Linking SIM Mass Comparisons to the KCRV on 1 kg

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Abstract

Within the frame of SIM (*Sistema Interamericano de Metrología*) some inter laboratory mass comparisons have been performed in different nominal values. The main objective of those comparisons was to evaluate the degree of equivalence of SIM National Metrology Institutes (NMIs) between themselves and between SIM's NMIs with NMIs from other metrological regions. This paper presents the degree of equivalence in 1 kg between SIM's NMIs and between SIM's NMIs with the Key Comparison Reference Value (KCRV) of CCM.M-K1.

Keywords: Mass, Mass comparisons

1. Introduction

In the frame of SIM, there were performed some mass comparisons between SIM's NMIs where the travelling standards used were stainless steal mass standards of different nominal values.

An important goal of these comparisons was to evaluate the degree of consistency between SIM NMIs in mass measurements.

This paper presents the evaluation of consistency between SIM NMIs and between SIM NMIs and the KCRV of CCM.M-K1 at 1 kg level.

2. Mass Comparisons used for this analysis

For the purpose of this paper were analysed the reported values in 1 kg of three comparisons performed in the frame of SIM and the reported values of the key comparison of CCM in 1 kg too.

- **SIM.7.16a** [1]
  Nominal value: 1 kg
  Participant NMIs: CENAM-Mexico, LANAMET-Nicaragua, CONACYT-El Salvador, LNMG-Guatemala, LACOMET-Costa Rica, CENAMEP-Panama,
  Pilot Laboratory: CENAM
  Date: May 2003 - Nov 2003

- **SIM.7.29 (SIM.M.M-S1)** [2]
  Nominal values: 1 kg, 100 g, 20 g, 5 g and 100 mg
  Participant NMIs: CEM-España, CENAM-Mexico, IBMETRO-Bolivia, INDECOPI-Peru, INEN-Ecuador, SIC-Colombia, SENCAMER-Venezuela
  Pilot Laboratories: CEM, CENAM
  Date: Jul 2004 – Jul 2005

- **SIM.7.31a (SIM.M.M-S2)** [3]
  Nominal values: 1 kg
  Participant NMIs: CENAM-Mexico, BSJ-Jamaica, LACOMET-Costa Rica, IBMETRO-Bolivia, CESMEC-Chile, INDECOPI-Peru, INTN-Paraguay
  Pilot Laboratory: CENAM
  Date: Apr 2005 - Jan 2006

- **CMM.M-K1** [4]
  Nominal value: 1 kg
  Participant NMIs: BIPM-International (BIPM is an International laboratory not a NMI), CSIRO-Australia, NRC-Canada, NIM-China, BNM-INM/CNAM-France, PTB-Germany, IMGC-Italy, NMIJ/AIST-Japan, KRISS-Republic of Korea, CENAM-Mexico, VSL-Netherlands, VNIIM-Russia, SMU-Slovakia, NPL-United Kingdom, NIST-USA
  Pilot Laboratory: BIPM
  Date: Feb 2005 - Oct 2007

All reports were published. For the Mass comparison SIM.7.29, only the reported results for 1 kg were used for the purpose of this paper.

For the SIM comparisons SIM.7.16a, SIM.729 and SIM.7.31a, mass differences between the participant NMIs and CENAM are reported in tables 1 to 3. In table 4 are reported mass differences between participant NMIs and CENAM in CCM.M.K1.

In second row of tables 1, 2, 3 and 4, are the expanded uncertainties reported by CENAM in SIM.7.16a, SIM.7.29, SIM.7.31a and CCM.M-K1 respectively.

Mass difference between participant NMIs of CCM.M-K1 and the KCRV are reported in table 5.

Table 1. Mass difference between NMI i and CENAM, in SIM.7.16a.

NMI	diff. mg	Unc. (k=2) mg
CENAM	---	0.15
LANAMET	0.17	0.54
CENAMEP	-0.06	0.43
LACOMET	-0.93	0.34
LNMG	0.4	1.0
CONACYT	0.4	1.0

Table 2. Mass difference between NMI i and CENAM, in SIM.7.29.

