Final Report : CCM.M-K3 comparison / 50 kg Mass

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Abstract

The CCM.M-K3 comparison is based on a decision taken by the "Comité Consultatif pour la Masse et les Grandeurs Apparentées" (CCM) during its 7th session in May 1999. The comparison is piloted by the BNM-LNE, organized in three petals (petal 1, 2 and 3), and uses two 50 kg travelling standards. Fourteen laboratories calibrated one of the travelling standards between March 2001 and February 2002. The key comparison reference value accepted by the participants is the median of the corrected laboratory results. The degree of equivalence of each laboratory with respect to the reference value and the degree of equivalence between two laboratories have been calculated. These terms and their expanded uncertainties are given in matrix form. A graphical presentation is also shown.

1. Introduction

The CCM.M-K3 comparison is based on a decision taken by the "Comité Consultatif pour la Masse et les Grandeurs Apparentées" (CCM) during its 7th session in May 1999.
CCM agreed that BNM-LNE would act as pilot laboratory.
NRC (CANADA) and PTB (GERMANY) accepted to be helping laboratories.
The aim of the comparison is to compare the results obtained by the participating laboratories when calibrating a 50 kg stainless steel mass standard.

2. Organisation

2.1 Participating laboratories

14 laboratories participated.

Laboratory		Country
Bureau National de Métrologie/Laboratoire National d'Essais	BNM/LNE	France
National Research Council of Canada	NRC	Canada
Physikalisch-Technische Bundesanstalt	PTB	Germany
Glowny Urzad Miar	GUM	Poland
Slovensky Metrologicky Ustav	SMU	Slovakia
Nederlands Meetinstituut Van Swinden Laboratorium	NMi VSL	Netherlands
National Physical Laboratory	NPL	United Kingdom

Swiss Federal Office of Metrology and Accreditation	METAS	Switzerland
Istituto di Metrologia ”G. Colonnetti”	IMGC	Italy
Korea Research Institute of Standards and Science	KRISS	Republic of Korea
National Metrology Institute of Japan / National Institute of Advanced Industrial Science and Technology	NMIJ/AIST	Japan
Swedish National Testing & Research Institute	SP	Sweden
Centro Espanol de Metrologia	CEM	Spain
Centro Nacional de Metrologia	CENAM	Mexico

2.2 Comparison scheme

Two travelling 50 kg standards circulated among the participants. The pilot laboratory, for the purpose of monitoring the stability of the travelling standards, held a third 50 kg standard called the “monitoring standard”.

The travel of the standards is set up in a circular form with three petals:

- two successive petals using the first travelling standard - petal 1 (March to July 2001) and petal 2 (September 2001 to March 2002).
- petal 3, using the second travelling standard (September 2001 to February 2002) for some European countries.

The two travelling standards are compared to the monitoring standard by the pilot laboratory at the beginning and at the end of each petal.

2.3 Characteristics of the Mass standards

The travelling and monitoring standards were manufactured by the ZWIEBEL Company from one single bar of stainless steel X 18 M 25 W. They are cylinders with a circular fork groove.

Table 1 : Characteristics of the standards

Parameter	**Value**	**expanded uncertainty** *(95% coverage)*
Density at 20°C	7 987.2 $kg.m^{-3}$	1.4 $kg.m^{-3}$
Magnetic susceptibility	$3.30.10^{-3}$	$0.60.10^{-3}$
Height	224.8 mm	0.20 mm
Diameter	190.0 mm	0.20 mm
Height of centre of gravity above base	110.9 mm	0.40 mm

Each standard is identified by a serial number engraved on the top plane face :
petals 1 and 2 : number **9**
petal 3 : number **6**

A handling fork was supplied with each standard.

2.4 Travelling conditions

Two types of packaging were used, one for the petals one and two and a second one for the petal 3.

For petals 1 and 2, a special package was designed for travelling by air freight without being accompanied. It encloses a recorder of temperature, moisture, and shock. The details of this packaging are presented in the document [5].

The figures 4 and 5 at the end of the document present the records of temperature and air moisture made during the petals 1 and 2.

For petal 3, a commercial package, carried by car was used.

Except for one recorder reading problem and the loss of one ATA carnet, no remarkable incident occurred. At the last return of the travelling standards, no damage was noted to the packages or to the standards themselves.

3. Results of the comparison

3.1 Stability of the travelling mass standards

The monitoring standard was stored in a wooden box in the BNM-LNE laboratory the whole time of the comparison.
BNM-LNE compared the travelling standards against the monitoring standard before and after each petal.

The results of these comparisons are given in tables 3a and 3b below.

Table 3a : Deviations *d* of the travelling standards from the monitoring standard

Date	travelling standard 6	travelling standard 9
Feb 2001	-33.6 mg	- 8.6 mg
Jul 2001	-33.9 mg	- 8.7 mg
Feb 2002	- 33.1 mg	- 8.5 mg

Table 3b : mean deviation $\overline{d}$ before and after a petal,
drift Δd of the travelling standards during a petal
and uncertainty $u(\overline{d})$ of this drift

Date	travelling standard 6			travelling standard 9		
	$\overline{d}$	$u(\overline{d})$	Δd	$\overline{d}$	$u(\overline{d})$	Δd
Feb 2001 to Jul 2001	BNM-LNE			petal 1		
	-33.75 mg	0.81 mg	-0.30 mg	- 8.65 mg	0.81 mg	-0.10 mg
Jul 2001 to Feb 2002	petal 3			petal 2		
	-33.50 mg	0.81 mg	+0.80 mg	- 8.60 mg	0.81 mg	0.20 mg

These results show that the mass of the two travelling standards did not change significantly during the comparison.

3.2 Results reported by the participants

Table 2 shows the results and combined uncertainties as given by the participants. Uncertainties are given with two significant digits

Table 2. Reported results of the participants. (m : mass of the travelling standard - m_0 nominal value of the standard, $u\ (m\text{-}m_0)$ standard uncertainty reported.

