Asia-Pacific Metrology Programme

Final Report on
APMP Comparison of 1 kg mass standard
APMP.M.M-K1 (APMP-IC-3-96)

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APMP Comparison of 1 kg mass standard

Abstract

This report summarizes the results of a comparison of 1 kg Mass Standards conducted between fifteen participating members of the Asia-Pacific Metrology Programme. The comparison commenced on August 15, 1999 and concluded on April 20, 2001. Two 1 kg OIML weights (Class E1) were used as travelling artifacts. They were enclosed in a wooden box, then placed in an aluminium container. There was no funding provided for the programme; however, the two artifacts were donated by Mettler Toledo, Switzerland. National Institute of Metrology (Thailand), NIMT acted as coordinating laboratory for the programme. The majority of the results of the participating laboratories are consistent with each other and with the key comparison reference value (KCRV) of comparison CCM.M-K1 to which this comparison is linked.

Introduction

Asia Pacific Metrology Programme (APMP) is a grouping of national and territorial measurement laboratories from the Asia-Pacific region in helping to develop international recognition for regional measurement competence and, hence, underpin confidence in regional traded products and services. One of the successful methods used by APMP to reach its objective is a comparison of a given artifact. Measurement comparisons bring the laboratories a confidence in the measurement standards and lead to the international acceptance of the measurement standards. At the 11th APMP Committee Meeting held on October 16, 1995 in Tsukuba, Japan, the member delegated from Thailand, proposed to the Committee to act as a programme coordinator for an APMP comparison of 1 kg mass standard programme. In June 1, 1998 National Institute of Metrology (Thailand), NIMT was established under National Metrological System Development Act B.E. 2540 (1997). The programme coordinator distributed the outline and questionnaire of the comparison to invite participation in the comparison and the measurement was started by NIMT in July 1999.

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1. General

The comparison in the field of mass standard was conducted between participating APMP member laboratories. The aim of the programme was to provide participating laboratories with an opportunity to compare national standards within the Asia Pacific Region and to share experience with each other.

2. Description of the programme

The artifacts were initially measured by NIMT in July 15, 1999, and then circulated between participants laboratories in four loops. At the end of each loop, the artifacts were returned to NIMT for re-measurement before being sent out to the participating laboratories in the next loop. Time taken for all fifteen participating laboratories to complete the measurement was approximately 19 months. After all the measurement results were received from participating laboratories, a draft report was prepared and sent to participants for review in September 7, 2001.

The participating laboratories are as follows:

1. Australia	National Measurement Laboratory (CSIRO-NML, NML for short)
2. Egypt	National Institute for Standards (NIS)
3. Hong Kong	Standard and Calibration Laboratory (SCL)
4. India	National Physical Laboratory (NPLI)
5. Japan	National Metrology Institute of Japan (NMIJ*)
6. Malaysia	National Metrology Laboratory, SIRIM Berhad (NML-SIRIM, SIRIM for short)
7. New Zealand	Measurement Standards Laboratory of New Zealand (MSL)
8. Philippines	Industrial Technology Development Institute (ITDI)
9. Republic of Korea	Korea Research Institute of Standards and Science (KRISS)
10. Singapore	Standards, Productivity and Innovation Board (SPRING*)
11. South Africa	National Metrology Laboratory (CSIR-NML, CSIR for short)
12. Syria	National Standards and Calibration Laboratory (NSCL)
13. Taiwan R.O.C.	Center for Measurement Standards (CMS)
14. Thailand	National Institute of Metrology (Thailand), NIMT
15. Vietnam	Vietnam Metrology Institute (VMI)

* At the time of the comparison measurements, the mass standards activities of Japan and Singapore were in organisations with the acronyms NRLM and PSB respectively. Both acronyms changed during the comparison through organisational restructuring.

3. Description of artifacts

The given artifacts circulated among the participants for calibration were

Stainless steel mass 1 kg (:), and
Stainless steel mass 1 kg (::)

The artifacts were placed in the wooden box, then placed in an aluminium container. The purchase/manufacturing cost of both artifacts was approximately 6,600 USD; however, they had no commercial value (not for sale).

Specifications for the artifacts are as follows:

	Weight (:)	**Weight (::)**
Nominal value	1 kg	1 kg
Class	OIML(E1)	OIML(E1)
Material	Stainless Steel	Stainless Steel
Volume at 20°C ± standard uncertainty	(124.9021 ± 0.0011) cm^3	(124.9048 ± 0.0011) cm^3
Volume expansion coefficient	48 E-6 /K	48 E-6 /K

4. Calibration time schedule

The fifteen participating laboratories were divided into 4 loops as described below.

A problem of the programme is that the A.T.A. Carnet was not recognised by custom formalities of some APMP member countries. This caused a difficulty in custom clearance of the artifacts and effected the starting date of the laboratory's measurement. The artifacts could not be exactly circulated follow the schedule and the programme finishing date was delayed.

Loop A

15 Jul. 1999 - 15 Aug. 1999	NIMT (Thailand)
15 Aug. 1999 - 15 Sep. 1999	CMS (Taiwan)
15 Oct. 1999 - 15 Nov. 1999	NMIJ (Japan)
15 Nov. 1999 - 15 Dec. 1999	NIMT (Thailand)

Loop B

15 Dec. 1999 - 15 Jan. 2000	NPLI (India)
15 Jan. 2000 - 15 Feb. 2000	NSCL (Syria)
15 Feb. 2000 - 15 Mar. 2000	MSL (New Zealand)
15 Mar. 2000 - 15 Apr. 2000	NIMT (Thailand)

Loop C

15 Apr. 2000 -	15 May 2000	SIRIM (Malaysia)
15 May 2000 -	15 Jun. 2000	ITDI (Philippines)
15 Jun. 2000 -	15 Jul. 2000	KRISS (Republic of Korea)
15 Jul. 2000 -	15 Aug 2000	NIMT (Thailand)

Loop D

15 Aug. 2000 -	15 Sep. 2000	NML (Australia)
15 Sep. 2000 -	15 Oct. 2000	SCL (Hong Kong)
15 Oct. 2000 -	15 Nov. 2000	SPRING (Singapore)
15 Nov. 2000 -	15 Dec. 2000	VMI (Vietnam)
15 Dec. 2000 -	15 Jan. 2001	CSIR (South Africa)
15 Jan. 2001 -	15 Feb. 2001	NIS (Egypt)
15 Feb. 2001 -	15 Mar. 2001	NIMT (Thailand)

5. Description of measurement method

After the first calibration of the artifacts was started at NIMT in July 1999, both artifacts were circulated between participants in four loops (designated A, B, C and D) following the calibration time schedule in section 4. Participating laboratories were asked to measure the artifacts as follows.

