FINAL REPORT OF THE MASS COMPARISON OF THE CALIBRATION OF STANDARD WEIGHTS BETWEEN SIM NMIs: CENAM, BSJ, TTBS and INDOCAL SIM.M.M-S16

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1. Introduction

Mass calibration is an important activity for National Institutes of Metrology, due to the amount of measurements on scientific, industrial and legal activities that require traceability to the national mass standards of each country.

In order to evaluate the stated uncertainty and degrees of equivalence between CENAM-Mexico, BSJ-Jamaica, TTBS-Trinidad and Tobago and INDOCAL-Dominican Republic on mass calibration, an inter-comparison was agreed between all participating laboratories. This comparison has been registered in the BIPM KCDB as SIM.M.M-S16.

For this comparison BSJ-Jamaica agreed to act as Pilot Laboratory and CENAM- Mexico accepted be the Support Laboratory.

2. Participant laboratories

The data of the participant laboratories are listed in Table 1.

Table 1. Participants of mass comparison

National Institute of Metrology	Acronym	Country	Technical Contact(s)
Centro Nacional de Metrología km 4.5 Carretera a los Cués, Mpio. El Marqués Querétaro, México	CENAM	MEXICO	Luis Omar Becerra Gregorio Alvarez Luis Manuel Peña
Bureau of Standard Jamaica 6 Winchester Road, Kingston 10, Jamaica, W.I.	BSJ	JAMAICA	Rupert Rigg Tweedsmuir Mitchell Carl Simpson
Trinidad & Tobago Bureau of Standards 1-2 Century Drive, Trincity Industrial Estate, Macoya, Tunapuna, Trinidad and Tobago, W.I.	TTBS	TRINIDAD AND TOBAGO	Theodore Reddock Erica Caruth

Instituto Dominicano para la Calidad Calle Presidente Vicini Burgos No. 60, Gazcue. Santo Domingo, República Dominicana	INDOCAL	DOMINICAN REPUBLIC	Magalys D'Oleo

3. Travelling Standard (weights)

A set of mass standards that were the property of the project **"*FOMENTO COORDINADO DE LA INFRAESTRUCTURA DE LA CALIDAD EN LA REGIÓN ANDINA, PTB-CAN*"** was be used for this comparison.

These travelling standards have the following nominal values and identification, (see Table 2):

Table 2. Set of travelling standards

Nominal value	Identification
2 kg	**141717**
1 kg	
200 g	
50 g	
1 g	
200 mg	

The travelling standards were circulated between all participating laboratories. Each time the travelling standards arrive at a participating laboratory, visual inspections were made of the surfaces, and the findings recorded.

Fig. 1. Travelling standards in the aluminum case.

Density (given in Table 3) and Magnetic properties of the travelling standards were measured at CENAM.

Table 3. Density of travelling standards.

Nominal value	Density	Stand. Unc. u, (k=1)
2 kg	8 011 kg m^{-3}	0.8 kg m^{-3}
1 kg	8 007 kg m^{-3}	1.6 kg m^{-3}
200 g	8 009 kg m^{-3}	0.8 kg m^{-3}
50 g	8 009 kg m^{-3}	1.0 kg m^{-3}
1 g	8 000 kg m^{-3}	35 kg m^{-3}
200 mg	8 000 kg m^{-3}	80 kg m^{-3}

The density of the travelling standards was measured at CENAM with the exception of 200 mg weight which was assumed. With regards to the magnetic properties of the weights, all the travelling standards were in accordance with specifications for class OIML E1.

4. Schedule of Comparison

The travelling standards were circulated among participants according to the schedule given in Table 4.

Table 4. Circulation of the travelling standards.

No.	National Metrology Institute	Arrival	Sending of results
1	CENAM-Mexico	14/03/2016	04/04/2016
2	INDOCAL- Dominican Republic	28/03/2016	25/04/2016
3	TTBS-Trinidad & Tobago	11/04/2016	16/05/2016
4	BSJ-Jamaica	25/04/2016	06/06/2016
5	CENAM-Mexico	09/05/2016	27/06/2016

5. Results

Each participant reported the conventional mass difference from nominal value (Δm_c = conventional mass value – nominal value) and the uncertainty associated for each travelling standard. Values as reported by participants are listed in Tables 5 and in figures 2 to 7.

Table 5. The table gives conventional mass differences from nominal value for travelling standards as reported by participants.

	CENAM$_1$		INDOCAL		TTBS		BSJ		CENAM$_2$	
	Δm_c mg	U, k=2 mg	Δm_c mg	U, k=2 mg	Δm_c mg	U, k=2 mg	Δm_c mg	U, k=2 mg	Δm_c mg	U, k=2 mg
200 mg	0.004 27	0.000 64	0.006	0.010	0.003 5	0.006 0	0.005 0	0.003 4	0.004 52	0.000 80
1 g	0.004 3	0.001 7	0.004 0	0.016	0.005 2	0.006 0	0.003 8	0.005 0	0.004 7	0.001 8
50 g	0.044 2	0.004 3	0.027	0.046	0.023	0.025	0.030	0.047	0.043 3	0.006 7
200 g	0.110	0.017	0.128	0.154	0.115	0.080	0.107	0.035	0.101	0.018
1 kg	0.173	0.083	0.20	0.76	0.15	0.30	0.17	0.26	0.162	0.083
2 kg	0.35	0.18	0.61	1.52	0.52	0.80	0.26	0.50	0.28	0.11

