Kilogram

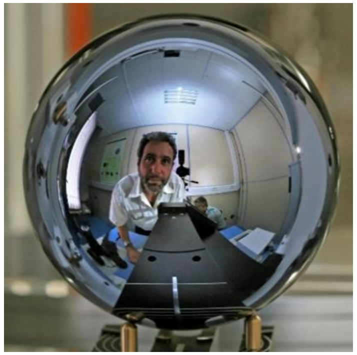
Isabel Spohr
TC-M Chair

Boras, Sweden
23 May 2019

Mass and Related Quantities

The kilogram

- **Redefinition,**
- **Progress towards implementation**
- **And future opportunities.**



Mass and Related Quantities

Revision of the SI; redefinition of the kilogram

- In November 2018 the General Conference on Weights and Measures (CGPM) voted on the revision of the SI
- This included the redefinition of the kilogram

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So – from 20th May 2019 the kilogram is defined in terms of the Planck constant, *h*

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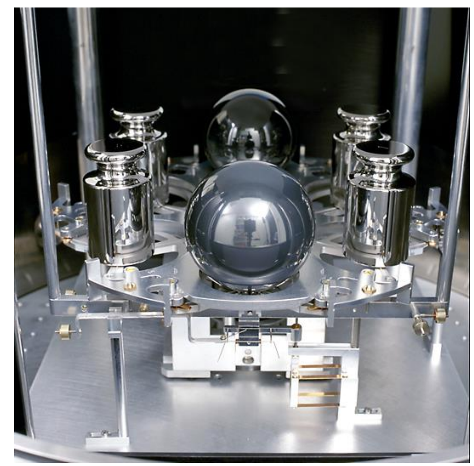
FROM

"The kilogram is the unit of mass; it is equal to the mass of the International Prototype of the Kilogram"

TO

"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 $6.62607015 \times 10^{-34}$ when expressed in the unit J·s, which is equal to $kg \cdot m^2 \cdot s^{-1}$, where the metre and the second are defined in terms of c and $\Delta\nu_{Cs}$."



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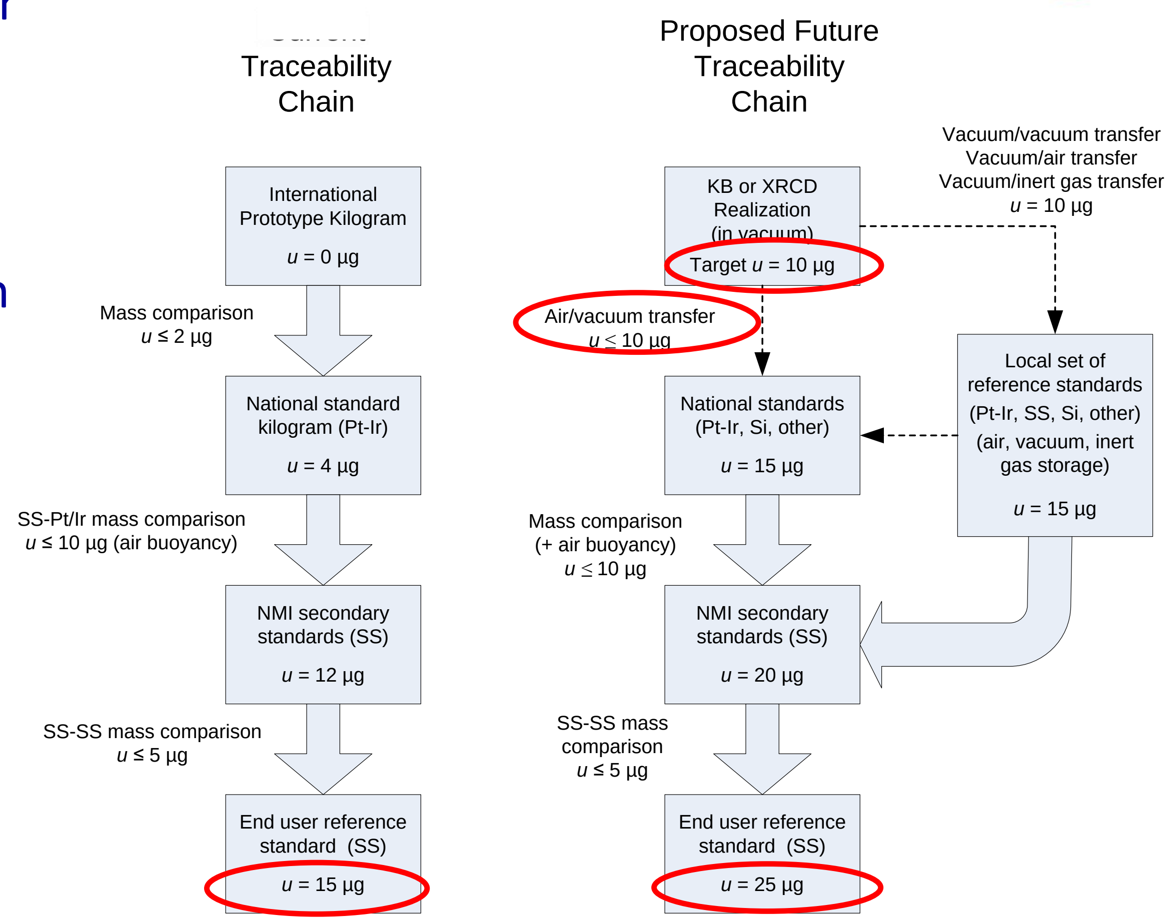
And – the traceability chain will be different

