

**UK COMPARISON OF STAINLESS STEEL SUB-MULTIPLES OF THE
KILOGRAM
1 kg, 200 g, 50 g, 500 mg**

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JULY 2025

UK Comparison of Stainless Steel Sub-Multiples of the Kilogram 1 kg, 200 g, 50 g, 500 mg

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ABSTRACT

The National Physical Laboratory (NPL) and the United Kingdom Accreditation Service (UKAS) has organised a comparison in mass using stainless steel weights as transfer standards with mass standards of nominal values 500 mg, 50 g, 200 g and 1 kg. All the participants submitted results for all the transfer standards. These results were all equivalent to the comparison reference value except for one result submitted for the 200 g transfer standard.

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ISSN 1754-2987

DOI: <https://doi.org/10.47120/npl.ENG75>

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This work was funded by the UK Government's Department for Science, Innovation & Technology through the UK's National Measurement System programmes.

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Approved on behalf of NPLML by
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1 INTRODUCTION

The National Physical Laboratory (NPL) and the United Kingdom Accreditation Service (UKAS) has organised a comparison in mass using stainless steel weights as transfer standards with mass standards of the following four nominal values:

0.5 g
50 g
200 g
1000 g

Its purpose was to evaluate the equivalence of mass measurement of stainless steel weights in the UK for International Organisation of Legal Metrology (OIML) weight accuracy classes E1 to F2 [1].

NPL has accepted the responsibility as the pilot laboratory.

1.1 PARTICIPANTS

The participants of the comparison are listed in Table 1.

Table 1. Participating Institutes

Institute
National Physical Laboratory (pilot)
Norfolk Calibration Services
Mettler-Toledo Ltd
Chamois Metrology Ltd
Glasgow Scientific Services
Northern Ireland Trading Standards Service
West Yorkshire Trading Standards Calibration Services
European Instruments Limited
Devon County Council t/a Heart of the South West Calibration Services
Warwickshire Trading Standards
Office for Product Safety and Standards (OPSS)

2 DESCRIPTION OF THE TRANSFER STANDARDS

The transfer standards are made of non-magnetic stainless steel and have the form and quality recommended by OIML [3] for weights of accuracy class E1. The set consists of weights of nominal values 1 kg, 200 g, 50 g and 500 mg. Details of each mass standard are given in Table 2.

Table 2. Information on the four transfer standards

Nominal Value	Identification	Volume at 20 °C	Uncertainty ($k=2$)	Coefficient of cubic expansion
<i>g</i>		<i>cm³</i>	<i>cm³</i>	<i>10⁻⁶ °C⁻¹</i>
1 000	NPLW99	124.912 2	0.002 4	45
200	NPLW99	25.484 7	0.000 5	45
50	NPLW99	6.218 3	0.000 7	45
0.5	NPLW99	0.062 5	0.000 4	45

3 SUMMARY OF THE RESULTS REPORTED BY THE PARTICIPANTS

3.1 REPORTED VALUES OF CONVENTIONAL MASS AND UNCERTAINTY

The reported conventional mass values and combined expanded uncertainties are given in Table 3 for the 1 kg and 200 g transfer standards and Table 4 for the 50 g and 500 mg transfer standards. $m - m_0$ represents the difference from the participants reported conventional mass values and the nominal mass values of the transfer standards.

The reported values received by the pilot laboratory have been randomised and anonymised, with each laboratory assigned a number between 1 and 11.

The results in Table 3 and Table 4 are used directly in Figure 1, Figure 2, Figure 3 and Figure 4 for the 1 kg, 200 g, 50 g and 500 mg standards respectively.

Table 3. Reported results found for the 1 kg and 200 g transfer standards.
 m conventional mass and m_0 nominal value of the standard, u_c combined expanded uncertainty ($k = 2$).

