

**Final Report on the  
EURAMET SUPPLEMENTARY COMPARISON OF MASS STANDARDS  
20 kg**

Comparison: EURAMET.M.M-S11 (1550)

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## 1. Abstract

In order to validate the participants' calibration measurement capabilities (CMCs) and to provide a basis for the submission of reviewed or new CMCs for National Metrology Institutes of member countries of the "Comité International des Poids et Mesures" (CIPM), supplementary comparisons of mass standards have been carried out under the auspices of the EURAMET. This is a comparison of the 20 kg stainless steel mass standard. The aim of this supplementary comparison was to compare the results obtained by NMIs in the calibration of 20 kg stainless steel weights. BEV, Austria was the pilot laboratory. Measurements were performed between 15 May 2022 – 28 June 2024.

The data analysis was carried out by Dr. Lars Nielsen (DFM).

The participants' results were in agreement with the comparison reference value except one laboratory (SMU, Slovakia), after two laboratories updated their values.

## 2. Introduction

This is a comparison of the 20 kg stainless steel mass standard. The objectives of the comparison were to validate the participants' calibration measurement capabilities (CMCs) and provide a basis for the submission of reviewed or new CMCs. The comparison was undertaken within the EURAMET. The comparison was piloted by BEV, Austria. It was initiated after the COOMET comparison became unfeasible due to the restrictions caused by the political situation.

The comparison was organised in three petals with stability measurement between petals.

13 laboratories measured the conventional (and true) mass of the travelling standard between May 2022 and May 2024. Note: NSC-IM was not able to make measurements due to the situation in Ukraine.

## 3. Participants

13 National Metrology Institutes took part in this key comparison. Among the participants, 12 are from EURAMET<sup>1</sup> members, and one is from GULFMET<sup>2</sup>

The participating laboratories are listed in Table 1.

Table 1

National Institute of Metrology	Acronym	Country
Bundesamt für Eich- und Vermessungswesen (Federal Office of Metrology and Surveying)	BEV	Austria
Bureau Luxembourgeois de Métrologie	ILNAS	Luxembourg
FPS Economy, DG Quality and Safety, Metrology Division	SMD	Belgium
Instituto Português da Qualidade	IPQ	Portugal
Slovenský Metrologický Ústav	SMU	Slovakia
Bulgarian Institute of Metrology	BIM	Bulgaria
Latvian National Metrology Centre Ltd. Metrology Bureau	LNMC LATMB	Latvia
Directorate of Measures and Precious Metals	DMDM	Serbia
Bureau of Metrology	BoM	North Macedonia
Kosovo Metrology Agency	KMA	Republika e Kosovës
Institutul Național de Metrologie	NIM -MD	Moldova
National Measurement and Calibration Center	SASO-NMCC	Saudi Arabia
Van Swinden Laboratorium	VSL	Netherlands

<sup>1</sup> European Association of National Metrology Institutes

<sup>2</sup> Gulf Association for Metrology

#### 4. MASS COMPARATOR USED BY PARTICIPANTS

The weighing instruments used by participating laboratories are listed in table 2.

Table 2. Weighing Instruments used by participant laboratories.

