Calibration campaign in anticipation of the kg redefinition: "Extraordinary Calibrations"

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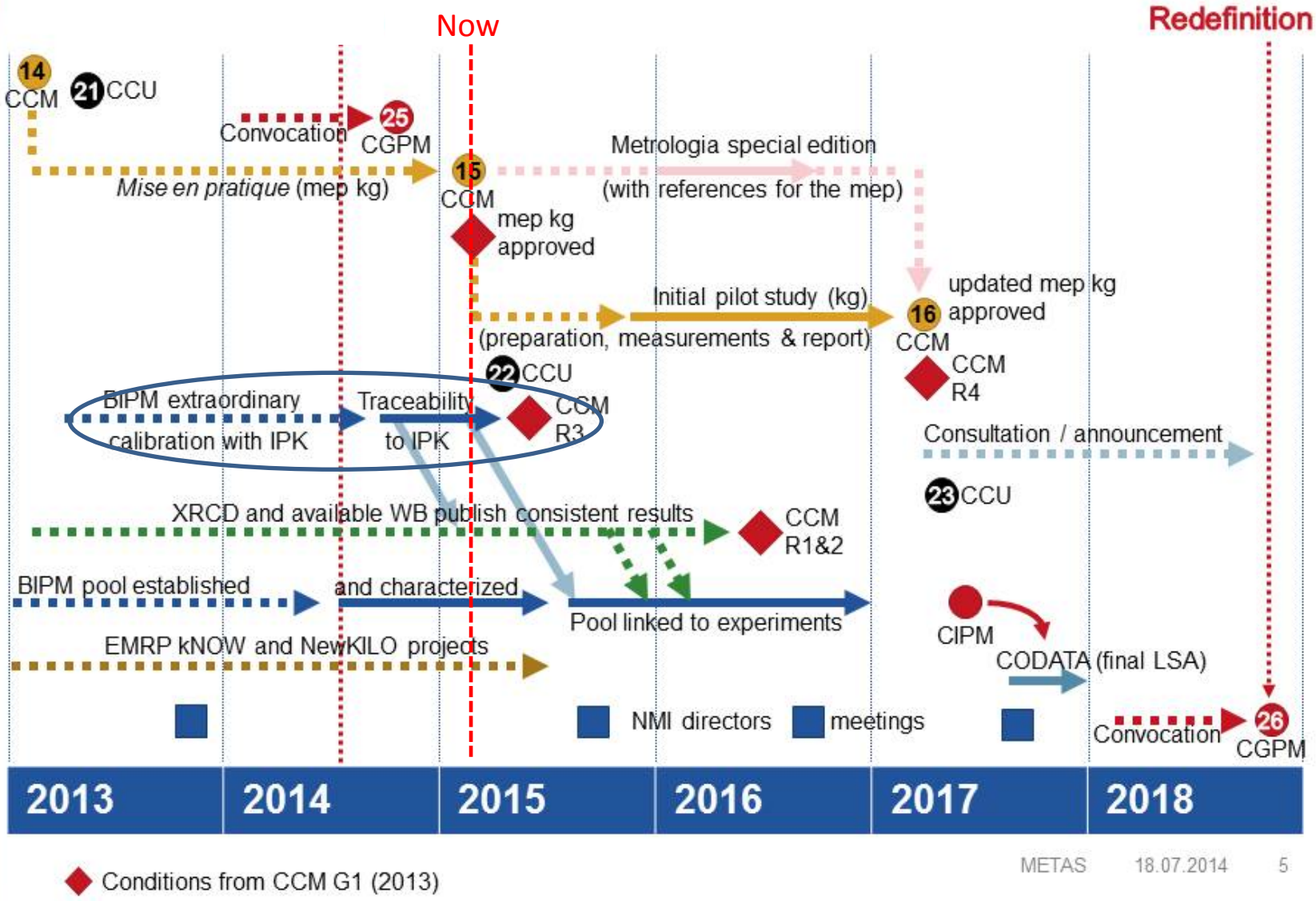
The CCM roadmap towards a redefinition in 2018



CCM Recommendation G1 (2013)

recommends that before the redefinition:

1. at least three independent experiments, including work from watt balance and XRCD experiments, yield consistent values of the Planck constant with relative standard uncertainties not larger than 5 parts in 10^8,

2. at least one of these results should have a relative standard uncertainty not larger than 2 parts in 10^8,

3. the BIPM prototypes, the BIPM ensemble of reference mass standards, and the mass standards used in the watt balance and XRCD experiments have been compared as directly as possible with the international prototype of the kilogram,

4. the procedures for the future realization and dissemination of the kilogram, as described in the *mise en pratique*, have been validated in accordance with the principles of the CIPM MRA.

