# The new definition of the kilogram and the current status of mass traceability

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26 March 2021

Bureau International des Poids et Mesures

# Plan

- Redefinition of the kilogram & its advantages
- *Mise-en-pratique* for the kilogram definition
- CCM detailed note on the dissemination process
- Dissemination of the Consensus Value
- Useful documents on the CCM webpage

# Redefinition of the kilogram


26th CGPM, Versailles, November 2018

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

- **invariant in time**
- **universally available**

The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant $h$ to be $6.626\,070\,15 \times 10^{-34}$ when expressed in the unit J s, which is equal to kg $m^2$ $s^{-1}$, where the metre and the second are defined in terms of $c$ and $\Delta\nu_{Cs}$.

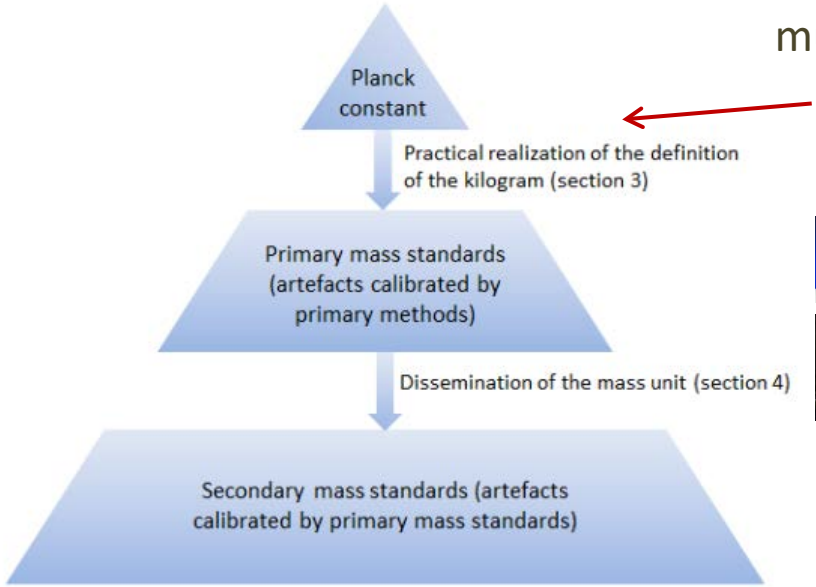
# *Mise-en-pratique* for the definition of the kilogram: I

SI Brochure – 9th edition (2019) – Appendix 2 04 August 2020

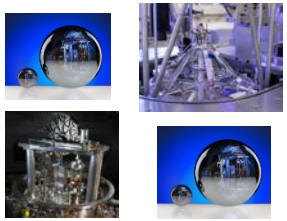
***Mise en pratique***
**for the definition of the kilogram in the SI**

**Consultative Committee for Mass and Related Quantities**

unique primary realization (in air)




multiple primary realizations (in vacuum)



# *Mise-en-pratique* for the definition of the kilogram: II

- Practical realization of the definition of the kilogram
  - Realization by comparing electrical power to mechanical power
  - Realization by the X-ray-crystal-density method
- Dissemination of the mass unit
  - Dissemination from a particular realization, CCM.M-K8 to support CMCs
  - Dissemination from the BIPM, through an ensemble of mass standards

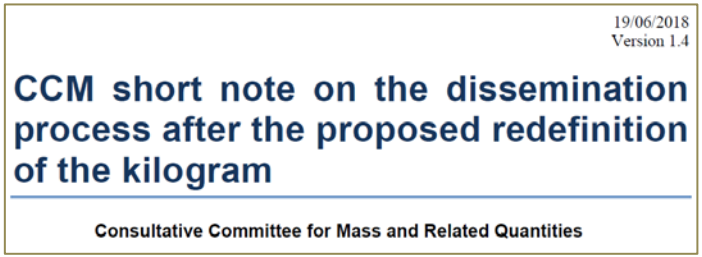
- Currently focus on the realization and dissemination at 1 kg; may be updated to include information on primary methods at different nominal mass values
- Update to take account of new methods and technological improvements

# CCM Recommendation G1 (2017)

- Inconsistency in the results of the realization experiments at the time of redefinition
- An internationally coordinated dissemination from the NMIs with realization experiments and the BIPM
- Dissemination based on the so-called “Consensus Value” as a common basis to ensure the continuity, temporal stability and equivalence of the mass unit
- Until dispersion in values between realization experiments becomes compatible with their individual uncertainties