NMI	Manufacturer	Type	Range	Resolution	Standard deviation of balance
BEV	BEV, Sartorius	Robot comparator based on CC20000 mass comparator	20 kg	1 mg	0,03 mg, 10 cycles ABA
ILNAS	Radwag	Mass comparator APP 30.4Y.KO	30,5 kg	1 mg	3,3 mg for 6 cycles ABBA
SMD	Radwag	Mass comparator Radwag AKM 2/20	20,5 kg	0,1 mg	3 mg for 10 cycles ABBA
		Sartorius C2000 S	500 g- 2 kg	0,01 mg	0,017 mg for 10 cycles
IPQ	August Sauter GmbH	Mechanical equal-arms balance	50 kg	5 mg	0,8 mg for 10 cycles ABBA
SMU	Mettler Toledo	Mass comparator KA-30/P	23 kg	2 mg	2 mg for 10 cycles ABBA
BIM	Mettler Toledo	Automatic mass comparator AX64004	64 kg	0,1 mg	0,4 mg for 10 cycles ABBA
LNMC LATM	Sartorius AG,	Mass comparator CC50002	61 kg	10 mg	2,9 mg for 30 cycles ABBA
DMDM	Sartorius AG,	Automatic mass comparator CC1000SL	1 kg	0,001 mg	0,002 mg for 120 cycles ABBA
	Sartorius AG,	Automatic mass comparator CC10000	10 kg	0,1 mg	0,2 mg for 120 cycles ABBA
	Sartorius AG,	Mass comparator CC20000	20 kg	1 mg	1 mg for 10 cycles ABBA
BoM	Sartorius AG,	Automatic mass comparator CC10000U-L	10,05 kg	0,01 mg	0,09 mg for 10 cycles ABBA
	Sartorius AG,	Automatic mass comparator CC500001S-L	51 kg	1 mg	1,23 mg for 10 cycles ABBA
KMA	Sartorius AG,	Mass comparator CCE 40K3	41 kg	2 mg	3 mg for 6 cycles ABBA
NIM -MD	Sartorius AG,	Mass comparator CCE 40K3	41 kg	2 mg	3,3 mg for 6 cycles ABBA
SASO- NMCC	Mettler Toledo	AX64004	64 kg	0,1 mg	0,2 mg
VSL	Voland	Voland 4050	20 kg	0,1 mg	0,3 mg, 5 cycles ABA

**Note:** Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by any of the participating organisations nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

## 5. TRAVELLING STANDARD

The travelling standard for this comparison was a 20 kg weight (stainless steel, OIML-form). The travelling standard and transportation box are presented in Picture 1.



Picture 1. The mass standard inside the box

The properties of the mass standard have been determined by BEV and are listed in Table 3.

Table 3. Data on the travelling standard

Identification	N
Nominal Value	20 kg
Density at 20 °C	7950,0 kg/m <sup>3</sup>
Standard uncertainty	1,4 kg/m <sup>3</sup>
Coefficient of cubic expansion	48 10 <sup>-6</sup> °C <sup>-1</sup>
Magnetic susceptibility	< 0,004
The centre of gravity height	101,3 mm, u(k=1)=0,2 mm
Height	224,3 mm
Diameter (head/bottom)	127,6 mm / 111,8 mm

## 6. CIRCULATION OF THE TRAVELLING STANDARD

For this comparison, the weight was circulated among participants according to the dates listed in Table 4. It took somewhat more time due to the customs delays and the fact that some laboratories joined later in the comparison.

BEV measured the mass of the standards at the beginning, three times in between and at the end of the circulation in order to evaluate the stability of the transfer standard.

Table 4. Circulation of the transfer standard

NMI	Arrival date	Departure date
BEV1	–	30.06.2022
ILNAS	01.07.2022	13.07.2022
SMD	18.07.2022	30.07.2022
IPQ	17.08.2022	12.09.2022
SMU	24.09.2022	20.01.2023
BIM	31.01.2023	08.02.2023
BEV2	12.02.2023	25.02.2023
LNMC LATMB	13.04.2023	27.04.2023
DMDM	05.05.2023	05.06.2023
BoM	05.06.2023	30.06.2023
KMA	03.07.2023	08.08.2023
NIM -MD	28.08.2023	26.10.2023
BEV3	12.11.2023	02.04.2024
SASO-NMCC	22.04.2024	21.05.2024
BEV4	07.06.2024	19.06.2024
VSL	19.06.2024	08.07.2024
BEV5	09.07.2024	–

## 7. Summary of the participants' results

Each participating laboratory was requested to provide the following information to the pilot laboratory:

- The conventional mass value of the travelling standard and the associated uncertainty.
- The mass value of the travelling standard and without uncertainty.
- Details of the balance used in the comparison.
- Details on the mass standards used, including their traceability.
- Laboratory conditions during the measurements.
- Uncertainty calculation of the conventional mass value.