Petal	Date	Laboratory	m-m_0	u(m-m_0)	Petal	Date	Laboratory	m-m_0	u_c
PETAL 1	March 01	CEM	+ 43.4 mg	5.8 mg					
	April 01	SP	+ 46.0 mg	4.0 mg					
	May 01	NMIJ / AIST	+ 44.8 mg	3.5 mg					
	June 01	KRISS	+ 39.8 mg	2.8 mg					
PETAL 2					**PETAL 3**	July 01	LNE	+ 18.0 mg	4.2 mg
						September	NMi VSL	+ 20 mg	12 mg
	October 01	CENAM	+ 42.4 mg	2.8 mg		October 01	PTB	+ 15.53 mg	0.98 mg
	November 01	NRC	+ 41.9 mg	1.5 mg		November 01	SMU	+ 16.7 mg	4.0 mg
	December 01	GUM	+ 38.1 mg	6.5 mg		December 01	METAS	+ 19.6 mg	2.5 mg
	January 02	NPL	+ 39.0 mg	2.8 mg		January 02	IMGC	+ 19.3 mg	5.0 mg

3.3 Corrected results

To compare the results m_A of the participants A related to three different petals and two different standards, we have to link them through the monitoring standard. The best way is to correct the result of a laboratory by the mean deviation $\bar{d}$ of the petal involved and given in the table 3b.

The corrected result of Lab A, is as follows :

$$mc_A = m_A - \bar{d} \tag{1}$$

Laboratory	*mc*	Laboratory	*mc*
CEM	+ 52.05 mg	NPL	+ 47.60 mg
SP	+ 54.65 mg	LNE	+ 51.50 mg
NMIJ / AIST	+ 53.45 mg	NMi VSL	+ 53.50 mg
KRISS	+ 48.45 mg	PTB	+ 49.03 mg
CENAM	+ 51.00 mg	SMU	+ 50.20 mg
NRC	+ 50.50 mg	METAS	+ 53.10 mg
GUM	+ 46.70 mg	IMGC	+ 52.80 mg

3.4 Reference value

The median of the corrected values mc_A was calculated. The value obtained is given in the following table.

Reference	Value	Expanded uncertainty *(95% coverage)*
median	+ 51.25 mg	2.1 mg

Figure 1 at the end of the document shows the corrected values mc_A of the participants with the median as reference value.

According to the previous CCM.M-K2 comparison [7], the median of the absolute deviations of the corrected masses *mc* is agreed by the participants as reference value mc_{ref}.

The uncertainty $u(mc_{ref})$ of the median, is calculated according to [6].

3.5 *Degree of equivalence of the participants*

The degree of equivalence deq_A of the A laboratory is equal to the difference $mc_A - mc_{ref}$ between the participant's corrected value and the reference value.

The uncertainty of the degree of equivalence $u(deq_A)$ takes into account the uncertainty components coming from the result given by the laboratory $u(m_A)$, the correction applied to this result $u(\bar{d})$, the drift of the travelling standard Δd (with the assumption of a rectangular distribution) and the uncertainty $u(mc_{ref})$ of the reference value :

$$u(deq_A) = \sqrt{u^2(m_A) + u^2(\bar{d}) + \frac{(\Delta d)^2}{12} + u^2(mc_{ref})} \qquad (5)$$

Table below gives the degree of equivalence deq_A of each laboratory with the assigned expanded uncertainty $U(deq)$ *(95% coverage)*.

(mg)	Median as reference value	
	deq_A	$U(deq_A)$
CEM	+ 0.8	12
SP	+ 3.4	8.4
NMIJ/AIST	+ 2.2	7.5
KRISS	- 2.8	6.2
CENAM	- 0.3	6.2
NRC	- 0.8	4.0
GUM	- 4.6	13
NPL	- 3.7	6.2
BNM-LNE	+ 0.3	8.8
NMi VSL	+ 2.3	24
PTB	- 2.2	3.3
SMU	- 1.1	8.4
METAS	+ 1.8	5.7
IMGC	+ 1.6	10

3.6 *Mass differences and uncertainties among participants*

Tables 4 to 5 give the mass differences and uncertainties for all participants. We have to distinguish between two cases, as follows.

3.6.1 Participant A and participant B of the same petal

The mass difference is independent of the measurements of the pilot laboratory.

$$\Delta m_{\mathrm{A,B}} = m_{\mathrm{A}} - m_{\mathrm{B}} \tag{6}$$

Again, the measurements of laboratory A and B are uncorrelated. The drift appears from the two measurements at the pilot laboratory at the beginning and at the end of the loop. Here, we have only one drift contribution to be considered for the mass difference between A and B.

$$u(\Delta m_{AB}) = \sqrt{u^2(m_A) + u^2(m_B) + u^2(\bar{d}) + \frac{(\Delta d)^2}{12}} \tag{7}$$

3.6.2 Participants A and B of different petals

The mass difference between A and B of two different loops is calculated by using the monitoring standard measurements as a link. The mass difference between A and B can be considered as to be independent of the measurements of the pilot laboratory.

$$\Delta m_{\mathrm{A,B}} = m_{\mathrm{A}} - m_{\mathrm{B}} \tag{8}$$

The measurements are considered uncorrelated. The uncertainty of their difference is calculated. The deviation between the travelling standard and the monitoring standard measurements is noted Δd_A for the petal of participant A and Δd_B for the petal of participant B.

$$u(\Delta m_{\mathrm{AB}}) = \sqrt{u^2(m_{\mathrm{A}}) + u^2(m_{\mathrm{B}}) + 2u^2(\bar{d}) + \frac{(\Delta d_A)^2}{12} + \frac{(\Delta d_B)^2}{12}} \tag{9}$$

The table 5 and 6 below give these results.