# Transition period using a Consensus Value

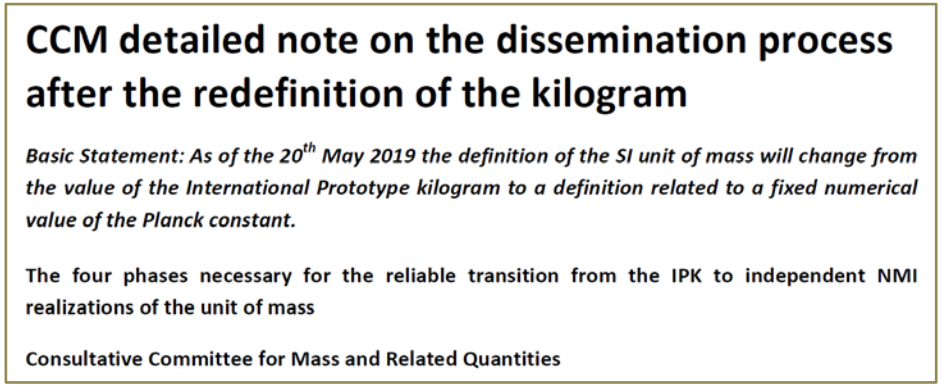
- Facilitate the smooth transition from traceability derived from the IPK to a point where the use of individual realization experiments for realization and dissemination becomes viable
- CV managed by the CCM Task Group on the Phases for the Dissemination of the kilogram following redefinition (CCM-TGPfD-kg) to ensure stability and continuity


19/06/2018
Version 1.4

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

Consultative Committee for Mass and Related Quantities

approved by the CIPM at its 107th meeting in June 2018


**CCM detailed note on the dissemination process after the redefinition of the kilogram**

***Basic Statement:** As of the 20th May 2019 the definition of the SI unit of mass will change from the value of the International Prototype kilogram to a definition related to a fixed numerical value of the Planck constant.*

**The four phases necessary for the reliable transition from the IPK to independent NMI realizations of the unit of mass**

**Consultative Committee for Mass and Related Quantities**

# Dissemination phases

| Phase | Time scale | Description | Source of traceability | Uncertainty of BIPM mass calibrations | Role of realization experiments | Dissemination of mass from NMIs with realization experiments |
|---|---|---|---|---|---|---|
| 0 | Until 20 May 19[1] | Traceability to the IPK | $m_{\mathrm{IPK}} \equiv 1$ kg<br>$u_{m_{\mathrm{IPK}}} \equiv 0$ | $u_{\mathrm{stab}}(t)$ | Measurement of $h$ | Dissemination from national prototype traceable to IPK |
| 1 | 20 May 19 - date 1[2] | Traceability to the Planck constant via the IPK, with additional uncertainty from the (new) definition | $m_{\mathrm{IPK}} = 1$ kg<br>$u_{m_{\mathrm{IPK}}} = 10\ \mu$g | $\approx \sqrt{u^2_{m_{\mathrm{IPK}}} + u^2_{\mathrm{stab}}(t)}$ | Contribute to Key Comparison (KC), improve and resolve discrepancies | Dissemination from national prototype traceable to IPK, with 10 µg added uncertainty |
| 2 | date 1 – date 2[3] | Traceability to the Planck constant, dissemination from a consensus value[4] (CV) | Consensus value (CV) | $\approx \sqrt{u^2_{\mathrm{CV}} + u^2_{\mathrm{stab}}(t)}$ | contribute to CV (via KC), improve experiments and resolve discrepancies | Dissemination from consensus value with uncertainty $\approx \sqrt{u^2_{\mathrm{CV}} + u^2_{\mathrm{stab,NMI}}(t)}$ |
| 3 | from date 2 | Traceability to the Planck constant, dissemination by individual realizations | Fixed value of $h$<br>$u(h) \equiv 0$ | (Uncertainty of BIPM realization experiment) | Realization of the unit of mass, Participation in KCs to demonstrate equivalence | Dissemination from validated realization experiments with the uncertainty of the experiment. The terms of the CIPM MRA are applicable. |

**Table 1: The four phases necessary for the reliable transition from the IPK to independent NMI realizations of the unit of mass**

1 20 May 2019 = implementation date of revised SI.

2 date 1 = CCM approval of the consensus value resulting from the first KC of realization experiments after the implementation of the revised SI, expected Q1 2020.

3 date 2 = 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.

4 CV (Consensus value). 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 and advising the CCM should it become clear that a consensus value is no longer required.

