CCM Workshop on the *mise en pratique* of the new definition of the kilogram

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A general method to reproduce the mass values assigned to BIPM working standards from 1889 to 2010

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Scope of the work

• The starting point are the available mass differences among 18 BIPM 1kg prototypes measured from 1889 to 2010..

• The scope is to reanalyze these data and deduce the absolute mass values over time of the involved prototypes. For that, a suitable mathematical model has been developed and is presented here.

• The results of this new determination of the absolute mass of the prototypes are compared to the absolute mass historically assigned by the BIPM to those prototypes.

• Notice that during the period 1992-2010 no direct mass measurement against IPK is available anymore. Therefore, the difficulty of extracting absolute mass values during this period is particularly challenging.
18 BIPM prototypes involved

**IPK (1889-1992)**
Six *témoins*: K1, 7, 8(41), 32, 43 and 47 (1889-1992)
Prototype 25 for special use (1889-2009)
Prototype 9 and 31 for routine use (1889-2009)
Working standard 42' (1990-2009)
Prototypes 63 and 73 (1990-2009)
Prototype 67 (1990-1999)
Prototype 77 (1997-2009)
Working standard 650 (1993-2009)
Prototypes 88 and 91 (2003-2009)

- Standards 9, 25 and 31 have been measured since 1889 up to nowadays.
- IPK and *témoins* were last measured in 1992.
Model to determine absolute masses from mass differences (I)

- **136 series** of mass comparisons distributed from 1889 to 2010. The time elapsed between consecutive series ranges between 1 month to several years.

- Each **serie** comprises **mass differences** among 2-11 prototypes.

- **Cleaning times** of each prototype are known.

- The data are analyzed series by series.

- In order to compute absolute mass values starting from mass differences, **one additional hypothesis** equation needs to be added to the system.
  - This hypothesis consists in **assuming the mass** of one prototype participating in the comparison to be **known**.
  - Our model tests **all** possible reasonable hypotheses. Each hypothesis leads to a set of absolute mass values. Our model compares all the sets of absolute mass values.
  - The model chooses the "right" absolute mass values by a **weighted mean** of the sets. The criterion to chose the weight is related to the degree of resemblance of one set with others.
Trying to reproduce at best the BIPM historical results:
We have one point of discrepancy, (also in the *temoins*), because during 23 years no intermediate measurement of any standard was done.

It seems that the BIPM assigned the mass values of the weighing 32387 \textbf{AFTER} knowledge of the results of the weighing 32448 which involved a “cleaning & washing” of IPK.
Temoin 32

Mass evolution with time of prototype 32
Temoin 32

Mass evolution with time of prototype 32

BIPM
Present calculation

6 µg

(1988, 32400) (1992, 34000)

Time (day)
Prototype 9

Mass evolution with time of prototype 9

10 µg

International Bureau of Weights and Measures
Prototype 31

Mass evolution with time of prototype 31

- BIPM
- Present calculation

10 µg

(time)


(mass/mass IPK) (mg)
Mass evolution with time of prototype 42'

10 µg
Prototype 63

Mass evolution with time of prototype 63

10 µg

International Bureau of Weights and Measures
Prototype 77

Mass evolution with time of prototype 77

BIPM
Present calculation

10 µg

International Bureau of Weights and Measures
Prototype 88

Mass evolution with time of prototype 88

- 2004
- 2009

5 µg

International Bureau of Weights and Measures
Prototype 91

Mass evolution with time of prototype 91

(time)

(mass-mass_PK) (mg)

4 μg
Working standard 650

Mass evolution with time of prototype 650

(time in days)

International Bureau of Weights and Measures
Uncertainties

\[ u_{\text{tot}} = \sqrt{u_{\text{massDiff}}^2 + u_{\text{propagation}}^2 + u_{\text{resemblance}}^2} \]

- \( u_{\text{massDiff}}^2 \): uncertainties of the mass differences used as input data.
- \( u_{\text{propagation}}^2 \): uncertainties due to the past mass values used to do the hypothesis.
- \( u_{\text{resemblance}}^2 \): uncertainty inversely proportional to the resemblance between the absolute mass values deduced from the different hypothesis.

Total uncertainty calculated for each data set. The same uncertainty will be attributed to all mass standards participating in the set (excepting IPK when present).
Total uncertainty

Temporal evolution of the mass uncertainty of BIPM prototypes; \( \sigma_{m} \text{ (mg)} = 0.003 \)

- IPK measured
- 2 Cleaning-washing
- 4 Cleaning-washing
- few standards

Temporal evolution of the mass uncertainty of BPM prototypes; \( \sigma_{m} \text{ (mg)} = 0.003 \)

- IPK measured
- few standards
- Many NL
- 2 CW
- 1 CW
Note

A written report on these calculations is in preparation.
Thank you for your attention