Report on the Calculation of the CCM Consensus Value for the Kilogram 2026

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1 Introduction

In 2017 the Consultative Committee for Mass and Related Quantities (CCM) reviewed the available experimental data which served as input for the least squares adjustment of the numerical value of the Planck constant for the new definition of the kilogram [1]. The set of eight results for the Planck constant was not statistically consistent with differences between determinations as large as four standard uncertainties. The CCM therefore requested in its meeting in 2017 that NMIs with a realization of the kilogram should adopt an agreed consensus value [2]. A new consensus value would be calculated after each of a series of biennial[1] key comparisons of realization experiments. This international coordination of the dissemination of the kilogram should be continued until the dispersion in values from individual realizations becomes compatible with their individual determined uncertainties.

The details of this approach are described in the "CCM detailed note on the dissemination process after the redefinition of the kilogram" [3]. The third consensus value, following the completion of the third key comparison, CCM.M-K8.2024, will be determined from the following three data sets following the rules established by the CCM:

1. the KCRV of the first CCM Key Comparison CCM.M-K8.2019;
2. the KCRV of the second CCM Key Comparison CCM.M-K8.2021;
3. the KCRV of the third CCM Key Comparison CCM.M-K8.2024.

The CCM had decided that the uncertainty of the consensus value should be 20 µg, unless a statistical analysis showed that this value should be increased. This uncertainty corresponds to the typical uncertainty of a "mature" realization experiment and sets the expectation on future uncertainties from individual realization experiments.

The BIPM Pt-Ir working standards were involved in all three comparisons. Therefore, the three data sets can be linked together based on the assumption that the BIPM as-maintained mass unit has been stable, within some uncertainty. Contrary to its name, the consensus value is not an absolute value but is expressed in terms of an offset from the BIPM as-maintained mass unit, which represents the mass of the IPK. The consensus value will be accessible to all NMIs having mass standards traceable to the BIPM, without the need of recalibration of mass standards.

2 The long-term stability of the BIPM working standards

For the combination of the results of the three data sets which contribute to the consensus value, it is necessary to have a common, stable reference which allows them to be linked. This reference is provided by the BIPM working standards which were used during all three campaigns. It is not necessary that the mass of the working standards is stable, what needs to remain stable is the mass unit maintained by the standards. If the mass of the standards changes, this change needs to be detected and the mass values attributed to the standards corrected accordingly. Since the stability of the BIPM as-maintained mass unit is essential for the calculation of the consensus value, we describe briefly the approach used by the BIPM.

Following the Extraordinary Calibrations using the IPK in 2014, the BIPM has put in place a new, hierarchical scheme of usage of its 12 Pt-Ir working standards. Three of them form the set of "standards for exceptional use". They are only used once every five years and they are cleaned and washed before use, to re-establish

[1] A periodicity of three years was decided by the CCM in 2023.

the mass they had during the Extraordinary Calibration campaign. They have been used twice since the Extraordinary Calibrations, in 2019 and in 2024. Three other standards form the set of “standards for limited use”. They are used once a year, and they are recalibrated every five years (the last time in 2024) using the standards for exceptional use. Finally, six standards form the set of “standards for current use”. They are calibrated once a year using the standards for limited use and are used throughout the year to provide calibrations to NMIs. The different levels of usage allow the detection of mass changes which are caused by the manipulation of the standards during the measurement process.

The uncertainty related to the stability of the BIPM as-maintained mass unit has been estimated as 5 µg for the period from 2019 to 2025 and as 5 µg for the period from 2021 to 2025. These uncertainties are significantly smaller than the ad-hoc uncertainty of the consensus value, which is 20 µg. Since the consensus value is calculated as the arithmetic mean of the three reference values mentioned in the introduction, the uncertainties do not enter into the calculation.

3 Data contributing to the consensus value of 2026

3.1 The KCRV of the first CCM Key Comparison, CCM.M-K8.2019

This comparison compared the realizations of four Kibble balances from BIPM, KRISS, NIST, NRC, the joule balance of NIM and two applications of the XRCD method by NMIJ and PTB.

The differences between mass values attributed by the participants of CCM.M-K8.2019 to a 1 kg mass standard and the values attributed using the BIPM working standards are shown in table 1.

Table 1: The differences between mass values attributed by the participants of CCM.M-K8.2019 to a 1 kg mass standard and the values attributed using the BIPM working standards, and related standard uncertainty (Table 7 of [5]).