NMI	diff. mg	Unc. (k=2) mg
CENAM	---	0.020
CEM	-0.020	0.086
SIC	-0.14	0.18
SENCAMER	1.19	0.25
INEN	-0.01	0.19
INDECOPI	-0.04	0.30
IBMETRO	-0.08	0.15

Table 3. Mass difference between NMI i and CENAM, in SIM.7.31a.

NMI	diff. mg	Unc. (k=2) mg
CENAM	---	0.030
BSJ	0.1	1.3
LACOMET	-0.054	0.055
IBMETRO	0.03	0.16
INDECOPI	-0.04	0.26
INTN	0.1	1.6
CESMEC	0.02	0.50

Table 4. Mass difference between NMI i and CENAM, in CCM.M-K1

NMI	diff. mg	Unc. (k=2) mg
CENAM	---	0.026
BIPM	0.001	0.036
VSL	-0.017	0.045
NIST	-0.020	0.047
NPL	0.001	0.041
NRC	-0.019	0.043
NMIJ	-0.022	0.038
VNIIM	0.047	0.055
CSIRO	0.003	0.039
PTB	-0.003	0.037
NIM	-0.003	0.053
SMU	0.058	0.052
KRISS	-0.003	0.039
IMGC	-0.002	0.038
BNM	0.004	0.034

Table 5. Mass difference between NMI i and KCRV, in CCM.M-K1

NMI	diff. mg	Unc. (k=2) mg
BIPM	0.003	0.024
VSL	-0.015	0.037
NIST	-0.018	0.039
NPL	0.002	0.032
NRC	-0.017	0.034
NMIJ	-0.020	0.028
VNIIM	0.049	0.048
CSIRO	0.005	0.029
PTB	-0.001	0.026
NIM	-0.001	0.046
SMU	0.060	0.044
KRISS	-0.001	0.029
IMGC	0.000	0.027
BNM	0.006	0.022
CENAM	0.002	0.027

All differences reported in tables 1 to 5, were evaluated for each particular comparison.

The uncertainty associated to each difference comprises the reported uncertainty for the corresponding participants and the stability of the standards used.

3. Evaluation of the degree of equivalence between SIM NMIs and KCRV in 1 kg

In order to link the results of SIM NMIs to the KCRV of CCM.M-K1, there were used the mass differences between participant NMIs and CENAM in the corresponding comparisons, due that CENAM is the only linking NMI between these SIM comparisons and the CCM's key comparison.

It is assumed that all results have systematic differences between themselves within the uncertainty interval of such differences.

The mass difference between the SIM's NMI i and the KCRV of CCM.M-K1 is calculated by,

(1)

$$diff(NMI_{ij} - KCRV) = diff(NMI_{ij} - CENAM_j) - diff(CENAM_{CCM} - KCRV)$$

where,

$diff(NMI_{ij} - CENAM_j)$ is the mass difference between the NMI i and CENAM in the comparison j,

$diff(CENAM_{CCM} - KCRV)$ is the mass difference between CENAM and the KCRV of CCM.M-K1

The uncertainty of these mass difference is evaluated by combination of the standard uncertainty of the mass difference between SIM's NMI i and CENAM in comparison j, the standard uncertainty of the mass difference between CENAM and the KCRV, a component of uncertainty due to the CENAM reproducibility, minus CENAM's reported uncertainties for the corresponding comparisons.

(2)

$$u(diff(NMI_i - KCRV)) = [u^2(diff(NMI_{ij} - CENAM_j)) - u^2(CENAM_j)$$
$$+ u^2(diff(CENAM - KCRV)) - u^2(CENAM_{CCM}) + u^2(CENAM')]^{1/2}$$

where,

$u(diff(NMI_{ij} - CENAM_j))$ is the standard uncertainty of the mass difference between the NMI i and CENAM for the comparison j,

$u(diff(CENAM - KCRV))$ is the standard uncertainty of the mass difference between CENAM and the KCRV of the CCM.M-K1,

$u(CENAM_j)$ is the reported uncertainty by CENAM in the comparison j,

$u(CENAM_{CCM})$ is the reported uncertainty by CENAM in the CCM.M-K1.