Figure 2. Results reported by participant laboratories for the 2 kg weight

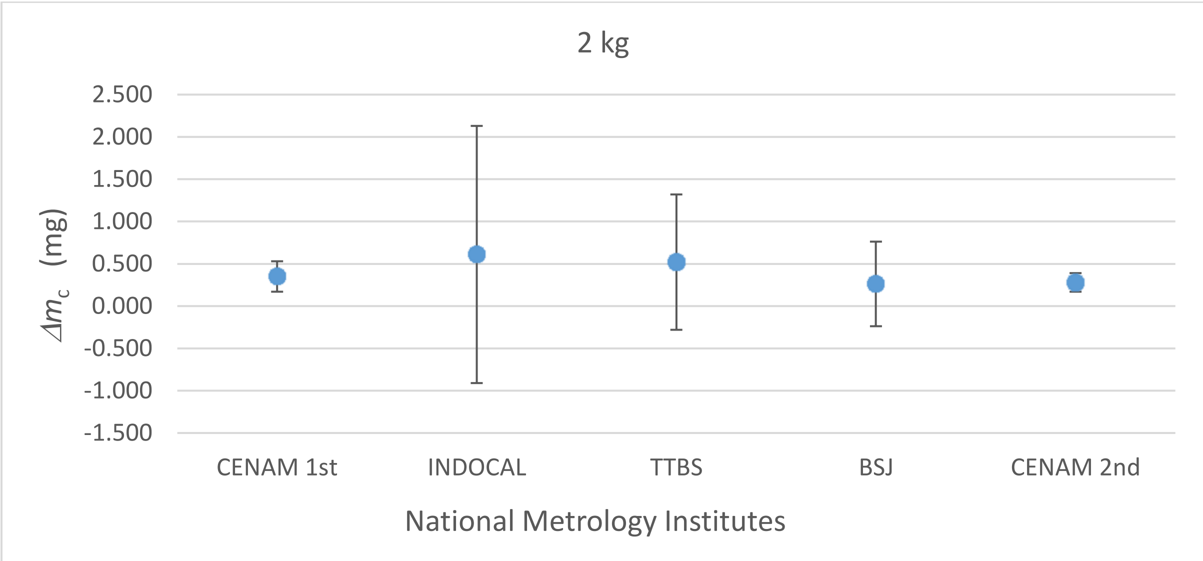


Figure 3. Results reported by participant laboratories for the 1 kg weight.

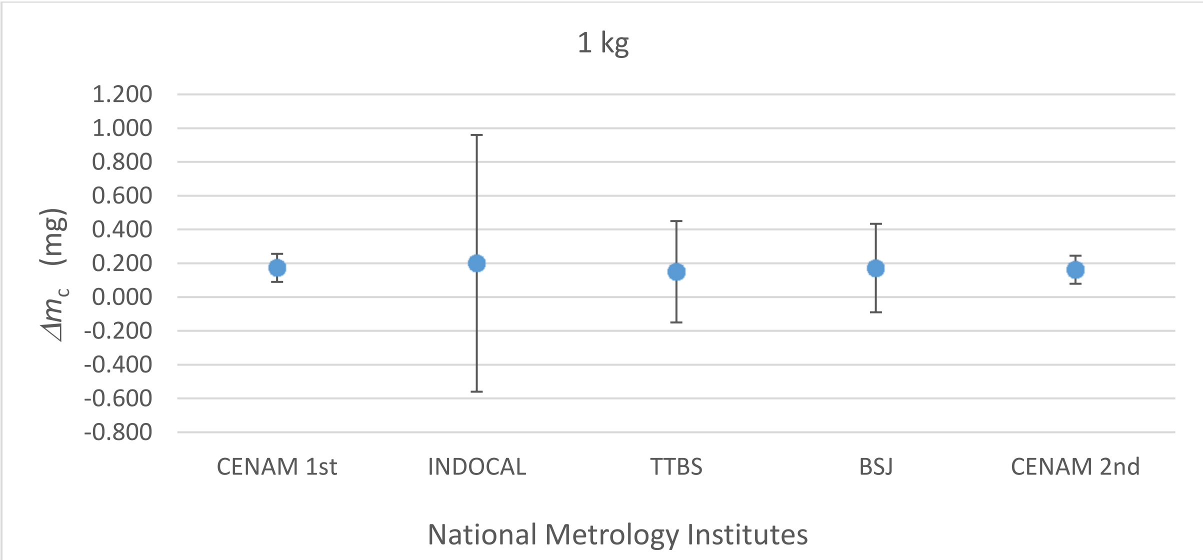


Figure 4. Results reported by participant laboratories for the 200 g weight.