5.1 The determination of mass and conventional mass value

For the determination of mass and conventional mass value, participating laboratories should carry out the substitution method ((ABBA) or (ABA) see OIML-R111) by using a weighing instrument with own weighing cycle design. The indication of weighing instrument should be used only for the difference between the indication of reference weight and the indication of test weight. The air buoyancy correction should be considered. An approximate formula of CIPM should be used for air density determination which required the data of temperature, humidity, and air pressure for calculation. The conventional mass can be calculated from mass value.

5.2. The uncertainty of measurement

For the uncertainty of measurement, it should be expressed in accordance with the International Organization for Standardization, “Guide to the Expression of Uncertainty in Measurement”,1993 (GUM) published by ISO or OIML International Recommendation R111.

If any laboratory did not follow to the published procedures, the description of the used procedure was required to attach to the measurement results presented to the programme coordinator (NIMT).

6. Results

A full calibration report with all relevant data and uncertainty estimates based on recommendation was requested to be sent to the programme coordinator (NIMT) while the artifacts were sent to the next participating laboratory. Fifteen APMP members participated in the comparison programme of 1 kg mass standard between August 1999 and March 2001. All fifteen laboratories were able to perform measurements and submit the measurement results to the programme coordinator.

The measurement results of the APMP comparison programme of 1 kg mass standards are summarised in Table 1. Each laboratory reported the measured mass value (true mass and conventional mass) that it assigned to each of the two travelling 1 kg artifacts, together with an expanded uncertainty for each value. The results are given in Table 1 as the deviation from 1 kg (with the deviation defined as measured mass value minus 1 kg). For all laboratories, the coverage factor *k* was within 0.1 of 2.0.

The values in Table 1 are also shown graphically in Figures 1 to 4.

The stability of the two travelling 1 kg artifacts was assessed in three ways. First, NIMT measured the mass values of each artifact before and after each measurement loop. No evidence of instability was found. Second, if either mass value is changing then this should be apparent from the mass difference between the artifacts measured by each laboratory during the comparison process. Figure 5 shows this mass difference *m*: - *m*::. Apparently *m*: - *m*:: may have decreased slightly (about 15 µg?) through the comparison. Third, the comparison analysis (which is presented in the next section) was repeated with the design matrix ***X*** expanded to include a drift parameter for each artifact. The calculated drift parameters were less than half their associated uncertainties, indicating that there was no significant drift in the mass values of the artifacts during the comparison.

Given this evidence of adequate long-term stability for the two travelling 1 kg artifacts, the measured mass differences in Figure 5 can be used to estimate the variability in the transfer process. The variations apparent in Figure 5 are larger than expected, given that most laboratories have 1 kg mass comparators with 1 µg resolution or better. Excluding the results of one laboratory with a 100 µg resolution comparator, the standard deviation of the values of *m*: - *m*:: in Figure 5 is 14 µg. This indicates a standard uncertainty of $14/\sqrt{2} = 10$ µg associated with each artifact due to variability in the transfer process.

7. Analysis and Linking to CCM.M-K1

The comparison results were analyzed and linked to the CCM 1 kg key comparison CCM.M-K1 using Generalised Least-Squares (sometimes known as Gauss-Markov) estimation. This analysis directly combines the APMP comparison results with the CCM.M-K1 results of the APMP link laboratories to estimate the degree of equivalence for each laboratory relative to the CCM.M-K1 KCRV (key comparison reference value) and the degree of equivalence between pairs of laboratories, as required by the MRA. No reference value is calculated - or required - for the APMP comparison.

A brief description of the analysis follows – a paper on the method has been submitted to *Metrologia*. The analysis is represented by

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{\beta} + \boldsymbol{e} \tag{1}$$

where $\boldsymbol{y}$ is a vector of the measurement results, $\boldsymbol{X}$ is a design matrix, $\boldsymbol{\beta}$ is a vector of unknowns and $\boldsymbol{e}$ is a vector of random errors or disturbances. Each measurement is represented in a row of a design matrix $\boldsymbol{X}$, while the measurement result is in the corresponding row of vector $\boldsymbol{y}$.

Three results are included for the deviations of the three link laboratories from the KCRV. From the *Final Report on CIPM key comparison of 1 kg standards in stainless steel (CCM.M-K1)*:

$$\text{KRISS} - \text{KCRV} = (-1 \pm 29)\ \mu\text{g} \tag{2a}$$
$$\text{NML} - \text{KCRV} = (5 \pm 29)\ \mu\text{g} \tag{2b}$$
$$\text{NMIJ} - \text{KCRV} = (-20 \pm 28)\ \mu\text{g} \tag{2c}$$

where the number following the symbol ± is the expanded uncertainty determined with a coverage factor $k = 2$. To explain, the first result is interpreted as the mass value assigned by KRISS to the average mass of the two travelling standard kilograms is -1 µg greater (1 µg less) than the KCRV. The KCRV for CCM.M-K1 is defined as the median value assigned by the participating laboratories to the average mass of the travelling standard kilograms. For APMP.M.M-K1, nineteen results are included for the measurements on artifact (:) and nineteen for the measurements on artifact (::). The measurement results are given in Columns 3 and 7 respectively of Table 1.

The equation describing each APMP comparison measurement for artifact (:) can be written

$$m{:}(\text{Lab}_i)_p - 1\ \text{kg} = \Delta_i - (1\ \text{kg} - m{:}) + e_{i,p} \tag{3}$$

where $m{:}(\text{Lab}_i)_p$ is the p^{th} value assigned to artifact (:) by laboratory i, $m{:}$ is the mass of artifact (:), Δ_i is the bias of laboratory i, and $e_{i,p}$ is a random error associated with the measurement. The same equation applies to artifact (::) with $m{::}$ in place of $m{:}$. Similarly, the equation for the CCM.M-K1 results of the link laboratories is

$$m_c(\text{Lab}_i) - K = \Delta_i - (K - m_c) + e_i \tag{4}$$

where m_c is the average mass of the CCM.M-K1 travelling standard kilograms, K is the key comparison reference value, and $m_c(\text{Lab}_i) - K$ is the measured deviation between the link laboratory i and the KCRV (see (2) above).

The known values are $m{:}(\text{Lab}_i)_p - 1$ kg, $m{::}(\text{Lab}_i)_p - 1$ kg, and $m_c(\text{Lab}_i) - K$. The unknowns are Δ_1 to Δ_{15}, 1 kg $- m{:}$, 1 kg $- m{::}$, and $K - m_c$. Solving the 41 equations defined by (3), the equivalent of (3) for artefact (::), and (4) requires a constraint. For this we choose $K - m_c = 0$ so that the values obtained for Δ_1 to Δ_{15} from the solution are the expected deviations of each laboratory's result from the KCRV. The constraint is in the 42$^{\text{nd}}$ row of $\boldsymbol{X}$. Design matrix $\boldsymbol{X}$ has 18 columns.

