CIPM MRA
Comparison reports

SIM.L-S2.2.n02

Gauge blocks measured by with mechanical probing techniques

SUPPLEMENTARY COMPARISON

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Report on SIM Supplementary Comparison

Gauge blocks measured by with mechanical probing techniques

SIM.L-S2.2.n02

Final Report

J. Campbell (INTI), B Eves (NRC),
C Castellanos (CENAM), R Morales (DICTUC),
D Cano (INACAL), W Barros (INMETRO), E Stanfield (NIST), David Plazas (INM)

Nov 2025

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Document control

Version Draft A.1	Issued on 16 April 2024.
Version Draft A.2	Issued on 27 May 2024.
Version Draft B	Issued on Aug 2024.

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.

During the June 2019 SIM Length Working Group meeting, it was decided to run a supplementary comparison of the measurement of long gauge blocks by mechanical comparison, SIM.L-S2.2.n02, with INTI, the National Metrology Institute (NMI) of Argentina as pilot of the comparison, and the National Research Council (NRC) Canada as co-pilot.

INTI provided the gauge blocks, registered the participants, processed the results and generated the reports in collaboration with NRC who provided the reference interferometry measurements for the gauges and served as a neutral third party for collection of the results.

1 Organization

1.1 Participants

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
CENAM	Miguel Viliesid Alonso Carlos Colin Castellanos CENAM, Centro Nacional de Metrología - km 4,5 Carretera a los Cues, El Marqués CP 76241, Querétaro, MEXICO	Tel. +52 442 211 0500 Fax +52 442 211 0577 e-mail: mviliesi@cenam.mx e-mail: ccolin@cenam.mx
DICTUC	Roberto Morales Patricia Suazo DICTUC, Laboratorio Nacional de Longitud Avenida Vicuña Mackenna 4860 – Macul – Santiago – (edificio nº 9 metrología), CHILE	Tel. 56 2 354 4624 Fax 56 2 354 4624 e-mail: rmoralez@dictuc.cl e-mail: psuazo@dictuc.cl
INACAL	Daniel Cano INACAL, Instituto Nacional de la Calidad, Calle De La Prosa N° 150 San Borja, Lima 41, PERÚ	Tel. 511 640 8820 Ext 1513 e-mail: jdcano@inacal.gob.pe
INM	Victor Hugo Gil David Plazas Jorge Luis Galvis Arroyave INM, Instituto Nacional de Metrología de Colombia Av. Carrera 50 No 26 - 55 Int. 2 Bogotá, D.C. - COLOMBIA	Tel. (571) 2542222 e-mail: vgil@inm.gov.co e-mail: dalplazas@inm.gov.co e-mail: jlugalvis@inm.gov.co
INMETRO	Wellington S. Barros INMETRO, Instituto Nacional de Metrologia, Normalização e Qualidade Industrial. Av. N.Sra. das Graças, 50 – Villa Operária –Xerém – Duque de Caixas – RJ. CEP 25250-020, BRASIL	Tel. +55 21 2679-9271 Fax +55 21 2679-9207 e-mail: wsbarros@inmetro.gov.br
INTI (pilot)	Jorge Campbell (pilot) INTI, Instituto Nacional de Tecnología Industrial, Av.General Paz 5445, B1650WAB San Martin ARGENTINA	Tel. +54 11 4724 6200 Ext: 7267 Fax +54 11 4713 4140 e-mail: jcampbell@inti.gob.ar
NIST	Eric Stanfield NIST, National Institute of Standards and Technology Building 220, Room A109 Gaithersburg, MD 20899-8211 USA	Tel. 1 301-975-4882 Fax. 1 301 975-8291 e-mail: eric.stanfield@nist.gov
NRC (co-pilot)	Brian Eves NRC, National Research Council 1200 Montreal Road, Building M36 Ottawa, Ontario K1A 0R6 Canada	Tel. 1 613 991 3279 e-mail: brian.eves@nrc-cnrc.gc.ca

1.2 Schedule

Table 2. Schedule of the comparison.

Laboratory	Original schedule	Date of measurement	Results received
NRC	January 2020	May 2021	May 2021
NIST	July 2020	June 2021	January 2024
INTI	February 2020	September 2021	February 2023
DICTUC	March 2020	May 2022	June 2022
INM	April 2020	September 2022	September 2022
INACAL	June 2020	November 2022	May 2023
CENAM	August 2020	April 2023	May 2023
INMETRO	October 2020	December 2023	December 2023
NRC	November 2020	July 2023	August 2023
INTI	December 2020	January 2024	January 2024

2 Artefacts

2.1 Description of artefacts

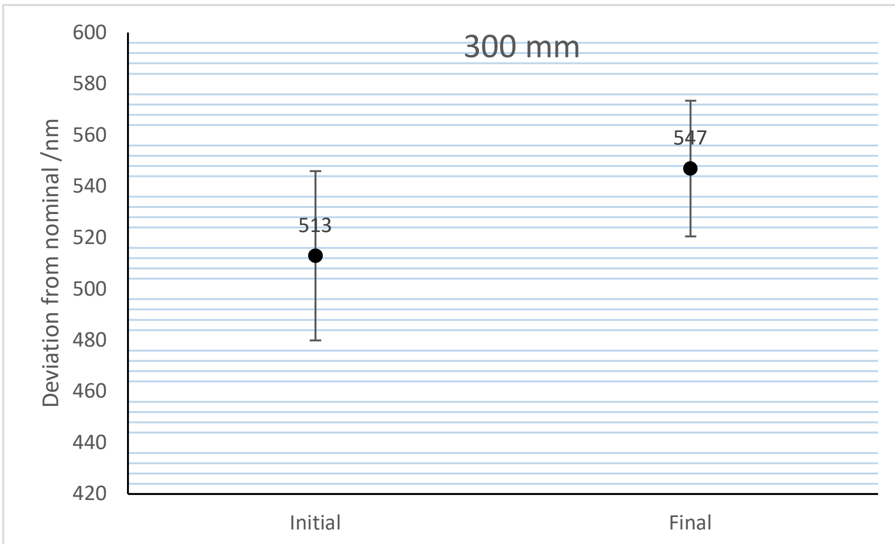
Two long gauge blocks made of steel with rectangular cross section according to the International Standard ISO 3650.

