judgement of the co-ordinator, both for standard 5256 parameter *Mr1*. The KIM-LIPI result was high but with a very small uncertainty which was considered too small to be realistic. The KRISS result was an order of magnitude high and an obvious error. Of the accepted 464 results, sixty were excluded from the KCRV calculations. A total of six parameters had one result excluded,

seven parameters had two results excluded, nine parameters had three results excluded, two parameters had four results excluded, one had five results excluded, leaving only ten of thirty-five parameters having no results excluded. Individual laboratory performance is shown in Table 9.

Table 9. Individual laboratory performance

	Results			Parameters excluded				
	Accept	**Excl**	**%**	**A277**	**7462**	**1286**	**5276**	**5256**
Australia NMIA	35	1	2.9%	-	-	-	-	*Rku*
Singapore NMC, A*Star	35	6	17.1%	-	-	-	*Rz, Rp, Rv*	*Rz, Rv, Rku*
UK NPL	25	1	4.0%	-	-	-	-	*Rsk*
Germany PTB	35	0	0	-	-	-	-	-
Hong Kong SCL	4	0	0	-	-	-	-	-
Thailand NIMT	35	0	0	-	-	-	-	-
Japan NMIJ	35	0	0	-	-	-	-	-
South Korea KRISS	34	5	14.7%	*Ra, RSm*	-	*RSm*	*Mr2*	*Rku, Mr1*[1]
USA NIST	21	1	4.8%	*Ra*[2]	-	-	-	-
India NPLI	20	8	40%	*B, Ra, Rz*	*Gr*	-	*Rp, Rsk*	*Rp, Rsk*
South Africa NMISA	25	1	4%	*Rz*	-	-	-	-
Egypt NIS	21	6	28.6%	*RSm*	-	-	-	*Ra, Rq, Rz, Rv, Rt*
China NIM	35	3	8.6%	-	-	-	-	*Rku, Rk, Mr2*
Chinese Teipei CMS	35	4	11.4%	-	-	-	*Rv*	*Rt, Rsk, Rvk*
Vietnam VMI	35	12	34.3%	*A, B*	*Gr*	-	*Rz, Rp, Rv*	*Rz, Rp, Rv, Rku, Rk, Rvk*
Indonesia KIM-LIPI	34	12	35.3%	*Rz, RSm*	-	*Ra, Rz, RSm*		*Ra, Rq, Rz, Rp, Rv, Rt, Rvk, Mr1*[1]
Accepted	464			76	15	47	164	162
Excluded		60		12	2	4	10	32
Percentage			12.9%	15.8%	13.3%	8.5%	6.1%	19.8%

[1] Parameter *Mr1* excluded by judgement of the co-ordinator as described previously.
[2] Refer to section 11 for discussion on stylus tip correction affecting this reported result.

Out of 464 accepted results, sixty were excluded which is 12.9%. The most consistent results were for standards 1286 and 5276. Figure 12 shows the overall performance of excluded results compared to submitted results. In general, the lower the total results excluded, the better that laboratory agreed with the key comparison reference value. Refer to the graphs in Appendix B for any particular parameter.

The higher incidence of results excluded toward the end of the schedule suggests a possible trend in the standards, however, the stability of the standards was considered good. As mentioned in section 8, the coarse standards, while considered stable, did show a bigger change over the two years of measurements than the fine standards and grooves. Looking at the parameters excluded from the last two laboratories VMI and KIM-LIPI do show that most outliers for the 5256 standard, however, for KIM-LIPI all removed parameters are lower than the KCRV while the NMIA final measurement was higher than the KCRV. This strongly suggests that any change in the standards is not the cause of outliers. It should also be noted that many parameters are mathematically related which means that a laboratory with one outlier is more likely to have a group of outliers, making the statistics potentially misleading. This can be seen easily in the NMC, A*Star results which have mostly peak parameters removed and is likely to be an issue for KIM-LIPI, VMI and NIS. This is further discussed in section 11.

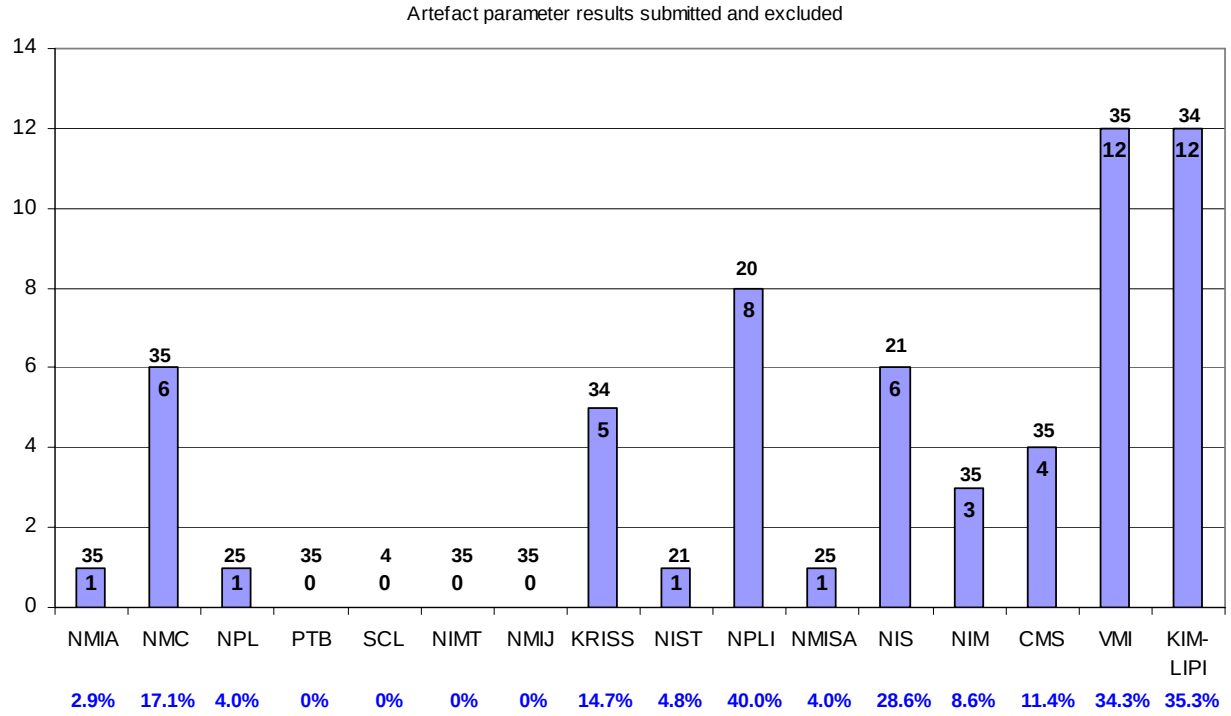


Figure 12. Laboratory results removed from KCRV calculation.

10. Comments on groove depth results

Results submitted for the three groove depths varied between stylus methods reporting *d* or *Pt*, defined in ISO 5436-1 and ISO 4287 respectively. Where some laboratories used interferometric methods, an approximation of *d* is reported. No results made using *d*, either by stylus or interferometric methods were excluded from reported reference values. It is known that NPLI, VMI and KIM-LIPI reported *Pt* instead of *d*. For the three grooves in the intercomparison, only NPLI and VMI had results determined as too large. This is what would be expected since the *Pt* calculation is made from maximum to minimum profile points over a longer sampling length. The KIM-LIPI *Pt* results for the three grooves were good.

11. Comments on parameter results

From Table 9, some patterns can be seen for some laboratories. For example, NMC A*Star had outlier results for some peak to valley parameters on the type *D* standards but only one other parameter. This may suggest a possible sensitivity to noise or a problem in the software algorithm, however, it is difficult to specify a particular problem as some other peak parameters were accepted. It is noted that NMC A*Star reported the older *Ry* instead of *Rz* whereas all other laboratories reported *Rz* or failed to acknowledge using the older parameter. VMI and KIM-LIPI also had peak parameter outliers, also on the type D artefacts. KRISS had outliers for *RSm* on both type C artefacts. NPLI had outliers with *Rp* and *Rsk* on both type D standards. All other outliers seem to be of random occurrence. Any cause for these must be assessed by the laboratory concerned. After completion of all measurements and initial circulation of data, some laboratories reported discovering errors in measurement of calculation of some parameters.

Only one known laboratory used a filter setting not specified in the protocol. NPLI reported using a 100:1 ratio where a 300:1 ratio was specified. It is not clear if this may have affected their low *Rsk* values. Since most NPLI results were acceptable, this in general did not appear to significantly affect the intercomparison.

A different than nominal tip radius could increase or decrease some parameters since the profile obtained from measurement is a dilation of the true surface due to the stylus geometry. If the profile exhibits steep slopes the profile dilation may be fairly significant, possibly affecting *Ra*, *Rq* and others. Participants were not asked to measure their stylus radius as part of the measurement process. Many laboratories acknowledge that the stylus tip is measured at periodic intervals or when erroneous results suggest errors and then the tip is measured either optically or by the razor-blade method [15]. It is understood that nearly all laboratories used a nominal 2 µm tip radius, however NIST reported using a 1.5 µm radius tip, SCL used a 1 µm tip while NPLI used a 4 µm tip.

Several NIST parameter results are larger than the reported KCRV although only one result was classed as an outlier. In discussions with NIST, it was found that they apply a correction to all results and report parameters with referral to a theoretical tip radius of zero. The magnitude of this correction can be significant for parameters such as *Ra* and is dependent on the surface measured and the tip geometry. NIST advises that the rationale for performing such tip correction comes from the definition of "mechanical surface: boundary of the erosion, by a spherical ball of radius *r*, of the locus of the centre of an ideal tactile sphere, also with radius *r*, rolled over the skin model of a workpiece" and that this definition appears both in ISO Standard 14406:2010 [9] and in Final Draft International Standard 25178-2 [10] dealing with areal surface texture parameters. NIST considers that the error caused by tip-size is justifiably removed for conformance with the GUM guideline (JCGM100:2008) [11] on treatment of significant systematic effects (section 3.2.4) although application of such a correction has not been a common practice and no other participating laboratories applied this correction. Therefore the intercomparison is marginally skewed since the NIST results are not a true comparison to all other results. In general though, due to a reasonable number of participants, this is not significant. If the single NIST outlier (for s/n A277 *Ra*) is excluded from analysis, the KCRV reduces by 3 nm and the remaining outliers for that parameter are removed regardless. NIST reports that if its tip-corrected profiles for this surface are numerically dilated using a 2 µm stylus radius, the *Ra* value decreases by 12.0 nm, yielding an estimate of 0.9377 µm for the uncorrected *Ra*. The uncorrected result would be in significantly better agreement with the KCRV. NIST results remain as submitted. The effect on other parameters such as *Rq*, are as of yet, not investigated. Further discussions will be required at the NMI and CCL level to determine a course of action, whether other laboratories follow or reject the NIST correction.

Since SCL submitted few results, any trend is more difficult to determine. For the two *Ra* and two *Rz* results, these all tended to be close to the KCRV and any effect from tip radius cannot be determined.

Some of the excluded results from NPLI were groove depths and *Rp*. A large stylus would not have significant effect on grooves and would likely have a reducing effect on *Rp* if the stylus could not reach valleys that a 2 μm tip would reach. The results given do not clearly identify any trend caused by variations in stylus radius.

12. Correlations due to traceability path

As listed in table 4, at the time of measurement for this intercomparison, most laboratories calibrate their own references traceable to the definition of the metre, except for five laboratories:

- NMC, A*STAR obtain some cross-referencing in their traceability through calibration of some standards at NPL;
- SCL obtain traceability through NPL;
- NIMT obtain traceability through NMIA;
- NPLI obtain traceability through PTB;
- NIS obtain traceability though KRISS and NPL
- VMI obtain traceability through NMIJ;
- KIM-LIPI obtain traceability through NPL.

If a strong correlation exists in these relationships, the E_n ratio of any parameter should be small between the related laboratories and some consistency in direction of offset should exist in the results compared to the other laboratories and the reference value. This does not show in any results for any laboratory:

- No pattern can be seen in the NMC, A*STAR results compared to the NPL results. Where some peak to valley NMC, A*STAR results are excluded, the equivalent results from NPL are good. Other results do not shift in direction or magnitude with the NPL results.
- The NIMT results do appear very close to those of NMIA, however, in general the results are also close to the reference values so any possible correlation is not apparent.
- The NPLI results show no trend relationship to the PTB results.
- Only one of the six removed parameters for NIS (s/n A277 *RSm*) matches that of the KRISS parameters removed. All other results are either within uncertainties or vary in apparently random fashion. The same conclusion is made in comparison to NPL results from which one parameter was excluded.
- The VMI results have more parameters excluded with again no apparent relationship to the NMIJ results.
- The KIM-LIPI results tend toward being below the NPL results for most parameters but not for all.

In conclusion, no laboratory that obtains its traceability via another laboratory shows any correlation to its source laboratory greater than any expected random variation in results.

13. Comments on softgauge results

The two softgauges as supplied by NPL were circulated in numerous formats with ten of sixteen laboratories submitting results. Numerical and graphical results of softgauge tests from each laboratory are shown in Appendix D.

Since there is no measurement, only a software output, no uncertainty value is reported. Two tables are provided for results comparison. A population standard deviation can be determined and used as a nominal type of uncertainty for calculation of an E_n value of each laboratory result to the average. Alternately, the difference of each result to the supplied NPL result is shown. Using either method, it can be seen that essentially all the results for both *Cos4* and *Sin_2_16* are very similar for NPL, PTB and NIST, all three laboratories using in-house developed software. This is possibly expected due to the well published developmental work these laboratories have conducted in this area. The NIS results, using Taylor Hobson Ultra software, also agree well with these three laboratories for *Sin_2_16* but not so well for *Cos4*. One possible reason for this could be that the *Sin_2_16* profile is repeated every 400 µm, including in the profile lead-in. The *Cos4* profile varies in amplitude, increasing in the lead-in and reducing in the lead-out. This would imply that software that incorrectly removes the lead-in and lead-out should get lower results for *Cos4* but not necessarily for *Sin_2_16*. This appears to be the case for the NIS results and should be investigated.

Note also that three laboratories, KRISS, NMISA and NIS, use a version of Taylor Hobson Ultra software while another, NIM, uses Talymap Gold software, produced by Digital Surf (France) but sold by Taylor Hobson (UK). Investigation of the data of just these laboratories suggests no direct relationship.

For other results, there may be some relationships between the softgauge results and the artefact results. For example, NMIA results for the *Sin_2_16 Ra* and *Rq* parameters are higher than the average and this can be seen in results of the same parameters on the type D 5276 and 5256 results, although any difference is within uncertainties. The difference is not seen on the type C standards A277 and 1286 for *Ra* so any relationship is probably coincidental.

14. Final conclusions and remarks

With sixteen laboratories participating in this intercomparison, a total of thirty-five parameters measured across five roughness standards and seven parameters on each of two softgauges, significant variation of results was always expected and this has proven to be the case. The measurement schedule planned was approximately twenty months and with some delays was completed in twenty-four months. The repeat measurements by the pilot laboratory showed overall acceptable stability of the standards, especially the grooves and fine surfaces, so as a general conclusion, the variation observed between some laboratory results is most likely from the measurement process and differences in software algorithms. In any measurement process you may expect 5% of results to lie outside the acceptable population. For the analysis made here on all artefact parameters, approximately 13% of submitted results have been determined to be outside statistically acceptable limits. This is not necessarily an unexpected event considering that many parameters are mathematically related. Overall, laboratory performance was mixed for all standards but worst on the larger type D roughness standard serial number 5256. Many laboratories may be satisfied with the outcomes of this intercomparison although some will have to review their systems and the effect that reported measured differences from any of the key comparison reference values may have on their surface texture calibration service.

15 Acknowledgements

Many thanks to the APMP Technical Committee for Length (TCL) Chair during the intercomparison period, Ms Siew Leng Tan of NMC, A*STAR for discussions and advice in preparing the protocol. Thanks to Dr Lena Jung and Dr Ludger Koenders of PTB for providing the two type D standards for this intercomparison and early discussions in development of some project details. Thanks to Dr Ted Vorburger and Mr Brian Renegar of NIST for providing the type C standard, serial number 1286 and additional project development including in-depth discussion on tip radius. Thanks to Professor Richard Leach of NPL for supplying the softgauges and both Richard and Dr Peter Harris of NPL for support in verifying the analysis methods (assessed using ideal data). Lastly, thank you to all participants for following the schedule as best as possible in measurement, submission of results and subsequent verification and discussions.

16 References

[1] ISO 3274 *Surface Texture – Instruments for the assessment of surface texture – Profile method*, International Organization for Standardization, Geneva, Switzerland, 1996.

[2] ISO 4287 *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters*, International Organization for Standardization, Geneva, Switzerland, 1997.

[3] ISO 4288 *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture*, International Organization for Standardization, Geneva, Switzerland, 1996.

[4] ISO 5436-1 *Geometrical Product Specifications (GPS) – Surface texture: Profile method; Measurement standards – Part 1: Material measures*, International Organization for Standardization, Geneva, Switzerland, 2000.

[5] ISO 5436-2 *Geometrical Product Specifications (GPS) - Surface texture: Profile method; Measurement standards - Part 2: Software measurement standards,* International Organization for Standardization, 2001

[6] ISO 11562 *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Metrological characteristics of phase correct filters*, International Organization for Standardization, Geneva, Switzerland, 1996.

[7] ISO 12179 *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Calibration of contact (stylus instruments)*, International Organization for Standardization, Geneva, Switzerland, 2000

[8] ISO 13565-2 *Geometrical Product Specifications (GPS) - Surface texture: Profile method - Part 2: Height characterization using the linear material ratio curve,* 1996

[9] ISO 14406 *Geometrical product specifications (GPS) - Extraction,* 2010

[10] ISO FDIS 25178-2 *Geometrical product specifications (GPS) - Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters*, 2011

[11] *JCGM 100:2008 – Evaluation of measurement data - Guide to the expression of uncertainty in measurement.*

[12] M.G Cox, "The Evaluation of Key Comparison Data", Metrologia, 2002, 39, 589-595.

[13] R. Kacker, R. Datla, A. Parr, "Combined result and associated uncertainty from interlaboratory evaluations based on the ISO *Guide*" Metrologia 39 (2002) p279-293.

[14] J.L. Gardiner, CCPR Key Comparison Processing Methods, Background Material, 1999

[15] J.F.Song and T.V. Vorburger, "Stylus Profiling at High Resolution and Low Force", Applied Optics 30, p42-50, 1991

[16] WJ Giardini, C. Calderon, F. Cheng-yen, K.K. Hau, C.S Kang, S.M. Lee, F. Lesha, A.M. MeKawi, R. Monteros, C. Quan, V. Roonwal, N. Sakano, R.P. Singhal, S.Y. Wong, S.Z.A. Zahwi, "International Comparison of Surface Texture Parameters Organized by the Asia Pacific Metrology Programme", Metrologia, 2002, 39, 225-229.

[17] EUROMET Supplementary Comparison, "Surface Texture", Project 600, Technical Report (Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, March 23, 2001).

[18] K. Doytchinov, F. Kornblit, C.C. Castellanos, J.C.V. Oliveira, T.B. Renegar, T.V. Vorburger, "International Comparison of Surface Roughness and Step Height (Depth) Standards, SIML-S2 (SIM 4.8)".

Appendix A. Documents submitted by each laboratory.

Lab	All	A277 Groove A			A277 Groove B			7462 Groove			A277 Roughness			5276 Roughness			5256 Roughness			1286 Roughness			Cos4 Softgauge	Sin_2_16 Softgauge
	Damage report	Results (AppC)	Report	Uncertainty Calculations	Results (AppC)	Report	Uncertainty Calculations	Results (AppC)	Report	Uncertainty Calculations	Results (AppC)	Report	Uncertainty Calculations	Results (AppC)	Report	Uncertainty Calculations	Results (AppC)	Report	Uncertainty Calculations	Results (AppC)	Report	Uncertainty Calculations	Results (AppC)	Results (AppC)
NMIA	Yes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NMC, A*STAR	No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NPL[1]	Yes	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	-	-
PTB[1]	Pictures	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
SCL	Yes	-	-	-	-	-	-	-	-	-	Y	Y	Y	-	-	-	-	-	-	Y	Y	Y	-	-
NIMT	Yes	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y[1]	Y	Y	Y[1]	Y	Y	Y	-	-	-
NMIJ	Yes	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	Y
KRISS	Yes	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y
NIST	Yes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NPLI	No	Y	-	-	Y	-	-	Y	-	-	Y	-	-	Y	-	-	Y	-	-	Y	-	-	-	-
NMISA	No	Y	-	-	Y	-	-	Y	-	-	Y	-	-	Y	-	-	Y	-	-	Y	-	-	Y	Y
NIS	No	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	Y
NIM[1]	No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
CMS	No	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	Y
VMI[1]	No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-
KIM-LIPI	Yes	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	Y	-	Y	-	-

[1] Indicates laboratory provided a project report rather than individual reports for each standard.

Appendix B. Artefact Results Graphs

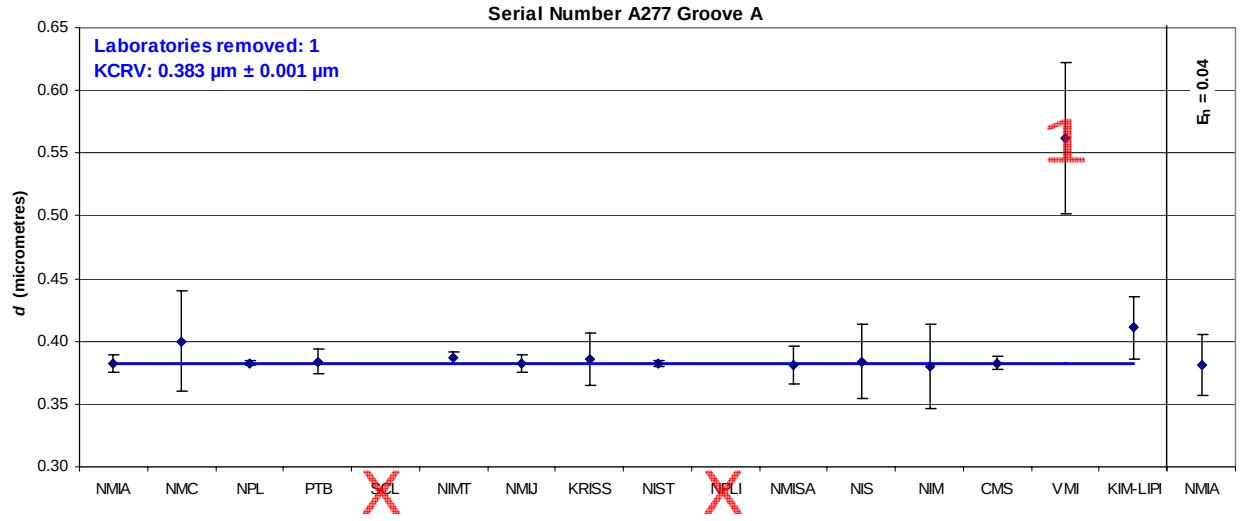
Graphs display the comparison of each laboratory result for each standard groove depth or parameter as listed in the graph title. All submitted results are displayed with expanded uncertainty. Where a laboratory did not submit a result, its position in that graph is crossed.

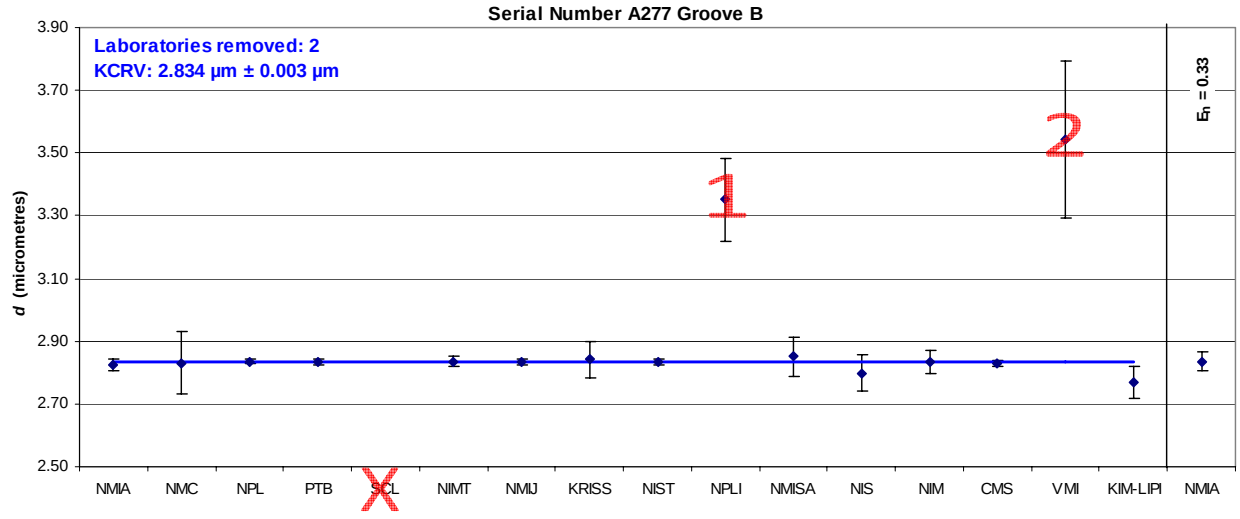
The key comparison reference value, KCRV, is determined by weighted mean method with outliers excluded one at a time (largest E_n from the KCRV) until the Birge ratio is less than the Birge limit. Usually this coincided with all values with an $E_n > 1$ removed, however, for some parameters, a reported value with an $E_n > 1$ may be accepted as part of the population since the Birge ratio was less than the Birge limit. The final KCRV is shown on each graph as a blue line **after** all outliers have been removed. Each outlier is labelled in order of exclusion.

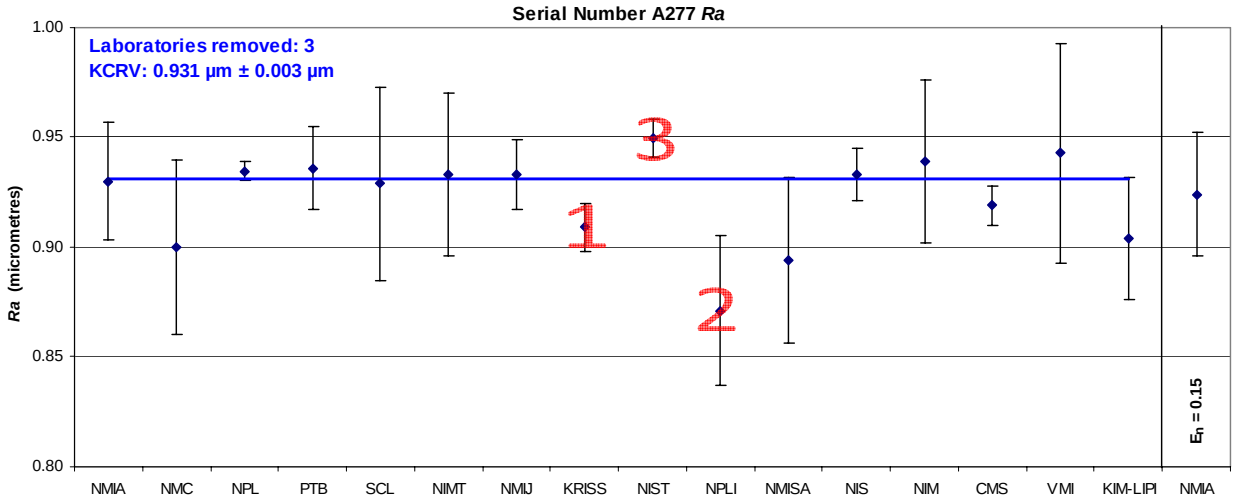
The final repeated measurement from the pilot laboratory NMIA is shown to the right in each graph. Only the first NMIA result is used to determine the KCRV. Refer to Appendix C for all submitted results and calculations of the initial KCRV with comments on each parameter results.

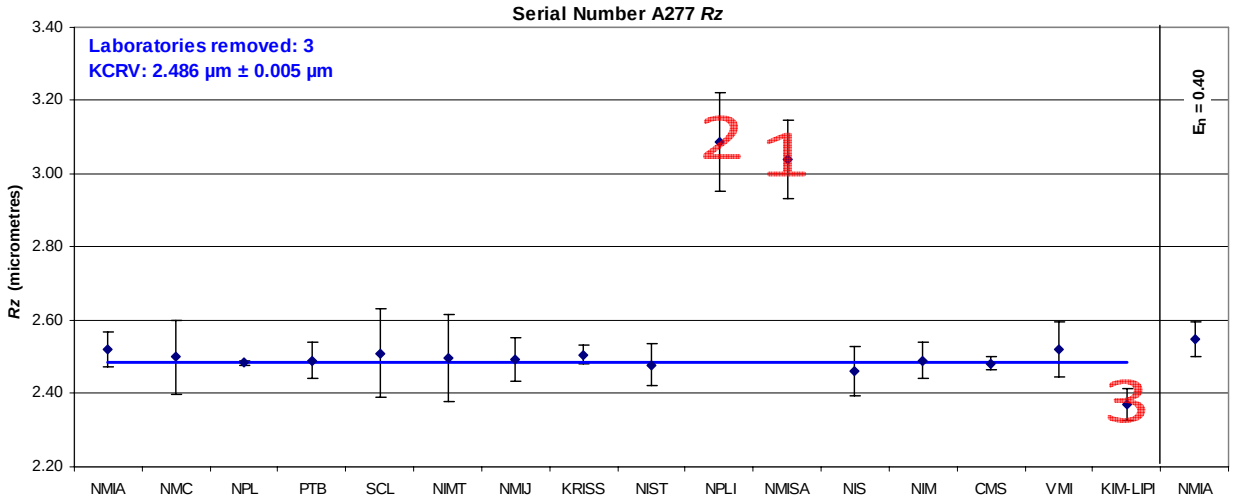
For simplicity, in graphs, NMC, A*Star is referred to as NMC.

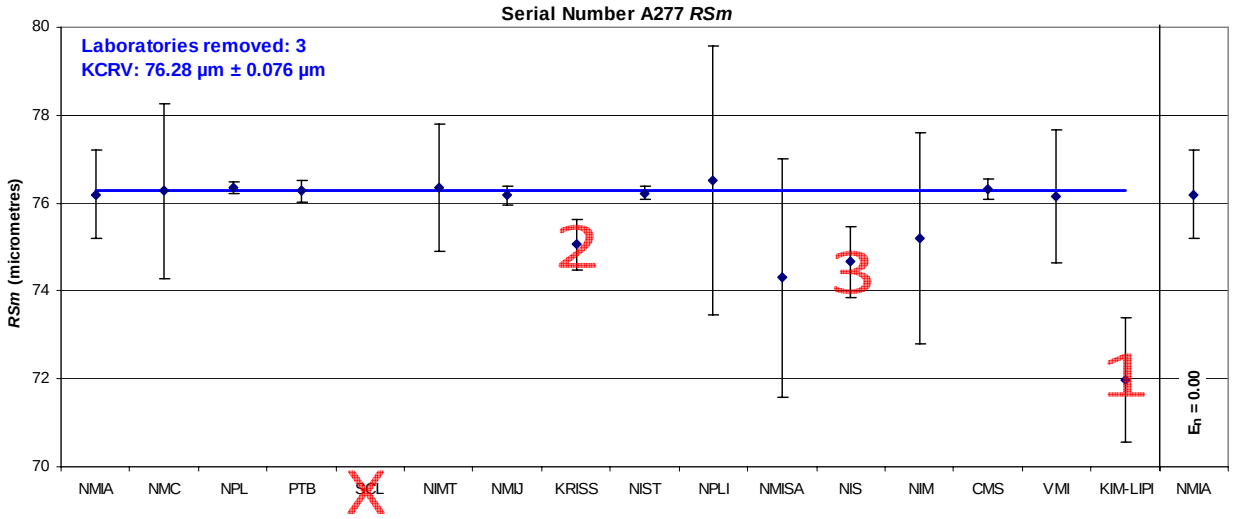
Serial number A277



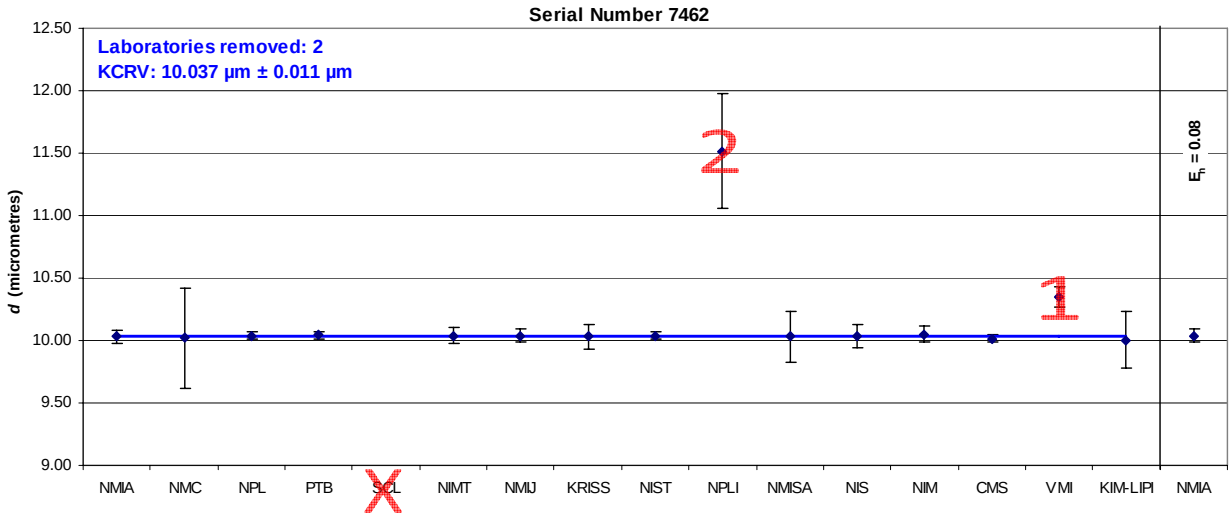



Serial Number A277 Ra
Laboratories removed: 3
KCRV: 0.931 µm ± 0.003 µm
Ra (micrometres)
1.00
0.95
0.90
0.85
0.80
En = 0.15
NMIA NMC NPL PTB SCL NIMT NMIJ KRISS NIST NPLI NMISA NIS NIM CMS VMI KIM-LIPI NMIA

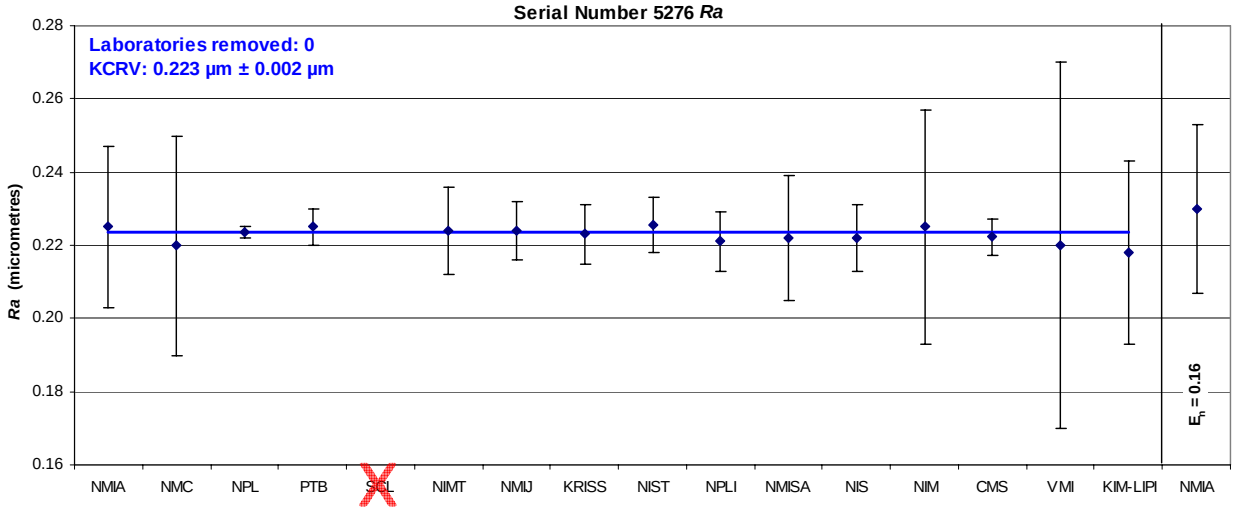

Serial Number A277 Rz
Laboratories removed: 3
KCRV: 2.486 µm ± 0.005 µm
Rz (micrometres)
3.40
3.20
3.00
2.80
2.60
2.40
2.20
En = 0.40
NMIA NMC NPL PTB SCL NIMT NMIJ KRISS NIST NPLI NMISA NIS NIM CMS VMI KIM-LIPI NMIA

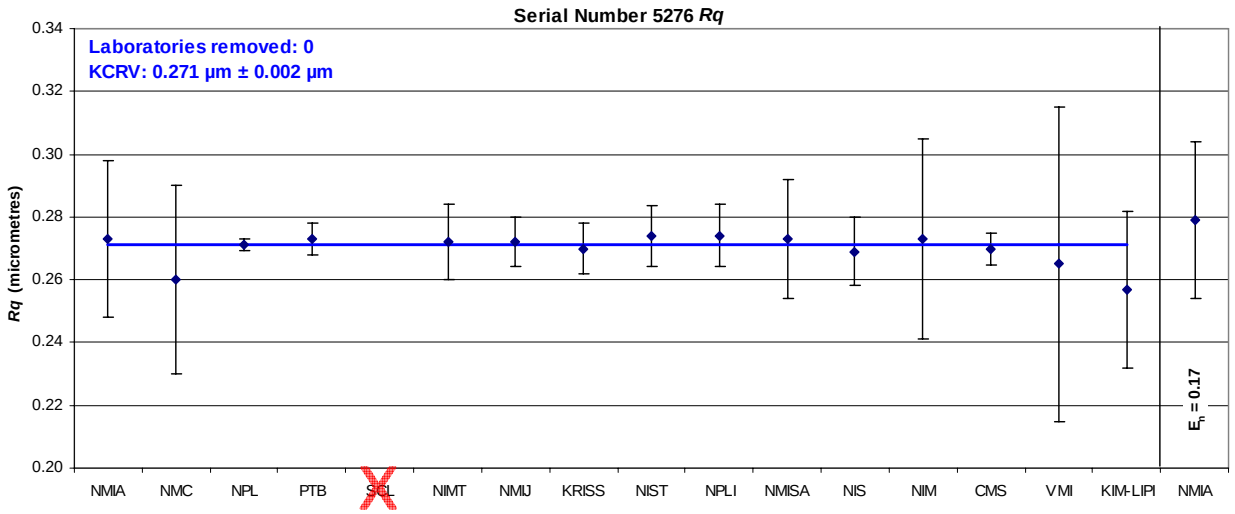

Serial Number A277 RSm
Laboratories removed: 3
KCRV: 76.28 µm ± 0.076 µm
RSm (micrometres)
80
78
76
74
72
70
En = 0.00
NMIA NMC NPL PTB SCL NIMT NMIJ KRISS NIST NPLI NMISA NIS NIM CMS VMI KIM-LIPI NMIA

