CIPM MRA
Comparison reports

EURAMET.L-K3.n01

Calibration of angle standards

KEY COMPARISON

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Report on EURAMET Key Comparison
Calibration of Angle Standards

EURAMET.L-K3.n01

Final Report

M Astrua (INRIM),

M Pisani (INRIM), D Tamakyarska (BIM), V Vasilev (BIM), M Pérez (CEM), F Dvořáček (CMI), MW Chang (CMS/ITRI), S Zelenika (DMDM), C Bantis (EIM), D Czułek (GUM), P Sosinowski (GUM), F Saraiva (IPQ), L Švedova (LATMB), J Salgado (LNE), K Vacharanukul (NIMT), P Cox (NMIA), MH Razman (NMIM), S Mortimer (NPL), A Sanjid (NPL-I), T Yepenov (RSE), F AlQahtani (SASO-NMCC), G Tang (SCL), Y Glushko (SE), A. Fursa (SE), R Koops (VSL), A Lassila (VTT MIKES)

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1 Introduction

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM or by the regional metrology organizations in collaboration with the Consultative Committees.

At its meeting in October 2018, the EURAMET Technical Committee for Length, EURAMET TC-L, decided upon a key comparison on angle measurements with INRIM as the pilot laboratory. The comparison was registered in March 2021, artefact circulation started in June 2021 and was completed in September 2023.

2 Organization

2.1 Participants

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, email
INRIM (Pilot)	Milena Astrua, Marco Pisani INRiM, Istituto Nazionale di Ricerca Metrologica, Div. Applied Metrology and Engineering strada delle Cacce, 91 10135 - Torino - Italy	Phone: +39 011 3919 963 m.astrua@inrim.it m.pisani@inrim.it
BIM	Denita Tamakyarska, Valentin Vasilev Bulgarian Institute of Metrology GD National Center of Metrology 52B, G.M. Dimitrov Blvd 1797 Sofia - Bulgaria	Phone: +359 9702 719 d.tamakjarska@bim.government.bg v.vasilev@bim.government.bg
CEM	Mª Mar Pérez CENTRO ESPAÑOL DE METROLOGÍA C/ del Alfar, 2 Tres Cantos – 28760 Madrid - Spain	Phone: +34 91 8074 801 mmperezh@cem.es
CMI	František Dvořáček CMI OI Liberec Slunecná 23 460 01 Liberec - Czech Republic	Phone: fdvoracek@cmi.cz
CMS/ITRI	Ming Wei Chang Bldg. 8, 321, Sec. 2, Kuang-Fu Rd., Hsinchu City, 30011 Taiwan, R.O.C.	Phone: +886 3 5743762 MWChang@itri.org.tw
DMDM	Slobodan Zelenika Directorate of Measures and Precious Metals Mike Alasa 14 11000 Belgrade - Serbia	Phone: +381 11 2024 421 zelenika@dmdm.rs
EIM	Christos Bantis	Phone: +302310569952

	Hellenic Institute of Metrology (EIM) Industrial Area of Thessaloniki, Block 45 57022 Sindos, Thessaloniki – Greece	bantis@eim.gr
GUM	Dariusz Czułek, Piotr Sosinowski Central Office of Measures (GUM) ul. Elektoralna 2, 00-139 Warsaw – Poland	Phone: +48 22 581 9543 d.czulek@gum.gov.pl piotr.sosinowski@gum.gov.pl
IPQ	Fernanda Saraiva Instituto Português da Qualidade Rua António Gião, 2 Almada 2829-513 CAPARICA – Portugal	Phone: +351 212 948 460 Fsaraiva@ipq.pt
LATMB	Larisa Švedova SIA "Latvijas nacionālais metroloģijas centrs" Metroloģijas birojs (LatMB) Kr. Valdemara street 157 - 1013 Riga - Latvia	Phone: +371 67 51 77 27 larisa.svedova@latmb.lv
LNE	José Salgado LNE 23 Avenue Albert Bartholomé - 75015 Paris – France	Phone: +33 1 40 43 39 57 +33 1 40 43 37 37 Jose-Antonio.Salgado@lne.fr
NIMT	Ketsaya Vacharanukul 3-4/5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120 Thailand	Phone: +66 25775100 ext. 1216 ketsaya@nimt.or.th
NMIA	Peter Cox NMIA, 1/153 Bertie Street Port Melbourne VIC 3207 Australia	Phone: +61 3 9644 4906 Peter.Cox@measurement.gov.au
NMIM	Razman Mohd Halim, Rafidah Rosli National Metrology Institute of Malaysia Lot PT 4803 Bandar Baru Salak Tinggi 43900 Sepang - Malaysia	Phone: +603-87781613 +603-87781616 razmanmh@sirim.my rafidahr@sirim.my
NPL	Steve Mortimer NPL Room F3-A6 Engineering Measurement Division Hampton Road, Teddington TW11 0LW - United Kingdom	Phone: +44 2089436373 steve.mortimer@npl.co.uk
NPL-I	Arifsanjid Arifsanjid LENGTH & DIMENSION STANDARDS National Physical Laboratory, Dr. K.S. Krishnan Road, New Delhi – 110012 - India	Phone: sanjid@nplindia.org
RSE	Tilek Yepenov Kazakhstan Institute of Standardisation and Metrology 010016, Astana city, Left bank, Mangilik El avenue, 11 - Kazakhstan	Phone: t.epenov@ksm.kz
SASO-NMCC	Faisal A. AlQahtani National Measurement and Calibration Center (Building No. 4) PO. B 3437 Riyadh 11471 Kingdom of Saudi Arabia	Phone: +966 5404 556 55 +966 1125 297 26 f.qahtany@saso.gov.sa
SCL	George Tang Standards and Calibration Laboratory 35/F Immigration Tower, 7 Gloucester Road Wanchai, Hong Kong, China	Phone: +852 2829 4839 +852 2829 4805 george.tang@itc.gov.hk
SE	Yuri Glushko, Anna Fursa SE "UKRMETRTESTSTANDART" Metrolohichna St, 4, Kyiv, Ukraine, 03143	Phone: +38 098 4239322 yglushko@ucsm.com.ua

VSL	Richard Koops VSL Thijsseweg 11, 2629 JA Delft, The Netherlands	Phone: +31 15 2691500 +31 6 31119917 rkoops@vsl.nl
VTT MIKES	Antti Lassila VTT MIKES Tekniikantie 1 02151 Espoo – Finland	Phone: +358 40 7678584 Antti.Lassila@vtt.fi

2.2 Schedule

Due to the high number of participants, the comparison was organized in two groups of NMIs measuring one optical polygon each: a first group inside EURAMET and a second one outside.

Table 2. Schedule of the comparison for group 1

RMO	Laboratory	Original schedule	Date of measurement	Results received
EURAMET	INRIM	June 2021	June 2021	
	EIM	July 2021	July 2021	December 2021
	IPQ	August 2021	August 2021	September 2021
	VSL	September 2021	September 2021	October 2021
	GUM	October 2021	October 2021	December 2021
	LNE	November 2021	November 2021	September 2022
Pilot Lab	INRIM	December 2021	December 2021	
	VTT MIKES	January 2022	January 2022	March 2022
	BIM	February 2022	February 2022	March 2022
	CEM	March 2022	March 2022	June 2022
	CMI	April 2022	April 2022	August 2022
Pilot Lab	INRIM	May 2022	May 2022	
	DMDM	June 2022	June 2022	July 2022
	NPL	July 2022	July 2022	August 2022
	LATMB	August 2022	August 2022	September 2022
Pilot Lab	INRIM	September 2022	September 2022	

Table 3. Schedule of the comparison for group 2

RMO	Laboratory	Original schedule	Date of measurement	Results received
EURAMET	INRIM	July 2021	July 2021	
APMP	NPL-I	August 2021	October 2021	July 2023
APMP	NIMT	September 2021	November 2021	March 2022
APMP	SCL	October 2021	October 2022	November 2022
APMP	CMS/ITRI	November 2021	February 2022	June 2022
APMP	NMIM	December 2021	April 2022	May 2022
APMP	NMIA	January 2022	June 2022	August 2022
Pilot Lab	INRIM	February 2022	September 2022	
GULFMET	SASO-NMCC	March 2022	June 2023	October 2023
COOMET	RSE	April 2022	January 2023	November 2023
COOMET	SE	May 2022	September 2023	September 2023
Pilot Lab	INRIM	June 2022	October 2023	

3 Artefacts

3.1 Description of artefacts

The artefacts to be calibrated are the following ones:

Table 4. List of artefacts.

Standard	Manufacturer	Model	Identification	Properties	Group
12-sided polygon	Moeller Wedel Optical		320	Face dimension: 25 mm diameter	Group 1
12-sided polygon	Matrix	STD.638	T4147	Face dimension: (16 x 16) mm	Group 2

Figure 1. Picture of angular standards

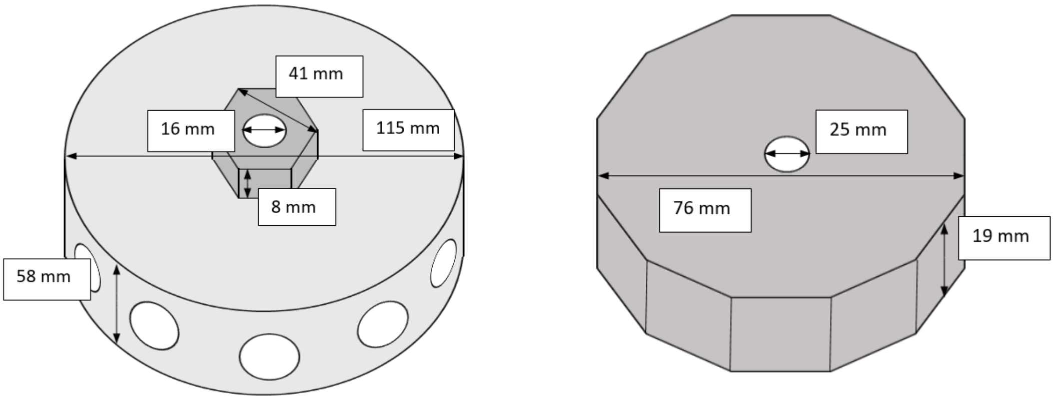


Figure 2. Dimensions of the two optical polygons

3.2 Stability of artefacts

INRIM made stability measurements on the two polygons before and during the comparison.

No instability was observed in the two artefacts, the maximum deviation being always less than the uncertainty value for all faces.

