Work program of the BIPM mass laboratories

M. Stock

CCM meeting
26-27 June 2025

Staff of the Physical Metrology Department

BIPM

Dr Michael STOCK
(CCEM, CCU)

Electricity

Impedance
(Resistance, Capacitance)

Dr Pierre GOURNAY
Principal Physicist

José Angel MORENO
Physicist

Benjamin ROLLAND
Assistant (Engineer)

Voltage

Dr Stéphane SOLVE
Principal Physicist (CCT)

Régis CHAYRAMY
Principal Technician

Kazuaki FUJITA
Secondee (NMIJ)
02/23-01/24

Mass

Kibble balance

Dr Hao FANG
Principal Physicist (CCM)

Dr Franck BIELSA
Principal Physicist
(CODATA TGFC)

Adrien KISS
Assistant (Engineer)

Mass calibr.
(also pressure, density)

Pedro CONCEIÇÃO
Principal Technician

Secondment to NIST QEMMS team:
April to August 2024
October to November 2025

Work program of the BIPM mass laboratory

- Providing mass calibrations to NMIs of Member States
- Organizing key comparisons of kg realizations
- Organizing key comparisons of secondary mass standards
- Developing and maintaining the ‘international Kibble balance’
- Providing Pt-Ir mass prototypes
- Providing internal calibration service of pressure gauges for BIPM departments

Guiding principles to ensure a stable BIPM mass unit

- Stable mass unit needed for comparing KCRVs of successive KCs of kg realizations and for calculation of Consensus Value
- Also needed for providing calibrations traceable to the last approved Consensus Value

- BIPM working standards calibrated against IPK in 2014
- for internal book-keeping we use mass values traceability to the IPK, but for calibrations the offset of the consensus value is applied
- new hierarchical system of mass standards with 3 significantly different levels of usage introduced in 2015
- significant reduction of the total number of weighings
- regular reports of status to CCM and CIPM

Guiding principles to ensure a stable BIPM mass unit

How to ensure a stable mass unit with artefact standards the mass of which can change

- Absolute mass stability is impossible

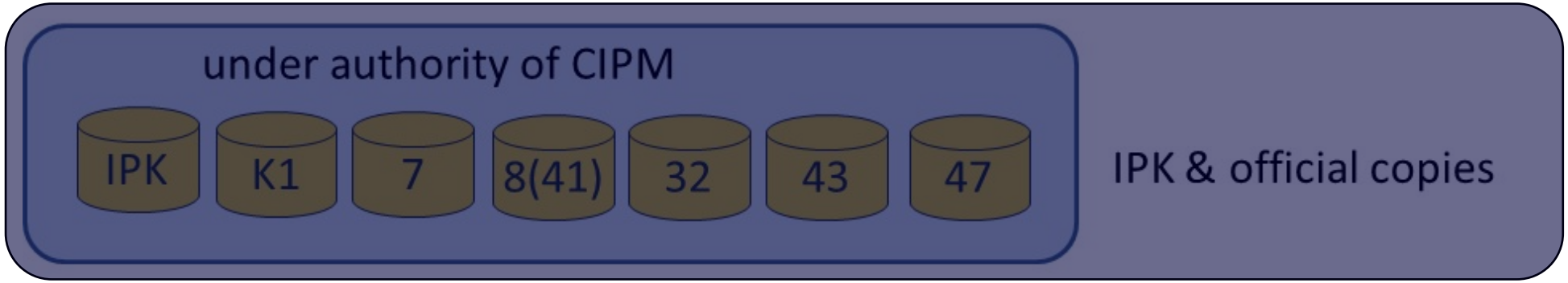
but also not required

- Mass changes must be correctly evaluated and the mass values corrected accordingly

m = 1.000 000 0xx kg

The mass standard together with the associated mass value represents the mass unit

Hierarchy of BIPM Pt-Ir working standards, introduced in 2015



25 73 91 — standards for exceptional use: (cleaned and washed before use) — $\frac{1\,use}{5\,years}$

9 31 650 — standards for limited use: — $\frac{1\,use}{year}$

42' 63 77 88 97 103 — standards for current use: — $\frac{4\text{ - }10\,uses}{year}$

Results of the 2024 recalibrations

- The attributed mass values of the working standards for limited use had been overestimated by 3 µg, well within uncertainty (5 µg)