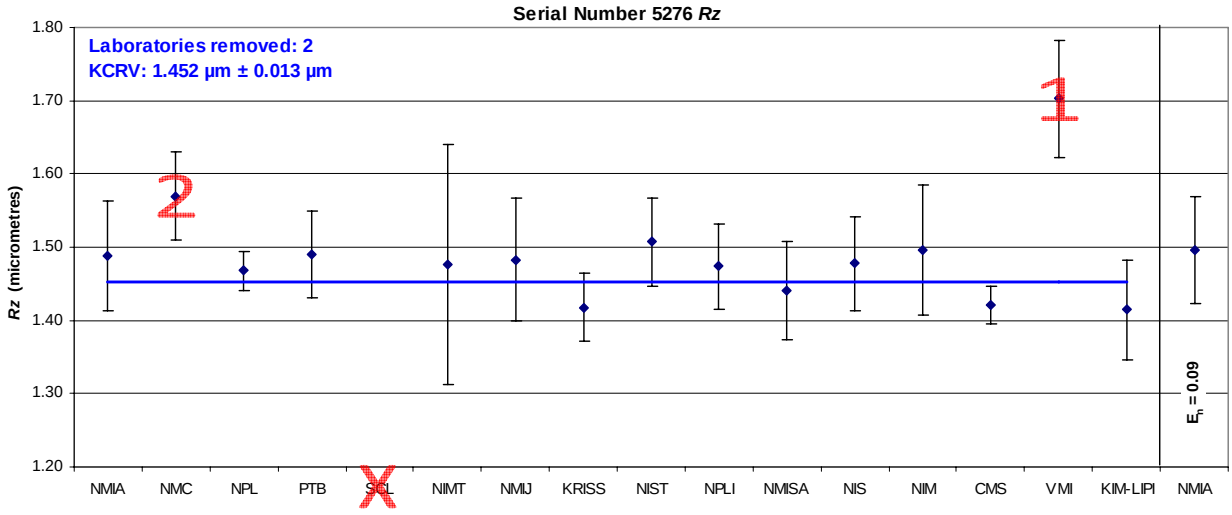
Serial number 7462

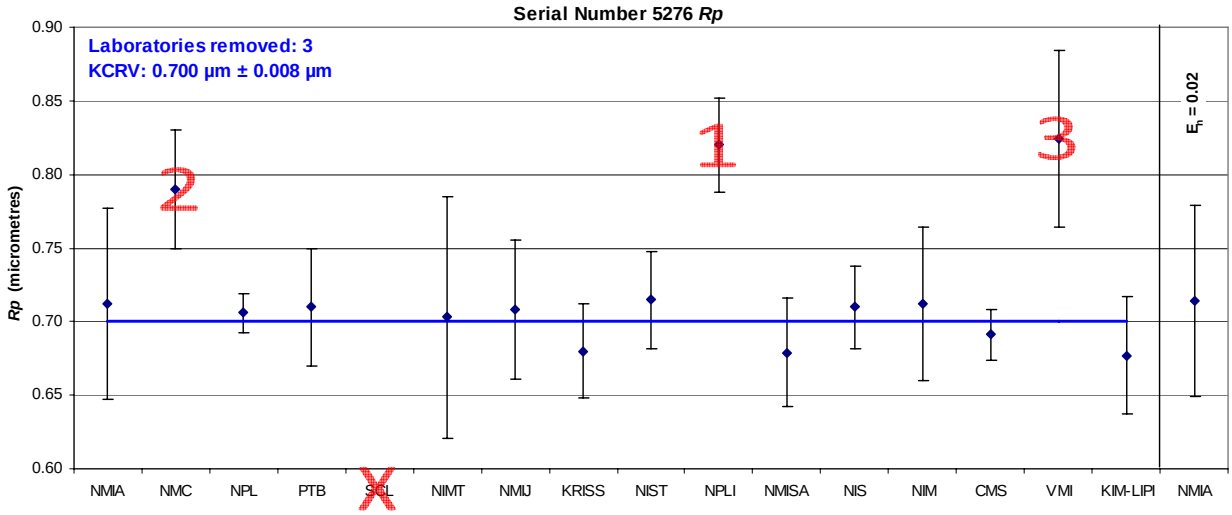


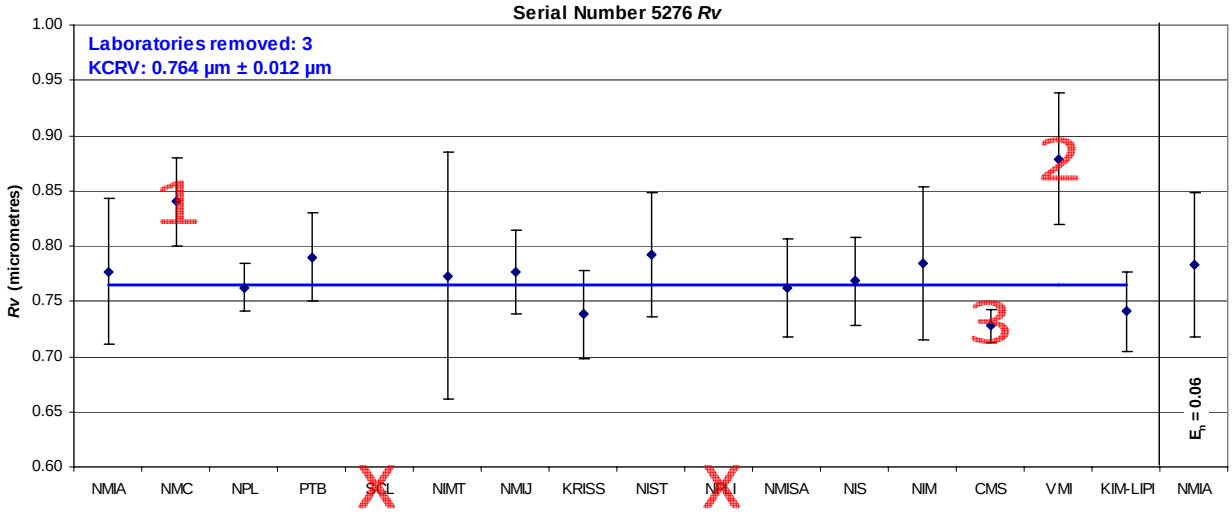
Serial number 5276

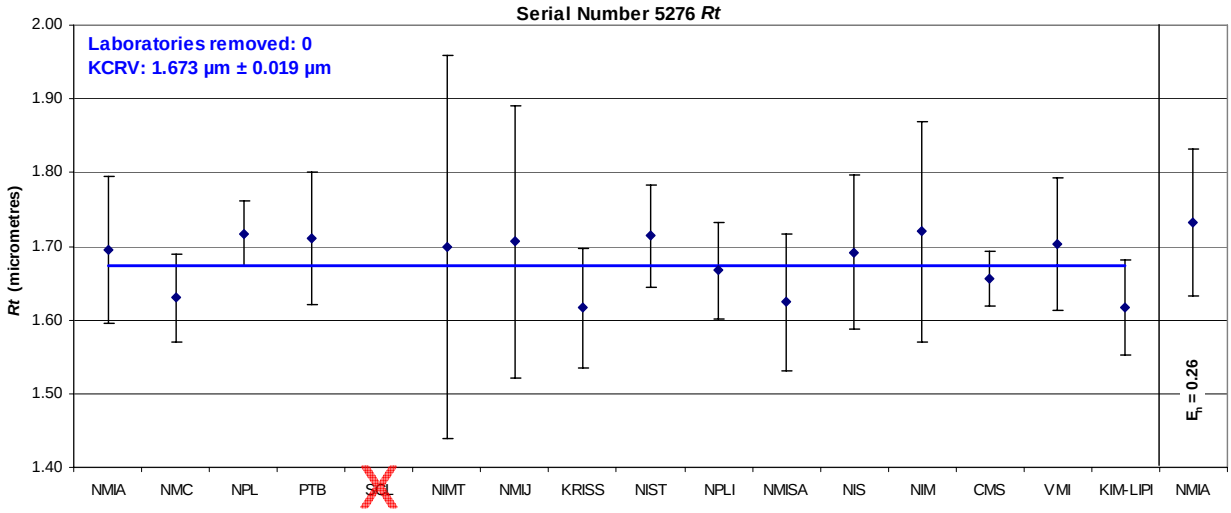


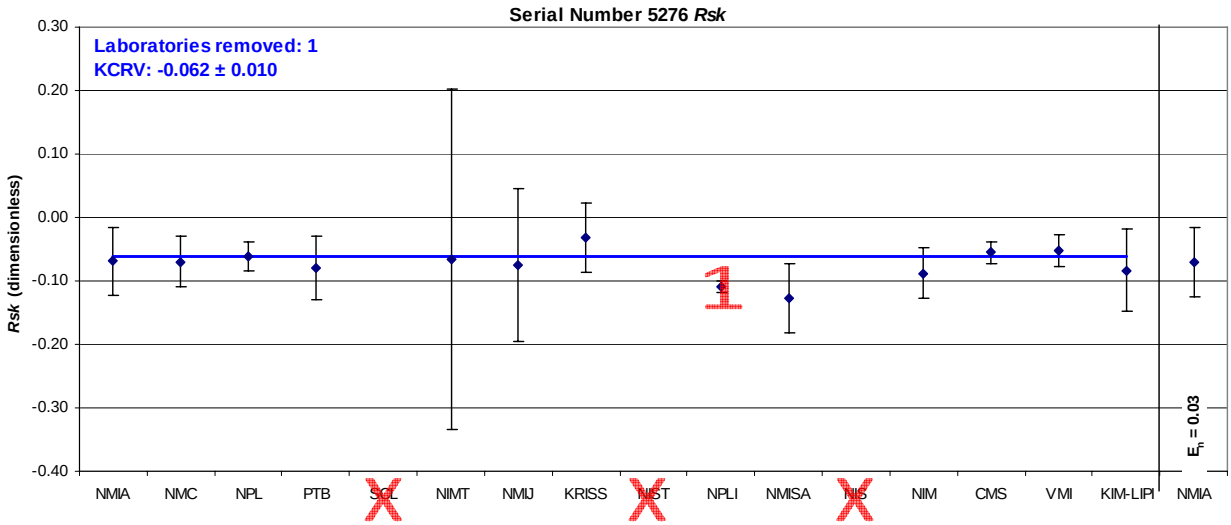


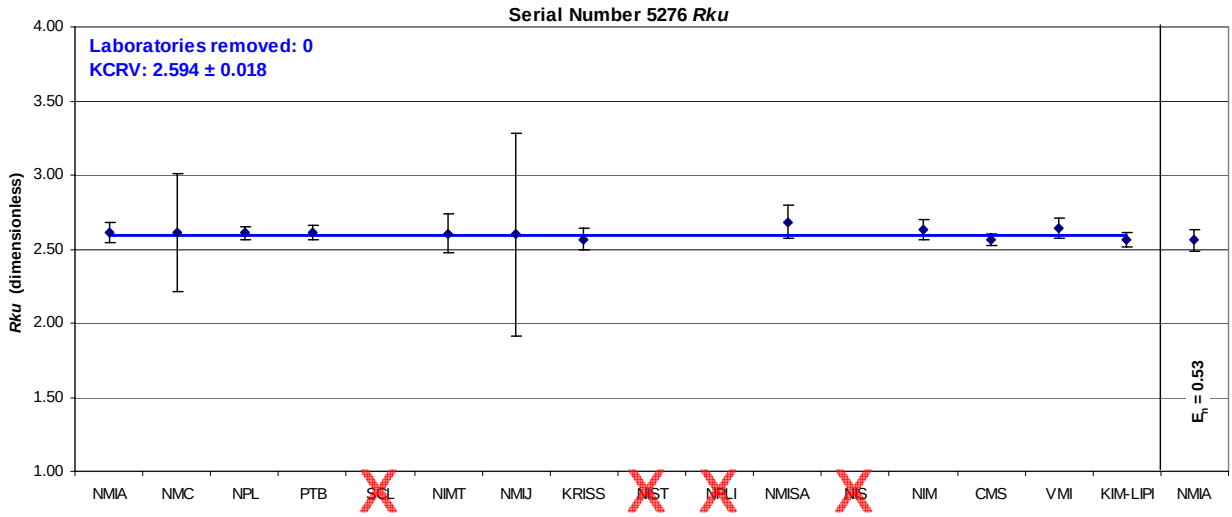

Serial Number 5276 Rz
Laboratories removed: 2
KCRV: 1.452 µm ± 0.013 µm
Rz (micrometres)
1.80
1.70
1.60
1.50
1.40
1.30
1.20
2
1
X
E_n = 0.09
NMIA NMC NPL PTB SCL NIMT NMIJ KRISS NIST NPLI NMISA NIS NIM CMS VMI KIM-LIPI NMIA

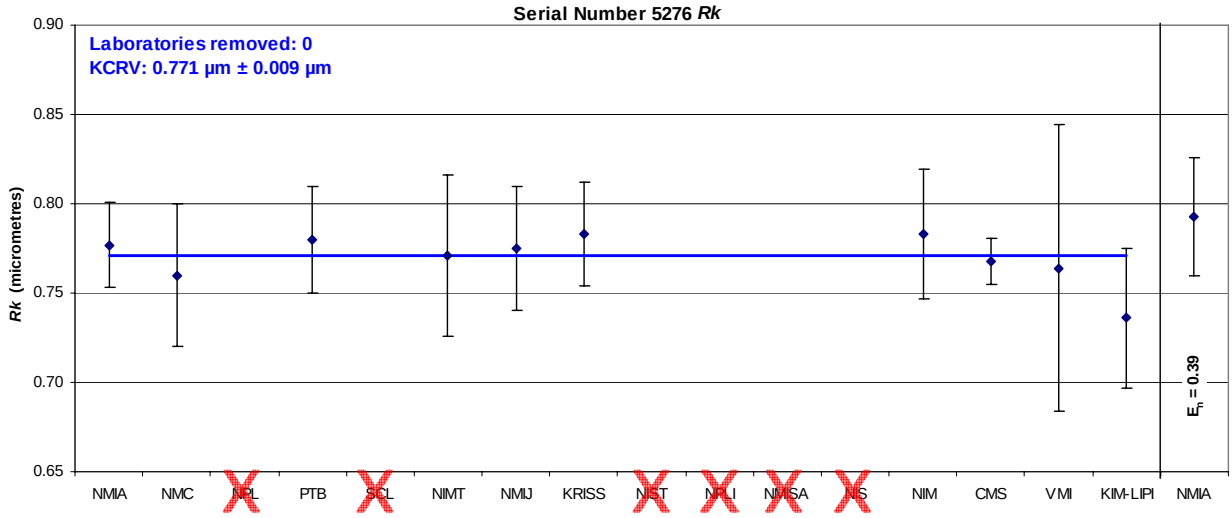

Serial Number 5276 Rp
Laboratories removed: 3
KCRV: 0.700 µm ± 0.008 µm
Rp (micrometres)
0.90
0.85
0.80
0.75
0.70
0.65
0.60
2
1
3
X
E_n = 0.02
NMIA NMC NPL PTB SCL NIMT NMIJ KRISS NIST NPLI NMISA NIS NIM CMS VMI KIM-LIPI NMIA

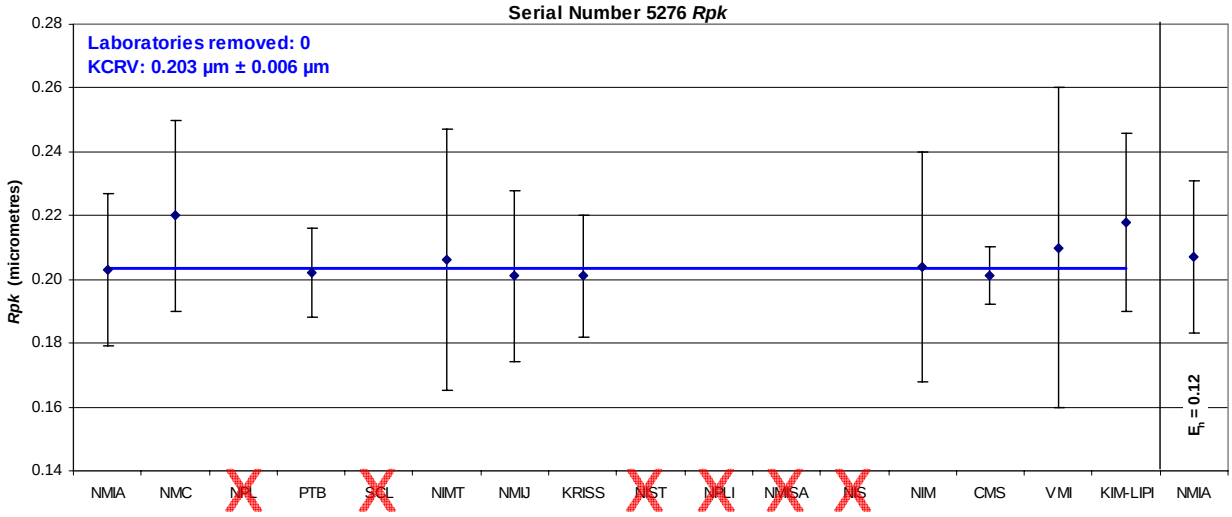

Serial Number 5276 Rv
Laboratories removed: 3
KCRV: 0.764 µm ± 0.012 µm
Rv (micrometres)
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
1
2
3
X
X
E_n = 0.06
NMIA NMC NPL PTB SCL NIMT NMIJ KRISS NIST NPLI NMISA NIS NIM CMS VMI KIM-LIPI NMIA

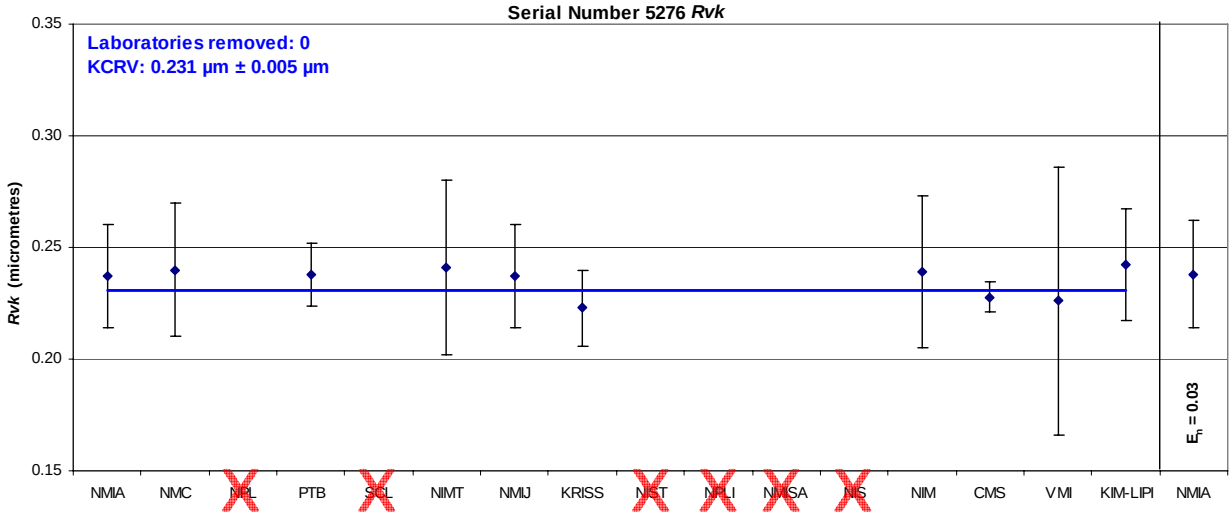

Serial Number 5276 Rt
Laboratories removed: 0
KCRV: 1.673 µm ± 0.019 µm
Rt (micrometres)
2.00
1.90
1.80
1.70
1.60
1.50
1.40
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
En = 0.26

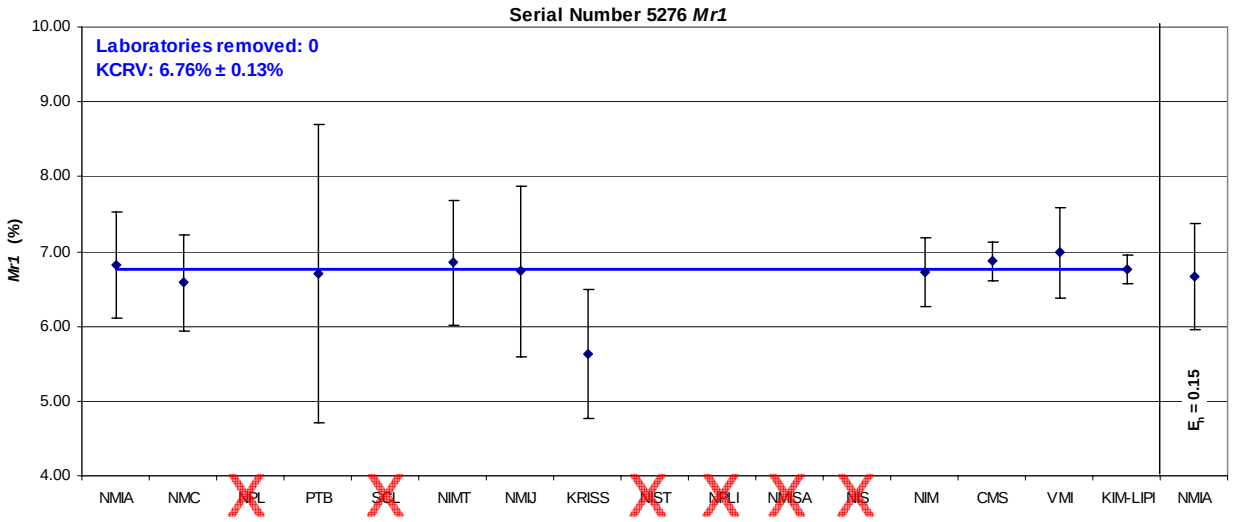

Serial Number 5276 Rsk
Laboratories removed: 1
KCRV: -0.062 ± 0.010
Rsk (dimensionless)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
En = 0.03

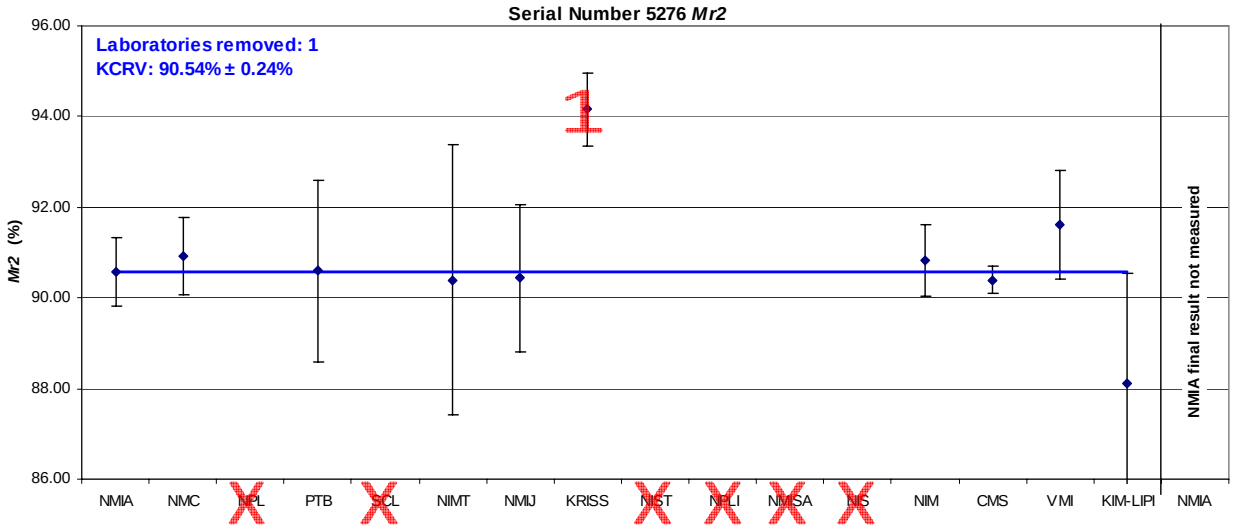

Serial Number 5276 Rku
Laboratories removed: 0
KCRV: 2.594 ± 0.018
Rku (dimensionless)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
En = 0.53


Serial Number 5276 Rk
Laboratories removed: 0
KCRV: 0.771 µm ± 0.009 µm
Rk (micrometres)
0.90
0.85
0.80
0.75
0.70
0.65
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
En = 0.39

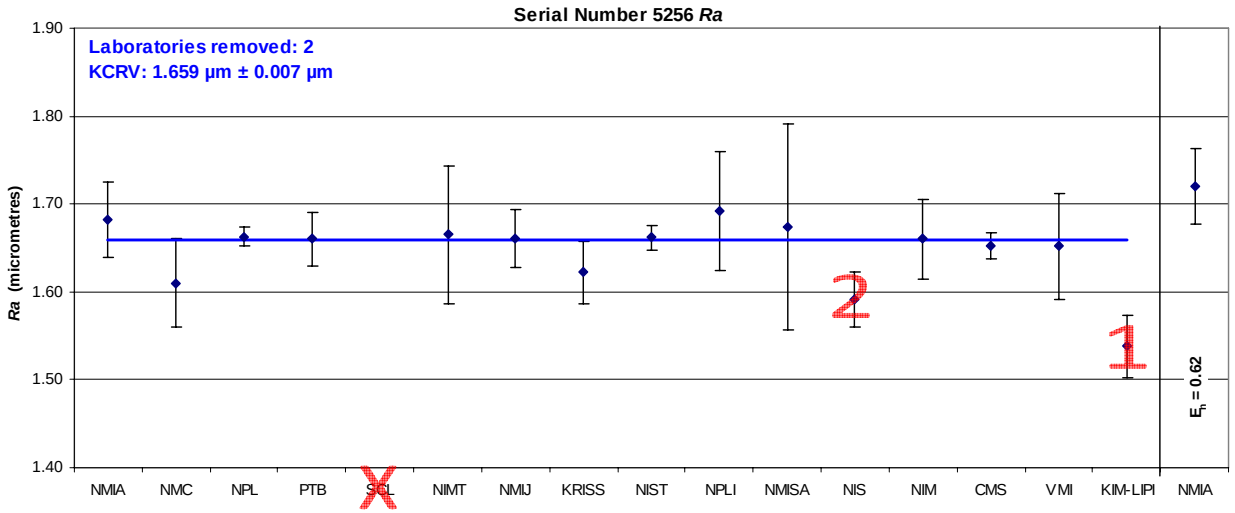

Serial Number 5276 Rpk
Laboratories removed: 0
KCRV: 0.203 µm ± 0.006 µm
Rpk (micrometres)
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
En = 0.12

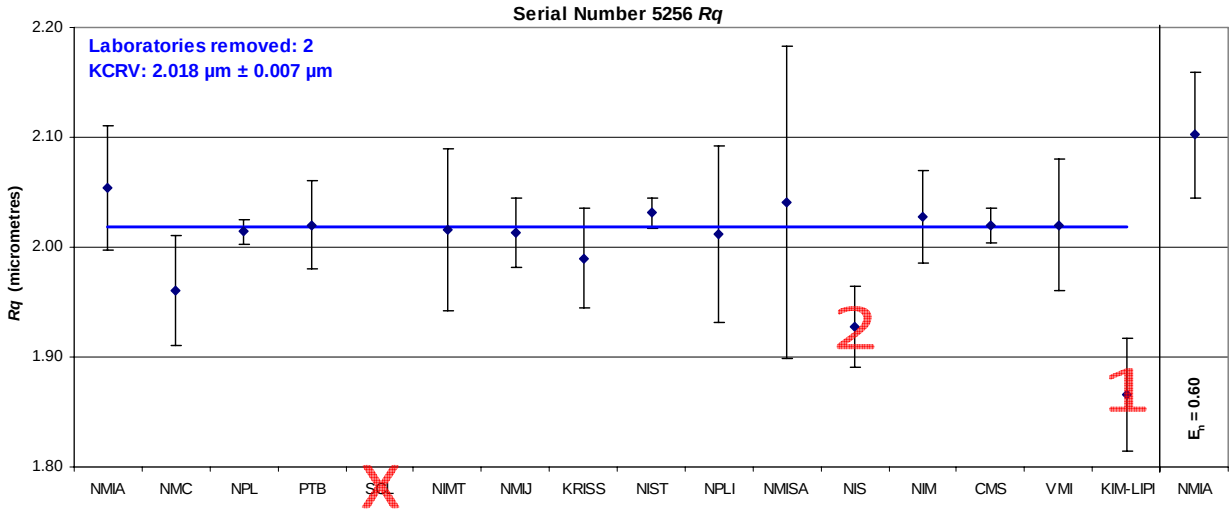

Serial Number 5276 Rvk
Laboratories removed: 0
KCRV: 0.231 µm ± 0.005 µm
Rvk (micrometres)
0.35
0.30
0.25
0.20
0.15
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
En = 0.03

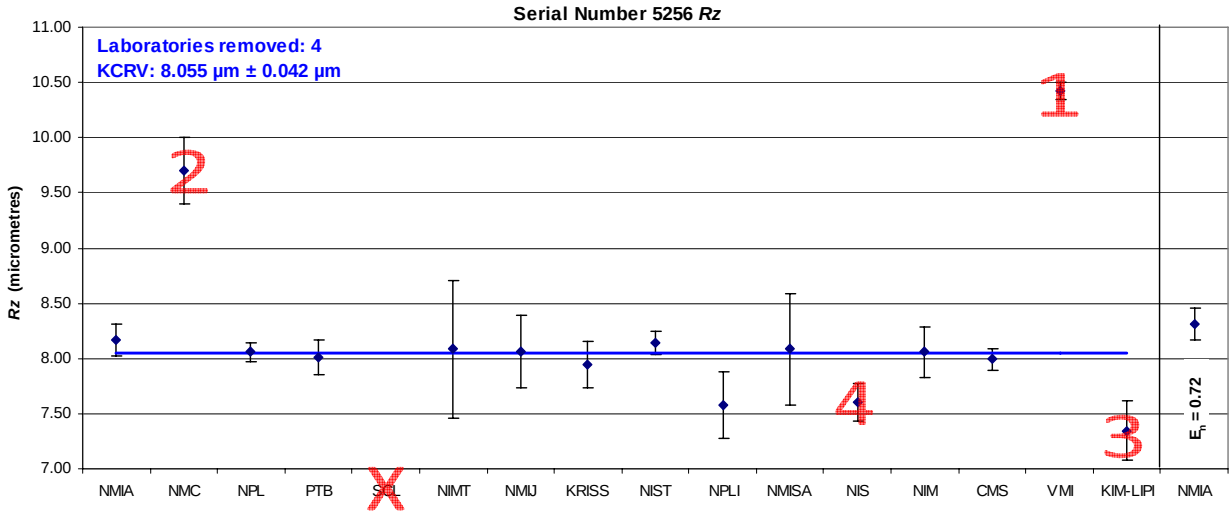


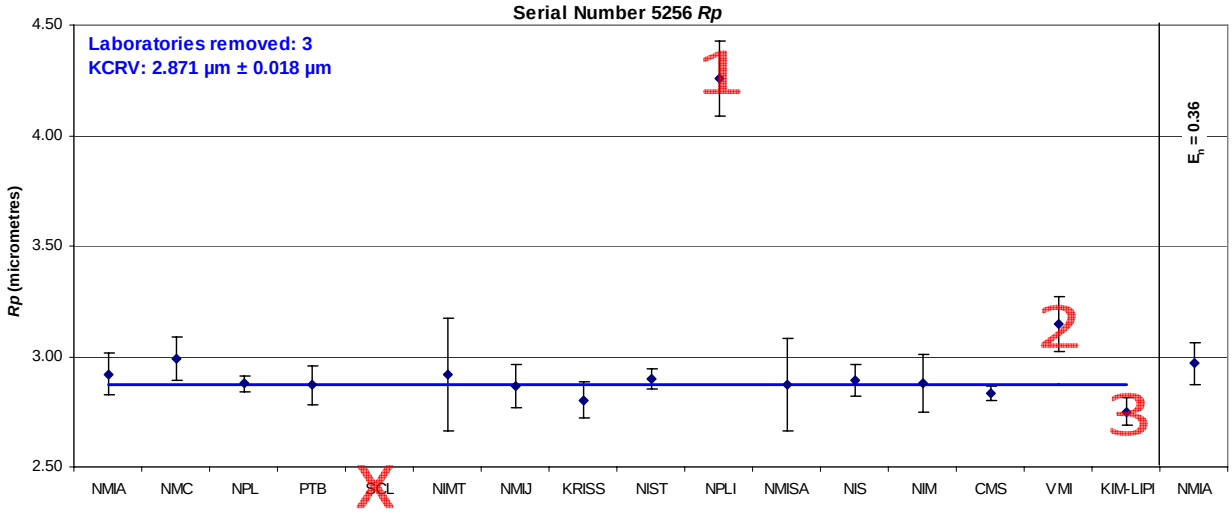


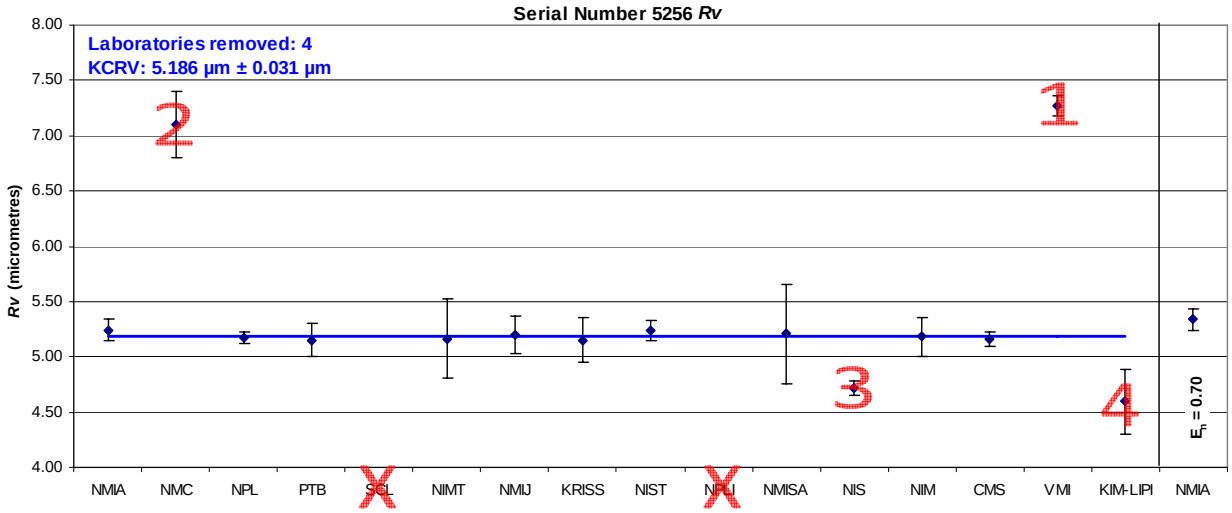
Serial number 5256

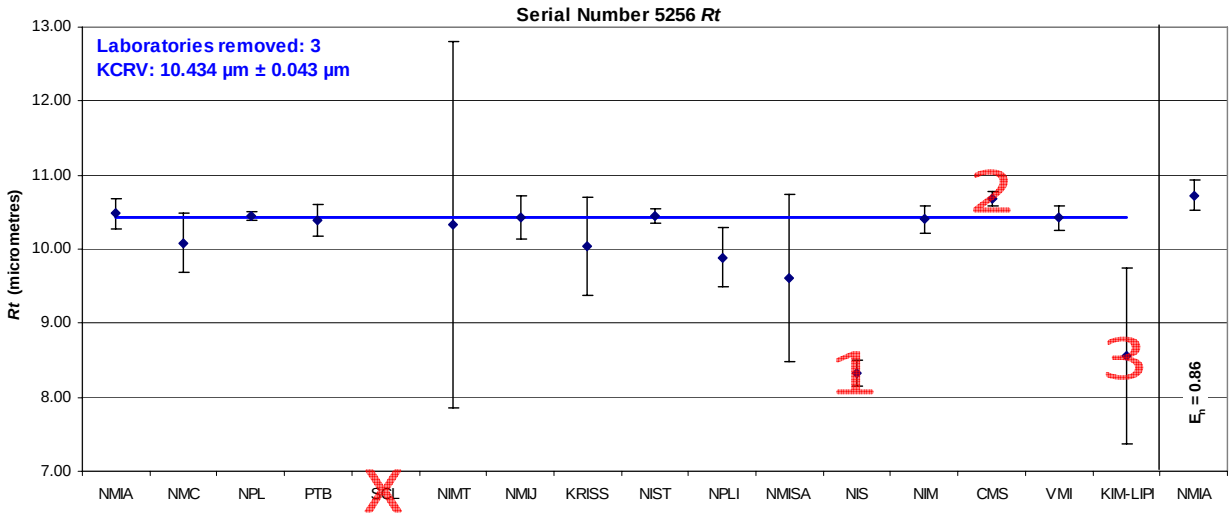


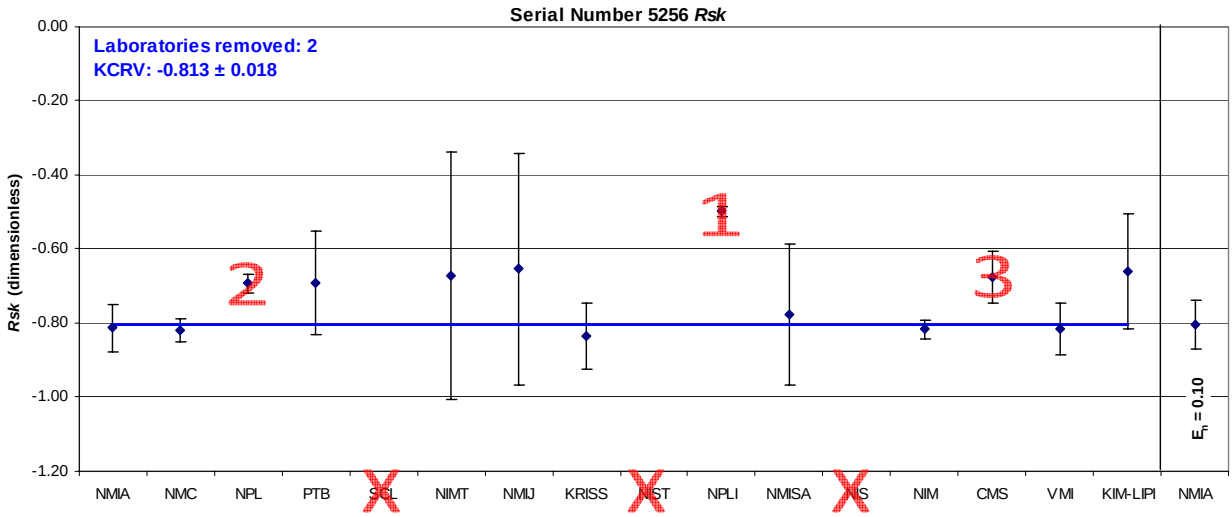

Serial Number 5256 Rq
Laboratories removed: 2
KCRV: 2.018 µm ± 0.007 µm
Rq (micrometres)
2.20
2.10
2.00
1.90
1.80
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
2
1
E_n = 0.60

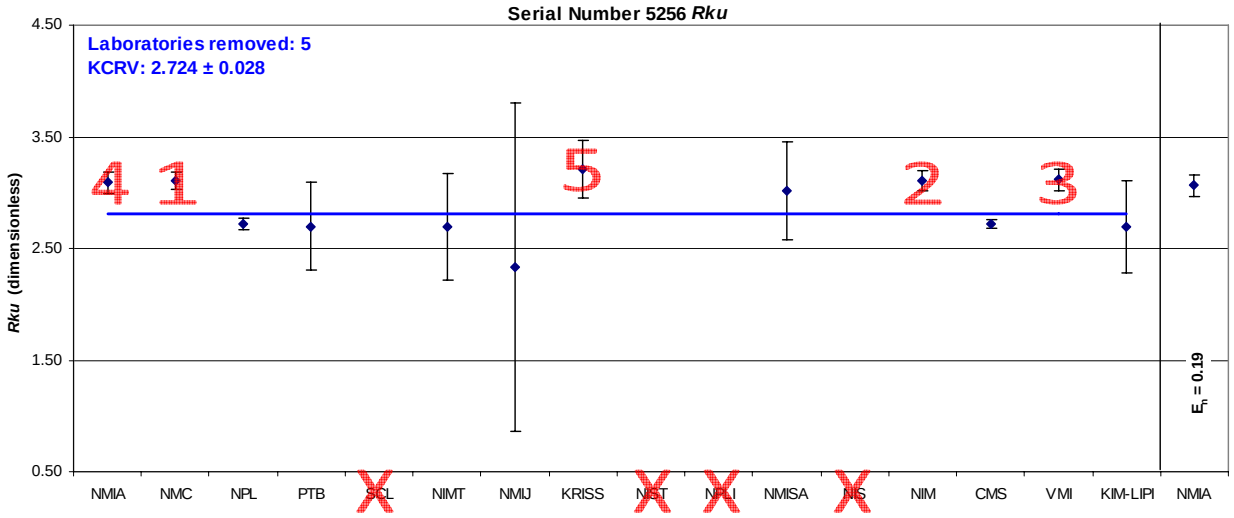

Serial Number 5256 Rz
Laboratories removed: 4
KCRV: 8.055 µm ± 0.042 µm
Rz (micrometres)
11.00
10.50
10.00
9.50
9.00
8.50
8.00
7.50
7.00
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
1
2
4
3
E_n = 0.72

