

**AFRIMETS**

**Supplementary Comparison**

**on**

**Calibration of External Micrometer**

**(AFRIMETS.L-S6.1.n02)**  
Renamed from (AFRIMETS.L-S5)

**(2019-2022)**

**Final report**

**2024**

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### **Abstract**

National Metrology Institutes from 12 African countries, namely Egypt, Nigeria, Kenya, Tanzania, Zambia, Zimbabwe, Botswana, and Mauritius have participated in an international supplementary comparison on the calibration of External Micrometer. This comparison was a part of larger supplementary comparison between 13 African countries for the calibration of hand measuring instruments. This larger comparison which was carried out during the period between December 2019 – December 2022 has been piloted by NIS, Egypt and has been registered in BIPM-KCDB database on December 2019 with the identifier AFRIMETS.L-S5. The artifacts have been prepared by NIS, Egypt and measured before sent to circulate between all participant countries in round-robin scheme and returned back again for NIS, Egypt where a final measurement was made for stability check. The main purpose of these comparisons is to support submission of CMCs for calibration of hand length measuring instruments in BIPM-KCDB.

## **1. Introduction**

In December 2019, the Egyptian National Institute of Standards (NIS), Egypt has initiated a comparison for the calibration of length hand measuring instruments which is considered the standard activity in most African metrology institutes. It was not possible to conduct comparison for the calibration all length hand measuring instruments, so a number of 6 hand measuring instruments have been selected, which are external micrometer, caliper, dial gauge, setting rods, pin gauges and feeler gauges. The comparison was carried out during the period from December 2019 to December 2022 and was piloted by NIS, Egypt. The comparison has been registered in BIPM-KCDB database on December 2019 by the identifier AFRIMETS.L-S5 and was given the internal AFRIMET identifier AFRIMETS L11. The comparisons were carried out according to the protocol approved by all participants before initiating the comparison. The artifacts have been prepared and measured by NIS, Egypt before they were circulated between all participant countries in round-robin scheme and returned back again for NIS, Egypt where a final measurement was made for stability check. The main purpose of these comparisons is to support submission of CMCs for calibration of hand length measuring instruments in BIPM-KCDB.

In this report, 12 African countries, namely Egypt, Morocco, Ghana, Nigeria, Ethiopia, Kenya, Tanzania, Zambia, Zimbabwe, Botswana, Mauritius and South Africa have participated in an international supplementary comparison on the calibration of External Micrometer. A micrometer of 75 to 100 mm range was prepared by NIS, Egypt for the comparison.

## 2. Participants

12 African countries, namely Egypt, Morocco, Ghana, Nigeria, Ethiopia, Kenya, Tanzania, Zambia, Zimbabwe, Botswana, Mauritius and South Africa have participated in an international supplementary comparison on the calibration of External Micrometer. NIS, Egypt was acting as the pilot laboratory. The rest of the 13 countries which are Malawi did not participate in the external micrometer comparison. The list of participants of this comparison are listed in the following table with their details:

**Table 1 shows the participants NMIs in the external micrometer comparison**

N.	Participant	Correspondence	E-mail Address Phone number	Address
1	NIS (Pilot) (Egypt)	Osama Terra (Organizer)	<a href="mailto:Osama.terra@gmail.com">Osama.terra@gmail.com</a> +201141172900	Tersa Street, Haram, Giza, Egypt. P. code: 12211, P.O. Box: 136 Giza
		Ahmed Elmelegy (Pilot lab.)	<a href="mailto:ahmedme3@yahoo.com">ahmedme3@yahoo.com</a> +201112145450	
2	LPEE/LNM (Morocco)	Lhossain Mechkour	<a href="mailto:mechkour@lpee.ma">mechkour@lpee.ma</a> Tel : +212 5 22 48 87 94	km 7, Route d'El Jadida, Casablanca – Maroc
3	GSA (Ghana)	Paul Date	<a href="mailto:date_105@msn.com">date_105@msn.com</a> Tel.: + 233 302 500065	P.O. Box MB 245 Okponglo, Legon-Madina Road, Accra
4	NMI/SON (Nigeria)	Bede Obayi	<a href="mailto:beobayi@yahoo.com">beobayi@yahoo.com</a>	52, Lome Crescent, Zone 7, Wuse, Abuja
5	NMIE (Ethiopia)	Tadesse Gergiso Birhan Tesfaye	<a href="mailto:tdsgrs@gmail.com">tdsgrs@gmail.com</a> <a href="mailto:bire31@yahoo.com">bire31@yahoo.com</a> Tel : +251 116 67 19 69	B67, 1405 Street, Woreda 6, Bole Sub city, Addis Ababa, Ethiopia. P.O. Box: 5722 Addis Ababa
6	KEBS (Kenya)	Calvin Bore	<a href="mailto:borec@kebs.org">borec@kebs.org</a> +254 20 6948 359	Dimensional Laboratory, Kenya Bureau of Standards, P.O. Box 54974 - 00200, Nairobi, Kenya.
7	TBS (Tanzania)	Joseph James Angela Charles	<a href="mailto:mahillaji@yahoo.co.uk">mahillaji@yahoo.co.uk</a> <a href="mailto:joseph.mahilla@tbs.go.tz">joseph.mahilla@tbs.go.tz</a> angela.charles@tbs.go.tz Tel.: + 255 22 2450206	Morogoro/Sam Nujoma Roads, Ubungo, P.O. Box 9524 Dar-es- Salaam
8	ZMA (Zambia)	Daniel Mutale	<a href="mailto:dmmutalezs@gmail.com">dmmutalezs@gmail.com</a> +260 955135366	Zambia Metrology Agency Plot # 4526 Lechwe House Freedom Way, Lusaka, Zambia. P.O.Box: 30989 Lusaka
9	SIRDC- NMI	Burnhard Gandah	<a href="mailto:bgandah@sirdc.ac.zw">bgandah@sirdc.ac.zw</a> <a href="mailto:burnhardg@gmail.com">burnhardg@gmail.com</a>	1574 Alpes Road, Technology Drive Hatcliffe P.O. Box 6640

	(Zimbabwe)		Tel: +263 778330014	Harare
10	BOBS (Botswana)	Modiriemang Kame Pamidzani Ntima	<a href="mailto:kame@bobstandards.bw">kame@bobstandards.bw</a> <a href="mailto:Ntima@bobstandards.bw">Ntima@bobstandards.bw</a> <a href="mailto:Pamidzani.ntima@gmail.com">Pamidzani.ntima@gmail.com</a> Tel. (+267) 3903200 Tel. (+267) 72607660	Private Bag B0 48 Gaborone
11	MSB (Mauritius)	Tomeswar Pryam Vaneeda Ramasawmy Pallut	<a href="mailto:tpyam@msb.intnet.mu">tpyam@msb.intnet.mu</a> <a href="mailto:vramasawmy@msb.intnet.mu">vramasawmy@msb.intnet.mu</a> +230 433 3648	Mauritius Standards Bureau Villa Road, Moka Postal code – 80805 Mauritius
12	NMISA (South Africa)	Zanele Nzimande Patrick Masina	<a href="mailto:znzimande@nmisa.org">znzimande@nmisa.org</a> <a href="mailto:pmasina@nmisa.org">pmasina@nmisa.org</a> Tel. +27 12 841 2944	Private Bag X34 Lynnwood Ridge Pretoria 0040

### 3. Form of Comparison

The comparison is made according to round robin scheme. All artifacts including the external micrometer are calibrated first at NIS, Egypt then shipped to the next country in the timetable, and so on. Malawi withdrew from the comparison since they were not ready by that time. Since not all countries participated in the 6 calibration activities, participants will differ from one report to the others. For External Micrometer, only 12 countries participated (shown in blue in figure 1).

