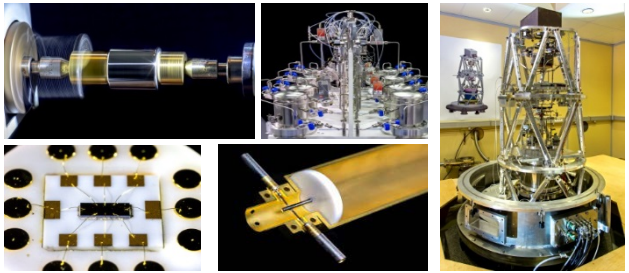
Report from the BIPM mass laboratory

Michael Stock

CCM

16-17 May 2019



Activities in Mass

Ongoing tasks

- mass calibrations (Pt-Ir, stainless steel) for NMIs (incl. volume/density, centre of gravity)
- provision of 1 kg Pt-Ir prototypes to Member States

Preparations for the new SI

- extraordinary calibrations with respect to the IPK (2014) ✅
- CCM pilot comparison of kg realizations (2016) ✅
- development of a Kibble balance for future realization of kilogram -> H. Fang
- creation of an ensemble of 1 kg mass standards (ERMS) to facilitate dissemination of new kg and for ongoing key comparison ✅

Future tasks

- organization of key comparisons of realizations of the kilogram
- ensuring uniform dissemination of the kilogram: determination of “consensus value”

Staff of the Physical Metrology Department

Dr Michael Stock
Dept. Director
(CCEM)

Impedance

Dr Pierre GOURNAY
Principal Physicist

Angel MORENO
Physicist

Benjamin ROLLAND
Assistant

Voltage

Dr Stéphane SOLVE
Principal Physicist

Régis CHAYRAMY
Principal Technician

Watt balance

Dr Hao FANG
Principal Physicist (CCM)

Dr Franck BIELSA
Physicist

Dr Shisong LI
Physicist

Adrien KISS
Assistant

ERMS

Dr Estefanía de MIRANDES
Principal physicist (CCU, 80 %)

Mass calibr.

Pauline BARAT
Assistant

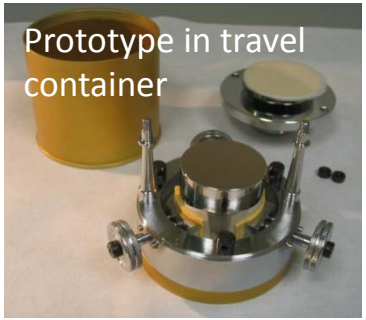
Pedro CONCEIÇAO
Principal Technician

Damien BAUTISTA
Technician

Bureau International des Poids et Mesures

Fabrication of new prototypes

2016: no. 110 for NIM, China
2017: no. 111 for KRISS, Rep. of Korea
2018: no. 107 for NPSL, Pakistan