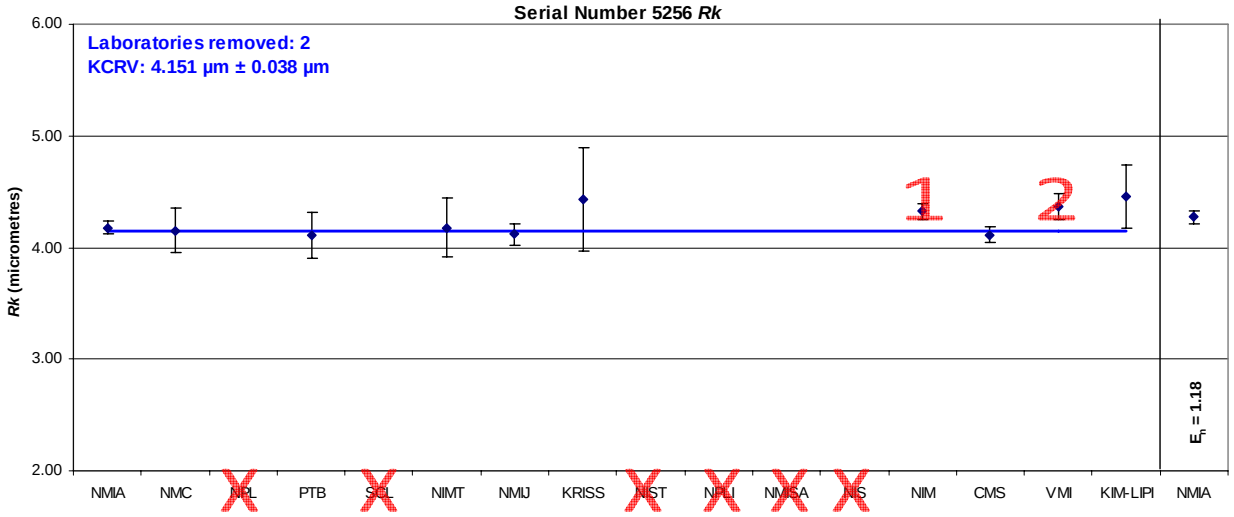

Serial Number 5256 Rp
Laboratories removed: 3
KCRV: 2.871 µm ± 0.018 µm
Rp (micrometres)
4.50
4.00
3.50
3.00
2.50
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA
1
2
3
E_n = 0.36

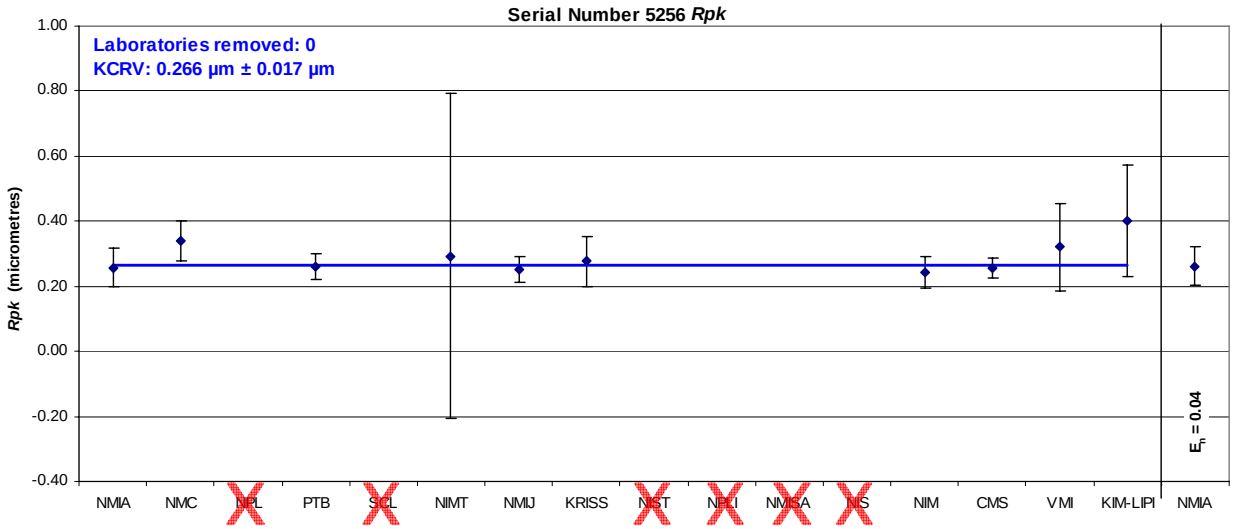

Serial Number 5256 Rv
Laboratories removed: 4
KCRV: 5.186 µm ± 0.031 µm
Rv (micrometres)
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
E_n = 0.70
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA

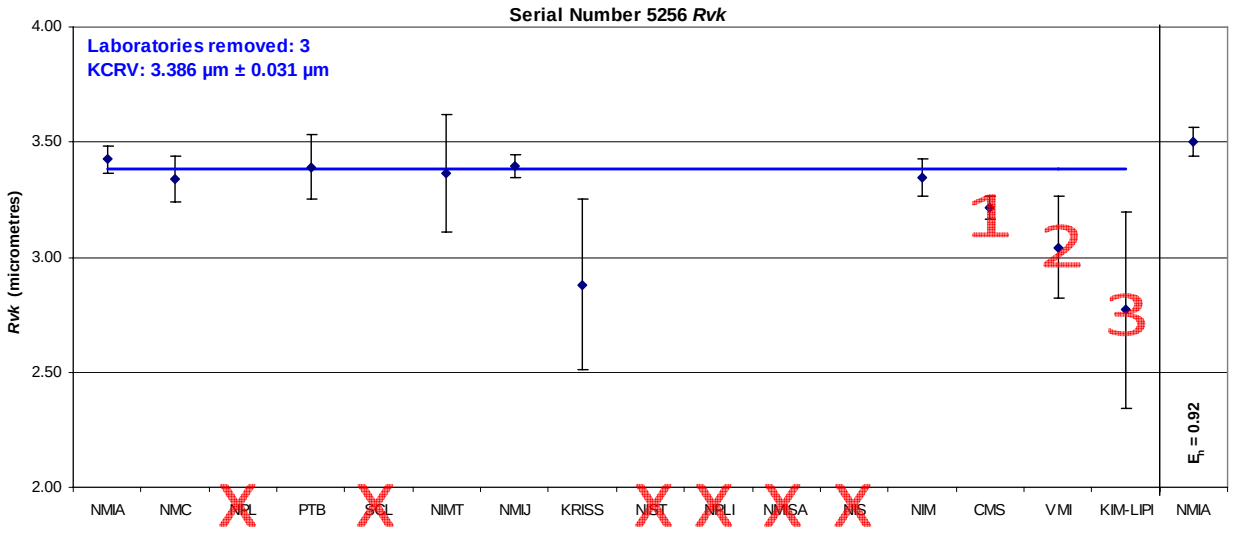

Serial Number 5256 Rt
Laboratories removed: 3
KCRV: 10.434 µm ± 0.043 µm
Rt (micrometres)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
E_n = 0.86
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA

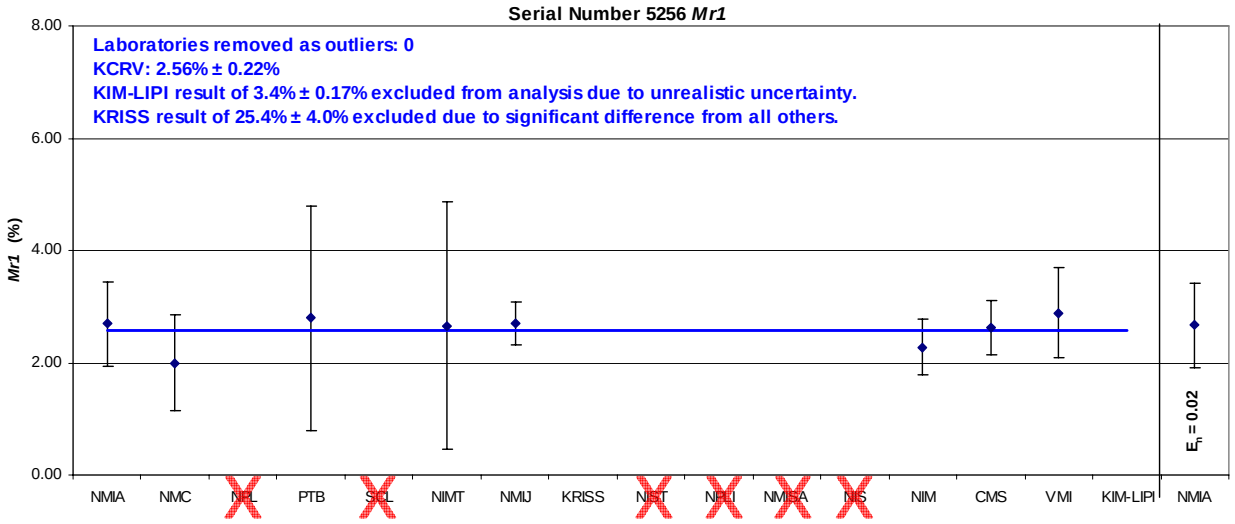

Serial Number 5256 Rsk
Laboratories removed: 2
KCRV: -0.813 ± 0.018
Rsk (dimensionless)
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
E_n = 0.10
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA

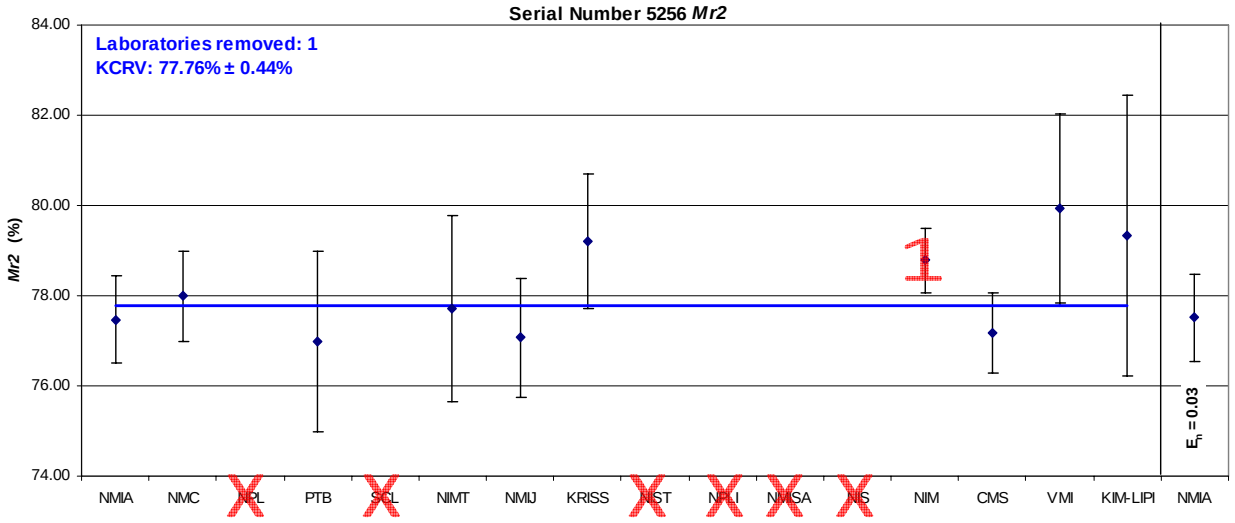

Serial Number 5256 Rku
Laboratories removed: 5
KCRV: 2.724 ± 0.028
Rku (dimensionless)
4.50
3.50
2.50
1.50
0.50
4
1
5
2
3
E_n = 0.19
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA


Serial Number 5256 Rk
Laboratories removed: 2
KCRV: 4.151 µm ± 0.038 µm
Rk (micrometres)
6.00
5.00
4.00
3.00
2.00
1
2
E_n = 1.18
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA

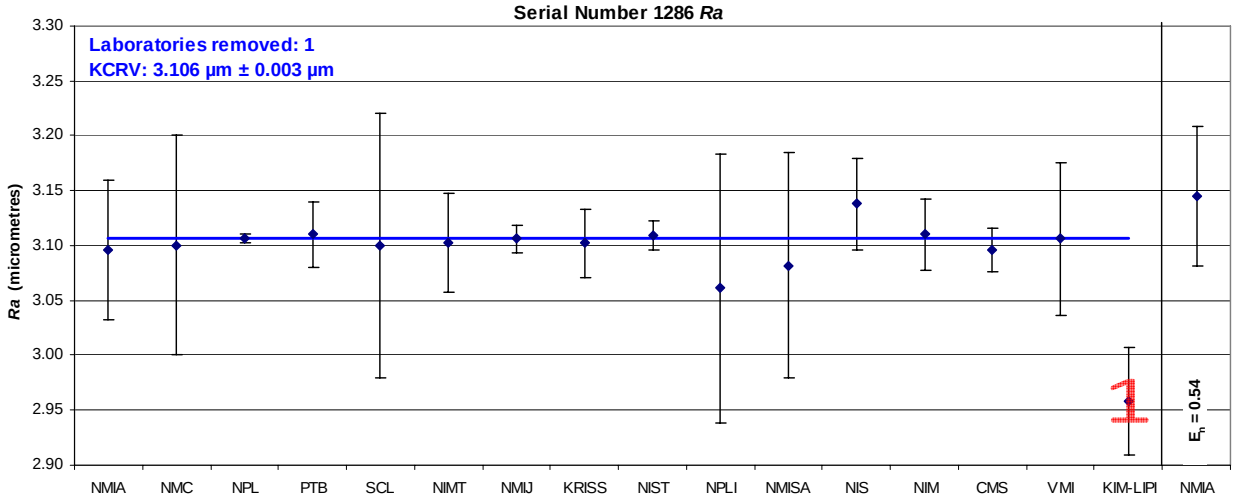

Serial Number 5256 Rpk
Laboratories removed: 0
KCRV: 0.266 µm ± 0.017 µm
Rpk (micrometres)
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
E_n = 0.04
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA

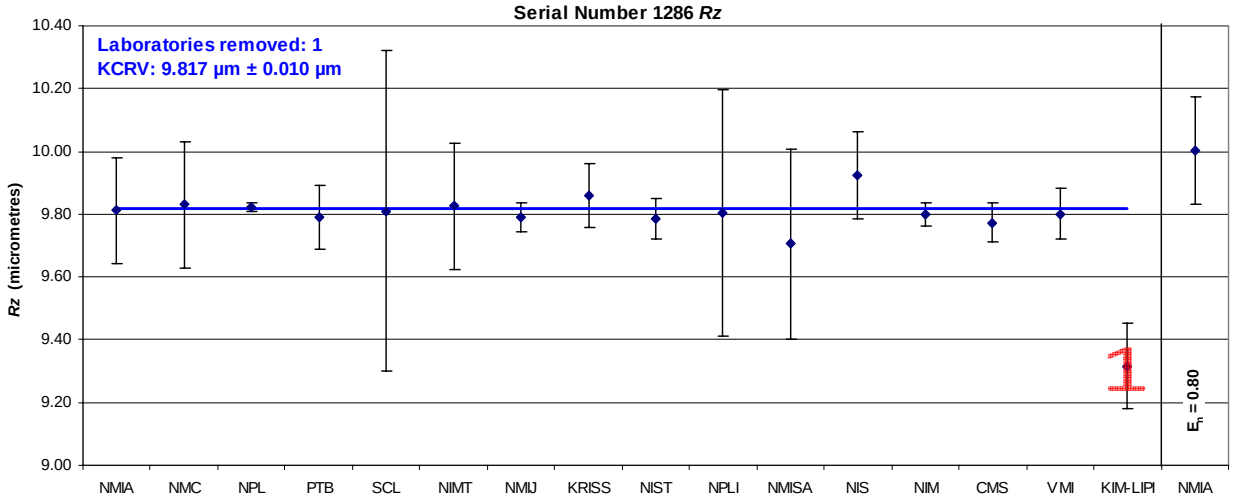

Serial Number 5256 Rvk
Laboratories removed: 3
KCRV: 3.386 µm ± 0.031 µm
Rvk (micrometres)
4.00
3.50
3.00
2.50
2.00
1
2
3
E_n = 0.92
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA

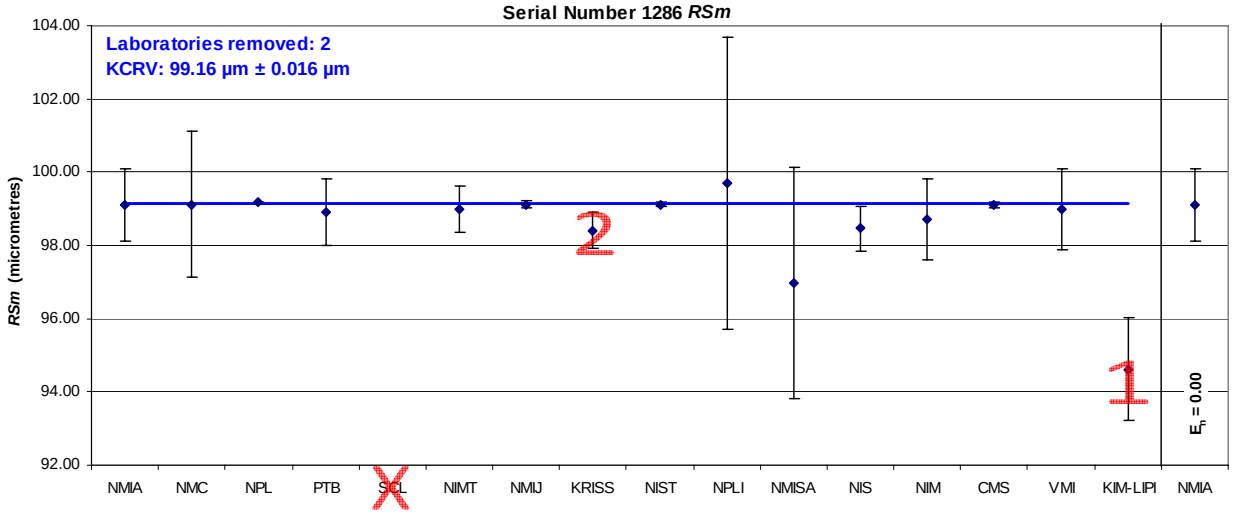

Serial Number 5256 Mr1
Laboratories removed as outliers: 0
KCRV: 2.56% ± 0.22%
KIM-LIPI result of 3.4% ± 0.17% excluded from analysis due to unrealistic uncertainty.
KRISS result of 25.4% ± 4.0% excluded due to significant difference from all others.
Mr1 (%)
8.00
6.00
4.00
2.00
0.00
E_n = 0.02
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA


Serial Number 5256 Mr2
Laboratories removed: 1
KCRV: 77.76% ± 0.44%
Mr2 (%)
84.00
82.00
80.00
78.00
76.00
74.00
1
E_n = 0.03
NMIA
NMC
NPL
PTB
SCL
NIMT
NMIJ
KRISS
NIST
NPLI
NMISA
NIS
NIM
CMS
VMI
KIM-LIPI
NMIA

Serial number 1286







Appendix C. Full reported results

Each laboratory submitted results using the Appendix C form in the protocol. These results were transcribed into the analysis spreadsheets to statistically determine and remove outliers from the parameter population using the E_n and Birge limit method.

Values listed for standard deviation and number of measurements (n) are for information only and are not used in calculations. Standard deviations are shown in graphs for a comparison of each laboratory's measurement variation. Some laboratories reported the Estimated Standard Deviation of the Mean (EDSM). These are adjusted to the standard deviations using that laboratories reported number of measurements, n, in the formula s = ESDM * √n.

Only the full submitted results are shown with the initial E_n ratios which are calculated from each laboratory result, the mean KCRV result and associated uncertainties at a confidence interval of 95%. E_n ratios above 1.0 are highlighted in red. Note that the order of outlier removal may be different to that implied by the initial E_n magnitudes. As each outlier is removed, the KCRV will change, therefore each laboratory E_n will change. Each iteration for outlier removal is not shown with the order of outlier removal listed in the text.

The coverage factor, *k*, of mean values is assumed to be from a large population which is consistent with the reported coverage factor for each laboratory.

Arithmetic mean calculations are for information only. The arithmetic mean of all results is shown on the upper graph as a **red** line.

Weighted mean of all results are shown on the graph as a **blue** line.

Where the Birge ratio is greater than the Birge limit, the laboratory with the worst result (largest $E_n > 1$) based on the weighted mean is excluded and all values recalculated. Subsequent iterations are not shown.

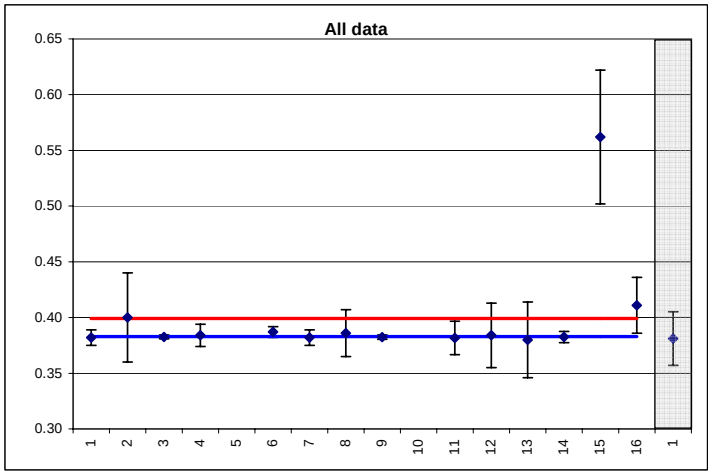
Refer to the page on each parameter for additional comments particular to that parameter.

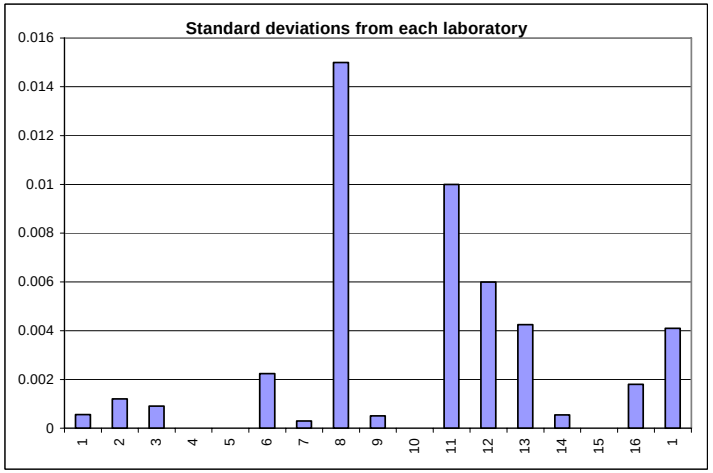
S/N A277 Groove A **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio* En Arithm	En Weighted	Reject
Australia	NMIA	07/08	1	0.3820	0.0006	0.0070	2.00	5	0.0035	1.2E-05	31184	81633	0.06	1.77	0.12	
Singapore	NMC	08/08	2	0.4000	0.0012	0.0400	2.00	5	0.0200	4.0E-04	1000	2500	0.73	0.02	0.43	
UK	NPL	09/08	3	0.3825	0.0009	0.0017	2.09	5	0.0008	6.6E-07	578131	1511453	0.20	2.43	0.18	
Germany	PTB	10/08	4	0.3840		0.0100	2.18	5	0.0046	2.1E-05	18249	47524	0.06	1.26	0.11	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	0.3870	0.0022	0.0047	2.00	5	0.0024	5.5E-06	69780	180309	3.09	1.49	0.86	
Japan	NMIJ	01/09	7	0.3820	0.0003	0.0070	2.00	5	0.0035	1.2E-05	31184	81633	0.06	1.77	0.12	
South Korea	KRISS	04/09	8	0.3860	0.0150	0.0210	2.78	5	0.0076	5.7E-05	6765	17525	0.17	0.59	0.15	
USA	NIST	06/09	9	0.3824	0.0005	0.0019	2.00	9	0.0010	9.0E-07	423712	1108033	0.23	2.42	0.21	
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11	0.3816	0.0100	0.0150	2.00	5	0.0075	5.6E-05	6784	17778	0.03	1.07	0.08	
Egypt	NIS	10/09	12	0.3840	0.0060	0.0290	2.00	5	0.0145	2.1E-04	1826	4756	0.01	0.51	0.04	
China	NIM	11/09	13	0.3800	0.0042	0.0340	1.96	5	0.0173	3.0E-04	1263	3323	0.03	0.55	0.08	
Ch Teipei	CMS	01/10	14	0.3825	0.0005	0.0050	2.00	20	0.0025	6.3E-06	61200	160000	0.02	2.00	0.07	
Vietnam	VMI	03/10	15	0.5620		0.0600	2.00	5	0.0300	9.0E-04	624	1111	35.66	2.70	2.99	Worst
Indonesia	KIM-LIPI	04/10	16	0.4110	0.0018	0.0250	2.00	25	0.0125	1.6E-04	2630	6400	5.07	0.46	1.12	
Australia rpt	NMIA	06/10	1	**0.3810**	0.0041	0.0240	2.00	6	0.0120	1.4E-04	2646	6944	0.024	0.73	0.08	
		Count		**14**						0.00214	1234332	3223978	45.42	*2.70*	***2.99***	= *Max*
		St Deviation		0.0477											***1.87***	= R_B
		ESDM		0.0127											***1.34***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**0.399**	0.0033	2.00	**0.0066**	1.7
Weighted	**0.383**	0.0006	2.00	**0.0011**	0.3

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for A277 groove A results:
No results given for SCL and NPLI.
VMI and KIM-LIPI report *Pt* instead of *d*. Both of these results are higher than the reference value.
NIMT, NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KRISS and NMISA have larger standard deviations than other laboratories.
CMS and KIM-LIPI made repeat measurements at the required locations.
Comparison of initial and final NMIA result is E_n = -0.04

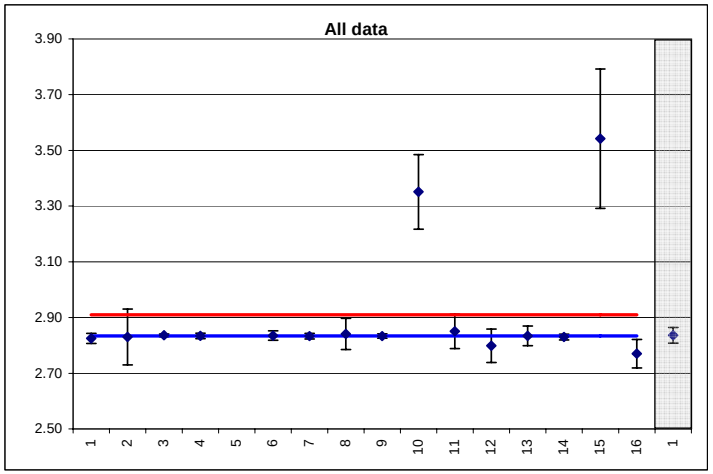
Submitted results: 14
Outliers removed: 1 (VMI)
Final population size: 13
Key Comparison Reference Value: *d* = 0.383 µm ± 0.001 µm
After outliers are removed, the KIM-LIPI E_n was 1.1 but remained in the accepted values since the Birge ratio was less than the Birge limit. If KIM-LIPI was removed also, the final KCRV does not change.

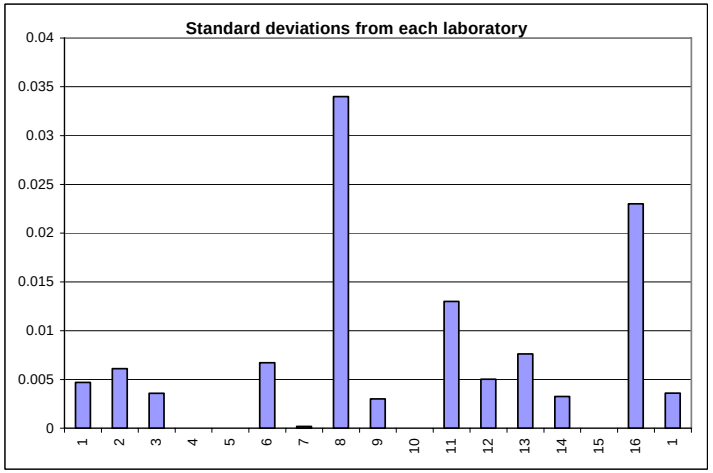
S/N A277 Groove B **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations $u^c(x_i)$ µm^2	$\frac{xi}{u^c(x_i)}$ µm^{-1}	$u^{-c}(x_i)$ µm^{-2}	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio* En Arithm	En Weighted	Reject
Australia	NMIA	07/08	1	2.8250	0.0047	0.0180	2.00	5	0.0090	8.1E-05	34877	12346	1.09	2.64	0.52	
Singapore	NMC	08/08	2	2.8300	0.0061	0.1000	2.00	5	0.0500	2.5E-03	1132	400	0.01	0.77	0.04	
UK	NPL	09/08	3	2.8360	0.0036	0.0050	2.65	5	0.0019	3.6E-06	796632	280900	0.72	2.73	0.28	
Germany	PTB	10/08	4	2.8340		0.0100	2.21	5	0.0045	2.0E-05	138415	48841	0.01	2.67	0.04	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	2.8350	0.0067	0.0170	2.00	5	0.0085	7.2E-05	39239	13841	0.00	2.37	0.03	
Japan	NMIJ	01/09	7	2.8330	0.0002	0.0100	2.00	5	0.0050	2.5E-05	113320	40000	0.08	2.70	0.13	
South Korea	KRISS	04/09	8	2.8410	0.0340	0.0560	2.78	5	0.0201	4.1E-04	7001	2464	0.11	1.11	0.12	
USA	NIST	06/09	9	2.8336	0.0030	0.0076	2.00	9	0.0038	1.4E-05	196233	69252	0.04	2.75	0.10	
India	NPLI	07/09	10	3.3510		0.1340	1.00		0.1340	1.8E-02	187	56	14.86	3.23	3.85	*Worst*
South Africa	NMISA	09/09	11	2.8502	0.0130	0.0620	2.00	5	0.0310	9.6E-04	2966	1041	0.26	0.88	0.25	
Egypt	NIS	10/09	12	2.7990	0.0050	0.0600	2.00	5	0.0300	9.0E-04	3110	1111	1.39	1.69	0.59	
China	NIM	11/09	13	2.8340	0.0076	0.0350	1.96	5	0.0179	3.2E-04	8887	3136	0.00	1.72	0.01	
Ch Teipei	CMS	01/10	14	2.8300	0.0033	0.0100	2.00	20	0.0050	2.5E-05	113200	40000	0.77	2.81	0.42	
Vietnam	VMI	03/10	15	3.5420		0.2500	2.00	5	0.1250	1.6E-02	227	64	32.04	2.52	2.83	
Indonesia	KIM-LIPI	04/10	16	2.7700	0.0230	0.0510	2.00	25	0.0255	6.5E-04	4260	1538	6.38	2.43	1.26	
Australia rpt	NMIA	06/10	1	2.8360	0.0036	0.0280	2.0	6	0.0140	2.0E-04	14469	5102	0.013	1.91	0.06	
		Count		**15**						0.03956	1459686	514989	57.77	*3.23*	***3.85***	= *Max*
		St Deviation		0.2218											***2.03***	= R_B
		ESDM		0.0573											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**2.910**	0.0133	2.00	**0.0265**	0.9
Weighted	**2.834**	0.0014	2.00	**0.0028**	0.1

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for A277 groove B results:
No result given for SCL.
NPLI, VMI and KIM-LIPI report *Pt* instead of *d*.
NIMT, NIS, NIM and SCL reported the ESDM which is converted to the standard deviation [*s* = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KRISS and KIM-LIPI have larger random surface variation than other laboratories.
CMS and KIM-LIPI made repeat measurements at the required locations.
Comparison of initial and final NMIA result is E_n = 0.33

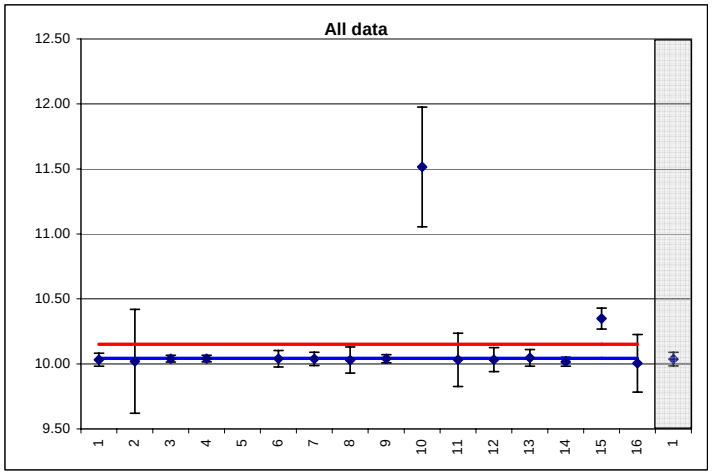
Submitted results: 15
Outliers removed: 2 (NPLI, VMI)
Final population size: 13
Key Comparison Reference Value: *d* = 2.834 µm ± 0.003 µm
After outliers are removed, the KIM-LIPI E_n was 1.2 but remained in the accepted values since the Birge ratio was less than the Birge limit. If Indonesia was removed also, the final KCRV does not change.

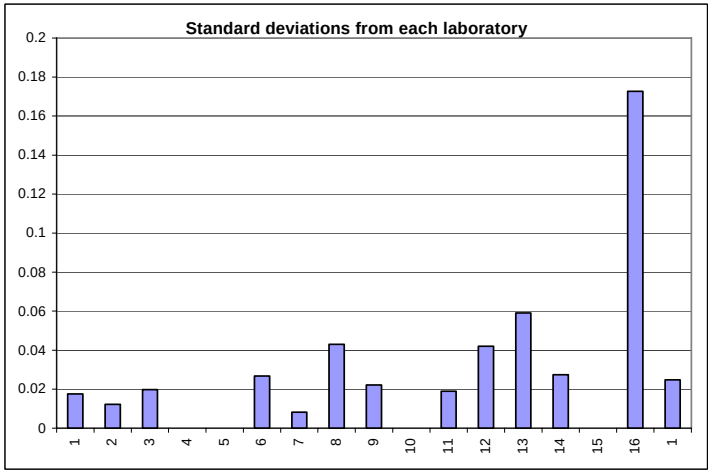
S/N 7462 Groove — **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	10.032	0.0176	0.050	2.00	15	**0.0250**	6.3E-04	16051	1600	0.20	1.38	**0.22**	
Singapore	NMC	08/08	2	10.020	0.0122	0.400	2.00	5	**0.2000**	4.0E-02	251	25	0.01	0.32	**0.06**	
UK	NPL	09/08	3	10.040	0.0198	0.026	2.87	5	**0.0091**	8.2E-05	122335	12185	0.12	1.48	**0.11**	
Germany	PTB	10/08	4	10.041		0.025	2.18	5	**0.0115**	1.3E-04	76350	7604	0.04	1.47	**0.08**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	10.040	0.0268	0.064	2.00	5	**0.0320**	1.0E-03	9805	977	0.01	1.17	**0.05**	
Japan	NMIJ	01/09	7	10.039	0.0082	0.051	2.00	5	**0.0255**	6.5E-04	15439	1538	0.03	1.29	**0.08**	
South Korea	KRISS	04/09	8	10.030	0.0430	0.100	2.00	5	**0.0500**	2.5E-03	4012	400	0.07	0.99	**0.13**	
USA	NIST	06/09	9	10.040	0.0222	0.031	2.00	8	**0.0155**	2.4E-04	41790	4162	0.04	1.44	**0.10**	
India	NPLI	07/09	10	11.515		0.460	1.00	15	**0.4600**	2.1E-01	54	5	10.24	2.93	**3.20**	
South Africa	NMISA	09/09	11	10.032	0.0190	0.205	2.00	5	**0.1025**	1.1E-02	955	95	0.01	0.55	**0.06**	
Egypt	NIS	10/09	12	10.033	0.0420	0.092	2.00	5	**0.0460**	2.1E-03	4741	473	0.05	1.02	**0.11**	
China	NIM	11/09	13	10.047	0.0590	0.064	1.96	5	**0.0327**	1.1E-03	9423	938	0.01	1.10	**0.06**	
Ch Teipei	CMS	01/10	14	10.017	0.0275	0.034	2.00	20	**0.0170**	2.9E-04	34661	3460	2.37	1.71	**0.73**	
Vietnam	VMI	03/10	15	10.349		0.080	2.00	5	**0.0400**	1.6E-03	6468	625	58.45	1.84	**3.79**	***Worst***
Indonesia	KIM-LIPI	04/10	16	10.005	0.1727	0.222	2.00	25	**0.1110**	1.2E-02	812	81	0.12	0.63	**0.17**	
Australia rpt	NMIA	06/10	1	10.038	0.0248	0.052	2.00	6	**0.0260**	6.8E-04	14849	1479	0.040	1.29	**0.10**	
		Count		**15**						0.28475	343147	34167.1	71.78	*2.93*	***3.79***	= *Max*
		St Deviation		0.3860											***2.26***	= R_B
		ESDM		0.0997											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**10.152**	0.0356	2.00	**0.0711**	0.7
Weighted	**10.043**	0.0054	2.00	**0.0108**	0.1

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 7462 groove results:
No results given for SCL.
NPLI, VMI and KIM-LIPI report *Pt* instead of *d*. Two of these results are significantly higher than the reference value.
NIMT, NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [*s* = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI has a larger standard deviation than other laboratories.
NPLI, CMS and KIM-LIPI made repeat measurements at the required locations.
Comparison of initial and final NMIA result is E_n = 0.08.

Submitted results: 15
Outliers removed: 2 (VMI, NPLI)
Final population size: 13
Key Comparison Reference Value: *d* = 10.037 µm ± 0.011 µm

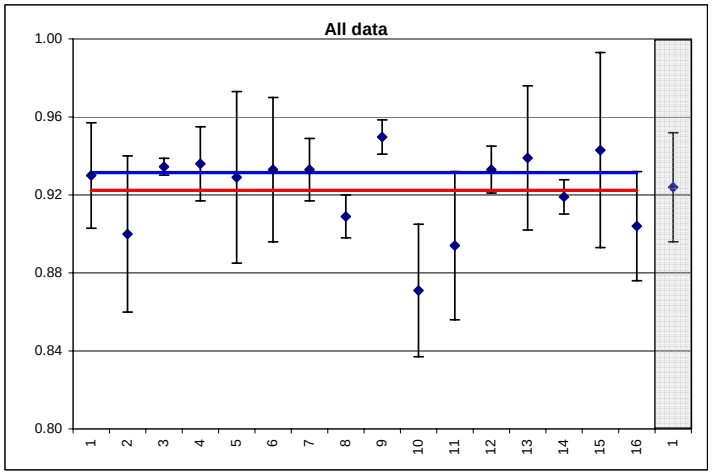
S/N A277 *Ra*

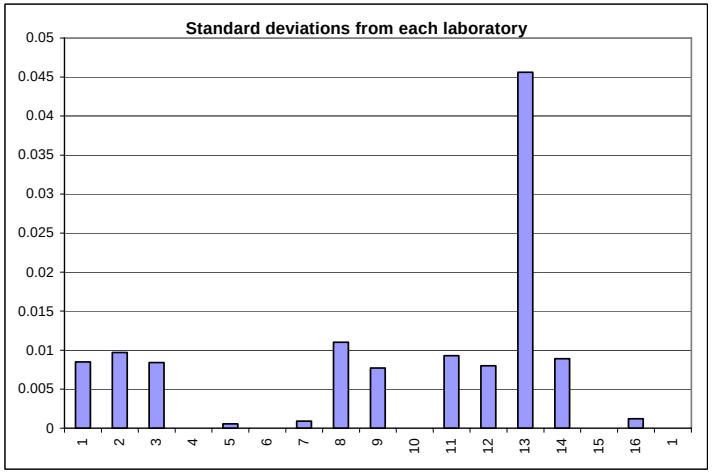
All data

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm^2	$\frac{xi}{u^c(x_i)}$ µm^{-1}	$u^{-c}(x_i)$ µm^{-2}	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	0.9300	0.0085	0.0270	2.00	20	**0.0135**	1.8E-04	5103	5487	0.01	0.27	**0.05**	
Singapore	NMC	08/08	2	0.9000	0.0097	0.0400	2.00	20	**0.0200**	4.0E-04	2250	2500	2.48	0.55	**0.79**	
UK	NPL	09/08	3	0.9345	0.0084	0.0043	2.13	20	**0.0020**	4.1E-06	229299	245370	2.23	1.31	**0.58**	
Germany	PTB	10/08	4	0.9360		0.0190	2.00	20	**0.0095**	9.0E-05	10371	11080	0.23	0.66	**0.23**	
Hong Kong	SCL	11/08	5	0.9290	0.0006	0.0440	1.96	16	**0.0224**	5.0E-04	1843	1984	0.01	0.15	**0.06**	
Thailand	NIMT	12/08	6	0.9330		0.0370	2.00		**0.0185**	3.4E-04	2726	2922	0.01	0.28	**0.04**	
Japan	NMIJ	01/09	7	0.9330	0.0009	0.0160	2.00	20	**0.0080**	6.4E-05	14578	15625	0.04	0.59	**0.09**	
South Korea	KRISS	04/09	8	0.9090	0.0110	0.0110	2.09	20	**0.0053**	2.8E-05	32815	36100	18.25	0.97	**1.98**	***Worst***
USA	NIST	06/09	9	0.9497	0.0077	0.0088	2.00	20	**0.0044**	1.9E-05	49278	51888	17.22	2.27	**1.97**	
India	NPLI	07/09	10	0.8710		0.0340	1.00		**0.0340**	1.2E-03	753	865	3.16	1.47	**1.77**	
South Africa	NMISA	09/09	11	0.8940	0.0093	0.0380	2.00	25	**0.0190**	3.6E-04	2476	2770	3.89	0.73	**0.98**	
Egypt	NIS	10/09	12	0.9330	0.0080	0.0120	2.00	20	**0.0060**	3.6E-05	25917	27778	0.06	0.73	**0.12**	
China	NIM	11/09	13	0.9390	0.0456	0.0370	1.96	20	**0.0189**	3.6E-04	2635	2806	0.16	0.44	**0.20**	
Ch Teipei	CMS	01/10	14	0.9190	0.0089	0.0088	2.00	15	**0.0044**	1.9E-05	47469	51653	8.05	0.28	**1.35**	
Vietnam	VMI	03/10	15	0.9430		0.0500	2.00	20	**0.0250**	6.3E-04	1509	1600	0.21	0.41	**0.23**	
Indonesia	KIM-LIPI	04/10	16	0.9040	0.0012	0.0280	2.00	100	**0.0140**	2.0E-04	4612	5102	3.85	0.63	**0.98**	
Australia rpt	NMIA	06/10	1	0.9240		0.0280	2.0	15	**0.0140**	2.0E-04	4714	5102	0.286	0.06	**0.27**	
		Count		**16**						0.00438	433635	465531	59.87	*2.27*	***1.98***	= *Max*
		St Deviation		0.0211											***2.00***	= R_B
		ESDM		0.0053											***1.32***	= R_B lim

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**0.922**	0.0041	2.00	**0.0083**	0.9
Weighted	**0.931**	0.0015	2.00	**0.0029**	0.3

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for A277 *Ra* results:
SCL, NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NIST apply a stylus tip correction which in effect increases the *Ra* value by 12 nm. The value used remains the original reported "corrected" *Ra* . If the uncorrected value of 0.9377 ± 0.0089 µm was used, the NIST value E_n would not be excluded with a final E_n of 0.60 after all other outliers are excluded. Refer to the report section 11 for further discussion.
NPLI uncertainty reported at k = 1.0.
NIM has a significantly higher standard deviation than any other laboratory.
KIM-LIPI made repeat measurements at the required locations.
Comparison of initial and final NMIA result is E_n = -0.15

Submitted results: 16
Outliers removed: 3 (KRISS, NPLI, NIST)
Final population size: 13
Key Comparison Reference Value: *Ra* = 0.931 µm ± 0.003 µm
After outliers are removed, the CMS E_n was 1.3 but remained in the accepted values since the Birge ratio was less than the Birge limit. If CMS was removed also, the final KCRV would change by +0.002 µm.