Table 3. List of artefacts.

Identification	Nominal length /mm	Expansion coefficient $/10^{-6}$ K^{-1}	Manufacturer
None	300	11.5 ± 0.1	Hommel Werke
87333	500	11.2 ± 0.1	KOBA

2.2 Stability of artefacts

The stability of the artefacts was established using the initial and final interferometric length measurements of NRC. The difference between the measurements were within the 95% confidence level of the measurement uncertainty and the artifacts are considered stable for the purposes of this comparison.



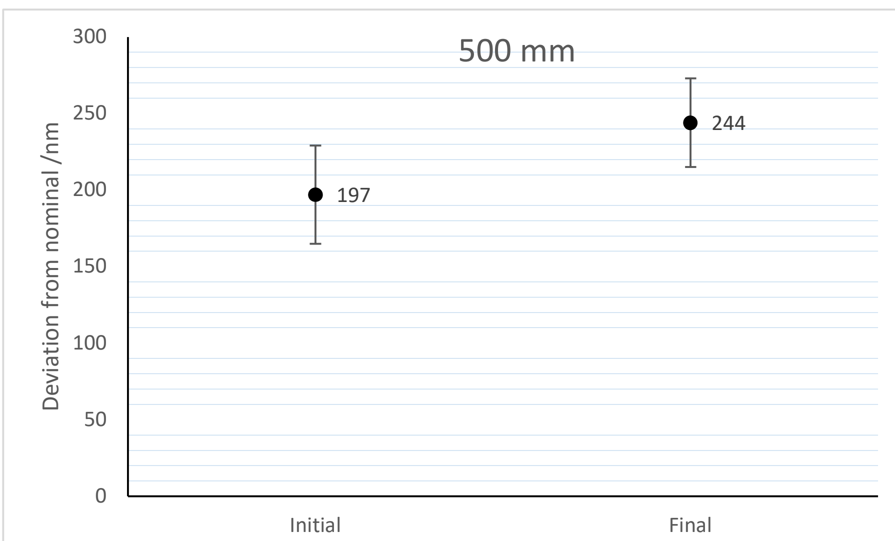


Figure 1. Stability of the (top) 300 mm gauge block and (bottom) 500 mm gauge block with serial number 87333 during comparison: initial and final reference length measurements of the co-pilot laboratory. Uncertainty bars show standard uncertainty (k=1).

2.3 Condition of artefacts at start/end of comparison

No damage was observed during the circulation.

The inspection reports of the first and last laboratory of the round are shown below in figure 2. (NRC and INMETRO)

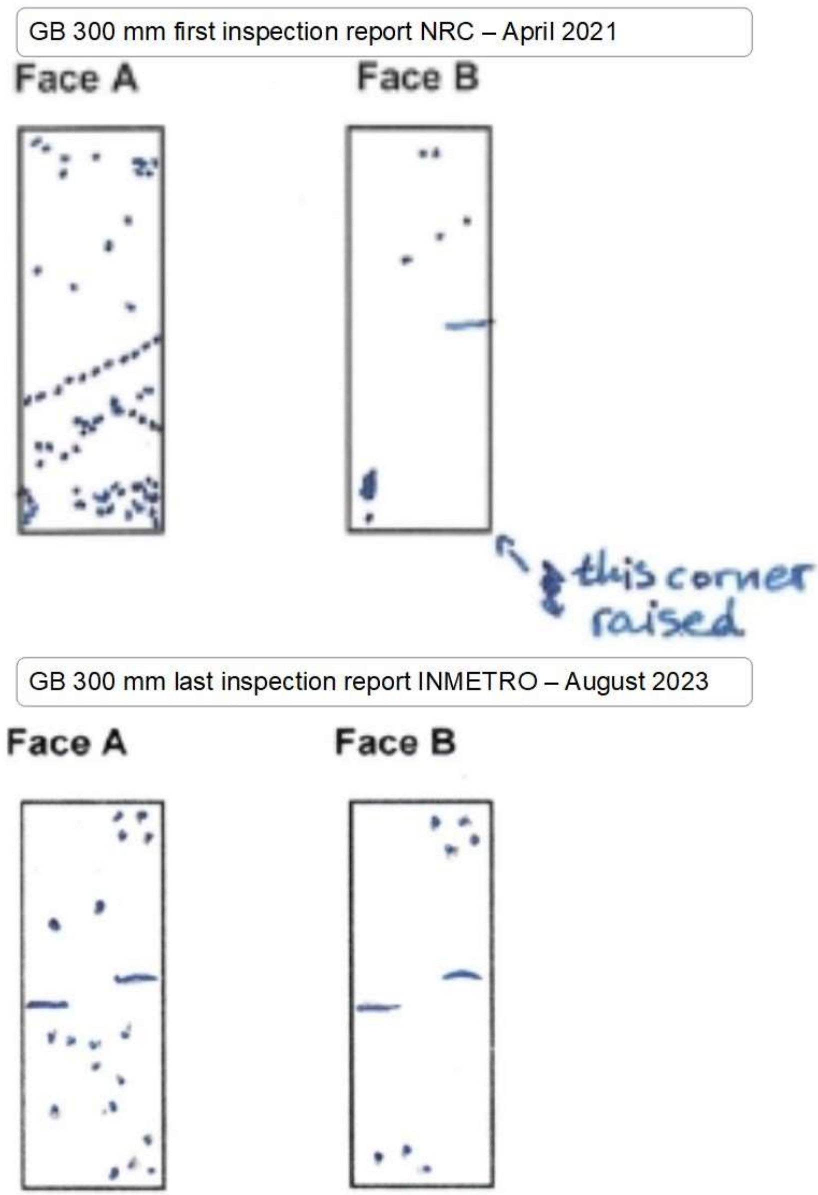


Figure 2.a The inspection reports for the first and last laboratory to measure the 300 mm block (NRC and INMETRO).