$u(CENAM')$ is the component due to the CENAM's reproducibility, which was estimated as 7 μg,

In table 6, are reported the calculated mass differences between SIM's NMIs and the KCRV of the CCM.M-K1, and the expanded uncertainties evaluated for those mass differences.

Table 6. Mass difference between NMI i and the KCRV of CCM.M-K1.

Comparison	NMI	Diff mg	U, k=2 mg
	CENAM	0.002	0.027
SIM.7.16a	LANAMET	0.17	0.52
	CENAMEP	-0.05	0.40
	LACOMET	-0.92	0.30
	LNMG	0.4	1.0
	CONACYT	0.4	1.0
SIM.7.31a (SIM.M-S2)	BSJ	0.1	1.3
	LACOMET	-0.052	0.049
	IBMETRO	0.03	0.15
	INDECOPI	-0.04	0.26
	INTN	0.1	1.6
	CESMEC	0.02	0.50
SIM.7.29, (SIM.M.M-S1)	CEM	-0.018	0.085
	SIC	-0.14	0.18
	SENCAMER	1.19	0.25
	INEN	-0.01	0.19
	INDECOPI	-0.04	0.30
	IBMETRO	-0.08	0.15

In figure 1, LACOMET 1 was calculated from its participation in SIM.7.16a and LACOMET 2 was calculated from its participation in SIM.7.31a.

Changes were reported in the traceability system of LACOMET between its participations in SIM.7.16a and SIM.7.31a.

IBMETRO 1 and INDECOPI 1 were calculated from SIM.7.31a results, and IBMETRO 2 and INDECOPI 2 were calculated from SIM.7.29 results.
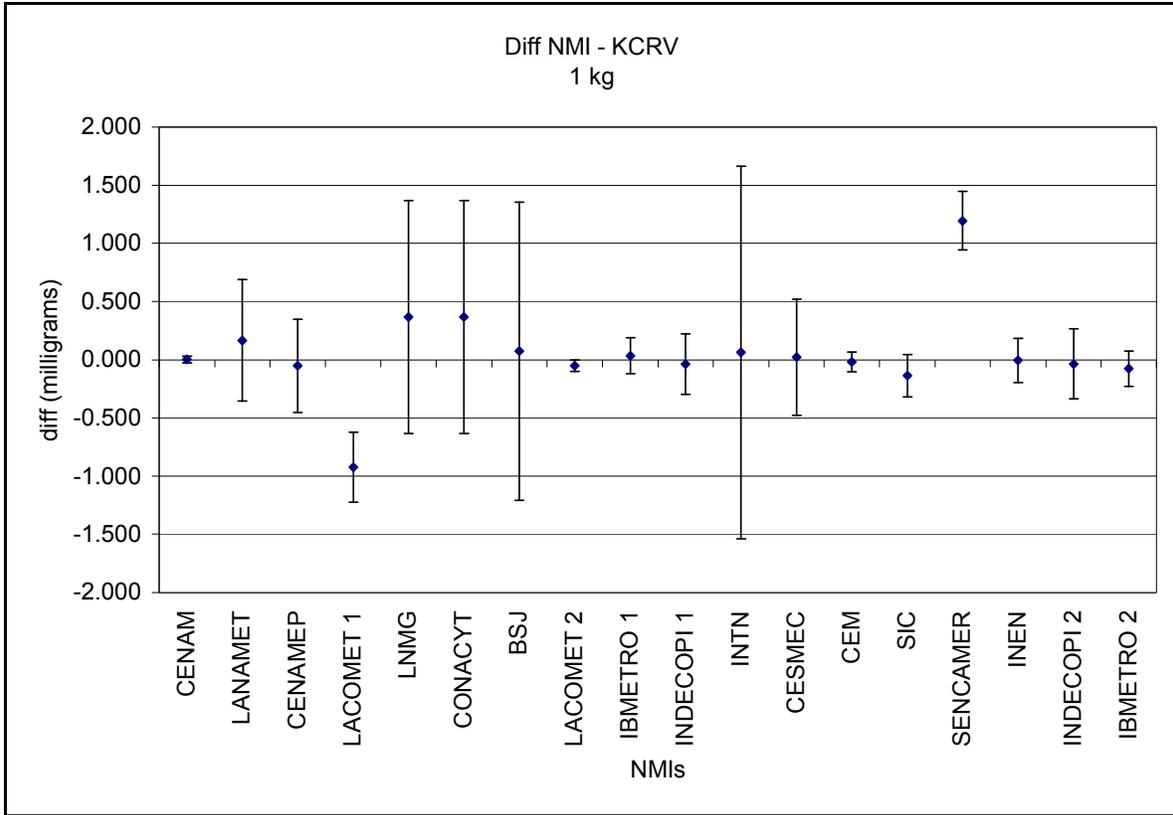
Figure 1. Mass differences between SIM's NMIs and the KCRV of CCM.M-K1 (1 kg). The uncertainties are plotted with k=2.