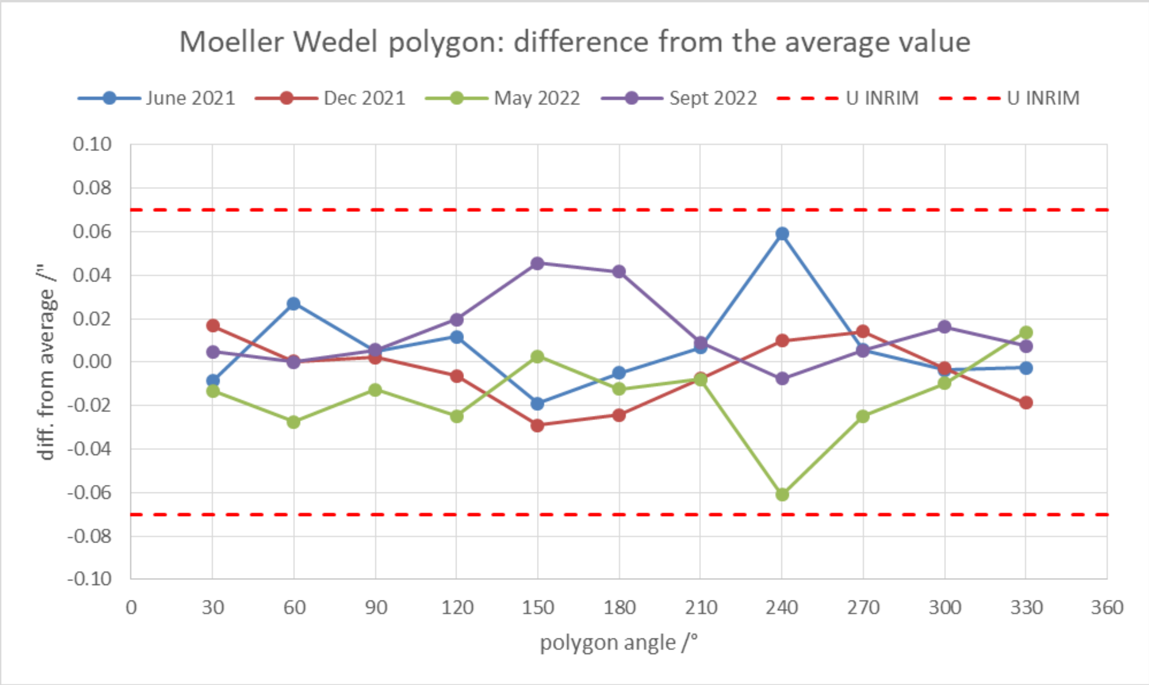


Figure 3. Stability of Moeller Wedel Optical polygon during comparison: interim angle measurements of the pilot laboratory. The red dashed lines represent the pilot expanded uncertainty (*k*=2).

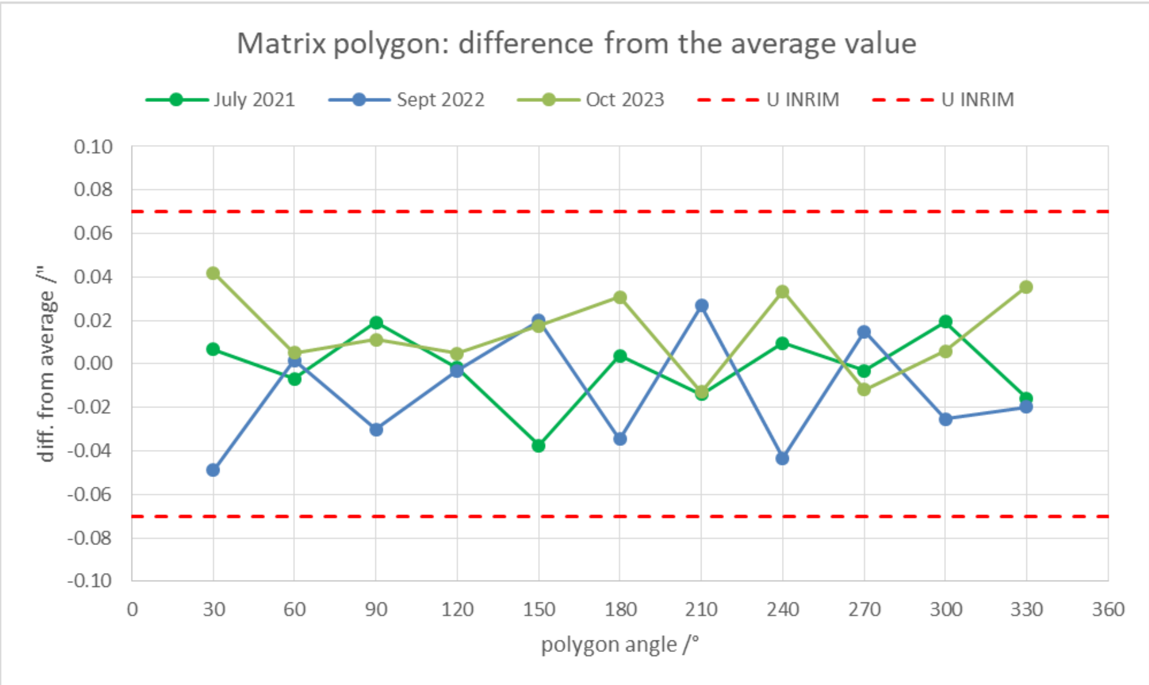


Figure 4. Stability of Matrix polygon during comparison: interim angle measurements of the pilot laboratory. The red dashed lines represent the pilot expanded uncertainty (*k*=2).

3.3 Condition of artefacts at start/end of comparison

The polygon manufactured by Moeller Wedel Optical (MWO) was in perfect conditions at the start of the comparison and no damage occurred during the circulation.

The polygon manufactured by Matrix had a small point of rust on face 30°, but INRIM measured the polygon with an autocollimator for several years without any problem. During the circulation, the condition of the artefact does not modify and the interim angle measurement performed by the pilot laboratory does not highlight any change in the measurand. Hence no additional uncertainty source due to the face imperfection has been added to the uncertainty budget.

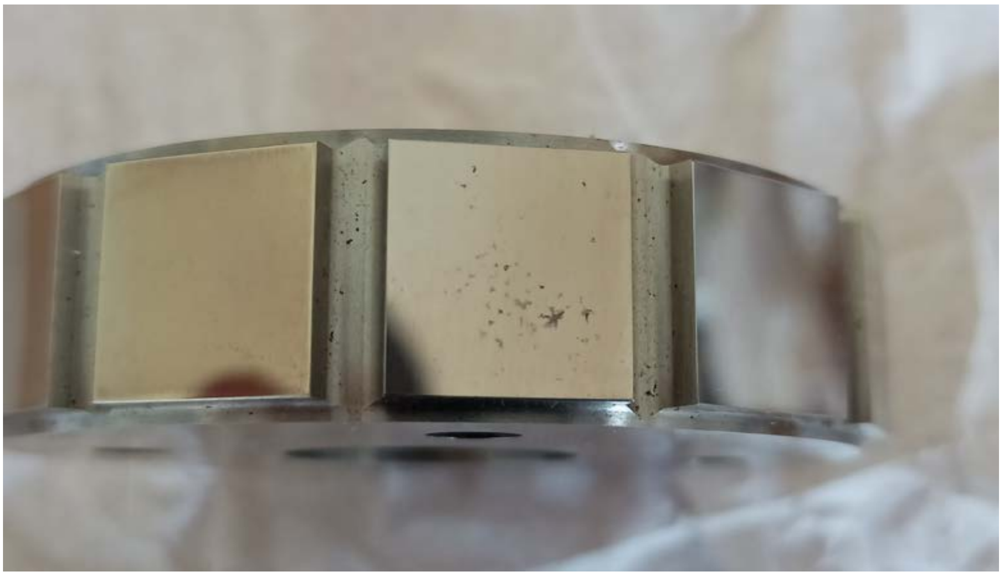


Figure 5. Picture of the defect on face 30° of Matrix polygon

4 Measuring instructions

4.1 Measurands

The optical polygon has reflecting side faces which serve as measuring faces. In ideal conditions, the individual measuring faces are perpendicular to the measuring plane. In practice, the measuring faces are not perpendicular to the measuring plane by small tilts referred to as pyramidal errors. In any case, the measuring plane is defined as the plane parallel to the base of the polygon.

The **pitch angles** α_i are the angles between the projections of two adjacent normals N_{i-1} and N_i in the measuring plane with the counting index (i=1,2,...,n). The deviations of the pitch angles from their nominal values of 360°/n are referred to as pitch angle deviations. The **measurand** is the deviation of the pitch angles from the nominal value.

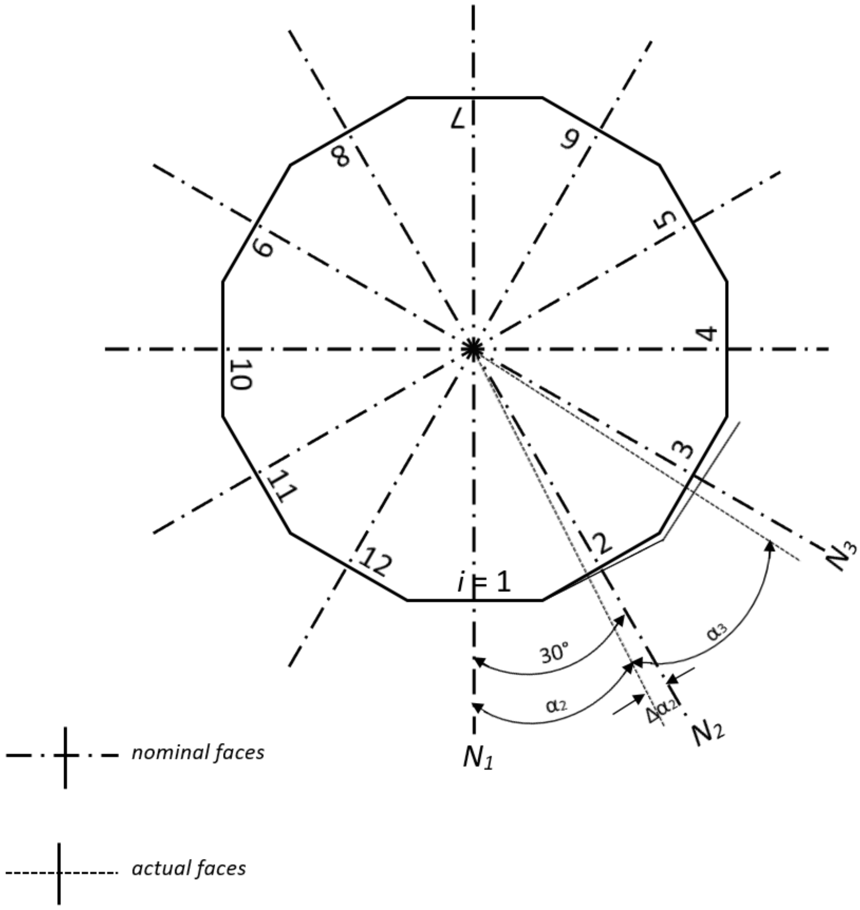


Figure 6. Drawing of optical polygon angles in case of polygon manufactured by Moeller Wedel

Measuring face index	$i = 1 \ldots n$	
Normals to the faces	N_i	
Pitch angles	α_i	(angles between $N_i - 1$ and N_i)
Pitch angle deviation	$\Delta\ \alpha_i = \alpha_i - \dfrac{360°}{n}$	(i = 2,3,…,n)