Table 4. Differences $\Delta m_{A,B}$ between laboratory A (left column) and laboratory B (top row)

	CEM	SP	NMIJ/AIST	KRISS	CENAM	NRC	GUM	NPL	LNE	NMi VSL	PTB	SMU	METAS	IMGC
CEM		- 2.6	- 1.4	+ 3.6	+ 1.1	+ 1.6	+ 5.3	+ 4.5	+ 0.5	- 1.5	+ 3.0	+ 1.8	- 1.0	- 0.8
SP	+ 2.6		+ 1.2	+ 6.2	+ 3.7	+ 4.2	+ 8.0	+ 7.1	+ 3.2	+ 1.2	+ 5.6	+ 4.5	+ 1.6	+ 1.9
NMIJ/AIST	+ 1.4	- 1.2		+ 5.0	+ 2.5	+ 3.0	+ 6.7	+ 5.8	+ 2.0	- 0.1	+ 4.4	+ 3.2	+ 0.4	+ 0.6
KRISS	- 3.6	- 6.2	- 5.0		- 2.6	- 2.1	+ 1.7	+ 0.8	- 3.1	- 5.1	- 0.6	- 1.8	- 4.6	- 4.4
CENAM	- 1.1	- 3.7	- 2.5	+ 2.6		+ 0.5	+ 4.3	+ 3.4	- 0.5	- 2.5	+ 2.0	+ 0.8	- 2.1	- 1.8
NRC	- 1.6	- 4.2	- 3.0	+ 2.1	- 0.5		+ 3.8	+ 2.9	- 1.0	- 3.0	+ 1.5	+ 0.3	- 2.6	- 2.3
GUM	- 5.3	- 8.0	- 6.7	- 1.7	- 4.3	- 3.8		- 0.9	- 4.8	- 6.8	- 2.3	- 3.5	- 6.4	- 6.1
NPL	- 4.5	- 7.1	- 5.8	- 0.8	- 3.4	- 2.9	+ 0.9		- 3.9	- 5.9	- 1.4	- 2.6	- 5.5	- 5.2
LNE	- 0.5	- 3.2	- 2.0	+ 3.1	+ 0.5	+ 1.0	+ 4.8	+ 3.9		- 2.0	+ 2.5	+ 1.3	- 1.6	- 1.3
NMi VSL	+ 1.5	- 1.2	+ 0.1	+ 5.1	+ 2.5	+ 3.0	+ 6.8	+ 5.9	+ 2.0		+ 4.5	+ 3.3	+ 0.4	+ 0.7
PTB	- 3.0	- 5.6	- 4.4	+ 0.6	- 2.0	- 1.5	+ 2.3	+ 1.4	- 2.5	- 4.5		- 1.2	- 4.0	- 3.8
SMU	- 1.8	- 4.5	- 3.2	+ 1.8	- 0.8	- 0.3	+ 3.5	+ 2.6	- 1.3	- 3.3	+ 1.2		- 2.9	- 2.6
METAS	+ 1.0	- 1.6	- 0.4	+ 4.6	+ 2.1	+ 2.6	+ 6.4	+ 5.5	+ 1.6	- 0.4	+ 4.0	+ 2.9		+ 0.3
IMGC	+ 0.8	- 1.9	- 0.6	+ 4.4	+ 1.8	+ 2.3	+ 6.1	+ 5.2	+ 1.3	- 0.7	+ 3.8	+ 2.6	- 0.3	

Table 5. Expanded uncertainties (95% coverage) of differences $\Delta m_{A,B}$ between laboratory A (left column) and laboratory B (top row)

	CEM	SP	NMIJ/AIST	KRISS	CENAM	NRC	GUM	NPL	LNE	NMi VSL	PTB	SMU	METAS	IMGC
CEM		14	14	13	13	12	18	13	15	27	12	14	13	15
SP	14		11	10	10	8.8	15	10	12	25	8.6	12	10	13
NMIJ/AIST	14	11		9.1	9.3	8.0	15	9.2	11	25	7.6	11	8.9	12
KRISS	13	10	9.1		8.2	6.8	14	8.2	10	25	6.4	10	7.9	12
CENAM	13	10	9.3	8.2		6.6	14	8.1	10	25	6.4	10	7.9	12
NRC	12	8.8	8.0	6.8	6.6		13	6.5	9.2	24	4.3	8.9	6.3	11
GUM	18	15	15	14	14	13		14	16	27	13	15	14	17
NPL	13	10	9.2	8.2	8.1	6.5	14		10	25	6.4	10	7.8	12
LNE	15	12	11	10	10	9.2	16	10		25	8.8	12	10	13
NMi VSL	27	25	25	25	25	24	27	25	25		24	25	25	26
PTB	12	8.6	7.6	6.4	6.4	4.3	13	6.4	8.8	24		8.4	5.6	10
SMU	14	12	11	10	10	8.9	15	10	12	25	8.4		10	13
METAS	13	10	8.9	7.9	7.9	6.3	14	7.8	10	25	5.6	10		11
IMGC	15	13	12	12	12	11	17	12	13	26	10	13	11	

