FINAL REPORT
Supplementary Comparison

CALIBRATION OF MASS AND CONVENTIONAL MASS OF WEIGHTS

2 kg, 1 kg, 200 g, 50 g, 1 g and 200 mg
SIM.M.M-S11
March 2018

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FINAL REPORT
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1. Introduction

This report describes the results of a supplementary comparison between SIM NMIs, which is being carried out in order to compare the degree of equivalence in mass and conventional mass calibration of high accuracy mass standards.

In March 2012, a meeting between the participant laboratories was carried out in La Paz – Bolivia as an activity within the framework of the cooperation project PTB–CAN. In that meeting the laboratories discussed about critical topics they face during calibration of weights at a high altitude above sea level; the conclusions were: first, is necessary to measure the density/volume of weights, as well as the determination of mass and with these values calculate the conventional mass; and second, the laboratories have to estimate the air density using the CIPM-2007 formula, both in order to guarantee the traceability for E_1 and E_2 standard weights. Because of that, the laboratories decide to organize a comparison including the calculation of mass and conventional mass, density and volume for E_2 standard weights.

This supplementary comparison was piloted by the Instituto Ecuatoriano de Normalización (INEN, Ecuador) and the Centro Nacional de Metrología (CENAM, Mexico) accepted to be the support laboratory; after the second semester of 2013 the Instituto Nacional de Metrología (INM, Colombia) continued with the activities of the pilot laboratory instead of INEN due to internal situations. Seven NMIs took part of this comparison.

Two sets of OIML class E_2 weights, property of the project "***FOMENTO COORDINADO DE LA INFRAESTRUCTURA DE LA CALIDAD EN LA REGIÓN ANDINA, PTB-CAN***" were used in the comparison as traveling standards. One set (SET 1) was employed to measure the mass and conventional mass values from the weights with the following nominal values: 2 kg, 1 kg, 200 g, 50 g, 1 g and 200 mg. These values are linked to the nominal values used in key comparisons CCM.M-K4 and CCM.M-K5.

The other set (SET 2), was used to measure the volume and density of the weights, with the following nominal values: 2 kg, 1 kg, 200 g, 50 g and 1 g; the results of the measurements done with SET 2 are shown in the supplementary report SIM.M.D-S5.

The standard weights of SET 1 were prepared by CENAM. CENAM measured the volume of the traveling standards with the exception of the 200 mg weight. The density value used for this mass standard was provided by the manufacturer. Magnetic properties of SET 1 were measured by CENAM (excepting 200 mg weight) in order to verify that all of them are in accordance with the requirements of the magnetic properties for E_2 accuracy class of the OIML R 111-1: 2004 [1].

For SET 1, the participant laboratories measured both mass and conventional mass for each travelling standard. Each NMI used their own methods for their measurements according to their procedures.

The standard weights were circulated among the NMIs from April 2012 to January 2013.

2. List of participant NMIs

The participant laboratories and their respective technical contacts are listed below:

- *Centro Nacional de Metrología (CENAM) / México.*
  - Luis Omar Becerra
  - Luis Manuel Peña
- *Instituto Boliviano de Metrología (IBMETRO) / Bolivia.*
  - Boris Escalante Vargas.
- *Instituto Nacional de Calidad (INACAL) / Perú.*
  - Aldo Martín Quiroga Rojas
  - Luz Cori Almonte
- *Instituto Nacional Metrología (INM) / Colombia.*
  - Álvaro Bermúdez Coronel
  - Jhon J. Escobar Soto
- *Instituto Ecuatoriano de Normalización (INEN) / Ecuador.*
  - Wilson Naula
- *Instituto Nacional de Tecnología y Normalización (INTN) / Paraguay.*
  - Arnaldo Florencio
  - María Lourdes Valenzuela
- *Laboratorio Costarricense de Metrología (LACOMET) / Costa Rica.*
  - Olman Ramos Alfaro
  - Marcela Prenda Peña

All the participant laboratories are NMIs belonging to SIM and all are signatories of the CIPM MRA

3 Traveling standards

The travelling standards used were two sets of weights, OIML class E_2 belonging to the project “***FOMENTO COORDINADO DE LA INFRAESTRUCTURA DE LA CALIDAD EN LA REGIÓN ANDINA, PTB-CAN***”. The first set, called SET 1, was used to measure the mass and conventional mass, with nominal values 2 kg, 1 kg, 200 g, 50 g, 1 g and 200 mg. The shape, material and identification of SET 1 are shown in Table 1.

Nominal value	Identification	Accuracy class	Material	Shape
2 kg, 1 kg, 200 g, 50 g , 1 g	141716	E_2	Stainless steel	Cylindrical
200 mg		E_2	Stainless steel	Wire

Table 1. Physical characteristics of SET 1 weights.

In May 2012 the volume of four weights (2 kg, 1 kg, 200 g, 50 g and 1 g) were measure at the Density Laboratory of CENAM. The results are shown in Table 2. The density of 200 mg weight was provided by calibration certificate of the manufacturer with an uncertainty of 2 % with *k = 2.*

Nominal value	Volume cm^3	Uncertainty (k = 2) cm^3
2 kg	251,051	0,048
1 kg	125,415	0,044
200 g	25,147 2	0,004 8
50 g	6,262 1	0,001 4
1 g	0,125 8	0,001 0
200 mg	-	-

Table 2. Volume and expanded uncertainty of the standards

The magnetic properties of the weights of SET 1 were measured by CENAM in June 2012 (excepting 200 mg weight), in order to verify that all of them are in accordance with the requirements of the magnetic properties for E_2 accuracy class established in OIML R 111-1: 2004 [1]. The results are shown in Table 3.

Nominal value	Magnetic polarization µT	Maximum polarization E_2 weights µT	Magnetic susceptibility χ	Maximum magnetic susceptibility E_2 weights
2 kg	-0,021	8	0,004 41	0,07
1 kg	-0,018	8	0,004 23	0,07
200 g	0,021	8	0,004 43	0,07
50 g	0,098	8	0,004 57	0,07
1 g	0,434	8	0,004 30	0,9
200 mg	-	-	-	-

Table 3. Magnetic polarization and magnetic susceptibility of the traveling standards

During the circulation among the participant laboratories, volume or magnetic properties of the weights were not measure by any participant.

4 Circulation Schedule

The traveling standards circulated according to the schedule shown in Table 4. CENAM as supporting laboratory started the measurements in April 2012. After such measurements, INEN as pilot laboratory, began the measurements in June 2012. The last measurement were made by INEN in January 2013 and CENAM in July 2013.

After its measurements, INEN sent its results to CENAM, who checked consistency between results of INEN and CENAM; once consistency was checked CENAM sent its results to INEN and after to INM, in order to continue with the analysis of all results reported by the participants.