Results vector $\hat{\boldsymbol{\beta}}$ (the estimated value of $\boldsymbol{\beta}$) is given by

$$\hat{\boldsymbol{\beta}} = \boldsymbol{C}\,\boldsymbol{X}^{\mathrm{T}}\,\boldsymbol{\Phi}^{-1}\,\boldsymbol{y} \tag{5}$$

with uncertainty (variance-covariance) matrix **C**

$$\boldsymbol{C} = (\boldsymbol{X}^{\mathrm{T}}\,\boldsymbol{\Phi}^{-1}\,\boldsymbol{X})^{-1}. \tag{6}$$

Hence, $\hat{\beta}_1$ (the first element of $\hat{\boldsymbol{\beta}}$), is an estimate of the unknown Δ_1.

Matrix $\boldsymbol{\Phi}$ is an input uncertainty (variance-covariance) matrix. The diagonal terms of $\boldsymbol{\Phi}$ are the variances (standard uncertainty squared) associated with each measurement plus the $(10\ \mu\text{g})^2$ variance associated with the transfer process. In each case, the standard uncertainty was calculated from the reported expanded uncertainty using $k = 2$. Off-diagonal terms in $\boldsymbol{\Phi}$ allow known correlations to be included (see below). Matrix $\boldsymbol{C}$ is the calculated variance-covariance matrix from which the uncertainties in the results of the analysis are obtained.

With the constraint $K - m_c = 0$, the first 15 elements of $\hat{\boldsymbol{\beta}}$ ($\hat{\beta}_1$ to $\hat{\beta}_{15}$) and the corresponding diagonal terms of $\boldsymbol{C}$ directly give the expected deviation of each laboratory's result from the KCRV and the variance associated with this deviation. For pairs of laboratories i and j, $\hat{\beta}_i - \hat{\beta}_j$ is the difference of their deviations from the KCRV and $C_{ii} + C_{jj} - 2C_{ij}$ is the variance associated with this difference.

Table 2 summarises the correlated uncertainties. The dominant correlation in this comparison is between each laboratory's measurements of artifacts (:) and (::). This intra-laboratory correlation is primarily due to the uncertainty in the common reference standard used for the measurements of the two travelling artifacts. Other less significant correlations arise for the link laboratories (a common reference standard is used by each link laboratory for the CCM and APMP comparisons) and for laboratories with a common source of traceability (for example; MSL and CMS-ITRI are both traceable to stainless steel working standards at BIPM, and SIRIM is traceable to NMIJ). In addition, all the measurement results are correlated with each other to a small extent through their common traceability to the BIPM working standard Pt-Ir kilograms (standard uncertainty $u = 2.3$ µg) and through the uncertainty in the air density formula. Picard and Fang (*Metrologia* **39**, 31-40, 2002) give the combined standard uncertainty in the CIPM air density formula as 76 mg.m^{-3} which corresponds to $u = 6$ µg in the air buoyancy correction when comparing Pt-Ir and stainless steel kilograms. Off-diagonal terms are included in $\mathbf{\Phi}$ to account for all these correlations.

The results of this analysis are summarised in Figure 6, which shows the mass value assigned by each laboratory, together with the expanded uncertainty in this mass value (calculated using $k = 2$). Zero mass value corresponds to the KCRV of comparison CCM.M-K1. Figure 6 shows that the majority of the results of the participating laboratories are consistent with each other and with the KCRV. For eleven laboratories, the expanded uncertainty bars cross the KCRV.

More detailed results of the analysis are given in Tables 3 to 6. Table 3 gives the deviation from the KCRV for each laboratory, together with the associated uncertainty. Note that the differences and uncertainties in Table 3 for the link laboratories differ by no more than 1 µg from the CCM.M-K1 values (see Equation 2). Table 4 gives the differences in assigned mass values between pairs of laboratories, Table 5 gives the expanded uncertainties in these differences, and Table 6 gives the ratio of these values. The differences given in Table 4 are close to the average differences that can be calculated from the measurement results in Table 1, except for differences from NMIJ whose results are heavily weighted by their CCM comparison results.

8. Conclusion

8.1 The majority of the results of the participating laboratories are consistent with each other and with the KCRV of CCM.M-K1.

8.2 The results for two laboratories differ significantly from the KCRV and from the results of the other laboratories.

8.3 Two participating laboratories in Loop C interchanged their time slots with each other.

8.4 One measuring result appeared to be anomalous; however, the participating laboratory re-measured and re-sent the corrected result to the programme coordinator.

8.5 The programme coordinator, who was responsible for the preparation of the comparison report, sent out the summary results in a draft A report to all participants on September 7, 2001 with a code number in place of the laboratory name. Each laboratory would see all results but would not know the owners of results other than its own.

8.6 Eight participating laboratories replied to programme coordinator (NIMT). Six participating laboratories agreed to the results, one participating laboratory made a correction to its conventional mass value, and one made a little change in its calculations.

8.7 At the draft B stage, the uncertainty for one laboratory was found by another laboratory to be significantly in error and was corrected.