	1 kg		200 g	
Laboratory ID	$m - m_0 / \text{mg}$	u_c / mg	$m - m_0 / \text{mg}$	u_c / mg
1	0.700	1.000	-0.120	0.100
2	0.900	0.799	-0.110	0.076
3	0.690	0.100	-0.061	0.025
4	0.600	3.200	-0.130	0.600
5	0.700	1.000	-0.180	0.200
6	0.520	0.500	-0.070	0.100
7	0.840	0.500	-0.030	0.100
8	0.480	0.250	-0.176	0.053
9	0.200	1.000	-0.070	0.200
10	0.703	0.045	-0.052	0.010
11	1.120	0.530	0.004	0.100
Reference value	0.697	0.040	-0.055	0.009

Table 4. Reported results found for the 50 g and 500 mg transfer standards.
 m conventional mass and m_0 nominal value of the standard, u_c combined expanded uncertainty ($k = 2$).

	50 g		500 mg	
Laboratory ID	$m - m_0 / \text{mg}$	u_c / mg	$m - m_0 / \text{mg}$	u_c / mg
1	-0.050 0	0.030 0	0.006 0	0.008 0
2	-0.054 0	0.017 4	0.006 0	0.004 2
3	-0.049 0	0.010 0	0.008 2	0.001 8
4	-0.070 0	0.200 0	0.013 0	0.050 0
5	-0.104 0	0.060 0	0.007 0	0.016 0
6	-0.061 0	0.030 0	0.008 2	0.008 0
7	-0.036 0	0.030 0	0.010 8	0.008 0
8	-0.053 0	0.016 0	0.008 8	0.003 8
9	0.006 0	0.060 0	0.009 0	0.016 0
10	-0.045 8	0.003 5	0.009 7	0.000 4
11	-0.029 0	0.033 0	0.008 7	0.008 3
Reference value	-0.046 6	0.003 1	0.009 6	0.000 4