No.	National Metrology Institute	Arrival
1	CENAM-Mexico	
2	INEN-Ecuador	2012-06-22
3	INACAL-Peru	2012-07-27
4	INTN-Paraguay	2012-08-31
5	LACOMET-Costa Rica	2012-10-02
6	INM-Colombia	2012-11-02
7	IBMETRO-Bolivia	2012-12-14
8	INEN-Ecuador	2013-01-25
9	CENAM-México	

Table 4. Schedule of circulation during the comparison

5. Surface damages of the traveling standards

Each participant laboratory examined and registered the surface conditions of the traveling standards at both reception and departure, using the established forms to record all the visible marks, scratches or damages that could happen on the weights during the circulation; the filled forms were sent to the pilot laboratory. A progressive damage of the traveling standards and an apparent deformation of the transportation box[8] were noticed after the end of the complete cycle of circulation, as is shown in images 1 to 5; this fact could potentially affect the stability of the travelling standards and the results reported by the participant laboratories.

[8] According to INACAL and INEN, the deformation of the transportation box happened during the travel from Quito (Ecuador) to Lima (Peru).

Image 1. Scratches on the surface of 2 kg weight after circulation

Image 2. Scratches on the surface of 1 kg weight after circulation

Image 3. Scratches on the surface of 200 g weight after circulation

Image 4. Scratches on the surface of 50 g weight after circulation

Image 5. Apparent damage inside the transportation box after circulation

6 Procedures and Measurement Methods

The participant laboratories determined the mass and conventional mass and their associated uncertainties for each traveling standard, using their own facilities, instruments and procedures according to the best capability of the laboratory. The calibration was done in mass value and the conventional mass value was calculated from the mass value.

Air density was determined with CIPM-2007 formula, in order to correct the air buoyancy effect [2].

The resolution of the weighing instruments used by participant laboratories are shown in Table 5.

Units in mg	CENAM	INEN	INACAL	INTN	LACOMET	INM	IBMETRO
2 kg	0,01	1	0,2	1	1	0,01	1
1 kg	0,002	0,01	0,1	0,01	0,01	0,001	0,01
200 g	0,01	0,01 0,001	0,01	0,01	0,001	0,001	0,01
50 g	0,001	0,001	0,001	0,001	0,001	0,001	0,01
1 g	0,000 1	0,000 1	0,000 1	0,000 1	0,001	0,000 1	0,000 1
200 mg	0,000 1	0,000 1	0,000 1	0,000 1	0,000 1	0,000 1	0,000 1

Table 5. Resolution of the weighing instruments used by NMIs

The resolution of instruments used by participant laboratories for measuring the environmental conditions during the calibration are shown in Table 6.

	CENAM	INEN	INACAL	INTN	IBMETRO	INM	LACOMET
TEMPERATURE t / °C	0,001 / 0,01	0,01	0,01	0,001	0,1	0,001	0,01
RELATIVE HUMIDITY h / %	0,01 / 0,1* 0,01	0,01	0,1	0,01	1	0,01	0,01
BAROMETRIC PRESSURE p / Pa	1	0,1	0,1	0,1	10	0,1	1

* Units in °C

Table 6. Resolution of devices for environmental conditions measurements used by NMIs

Table 7 shows the traceability of the mass standard used by the participant laboratories, to indicate the possible correlation of the traceability source of the standards.

	CENAM	INEN	INACAL	INTN	IBMETRO	INM	LACOMET
2 kg	CENAM	CENAM	CEM	INMETRO	LATU	PTB	CENAM – METAS
1 kg	CENAM	CENAM	CEM	INTI	LATU	PTB	CENAM – METAS
200 g	CENAM	CENAM	CEM	INTI	LATU	PTB	CENAM
50 g	CENAM	CENAM	CEM	ZMK	LATU	PTB	CENAM
1 g	CENAM	CENAM	CEM	INTI	LATU	PTB	CENAM
200 mg	CENAM	CENAM	CEM	INTI	LATU	PTB	CENAM

Table 7. Mass traceability of NMIs

Table 8 shows the dates of calibration of the mass standards reported in Table 7. An overdue calibration could introduce a drift that may affect the results of the calibration.

	CENAM	INEN	INACAL	INTN	IBMETRO	INM	LACOMET
2 kg	2012	2011	2011	2010	2013	2009	2011 - 2008
1 kg	2011	2011	2012	2010	2013	2006	2011 – 2008
200 g	2011	2011	2012	2010	2013	2010	2011
50 g	2011	2011	2012	2011	2013	2010	2011
1 g	2011	2011	2012	2010	2013	2010	2011
200 mg	2011	2011	2012	2010	2013	2010	2011

Table 8. Dates of last calibration of mass standards of NMIs

7 Results of the measurements

The subdivision method was used by CENAM, INEN and INACAL. INTN, INM, LACOMET and IBMETRO used the direct comparison method. Table 9 and Table 10 show the mass correction value calculated by each participant laboratory and its associated uncertainty with a coverage factor equal to 1 (k = 1). These tables include a second measurement done by CENAM after the second measurement done by INEN, due to the high damage of the traveling standards during circulation.

Nominal Value	2 kg		1 kg		200 g	
	Mass correction value mg	u (k = 1) mg	Mass correction value mg	u (k = 1) mg	Mass correction value mg	u (k = 1) mg
CENAM1	1,02	0,065	0,459	0,027	0,204 9	0,004 5
INEN1	1,70	0,53	0,487	0,040	0,198 6	0,007 8
INACAL	1,42	0,26	0,50	0,10	0,271	0,036
INTN	1,7	1,5	0,63	0,25	0,28	0,05
LACOMET	1,08	0,43	0,554	0,045	0,227	0,015
INM	1,14	0,174	0,502	0,029 2	0,233	0,011 6
IBMETRO	--	--	--	--	--	--
INEN2	1,08	0,53	0,538	0,039	0,246	0,007
CENAM2	1,26	0,088	0,540	0,026	0,253 2	0,008 0

Table 9. Mass correction values reported for nominal values 2 kg, 1 kg and 200 g

Nominal Value	50 g		1 g		200 mg	
	Mass correction value mg	u (k = 1) mg	Mass correction value mg	u (k = 1) mg	Mass correction value mg	u (k = 1) mg
CENAM1	0,040 1	0,001 6	0,005 3	0,000 5	0,003 83	0,000 275
INEN1	0,038 9	0,003 4	0,005 02	0,000 29	0,003 91	0,000 16
INACAL	0,048	0,004	0,005 5	0,001 1	0,004 9	0,000 5
INTN	0,045	0,015	0,006	0,005	0,004	0,003
LACOMET	0,045 4	0,007 1	0,003 3	0,002 6	0,004 83	0,000 81
INM	0,052	0,003 5	0,006 4	0,001 16	0,005 0	0,000 47
IBMETRO	--	--	--	--	--	--
INEN2	0,054 2	0,003 2	0,006 11	0,000 28	0,004 77	0,000 16
CENAM2	0,061 3	0,002 6	0,006 30	0,000 53	0,004 55	0,000 28

Table 10. Mass correction values reported for nominal values 50 g, 1 g and 200 mg

IBMETRO decided not to report mass values, so only conventional mass values were considered from IBMETRO for this supplementary comparison.