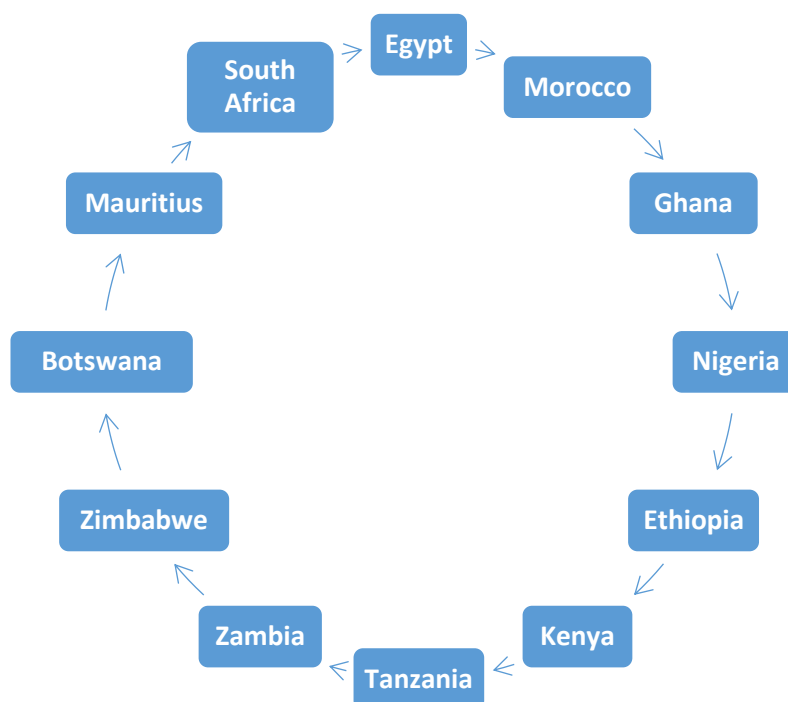


Figure 1: The transportation sequence and measurements of the artifacts.

#### 4. Timetable

The sequence of transferring the standards was made according to the protocol. However, delays occur due to the Covid-19 pandemic which took place at the start of the comparison in 2020. Table 2 shows the comparison planned timetable at the protocol. A delay of around one and half year almost from the planned time table.

Table 2 shows the comparison time table at the protocol

Activity	Start Date	End date	Remarks
First calibration at NIS, Egypt	25 November 2019	10 December 2019	
Delivery to LPEE/LNM, Morocco	11 December 2019	31 December 2019	
Calibration at LPEE/LNM, Morocco	1 January 2020	15 January 2020	
Delivery to GSA, Ghana	16 January 2020	5 February 2020	
Calibration at GSA, Ghana	6 February 2020	20 February 2020	
Delivery to NMI/SON, Nigeria	21 February 2020	10 March 2020	
Calibration at NMI/SON, Nigeria	11 March 2020	25 March 2020	
Delivery to NMIE, Ethiopia	26 March 2020	15 April 2020	
Calibration at NMIE, Ethiopia	16 April 2020	30 April 2020	
Delivery to KEBS, Kenya	1 May 2020	20 May 2020	
Calibration at KEBS, Kenya	21 May 2020	5 June 2020	
Delivery to TBS, Tanzania	6 June 2020	26 June 2020	
Calibration at TBS, Tanzania	27 June 2020	12 July 2020	
Delivery to MBS, Malawi	13 July 2020	3 August 2020	Withdrawn
Calibration at MBS, Malawi	4 August 2020	20 August 2020	
Delivery to ZABS, Zambia	21 August 2020	10 September 2020	
Calibration at ZABS, Zambia	11 September 2020	30 September 2020	
Delivery to SIRDC/NMI, Zimbabwe	1 October 2020	20 October 2020	
Calibration at SIRDC/NMI, Zimbabwe	21 October 2020	5 November 2020	
Delivery to BOBS, Botswana	6 November 2020	26 November 2020	
Calibration at BOBS, Botswana	27 November 2020	12 December 2020	
Delivery to MSB, Mauritius	13 December 2020	2 January 2021	
Calibration at MSB, Mauritius	3 January 2021	18 January 2021	
Delivery to NMISA, South Africa	19 January 2021	9 February 2021	
Calibration at NMISA, South Africa	10 February 2021	28 February 2021	
Delivery to NIS, Egypt	1 March 2021	20 March 2021	

Calibration at NIS, Egypt	21 March 2021	5 April 2021	
Final Chance for Submitting the Results	6 April 2021	20 April 2021	
Pre-Draft A	21 April 2021	20 June 2021	

## 5. Description of the artifact:

NIS artifact is an External Micrometer as shown in figure 2 that ranges from 75–100 mm.



Figure 2: photograph of External Micrometer (similar one)

## 6. Calibration method used by each participant

Different methods are used by each participant for the calibration of External Micrometer. The used methods by each participant are summarized in table 3.

Table 3 methods used for calibration of External Micrometer by each participant

Nr.	Participant	Method used for calibration of External Micrometer
1	NIS (Pilot) (Egypt)	Reference Gauge Blocks Set
2	LPEE/LNM (Morocco)	grade K Mitutoyo 122-gauge blocks set
3	Ghana (GSA)	Koba gauge block with serial number 88141
4	NMI/SON (Nigeria)	Gauge Blocks combination
5	NMIE (Ethiopia)	Not mentioned
6	KEBS (Kenya)	Gauge blocks grade 0
7	TBS (Tanzania)	Standard gauge block Set with serial No. 1500223
8	ZMA (Zambia)	Gauge blocks set
9	SIRDC- NMI (Zimbabwe)	Gauge blocks set s. no. 0905759
10	BOBS (Botswana)	TRIMOS s. no. 1207
11	MSB (Mauritius)	Grade K Gauge blocks set
12	NMISA (South Africa)	Gauge blocks set

## 7. Calibration results

The following table (table 4) shows the results for all participant in External Micrometer calibration comparison. The results of each participant and the



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calibration uncertainty for the calibration of the External Micrometer are shown as a single row in table 4.

