Final Report

Of

APMP Comparison of Mass Standards

APMP.M.M-K2 (Sub) multiples mass key comparison

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Final Report of APMP Comparison of Mass Standards
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ABSTRACT

This report summarizes the results of a comparison of Mass Standards conducted between eleven participating members, including the pilot laboratory, of the Asia-Pacific Metrology Program (APMP). One Set of five weights with nominal mass values: 10 kg, 500 g, 20 g, 2 g, and 100 mg were used as traveling artifacts. These nominal values were chosen as they followed the nominal values of CCM.M-K2. The program was piloted by the National Physical Laboratory New Delhi, India (NPLI) and Center for Measurement Standards, Industrial Technology Research Institute (CMS-ITRI),Taiwan, Korea Research Institute of Standards and Science (KRISS), Korea and Measurement Standard Laboratory, (MSL) New Zealand have provided all other help to successfully organize and run the comparison. The set of five weights was circulated among all the participating laboratories in July 2004 and received back from the last participant in March 2007. The final report of this comparison is being given in this document.

1. Introduction

As per decision of the APMP-TCM meeting held in November 2001, Dr. C. Sutton, then TCM Chairman, formed a management group of four national metrology institutes headed by NPL India to initiate the APMP (sub) multiples mass key comparison, APMP.M.M-K2 in the Asia Pacific Region. This regional comparison complements the CCM key comparison CCM.M-K2 (1996) in a similar range and extends the demonstration of metrological equivalence to economies in the APMP region. This comparison is similar to that of CCM.M-K2 and uses a set of five weights, of denominations 10 kg, 500 g, 20 g, 2 g, and 100 mg. These nominal values have been chosen, because they cover the range of weights mostly used in practice and because a box containing these mass standards can easily be transported by hand-carrying .The comparison is at the class E1 level. The laboratories in the region that have taken part in CCM.M-K2 will act as links to that CCM comparison enabling degrees of equivalence to be calculated.

2. Objectives

The main objectives of this inter-comparison are to:-

- To facilitate the demonstration of metrological equivalence between the participating laboratories, in Asia-Pacific Region, and to check the validity of quoted calibration measurement capabilities (CMCs).

- To extend the demonstration of metrological equivalence to the majority of the Asia-Pacific countries, including those who do not usually take part in high level comparisons. It is also intended to complement the metrological equivalence of the Comite Consultatif pour la Masse et les Grandeurs Apparentees (CCM) with two of the participating APMP members (Australia and Korea) having previously taken part in a corresponding key comparison (CCM.M.K2).

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[1] National Physical Laboratory, India (NPLI)
[2] Measurement Standard Laboratories (MSL), New Zealand
[3] Center for Measurement Standards -Industrial Technology Research Institute (CMS-ITRI), Taiwan
[4] Korea Research Institute of Standards and Science (KRISS), Korea
[5] National Measurement Institute (NMIA), Australia
[6] Standard Calibration Laboratory (SCL), Hong Kong.
[7] National Metrology Center (NMC, A-STAR), Singapore
[8] National Institute of Metrology (Thailand), NIMT
[9] National Metrology Laboratory (NML- SIRIM), Malaysia
[10] National Institute of Science (KIM-LIPI). Indonesia
[11] National Metrology Institute of South Africa (NMISA)

- To ensure the harmonization of primary mass measurements throughout the Asia-Pacific Region and rest of the world in the proposed comprehensive mass range (100 mg to 10 kg).

- To enable the degrees of equivalence of the participating laboratories to be determined using the links to the CCM comparison and the Key Comparison Reference Value (KCRV) found in that comparison.

- To enable a high level technology transfer from the larger to the smaller National Metrology Institutes (NMIs).

3. Organization

According to the plan four NMIs have agreed to help, organize and run the comparison to cut down the burden on any one NMI and to speed up the comparison process. These four NMIs are as following:-

- National Physical Laboratory, India (NPLI)   **:** Contact person -   Mr. Tripurari Lal

- Center for Measurement Standards-   **:** Contact person -   Mr. Feng-Yu-Yang
  Industrial Technology Research Institute
  (CMS-ITRI) Taiwan

- Korea Research Institute of Standards and   **:** Contact Person -   Dr. Jin Wan Chung
  Science (KRISS), Korea

- Measurement Standard Laboratory, (MSL)   **:** Contact person   -   Dr. Chris Sutton
  New Zealand

These four NMIs form a Technical Management Group for the comparison. The Group is headed by Mr. Tripurari Lal. NPL India and agreed to take overall responsibility for the comparison and CMS-ITRI, KRISS and MSL have offered to provide all possible help to organize and run the programme,

NMIs of the following countries have expressed their interest in participating in APMP.M.M-K2 key comparison: -

Australia, Hong Kong, Indonesia, Korea, Malaysia, New Zealand, Philippines, Singapore, South Africa, Thailand and Taiwan.

Later on Philippines had withdrawn its participation, in this Intercomparison.

The pilot laboratory was the NPLI, New Delhi with its address as follows:

> Mr. Tripurari Lal (Contact Person)
> National Physical Laboratory,
> Dr, K.S. Krishnan Road, New Delhi-110012, India
> Tel: 91-11- 45608348
> Fax: 91- 11- 45609310
> E-mail: tlal@nplindia.ernet.in

The set of five weights of denominations 10 kg, 500 g, 20 g, 2 g, and 100 mg was circulated among all the participating laboratories from July 2004 and from the last participant the set has arrived at the pilot laboratory in March 2007.

4. Participants

The participating laboratories are as given in the following table:

Sr. No.	Name of the laboratory	Country
1	National Metrology Institute of Australia (NMIA)	Australia
2	Standards and Calibration Laboratory-The Government of the Hong Kong, Special Administrative Region (SCL)	Hong Kong
3	National Metrology Centre, Agency for Science, Technology and Research (NMC. A-STAR)	Singapore
4	National Metrology Laboratory SIRIM (NML-SIRIM)	Malaysia
5	Center for Measurement Standards- Industrial Technology Research Institute (CMS-ITRI)	Taiwan
6	Indonesian Institute of Sciences (KIM-LIPI)	Indonesia
7	Korea Research Institute of Standards and Science (KRISS)	Korea
8	Measurement Standards Laboratory, Industrial Research Limited (MSL- IRL)	New Zealand
9	National Metrology Institute of South Africa (NMISA)	South Africa
10	National Institute of Metrology , Thailand (NIMT)	Thailand
11	National Physical Laboratory, India (NPLI) (Pilot Laboratory)	India

5. Description of artifacts

Masses

Two sets of five mass standards each of the OIML design and of quality class E1, have been acquired with the following nominal mass values: -

Nominal value
10 kg
500 g
20 g
2 g
100 mg

These traveling standards are made of non-magnetic stainless steel and have the form and quality recommended by OIML for weights of accuracy class E1. One of the two sets, identified as **AA** has been purchased by KRISS Korea and the other set identified as **AB** by CMS-ITRI Taiwan**.** The mass standards of these sets had been calibrated by NPLI, and observed for their stability during about six months. No significant instability has been found. The set AA was circulated among the participating laboratories as per time schedule given below.

6. Transportation and Time Schedule

For transportation, the standards were kept inside a wooden box and fixed in appropriate holes just by being wrapped in low-fluffy paper.

The second set **AB** had been used as the monitoring standards to check the stability of the mass values of the traveling standards during the circulating period while it returned to NPLI as per the scheduled plan.

Schedule Plan of APMP.M.M-K2

NMI	Country	Month of arrival	
NPLI	India	---------------------	
CMS/ITRI	Taiwan	August	2004
NMIA	Australia	November	2004
NMISA	South Africa	December	2004
NPLI	India	May	2005
KRISS	Korea	July	2005
SCL	Hong Kong	September	2005
NMC, A-STAR	Singapore	December	2005
NML-SIRIM	Malaysia	January	2006
NPLI	India	April	2006
MSL	New Zealand	June	2006
KIM-LIPI	Indonesia	September	2006
NIMT	Thailand	January	2007
NPLI	India	March	2007

After the first calibration, at the starting the circulation of the traveling mass standards, these were recalibrated second and third times in between and fourth time at the end of the comparison, at NPLI, the pilot laboratory, to check the stability of their mass values, using the monitoring standards **AB.**

A problem of the program was that A.T.A. Carnet was not used for the transportation of the artifacts because of the reason that custom authorities of some APMP member countries do not recognize A.T.A. Carnet. This caused a difficulty in custom clearance of the artifacts and delayed the starting date of the laboratory's measurement. Also due to various local problems of some of the participating laboratories, the artifacts could not be circulated exactly following the planed time schedule and the program finishing date was delayed.