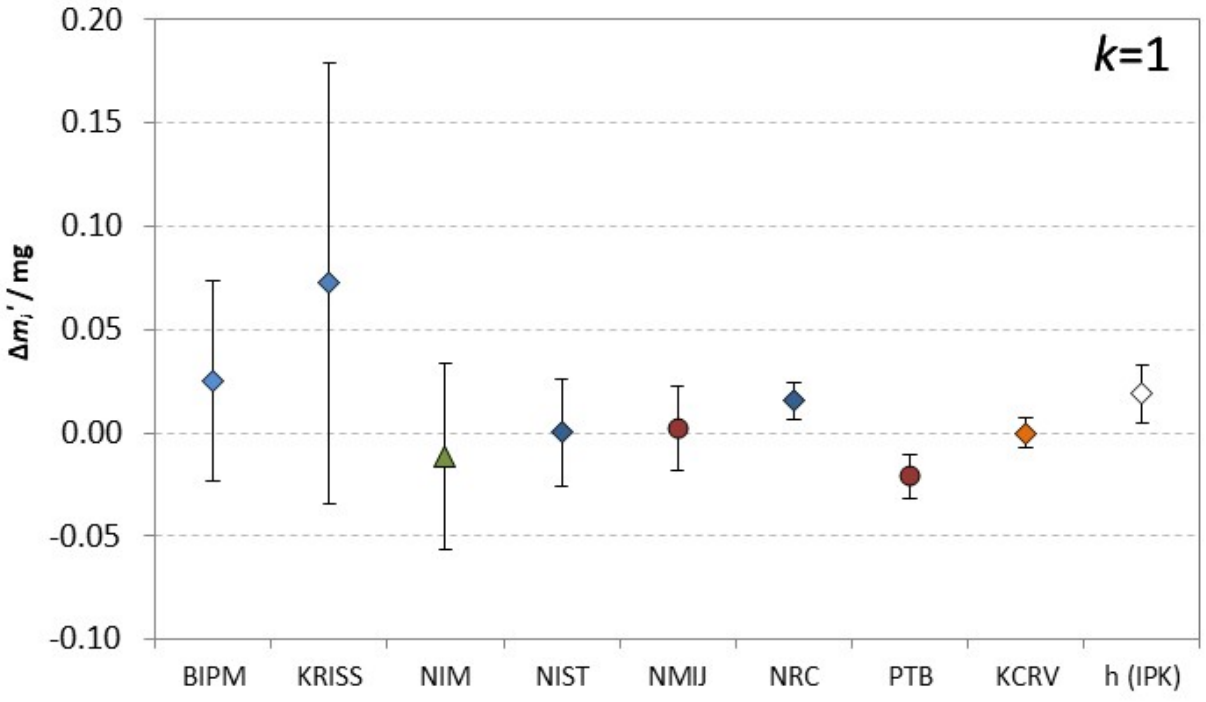
- The attributed mass values of the working standards for current use had been overestimated by 3 µg as those of the limited use standards

Conclusions

- The hierarchical scheme of usage works reliably
- The annual correction for contamination of the limited use standards (1.5 µg) was slightly too high and will be reduced to 1.0 µg for the coming 5 years

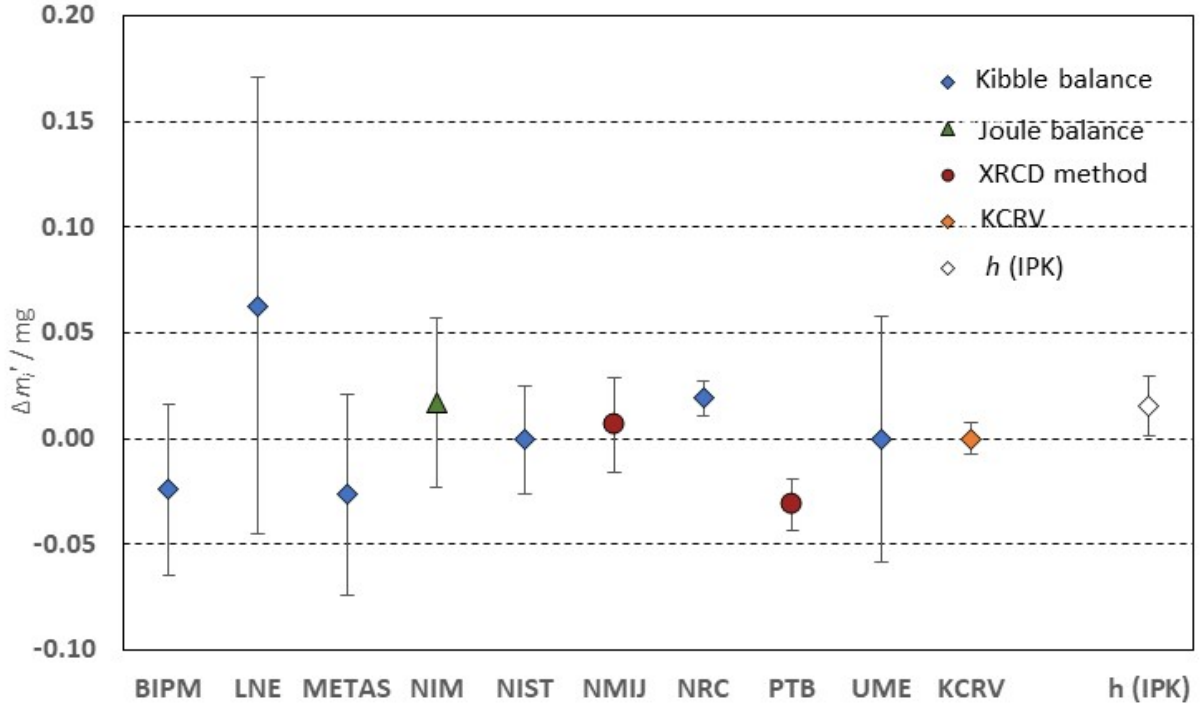
Reminder of the two previous comparisons of kg realizations

CCM.M-K8.2019



7 participants
KCRV = -0.0188 mg, u = 0.0075 mg
NRC – PTB = 0.0364 mg

CCM.M-K8.2021



9 participants
KCRV = -0.0152 mg, u = 0.0074 mg
NRC – PTB = 0.0501 mg

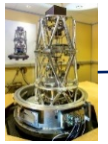
Third key comparison of kg realization
CCM.M-K8.2024