Institute	$\boldsymbol{m_i^{\mathrm{NMI}} - m_i^{\mathrm{BIPM}}}$ **/ mg**	$\boldsymbol{u(\Delta m_i)}$ **/ mg**
BIPM	0.0064	0.0491
KRISS	0.0536	0.1072
NIM	-0.0305	0.0456
NIST	-0.0185	0.0270
NMIJ	-0.0166	0.0214
NRC	-0.0034	0.0118
PTB	-0.0399	0.0128
KCRV (Weighted mean)	-0.0188	0.0075

The difference between mass determinations of a 1 kg standard based on the key comparison reference value (weighted mean of the seven realizations) and on the BIPM as-maintained mass unit is -18.8 µg with a standard uncertainty of 7.5 µg. Combined with the uncertainty of 5 µg for the stability of the as-maintained mass unit from 2019 to 2025, the uncertainty of the KCRV, as maintained in 2025, is 9.0 µg.

3.2 The KCRV of the second CCM Key Comparison, CCM.M-K8.2021

This comparison compared the realizations of seven Kibble balances from BIPM, LNE, METAS, NIM, NIST, NRC and UME and two applications of the XRCD method by NMIJ and PTB.

The differences between mass values attributed by the participants of CCM.M-K8.2021 to a 1 kg mass standard and the values attributed using the BIPM working standards are shown in table 2.

The difference between mass determinations for a 1 kg standard based on the key comparison reference value (weighted mean of the nine realizations) and on the BIPM as-maintained mass unit is -15.2 µg with a standard uncertainty of 7.4 µg. Combined with the uncertainty of 5 µg for the stability of the as-maintained mass unit from 2021 to 2025, the uncertainty of the KCRV, as maintained in 2025, is 8.9 µg.

Table 2: The differences between mass values attributed by the participants of CCM.M-K8.2021 to a 1 kg mass standard and the values attributed using the BIPM working standards, and related standard uncertainty (Table 6 of [6]).

Institute	$\boldsymbol{m_i^{\mathrm{NMI}} - m_i^{\mathrm{BIPM}}}$ **/ mg**	$\boldsymbol{u(\Delta m_i)}$ **/ mg**
BIPM	-0.0391	0.0412
LNE	0.0477	0.1081
METAS	-0.0415	0.0481
NIM	0.0020	0.0406
NIST	-0.0158	0.0266
NMIJ	-0.0086	0.0234
NRC	0.0038	0.0112
PTB	-0.0463	0.0142
UME	-0.0152	0.0585
KCRV (Weighted mean)	-0.0152	0.0074

3.3 The KCRV of the third CCM Key Comparison, CCM.M-K8.2024

This comparison compared the realizations of seven Kibble balances from BIPM, LNE, METAS, NIM, NIST, NRC and UME and three applications of the XRCD method by CMS/ITRI, NMIJ and PTB.

The differences between mass values attributed by the participants of CCM.M-K8.2021 to a 1 kg mass standard and the values attributed using the BIPM working standards are shown in table 3. The KCRV was calculated as the weighted mean of the participants' result without that of CMS/ITRI, which is not a Member State.

The difference between mass determinations for a 1 kg standard based on the key comparison reference value (weighted mean of the nine realizations) and on the BIPM as-maintained mass unit is -10.7 µg with a standard uncertainty of 6.4 µg.

Table 3: The differences between mass values attributed by the participants of CCM.M-K8.2024 to a 1 kg mass standard and the values attributed using the BIPM working standards, and related standard uncertainty (Table 6 of [7]).

Institute	$m_i^{\mathrm{NMI}} - m_i^{\mathrm{BIPM}}$ **/ mg**	$u(\Delta m_i)$ **/ mg**
BIPM	-0.0178	0.0361
CMS/ITRI	0.0040	0.0371
LNE	-0.0008	0.0368
METAS	-0.0511	0.0541
NIM	-0.0322	0.0293
NIST	-0.0150	0.0135
NMIJ	-0.0215	0.0210
NRC	0.0095	0.0118
PTB	-0.0185	0.0137
UME	-0.0359	0.0367
KCRV (Weighted mean)	-0.0107	0.0064

4 Calculation of the consensus value of 2026

Figure 1 shows the results of all participants of the three key comparisons and in the Pilot Study of 2016. The BIPM as-maintained mass unit serves as the common baseline for combining the results of the comparisons. The graph allows to quantify the reproducibility of the different realization experiments. In general, there is good agreement between the results obtained in the key comparisons from 2019 to 2024.