7. **Results and Analysis**

7.1 **Values of mass and combined uncertainty**

Table 1 shows the results of the reported mass values and their combined standard uncertainties as given by the participants and the pilot laboratories. The number of digits has been restricted to a maximum of three significant ones in the uncertainty and to a minimum giving a tenth of a microgram.

7.2 **Stability of the traveling standards**

NPLI measured the monitoring standards AB, using subdivision/multiplication method, against its 1 *kg* transfer standards.

The 1 *kg* transfer standards have been linked to the national prototype kilogram no. k-57 of India. The monitoring standards were stored in controlled environment conditions in the Mass Laboratory of NPLI during the whole time of the inter-comparison. The monitoring standards then used to calibrate the traveling standards before and after each loop during the period of the inter-comparison.

Table 1

Results for traveling standards measured and reported from the participants and the pilot laboratories. The value m_A (= $m_{Areported}$ - m_0) represent residual value from the nominal mass value and u_c is combined standard uncertainty (k=1) claimed by each laboratory.

Participating Laboratories	10 kg		500 g		20 g		2 g		100 mg	
	m_A / mg	u_c / mg	m_A / mg	u_c / mg	m_A / mg	u_c / mg	m_A / mg	u_c / mg	m_A / mg	u_c / mg
NPLI	-1.900	1.160	- 0.043	0.022	+ 0.008	0.0032	+ 0.0021	0.0008	- 0.0009	0.0008
CMS-ITRI	-2.650	1.140	- 0.038	0.012	+ 0.018	0.0030	+ 0.0014	0.0004	- 0.0010	0.0002
NMIA	-1.820	0.479	- 0.019	0.015	+ 0.009	0.0023	+ 0.0012	0.0006	- 0.0013	0.0003
NMISA	-0.208	0.912	- 0.012	0.042	+ 0.015	0.0054	+ 0.0034	0.0040	- 0.0011	0.0025
NPLI	-2.200	1.160	- 0.023	0.022	+ 0.010	0.0034	+ 0.0042	0.0008	- 0.0004	0.0008
KIM-LIPI	-0.800	0.530	- 0.020	0.013	+ 0.009	0.0021	+ 0.0022	0.0006	- 0.0010	0.0005
KRISS	-2.400	0.190	- 0.030	0.008	+ 0.010	0.0015	+ 0.0018	0.0004	- 0.0010	0.0002
SCL	-3.000	1.000	- 0.009	0.025	+ 0.009	0.0040	+ 0.0010	0.0020	- 0.0015	0.0006
NIMT	-2.200	0.250	- 0.057	0.018	+ 0.005	0.0012	+ 0.0007	0.0003	- 0.0012	0.0002
NPLI	-1.700	1.160	- 0.030	0.022	+ 0.010	0.0025	+ 0.0050	0.0008	- 0.0002	0.0008
NMC, A-STAR	-2.200	0.500	- 0.029	0.020	+ 0.008	0.0040	+ 0.0028	0.0008	- 0.0013	0.0008
MSL	-2.400	0.171	- 0.035	0.008	+ 0.005	0.0006	+ 0.0006	0.0001	- 0.0013	0.0001
NML-SIRIM	-2.200	0.900	- 0.022	0.025	+ 0.009	0.0026	+ 0.0023	0,0011	- 0.0020	0.0003
NPLI	-0.800	1.160	- 0.044	0.022	+ 0.013	0.0024	+ 0.0042	0.000 8	- 0.0002	0.0008

.Table 2 shows the differences between the two NPLI measurements of the traveling standards AA, before and after each loop of the circulation cycle (also refer Table 1). The changes in mass values of the traveling standards in most cases are well below the measurement uncertainties. Only the 2 g standards have changed in mass more than the magnitude of the uncertainties, but not more than the spread of the mass values.

In addition, graphs of the results for all the participants' results (Figures 1 to 5) do not show any clear trend in the mass value of any of the traveling standards. On this basis, the mass of each traveling standard is taken as stable throughout the comparison process. Any variability in the mass of each traveling standard is allowed for by including the standard deviation of the mass values measured by the pilot laboratory as a component uncertainty in the analysis. These standard deviations are also shown in Table 2.

Table 2

Successive mass differences Δm of the traveling standards measured at NPLI during the comparison and the variability of the pilot laboratory results calculated as the standard deviation of the four measured values for each of the five traveling standards

Nominal Mass (m_0)	Δm/mg			Standard Deviation (mg)
	(AA2 – AA1)	(AA3 – AA2)	(AA4 – AA3)	
10 kg	- 0.30	+ 0.50	+ 0.90	0.60
500 g	+ 0.02	- 0.007	- 0.014	0.010
20 g	+ 0.002	+ 0.000	+ 0.003	0.002 1
2 g	+ 0.002 1	+ 0.000 8	- 0.000 8	0.001 2
100 mg	+ 0.000 5	+ 0.000 2	0.000 0	0.000 3

7.3 Analysis and Linking to CCM.M-K2

The results were analyzed and linked to CCM.M-K2 using the method in [6]. This method links APMP.M.M-K2 to CCM.M-K2 and gives the degrees of equivalence required by the MRA without the need for an APMP.M.M-K2 reference value. The analysis was performed five times, once for each traveling standard.

For each analysis, **the inputs are**:

- The measurement results given in Table 1.
- The measurement results of the two link laboratories NMIA and KRISS in CCM.M-K2.
- The KCRV (zero in each case) and its uncertainty.
- The standard uncertainty due to instability of the traveling standard, taken as the standard deviation of the four measurement results of the pilot laboratory. This uncertainty was added in quadrature to the uncertainty in the measurement result for each participating laboratory other than the pilot laboratory.
- The correlated uncertainty between the four measurement results of the pilot laboratory.
- The correlated uncertainty between the measurement results in CCM.M-K2 and APMP.M.M-K2 for NMIA and for KRISS.

Outputs of the analysis are:

- The difference between each participant's assigned mass value and the KCRV of CCM.M-K2, along with the standard uncertainty associated with this difference.
- Pair-wise differences between the results of the participating laboratories and the standard uncertainty associated with each of these differences.

The results of these analyses are given in Table 3 which, for each traveling standard, shows the difference between the result for each participating laboratory and the CCM.M-K2 key comparison reference value along with the expanded uncertainty in this difference. These results are also shown in Figures 6 to 10 with zero mass value corresponding to the KCRV of CCM.M-K2.

Table 3

Deviation from the KCRV (key comparison reference value of CCM.M-K2) and associated expanded uncertainty U (k=2) for each participating Laboratory and for each of the five traveling standards.

Participating Laboratory	10 kg		500 g		20 g		2 g		100 mg	
	$m - KCRV$ (mg)	U (mg)	$m - KCRV$ (mg)	U (mg)	$m - KCRV$ (mg)	U (mg)	$m - KCRV$ (mg)	U (mg)	$m - KCRV$ (mg)	U (mg)
NPLI	0.351	2.486	- 0.009	0.048	- 0.0001	0.0076	0.0022	0.0028	0.0005	0.0018
CMS-ITRI	- 0.649	2.754	- 0.012	0.039	0.0062	0.0093	- 0.0003	0.0035	-0.0001	0.0012
NMIA	- 0.083	0.756	0.001	0.035	- 0.0031	0.0068	- 0.0009	0.0020	-0.0002	0.0010
NMISA	1.793	2.391	0.014	0.089	0.0032	0.0130	0.0017	0.0087	-0.0002	0.0051
KIM-LIPI	1.201	1.875	0.006	0.039	- 0.0028	0.0083	0.0005	0.0036	-0.0001	0.0015
KRISS	- 0.198	0.448	0.000	0.019	- 0.0016	0.0054	0.0005	0.0019	-0.0002	0.0008
SCL	- 0.999	2.527	0.017	0.058	- 0.0028	0.0108	- 0.0007	0.0053	-0.0006	0.0016
NIMT	- 0.199	1.624	- 0.031	0.047	- 0.0068	0.0076	- 0.0010	0.0035	-0.0003	0.0012
NMC, A-STAR	- 0.199	1.841	- 0.003	0.049	- 0.0038	0.0108	0.0011	0.0038	-0.0004	0.0020
MSL	- 0.399	1.583	- 0.009	0.034	- 0.0068	0.0073	- 0.0011	0.0033	-0.0004	0.0011
NML-SIRIM	- 0.199	2.373	0.004	0.058	- 0.0028	0.0089	0.0006	0.0041	-0.0011	0.0013

The expanded uncertainty has been calculated using a coverage factor of $k = 2$. This will be an under-estimate for 95% confidence limits. While the effective degrees of freedom reported by each laboratory for their results is sufficiently large to justify using $k = 2$ in each case, the estimate of the uncertainty due to instability in each traveling standard is evaluated with only three degrees of freedom and this uncertainty due to instability is significant. The ratio of the measurement uncertainty reported by each participant to the instability uncertainty is typically in the range 0.25 to 1. In practice, the results show that this under-estimate of k is of no consequence.