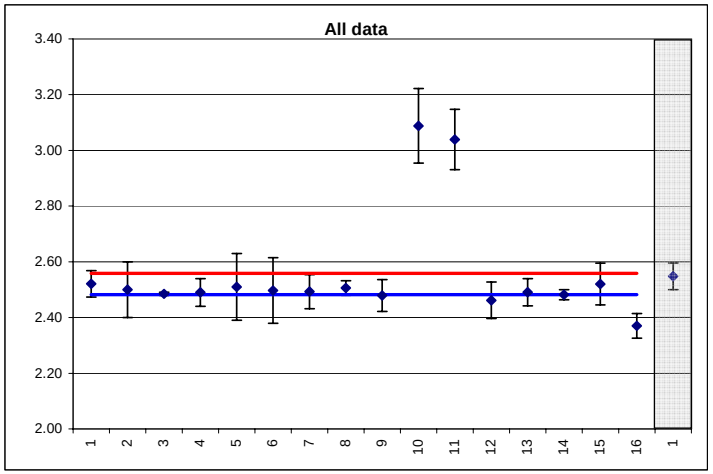
S/N A277 *Rz* — **All data**

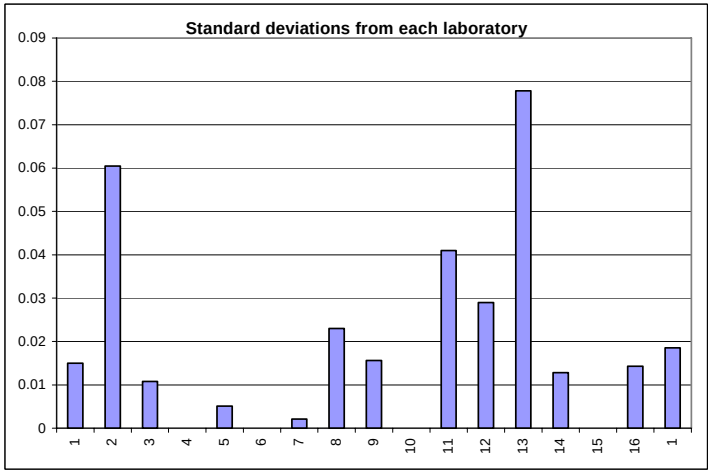
Mean and uncertainty calculations — *En & Birge ratio*

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	$u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	2.5210	0.0150	0.0470	2.00	20	**0.0235**	5.5E-04	4565	1811	2.78	0.71	**0.83**	
Singapore	NMC	08/08	2	2.5000	0.0605	0.1000	2.00	20	**0.0500**	2.5E-03	1000	400	0.13	0.57	**0.18**	
UK	NPL	09/08	3	2.4850	0.0108	0.0060	2.13	20	**0.0028**	7.9E-06	313172	126025	1.29	2.96	**0.41**	
Germany	PTB	10/08	4	2.4900		0.0500	2.00	20	**0.0250**	6.3E-04	3984	1600	0.11	1.23	**0.16**	
Hong Kong	SCL	11/08	5	2.5100	0.0051	0.1200	1.96	16	**0.0612**	3.7E-03	670	267	0.21	0.39	**0.23**	
Thailand	NIMT	12/08	6	2.4970		0.1180	2.00		**0.0590**	3.5E-03	717	287	0.07	0.51	**0.13**	
Japan	NMIJ	01/09	7	2.4930	0.0021	0.0610	2.00	20	**0.0305**	9.3E-04	2680	1075	0.13	1.00	**0.18**	
South Korea	KRISS	04/09	8	2.5060	0.0230	0.0260	2.09	20	**0.0124**	1.5E-04	16193	6462	3.79	1.48	**0.91**	
USA	NIST	06/09	9	2.4790	0.0156	0.0570	2.00	20	**0.0285**	8.1E-04	3052	1231	0.01	1.28	**0.05**	
India	NPLI	07/09	10	3.0880		0.1340	1.00		**0.1340**	1.8E-02	172	56	20.47	3.89	**4.52**	
South Africa	NMISA	09/09	11	3.0390	0.0410	0.1078	2.00	25	**0.0539**	2.9E-03	1046	344	106.87	4.35	**5.16**	***Worst***
Egypt	NIS	10/09	12	2.4620	0.0290	0.0660	2.00	20	**0.0330**	1.1E-03	2261	918	0.36	1.37	**0.30**	
China	NIM	11/09	13	2.4910	0.0778	0.0490	1.96	20	**0.0250**	6.3E-04	3986	1600	0.14	1.23	**0.19**	
Ch Teipei	CMS	01/10	14	2.4820	0.0128	0.0180	2.00	15	**0.0090**	8.1E-05	30642	12346	0.00	2.54	**0.01**	
Vietnam	VMI	03/10	15	2.5200		0.0750	2.00	20	**0.0375**	1.4E-03	1792	711	1.04	0.49	**0.51**	
Indonesia	KIM-LIPI	04/10	16	2.3700	0.0143	0.0440	4.00	100	**0.0110**	1.2E-04	19587	8264	103.29	3.76	**2.52**	
Australia rpt	NMIA	06/10	1	2.5480	0.0185	0.0480	2.00	15	**0.0240**	5.8E-04	4424	1736	7.609	0.19	**1.37**	
		Count		**16**						0.037	405518	163397	240.69	*4.35*	***5.16***	= *Max*
		St Deviation		0.2004											***4.01***	= R_B
		ESDM		0.0501											***1.32***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**2.558**	0.0120	2.00	**0.0240**	0.9
Weighted	**2.482**	0.0025	2.00	**0.0049**	0.2

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for A277 *Rz* results:
NMC A*Star reports *Ry* instead of *Rz*.
SCL, NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
NIM and NMC A*Star have higher standard deviations than any other laboratory.
KIM-LIPI made repeat measurements at the required locations.
Comparison of initial and final NMIA result is E_n = 0.40

Submitted results: 16
Outliers removed: 3 (NMISA, NPLI, KIM-LIPI)
Final population size: 13
Key Comparison Reference Value: *Ra* = 2.486 µm ± 0.005 µm

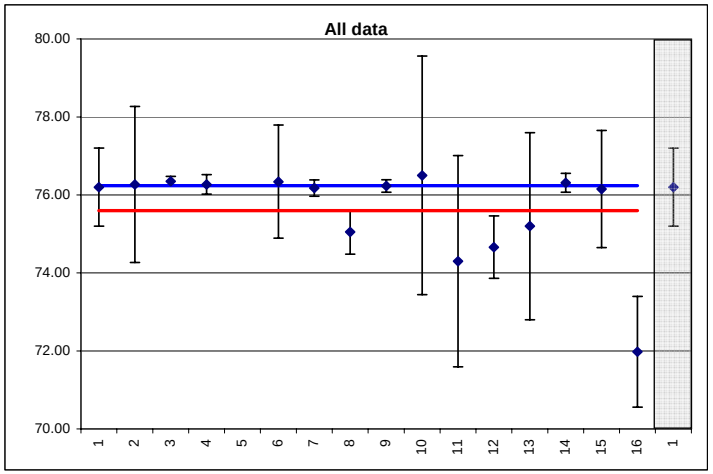
S/N A277 *RSm*

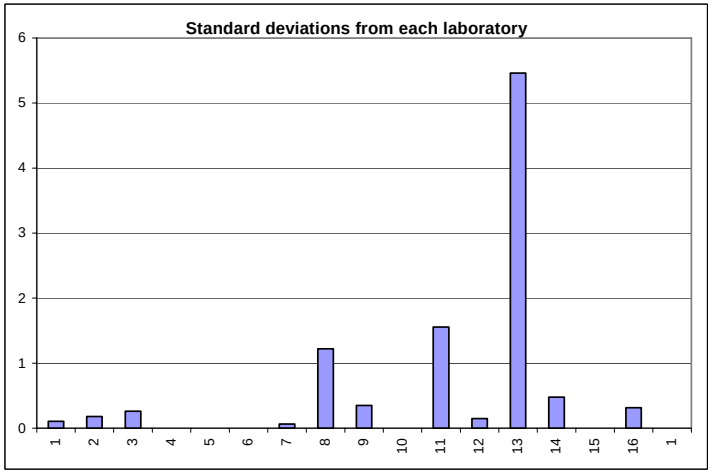
All data

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	76.200	0.1070	1.000	2.00	20	**0.5000**	2.5E-01	305	4	0.00	0.53	**0.03**	
Singapore	NMC	08/08	2	76.270	0.1812	2.000	2.00	20	**1.0000**	1.0E+00	76	1	0.00	0.32	**0.02**	
UK	NPL	09/08	3	76.351	0.2594	0.125	2.15	20	**0.0581**	3.4E-03	22588	296	3.99	1.38	**0.80**	
Germany	PTB	10/08	4	76.270		0.250	2.13	20	**0.1174**	1.4E-02	5536	73	0.09	1.14	**0.13**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	76.340		1.450	2.00		**0.7250**	5.3E-01	145	2	0.02	0.48	**0.07**	
Japan	NMIJ	01/09	7	76.176	0.0648	0.208	2.00	20	**0.1040**	1.1E-02	7043	92	0.32	1.01	**0.27**	
South Korea	KRISS	04/09	8	75.050	1.2230	0.570	2.09	20	**0.2727**	7.4E-02	1009	13	18.87	0.71	**2.06**	
USA	NIST	06/09	9	76.230	0.3508	0.160	2.00	20	**0.0800**	6.4E-03	11911	156	0.00	1.14	**0.03**	
India	NPLI	07/09	10	76.500		3.060	1.00		**3.0600**	9.4E+00	8	0	0.01	0.29	**0.09**	
South Africa	NMISA	09/09	11	74.300	1.5559	2.710	2.00	25	**1.3550**	1.8E+00	40	1	2.04	0.47	**0.71**	
Egypt	NIS	10/09	12	74.661	0.1475	0.801	2.00	20	**0.4005**	1.6E-01	465	6	15.44	0.98	**1.96**	
China	NIM	11/09	13	75.200	5.4600	2.400	1.96	20	**1.2245**	1.5E+00	50	1	0.71	0.16	**0.43**	
Ch Teipei	CMS	01/10	14	76.310	0.4790	0.240	2.00	20	**0.1200**	1.4E-02	5299	69	0.39	1.22	**0.30**	
Vietnam	VMI	03/10	15	76.150		1.500	2.00	20	**0.7500**	5.6E-01	135	2	0.01	0.35	**0.06**	
Indonesia	KIM-LIPI	04/10	16	71.980	0.3152	1.420	2.00	100	**0.7100**	5.0E-01	143	2	35.91	2.39	**2.99**	***Worst***
Australia rpt	NMIA	06/10	1	76.200	0.0002	1.00	2.00	15	**0.5000**	2.5E-01	305	4	0.005	0.53	**0.03**	
		Count		**15**						15.8248	54755	718.242	77.83	*2.39*	***2.99***	= *Max*
		St Deviation		1.2205											***2.36***	= R_B
		ESDM		0.3151											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**75.599**	0.2652	2.00	**0.5304**	0.7
Weighted	**76.235**	0.0373	2.00	**0.0746**	0.1

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for A277 *RSm* results:
No result given for SCL.
NMC A*Star reports *Sm* instead of *RSm*.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [*s* = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
NIM has a higher standard deviation than any other laboratory.
KIM-LIPI made repeat measurements at the required locations.
Comparison of initial and final NMIA result is E_n = 0.00

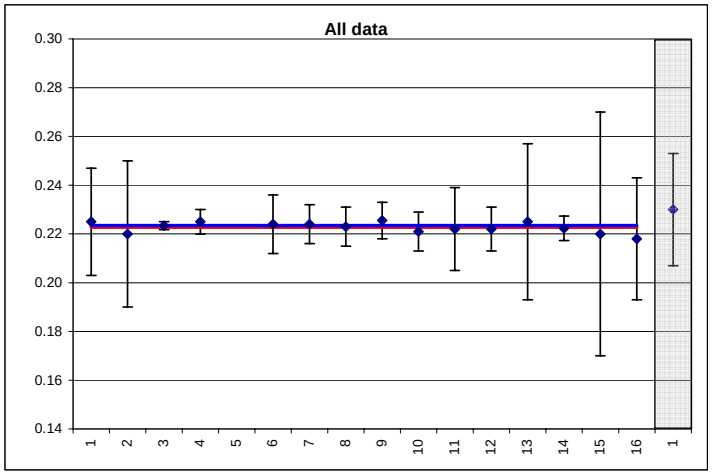
Submitted results: 15
Outliers removed: 3 (KIM-LIPI, KRISS, NIS)
Final population size: 12
Key Comparison Reference Value: *RSm* = 76.28 µm ± 0.076 µm

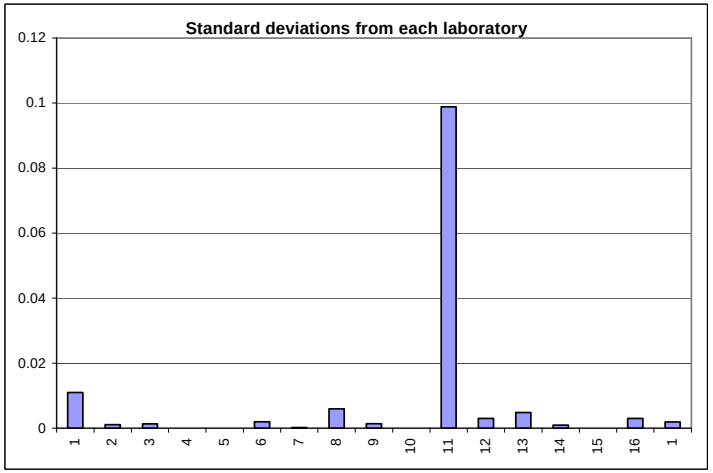
S/N 5276 ***Ra*** **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**0.2250**	0.0110	0.0220	2.00	12	**0.0110**	1.2E-04	1860	8264	0.02	0.10	**0.07**	
Singapore	NMC	08/08	2	**0.2200**	0.0011	0.0300	2.00	12	**0.0150**	2.3E-04	978	4444	0.05	0.09	**0.11**	
UK	NPL	09/08	3	**0.2234**	0.0014	0.0016	2.05	12	**0.0008**	6.1E-07	366734	1641602	0.00	0.13	**0.02**	
Germany	PTB	10/08	4	**0.2250**		0.0050	2.00	12	**0.0025**	6.3E-06	36000	160000	0.39	0.32	**0.30**	***Worst***
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**0.2240**	0.0020	0.0120	2.00	12	**0.0060**	3.6E-05	6222	27778	0.01	0.10	**0.05**	
Japan	NMIJ	01/09	7	**0.2240**	0.0002	0.0080	2.00	12	**0.0040**	1.6E-05	14000	62500	0.02	0.14	**0.07**	
South Korea	KRISS	04/09	8	**0.2230**	0.0060	0.0080	2.20	12	**0.0036**	1.3E-05	16864	75625	0.01	0.03	**0.05**	
USA	NIST	06/09	9	**0.2255**	0.0014	0.0075	2.00	12	**0.0038**	1.4E-05	16036	71111	0.30	0.31	**0.27**	
India	NPLI	07/09	10	**0.2210**		0.0080	1.00	12	**0.0080**	6.4E-05	3453	15625	0.09	0.17	**0.30**	
South Africa	NMISA	09/09	11	**0.2220**	0.0988	0.0170	2.00	13	**0.0085**	7.2E-05	3073	13841	0.03	0.04	**0.08**	
Egypt	NIS	10/09	12	**0.2220**	0.0030	0.0090	2.00	12	**0.0045**	2.0E-05	10963	49383	0.10	0.06	**0.16**	
China	NIM	11/09	13	**0.2250**	0.0048	0.0320	1.96	12	**0.0163**	2.7E-04	844	3752	0.01	0.07	**0.05**	
Ch Teipei	CMS	01/10	14	**0.2223**	0.0009	0.0050	2.00	12	**0.0025**	6.3E-06	35568	160000	0.21	0.05	**0.22**	
Vietnam	VMI	03/10	15	**0.2200**		0.0500	2.00	12	**0.0250**	6.3E-04	352	1600	0.02	0.05	**0.07**	
Indonesia	KIM-LIPI	04/10	16	**0.2180**	0.0030	0.0250	2.00	60	**0.0125**	1.6E-04	1395	6400	0.19	0.18	**0.22**	
Australia rpt	NMIA	06/10	1	**0.2300**	0.0019	0.0230	2.00	12	**0.0115**	1.3E-04	1739	7561	0.325	0.31	**0.28**	
		Count		**15**						0.00164	514341	2301924	1.46	*0.32*	***0.30***	= *Max*
		St Deviation		0.0022											***0.32***	= R_B
		ESDM		0.0006											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**0.223**	0.0027	2.00	**0.0054**	2.4
Weighted	**0.223**	0.0007	2.00	**0.0013**	0.6

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Ra* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NMISA has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.16.

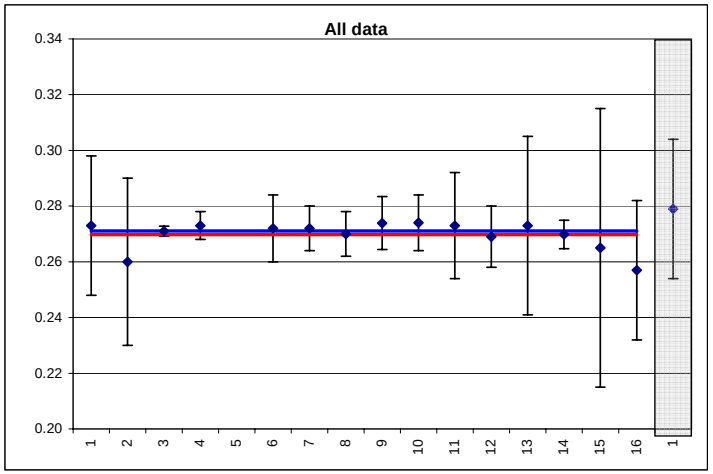
Submitted results: 15
Outliers removed: 0
Final population size: 15
Key Comparison Reference Value: *Ra* = 0.223 µm ± 0.002 µm

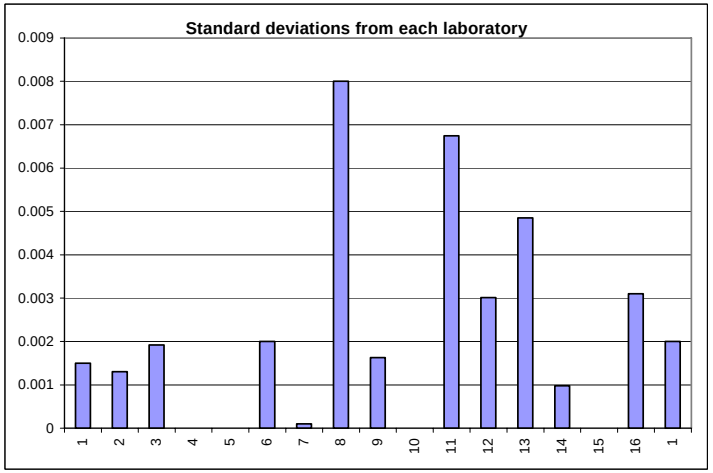
S/N 5276 *Rq* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**0.2730**	0.0015	0.0250	2.00	12	**0.0125**	1.6E-04	1747	6400	0.02	0.13	**0.08**	
Singapore	NMC	08/08	2	**0.2600**	0.0013	0.0300	2.00	12	**0.0150**	2.3E-04	1156	4444	0.54	0.32	**0.37**	
UK	NPL	09/08	3	**0.2710**	0.0019	0.0018	2.06	12	**0.0009**	7.6E-07	354943	1309753	0.01	0.22	**0.03**	
Germany	PTB	10/08	4	**0.2730**		0.0050	2.00	12	**0.0025**	6.3E-06	43680	160000	0.59	0.44	**0.37**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**0.2720**	0.0020	0.0120	2.00	12	**0.0060**	3.6E-05	7556	27778	0.02	0.17	**0.08**	
Japan	NMIJ	01/09	7	**0.2720**	0.0001	0.0080	2.00	12	**0.0040**	1.6E-05	17000	62500	0.05	0.23	**0.11**	
South Korea	KRISS	04/09	8	**0.2700**	0.0080	0.0080	2.20	12	**0.0036**	1.3E-05	20419	75625	0.09	0.03	**0.13**	
USA	NIST	06/09	9	**0.2739**	0.0016	0.0095	2.00	12	**0.0048**	2.3E-05	12140	44321	0.35	0.38	**0.29**	
India	NPLI	07/09	10	**0.2740**		0.0100	1.00	12	**0.0100**	1.0E-04	2740	10000	0.09	0.37	**0.29**	
South Africa	NMISA	09/09	11	**0.2730**	0.0067	0.0190	2.00	13	**0.0095**	9.0E-05	3025	11080	0.04	0.17	**0.10**	
Egypt	NIS	10/09	12	**0.2690**	0.0030	0.0110	2.00	12	**0.0055**	3.0E-05	8893	33058	0.14	0.06	**0.19**	
China	NIM	11/09	13	**0.2730**	0.0048	0.0320	1.96	12	**0.0163**	2.7E-04	1024	3752	0.01	0.10	**0.06**	
Ch Teipei	CMS	01/10	14	**0.2698**	0.0010	0.0051	2.00	12	**0.0026**	6.5E-06	41492	153787	0.25	0.01	**0.24**	
Vietnam	VMI	03/10	15	**0.2650**		0.0500	2.00	12	**0.0250**	6.3E-04	424	1600	0.06	0.09	**0.12**	
Indonesia	KIM-LIPI	04/10	16	**0.2570**	0.0031	0.0250	2.00	60	**0.0125**	1.6E-04	1645	6400	1.27	0.50	**0.56**	***Worst***
Australia rpt	NMIA	06/10	1	**0.2790**	0.0020	0.0250	2.00	12	**0.0125**	1.6E-04	1786	6400	0.402	0.36	**0.32**	
		Count		**15**						0.00175	517882	1910498	3.55	*0.50*	***0.56***	= *Max*
		St Deviation		0.0051											***0.50***	= R_B
		ESDM		0.0013											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**0.270**	0.0028	2.00	**0.0056**	2.1
Weighted	**0.271**	0.0007	2.00	**0.0014**	0.5

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rq* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
KRISS and NMISA have significantly higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.17.

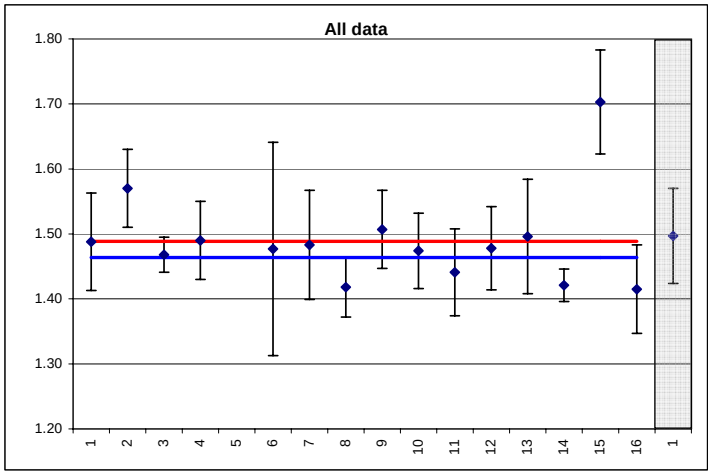
Submitted results: 15
Outliers removed: 0
Final population size: 15
Key Comparison Reference Value: *Rq* = 0.271 µm ± 0.002 µm

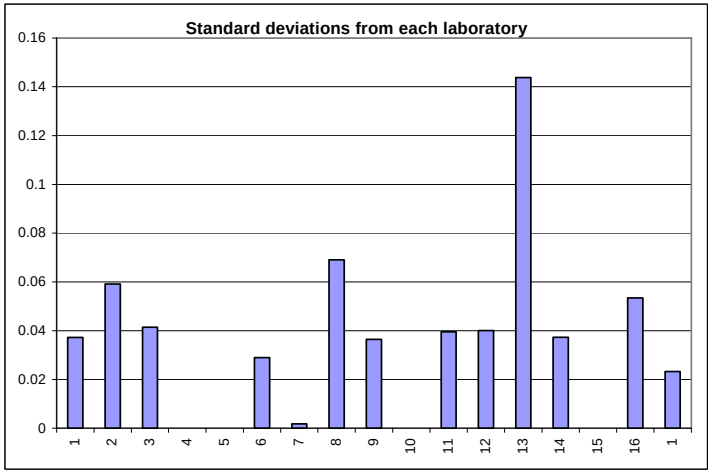
S/N 5276 *Rz* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**1.488**	0.0372	0.075	2.00	12	**0.0375**	1.4E-03	1058	711	0.42	0.01	**0.32**	
Singapore	NMC	08/08	2	**1.570**	0.0592	0.060	2.00	12	**0.0300**	9.0E-04	1744	1111	12.57	1.28	**1.73**	
UK	NPL	09/08	3	**1.468**	0.0414	0.027	2.28	12	**0.0118**	1.4E-04	10468	7131	0.13	0.61	**0.15**	
Germany	PTB	10/08	4	**1.490**		0.060	2.00	12	**0.0300**	9.0E-04	1656	1111	0.77	0.02	**0.43**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**1.477**	0.0290	0.164	2.00	12	**0.0820**	6.7E-03	220	149	0.03	0.07	**0.08**	
Japan	NMIJ	01/09	7	**1.483**	0.0018	0.084	2.00	12	**0.0420**	1.8E-03	841	567	0.21	0.06	**0.23**	
South Korea	KRISS	04/09	8	**1.418**	0.0690	0.046	2.20	12	**0.0209**	4.4E-04	3243	2287	4.77	1.40	**0.96**	
USA	NIST	06/09	9	**1.507**	0.0364	0.060	2.00	12	**0.0300**	9.0E-04	1674	1111	2.09	0.29	**0.71**	
India	NPLI	07/09	10	**1.474**		0.058	1.00	12	**0.0580**	3.4E-03	438	297	0.03	0.24	**0.17**	
South Africa	NMISA	09/09	11	**1.441**	0.0395	0.067	2.00	13	**0.0335**	1.1E-03	1284	891	0.46	0.68	**0.33**	
Egypt	NIS	10/09	12	**1.478**	0.0400	0.064	2.00	12	**0.0320**	1.0E-03	1443	977	0.20	0.16	**0.22**	
China	NIM	11/09	13	**1.496**	0.1438	0.088	1.96	12	**0.0449**	2.0E-03	742	496	0.52	0.08	**0.36**	
Ch Teipei	CMS	01/10	14	**1.421**	0.0373	0.025	2.00	12	**0.0125**	1.6E-04	9094	6400	11.64	2.09	**1.52**	
Vietnam	VMI	03/10	15	**1.703**		0.080	2.00	12	**0.0400**	1.6E-03	1064	625	35.81	2.60	**2.95**	***Worst***
Indonesia	KIM-LIPI	04/10	16	**1.415**	0.0534	0.068	2.00	60	**0.0340**	1.2E-03	1224	865	2.05	1.04	**0.70**	
Australia rpt	NMIA	06/10	1	**1.497**	0.0232	0.073	2.00	12	**0.0365**	1.3E-03	1124	751	0.835	0.11	**0.45**	
		Count		**15**						0.02361	36195	24729.3	71.69	*2.60*	***2.95***	= *Max*
		St Deviation		0.0713											***2.26***	= R_B
		ESDM		0.0184											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**1.489**	0.0102	2.00	**0.0205**	1.4
Weighted	**1.464**	0.0064	2.00	**0.0127**	0.9

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rz* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
China has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.09.

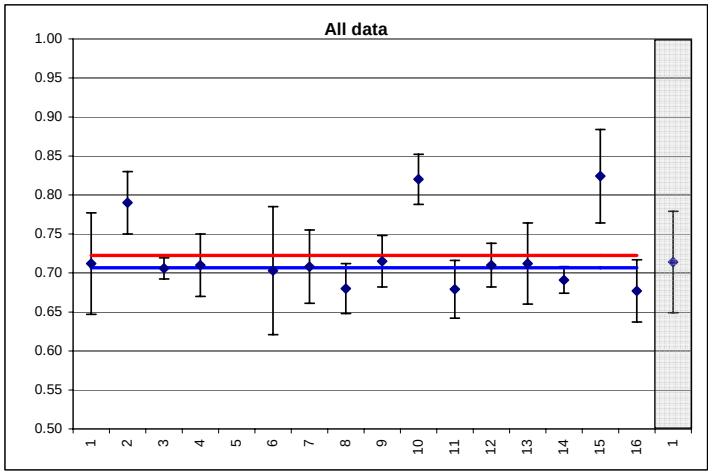
Submitted results: 15
Outliers removed: 2 (VMI, NMC A*Star)
Final population size: 13
Key Comparison Reference Value: *Rz* = 1.452 µm ± 0.013 µm
After outliers are removed, the CMS E_n was 1.05 but remained in the accepted values since the Birge ratio was less than the Birge limit. If CMS was removed also, the final KCRV would change by +0.013 µm.

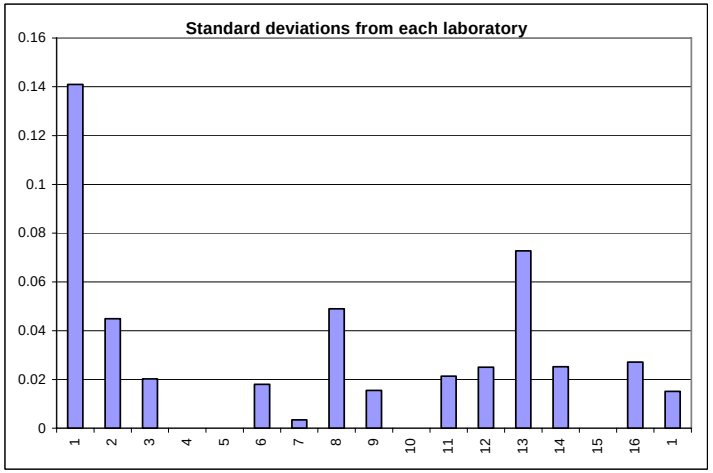
S/N 5276 *Rp* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$\frac{}{u^{-c}(x_i)}$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**0.7120**	0.1410	0.0650	2.00	12	**0.0325**	1.1E-03	674	947	0.03	0.16	**0.08**	
Singapore	NMC	08/08	2	**0.7900**	0.0449	0.0400	2.00	12	**0.0200**	4.0E-04	1975	2500	17.39	1.62	**2.05**	
UK	NPL	09/08	3	**0.7058**	0.0203	0.0135	2.28	12	**0.0059**	3.5E-05	20132	28523	0.02	0.92	**0.05**	
Germany	PTB	10/08	4	**0.7100**		0.0400	2.00	12	**0.0200**	4.0E-04	1775	2500	0.03	0.30	**0.08**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**0.7030**	0.0180	0.0820	2.00	12	**0.0410**	1.7E-03	418	595	0.01	0.23	**0.04**	
Japan	NMIJ	01/09	7	**0.7080**	0.0034	0.0470	2.00	12	**0.0235**	5.5E-04	1282	1811	0.00	0.30	**0.03**	
South Korea	KRISS	04/09	8	**0.6800**	0.0490	0.0320	2.20	12	**0.0145**	2.1E-04	3214	4727	3.35	1.24	**0.81**	
USA	NIST	06/09	9	**0.7150**	0.0155	0.0330	2.00	12	**0.0165**	2.7E-04	2626	3673	0.26	0.21	**0.25**	
India	NPLI	07/09	10	**0.8200**		0.0320	1.00	12	**0.0320**	1.0E-03	801	977	12.56	2.85	**3.45**	***Worst***
South Africa	NMISA	09/09	11	**0.6790**	0.0214	0.0370	2.00	13	**0.0185**	3.4E-04	1984	2922	2.23	1.12	**0.73**	
Egypt	NIS	10/09	12	**0.7100**	0.0250	0.0280	2.00	12	**0.0140**	2.0E-04	3622	5102	0.06	0.41	**0.12**	
China	NIM	11/09	13	**0.7120**	0.0727	0.0520	1.96	12	**0.0265**	7.0E-04	1012	1421	0.04	0.20	**0.10**	
Ch Teipei	CMS	01/10	14	**0.6910**	0.0252	0.0170	2.00	12	**0.0085**	7.2E-05	9564	13841	3.37	1.51	**0.84**	
Vietnam	VMI	03/10	15	**0.8240**		0.0600	2.00	12	**0.0300**	9.0E-04	916	1111	15.31	1.66	**1.94**	
Indonesia	KIM-LIPI	04/10	16	**0.6770**	0.0271	0.0400	2.00	60	**0.0200**	4.0E-04	1693	2500	2.19	1.09	**0.73**	
Australia rpt	NMIA	06/10	1	**0.7140**	0.0151	0.0650	2.00	12	**0.0325**	1.1E-03	676	947	0.052	0.13	**0.11**	
		Count		**15**						0.00825	51687.3	73148.6	56.84	*2.85*	***3.45***	= *Max*
		St Deviation		0.0482											***2.01***	= R_B
		ESDM		0.0125											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**0.722**	0.0061	2.00	**0.0121**	1.7
Weighted	**0.707**	0.0037	2.00	**0.0074**	1.0

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rp* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NMIA has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.02.

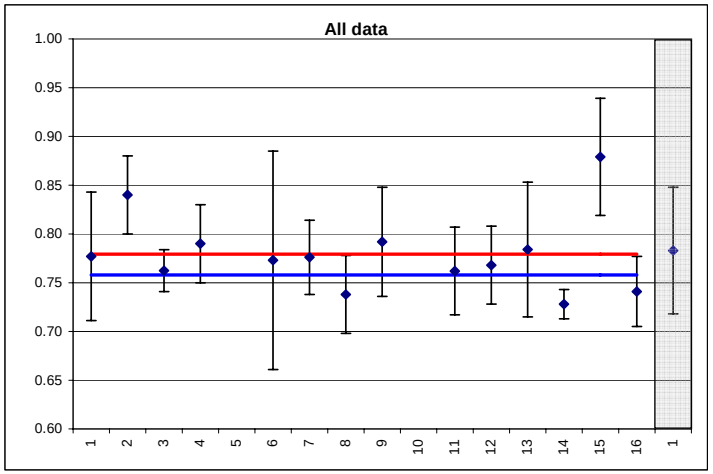
Submitted results: 15
Outliers removed: 3 (NPLI, NMC A*Star, VMI)
Final population size: 12
Key Comparison Reference Value: *Rp* = 0.700 µm ± 0.008 µm

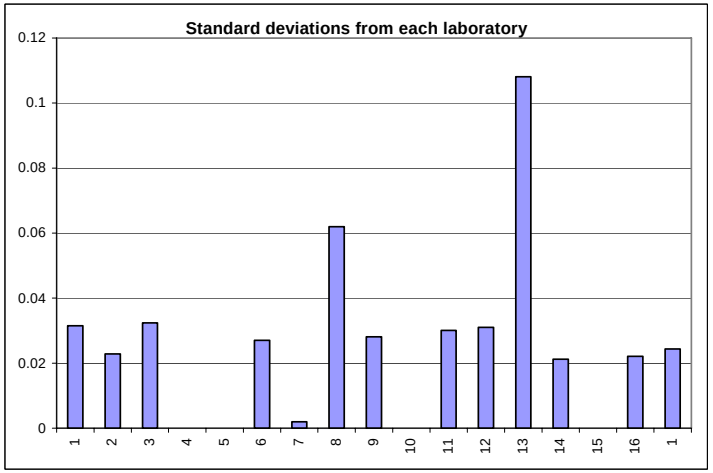
S/N 5276 *Rv* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**0.7770**	0.0315	0.0660	2.00	12	**0.0330**	1.1E-03	713	918	0.34	0.03	**0.29**	
Singapore	NMC	08/08	2	**0.8400**	0.0228	0.0400	2.00	12	**0.0200**	4.0E-04	2100	2500	16.88	1.43	**2.01**	***Worst***
UK	NPL	09/08	3	**0.7623**	0.0324	0.0214	2.28	12	**0.0094**	8.8E-05	8653	11351	0.23	0.66	**0.19**	
Germany	PTB	10/08	4	**0.7900**		0.0400	2.00	12	**0.0200**	4.0E-04	1975	2500	2.59	0.25	**0.79**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**0.7730**	0.0270	0.1120	2.00	12	**0.0560**	3.1E-03	246	319	0.07	0.06	**0.14**	
Japan	NMIJ	01/09	7	**0.7760**	0.0020	0.0380	2.00	12	**0.0190**	3.6E-04	2150	2770	0.91	0.08	**0.47**	
South Korea	KRISS	04/09	8	**0.7380**	0.0620	0.0400	2.20	12	**0.0182**	3.3E-04	2232	3025	1.19	0.97	**0.48**	
USA	NIST	06/09	9	**0.7920**	0.0281	0.0560	2.00	12	**0.0280**	7.8E-04	1010	1276	1.49	0.22	**0.60**	
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11	**0.7620**	0.0301	0.0450	2.00	13	**0.0225**	5.1E-04	1505	1975	0.03	0.37	**0.09**	
Egypt	NIS	10/09	12	**0.7680**	0.0310	0.0400	2.00	12	**0.0200**	4.0E-04	1920	2500	0.26	0.27	**0.25**	
China	NIM	11/09	13	**0.7840**	0.1081	0.0690	1.96	12	**0.0352**	1.2E-03	633	807	0.55	0.07	**0.38**	
Ch Teipei	CMS	01/10	14	**0.7280**	0.0212	0.0150	2.00	12	**0.0075**	5.6E-05	12942	17778	15.82	2.48	**1.72**	
Vietnam	VMI	03/10	15	**0.8790**		0.0600	2.00	12	**0.0300**	9.0E-04	977	1111	16.31	1.62	**2.00**	
Indonesia	KIM-LIPI	04/10	16	**0.7410**	0.0221	0.0360	2.00	60	**0.0180**	3.2E-04	2287	3086	0.87	0.99	**0.45**	
Australia rpt	NMIA	06/10	1	**0.7830**	0.0244	0.0650	2.00	12	**0.0325**	1.1E-03	741	947	0.600	0.06	**0.38**	
		Count		**14**						0.01001	39344	51916.5	57.55	*2.48*	***2.01***	= *Max*
		St Deviation		0.0397											***2.10***	= R_B
		ESDM		0.0106											***1.34***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**0.779**	0.0071	2.00	**0.0143**	1.8
Weighted	**0.758**	0.0044	2.00	**0.0088**	1.2

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rv* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NIM has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.06.

