CCM short note on the dissemination process after the proposed redefinition of the kilogram

Consultative Committee for Mass and Related Quantities

1. Introduction

This note proposes how the *mise en pratique* for the definition of the kilogram should be developed to bring it in line with CCM Recommendation G1 (2017) on the dissemination process after the proposed redefinition of the kilogram. It adds greater detail to some elements of the paper: *Maintaining and disseminating the kilogram following its redefinition*, published in *Metrologia* 54(6), S99-S107.

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It was presented, discussed and commented at the 106th CIPM meeting in October 2017, commented and approved by the CCM in April 2018. This note will be published on the CCM web site after its final approval by the CIPM at its 107th meeting in June 2018. The CCM President established early 2018 a task group (members above plus Lars Nielsen (DFM), Horst Bettin (chair CCM WGR-kg, PTB) and Nieves Medina (CEM)) for the preparation of a detailed version of this note (including more detailed calculations) to be approved at the 17th CCM meeting. The first draft of the detailed note should be available before the 26th CGPM.

2. Dissemination of the kilogram after the proposed redefinition

2.1. General principles

The dissemination of the kilogram after the redefinition will be coordinated by the CCM and its mass metrology experts, together with the BIPM, and will be performed according to the following general principles:

- Understanding and developing confidence in new realizations of the kilogram,
- Best practice and experience of dissemination from an ensemble of mass standards (including mathematical modelling),
- Stability and managed continuity of the disseminated mass scale,
- Periodic establishment of primary traceability link from realization experiments.

2.2. Dissemination phases and time scale

Ultimately, the dissemination of the kilogram after the redefinition will take place according to the *mise en pratique* for the definition of the kilogram. The continuity and ongoing global equivalence of the SI unit of mass will be reached in three consecutive phases according to the table below.

2.3. Definition of the terms used

KCRV (Key Comparison Reference Value): Output of a statistical analysis of all the data from available realizations of the kilogram having participated in a key comparison of realizations of the kilogram, following the principles of the CIPM MRA.

u_{KCRV}: uncertainty associated to the key comparison reference value.

CV (Consensus value): Output of a statistical analysis of all the data from available realizations of the kilogram to be used as the highest source of traceability to the redefined kilogram during phase 2. The consensus value (CV) will be managed by a CCM task group to ensure stability and continuity, taking all new realizations and comparisons into account. It could be identical to the KCRV but could also be calculated using additional weighting factors (see 3.2).

u_{CV}: uncertainty associated to the consensus value.

$u_{\mathrm{m_{IPK}}}$: uncertainty associated to the mass of the International Prototype of the Kilogram (IPK) after the redefinition. The uncertainty of the adjusted value of h of 1 part in 108, prior to the redefinition, will be attributed to the mass of the IPK right after the redefinition. Therefore $u_{\mathrm{m_{IPK}}} = 10$ µg.

$u_{\mathrm{stab}}(\mathrm{t})$: uncertainty associated to the stability of BIPM working standards at time t. At the present time (May 2018) $u_{\mathrm{stab}}(\mathrm{t}) \approx 5$ µg.

$u_{\mathrm{stab.NMI}}(\mathrm{t})$: uncertainty associated to the stability of the NMI mass standards used to disseminate the consensus value.