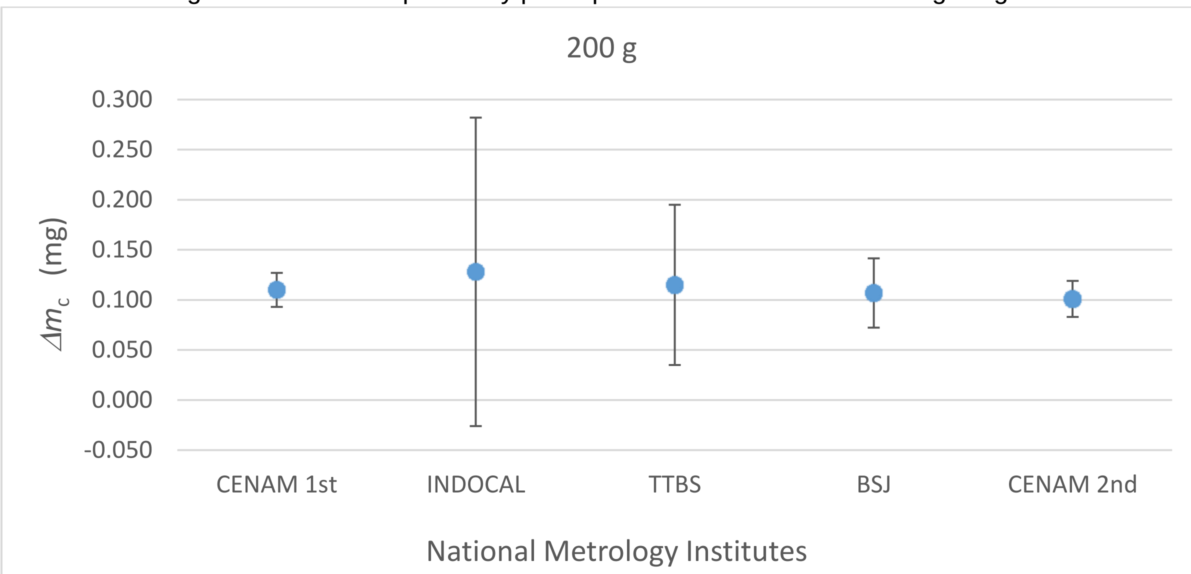


Figure 5. Results reported by participant laboratories for the 50 g weight.

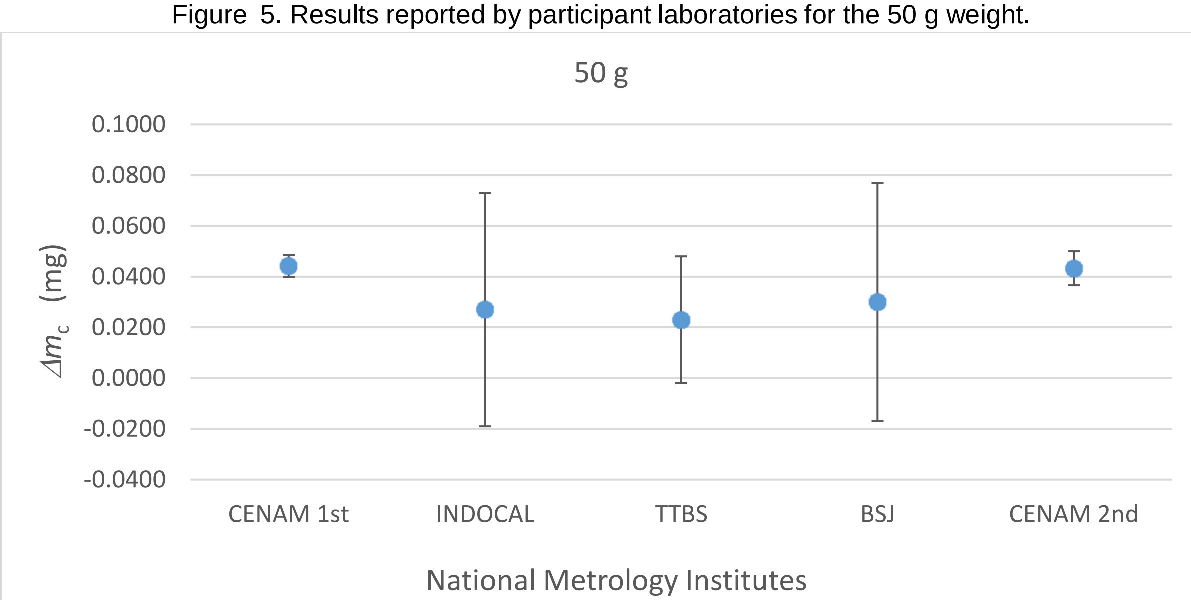


Figure 6. Results reported by participant laboratories for the 1 g weight.