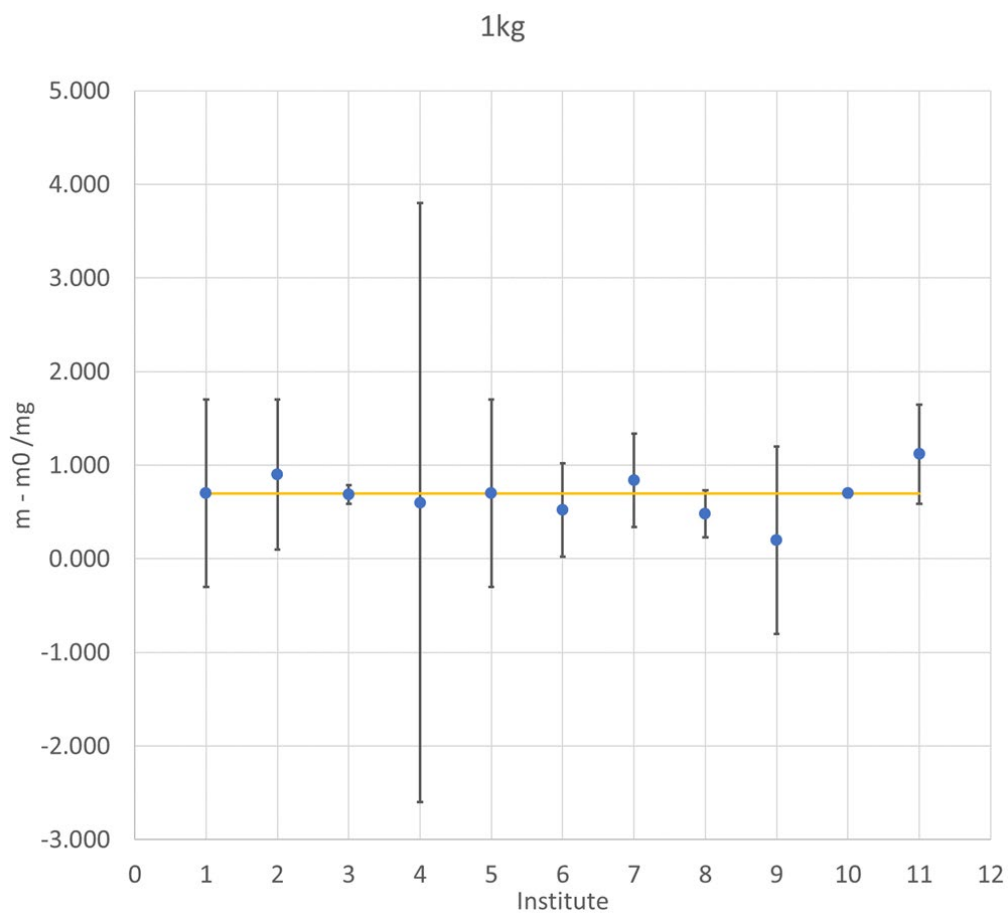


Figure 1. Results of the 1 kg mass standard for all participants. The yellow line represents the comparison reference value. Error bars show the combined expanded uncertainty ($k = 2$). The comparison reference value has an expanded uncertainty ($k = 2$) of 0.040 mg.

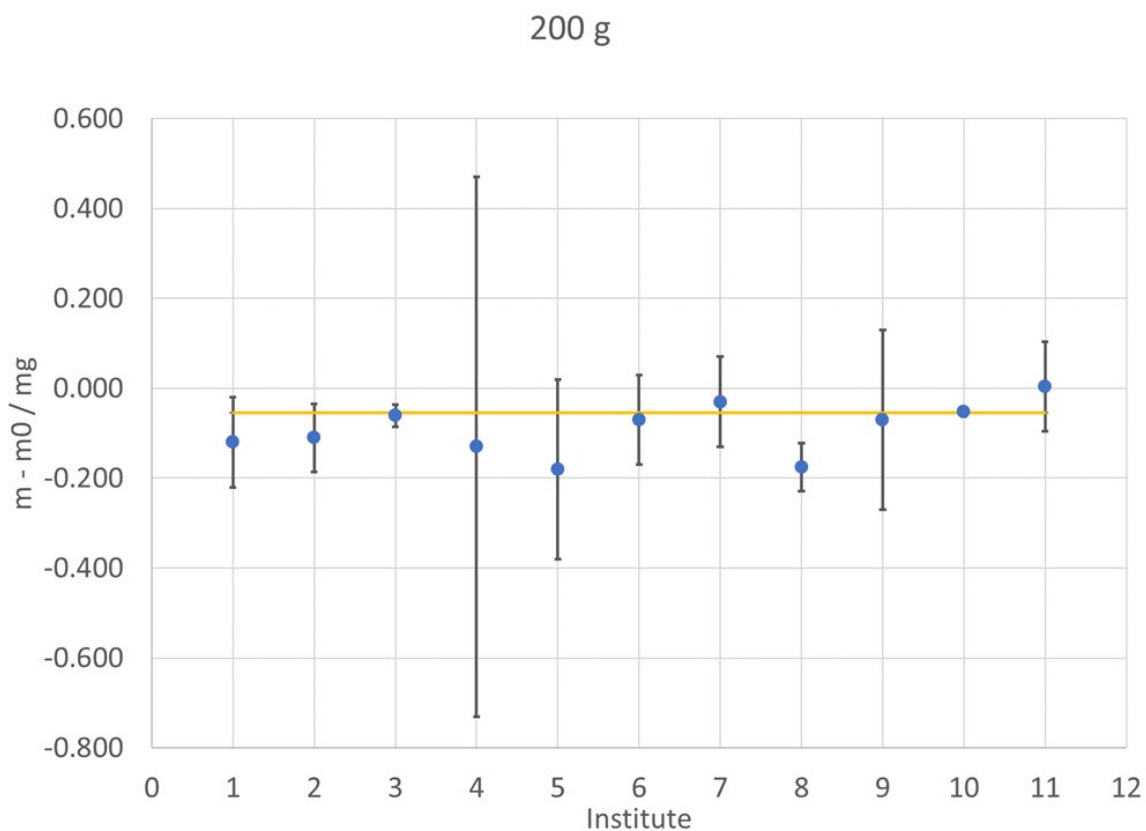


Figure 2. Results of the 200 g mass standard for all participants. The yellow line represents the comparison reference value. Error bars show the combined expanded uncertainty ($k = 2$). The comparison reference value has an expanded uncertainty ($k = 2$) of 0.009 mg.