8 Conclusion

- All the laboratories results are consistent with the KCRV of CCM.M-K2 with $k = 2$. This can be seen in Figures 6 to 10 where the expanded uncertainty bars for all the results cross the line of zero mass.

- The results of all the laboratories are consistent with each other for 100 mg, 2 g, 500 g and 10 kg. For these mass values, in all cases the expanded uncertainty in each pair-wise difference is not significantly smaller than the difference.

- For 20 g, the vast majority of the laboratory results are consistent with each other. There are only two laboratory to laboratory differences where the expanded uncertainty in the pair-wise difference is significantly smaller than the difference (by a factor of 0.64). In these two cases, consistency would be restored with a more correct calculation of k.

9. References

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[5]. M Gläser et al.: Final report on CIPM key comparison of multiples and submultiples of the kilogram (CCM.M-K2), *Metrologia* **40 ,** 2003.

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Table 4

10 kg

Difference in assigned mass values between laboratory A and laboratory B（in **mg**)

Value	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.000	1.000	0.434	-1.442	-0.850	0.549	1.350	0.550	0.550	0.750	0.550
CMS-ITRI	-1.000	0.000	-0.566	-2.442	-1.850	-0.451	0.350	-0.450	-0.450	-0.250	-0.450
NMIA	-0.434	0.566	0.000	-1.876	-1.284	0.115	0.916	0.116	0.116	0.316	0.116
NMISA	1.442	2.442	1.876	0.000	0.592	1.991	2.792	1.992	1.992	2.192	1.992
KIM-LIPI	0.850	1.850	1.284	-0.592	0.000	1.399	2.200	1.400	1.400	1.600	1.400
KRISS	-0.549	0.451	-0.115	-1.991	-1.399	0.000	0.801	0.001	0.001	0.201	0.001
SCL	-1.350	-0.350	-0.916	-2.792	-2.200	-0.801	0.000	-0.800	-0.800	-0.600	-0.800
NIMT	-0.550	0.450	-0.116	-1.992	-1.400	-0.001	0.800	0.000	0.000	0.200	0.000
NMC,A-STAR	-0.550	0.450	-0.116	-1.992	-1.400	-0.001	0.800	0.000	0.000	0.200	0.000
MSL	-0.750	0.250	-0.316	-2.192	-1.600	-0.201	0.600	-0.200	-0.200	0.000	-0.200
NML-SIRIM	-0.550	0.450	-0.116	-1.992	-1.400	-0.001	0.800	0.000	0.000	0.200	0.000

Expanded uncertainty of the difference in assigned mass values between laboratory A and laboratory B (in **mg**)

U [k=2]	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	2.49	3.44	2.56	3.16	2.79	2.49	3.27	2.63	2.77	2.61	3.15
CMS-ITRI	3.44	2.75	2.82	3.38	3.03	2.76	3.47	2.89	3.01	2.86	3.36
NMIA	2.56	2.82	0.76	2.46	1.97	0.81	2.60	1.73	1.93	1.69	2.45
NMISA	3.16	3.38	2.46	2.39	2.71	2.40	3.20	2.54	2.69	2.52	3.07
KIM-LIPI	2.79	3.03	1.97	2.71	1.87	1.88	2.83	2.06	2.24	2.03	2.69
KRISS	2.49	2.76	0.81	2.40	1.88	0.45	2.53	1.63	1.85	1.59	2.38
SCL	3.27	3.47	2.60	3.20	2.83	2.53	2.53	2.67	2.81	2.64	3.18
NIMT	2.63	2.89	1.73	2.54	2.06	1.63	2.67	1.62	2.03	1.80	2.52
NMC,A-STAR	2.77	3.01	1.93	2.69	2.24	1.85	2.81	2.03	1.84	2.00	2.67
MSL	2.61	2.86	1.69	2.52	2.03	1.59	2.64	1.80	2.00	1.58	2.50
NML-SIRIM	3.15	3.36	2.45	3.07	2.69	2.38	3.18	2.52	2.67	2.50	2.37

Ratio of the laboratory-to-laboratory difference to the expanded uncertainty for each pair-wise combination of laboratories

Value / U	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.000	0.290	0.170	-0.456	-0.304	0.221	0.413	0.209	0.199	0.288	0.175
CMS-ITRI	-0.290	0.000	-0.201	-0.723	-0.610	-0.164	0.101	-0.156	-0.149	-0.087	-0.134
NMIA	-0.170	0.201	0.000	-0.762	-0.653	0.142	0.353	0.067	0.060	0.187	0.047
NMISA	0.456	0.723	0.762	0.000	0.219	0.831	0.874	0.784	0.742	0.871	0.648
KIM-LIPI	0.304	0.610	0.653	-0.219	0.000	0.744	0.778	0.679	0.626	0.788	0.520
KRISS	-0.221	0.164	-0.142	-0.831	-0.744	0.000	0.316	0.001	0.001	0.126	0.000
SCL	-0.413	-0.101	-0.353	-0.874	-0.778	-0.316	0.000	-0.300	-0.285	-0.227	-0.251
NIMT	-0.209	0.156	-0.067	-0.784	-0.679	-0.001	0.300	0.000	0.000	0.111	0.000
NMC, A-STAR	-0.199	0.149	-0.060	-0.742	-0.626	-0.001	0.285	0.000	0.000	0.100	0.000
MSL	-0.288	0.087	-0.187	-0.871	-0.788	-0.126	0.227	-0.111	-0.100	0.000	-0.080
NML-SIRIM	-0.175	0.134	-0.047	-0.648	-0.520	0.000	0.251	0.000	0.000	0.080	0.000

Table 5

500 g

Difference in assigned mass values between laboratory A and laboratory B (in **mg**)

Value	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.0000	0.0030	-0.0098	-0.0230	-0.0150	-0.0093	-0.0260	0.0220	-0.0060	0.0000	-0.0130
CMS-ITRI	-0.0030	0.0000	-0.0128	-0.0260	-0.0180	-0.0123	-0.0290	0.0190	-0.0090	-0.0030	-0.0160
NMIA	0.0098	0.0128	0.0000	-0.0132	-0.0052	0.0005	-0.0162	0.0318	0.0038	0.0098	-0.0032
NMISA	0.0230	0.0260	0.0132	0.0000	0.0080	0.0137	-0.0030	0.0450	0.0170	0.0230	0.0100
KIM-LIPI	0.0150	0.0180	0.0052	-0.0080	0.0000	0.0057	-0.0110	0.0370	0.0090	0.0150	0.0020
KRISS	0.0093	0.0123	-0.0005	-0.0137	-0.0057	0.0000	-0.0167	0.0313	0.0033	0.0093	-0.0037
SCL	0.0260	0.0290	0.0162	0.0030	0.0110	0.0167	0.0000	0.0480	0.0200	0.0260	0.0130
NIMT	-0.0220	-0.0190	-0.0318	-0.0450	-0.0370	-0.0313	-0.0480	0.0000	-0.0280	-0.0220	-0.0350
NMC, A-STAR	0.0060	0.0090	-0.0038	-0.0170	-0.0090	-0.0033	-0.0200	0.0280	0.0000	0.0060	-0.0070
MSL	0.0000	0.0030	-0.0098	-0.0230	-0.0150	-0.0093	-0.0260	0.0220	-0.0060	0.0000	-0.0130
NML-SIRIM	0.0130	0.0160	0.0032	-0.0100	-0.0020	0.0037	-0.0130	0.0350	0.0070	0.0130	0.0000

Expanded uncertainty of the difference in assigned mass values between laboratory A and laboratory B (in **mg**)

U [k=2]	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.0475	0.0530	0.0537	0.0958	0.0530	0.0486	0.0685	0.0595	0.0610	0.0496	0.0685
CMS-ITRI	0.0530	0.0387	0.0461	0.0918	0.0453	0.0401	0.0628	0.0528	0.0544	0.0412	0.0628
NMIA	0.0537	0.0461	0.0354	0.0922	0.0461	0.0375	0.0634	0.0535	0.0551	0.0421	0.0634
NMISA	0.0958	0.0918	0.0922	0.0887	0.0918	0.0893	0.1015	0.0957	0.0966	0.0898	0.1015
KIM-LIPI	0.0530	0.0453	0.0461	0.0918	0.0387	0.0401	0.0628	0.0528	0.0544	0.0412	0.0628
KRISS	0.0486	0.0401	0.0375	0.0893	0.0401	0.0187	0.0591	0.0484	0.0502	0.0355	0.0591
SCL	0.0685	0.0628	0.0634	0.1015	0.0628	0.0591	0.0582	0.0684	0.0697	0.0599	0.0764
NIMT	0.0595	0.0528	0.0535	0.0957	0.0528	0.0484	0.0684	0.0473	0.0608	0.0494	0.0684
NMC, A-STAR	0.0610	0.0544	0.0551	0.0966	0.0544	0.0502	0.0697	0.0608	0.0491	0.0511	0.0697
MSL	0.0496	0.0412	0.0421	0.0898	0.0412	0.0355	0.0599	0.0494	0.0511	0.0339	0.0599
NML-SIRIM	0.0685	0.0628	0.0634	0.1015	0.0628	0.0591	0.0764	0.0684	0.0697	0.0599	0.0582