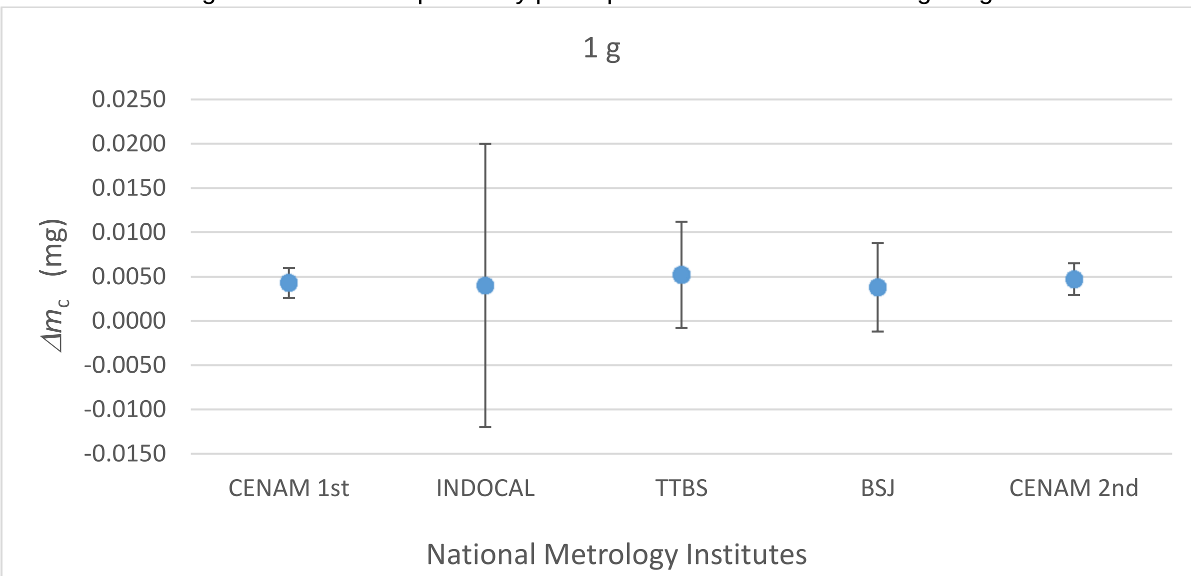
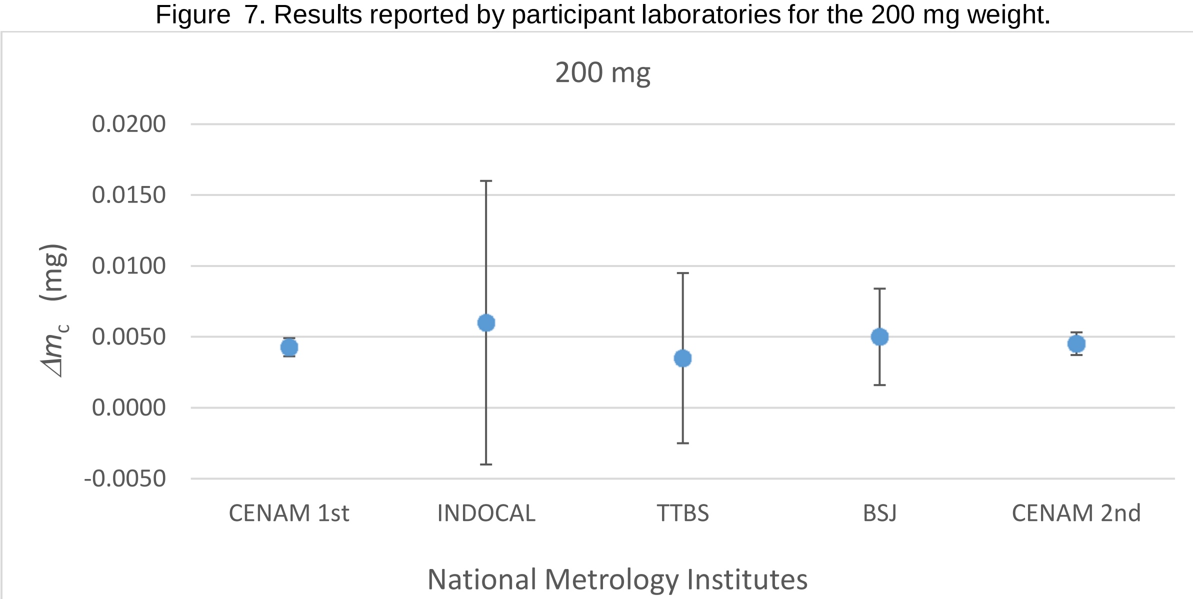


Figure 7. Results reported by participant laboratories for the 200 mg weight.



6. Degrees of Equivalence between participants

The degree of equivalence between participant laboratories was calculated as follow:

$$d_{ij} = X_i - X_j \tag{1}$$

Where

d_{ij} degree of equivalence between laboratory *i* and laboratory *j*
X_i conventional mass result of participant *i*
X_j conventional mass result of participant *j*

The standard uncertainty of the differences are calculated as follow,

$$u_{d_{ij}} = u_{X_i}^2 + u_{X_j}^2 + u_{inst}^2 \tag{2}$$

Where

$u_{d_{ij}}$ standard uncertainty of the conventional mass difference between laboratory *i* and laboratory *j*
u_{X_i} standard uncertainty of the conventional mass result of laboratory *i*
u_{X_j} standard uncertainty of the conventional mass result of laboratory *j*
u_{inst} standard uncertainty due to the instability of the travelling mass standard, evaluated assuming an uniform distribution from fist and final measurement of CENAM,

$$u_{inst} = \frac{X_{CENAM\ 2} - X_{CENAM\ 1}}{\sqrt{12}} \tag{3}$$

The instability of the weights during the circulation was determined from initial and final measurements made at CENAM. For this comparison, the CENAMs results were used to linking the measurement results of participant laboratories to CCM key comparisons CCM.M-K5 and CCM.M-K4.

Table 6. Mass difference estimated from CENAM measurements for each travelling standard, and CENAM mean values and their expanded uncertainties.

Nominal Value	**Estimated drift in conventional mass** $X_{CENAM\ 2} - X_{CENAM\ 1}$	**CENAM mean value**	
	mg	Δm_c mg	U, k=2 mg
200 mg	0.000 25	0.004 40	0.000 72
1 g	0.000 4	0.004 5	0.001 8
50 g	-0.000 9	0.043 8	0.005 6
200 g	-0.009	0.106	0.018
1 kg	-0.011	0.168	0.083
2 kg	-0.07	0.32	0.15

Table 7. Degree of equivalence between participant laboratories calculated in conventional mass and their corresponding expanded uncertainties.