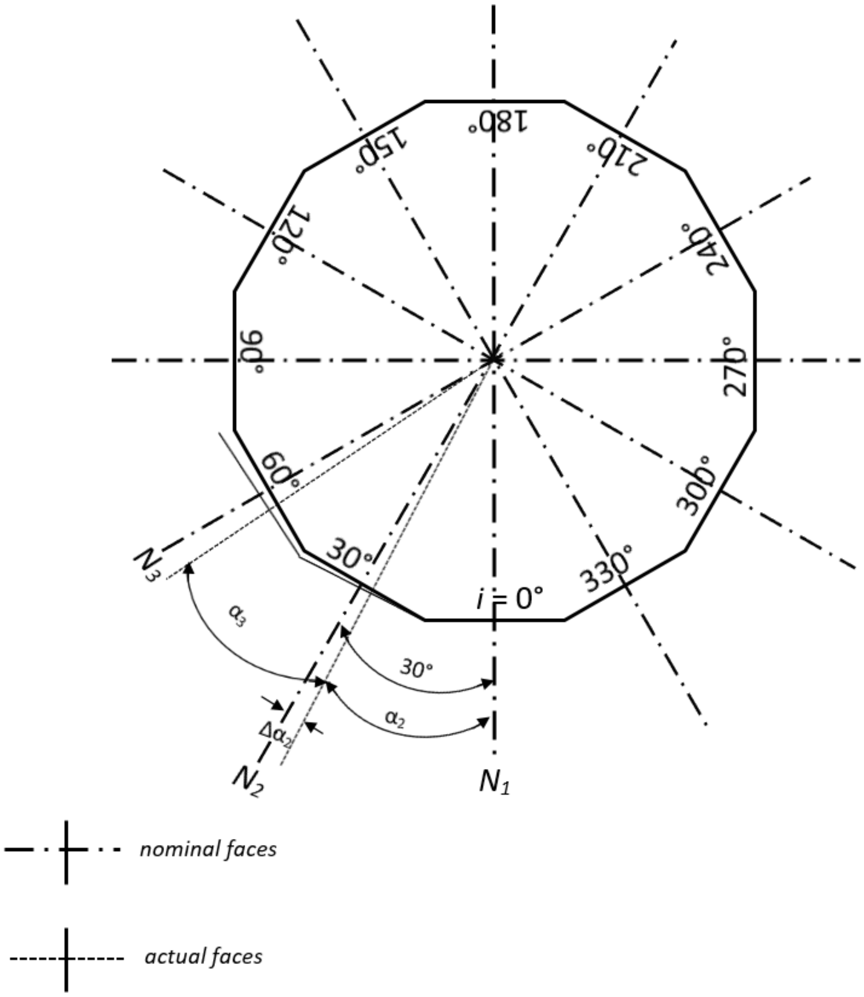


Figure 7. Drawing of optical polygon angles in case of polygon manufactured by Matrix

The positive count direction of the polygon angle corresponds to the count direction of the face (index i). Please, note that in polygon made by Moeller Wedel the positive count direction is counterclockwise (as in the drawing of figure 6), while in polygon made by Matrix the positive count direction is clockwise (as in the drawing of figure 7).

5 Apparatus and measurement methods

A short description of the measurement apparatus used by the participants is given below. Descriptions are taken and/or summarized from the partner's reports. It is worth noting that the CMC entries in the table 5 are given as quantities as reported in the KCDB (https://www.bipm.org/kcdb/).

Table 5. Instrumentation, traceability and CMC entries of participant laboratories

Participant	Instrument used	Traceability	CMC entry (k=2)
INRIM	Home made rotary table based on two Heidenhain ERA 4200 encoders and MWO Elcomat 3000 autocollimator		U = 0.07″
BIM	Reference table A.G. Davis – AA GAUGE, model RT8-BBME, and Taylor Hobson DA20 autocollimator		U = 1″

CEM	Rotary table CEM_TEK, fitted with angular encoder RON 905, and MWO Elcomat 3000 autocollimator		*U* = 0.18”
CMI	Self-calibration rotary table SCMS-127 and MWO Elcomat 3000 autocollimator		*U* = 0.6”
CMS/ITRI	Rotary table model ABR1000 by Aerotech and two autocollimators		*U* = 0.23”
DMDM	Moeller Wedel Goniometer-spectrometer	METAS	*U* = 0.2”
EIM	Eimeldingen DP-300-A2021-000 Rotary Table with Heidenhain Ron 905 encoder and MWO ELCOMAT 2000 autocollimator		-
GUM	Rotary stage RT400UP with air bearing and angle encoder Heidenhain RON 905 and an autocollimator		*U* = 0.08”
IPQ	Moore precision index table and MWO Autocollimator		*U* = 1”
LATMB	GS2 goniometer manufactured by Arsenal (Ukraine) and an autocollimator		*U* = 3”
LNE	Home made rotary table based on two Heidenhain Ron 905 encoders and MWO Elcomat HR autocollimator		*U* = 0.1”
NIMT	Self-calibration angle system and MWO autocollimator Elcomat 3000		*U* = 0.2”
NMIA	Two Moore 1440 precision index tables and Taylor Hobson DA20 autocollimator		*U* = 0.2”
NMIM	Moore 1440 precision index table and MWO Elcomat 3000 autocollimator	METAS	-
NPL	Moore 1440 precision index table and Taylor Hobson Ultra High Precision autocollimator		*U* = 0.11”
NPL-I	Continuous type rotary table and two autocollimators: MWO Elcomat 2000 and Hilger Watts HW98450		-
RSE	Index table and MWO autocollimator		-
SASO-NMCC	7” Ultradex Style “B” Index Table manufactured by AAGAUGE and MWO Elcomat 3000 autocollimator	TUBITAK UME	-
SCL	Moore index table 1440 and an autocollimator		*U* = 0.2”
SE	Angle Measuring System GS-1L (rotating table with a built-in ring laser and an autocollimator)		*U* = 0.16”
VSL	PI-Micos UPR-270-AIR and two autocollimators		*U* = 0.3”
VTT MIKES	Eimeldingen DP400NC rotary table with Heidenhein ERO 725 angle encoder and two MWO autocollimators: Elcomat HR and Elcomat 3000		*U* = 0.2”

6 Results

6.1 Results and standard uncertainties as reported by participants

The submitted results are collected in the tables below.

Table 5. Pitch angle deviations (in arcsec) of polygon manufactured by Moeller Wedel Optical.

	polygon manufactured by Moeller Wedel Optical – group 1											
Lab	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-1**
INRIM	0.290	-0.290	-0.690	-0.490	-0.200	0.080	0.590	0.020	0.210	0.160	0.360	-0.040
EIM	0.278	-0.305	-0.693	-0.513	-0.155	0.107	0.556	-0.016	0.271	0.167	0.345	-0.047
IPQ	0.140	-0.280	-0.640	-0.480	-0.180	-0.030	0.610	0.050	0.340	0.140	0.300	0.030
VSL	0.350	-0.300	-0.700	-0.620	-0.160	0.180	0.560	-0.110	0.350	0.130	0.420	-0.100
GUM	0.250	-0.340	-0.650	-0.480	-0.250	0.050	0.660	0.020	0.200	0.150	0.390	0.000
LNE	0.303	-0.336	-0.671	-0.539	-0.168	0.063	0.595	0.003	0.268	0.160	0.350	-0.028
VTT MIKES	0.320	-0.333	-0.702	-0.536	-0.130	0.094	0.551	-0.055	0.310	0.180	0.340	-0.043
BIM	0.290	-0.340	-0.670	-0.490	-0.190	0.090	0.590	-0.020	0.260	0.170	0.360	-0.060
CEM	0.320	-0.330	-0.680	-0.520	-0.150	0.080	0.580	-0.040	0.270	0.150	0.350	-0.040
CMI	0.317	-0.307	-0.693	-0.530	-0.167	0.094	0.572	-0.014	0.277	0.150	0.323	-0.023
DMDM	0.300	-0.030	-0.340	-0.210	-0.120	0.220	0.530	0.080	0.070	-0.090	-0.160	-0.250
NPL	0.283	-0.356	-0.704	-0.529	-0.145	0.093	0.589	-0.011	0.273	0.172	0.364	-0.028
LATMB	0.410	-0.420	-1.050	-0.400	-0.080	0.530	0.650	-0.340	-0.290	0.020	0.700	0.270

Table 6. Standard uncertainties of pitch angle deviations (in arcsec) for polygon manufactured by Moeller Wedel Optical.

	polygon manufactured by Moeller Wedel Optical – group 1											
Lab	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-1**
INRIM	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
EIM	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
IPQ	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
VSL	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
GUM	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.045
LNE	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
VTT MIKES	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
BIM	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510
CEM	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
CMI	0.028	0.030	0.036	0.032	0.029	0.033	0.037	0.038	0.036	0.032	0.026	0.028
DMDM	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
NPL	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
LATMB	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600

Table 7. Pitch angle deviations (in arcsec) of polygon manufactured by Matrix.

	polygon manufactured by Matrix – group 2											
Lab	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1
INRIM	1.52	-3.20	3.18	-3.70	0.75	-0.03	2.04	-1.85	1.81	3.23	-1.12	-2.64
NPL-I	1.72	-2.34	3.42	-4.17	0.92	-0.40	1.31	-2.79	2.81	2.49	-1.27	-2.16
NIMT	1.52	-3.19	3.21	-3.73	0.73	-0.05	2.08	-2.02	1.97	3.30	-1.13	-2.69
CMS	1.46	-3.14	3.18	-3.62	0.65	-0.14	2.09	-1.91	2.05	3.21	-1.14	-2.69
NMIM	1.45	-3.01	3.31	-3.68	0.56	-0.18	2.08	-1.71	1.77	3.07	-0.90	-2.79
NMIA	1.28	-3.34	3.20	-4.22	0.71	0.86	1.28	-1.22	1.77	2.71	-1.58	-1.46
SCL	1.50	-3.18	3.16	-3.71	0.78	-0.09	2.08	-2.01	1.96	3.27	-1.09	-2.65
RSE	1.23	-1.97	2.37	-2.80	1.14	-0.62	1.69	-1.74	1.16	1.32	0.14	-1.91
SASO	1.64	2.84	1.60	-2.60	0.27	-0.01	2.25	-1.89	1.93	2.96	-0.94	-2.71
SE	1.53	-2.97	3.13	-3.78	0.78	-0.13	2.13	-2.24	1.91	3.56	-0.92	-3.00

Table 8. Standard uncertainties of pitch angle deviations (in arcsec) for polygon manufactured by Matrix.

	polygon manufactured by Matrix – group 2											
Lab	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1
INRIM	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
NPL-I	0.810	0.840	1.020	0.870	0.870	0.800	0.840	0.890	1.040	0.820	0.830	0.830
NIMT	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
CMS	0.075	0.075	0.075	0.075	0.080	0.075	0.075	0.080	0.080	0.080	0.080	0.075
NMIM	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
NMIA	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120
SCL	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
RSE	0.454	0.269	0.499	0.266	0.429	0.269	0.439	0.276	0.443	0.268	0.451	0.271
SASO	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240
SE	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080

7 Analysis

7.1 Calculation of the KCRV

Each laboratory reports a measured value, x_i, and its associated standard uncertainty $u(x_i)$ for each pitch angle.

The key comparison reference value (KCRV) is calculated as the weighted mean of the participant results for each pitch angle.