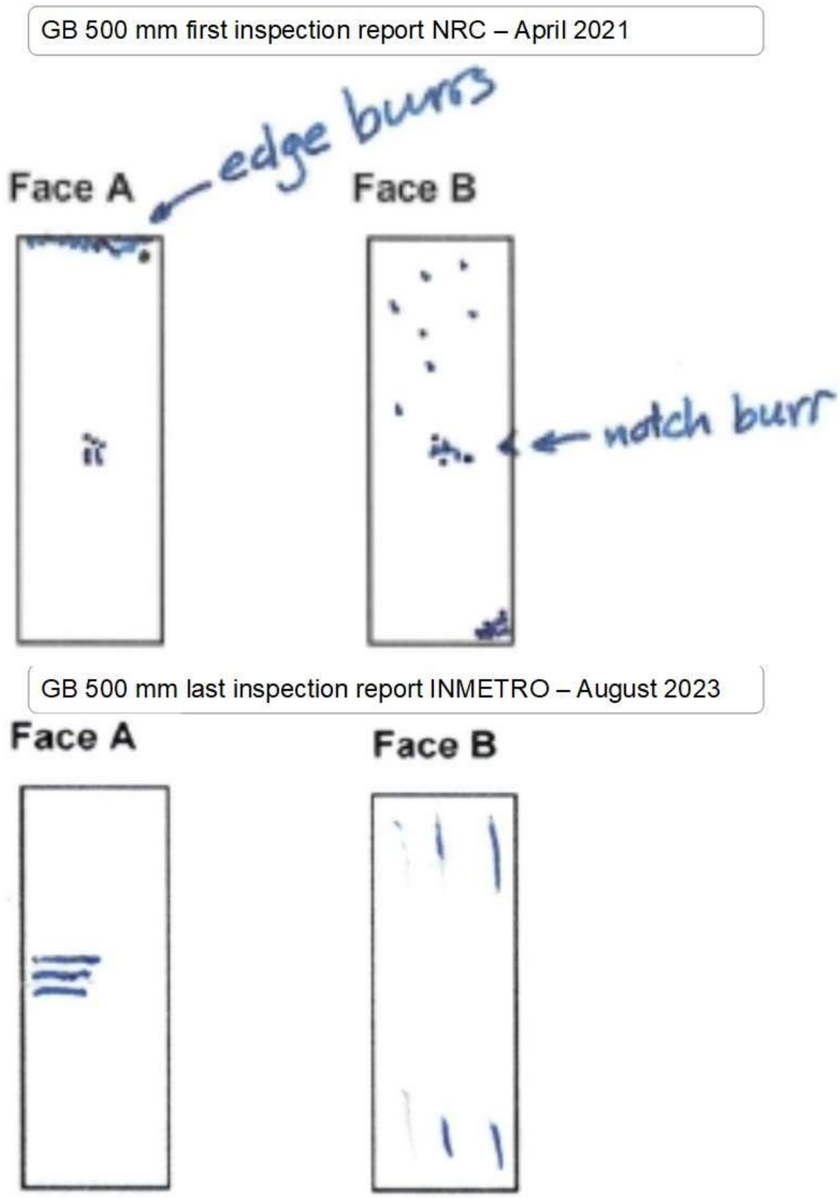


Figure 2.b The inspection reports for the first and last laboratory to measure the 500 mm block (NRC and INMETRO).

3 Measuring instructions

3.1 Measurands

The measurand is the deviation of the central length of the GB with respect to its nominal length, as defined in ISO 3650. Deviation of the central length l is the difference between the measured central length l_c and the nominal length l_n calculated as:

$$l = l_c - l_n$$

4 Results

4.1 Results and standard uncertainties as reported by participants

The deviation from nominal length for the gauge blocks is shown in table 4 and the standard uncertainties reported by the participants is shown in table 5.

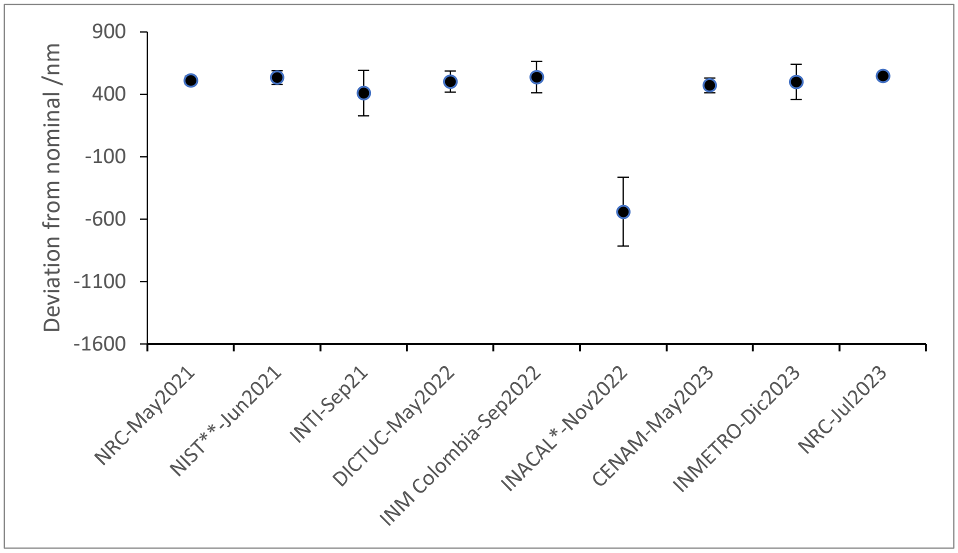
Table 4. Deviation from nominal length (in nm) of the steel gauge blocks, as reported by the laboratories.

	Gauge blocks nominal length	
	300 mm	**500 mm**
Lab	**Deviation from nominal length (nm)**	
NRC	513	197
NIST	535	165
INTI	452	50
DICTUC	503	470
INM	538	409
INACAL	-540	-1090
CENAM	473	324
INMETRO	500	140
NRC	547	244

Table 5. Standard uncertainties (in nm), as reported by the laboratories.

	Gauge blocks nominal length	
	300 mm	**500 mm**
Lab	**Standard uncertainties (nm)**	
NRC	33	32
NIST	55	86
INTI	182	287
DICTUC	85	125
INM	126	228
INACAL	275	335
CENAM	59	95
INMETRO	140	216
NRC	27	29

Shown in figure 3 are the results for both gauge blocks. The error bars represent the standard uncertainty of the measurements.