Participating Laboratory	Date of measurement	Mass (:) Dev. from nominal mass (mg)	Uncer.(:) k = 2 (mg)	Conv. mass (:) Dev. from nominal mass (mg)	Uncer.(:) k = 2 (mg)	Mass (::) Dev. from nominal mass (mg)	Uncer.(::) k = 2 (mg)	Conv. mass (::) Dev. from nominal mass (mg)	Uncer.(::) k = 2 (mg)
NIMT-1	20-21 Jul. 1999	0.081	0.032	0.198	0.032	-0.127	0.032	-0.013	0.032
CMS	19-27 Aug. 1999	0.099	0.026	0.216	0.026	-0.113	0.026	-0.005	0.026
NMIJ	Sep. 1999	0.115	0.076	0.233	0.076	-0.089	0.076	0.025	0.076
NIMT-2	30 Nov.-1Dec.1999	0.090	0.032	0.207	0.032	-0.125	0.032	-0.011	0.032
NPLI	28-31 Dec.1999	0.101	0.028	0.219	0.028	-0.097	0.028	0.021	0.028
NSCL	Feb. 2000	0.17	0.21	0.28	0.21	-0.03	0.19	0.09	0.19
MSL	Feb.-Mar. 2000	0.114	0.041	0.232	0.041	-0.068	0.041	0.050	0.041
NIMT-3	30-31 Mar. 2000	0.123	0.032	0.241	0.032	-0.088	0.032	0.026	0.032
SIRIM	24 Apr. 2000	0.120	0.110	0.240	0.110	-0.070	0.110	0.050	0.110
ITDI	May-Jun. 2000	0.281	0.073	0.398	0.073	0.118	0.069	0.236	0.069
KRISS	23 Jun.-11 Jul.2000	0.095	0.029	0.213	0.029	-0.099	0.029	0.015	0.029
NIMT-4	8-9 Aug. 2000	0.080	0.032	0.197	0.032	-0.086	0.032	0.028	0.032
NML	Sep. 2000	0.094	0.030	0.211	0.030	-0.094	0.030	0.024	0.030
SCL	Oct. 2000	0.087	0.044	0.204	0.044	-0.093	0.044	0.025	0.044
SPRING	Nov. 2000	0.18	0.13	0.3	0.13	0.03	0.12	0.15	0.12
VMI	8-30 Dec.2000	-0.022	0.042	0.095	0.042	-0.214	0.042	-0.096	0.042
CSIR	8 Jan. 2001	0.100	0.040	0.217	0.040	-0.095	0.040	0.023	0.040
NIS	22-26 Nov. 2001	0.039	0.041	0.157	0.041	-0.154	0.041	-0.037	0.041
NIMT-5	18-19 Jun. 2001	0.092	0.032	0.209	0.032	-0.097	0.032	0.017	0.032

Table 1.: Measurement results for APMP.M.M-K1 (APMP-IC-3-96).

	Intra-laboratory	Intra-laboratory: CCM-APMP	Inter-laboratory: Traceability to BIPM	Inter-laboratory: Traceable to another APMP laboratory
NIMT	15			14 (NML)
CMS	12		12	
NMIJ	37	13		
NPLI	13			
NSCL	75			
MSL	19		12	
SIRIM	50			37 (NMIJ)
ITDI	26			14 (NML)
KRISS	14	14		
NML	14	14		
SCL	17			
SPRING	24			19 (MSL)
VMI	20			
CSIR	19			
NIS	20			

Table 2: Correlated standard uncertainties in micrograms. Not shown are the correlated uncertainties due to the air buoyancy formula and due to the BIPM working standard Pt-Ir kilograms (see text).

	Difference from KCRV /μg	**Expanded Uncertainty *U* /μg**
NIMT	-4	33
CMS	-5	32
NMIJ	-20	28
NPLI	4	33
NSCL	71	177
MSL	25	44
SIRIM	27	107
ITDI	203	65
KRISS	-1	29
NML	4	29
SCL	-1	44
SPRING	109	96
VMI	-116	45
CSIR	4	44
NIS	-56	45

Table 3: Deviation from the KCRV (key comparison reference value of CCM.M-K1) and associated expanded uncertainty *U* for each participating laboratory. Uncertainty *U* includes the 2.2 μg uncertainty in the KCRV.

	NIMT	CMS	NMIJ	NPLI	NCSL	MSL	SIRIM	ITDI	KRISS	NML	SCL	SPRING	VMI	CSIR	NIS
NIMT		1	16	-8	-75	-29	-31	-207	-3	-9	-3	-113	112	-8	52
CMS	-1		14	-9	-77	-30	-32	-208	-4	-10	-4	-114	111	-10	51
NMIJ	-16	-14		-23	-91	-44	-46	-223	-19	-24	-18	-129	97	-24	36
NPLI	8	9	23		-68	-21	-23	-199	5	-1	5	-105	120	-1	60
NSCL	75	77	91	68		47	45	-132	72	67	73	-38	188	67	127
MSL	29	30	44	21	-47		-2	-178	26	20	26	-84	141	21	81
SIRIM	31	32	46	23	-45	2		-176	28	22	28	-82	143	23	83
ITDI	207	208	223	199	132	178	176		204	198	204	94	319	199	259
KRISS	3	4	19	-5	-72	-26	-28	-204		-6	0	-110	115	-6	55
NML	9	10	24	1	-67	-20	-22	-198	6		6	-104	121	0	60
SCL	3	4	18	-5	-73	-26	-28	-204	0	-6		-110	115	-6	55
SPRING	113	114	129	105	38	84	82	-94	110	104	110		225	105	165
VMI	-112	-111	-97	-120	-188	-141	-143	-319	-115	-121	-115	-225		-121	-61
CSIR	8	10	24	1	-67	-21	-23	-199	6	0	6	-105	121		60
NIS	-52	-51	-36	-60	-127	-81	-83	-259	-55	-60	-55	-165	61	-60	

Table 4: Difference in assigned mass value (A-B, in micrograms) between laboratory A (left column) and laboratory B (top row). For example, the mass determined by NPLI is 8 µg higher than the mass determined by NIMT.

	NIMT	**CMS**	**NMIJ**	**NPLI**	**NSCL**	**MSL**	**SIRIM**	**ITDI**	**KRISS**	**NML**	**SCL**	**SPRING**	**VMI**	**CSIR**	**NIS**
NIMT		38	39	40	178	49	109	59	39	17	49	99	50	49	50
CMS	38		37	38	178	38	109	68	38	38	48	98	49	47	49
NMIJ	39	37		39	178	48	35	68	35	35	48	98	50	48	49
NPLI	40	38	39		178	49	109	68	39	39	49	99	50	48	50
NSCL	178	178	178	178		180	205	187	178	178	180	200	181	180	181
MSL	49	38	48	49	180		113	74	49	49	57	90	58	56	57
SIRIM	109	109	35	109	205	113		123	109	109	113	142	113	113	113
ITDI	59	68	68	68	187	74	123		68	58	74	113	75	74	75
KRISS	39	38	35	39	178	49	109	68		36	48	99	50	48	49
NML	17	38	35	39	178	49	109	58	36		48	99	50	48	49
SCL	49	48	48	49	180	57	113	74	48	48		103	58	56	57
SPRING	99	98	98	99	200	90	142	113	99	99	103		103	103	103
VMI	50	49	50	50	181	58	113	75	50	50	58	103		57	58
CSIR	49	47	48	48	180	56	113	74	48	48	56	103	57		57
NIS	50	49	49	50	181	57	113	75	49	49	57	103	58	57	

Table 5: Expanded uncertainties (in micrograms with $k = 2$) for the corresponding values in Table 4.