The uncertainty claimed by each participant had to be supported by the relevant uncertainty budget, which followed the template provided in the technical protocol. The project has not collected uncertainty for the true mass result because, in most of the laboratories, it is not significantly different.

The results of laboratories are listed in Table 5 as

$$y_i = m_i - m_0$$

where

$y_i$ : is the mass of the travelling standard as reported by Participant  $i$

$m_0$ : is the nominal mass of the travelling standard, 20 kg.

Table 5. Results as reported by participants

NMI	Starting date of the measurements	$y_i$		$u_{\text{lab}}(y_i)$
		True mass	Conventional mass	Uncertainty (k=1)
		mg	mg	mg
BEV1	18.05.2022	30,90	12,10	0,55
ILNAS	06.07.2022	31,8	13,0	5,0
SMD	18.07.2022	34,0	15,1	1,7
IPQ	26.08.2022	33,3	14,4	2,6
SMU	04.11.2022	18,1	-0,8	2,5
BIM	02.02.2023	36,1	17,3	4,0
BEV2	23.02.2023	30,30	11,50	0,55
LATMB	14.04.2023	37,6	19,3	5,0
DMDM	08.05.2023	33,3	14,4	1,7
BoM1	05.06.2023	26,1	7,2	1,7
BoM2	05.06.2023	36,0	17,0	1,7
BoM3	05.06.2023	28,7	9,8	1,7
KMA	06.07.2023	27,0	10,8	4,8
NIM-MD	15.09.2023	30,2	11,4	8,7
BEV3	14.11.2023	31,48	12,68	0,60
SASO	23.04.2024	31,50	12,60	0,85
BEV4	10.06.2024	31,50	12,70	0,55
VSL1	28.06.2024	28,0	9,0	1,5
VSL2	28.06.2024	28,0	9,0	2,0
BEV5	11.07.2024	31,10	12,30	0,55

## 8. Calculation of reference value and evaluation of the results

### 8.1 Stability

The stability of the transfer standards was monitored by BEV. The transfer standard was measured five times. The results of the stability measurements are given in Table 6 as the measured deviation of the conventional mass from the nominal mass of the transfer standard during the stability measurements. U is the associated expanded uncertainty.

Table 6. Results of the stability measurements in BEV

Date	Conv. Mass	U(k=2) mg
17.05.2022	12,1	1,1
23.02.2023	11,5	1,1
14.11.2023	12,68	1,2
10.06.2024	12,7	1,1
11.07.2024	12,3	1,1

The measurements of the pilot laboratory had a 0,95 mg correlation estimated from the uncertainty analysis of the results. Taking into account the correlation between the BEV results a small drift of the transfer was noticed.

We assumed that the magnetic properties of the standard are not contributing significantly to the instability of the reference values, additionally to the uncertainties estimated by the participating laboratories.

## 8.2 Analysis of the Results

The results were analysed using the method of least squares as described in two DFM reports [3][4]. The measured quantities  $\mathbf{y}$  are assumed to be realisations of a multivariate random variable with expectation

$$E(\mathbf{y}) = \mathbf{X}\mathbf{a},$$

where  $\mathbf{X}$  is a known design matrix characterising the measurements performed, and  $\mathbf{a}$  is an unknown vector characterising the circulated travelling standard.

The covariance matrix  $\mathbf{\Sigma}$  associated with the observed values  $\mathbf{y}$  consists of two parts:  $\mathbf{\Sigma} = \mathbf{\Sigma}_{\text{lab}} + \mathbf{\Sigma}_{\text{obj}}$ . The first part,  $\mathbf{\Sigma}_{\text{lab}}$ , is the covariance matrix contribution from the participating laboratories with elements  $u_{\text{lab}}(y_i)$ , whereas the second part,  $\mathbf{\Sigma}_{\text{obj}}$ , is the covariance matrix contribution from the measurement object with diagonal elements  $u_{\text{obj}}^2(y_i)$  and off-diagonal elements equal to 0.