The weighted mean, $\overline{x}_w$, is given by:

$$\overline{x}_w = \sum_{i=1}^{I} w_i \cdot x_i \tag{1}$$

where the normalised weight, w_i , for the result x_i is given by:

$$w_i = C \cdot \frac{1}{[u(x_i)]^2} \tag{2}$$

and the normalising factor, C, is given by:

$$C = \frac{1}{\sum_{i=1}^{I} \left(\frac{1}{u(x_i)} \right)^2} \tag{3}$$

The uncertainty of the weighted mean is calculated as:

$$u(\overline{x}_w) = \sqrt{\frac{1}{\sum_{i=1}^{I} \left(\frac{1}{u(x_i)} \right)^2}} = \sqrt{C} \tag{4}$$

After deriving the weighted mean and its associated standard uncertainty, the deviation of each laboratory's result from the weighted mean is determined simply as $x_i - \overline{x}_w$. The uncertainty of this deviation is calculated as a combination of the uncertainties of the result, $u(x_i)$, and the uncertainty of the weighted mean $u(\overline{x}_w)$. The uncertainty of the deviation from the weighted mean is given by equation (5), which includes a minus sign to take into account the correlation between the two uncertainties (it would be a plus sign if dealing with uncorrelated uncertainties, such as when comparing data from two separate laboratories).

$$u(x_i - \overline{x}_w) = \sqrt{[u(x_i)]^2 - [u_{int}(\overline{x}_w)]^2} \tag{5}$$

The degrees of equivalence for each laboratory and each pitch angle with respect to the KCRV is evaluated using E_n values defined as the ratio of the deviation from the weighted mean, divided by the expanded uncertainty of this deviation:

$$E_n = \frac{x_i - \overline{x}_w}{2\sqrt{[u(x_i)]^2 - [u_{\text{int}}(\overline{x}_w)]^2}} \tag{6}$$

For the determination of the key comparison reference value KCRV, statistical consistency of the results contributing to the KCRV is required. To this purpose, the so-called Birge ratio R_B is used: this parameter compares the observed spread of the results with the spread expected from the individual reported uncertainties.

The application of least squares algorithms and the χ^2-test leads to the Birge ratio

$$R_B = \frac{u_{ext}(\bar{x}_w)}{u(\bar{x}_w)}, \tag{7}$$

where $u_{ext}(\bar{x}_w)$ is the external standard deviation

$$u_{ext}(\bar{x}_w) = \sqrt{\frac{1}{(I-1)} \cdot \frac{\sum_{i=1}^{I} w_i (x_i - \bar{x}_w)^2}{\sum_{i=1}^{I} w_i}}. \tag{8}$$

The Birge ratio has an expectation value of R_B = 1, when considering standard uncertainties. For a coverage factor of k = 2, the expectation value is increased and the data in a comparison are consistent provided that

$$R_B < \sqrt{1 + \sqrt{8/(I-1)}} \tag{9}$$

where I is the number of laboratories. As an example, in case of I = 13 (group 1) or I = 10 (group 2), data are consistent provided that R_B < 1.35 or 1.39, respectively.

Hence, if the Birge ratio criterion is not satisfied, the result with largest $|E_n|$ is considered as inconsistent result and is excluded from the contribution to the weighted mean – *i.e.* it has a weighting of zero. Because inconsistent results are no longer correlated with the weighted mean, when calculating their deviation from the weighted mean, and when calculating their E_n value, a positive sign is used in equation (5) and consequently in the denominator of equation (6).

This process is iterated until Eq. (9) is fulfilled, hence there are no inconsistent results contributing to the weighted mean, even if values for $|E_n|$> 1 are remaining.

Table 9. Key comparison reference value $\bar{x}_w$ and associated standard uncertainty $u(\bar{x}_w)$ expressed in arcsecond for the polygon manufactured by Moeller Wedel Optical

	polygon manufactured by Moeller Wedel – group 1											
	1-2	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-1**
$\bar{x}_w$	0.304	-0.322	-0.682	-0.522	-0.165	0.085	0.582	-0.016	0.268	0.160	0.349	-0.036
$u(\bar{x}_w)$	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012

Table 10. Key comparison reference value $\bar{x}_w$ and associated standard uncertainty $u(\bar{x}_w)$ expressed in arcsecond for the polygon manufactured by Matrix

	polygon manufactured by Matrix – group 2											
	1-2	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-1**
$\bar{x}_w$	1.496	-3.161	3.174	-3.691	0.733	-0.081	2.071	-1.902	1.886	3.232	-1.080	-2.649
$u(\bar{x}_w)$	0.029	0.029	0.029	0.030	0.029	0.030	0.030	0.032	0.029	0.033	0.030	0.032

7.2 Calculation of Degrees of Equivalence

The Degree of Equivalence, DoE, for a laboratory result x_i is calculated simply as $x_i - \bar{x}_w$. The uncertainty of the DoE is calculated using either

$$u(x_i - \bar{x}_w) = \sqrt{[u(x_i)]^2 - [u_{int}(\bar{x}_w)]^2}$$ for results which contributed to the weighted mean

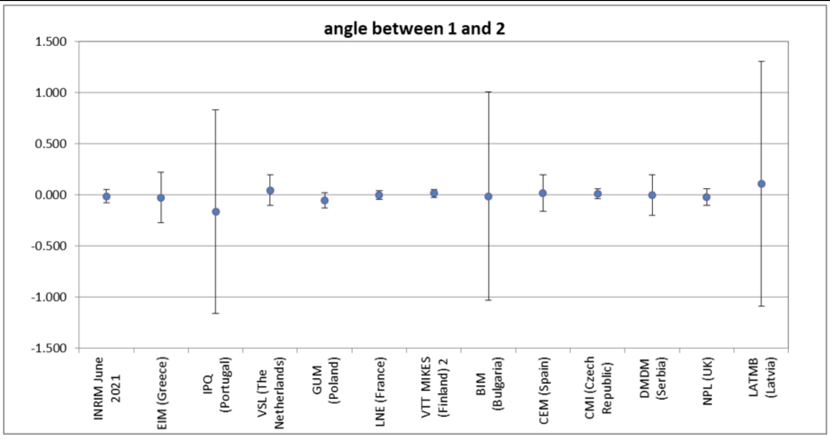
or

$$u(x_i - \bar{x}_w) = \sqrt{[u(x_i)]^2 + [u_{\mathrm{int}}(\bar{x}_w)]^2}$$ for results which made no contribution.

Tables 11 to 16 summarize the degrees of equivalence for participants of group 1, while tables 17 to 22 refer to participants of group 2. Results with $|E_n| > 1$ are highlighted in grey. The indication “1” in column “On/off” means that the corresponding value was considered for evaluating the reference value; otherwise, the indication is “0”.

Table 11.
Group 1: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 1 and 2 and angle between 2 and 3)

	Angle between 1 and 2				Angle between 2 and 3			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	-0.014	0.066	0.21	1	0.032	0.066	0.48	1
EIM	-0.026	0.249	0.10	1	0.017	0.249	0.07	1
IPQ	-0.164	1.000	0.16	1	0.042	1.000	0.04	1
VSL	0.046	0.148	0.31	1	0.022	0.148	0.15	1
GUM	-0.054	0.077	0.70	1	-0.018	0.076	0.24	1
LNE	-0.001	0.044	0.02	1	-0.014	0.044	0.32	1
VTT MIKES	0.016	0.038	0.42	1	-0.011	0.038	0.29	1
BIM	-0.014	1.020	0.01	1	-0.018	1.020	0.02	1
CEM	0.016	0.178	0.09	1	-0.008	0.178	0.05	1
CMI	0.013	0.050	0.27	1	0.015	0.055	0.27	1
DMDM	-0.004	0.199	0.02	1	0.292	0.199	1.47	1
NPL	-0.021	0.083	0.25	1	-0.034	0.083	0.41	1
LATMB	0.106	1.200	0.09	1	-0.098	1.200	0.08	1
	Consistency: R_B = 0.543				**R_B = 0.963**			



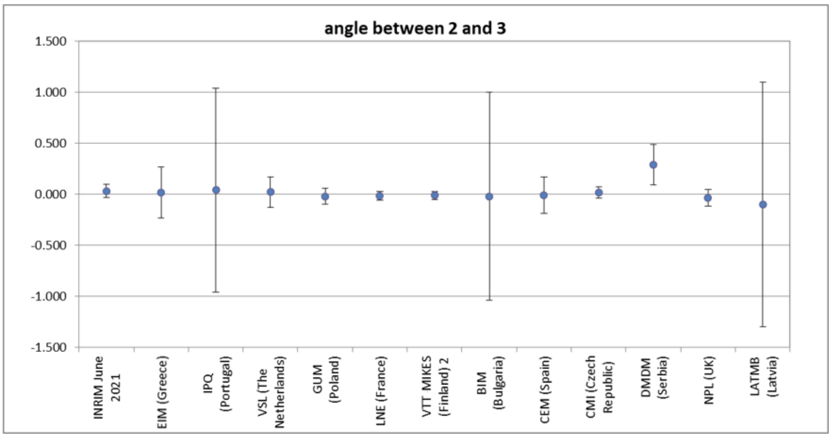
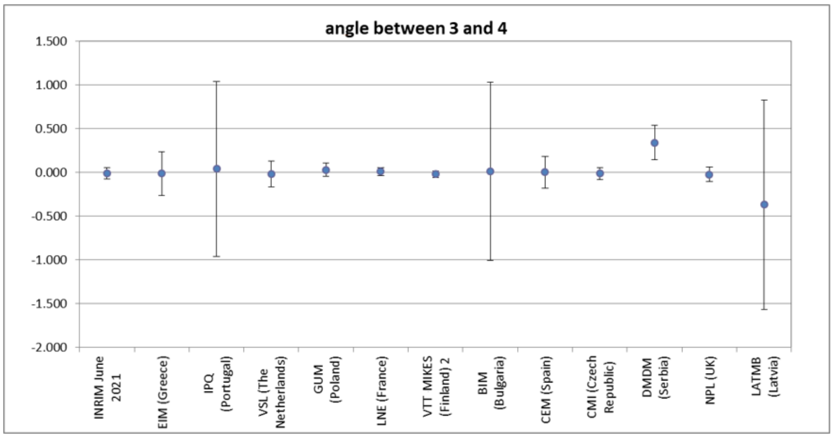


Table 12.
Group 1: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 3 and 4 and angle between 4 and 5)

	Angle between 3 and 4				Angle between 4 and 5			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	-0.008	0.066	0.12	1	0.032	0.066	0.48	1
EIM	-0.011	0.249	0.04	1	0.009	0.249	0.04	1
IPQ	0.042	1.000	0.04	1	0.042	1.000	0.04	1
VSL	-0.018	0.148	0.12	1	-0.098	0.148	0.66	1
GUM	0.032	0.076	0.42	1	0.042	0.076	0.55	1
LNE	0.011	0.044	0.25	1	-0.017	0.044	0.39	1
VTT MIKES	-0.020	0.038	0.53	1	-0.014	0.038	0.37	1
BIM	0.012	1.020	0.01	1	0.032	1.020	0.03	1
CEM	0.002	0.178	0.01	1	0.002	0.178	0.01	1
CMI	-0.011	0.068	0.16	1	-0.008	0.059	0.14	1
DMDM	0.342	0.199	1.72	1	0.312	0.199	1.57	1
NPL	-0.022	0.083	0.27	1	-0.007	0.083	0.09	1
LATMB	-0.368	1.200	0.31	1	0.122	1.200	0.10	1
	Consistency: R_B = 1.087				**R_B = 1.095**			