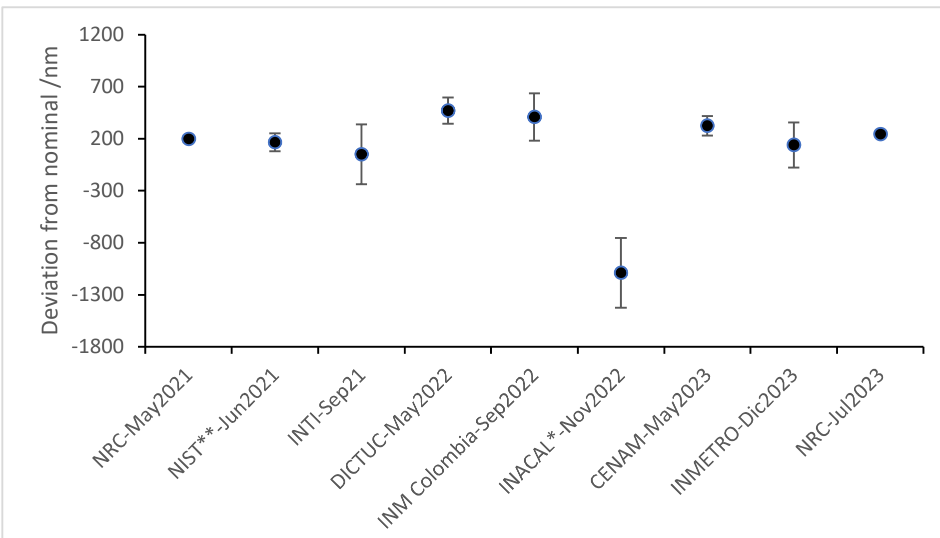


Figure 3. Deviation from nominal length for the 300 mm steel gauge block (top) and the 500 mm steel gauge block (bottom). The error bars represent the standard uncertainty bars.

** values revised before draft A*

Because the results sent by INACAL were far from the consensus values (and were of the opposite sign) the co-pilot (who collected and processed the data) invited them to review them.

Hi Daniel, I've just finished aggregating the results for the SIM.L-S8.2019 comparison. Please have a careful look at your results as there appears to be a discrepancy between them and the consensus values. Your measurement values as communicated to me are as follows:

Block	*Value /nm*	*Uncertainty (k=2) /nm*
300 mm	*-1180*	*550*
500 mm	*-210*	*670*

….. Brian EVES - February 01, 2024

I have reviewed my results and it appears that there is a sign error when performing the calculation, please consider these measurements.

DANIEL CANO URIBE - February 13, 2024

*** revised after draft A*

NIST provided lengths of the blocks with a correction for the orientation of the block and they wished to change the orientation reported from vertical to horizontal.

Brian : Just curious, is this data shown all based on the vertical or horizontal length? Mechanical, I suspect, could be done on a horizontal length measuring machine instead of a vertical comparator like we use.

Eric Stanfiel - February 16, 2024

The protocol states that the measurand is the central length deviation as specified in ISO 3650. In ISO 3650 Section 5.4 it states that the measurand for gauges under 100 mm is specified with the gauges oriented vertically while the measurand for gauges greater than 100 mm the gauges are oriented horizontally. I don't actually know how the individual labs measured their master gauges but they should be reporting the length for the horizontal orientation.
….. Brian EVES - February 16, 2024

… For steel, we use in simplified form from vertical to horizontal +0.18E-06L^2. That would be +16 nm for the 300 mm and +45 nm for the 500 mm.

For horizontal orientation our results should be:

300 mm +535 nm
500 mm +165 nm
…… Eric Stanfield - February 16, 2024

4.2 Measurement uncertainties

Shown in table 6 are the uncertainty equations for the CMCs of the participants. Note that the uncertainty equations have been reformatted into quantity equations as necessary. The uncertainty budgets for the submitted results can be found in Appendix B.

Table 6. .Expanded uncertainty equations for the CMCs of the participants as listed in the KCDB. The uncertainty equations have been reformatted into quantity equations where necessary.

Lab	CMC equation
NIST	31 nm + 0.26e-6 L
INTI	Q[150 nm, 1.1e-6 L]
DICTUC	Q[81 nm, 0.46e-6 L]
INM	Q[65 nm, 0.91e-6 L]
INACAL	-
CENAM	Q[21 nm, 0.49e-6 L]
INMETRO	Q[100 nm, 0.70e-6 L]
NRC	Q[30 nm, 0.10E-6 L]

4.3 Changes to results after Draft A.1

The NIST values for both gauges were revised after the release of draft A.1. The changes were minor and did not impact the agreement between the NIST results and the comparison reference value. The results shown in tables 4 and 5 are the modified results.

5 Analysis

5.1 Calculation of the comparison reference value

The comparison reference values for the measurands are derived from a weighted fit of the initial and final interferometry measurements performed by NRC. The weights are calculated according to

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

where the measurements are given by the measured values, x_i , and their associated standard uncertainty $u(x_i)$. The normalising factor, C, is

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

where the total number of NRC measurements, in this case only two, is represented by I. The calculated weighted mean, $\bar{x}_w$, is simply

$$\bar{x}_w = \sum_{i=1}^{I} w_i \cdot x_i \, , \tag{3}$$

and the associated uncertainty of the weighted mean is

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

The reference values and the associated uncertainties for the measurands are shown in table 7.

Table 7. Comparison reference value $\bar{x}_w$ and associated standard uncertainty $u(\bar{x}_w)$.

	Deviation from nominal value /nm	
	300	**500**
$\bar{x}_w$ / nm	534	223
$u(\bar{x}_w)$ / nm	21	21

The initial and final reference measurements at NRC were performed by different operators and used independently-evaluated phase corrections as well as separate calibrations of the laser wavelengths, temperature sensors, barometer and hygrometer. The dominant uncertainty contributions are thus expected to be uncorrelated between these two measurements, which is why we use the usual weighted mean to combine them. If the initial and final reference measurements were instead treated as fully-correlated, the standard uncertainty of the comparison reference value would increase to ca. 30 nm. This increase does not affect the outcome of the comparison: the same participant results are deemed equivalent with either choice of reference value calculation.