Ratio of the laboratory-to-laboratory difference to the expanded uncertainty for each pair-wise combination of laboratories

Value / U	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.000	0.057	-0.182	-0.240	-0.283	-0.191	-0.379	0.369	-0.098	0.000	-0.190
CMS-ITRI	-0.057	0.000	-0.277	-0.283	-0.398	-0.307	-0.462	0.360	-0.165	-0.073	-0.255
NMIA	0.182	0.277	0.000	-0.143	-0.113	0.013	-0.256	0.594	0.069	0.232	-0.051
NMISA	0.240	0.283	0.143	0.000	0.087	0.153	-0.030	0.470	0.176	0.256	0.098
KIM-LIPI	0.283	0.398	0.113	-0.087	0.000	0.143	-0.175	0.701	0.165	0.364	0.032
KRISS	0.191	0.307	-0.013	-0.153	-0.143	0.000	-0.283	0.646	0.066	0.262	-0.063
SCL	0.379	0.462	0.256	0.030	0.175	0.283	0.000	0.702	0.287	0.434	0.170
NIMT	-0.369	-0.360	-0.594	-0.470	-0.701	-0.646	-0.702	0.000	-0.460	-0.445	-0.512
NMC, A-STAR	0.098	0.165	-0.069	-0.176	-0.165	-0.066	-0.287	0.460	0.000	0.117	-0.100
MSL	0.000	0.073	-0.232	-0.256	-0.364	-0.262	-0.434	0.445	-0.117	0.000	-0.217
NML-SIRIM	0.190	0.255	0.051	-0.098	-0.032	0.063	-0.170	0.512	0.100	0.217	0.000

Table 6

20 g

Difference in assigned mass values between laboratory A and laboratory B （in **mg**）

Value	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.00000	-0.00631	0.00299	-0.00331	0.00269	0.00145	0.00269	0.00669	0.00369	0.00669	0.00269
CMS-ITRI	0.00631	0.00000	0.00930	0.00300	0.00900	0.00776	0.00900	0.01300	0.01000	0.01300	0.00900
NMIA	-0.00299	-0.00930	0.00000	-0.00630	-0.00030	-0.00154	-0.00030	0.00370	0.00070	0.00370	-0.00030
NMISA	0.00331	-0.00300	0.00630	0.00000	0.00600	0.00476	0.00600	0.01000	0.00700	0.01000	0.00600
KIM-LIPI	-0.00269	-0.00900	0.00030	-0.00600	0.00000	-0.00124	0.00000	0.00400	0.00100	0.00400	0.00000
KRISS	-0.00145	-0.00776	0.00154	-0.00476	0.00124	0.00000	0.00124	0.00524	0.00224	0.00524	0.00124
SCL	-0.00269	-0.00900	0.00030	-0.00600	0.00000	-0.00124	0.00000	0.00400	0.00100	0.00400	0.00000
NIMT	-0.00669	-0.01300	-0.00370	-0.01000	-0.00400	-0.00524	-0.00400	0.00000	-0.00300	0.00000	-0.00400
NMC, A-STAR	-0.00369	-0.01000	-0.00070	-0.00700	-0.00100	-0.00224	-0.00100	0.00300	0.00000	0.00300	-0.00100
MSL	-0.00669	-0.01300	-0.00370	-0.01000	-0.00400	-0.00524	-0.00400	0.00000	-0.00300	0.00000	-0.00400
NML-SIRIM	-0.00269	-0.00900	0.00030	-0.00600	0.00000	-0.00124	0.00000	0.00400	0.00100	0.00400	0.00000

Expanded uncertainty of the difference in assigned mass values between laboratory A and laboratory B (in **mg**)

U [k=2]	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.00760	0.00861	0.00739	0.01252	0.00748	0.00659	0.01016	0.00673	0.01016	0.00632	0.00811
CMS-ITRI	0.00861	0.00935	0.00918	0.01365	0.00925	0.00854	0.01153	0.00865	0.01153	0.00834	0.00977
NMIA	0.00739	0.00918	0.00684	0.01292	0.00812	0.00662	0.01065	0.00744	0.01065	0.00707	0.00871
NMISA	0.01252	0.01365	0.01292	0.01304	0.01297	0.01248	0.01468	0.01255	0.01468	0.01234	0.01335
KIM-LIPI	0.00748	0.00925	0.00812	0.01297	0.00832	0.00740	0.01071	0.00753	0.01071	0.00716	0.00879
KRISS	0.00659	0.00854	0.00662	0.01248	0.00740	0.00535	0.01011	0.00665	0.01011	0.00623	0.00804
SCL	0.01016	0.01153	0.01065	0.01468	0.01071	0.01011	0.01079	0.01020	0.01273	0.00993	0.01116
NIMT	0.00673	0.00865	0.00744	0.01255	0.00753	0.00665	0.01020	0.00765	0.01020	0.00638	0.00816
NMC, A-STAR	0.01016	0.01153	0.01065	0.01468	0.01071	0.01011	0.01273	0.01020	0.01079	0.00993	0.01116
MSL	0.00632	0.00834	0.00707	0.01234	0.00716	0.00623	0.00993	0.00638	0.00993	0.00729	0.00782
NML-SIRIM	0.00811	0.00977	0.00871	0.01335	0.00879	0.00804	0.01116	0.00816	0.01116	0.00782	0.00889

Ratio of the laboratory-to-laboratory difference to the expanded uncertainty for each pair-wise combination of laboratories

Value / U	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.000	-0.732	0.405	-0.264	0.360	0.221	0.265	0.994	0.363	1.059	0.332
CMS-ITRI	0.732	0.000	1.014	0.220	0.973	0.908	0.781	1.502	0.868	1.560	0.921
NMIA	-0.405	-1.014	0.000	-0.488	-0.037	-0.233	-0.028	0.497	0.066	0.523	-0.035
NMISA	0.264	-0.220	0.488	0.000	0.463	0.381	0.409	0.797	0.477	0.811	0.450
KIM-LIPI	-0.360	-0.973	0.037	-0.463	0.000	-0.167	0.000	0.531	0.093	0.559	0.000
KRISS	-0.221	-0.908	0.233	-0.381	0.167	0.000	0.123	0.788	0.222	0.841	0.154
SCL	-0.265	-0.781	0.028	-0.409	0.000	-0.123	0.000	0.392	0.079	0.403	0.000
NIMT	-0.994	-1.502	-0.497	-0.797	-0.531	-0.788	-0.392	0.000	-0.294	0.000	-0.490
NMC, A-STAR	-0.363	-0.868	-0.066	-0.477	-0.093	-0.222	-0.079	0.294	0.000	0.302	-0.090
MSL	-1.059	-1.560	-0.523	-0.811	-0.559	-0.841	-0.403	0.000	-0.302	0.000	-0.511
NML-SIRIM	-0.332	-0.921	0.035	-0.450	0.000	-0.154	0.000	0.490	0.090	0.511	0.000

Table 7

2 g

Difference in assigned mass values between laboratory A and laboratory B (in **mg**)

Value	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.00000	0.00247	0.00311	0.00047	0.00167	0.00167	0.00287	0.00317	0.00107	0.00327	0.00157
CMS-ITRI	0.00247	0.00000	0.00063	-0.00200	-0.00080	-0.00081	0.00040	0.00070	-0.00140	0.00080	-0.00090
NMIA	-0.00311	-0.00063	0.00000	-0.00263	-0.00143	-0.00144	-0.00023	0.00007	-0.00203	0.00017	-0.00153
NMISA	-0.00047	0.00200	0.00263	0.00000	0.00120	0.00119	0.00240	0.00270	0.00060	0.00280	0.00110
KIM-LIPI	-0.00167	0.00080	0.00143	-0.00120	0.00000	-0.00001	0.00120	0.00150	-0.00060	0.00160	-0.00010
KRISS	-0.00167	0.00081	0.00144	-0.00119	0.00001	0.00000	0.00121	0.00151	-0.00059	0.00161	-0.00009
SCL	-0.00287	-0.00040	0.00023	-0.00240	-0.00120	-0.00121	0.00000	0.00030	-0.00180	0.00040	-0.00130
NIMT	-0.00317	-0.00070	-0.00007	-0.00270	-0.00150	-0.00151	-0.00030	0.00000	-0.00210	0.00010	-0.00160
NMC,A-STAR	-0.00107	0.00140	0.00203	-0.00060	0.00060	0.00059	0.00180	0.00210	0.00000	0.00220	0.00050
MSL	-0.00327	-0.00080	-0.00017	-0.00280	-0.00160	-0.00161	-0.00040	-0.00010	-0.00220	0.00000	-0.00170
NML-SIRIM	-0.00157	0.00090	0.00153	-0.00110	0.00010	0.00009	0.00130	0.00160	-0.00050	0.00170	0.00000