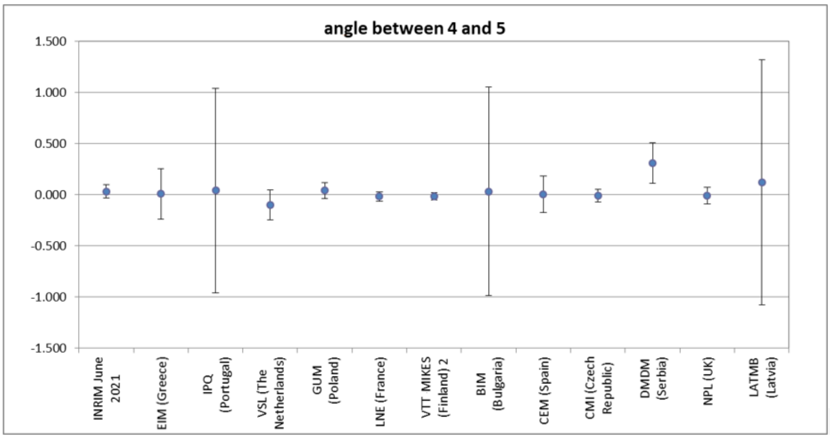
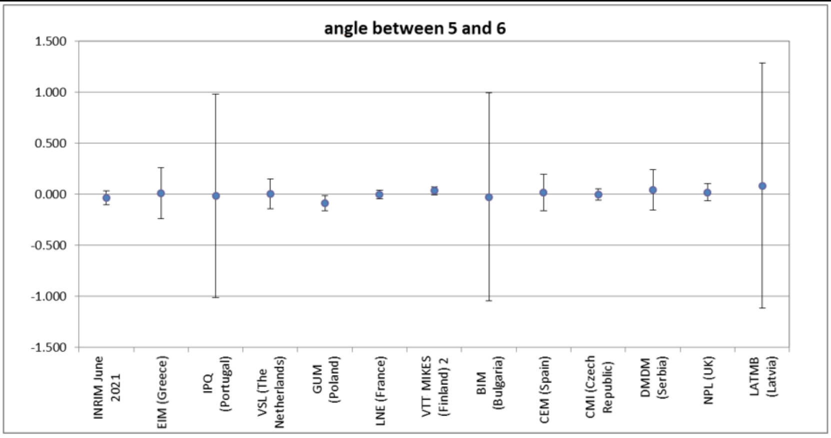


Table 13.
Group 1: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 5 and 6 and angle between 6 and 7)

	Angle between 5 and 6				Angle between 6 and 7			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	-0.035	0.066	0.53	1	-0.005	0.066	0.08	1
EIM	0.010	0.249	0.04	1	0.022	0.249	0.09	1
IPQ	-0.015	1.000	0.01	1	-0.115	1.000	0.12	1
VSL	0.005	0.148	0.03	1	0.095	0.148	0.64	1
GUM	-0.085	0.076	1.11	1	-0.035	0.076	0.46	1
LNE	-0.003	0.044	0.06	1	-0.022	0.044	0.51	1
VTT MIKES	0.035	0.038	0.92	1	0.009	0.038	0.23	1
BIM	-0.025	1.020	0.02	1	0.005	1.020	0.00	1
CEM	0.015	0.178	0.08	1	-0.005	0.178	0.03	1
CMI	-0.002	0.053	0.04	1	0.009	0.060	0.15	1
DMDM	0.045	0.199	0.23	1	0.135	0.199	0.68	1
NPL	0.020	0.083	0.24	1	0.008	0.083	0.09	1
LATMB	0.085	1.200	0.07	1	0.445	1.200	0.37	1
	Consistency: R_B = 0.838				**R_B = 0.701**			



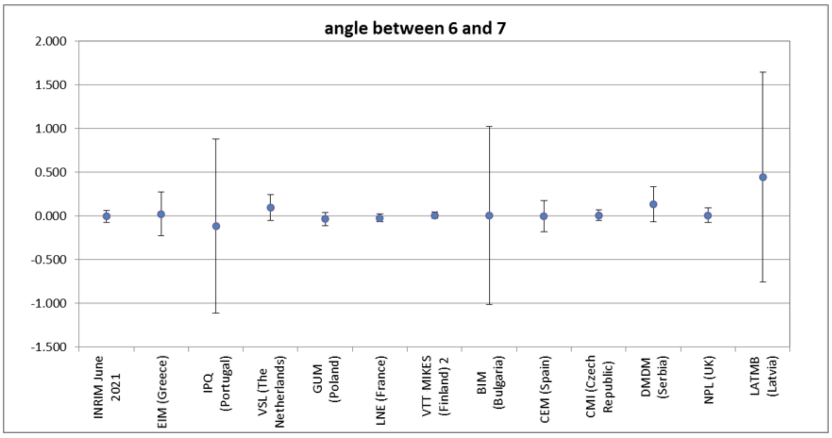
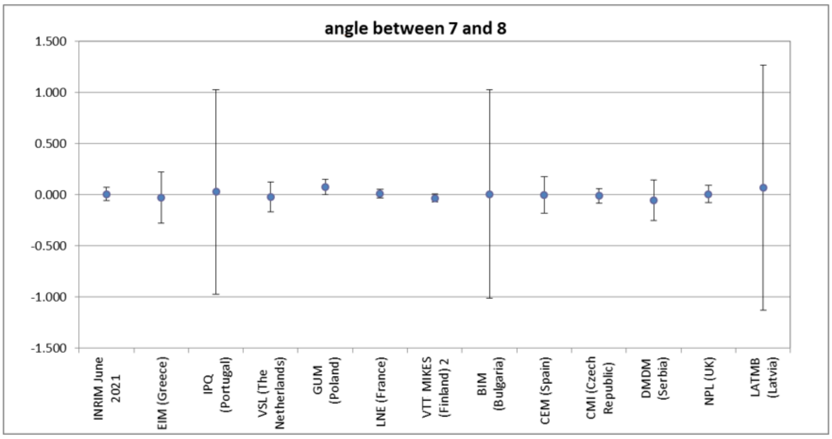


Table 14.
Group 1: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 7 and 8 and angle between 8 and 9)

	Angle between 7 and 8				Angle between 8 and 9			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	0.008	0.066	0.12	1	0.036	0.066	0.55	1
EIM	-0.026	0.249	0.10	1	0.000	0.249	0.00	1
IPQ	0.028	1.000	0.03	1	0.066	1.000	0.07	1
VSL	-0.022	0.148	0.15	1	-0.094	0.148	0.63	1
GUM	0.078	0.076	1.02	1	0.036	0.076	0.48	1
LNE	0.013	0.044	0.30	1	0.019	0.044	0.44	1
VTT MIKES	-0.031	0.038	0.82	1	-0.039	0.038	1.03	1
BIM	0.008	1.020	0.01	1	-0.004	1.020	0.00	1
CEM	-0.002	0.178	0.01	1	-0.024	0.178	0.13	1
CMI	-0.010	0.070	0.14	1	0.002	0.071	0.03	1
DMDM	-0.052	0.199	0.26	1	0.096	0.199	0.48	1
NPL	0.007	0.082	0.08	1	0.005	0.082	0.06	1
LATMB	0.068	1.200	0.06	1	-0.324	1.200	0.27	1
	Consistency: R_B = 0.738				**R_B = 0.834**			



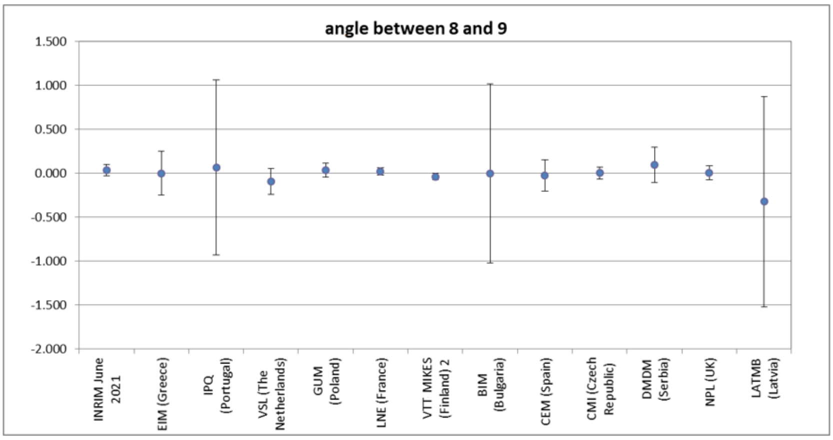
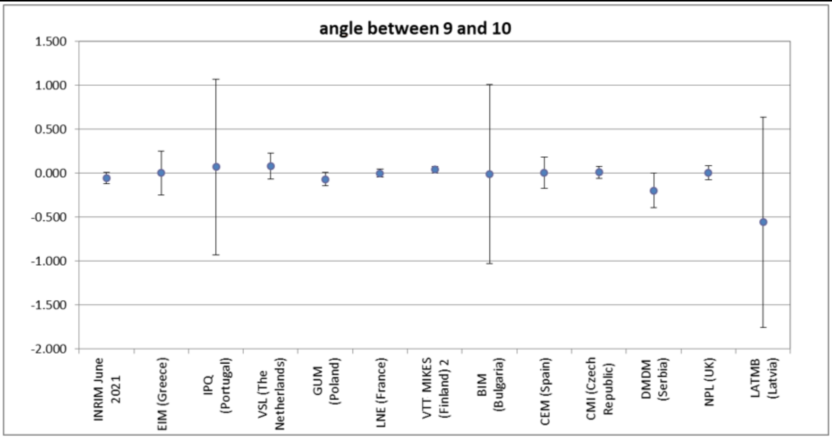


Table 15.
Group 1: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 9 and 10 and angle between 10 and 11)

	Angle between 9 and 10				Angle between 10 and 11			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	-0.058	0.066	0.88	1	0.000	0.066	0.00	1
EIM	0.003	0.249	0.01	1	0.007	0.249	0.03	1
IPQ	0.072	1.000	0.07	1	-0.020	1.000	0.02	1
VSL	0.082	0.148	0.56	1	-0.030	0.148	0.20	1
GUM	-0.068	0.076	0.89	1	-0.010	0.076	0.13	1
LNE	0.000	0.044	0.01	1	0.000	0.044	0.01	1
VTT MIKES	0.042	0.038	1.12	1	0.020	0.038	0.53	1
BIM	-0.008	1.020	0.01	1	0.010	1.020	0.01	1
CEM	0.002	0.178	0.01	1	-0.010	0.178	0.05	1
CMI	0.009	0.067	0.14	1	-0.010	0.059	0.16	1
DMDM	-0.198	0.199	1.00	1	-0.250	0.199	1.26	1
NPL	0.005	0.083	0.07	1	0.012	0.083	0.15	1
LATMB	-0.558	1.200	0.46	1	-0.140	1.200	0.12	1
	Consistency: R_B = 1.125				**R_B = 0.791**			