Link between the kg and the Planck constant

1. Step: determine the numerical value of *h* in the present SI

other SI base units (s, m)

present definition
of the kilogram: IPK

Planck constant (*h*)

2. Step: redefine the kilogram by fixing this numerical value

Planck constant (*h*) fixed

new definition
of the kilogram

The old and the new kg shall be of the same magnitude
-> the numerical value of *h* needs to be measured correctly in the present SI
-> improved traceability of *h* determinations wrt IPK -> Extraord. Calibrations

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Traceability of the BIPM mass unit in 2013

- Definition of the kilogram: mass of the international prototype of the kilogram (IPK)
- IPK only available on very rare occasions, last time 1988-1992 (3rd PV)
- Since 1992, the mass unit is maintained by the BIPM on a set of 10 working standards, calibrated against the IPK
  -> "as-maintained BIPM mass unit"
- The working standards do not have perfectly stable masses
- The "as-maintained BIPM mass unit" is traceable to the IPK, but is not identical to the mass of the IPK

Extraordinary calibrations

Objective: **Provide improved traceability to the IPK for NMIs measuring *h***

Phase 1:

- Cleaning and washing of IPK and 6 official copies
- Comparison of the 6 official copies with respect to the IPK
- Re-calibration of BIPM working standards against IPK (last time 3rd Periodic Verification, 1992)

  -> reduced calibration uncertainty
- Selection of two reference standards for Phase 2
- Study of the long-term re-contamination of IPK and official copies

Phase 2:

- Calibration of NMI standards with respect to two BIPM reference standards recently linked to the IPK

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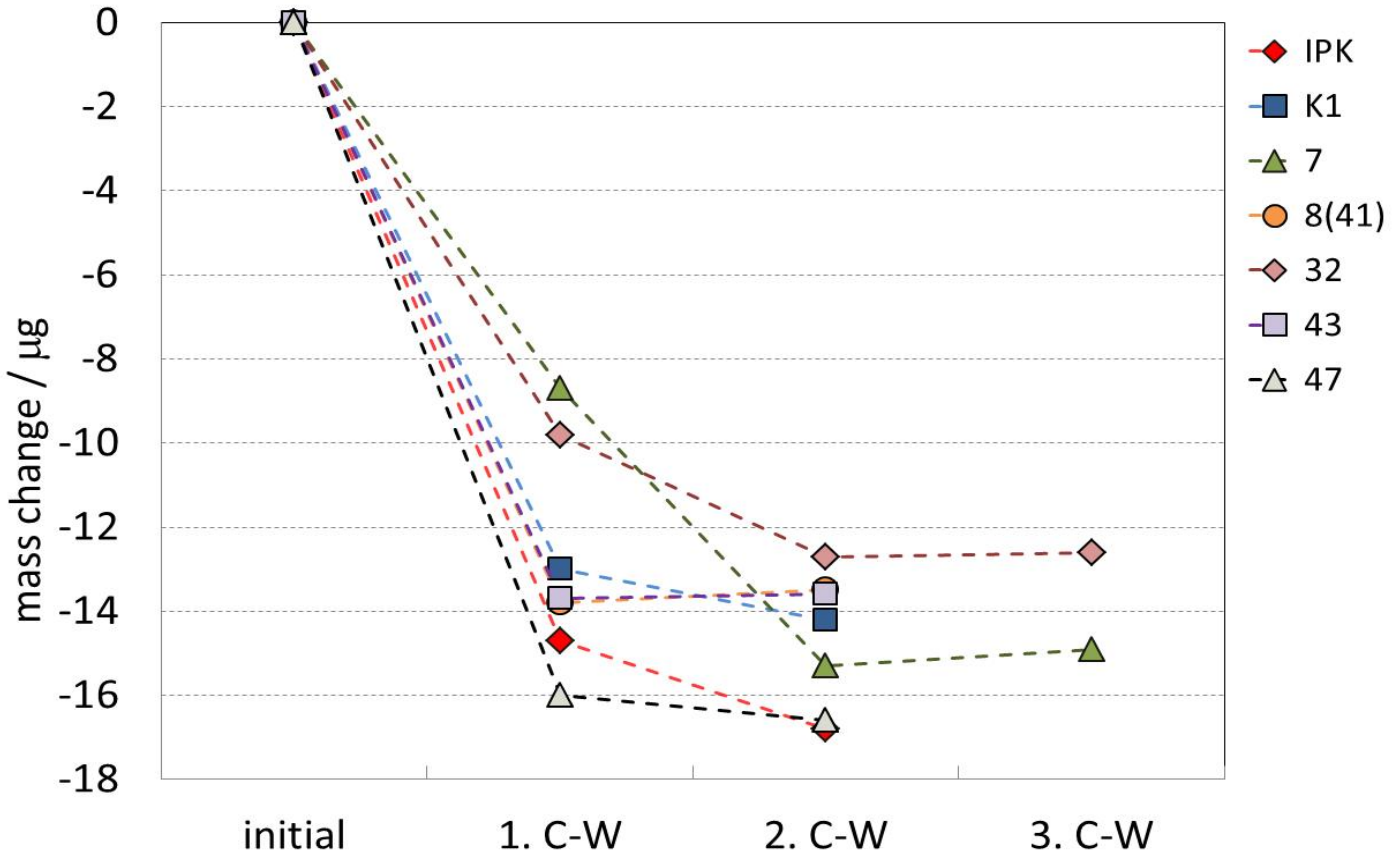
Analysis and interpretation of results of Phase 1