4. Evaluation of the degree of equivalence between SIM's NMIs and participant NMIs of CCM.M-K1

The mass difference between two NMIs that did not participate in the same comparison could be estimated using the corresponding difference of each NMI and CENAM.

$$diff\,(NMI_{ij} - NMI_{kl}) = diff\,(NMI_{ij} - CENAM_j) + diff\,(NMI_{kl} - CENAM_l) \tag{3}$$

where,

$diff(NMI_{ij} - CENAM_j)$ is the mass difference between the NMI i and CENAM in the comparison j,

$diff(lNMI_{kl} - CENAM_l)$ is the mass difference between the NMI k and CENAM in the comparison l,

the standard uncertainty of this difference is calculated from,

$$\tag{4}$$

$$u\bigl(diff\,(NMI_{ij} - NMI_{kl})\bigr) = [u^2\bigl(diff\,(NMI_{ij} - CENAM_j)\bigr) - u^2\bigl(CENAM_j\bigr)$$
$$+ u^2\bigl(diff\,(NMI_{kl} - CENAM_l)\bigr) - u^2\bigl(CENAM_l\bigr) + u^2\bigl(CENAM'\bigr)]^{\frac{1}{2}}$$

where,
$u\bigl(diff\,(NMI_{kl} - CENAM_l)\bigr)$ is the standard uncertainty of the mass difference between the NMI k and CENAM for the comparison l,
$u\bigl(CENAM_l\bigr)$ is the reported uncertainty by CENAM in the comparison l.

    From formula 4, it is possible to estimate the degree of equivalence among SIM's NMIs and between SIM's NMIs and participant NMIs of CCM.M-K1, see tables 7, 8 and 9.

Table 7. Mass differences between NMI A minus NMI B and the expanded uncertainty. Values in milligrams.