- Traceability to IPK is by in air comparison, uncertainties mainly from;
  - Mass Stability
  - Air buoyancy correction
- New traceability involves air/vacuum transfer, uncertainties mainly from;
  - Realisation uncertainty
  - Sorption
  - Mass stability



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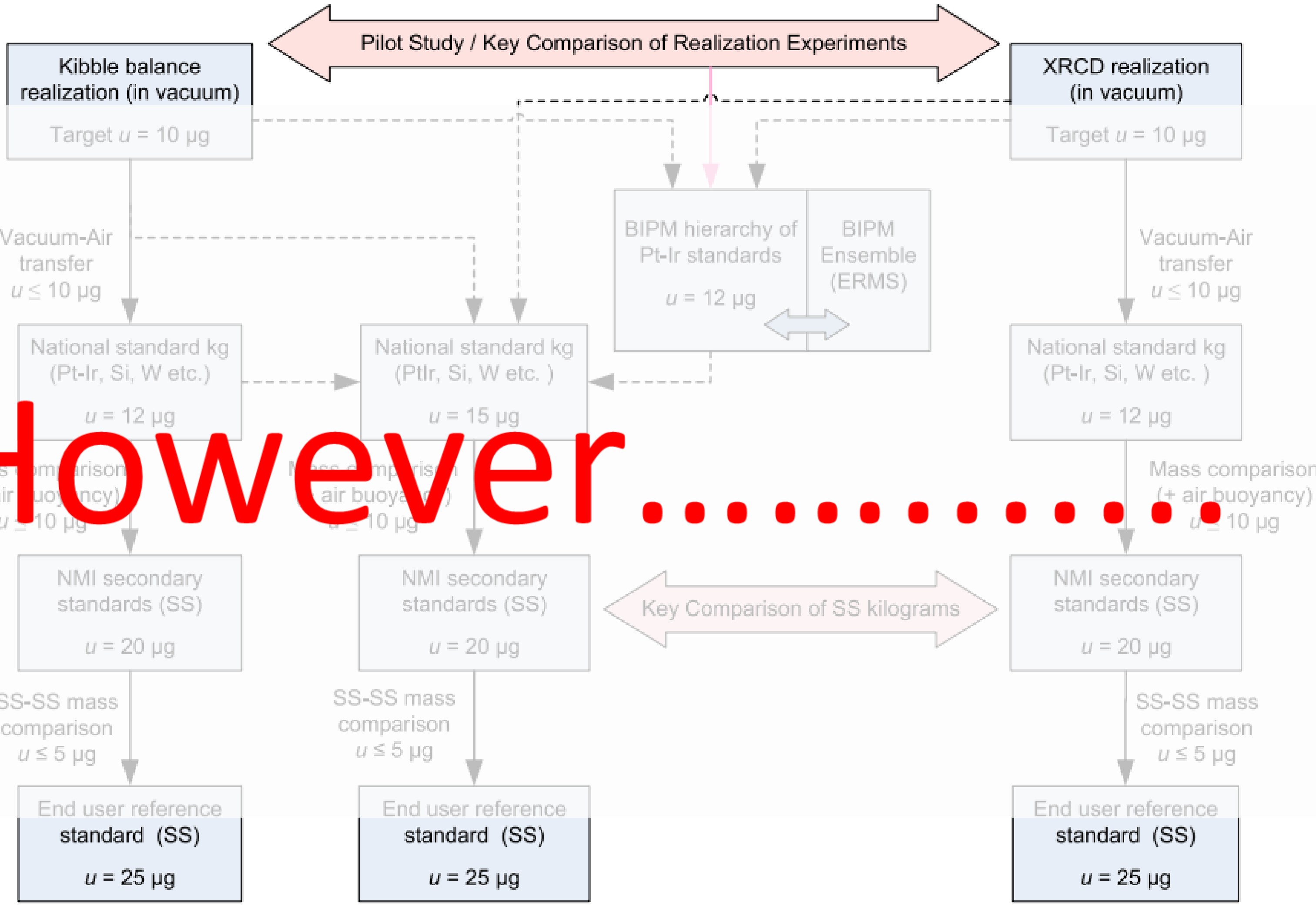
In practice this is how it could be implemented