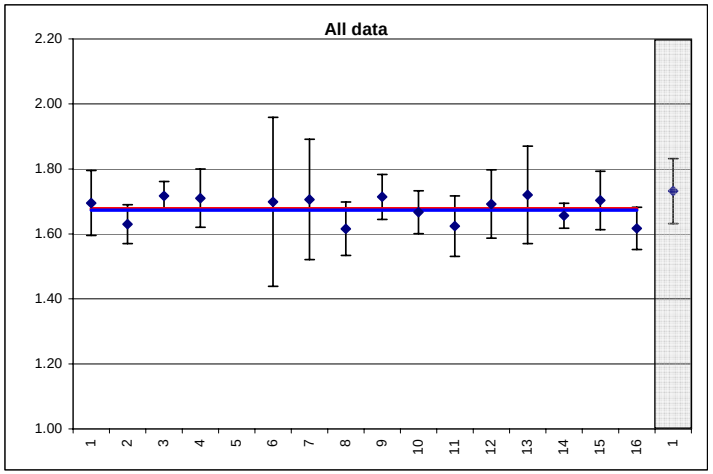
Submitted results: 14
Outliers removed: 3 (NMC A*Star, VMI, CMS)
Final population size: 11
Key Comparison Reference Value: *Rv* = 0.764 µm ± 0.012 µm

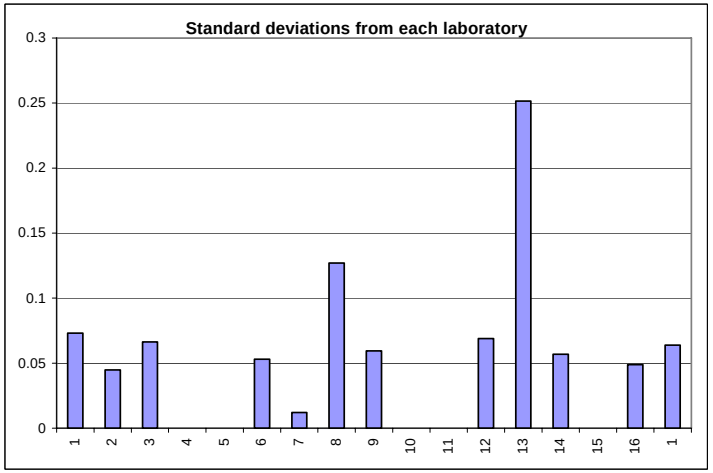
S/N 5276 *Rt* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**1.695**	0.0731	0.100	2.00	12	**0.0500**	2.5E-03	678	400	0.19	0.17	**0.21**	
Singapore	NMC	08/08	2	**1.630**	0.0449	0.060	2.00	12	**0.0300**	9.0E-04	1811	1111	2.07	0.71	**0.69**	
UK	NPL	09/08	3	**1.717**	0.0663	0.044	2.28	12	**0.0193**	3.7E-04	4610	2685	5.16	0.73	**0.92**	***Worst***
Germany	PTB	10/08	4	**1.710**		0.090	2.00	12	**0.0450**	2.0E-03	844	494	0.67	0.34	**0.40**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**1.699**	0.0530	0.260	2.00	12	**0.1300**	1.7E-02	101	59	0.04	0.08	**0.10**	
Japan	NMIJ	01/09	7	**1.706**	0.0121	0.185	2.00	12	**0.0925**	8.6E-03	199	117	0.13	0.15	**0.18**	
South Korea	KRISS	04/09	8	**1.616**	0.1270	0.082	2.20	12	**0.0373**	1.4E-03	1163	720	2.35	0.71	**0.68**	
USA	NIST	06/09	9	**1.714**	0.0594	0.069	2.00	12	**0.0345**	1.2E-03	1440	840	1.40	0.48	**0.57**	
India	NPLI	07/09	10	**1.667**		0.066	1.00	12	**0.0660**	4.4E-03	383	230	0.01	0.15	**0.09**	
South Africa	NMISA	09/09	11	**1.624**		0.093	2.00	13	**0.0465**	2.2E-03	751	462	1.12	0.55	**0.52**	
Egypt	NIS	10/09	12	**1.692**	0.0690	0.105	2.00	12	**0.0525**	2.8E-03	614	363	0.13	0.13	**0.18**	
China	NIM	11/09	13	**1.720**	0.2515	0.150	1.96	12	**0.0765**	5.9E-03	294	171	0.37	0.28	**0.31**	
Ch Teipei	CMS	01/10	14	**1.656**	0.0570	0.038	2.00	12	**0.0190**	3.6E-04	4587	2770	0.82	0.45	**0.41**	
Vietnam	VMI	03/10	15	**1.703**		0.090	2.00	12	**0.0450**	2.0E-03	841	494	0.44	0.27	**0.32**	
Indonesia	KIM-LIPI	04/10	16	**1.617**	0.0489	0.065	2.00	60	**0.0325**	1.1E-03	1531	947	2.99	0.85	**0.83**	
Australia rpt	NMIA	06/10	1	**1.732**	0.0638	0.100	2.00	12	**0.0500**	2.5E-03	693	400	1.385	0.52	**0.58**	
		Count		**15**						0.05241	19847.5	11862.3	17.88	*0.85*	***0.92***	= *Max*
		St Deviation		0.0390											***1.13***	= R_B
		ESDM		0.0101											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**1.678**	0.0153	2.00	**0.0305**	1.8
Weighted	**1.673**	0.0092	2.00	**0.0184**	1.1

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rt* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NIM has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.26.

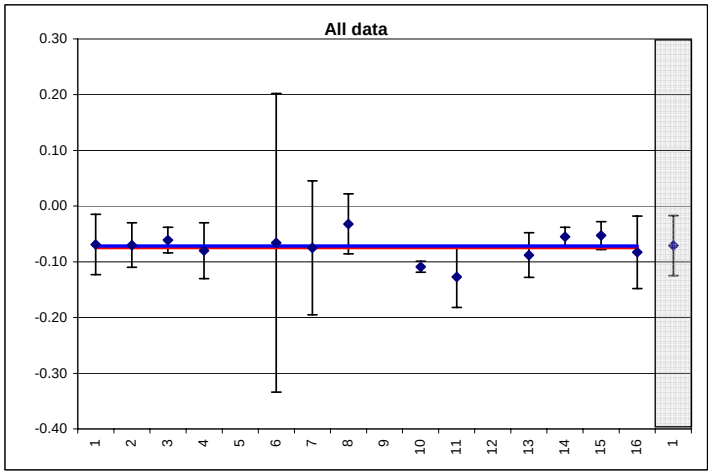
Submitted results: 15
Outliers removed: 0
Final population size: 15
Key Comparison Reference Value: *Rt* = 1.673 µm ± 0.019 µm

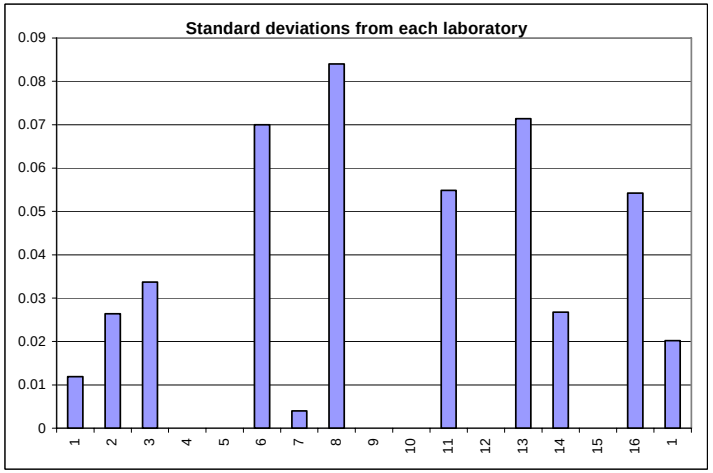
S/N 5276 *Rsk* **All data**

Country	Lab	Date	No.	x_i dimensionless	st dev	$U_{95\%}$	k	n	$u(x_i)$	Mean and uncertainty calculations: $u^c(x_i)$	$\frac{xi}{u^c(x_i)}$	$u^{-c}(x_i)$	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio* En Arithm	En Weighted	Reject
Australia	NMIA	07/08	1	**-0.069**	0.0119	0.054	2.00	11	**0.0270**	7.3E-04	-95	1372	0.01	0.09	**0.04**	
Singapore	NMC	08/08	2	**-0.070**	0.0264	0.040	2.00	12	**0.0200**	4.0E-04	-175	2500	0.00	0.09	**0.03**	
UK	NPL	09/08	3	**-0.061**	0.0337	0.023	2.23	12	**0.0103**	1.1E-04	-573	9401	1.02	0.40	**0.42**	
Germany	PTB	10/08	4	**-0.080**		0.050	2.00	12	**0.0250**	6.3E-04	-128	1600	0.12	0.10	**0.17**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**-0.066**	0.0700	0.268	2.00	12	**0.1340**	1.8E-02	-4	56	0.00	0.03	**0.02**	
Japan	NMIJ	01/09	7	**-0.075**	0.0040	0.120	2.00	12	**0.0600**	3.6E-03	-21	278	0.00	0.00	**0.03**	
South Korea	KRISS	04/09	8	**-0.032**	0.0840	0.054	2.20	12	**0.0245**	6.0E-04	-53	1660	2.58	0.71	**0.72**	
USA	NIST	06/09	9													
India	NPLI	07/09	10	**-0.109**		0.010	1.00	12	**0.0100**	1.0E-04	-1090	10000	14.14	1.28	**2.82**	***Worst***
South Africa	NMISA	09/09	11	**-0.127**	0.0549	0.055	2.00	13	**0.0275**	7.6E-04	-168	1322	4.09	0.87	**1.00**	
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**-0.088**	0.0714	0.040	1.96	12	**0.0204**	4.2E-04	-211	2401	0.66	0.29	**0.41**	
Ch Teipei	CMS	01/10	14	**-0.055**	0.0267	0.017	2.00	12	**0.0085**	7.2E-05	-761	13841	3.72	0.64	**0.86**	
Vietnam	VMI	03/10	15	**-0.053**		0.025	2.00	12	**0.0125**	1.6E-04	-339	6400	2.17	0.61	**0.69**	
Indonesia	KIM-LIPI	04/10	16	**-0.083**	0.0542	0.065	2.00	60	**0.0325**	1.1E-03	-79	947	0.13	0.12	**0.18**	
Australia rpt	NMIA	06/10	1	**-0.071**	0.0202	0.054	2.00	12	**0.0270**	7.3E-04	-97	1372	0.000	0.06	**0.01**	
		Count		**13**						0.02658	-3697	51776.5	28.63	*1.28*	***2.82***	*= Max*
		St Deviation		0.0245											***1.54***	*= R_B*
		ESDM		0.0068											***1.35***	*= R_B lim*

	Mean	u_{st}	k	U_{exp}	
	µm	µm		µm	%
Arithmetic	**-0.074**	0.0125	2.00	**0.0251**	-33.7
Weighted	**-0.071**	0.0044	2.00	**0.0088**	-12.3

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rsk* results:
SCL, NIST and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
No standard deviation is unique.
Comparison of initial and final NMIA result is E_n = -0.03.

Submitted results: 13
Outliers removed: 1 (NPLI)
Final population size: 12
Key Comparison Reference Value: *Rsk* = -0.062 ± 0.010
After outliers are removed, the NMISA E_n was 1.2 but remained in the accepted values since the Birge ratio was less than the Birge limit. If NMISA was removed also, the final KCRV would change by +0.002.

S/N 5276 *Rku*

All data

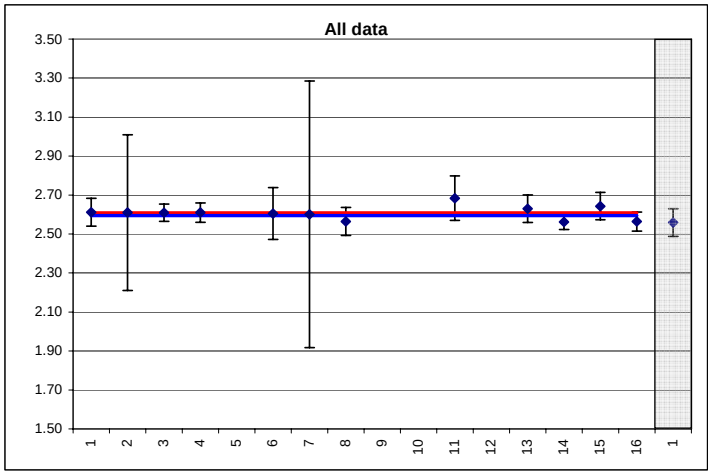
Country	Lab	Date	No.	x_i dimensionless	st dev	$U_{95\%}$	k	n	$u(x_i)$	$u^c(x_i)$	$\frac{xi}{u^c(x_i)}$	$u^{-c}(x_i)$	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**2.612**	0.0378	0.071	2.00	12	**0.0355**	1.3E-03	2073	793	0.25	0.04	**0.24**	
Singapore	NMC	08/08	2	**2.610**	0.0325	0.400	2.00	12	**0.2000**	4.0E-02	65	25	0.01	0.01	**0.04**	
UK	NPL	09/08	3	**2.609**	0.0560	0.044	2.09	12	**0.0211**	4.4E-04	5887	2256	0.48	0.01	**0.31**	
Germany	PTB	10/08	4	**2.610**		0.050	2.00	12	**0.0250**	6.3E-04	4176	1600	0.39	0.03	**0.29**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**2.605**	0.0330	0.133	2.00	12	**0.0665**	4.4E-03	589	226	0.03	0.02	**0.08**	
Japan	NMIJ	01/09	7	**2.601**	0.0250	0.684	2.00	12	**0.3420**	1.2E-01	22	9	0.00	0.01	**0.01**	
South Korea	KRISS	04/09	8	**2.564**	0.1060	0.072	2.20	12	**0.0327**	1.1E-03	2394	934	0.86	0.44	**0.41**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11	**2.684**	0.0697	0.114	2.00	13	**0.0570**	3.2E-03	826	308	2.47	0.57	**0.78**	***Worst***
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**2.630**	0.1257	0.071	1.96	12	**0.0362**	1.3E-03	2004	762	0.96	0.22	**0.49**	
Ch Teipei	CMS	01/10	14	**2.562**	0.0339	0.038	2.00	12	**0.0190**	3.6E-04	7097	2770	2.91	0.58	**0.77**	
Vietnam	VMI	03/10	15	**2.643**		0.070	2.00	12	**0.0350**	1.2E-03	2158	816	1.93	0.36	**0.67**	
Indonesia	KIM-LIPI	04/10	16	**2.564**	0.0188	0.049	2.00	60	**0.0245**	6.0E-04	4272	1666	1.54	0.52	**0.58**	
Australia rpt	NMIA	06/10	1	**2.559**	0.0271	0.071	2.00	12	**0.0355**	1.3E-03	2031	793	0.996	0.49	**0.48**	
		Count		**12**						0.17153	31562	12165.3	11.82	*0.58*	***0.78***	= *Max*
		St Deviation		0.0351											***1.04***	= R_B
		ESDM		0.0101											***1.36***	= R_B *lim*

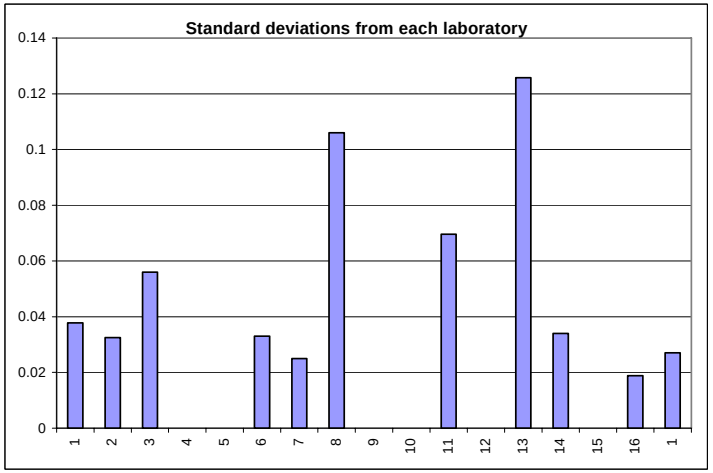
Mean and uncertainty calculations

En & Birge ratio

	Mean	u_{st}	k	U_{exp}	
	µm	µm		µm	%
Arithmetic	**2.608**	0.0345	2.00	**0.0690**	2.6
Weighted	**2.594**	0.0091	2.00	**0.0181**	0.7

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rku* results:
SCL, NIST, NPLI and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS and NIM have higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = -0.53.

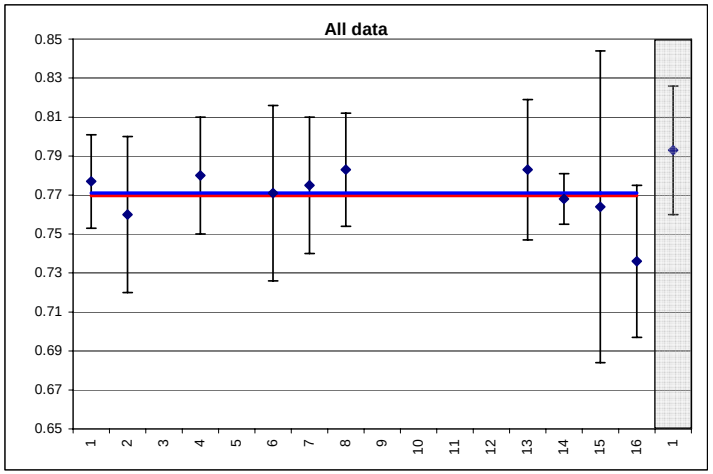
Submitted results: 12
Outliers removed: 0
Final population size: 12
Key Comparison Reference Value: *Rku* = 2.594 ± 0.018

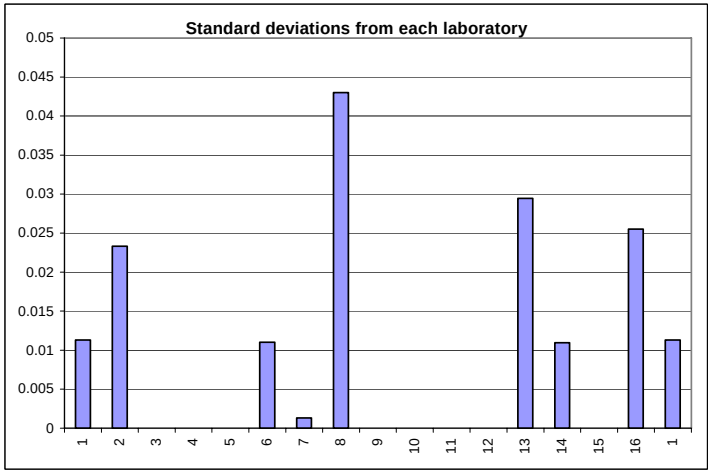
S/N 5276 *Rk* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**0.777**	0.0113	0.024	2.00	12	**0.0120**	1.4E-04	5396	6944	0.24	0.27	**0.23**	
Singapore	NMC	08/08	2	**0.760**	0.0233	0.040	2.00	12	**0.0200**	4.0E-04	1900	2500	0.31	0.23	**0.27**	
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**0.780**		0.030	2.00	12	**0.0150**	2.3E-04	3467	4444	0.35	0.32	**0.29**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**0.771**	0.0110	0.045	2.00	12	**0.0225**	5.1E-04	1523	1975	0.00	0.03	**0.00**	
Japan	NMIJ	01/09	7	**0.775**	0.0013	0.035	2.00	12	**0.0175**	3.1E-04	2531	3265	0.05	0.14	**0.11**	
South Korea	KRISS	04/09	8	**0.783**	0.0430	0.029	2.20	12	**0.0132**	1.7E-04	4506	5755	0.82	0.42	**0.39**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**0.783**	0.0294	0.036	1.96	12	**0.0184**	3.4E-04	2321	2964	0.42	0.35	**0.32**	
Ch Teipei	CMS	01/10	14	**0.768**	0.0110	0.013	2.00	12	**0.0065**	4.2E-05	18178	23669	0.22	0.09	**0.20**	
Vietnam	VMI	03/10	15	**0.764**		0.080	2.00	12	**0.0400**	1.6E-03	478	625	0.03	0.07	**0.09**	
Indonesia	KIM-LIPI	04/10	16	**0.736**	0.0255	0.039	2.00	60	**0.0195**	3.8E-04	1936	2630	3.24	0.82	**0.88**	***Worst***
Australia rpt	NMIA	06/10	1	**0.793**	0.0113	0.033	2.00	12	**0.0165**	2.7E-04	2913	3673	1.765	0.66	**0.64**	
		Count		**10**						0.00412	42233.8	54772.2	5.69	*0.82*	***0.88***	= *Max*
		St Deviation		0.0142											***0.79***	= R_B
		ESDM		0.0045											***1.39***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	0.770	0.0064	2.00	0.0128	1.7
Weighted	0.771	0.0043	2.00	0.0085	1.1

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rk* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS has a higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.39.

Submitted results: 10
Outliers removed: 0
Final population size: 10
Key Comparison Reference Value: *Rk* = 0.771 µm ± 0.009 µm

S/N 5276 *Rpk*

All data

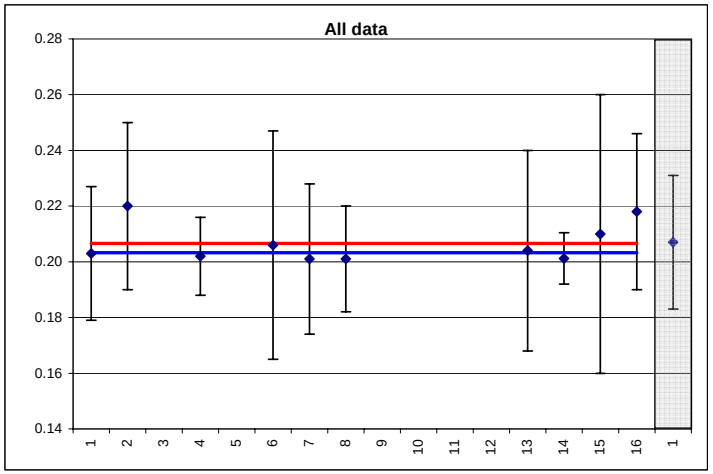
Country	Lab	Date	No.	x_i	st dev	$U_{95\%}$	k	n	$u(x_i)$	$u^c(x_i)$	$\frac{xi}{u^c(x_i)}$	$u^{-c}(x_i)$	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En* Arithm	*En* Weighted	*Reject*
				µm	µm	µm			µm	µm^2	µm^{-1}	µm^{-2}				
Australia	NMIA	07/08	1	**0.2030**	0.0074	0.024	2.00	12	**0.0120**	1.4E-04	1410	6944	0.00	0.14	**0.01**	
Singapore	NMC	08/08	2	**0.2200**	0.0119	0.030	2.00	12	**0.0150**	2.3E-04	978	4444	1.24	0.43	**0.55**	***Worst***
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**0.2020**		0.014	2.00	12	**0.0070**	4.9E-05	4122	20408	0.03	0.27	**0.08**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**0.2060**	0.0080	0.041	2.00	12	**0.0205**	4.2E-04	490	2380	0.02	0.01	**0.07**	
Japan	NMIJ	01/09	7	**0.2010**	0.0021	0.027	2.00	12	**0.0135**	1.8E-04	1103	5487	0.03	0.20	**0.08**	
South Korea	KRISS	04/09	8	**0.2010**	0.0280	0.019	2.20	12	**0.0086**	7.5E-05	2695	13407	0.07	0.26	**0.11**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**0.2040**	0.0305	0.036	1.96	12	**0.0184**	3.4E-04	605	2964	0.00	0.07	**0.02**	
Ch Teipei	CMS	01/10	14	**0.2012**	0.0122	0.009	2.00	12	**0.0046**	2.1E-05	9509	47259	0.20	0.41	**0.19**	
Vietnam	VMI	03/10	15	**0.2100**		0.050	2.00	12	**0.0250**	6.3E-04	336	1600	0.07	0.07	**0.13**	
Indonesia	KIM-LIPI	04/10	16	**0.2180**	0.0123	0.028	2.00	60	**0.0140**	2.0E-04	1112	5102	1.11	0.38	**0.51**	
Australia rpt	NMIA	06/10	1	**0.2070**	0.0087	0.024	2.00	12	**0.0120**	1.4E-04	1438	6944	0.096	0.01	**0.15**	
		Count		**10**						0.00227	22359.3	109996	2.78	*0.43*	***0.55***	= *Max*
		St Deviation		0.0071											***0.56***	= R_B
		ESDM		0.0022											***1.39***	= R_B *lim*

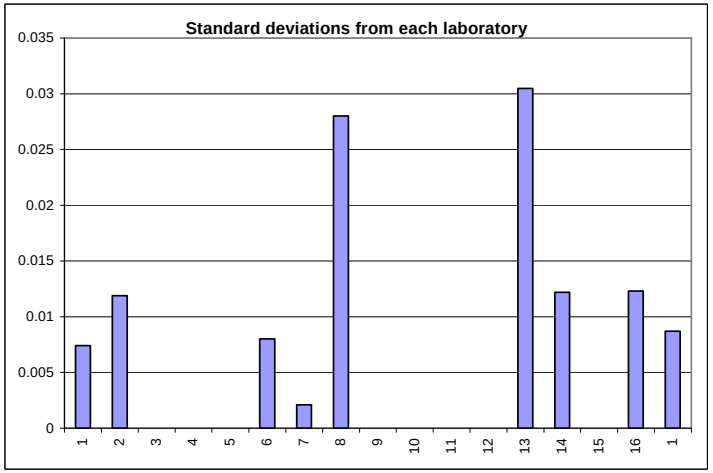
Mean and uncertainty calculations

En & Birge ratio

	Mean	u_{st}	k	U_{exp}	
	µm	µm		µm	%
Arithmetic	**0.207**	0.0048	2.00	**0.0095**	4.6
Weighted	**0.203**	0.0030	2.00	**0.0060**	3.0

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rpk* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS and NIM have significantly higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.12.

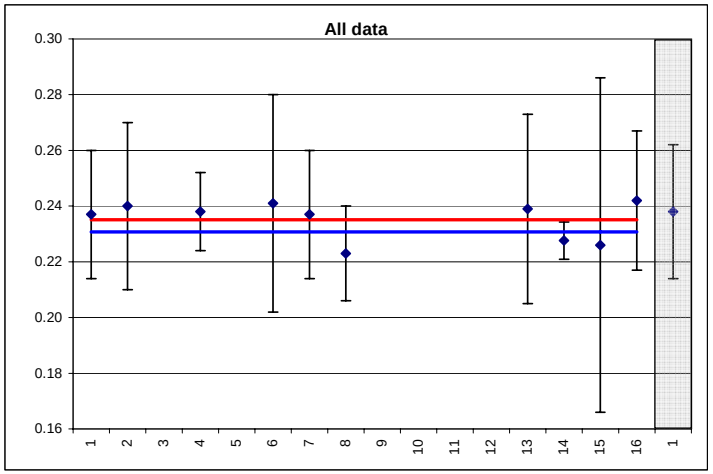
Submitted results: 10
Outliers removed: 0
Final population size: 10
Key Comparison Reference Value: *Rpk* = 0.203 µm ± 0.006 µm

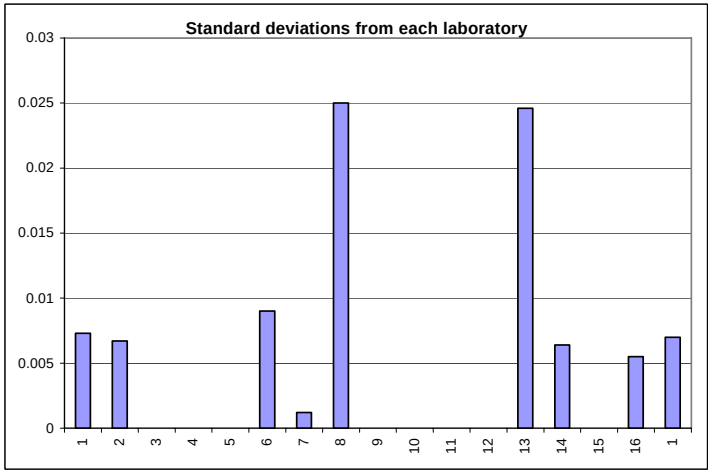
S/N 5276 *Rvk* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**0.2370**	0.0073	0.0230	2.00	12	**0.0115**	1.3E-04	1792	7561	0.30	0.08	**0.27**	
Singapore	NMC	08/08	2	**0.2400**	0.0067	0.0300	2.00	12	**0.0150**	2.3E-04	1067	4444	0.38	0.16	**0.31**	
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**0.2380**		0.0140	2.00	12	**0.0070**	4.9E-05	4857	20408	1.08	0.17	**0.49**	***Worst***
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**0.2410**	0.0090	0.0390	2.00	12	**0.0195**	3.8E-04	634	2630	0.28	0.15	**0.26**	
Japan	NMIJ	01/09	7	**0.2370**	0.0012	0.0230	2.00	12	**0.0115**	1.3E-04	1792	7561	0.30	0.08	**0.27**	
South Korea	KRISS	04/09	8	**0.2230**	0.0250	0.0170	2.20	12	**0.0077**	6.0E-05	3735	16747	1.00	0.62	**0.44**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**0.2390**	0.0246	0.0340	1.96	12	**0.0173**	3.0E-04	794	3323	0.23	0.11	**0.24**	
Ch Teipei	CMS	01/10	14	**0.2276**	0.0064	0.0067	2.00	12	**0.0034**	1.1E-05	20281	89107	0.86	0.63	**0.37**	
Vietnam	VMI	03/10	15	**0.2260**		0.0600	2.00	12	**0.0300**	9.0E-04	251	1111	0.02	0.15	**0.08**	
Indonesia	KIM-LIPI	04/10	16	**0.2420**	0.0055	0.0250	2.00	60	**0.0125**	1.6E-04	1549	6400	0.82	0.26	**0.44**	
Australia rpt	NMIA	06/10	1	**0.2380**	0.0070	0.0240	2.00	12	**0.0120**	1.4E-04	1653	6944	0.369	0.11	**0.30**	
		Count		**10**						0.00235	36751.2	159294	5.27	*0.63*	***0.49***	= *Max*
		St Deviation		0.0069											***0.77***	= R_B
		ESDM		0.0022											***1.39***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**0.235**	0.0048	2.00	**0.0097**	4.1
Weighted	**0.231**	0.0025	2.00	**0.0050**	2.2

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Rvk* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS and NIM have significantly higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.03.

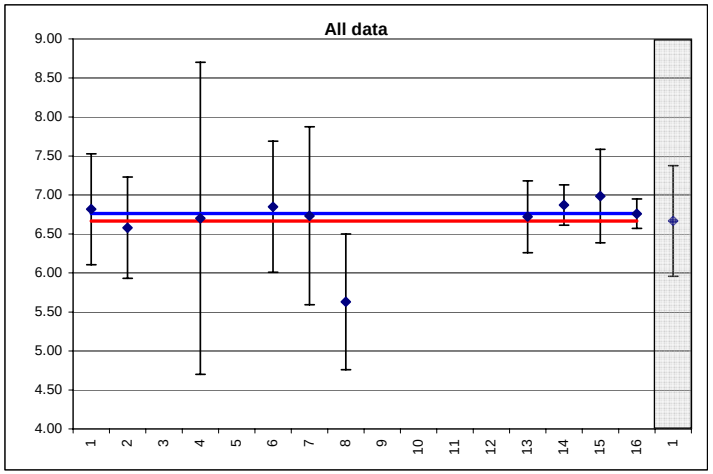
Submitted results: 10
Outliers removed: 0
Final population size: 10
Key Comparison Reference Value: *Rvk* = 0.231 µm ± 0.005 µm

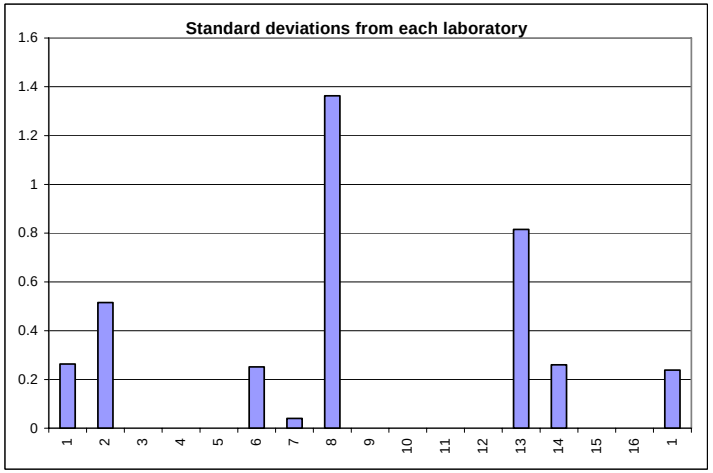
S/N 5276 ***Mr1*** **All data**

Country	Lab	Date	No.	x_i %	st dev %	$U_{95\%}$ %	k	n	$u(x_i)$ %	Mean and uncertainty calculations: $u^c(x_i)$ μm^2	$\frac{xi}{u^c(x_i)}$ μm^{-1}	$u^{-c}(x_i)$ μm^{-2}	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**6.817**	0.263	0.712	2.20	12	**0.3236**	1.0E-01	65	10	0.03	0.20	**0.08**	
Singapore	NMC	08/08	2	**6.580**	0.5149	0.650	2.00	12	**0.3250**	1.1E-01	62	9	0.31	0.12	**0.27**	
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**6.700**		2.000	2.00	12	**1.0000**	1.0E+00	7	1	0.00	0.02	**0.03**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**6.848**	0.25	0.841	2.00	12	**0.4205**	1.8E-01	39	6	0.04	0.21	**0.10**	
Japan	NMIJ	01/09	7	**6.733**	0.04	1.141	2.00	12	**0.5705**	3.3E-01	21	3	0.00	0.06	**0.02**	
South Korea	KRISS	04/09	8	**5.630**	1.36	0.870	2.20	12	**0.3955**	1.6E-01	36	6	8.18	1.13	**1.29**	***Worst***
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**6.720**	0.8151	0.460	1.96	12	**0.2347**	5.5E-02	122	18	0.03	0.10	**0.09**	
Ch Teipei	CMS	01/10	14	**6.870**	0.2600	0.260	2.00	12	**0.1300**	1.7E-02	407	59	0.70	0.53	**0.37**	
Vietnam	VMI	03/10	15	**6.985**		0.600	2.00	12	**0.3000**	9.0E-02	78	11	0.56	0.48	**0.36**	
Indonesia	KIM-LIPI	04/10	16	**6.760**		0.190	2.00	60	**0.0950**	9.0E-03	749	111	0.00	0.28	**0.00**	
Australia rpt	NMIA	06/10	1	**6.667**	0.24	0.709	2.00	12	**0.3545**	1.3E-01	53	8	0.070	0.00	**0.13**	
		Count		**10**						2.04005	1584.65	234.378	9.86	*1.13*	***1.29***	= *Max*
		St Deviation		0.3797											***1.05***	= R_B
		ESDM		0.1201											***1.39***	= R_B *lim*

	Mean μm	u_{st} μm	k	U_{exp} μm	%
Arithmetic	**6.664**	0.1428	2.00	**0.2857**	4.3
Weighted	**6.761**	0.0653	2.00	**0.1306**	1.9

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Mr1* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS have significantly higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = -0.15.

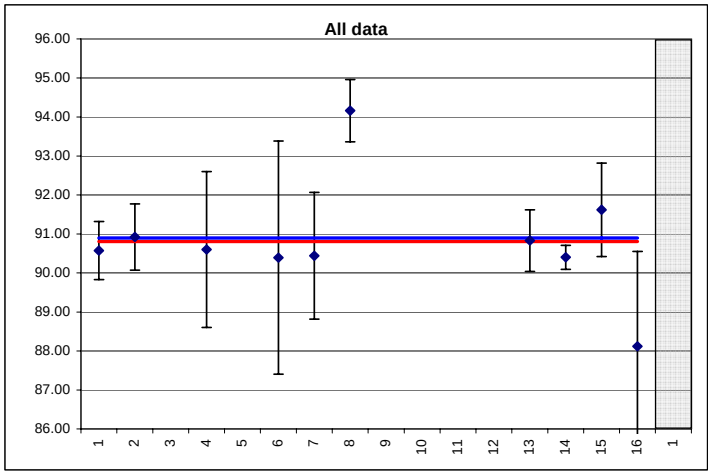
Submitted results: 10
Outliers removed: 0
Final population size: 10
Key Comparison Reference Value: *Mr1* = 6.76% ± 0.13%
After outliers are removed, the South Korea E_n was 1.29 but remained in the accepted values since the Birge ratio was less than the Birge limit. If South Korea was removed, the final KCRV would change by +0.06%.

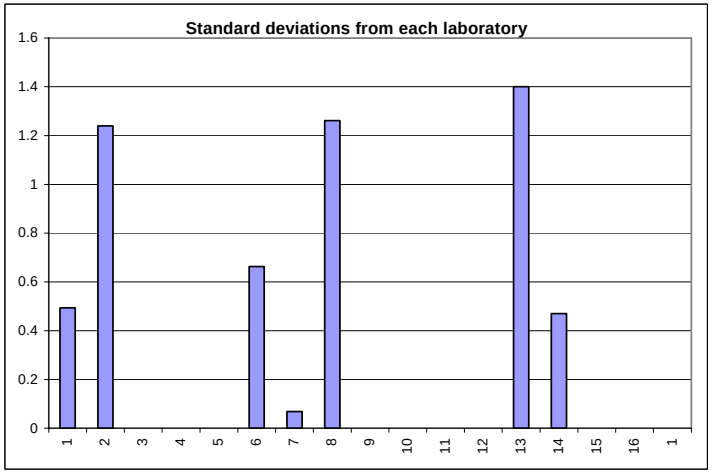
S/N 5276 ***Mr2*** **All data**

Country	Lab	Date	No.	x_i %	st dev %	$U_{95\%}$ %	k	n	$u(x_i)$ %	Mean and uncertainty calculations: $u^c(x_i)$ μm^2	$\frac{xi}{u^c(x_i)}$ μm^{-1}	$u^{-c}(x_i)$ μm^{-2}	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**90.575**	0.494	0.745	2.20	12	**0.3386**	1.1E-01	790	9	0.89	0.26	**0.41**	
Singapore	NMC	08/08	2	**90.920**	1.240	0.850	2.18	12	**0.3899**	1.5E-01	598	7	0.00	0.12	**0.03**	
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**90.600**		2.000	2.00	12	**1.0000**	1.0E+00	91	1	0.09	0.10	**0.15**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**90.393**	0.66	2.988	2.00	12	**1.4940**	2.2E+00	40	0	0.11	0.14	**0.17**	
Japan	NMIJ	01/09	7	**90.439**	0.07	1.623	2.00	12	**0.8115**	6.6E-01	137	2	0.32	0.22	**0.28**	
South Korea	KRISS	04/09	8	**94.160**	1.26	0.800	2.20	12	**0.3636**	1.3E-01	712	8	80.63	3.55	**3.93**	***Worst***
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**90.830**	1.3998	0.790	1.96	12	**0.4031**	1.6E-01	559	6	0.03	0.03	**0.08**	
Ch Teipei	CMS	01/10	14	**90.400**	0.4700	0.310	2.00	12	**0.1550**	2.4E-02	3763	42	10.19	0.69	**1.29**	
Vietnam	VMI	03/10	15	**91.617**		1.200	2.00	12	**0.6000**	3.6E-01	254	3	1.45	0.62	**0.59**	
Indonesia	KIM-LIPI	04/10	16	**88.120**		2.430	2.00	60	**1.2150**	1.5E+00	60	1	5.22	1.08	**1.14**	
Australia rpt	NMIA	06/10	1													
		Count		**10**						6.31221	7004.44	77.061	98.92	*3.55*	***3.93***	= *Max*
		St Deviation		1.4795											***3.32***	= R_B
		ESDM		0.4679											***1.39***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**90.805**	0.2512	2.00	**0.5025**	0.6
Weighted	**90.895**	0.1139	2.00	**0.2278**	0.3

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5276 *Mr2* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
NIM, KRISS and NMC A*Star have significantly higher standard deviations than any other laboratory.
The final NMIA result was not recorded so no E_n was calculated.