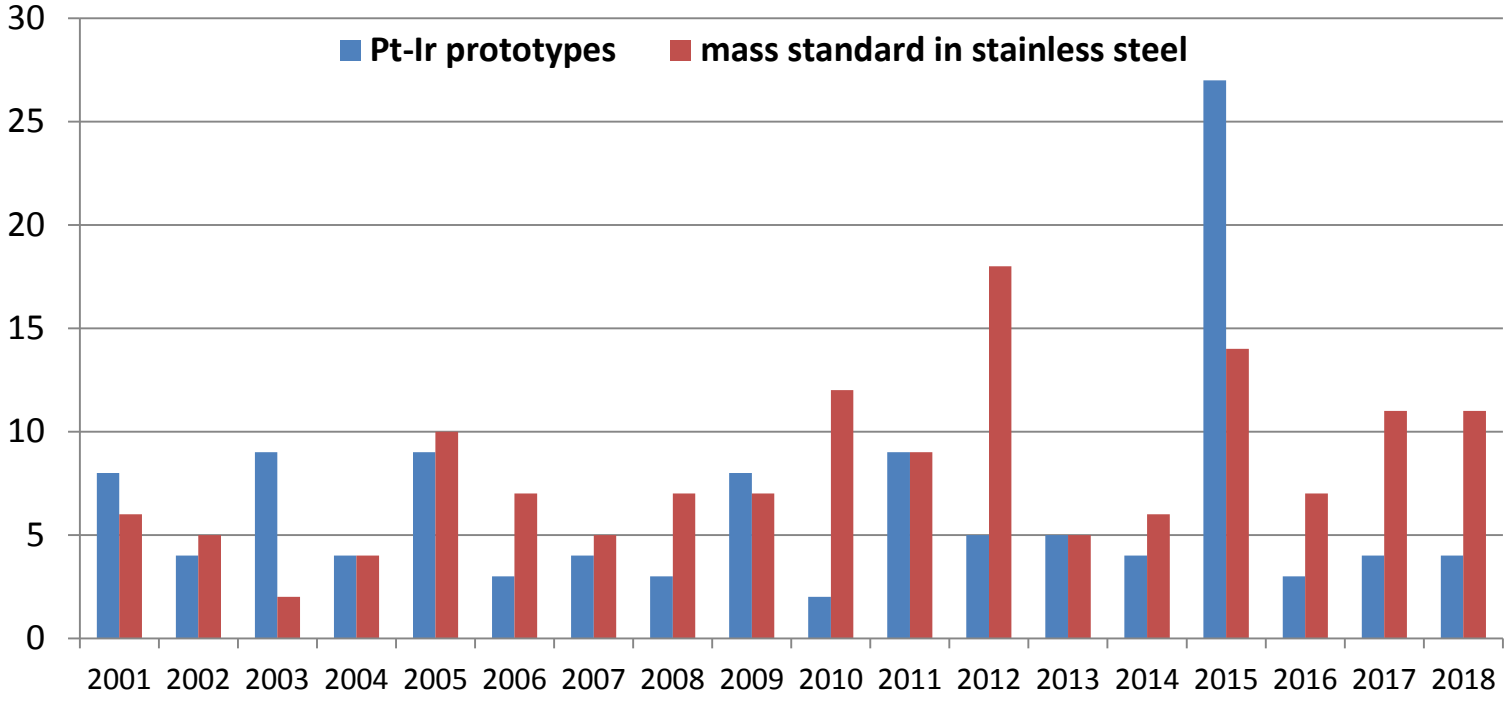


Fabrication of prototype no. 112 completed, informal purchase request received

Fabrication of three more prototypes no. 113 – 115 under way (2 informal requests)

Since 1889, 111 Pt-Ir prototypes provided to 44 NMIs and the BIPM

Number of calibrations of mass standards per year



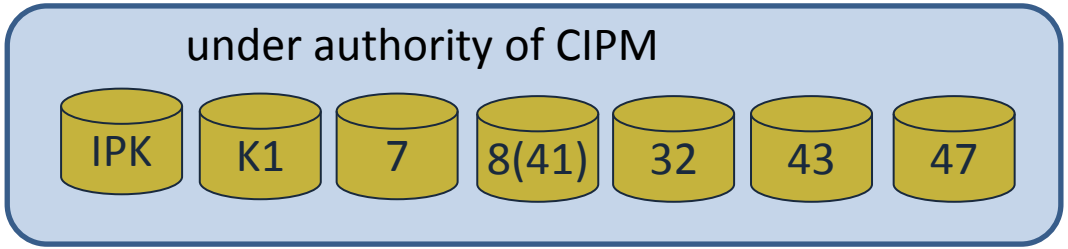
On average per year: 5 Pt-Ir prototypes
10 stainless steel standards

Bureau International des Poids et Mesures

Guiding principles to ensure a stable BIPM mass unit

- BIPM working standards calibrated against IPK in 2014
- significant mass changes since 3rd PV in 1992, attributed to wear
- new hierarchical system of mass standards with significantly different level of usage since 2015
- significant reduction of the total number of weighings
- plan to use of subset of official copies for periodical verifications (every 10 years)
- regular reports of status to CCM and CIPM

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



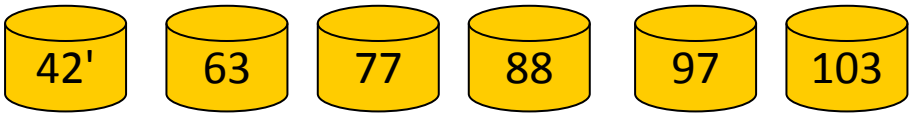
IPK & official copies: $\frac{1 \text{use of } 2 \text{ copies}}{10 \text{ years}}$

prototypes for exceptional use:
(to be cleaned before use)