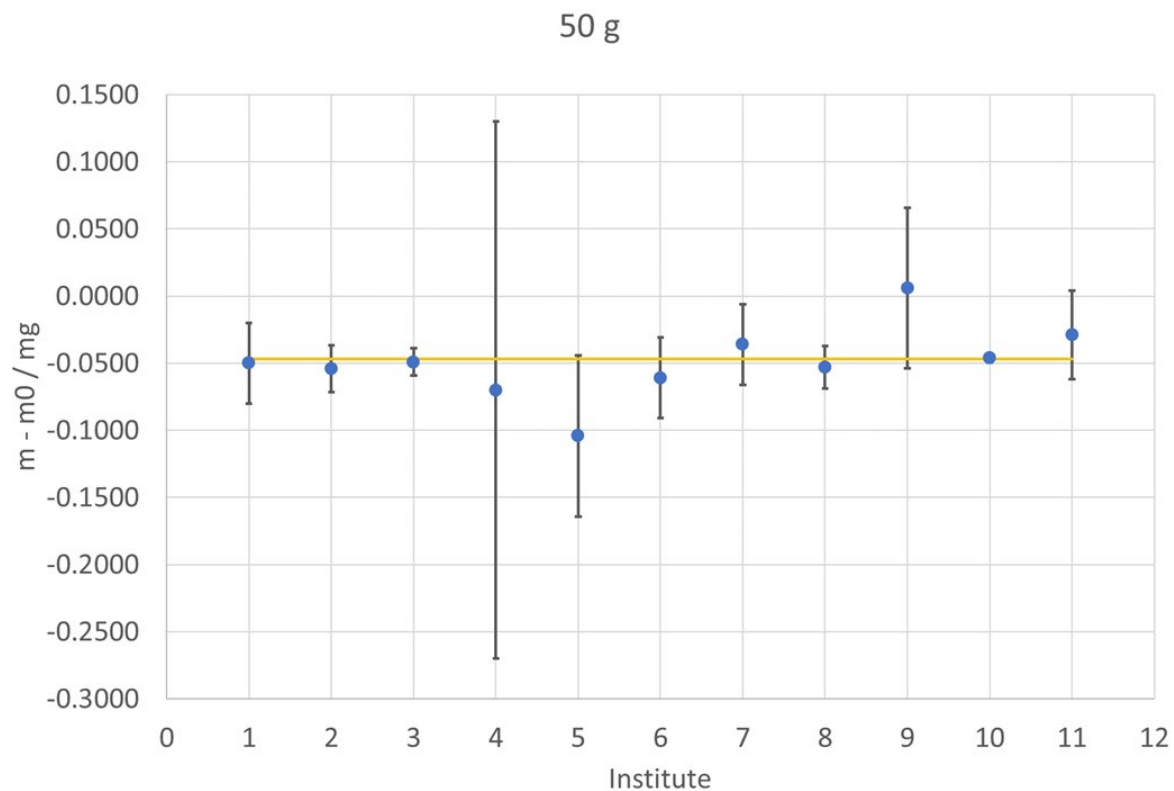


Figure 3. Results of the 50 g mass standard for all participants. The yellow line represents the comparison reference value. Error bars show the combined expanded uncertainty ($k = 2$). The comparison reference value has an expanded uncertainty ($k = 2$) of 0.0031 mg.