However……………

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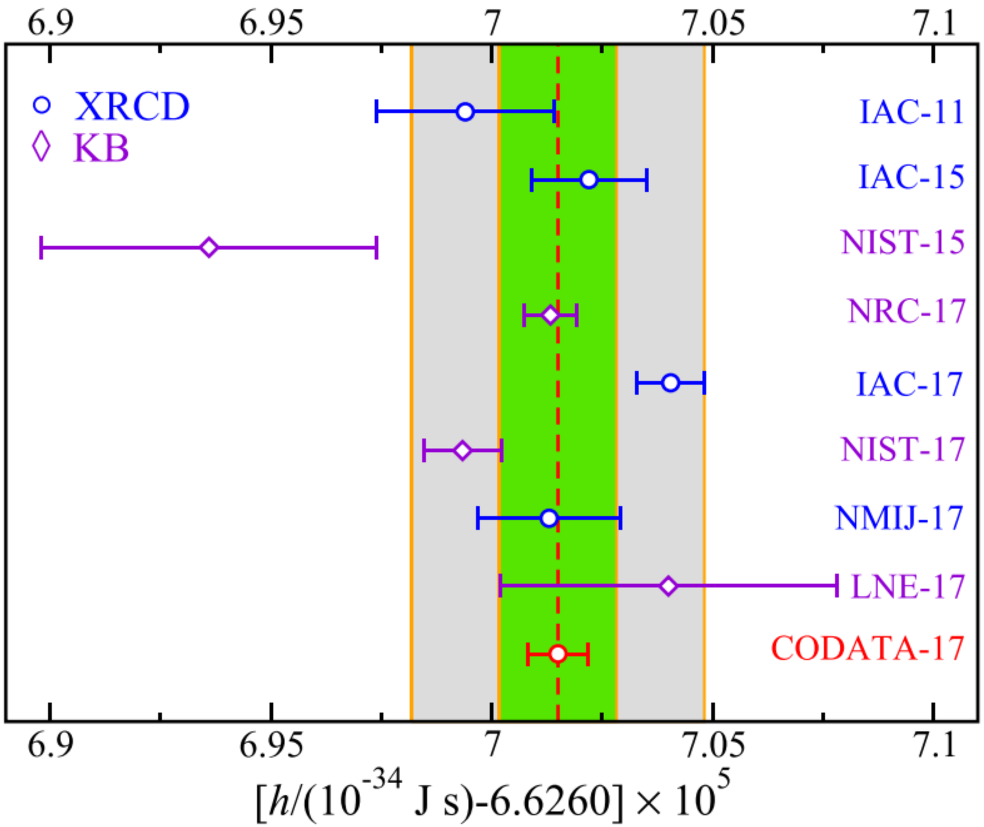
……The realisation experiments are not in ideal agreement

- Experiments which contributed values to CODATA 2017 are not in good enough agreement
- We need to be able to (maintain and) disseminate a consistent value for the kilogram (consistency better than ± 10 µg)
- The CCM has recommended the use of an interim **Consensus Value** for the kilogram until enough realisation experiments have demonstrated consistency and temporal stability

Values from the realisation experiments



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How will a Consensus Value for the kilogram work?