$\frac{1 \text{use}}{5 \text{ years}}$

standards for limited use:

$\frac{1 \text{use}}{\text{year}}$



standards for current use:

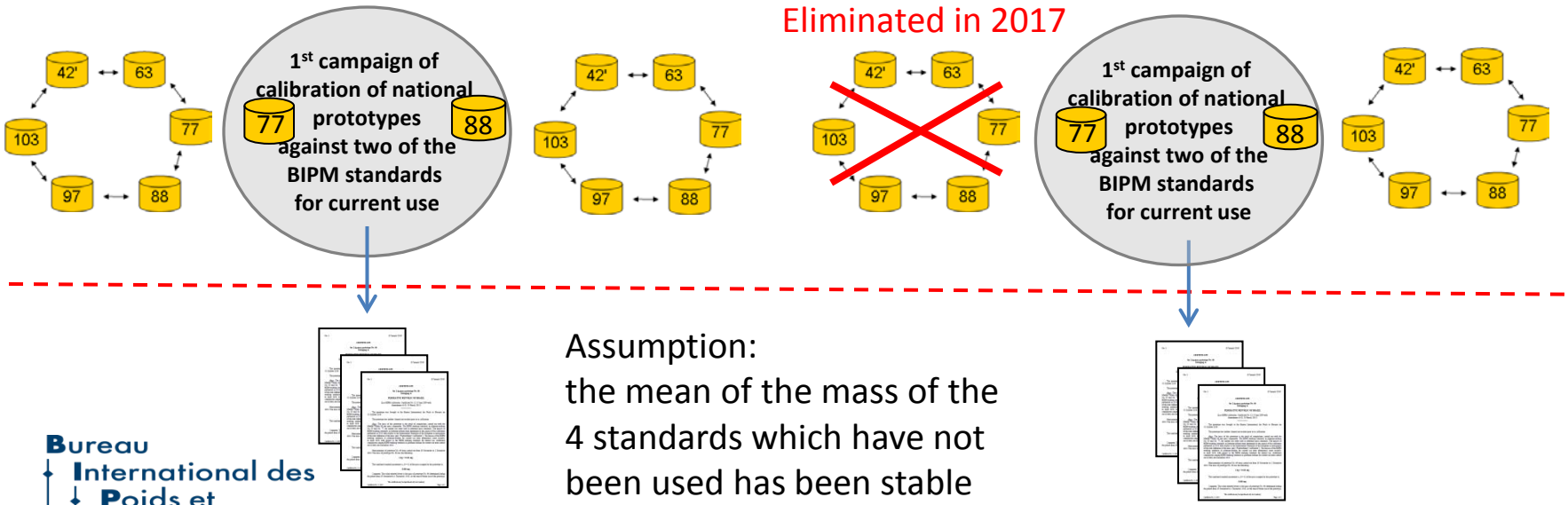
$\frac{4 - 10 \text{ uses}}{\text{year}}$

Bureau International des Poids et Mesures

Use of BIPM standards for current use

Calibrations for NMIs grouped into two batches per year

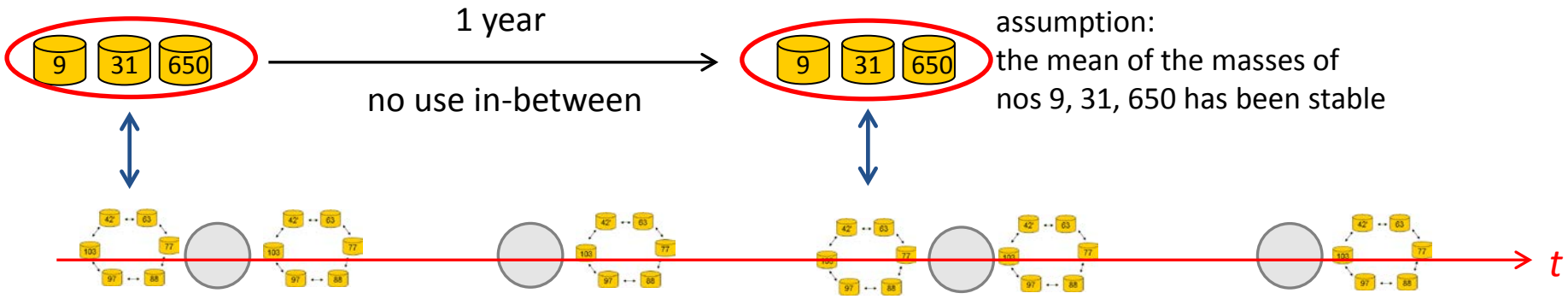
- less weighings (-> better stability)
- more efficient
- but: service not permanently available