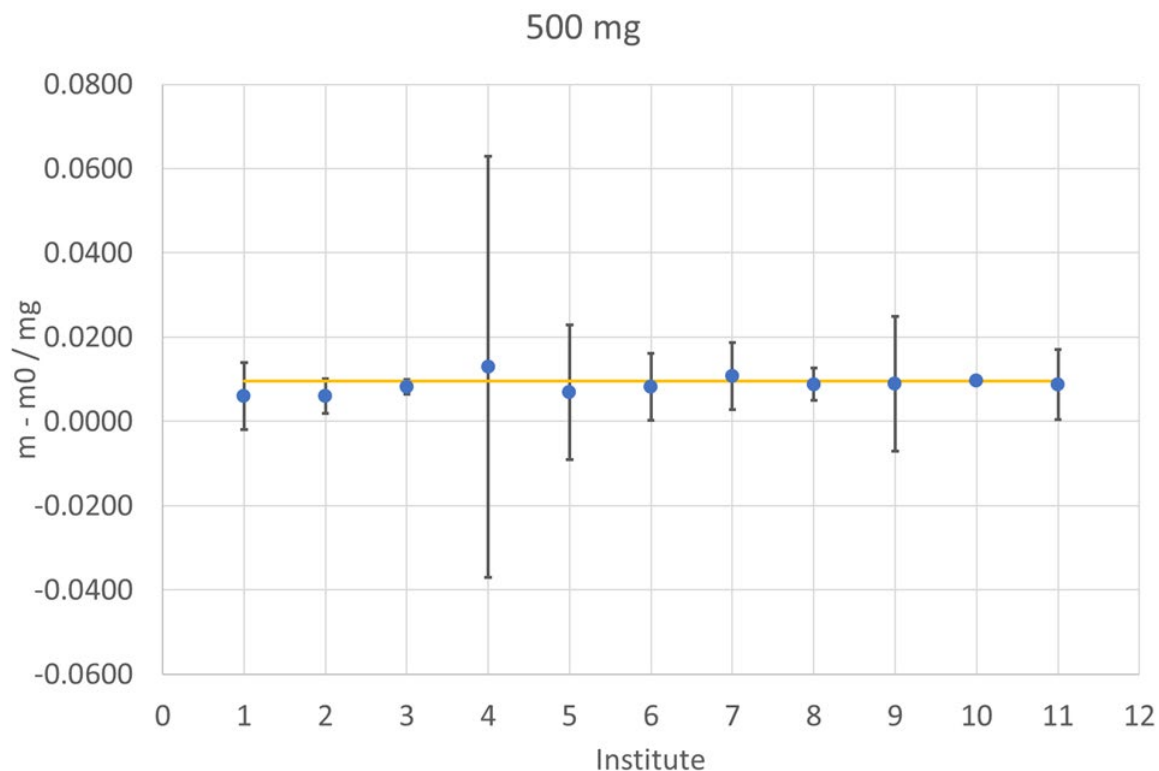


Figure 4. Results of the 500 mg mass standard for all participants. The yellow line represents the comparison reference value. Error bars show the combined expanded uncertainty ($k = 2$). The comparison reference value has an expanded uncertainty ($k = 2$) of 0.0004 mg.

4 ANALYSIS OF RESULTS

4.1 STABILITY OF THE TRANSFER STANDARDS

NPL measured the conventional mass of the transfer standards at the middle and at the end of the comparison. The stability of the transfer standards is shown in Figure 5, Figure 6, Figure 7 and Figure 8 for the 1 kg, 200 g, 50 g and 500 mg standards respectively.

$m - m_0$ represents the difference from the conventional mass value and the nominal mass value of the transfer standard.

The analysis shows that the transfer standards are stable within the uncertainties of the pilot laboratory measurements.

