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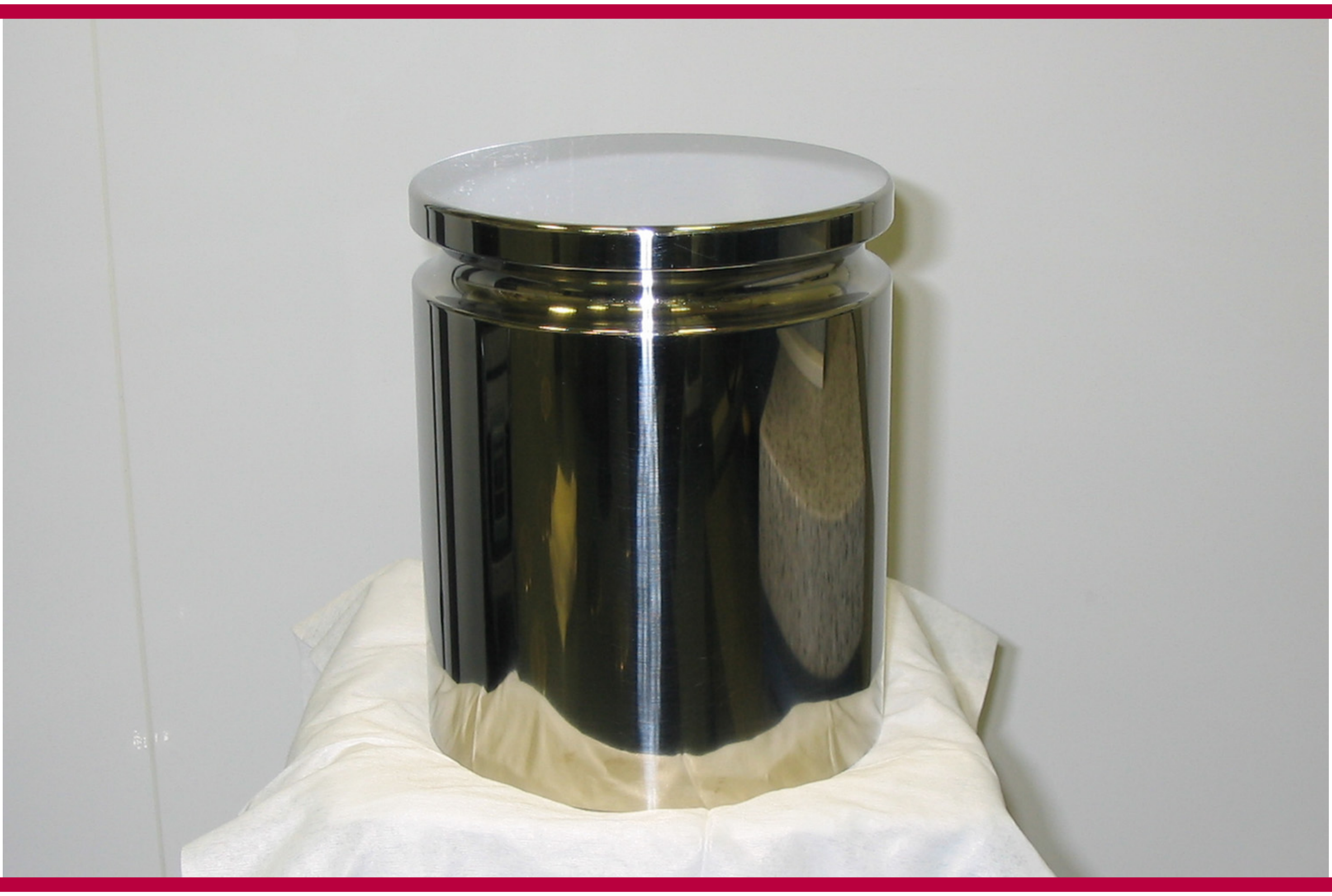

Euromet 832: 50 kg comparison

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Mittatekniikan keskus

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Abstract

A 50 kg mass comparison between five national laboratories (Metrosert, MIKES, EIM, LNMC, JV) was carried out in 2004-2006. MIKES was the pilot laboratory. The results show a good agreement between the laboratories. After the comparison a link to PTB and to CCM.M-K3 was established. The reference value of this comparison, PTB result and the CCM.M-K3 reference value agree within the uncertainties.