# Consensus Value and its uncertainty

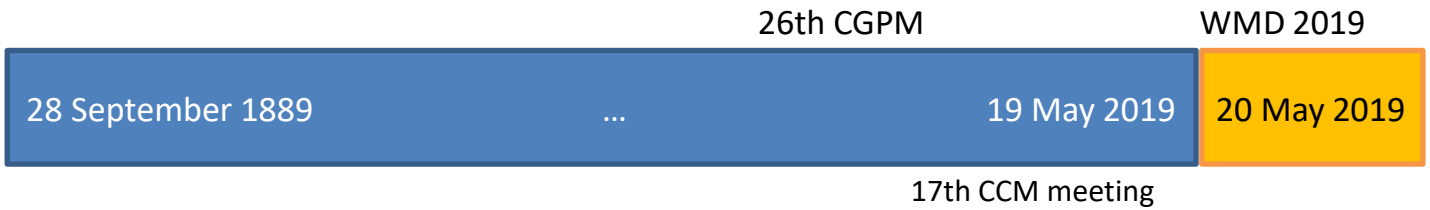
- Determination
  - KC for the realization experiment takes place every 2 years
  - CV based on an average of the last 3 KCRVs (to ensure temporal stability)
  - initial value based on IPK, Pilot study results, Ref. Value of first KC
- Dissemination
  - KC piloted by the BIPM
  - CV maintained and disseminated by the BIPM using their Pt/Ir standards
  - BIPM continues to provide calibrations for NMIs but traceability is switched from the IPK to the CV following the completion of the 1st KC of realization experiments
- Uncertainty
  - The uncertainty in the Consensus Value is 20 µg

# Criteria for moving from the phase 2 to phase 3

- A minimum of five consistent realization experiments which:
  - Achieve KC results with a relative standard uncertainty of $4 \times 10^{-8}$ or better
  - Demonstrate consistency with the KCRV
  - Demonstrate stability by producing consistent (equivalent) results for two consecutive KCs
- At least two of the realization experiments meeting the above criteria should have uncertainties less than $2 \times 10^{-8}$
- The consistent set of experiments must include two independent methods of realizing the SI unit of mass (*e.g.* Kibble balance and XRCD experiments)
- The difference between the Consensus Value for the kilogram (determined from last 3 KC results) and the KCRV for the final KC is less than $5 \times 10^{-9}$

# Dissemination: phase 0

## Past traceability to the IPK




Source of traceability

$m_{\mathrm{IPK}} \equiv 1$ kg

$u_{m_{\mathrm{IPK}}} \equiv 0$

Uncertainty of BIPM mass calibration

$u_{\mathrm{stab}}(t) \approx 5$ µg

# Dissemination: phase 1

## Traceability to *h* through the IPK


Source of traceability

$m_{\mathrm{IPK}} = 1$ kg

$u_{m_{\mathrm{IPK}}} = 10$ µg

Uncertainty of BIPM mass calibration

$$\sqrt{u^2_{m_{\mathrm{IPK}}} + u^2_{\mathrm{stab}}(t)} \approx 12\ \mu\mathrm{g}$$

# Traceability to *h* through the IPK

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**Note on the impact of the redefinition of the kilogram on BIPM mass calibration uncertainties**

## CMC adjustments of about 20 NMIs

**Adjustment of the mass uncertainty of BIPM calibration certificates issued before 20 May 2019**

Prior to the decision to redefine the kilogram, all NMIs took traceability, directly or indirectly, from the IPK. This will continue to be the case immediately after 20 May 2019. The mass of the IPK will then have an associated uncertainty of 10 µg.

NMIs will need to review and, where necessary, adjust their uncertainty budgets for measurements made after 20 May 2019 by:

1. Adding 10 µg in quadrature to the existing uncertainty given by the BIPM for those standard(s) by which they achieve traceability to the BIPM
2. Updating their uncertainty budgets with the new uncertainty for the standard(s)

The mass values stated on the BIPM certificates remain valid.

# Dissemination: phase 2

## Dissemination of the Consensus Value


Source of traceability

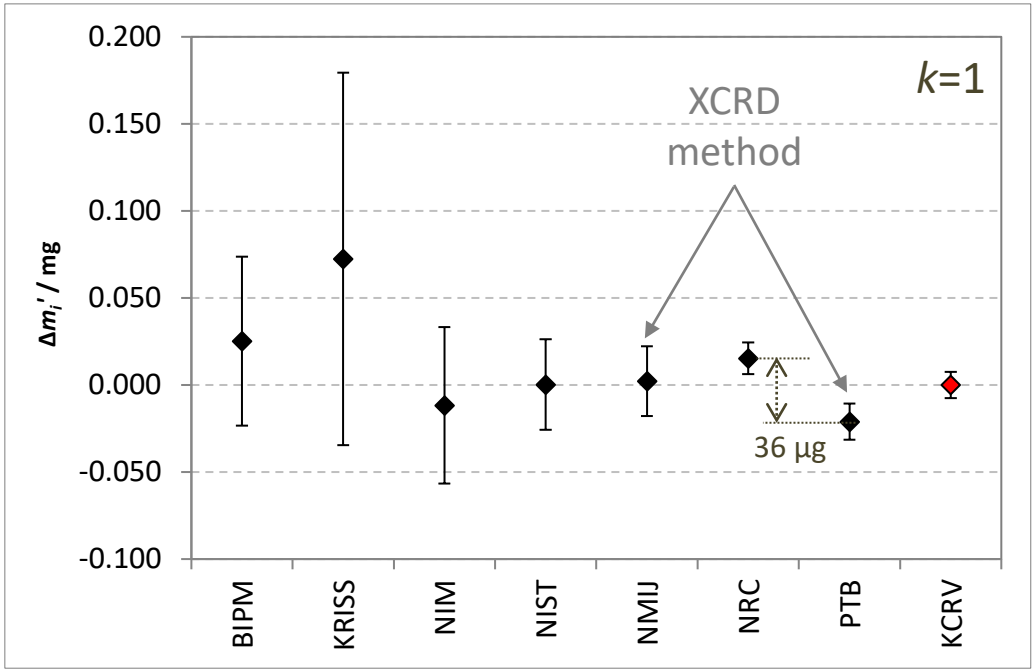
Consensus Value (CV)