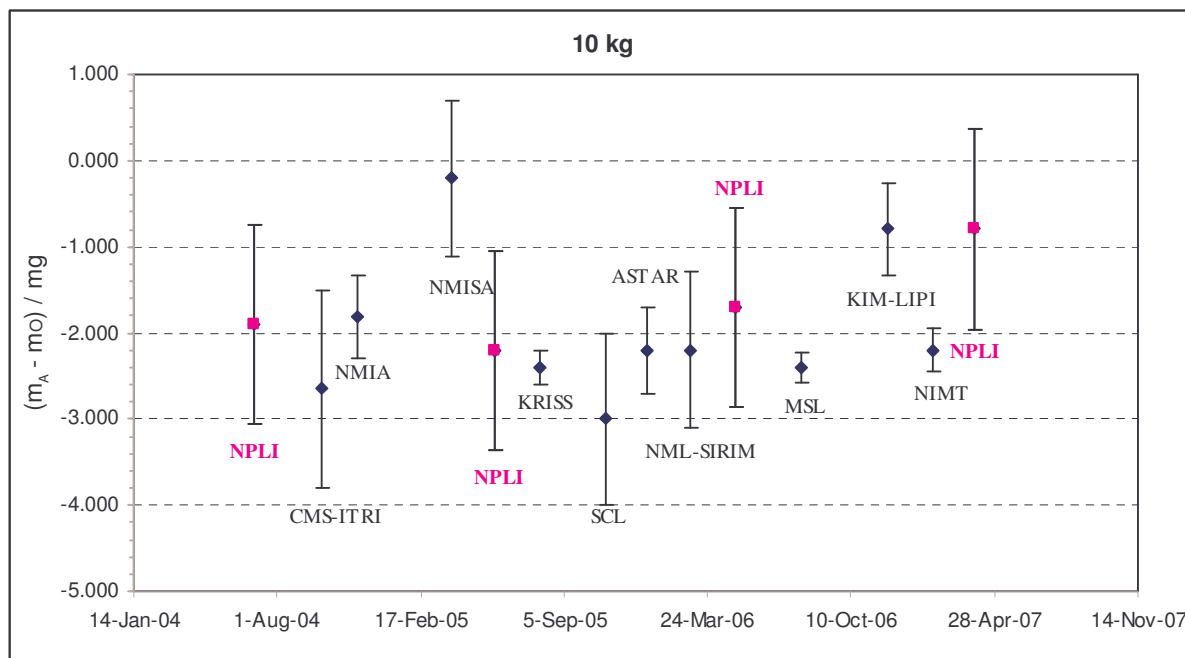Expanded uncertainty of the difference in assigned mass values between laboratory A and laboratory B (in **mg**)

U [k=2]	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.00279	0.00305	0.00282	0.00855	0.00322	0.00267	0.00505	0.00305	0.00339	0.00288	0.00375
CMS-ITRI	0.00305	0.00347	0.00349	0.00879	0.00382	0.00337	0.00546	0.00368	0.00397	0.00354	0.00428
NMIA	0.00282	0.00349	0.00205	0.00872	0.00364	0.00235	0.00534	0.00349	0.00380	0.00335	0.00412
NMISA	0.00855	0.00879	0.00872	0.00871	0.00885	0.00867	0.00967	0.00879	0.00892	0.00874	0.00906
KIM-LIPI	0.00322	0.00382	0.00364	0.00885	0.00362	0.00353	0.00556	0.00382	0.00410	0.00369	0.00440
KRISS	0.00267	0.00337	0.00235	0.00867	0.00353	0.00186	0.00526	0.00337	0.00369	0.00322	0.00402
SCL	0.00505	0.00546	0.00534	0.00967	0.00556	0.00526	0.00532	0.00546	0.00566	0.00537	0.00588
NIMT	0.00305	0.00368	0.00349	0.00879	0.00382	0.00337	0.00546	0.00347	0.00397	0.00354	0.00428
NMC,A-STAR	0.00339	0.00397	0.00380	0.00892	0.00410	0.00369	0.00566	0.00397	0.00378	0.00384	0.00453
MSL	0.00288	0.00354	0.00335	0.00874	0.00369	0.00322	0.00537	0.00354	0.00384	0.00332	0.00416
NML-SIRIM	0.00375	0.00428	0.00412	0.00906	0.00440	0.00402	0.00588	0.00428	0.00453	0.00416	0.00410

Ratio of the laboratory-to-laboratory difference to the expanded uncertainty for each pair-wise combination of laboratories

Value / U	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.000	0.813	1.101	0.056	0.521	0.624	0.569	1.043	0.317	1.139	0.420
CMS-ITRI	-0.813	0.000	0.181	-0.227	-0.209	-0.239	0.073	0.190	-0.353	0.226	-0.210
NMIA	-1.101	-0.181	0.000	-0.302	-0.393	-0.610	-0.043	0.020	-0.534	0.051	-0.371
NMISA	-0.056	0.227	0.302	0.000	0.136	0.138	0.248	0.307	0.067	0.321	0.121
KIM-LIPI	-0.521	0.209	0.393	-0.136	0.000	-0.002	0.216	0.393	-0.146	0.434	-0.023
KRISS	-0.624	0.239	0.610	-0.138	0.002	0.000	0.229	0.447	-0.161	0.499	-0.023
SCL	-0.569	-0.073	0.043	-0.248	-0.216	-0.229	0.000	0.055	-0.318	0.075	-0.221
NIMT	-1.043	-0.190	-0.020	-0.307	-0.393	-0.447	-0.055	0.000	-0.529	0.028	-0.374
NMC,A-STAR	-0.317	0.353	0.534	-0.067	0.146	0.161	0.318	0.529	0.000	0.573	0.110
MSL	-1.139	-0.226	-0.051	-0.321	-0.434	-0.499	-0.075	-0.028	-0.573	0.000	-0.408
NML-SIRIM	-0.420	0.210	0.371	-0.121	0.023	0.023	0.221	0.374	-0.110	0.408	0.000

Table 8

100 mg

Difference in assigned mass values between laboratory A and laboratory B （in **mg**）

Value	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.00000	0.00057	0.00067	0.00067	0.00057	0.00078	0.00107	0.00077	0.00087	0.00087	0.00157
CMS-ITRI	-0.00057	0.00000	0.00009	0.00010	0.00000	0.00020	0.00050	0.00020	0.00030	0.00030	0.00100
NMIA	-0.00067	-0.00009	0.00000	0.00001	-0.00009	0.00011	0.00041	0.00011	0.00021	0.00021	0.00091
NMISA	-0.00067	-0.00010	-0.00001	0.00000	-0.00010	0.00010	0.00040	0.00010	0.00020	0.00020	0.00090
KIM-LIPI	-0.00057	0.00000	0.00009	0.00010	0.00000	0.00020	0.00050	0.00020	0.00030	0.00030	0.00100
KRISS	-0.00078	-0.00020	-0.00011	-0.00010	-0.00020	0.00000	0.00030	0.00000	0.00010	0.00010	0.00080
SCL	-0.00107	-0.00050	-0.00041	-0.00040	-0.00050	-0.00030	0.00000	-0.00030	-0.00020	-0.00020	0.00050
NIMT	-0.00077	-0.00020	-0.00011	-0.00010	-0.00020	0.00000	0.00030	0.00000	0.00010	0.00010	0.00080
NMC, A-STAR	-0.00087	-0.00030	-0.00021	-0.00020	-0.00030	-0.00010	0.00020	-0.00010	0.00000	0.00000	0.00070
MSL	-0.00087	-0.00030	-0.00021	-0.00020	-0.00030	-0.00010	0.00020	-0.00010	0.00000	0.00000	0.00070
NML-SIRIM	-0.00157	-0.00100	-0.00091	-0.00090	-0.00100	-0.00080	-0.00050	-0.00080	-0.00070	-0.00070	0.00000

Expanded uncertainty of the difference in assigned mass values between laboratory A and laboratory B (in **mg**)