4. Mass Comparator used by participants

Laboratory	Manufacturer	Type	Resolution	Standard deviation (1)	Degree of freedom
CEM	Schenk	FW18	1 mg	1.7 mg	237
SP	Sartorius	CC 50000S	1 mg	2.5 mg	50
NMIJ/AIST	Sartorius	C50000S	1 mg	4.0 mg	9
KRISS	Sartorius	CC 50001S-L	1 mg	1.6 mg	97
CENAM	Sartorius	CC 50000S	2 mg	1.5 mg	5
NRC	Sartorius	CC 50000S	1 mg	2.6 mg	18
GUM	Sartorius	CC 50001S-L	1 mg	≤ 4 mg	5
NPL	Oertling	Equal arm two pan balance	0.5 mg	6.7 mg	99
	Sartorius	CC60000 *(special edition)*	5 mg	8.7 mg	99
LNE	Sartorius *modified by SIOS*	CC 50000S *(special edition)*	2 mg	2.8 mg	126
NMi VSL	Mettler-Toledo	PK60 MC	10 mg	8.91 mg	> 13
PTB	Sauter *modified by PTB*	Equal arm, inductive position sensor	<0.001 mg	1.57 mg	29
SMU	Slovak Institute of Metrology	SMU 100 kg (2)	1 mg	1 – 2 mg	98
METAS	Mettler-Toledo	AX64004	0.1 mg	0.15 mg	infinite
IMGC	IMGC-CNR	Equal-arm (3)	1.28 V/g	0.6 mg	> 50

(1) Standard deviation of repeatability or reproducibility of the result of one comparison process
(2) 100 kg electronic mass comparator with built-in weights and loading mechanism
(3) equal-arm, electromagnetic compensation, magnetically damped, automatic, 4-position carrousel, 50 kg capacity

5. References

[1] Comité consultatif pour la masse et les grandeurs apparentées, Report of the 7th meeting 1999, BIPM, Sèvres, 1999,

[2] Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes, BIPM, Paris, 14 October 1999

[3] Weights of classes E_1, E_2, F_1, F_2, M_1, M_2, M_3, International recommendation OIML R 111, OIML, Paris 1994

[4] Guide to the Expression of Uncertainty in Measurement, International Organization for Standardization, Geneva, Switzerland, 1993

[5] Study for a 50 kg key comparison. A. GOSSET – T. MADEC
Working document for the 7th meeting of CCM 1999.

[6] Müller, J.W.: Possible advantages of a robust evaluation of comparisons, Rapport BIPM-95/2, BIPM, Sèvres 1995

[7] Draft B: CCM-M.K2 comparison of multiples and submultiples of the kilogram
11 November 2001 Dr GLAESER

Figure captions

Fig.1 Corrected results of the participants with the median chosen as reference value.

Fig.2 Travelling conditions of petal 1.

Fig.3 Travelling conditions of petal 2.

Annex

Files for Key comparison Data Base.

- figure 1 -
Corrected mass mc (expanded uncertainties 95% coverage)
median as reference value