$u_{\mathrm{CV}} = 20$ µg

Uncertainty of BIPM mass calibration

$\sqrt{u_{\mathrm{CV}}^2 + u_{\mathrm{stab}}^2(t)} \approx 21$ µg

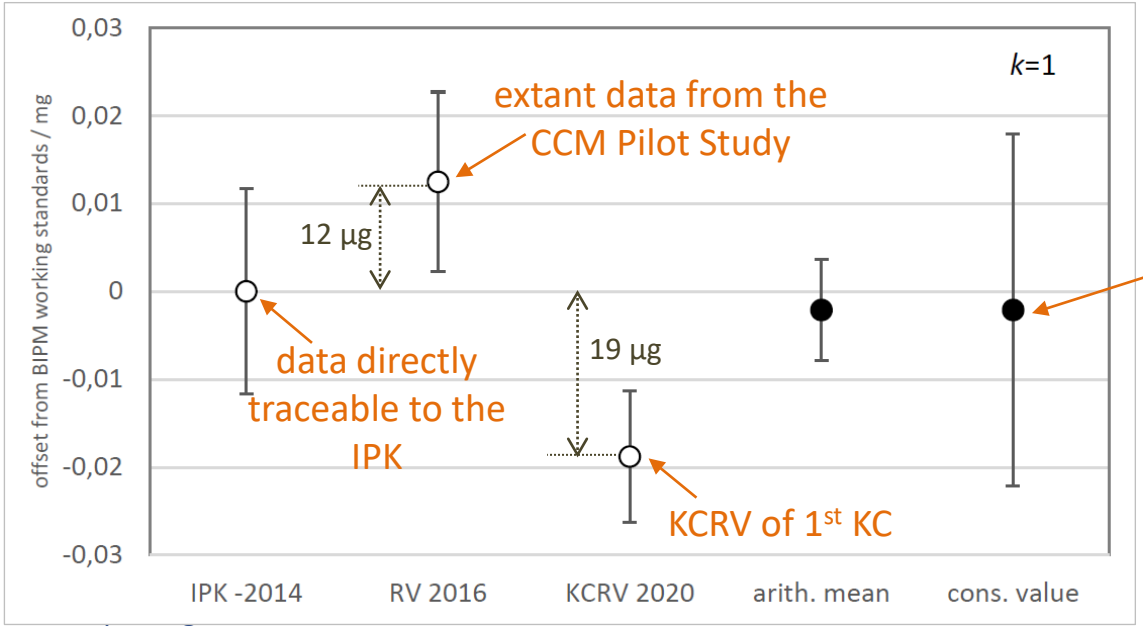
# First KC of realization experiments CCM.M-K8.2019




- 7 participants: 5 Kibble/Joule balances, 2 XRCD
- Travelling standards of each participant: measured in vacuum, stability check (not all NMIs due to travel restrictions)
- Measurement started in Sept. 2019 and completed in Feb. 2020
- Final Report published in Oct. 2020
- KCRV calculated as the weighted mean of the participants' results with $u_R$ ($x_R$ ) = 7.5 µg

# Calculation of the first Consensus Value

- Consensus Value based on an arithmetic mean of 3 sets of data
- 3 data sets are linked together by BIPM Pt/Ir mass standards
- CV expressed in terms of an offset from the BIPM as-maintained mass unit




**1 kg - 2 µg with a standard uncertainty of 20 µg** with respect to the mass value of the IPK. This means that the mass of the IPK, based on the consensus value is 1 kg - 2 µg.