5.2 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 the normal rules for the propagation of uncertainty. Note that unlike a key comparison the reference value is independent of the participating laboratories results. The normalized error is given by

$$E_n = \frac{x_i - \bar{x}_w}{2\sqrt{u^2(x_i) + u^2(\bar{x}_w)}}. \tag{5}$$

The DoE and E_n values for the two gauge blocks are shown in table 7.

Table 8. The degrees of equivalence $x_i - \bar{x}_w$, the associated expanded uncertainty $\boldsymbol{u}(\boldsymbol{x_i} - \bar{\boldsymbol{x}}_{\boldsymbol{w}})$, and the normalized error for both gauge blocks.

	300			500		
	Degree of Equivalence /nm		E_n	Degree of Equivalence /nm		E_n
	$x_i - \bar{x}_w$	$u(x_i - \bar{x}_w)$		$x_i - \bar{x}_w$	$u(x_i - \bar{x}_w)$	

NIST	1	120	0.01	-58	180	-0.33
INTI	-123	370	-0.34	-173	580	-0.30
DICTUC	-31	180	-0.18	247	250	0.97
INM	4	250	0.02	186	460	0.41
INACAL	-1074	550	-1.95	-1313	670	-1.96
CENAM	-61	130	-0.49	101	190	0.52
INMETRO	-34	280	-0.12	-83	430	-0.19

5.3 Discussion of results

The only disagreement between the comparison reference values and the participating laboratories is for both results of INACAL. Both measurands are shorter than the reference by approximately a micrometre. INACAL revised their submission before the release of draft A.1.

6 Appendices

6.1 Appendix A: Equipment and measuring processes of the participants

Participant	Equipment
NRC	Interferometer (reference value)
NIST	Two-Point Contact Comparator Mahr/Federal 130B-16 (Vertical operating device)
INTI	Heterodyne Laser Measurement System Hewlett Packard 5518A
DICTUC	Universal measuring machine MAHR ULM 600E
INM-Colombia	Tesa UPD comparator - (Vertical operating device)
INACAL	Horizontal Measuring Instrument LABCONCENPT Nano 1100
CENAM	Vertical Gauge Blocks Comparator Model : UPD
INMETRO	Aus Jena 1-D Universal Measuring Machine

NRC

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Twyman-Green Interferometer	NRC Gauge-Block Interferometer	N/A	0 to 1000	N/A

Instrument description: The NRC Gauge-Block Interferometer, constructed and developed in-house, is a Twyman-Green interferometer employing frequency-stabilized HeNe lasers at 544 nm, 612 nm, and 633 nm. Readout is by phase-stepping interferometry. Part temperature is monitored by thermistors in copper blocks held in contact with the gauge near the Airy points.
Type of instrument: Twyman-Green Interferometer.
Traceability: To NRC's realization of the SI second.
Calibration method of your reference: The 633 nm laser was calibrated by beat-note comparison with an iodine-stabilized HeNe laser which is itself regularly calibrated using an optical frequency comb. The 544 nm and 612 nm lasers were calibrated using the optical frequency comb directly. The repetition rate and carrier-envelope offset of the comb are traceable to NRC's realization of the SI second.

Interval of temperature during measurements: 19.984 °C to 20.017 °C	
Orientation in which the block has been measured: Horizontal	

NIST

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Two-Point Contact Comparator (Mahr/Federal)	130B-16		125 - 500	Computer program controlled based on number of measurements or every 3 months, whichever comes first.

Orientation: Vertical

INTI

1-D measuring machine (SIP MUL1000 Two-Point Contact), stylus, gauge blocks substitution and length interferometer (Heterodyne Laser Measurement System Hewlett Packard 5518A)

DICTUC

Instrument description: Universal measuring machine inside an acrylic dome, with 5 pt100 contact temperature sensors, and software to correct deviations of the reference and to apply temperature corrections. The calibration is performed by mechanical comparison.
Type of instrument: 1-D horizontal comparator stylus. Measuring with gauge blocks substitution

INM-Colombia

Instrument description: Mitutoyo steel block 300 mm and 500 mm Tesa UPD comparator, 0.5 mm to 500 mm Fluke Thermometer
Type of instrument: • Mitutoyo Metric rectangular steel gage block set 300 mm and 500 mm • Tesa UPD comparator; direct measurement of gauge blocks • Fluke Therommeter

Orientation: Vertical

INACAL

Type	Model	Serial number	Measurement range	Date of last calibration
Gauge Block grade K	BM1-8R-K/YJ	808611	125 mm a 500 mm	18/1/2022
Horizontal Measuring Instrument	LABCONCEPT NANO 1100	1136/V3	0 m a 1m (measurement comparison)	10/10/2017
Digital thermometer	2490-2	H17060348	-200 °C a 400 °C	2022-05-24

Instrument description:	Gauge Block of 125 mm to 500 mm
Type of instrument:	Grade K (Steel)
Traceability:	Centro Español de Metrología (CEM - SPAIN)
Calibration method of your reference:	Comparison Interferometer laser He-Ne (633 nm)
Interval of temperature during measurements:	20 °C ± 0,5 °C
Orientation in which the block has been measured:	Horizontally

Instrument description:	Universal length Measuring Machine 1D
Type of instrument:	0 m a 1 m (measurement comparison)
Traceability:	TRIMOS / METAS
Calibration method of your reference:	Comparison with interferometer

Instrument description:	Digital thermometer
Type of instrument:	-200 °C a 400 °C / 0,01 °C / PT100 class A
Traceability:	INSTITUTO NACIONAL DE METROLOGÍA (INACAL)
Calibration method of your reference:	Comparison with two Digital thermometer of uncertainty 0,0164 °C to 0,0199 °C

CENAM

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
VERTICAL GAUGE BLOCKS COMPARATOR	upd	7Q01	0.5-500	2021-12-15 CUM-CC-740-700/2021

Instrument description:
VERTICAL GAUGE BLOCKS COMPARATOR USING A GB REFERENCE CALIBRATED BY INTERFEROMETRY