**Table 4. Calibration results by each participant.**

Nr.	Institute, Country	Nominal 75	U, mm	Nominal 77.5	U, mm	Nominal 80.1	U, mm	Nominal 82.7	U, mm	Nominal 85.3	U, mm
1	NIS (Egypt) (Pilot)	75.000	0.002	77.501	0.002	80.101	0.002	82.701	0.002	85.301	0.002
2	LPEE/LNM (Morocco)	75.000	0.008	77.500	0.008	80.100	0.008	82.700	0.008	85.300	0.008
3	GSA (Ghana)	75.000	0.00164	N.P.	N.P.	80.100	0.00164	82.700	0.00164	85.300	0.00164
4	NMI/SON (Nigeria)	75.000	0.0069	77.500	0.0070	80.070	0.0636	82.700	0.0075	85.300	0.0083
5	NMIE (Ethiopia)	75.000	0.00586	77.500	0.00586	80.100	0.00586	82.700	0.00586	85.300	0.00586
6	KEBS (Kenya)	75.000	0.006	77.500	0.006	80.100	0.006	82.700	0.006	85.300	0.006
7	TBS (Tanzania)	75.000	0.003	77.500	0.003	80.110	0.003	82.700	0.003	85.300	0.003
8	ZMA (Zambia)	75.00	0.01	77.50	0.01	80.10	0.01	82.70	0.01	85.30	0.01
9	SIRDC- NMI (Zimbabwe)	75.000	0.008	77.500	0.008	80.101	0.008	82.700	0.008	85.300	0.008
10	BOBS (Botswana)	74.997	0.0074	77.500	0.0074	80.099	0.0074	82.701	0.0074	85.299	0.0074
11	MSB (Mauritius)	75.000	0.004	77.503	0.004	80.102	0.004	82.701	0.004	85.301	0.004
12	NMISA (South Africa)	75.00	0.012	77.50	0.012	80.10	0.012	82.70	0.012	85.3	0.012
1	NIS (Egypt) (After)	75.000	0.002	77.500	0.002	80.101	0.002	82.700	0.002	85.301	0.002

N.P.: not participated

Nr.	Institute, Country	Nominal	U, mm	Nominal	U, mm	Nominal	U, mm	Nominal	U, mm
		87.9		90		95.2		100	
1	NIS (Egypt) (Pilot)	87.901	0.002	90.000	0.002	95.201	0.002	100.001	0.002
2	LPEE/LNM (Morocco)	87.900	0.008	90.000	0.008	95.200	0.008	100.000	0.008
3	GSA (Ghana)	87.900	0.00164	90.000	0.00164	95.200	0.00164	100.000	0.00164
4	NMI/SON (Nigeria)	87.900	0.0084	90.000	0.0073	95.21	0.0112	100.000	0.0077
5	NMIE (Ethiopia)	87.900	0.00586	90.000	0.00586	95.200	0.00586	100.000	0.00586
6	KEBS (Kenya)	87.900	0.006	90.000	0.006	95.200	0.006	100.000	0.006
7	TBS (Tanzania)	87.900	0.003	90.000	0.003	95.200	0.003	100.000	0.003
8	ZMA (Zambia)	87.90	0.01	90.00	0.01	95.200	0.01	100.00	0.01
9	SIRDC- NMI (Zimbabwe)	87.902	0.008	90.000	0.008	95.200	0.008	100.001	0.008
10	BOBS (Botswana)	87.899	0.0074	89.997	0.0074	95.200	0.0074	99.999	0.0074
11	MSB (Mauritius)	87.902	0.004	90.004	0.004	95.203	0.004	100.003	0.004
12	NMISA (South Africa)	87.90	0.012	90.00	0.012	95.20	0.012	100.00	0.012
1	NIS (Egypt) (After)	87.901	0.002	90.001	0.002	95.20	0.002	100.001	0.002

**8. Traceability**

Reference for the calibration of the External Micrometer should be traceable to SI unit of length though unbroken traceability chain. The following table demonstrates the traceability of the measurement of each participant that are deduced from the calibration report.

**Table 5. Traceability of calibration results by each participant.**

Nr.	Participant	Traceability
1	NIS (Egypt)	To SI units of length through NIS primary length standard (He Ne 633 laser)
2	LPEE/LNM (Morocco)	To SI units of length through Mitutoyo Japan Accredited JCSS
3	GSA (Ghana)	Traceable to the SI (International System of Units) through Zentrum fur Messen and Kalibrieren and ANALYTIK GmbH (D-K-15186-01-00)
4	NMI/SON (Nigeria)	Not mentioned
5	NMIE (Ethiopia)	Not mentioned
6	KEBS (Kenya)	To SI units of length through NMISA standards
7	TBS (Tanzania)	To SI units of length through NMISA standards

8	ZMA (Zambia)	To SI units of length through NMISA standards
9	SIRDC- NMI (Zimbabwe)	To SI units of length through NMISA standards
10	BOBS (Botswana)	To SI units of length through NMISA standards
11	MSB (Mauritius)	To SI units of length through NMISA standards
12	NMISA (South Africa)	To the national measuring standard for length

The status of some NMIs having traceability through NMISA standards did not affect the analysis of comparison results.

## 9. Analysis of the results

### 9.1. Transportation Stability

Drifts of the artifact's values can occur during the transportation of the artifacts and handling over the long period of comparison. Therefore, a stability check must be performed to assure that this change will not affect the comparison results. The instability of the artifacts is assessed according to the following equation:

$$\Delta_{ins} = |x_{NIS_2} - x_{NIS_1}|$$

where,  $x_{NIS_2}$  is the measurement of the pilot (NIS, Egypt) after the comparison and  $x_{NIS_1}$  is the measurement of the pilot before the comparison. The instability of each artifact during the transportation will add additional contribution to the uncertainty of the reference value:

$$u_{ad}(x_i) = \frac{\Delta_{ins}}{2\sqrt{3}}$$

Additional criteria are applied to ensure the stability of the results which is:

$$\Delta_{ins} \leq 0.9 \sqrt{u_{CRV}^2 + u_{min}^2}$$

where, the  $u_{CRV}$  is the uncertainty in the comparison reference value and  $u_{min}$  is the uncertainty of the participant with the lowest uncertainty.