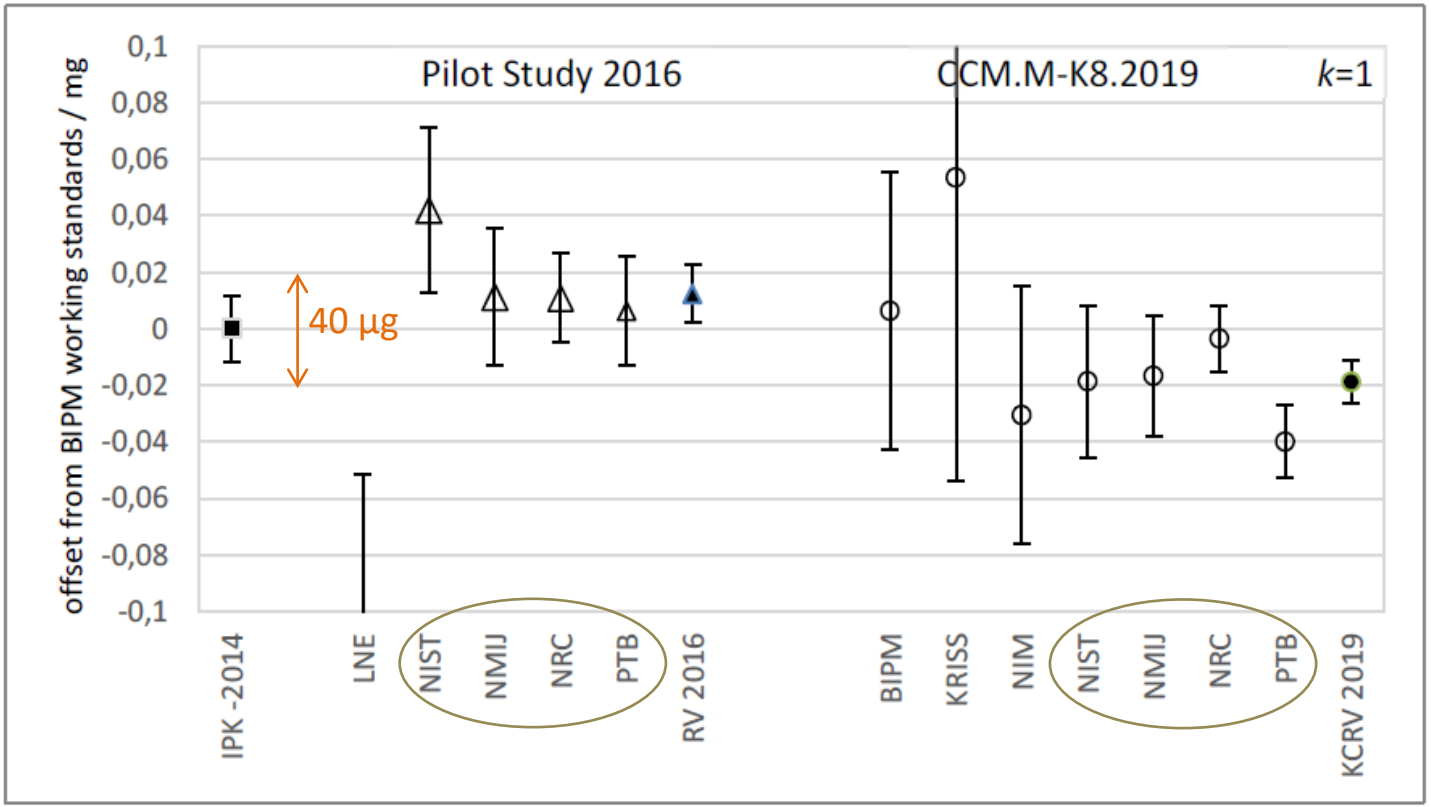
# Dissemination of the Consensus Value

- **no adjustment to the international mass scale needs to be made**, only the uncertainty needs to be increased
- adjustments to the CMCs of NMIs may be necessary to take into account the increased uncertainty in the CV relative to the current uncertainty in the IPK
- draft adjustments calculated by an ad-hoc TG of the CCM WGM and circulated to the affected NMIs for approval → discussed at the coming WGM meeting