SIM.7.16a

Group	A\B	CENAM diff	CENAM Unc k=2	LANAMET diff	LANAMET Unc k=2	CENAMEP diff	CENAMEP Unc k=2	LACOMET diff	LACOMET Unc k=2	LNMG diff	LNMG Unc k=2	CONACYT diff	CONACYT Unc k=2
SIM.7.31a / SIM.M.M-S2	BSJ	0.1	1.3	-0.1	1.4	0.1	1.3	1.0	1.3	-0.3	1.6	-0.3	1.6
	LACOMET	-0.054	0.055	-0.22	0.52	0.00	0.40	0.87	0.30	-0.4	1.0	-0.4	1.0
	IBMETRO	0.03	0.16	-0.13	0.54	0.09	0.43	0.96	0.34	-0.3	1.0	-0.3	1.0
	INDECOPI	-0.04	0.26	-0.21	0.58	0.02	0.48	0.89	0.40	-0.4	1.0	-0.4	1.0
	INTN	0.1	1.6	-0.1	1.7	0.1	1.6	1.0	1.6	-0.3	1.9	-0.3	1.9
	CESMEC	0.02	0.50	-0.15	0.72	0.08	0.64	0.95	0.58	-0.3	1.1	-0.3	1.1
SIM.7.29 / SIM.M.M-S1	CEM	-0.020	0.086	-0.19	0.53	0.04	0.41	0.91	0.31	-0.4	1.0	-0.4	1.0
	SIC	-0.14	0.18	-0.30	0.55	-0.08	0.44	0.79	0.35	-0.5	1.0	-0.5	1.0
	SENCAMER	1.19	0.25	1.03	0.58	1.25	0.47	2.12	0.39	0.8	1.0	0.8	1.0
	INEN	-0.01	0.19	-0.17	0.55	0.05	0.44	0.92	0.36	-0.4	1.0	-0.4	1.0
	INDECOPI	-0.04	0.30	-0.20	0.60	0.02	0.50	0.89	0.42	-0.4	1.0	-0.4	1.0
	IBMETRO	-0.08	0.15	-0.24	0.54	-0.02	0.43	0.85	0.34	-0.4	1.0	-0.4	1.0
CCM.M.K1	BIPM	0.001	0.036	-0.16	0.52	0.06	0.40	0.93	0.30	-0.4	1.0	-0.4	1.0
	VSL	-0.017	0.045	-0.18	0.52	0.04	0.40	0.91	0.30	-0.4	1.0	-0.4	1.0
	NIST	-0.020	0.047	-0.19	0.52	0.04	0.40	0.91	0.30	-0.4	1.0	-0.4	1.0
	NPL	0.001	0.041	-0.16	0.52	0.06	0.40	0.93	0.30	-0.4	1.0	-0.4	1.0
	NRC	-0.019	0.043	-0.18	0.52	0.04	0.40	0.91	0.30	-0.4	1.0	-0.4	1.0
	NMIJ	-0.022	0.038	-0.19	0.52	0.03	0.40	0.90	0.30	-0.4	1.0	-0.4	1.0
	VNIIM	0.047	0.055	-0.12	0.52	0.10	0.40	0.97	0.30	-0.3	1.0	-0.3	1.0
	CSIRO	0.003	0.039	-0.16	0.52	0.06	0.40	0.93	0.30	-0.4	1.0	-0.4	1.0
	PTB	-0.003	0.037	-0.17	0.52	0.05	0.40	0.92	0.30	-0.4	1.0	-0.4	1.0
	NIM	-0.003	0.053	-0.17	0.52	0.05	0.40	0.92	0.30	-0.4	1.0	-0.4	1.0
	SMU	0.058	0.052	-0.11	0.52	0.11	0.40	0.98	0.30	-0.3	1.0	-0.3	1.0
	KRISS	-0.003	0.039	-0.17	0.52	0.05	0.40	0.92	0.30	-0.4	1.0	-0.4	1.0
	IMGC	-0.002	0.038	-0.17	0.52	0.05	0.40	0.92	0.30	-0.4	1.0	-0.4	1.0
	BNM	0.004	0.034	-0.16	0.52	0.06	0.40	0.93	0.30	-0.4	1.0	-0.4	1.0

Table 8. Mass differences between NMI A minus NMI B and the expanded uncertainty. Values in milligrams.