Therefore, the total combined uncertainty for each participant after adding the uncertainty due to the stability will be

$$u_a^2(x_i) = u^2(x_i) + u_{ad}^2(x_i)$$

Table 6. Stability measurement for each artifact

Nominal Length, (mm)	$\Delta_{ins}$ (mm)	$u_{ad}(x_i)$ (mm)	$0.9 \sqrt{u_{CRV}^2 + u_{min}^2}$ mm	Status
75.00	0.0000	0.0000	0.00210	Fulfilled
77.50	0.0010	0.0003	0.00241	Fulfilled
80.10	0.0000	0.0000	0.00206	Fulfilled
82.70	0.0010	0.0003	0.00203	Fulfilled
85.30	0.0000	0.0000	0.00203	Fulfilled
87.90	0.0000	0.0000	0.00203	Fulfilled
90.00	0.0010	0.0003	0.00753	Fulfilled
95.20	0.0010	0.0003	0.00203	Fulfilled
100.00	0.0000	0.0000	0.00203	Fulfilled

Table 7. correction of combined uncertainties for each participant

Nr.	Institute, Country	Nominal	U <sub>a</sub> (X <sub>i</sub> ),	Nominal	U <sub>a</sub> (X <sub>i</sub> ),	Nominal	U <sub>a</sub> (X <sub>i</sub> ),	Nominal	U <sub>a</sub> (X <sub>i</sub> ),	Nominal	U <sub>a</sub> (X <sub>i</sub> ),
		75	mm	77.5	mm	80.1	mm	82.7	mm	85.3	mm
1	NIS (Egypt) (Pilot)	75.0000	0.0010	77.5010	0.0010	80.1010	0.0010	82.7010	0.0010	85.3010	0.0010
2	LPEE/LNM (Morocco)	75.0000	0.0040	77.5000	0.0040	80.1000	0.0040	82.7000	0.0040	85.3000	0.0040
3	GSA (Ghana)	75.0000	0.0008	N.P.	N.P.	80.1000	0.0008	82.7000	0.0009	85.3000	0.0008
4	NMI/SON (Nigeria)	75.0000	0.0035	77.5000	0.0035	80.0700	0.0318	82.7000	0.0038	85.3000	0.0042
5	NMIE (Ethiopia)	75.0000	0.0029	77.5000	0.0029	80.1000	0.0029	82.7000	0.0029	85.3000	0.0029
6	KEBS (Kenya)	75.0000	0.0030	77.5000	0.0030	80.1000	0.0030	82.7000	0.0030	85.3000	0.0030
7	TBS (Tanzania)	75.0000	0.0015	77.5000	0.0015	80.1100	0.0015	82.7000	0.0015	85.3000	0.0015
8	ZMA (Zambia)	75.0000	0.0050	77.5000	0.0050	80.1000	0.0050	82.7000	0.0050	85.3000	0.0050
9	SIRDC- NMI (Zimbabwe)	75.0000	0.0040	77.5000	0.0040	80.1010	0.0040	82.7000	0.0040	85.3000	0.0040
10	BOBS (Botswana)	74.9970	0.0037	77.5000	0.0037	80.0990	0.0037	82.7010	0.0037	85.2990	0.0037
11	MSB (Mauritius)	75.0000	0.0020	77.5030	0.0020	80.1020	0.0020	82.7010	0.0020	85.3010	0.0020
12	NMISA (South Africa)	75.0000	0.0060	77.5000	0.0060	80.1000	0.0060	82.7000	0.0060	85.3000	0.0060
	Institute, Country	Nominal	U <sub>a</sub> (X <sub>i</sub> ),	Nominal	U <sub>a</sub> (X <sub>i</sub> ),	Nominal	U <sub>a</sub> (X <sub>i</sub> ),	Nominal	U <sub>a</sub> (X <sub>i</sub> ),		
		87.9	mm	90	mm	95.2	mm	100	mm		
1	NIS (Egypt) (Pilot)	87.901	0.001	90.000	0.0010	95.201	0.00104	100.001	0.001		
2	LPEE/LNM (Morocco)	87.900	0.004	90.000	0.0040	95.200	0.00401	100.000	0.004		
3	GSA (Ghana)	87.900	0.00082	90.000	0.0009	95.200	0.00087	100.000	0.00082		
4	NMI/SON (Nigeria)	87.900	0.0042	90.000	0.0037	95.210	0.00561	100.000	0.00385		
5	NMIE (Ethiopia)	87.900	0.00293	90.000	0.0029	95.200	0.00294	100.000	0.00293		
6	KEBS (Kenya)	87.900	0.003	90.000	0.0030	95.200	0.00301	100.000	0.003		
7	TBS (Tanzania)	87.900	0.0015	90.000	0.0015	95.200	0.00153	100.000	0.0015		
8	ZMA (Zambia)	87.900	0.005	90.000	0.0050	95.200	0.00501	100.000	0.005		
9	SIRDC- NMI (Zimbabwe)	87.902	0.004	90.000	0.0040	95.200	0.00401	100.001	0.004		
10	BOBS (Botswana)	87.899	0.0037	89.997	0.0037	95.200	0.00371	99.999	0.0037		
11	MSB (Mauritius)	87.902	0.002	90.004	0.0020	95.203	0.00202	100.003	0.002		
12	NMISA (South Africa)	87.900	0.006	90.000	0.0060	95.200	0.00601	100.000	0.006		

N.P.: not participated

## 9.2. Reference value of the comparison

The CRV (comparison reference value) was calculated using the weighted mean method according to the equation:

$$x_{CRV} = \sum_{i=1}^N w_i x_i$$

Where  $w_i$  is the weights and is calculated by the equation:

$$w_i = \frac{u_a^{-2}(x_i)}{\sum_{i=1}^N u_a^{-2}(x_i)}$$

and where  $u_a^2$  is the uncertainty contribution of each participant including the uncertainty due to the stability analysis:

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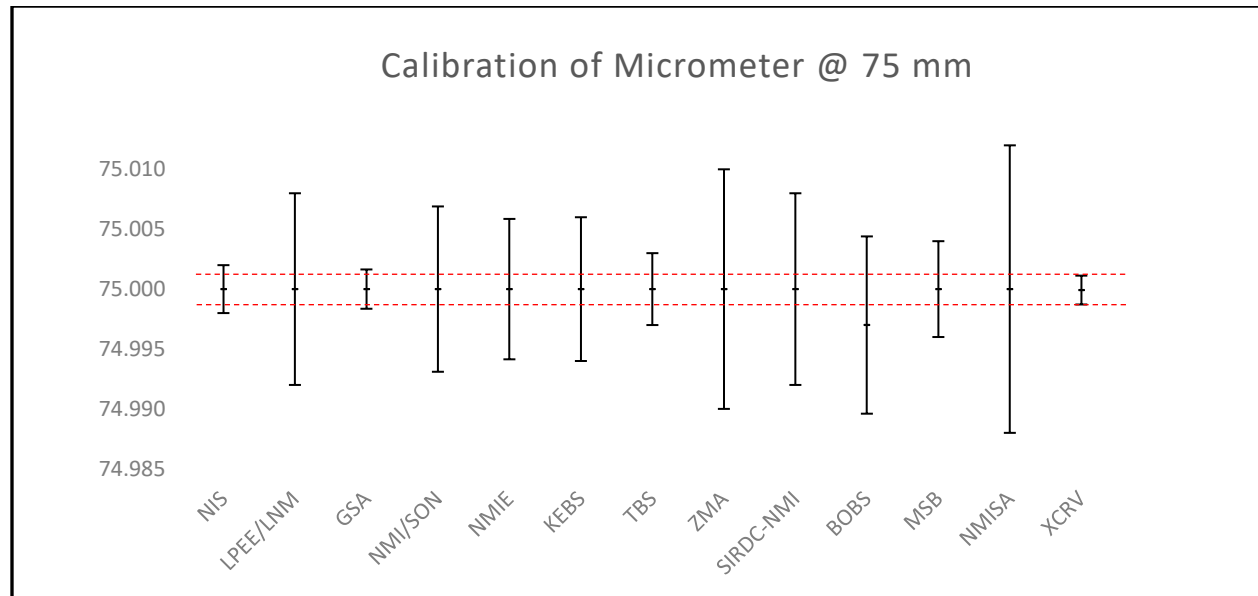
The standard uncertainty in the CRV value is calculated according to the following equation:

$$u(x_{CRV}) = \frac{\sqrt{\sum_{i=1}^N \frac{u^2(x_i)}{u_a^4(x_i)}}}{\sum_{i=1}^N u_a^{-2}(x_i)}$$