	NIMT	CMS	NMIJ	NPLI	NSCL	MSL	SIRIM	ITDI	KRISS	NML	SCL	SPRING	VMI	CSIR	NIS
NIMT		0.03	0.41	-0.19	-0.42	-0.59	-0.28	-3.52	-0.07	-0.50	-0.06	-1.14	2.24	-0.17	1.04
CMS	-0.03		0.39	-0.24	-0.43	-0.79	-0.30	-3.08	-0.11	-0.26	-0.08	-1.16	2.27	-0.20	1.04
NMIJ	-0.41	-0.39		-0.61	-0.51	-0.92	-1.35	-3.27	-0.53	-0.69	-0.38	-1.31	1.95	-0.50	0.74
NPLI	0.19	0.24	0.61		-0.38	-0.43	-0.21	-2.91	0.13	-0.02	0.10	-1.06	2.40	-0.01	1.20
NSCL	0.42	0.43	0.51	0.38		0.26	0.22	-0.71	0.41	0.37	0.40	-0.19	1.04	0.37	0.70
MSL	0.59	0.79	0.92	0.43	-0.26		-0.02	-2.40	0.54	0.41	0.46	-0.94	2.44	0.36	1.40
SIRIM	0.28	0.30	1.35	0.21	-0.22	0.02		-1.44	0.26	0.20	0.25	-0.58	1.26	0.20	0.73
ITDI	3.52	3.08	3.27	2.91	0.71	2.40	1.44		2.99	3.39	2.75	0.83	4.25	2.69	3.46
KRISS	0.07	0.11	0.53	-0.13	-0.41	-0.54	-0.26	-2.99		-0.16	0.00	-1.12	2.31	-0.11	1.11
NML	0.50	0.26	0.69	0.02	-0.37	-0.41	-0.20	-3.39	0.16		0.12	-1.06	2.43	0.01	1.22
SCL	0.06	0.08	0.38	-0.10	-0.40	-0.46	-0.25	-2.75	0.00	-0.12		-1.07	2.00	-0.10	0.95
SPRING	1.14	1.16	1.31	1.06	0.19	0.94	0.58	-0.83	1.12	1.06	1.07		2.18	1.02	1.59
VMI	-2.24	-2.27	-1.95	-2.40	-1.04	-2.44	-1.26	-4.25	-2.31	-2.43	-2.00	-2.18		-2.10	-1.04
CSIR	0.17	0.20	0.50	0.01	-0.37	-0.36	-0.20	-2.69	0.11	-0.01	0.10	-1.02	2.10		1.05
NIS	-1.04	-1.04	-0.74	-1.20	-0.70	-1.40	-0.73	-3.46	-1.11	-1.22	-0.95	-1.59	1.04	-1.05	

Table 6: Ratio of the laboratory-to-laboratory difference from Table 4 to the expanded uncertainty in this difference from Table 5 for each pair-wise combination of laboratories. Values with a magnitude that exceeds 1.0 or 2.0 are shown with different shading respectively.

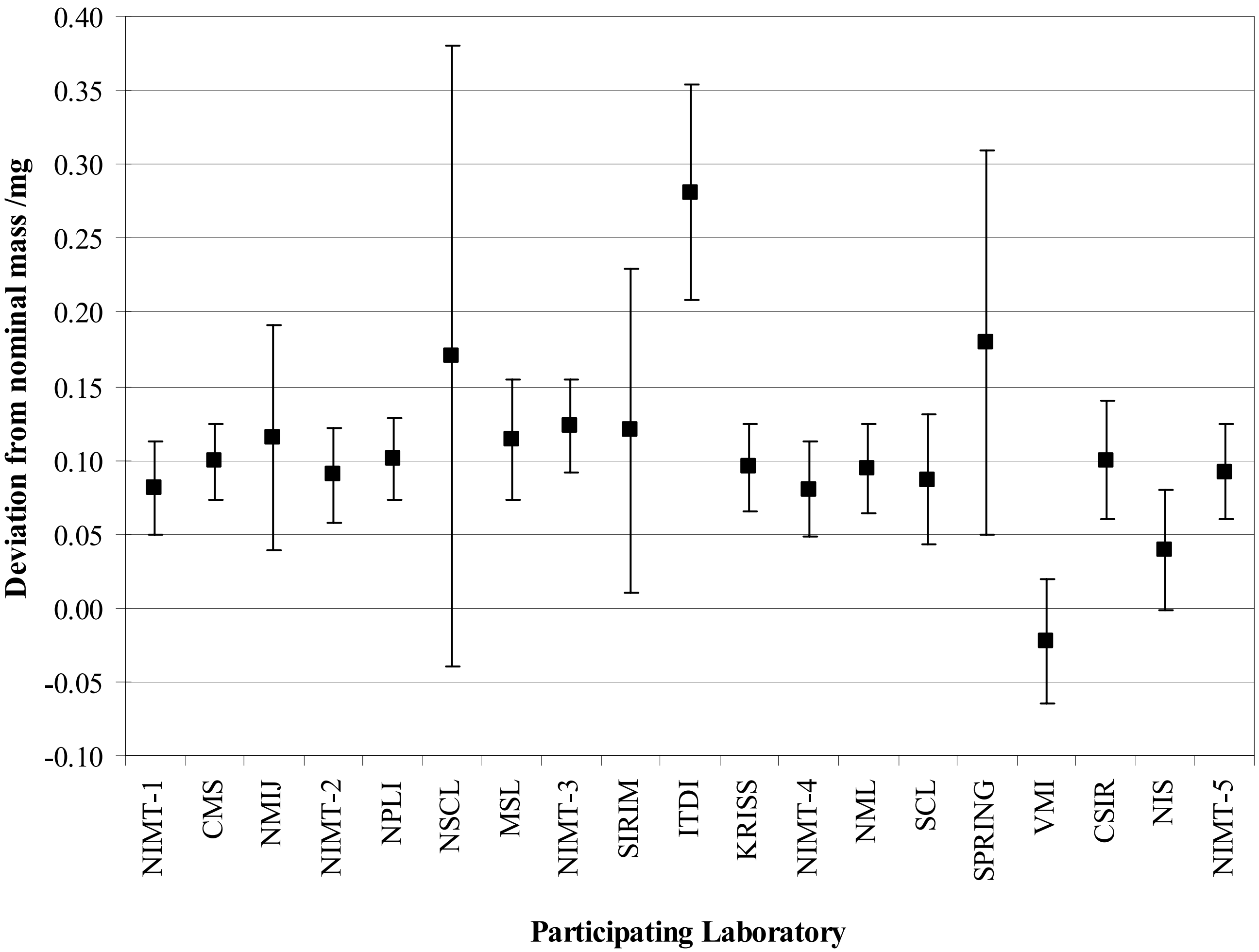

Figure 1: Measured mass values (true masses) minus nominal mass (1 kg) with expanded uncertainties for artifact (:).