Submitted results: 10
Outliers removed: 1 (South Korea)
Final population size: 9
Key Comparison Reference Value: *Mr2* = 90.54% ± 0.24%
After outliers are removed, the Indonesia E_n was 0.99 and the Vietnam E_n was 0.88.

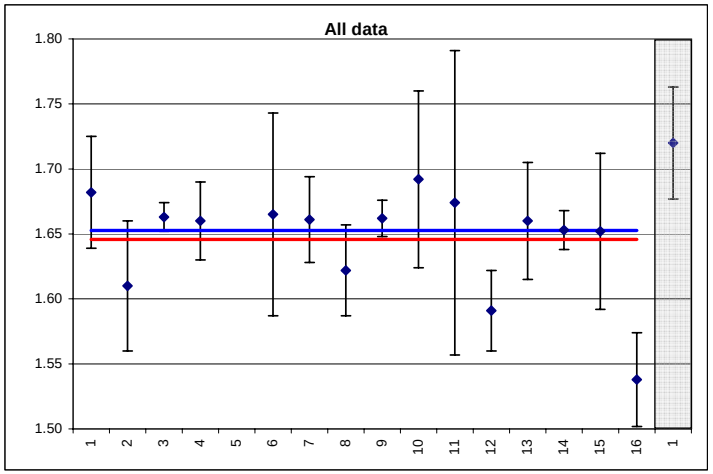
S/N 5256 *Ra*

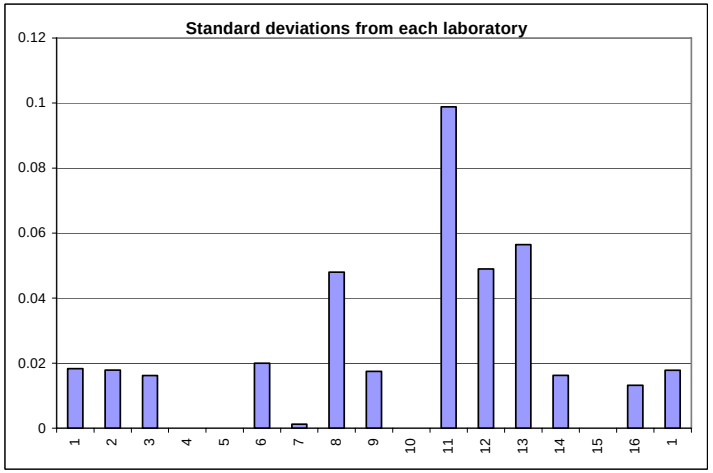
All data

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**1.682**	0.0183	0.043	2.00	12	**0.0215**	4.6E-04	3639	2163	1.86	0.79	**0.67**	
Singapore	NMC	08/08	2	**1.610**	0.0179	0.050	2.00	12	**0.0250**	6.3E-04	2576	1600	2.92	0.68	**0.85**	
UK	NPL	09/08	3	**1.663**	0.0162	0.011	2.28	12	**0.0048**	2.3E-05	71446	42962	4.56	0.91	**0.82**	
Germany	PTB	10/08	4	**1.660**		0.030	2.00	12	**0.0150**	2.3E-04	7378	4444	0.24	0.42	**0.24**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**1.665**	0.0200	0.078	2.00	12	**0.0390**	1.5E-03	1095	657	0.10	0.24	**0.16**	
Japan	NMIJ	01/09	7	**1.661**	0.0012	0.033	2.00	12	**0.0165**	2.7E-04	6101	3673	0.25	0.42	**0.25**	
South Korea	KRISS	04/09	8	**1.622**	0.0480	0.035	2.20	12	**0.0159**	2.5E-04	6409	3951	3.72	0.62	**0.86**	
USA	NIST	06/09	9	**1.662**	0.0175	0.014	2.00	12	**0.0070**	4.9E-05	33918	20408	1.77	0.78	**0.61**	
India	NPLI	07/09	10	**1.692**		0.068	1.00	12	**0.0680**	4.6E-03	366	216	0.33	0.66	**0.58**	
South Africa	NMISA	09/09	11	**1.674**	0.0988	0.117	2.00	13	**0.0585**	3.4E-03	489	292	0.13	0.24	**0.18**	
Egypt	NIS	10/09	12	**1.591**	0.0490	0.031	2.00	12	**0.0155**	2.4E-04	6622	4162	15.84	1.58	**1.95**	
China	NIM	11/09	13	**1.660**	0.0565	0.045	1.96	12	**0.0230**	5.3E-04	3149	1897	0.10	0.30	**0.16**	
Ch Teipei	CMS	01/10	14	**1.653**	0.0163	0.015	2.00	12	**0.0075**	5.6E-05	29387	17778	0.00	0.34	**0.02**	
Vietnam	VMI	03/10	15	**1.652**		0.060	2.00	12	**0.0300**	9.0E-04	1836	1111	0.00	0.10	**0.01**	
Indonesia	KIM-LIPI	04/10	16	**1.538**	0.0132	0.036	2.00	60	**0.0180**	3.2E-04	4747	3086	40.60	2.75	**3.14**	***Worst***
Australia rpt	NMIA	06/10	1	**1.720**	0.0178	0.043	2.00	11	**0.0215**	4.6E-04	3721	2163	9.800	1.63	**1.55**	
		Count		**15**						0.01352	179157	108403	72.43	*2.75*	***3.14***	= *Max*
		St Deviation		0.0400											***2.27***	= R_B
		ESDM		0.0103											***1.33***	= R_B lim

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**1.646**	0.0078	2.00	**0.0155**	0.9
Weighted	**1.653**	0.0030	2.00	**0.0061**	0.4

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Ra* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NMISA has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.62.

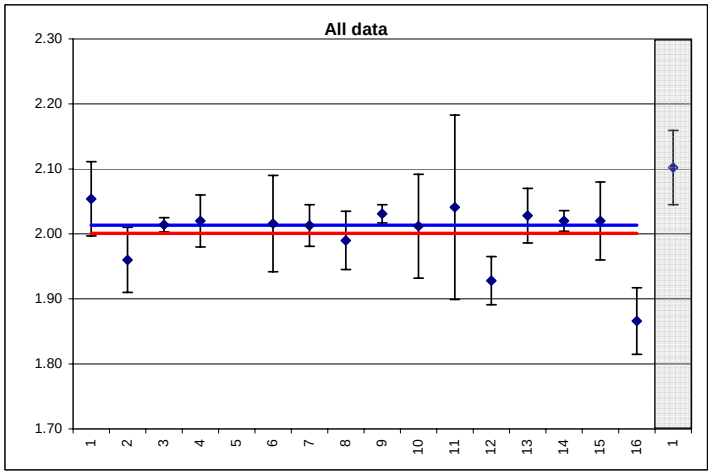
Submitted results: 15
Outliers removed: 2 (KIM-LIPI, NIS)
Final population size: 13
Key Comparison Reference Value: *Ra* = 1.659 µm ± 0.007 µm
After outliers are removed, the KRISS E_n was 1.02 but remained in the accepted values since the Birge ratio was less than the Birge limit. If KRISS was removed also, the final KCRV would change by +0.002 µm.

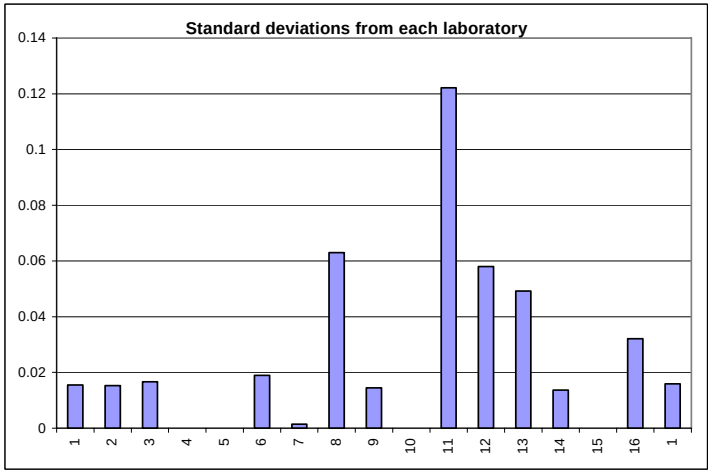
S/N 5256 *Rq* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**2.054**	0.0155	0.057	2.00	12	**0.0285**	8.1E-04	2529	1231	2.05	0.89	**0.71**	
Singapore	NMC	08/08	2	**1.960**	0.0153	0.050	2.00	12	**0.0250**	6.3E-04	3136	1600	4.53	0.77	**1.06**	
UK	NPL	09/08	3	**2.014**	0.0167	0.011	2.28	12	**0.0048**	2.3E-05	86525	42962	0.03	0.63	**0.06**	
Germany	PTB	10/08	4	**2.020**		0.040	2.00	12	**0.0200**	4.0E-04	5050	2500	0.12	0.44	**0.17**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**2.016**	0.0190	0.074	2.00	12	**0.0370**	1.4E-03	1473	730	0.01	0.20	**0.04**	
Japan	NMIJ	01/09	7	**2.013**	0.0014	0.032	2.00	12	**0.0160**	2.6E-04	7863	3906	0.00	0.33	**0.01**	
South Korea	KRISS	04/09	8	**1.990**	0.0630	0.045	2.20	12	**0.0205**	4.2E-04	4756	2390	1.29	0.22	**0.51**	
USA	NIST	06/09	9	**2.031**	0.0145	0.014	2.00	12	**0.0070**	4.9E-05	41449	20408	6.45	1.33	**1.16**	
India	NPLI	07/09	10	**2.012**		0.080	1.00	12	**0.0800**	6.4E-03	314	156	0.00	0.14	**0.02**	
South Africa	NMISA	09/09	11	**2.041**	0.1221	0.142	2.00	13	**0.0710**	5.0E-03	405	198	0.15	0.28	**0.20**	
Egypt	NIS	10/09	12	**1.928**	0.0580	0.037	2.00	12	**0.0185**	3.4E-04	5633	2922	21.22	1.77	**2.27**	
China	NIM	11/09	13	**2.028**	0.0492	0.042	1.96	12	**0.0214**	4.6E-04	4417	2178	0.48	0.59	**0.35**	
Ch Teipei	CMS	01/10	14	**2.020**	0.0137	0.016	2.00	12	**0.0080**	6.4E-05	31563	15625	0.72	0.80	**0.39**	
Vietnam	VMI	03/10	15	**2.020**		0.060	2.00	12	**0.0300**	9.0E-04	2244	1111	0.05	0.31	**0.11**	
Indonesia	KIM-LIPI	04/10	16	**1.866**	0.0321	0.051	2.00	60	**0.0255**	6.5E-04	2870	1538	33.33	2.50	**2.86**	***Worst***
Australia rpt	NMIA	06/10	1	**2.102**	0.0159	0.057	2.00	11	**0.0285**	8.1E-04	2588	1231	9.705	1.69	**1.55**	
		Count		**15**						0.01781	200227	99456.4	70.42	*2.50*	***2.86***	= *Max*
		St Deviation		0.0487											***2.24***	= R_B
		ESDM		0.0126											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**2.001**	0.0089	2.00	**0.0178**	0.9
Weighted	**2.013**	0.0032	2.00	**0.0063**	0.3

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rq* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NMISA has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.60.

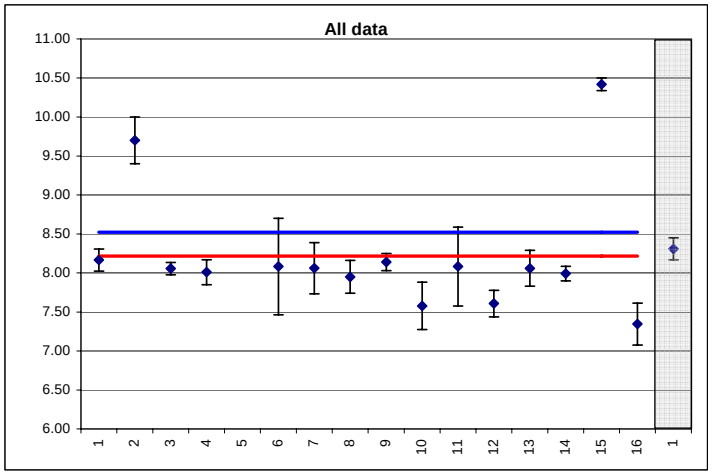
Submitted results: 15
Outliers removed: 2 (KIM-LIPI, NIS)
Final population size: 13
Key Comparison Reference Value: *Rq* = 2.018 µm ± 0.007 µm
After outliers are removed, the NMC A*Star E_n was 1.2 but remained in the accepted values since the Birge ratio was less than the Birge limit. If NMC A*Star was removed also, the final KCRV would change by only +0.001 µm.

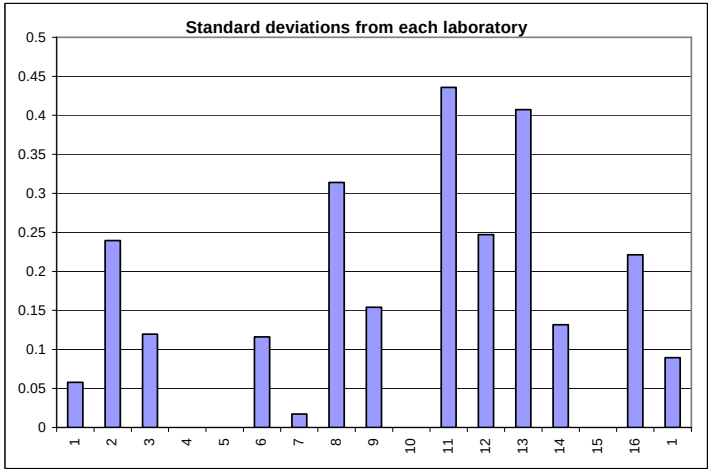
S/N 5256 *Rz* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: En Arithm	En Weighted	Reject
Australia	NMIA	07/08	1	**8.165**	0.0579	0.140	2.00	10	**0.0700**	4.9E-03	1666	204	26.18	0.32	**2.48**	
Singapore	NMC	08/08	2	**9.700**	0.2396	0.300	2.00	12	**0.1500**	2.3E-02	431	44	61.55	4.77	**3.89**	
UK	NPL	09/08	3	**8.056**	0.1196	0.079	2.28	12	**0.0346**	1.2E-03	6710	833	181.77	1.42	**5.38**	
Germany	PTB	10/08	4	**8.010**		0.160	2.00	12	**0.0800**	6.4E-03	1252	156	41.14	1.15	**3.13**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**8.083**	0.1160	0.618	2.00	12	**0.3090**	9.5E-02	85	10	2.03	0.21	**0.71**	
Japan	NMIJ	01/09	7	**8.061**	0.0172	0.328	2.00	12	**0.1640**	2.7E-02	300	37	7.94	0.46	**1.40**	
South Korea	KRISS	04/09	8	**7.950**	0.3140	0.210	2.20	12	**0.0955**	9.1E-03	873	110	36.05	1.18	**2.69**	
USA	NIST	06/09	9	**8.140**	0.1540	0.110	2.00	12	**0.0550**	3.0E-03	2691	331	48.53	0.56	**3.31**	
India	NPLI	07/09	10	**7.577**		0.304	1.00	12	**0.3040**	9.2E-02	82	11	9.69	2.03	**3.09**	
South Africa	NMISA	09/09	11	**8.082**	0.4356	0.505	2.00	13	**0.2525**	6.4E-02	127	16	3.05	0.26	**0.87**	
Egypt	NIS	10/09	12	**7.608**	0.2470	0.170	2.00	12	**0.0850**	7.2E-03	1053	138	115.92	3.23	**5.27**	
China	NIM	11/09	13	**8.060**	0.4074	0.230	1.96	12	**0.1173**	1.4E-02	585	73	15.58	0.64	**1.99**	
Ch Teipei	CMS	01/10	14	**7.991**	0.1316	0.094	2.00	12	**0.0470**	2.2E-03	3617	453	128.19	1.82	**5.29**	
Vietnam	VMI	03/10	15	**10.419**		0.080	2.00	12	**0.0400**	1.6E-03	6512	625	2246.41	19.35	**21.62**	***Worst***
Indonesia	KIM-LIPI	04/10	16	**7.345**	0.2214	0.269	2.00	60	**0.1345**	1.8E-02	406	55	76.73	3.10	**4.34**	
Australia rpt	NMIA	06/10	1	**8.309**	0.0894	0.141	2.00	10	**0.0705**	5.0E-03	1672	201	9.227	0.57	**1.47**	
		Count		**15**						0.36858	26389.4	3096.21	3000.76	*19.35*	***21.62***	= *Max*
		St Deviation		0.7961											***14.64***	= R_B
		ESDM		0.2056											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**8.216**	0.0405	2.00	**0.0809**	1.0
Weighted	**8.523**	0.0180	2.00	**0.0359**	0.4

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rz* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NMISA and NIM have higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.72.

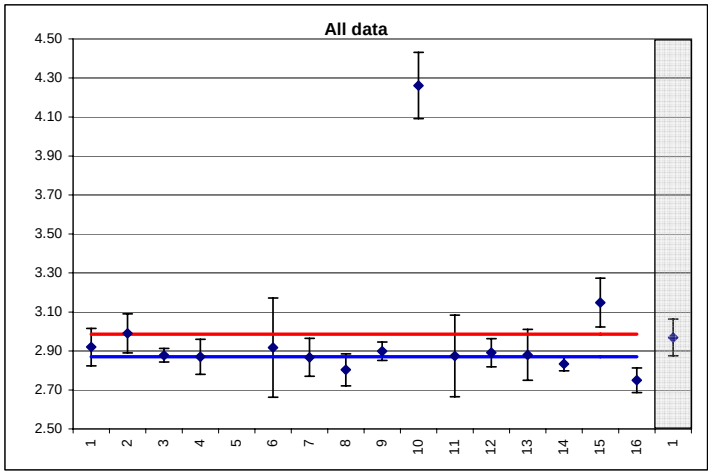
Submitted results: 15
Outliers removed: 4 (VMI, NMC A*Star, KIM-LIPI, NIS)
Final population size: 11
Key Comparison Reference Value: *Rz* = 8.055 µm ± 0.042 µm
After outliers are removed, the NPLI E_n was 1.5 but remained in the accepted values since the Birge ratio was less than the Birge limit.
If NPLI was removed also, the final KCRV would change by only +0.002 µm.

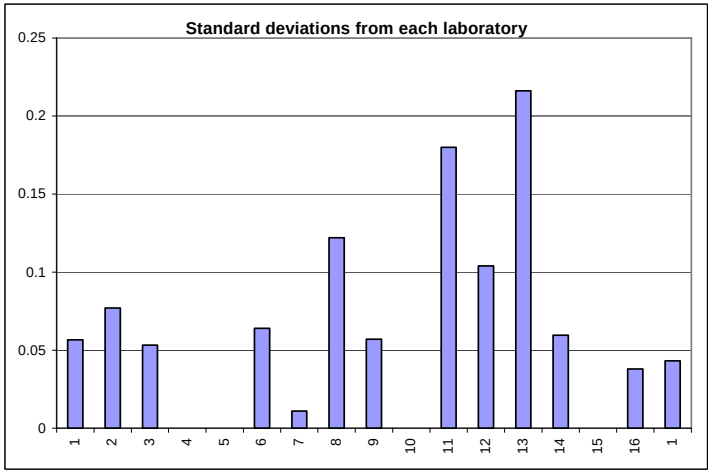
S/N 5256 *Rp* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**2.920**	0.0567	0.096	2.00	12	**0.0480**	2.3E-03	1267	434	1.07	0.64	**0.51**	
Singapore	NMC	08/08	2	**2.990**	0.0771	0.100	2.00	12	**0.0500**	2.5E-03	1196	400	5.72	0.04	**1.18**	
UK	NPL	09/08	3	**2.878**	0.0531	0.035	2.28	12	**0.0154**	2.4E-04	12213	4244	0.24	2.10	**0.20**	
Germany	PTB	10/08	4	**2.870**		0.090	2.00	12	**0.0450**	2.0E-03	1417	494	0.00	1.18	**0.00**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**2.917**	0.0640	0.254	2.00	12	**0.1270**	1.6E-02	181	62	0.13	0.27	**0.18**	
Japan	NMIJ	01/09	7	**2.867**	0.0110	0.097	2.00	12	**0.0485**	2.4E-03	1219	425	0.00	1.14	**0.03**	
South Korea	KRISS	04/09	8	**2.803**	0.1220	0.082	2.20	12	**0.0373**	1.4E-03	2018	720	3.27	2.02	**0.81**	
USA	NIST	06/09	9	**2.899**	0.0571	0.047	2.00	12	**0.0235**	5.5E-04	5249	1811	1.48	1.44	**0.57**	
India	NPLI	07/09	10	**4.261**		0.170	1.00	12	**0.1700**	2.9E-02	147	35	66.91	7.33	**8.14**	***Worst***
South Africa	NMISA	09/09	11	**2.874**	0.1800	0.209	2.00	13	**0.1045**	1.1E-02	263	92	0.00	0.52	**0.02**	
Egypt	NIS	10/09	12	**2.891**	0.1040	0.072	2.00	12	**0.0360**	1.3E-03	2231	772	0.33	1.16	**0.28**	
China	NIM	11/09	13	**2.880**	0.2162	0.130	1.96	12	**0.0663**	4.4E-03	655	227	0.02	0.78	**0.07**	
Ch Teipei	CMS	01/10	14	**2.833**	0.0596	0.035	2.00	12	**0.0175**	3.1E-04	9251	3265	4.57	2.98	**0.96**	
Vietnam	VMI	03/10	15	**3.148**		0.125	2.00	12	**0.0625**	3.9E-03	806	256	19.73	1.25	**2.20**	
Indonesia	KIM-LIPI	04/10	16	**2.750**	0.0379	0.063	2.00	60	**0.0315**	9.9E-04	2771	1008	14.61	3.22	**1.85**	
Australia rpt	NMIA	06/10	1	**2.969**	0.0431	0.094	2.00	10	**0.0470**	2.2E-03	1344	453	4.399	0.16	**1.03**	
		Count		**15**						0.07821	40884.4	14243.4	118.09	*7.33*	***8.14***	= *Max*
		St Deviation		0.3638											***2.90***	= R_B
		ESDM		0.0939											***1.33***	= R_B lim

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**2.985**	0.0186	2.00	**0.0373**	1.2
Weighted	**2.870**	0.0084	2.00	**0.0168**	0.6

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rp* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NIM and NMISA have higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.36.

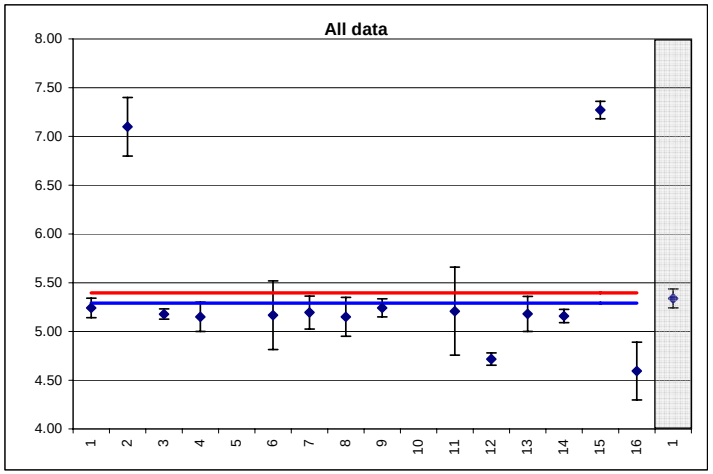
Submitted results: 15
Outliers removed: 3 (NPLI, VMI, KIM-LIPI)
Final population size: 12
Key Comparison Reference Value: *Rp* = 2.871 µm ± 0.018 µm
After outliers are removed, the NMC A*Star E_n was 1.2 but remained in the accepted values since the Birge ratio was less than the Birge limit. If NMC A*Star was removed also, the final KCRV would change by only +0.004 µm.

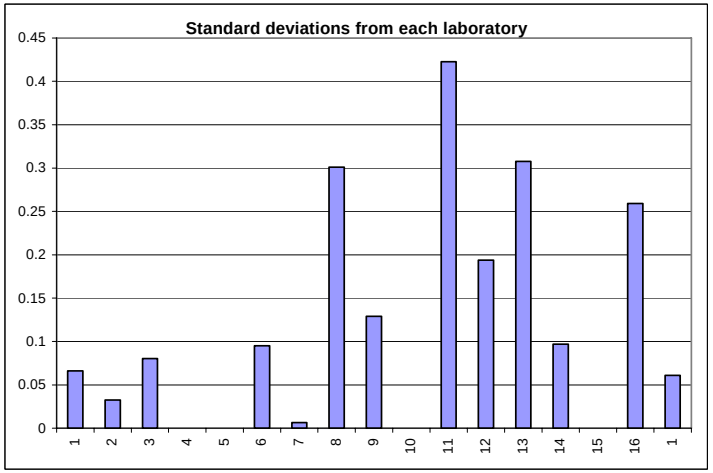
S/N 5256 *Rv* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**5.241**	0.0660	0.099	2.00	11	**0.0495**	2.5E-03	2139	408	1.06	1.35	**0.50**	
Singapore	NMC	08/08	2	**7.100**	0.0326	0.300	2.00	12	**0.1500**	2.3E-02	316	44	145.27	5.58	**6.00**	
UK	NPL	09/08	3	**5.178**	0.0804	0.053	2.28	12	**0.0232**	5.4E-04	9583	1851	24.08	2.78	**1.93**	
Germany	PTB	10/08	4	**5.150**		0.150	2.00	12	**0.0750**	5.6E-03	916	178	3.59	1.53	**0.93**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**5.166**	0.0950	0.352	2.00	12	**0.1760**	3.1E-02	167	32	0.51	0.65	**0.36**	
Japan	NMIJ	01/09	7	**5.194**	0.0066	0.169	2.00	12	**0.0845**	7.1E-03	727	140	1.35	1.13	**0.57**	
South Korea	KRISS	04/09	8	**5.150**	0.3010	0.200	2.20	12	**0.0909**	8.3E-03	623	121	2.44	1.18	**0.70**	
USA	NIST	06/09	9	**5.242**	0.1289	0.093	2.00	12	**0.0465**	2.2E-03	2424	462	1.16	1.41	**0.52**	
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11	**5.208**	0.4228	0.451	2.00	13	**0.2255**	5.1E-02	102	20	0.14	0.41	**0.19**	
Egypt	NIS	10/09	12	**4.717**	0.1940	0.063	2.00	12	**0.0315**	9.9E-04	4754	1008	333.28	7.93	**8.42**	
China	NIM	11/09	13	**5.180**	0.3076	0.180	1.96	12	**0.0918**	8.4E-03	614	119	1.49	1.14	**0.62**	
Ch Teipei	CMS	01/10	14	**5.158**	0.0969	0.068	2.00	12	**0.0340**	1.2E-03	4462	865	15.55	2.67	**1.84**	
Vietnam	VMI	03/10	15	**7.271**		0.090	2.00	12	**0.0450**	2.0E-03	3591	494	1933.93	17.51	**21.11**	***Worst***
Indonesia	KIM-LIPI	04/10	16	**4.595**	0.2593	0.296	2.00	60	**0.1480**	2.2E-02	210	46	22.18	2.66	**2.35**	
Australia rpt	NMIA	06/10	1	**5.339**	0.0610	0.098	2.00	10	**0.0490**	2.4E-03	2224	416	0.918	0.50	**0.46**	
		Count		**14**						0.16502	30627.1	5787.36	2486.02	*17.51*	***21.11***	= *Max*
		St Deviation		0.7830											***13.83***	= R_B
		ESDM		0.2093											***1.34***	= R_B lim

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**5.396**	0.0290	2.00	**0.0580**	1.1
Weighted	**5.292**	0.0131	2.00	**0.0263**	0.5

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rv* results:
SCL and NPLI did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NMISA has higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.70.

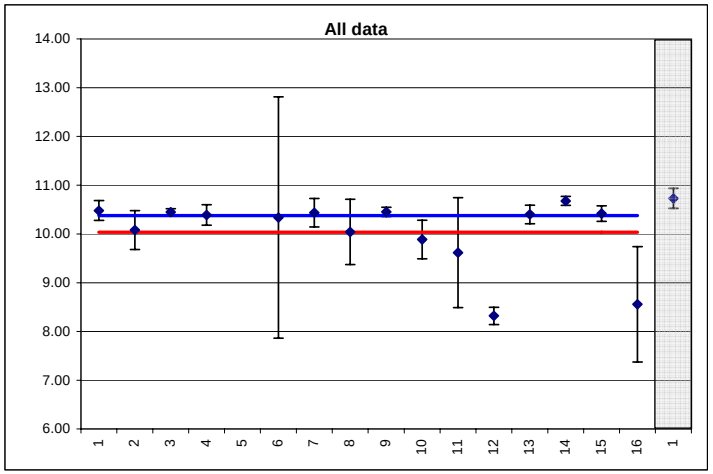
Submitted results: 14
Outliers removed: 4 (VMI, NMC A*Star, NIS, KIM-LIPI)
Final population size: 11
Key Comparison Reference Value: *Rv* = 5.186 µm ± 0.031 µm

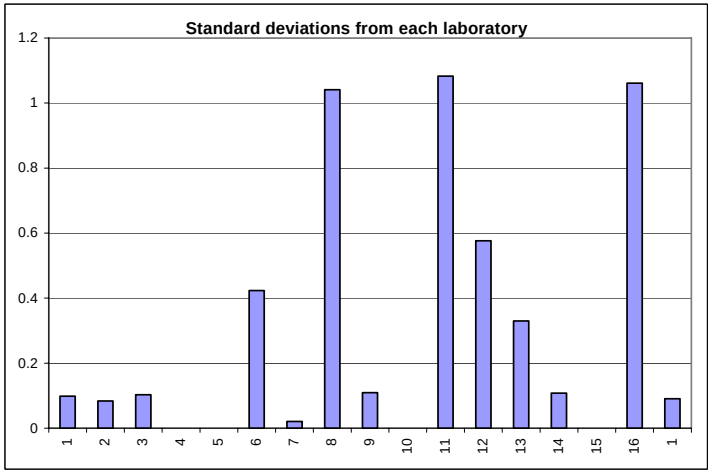
S/N 5256 *Rt* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En* Arithm	*En* Weighted	*Reject*
Australia	NMIA	07/08	1	**10.480**	0.0982	0.204	2.00	12	**0.1020**	1.0E-02	1007	96	1.06	1.50	**0.51**	
Singapore	NMC	08/08	2	**10.080**	0.0835	0.400	2.00	12	**0.2000**	4.0E-02	252	25	2.18	0.10	**0.73**	
UK	NPL	09/08	3	**10.448**	0.1030	0.068	2.28	12	**0.0298**	8.9E-04	11746	1124	6.00	1.84	**0.94**	
Germany	PTB	10/08	4	**10.390**		0.210	2.00	12	**0.1050**	1.1E-02	942	91	0.02	1.18	**0.07**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**10.337**	0.4230	2.475	2.00	12	**1.2375**	1.5E+00	7	1	0.00	0.12	**0.02**	
Japan	NMIJ	01/09	7	**10.435**	0.0207	0.292	2.00	12	**0.1460**	2.1E-02	490	47	0.17	1.10	**0.20**	
South Korea	KRISS	04/09	8	**10.040**	1.0410	0.670	2.20	12	**0.3045**	9.3E-02	108	11	1.21	0.01	**0.50**	
USA	NIST	06/09	9	**10.452**	0.1091	0.093	2.00	12	**0.0465**	2.2E-03	4834	462	2.74	1.79	**0.77**	
India	NPLI	07/09	10	**9.887**		0.396	1.00	12	**0.3960**	1.6E-01	63	6	1.52	0.33	**1.23**	
South Africa	NMISA	09/09	11	**9.617**	1.0831	1.127	2.00	13	**0.5635**	3.2E-01	30	3	1.81	0.37	**0.67**	
Egypt	NIS	10/09	12	**8.319**	0.5760	0.178	2.00	12	**0.0890**	7.9E-03	1050	126	533.64	6.18	**11.29**	***Worst***
China	NIM	11/09	13	**10.400**	0.3301	0.190	1.96	12	**0.0969**	9.4E-03	1107	106	0.07	1.27	**0.13**	
Ch Teipei	CMS	01/10	14	**10.677**	0.1081	0.093	2.00	12	**0.0465**	2.2E-03	4938	462	42.19	2.75	**3.00**	
Vietnam	VMI	03/10	15	**10.419**		0.160	2.00	12	**0.0800**	6.4E-03	1628	156	0.30	1.44	**0.27**	
Indonesia	KIM-LIPI	04/10	16	**8.557**	1.0611	1.185	2.00	60	**0.5925**	3.5E-01	24	3	1.81	1.23	**1.53**	
Australia rpt	NMIA	06/10	1	**10.728**	0.0908	0.203	2.00	10	**0.1015**	1.0E-02	1041	97	12.098	2.35	**1.71**	
		Count		**15**						2.56124	28226.5	2720.64	602.32	*6.18*	***11.29***	*= Max*
		St Deviation		0.7041											***6.56***	*= R_B*
		ESDM		0.1818											***1.33***	*= R_B lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**10.036**	0.1067	2.00	**0.2134**	2.1
Weighted	**10.375**	0.0192	2.00	**0.0383**	0.4

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rt* results:
SCL did not submit a result.
NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
South Korea, South Africa and Indonesia have significantly higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.86.

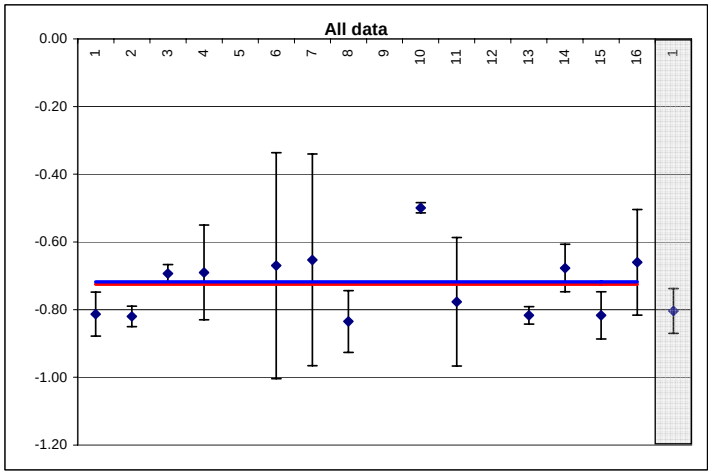
Submitted results: 15
Outliers removed: 3 (NIS, CMS, KIM-LIPI)
Final population size: 12
Key Comparison Reference Value: *Rt* = 10.434 µm ± 0.043 µm
After outliers are removed, the NPLI E_n was 1.5 but remained in the accepted values since the Birge ratio was less than the Birge limit.
If NPLI was removed also, the final KCRV would change by only +0.002 µm.

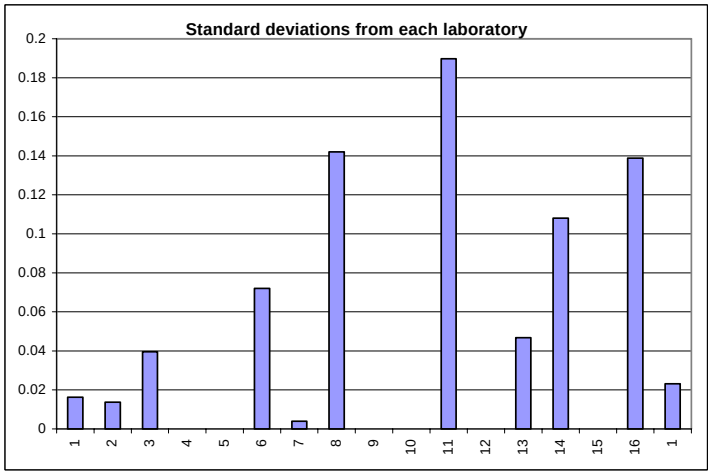
S/N 5256 *Rsk* **All data**

Country	Lab	Date	No.	x_i dimensionless	st dev	$U_{95\%}$	k	n	$u(x_i)$	Mean and uncertainty calculations: $u^c(x_i)$	$\underline{xi}$ $u^c(x_i)$	$u^{-c}(x_i)$	$\underline{(x_i-x_w)^c}$ $u^c(x_i)$	*En & Birge ratio* En Arithm	En Weighted	Reject
Australia	NMIA	07/08	1	**-0.813**	0.0163	0.065	2.00	12	**0.0325**	1.1E-03	-770	947	8.54	1.13	**1.44**	
Singapore	NMC	08/08	2	**-0.820**	0.0137	0.030	2.00	12	**0.0150**	2.3E-04	-3644	4444	46.23	1.82	**3.16**	
UK	NPL	09/08	3	**-0.693**	0.0396	0.026	2.52	12	**0.0103**	1.1E-04	-6510	9394	5.88	0.63	**0.87**	
Germany	PTB	10/08	4	**-0.690**		0.140	2.00	12	**0.0700**	4.9E-03	-141	204	0.16	0.24	**0.20**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**-0.670**	0.0720	0.334	2.00	12	**0.1670**	2.8E-02	-24	36	0.08	0.16	**0.14**	
Japan	NMIJ	01/09	7	**-0.653**	0.0040	0.313	2.00	12	**0.1565**	2.4E-02	-27	41	0.17	0.23	**0.21**	
South Korea	KRISS	04/09	8	**-0.835**	0.1420	0.091	2.20	12	**0.0414**	1.7E-03	-488	584	8.00	1.10	**1.27**	
USA	NIST	06/09	9													
India	NPLI	07/09	10	**-0.499**		0.015	1.00	12	**0.0150**	2.3E-04	-2218	4444	213.18	4.95	**11.39**	***Worst***
South Africa	NMISA	09/09	11	**-0.777**	0.1897	0.190	2.00	13	**0.0949**	9.0E-03	-86	111	0.39	0.27	**0.31**	
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**-0.817**	0.0468	0.026	1.96	12	**0.0133**	1.8E-04	-4643	5683	55.68	1.84	**3.46**	
Ch Teipei	CMS	01/10	14	**-0.677**	0.1081	0.070	2.00	12	**0.0350**	1.2E-03	-553	816	1.37	0.58	**0.58**	
Vietnam	VMI	03/10	15	**-0.817**		0.070	2.00	12	**0.0350**	1.2E-03	-667	816	8.00	1.12	**1.39**	
Indonesia	KIM-LIPI	04/10	16	**-0.660**	0.1388	0.156	2.00	60	**0.0780**	6.1E-03	-108	164	0.55	0.40	**0.37**	
Australia rpt	NMIA	06/10	1	**-0.804**	0.0231	0.066	2.00	11	**0.0330**	1.1E-03	-738	918	6.790	1.01	**1.28**	
		Count		**13**						0.07831	-19879	27686	348.24	*4.95*	***11.39***	*= Max*
		St Deviation		0.0986											***5.39***	*= R_B*
		ESDM		0.0273											***1.35***	*= R_B lim*

	Mean	u_{st}	k	U_{exp}	
	µm	µm		µm	%
Arithmetic	**-0.725**	0.0215	2.00	**0.0431**	-5.9
Weighted	**-0.718**	0.0060	2.00	**0.0120**	-1.7

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rsk* results:
SCL, NIST and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
KIM-LIPI repeated the measurement set 5 times.
NMISA, KRISS, and KIM-LIPI had the highest standard deviations.
Comparison of initial and final NMIA result is E_n = 0.10.