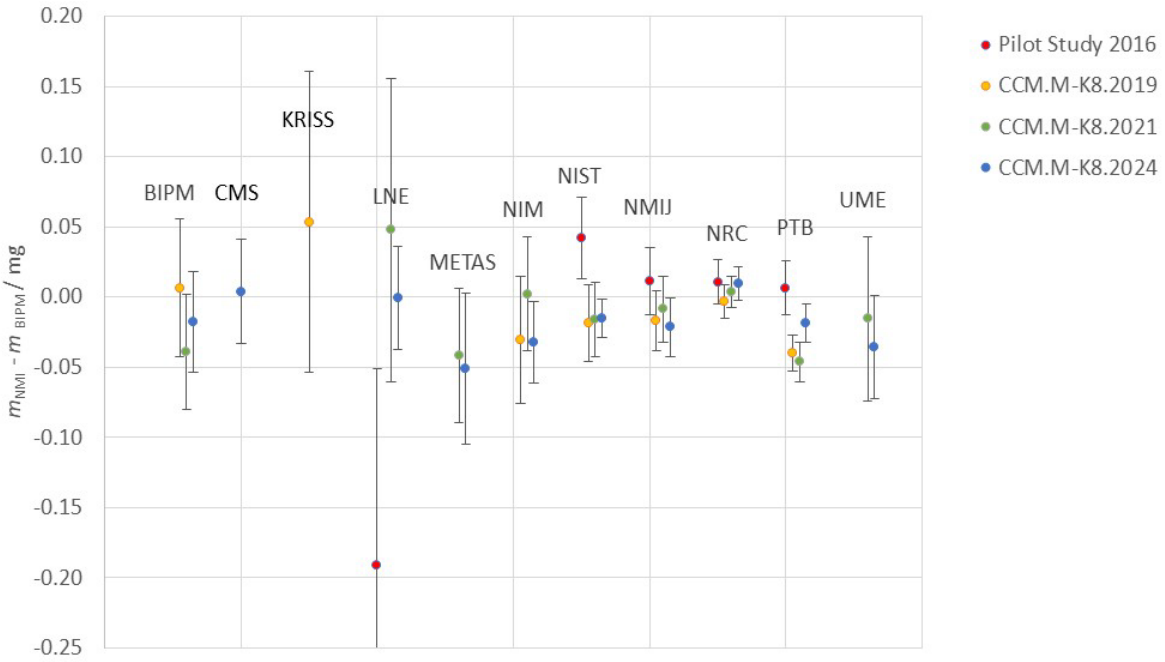

Fig 1.: Comparison of the results of the participants obtained in the Pilot Study of 2016, and in the 2019, 2021 and 2024 Key Comparisons, and the associated standard uncertainties.

The three contributions to the consensus value of 2026 are shown in table 4 and on figure 2. The arithmetic mean of the three results is -14.9 µg with a standard uncertainty of 4.7 µg. This represents a change of –7.9 µg with respect to the previous consensus value. However, as described in the CCM detailed note on the dissemination process after the redefinition of the kilogram, changes in the consensus value between consecutive Key Comparisons will be reviewed and, if necessary, limited to ± 5 µg. This limit on the change in the Consensus Value is intended to ensure its temporal stability by reducing its sensitivity to changes in the (evolving) realization experiments and variations in the group of NMIs participating in the periodic comparisons. A review was undertaken by the CCM Task Group on the Phases for the Dissemination of the kilogram following redefinition (CCM-TGPfD-kg) and as a consequence of this review, the third consensus value will be 1 kg -12 µg, with an uncertainty of 20 µg.

Table 4: Values and uncertainties of the three contributions to the determination of the consensus value of 2026. The uncertainties include the contribution from the instability of the BIPM working standards.

Contribution to consensus value 2026	deviation from BIPM as-maintained mass unit	unc. / µg
KCRV CCM.M-K8.2019	-18.8	9.0
KCRV CCM.M-K8.2021	-15.2	8.9
KCRV CCM.M-K8.2024	-10.7	6.4