BIPM

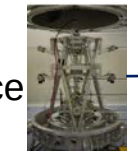
Pilot laboratory:	BIPM	
Conditions for participation	$u(m) < 200$ µg at 1 kg peer reviewed publication for first-time participants	
Participants (10)	6 Kibble balances: BIPM, LNE, METAS, NIST, NRC, UME 1 Joule balance: NIM 3 XRCD: NMIJ, PTB, CMS/ITRI (strongly correlated with PTB)	
Timeline	Technical Protocol	June 2024
	BIPM measurements	March to mid-April 2025
	travelling standards returned	25 April 2025 (except 1 NMI, still at BIPM)
	all measurement reports from NMIs received	
	reports on mass stability received:	7 of 10
	Draft A not yet available	

Organization of the comparison

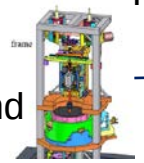
BIPM



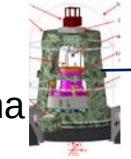
LNE France



METAS Switzerland



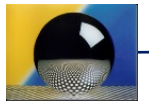
NIM China



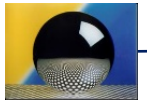
NRC Canada

NIST USA

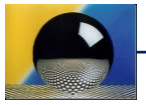
PTB Germany



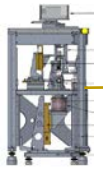
NMIJ Japan



CMS/ITRI Chinese Taipei

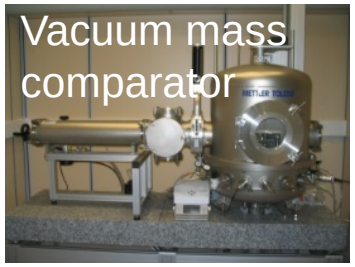


UME Türkiye

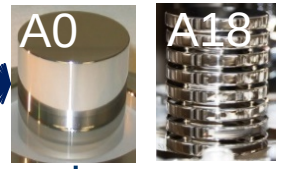


calibration in vacuum

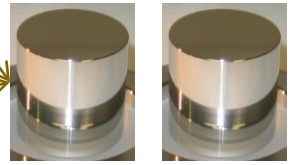
calibration in air



BIPM Pt-Ir sorption standards **(vacuum)**



vac.-air transfer



BIPM working standards **(air)**

IPK (last used in 2014)

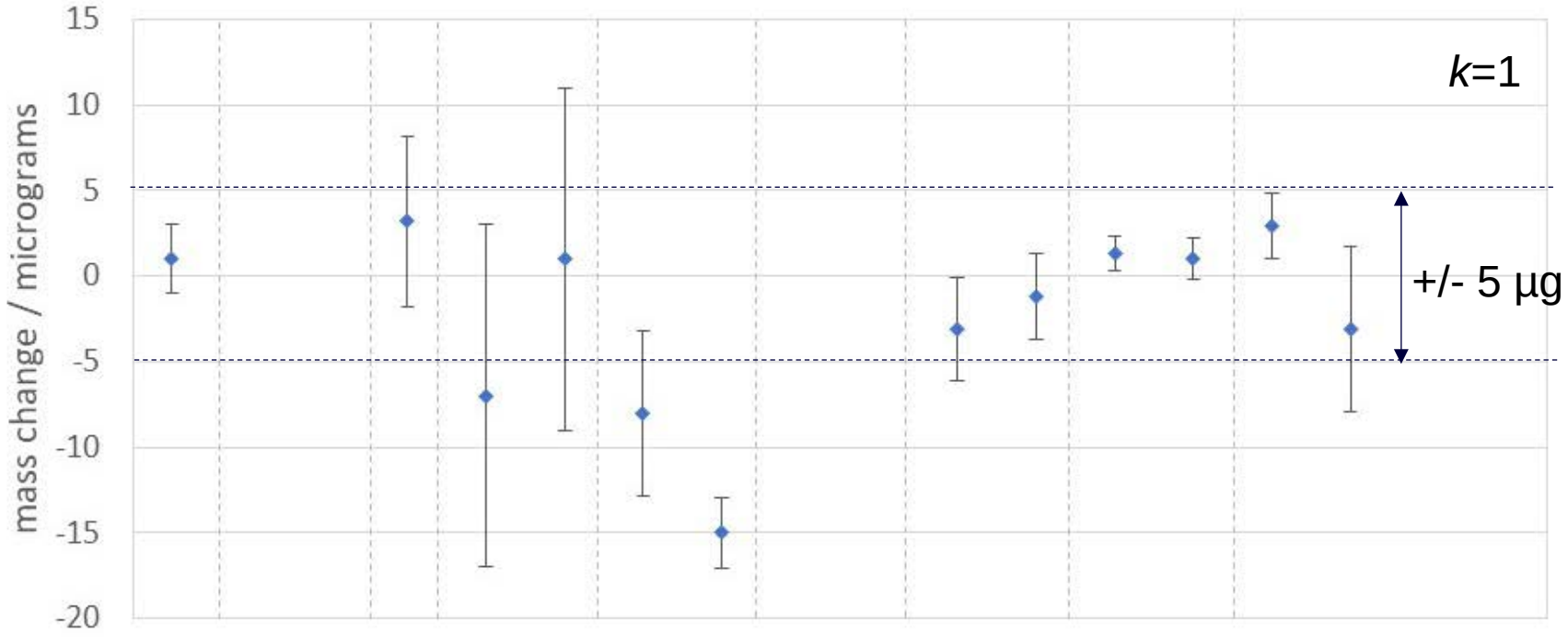
Comparison of the participants' mass standards in vacuum and in air at the BIPM

Stability of the travelling standards

Mass changes $\Delta m_{i,j} = m_{\text{after},i,j} - m_{\text{before},i,j}$ with $u(\Delta m_{i,j})$ determined by the participants