Table 11 and Table 12 shows the conventional mass correction value calculated by each participant laboratory and its associated uncertainty with a coverage factor equal to 1 (k = 1).

Nominal value	2 kg		1 kg		200 g	
	Conventional mass correction value mg	u (k = 1) mg	Conventional mass correction value mg	u (k = 1) mg	Conventional mass correction value mg	u (k = 1) mg
CENAM1	-0,24	0,070	-0,039	0,038	0,028	0,005 5
INEN1	0,44	0,53	-0,011	0,040	0,022 0	0,007 8
INACAL	0,16	0,26	0,01	0,10	0,094	0,036
INTN	0,4	1,5	0,13	0,25	0,09	0,05
LACOMET	-0,18	0,43	0,056	0,045	0,050	0,015
INM	-0,12	0,174	0,003	0,029 2	0,057	0,011 6
IBMETRO	-1,856	4,200	-0,571	0,165 1	0,075	0,038 3
INEN2	-0,18	0,53	0,040	0,039	0,069	0,007
CENAM2	0,001	0,093	0,042	0,037	0,076 6	0,008 5

Table 11. Conventional mass correction values reported for nominal values 2 kg, 1 kg and 200 g

Nominal value	50 g		1 g		200 mg	
	Conventional mass correction value mg	u (k = 1) mg	Conventional mass correction value mg	u (k = 1) mg	Conventional mass correction value mg	u (k = 1) mg
CENAM$_1$	0,025 5	0,001 8	0,004 3	0,000 8	0,003 83	0,000 41
INEN$_1$	0,024 4	0,003 4	0,004 06	0,000 29	0,003 91	0,000 16
INACAL	0,034	0,004	0,004 6	0,001 1	0,004 6	0,000 5
INTN	0,030	0,015	0,005	0,005	0,004	0,003
LACOMET	0,030 9	0,007 1	0,002 3	0,002 6	0,004 83	0,000 81
INM	0,038	0,003 5	0,005 5	0,001 16	0,005 0	0,000 47
IBMETRO	0,047	0,010 2	0,004	0,003 1	0,003	0,002 0
INEN$_2$	0,039 7	0,003 2	0,005 15	0,000 28	0,004 77	0,000 16
CENAM$_2$	0,046 8	0,002 8	0,005 3	0,000 8	0,004 55	0,000 41

Table 12. Conventional mass correction values reported for nominal values 50 g, 1 g and 200 mg

The results reported by all the participant laboratories, as well as the uncertainty analysis, were made according to "*Guide to the expression of Uncertainty in Measurements*" GUM [3].

8 Results Analysis

8.1 Consistency between CENAM and INEN

Before determining the reference values for mass and conventional mass, a consistency check between the pilot laboratory (INEN) and the support laboratory (CENAM) was performed, in order to verify that the measurements of the pilot laboratory are equivalent to those made by the support laboratory and, in this way, to ensure the reference value established by the pilot laboratory.

The normalized error criteria [4] was used to check the consistency between these measurements, according to the equation (1)

$$E_n = \frac{\Delta x_{INEN_1} - \Delta x_{CENAM_1}}{\sqrt{U^2(INEN_1) + U^2(CENAM_1)}} \quad (1)$$

where

Δx_{INEN_1}: mass (or conventional mass) correction value measured by INEN at the beginning of measurements

Δx_{CENAM_1}: mass (or conventional mass) correction value measured by CENAM at the beginning of measurements

$U(INEN_1)$: expanded uncertainty in mass (or conventional mass) calculated by INEN at the beginning of measurements

$U(CENAM_1)$: expanded uncertainty in mass (or conventional mass) calculated by CENAM at the beginning of measurements

Table 13 shows the values of normalized error calculated for mass and conventional mass correction values reported by CENAM and INEN.

Nominal value	2 kg	1 kg	200 g	50 g	1 g	200 mg
Normalized error in mass	0,64	0,29	-0,35	-0,15	-0,22	0,12
Normalized error in conventional mass	0,63	0,25	-0,33	-0,14	-0,14	0,09

Table 13. Normalized error between $CENAM_1$ and $INEN_1$

8.2 Stability of traveling standards

The stability of traveling standards was assessed by INEN by measuring the mass and conventional mass values before and after the comparison. Nevertheless, the high level of damage of the traveling standards reported in Section 5 made necessary to check if the measurements done by INEN and CENAM at the beginning and at the end of circulation of the traveling standards are statistically coherent, and to verify if a strong drift was observed during the circulation. Tables 14 and 15 show the consistency of the results reported by INEN ($INEN_1$ vs $INEN_2$) and CENAM ($CENAM_1$ vs $CENAM_2$) using equation (1).

Nominal value	2 kg	1 kg	200 g	50 g	1 g	200 mg
Normalized error in mass	1,10	1,08	2,63	3,47	0,69	0,92
Normalized error in conventional mass	1,04	0,76	2,43	3,20	0,44	0,62

Table 14. Normalized error between $CENAM_2$ and $CENAM_1$

Nominal value	2 kg	1 kg	200 g	50 g	1 g	200 mg
Normalized error in mass	-0,41	0,46	2,26	1,64	1,35	1,90
Normalized error in conventional mass	-0,41	0,26	2,24	1,64	1,35	1,90

Table 15. Normalized error between $INEN_2$ and $INEN_1$

Results of Tables 14 and 15 shows inconsistent measurements done in mass value and conventional mass value taking into account results from CENAM and INEN.

According to section 5 of this document, the principal damage on the weights would happen during the transportation from Quito (Ecuador) to Lima (Peru), rejecting the values of $INEN_1$ and $CENAM_1$. Because of that, the results reported by INACAL and $CENAM_2$ were considered to estimate the drift and the uncertainty due to stability of each traveling standard, according to the equations (2) and (3).

$$\Delta x = \Delta x_{CENAM_2} - \Delta x_{INACAL} \quad (2)$$

$$u(\Delta x) = \sqrt{\frac{\left(\Delta x_{CENAM_2} - \Delta x_{INACAL}\right)^2}{12}} \quad (3)$$

where

Δx_{INACAL} : value of mass (or conventional mass) measured by INACAL.

Δx_{CENAM_2}: value of mass (or conventional mass) measured by $CENAM_2$.