	CENAM		INDOCAL		TTBS		JBS	
	Δm_c, mg	U, k = 2 mg	Δm_c, mg	U, k = 2 mg	Δm_c, mg	U, k = 2 mg	Δm_c, mg	U, k = 2 mg
200 mg								
CENAM			-0.002	0.010	0.000 9	0.006 0	-0.000 6	0.003 5
INDOCAL	0.002	0.010			0.003	0.012	0.001	0.011
TTBS	-0.000 9	0.006 0	-0.003	0.012			-0.001 5	0.006 9
BSJ	0.000 6	0.003 5	-0.001	0.011	0.001 5	0.006 9		
1 g								
CENAM			0.001	0.016	-0.000 7	0.006 3	0.000 7	0.005 3
INDOCAL	-0.001	0.016			-0.001	0.017	0.000	0.017
TTBS	0.000 7	0.006 3	0.001	0.017			0.001 4	0.007 8
BSJ	-0.000 7	0.005 3	0.000	0.017	-0.001 4	0.007 8		
50 g								
CENAM			0.017	0.046	0.021	0.026	0.014	0.047
INDOCAL	-0.017	0.046			0.004	0.052	-0.003	0.066
TTBS	-0.021	0.026	-0.004	0.052			-0.007	0.053
BSJ	-0.014	0.047	0.003	0.066	0.007	0.053		
200 g								
CENAM			-0.02	0.16	-0.009	0.082	-0.001	0.039
INDOCAL	0.02	0.16			0.01	0.17	0.02	0.16
TTBS	0.009	0.082	-0.01	0.17			0.008	0.087
BSJ	0.001	0.039	-0.02	0.16	-0.008	0.087		
1 kg								
CENAM			-0.03	0.76	0.02	0.31	0.00	0.27
INDOCAL	0.03	0.76			0.05	0.82	0.03	0.80
TTBS	-0.02	0.31	-0.05	0.82			-0.02	0.40
BSJ	0.00	0.27	-0.03	0.80	0.02	0.40		
2 kg								
CENAM			-0.3	1.5	-0.21	0.81	0.05	0.52
INDOCAL	0.3	1.5			0.1	1.7	0.4	1.6
TTBS	0.21	0.81	-0.1	1.7			0.26	0.94
BSJ	-0.05	0.52	-0.4	1.6	-0.26	0.94		

7. Link to the SIM NMIs to Key Comparison Reference Values of CCM.M-K5 and CCM.M-K4

In order to evaluate the agreement of SIM NMIs results with the Key Comparison reference values of CCM.M-K5 (200 mg, 1 g, 50 g, 200 g and 2 kg) and the CCM.M-K4 (1 kg) respectively, CENAM's results were used to link this SIM Comparison to the corresponding CCM key comparisons.

The mass difference between CENAM and the corresponding Key Comparison Reference Values (KCRV) are listed in Table 8, as well as uncertainties of CENAM results and the particular KCRVs stated in the corresponding reports [4] and [5].

Table 8. Degree of equivalence between CENAM and the corresponding KCRVs reported in comparisons CCM.M-K5 and CCM.M-K4. The standard uncertainty of results reported by CENAM in the corresponding comparisons as well as the standard uncertainty of the KCRVs are listed in the next table too.

	CENAM - KCRV	$u(D_{\mathrm{CENAM}})$, k = 1	$u(X_{\mathrm{CENAM}})$, k = 1.	$u(X_{KCRV})$, k = 1.
	mg	mg	mg	mg
CCM.M-K5				
200 mg	-0.000 45	0.000 39	0.000 20	0.000 24
1 g	-0.000 7	0.000 84	0.000 70	0.000 29
50 g	0.000 7	0.003 16	0.002 8	0.001 15
200 g	0.000 1	0.004 78	0.004 0	0.002 24
2 kg	0.02	0.067 9	0.062	0.021 43
CCM.M-K4				
1 kg	-0.011 6	0.013 4	0.0142	0.0062

Note: In CCM.M-K4 and CCM.M-K5 were circulated two mass standards for each nominal value, but in CCM.M-K5 there were not reported a mean value among the two results for each nominal value and its corresponding uncertainty, however the values of the mean values and the corresponding uncertainties were calculated and reported in Table 8.

The degree of equivalence between SIM NMIs and KCRVs are calculated as follow

$$D_i = d_{iCENAM} C + D_{CENAM} \tag{3}$$

Where

D_i Degree of equivalence between laboratory *i* and reference value of the corresponding Key Comparison

d_{iCENAM} degree of equivalence between laboratory *i* and CENAM (in conventional mass value)

D_{CENAM} degree of equivalence between CENAM and the reference value in the corresponding Key Comparison of CCM[1] (KCRV in mass value)

C is the factor to convert conventional mass value into mass value (according to the corresponding density of the travelling standard ρ)

$$C = \left(1 - \frac{1.2}{8000}\right) / \left(1 - \frac{1.2}{\rho}\right) \tag{4}$$

[1] CCM - Consultative Committee for Mass and Related Quantities is a consultative committee of the CIPM.

Expanding the difference,

$$D_i = (X_i - X_{CENAM\ SIM})\left(1 - \frac{1.2}{8000}\right)/\left(1 - \frac{1.2}{\rho}\right) + (X_{CENAM\ CCM} - X_{KCRV}) \quad (5)$$

Whit

$X_{CENAM\ SIM}$	CENAM result (in conventional mass) reported in this SIM comparison
$X_{CENAM\ CCM}$	CENAM result (in mass value) reported in the corresponding CCM key comparison
X_{KCRV}	CCM Key Comparison Reference Value

The standard uncertainty of the differences are calculated as follow,

$$u_{D_i} = u_{X_i}^2 + (u_{CENAM\ SIM} - u_{CENAM\ CCM})^2 + u_{inst}^2 + u_{KCRV}^2 \quad (6)$$

Where

u_{X_i}	standard uncertainty of the conventional mass result of laboratory *i* in this SIM comparison
$u_{CENAM\ SIM}$	standard uncertainty of the conventional mass result of CENAM in this SIM comparison
u_{inst}	standard uncertainty due to the instability of the travelling mass standard of this comparison
$u_{CENAM\ CCM}$	standard uncertainty of the mass result of CENAM in the corresponding CCM key comparison
u_{KCRV}	standard uncertainty of the Reference Value of corresponding CCM key comparison, KCRV

Note: The contribution due the density of the travelling standards (for the correction factor to convert conventional mass into mass) was considered negligible.