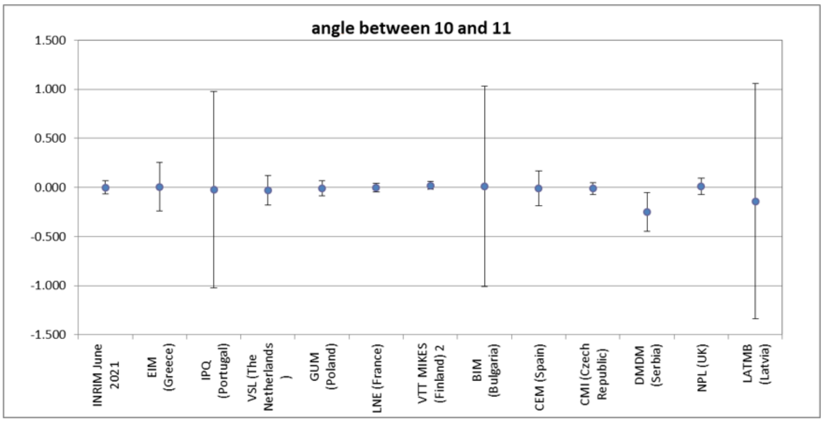
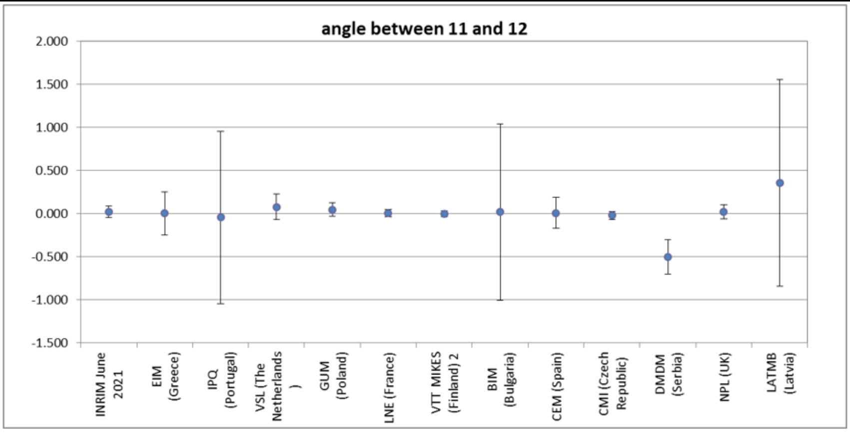


Table 16.
Group 1: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 11 and 12 and angle between 12 and 1)

	Angle between 11 and 12				Angle between 12 and 1			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	0.011	0.066	0.16	1	-0.004	0.066	0.06	1
EIM	-0.004	0.249	0.02	1	-0.011	0.249	0.05	1
IPQ	-0.049	1.000	0.05	1	0.066	1.000	0.07	1
VSL	0.071	0.148	0.48	1	-0.064	0.148	0.43	1
GUM	0.041	0.077	0.53	1	0.036	0.087	0.41	1
LNE	0.001	0.044	0.02	1	0.008	0.044	0.17	1
VTT MIKES	-0.009	0.039	0.24	1	-0.007	0.038	0.19	1
BIM	0.011	1.020	0.01	1	-0.024	1.020	0.02	1
CEM	0.001	0.178	0.00	1	-0.004	0.178	0.02	1
CMI	-0.026	0.047	0.56	1	0.013	0.050	0.26	1
DMDM	-0.509	0.201	2.53	0	-0.214	0.199	1.08	1
NPL	0.015	0.083	0.18	1	0.008	0.083	0.09	1
LATMB	0.351	1.200	0.29	1	0.306	1.200	0.25	1
	Consistency: R_B = 0.579				**R_B = 0.712**			



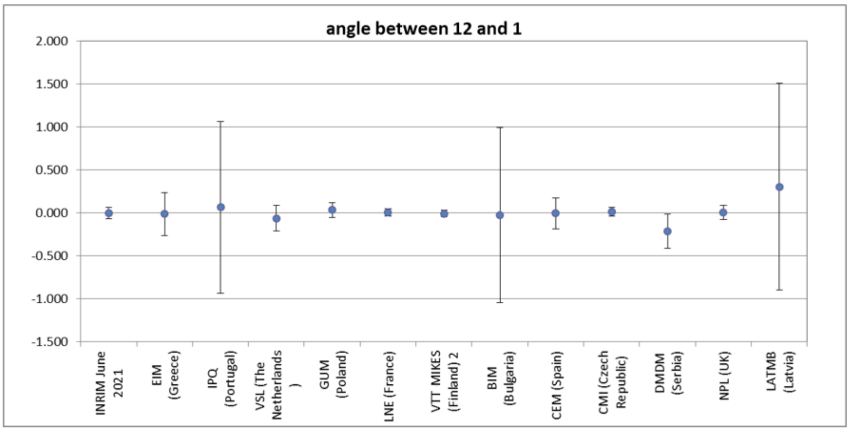
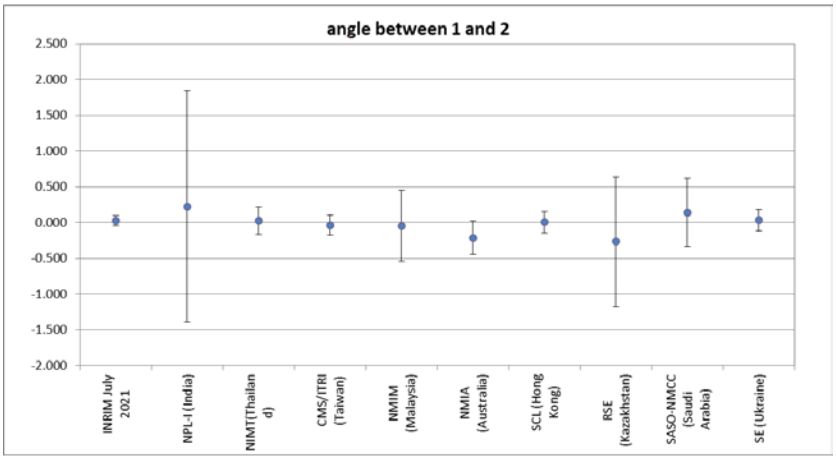


Table 17.
Group 2: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 1 and 2 and angle between 2 and 3)

	Angle between 1 and 2				Angle between 2 and 3			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	0.024	0.069	0.35	1	-0.039	0.068	0.56	1
NPL-I	0.224	1.619	0.14	1	0.821	1.679	0.49	1
NIMT	0.024	0.191	0.13	1	-0.029	0.191	0.15	1
CMS	-0.036	0.138	0.26	1	0.021	0.138	0.15	1
NMIM	-0.046	0.497	0.09	1	0.151	0.497	0.30	1
NMIA	-0.216	0.233	0.93	1	-0.179	0.233	0.77	1
SCL	0.004	0.149	0.03	1	-0.019	0.149	0.13	1
RSE	-0.269	0.906	0.30	1	1.187	0.541	2.19	0
SASO	0.140	0.476	0.29	1	6.001	0.484	12.41	0
SE	0.034	0.149	0.23	1	0.191	0.149	1.28	1
	Consistency: R_B = 0.730				**R_B = 1.208**			



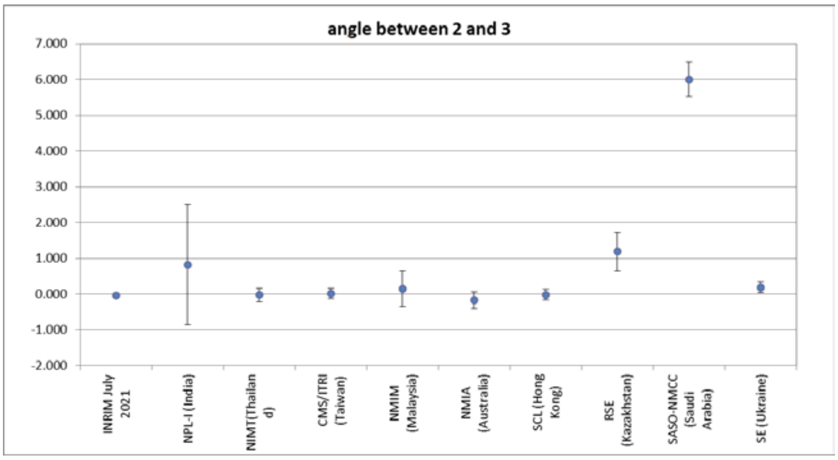
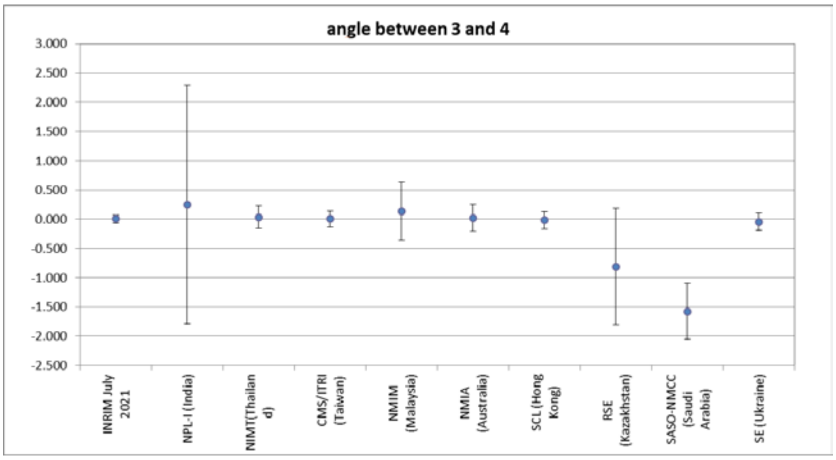


Table 18.
Group 2: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 3 and 4 and angle between 4 and 5)

	Angle between 3 and 4				Angle between 4 and 5			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	0.006	0.069	0.09	1	-0.009	0.067	0.13	1
NPL-I	0.246	2.039	0.12	1	-0.479	1.739	0.28	1
NIMT	0.036	0.191	0.19	1	-0.039	0.191	0.20	1
CMS	0.006	0.138	0.05	1	0.071	0.138	0.52	1
NMIM	0.136	0.497	0.27	1	0.011	0.496	0.02	1
NMIA	0.026	0.233	0.11	1	-0.529	0.247	2.14	0
SCL	-0.014	0.149	0.09	1	-0.019	0.148	0.12	1
RSE	-0.808	0.996	0.81	1	0.887	0.529	1.68	1
SASO	-1.574	0.484	3.25	0	1.087	0.484	2.25	0
SE	-0.044	0.149	0.29	1	-0.089	0.148	0.60	1
	Consistency: R_B = 0.662				**R_B = 1.404**			