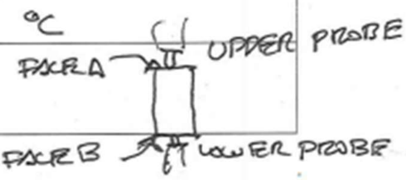
Type of instrument:
ELECTROMECHANICAL GAUGE BLOCK COMPARATOR

Traceability
UNIT LENGTH MÉXICO
UNIT LENGTH GERMANY

Calibration method of your reference:
GB BY INTERFEROMETRY

Interval of temperature during measurements:
GB 300 mm 20.05 - 20.09 °C
GB 500 mm 19.98 - 20.12 °C

Orientation in which the block has been measured:
VERTICAL



Laboratory: CENAM (MÉXICO)

Date: 2023-05-18 Name and Signature CARLOS COLÍN C

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INMETRO

Type.	Model.	Serial number.	Measurement range	Date of last calibration
1-D measuring machine	Aus Jena	N/A	1000 mm	N/A
Thermometer	Onset	UX100-003	18 °C – 22°C	08/02/2023
Gauge Blocks Steel	Frank	BP 006 – BP008	100 mm – 1000 mm	02/01/2023
Laser Measurement System	Agilent	5519B		09/02/2023

Instrument description. Type of instrument:

1-D Universal Measuring Machine (Two-Point Contact);

Gauge Blocks Steel: 300 and 500 mm Grade K;

Laser Measurement System (He Ne - 633 nm).

Traceability:

Gauge Blocks - Laboratório de Interferometria - Laint (Inmetro);

Laser Measurement System - Laboratório de Interferometria - Laint (Inmetro);

Thermometer - Laboratório de Termometria - Later (Inmetro);

Calibration method of your reference: Gauge Block by Interferometry.

Orientation in which the block has been measured: Horizontallly.

Interval of temperature during measurements: 19,9 °C – 20,2 °C.

Laboratory: Laboratório de Metrologia Dimensional (Lamed) – Inmetro.

6.2 Appendix B: Measurements Uncertainly Budgets of the participants

NIST

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\lvert c_i \rvert \equiv \partial l/\partial x_i$	Combined Standard Uncertainty. $u_i \equiv \lvert c_i \rvert\ u(x_i)$ (nm)
Masters (l_S)	6.5 + 0.05L	1	(6.5 + 0.05L)
Reproducibility[1] (l_R)	8.1 + 0.11L	1	(8.1 + 0.11L)
Scale (S)	3.0 nm	1	3.0
CTE_{Test} (α_T)	0.66 °C^{-1}	0.1	0.066L
$CTE_{Master\ \#1}$ (α_S)	0.66 °C^{-1}	0.1	0.066L
Thermometer (T)	0.01 °C	α_T - α_S[2]	0
Thermal Gradient (δ)[3]	0.003 °C	α_{AVG}	0.033L
Elastic Deformation (Δ)	7 nm	1	7
COMBINED STANDARD UNCERTAINTY (*k* = 1)			**$u_{c\ LINEAR}$ = (10.3 + 0.15L) nm, L is in mm**
Expanded Unc., U (k=2) Min = 55 nm Max = 169 nm			
Range 125 mm to 500 mm			
Effective degrees of freedom			

INTI

Gage Block :	300 mm	NN	0,0000115 1/K
Source of uncertainty	Standard uncertainty	Sensitivity Coefficient	Combined Standard Uncertainty
xi	**u(xi)**	**|ci| = δl/δxi**	**ui=|ci|.u(xi)**
			µm
Calibration of the standard	0,06	1,00	0,06
Difference in lengths (standard desviation)	0,05	1,00	0,05
Difference in lengths (laser vaccum wavelengtl	6,00E-008	0,43	0,00
Temperature of standard gage	0,03	3,51	0,11
Temperature of unknow gage	0,03	3,45	0,11
Thermal expansion coefficient standard gage	5,77E-007	3959,30	0,00
Thermal expansion coefficient unknow gage	5,77E-007	2209,31	0,00
Misalignment	0,03	1	0,03
Zero detection on standard gage	0,01	1	0,01
Zero detection on unknow gage	0,01	1	0,01
Refractive index	4,00E-007	0,43	0,00
Suma cuadrática			0,03
COMBINED STANDARD UNCERTAINTY (k = 1)			0,18
Effective degrees of freedom			32

Gage Block :	500 mm	87333	0,0000112 1/K
Source of uncertainty	Standard uncertainty	Sensitivity Coefficient	Combined Standard Uncertainty
xi	**u(xi)**	**|ci| = δl/δxi**	**ui=|ci|.u(xi)**
			µm
Calibration of the standard	0,19	1,00	0,19
Difference in lengths (standard desviation)	0,06	1,00	0,06
Difference in lengths (laser vaccum wavelengtl	6,00E-008	0,15	0,00
Temperature of standard gage	0,03	5,75	0,15
Temperature of unknow gage	0,03	5,60	0,14
Thermal expansion coefficient standard gage	5,77E-007	59317,83	0,03
Thermal expansion coefficient unknow gage	5,77E-007	57567,83	0,03
Misalignment	0,03	1	0,03
Zero detection on standard gage	0,01	1	0,01
Zero detection on unknow gage	0,01	1	0,01
Refractive index	4,00E-007	0,15	0,00
Suma cuadrática			0,08
COMBINED STANDARD UNCERTAINTY (k = 1)			0,29
Effective degrees of freedom			61

DICTUC

Nominal length **: 300 mm**
Material : Steel
Thermal exp. standard gauge block : $1{,}14*10^{-5}$ 1/°C
Thermal exp. gauge block : $1{,}15*10^{-5}$ 1/°C
Temperature during all calibration : (20,01 to 20,03) °C
Date of measurement : April 13 / 2022