In order to evaluate the consistency between the mass result respects to the corresponding KCRV, the normalized error was calculated as follow,

$$E_n = \frac{D_i}{U_{D_i}}$$

Where

U_{D_i}	is the expanded uncertainty (k = 2) associated to the degree of equivalence between the mass result of SIM NMI I and the corresponding KCRV

The degrees of equivalence between SIM NMIs and KCRV of CCM are listen in Table 9, as well as the corresponding normalized errors.

Table 9. Degrees of equivalence between SIM NMIs and the corresponding KCRVs. The normalized errors are shown too.

	D_i, mg	U, k=2 mg	E_n
200 mg			
INDOCAL	0.001	0.010	0.12
TTBS	-0.001 3	0.006 0	0.22
BSJ	0.000 2	0.003 5	0.05
1 g			
INDOCAL	-0.001	0.016	0.07
TTBS	0.000 0	0.006 0	0.01
BSJ	-0.001 4	0.005 1	0.27
50 g			
INDOCAL	-0.016	0.046	0.35
TTBS	-0.020	0.025	0.80
BSJ	-0.013	0.047	0.28
200 g			
INDOCAL	0.02	0.15	0.15
TTBS	0.010	0.081	0.12
BSJ	0.001	0.037	0.04
1 kg			
INDOCAL	0.02	0.76	0.03
TTBS	-0.03	0.31	0.09
BSJ	-0.01	0.27	0.03
2 kg			
INDOCAL	0.3	1.5	0.21
TTBS	0.22	0.80	0.28
BSJ	-0.03	0.51	0.07

Figure 8. Degree of equivalence between SIM NMIs and KCRV for 2 kg weight.

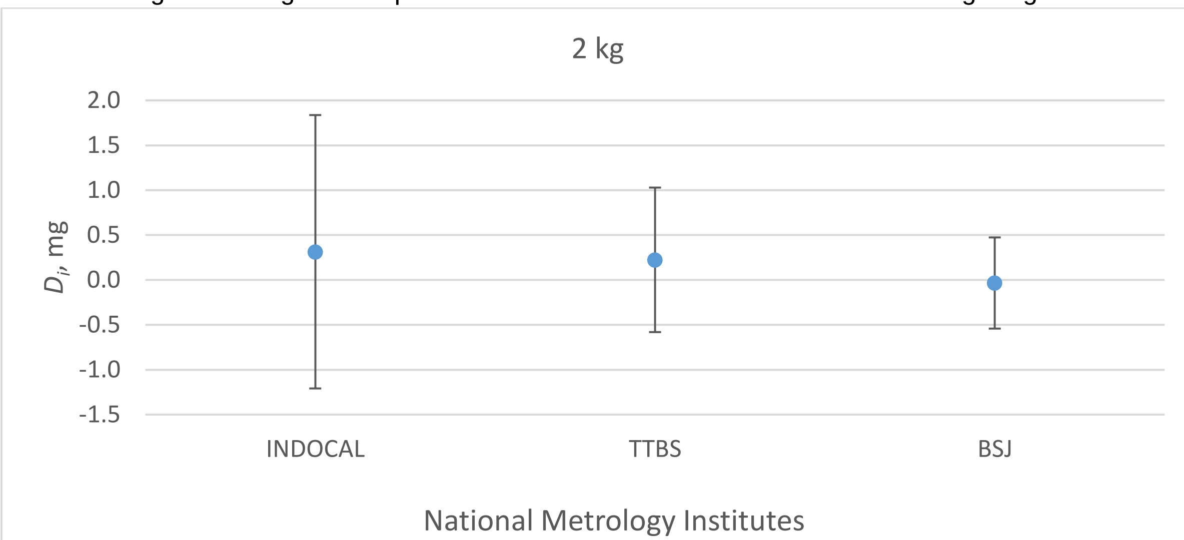


Figure 9. Degree of equivalence between SIM NMIs and KCRV for 1 kg weight.

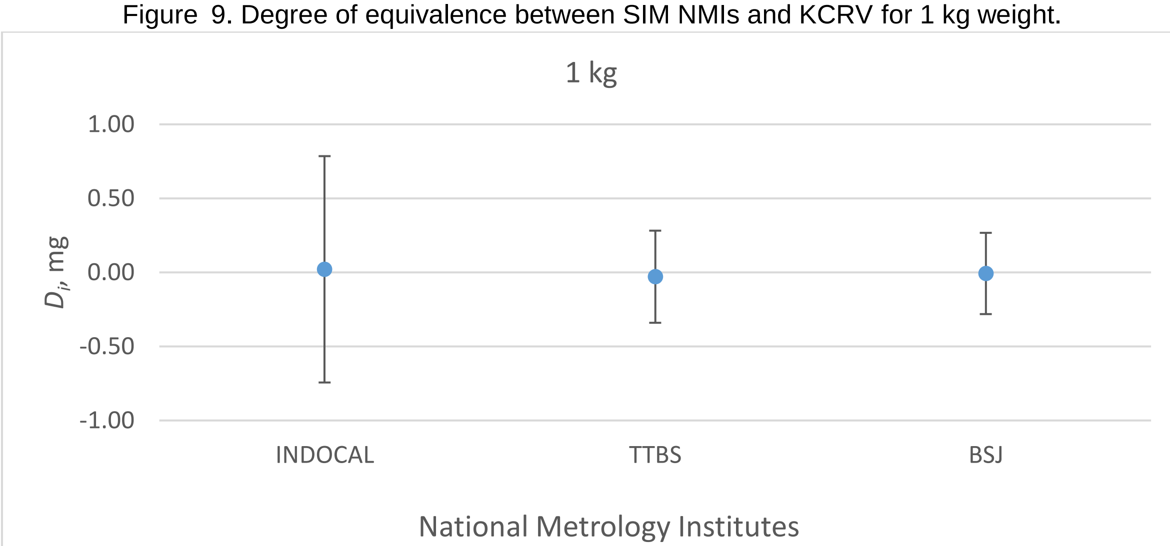


Figure 10. Degree of equivalence between SIM NMIs and KCRV for 200 g weight.