Submitted results: 13
Outliers removed: 3 (NPLI, NPL, CMS)
Final population size: 10
Key Comparison Reference Value: *Rsk* = -0.813 ± 0.018

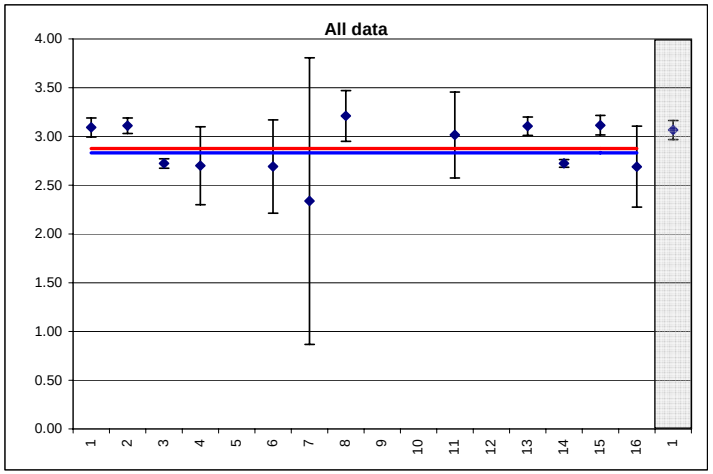
S/N 5256 *Rku*

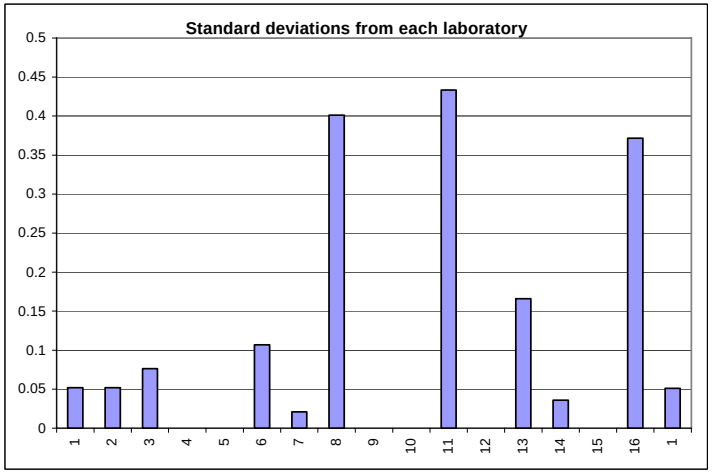
All data

Country	Lab	Date	No.	x_i	st dev	$U_{95\%}$	k	n	$u(x_i)$	Mean and uncertainty calculations: $u^c(x_i)$	$\frac{xi}{u^c(x_i)}$	$\frac{xi}{u^{-c}(x_i)}$	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: En Arithm	En Weighted	Reject
				dimensionless												
Australia	NMIA	07/08	1	**3.092**	0.0521	0.097	2.00	12	**0.0485**	2.4E-03	1314	425	28.85	1.24	**2.61**	
Singapore	NMC	08/08	2	**3.110**	0.0519	0.080	2.00	12	**0.0400**	1.6E-03	1944	625	48.48	1.42	**3.34**	***Worst***
UK	NPL	09/08	3	**2.723**	0.0763	0.049	2.43	12	**0.0202**	4.1E-04	6697	2459	28.95	1.00	**1.99**	
Germany	PTB	10/08	4	**2.700**		0.400	2.00	12	**0.2000**	4.0E-02	68	25	0.43	0.41	**0.33**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**2.691**	0.1070	0.478	2.00	12	**0.2390**	5.7E-02	47	18	0.35	0.37	**0.29**	
Japan	NMIJ	01/09	7	**2.337**	0.0210	1.471	2.00	12	**0.7355**	5.4E-01	4	2	0.45	0.36	**0.34**	
South Korea	KRISS	04/09	8	**3.210**	0.4010	0.260	2.20	12	**0.1182**	1.4E-02	230	72	10.26	1.12	**1.45**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11	**3.015**	0.4332	0.441	2.00	13	**0.2205**	4.9E-02	62	21	0.69	0.30	**0.42**	
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**3.105**	0.1659	0.094	1.96	12	**0.0480**	2.3E-03	1350	435	32.52	1.33	**2.82**	
Ch Teipei	CMS	01/10	14	**2.723**	0.0358	0.040	2.00	12	**0.0200**	4.0E-04	6808	2500	29.43	1.02	**2.33**	
Vietnam	VMI	03/10	15	**3.115**		0.100	2.00	12	**0.0500**	2.5E-03	1246	400	32.15	1.36	**2.76**	
Indonesia	KIM-LIPI	04/10	16	**2.690**	0.3717	0.415	2.00	60	**0.2075**	4.3E-02	62	23	0.46	0.42	**0.34**	
Australia rpt	NMIA	06/10	1	**3.066**	0.0512	0.097	2.00	11	**0.0485**	2.4E-03	1303	425	23.379	1.09	**2.35**	
		Count		**12**						0.75328	19831.7	7003.99	213.02	*1.42*	***3.34***	= *Max*
		St Deviation		0.2661											***4.40***	= R_B
		ESDM		0.0768											***1.36***	= R_B *lim*

	Mean	u_{st}	k	U_{exp}	
	µm	µm		µm	%
Arithmetic	**2.876**	0.0723	2.00	**0.1447**	5.0
Weighted	**2.831**	0.0119	2.00	**0.0239**	0.8

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rku* results:
SCL, NIST, NPLI and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS, NMISA and KIM-LIPI have higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = -0.19.

Submitted results: 12
Outliers removed: 5 (NMC A*Star, NIM, VMI, NMIA, KRISS)
Final population size: 7
Key Comparison Reference Value: *Rku* = 2.724 ± 0.028

S/N 5256 *Rk*

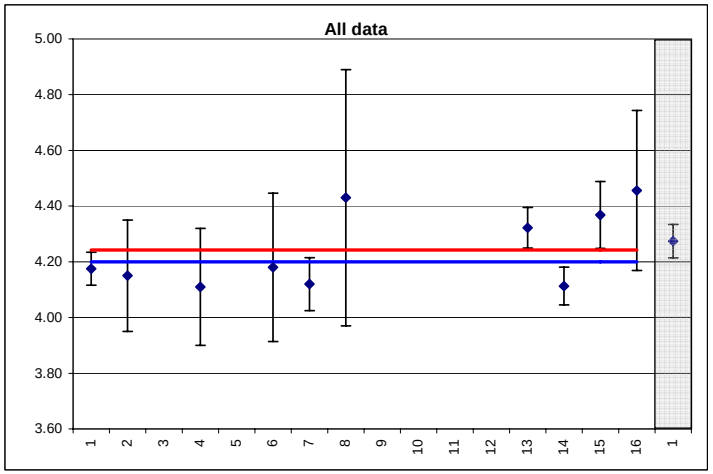
All data

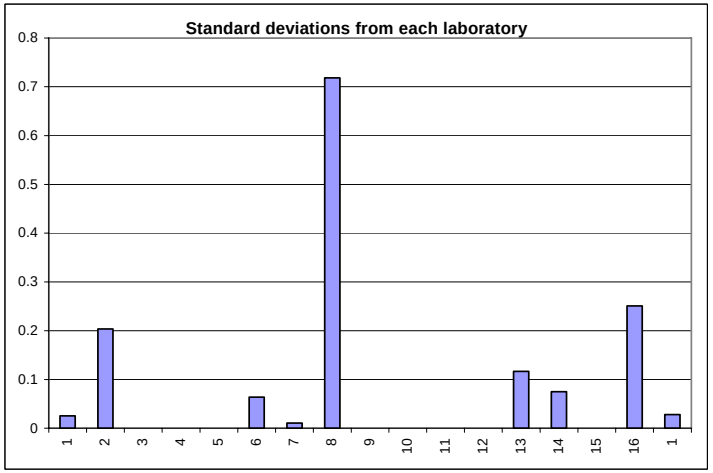
Mean and uncertainty calculations

Country	Lab	Date	No.	x_i	st dev	$U_{95\%}$	k	n	$u(x_i)$	$u^c(x_i)$	$\frac{xi}{u^c(x_i)}$	$u^{-c}(x_i)$	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En* Arithm	*En* Weighted	*Reject*
				µm	µm	µm			µm	µm^2	µm^{-1}	µm^{-2}				
Australia	NMIA	07/08	1	**4.175**	0.0253	0.059	2.00	12	**0.0295**	8.7E-04	4797	1149	0.69	0.76	**0.36**	
Singapore	NMC	08/08	2	**4.150**	0.2038	0.200	2.11	12	**0.0948**	9.0E-03	462	111	0.27	0.44	**0.24**	
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**4.110**		0.210	2.00	12	**0.1050**	1.1E-02	373	91	0.73	0.60	**0.42**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**4.180**	0.0640	0.266	2.00	12	**0.1330**	1.8E-02	236	57	0.02	0.23	**0.07**	
Japan	NMIJ	01/09	7	**4.120**	0.0109	0.095	2.00	12	**0.0475**	2.3E-03	1826	443	2.80	1.05	**0.79**	
South Korea	KRISS	04/09	8	**4.430**	0.7180	0.460	2.20	12	**0.2091**	4.4E-02	101	23	1.22	0.40	**0.50**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**4.322**	0.1167	0.073	1.96	12	**0.0372**	1.4E-03	3116	721	10.82	0.80	**1.53**	***Worst***
Ch Teipei	CMS	01/10	14	**4.113**	0.0751	0.068	2.00	12	**0.0340**	1.2E-03	3558	865	6.47	1.36	**1.15**	
Vietnam	VMI	03/10	15	**4.368**		0.120	2.00	12	**0.0600**	3.6E-03	1213	278	7.89	0.91	**1.36**	
Indonesia	KIM-LIPI	04/10	16	**4.456**	0.2506	0.287	2.00	60	**0.1435**	2.1E-02	216	49	3.20	0.72	**0.89**	
Australia rpt	NMIA	06/10	1	**4.274**	0.0280	0.060	2.00	10	**0.0300**	9.0E-04	4749	1111	6.171	0.35	**1.09**	
		Count		**10**						0.11128	15899.2	3786	34.10	*1.36*	***1.53***	= *Max*
		St Deviation		0.1371											***1.95***	= R_B
		ESDM		0.0434											***1.39***	= R_B *lim*

	Mean	u_{st}	k	U_{exp}	
	µm	µm		µm	%
Arithmetic	**4.242**	0.0334	2.00	**0.0667**	1.6
Weighted	**4.199**	0.0163	2.00	**0.0325**	0.8

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rk* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS has a higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 1.18.

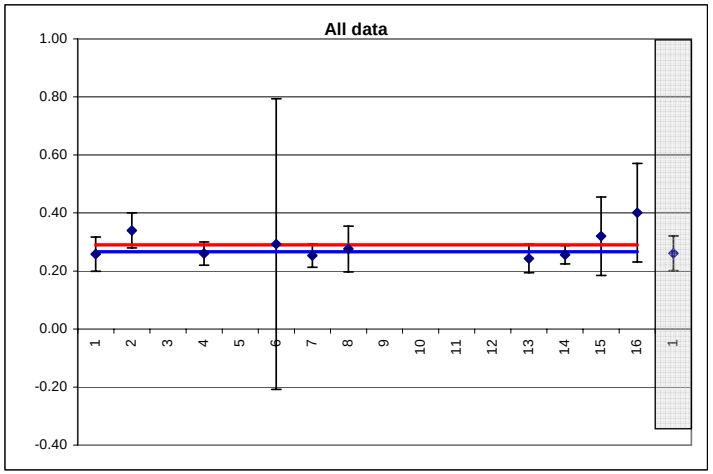
Submitted results: 10
Outliers removed: 2 (NIM, VMI)
Final population size: 8
Key Comparison Reference Value: *Rk* = 4.151 µm ± 0.038 µm
After outliers are removed, the KIM-LIPI E_n was 1.05 but remained in the accepted values since the Birge ratio was less than the Birge limit. If KIM-LIPI was also removed, the final KCRV would change by only -0.005 µm.

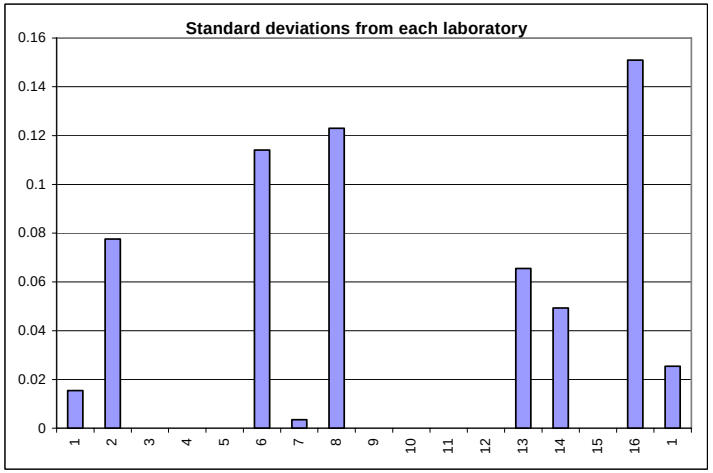
S/N 5256 *Rpk* **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**0.258**	0.0154	0.059	2.00	11	**0.0295**	8.7E-04	296	1149	0.08	0.39	**0.13**	
Singapore	NMC	08/08	2	**0.340**	0.0776	0.060	2.15	12	**0.0279**	7.8E-04	437	1284	7.02	0.61	**1.19**	***Worst***
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**0.260**		0.040	2.00	12	**0.0200**	4.0E-04	650	2500	0.09	0.43	**0.14**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**0.293**	0.1140	0.501	2.00	12	**0.2505**	6.3E-02	5	16	0.01	0.01	**0.05**	
Japan	NMIJ	01/09	7	**0.253**	0.0035	0.040	2.00	12	**0.0200**	4.0E-04	633	2500	0.43	0.54	**0.30**	
South Korea	KRISS	04/09	8	**0.276**	0.1230	0.079	2.20	12	**0.0359**	1.3E-03	214	776	0.08	0.14	**0.12**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**0.243**	0.0655	0.049	1.96	12	**0.0250**	6.3E-04	389	1600	0.85	0.63	**0.45**	
Ch Teipei	CMS	01/10	14	**0.256**	0.0493	0.032	2.00	12	**0.0160**	2.6E-04	1000	3906	0.40	0.53	**0.28**	
Vietnam	VMI	03/10	15	**0.320**		0.135	2.00	12	**0.0675**	4.6E-03	70	219	0.64	0.21	**0.40**	
Indonesia	KIM-LIPI	04/10	16	**0.401**	0.1509	0.170	2.00	60	**0.0850**	7.2E-03	56	138	2.52	0.62	**0.79**	
Australia rpt	NMIA	06/10	1	**0.261**	0.0254	0.060	2.00	12	**0.0300**	9.0E-04	290	1111	0.029	0.35	**0.08**	
		Count		**10**						0.07915	3748.78	14088.7	12.11	*0.63*	***1.19***	= *Max*
		St Deviation		0.0501											***1.16***	= R_B
		ESDM		0.0158											***1.39***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**0.290**	0.0281	2.00	**0.0563**	19.4
Weighted	**0.266**	0.0084	2.00	**0.0168**	6.3

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rpk* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KIM-LIPI, KRISS and NIMT have significantly higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.04.

Submitted results: 10
Outliers removed: 0
Final population size: 10
Key Comparison Reference Value: *Rpk* = 0.266 µm ± 0.017 µm
The NMC A*Star E_n was 1.2 but remained in the accepted values since the Birge ratio was less than the Birge limit. If NMC A*Star was removed, the final KCRV would change by -0.007 µm.

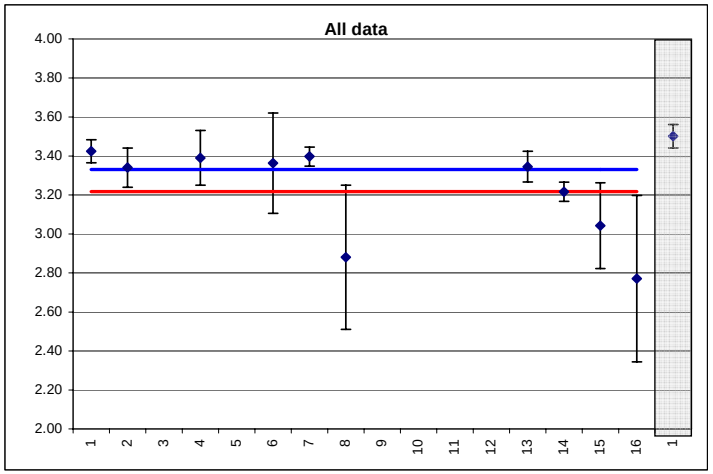
S/N 5256 *Rvk* **All data**

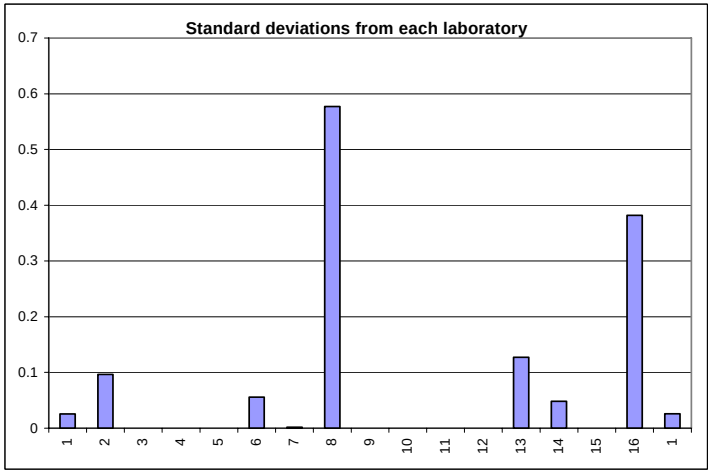
Mean and uncertainty calculations | ***En & Birge ratio***

Country	Lab	Date	No.	x_i	st dev	$U_{95\%}$	k	n	$u(x_i)$	$u^c(x_i)$	$\frac{xi}{u^c(x_i)}$	$u^{-c}(x_i)$	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En*	*En*	*Reject*
				µm	µm	µm			µm	µm^2	µm^{-1}	µm^{-2}		*Arithm*	*Weighted*	
Australia	NMIA	07/08	1	**3.424**	0.0254	0.059	2.00	12	**0.0295**	8.7E-04	3935	1149	9.96	2.31	**1.44**	
Singapore	NMC	08/08	2	**3.340**	0.0965	0.100	2.00	12	**0.0500**	2.5E-03	1336	400	0.03	1.02	**0.09**	
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**3.390**		0.140	2.00	12	**0.0700**	4.9E-03	692	204	0.71	1.11	**0.42**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**3.363**	0.0560	0.257	2.00	12	**0.1285**	1.7E-02	204	61	0.06	0.55	**0.12**	
Japan	NMIJ	01/09	7	**3.397**	0.0020	0.049	2.00	12	**0.0245**	6.0E-04	5659	1666	7.28	2.16	**1.19**	
South Korea	KRISS	04/09	8	**2.880**	0.5770	0.370	2.20	12	**0.1682**	2.8E-02	102	35	7.19	0.90	**1.22**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**3.345**	0.1271	0.079	1.96	12	**0.0403**	1.6E-03	2059	616	0.12	1.23	**0.17**	
Ch Teipei	CMS	01/10	14	**3.216**	0.0485	0.049	2.00	12	**0.0245**	6.0E-04	5358	1666	21.99	0.01	**2.07**	***Worst***
Vietnam	VMI	03/10	15	**3.042**		0.220	2.00	12	**0.1100**	1.2E-02	251	83	6.90	0.76	**1.30**	
Indonesia	KIM-LIPI	04/10	16	**2.771**	0.3817	0.427	2.00	60	**0.2135**	4.6E-02	61	22	6.88	1.03	**1.31**	
Australia rpt	NMIA	06/10	1	**3.501**	0.0258	0.060	2.00	10	**0.0300**	9.0E-04	3890	1111	32.155	3.15	**2.60**	
		Count		**10**						0.11357	19656.1	5901.16	61.13	*2.31*	***2.07***	= *Max*
		St Deviation		0.2360											***2.61***	= R_B
		ESDM		0.0746											***1.39***	= R_B *lim*

	Mean	u_{st}	k	U_{exp}	
	µm	µm		µm	%
Arithmetic	**3.217**	0.0337	2.00	**0.0674**	2.1
Weighted	**3.331**	0.0130	2.00	**0.0260**	0.8

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Rvk* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS and KIM-LIPI have significantly higher standard deviations than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.92.

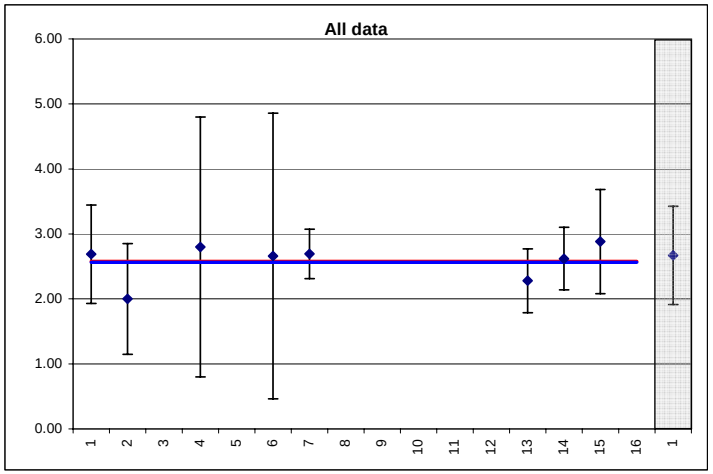
Submitted results: 10
Outliers removed: 3 (CMS, VMI, KIM-LIPI)
Final population size: 7
Key Comparison Reference Value: *Rvk* = 3.386 µm ± 0.031 µm
After outliers are removed, the KRISS E_n was 1.4 but remained in the accepted values since the Birge ratio was less than the Birge limit. If KRISS was removed also, the final KCRV would change by +0.004 µm.

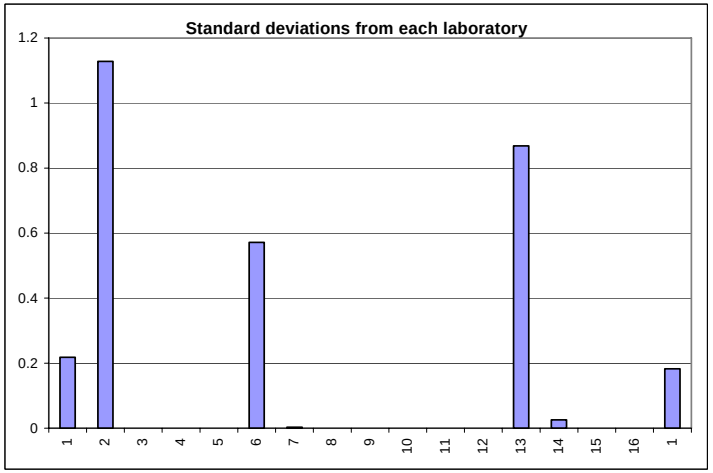
S/N 5256 ***Mr1*** **All data**

Country	Lab	Date	No.	x_i %	st dev %	$U_{95\%}$ %	k	n	$u(x_i)$ %	Mean and uncertainty calculations: $u^c(x_i)$ μm^2	$\frac{xi}{u^c(x_i)}$ μm^{-1}	$u^{-c}(x_i)$ μm^{-2}	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**2.688**	0.218	0.757	2.00	12	**0.3785**	1.4E-01	19	7	0.11	0.13	**0.16**	
Singapore	NMC	08/08	2	**2.000**	1.128	0.850	2.00	12	**0.4250**	1.8E-01	11	6	1.77	0.61	**0.64**	***Worst***
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**2.800**		2.000	2.00	12	**1.0000**	1.0E+00	3	1	0.06	0.11	**0.12**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**2.660**	0.572	2.197	2.00	12	**1.0985**	1.2E+00	2	1	0.01	0.04	**0.04**	
Japan	NMIJ	01/09	7	**2.693**	0.003	0.380	2.00	12	**0.1900**	3.6E-02	75	28	0.46	0.20	**0.29**	
South Korea	KRISS	04/09	8													
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**2.280**	0.8685	0.490	1.96	12	**0.2500**	6.3E-02	36	16	1.30	0.46	**0.53**	
Ch Teipei	CMS	01/10	14	**2.620**	0.0260	0.480	2.00	12	**0.2400**	5.8E-02	45	17	0.05	0.07	**0.10**	
Vietnam	VMI	03/10	15	**2.883**		0.800	2.00	12	**0.4000**	1.6E-01	18	6	0.63	0.34	**0.38**	
Indonesia	KIM-LIPI	04/10	16													
Australia rpt	NMIA	06/10	1	**2.670**	0.183	0.755	2.00	10	**0.3775**	1.4E-01	19	7	0.078	0.11	**0.13**	
		Count		**8**						2.84679	209.423	81.6572	4.37	*0.61*	***0.64***	= *Max*
		St Deviation		0.2925											***0.79***	= R_B
		ESDM		0.1034											***1.44***	= R_B *lim*

	Mean x_i µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**2.578**	0.2109	2.00	**0.4218**	16.4
Weighted	**2.565**	0.1107	2.00	**0.2213**	8.6

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Mr1* results:
The KRISS result of *Mr1* = 25.4% ± 4.0% has been excluded from the population as an obvious error.
The KIM-LIPI result is high with a very small uncertainty of *Mr1* = 3.540% +/- 0.140% and has been excluded to avoid distorting the analysis.
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NMC A*Star, NIM and NIMT have significantly higher standard deviations than the remaining laboratories.
Comparison of initial and final NMIA result is E_n = -0.02.

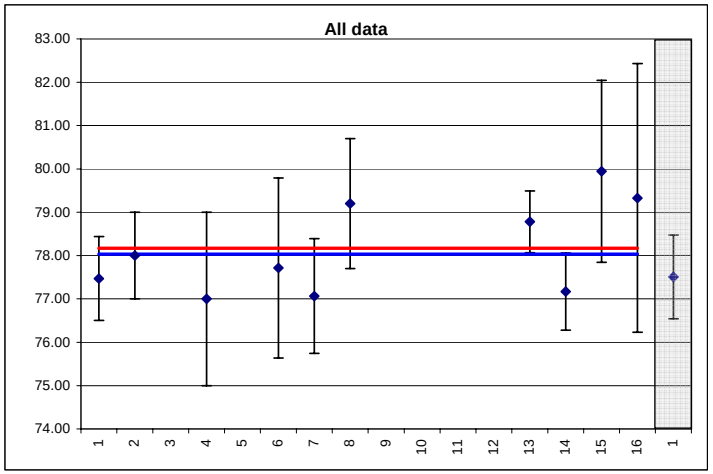
Submitted results: 10. Accepted results: 8.
Outliers removed: 0
Final population size: 8
Key Comparison Reference Value: *Mr1* = 2.56% ± 0.22%

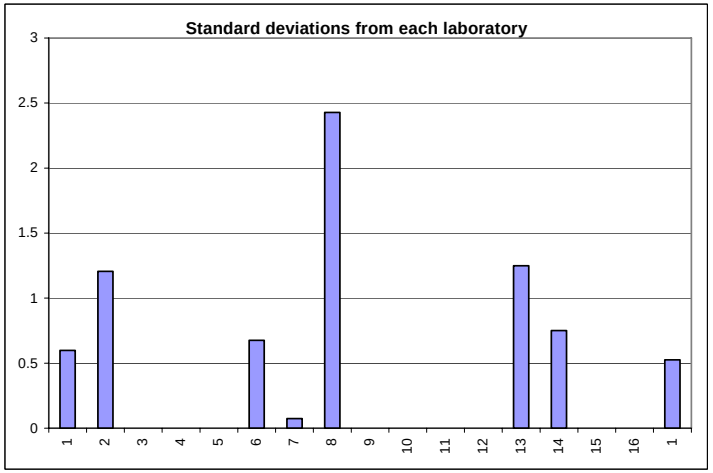
S/N 5256 *Mr2* **All data**

Country	Lab	Date	No.	x_i %	st dev %	$U_{95\%}$ %	k	n	$u(x_i)$ %	Mean and uncertainty calculations: $u^c(x_i)$ μm^2	$\frac{xi}{u^c(x_i)}$ μm^{-1}	$u^{-c}(x_i)$ μm^{-2}	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	**77.471**	0.5977	0.968	2.00	12	**0.4840**	2.3E-01	331	4	1.36	0.63	**0.54**	
Singapore	NMC	08/08	2	**78.000**	1.2060	1.000	2.00	12	**0.5000**	2.5E-01	312	4	0.00	0.15	**0.03**	
UK	NPL	09/08	3													
Germany	PTB	10/08	4	**77.000**		2.000	2.00	12	**1.0000**	1.0E+00	77	1	1.07	0.56	**0.51**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	**77.715**	0.6750	2.078	2.00	12	**1.0390**	1.1E+00	72	1	0.09	0.21	**0.15**	
Japan	NMIJ	01/09	7	**77.066**	0.0740	1.325	2.00	12	**0.6625**	4.4E-01	176	2	2.14	0.77	**0.70**	
South Korea	KRISS	04/09	8	**79.200**	2.4270	1.500	2.20	12	**0.6818**	4.6E-01	170	2	2.92	0.65	**0.75**	
USA	NIST	06/09	9													
India	NPLI	07/09	10													
South Africa	NMISA	09/09	11													
Egypt	NIS	10/09	12													
China	NIM	11/09	13	**78.780**	1.2498	0.710	1.96	12	**0.3622**	1.3E-01	600	8	4.23	0.69	**0.93**	***Worst***
Ch Teipei	CMS	01/10	14	**77.170**	0.7500	0.890	2.00	12	**0.4450**	2.0E-01	390	5	3.78	0.96	**0.90**	
Vietnam	VMI	03/10	15	**79.946**		2.100	2.00	12	**1.0500**	1.1E+00	73	1	3.31	0.82	**0.90**	
Indonesia	KIM-LIPI	04/10	16	**79.330**		3.100	2.00	60	**1.5500**	2.4E+00	33	0	0.70	0.37	**0.41**	
Australia rpt	NMIA	06/10	1	**77.510**	0.5259	0.968	2.00	10	**0.4840**	2.3E-01	331	4	1.177	0.59	**0.51**	
		Count		**10**						7.30181	2233.25	28.6185	19.61	*0.96*	***0.93***	= *Max*
		St Deviation		1.0669											***1.48***	= R_B
		ESDM		0.3374											***1.39***	= R_B lim

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**78.168**	0.2702	2.00	**0.5404**	0.7
Weighted	**78.035**	0.1869	2.00	**0.3739**	0.5

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 5256 *Mr2* results:
NPL, SCL, NIST, NPLI, NMISA and NIS did not submit a result.
NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
KIM-LIPI repeated the measurement set 5 times.
KRISS has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.03.

Submitted results: 10
Outliers removed: 1 (NIM)
Final population size: 9
Key Comparison Reference Value: *Mr2* = 77.76% ± 0.44%
The NIM result had an E_n of 0.93 but was removed since the Birge ratio was greater than the Birge limit. While the NIM result was closer to the KCRV than VMI and CMS, its uncertainty was significantly smaller. After removal of NIM, the VMI E_n was 1.02 but kept due to an acceptable Birge ratio. The CMS E_n was then 0.60.

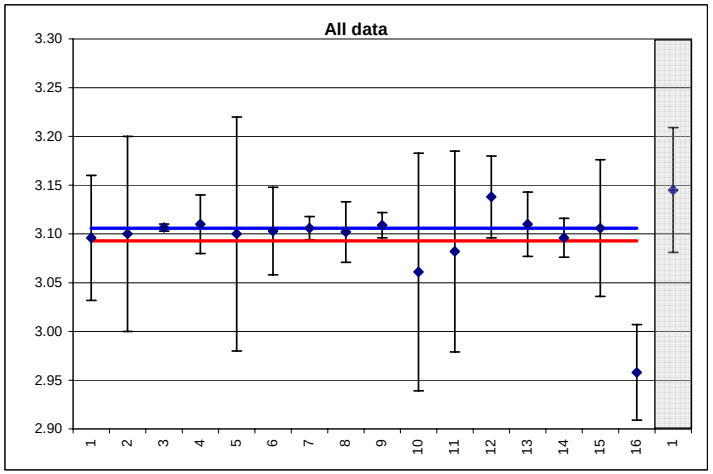
S/N 1286 *Ra*

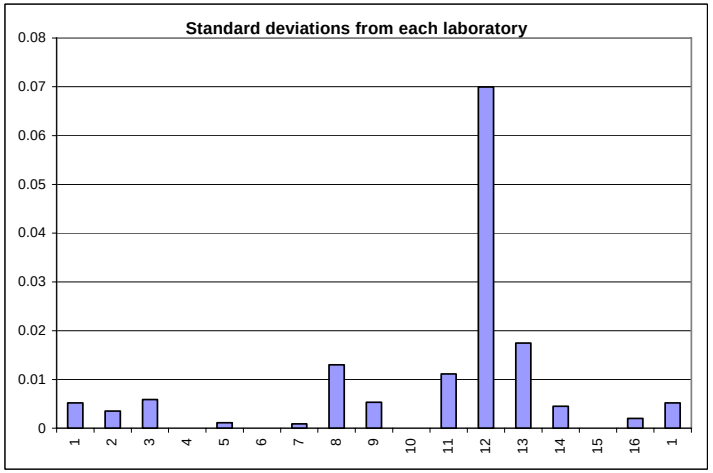
All data

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	3.0960	0.0052	0.0640	2.00	15	0.0320	1.0E-03	3023	977	0.10	0.05	**0.15**	
Singapore	NMC	08/08	2	3.1000	0.0035	0.1000	2.00	15	0.0500	2.5E-03	1240	400	0.01	0.07	**0.06**	
UK	NPL	09/08	3	3.1065	0.0059	0.0036	2.15	15	0.0017	2.8E-06	1108009	356674	0.13	0.64	**0.13**	
Germany	PTB	10/08	4	3.1100		0.0300	2.00		0.0150	2.3E-04	13822	4444	0.07	0.47	**0.14**	
Hong Kong	SCL	11/08	5	3.1000	0.0011	0.1200	1.96	16	0.0612	3.7E-03	827	267	0.01	0.06	**0.05**	
Thailand	NIMT	12/08	6	3.1030		0.0450	2.00		0.0225	5.1E-04	6129	1975	0.02	0.21	**0.06**	
Japan	NMIJ	01/09	7	3.1060	0.0009	0.0120	2.00	15	0.0060	3.6E-05	86278	27778	0.00	0.55	**0.01**	
South Korea	KRISS	04/09	8	3.1020	0.0130	0.0310	2.14	15	0.0145	2.1E-04	14782	4765	0.07	0.25	**0.13**	
USA	NIST	06/09	9	3.1090	0.0053	0.0130	2.00	15	0.0065	4.2E-05	73586	23669	0.23	0.66	**0.23**	
India	NPLI	07/09	10	3.0610		0.1220	1.00	15	0.1220	1.5E-02	206	67	0.14	0.26	**0.37**	
South Africa	NMISA	09/09	11	3.0820	0.0111	0.1030	2.00	15	0.0515	2.7E-03	1162	377	0.22	0.10	**0.23**	
Egypt	NIS	10/09	12	3.1380	0.0700	0.0420	2.00	15	0.0210	4.4E-04	7116	2268	2.34	0.96	**0.76**	
China	NIM	11/09	13	3.1100	0.0174	0.0330	1.96	15	0.0168	2.8E-04	10971	3528	0.06	0.44	**0.12**	
Ch Teipei	CMS	01/10	14	3.0960	0.0045	0.0200	2.00	15	0.0100	1.0E-04	30960	10000	0.98	0.11	**0.49**	
Vietnam	VMI	03/10	15	3.1060		0.0700	2.00	12	0.0350	1.2E-03	2536	816	0.00	0.18	**0.00**	
Indonesia	KIM-LIPI	04/10	16	2.9580	0.0020	0.0490	2.00	60	0.0245	6.0E-04	4928	1666	36.44	2.53	**3.01**	***Worst***
Australia rpt	NMIA	06/10	1	3.1450	0.0052	0.0640	2.00	15	0.0320	1.0E-03	3071	977	1.493	0.78	**0.61**	
		Count		**16**						0.02848	1365575	439671	40.81	*2.53*	***3.01***	= *Max*
		St Deviation		0.0392											***1.65***	= R_B
		ESDM		0.0098											***1.32***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**3.093**	0.0105	2.00	**0.0211**	0.7
Weighted	**3.106**	0.0015	2.00	**0.0030**	0.1

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 1286 *Ra* results:
SCL, NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
NIS has a significantly higher standard deviation than any other laboratory.
NPLI, CMS and KIM-LIPI made repeat measurements at the required locations.
Comparison of initial and final NMIA result is E_n = 0.54

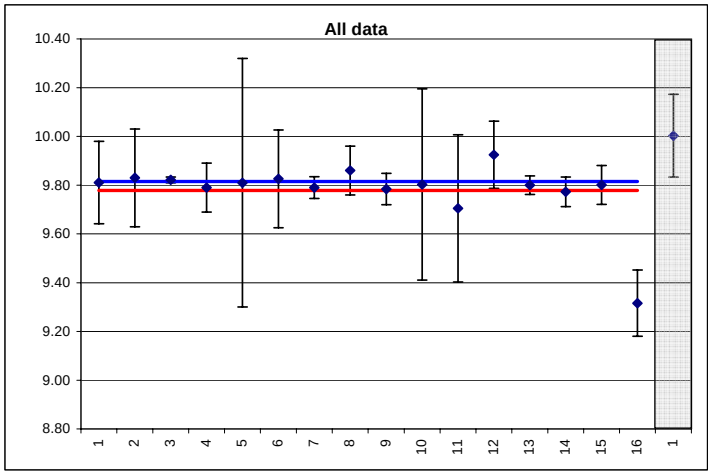
Submitted results: 16
Outliers removed: 1 (KIM-LIPI)
Final population size: 15
Key Comparison Reference Value: *Ra* = 3.106 µm ± 0.003 µm

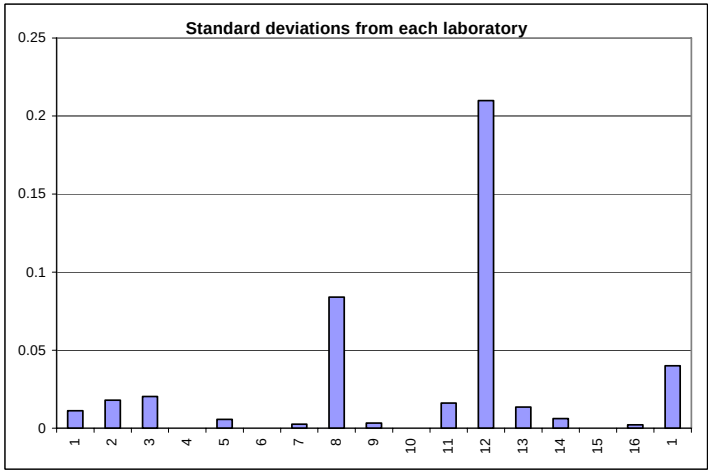
S/N 1286 ***Rz*** **All data**

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm^2	$\frac{xi}{u^c(x_i)}$ µm^{-1}	$u^{-c}(x_i)$ µm^{-2}	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	9.811	0.0113	0.169	2.00	15	0.0845	7.1E-03	1374	140	0.00	0.18	**0.02**	
Singapore	NMC	08/08	2	9.830	0.0179	0.200	2.00	15	0.1000	1.0E-02	983	100	0.02	0.25	**0.08**	
UK	NPL	09/08	3	9.822	0.0204	0.012	2.20	15	0.0055	3.0E-05	330128	33611	1.82	0.65	**0.48**	
Germany	PTB	10/08	4	9.790		0.100	2.00		0.0500	2.5E-03	3916	400	0.24	0.10	**0.25**	
Hong Kong	SCL	11/08	5	9.810	0.0056	0.510	1.96	16	0.2602	6.8E-02	145	15	0.00	0.06	**0.01**	
Thailand	NIMT	12/08	6	9.826		0.201	2.00		0.1005	1.0E-02	973	99	0.01	0.23	**0.06**	
Japan	NMIJ	01/09	7	9.790	0.0026	0.045	2.00	15	0.0225	5.1E-04	19338	1975	1.20	0.15	**0.54**	
South Korea	KRISS	04/09	8	9.860	0.0840	0.100	2.14	20	0.0467	2.2E-03	4515	458	0.94	0.68	**0.45**	
USA	NIST	06/09	9	9.784	0.0033	0.064	2.00	15	0.0320	1.0E-03	9555	977	0.92	0.07	**0.47**	
India	NPLI	07/09	10	9.803		0.392	1.00		0.3920	1.5E-01	64	7	0.00	0.06	**0.03**	
South Africa	NMISA	09/09	11	9.705	0.0161	0.302	2.00	15	0.1510	2.3E-02	426	44	0.53	0.24	**0.36**	
Egypt	NIS	10/09	12	9.925	0.2100	0.138	2.00	15	0.0690	4.8E-03	2085	210	2.56	0.96	**0.80**	
China	NIM	11/09	13	9.800	0.0136	0.038	1.96	15	0.0194	3.8E-04	26072	2660	0.57	0.29	**0.37**	
Ch Teipei	CMS	01/10	14	9.773	0.0062	0.061	2.00	15	0.0305	9.3E-04	10506	1075	1.86	0.05	**0.67**	
Vietnam	VMI	03/10	15	9.801		0.080	2.00		0.0400	1.6E-03	6126	625	0.12	0.22	**0.17**	
Indonesia	KIM-LIPI	04/10	16	9.316	0.0022	0.136	2.00	60	0.0680	4.6E-03	2015	216	53.77	3.04	**3.66**	***Worst***
Australia rpt	NMIA	06/10	1	10.003	0.0401	0.170	2.00	15	0.0850	7.2E-03	1384	138	4.911	1.23	**1.11**	
		Count		**16**						0.28995	418220	42611.8	64.57	*3.04*	***3.66***	= *Max*
		St Deviation		0.1312											***2.07***	= R_B
		ESDM		0.0328											***1.32***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**9.778**	0.0337	2.00	**0.0673**	0.7
Weighted	**9.815**	0.0048	2.00	**0.0097**	0.1

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 1286 *Rz* results:
NMC A*Star reports *Ry* instead of *Rz*.
SCL, NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
NIS has a significantly higher standard deviation than any other laboratory.
Comparison of initial and final NMIA result is E_n = 0.80.