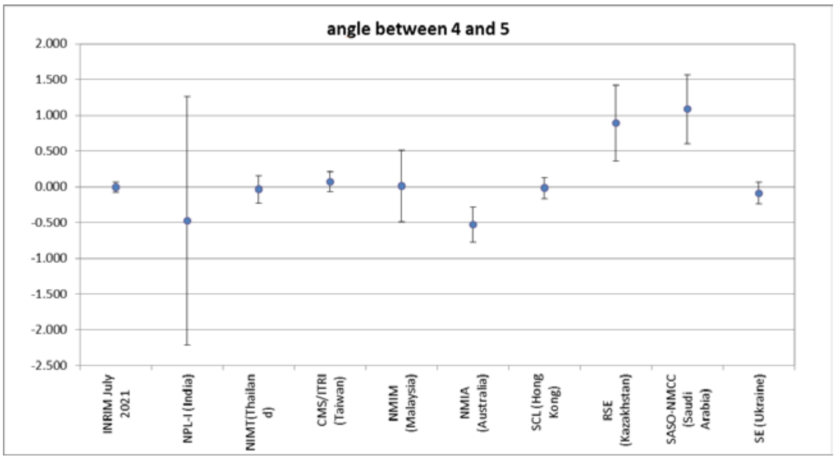
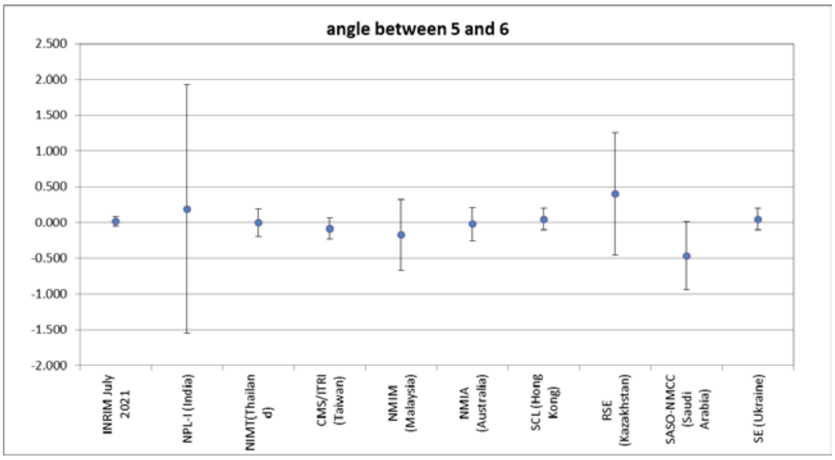


Table 19.
Group 2: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 5 and 6 and angle between 6 and 7)

	Angle between 5 and 6				Angle between 6 and 7			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	0.017	0.068	0.25	1	0.051	0.068	0.75	1
NPL-I	0.187	1.739	0.11	1	-0.319	1.599	0.20	1
NIMT	-0.003	0.191	0.01	1	0.031	0.191	0.16	1
CMS	-0.083	0.149	0.56	1	-0.059	0.138	0.43	1
NMIM	-0.173	0.497	0.35	1	-0.099	0.496	0.20	1
NMIA	-0.023	0.233	0.10	1	0.941	0.247	3.80	0
SCL	0.047	0.149	0.32	1	-0.009	0.149	0.06	1
RSE	0.402	0.856	0.47	1	-0.536	0.535	1.00	1
SASO	-0.468	0.476	0.98	1	0.074	0.476	0.15	1
SE	0.047	0.149	0.32	1	-0.049	0.149	0.33	1
	Consistency: R_B = 0.891				**R_B = 0.920**			



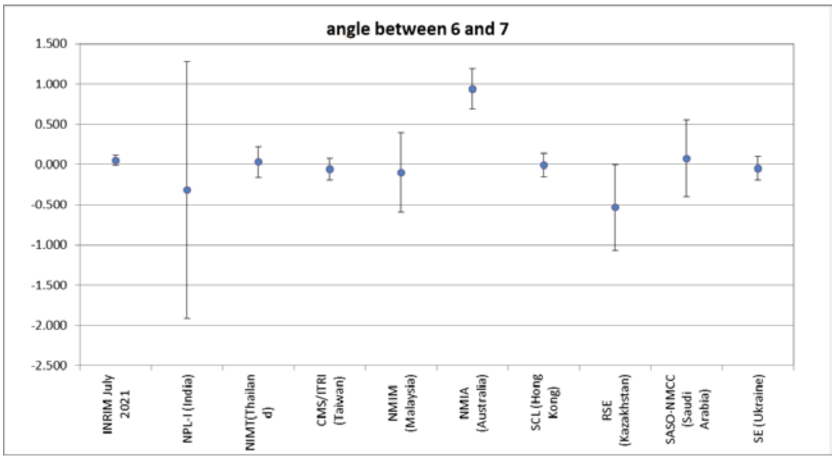
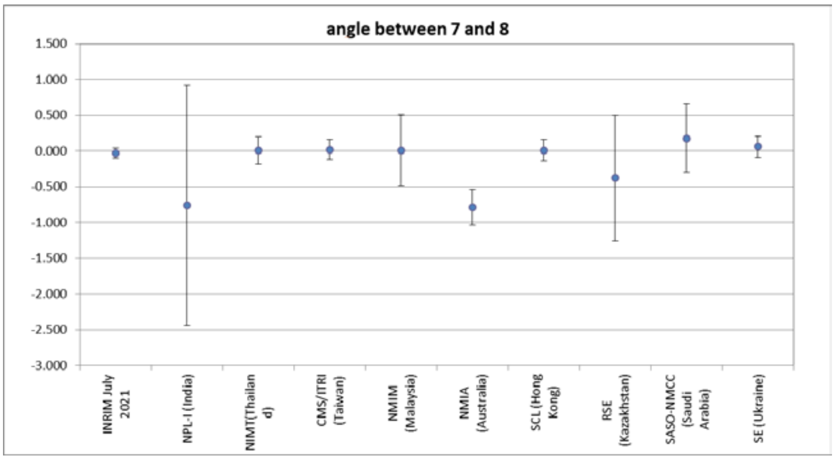


Table 20.
Group 2: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 7 and 8 and angle between 8 and 9)

	Angle between 7 and 8				Angle between 8 and 9			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	-0.031	0.067	0.46	1	0.052	0.063	0.83	1
NPL-I	-0.761	1.679	0.45	1	-0.888	1.779	0.50	1
NIMT	0.009	0.191	0.05	1	-0.118	0.189	0.62	1
CMS	0.019	0.138	0.14	1	-0.008	0.146	0.06	1
NMIM	0.009	0.496	0.02	1	0.192	0.496	0.39	1
NMIA	-0.791	0.247	3.20	0	0.682	0.249	2.74	0
SCL	0.009	0.148	0.06	1	-0.108	0.146	0.74	1
RSE	-0.381	0.876	0.43	1	0.167	0.548	0.30	1
SASO	0.176	0.476	0.37	1	0.010	0.476	0.02	1
SE	0.059	0.148	0.40	1	-0.338	0.173	1.96	0
	Consistency: R_B = 0.634				**R_B = 0.965**			



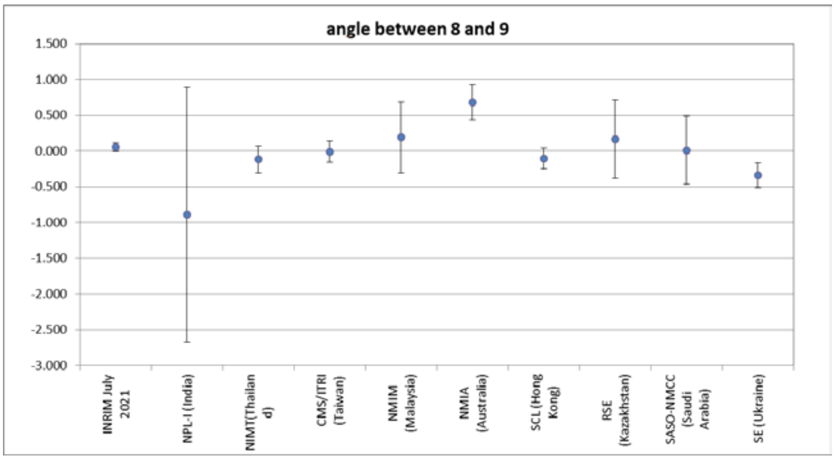
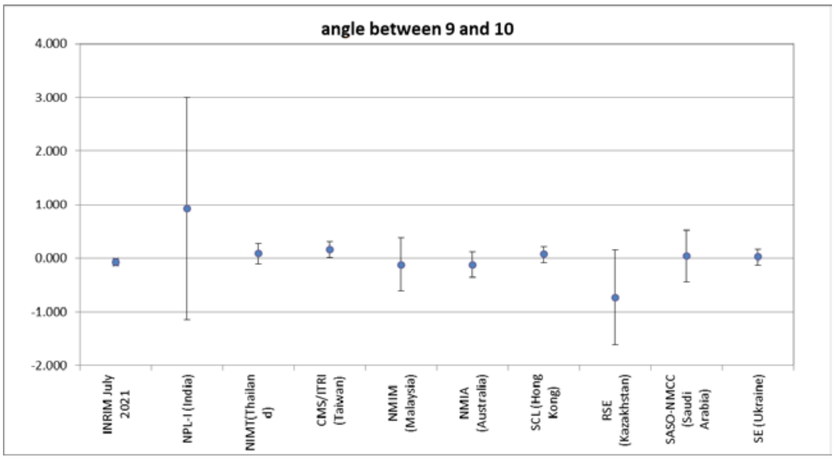


Table 21.
Group 2: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 9 and 10 and angle between 10 and 11)

	Angle between 9 and 10				Angle between 10 and 11			
Lab	$x_i - \overline{x}_w$	$U(x_i - \overline{x}_w)$	E_n	On/off	$x_i - \overline{x}_w$	$U(x_i - \overline{x}_w)$	E_n	On/off
INRIM	-0.076	0.068	1.11	1	-0.002	0.062	0.03	1
NPL-I	0.924	2.079	0.44	1	-0.742	1.639	0.45	1
NIMT	0.084	0.191	0.44	1	0.068	0.189	0.36	1
CMS	0.164	0.149	1.10	1	-0.022	0.146	0.15	1
NMIM	-0.116	0.497	0.23	1	-0.162	0.496	0.33	1
NMIA	-0.116	0.233	0.50	1	-0.522	0.249	2.10	0
SCL	0.074	0.149	0.50	1	0.038	0.146	0.26	1
RSE	-0.729	0.884	0.82	1	-1.912	0.540	3.54	0
SASO	0.043	0.476	0.09	1	-0.276	0.476	0.58	1
SE	0.024	0.149	0.16	1	0.328	0.173	1.90	0
	Consistency: R_B = 1.220				**R_B = 0.745**			