Correction will be applied $\delta m_{\text{stab},i,j} = \frac{1}{2}\Delta m_{i,j}$

Uncertainty contribution $\left(u_{\text{stab},i,j}\right)^2 = u(\Delta m_{i,j})^2 + \left(\frac{1}{2\sqrt{3}}\Delta m_{i,j}\right)^2$

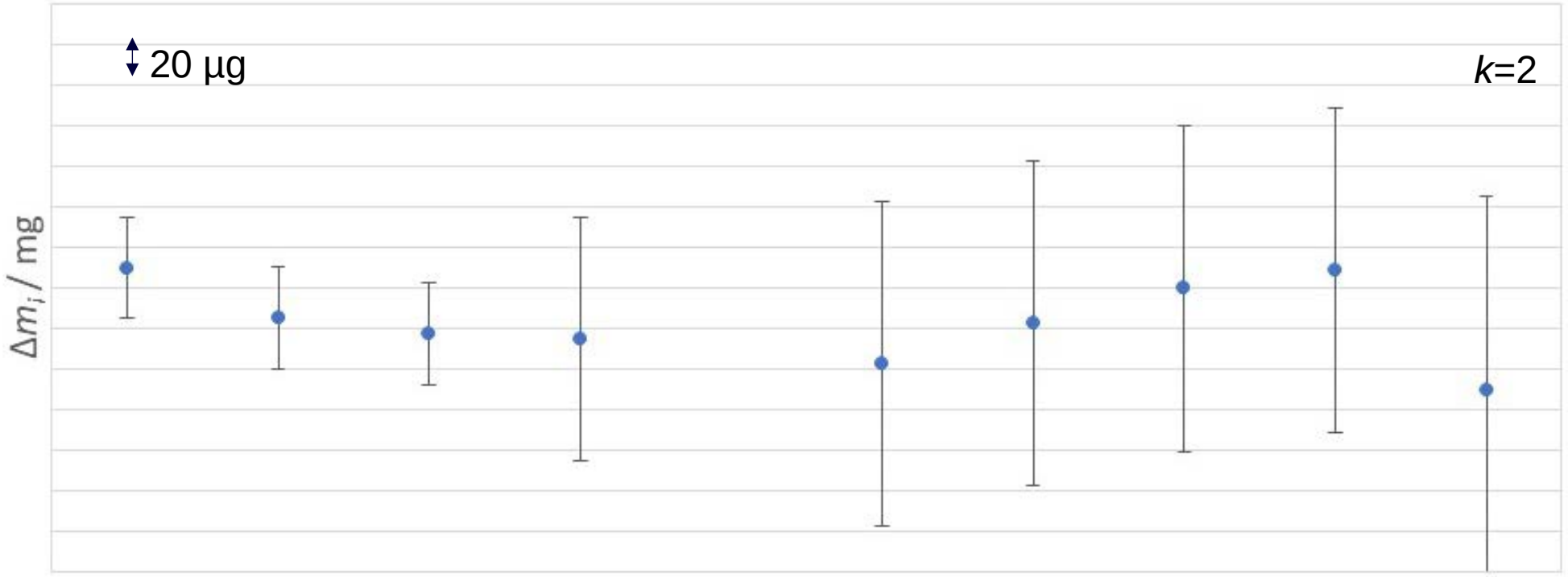


For 9/12: within +/- 5 µg

For 11/12: within +/- 10 µg

CCM.M-K8.2024: Preliminary results

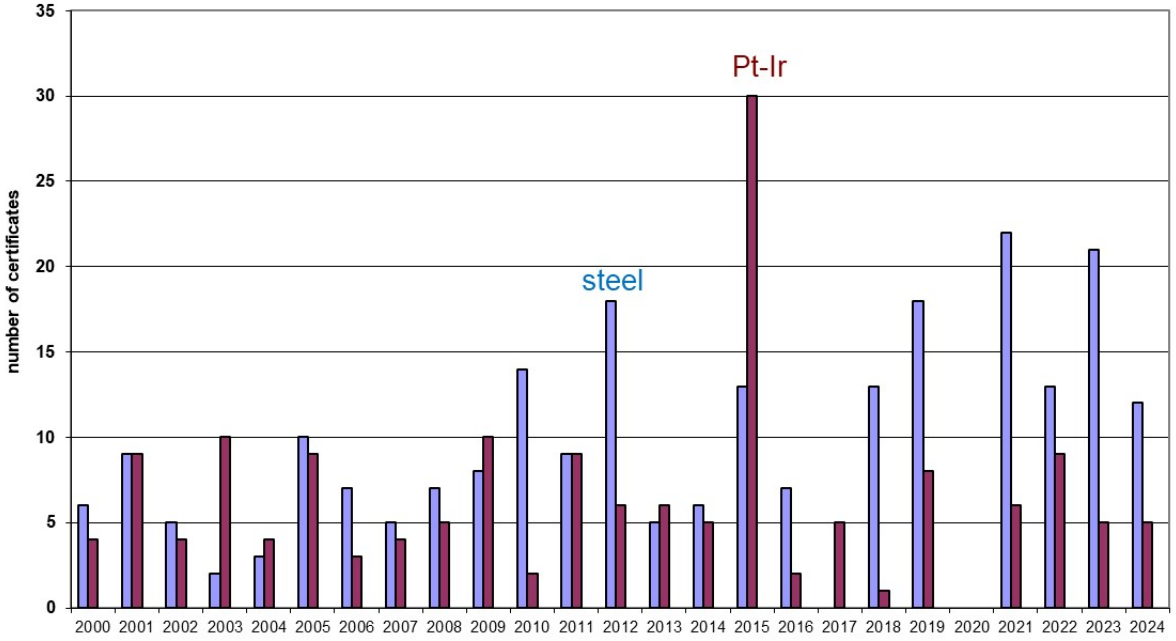
Uncertainties ‘homogenized’