Source of uncertainty x_i	Standard uncertainty $u(x_i)$		Sensitivity Coefficient. $\|c_i\| \equiv \partial l/\partial x_i$	Combined Standard Uncertainty. $u_i \equiv \|c_i\|\ u(x_i)$
u (ls) Calibration of standard gauge block	18,58	nm	1	18,58
u (l cer) standard gauge block certificate	16,00	nm		
u (l der) standard gauge block drift	9,45	nm		
u (d) Measured difference between gauge blocks	24,98	nm	1	24,98
u (d com) gauge blocks comparator	20,00	nm		
u (d rep) repeated observations	2,76	nm		
u (d res) comparator indication	2,89	nm		
u (d al) sensor alignment	8,16	nm		
u (d des) probing deviation	11,89	nm		
u (d defe) elastic deformation	0,18	nm		
u (αr) Thermal expansion standard gauge block	6,58E-07	1/°C	0	0
u (αc) Thermal expansion gauge block	6,64E-07	1/°C		
u (θ) Temperature	0,029	°c	0	0
u (cal) termistor certificate	0,025	°c		
u (res) indication termistor	0,003	°c		
u (Δ) thermal gradient	0,014	°c		
u ($\delta\theta$) Temperature difference between gauge blocks	0,012	°c	$-l_s\alpha_s$	39,84
u ($\delta\alpha$) Thermal exp. difference between gauge blocks	2,9E-07	1/°C	$-l_s\theta$	1,73
Second order terms:				
Effects of temperature on standard gauge block $\theta_s\alpha_s$	1,90E-08	1/°C	l_s	5,70
Effects of temperature on gauge block $\theta_s\alpha$	1,92E-08	1/°C	l_s	5,75
Temperature difference between gauge blocks $\delta\theta\ \alpha$	7,67E-09	1/°C	l_s	2,30
COMBINED STANDARD UNCERTAINTY (*k* = 1)				**51** nm
CMC declared (k=1). This will be our official result				**85 nm**
Effective degrees of freedom				

Nominal length : **500 mm**
Material : Steel
Thermal exp. standard gauge block : $1{,}14 \cdot 10^{-5}$ 1/°C
Thermal exp. gauge block : $1{,}12 \cdot 10^{-5}$ 1/°C
Temperature during all calibration : (19,95 to 19,99) °C
Date of measurement : April 20 / 2022

Source of uncertainty x_i	Standard uncertainty $u(x_i)$		Sensitivity Coefficient. $\lvert c_i \rvert \equiv \partial l / \partial x_i$	Combined Standard Uncertainty. $u_i \equiv \lvert c_i \rvert\, u(x_i)$
u (ls) Calibration of standard gauge block	31,45	nm	1	31,45
u (l cer) standard gauge block certificate	30,00	nm		
u (l der) standard gauge block drift	9,45	nm		
u (d) Measured difference between gauge blocks	31,75	nm	1	31,75
u (d com) gauge blocks comparator	20,00	nm		
u (d rep) repeated observations	16,10	nm		
u (d res) comparator indication	2,89	nm		
u (d al) sensor alignment	8,16	nm		
u (d des) probing deviation	16,54	nm		
u (d defe) elastic deformation	0,18	nm		
u (αr) Thermal expansion standard gauge block	6,58E-07	1/°C	0	0
u (αc) Thermal expansion gauge block	6,47E-07	1/°C		
u (θ) Temperature	0,033	°c	0	0
u (cal) termistor certificate	0,025	°c		
u (res) indication termistor	0,003	°c		
u (Δ) thermal gradient	0,021	°c		
u ($\delta\theta$) Temperature difference between gauge blocks	0,012	°c	-lsαs	64,66
u ($\delta\alpha$) Thermal exp. difference between gauge blocks	2,9E-07	1/°C	-lsθ	2,89
Second order terms:				
Effects of temperature on standard gauge block $\theta_s\alpha_s$	2,17E-08	1/°C	ls	10,83
Effects of temperature on gauge block $\theta_s\alpha$	2,13E-08	1/°C	ls	10,64
Temperature difference between gauge blocks $\delta\theta\ \alpha$	7,47E-09	1/°C	ls	3,73
COMBINED STANDARD UNCERTAINTY (*k* = 1)				**80** nm
CMC declared (k=1). This will be our official result				**125 nm**
Effective degrees of freedom				

INM

Block 300 mm

Source of uncertainty *xi*		**Standard uncertainty *u(xi)***		**Sensitivity Coefficient $\lvert c_i \rvert \equiv \partial l / \partial x_i$**		**Combined Standard Uncertainty $u_i \equiv \lvert c_i \rvert u(x_i)$**
Difference between blocks	*d*	*u(d)*	52.8	1		52.8
Comparator	*comp*	*u(comp)*	30.5			
Standard gauge block drift	*drift*	*u(drift)*	36.4			
Comparator Resolution	*res*	*u(res)*	1.4			
Damaged measuring faces	δv	$u(\delta v)$	11.5			
Block compression	δc	$u(\delta c)$	19.9			
CTE standard gauge block	αs	$u(\alpha s)$	2.9E-07	$ls\ \theta s$	-123449886	-35.6
CTE test gauge block	α	$u(\alpha)$	5.8E-07	$-L(\delta\theta+\theta s)$	1.18E+08	68.2
Temperature difference between gauge blocks	$\delta\theta$	$u(\delta\theta)$	2.3E-02	$-L\alpha$	-3.45E+03	-80.9
Temperature Measurement	θs	$u(\theta s)$	2.3E-02	$(ls\ \alpha s-L\ \alpha)$	-2.10E+02	-4.9
Standard gauge block calibration	*ls*	*u(ls)*	15.0		1	15.0
		$u(d)u(\alpha)$	3.0E-05	$-(\delta\theta+\theta s)$	0.394	1.2E-05
		$u(ls)u(\alpha)$	8.7E-06	$(\delta\theta+\theta s)$	-0.394	-3.4E-06
		$u(\alpha)u(\delta\theta)$	1.4E-08	$-L$	-300000580	-4.06
		$u(\alpha)u(\theta s)$	1.4E-08	$-L$	-300000741	-4.06
		$u(\delta\theta)u(d)$	1.24	$-\alpha$	-1.15E-05	-1.4E-05
		$u(\delta\theta)u(ls)$	0.35	$-\alpha$	-1.15E-05	-4.0E-06
		$u(\theta s)u(d)$	1.24	$-\alpha$	-1.15E-05	-1.4E-05
		$u(\theta s)u(ls)$	0.35	$\alpha s-\alpha$	-7.00E-07	-2.5E-07
		$u(\alpha s)u(ls)$	4.3E-06	θs	-0.4115	-1.8E-06
		$u(\alpha s)u(\theta s)$	6.8E-09	ls	299999723	2.03
COMBINED STANDARD UNCERTAINTY (k=1) (nm)						**125**
Effective degrees of freedom						**194.8**