In Table 16 the drifts in mass of each standard and their associated uncertainties calculated using the equations (2) and (3) are shown

Nominal value	2 kg	1 kg	200 g	50 g	1 g	200 mg
Drift (mg)	-0,16	0,040	-0,017 8	0,013 3	0,000 80	-0,000 35
Uncertainty due to instability (mg)	0,05	0,012	0,005 1	0,003 8	0,000 23	0,000 10

Table 16. Calculated drift and uncertainty due to instability for each standard calculated using the results of INACAL and $CENAM_2$

8.3 Reference values for the comparison

The reference values for mass and conventional mass were calculated according to the mathematical model proposed in [5] using the results reported by each participant laboratory. According to the previous section, results of $CENAM_1$ and $INEN_1$ were not considered in the calculations.

According to the Table 7, the reference standards from CENAM and INEN were calibrated at CENAM, therefore there is a correlation between these two laboratories. Assuming a correlation between CENAM and INEN equal to 0,7, we have

$$r\left(m_{CENAM}^{ref}, m_{INEN}^{ref}\right) = 0{,}7$$

Using the equation (14) of GUM [3] and the previous result, the covariance between CENAM and INEN is given by

$$u\left(\Delta m_{CENAM,INEN}\right) = 0{,}7 \cdot u(\Delta m_{CENAM}) \cdot u(\Delta m_{INEM}) \quad (4)$$

In a similar way and according to the Table 7, there is a correlation between CENAM and LACOMET and INEN and LACOMET Then their covariance are

$$u\left(\Delta m_{CENAM,LACOMET}\right) = 0{,}7 \cdot u(\Delta m_{CENAM}) \cdot u(\Delta m_{LACOMET}) \quad (5)$$

$$u\left(\Delta m_{INEN,LACOMET}\right) = 0{,}7 \cdot u(\Delta m_{INEN}) \cdot u(\Delta m_{LACOMET})$$

Finally, a chi-squared test is used for analyzing the consistency of the estimated value.

The criterion used for the consistency of the estimated value is given for a confidence level of 95 % with a probability p calculated using the inequality

$$p = P\{\chi^2(\nu) > \chi^2_{obs}\}$$

With a number of degrees of freedom $\upsilon = 5$. According to the above criterion, if the probability is more than 0,05, the estimated value is consistent.

8.3.1 Conventional mass value correction

Table 17 includes each mass correction value calculated by each participant laboratory, the estimated reference value of mass correction and its associated uncertainties $u(\Delta m)$ and $u(\Delta \widehat{m})$.

Participant Laboratory	Nominal value	Δm mg	u(Δm) mg	$\Delta \widehat{m}$ mg	u($\Delta \widehat{m}$) mg	χ^2_{obs}
INACAL	2 kg	1,42	0,26	1,27	0,07	1,19
INTN		1,7	1,5			
LACOMET		1,08	0,43			
INM		1,14	0,174			
$INEN_2$		1,08	0,53			
$CENAM_2$		1,26	0,088			
INACAL	1 kg	0,50	0,10	0,522	0,020	1,21
INTN		0,63	0,25			
LACOMET		0,554	0,045			
INM		0,502	0,029 2			
$INEN_2$		0,538	0,039			
$CENAM_2$		0,540	0,026			
INACAL	200 g	0,271	0,036	0,248	0,006	6,38
INTN		0,28	0,05			
LACOMET		0,227	0,015			
INM		0,233	0,011 6			
$INEN_2$		0,246	0,007			
$CENAM_2$		0,253 2	0,008 0			
INACAL	50 g	0,048	0,004	0,0538	0,002 6	7,12
INTN		0,045	0,015			
LACOMET		0,045 4	0,007 1			
INM		0,052	0,003 5			
$INEN_2$		0,054 2	0,003 2			
$CENAM_2$		0,061 3	0,002 6			
INACAL	1 g	0,005 5	0,001 1	0,006 3	0,000 3	2,74
INTN		0,006	0,005			
LACOMET		0,003 3	0,002 6			
INM		0,006 4	0,001 16			
$INEN_2$		0,006 11	0,000 28			
$CENAM_2$		0,006 30	0,000 53			
INACAL	200 mg	0,004 9	0,000 5	0,004 75	0,000 15	1,49
INTN		0,004	0,003			
LACOMET		0,004 83	0,000 81			
INM		0,005 0	0,000 47			
$INEN_2$		0,004 77	0,000 16			
$CENAM_2$		0,004 55	0,000 28			

Table 17. Estimated reference value for mass correction, its uncertainty and the result for chi-squared consistency test

Figures 1 to 6 show the values and the uncertainties reported by each participant laboratory and the reference value and its uncertainty.

In figures 1 to 6 the uncertainty values are expressed with a coverage factor $k = 2$.

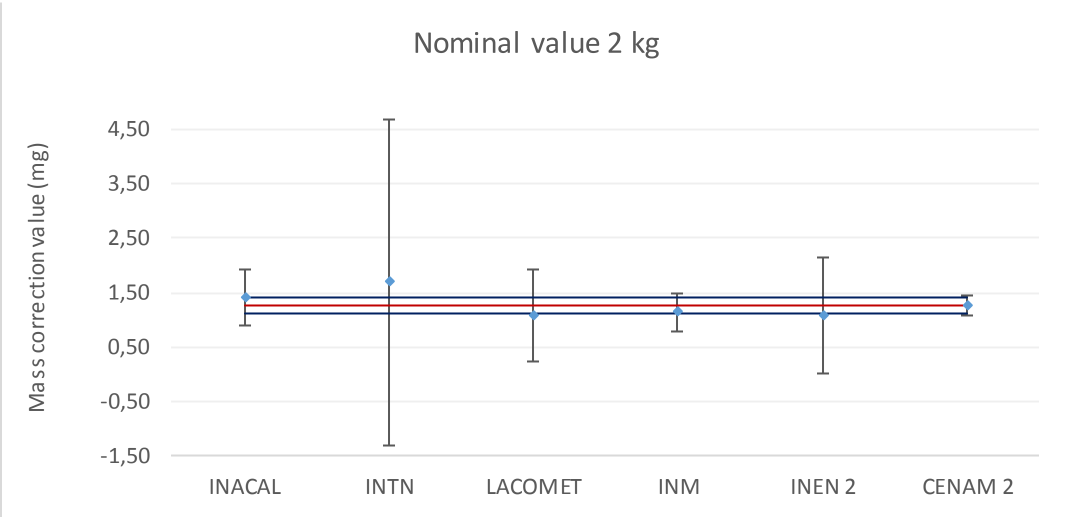

Figure 1. Reported values of mass correction value for 2 kg weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