Tiivistelmä

Mittatekniikan keskus (MIKES) ja neljä muuta kansallista laboratoriota Euroopasta osallistuivat 50 kg punnuksen vertailuun. Vertailu toteutettiin 2004-2006. Vertailun koordinaattorina oli MIKES. Laboratorioiden tulosten välillä oli hyvä yhtäpitävyys. Vertailun jälkeen punnus lähetettiin PTB:lle, josta saatiin vertailuarvo ja linkki CCM.M-K3 avainvertailuun. Vertailun referenssiarvon, PTB:n tuloksen ja CCM.M-K3 referenssiarvon välillä oli epävarmuudet huomioon ottaen hyvä yhtäpitävyys.

Contents

1 Introduction

The EUROMET 832: 50 kg comparison was originally planned as a bilateral comparison between MIKES and Metrosert to test the new mass comparator of Metrosert. There was also interest to extend the comparison to other laboratories. Finally, five national laboratories took part to the comparison. The travelling standard was also measured by PTB in order to get a link to the corresponding CCM comparison.

2 Organisation

2.1 Participating laboratories

Five laboratories participated.

Laboratory		***Country***
AS Metrosert	Metrosert	Estonia
Centre for Metrology and Accreditation	MIKES	Finland
Hellenic Institute of Metrology	EIM	Greece
Latvian National Metrology Centre Ltd	LNMC	Latvia
Justervesenet	JV	Norway

2.2 Comparison scheme

A travelling standard of 50 kg was circulated among the participants. The travelling scheme was the following: MIKES – Metrosert – LNMC – MIKES – JV – EIM – MIKES. At MIKES the mass of the travelling standard was determined three times. The result of the first measurement was used in the comparison. The other two measurements were used to monitor the stability of the weight.

2.3 Characteristics of the mass standard

The travelling standard was manufactured by MIKES from a single piece of stainless steel (W No 1.4439). The form of the weight is a cylinder with a lifting groove. The characteristics of the standard are given in Table 1. The standard has no identification mark. The MIKES number of the weight is P20 50kg.

The density of the travelling standard was determined from test pieces cut from the same raw material as the weight.

Table 1: Characteristics of the travelling standard

Parameter	Value	Expanded uncertainty (k=2)
Density	8003,8 kg/m^3	3,0 kg/m^3
Magnetic susceptibility	0,003	0,001
Height	225,3 mm	0,5 mm
Diameter	190,0 mm	0,5 mm
Centre of gravity from base	111 mm	1 mm

2.4 Travelling methods

The weight was transported to the first two laboratories by car. The weight was packed to its own storage box made of plywood.

To the other two laboratories the weight was transported by commercial air freight. The storage box was packed into a plastic transport box. The total weight of the box was about 60 kg. No damage to the packages or to the standard was observed.

3 Results of the comparison

3.1 Stability of the travelling mass standard

The MIKES laboratory monitored the stability of the travelling standard by measuring its mass against five 10 kg standards which were made from the same material as the travelling standard. These comparisons were made at the beginning, in the middle and at the end of the circulation.

The results of the stability comparison are given in Table 2. The standard uncertainty of the mass stability value d contains only the contributions which are relevant for the determination of mass change. They are the mass difference between the travelling standard and the monitoring standard, stability of the monitoring standard, air buoyancy difference and the linearity of the mass comparator. The uncertainty of d_{av} is the uncertainty of the average of the three d values. The drift Δd is less than the uncertainty with which it can be determined. Therefore, no correction was made for the drift in the travelling standard. The uncertainty due to the drift is included in the uncertainty budget. The average mass stability value is needed for the link value.