Block 500 mm (87333)

Source of uncertainty *xi*		**Standard uncertainty *u(xi)***		**Sensitivity Coefficient |ci|≡∂l/∂xi**		**Combined Standard Uncertainty ui≡|ci|u(xi)**
Difference between blocks	*d*	*u(d)*	80.8	1		80.8
Comparator	*comp*	*u(comp)*	30.5			
Standard gauge block drift	*drift*	*u(drift)*	47.3			
Comparator Resolution	*res*	*u(res)*	1.4			
Damaged measuring faces	δv	$u(\delta v)$	11.5			
Block compression	δc	$u(\delta c)$	56.7			
CTE standard gauge block	αs	$u(\alpha s)$	2.9E-07	$ls\ \theta s$	-106249888.7	-30.7
CTE test gauge block	α	$u(\alpha)$	5.8E-07	$-L(\delta\theta+\theta s)$	7.13E+07	41.1
Temperature difference between gauge blocks	$\delta\theta$	$u(\delta\theta)$	3.6E-02	$-L\alpha$	-5.60E+03	-203.2
Temperature Measurement	θs	$u(\theta s)$	3.6E-02	$(ls\ \alpha s - L\ \alpha)$	-2.00E+02	-7.3
Standard gauge block calibration	*ls*	*u(ls)*	20.0		1	20.0
		$u(d)u(\alpha)$	4.7E-05	$-(\delta\theta+\theta s)$	0.1425	6.6E-06
		$u(ls)u(\alpha)$	1.2E-05	$(\delta\theta+\theta s)$	-0.1425	-1.6E-06
		$u(\alpha)u(\delta\theta)$	2.1E-08	$-L$	-500000759	-1.0E+01
		$u(\alpha)u(\theta s)$	2.1E-08	$-L$	-500000759	-1.0E+01
		$u(\delta\theta)u(d)$	2.93	$-\alpha$	-1.12E-05	-3.3E-05
		$u(\delta\theta)u(ls)$	0.73	$-\alpha$	-1.12E-05	-8.1E-06
		$u(\theta s)u(d)$	2.93	$-\alpha$	-1.12E-05	-3.3E-05
		$u(\theta s)u(ls)$	0.73	$\alpha s-\alpha$	-4.00E-07	-2.9E-07
		$u(\alpha s)u(ls)$	5.8E-06	θs	-0.2125	-1.2E-06
		$u(\alpha s)u(\theta s)$	1.0E-08	ls	499999476	5.24
COMBINED STANDARD UNCERTAINTY CENTRAL LENGTH (k=1) (nm)						**226.2**
Effective degrees of freedom						**146**

INACAL

UNCERTAINTY BUDGET OF GUAGE BLOCK 300 mm

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient $\lvert c_i \rvert = \partial I / \partial x_i$	Combined Standard Uncertainty $u_i = \lvert c_i \rvert u(x_i)$
$u(l_s)$	193	1	193
$u(d)$	112	1	112
$u(\theta_s)$	0,17	0,7*L	0,12*L
$u(\delta\theta)$	0,029	11,5*L	0,33*L
$u(\alpha_s)$	0,29	0,5*L	0,14*L
$u(\alpha)$	0,66	-0,55*L	-0,37*L
$u(\alpha_s) * u(\theta_s)$	0,05	L	0,05*L
$u(\alpha) * u(\theta_s)$	0,12	L	0,12*L
$u(\delta\theta) * u(\alpha)$	0,02	L	0,02*L
Combined standard Uncertainty (k=1)			$\sqrt{49822\ \text{nm} + 0{,}30 * L^2}$
Combined standard Uncertainty (k=1) (nm)			277
Effective degrees of freedom			90

UNCERTAINTY BUDGET OF GUAGE BLOCK 500 mm

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient $\lvert c_i \rvert = \partial I / \partial x_i$	Combined Standard Uncertainty $u_i = \lvert c_i \rvert u(x_i)$
$u(l_s)$	159	1	193
$u(d)$	114	1	112
$u(\theta_s)$	0,17	0,7*L	0,12*L
$u(\delta\theta)$	0,029	11,5*L	0,33*L
$u(\alpha_s)$	0,29	0,5*L	0,14*L
$u(\alpha)$	0,66	-0,55*L	-0,37*L
$u(\alpha_s) * u(\theta_s)$	0,05	L	0,05*L
$u(\alpha) * u(\theta_s)$	0,12	L	0,12*L
$u(\delta\theta) * u(\alpha)$	0,02	L	0,02*L
Combined standard Uncertainty (k=1)			$\sqrt{38156 \text{ nm} + 0{,}30 * L^2}$
Combined standard Uncertainty (k=1) (nm)			336
Effective degrees of freedom			90

CENAM

	Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\lvert c_i \rvert = \partial l / \partial x_i$	Combined Standard Uncertainty. $u_i = \lvert c_i \rvert\, u(x_i)$	
	GB LENGTH	—	—	300	500
1)	COMPARATOR	6.51	1	5.73	5.73
2)	REFERENCE GB	8+0.1L	1	38.00	58.00
3)	TEMP. MEASUREMENT	0.026	$L\delta\alpha$	3.12	5.20
4)	DIFF. COEF. EXP. TE	0.28	$L\theta_s$	21.00	35.00
5)	CET GB REF.	0.25	$-L\delta\theta$	0.90	1.52
6)	DIFF. TEMP. GB	0.012	$-L\alpha$	39.24	65.40
7)	SECOND DEG. TERMS	1.624	$\varepsilon(\delta\alpha, \theta_s, \delta\theta, \alpha, L)$	0.46	0.65
	COMBINED STANDARD UNCERTAINTY (*k* = 1)			118	189
	Effective degrees of freedom			253	243

INMETRO

Not available