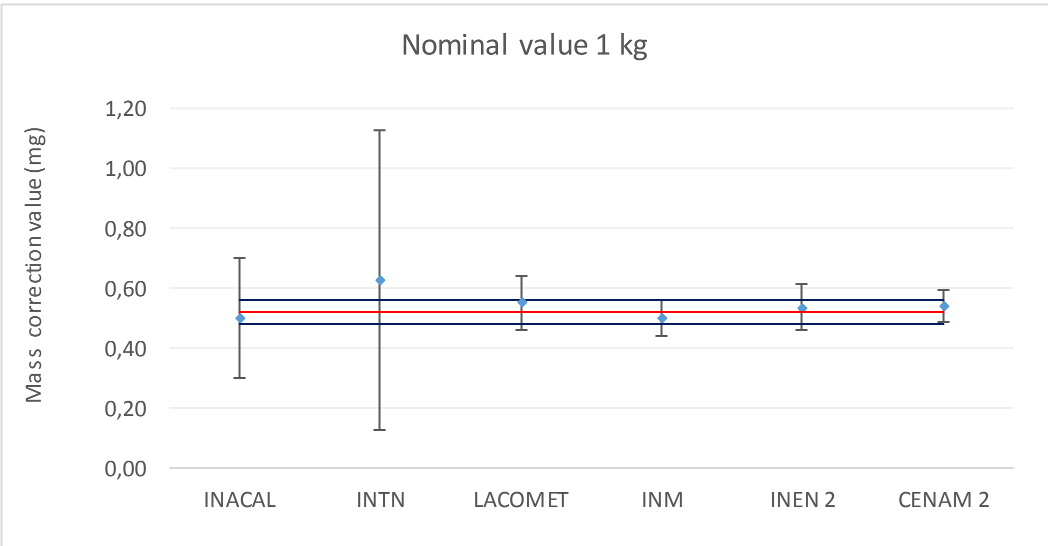

Figure 2. Reported values of mass correction value for 1 kg weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

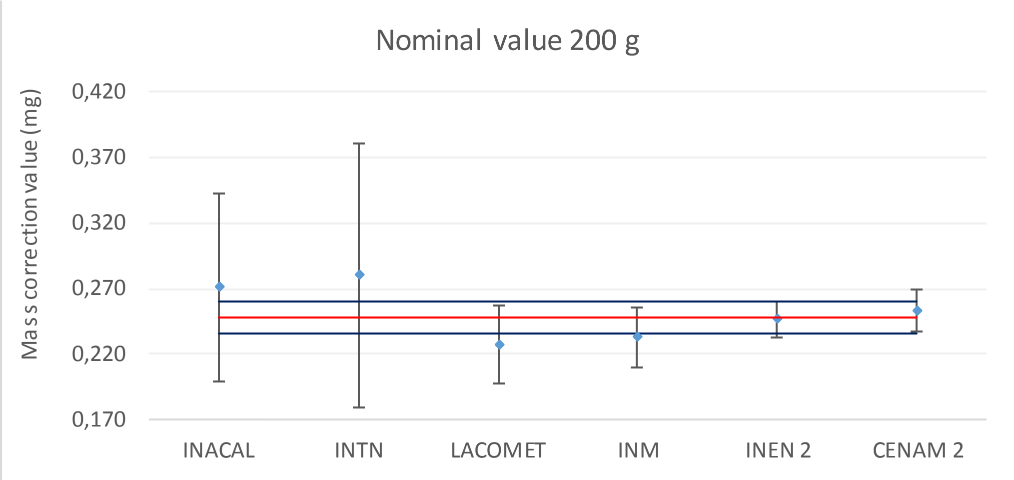

Figure 3. Reported values of mass correction value for 200 g weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

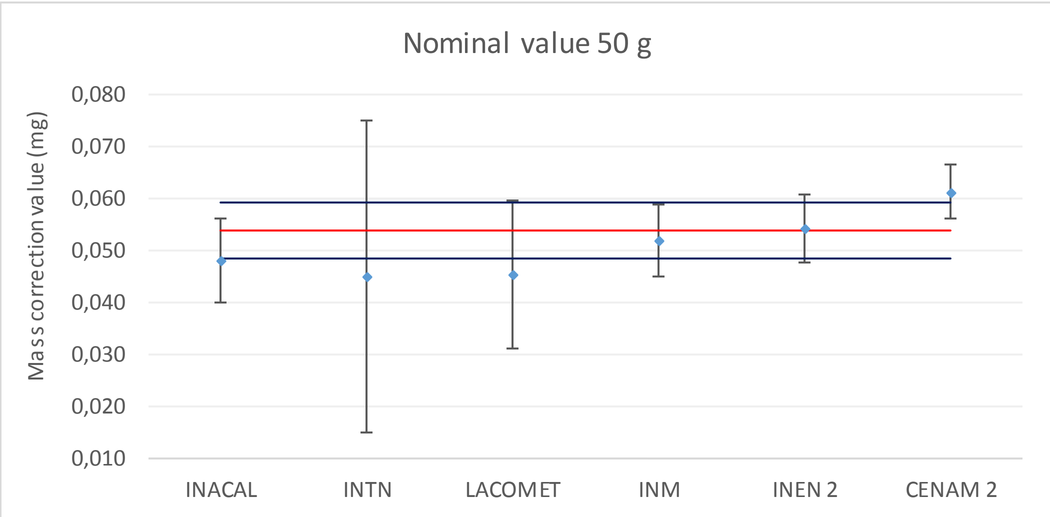

Figure 4. Reported values of mass correction value for 50 g weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

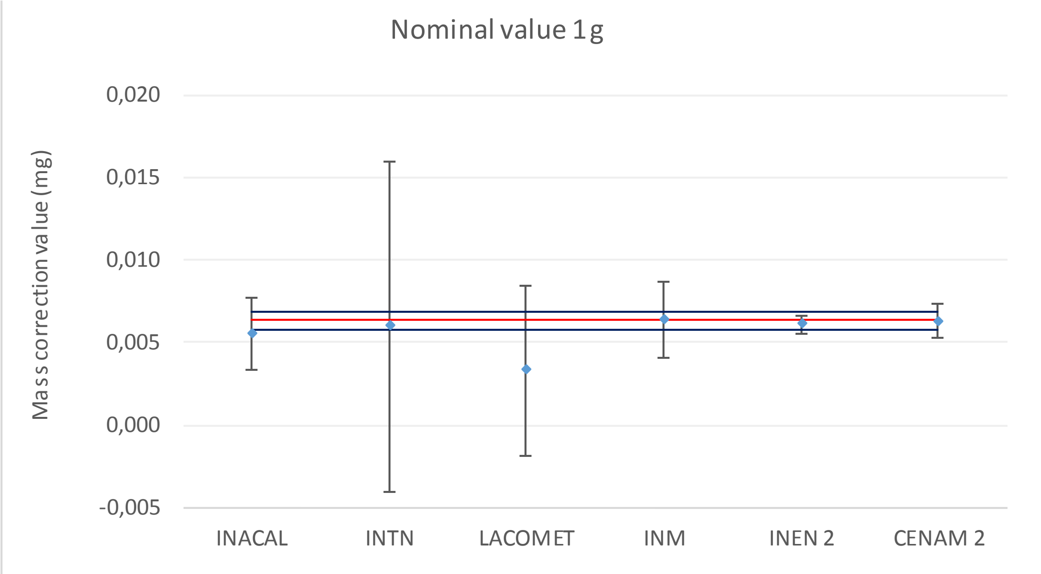

Figure 5. Reported values of mass correction value for 1 g weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