Requirements

- Consistency with IPK, linked to all available realisation experiments, temporal stability, easy access for dissemination

Determination

- KCs for the realisation experiment will take place every 2 years
- CV will be based on an average of the last 3 KCRVs (to ensure temporal stability)
- Initial value will be based on; IPK, Pilot study results (2016),

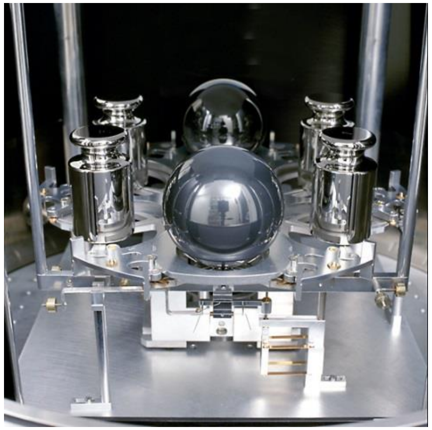
  Reference Value of first KC (2019-2020)

Dissemination

- KCs will be piloted by the BIPM
- CV will be maintained and disseminated by the BIPM using their PtIr standards
- BIPM will continue to provide calibrations for NMIs but traceability will switch from the IPK to the CV following the completion of the first KC of realisation experiments

Uncertainty

- It is proposed that the uncertainty in the consensus value be ± 20 µg



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Implementation -Avogadro kilogram

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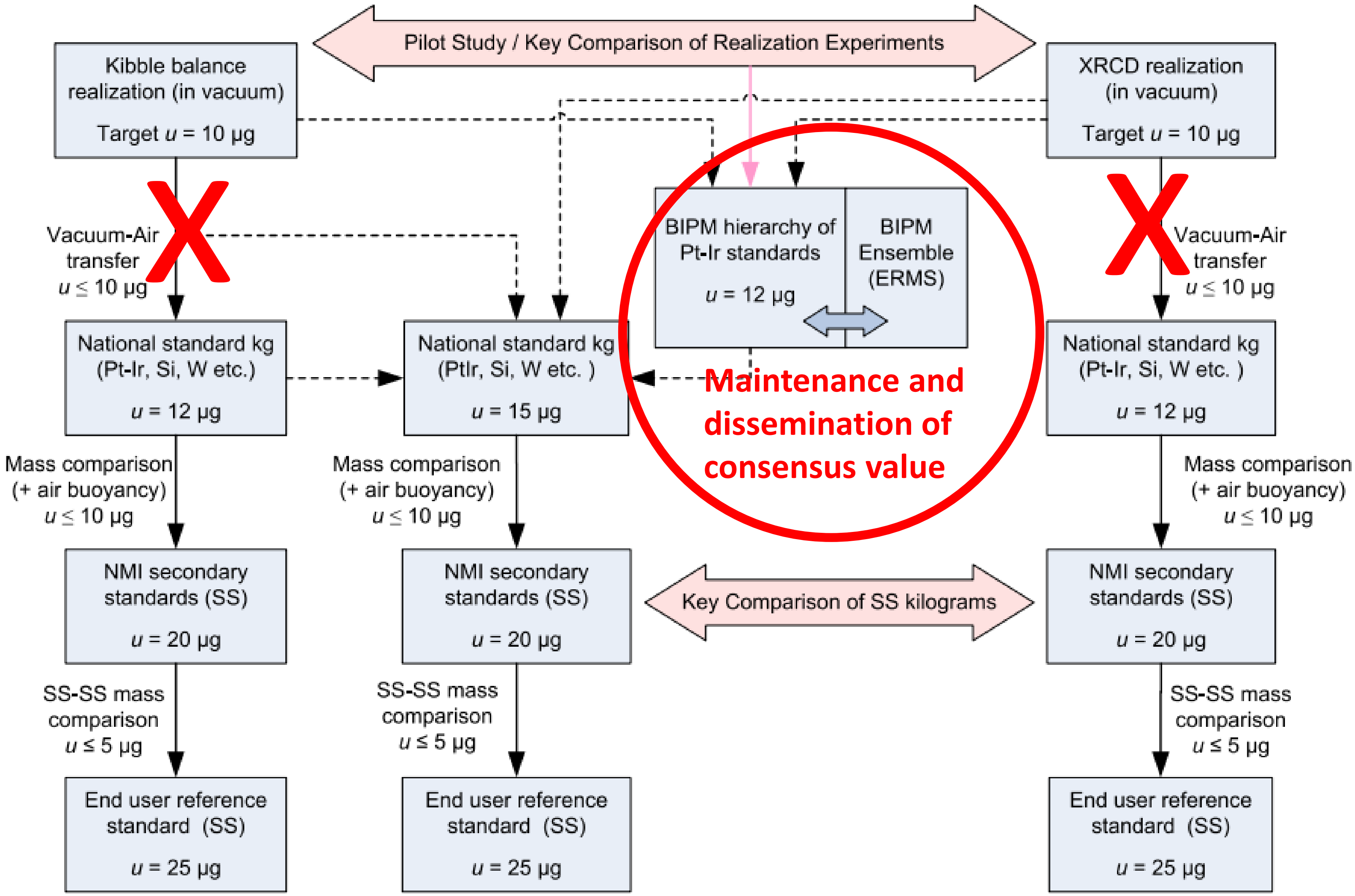