	A\B	CEM		SIC		SENCAMER		INEN		INDECOPI		IBMETRO	
		diff	Unc k=2	diff	Unc k=2	diff	Unc k=2	diff	Unc k=2	diff	Unc k=2	diff	Unc k=2
SIM.7.16a	LANAMET	0.19	0.53	0.30	0.55	-1.03	0.58	0.17	0.55	0.20	0.60	0.24	0.54
	CENAMEP	-0.04	0.41	0.08	0.44	-1.25	0.47	-0.05	0.44	-0.02	0.50	0.02	0.43
	LACOMET	-0.91	0.31	-0.79	0.35	-2.12	0.39	-0.92	0.36	-0.89	0.42	-0.85	0.34
	LNMG	0.4	1.0	0.5	1.0	-0.8	1.0	0.4	1.0	0.4	1.0	0.4	1.0
	CONACYT	0.4	1.0	0.5	1.0	-0.8	1.0	0.4	1.0	0.4	1.0	0.4	1.0
SIM.M.M-S2 SIM.7.31a	BSJ	0.1	1.3	0.2	1.3	-1.1	1.3	0.1	1.3	0.1	1.3	0.1	1.3
	LACOMET	-0.03	0.10	0.09	0.19	-1.25	0.25	-0.04	0.20	-0.01	0.30	0.03	0.16
	IBMETRO	0.05	0.18	0.17	0.24	-1.16	0.29	0.04	0.25	0.07	0.34	0.11	0.22
	INDECOPI	-0.02	0.27	0.10	0.32	-1.23	0.36	-0.03	0.32	0.00	0.40	0.04	0.30
	INTN	0.1	1.6	0.2	1.6	-1.1	1.6	0.1	1.6	0.1	1.6	0.1	1.6
CCM.M.K1	CESMEC	0.04	0.51	0.16	0.53	-1.17	0.56	0.03	0.54	0.06	0.58	0.10	0.52
	BIPM	0.021	0.088	0.14	0.18	-1.19	0.25	0.01	0.19	0.04	0.30	0.08	0.15
	VSL	0.003	0.092	0.12	0.18	-1.21	0.25	-0.01	0.19	0.02	0.30	0.06	0.16
	NIST	0.000	0.093	0.12	0.19	-1.21	0.25	-0.01	0.19	0.02	0.30	0.06	0.16
	NPL	0.021	0.091	0.14	0.18	-1.19	0.25	0.01	0.19	0.04	0.30	0.08	0.15
	NRC	0.001	0.091	0.12	0.18	-1.21	0.25	-0.01	0.19	0.02	0.30	0.06	0.15
	NMIJ	-0.002	0.089	0.12	0.18	-1.21	0.25	-0.01	0.19	0.02	0.30	0.06	0.15
	VNIIM	0.067	0.098	0.19	0.19	-1.14	0.26	0.06	0.20	0.09	0.30	0.13	0.16
	CSIRO	0.023	0.090	0.14	0.18	-1.19	0.25	0.01	0.19	0.04	0.30	0.08	0.15
	PTB	0.017	0.089	0.14	0.18	-1.19	0.25	0.01	0.19	0.04	0.30	0.08	0.15
	NIM	0.017	0.097	0.14	0.19	-1.19	0.25	0.01	0.20	0.04	0.30	0.08	0.16
	SMU	0.078	0.096	0.20	0.19	-1.13	0.25	0.07	0.20	0.10	0.30	0.14	0.16
	KRISS	0.017	0.090	0.14	0.18	-1.19	0.25	0.01	0.19	0.04	0.30	0.08	0.15
	IMGC	0.018	0.089	0.14	0.18	-1.19	0.25	0.01	0.19	0.04	0.30	0.08	0.15
	BNM	0.024	0.088	0.14	0.18	-1.19	0.25	0.01	0.19	0.04	0.30	0.08	0.15

SIM.7.29 (SIM.M.M-S1)

Table 9. Mass differences between NMI A minus NMI B and the expanded uncertainty. Values in milligrams.

SIM.7.31a (SIM.M.M.-S2)