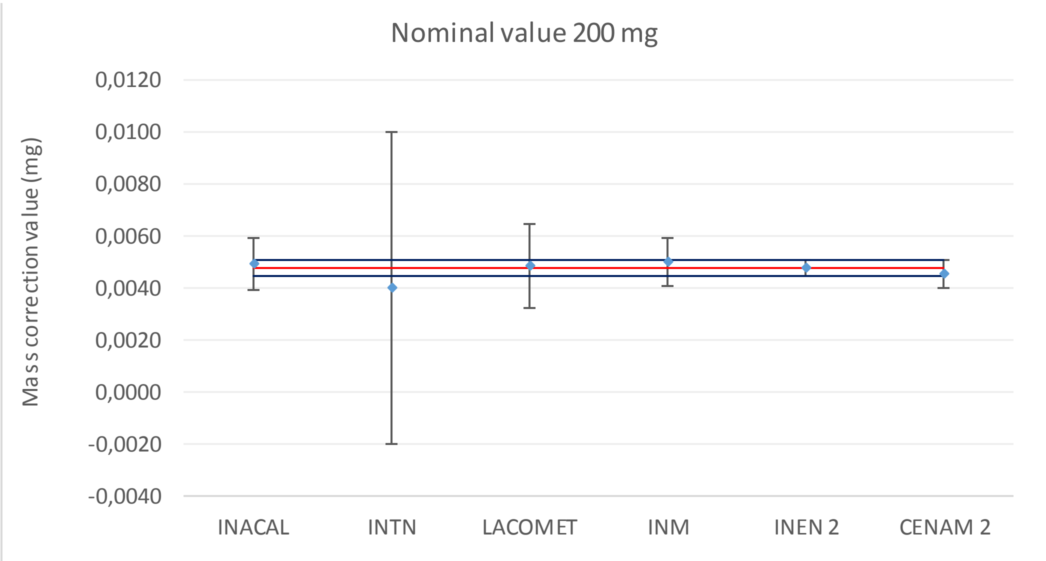

Figure 6. Reported values of mass correction value for 200 mg weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

8.3.2 Conventional mass value correction

For calculating the reference value for conventional mass correction it is necessary to realize that, according to Table 11 and 12, we need to include the results reported by IBMETRO, also taking into account the results of stability reported in previous section and the results reported by each participant laboratory (see Tables 9 to 12).

With a number of degrees of freedom $\upsilon = 6$. According to the above criterion, if the probability is major than 0,05 the estimated value is consistent.

Participant laboratory	Nominal value	Δm_c mg	u(Δm_c) mg	$\Delta \hat{m}_c$ mg	u($\Delta \hat{m}_c$) mg	χ^2_{obs}
INACAL	2 kg	0,16	0,26	0,01	0,08	1,39
INTN		0,4	1,5			
LACOMET		-0,18	0,43			
INM		-0,12	0,174			
IBMETRO		-1,856	4,200			
INEN$_2$		-0,18	0,53			
CENAM$_2$		0,001	0,093			
INACAL	1 kg	0,01	0,10	0,020*	0,023*	1,14*
INTN		0,13	0,25			
LACOMET		0,056	0,045			
INM		0,003	0,029 2			
IBMETRO		-0,571	0,165 1			
INEN$_2$		0,040	0,039			
CENAM$_2$		0,042	0,037			
INACAL	200 g	0,094	0,036	0,071	0,006	6,18
INTN		0,09	0,05			
LACOMET		0,050	0,015			
INM		0,057	0,011 6			
IBMETRO		0,075	0,038 3			
INEN$_2$		0,069	0,007			
CENAM$_2$		0,076 6	0,008 5			
INACAL	50 g	0,034	0,004	0,039 9	0,002 5	7,69
INTN		0,030	0,015			
LACOMET		0,030 9	0,007 1			
INM		0,038	0,003 5			
IBMETRO		0,047	0,010 2			
INEN$_2$		0,039 7	0,003 2			
CENAM$_2$		0,046 8	0,002 8			
INACAL	1 g	0,004 6	0,001 1	0,005 32	0,000 28	3,04
INTN		0,005	0,005			
LACOMET		0,002 3	0,002 6			
INM		0,005 5	0,001 16			
IBMETRO		0,004	0,003 1			
INEN$_2$		0,005 15	0,000 28			
CENAM$_2$		0,0053	0,000 8			
INACAL	200 mg	0,004 6	0,000 5	0,004 77	0,000 12	1,97
INTN		0,004	0,003			
LACOMET		0,004 83	0,000 81			
INM		0,005 0	0,000 47			
IBMETRO		0,003	0,002 0			
INEN$_2$		0,004 77	0,000 16			
CENAM$_2$		0,004 55	0,000 41			

*Note: Due to the high difference between the conventional mass value reported by IBMETRO compared with the others participant laboratories, this value was not included in the calculation of the reference value and the associated uncertainty

Table 18. Estimated reference value for conventional mass correction, its uncertainty and the result for chi-squared consistency test

Table 18 includes the conventional mass correction value calculated by each participant laboratory, the estimated reference value of conventional mass correction and its uncertainty associated, and the chi-squared consistency test, taking into account that the critical value for consistency is

$$x^2(\upsilon = 6) = 12{,}592$$

excepting the reference value for 1 kg conventional mass value, in which the critical value for consistency is

$$x^2(\upsilon = 5) = 11{,}070$$

Figure 7 to 12 show the values and the uncertainties reported by each participant laboratory and the reference value and its uncertainty.

In figure 7 to 12, the uncertainty values are expressed with a coverage factor $k = 2$.

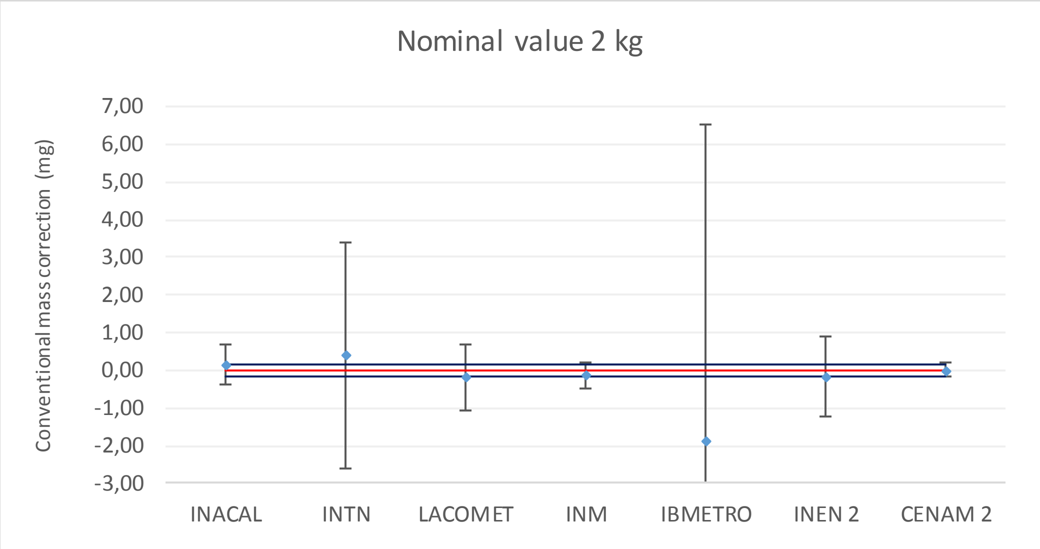

Figure 7. Reported values of conventional mass correction for 2 kg weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