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Evolution of traceability for the SI unit of mass

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	today – date 1[1]	Present traceability	$m_{IPK} \equiv 1$ 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	$m_{IPK} = 1$ kg $u_{m_{\mathrm{IPK}}} = 10\ \mu g$	$\approx\sqrt{u^2_{m_{\mathrm{IPK}}} + u^2_{\mathrm{stab}}(t)}$	Contribute to Key Comparison (KC)	Dissemination from national prototype traceable to IPK, with 10 µg added uncertainty
2	date 2 - date 3[3]	Dissemination via a consensus value[4] (CV)	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 ≈ $\sqrt{u^2_{\mathrm{CV}} + u^2_{\mathrm{stab.NMI}}(t)}$
3	from date 3	Dissemination by individual realizations	Fixed value of *h* u(*h*) ≡ 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 validated realization experiments with the uncertainty of the experiment. The terms of the CIPM MRA are applicable.

Date 1: 20 May 19 **Date 2: CV following first KCRV (early 2020)** **Date 3: Agreement and stability of realisation experiments (2030-2040?)**

The role of EURAMET

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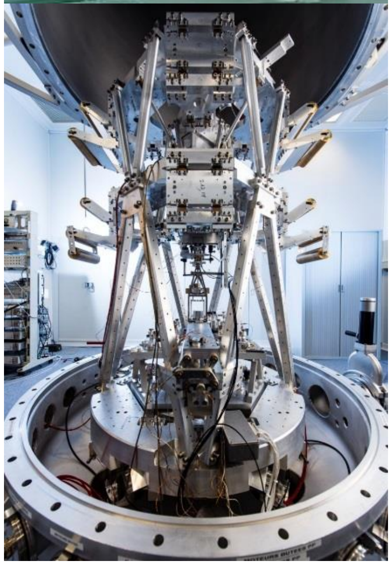
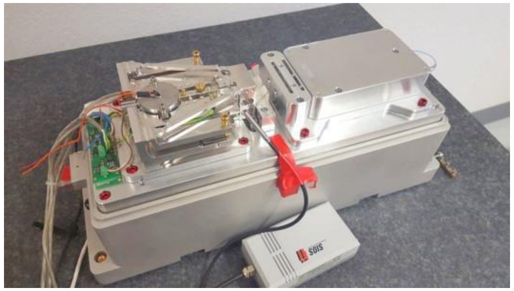
- EURAMET NMIs have a significant number of the realisation experiments which will contribute to the consensus value of the kilogram both initially (2020) or longer term
- EURAMET Chairs and provide the majority of member to the CCM Task Group overseeing the implementation of the kilogram redefinition
- European NMIs are leading research into maximising the benefits of the new kilogram definition by looking at shop floor implementation and miniaturisation



Mass and Related Quantities

The future - SI on the shop floor

- Experiments at NPL, METAS and PTB, for example, combined with new operating principles, have demonstrated that the Kibble balance can be mechanically relatively simple
- If room temperature voltage and resistance standards can be used a Kibble balance for use in industry can be developed
- This will allow;
  - Direct shop floor traceability to the SI
  - Self calibration
  - On-the-fly and dynamic mass measurements for (e.g.)
- The Kibble balance principle can also be used for SI traceable torque and force measurements