Table 2: The mass stability value of the travelling standard *d*, its uncertainty and its change $\Delta d = max(d)-min(d)$ during the comparison. The average mass stability value d_{av} and its estimated uncertainty are also given.

Date	Quantity	Value (*d* - 50 kg)	Standard uncertainty (k=1)
November 2004	*d*	196,1 mg	3 mg
April 2005	*d*	196,7 mg	3 mg
January 2006	*d*	194,8 mg	3 mg
Average	d_{av}	195,9 mg	2,5 mg
Drift	Δd	1,9 mg	

3.2 Results reported by the participants

Table 3 shows the results and the uncertainties as given by the participants. All participants have used the coverage factor k=2. The results are also given in Fig. 1.

Table 3. Reported results of the participants

Laboratory	*Date*	$m_A - m_0$	$u(m_A)$	$U(m_A)$
MIKES	Oct 2004	196 mg	10 mg	20 mg
Metrosert	Dec 2004	199 mg	6 mg	12 mg
LNMC	Jan 2005	209 mg	17 mg	34 mg
JV	Jun 2005	187,2 mg	7,6 mg	15,2 mg
EIM	Aug 2005	196,3 mg	5,5 mg	10,9 mg

In Table 3, m_A is the mass of the travelling standard, m_0 is the nominal mass value, $u(m_A)$ is standard uncertainty and $U(m_A)$ is expanded uncertainty.

3.3 Corrections to the results

No corrections to the original results were made since all participants measured the same travelling standard and the drift of the travelling standard was negligible .

3.4 Reference value

The weighed mean of all participants was taken as the reference value. The reference value and its uncertainty were calculated using formulas in Ref. [1]. The reference value and its standard uncertainty are given in Table 4.

Table 4. Reference value m_{ref} and its standard uncertainty $u(m_{ref})$.

Reference value	$m_{ref} - m_0$	$u(m_{ref})$
Weighed mean	195,8	3,3 mg

Additionally, the median m_{median} and its standard uncertainty u_{median} were calculated according to Ref. [2]. The results were $m_{median} - m_o$ = 196,3 mg and u_{median} = 2,5 mg.

Because of the small number of participants the uncertainty of the median is not very reliable. Nevertheless the difference between the weighed mean and the median is not significant. Since there are no outliers (the χ^2 - test [1] was passed) the weighed average was chosen as the reference value. Covariances between the laboratory values were not considered to be significant.

3.5 Degree of equivalence of the participants

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

The uncertainty of the degree of equivalence $u(deg_A)$ has the following uncertainty components; the uncertainty given by the laboratory $u(m_A)$, the uncertainty of drift of the travelling standard $\Delta d/\sqrt{12}$ (rectangular distribution), the uncertainty of the determination of the drift $u(d_{av})$ and the uncertainty of the reference value $u(m_{ref})$.

$$u(deq_A) = \sqrt{u^2(m_A) + \frac{(\Delta d)^2}{12} + u^2(d_{av}) - u^2(m_{ref})} \quad (1)$$

The correlation between the laboratory value and the reference value is included in Eq. 1 (see Ref [1], Eq. 5).

Table 5 gives the degree of equivalence deq_A of each laboratory with assigned uncertainty $U(deg_A)$ (95 % coverage). The results are also shown in Fig. 2.

Table 5. Degree of equivalence

	deq_A mg	$U(deg_A)$ mg
MIKES	0,2	19,0
Metrosert	3,2	11,3
LNMC	13,2	33,8
JV	-8,6	14,6
EIM	0,5	10,1

3.6 Mass differences and uncertainties between participants

Table 6 gives the mass differences and uncertainties between participants. The mass difference is independent of the reference value. The following formulas were used:

$$\Delta m_{A,B} = m_A - m_B \quad (2)$$

$$U(\Delta m_{A,B}) = 2 \cdot \sqrt{u_A^2 + u_B^2 + u^2(d_{av}) + \frac{(\Delta d)^2}{12}} \quad (3)$$

Table 6. Differences $\Delta m_{A,B}$ between laboratory A (left column) and laboratory B (top row) and the corresponding expanded uncertainties (95 % coverage) $U_{A,B}$.