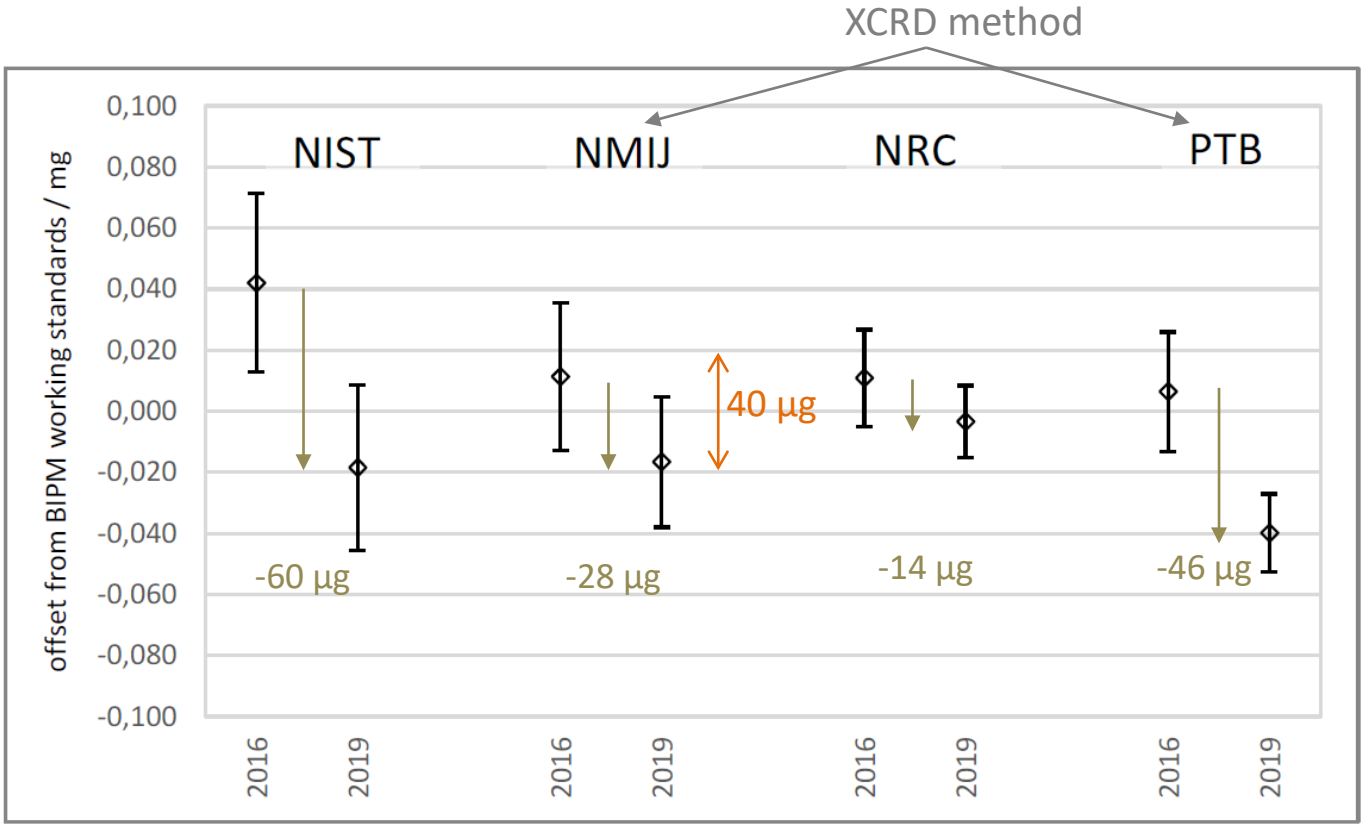
BIPM

**Note on the impact of the beginning of Phase 2 of the kilogram dissemination process on BIPM mass calibrations**

# kilogram realizations vs as-maintained BIPM mass unit



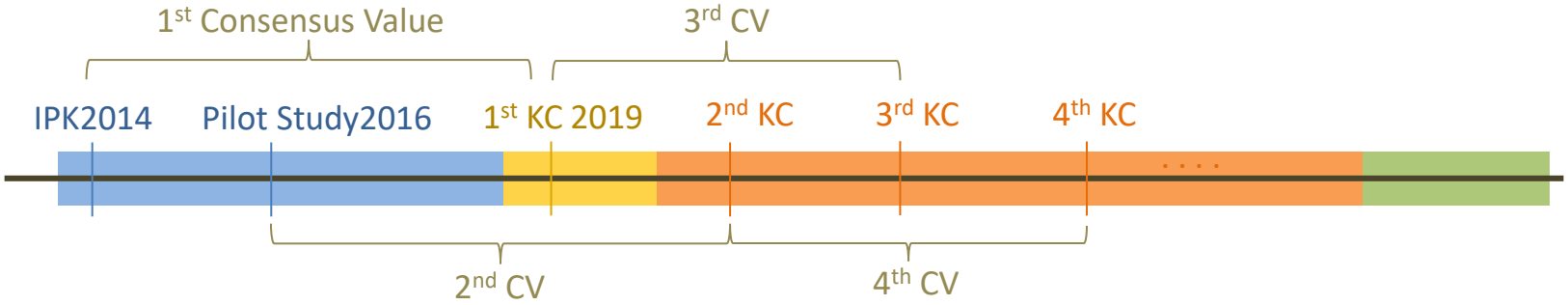
# Comparison of the results in 2016 and in 2019