U [k=2]	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.00182	0.00177	0.00178	0.00528	0.00199	0.00173	0.00209	0.00177	0.00235	0.00173	0.00182
CMS-ITRI	0.00177	0.00119	0.00113	0.00510	0.00143	0.00104	0.00157	0.00110	0.00191	0.00105	0.00119
NMIA	0.00178	0.00113	0.00096	0.00511	0.00145	0.00093	0.00159	0.00113	0.00192	0.00108	0.00121
NMISA	0.00528	0.00510	0.00511	0.00512	0.00518	0.00509	0.00522	0.00510	0.00533	0.00509	0.00512
KIM-LIPI	0.00199	0.00143	0.00145	0.00518	0.00150	0.00138	0.00181	0.00143	0.00211	0.00139	0.00150
KRISS	0.00173	0.00104	0.00093	0.00509	0.00138	0.00081	0.00152	0.00104	0.00187	0.00098	0.00113
SCL	0.00209	0.00157	0.00159	0.00522	0.00181	0.00152	0.00163	0.00157	0.00221	0.00153	0.00163
NIMT	0.00177	0.00110	0.00113	0.00510	0.00143	0.00104	0.00157	0.00119	0.00191	0.00105	0.00119
NMC, A-STAR	0.00235	0.00191	0.00192	0.00533	0.00211	0.00187	0.00221	0.00191	0.00196	0.00188	0.00196
MSL	0.00173	0.00105	0.00108	0.00509	0.00139	0.00098	0.00153	0.00105	0.00188	0.00114	0.00114
NML-SIRIM	0.00182	0.00119	0.00121	0.00512	0.00150	0.00113	0.00163	0.00119	0.00196	0.00114	0.00128

Ratio of the laboratory-to-laboratory difference to the expanded uncertainty for each pair-wise combination of laboratories

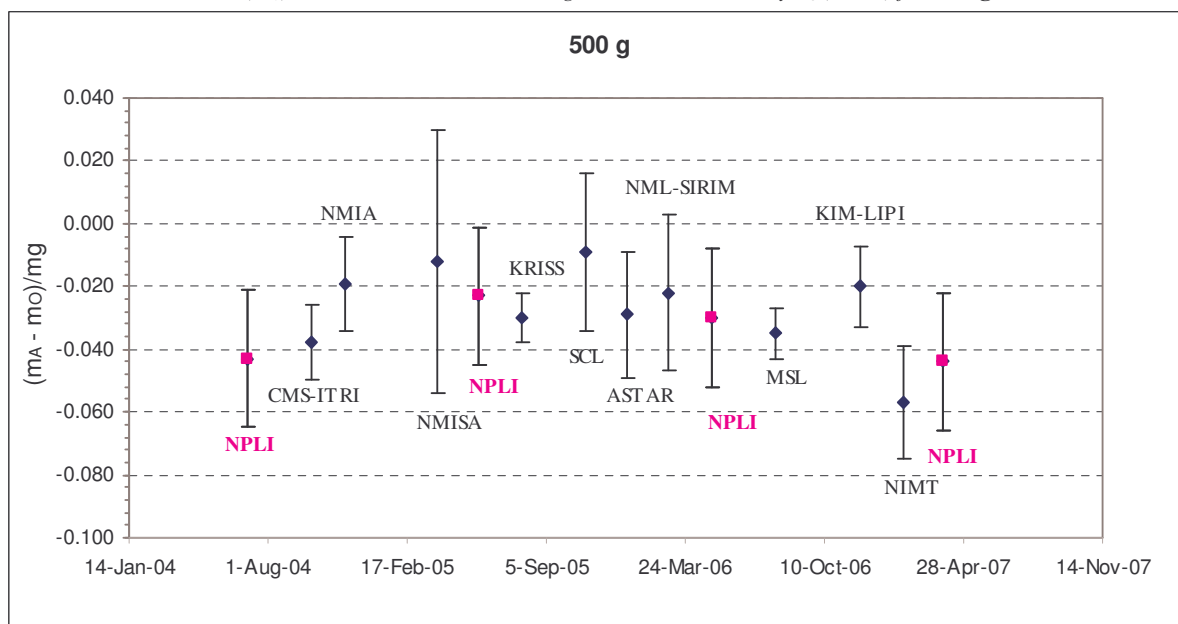| Value / U	NPLI	CMS-ITRI	NMIA	NMISA	KIM-LIPI	KRISS	SCL	NIMT	NMC A-STAR	MSL	NML-SIRIM
NPLI	0.000	0.325	0.373	0.128	0.289	0.450	0.515	0.439	0.372	0.505	0.864
CMS-ITRI	-0.325	0.000	0.080	0.020	0.000	0.194	0.319	0.181	0.157	0.286	0.840
NMIA	-0.373	-0.080	0.000	0.002	-0.062	0.121	0.258	0.097	0.109	0.195	0.749
NMISA	-0.128	-0.020	-0.002	0.000	-0.019	0.020	0.077	0.020	0.038	0.039	0.176
KIM-LIPI	-0.289	0.000	0.062	0.019	0.000	0.146	0.276	0.140	0.142	0.216	0.667
KRISS	-0.450	-0.194	-0.121	-0.020	-0.146	0.000	0.195	-0.002	0.052	0.099	0.704
SCL	-0.515	-0.319	-0.258	-0.077	-0.276	-0.195	0.000	-0.191	-0.091	-0.131	0.307
NIMT	-0.439	-0.181	-0.097	-0.020	-0.140	0.002	0.191	0.000	0.052	0.095	0.672
NMC, A-STAR	-0.372	-0.157	-0.109	-0.038	-0.142	-0.052	0.091	-0.052	0.000	0.000	0.357
MSL	-0.505	-0.286	-0.195	-0.039	-0.216	-0.099	0.131	-0.095	0.000	0.000	0.614
NML-SIRIM	-0.864	-0.840	-0.749	-0.176	-0.667	-0.704	-0.307	-0.672	-0.357	-0.614	0.000