Assumption:
the mean of the mass of the 4 standards which have not been used has been stable

Bureau International des Poids et Mesures

Use of BIPM standards for limited use



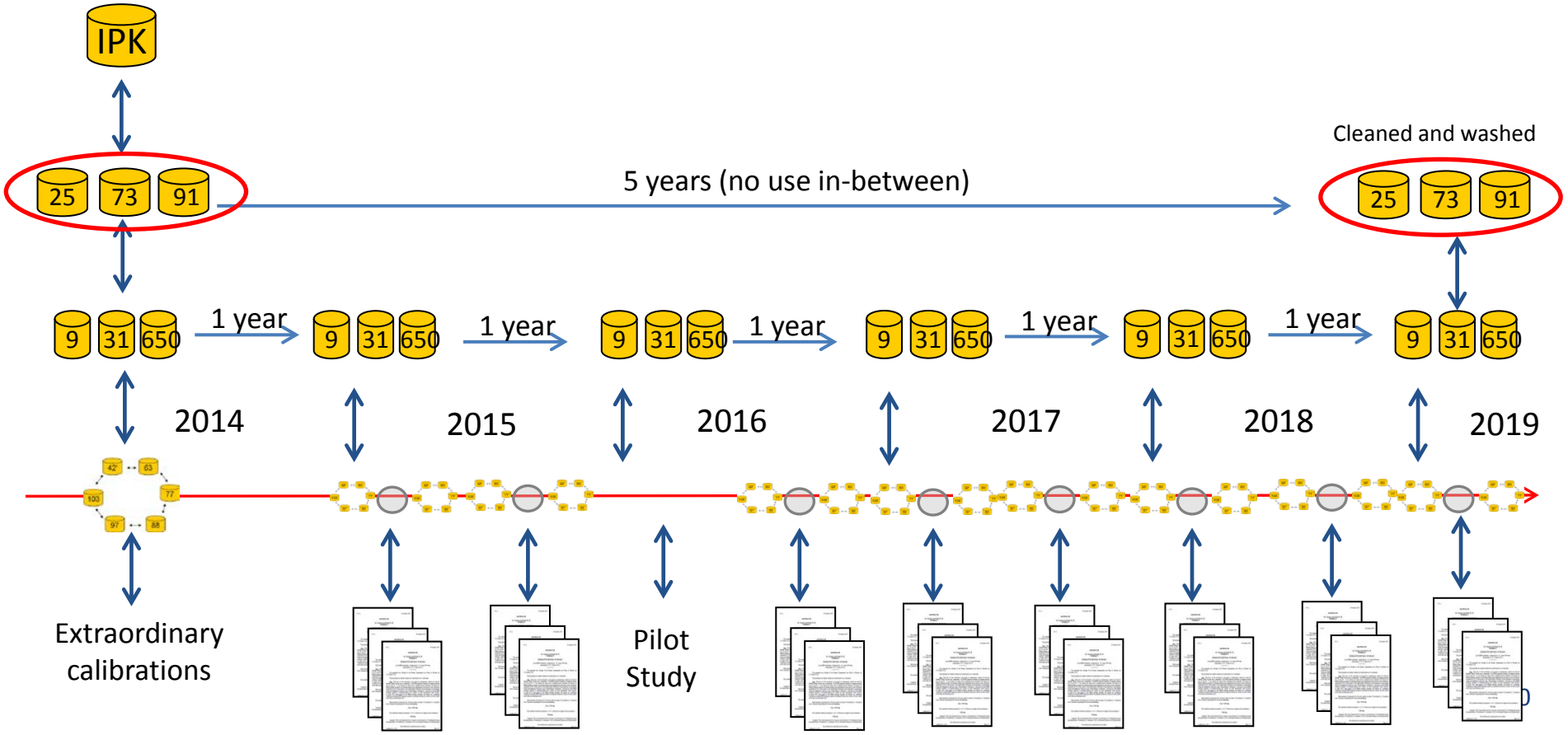
during 1 year, mass evolution of standards for current use derived from mass differences using two types of models:

- least-squares adjustment based on assumption that standards not used are stable (treating each campaign separately)
- deterministic models (using accumulated data)

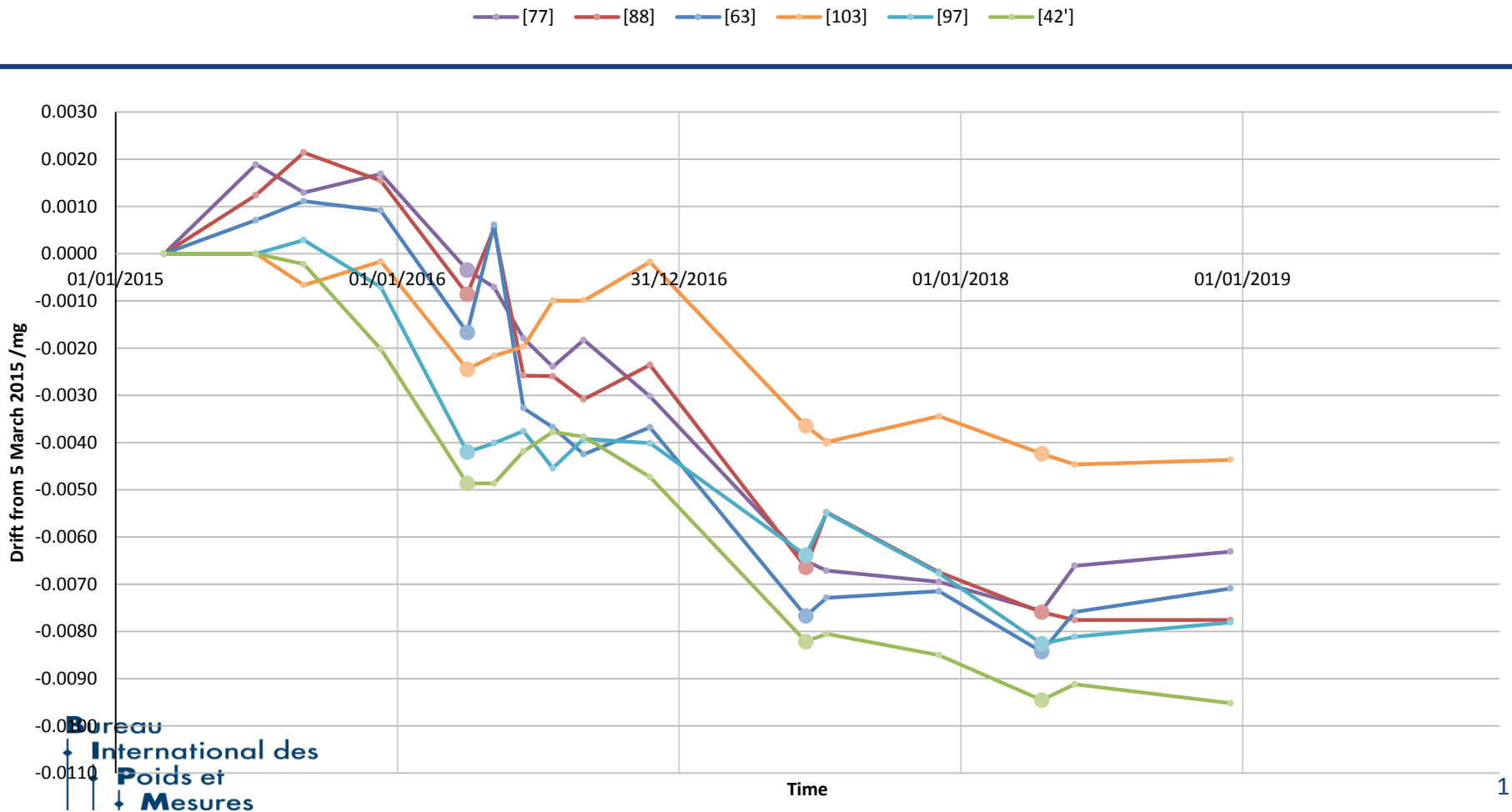
if results are model dependent -> investigation of the situation