# Next steps

- Repeat the CCM.M-K8 (scheduled to take place every 2 years)
- Determination of the 2nd Consensus Value
  - based on results of CCM Pilot Study, KCRVs of the 1st KC and of the 2nd KC
  - check of the temporal stability of the CV
- Dissemination of the 2nd Consensus Value

- Iteration until the decision of the CCM to go into Phase 3



# Dissemination: phase 3

## Dissemination by individual realizations

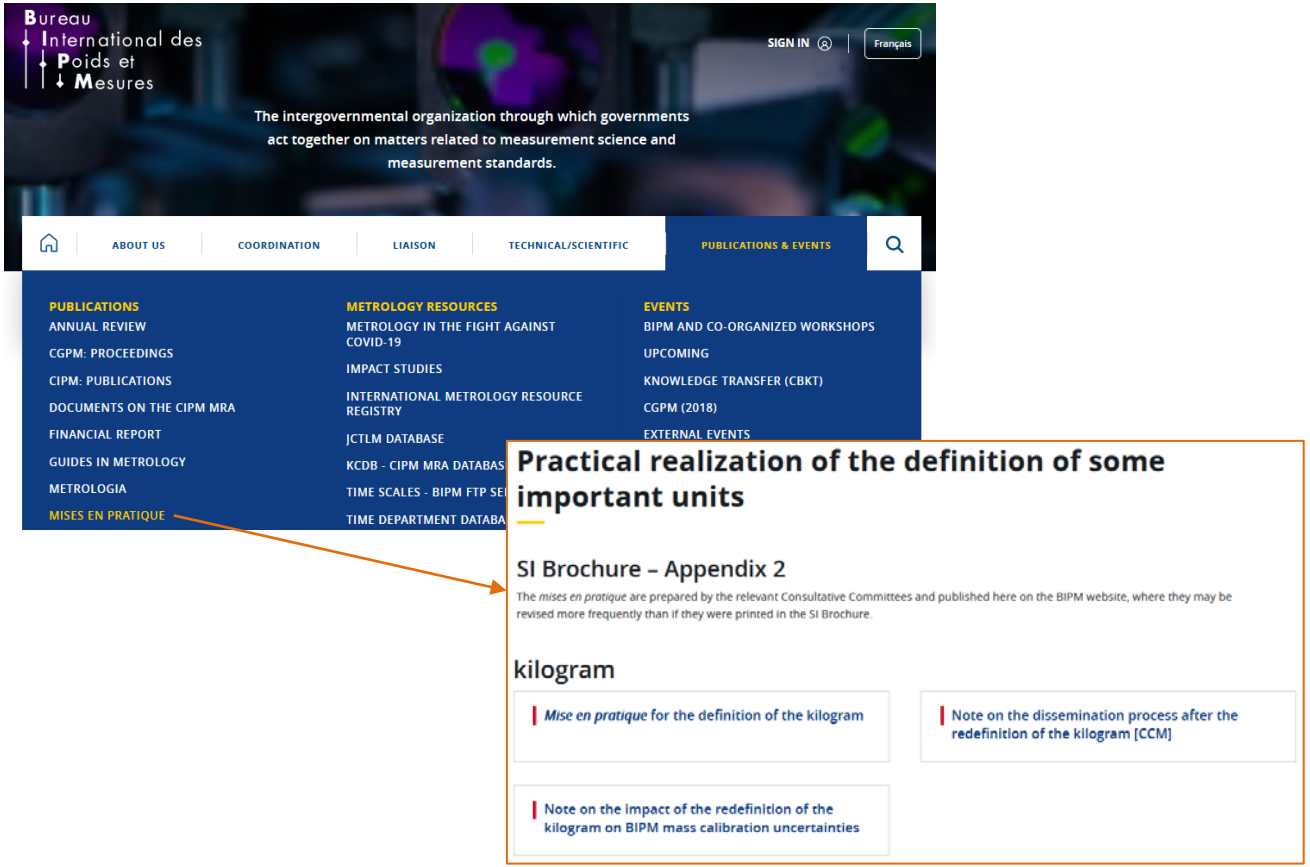
Dispersion compatible with individual realizations