Submitted results: 16
Outliers removed: 1 (KIM-LIPI)
Final population size: 15
Key Comparison Reference Value: *Rz* = 9.817 µm ± 0.010 µm

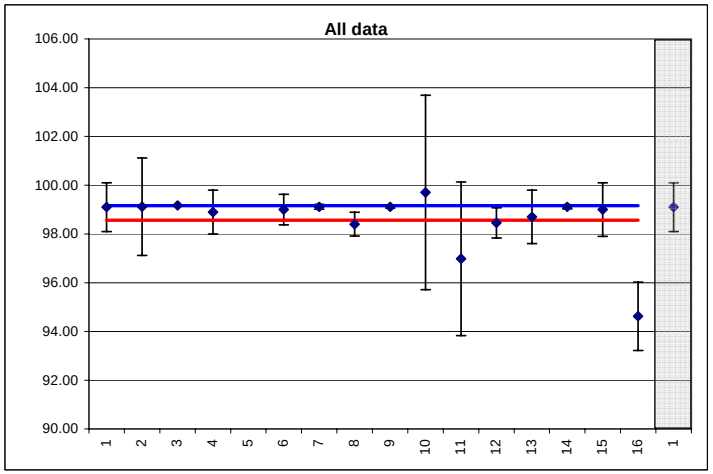
S/N 1286 *RSm*

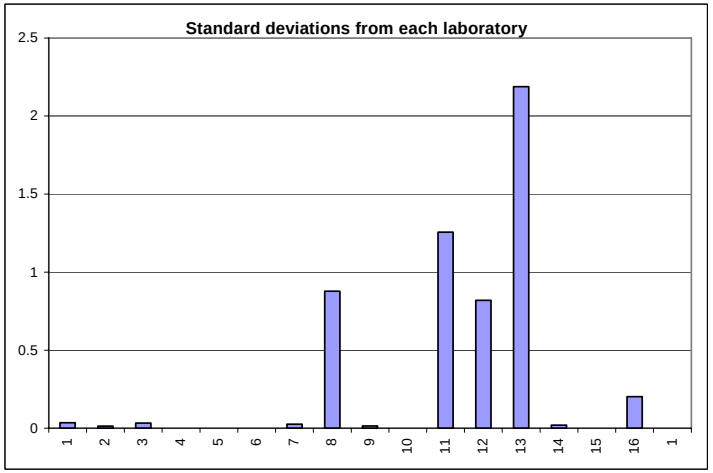
All data

Country	Lab	Date	No.	x_i µm	st dev µm	$U_{95\%}$ µm	k	n	$u(x_i)$ µm	Mean and uncertainty calculations: $u^c(x_i)$ µm²	$\frac{xi}{u^c(x_i)}$ µm⁻¹	$u^{-c}(x_i)$ µm⁻²	$\frac{(x_i-x_w)^c}{u^c(x_i)}$	*En & Birge ratio*: *En Arithm*	*En Weighted*	*Reject*
Australia	NMIA	07/08	1	99.1	0.0352	1.000	2.00	15	0.5000	2.5E-01	396	4	0.01	0.46	**0.06**	
Singapore	NMC	08/08	2	99.12	0.0129	2.000	2.00	15	1.0000	1.0E+00	99	1	0.00	0.27	**0.02**	
UK	NPL	09/08	3	99.169	0.0329	0.019	2.20	15	0.0086	7.5E-05	1329579	13407	1.52	0.98	**0.43**	
Germany	PTB	10/08	4	98.9		0.900	2.28	15	0.3947	1.6E-01	635	6	0.43	0.31	**0.29**	
Hong Kong	SCL	11/08	5													
Thailand	NIMT	12/08	6	99		0.628	2.00		0.3140	9.9E-02	1004	10	0.25	0.49	**0.25**	
Japan	NMIJ	01/09	7	99.114	0.0248	0.099	2.00	15	0.0495	2.5E-03	40451	408	0.80	0.88	**0.44**	
South Korea	KRISS	04/09	8	98.4	0.8770	0.490	2.14	15	0.2290	5.2E-02	1877	19	10.97	0.21	**1.55**	
USA	NIST	06/09	9	99.113	0.0151	0.054	2.00	15	0.0270	7.3E-04	135957	1372	2.82	0.89	**0.81**	
India	NPLI	07/09	10	99.7		3.988	1.00		3.9880	1.6E+01	6	0	0.02	0.28	**0.14**	
South Africa	NMISA	09/09	11	96.98	1.2569	3.151	2.00	15	1.5755	2.5E+00	39	0	1.91	0.49	**0.69**	
Egypt	NIS	10/09	12	98.457	0.8200	0.621	2.00	15	0.3105	9.6E-02	1021	10	5.10	0.12	**1.13**	
China	NIM	11/09	13	98.7	2.1875	1.100	1.96	15	0.5612	3.1E-01	313	3	0.67	0.11	**0.42**	
Ch Teipei	CMS	01/10	14	99.11	0.0205	0.088	2.00	15	0.0440	1.9E-03	51193	517	1.21	0.88	**0.54**	
Vietnam	VMI	03/10	15	99		1.100	2.00	15	0.5500	3.0E-01	327	3	0.08	0.34	**0.14**	
Indonesia	KIM-LIPI	04/10	16	94.62	0.2022	1.400	2.00	60	0.7000	4.9E-01	193	2	42.03	2.58	**3.24**	***Worst***
Australia rpt	NMIA	06/10	1	99.1		1.000	2.00		0.5000	2.5E-01	396	4	0.014	0.46	**0.06**	
		Count		**15**						21.1523	1563092	15763.6	67.84	*2.58*	***3.24***	= *Max*
		St Deviation		1.2470											***2.20***	= R_B
		ESDM		0.3220											***1.33***	= R_B *lim*

	Mean µm	u_{st} µm	k	U_{exp} µm	%
Arithmetic	**98.566**	0.3066	2.00	**0.6132**	0.6
Weighted	**99.158**	0.0080	2.00	**0.0159**	0.0

$$R_B < \sqrt{1+\sqrt{8/(n-1)}}$$





Comments for 1286 *RSm* results:
No result given by SCL.
SCL, NIS, NIM and CMS reported the ESDM which is converted to the standard deviation [s = ESDM * sqrt(n)].
NPLI uncertainty reported at k = 1.0.
NIM has a significantly higher standard deviation than any other laboratory.
The uncertainty for CMS is very small. Since the value is acceptable, this significantly affects which laboratories are outliers.
Comparison of initial and final NMIA result is E_n = 0.00.

Submitted results: 15
Outliers removed: 2 (KIM-LIPI, KRISS)
Final population size: 13
Key Comparison Reference Value: *RSm* = 99.16 µm ± 0.016 µm
After outliers are removed, NIS had an E_n of 1.1 but remained in the accepted values since the Birge ratio was less than the Birge limit. If this result was removed, the final KCRV changes by only +0.001 µm.

Appendix D. Softgauge results

Submitted results and graphs are shown for the Cos4 softgauge, including the software and the file format used. Uncertainties are not applicable. Two comparisons are determined; an E_n value and a difference from the supplied NPL value. Some results from NIS are excluded in mean calculations.

Softgauge Cos4 results

Note: Singapore, Hong Kong, Thailand, South Korea, India, China, Vietnam and Indonesia did not submit any results. Uncertainty not applicable.

Laboratory	Date		No.	Software	File	Cutoff	Filter	*Ra*	*Rq*	*Rz*	*Rp*	*Rv*	*Rt*	*RSm*
				µm	µm	mm		µm	µm	µm	µm	µm	µm	µm
Australia	07/08	NMIA	1	Turbo Wave v7.20	4PTB.SMD, ASC	0.8	off	0.498000	0.572000	1.754500	0.880500	0.874000	2.005000	200.000000
UK	09/08	NPL	3	Softgauges 1.01	4NPL.SMD	0.8	off	0.528782	0.589208	1.806400	0.910959	0.895441	1.998763	199.999972
Germany	10/08	PTB	4	RPTB v1.46	4PTB.SMD	0.8	off	0.528760	0.598850	1.806360	0.910920	0.895440	1.998760	199.980000
Japan	01/09	NMIJ	7	NMIJ v1.1	PRF	0.8	off	0.446000	0.500000	1.590000	0.806000	0.784000	1.999000	200.000000
South Korea	04/09	KRISS	8	FTS Ultra v4.3.14	PRF	0.8	off	0.497400	0.576300	1.718300	0.868500	0.849800	1.995700	197.490000
USA	06/09	NIST	9	NIST 'SMATS' web-based [1]	ASC	0.8	off	0.528780	0.589190	1.806360	0.910890	0.895440	1.998760	199.999970
South Africa	09/09	NMISA	11	Ultra v5.11.6.17	?	0.8	off	0.560700	0.625800	1.860800	0.930200	0.930600	1.955900	196.300000
Egypt	10/09	NIS	12	Ultra v5.16.2.0	SMD	?	off	0.445500	0.531200	~~0.002800~~	~~0.001400~~	~~0.001400~~	~~0.002800~~	197.650000
China	11/09	NIM	13	Talymap Gold v5.1.1.5374	PRF	?	off	0.445500	0.531100	1.998600	1.000000	0.998500	1.998600	199.520000
Ch Teipei	01/10	CMS	14	?	SMD	0.8	off	0.445500	0.531200	1.657000	0.824500	0.832500	1.998800	200.000700
							Arithmetic Mean	**0.492492**	**0.564485**	**1.777591**	**0.893608**	**0.883969**	**1.994365**	**199.094064**
							St Deviation	0.0440	0.0392	0.1183	0.0579	0.0608	0.0146	1.3959
							Count	**10**	**10**	**9**	**9**	**9**	**9**	**10**

[1] NIST software: Surface Metrology Algorithm Testing System (SMATS), http://physics.nist.gov/smats

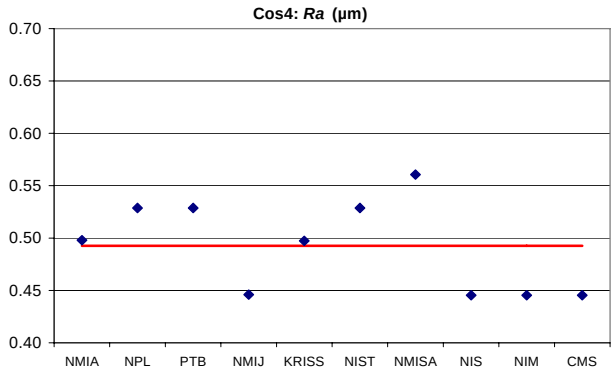
Calculation of E_n for each laboratory to arithmetic mean using the population standard deviation as nominal uncertainties.

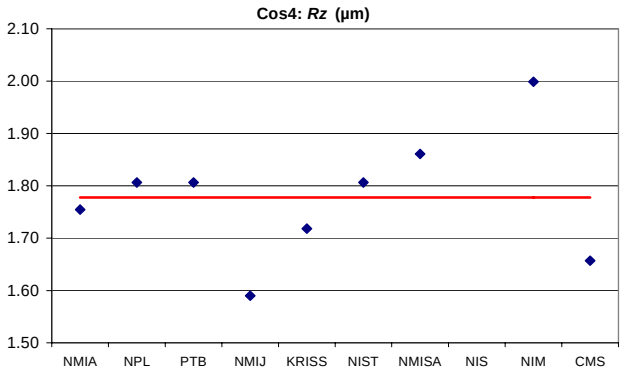
				Software	File	Cutoff	Filter	*Ra*	*Rq*	*Rz*	*Rp*	*Rv*	*Rt*	*RSm*
				µm	µm	mm		En	En	En	En	En	En	En
Australia	07/08	NMIA	1	Turbo Wave v7.20	4PTB.SMD, ASC	0.8	off	0.09	0.14	-0.14	-0.16	-0.12	0.51	0.46
UK	09/08	NPL	3	Softgauges 1.01	4NPL.SMD	0.8	off	0.58	0.45	0.17	0.21	0.13	0.21	0.46
Germany	10/08	PTB	4	RPTB v1.46	4PTB.SMD	0.8	off	0.58	0.62	0.17	0.21	0.13	0.21	0.45
Japan	01/09	NMIJ	7	NMIJ v1.1	PRF	0.8	off	-0.75	-1.16	-1.12	-1.07	-1.16	0.22	0.46
South Korea	04/09	KRISS	8	FTS Ultra v4.3.14	PRF	0.8	off	0.08	0.21	-0.35	-0.31	-0.40	0.06	-0.81
USA	06/09	NIST	9	NIST 'SMATS' web-based [1]	ASC	0.8	off	0.58	0.45	0.17	0.21	0.13	0.21	0.46
South Africa	09/09	NMISA	11	Ultra v5.11.6.17	?	0.8	off	1.10	1.11	0.50	0.45	0.54	-1.86	-1.42
Egypt	10/09	NIS	12	Ultra v5.16.2.0	SMD	?	off	-0.75	-0.60	-	-	-	-	-0.73
China	11/09	NIM	13	Talymap Gold v5.1.1.5374	PRF	?	off	-0.75	-0.60	1.32	1.30	1.33	0.20	0.22
Ch Teipei	01/10	CMS	14	?	SMD	0.8	off	-0.75	-0.60	-0.72	-0.84	-0.60	0.21	0.46

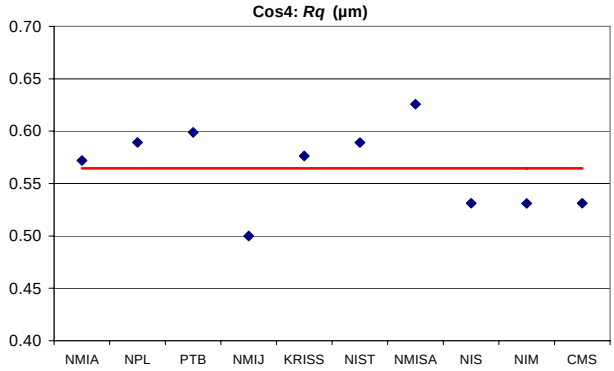
Difference from NPL values

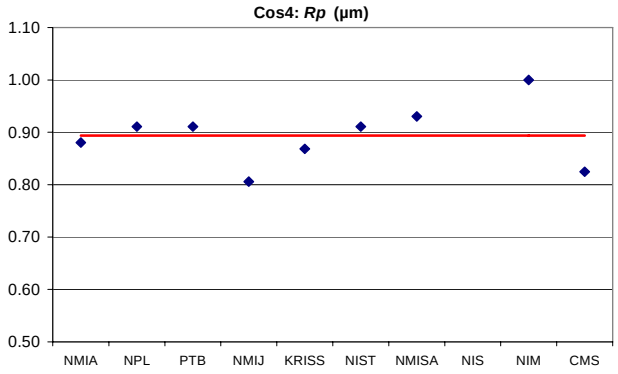
				Software	File	Cutoff	Filter	*Ra*	*Rq*	*Rz*	*Rp*	*Rv*	*Rt*	*RSm*
				µm	µm	mm		µm	µm	µm	µm	µm	µm	µm
Australia	07/08	NMIA	1	Turbo Wave v7.20	4PTB.SMD, ASC	0.8	off	-0.030782	-0.017208	-0.051900	-0.030459	-0.021441	0.006237	0.000028
UK	09/08	NPL	3	Softgauges 1.01	4NPL.SMD	0.8	off	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Germany	10/08	PTB	4	RPTB v1.46	4PTB.SMD	0.8	off	-0.000022	0.009642	-0.000040	-0.000039	-0.000001	-0.000003	-0.019972
Japan	01/09	NMIJ	7	NMIJ v1.1	PRF	0.8	off	-0.082782	-0.089208	-0.216400	-0.104959	-0.111441	0.000237	0.000028
South Korea	04/09	KRISS	8	FTS Ultra v4.3.14	PRF	0.8	off	-0.031382	-0.012908	-0.088100	-0.042459	-0.045641	-0.003063	-2.509972
USA	06/09	NIST	9	NIST 'SMATS' web-based [1]	ASC	0.8	off	-0.000002	-0.000018	-0.000040	-0.000069	-0.000001	-0.000003	-0.000002
South Africa	09/09	NMISA	11	Ultra v5.11.6.17	?	0.8	off	0.031918	0.036592	0.054400	0.019241	0.035159	-0.042863	-3.699972
Egypt	10/09	NIS	12	Ultra v5.16.2.0	SMD	?	off	-0.083282	-0.058008	-1.803600	-0.909559	-0.894041	-1.995963	-2.349972
China	11/09	NIM	13	Talymap Gold v5.1.1.5374	PRF	?	off	-0.083282	-0.058108	0.192200	0.089041	0.103059	-0.000163	-0.479972
Ch Teipei	01/10	CMS	14	?	SMD	0.8	off	-0.083282	-0.058008	-0.149400	-0.086459	-0.062941	0.000037	0.000728

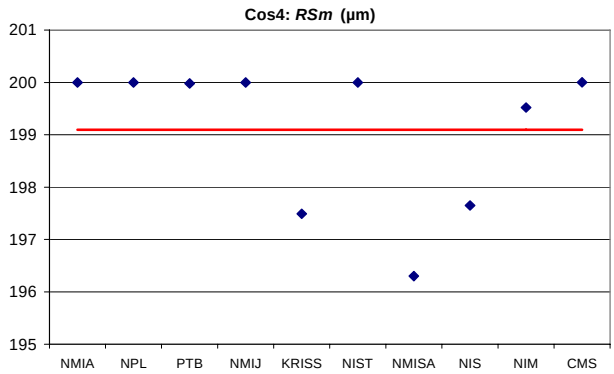
The red line in each graph is the average of all results.

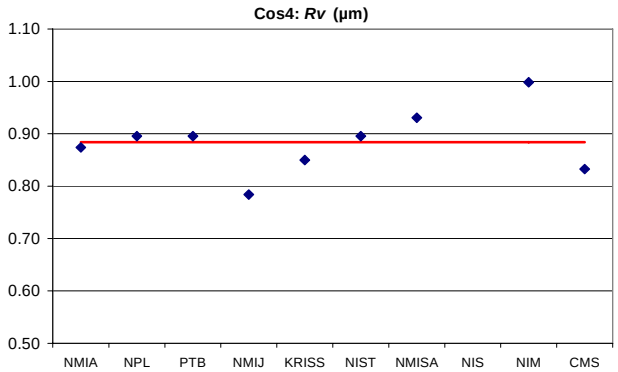


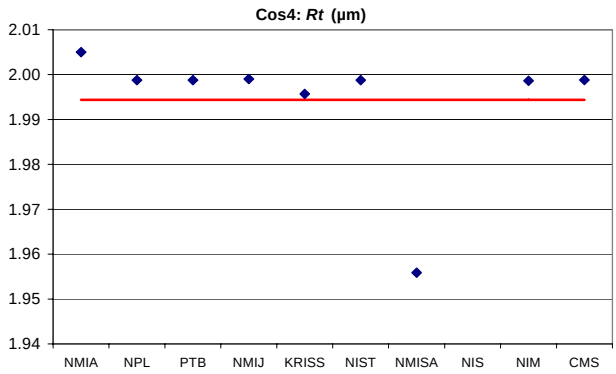












Submitted results and graphs are shown for the Sin_2_16 softgauge, including the software and the file format used. Uncertainties are not applicable. Two comparisons are determined; an E_n value and a difference from the supplied NPL value. NIS did not submit a result for *RSm*.

Softgauge Sin_2_16 results

Note: Singapore, Hong Kong, Thailand, South Korea, India, China, Vietnam and Indonesia did not submit a result. Uncertainty not applicable.

Laboratory	Date		No.	Software	File	Cutoff	Filter	*Ra*	*Rq*	*Rz*	*Rp*	*Rv*	*Rt*	*RSm*
				µm	µm	mm		µm	µm	µm	µm	µm	µm	µm
Australia	07/08	NMIA	1	Turbo Wave v7.20	4PTB.SMD, ASC	0.8	off	0.412000	0.505000	1.990000	0.995000	0.995000	1.990000	50.000000
UK	09/08	NPL	3	Softgauges 1.01	4NPL.SMD	0.8	off	0.405566	0.500000	1.990376	0.995188	0.995188	1.990376	49.999991
Germany	10/08	PTB	4	RPTB v1.46	4PTB.SMD	0.8	off	0.405560	0.500020	1.990340	0.995170	0.995170	1.990340	50.000000
Japan	01/09	NMIJ	7	NMIJ v1.1	PRF	0.8	off	0.405000	0.500000	1.990000	0.995000	0.995000	1.990000	50.000000
South Korea	04/09	KRISS	8	FTS Ultra v4.3.14	PRF	0.8	off	0.404700	0.499000	1.986500	0.993200	0.993200	1.986500	50.000000
USA	06/09	NIST	9	NIST 'SMATS' web-based [1]	ASC	0.8	off	0.405510	0.500000	1.990340	0.995170	0.995170	1.990340	50.000080
South Africa	09/09	NMISA	11	Ultra v5.11.6.17	?	0.8	off	0.403800	0.497900	1.981700	0.991900	0.989700	1.981700	50.000000
Egypt	10/09	NIS	12	Ultra v5.16.2.0	SMD	?	off	0.405700	0.500100	1.990400	0.995200	0.995200	1.990400	no result
China	11/09	NIM	13	Talymap Gold v5.1.1.5374	PRF	?	off	0.404700	0.499000	1.986600	0.993300	0.993300	1.986600	50.000000
Ch Teipei	01/10	CMS	14	?	SMD	0.8	off	0.405500	0.500000	1.990400	0.995200	0.995200	1.990400	56.632700
							Arithmetic Mean	**0.405804**	**0.500102**	**1.988473**	**0.994348**	**0.994103**	**1.988473**	**50.736975**
							St Deviation	0.0023	0.0019	0.0030	0.0012	0.0018	0.0030	2.2109
							Count	**10**	**10**	**9**	**9**	**9**	**9**	**9**

[1] NIST software: Surface Metrology Algorithm Testing System (SMATS), http://physics.nist.gov/smats

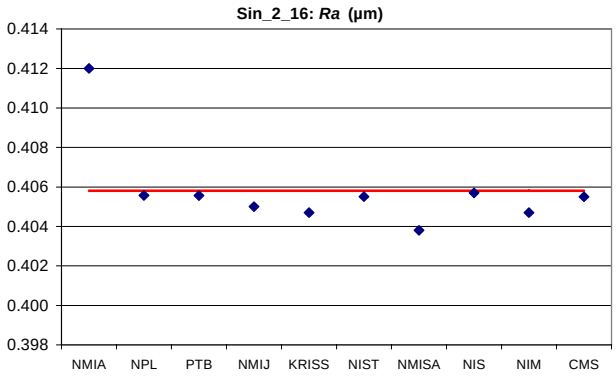
Calculation of E_n for each laboratory to arithmetic mean using the population standard deviation as nominal uncertainties.

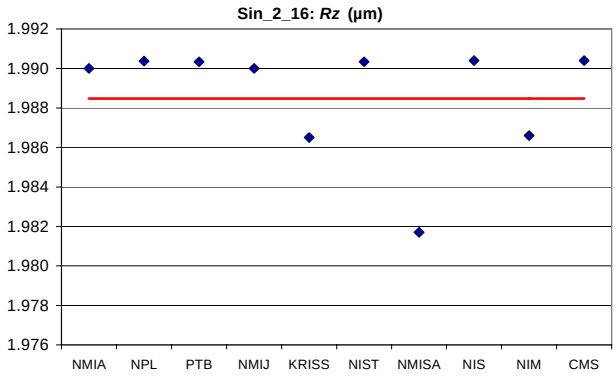
Laboratory	Date		No.	Software	File	Cutoff	Filter	*Ra*	*Rq*	*Rz*	*Rp*	*Rv*	*Rt*	*RSm*
				µm	µm	mm		*En*	*En*	*En*	*En*	*En*	*En*	*En*
Australia	07/08	NMIA	1	Turbo Wave v7.20	4PTB.SMD, ASC	0.8	off	1.94	1.86	0.36	0.38	0.34	0.36	-0.24
UK	09/08	NPL	3	Softgauges 1.01	4NPL.SMD	0.8	off	-0.07	-0.04	0.45	0.48	0.42	0.45	-0.24
Germany	10/08	PTB	4	RPTB v1.46	4PTB.SMD	0.8	off	-0.08	-0.03	0.44	0.47	0.41	0.44	-0.24
Japan	01/09	NMIJ	7	NMIJ v1.1	PRF	0.8	off	-0.25	-0.04	0.36	0.38	0.34	0.36	-0.24
South Korea	04/09	KRISS	8	FTS Ultra v4.3.14	PRF	0.8	off	-0.35	-0.42	-0.46	-0.66	-0.35	-0.46	-0.24
USA	06/09	NIST	9	NIST 'SMATS' web-based [1]	ASC	0.8	off	-0.09	-0.04	0.44	0.47	0.41	0.44	-0.24
South Africa	09/09	NMISA	11	Ultra v5.11.6.17	?	0.8	off	-0.63	-0.83	-1.59	-1.41	-1.69	-1.59	-0.24
Egypt	10/09	NIS	12	Ultra v5.16.2.0	SMD	?	off	-0.03	0.00	0.45	0.49	0.42	0.45	n/a
China	11/09	NIM	13	Talymap Gold v5.1.1.5374	PRF	?	off	-0.35	-0.42	-0.44	-0.60	-0.31	-0.44	-0.24
Ch Teipei	01/10	CMS	14	?	SMD	0.8	off	-0.10	-0.04	0.45	0.49	0.42	0.45	1.89

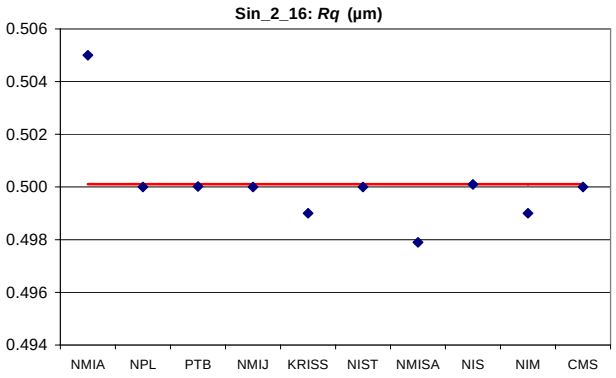
Difference from NPL values

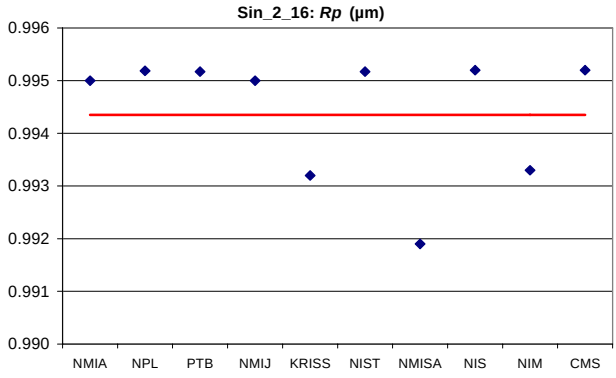
Laboratory	Date		No.	Software	File	Cutoff	Filter	*Ra*	*Rq*	*Rz*	*Rp*	*Rv*	*Rt*	*RSm*
				µm	µm	mm		µm	µm	µm	µm	µm	µm	µm
Australia	07/08	NMIA	1	Turbo Wave v7.20	4PTB.SMD, ASC	0.8	off	0.006434	0.005000	-0.000376	-0.000188	-0.000188	-0.000376	0.000009
UK	09/08	NPL	3	Softgauges 1.01	4NPL.SMD	0.8	off	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Germany	10/08	PTB	4	RPTB v1.46	4PTB.SMD	0.8	off	-0.000006	0.000020	-0.000036	-0.000018	-0.000018	-0.000036	0.000009
Japan	01/09	NMIJ	7	NMIJ v1.1	PRF	0.8	off	-0.000566	0.000000	-0.000376	-0.000188	-0.000188	-0.000376	0.000009
South Korea	04/09	KRISS	8	FTS Ultra v4.3.14	PRF	0.8	off	-0.000866	-0.001000	-0.003876	-0.001988	-0.001988	-0.003876	0.000009
USA	06/09	NIST	9	NIST 'SMATS' web-based [1]	ASC	0.8	off	-0.000056	0.000000	-0.000036	-0.000018	-0.000018	-0.000036	0.000089
South Africa	09/09	NMISA	11	Ultra v5.11.6.17	?	0.8	off	-0.001766	-0.002100	-0.008676	-0.003288	-0.005488	-0.008676	0.000009
Egypt	10/09	NIS	12	Ultra v5.16.2.0	SMD	?	off	0.000134	0.000100	0.000024	0.000012	0.000012	0.000024	n/a
China	11/09	NIM	13	Talymap Gold v5.1.1.5374	PRF	?	off	-0.000866	-0.001000	-0.003776	-0.001888	-0.001888	-0.003776	0.000009
Ch Teipei	01/10	CMS	14	?	SMD	0.8	off	-0.000066	0.000000	0.000024	0.000012	0.000012	0.000024	6.632709

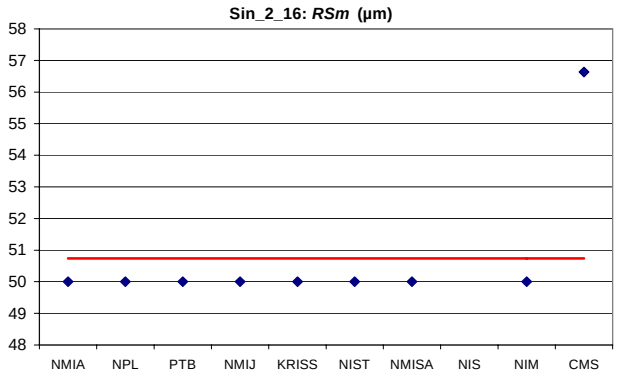
The red line in each graph is the average of all results.

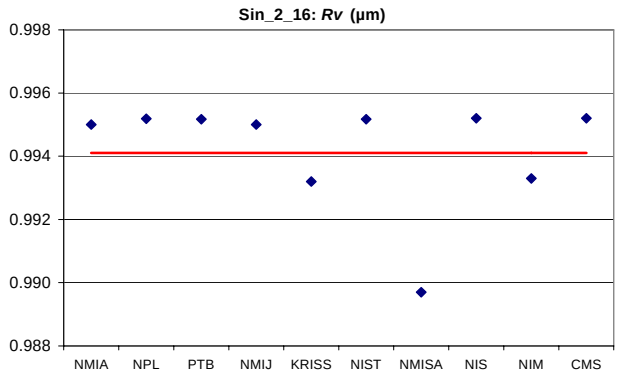


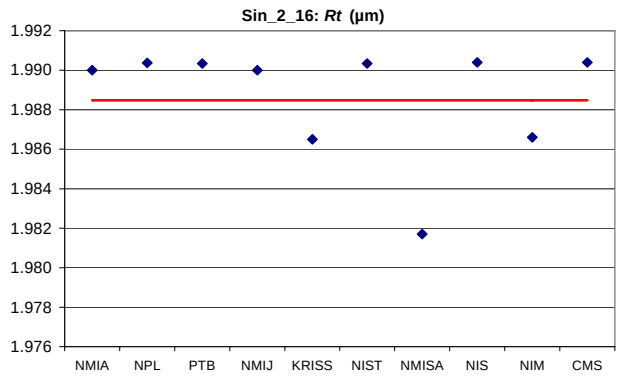












Appendix E. Alternative analysis by degree of equivalence method

The submitted results were also assessed using the degree of equivalence method as described by M. Cox in [12] for information purposes only. The calculations are not shown. The additional outliers produced by this method compared to the Birge ratio method are shown in blue. Note that the order of exclusion was not always the same. Table E1 is comparable to Table 8 for the Birge method.

Table E1. Results of outlier exclusion and key comparison reference value

S/N	Param	Initial		Outliers removed						Final			Change
		n	KCRV µm	First	Second	Third	Fourth	Fifth	Sixth	n	**KCRV µm**	U95%	µm
A277	**Gr A**	14	0.383	VMI	KIM-LIPI					12	**0.383**	0.001	-
	Gr B	15	2.834	VMI	NPLI	KIM-LIPI				12	**2.834**	0.003	-
	Ra	16	0.931	NPLI	KRISS	NIST	CMS	KIM-LIPI	NMISA	10	**0.932**	0.007	-
	Rz	16	2.482	NPLI	NMISA	KIM-LIPI				13	**2.486**	0.005	0.005
	RSm	15	76.235	KIM-LIPI	NIS	KRISS				12	**76.284**	0.076	0.049
7462	**Groove**	15	10.043	NPLI	VMI					13	**10.037**	0.011	-0.006
1286	***Ra***	16	3.106	KIM-LIPI						15	**3.106**	0.003	-
	Rz	16	9.815	KIM-LIPI						15	**9.817**	0.010	0.003
	RSm	15	99.158	KIM-LIPI	NPL	KRISS	NIST	NMIJ		10	**99.106**	0.065	-0.052
5276	***Ra***	15	0.223							15	**0.223**	0.001	-
	Rq	15	0.271							15	**0.271**	0.001	-
	Rz	15	1.464	VMI	NMC	CMS	KRISS			11	**1.470**	0.017	0.006
	Rp	15	0.707	NPLI	VMI	NMC				12	**0.700**	0.008	-0.007
	Rv	14	0.758	VMI	NMC	CMS				11	**0.764**	0.011	0.006
	Rt	15	1.673	NPL						14	**1.660**	0.021	-0.013
	Rsk	13	-0.071	NPLI	NMISA					11	**-0.060**	0.010	0.011
	Rku	12	2.594							12	**2.594**	0.018	-
	Rk	10	0.771							10	**0.771**	0.009	-
	Rpk	10	0.203							10	**0.203**	0.006	-
	Rvk	10	0.231							10	**0.231**	0.005	-
	Mr1	10	6.761	KRISS						9	**6.793**	0.132	0.032
	Mr2	10	90.895	KRISS	KIM-LIPI					8	**90.563**	0.241	-0.332
5256	***Ra***	15	1.653	KIM-LIPI	NIS	KRISS	NMC			11	**1.661**	0.006	0.008
	Rq	15	2.013	KIM-LIPI	NIS	NMC				12	**2.019**	0.007	0.006
	Rz	15	8.523	VMI	NMC	KIM-LIPI	NIS	NPLI		10	**8.040**	0.046	-0.483
	Rp	15	2.870	NPLI	VMI	KIM-LIPI	NMC	CMS	KRISS	9	**2.885**	0.022	0.015
	Rv	14	5.292	VMI	NMC	NIS	KIM-LIPI			10	**5.186**	0.031	-0.106
	Rt	15	10.375	NIS	KIM-LIPI	NPLI	CMS			11	**10.418**	0.063	0.043
	Rsk	13	-0.718	NPLI	NPL	CMS				10	**-0.813**	0.018	-0.095
	Rku	12	2.831	NMC	VMI	NIM	NMIA	KRISS		7	**2.724**	0.028	-0.108
	Rk	10	4.199	NIM	VMI	KIM-LIPI				7	**4.146**	0.038	-0.054
	Rpk	10	0.266	NMC						9	**0.259**	0.018	-0.007
	Rvk	10	3.331	KIM-LIPI	KRISS	CMS	VMI			6	**3.390**	0.031	0.059
	Mr1	8	2.565							8	**2.565**	0.221	-
	Mr2	10	78.035	NIM	KRISS	VMI				7	**77.482**	0.472	-0.553
Totals	**35**	**464**								**377**			
Removed										**87**			

For the degree of equivalence method, eighty-seven of 464 results are excluded (18.8%). Compare this to the results in table 8 using the Birge method from which sixty results (12.9%) were excluded. For individual laboratory performance, Figure E1 shows the ratio of parameters excluded to those submitted.

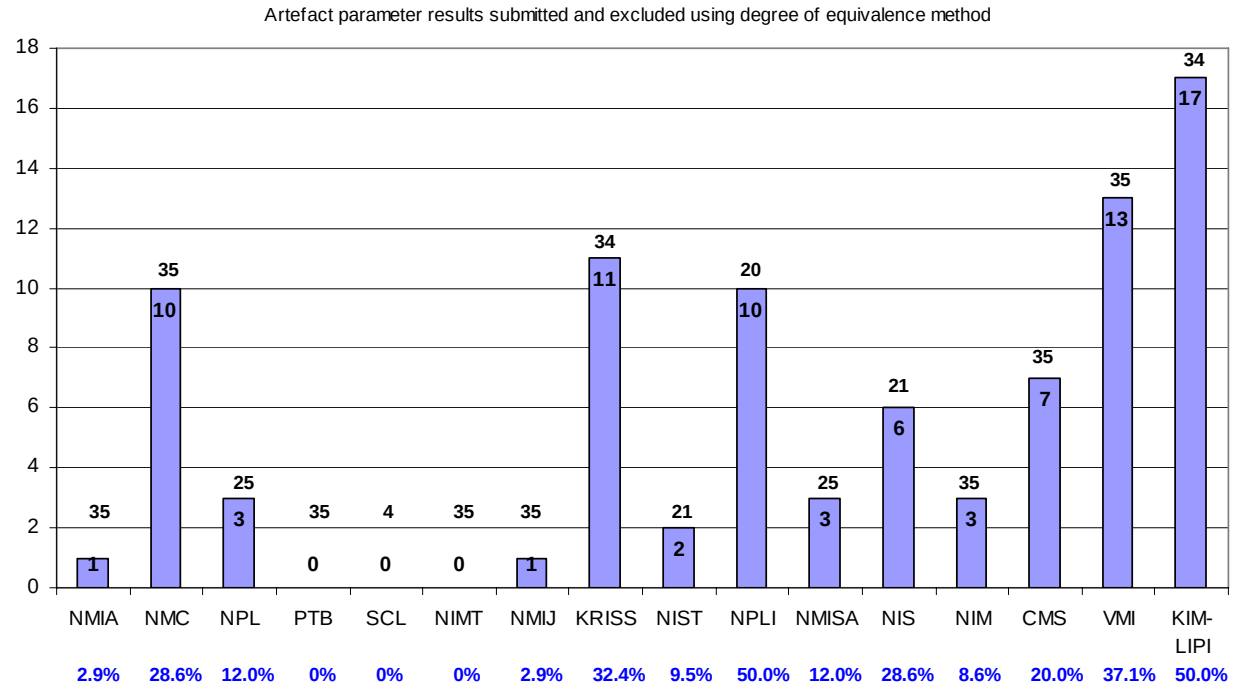


Figure E1. Laboratory results removed from key comparison reference value using degree of equivalence method.

Only six of the sixteen laboratories had no additional outliers under this analysis method. Some laboratories had up to six additional outliers removed compared to the Birge method. This may be due to the Birge ratio method being used in conjunction with the E_n ratio where these two calculations are not directly related. The degree of equivalence method is more statistically rigorous; therefore this analysis has been included for participants' information and their own further investigation.