- Change of the mass of the IPK and official copies after cleaning-washing ?
- Does the mass drift of the official copies with respect to IPK continue ?
- Recalibration of working standards:

  Are the masses of the working standards (wrt IPK) as expected ?

Effect of cleaning and washing on IPK and six official copies



average mass loss: 15 µg standard deviation: 2 µg

➡ IPK and six official copies behaved consistently;
in general 2 cleaning-washing operations are sufficient

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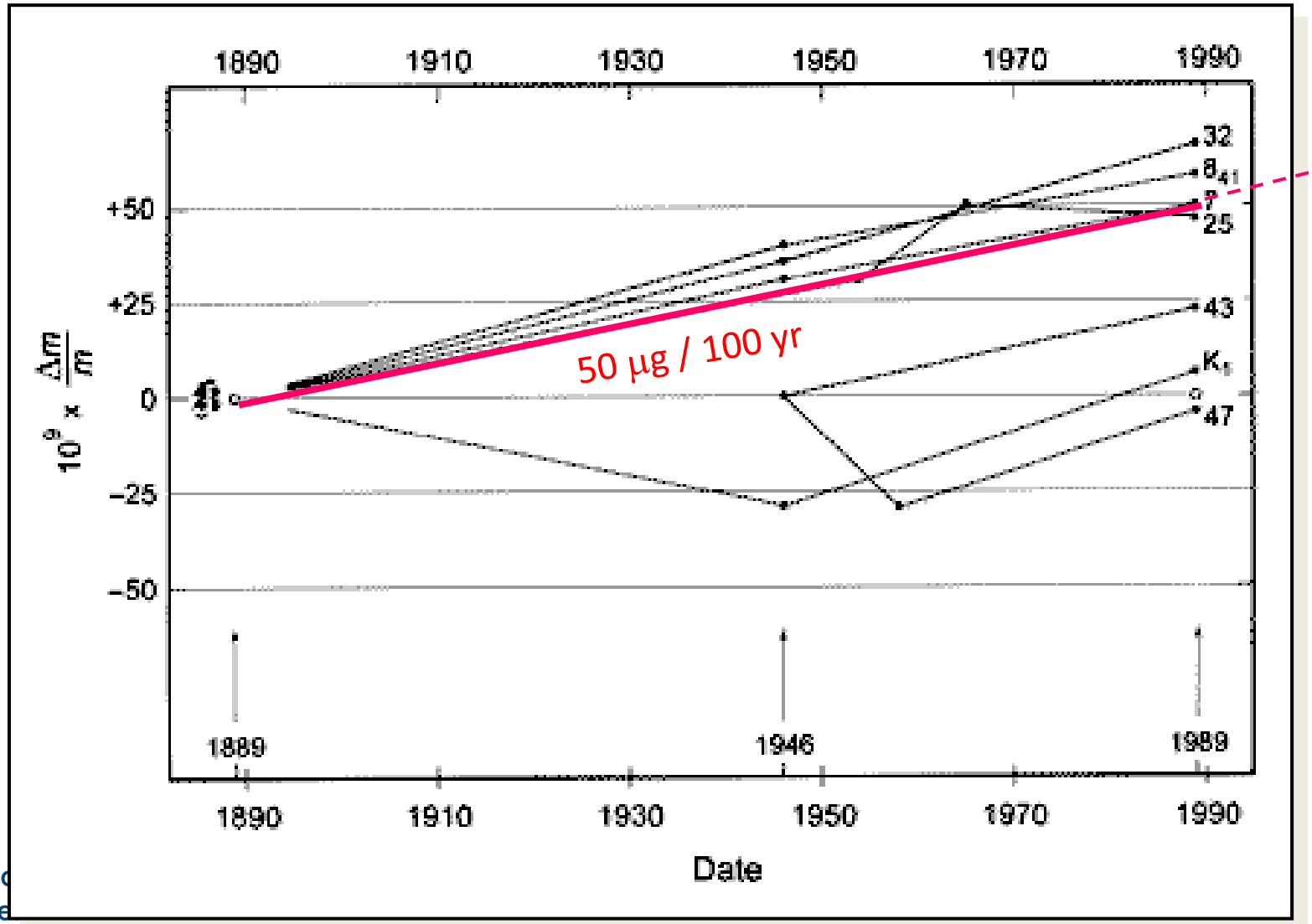
Does the mass drift of the official copies wrt IPK continue ?