	MIKES		Metrosert		LNMC		JV		EIM	
	$\Delta m_{A,B}$ mg	$U_{A,B}$ mg	$\Delta m_{A,B}$ mg	$U_{A,B}$ mg	$\Delta m_{A,B}$ mg	$U_{A,B}$ mg	$\Delta m_{A,B}$ mg	$U_{A,B}$ mg	$\Delta m_{A,B}$ mg	$U_{A,B}$ mg
MIKES			-3	23,4	-13,0	39,5	8,8	25,4	-0,3	22,8
Metrosert	3	23,4			-10	36,4	11,8	20,0	2,7	17,0
LNMC	13,0	39,5	10	36,4			21,8	37,6	12,7	36,1
JV	-8,8	25,4	-11,8	20,0	-21,8	37,6			-9,1	19,4
EIM	0,3	22,8	-2,7	17,0	-12,7	36,1	9,1	19,4		

4 Mass Comparators used by the participants

Table 7 gives some information on the mass comparators.

Table 7. Mass comparators

Laboratory	Manufacturer	Type	Resolution	Standard deviation[1]	Weight handling
MIKES	Mettler-Toledo	KA 50	5 mg	10 mg	Automatic
Metrosert	Mettler-Toledo	AX64004	0,1 mg	0,2 mg	Automatic
LNMC	Sartorius	CC50002	10 mg	9 mg	Manual
JV	Sartorius	CC50000S	1 mg	5 mg	Automatic
EIM	Sartorius	CC50001S-L	1 mg	2 mg	Automatic

[1] The standard deviation is the repeatability or reproducibility of the result of one comparison process.

5 Mass standards used by the participants

Some details of the mass standards used in this comparison are given in Table 8.

Table 8. Mass standards

Laboratory	Description	No of reference sets	Density	*U(density)*	*U(mass)*	Standards calibrated by
MIKES	5*10 kg	1	8006 kg/m^3	2,6 kg/m^3	7 mg	MIKES
Metrosert	3*10 kg + 20 kg	2	8011 kg/m^3	2,6 kg/m^3	9,5 mg	Metrosert
LNMC	2*20 kg + 10 kg	1	8000 kg/m^3	80 kg/m^3	28 mg	LNMC, DFM
JV	50 kg	1	8053 kg/m^3	5 kg/m^3	13,2 mg	JV
EIM	50 kg	2	8009 kg/m^3	2,5 kg/m^3	10 mg	PTB

6 Uncertainty budgets given by the participants

A summary of uncertainty components is given in Table 9.

Table 9. The main uncertainty components.

Uncertainty component / LAB	*MIKES mg*	*Metrosert mg*	*LNMC mg*	*JV mg*	*EIM mg*
reference mass	3,5	4,7	14,0	6,6	5,0
air buoyancy	1,85	1,87	0,5	2,3	1,8
mass difference	5,0	0,2	2,2	0,951	0,76
Mass comparator	5,8	3,0	9,0	0,29	0,96
Reproducibility	5,0	1,5		2,69	1,12
Combined standard uncertainty	**10,0**	**6,2**	**17,0**	**7,6**	**5,4**
No of measurements (days x No/day)	6 x 90	12 x 40	35	9 x 20	6 x 9
Coverage factor (95 % coverage)	2	2	2	2	2

7 Environmental conditions

Table 10 gives the minimum and maximum values for environmental parameters in the laboratories during the comparison.