Calculation of the CRV and its uncertainty are given in table 6 and figure 2. The calculation is made after removing the inconsistent data according to section 9.3

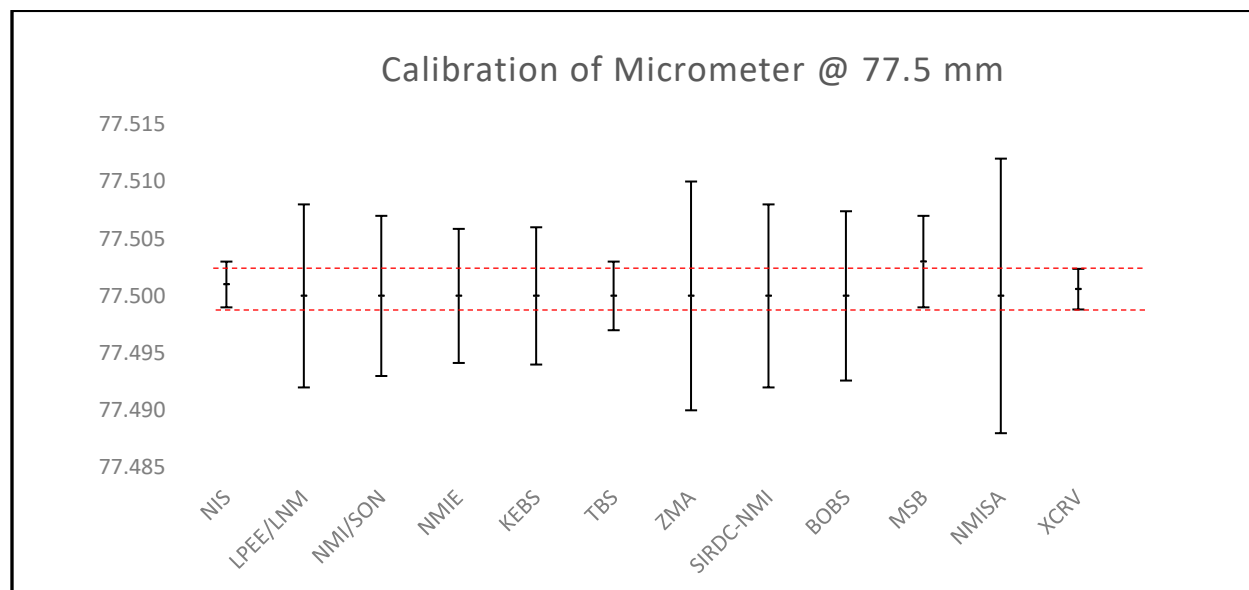
**Table 8. Comparison CRV and its uncertainty**

Nominal Length , (mm)	CRV value (length) (mm)	Expanded Uncertainty (@ $k=2$ ), (mm)
75.00	74.99992	0.00120
77.50	77.50059	0.00178
80.10	80.10045	0.00111
82.70	82.70036	0.00103
85.30	85.30032	0.00104
87.90	87.90042	0.00104
90.00	90.00022	0.00103
95.20	95.20057	0.00104
100.00	100.00046	0.00103

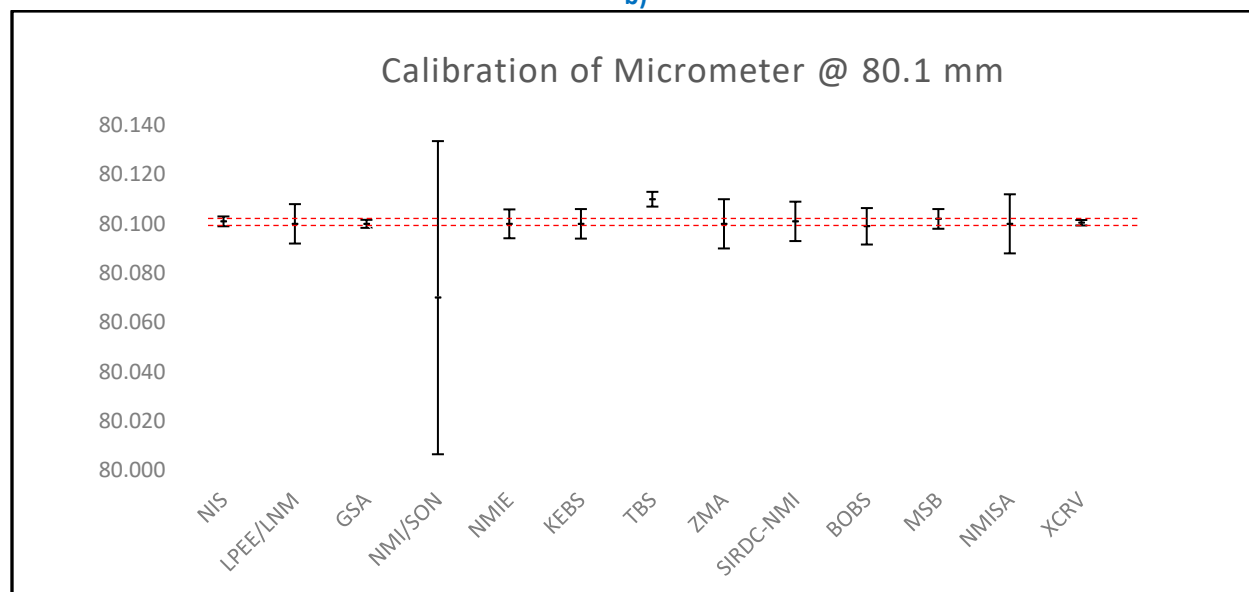


a)