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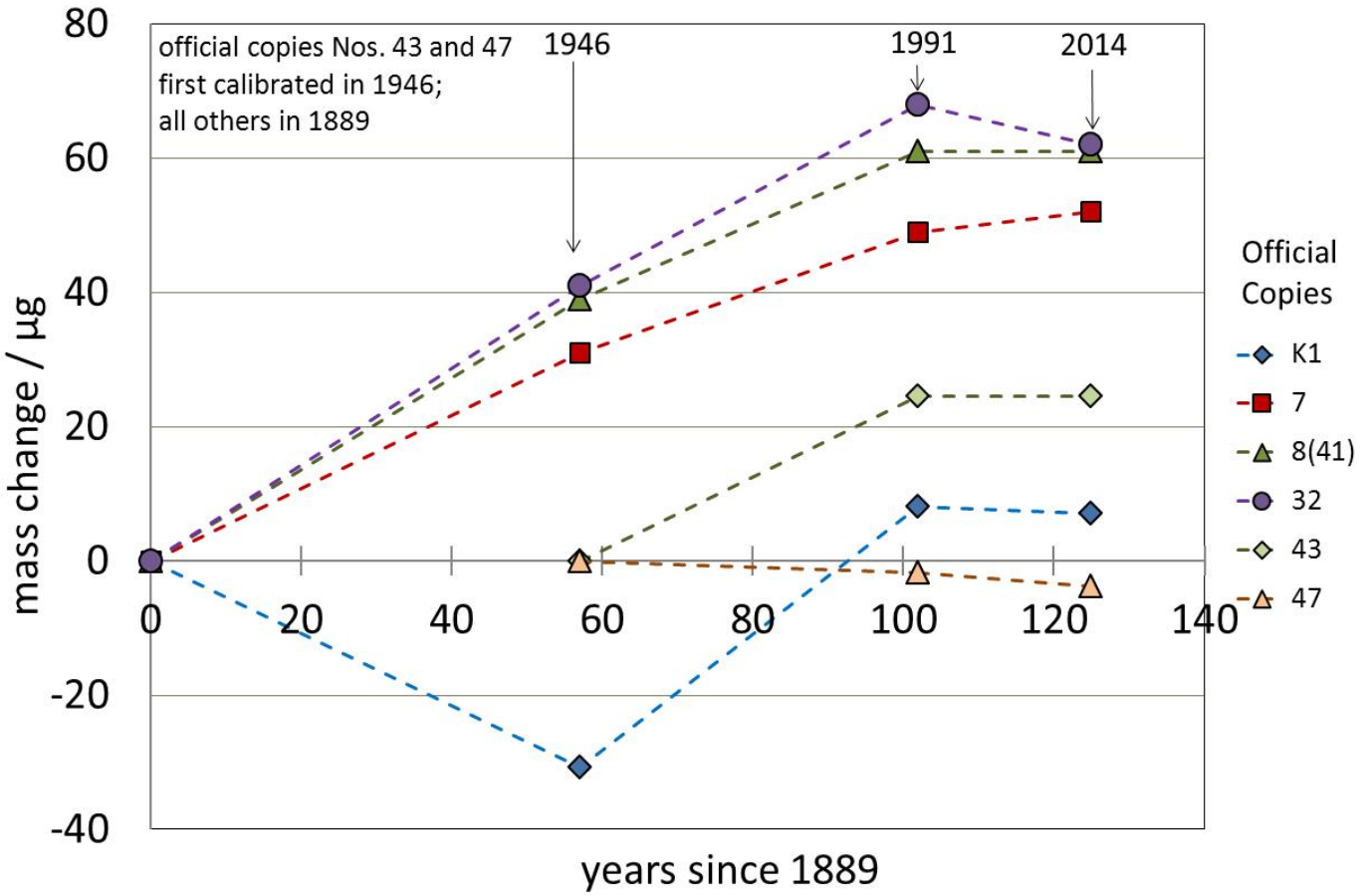
Mass evolution of the official copies wrt to the IPK