Source of traceability
Fixed value of $h$
$u\ (h) \equiv 0$

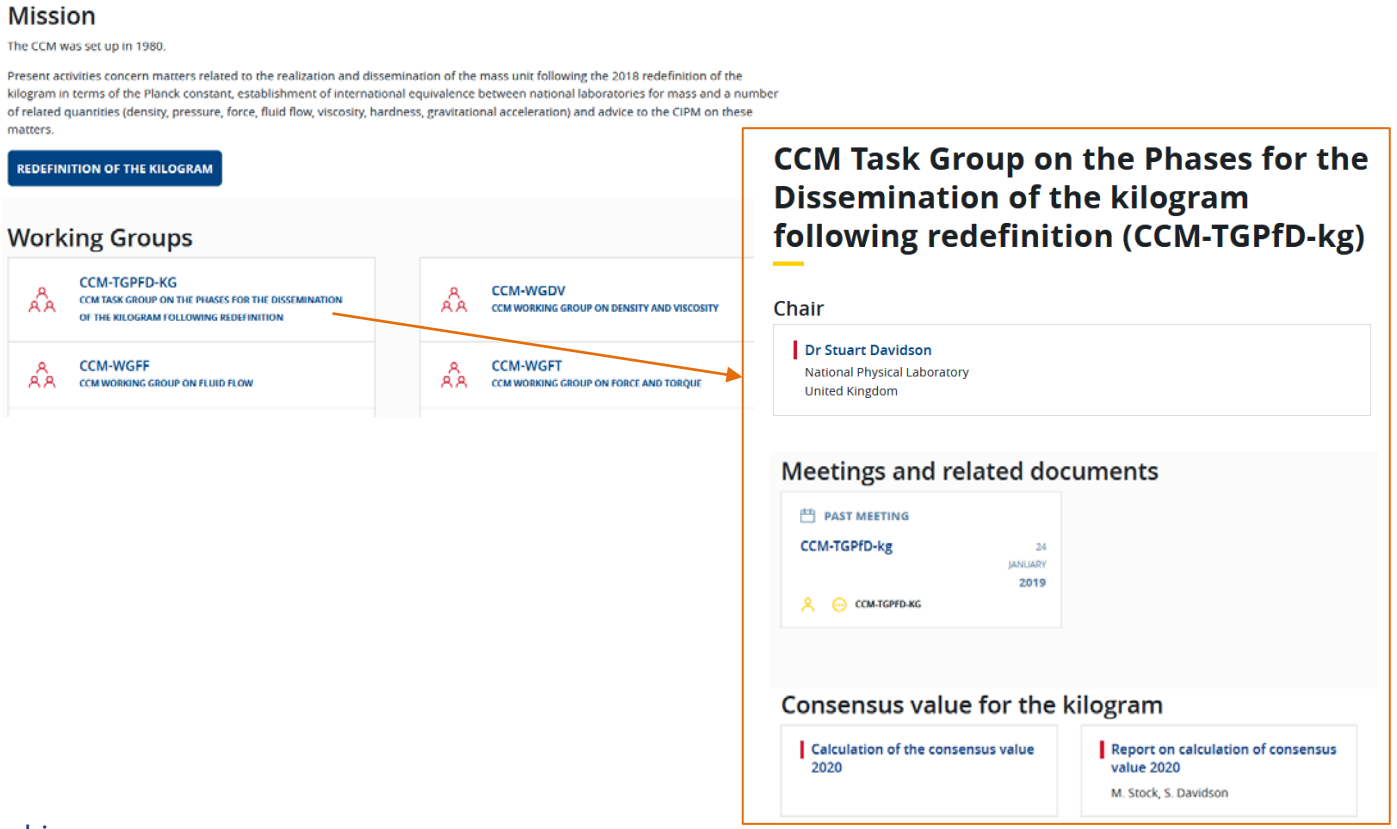
Uncertainty of validated realization experiments (CIPM MRA)

# Documents on the current CCM webpage

# Documents on the new BIPM website



# Documents on the new CCM webpage: I



# Documents on the new CCM webpage: II

## Consultative Committee for Mass and Related Quantities (CCM)

**President**

Dr P. Richard
CIPM Member

**Executive Secretary**

Dr H. Fang
BIPM

ALL MEMBERS

### Mission

The CCM was set up in 1980.

Present activities concern matters related to the realization and dissemination of
kilogram in terms of the Planck constant, establishment of international equivale
of related quantities (density, pressure, force, fluid flow, viscosity, hardness, gravi
matters.

REDEFINITION OF THE KILOGRAM

## Redefinition of the kilogram

**Documents related to the redefinition of the kilogram:**

- Information for users about the redefinition of the kilogram
- Mise-en-pratique for the definition of the kilogram
- Note on the impact of the redefinition of the kilogram on BIPM mass calibration uncertainties
- Note on the dissemination process after the redefinition of the kilogram
- Final Report on the CCM Pilot Study of future realizations of the kilogram
- Maintaining and disseminating the kilogram following its redefinition
- Focus on Realization, Maintenance and Dissemination of the Kilogram

CCM

Thank you for your attention !