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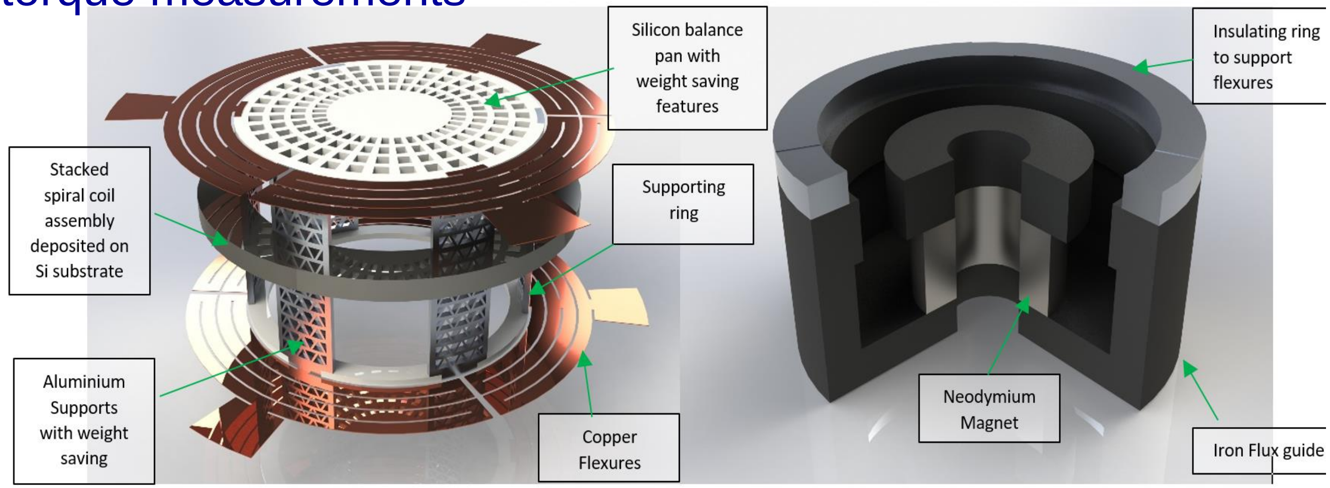
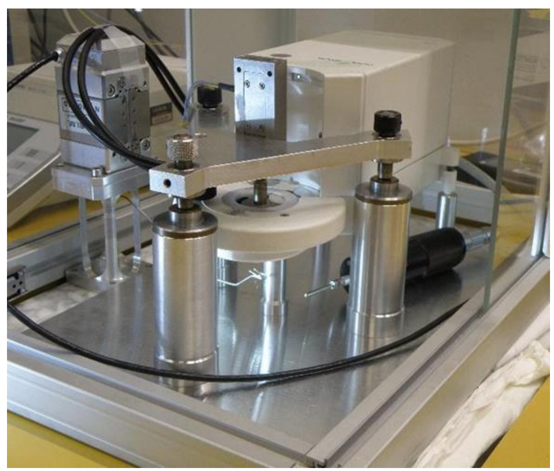
The future - miniaturisation

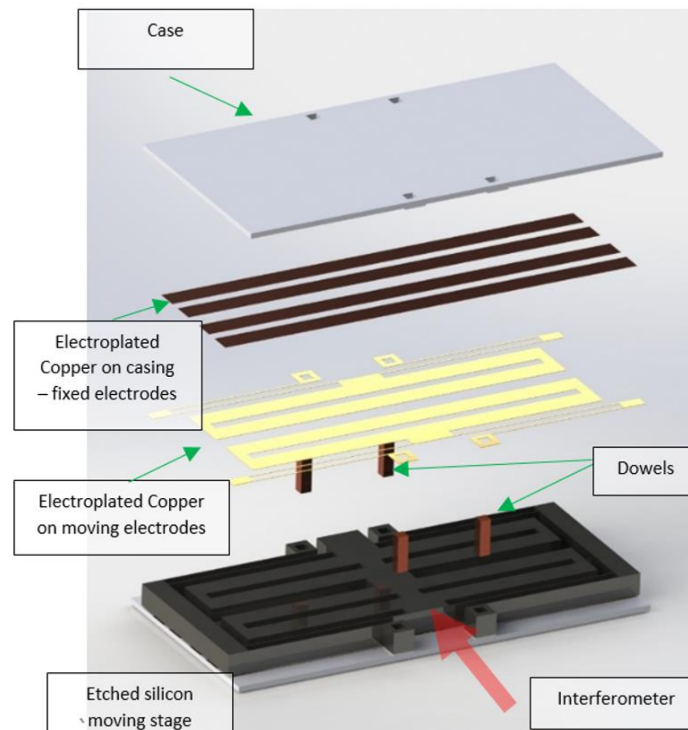
- Miniaturisation improves uncertainties and gives direct SI traceability for micro-mass, force and torque measurements



- INRIM, LNE, METAS, NPL and PTB are undertaking research into micro-mass and force measurement devices

- These will have potential benefits for (e.g.):
  - Pharmaceuticals and personalised medicine
  - Nano-fabrication
  - Micro-robotics
  - Materials measurement
  - Ionising radiation





Thank you for your attention.

Thanks to Stuart Davidson
Convenor EURAMET SC- Mass
Chair CCM WGD-kg

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