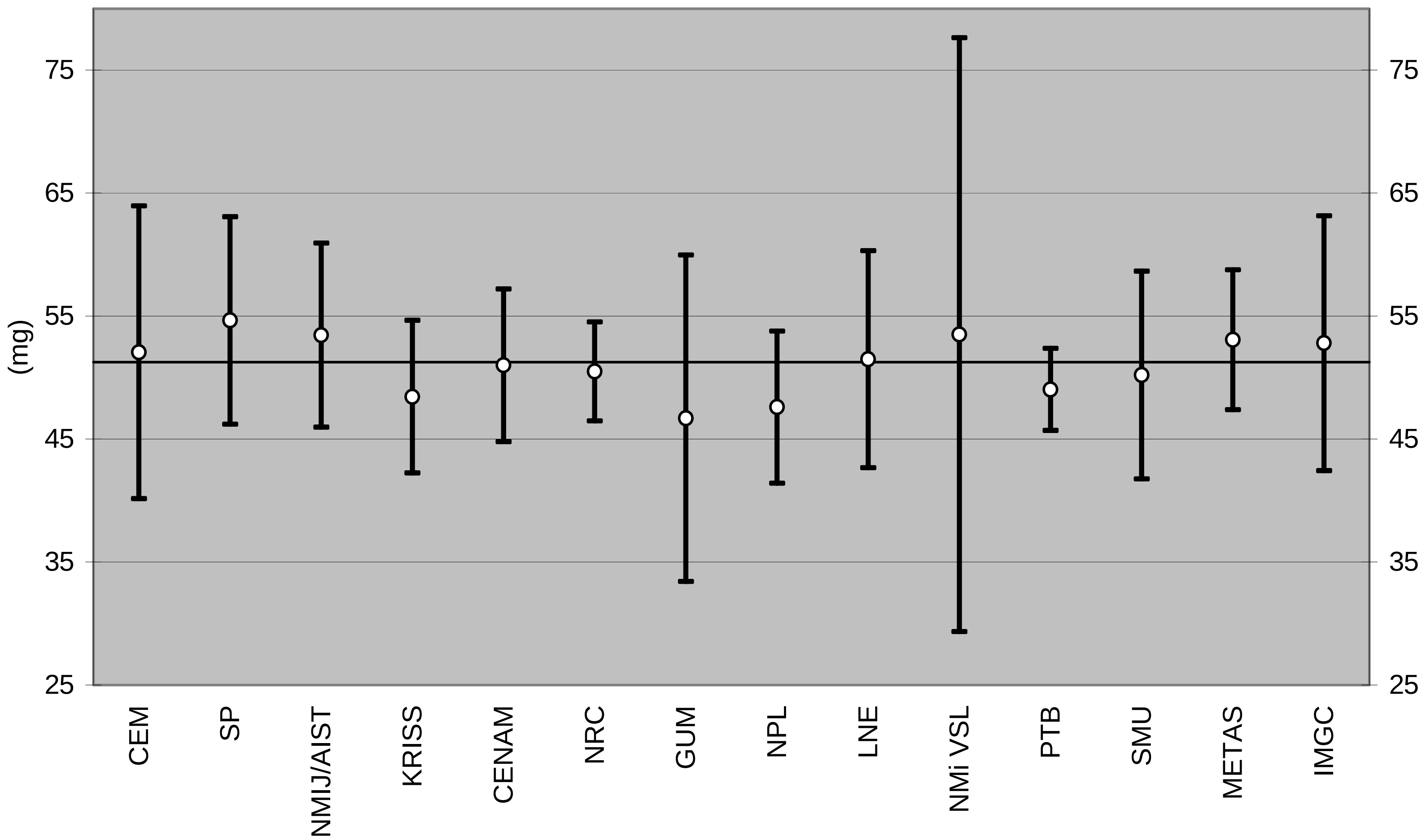


figure 2 : Travelling conditions of petal 1

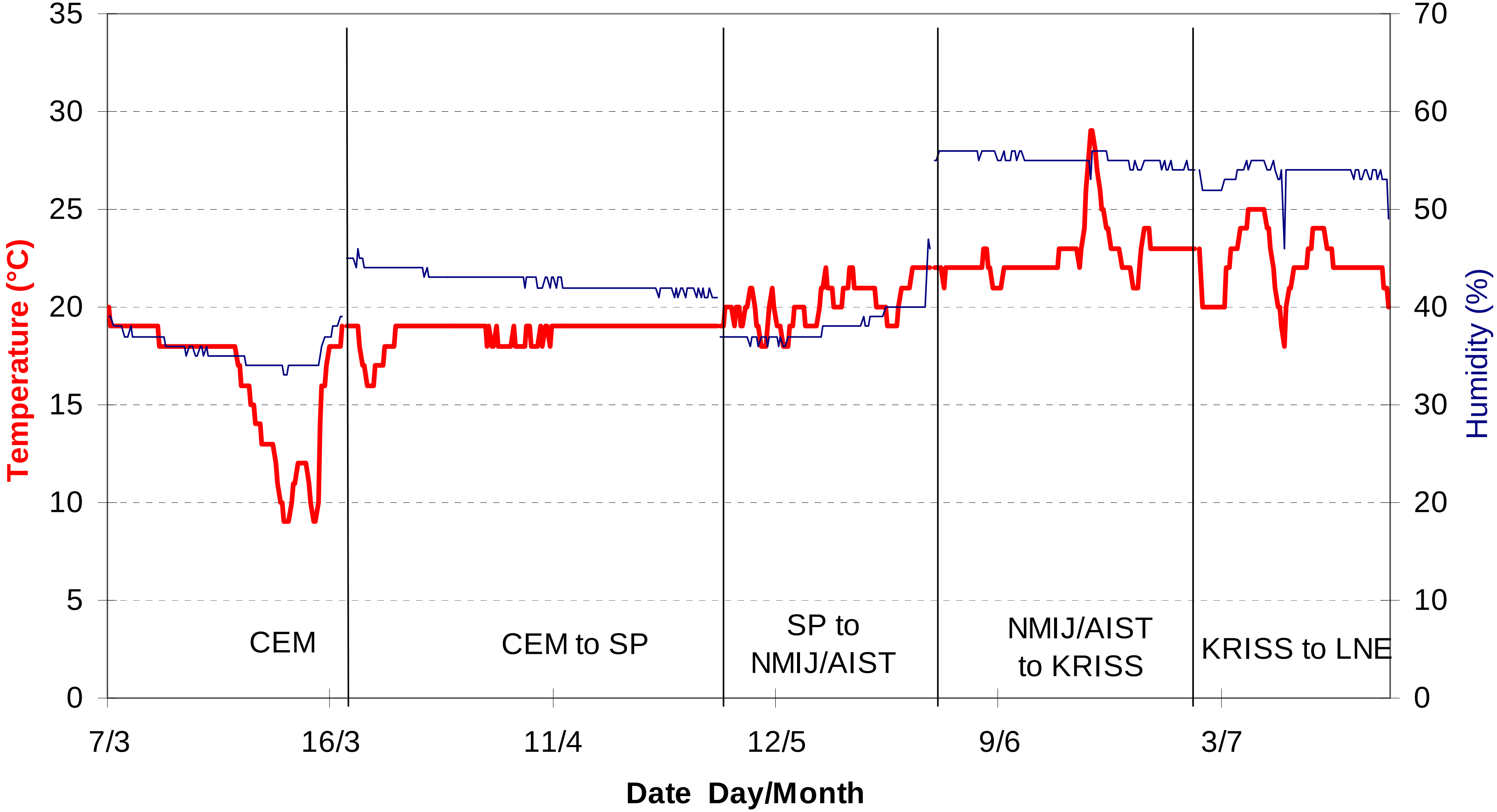
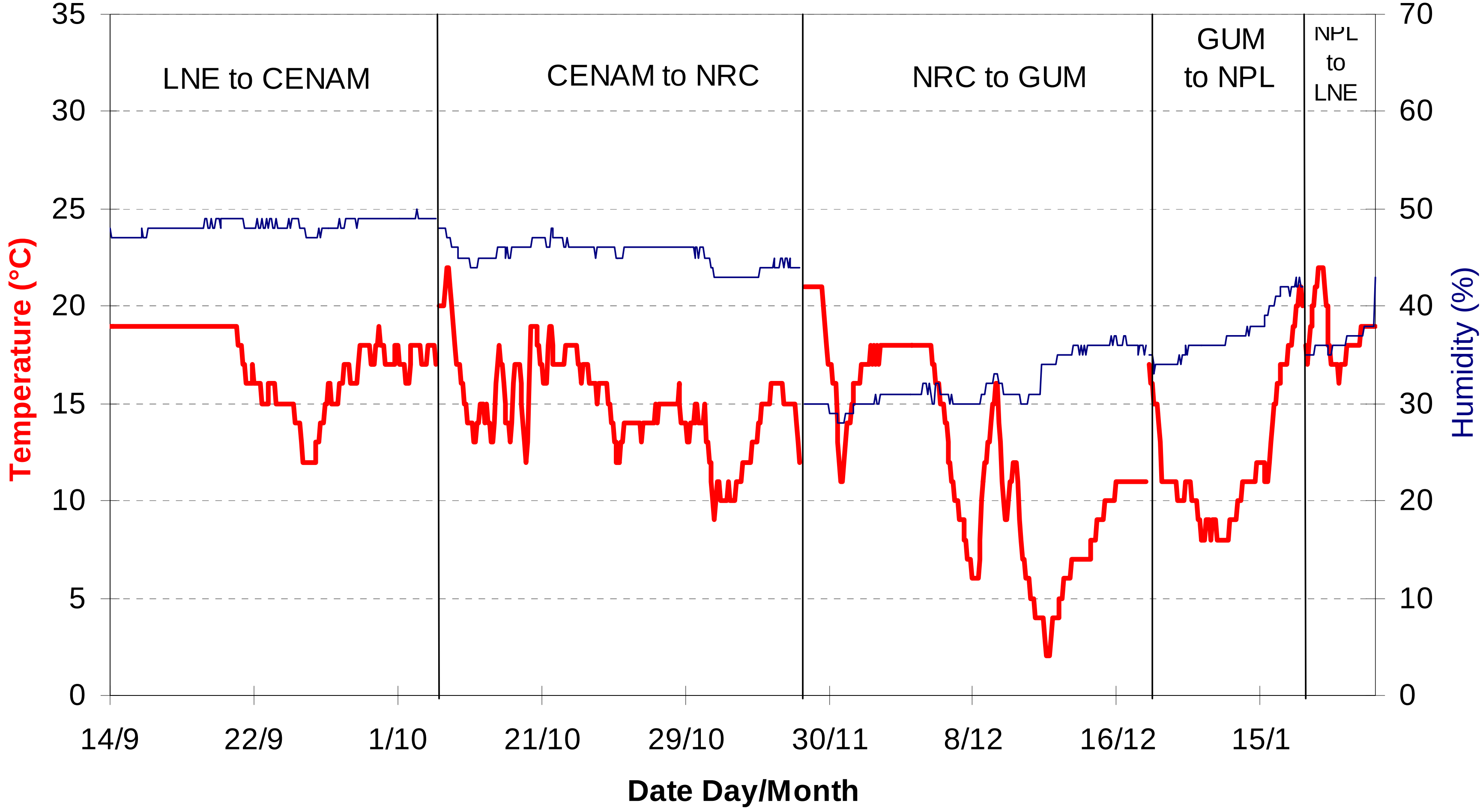