Table 10. Environmental conditions during the comparison

Quantity / LAB	*MIKES*		*Metrosert*		*LNMC*		*JV*		*EIM*	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
Temperature (°C)	20,2	20,8	19,7	19,8	20	20,7	20,7	20,7	22,9	23,2
Pressure (hPa)	1011	1024	993	1019	995	1015	995	1017	1006	1020
Humidity (%RH)	40	45	39	44	44	49	49	50	49	61
Air density (kg/m^3)	1,200	1,212	1,177	1,209	1,184	1,198	1,174	1,200	1,177	1,193

8 Link to the CCM.M-K3 comparison

None of the participants took part to the CCM 50 kg comparison [3]. To have a link to a laboratory which participated the CCM comparison the travelling standard was sent to PTB for mass determination. Before and after the measurements at PTB the mass of the standard was determined at MIKES against the same monitoring standards as were used in the comparison. These measurements were made in June – July 2006 and in September 2006. A summary of the results is given in Table 11 and in Fig. 3.

The monitoring standards were calibrated three times during this comparison. In the first two calibrations no mass change was observed. In the last calibration (September 2006) an increase of the monitoring mass of about 1,1 mg from the previous value was observed. This change was made to the stability values before and after the PTB measurements.

Table 11. Results for the transfer standard from the link measurements.

Mass value	m_0 *(kg)*	m-m_0 (mg)	u (mg)	$U(k=2)$ (mg)
ref value	50	195,8	3,3	6,6
average stability value (ref)	50	195,9	2,6	
stability value (before PTB)	50	194,6	3,0	
PTB value	50	199	2,0	4,0
stability value (after PTB)	50	197,1	3,0	
average stability value (PTB)	50	195,8	2,6	
change of stability value (PTB – ref)	0	-0,1	3,7	
difference: reference value – PTB	0	-3,2	5,3	10,6
difference: PTB – CCM.M-K3 [3]	0	-2,2	1,65	3,3
CCM.M-K3 value (estimated)	50	201,2	2,6	5,2
difference: reference value – CCM.M-K3	0	-5,4	5,6	11,2

The mass difference between the reference value and the PTB value was calculated to be -3 mg with an expanded uncertainty of 11 mg. The uncertainty contains the following components: reference value, PTB value and two average stability values.

PTB has taken part to the CCM 50 kg key comparison. At the CCM comparison the PTB result was 2,2 mg lower than the CCM reference value. If the PTB value for the travelling standard is corrected with this result the difference between the reference values of this comparison and the CCM comparison is -5 mg (U=12 mg).

Table 12 gives the calculated mass differences between the participating laboratories and PTB. Also mass differences between the participating laboratories and the estimated CCM.M-K3 comparison reference value are given. The uncertainty between laboratory A and the CCM.M-K3 reference value includes the following components: laboratory value $u(m_A)$, the difference between the PTB value and the CCM reference value, PTB value and two average stability values.

Table 12. Mass differences between the laboratories and PTB and the calculated CCM.M-K3 reference value with expanded uncertainties.

	m_{lab}-m_{PTB}	*U (k=2)*	m_{lab}-m_{ccm}	*U (k=2)*
	mg	mg	mg	mg
MIKES	-3	22	-5	23
Metrosert	0	15	-2	16
LNMC	10	35	8	36
JV	-12	17	-14	18
EIM	-3	14	-5	15

Because the 50 kg mass standards of EIM have been calibrated by PTB there is a correlation between the EIM mass values and the PTB mass values. There is also a correlation between the PTB values at CCM.M-K3 comparison and at this comparison. Because of the relatively large uncertainties in this comparison these correlations were not considered to be very significant.

9 Conclusions

The results of this 50 kg comparison shows good agreement between the participating laboratories. A link to PTB and to the reference value of the CCM.M-K3 comparison was established. The difference between the reference value of this comparison and the CCM.M-K3 comparison agree within the calculated uncertainties.

10 Acknowledgements

The authors want to tank Michael Borys for the link to PTB and Stuart Davidson for useful comments to the manuscript.