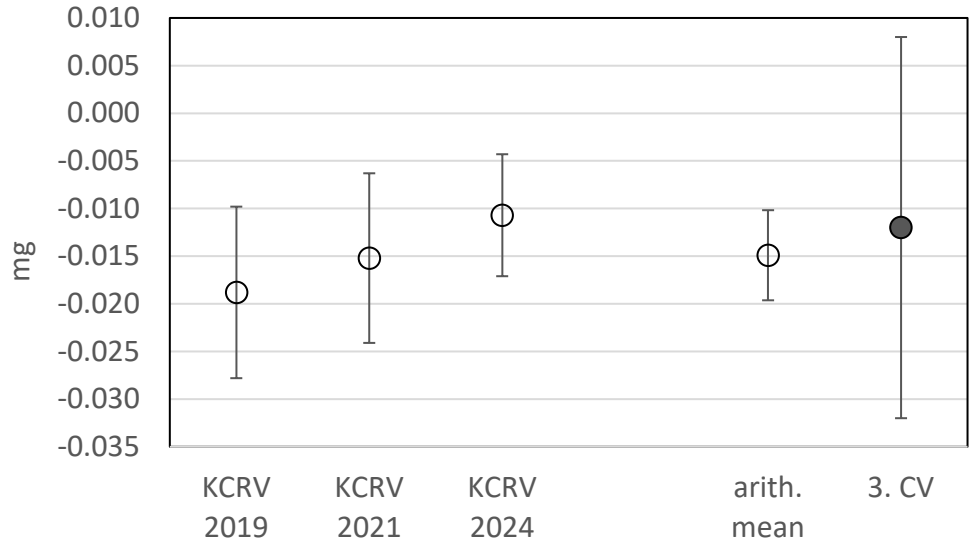

Fig 2.: The three values contributing to the consensus value of 2026 (third consensus value): key comparison reference values (KCRVs) of CCM.M-K8.2019, CCM.M-K8.2021 and CCM.M-K8.2024, expressed as differences from the BIPM as-maintained mass unit. The consensus value is chosen as -0.012 mg to limit the change from the previous consensus value to -0.005 mg.

The mass values of 1 kg standards based on the consensus value of 2026 will be 12 µg lower than those based on the BIPM as-maintained mass unit. They will be 5 µg lower than those based on the consensus value implemented in 2023.

Traceability for the SI unit of mass will be taken from the 2026 consensus value of the kilogram commencing 1 March 2026.

To achieve consistency with the consensus value of 2026, all NMIs would need to reduce the mass value of their national as-maintained mass unit by 5 µg with respect to the consensus value of 2023 or by 12 µg with respect to the mass value based on the IPK. The adoption of the consensus value of 2026 requires no further adjustment to the published CMCs of NMIs since the uncertainty of the consensus value has not changed.

5 Phases of the dissemination of the kilogram since its redefinition

Table 5 gives an overview of the past and future basis for the dissemination of the kilogram. The consensus values are not absolute values but have to be expressed as an offset from a stable reference. This reference is the mass unit maintained by the BIPM, which represents the mass of the IPK.

Table 5: Past and future basis for the dissemination of the kilogram since its redefinition.

Date of implementation	Basis for dissemination	Uncertainty
20 May 2019	m(IPK) = 1 kg	10 µg
1 February 2021	Consensus value 2021 m(IPK) = 1 kg – 2 µg	20 µg
1 March 2023	Consensus value 2023 m(IPK) = 1 kg – 7 µg	20 µg
1 March 2026	Consensus value 2026 m(IPK) = 1 kg – 12 µg	20 µg

6 References

[1] P. J. Mohr *et al*., "Data and analysis for the CODATA 2017 special fundamental constants adjustment", *Metrologia* **55** (2018) 125-146

[2] Report of the 16th meeting of the CCM, 2017, Recommendation G1 (2017) "For a new definition of the kilogram in 2018", available on the BIPM web site www.bipm.org

[3] CCM, 2019, "CCM detailed note on the dissemination process after the redefinition of the kilogram", available on the BIPM web site www.bipm.org

[4] M. Stock *et al*., "Final report on CCM Pilot Study CCM.R-kg-P1 - Comparison of future realizations of the kilogram", CCM working document CCM/17-03-7B2, available on the BIPM web site: www.bipm.org

[5] M. Stock, *et al*., "Report on the CCM key comparison of kilogram realizations CCM.M-K8.2019", *Metrologia* **57** (2020) 07030

[6] M. Stock *et al*., "Final report on the CCM key comparison of kilogram realizations CCM.M-K8.2021", *Metrologia* **60** (2023) 07003

[7] M. Stock et al., "CCM.M-K8.2024, Key comparison of kilogram realizations, Final report", 2025, available on BIPM web site: https://www.bipm.org/documents/d/guest/ccm-m-k8-2024

7 List of Acronyms

BIPM - Bureau International des Poids et Mesures (International Bureau of Weights and Measures)

CCM - Consultative Committee for Mass and Related Quantities

CODATA - Committee on Data for Science and Technology

IPK - International Prototype of the Kilogram

KC - Key Comparison

KCRV - Key Comparison Reference Value

RV - Reference value

XRCD - X-ray Crystal Density