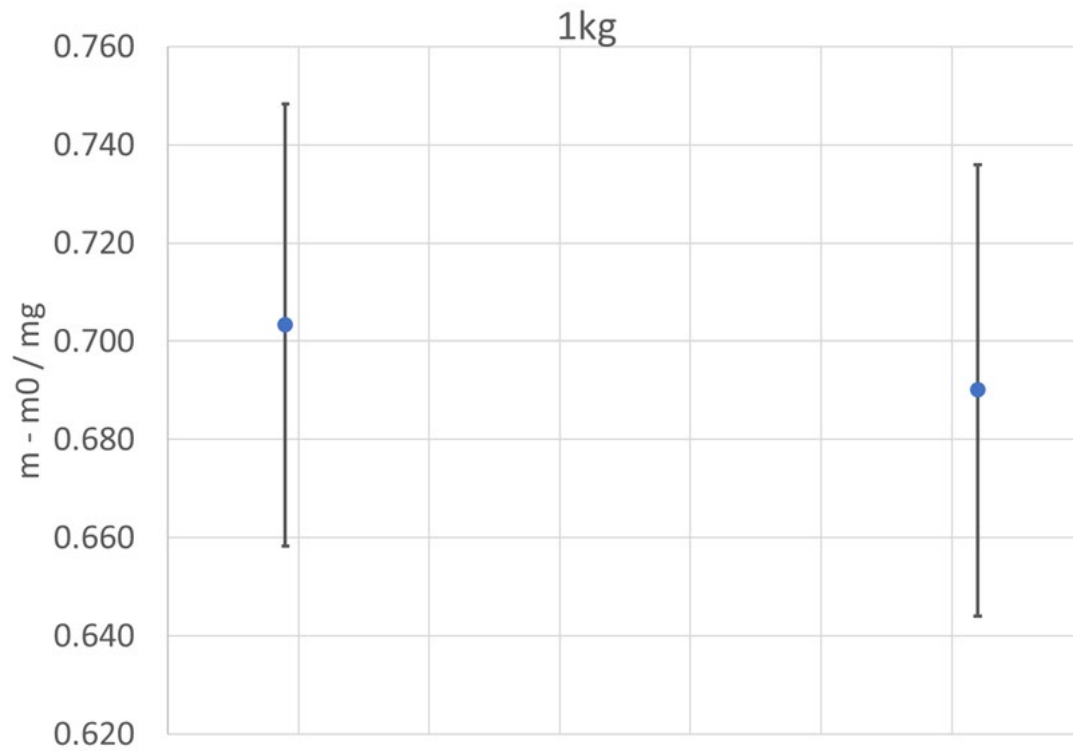


Figure 5. Stability of the 1 kg mass measured at NPL

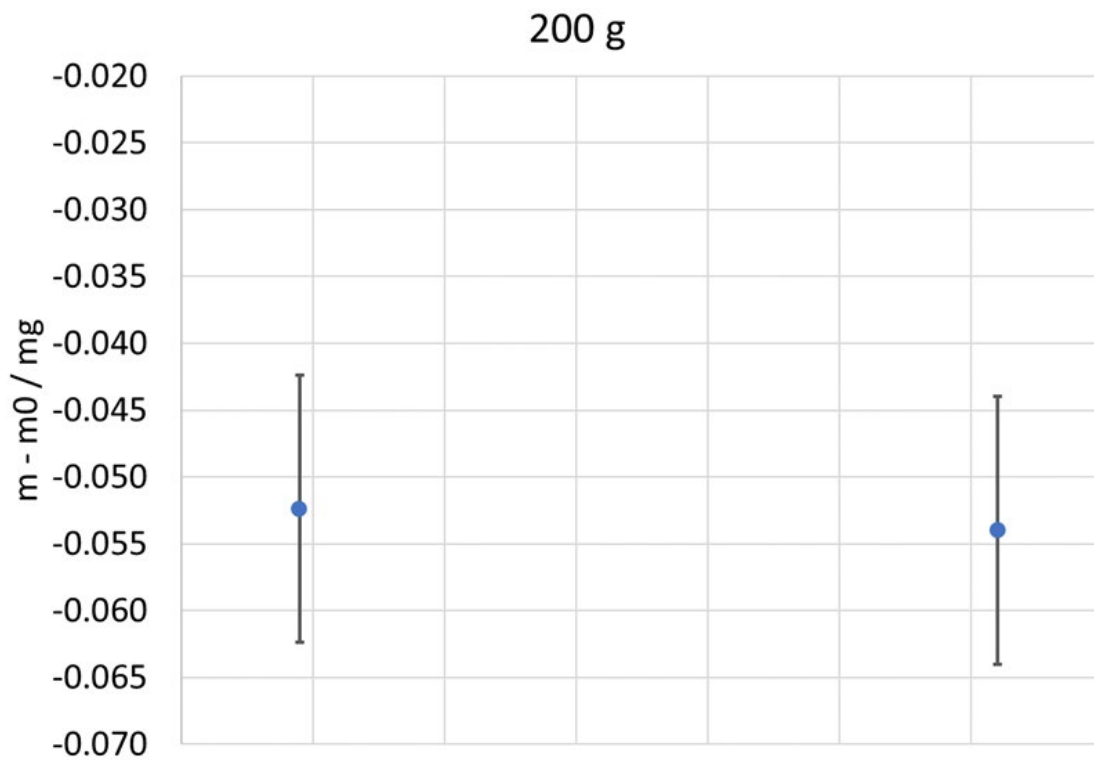


Figure 6. Stability of the 200 g mass measured at NPL

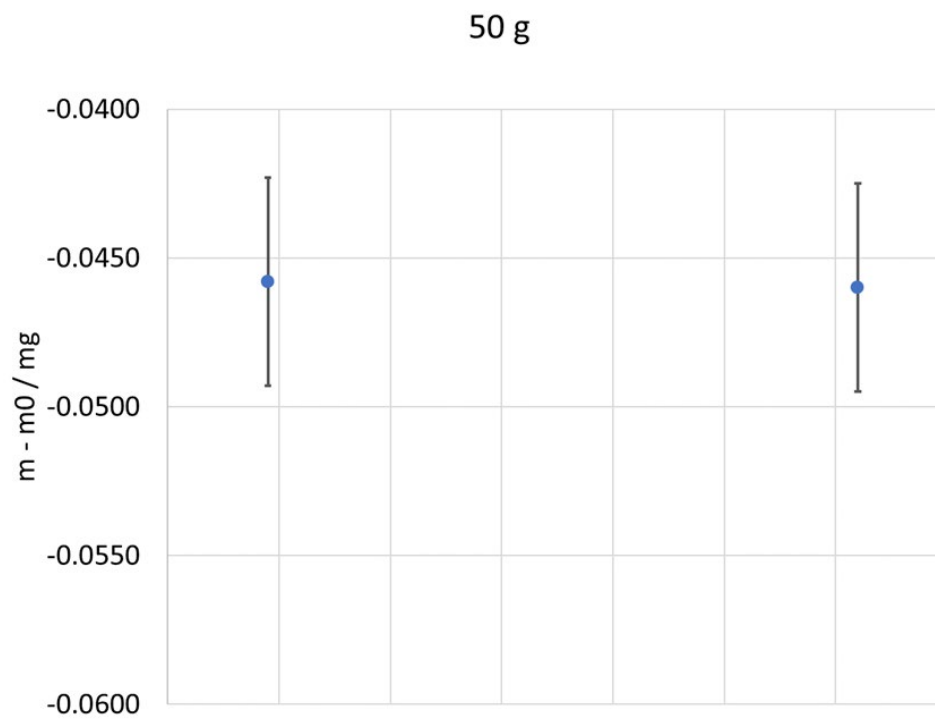


Figure 7. Stability of the 50 g mass measured at NPL

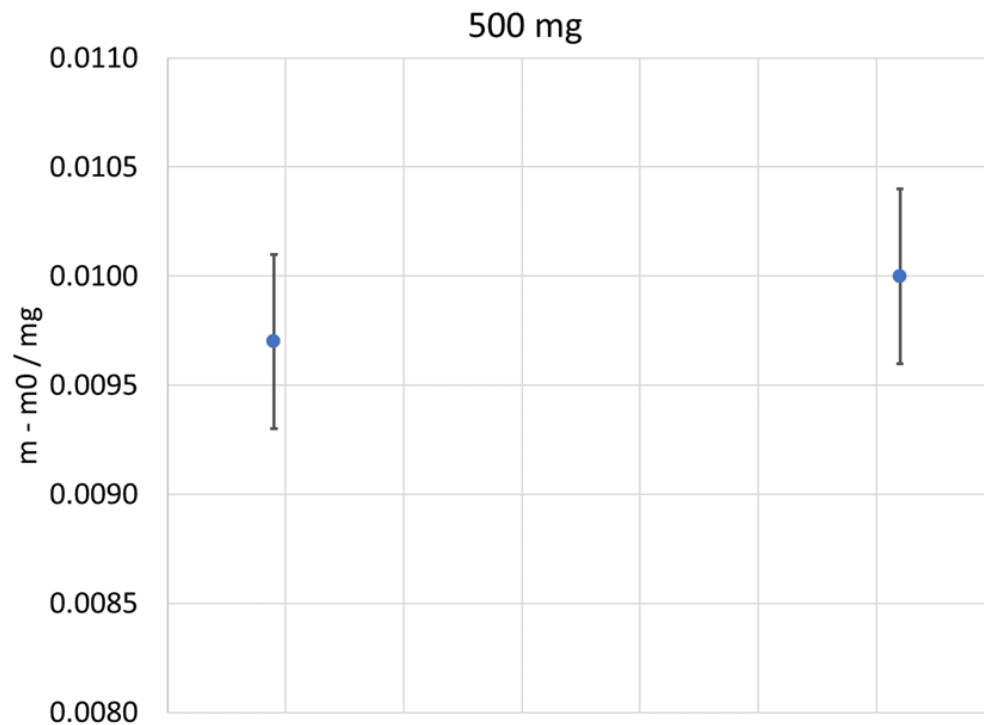


Figure 8. Stability of the 500 mg mass measured at NPL

4.2 CALCULATION OF REFERENCE VALUES AND ASSOCIATED UNCERTAINTIES

The reference value of the comparison was calculated using least square adjustment and satisfies the following three conditions:

1. Traveling standard has good stability.
2. There is no mutual dependence of the institute's measurement.
3. Gaussian distribution can be assigned for measurements of each institute.

The reference value was considered to be the weighted mean of the institute's measurements. Where the weights of each measurement, are the reciprocal of variance.