11 References

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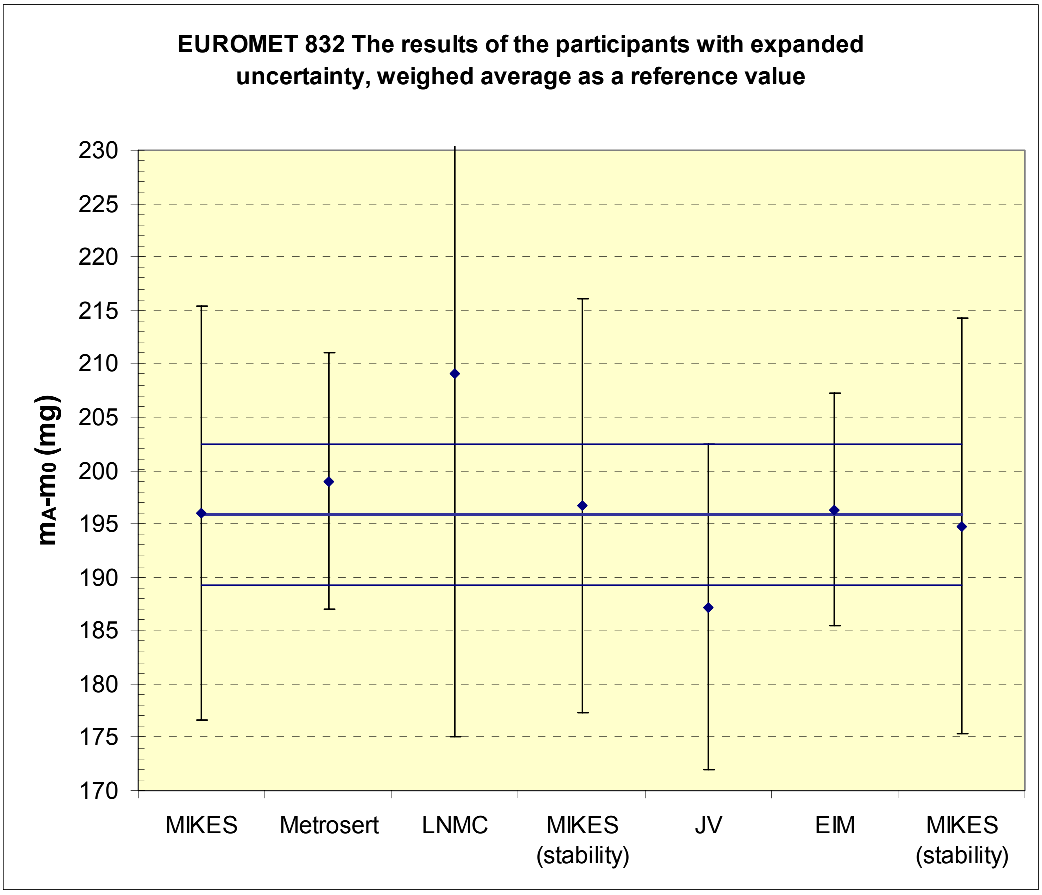

Fig 1. Original results from the participants with expanded uncertainties. The thick solid line is the reference value and the thin solid line is the expanded uncertainty of the reference value.