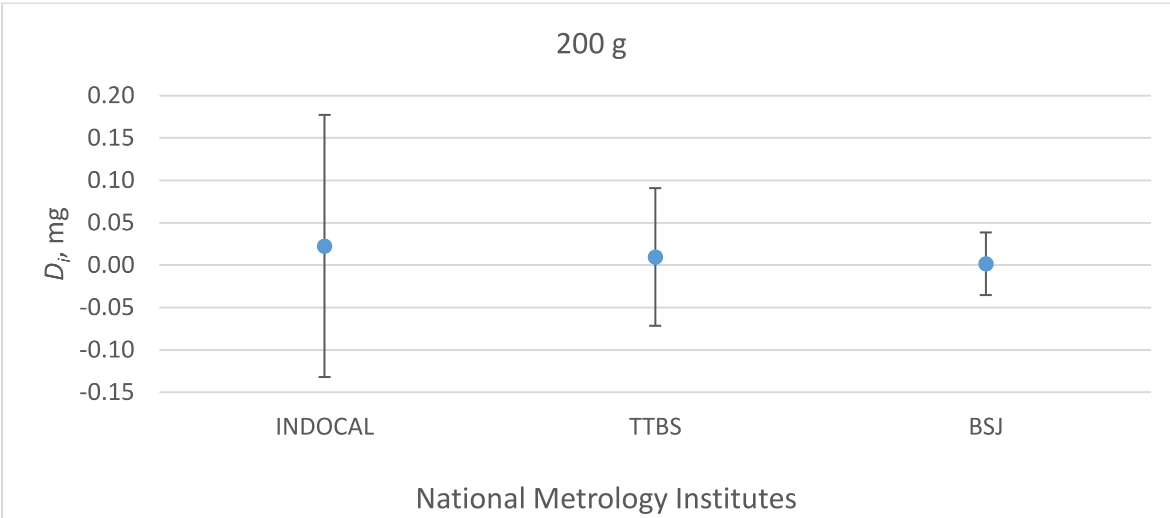


Figure 11. Degree of equivalence between SIM NMIs and KCRV for 50 g weight.

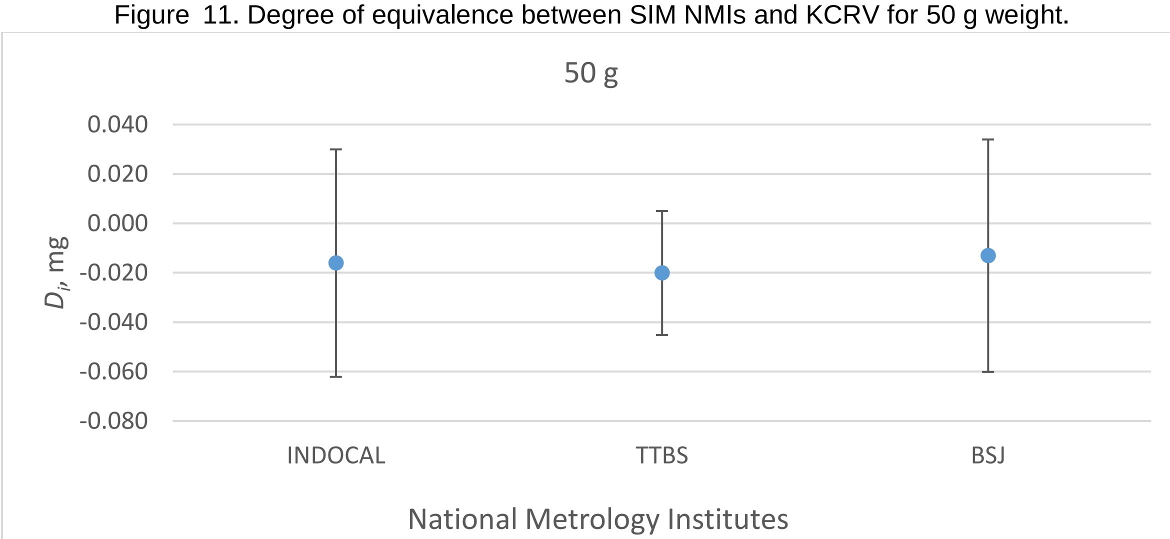


Figure 12. Degree of equivalence between SIM NMIs and KCRV for 1 g weight.