Reference value of this comparison was:

$$m_{ref} = (m_{wm} - m_0) * 1000$$

Where:

m_{wm} – Weighted mean (g)

m_0 – Nominal value (g)

m_{ref} – Reference value (mg)

$$m_{wm} = \frac{\sum_{i=1}^n \omega_i x_i}{\sum_{i=1}^n \omega_i}$$

$$\omega_i = \frac{1}{\sigma_i^2}$$

$i = 1, 2, 3, \dots, n$ – indexing number of each measurement.

n – Total number of measurements

σ_i – Standard uncertainty associated with the value

The uncertainty of the reference value was calculated based on reciprocal relation mentioned above.

Standard uncertainty: $u(m_{ref}) = \sqrt{\frac{1}{\sum_{i=1}^n \omega_i}}$

Expanded uncertainty: $U(m_{ref}) = 2u(m_{ref})$

Least square consistency check was performed for every nominal mass.

4.3 EQUIVALENCE BETWEEN THE PARTICIPANTS AND THE REFERENCE VALUE

The equivalence between the participants results and the reference value is shown in Figure 1, Figure 2, Figure 3 and Figure 4 for the 1 kg, 200 g, 50 g and 500 mg standards respectively.

All the participants data, except for one result for the 200 g transfer standard, were equivalent to the comparison reference value.

5 CONCLUSIONS

All the participants submitted results for all the transfer standards. Stability measurements on the transfer standards were done in the middle and end of the comparison and showed the standards to have good mass stability. The participant results were all equivalent to the comparison reference values except for one result submitted for the 200 g transfer standard.

6 REFERENCES

- [1] OIML R111-1 2004 Weights of classes E₁, E₂, F₁, F₂, M₁, M₁₋₂, M₂, M₂₋₃ and M₃ Part 1: Metrological and technical requirements *OIML*