Figure 1

Graph indicates the difference $(m_A - m_0)$ between the measured mass value (m_A) of the participant laboratory minus the nominal mass value (m_0) with the error bars showing standard uncertainty u_c ($k =1$) for **10 kg** mass standard
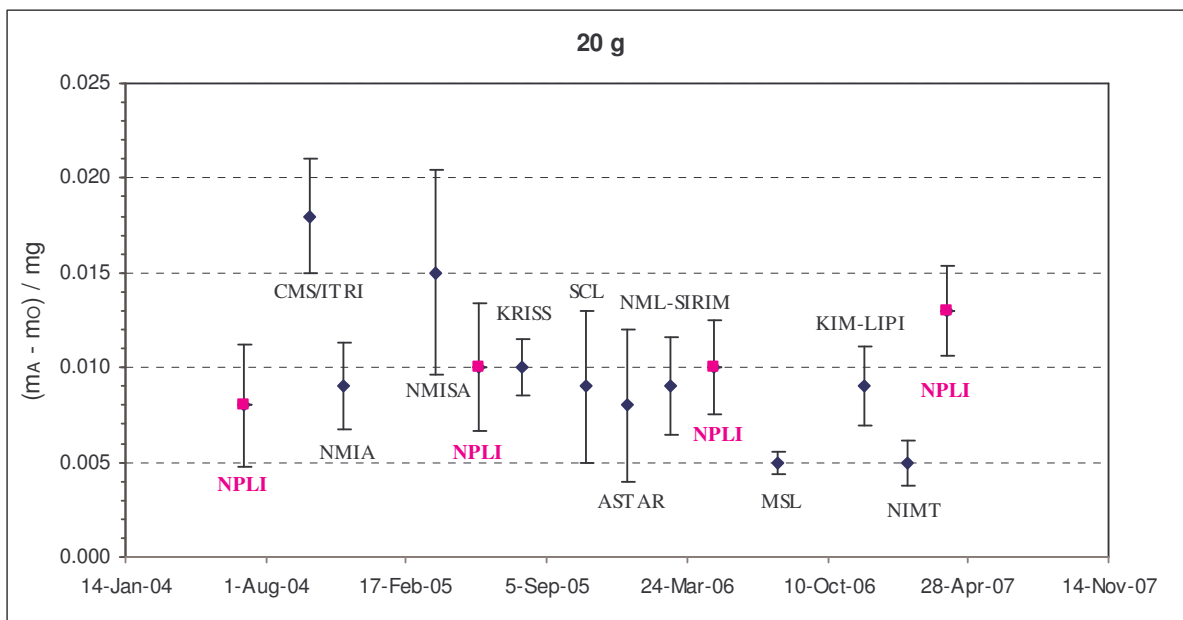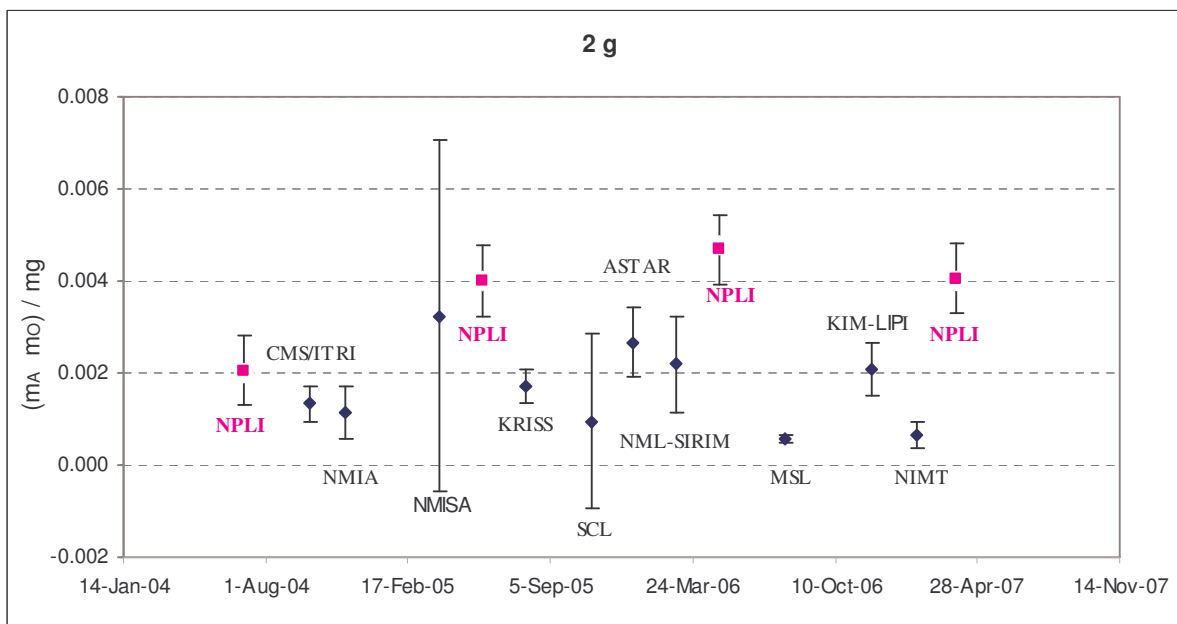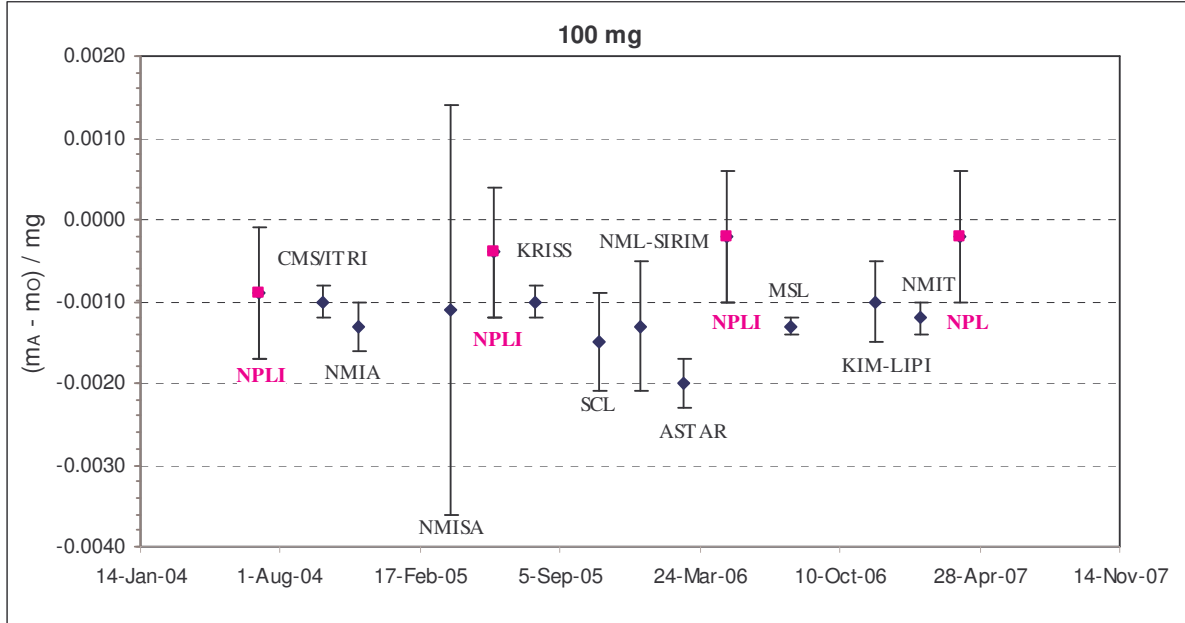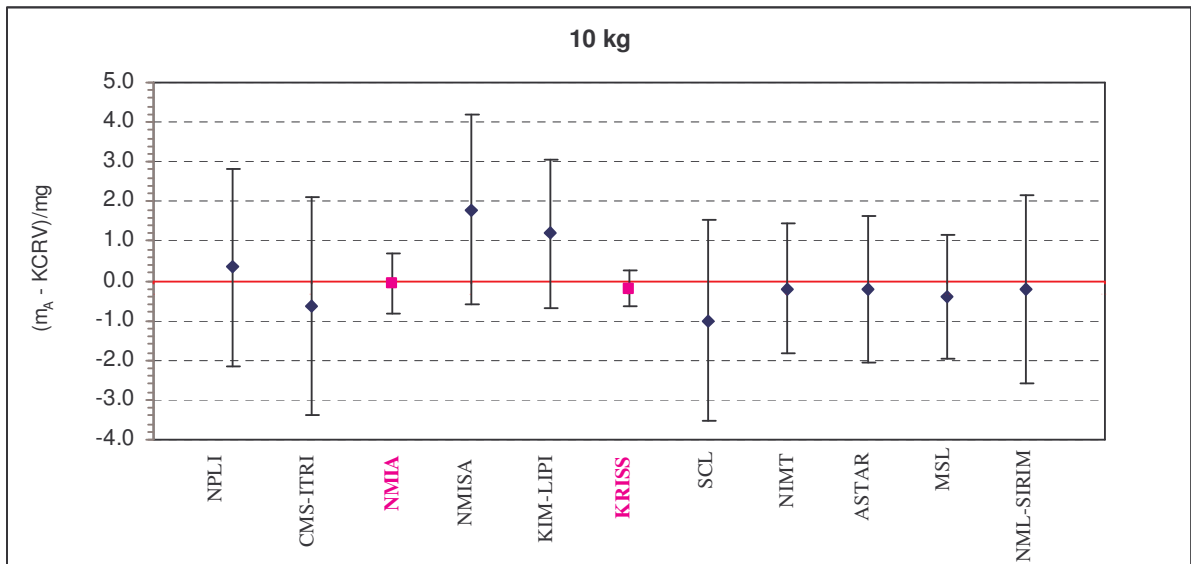

Figure 2

Graph indicates the difference $(m_A - m_0)$ between the measured mass value (m_A) of the participant laboratory minus the nominal mass value (m_0) with the error bars showing standard uncertainty u_c ($k =1$) for **500 g** mass standard.
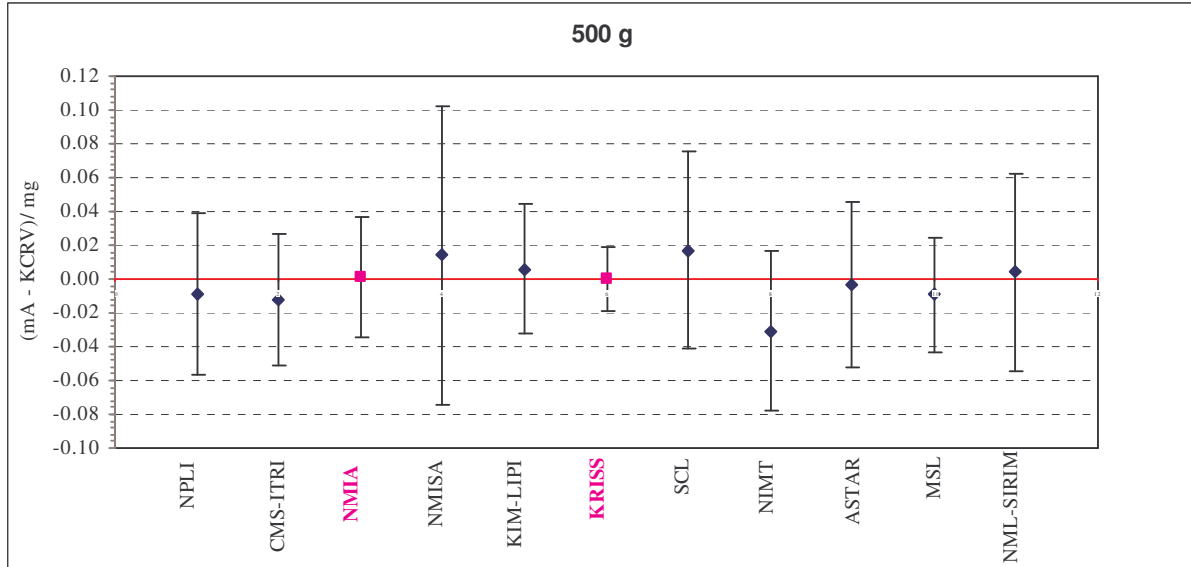
Figure 3