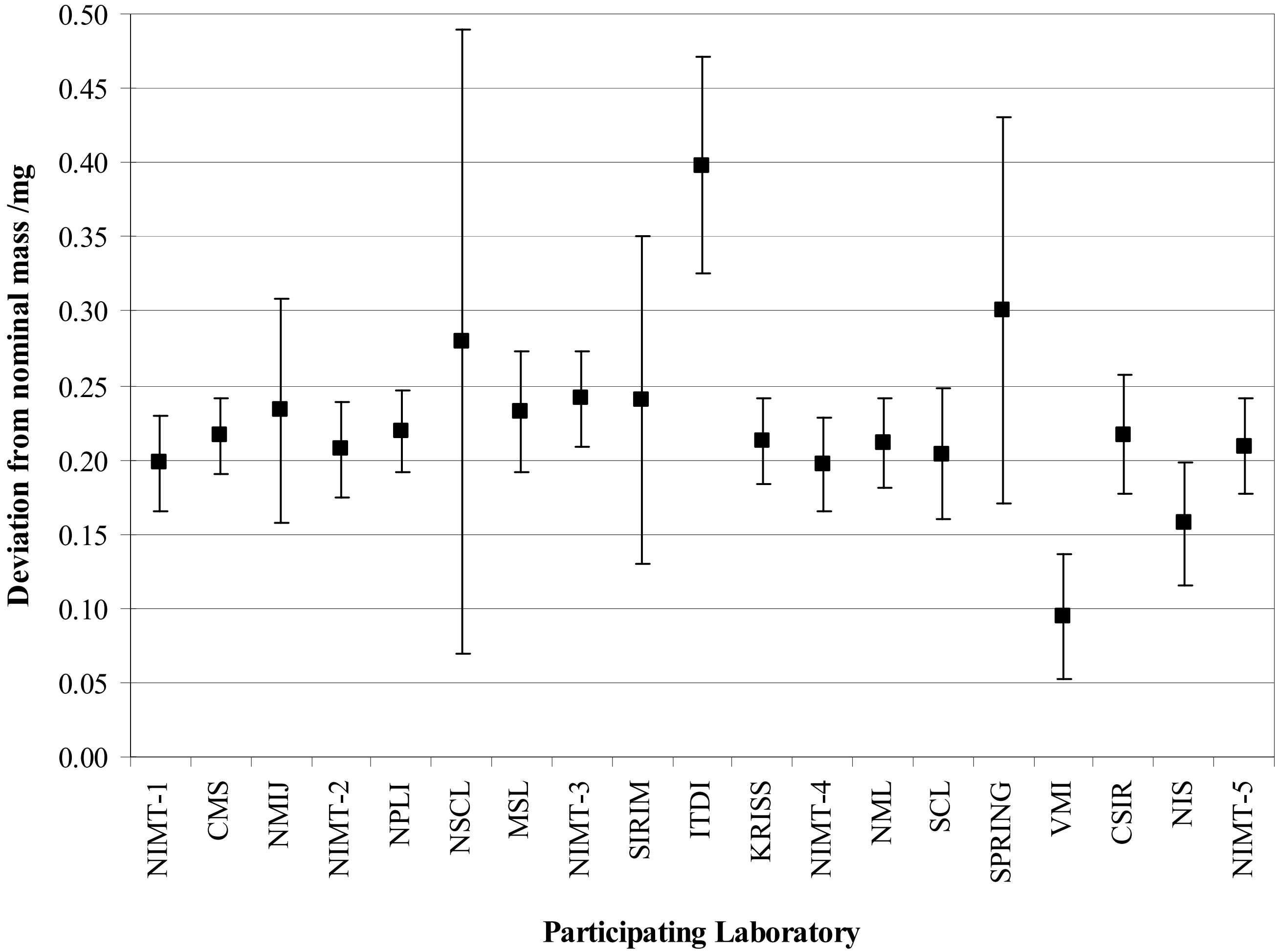

Figure 2: Measured conventional mass values minus nominal mass (1 kg) with expanded uncertainties for artifact (:).