## Final report: Calibration of External Micrometer

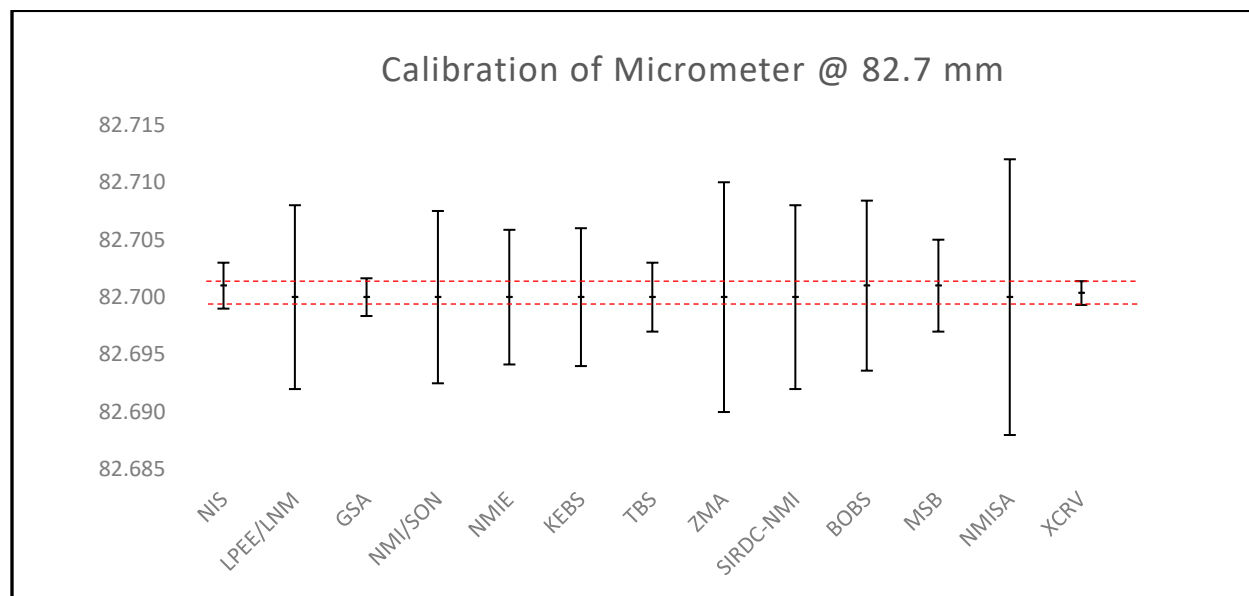


b)

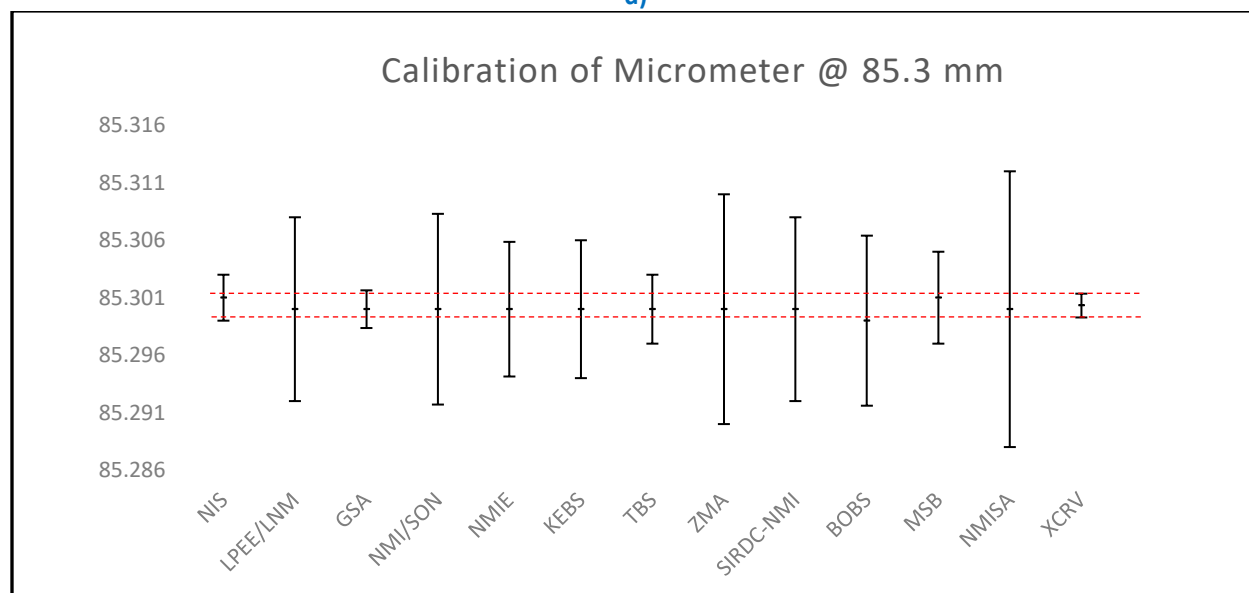


c)

## Final report: Calibration of External Micrometer

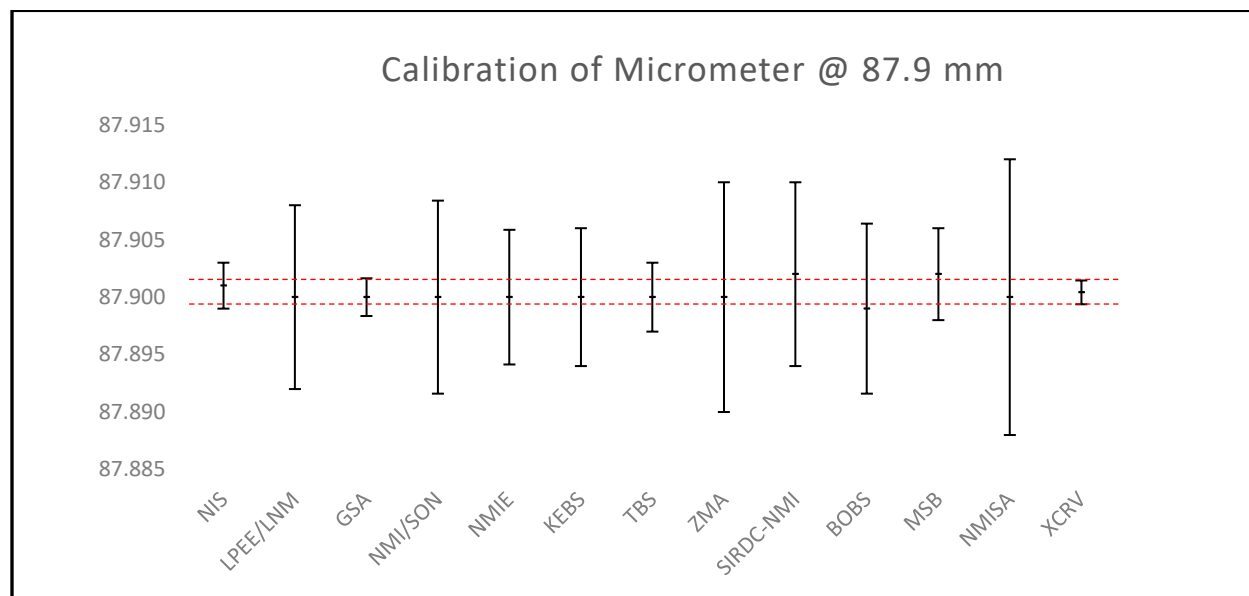


d)