average change wrt to IPK: -1 µg standard deviation: 3 µg

IPK and six official copies have formed a consistent set of mass standards

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Results for prototype n° 34

- Belongs to French Academie of Sciences
- Participated in the 3rd PV, not used since then, kept in Paris
- Brought to the BIPM in September 2014
- Cleaned and washed: -19.6 µg after 22 years since last c-w

  (mass losses of IPK and copies ranged from 13 to 17 µg)
- Recalibration wrt IPK: -1 µg from result obtained at 3rd PV

Result is consistent with those for official copies -> Storage environment has no significant effect on mass

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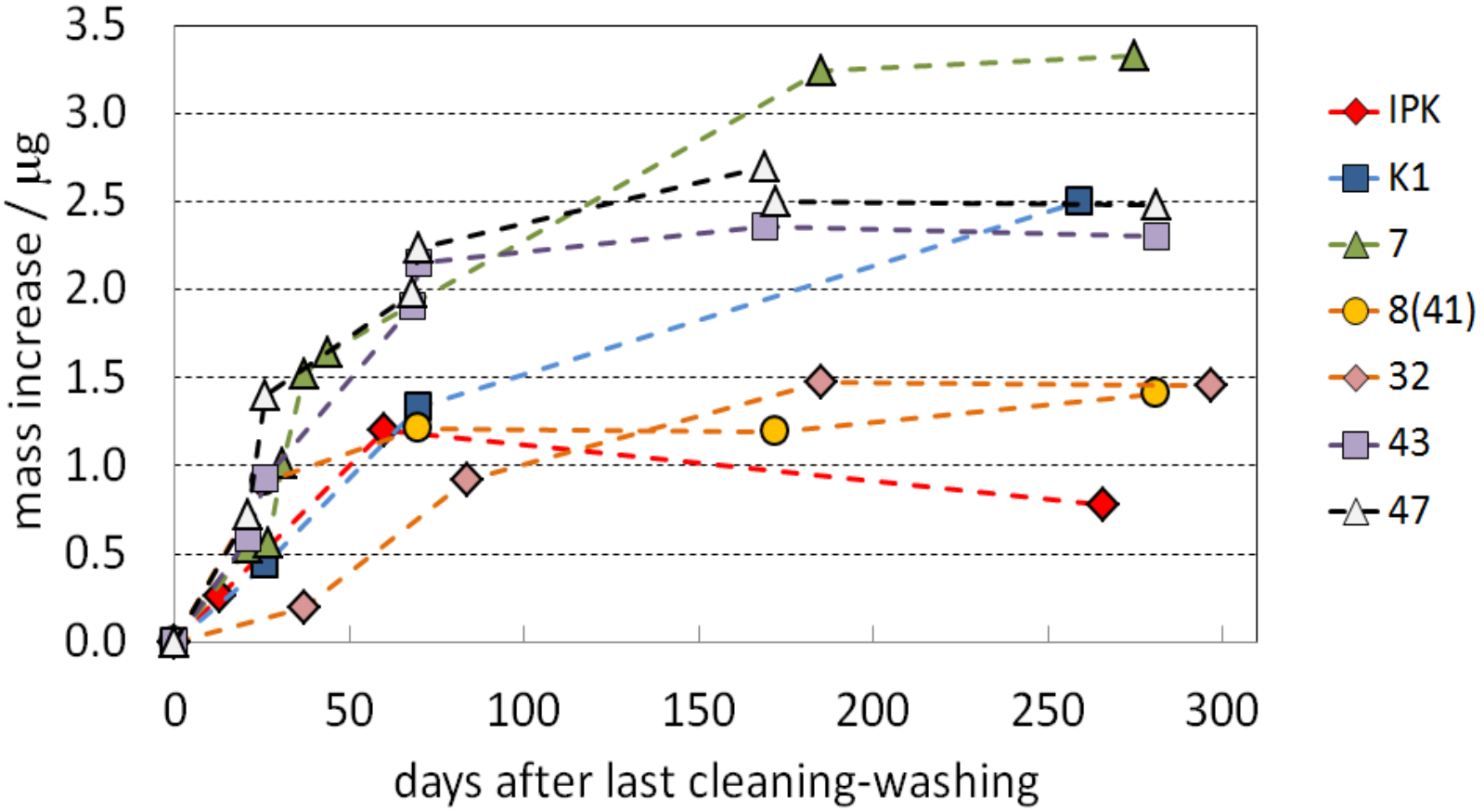
Recontamination study