Known corrections for mass changes applied, but 3 are still missing

Usage of the BIPM mass calibration service

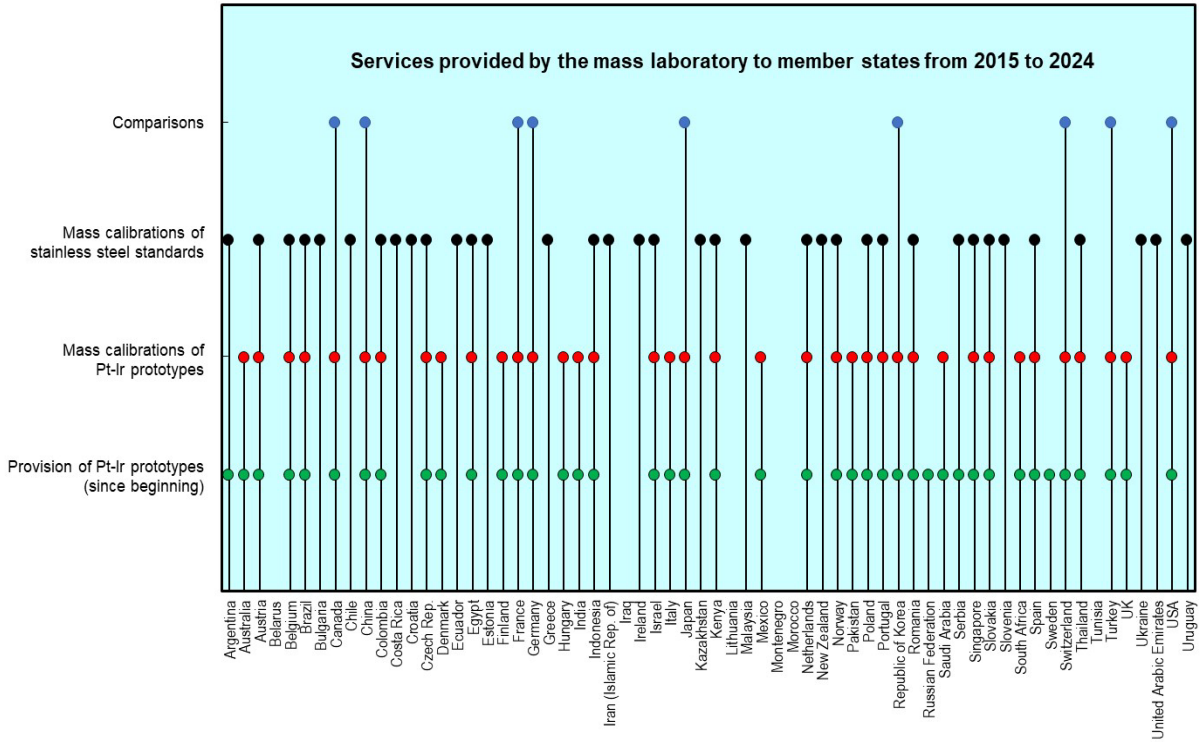
Number of calibration certificates per year



On average 6 Pt-Ir prototypes and 12 stainless steel standards per year

Calibrations can include determinations of volume/density and centre-of-mass if requested

Services provided to Member States



91 % of Member States served

Quality Assurance

- The mass calibration service is covered by a QMS based on ISO/IEC 17025:2017
- Internal audit: every year
- External audit: every 4 years

  Last in 2024 without any major non-conformity

  Most of the findings were suggestions intended to improve the calibration results, but do not affect the quality of the results produced.

Fabrication of new prototypes

2016: no. 110 for NIM, China
2017: no. 111 for KRISS, Rep. of Korea
2018: no. 107 for NPSL, Pakistan
2019: no. 112 for SNSU-BSN, Indonesia
2020: no. 113 reserved
2022: nos. 114 & 115 for NIM, China

Cost for Pt-Ir alloy from Johnson-Matthey has increased dramatically (about 80 k€ for 1 kg in 2024)