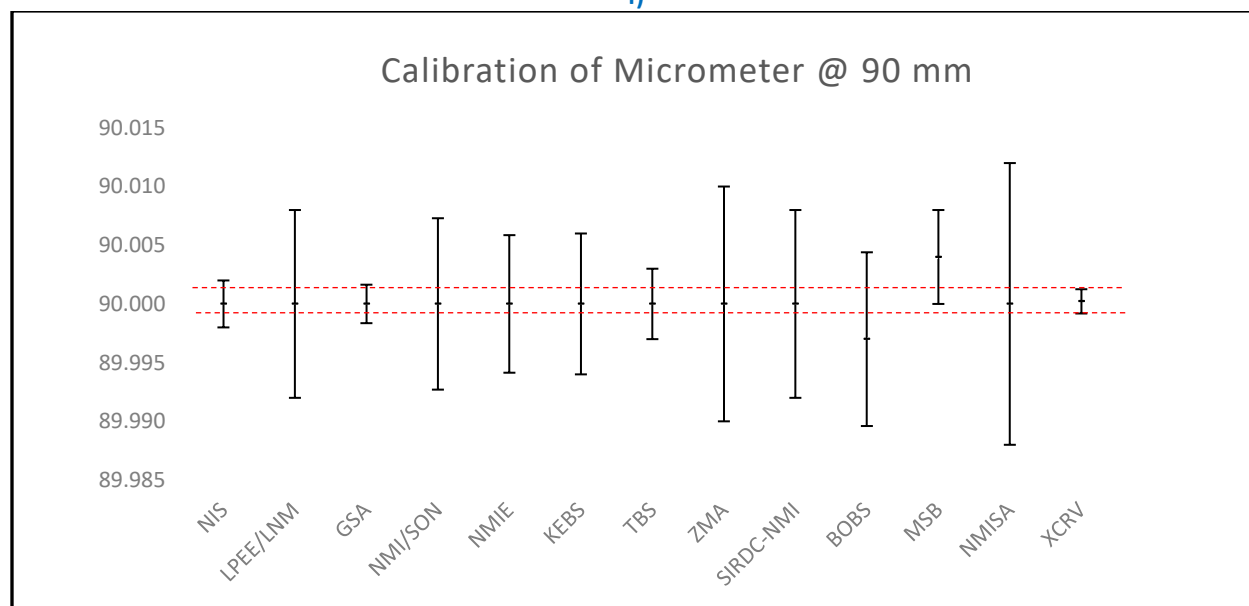


e)

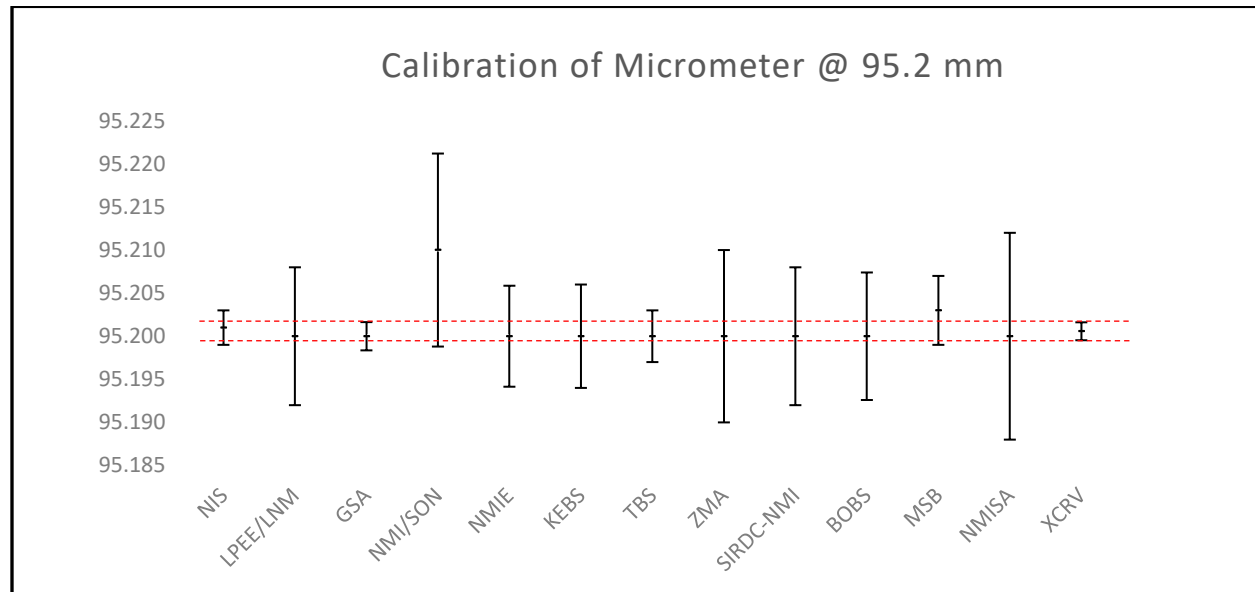
## Final report Calibration of External Micrometer



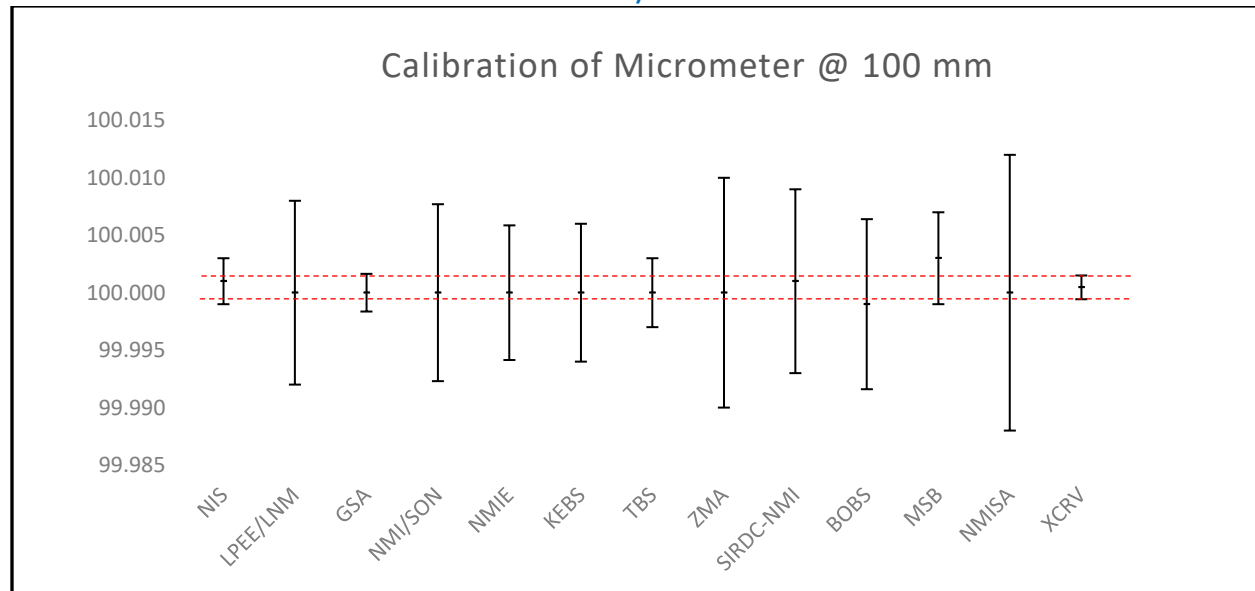
f)



h)



i)



j)

Figure 3. The results of the participants in comparison with the CRV and its uncertainty (expanded), a, b, c, d, e, f, i & j. dashed lines are uncertainty limits for each CRV.