*Graph indicates the difference ($m_A - m_0$) between the measured mass value (m_A) of the participant laboratory minus the nominal mass value (m_0) with the error bars showing standard uncertainty u_c ($k = 1$) for **20 g** mass standard.*

Figure 4

*Graph indicates the difference ($m_A - m_0$) between the measured mass value (m_A) of the participant laboratory minus The nominal mass value (m_0) with the error bars showing standard uncertainty u_c ($k = 1$) for **2 g** mass standard*

Figure 5

*Graph indicates the difference ($m_A - m_0$) between the measured mass value(m_A) of the participant laboratory Minus the nominal mass value(m_0) with the error bars showing standard uncertainty u_c (k =1) for **100** **mg** mass standard.*
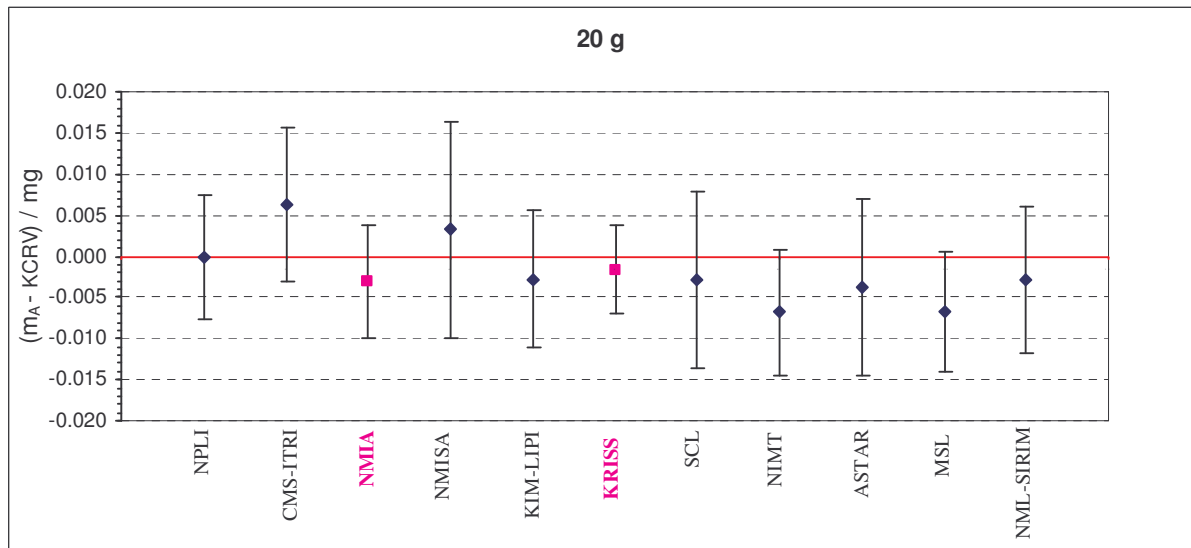

Figure 6

The graph indicates the difference between each participant's mass value (m_A) and the key comparison reference value (KCRV) of CCM.M-K2 with bars representing expanded uncertainties U (k=2). Link laboratories to CCM.M-K2 are shown by the rectangular pink marker.
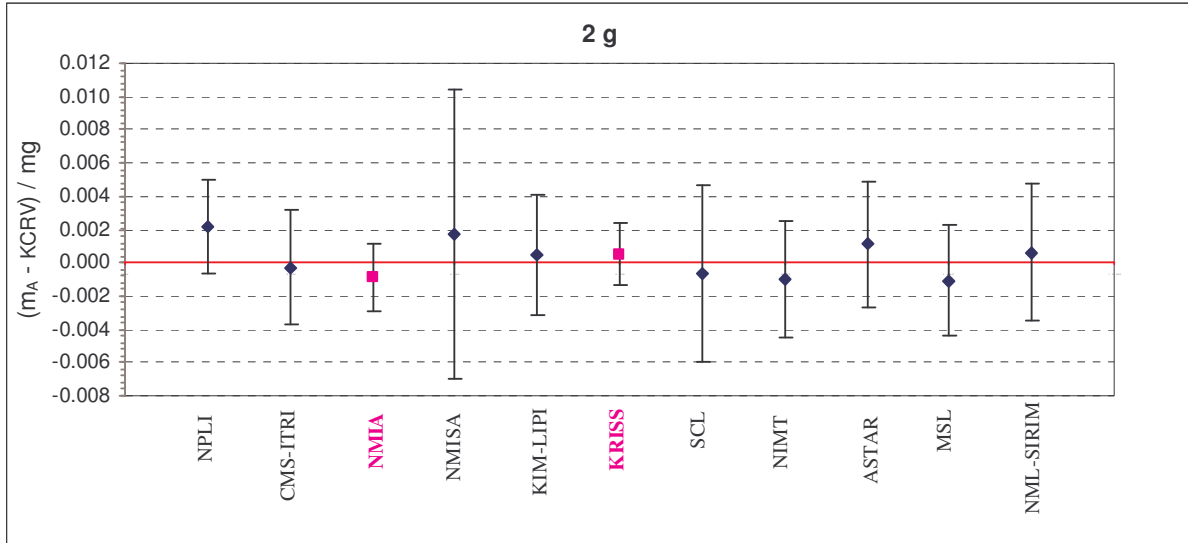
Figure 7

The graph indicates the difference between each participant's mass value (m_A) and the key comparison reference value (KCRV) of CCM.M-K2 with bars representing expanded uncertainties U (k=2). Link laboratories to CCM.M-K2 are shown by the rectangular pink marker

500 g

Figure 8

The graph indicates the difference between each participant's mass value (m_A) and the key comparison reference value (KCRV) of CCM.M-K2 with bars representing expanded uncertainties U (k=2). Link laboratories to CCM.M-K2 are shown by the rectangular pink marker
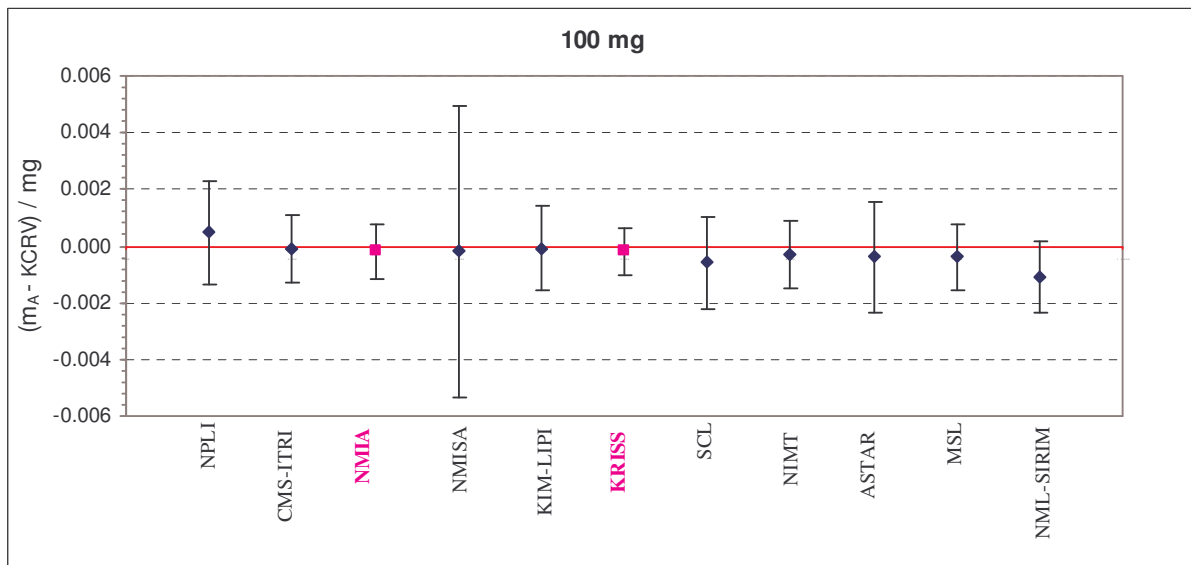

20 g

Figure 9

The graph indicates the difference between each participant's mass value (m_A) and the key comparison reference value (KCRV) of CCM.M-K2 with bars representing expanded uncertainties U (k=2). Link laboratories to CCM.M-K2 are shown by the rectangular pink marker

Figure 10

The graph indicates the difference between each participant's mass value (m_A) and the key comparison reference value (KCRV) of CCM.M-K2 with bars representing expanded uncertainties U (k=2). Link laboratories to CCM.M-K2 are shown by the rectangular pink marker

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