figure 3 : Travelling conditions of petal 2



ANNEX 1/4

Key comparison CCM.M-K3

MEASURAND : **Mass**
NOMINAL VALUE : **50 kg**

The comparison is organized in three petals (petal 1, 2 and 3) pivoted around the pilot laboratory, the BNM-LNE, and two different travelling standards are used.

m_i	**mass of the travelling standard measured by laboratory *i***
m_0	**mass nominal value of the travelling standard**
u_i:	**combined standard uncertainty of ($m_i - m_0$)**
d_P	**mean deviation of the travelling standard from the monitoring standard measured by the pilot before and after petal P : $d_P = d_{P(end)} - d_{P(start)}$**
m_{Ci}	**corrected result of laboratory *i* : $m_{Ci} = (m_i - m_0) - d_P$**
S/N	**travelling standard serial number**

Lab *i*	$m_i - m_0$ mg	u_i mg	S/N	d_P mg	m_{Ci} mg	Date of measurement
CEM	43.4	5.8	9	-8.7	52.1	Mar 01
SP	46.0	4.0	9	-8.7	54.7	Apr 01
NMIJ/AIST	44.8	3.5	9	-8.7	53.5	May 01
KRISS	39.8	2.8	9	-8.7	48.5	Jun 01
CENAM	42.4	2.8	9	-8.6	51.0	Oct 01
NRC	41.9	1.5	9	-8.6	50.5	Nov 01
GUM	38.1	6.5	9	-8.6	46.7	Dec 01
NPL	39.0	2.8	9	-8.6	47.6	Jan 02
BNM-LNE	18.0	4.2	6	-33.5	51.5	Jul 01
NMi-VSL	20	12	6	-33.5	54	Sep 01
PTB	15.53	0.98	6	-33.5	49.03	Oct 01
SMU	16.7	4.0	6	-33.5	50.2	Nov 01
METAS	19.6	2.5	6	-33.5	53.1	Dec 01
IMGC	19.3	5.0	6	-33.5	52.8	Jan02

	Petal 1
	Petal 2
	Petal 3

ANNEX 2/4

Key comparison CCM.M-K3

MEASURAND : **Mass**
NOMINAL VALUE: **50 kg**

The key comparison reference value, m_{CR}, is the median of the corrected laboratory results m_{Ci}. Its standard uncertainty, u_R, is obtained as the standard uncertainty of the median of the m_{Ci} values.
m_{CR} = 51.25 mg u_R = 1.1 mg

The degree of equivalence of each laboratory with respect to the reference value is given by a pair of terms:
$D_i = (m_{Ci} - m_{CR})$ and U_i, its expanded uncertainty (k = 2), both expressed in mg.
$U_i = 2.[u^2(m_i) + u^2(d_P) + (d_{P(end)} - d_{P(start)})^2/12 + u^2(m_{CR})]^{½}$

The degree of equivalence between two laboratories is given by a pair of terms:
$D_{ij} = D_i - D_j = (m_{Ci} - m_{Cj})$ and U_{ij}, its expanded uncertainty (k = 2), both expressed in mg.
Lab *i* and Lab *j* from the same petal *P* : $U_{ij} = 2.[u^2(m_i) + u^2(m_j) + u^2(d_P) + (d_{P(end)} - d_{P(start)})^2/12]^{½}$
Lab *i* and Lab *j* from different petals : $U_{ij} = 2.[u^2(m_i) + u^2(d_{Pi}) + (d_{Pi(end)} - d_{Pi(start)})^2/12 + u^2(m_j) + u^2(d_{Pj}) + (d_{Pj(end)} - d_{Pj(start)})^2/12]^{½}$