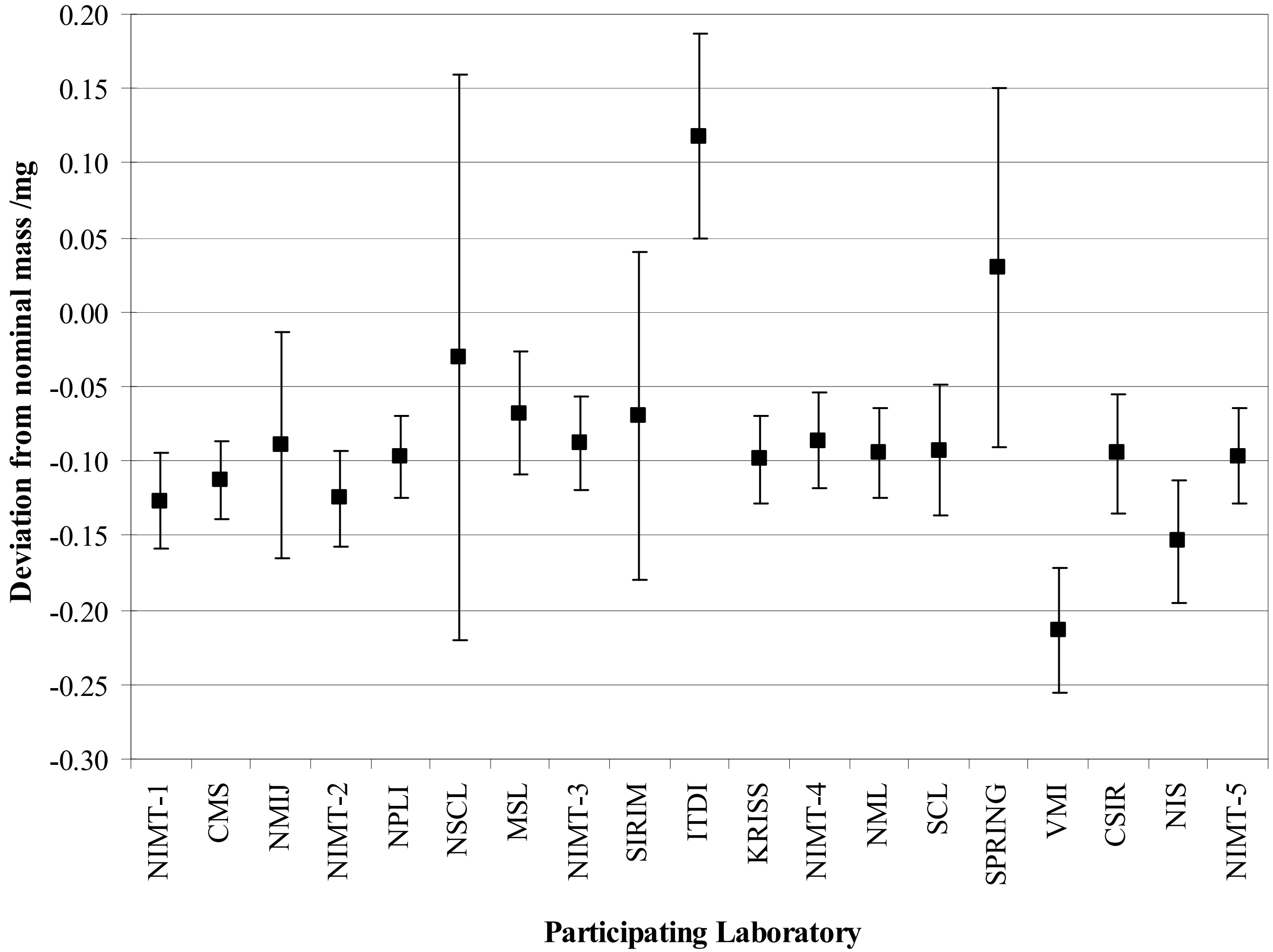

Figure 3: Measured mass values (true masses) minus nominal mass (1 kg) with expanded uncertainties for artifact (::).

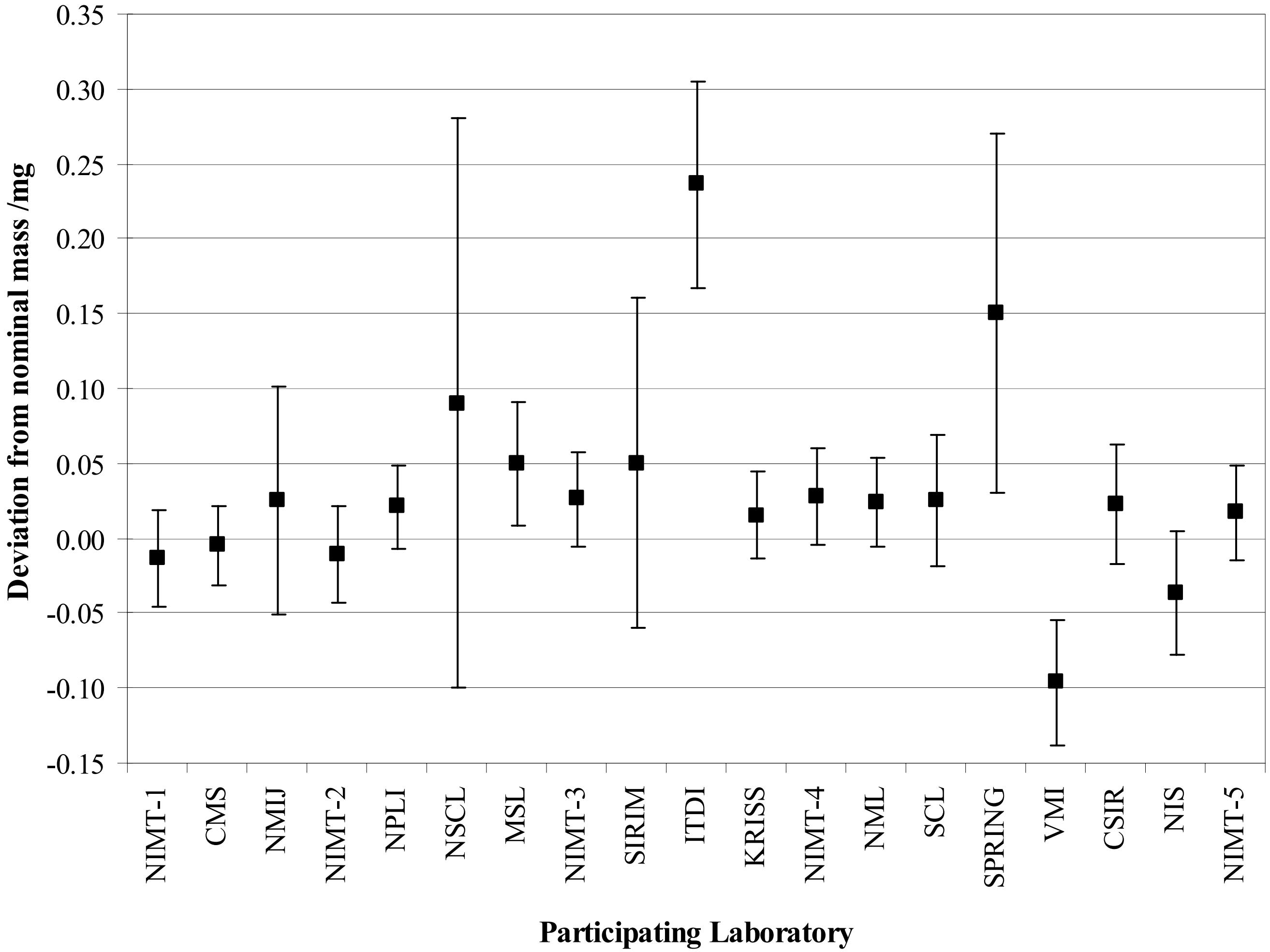

Figure 4: Measured conventional mass values minus nominal mass (1 kg) with expanded uncertainties for artifact (::).