Group	A\B	BSJ diff	BSJ Unc k=2	LACOMET diff	LACOMET Unc k=2	IBMETRO diff	IBMETRO Unc k=2	INDECOPI diff	INDECOPI Unc k=2	INTN diff	INTN Unc k=2	CESMEC diff	CESMEC Unc k=2
SIM.7.16a	LANAMET	0.1	1.4	0.22	0.52	0.13	0.54	0.21	0.58	0.1	1.7	0.15	0.72
SIM.7.16a	CENAMEP	-0.1	1.3	0.00	0.40	-0.09	0.43	-0.02	0.48	-0.1	1.6	-0.08	0.64
SIM.7.16a	LACOMET	-1.0	1.3	-0.87	0.30	-0.96	0.34	-0.89	0.40	-1.0	1.6	-0.95	0.58
SIM.7.16a	LNMG	0.3	1.6	0.4	1.0	0.3	1.0	0.4	1.0	0.3	1.9	0.3	1.1
SIM.7.16a	CONACYT	0.3	1.6	0.4	1.0	0.3	1.0	0.4	1.0	0.3	1.9	0.3	1.1
SIM.7.29 SIM.M.M.-S1	CEM	-0.1	1.3	0.03	0.10	-0.05	0.18	0.02	0.27	-0.1	1.6	-0.04	0.51
SIM.7.29 SIM.M.M.-S1	SIC	-0.2	1.3	-0.09	0.19	-0.17	0.24	-0.10	0.32	-0.2	1.6	-0.16	0.53
SIM.7.29 SIM.M.M.-S1	SENCAMER	1.1	1.3	1.25	0.25	1.16	0.29	1.23	0.36	1.1	1.6	1.17	0.56
SIM.7.29 SIM.M.M.-S1	INEN	-0.1	1.3	0.04	0.20	-0.04	0.25	0.03	0.32	-0.1	1.6	-0.03	0.54
SIM.7.29 SIM.M.M.-S1	INDECOPI	-0.1	1.3	0.01	0.30	-0.07	0.34	0.00	0.40	-0.1	1.6	-0.06	0.58
SIM.7.29 SIM.M.M.-S1	IBMETRO	-0.1	1.3	-0.03	0.16	-0.11	0.22	-0.04	0.30	-0.1	1.6	-0.10	0.52
CCM.M.K1	BIPM	-0.1	1.3	0.055	0.054	-0.03	0.16	0.04	0.26	-0.1	1.6	-0.02	0.50
CCM.M.K1	VSL	-0.1	1.3	0.037	0.061	-0.05	0.16	0.02	0.26	-0.1	1.6	-0.04	0.50
CCM.M.K1	NIST	-0.1	1.3	0.034	0.062	-0.05	0.16	0.02	0.26	-0.1	1.6	-0.04	0.50
CCM.M.K1	NPL	-0.1	1.3	0.055	0.058	-0.03	0.16	0.04	0.26	-0.1	1.6	-0.02	0.50
CCM.M.K1	NRC	-0.1	1.3	0.035	0.059	-0.05	0.16	0.02	0.26	-0.1	1.6	-0.04	0.50
CCM.M.K1	NMIJ	-0.1	1.3	0.032	0.055	-0.05	0.16	0.02	0.26	-0.1	1.6	-0.04	0.50
CCM.M.K1	VNIIM	0.0	1.3	0.101	0.068	0.02	0.16	0.09	0.26	0.0	1.6	0.03	0.50
CCM.M.K1	CSIRO	-0.1	1.3	0.057	0.056	-0.03	0.16	0.04	0.26	-0.1	1.6	-0.02	0.50
CCM.M.K1	PTB	-0.1	1.3	0.051	0.055	-0.04	0.16	0.04	0.26	-0.1	1.6	-0.02	0.50
CCM.M.K1	NIM	-0.1	1.3	0.051	0.067	-0.04	0.16	0.04	0.26	-0.1	1.6	-0.02	0.50
CCM.M.K1	SMU	0.0	1.3	0.112	0.066	0.03	0.16	0.10	0.26	0.0	1.6	0.04	0.50
CCM.M.K1	KRISS	-0.1	1.3	0.051	0.056	-0.04	0.16	0.04	0.26	-0.1	1.6	-0.02	0.50
CCM.M.K1	IMGC	-0.1	1.3	0.052	0.055	-0.03	0.16	0.04	0.26	-0.1	1.6	-0.02	0.50
CCM.M.K1	BNM	-0.1	1.3	0.058	0.053	-0.03	0.16	0.04	0.26	-0.1	1.6	-0.02	0.50

5. Conclusions

From this evaluation it is possible to estimate the degree of equivalence of SIM's NMIs with the KCRV of CCM.M-K1, and the degree of equivalence between SIM's NMIs themselves and between SIM's NMIs and participant NMIs of CCM.M-K1.

LACOMET, IBMETRO and INDECOPI participated in two of the analysed comparisons, from those results it is possible to confirm that IBMETRO and INDECOPI participations throw differences against the KCRV consistent enough within the uncertainty intervals.

LACOMET participations show on the other hand, differences that are not consistent within the uncertainty intervals. This situation is mainly due that LACOMET's significant changes in its traceability chain.

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