Phase	Time scale	Description	Source of traceability	Uncertainty of BIPM mass standards	Role of realization experiments	Dissemination of mass from NMIs with realization experiments
0	today - date 1[1]	Present traceability	$m_{\mathrm{IPK}} \equiv 1$ kg $u_{m_{\mathrm{IPK}}} \equiv 0$	$u_{\mathrm{stab}}(t)$	Measurement of h	Dissemination from national prototype traceable to IPK
1	date 1 - date 2[2]	Present traceability, taking into account the additional uncertainty coming from the new definition	$m_{\mathrm{IPK}} = 1$ kg $u_{m_{\mathrm{IPK}}} = 10\ \mu$g	$\approx \sqrt{u^2_{m_{\mathrm{IPK}}} + u^2_{\mathrm{stab}}(t)}$	Contribute to key comparison	Dissemination from national prototype traceable to IPK, with 10 µg add. uncertainty
2	date 2 - date 3[3]	Dissemination of the consensus value	Consensus value (CV)	$\approx \sqrt{u^2_{\mathrm{CV}} + u^2_{\mathrm{stab}}(t)}$	Contribute to CV, improve experiments to resolve discrepancies	Dissemination from consensus value with uncertainty $\approx \sqrt{u^2_{\mathrm{CV}} + u^2_{\mathrm{stab.NMI}}(t)}$
3	from date 3	Dissemination of individual realizations	Fixed value of h $u(h) \equiv 0$	$\approx \sqrt{u^2_{\mathrm{KCRV}} + u^2_{\mathrm{stab}}(t)}$	Realization of the unit of mass, Participation in KCs to demonstrate equivalence	Dissemination from realization experiment with the uncertainty of their realization experiment. The terms of the CIPM MRA are applicable.

[1] date 1 = implementation date of revised SI, 20 May 2019.

[2] date 2 = date of CCM approval of the consensus value resulting from the first key comparison of realization experiments after the implementation of the revised SI, expected Q1 2020.

[3] date 3 = date of CCM decision that dissemination from consensus value no longer necessary, because dispersion of calibration results from validated primary realization experiments is compatible with their individual uncertainties.

3. The different phases in detail

3.1. Phase 1: Present traceability, with additional uncertainty component

At the date of implementation of the revised SI, 20 May 2019, the reference quantity for the mass unit changes from the mass of the IPK to the fixed numerical value of the Planck constant. At that time, the uncertainty of the adjusted value of the Planck constant[1] prior to the redefinition of 1 part in 10^8 will be attributed to the mass of the IPK, which will then have an uncertainty of 10 µg.
At the date of implementation most, if not all, NMIs of Member States will have calibration certificates from the BIPM, for past calibrations traceable to the IPK. The uncertainties of these calibrations are in the range of 3.5 µg to 7 µg for Pt-Ir standards and of 10 µg to 15 µg for 1 kg stainless steel standards. On implementation day the uncertainty of the IPK within the revised SI, 10 µg, needs to be added in quadrature to the uncertainty stated on past BIPM calibration certificates. This will bring the uncertainty in the range of 11 µg to 12 µg for Pt-Ir standards, and 14 µg to 18 µg for 1 kg stainless steel standards. The calibration values will not change, since efforts have been made to ensure that the kilogram has the same magnitude - within the uncertainty - before and after the redefinition.

The BIPM will issue a note about this to all NMIs which have received calibrations in the past. It is not planned to issue amendments to previous calibration certificates.

Calibrations at the BIPM carried out between the implementation date and the agreement of the consensus value resulting from the first key comparison of kilogram realizations (phase 1) would continue to be based on the BIPM working standards, traceable to the IPK, but taking into account the additional uncertainty in the mass of the IPK of 10 µg. This fact will be clearly indicated on the certificates. After the implementation day, NMIs should also include the additional uncertainty component of 10 µg in the calculation of uncertainties quoted on calibration certificates for their own customers. In deciding about the necessity to inform recipients of past NMI calibrations about the additional uncertainty component, the uncertainty of these calibrations should be taken into account. In most cases the changes in the quoted uncertainties would be negligible.