The square root of the diagonal elements of  $\mathbf{\Sigma}_{\text{lab}}$  are the standard uncertainties  $u_{\text{lab}}(y_i)$  given in Table 7.

The off-diagonal elements were calculated based on the following assumptions:

1. The covariances between BEV measurements are  $(0,95 \text{ mg})^2$ .
2. The covariances between all the laboratories due to the kilogram realisation are  $(0,80 \text{ mg})^2$ .

To finalise the drift and instability estimation, only the results of BEV were included.

Using a linear drift model over time with no random changes of the circulated mass is assumed; that is  $u_{\text{obj}}(y_i) = 0 \text{ mg}$ . This assumption failed, which indicates that non-zero uncertainty contributions  $u_{\text{obj}}(y_i)$  due to random variation in the mass of the circulated standard have to be included in the adjustment. This has been done by assuming a common uncertainty contribution  $u_{\text{obj}}(y_i) = \sigma$ , independent of the measurement object, and by adjusting  $\sigma$  to give an observed chi-square value  $\chi_{\text{obs}}^2$  equal to the expectation value  $E(\chi^2(\nu)) = \nu$  of the adjustment. Since the BEV2 value appeared to be slightly discrepant, therefore  $s_{\text{stab}}$  was adjusted to  $u_{\text{obj}}(y_i) = 0,34 \text{ mg}$ . This uncertainty contribution  $u_{\text{obj}}(y_i)$  is given in Table 7.

The calculated drift was found to be 0,00080 mg/day with a standard uncertainty of 0,00069 mg/day. Even if this drift is not really significant, we included it in the calculations. (This change was about 0,69 mg during the 785 days of the comparison).

The conventional mass corrections  $y_i = m_i - 20 \text{ kg}$  and associated standard uncertainties  $u_{\text{lab}}(y_i)$ ,  $i = 1, \dots, 20$ , submitted by the 13 participants (including pilot and repeated calculations) are listed in Table 5.

In Table 7, under the heading 'Results' these data are partly repeated. The column headed 'Time' indicates the time  $t_i$  of the measurement relative to the first measurements in the comparison. The resulting reference value  $\hat{y}_i$  and associated standard uncertainties  $u(\hat{y}_i)$ , for all submitted results are listed in Table 7. For each result of the comparison, a normalised deviation  $d_i = (y_i - \hat{y}_i)/u(y_i - \hat{y}_i)$  has been calculated. The results are shown in Figure 1.