Lab *j* ⇨

Lab *i* ⇩

			CEM		SP		NMIJ/AIST		KRISS		CENAM		NRC		GUM	
	D_i / mg	U_i / mg	D_{ij} / mg	U_{ij} / mg	D_{ij} / mg	U_{ij} / mg	D_{ij} / mg	U_{ij} / mg	D_{ij} / mg	U_{ij} / mg	D_{ij} / mg	U_{ij} / mg	D_{ij} / mg	U_{ij} / mg	D_{ij} / mg	U_{ij} / mg
CEM	**0.8**	12			**-2.6**	14	**-1.4**	14	**3.6**	13	**1.1**	13	**1.6**	12	**5.3**	18
SP	**3.4**	8.4	**2.6**	14			**1.2**	11	**6.2**	10	**3.7**	10	**4.2**	8.8	**8.0**	15
NMIJ/AIST	**2.2**	7.5	**1.4**	14	**-1.2**	11			**5.0**	9.1	**2.5**	9.3	**3.0**	8.0	**6.7**	15
KRISS	**-2.8**	6.2	**-3.6**	13	**-6.2**	10	**-5.0**	9.1			**-2.6**	8.2	**-2.1**	6.8	**1.7**	14
CENAM	**-0.3**	6.2	**-1.1**	13	**-3.7**	10	**-2.5**	9.3	**2.6**	8.2			**0.5**	6.6	**4.3**	14
NRC	**-0.8**	4.0	**-1.6**	12	**-4.2**	8.8	**-3.0**	8.0	**2.1**	6.8	**-0.5**	6.6			**3.8**	13
GUM	**-4.6**	13	**-5.3**	18	**-8.0**	15	**-6.7**	15	**-1.7**	14	**-4.3**	14	**-3.8**	13		
NPL	**-3.7**	6.2	**-4.5**	13	**-7.1**	10	**-5.8**	9.2	**-0.8**	8.2	**-3.4**	8.1	**-2.9**	6.5	**0.9**	14
BNM-LNE	**0.3**	8.8	**-0.5**	15	**-3.2**	12	**-2.0**	11	**3.1**	10	**0.5**	10	**1.0**	9.2	**4.8**	16
NMi-VSL	**2**	24	**1.5**	27	**-1.2**	25	**0.1**	25	**5.1**	25	**2.5**	25	**3.0**	24	**6.8**	27
PTB	**-2.2**	3.3	**-3.0**	12	**-5.6**	8.6	**-4.4**	7.6	**0.6**	6.4	**-2.0**	6.4	**-1.5**	4.3	**2.3**	13
SMU	**-1.1**	8.4	**-1.8**	14	**-4.5**	12	**-3.2**	11	**1.8**	10	**-0.8**	10	**-0.3**	8.9	**3.5**	15
METAS	**1.8**	5.7	**1.0**	13	**-1.6**	10	**-0.4**	8.9	**4.6**	7.9	**2.1**	7.9	**2.6**	6.3	**6.4**	14
IMGC	**1.6**	10	**0.8**	15	**-1.9**	13	**-0.6**	12	**4.4**	12	**1.8**	12	**2.3**	11	**6.1**	17

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Key comparison CCM.M-K3

MEASURAND : **Mass**
NOMINAL VALUE: **50 kg**

The key comparison reference value, m_{CR}, is the median of the corrected laboratory results m_{Ci}. Its standard uncertainty, u_R, is obtained as the standard uncertainty of the median of the m_{Ci} values.
m_{CR} = 51.25 mg u_R = 1.1 mg

The degree of equivalence of each laboratory with respect to the reference value is given by a pair of terms:
$D_i = (m_{Ci} - m_{CR})$ and U_i, its expanded uncertainty (k = 2), both expressed in mg.
$U_i = 2.[u^2(m_i) + u^2(d_P) + (d_{P(end)} - d_{P(start)})^2/12 + u^2(m_{CR})]^{½}$

The degree of equivalence between two laboratories is given by a pair of terms:
$D_{ij} = D_i - D_j = (m_{Ci} - m_{Cj})$ and U_{ij}, its expanded uncertainty (k = 2), both expressed in mg.
Lab i and Lab j from the same petal P : **$U_{ij} = 2.[u^2(m_i) + u^2(m_j) + u^2(d_P) + (d_{P(end)} - d_{P(start)})^2/12]^{½}$**
Lab i and Lab j from different petals : **$U_{ij} = 2.[u^2(m_i) + u^2(d_{Pi}) + (d_{Pi(end)} - d_{Pi(start)})^2/12 + u^2(m_j) + u^2(d_{Pj}) + (d_{Pj(end)} - d_{Pj(start)})^2/12]^{½}$**