- initial mass increase 0.01 - 0.03 µg/day (IPK: 0.02 µg/day, 3rd PV: 0.037 µg/day)
- mass increase reduces after about 100 days
- mass increases in general smaller as observed during 3rd PV

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“As-maintained” BIPM mass unit compared with the IPK

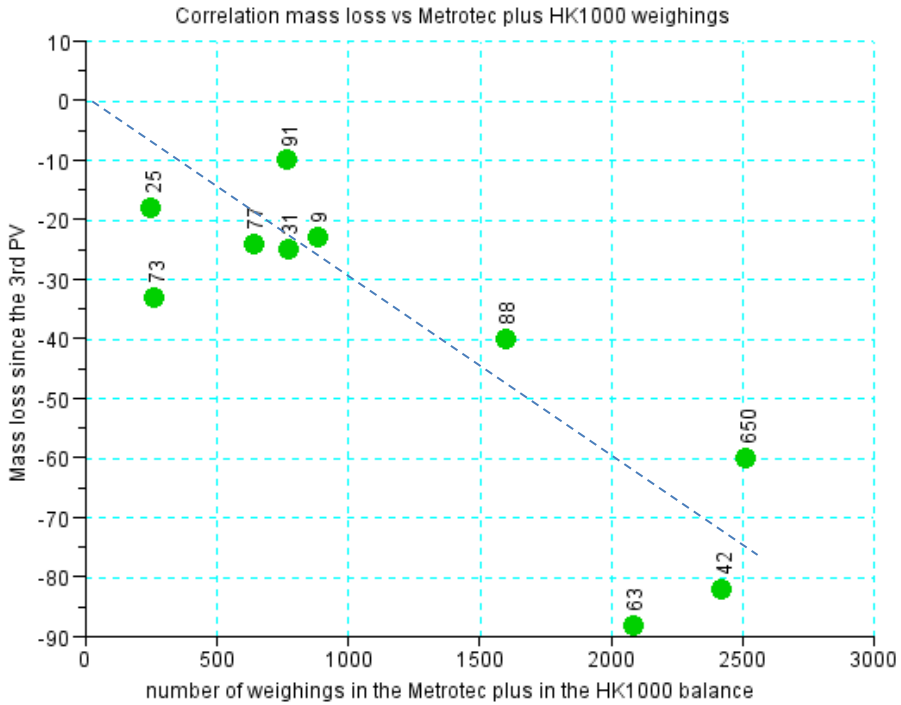
- Reminder: “as-maintained” mass unit traceable to the IPK, measured in 1992
- BIPM mass unit has been found to be 35 μg different from mass of IPK:

$$m(X)_{maintained} - m(X)_{IPK} = + 35\ \mu g$$

- All BIPM working standards have lost mass wrt to the IPK since 1992 (3rd PV), between 18 μg and 88 μg
- The relative drift within the set of working standards had been noticed by BIPM, but not the common drift (because IPK was not available)
- The undetected common drift has led to the offset of the BIPM mass unit

How can the mass losses be explained ?

The standards which have been used most often, show the greatest mass losses



Hypothesis: the mass losses might be due to wear during the measurements

- statistical analyses of the large amount of weighing data
- experimental analyses of weighing procedures

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Conclusions

- The IPK and its six official copies have behaved in a consistent way during cleaning and washing: -15 µg with std.dev. of 2 µg
- The mass losses due to c-w and the slopes of initial mass gain are smaller than those observed at the 3rd PV (similar observations were made on earlier occasions)
- The masses of the six official copies have changed on average by only 1 µg since the 3rd PV
- The long-term drift between the official copies and the IPK is not confirmed
- Prototype n° 34, kept at the French Academie of Sciences since the 3rd PV, shows a very similar behaviour
- The “as-maintained” BIPM mass unit was found offset by 35 µg
- Results for IPK and official copies published in Metrologia 2015, No. 2