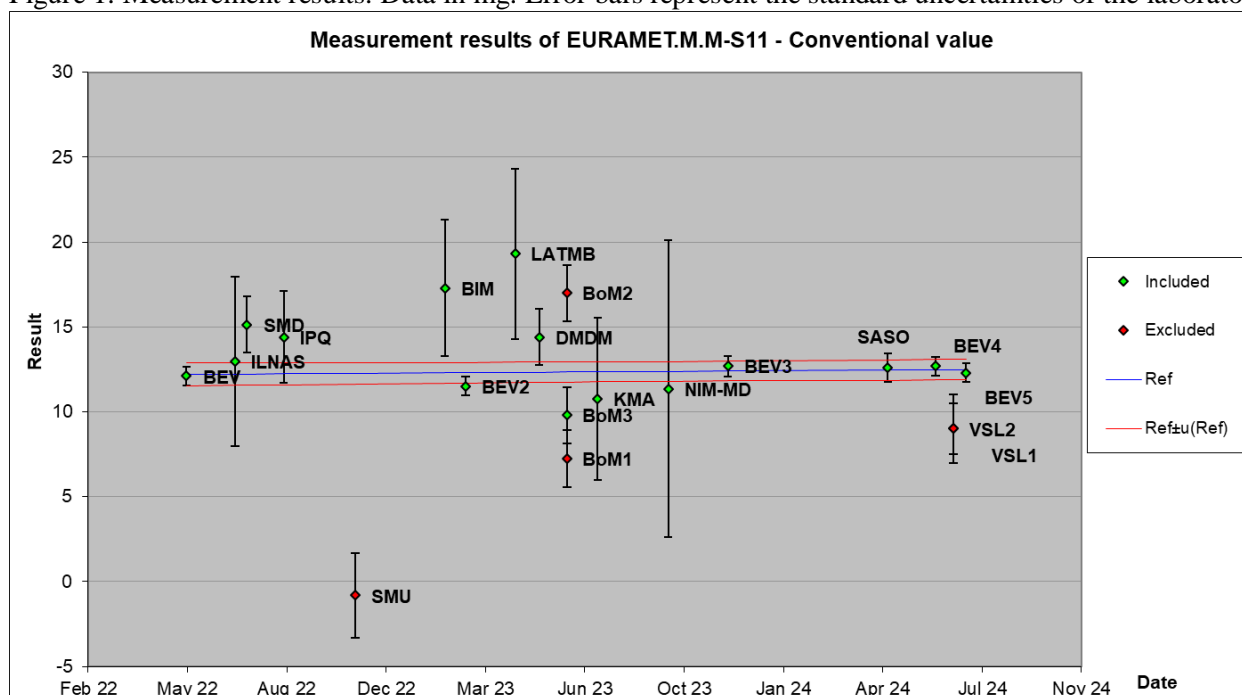
As the next step, results with normalised deviations outside the range  $-2 < d < +2$  were sequentially excluded. These are discrepant results at a 5 % level of significance. There are four such results in Table 8.

If the measurement results included are identified in Table 7 under the heading 'Included?' (y = yes, n = no) Figure 2 shows the degree of equivalence of the measurements.

Table 7. Results for conventional mass

NMI	Time day	Results		Stability $u_{obj}(y_i)$ mg	Reference value		Norm. deviation $d_i$	Included? (y/n)
		$y_i$ mg	$u_{lab}(y_i)$ mg		$\hat{y}_i$ mg	$u(\hat{y}_i)$ mg		
BEV	0	12,10	0,55	0,34	12,20	0,67	-0,35	y
ILNAS	49	13,0	5,0	0,34	12,22	0,66	0,15	y
SMD	61	15,1	1,7	0,34	12,22	0,65	1,82	y
IPQ	98	14,4	2,6	0,34	12,24	0,64	0,84	y
SMU	170	-0,8	2,5	0,34	12,26	0,62	-5,20	n
BIM	260	17,3	4,0	0,34	12,29	0,61	1,25	y
BEV2	281	11,50	0,55	0,34	12,30	0,60	-1,93	y
LATMB	331	19,3	5,0	0,34	12,32	0,59	1,40	y
DMDM	355	14,4	1,7	0,34	12,33	0,59	1,28	y
BoM1	383	7,2	1,7	0,34	12,34	0,59	-2,98	n
BoM2	383	17,0	1,7	0,34	12,34	0,59	2,81	n
BoM3	383	9,8	1,7	0,34	12,34	0,59	-1,57	y
KMA	414	10,8	4,8	0,34	12,35	0,59	-0,33	y
NIM-MD	485	11,4	8,7	0,34	12,37	0,58	-0,12	y
BEV3	545	12,68	0,60	0,34	12,40	0,58	0,57	y
SASO	706	12,60	0,85	0,34	12,45	0,60	0,19	y
BEV4	754	12,70	0,55	0,34	12,47	0,61	0,56	y
VSL1	772	9,0	1,5	0,34	12,48	0,61	-2,29	n
VSL2	772	9,0	2,0	0,34	12,48	0,61	-1,77	y
BEV5	785	12,30	0,55	0,34	12,48	0,61	-0,45	y

Figure 1. Measurement results. Data in mg. Error bars represent the standard uncertainties of the laboratories.