Lab *j* ⇨

Lab *i* ⇩

			NPL		BNM-LNE		NMi-VSL		PTB		SMU		METAS		IMGC	
	D_i / mg	U_i	D_{ij} / mg	U_{ij}	D_{ij} / mg	U_{ij}	D_{ij} / mg	U_{ij}	D_{ij} / mg	U_{ij}	D_{ij} / mg	U_{ij}	D_{ij} / mg	U_{ij}	D_{ij} / mg	U_{ij}
CEM	0.8	12	4.5	13	0.5	15	-1.5	27	3.0	12	1.8	14	-1.0	13	-0.8	15
SP	3.4	8.4	7.1	10	3.2	12	1.2	25	5.6	8.6	4.5	12	1.6	10	1.9	13
NMIJ	2.2	7.5	5.8	9.2	2.0	11	-0.1	25	4.4	7.6	3.2	11	0.4	8.9	0.6	12
KRISS	-2.8	6.2	0.8	8.2	-3.1	10	-5.1	25	-0.6	6.4	-1.8	10	-4.6	7.9	-4.4	12
CENAM	-0.3	6.2	3.4	8.1	-0.5	10	-2.5	25	2.0	6.4	0.8	10	-2.1	7.9	-1.8	12
NRC	-0.8	4.0	2.9	6.5	-1.0	9.2	-3.0	24	1.5	4.3	0.3	8.9	-2.6	6.3	-2.3	11
GUM	-4.6	13	-0.9	14	-4.8	16	-6.8	27	-2.3	13	-3.5	15	-6.4	14	-6.1	17
NPL	-3.7	6.2			-3.9	10	-5.9	25	-1.4	6.4	-2.6	10	-5.5	7.8	-5.2	12
BNM-LNE	0.3	8.8	3.9	10			-2.0	25	2.5	8.8	1.3	12	-1.6	10	-1.3	13
NMi-VSL	2.3	24	5.9	25	2.0	25			4.5	24	3.3	25	0.4	25	0.7	26
PTB	-2.2	3.3	1.4	6.4	-2.5	8.8	-4.5	24			-1.2	8.4	-4.0	5.6	-3.8	10
SMU	-1.1	8.4	2.6	10	-1.3	12	-3.3	25	1.2	8.4			-2.9	10	-2.6	13
METAS	1.8	5.7	5.5	7.8	1.6	10	-0.4	25	4.0	5.6	2.9	10			0.3	11
IMGC	1.6	10	5.2	12	1.3	13	-0.7	26	3.8	10	2.6	13	-0.3	11		

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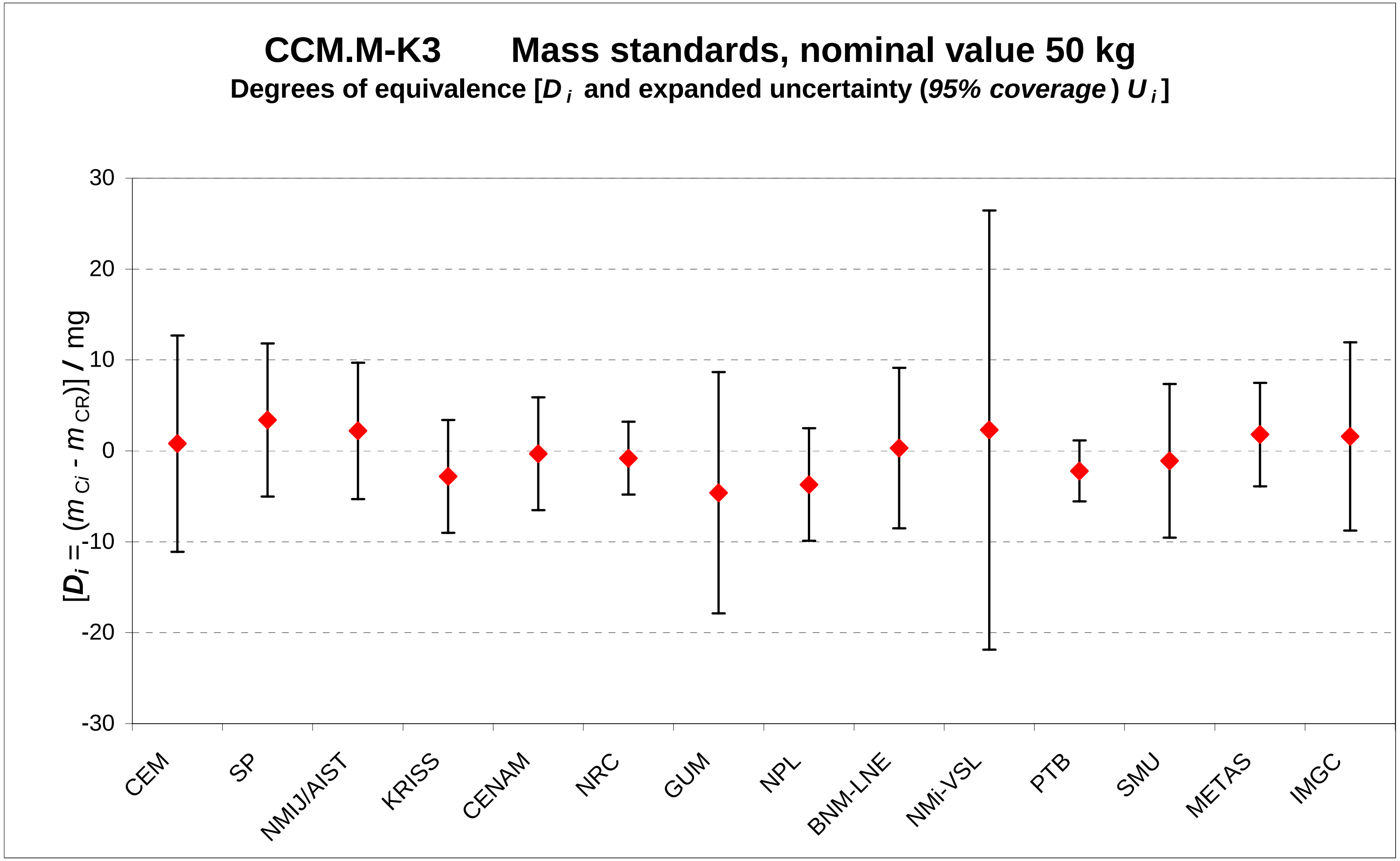

CCM.M-K3 Mass standards, nominal value 50 kg
Degrees of equivalence [D_i and expanded uncertainty (*95% coverage*) U_i]
[D_i = (m_{Ci} - m_{CR})] / mg
30
20
10
0
-10
-20
-30
CEM
SP
NMIJ/AIST
KRISS
CENAM
NRC
GUM
NPL
BNM-LNE
NMi-VSL
PTB
SMU
METAS
IMGC