Decision in 2024 to stop providing prototypes

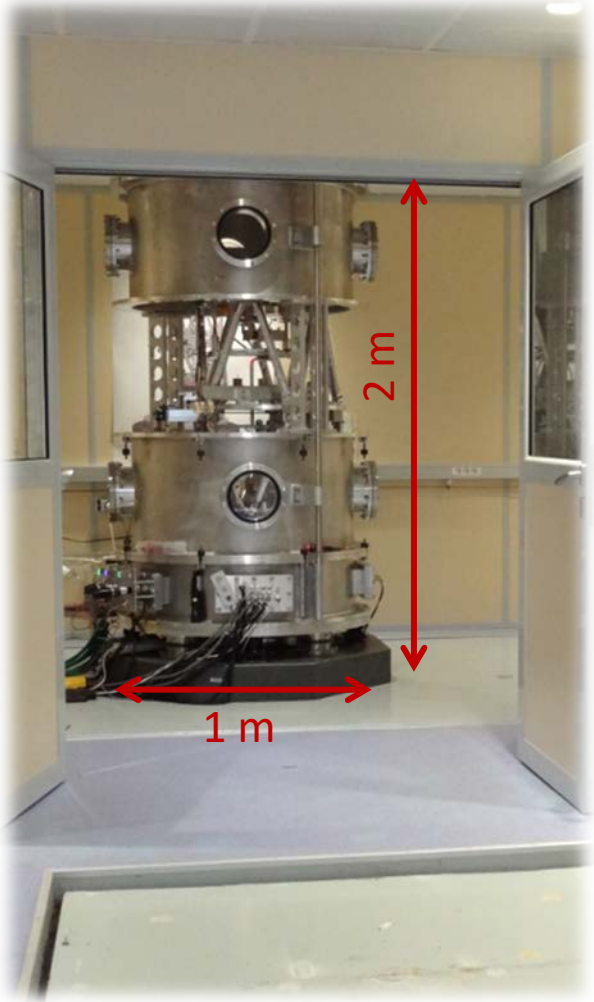
Provision of a last set of sorption standards for an NMI accepted (prototype + stack)

45 countries have received at least one Pt-Ir prototype (and up to 8) since the beginning

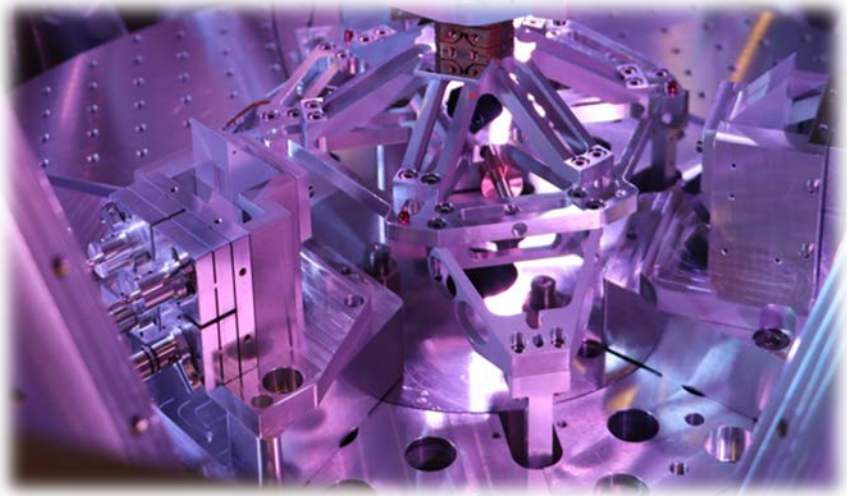

Final polishing of a Pt-Ir prototype


Prototype in travel container

The BIPM Kibble balance: apparatus



- magnetic flux density 0.47 T
- bifilar coil (each 26 layers & 1400 turns)
- current 10 mA for a 1 kg mass
- standard resistor 100 Ω
- voltage drop 1 V
- velocity 1 mm/s
- induced voltage 0.5 V



The BIPM Kibble balance: progress since 2023

BIPM

Main progress

- improvement on the S/N ratio of voltage-to-velocity ratio in velocity phase
- improvement on detection for vertical alignment of interferometer beams
- new absolute gravity measurement, supported by LNE
- study & improvement on electrical grounding