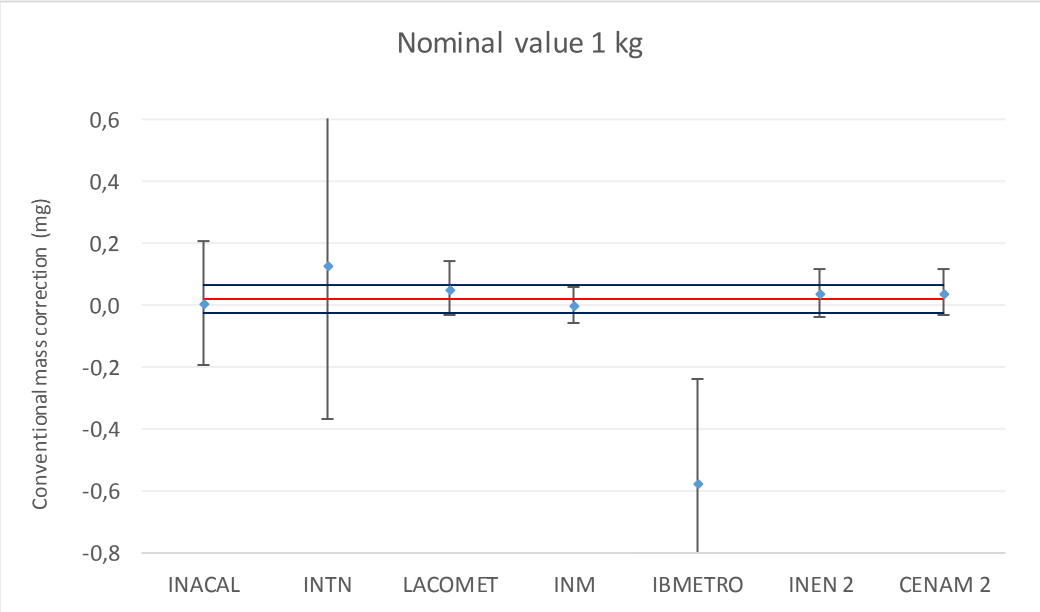

Figure 8. Reported values of conventional mass correction for 1 kg weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

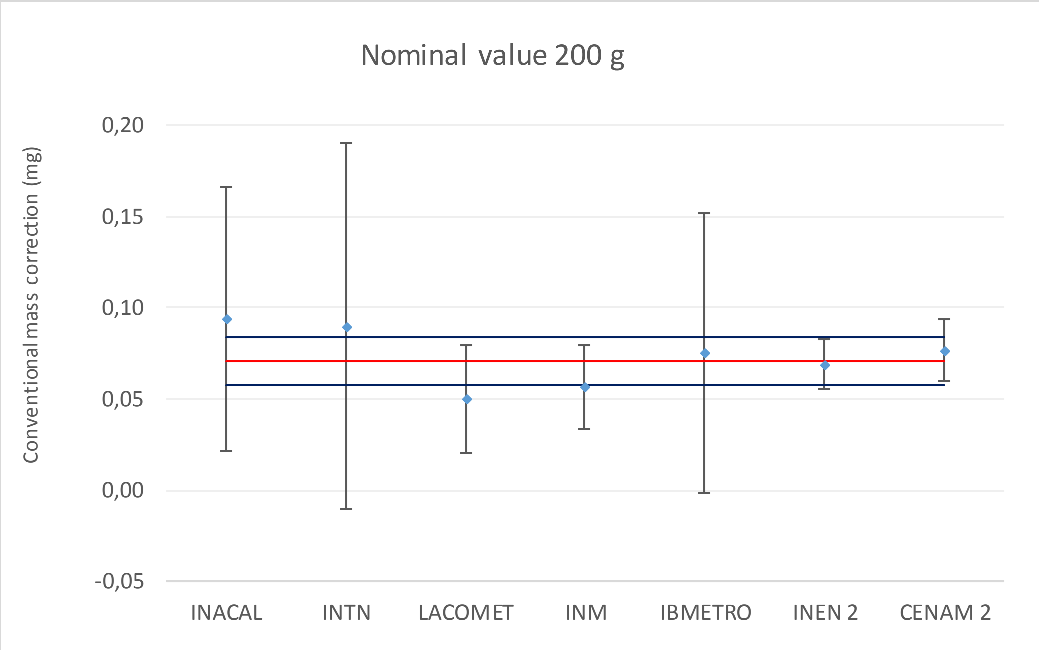

Figure 9. Reported values of conventional mass correction for 200 g weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

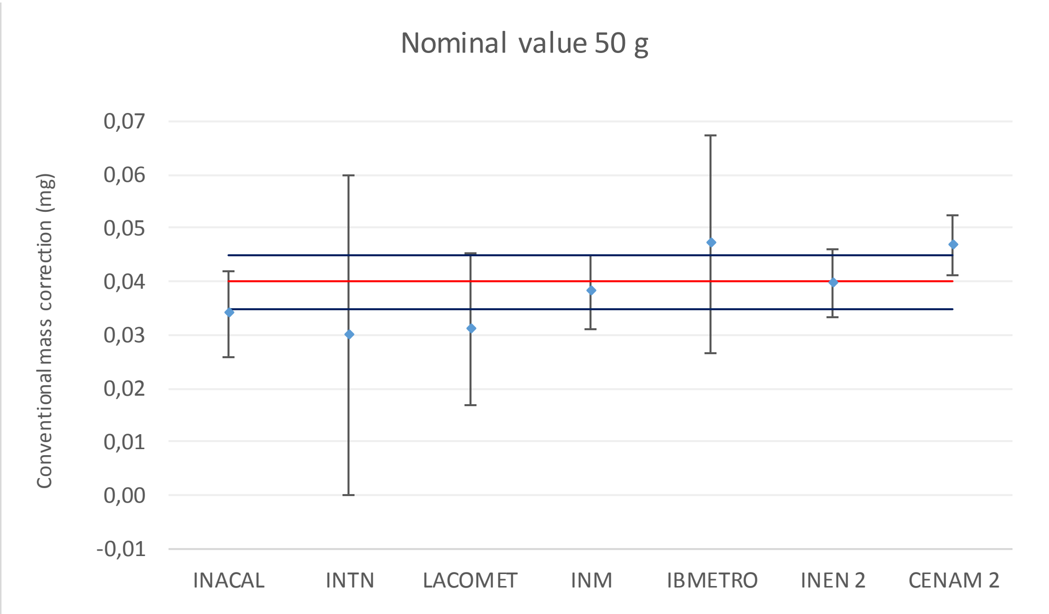

Figure 10. Reported values of conventional mass correction for 50 g weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