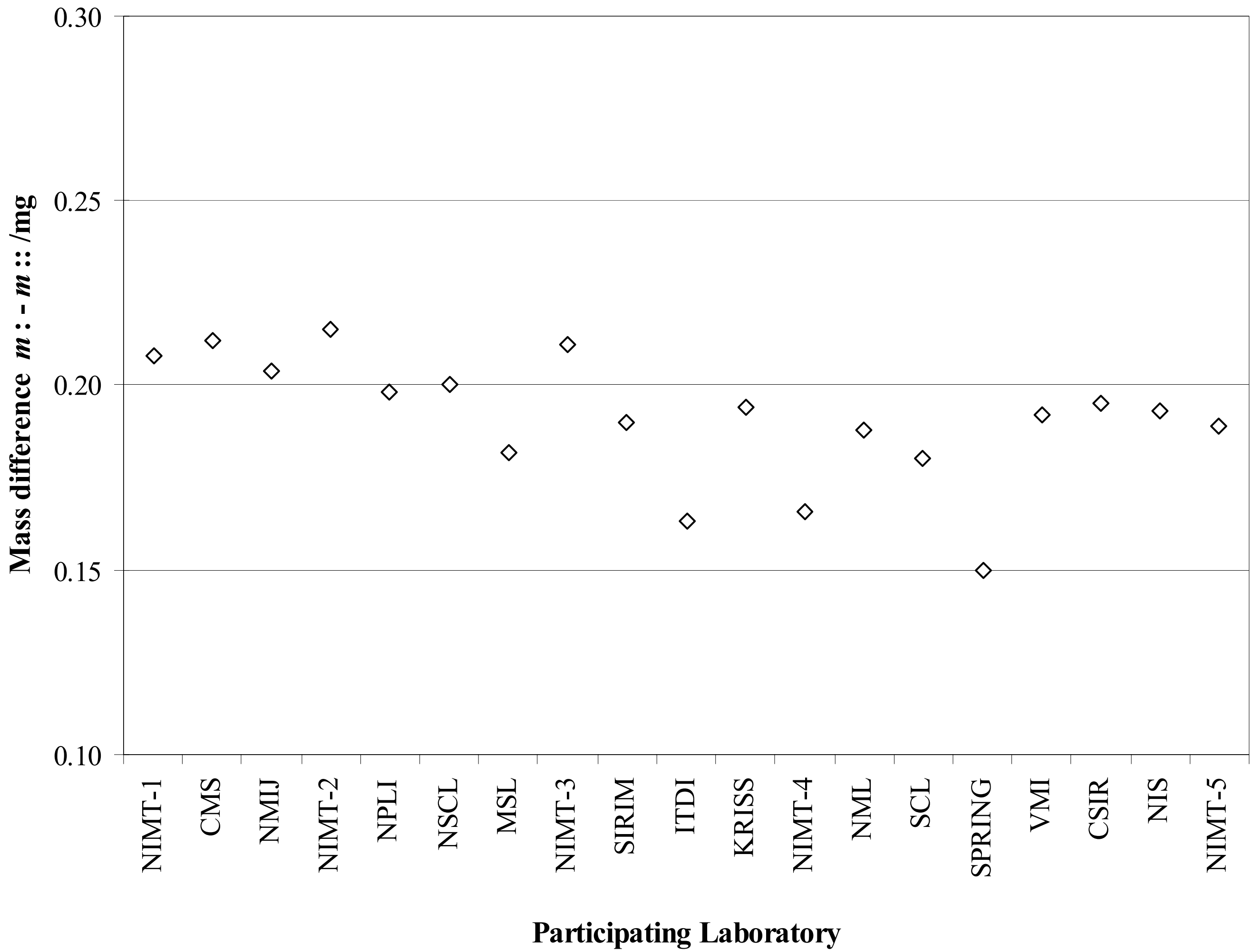

Figure 5: The mass difference between artifact (:) and artifact (::) measured by each laboratory. As control laboratory, NIMT measured this difference five times.

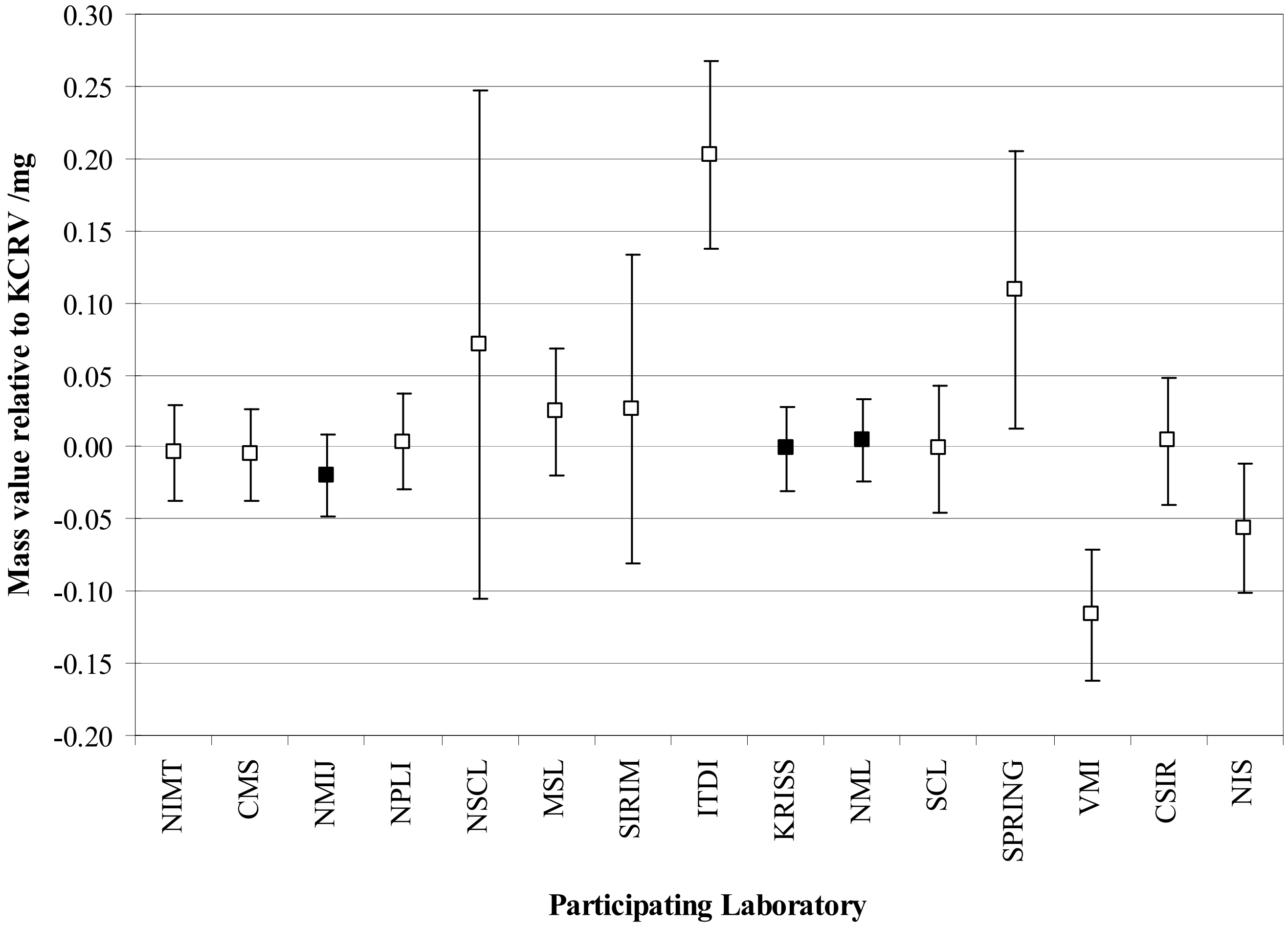

Figure 6: Mass values assigned by the participating laboratories with bars representing expanded uncertainties. Zero mass value corresponds to the key comparison reference value of CCM.M-K1. Link laboratories to CCM.M-K1 are shown by the solid markers.