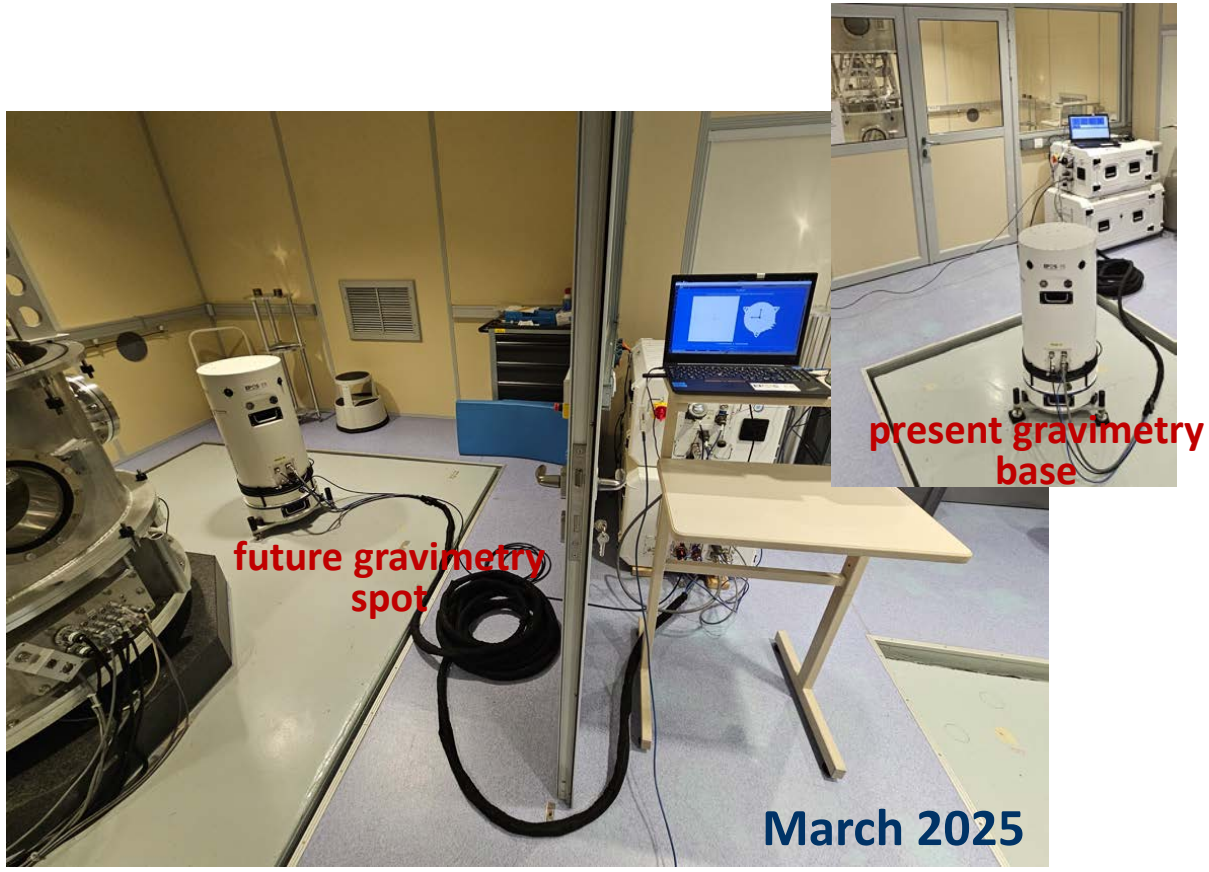
Participation in CCM.M-K8

- measurements carried out November-December 2024
- measurement uncertainty 36 µg
- dominated by alignment uncertainty 27 µg, still limited by parasitic coil vertical rotation

Collaborations

- Tsinghua University: provision of a compact magnetic circuit developed by Tsinghua Univ. (Shisong Li), 2024
- LNE: absolute gravity measurement, March 2025
- NIST: secondment of Franck Bielsa to NIST April – August 2024 & October – November 2025
- Gregor Dudle, Eastern Switzerland Univ. of Appl. Sciences: Monte Carlo simulation of KB, Sept. – Dec. 2025

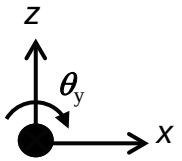
Free-fall acceleration of gravity

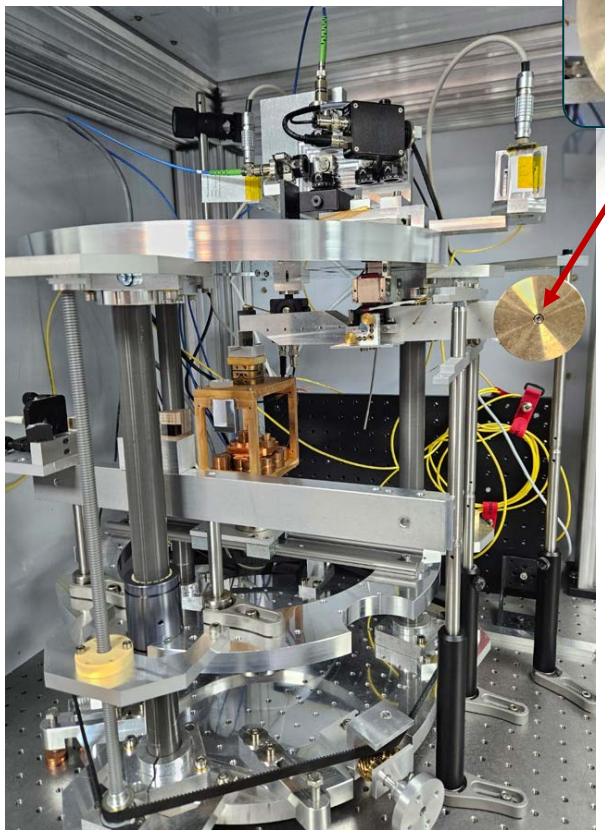


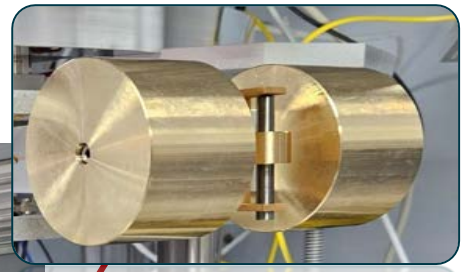
- new absolute measurement using an AQG-B01 quantum gravimeter conducted in partnership with LNE-OP & Pgravi
- result confirmed by measuring the difference between LNE and BIPM sites
- result agreed with the values measured in 2009 (ICAG 2009) and 2019 (by METAS) with FG5 absolute gravimeters within few µgal

- absolute measurement on future gravimetry spot using the quantum gravimeter
- spatial gradient measurement repeated using a CG6 relative gravimeter

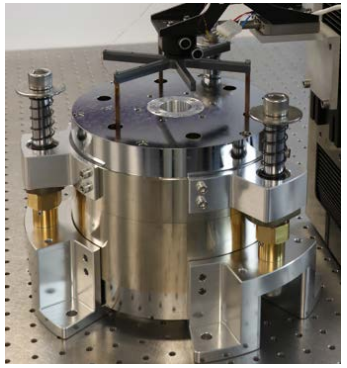
Single-pan beam balance for compact KB



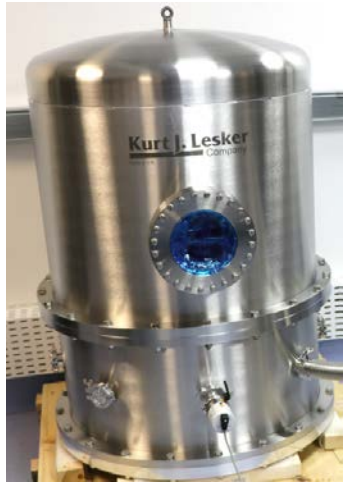




counterweight



compact magnet
(Tsinghua Univ.)