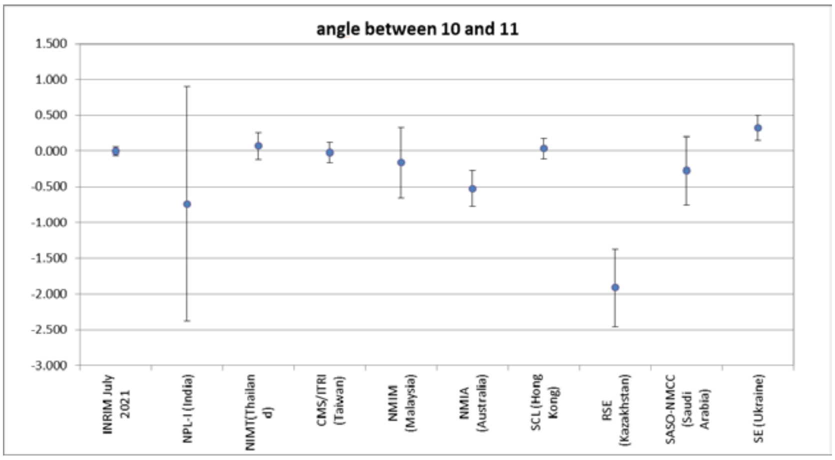
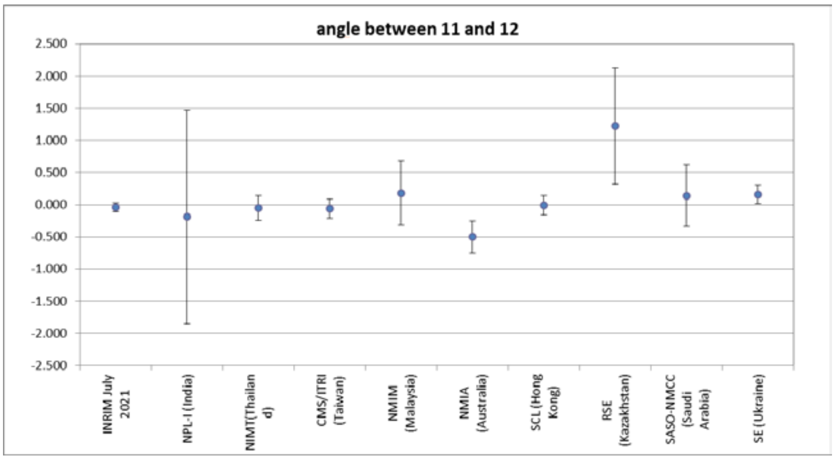
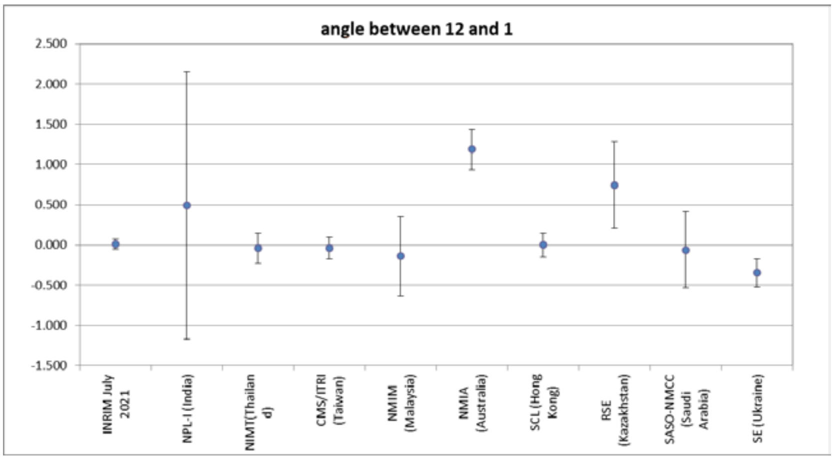


Table 22.
Group 2: Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle between 11 and 12 and angle between 12 and 1)

	Angle between 11 and 12				Angle between 12 and 1			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
INRIM	-0.040	0.067	0.60	1	0.009	0.063	0.14	1
NPL-I	-0.190	1.659	0.11	1	0.489	1.659	0.29	1
NIMT	-0.050	0.191	0.26	1	-0.041	0.189	0.22	1
CMS	-0.060	0.148	0.41	1	-0.041	0.136	0.31	1
NMIM	0.180	0.496	0.36	1	-0.141	0.496	0.29	1
NMIA	-0.500	0.247	2.02	0	1.189	0.248	4.79	0
SCL	-0.010	0.148	0.07	1	-0.001	0.147	0.01	1
RSE	1.221	0.900	1.36	1	0.744	0.538	1.38	1
SASO	0.138	0.476	0.29	1	-0.062	0.476	0.13	1
SE	0.160	0.148	1.08	1	-0.351	0.172	2.04	0
	Consistency: R_B = 1.316				**R_B = 1.120**			





7.3 Discussion of results

EIM, NMIM, NPL-I, RSE and SASO/NMCC do not have CMC in this field; so, their uncertainty value may be a tentative for a future CMC.

CMI, CMS/ITRI, LATMB, LNE, NPL, SCL, VSL and VTT MIKES stated lower uncertainties than their CMC.

Other participants communicated uncertainties equal to their approved CMC.

There is no correlation between laboratories, since some participants declare traceability to other NMIs that are outside the comparison (see table 5).

Stability of artifacts was maintained along the comparison.

In general, there was a good agreement between the results sent by laboratories of group 1: i.e. 10 out of 156 results show En >1 (6 of them from DMDM, 2 from GUM, 2 from VTT MIKES). The results are not so good for group 2, since 22 out of 120 results show En >1 (7 of them from NMIA, 5 from RSE, 5 from SE, 3 from SASO/NMCC, 1 from INRIM, 1 from CMS).

7.4 Support for CMCs/service categories

The service categories and CMCs supported by this comparison can be found by looking up key comparison topic K3 in the CCL Competence Matrix.

8 Comments by partners

8.1 Comments before draft A

According to the Key-comparison guidelines, after the initial overview of the submitted results and a provisional calculation of reference values, the NMIs having possible outliers were asked by the pilot to check their results for arithmetic, typographical or trascription errors. Here below are copied the NMI’s comment submitted.

Comments from DMDM 28/09/2022

Submitted results (incl. sign) look correct to me.

Comments from GUM 30/09/2022

We analyzed the submitted report of GUM and we see no mistake in the reported results. The only thing that may be confusing is the way the degrees of freedom presentation and this has been corrected.

Comments from VTT MIKES 18/10/2022

It was noticed during the checking of the results for draft A, that used alignment method was different from what was instructed in TP. At VTT MIKES normal procedure to align polygons is to use faces 0°, 90°, 180°, 270° and main autocollimator to adjust both autocollimator and polygon perpendicular to axis of rotation. The method proposed in TP was not used since the top of the rotary table is not good enough flat to guarantee correct orientation of the polygon. Now in case if there is some error in orientation of normal of the base of the polygon versus average orientation of 0°, 90°, 180°, 270° faces then the pyramid error will be larger. This was considered in updated uncertainty estimate. Also face flatness contribution to uncertainty was increased.

Comments from CEM 26/05/2023

We have check the results sent it and we have found that we have an error in the sign of the results. We sent you the error, not the pitch angle deviation. I send you again the appendixB_C.

Comments from NMIA 24/10/2023

I did not find any simple arithmetic, typographical or transcription errors. We did have some signal strength problems with our autocollimator during the calibration and this may have affected the reliability of our results to a greater degree than we initially expected. Unfortunately our results are what they are.

Comments from SASO 24/10/2023

This is a confirmation about our report submitted on. We would like to confirm you that regarding our.

Comments from SE 07/11/2023

We corrected the text of the report. We reviewed our results again and could not find not any mistake in them. But due to reasons mentioned in our report we admit that differences between the polygon flat angles measured by different participants can be considerable ones. In our opinion the optical systems of different design, different characteristics and different measurement information processing systems can determine the space position of the perpendicular to non-flat window by different way. In case of the significant differences appearance, we still suggest to provide the additional round with a polygon of better flatness characteristics.

Comments from CMS/ITRI 05/12/2023

There is a problem with the CMS report. The data with opposite signs is on Pg.14/16. CMS/ITRI measurement results correction is as the attachment.

8.2 Comments after draft A1

Comments from NMIA 11/01/2024

All of NMIA's numbers have been transcribed correctly. It seems that we have some major problems with our system at the moment. I suspect our autocollimator is at fault.

Comments from NPL-I 18/01/2024

There is a typographical mistake in the reported results. **Actually, the reported uncertainty of each face is at k = 1 instead of k = 2 on page 13/15**. It is also evident from the uncertainty budget provided on the page 14/15.
The corrections are marked in the attachment. Kindly consider the modified uncertainty values (they will be double of the earlier reported uncertainty values).
I would like to apologies for the inconvenience

8.3 Comments after draft A2

Comments from SE 03/08/2024

Thank you for sharing Draft A2 of our Key Comparison.
I have reviewed the document and noticed that the results for SE UKRMETRTESTSTANDART are missing. Could you please check why these results are not included?

Reply from INRIM 27/08/2024

I apologize, I made a mistake! Data from SE were reported in the first excel sheet (Comparison data), but not in the second one (Comparison evaluation).
I wait for other eventual feedback until the end of August, then I will circulate the correct file.

Comments from GUM 05/08/2024

Thank you for sending the EURAMET.L-K3.n01 comparison: Draft A2 results.
Generally, the GUM results are OK, although for two walls we obtained results slightly above 1 (1.02 and 1.11), while reducing these results by 0.01 would cause En to be below 1.0.
The reason may be, despite good centering, a slight shift of the autocollimator optical axis relative to the center of the prism wall and the flatness of the wall.
Despite this, it seems that we should not change our results and uncertainties, as long as the Birge ratio is ok.

Comments from RSE 14/08/2024

Thank you for the Draft you provided. I've read it, all the data is correct.
Can we increase the uncertainties in some of the results between the angles?
If yes, let us know, we will adjust our protocol.

Reply from INRIM 28/08/2024

In order to answer your request, I've consulted the guide CIPM MRA-D-05 "Measurement comparison in the context of the CIPM MRA".
According to this document, at Draft A stage the uncertainty values reported by one participant can be changed only with the agreement of all participants and on the basis of a clear failure of the travelling standard or some other phenomenon that renders the comparison or part of it invalid. (4.7 Report of a CIPM key comparison).
The results reported in Draft A do not show drifts or anomalies that can invalidate the comparison.
Hence, I'm sorry but it seems that at this stage it is not possible for you to increase the uncertainties you have declared in your report.
Anyway, I send a copy of this email to EURAMET TC-L chair, Sten Bergstrand, to ask him an opinion on that topic.

Reply from TC-L chair 10/09/2024

Thank you for your requests. I have understood that the reported measurement results were recorded correctly and that the request to increase uncertainties was filed after the results were shared between the participants. I therefore agree with Milena that the reported values cannot be changed, and that the analysis of the comparison should move forward.
Further guidance on how to proceed from here is offered in CCL-GD-1, item 8
https://www.bipm.org/documents/20126/30125568/CCL-GD-1+Running+of+MRA+comparisons+in+length+metrology+and+monitoring+their+impact+on+CMCs/974865cb-9ff5-47b4-d1a0-18d42aae05f1

In this case indicating that an Executive Report is foreseen at the end of the Reporting cycle.
As I am unable to identify any KazStandard CMC on angles in the KCDB and this seems to be the first attempt to declare proficiency on angle metrology, there is no action foreseen on existing CMCs.
KazStandard has observer status in EURAMET, and should an internal evaluation arrive at the conclusion that Capacity Building activities are required with EURAMET's assistance, I recommend KazStandard to contact either or both of Tanasko Tasic Tanasko.Tasic@euramet.org (General CBKT Officer, Euramet Secretariat) and Tanfer Yandayan tanfer.yandayan@tubitak.gov.tr (TC-Length CBKT specialist [and highly proficient in angle metrology], Tubitak UME) to help organizing such activities.

Comments from VTT MIKES 20/08/2024

Our results seem to be as we reported.
When going through the analysis. It seems that DMDM has 6 (total) En>1 of total 12. This clearly indicates that their uncertainty is not correct.
Even though the Birge ratio failed only for 1 angle when DMDM En>1, since in this kind of measurement all angle results are related to each other I think that it is justified to exclude DMDM from all ref value calculations.