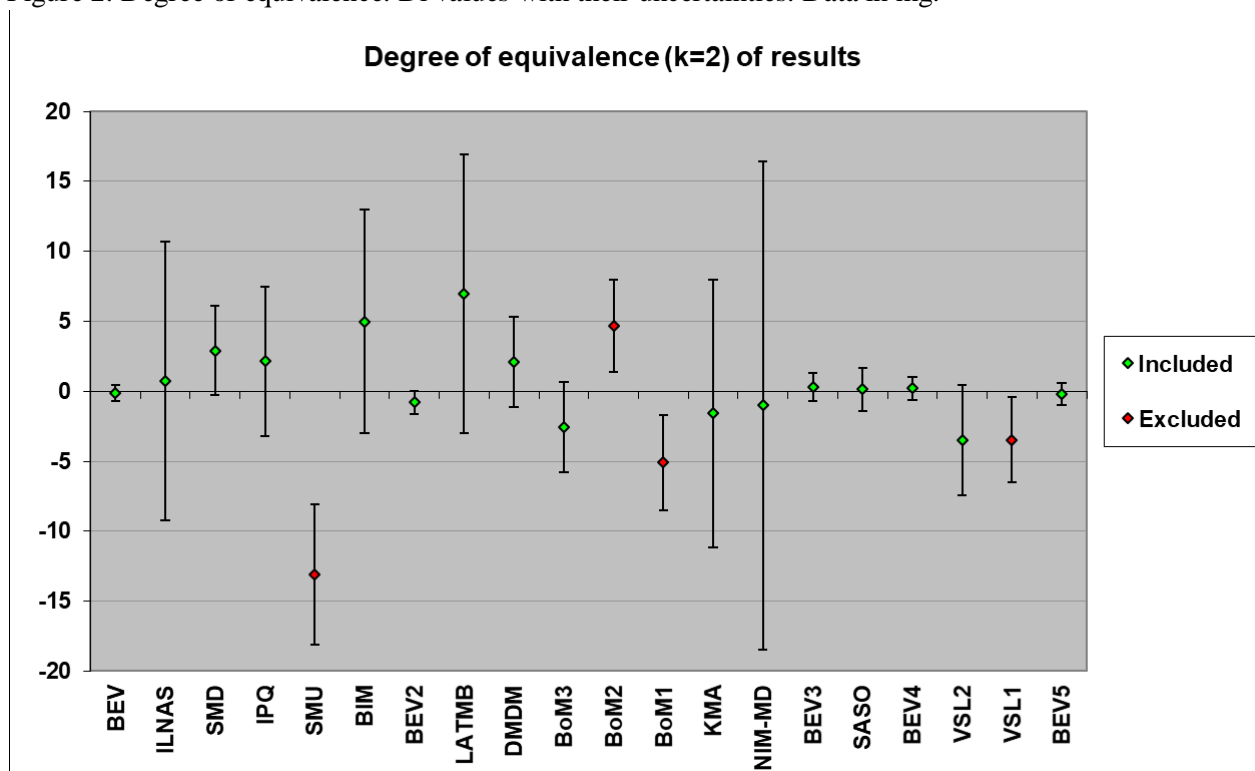


The Table 8 shows the results only one, the first BEV measurement.

Table 8. Results

NMI	$m'_i$	$m_{ref_i}$	$d_i$	$U(d_i)$	$E_n$
	Conv. mass	Conventional mass of the ref. at the time of the measurement	Difference from reference value	Expanded uncertainty of the difference	Abs. normalised error
	mg	mg	mg	mg	
BEV	12,1	12,31	-0,21	1,1	0,43
BIM	17,3	12,54	4,75	8	0,60
BoM	7,2	12,64	-5,40	3,3	1,67
BoM2	17	12,64	4,36	3,3	1,39
BoM3	9,8	12,64	-2,84	3,3	0,91
DMDM	14,4	12,62	1,78	3,3	0,57
ILNAS	13,0	12,35	0,61	10	0,06
IPQ	14,4	12,40	2,00	5,2	0,39
KMA	10,8	12,67	-1,90	9,6	0,20
LATMB	19,3	12,60	6,70	10	0,67
NIM-MD	11,4	12,73	-1,37	17,5	0,08
SASO	12,6	12,92	-0,32	1,7	0,24
SMD	15,1	12,37	2,77	3,3	0,88
SMU	-0,8	12,46	-13,28	5,0	2,73
VSL	9	12,98	-3,98	3,0	1,41
VSL2	9	12,98	-3,98	4,0	1,0