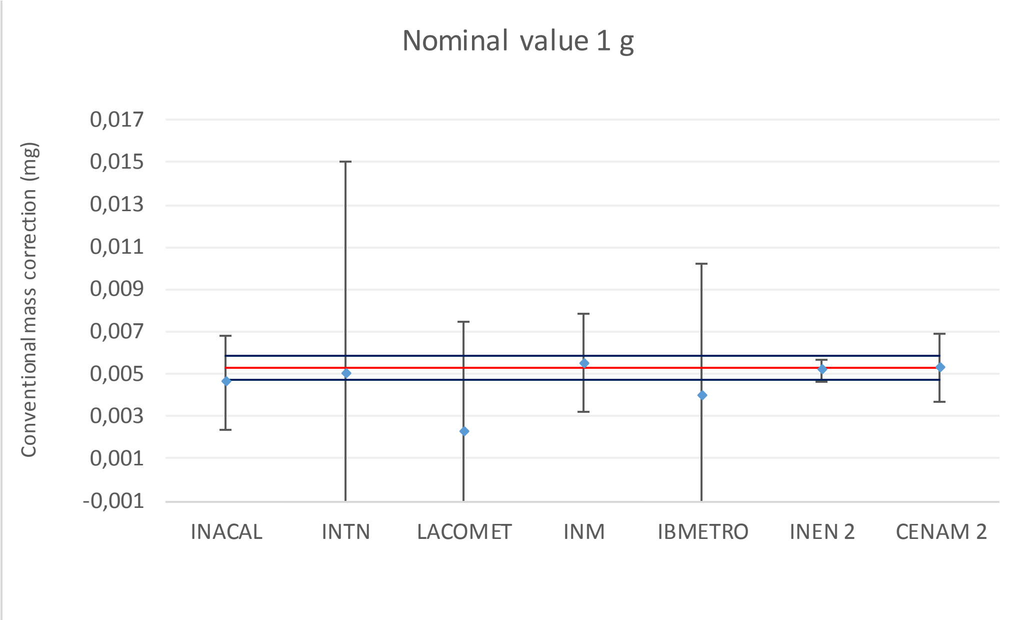

Figure 11. Reported values of conventional mass correction for 1 g weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

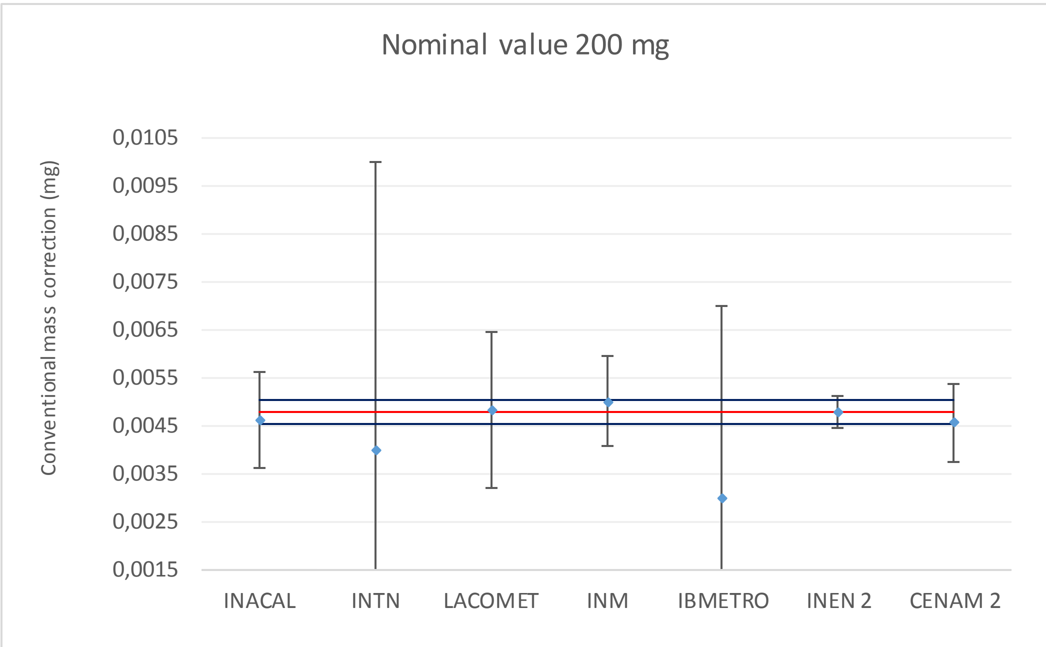

Figure 12. Reported values of conventional mass correction for 200 mg weight by each laboratory. The reference value is represented by the red line and its uncertainty by the blue lines

9 Conclusions

According to the results of this supplementary comparison, it is possible to conclude:

- There is a general consistency of the measurements in mass correction and conventional mass correction values, although one participant laboratory has a value of d_i major than 2 for the conventional mass value of 1 kg weight.

- Some of the participant laboratories reported an expanded uncertainty associated to the conventional mass of 2 kg weight larger than one third of the corresponding maximum permissible error for weights class OIML E_2.

  For the 1 kg, 50 g, 200 g, 1 g and 200 mg weights, all the values of expanded uncertainty of the conventional mass reported are lower than one third of the maximum permissible error for E_2 weights, which is the maximum value for the expanded uncertainty recommended in OIML R111-1:2004.

- There is a strong drift in travelling standards related to visible damages on them, especially in 200 g and 50 g weights. One possibility of this damage can be associated with an apparent deformation of the transportation box, but even so is difficult to explain all the scratches reported in Images 1 to 4.

10 References

[1] OIML R 111-1 Edition 2004 (E). Weights of classes E_1, E_2, F_1, F_2, M_1, M_{1-2}, M_2, M_{2-3} and M_3 Part 1: Metrological and technical requirements. Organisation Internationale de Métrologie Légale.

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[3] JCGM 100:2008 Evaluation of measurement data – Guide to the expression of uncertainty in measurements
http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

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[5] Nielsen, L., "*Evaluation of measurements by the method of least squares*". Danish Institute of Fundamental Metrology (DFM), Lyngby, DK. DFM-99-R39, 3208 LN, 2000-02-25.