### 9.3. Consistency check of the results

Before calculating the CRV and its uncertainty a consistency of the comparison results must be examined. To determine the consistency of comparisons results Chi-square value  $\chi_{obs}^2$  is calculated according to the following equation:



$$\chi_{obs}^2 = \sum_{i=1}^n \frac{(x_i - x_{CRV})^2}{u_a^2(x_i)} \quad 3$$

For the data to be consistent, the following condition must satisfy

$$\Pr\{\chi^2(\nu) > \chi_{obs}^2\} < 0.05 \quad 4$$

Where  $\nu$  is the degrees of freedom which is the number of participant minus one and  $P_r$  denotes “probability of” and  $\chi^2(\nu)$  is the inverse of the chi-square cumulative distribution function with degree of freedom specified by  $\nu$  for the probability of 0.05 (corresponding to the 95 % level of confidence). In this case, the participant with the highest value of  $\chi_{obs}^2$  is excluded from the next round of evaluation and a new reference value, reference standard uncertainty, and chi-squared values are calculated again without the excluded laboratory. If the consistency check did not fail then y was accepted as the  $x_{CRV}$  and the  $u(x_{CRV})$  are accepted. The number of participants  $N=12$ , therefore, the degrees of freedom  $\nu = N - 1 = 11$ . From the Chi-Square table at 95 % confidence level, we obtain  $\chi_{0.05}^2 = 19.68$ .

**Table 9: Consistency check (Not satisfied)**

Nominal length, (mm)	$\chi_{obs}^2$	$\chi_{0.05}^2$ ( $\nu=11$ )	Consistency $\chi_{obs}^2 \leq \chi_{0.05}^2$ ?
75.00	<b>0.64</b>	<b>19.68</b>	<b>Satisfied</b>
77.50	<b>1.77</b>	<b>19.68</b>	<b>Satisfied</b>
80.10	<b>37.987</b>	<b>19.68</b>	<b>Not Satisfied</b>
82.70	<b>0.798</b>	<b>19.68</b>	<b>Satisfied</b>
85.30	<b>0.952</b>	<b>19.68</b>	<b>Satisfied</b>
87.90	<b>1.678</b>	<b>19.68</b>	<b>Satisfied</b>
90.00	<b>4.405</b>	<b>19.68</b>	<b>Satisfied</b>
95.20	<b>5.173</b>	<b>19.68</b>	<b>Satisfied</b>
100.00	<b>2.577</b>	<b>19.68</b>	<b>Satisfied</b>

- The results from the following participants are removed before calculating the CRV and its uncertainty for the data to be consistent
  - Participant TBS @ (80.1 mm)

After removing these results from the CRV calculation:  $\nu = 10$  in the consistency check.

Table 10: Consistency check (satisfied)

Nominal Length, (mm)	$\chi^2_{obs}$	$\chi^2_{0.05} (\nu=10)$	Consistency $\chi^2_{obs} \leq \chi^2_{0.05} ?$
80.1	2.366	18.31	Satisfied

#### 9.4. Performance Evaluation

The purpose of the evaluation of performance methods is to provide a normalized performance evaluation so that all results are comparable and the performance of each participant can be measured. In such calibration schemes, the performance of the participants is evaluated by measuring whether the results of the participants are within the uncertainty of the CRV. The performance is evaluated using the normalized error number  $E_n$ , where;

$$E_n = \frac{(x_i - x_{CRV})}{\sqrt{U_{a_i}^2 + U_{CRV}^2}}$$

Where;  $x_i$  and  $U_{a_i}$  are the result and its corresponding adjusted expanded uncertainty of each participant, respectively.  $x_{CRV}$  and  $U_{CRV}$  are the CRV and its expanded uncertainty, respectively.  $E_n$  is interpreted as follows:

$|E_n| \leq 1 \rightarrow$  Satisfactory performance

$|E_n| > 1 \rightarrow$  Unsatisfactory performance

Table 11. Evaluation of performance for the participants using  $E_n$ 

Nominal Length, (mm)	$ E_n $											
	NIS (Egypt) (Pilot)	LPEE/LNM (Morocco)	GSA (Ghana)	NMI/SON (Nigeria)	NMIE (Ethiopia)	KEBS (Kenya)	TBS (Tanzania)	ZMA (Zambia)	SIRDC- NMI (Zimbabwe)	BOBS (Botswana)	MSB (Mauritius)	NMISA (South Africa)
75.00	0.03	0.01	0.04	0.01	0.01	0.01	0.02	0.01	0.01	0.39	0.02	0.01
77.50	0.15	0.07	N.E.	N.E.	0.08	0.10	0.09	0.17	0.06	0.07	0.08	0.55
80.10	0.24	0.06	0.23	0.48	0.08	0.07	2.98	0.04	0.07	0.19	0.37	0.04
82.70	0.29	0.04	0.03	0.18	0.05	0.06	0.06	0.11	0.04	0.04	0.09	0.16
85.30	0.30	0.04	0.03	0.16	0.04	0.05	0.05	0.10	0.03	0.04	0.18	0.17
87.90	0.26	0.05	0.03	0.21	0.05	0.07	0.07	0.13	0.04	0.20	0.19	0.38
90.00	0.10	0.03	0.02	0.11	0.03	0.04	0.04	0.07	0.02	0.03	0.43	0.92
95.20	0.19	0.07	0.05	0.30	0.84	0.10	0.09	0.18	0.06	0.07	0.08	0.59
100.00	0.24	0.06	0.04	0.24	0.06	0.08	0.08	0.15	0.05	0.07	0.20	0.61

N.E.: not evaluated

## **10. Conclusion:**

- The results from 12 National Metrology Institutes from Egypt, Morocco, Ghana, Nigeria, Ethiopia, Kenya, Tanzania, Zambia, Zimbabwe, Botswana, Mauritius and South Africa have participated in an AFRIMET supplementary comparison on the calibration of External Micrometer. The comparison reference value has obtained from the results using the weighted mean method after performing consistency check of the results using the Chi-square method. The Normalized error number  $E_n$  is used to evaluate the performance of all participants. All results are found satisfactory except TBS, Tanzania at 80.1 mm is found unsatisfactory ( $E_n > 1$ ).
- The participants of Ghana & Nigeria do not report their results at calibration point of 77.5 mm so they are not evaluated at this point.

## **List of References**

- [1] Guide to preparation of Key Comparison Reports in Dimensional Metrology (GD3), A Lewis, T Coveney 30 Nov 2020.
- [2] Measurement comparisons in the CIPM MRA, Guidelines for organizing, participating and reporting, CIPM MRA-G-11
- [3] M. G. Cox, "The evaluation of key comparison data", metrologia, 39, 589-595, 2002.