Vacuum chamber

Coil suspension parasitic movement in velocity phase

- Compensation of horizontal arc-motion on x-axis
- horizontal displacement along x & y axis: about 1 µm
- angular displacement
  - ✓ vertical rotation: a few µrad
  - ✓ horizontal tilts around x and y axis: about 1 µrad
- measurements limited by position sensors (beam quality & PSD size)

Outlook of KB work

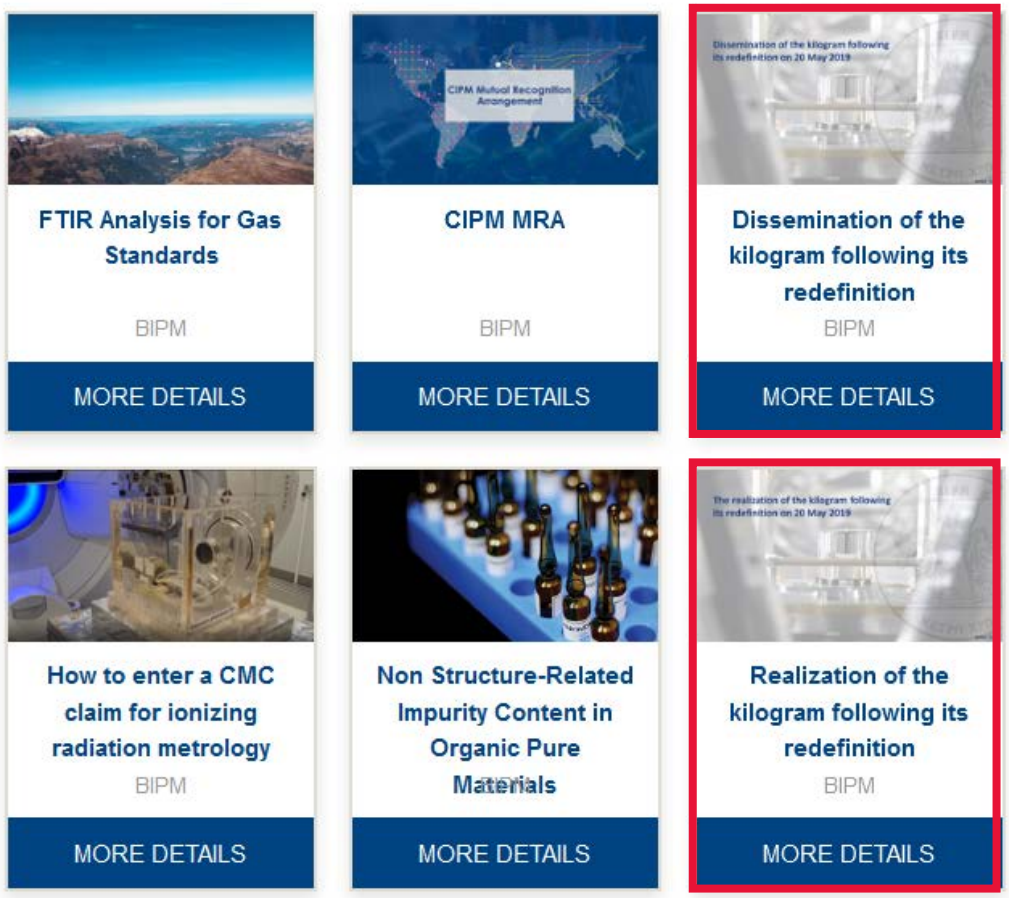
Principle Kibble balance

- Further improvement of electrical grounding
- Operation using mass of 500 g or lower
- Change position sensors' operation from dc to ac mode
- Better evaluation of uncertainty budget (Monte Carlo, digital twin,…)
- Participation in the 4th CCM.M-K8.2027

Compact Kibble balance

- Further characterization of the single-pan beam balance
- Continuing the design & development of additional elements
- Integration of all components & balance operation
- Preparation for vacuum operation

E-learning courses on realization and dissemination of the kilogram



About 100 users each

- e-learning.bipm.org

Outlook

Elements taken from the Strategy being prepared for CGPM 2026:

- Coordinate the 3-yearly key comparison of kg realizations (periodicity might change)
- Coordinate a comparison of secondary mass standards, about every 10 years
- Maintain the BIPM Kibble balance as the ‘international KB’ to support a robust system of kg realization
- Provide mass calibrations to NMIs without realization experiment
- Pioneer the implementation of Digital Calibration Certificates
- Develop and deliver knowledge transfer in the fields of realization of the kilogram using a Kibble balance and dissemination of the kilogram

Questions

- Any ideas for knowledge transfer activities at the BIPM (considering the small number of staff) ?

  Presently: - 2 e-learning courses on BIPM web site
  - a dedicated day for KT at KBTW in November 2025 at BIPM
  - CCM webinars

- What will be the basis for dissemination in Phase 3 (relevant for all NMIs with KBs or XRCD):

  - independent realizations with uncertainties which in many cases would be > 20 µg
  - the ‘international mean kg’ (CV) derived from key comparisons with an ‘ad-hoc’ uncertainty of 20 µg (as at present)
  - the ‘international mean kg’ (CV) derived from key comparisons with a calculated uncertainty of the weighted mean of << 10 µg

Thank you