Figure 2. Degree of equivalence. Di values with their uncertainties. Data in mg.



Repeating the calculations for the (true) mass values, we established that the normalised deviations found in the analysis based on mass values are very similar to those based on conventional values.

The measurement results for (true) mass are not included because they do not give more information about the performance of the laboratories.

We have to note here that two laboratories had some discrepancies in the calculation of the true and conventional mass, and for the laboratory KMA the difference was significant. Since the conventional mass was the subject of the comparison, this is only a remark.

## 9. Conclusions

The comparison EURAMET.M.M-S11 was piloted by BEV, and thirteen laboratories calibrated the conventional (and true) mass of the 20 kg transfer standard.

The pilot asked three laboratories to review their results because they appeared to be discrepant.

BoM results are reported three times. The initial and second results were discrepant and, therefore not included in the calculation of the reference value.

Statement of BoM sent to the pilot laboratory.

BoM analysed all measurements, which were obtained in the previous year with transfer standard and compared each other. Most of the measurements (using dissemination method and method of direct comparison one by one) give results for conventional mass between 7-10 mg. Taking it into consideration, BoM submitted a third result, which was not discrepant.

The final result was submitted after comparing the results of all internal BoM calibrations, including calibrations by the dissemination (multiplication) method on a 1 kg reference standard and by direct comparison with a 20 kg reference standard. Both methods have similar measurement uncertainty, as reported. The only change that impacted the final result was the drift of the 20 kg reference standard, which was not taken into account in the initial results and gave discrepant results.

VSL results are reported twice. The initial result was discrepant and, therefore, not included in the calculation of the reference value.

VSL revised the uncertainty calculation, which was underestimated initially.

The result from SMU was discrepant but no second results were submitted or explanation sent.

The degrees of equivalence of the results otherwise show a good agreement of participants' results with the reference value.

EURAMET Guide on Comparisons [2] suggests that the participants should give a written statement indicating if their results are consistent with the CMC claims.

The pilot accessed the KCDB for the actual CMC values (on 23 September 2024). Two laboratories gave larger uncertainty in this comparison than the existing CMCs: BEV and SMU.

Following are the participants' statements regarding the CMCs.

BEV: BEV gave an expanded uncertainty of 1,1 mg. The 1,0 mg CMC value was not reached in this comparison due to some smaller unwanted influences and the rounding up. It is also due to the fact that the uncertainty of the kilogram realisation was not incorporated in the CMC values world wide because BIPM-CCM decided that the change was small. BEV notes that some of the stability measurements were not carried out using multiplication, but direct comparison.

SMU has not send comments. SMU will need to propose corrective actions based on their value not agreeing with the reference value.

## 10. References

- [1] Measurement comparisons in the CIMP MRA. [CIPM RGA-G-11](#)
- [2] EURAMET Guide on Comparisons [No. 4 | Guide on Comparisons | Version 2.0 | 2021-04-27](#)
- [3] Lars Nielsen, Evaluation of measurement intercomparison by the method of least squares, DFM-99-R39
- [4] Lars Nielsen, Identification and handling of discrepant measurements in key Comparisons, DFM-02-R28
- [5] BIPM – KCDB Calibration and Measurement Capabilities Mass and related quantities: <https://kcdb.bipm.org/appendixC/search.asp?s-service=M/Mass.1.1>