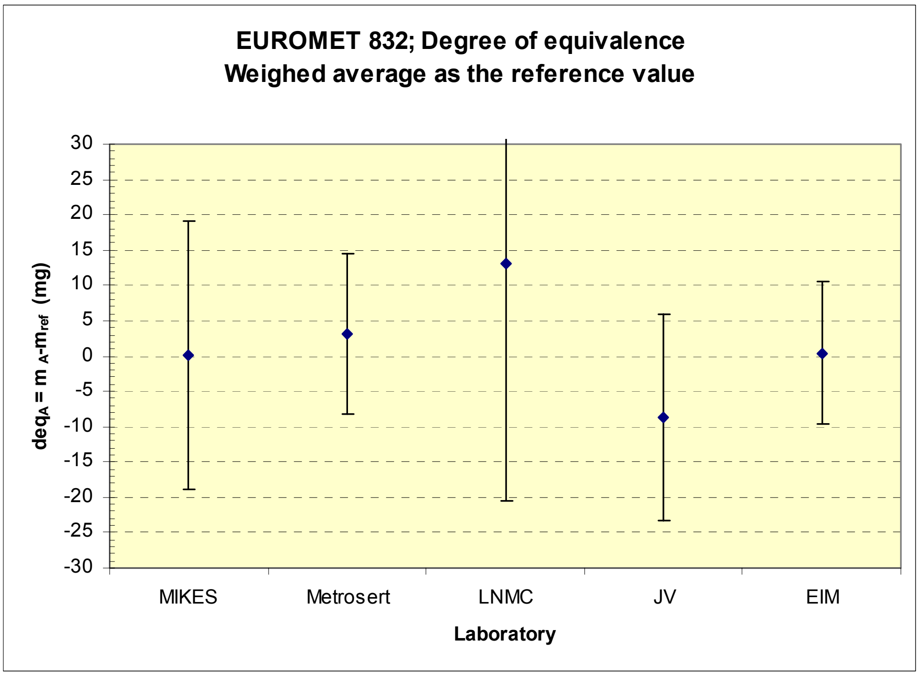

Fig 2. Degree of equivalence deq_A and the expanded uncertainty $U(deq_A)$

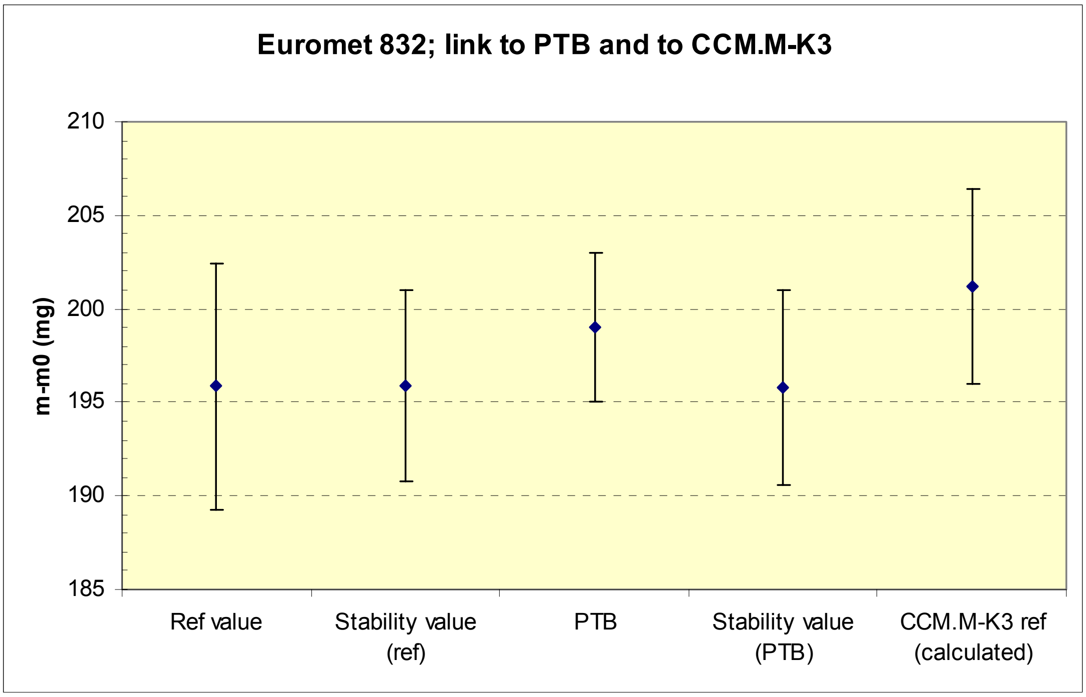

Fig 3. The reference value of the comparison, stability values and the link values with expanded uncertainties.

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