3.2. Phase 2: Dissemination of the consensus value

During a transition period following the SI revision (phase 2), the determination of a consensus value for the kilogram is crucial to the continuity and ongoing global equivalence of the SI unit of mass. As stated in Section 3.1 the traceability to the kilogram directly after the revision will be based on the BIPM working standards, traceable to the IPK, but with an additional uncertainty component of 10 µg. Soon after the SI revision in 2019 a key comparison of realization experiments will be undertaken. This may take the form of a parallel comparison between the BIPM and participating laboratories but equally could be run as a series of bi-lateral comparisons, giving the participants flexibility in when they run their realization experiments. Participation to the key comparison of realization experiments will be restricted to NMIs having published results in peer reviewed journals with a standard uncertainty lower or equal to 5.0×10^{-7}. Each time an independent realization participates in the ongoing key comparison, the key comparison reference value will be updated and the agreed consensus value for the kilogram will be reviewed by CCM (but not necessarily changed). The KCRV will be calculated using a recognized methodology (for example using a weighted mean based on the stated uncertainty of the participant's values). The consensus value will be derived from all results contributing to the KCRV. Updating of the consensus value will be supervised by a CCM

[1] The uncertainty of the adjusted value of the Planck constant in the 2017 CODATA special adjustment of fundamental constants is 1 part in 10^8.

task group to avoid significant step changes as a consequence of new comparison results. Its uncertainty will depend on the uncertainty of the individual realizations as well as their dispersion.

To maintain the stability of the consensus value an additional weighting may be applied to the values produced by the realization experiments. The additional weighting should be based on statistical analysis and could reflect factors such as the stability of values from the experiment over time.
The consensus value will initially be based on the BIPM working standards and will be revised taking into account new values from realization experiments. These values will start with a low weighting which should increase with further contributions from the individual experiment[2]. It is the objective to keep the consensus value stable well within the uncertainty calculated (which should remain at 10 µg). This mechanism allows the pilot laboratory of the KC to be able to disseminate the consensus value to all NMIs.

The first CMCs based on realization experiments could be requested by the participating NMIs after the publication of the final report of the initial key comparison (or the individual bi-lateral comparisons with the BIPM) following the revision of the SI. However, the CMCs will need to state the uncertainty with which the SI unit of mass can be disseminated by the individual laboratories from the consensus value, including its uncertainty. The CCM task group will advise the CCM should it become clear that a consensus value is no longer required. The CMCs will only be published just before starting phase 3.

3.6. Phase 3: Dissemination of individual realizations

As soon as the CCM determines that the dispersion of the results from individual realization experiments is compatible with the uncertainties of the individual realizations, these realizations can then provide direct traceability for the kilogram. This will be done via the standard CIPM MRA process for evaluating degrees of equivalence between independent realizations. Each individual realizations need to have demonstrated equivalence via the KC before they can provide direct traceability.

Phase 3 is reached as soon as there are no significant unresolved discrepancies between dissemination from the consensus value and dissemination from individual realizations. The only condition for the dissemination of individual realizations is that the corresponding CMC entries are available in the KCDB.

When phase 3 is reached, the BIPM will continue to provide calibrations to the member states not having a realization experiment either using the KCRV (which will then replace the CV) maintained via conventional mass standards or using their realization of the kilogram. The scientific choice to start phase 3 will be reviewed and agreed by the CCM.

4. Note

The CIPM MRA provides sufficient protection to ensure that there will be no international recognition of calibrations based on individual realizations until the evidence supports this practice. By common agreement, the CCM will not accept or publish CMCs for the realization of the redefined kilogram until the end of phase 2 is in sight, and no significant unresolved discrepancies in the on-going key comparison results of NMIs applying for CMCs.

[2] For example initial values from the realization experiments (as part of the first key comparison) could be given a weighing to be defined. The results from subsequent comparisons using the same experiment could be given an increasing weight (experiments with an existing provenance of producing values of the Planck constant up to the redefinition could be given higher weighting since they could be regarded as already having demonstrated a stability of performance).

5. Guidance documents

Based on this short note, the CCM will establish a more detailed guidance document for its members and for the NMIs. The final version of the guidance document will be approved at the next CCM meeting before the date of implementation of the revised SI.

According to section 3.1, the BIPM will issue a note on the present traceability, with additional uncertainty component in order to guide the users on the practical consequences of phase 1.