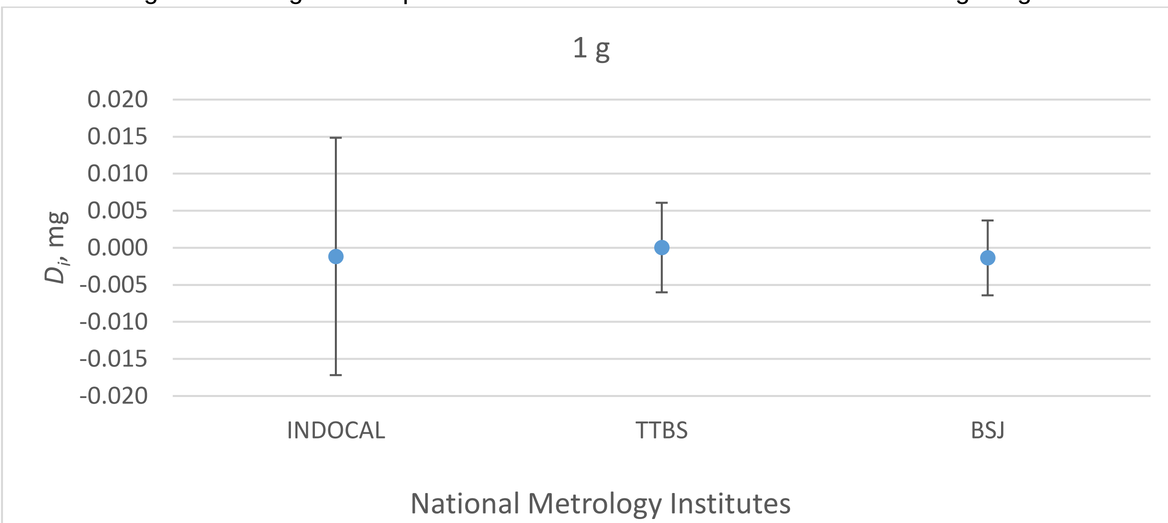
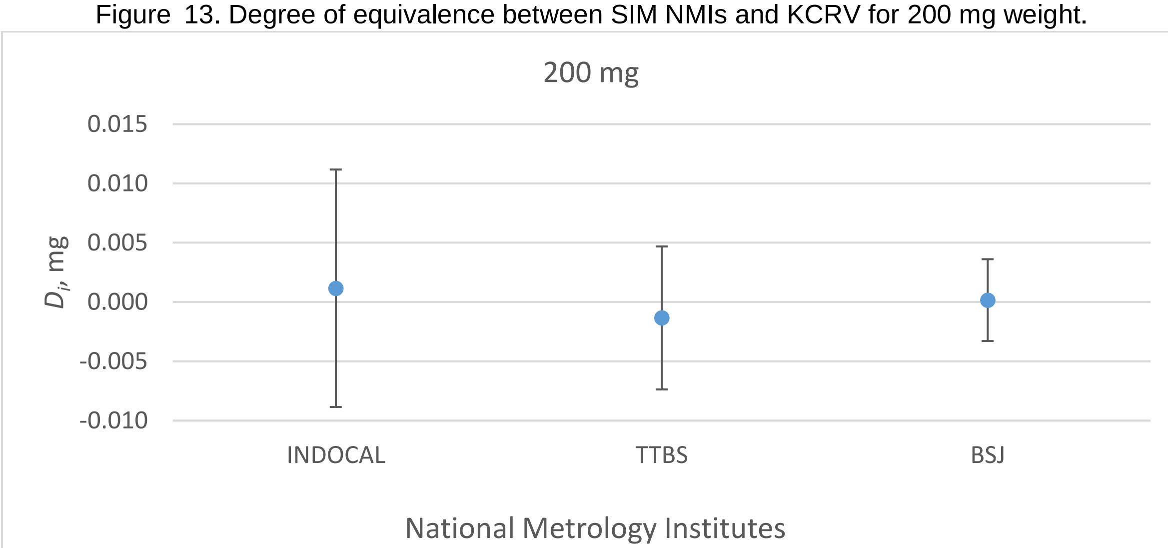


Figure 13. Degree of equivalence between SIM NMIs and KCRV for 200 mg weight.



8. Conclusions

The main objectives of this SIM comparison were:

- to evaluate the stated uncertainty offered by INDOCAL-Dominican Republic, TTBS-Trinidad & Tobago and BSJ-Jamaica in the calibration of mass standards.
- to evaluate the degree of equivalence between INDOCAL-Dominican Republic, TTBS-Trinidad & Tobago and BSJ-Jamaica in the calibration of mass standards
- to evaluate the degree of equivalence between INDOCAL-Dominican Republic, TTBS-Trinidad & Tobago and BSJ-Jamaica with the corresponding Key Comparison Reference Values of CCM.

In order to reach these objectives, six (6) stainless steel weights were measured in each country's respective laboratory from March to May, 2016.

For the measurements, each laboratory used their own facilities, equipment, mass standards and procedures.

From results reported by participants (see Table 5), the degree of equivalence between participants in the scope range of this comparison as well as the normalized errors were calculated. Results are reported in Table 7.

In order to evaluate the international equivalence of results reported by participants, the degree of equivalence between results reported by SIM NMIs and the reference values of the key comparisons CCM.M-K4 and CCM.M-K5 were calculated as well as the normalized errors (see Table 9).

From the data in Table 9, it can be noted that results reported by all participants are consistent within the reported uncertainty. The largest normalized error against the key comparison reference value of the CCM was *0.8*.

Results of participant laboratories in this comparison would support their Calibration and Measurements Capabilities (CMCs) of the CIPM Mutual Recognition Agreement, or their eventually submission to this agreement in the range and the uncertainty scope of this comparison.

9. References

[1] JCGM 100:2008. “Evaluation of measurement data — Guide to the expression of uncertainty in measurement”. (2008)

[2] SIM.M.M-S4. “The Bilateral Comparison of the Calibrations of Standard Weights between CENAM-Mexico and INEN-Ecuador”. (2009)

[3] Cox, M. G. (2002). The Evaluation of Key Comparison Data.

[4] A. Picard et al. CCM.M-K4 Final Report - Key comparison of 1 kg stainless steel mass standards CCM.M-K4 Organized by the Working Group on Mass Standards of the Consultative Committee for Mass and Related Quantities (CCM)

[5] A. Ooiwa et al. Report on CIPM key comparison of the second phase of multiples and submultiples of the kilogram (CCM.M-K5)