Bureau International des Poids et Mesures

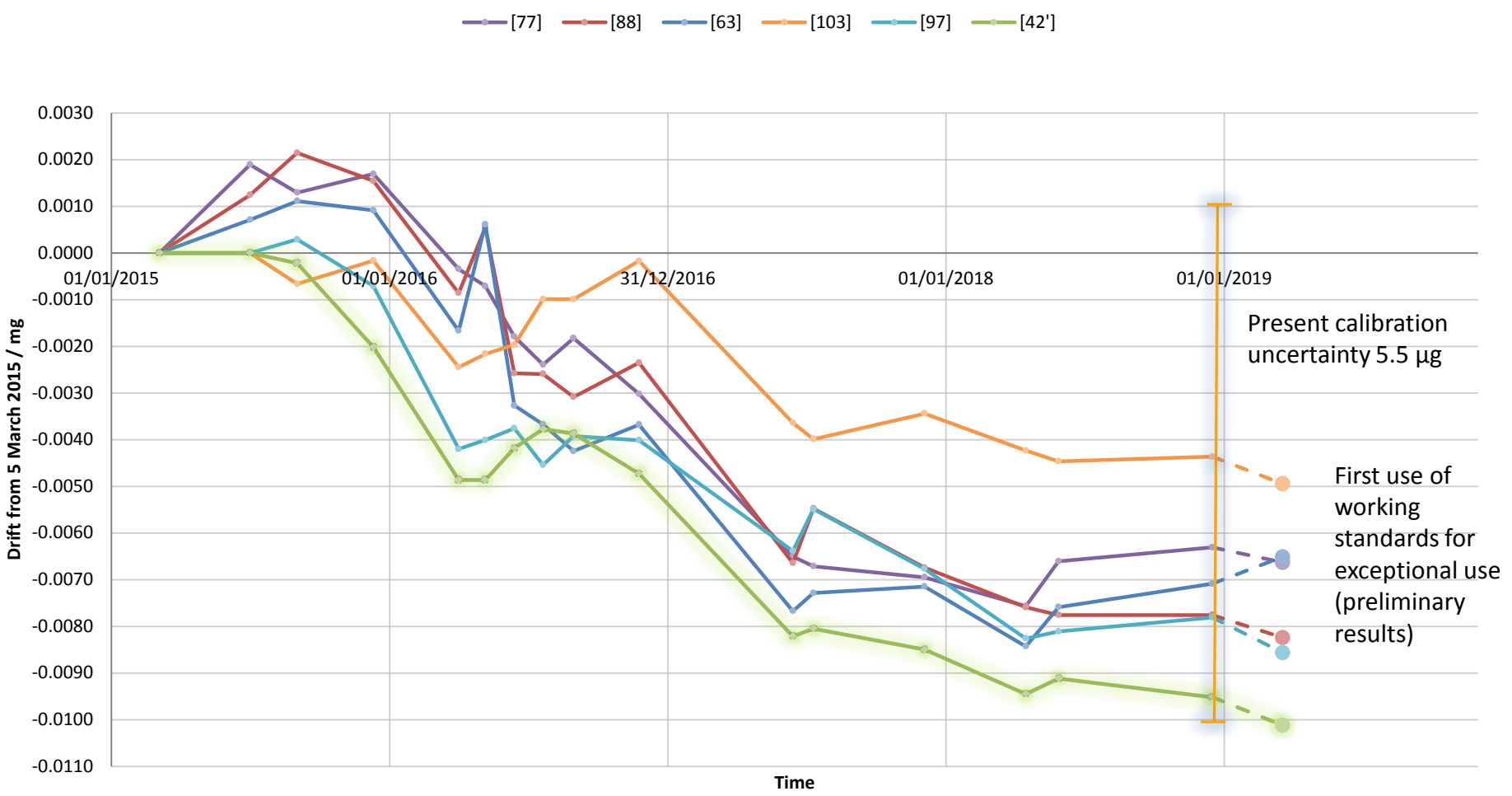
Use of BIPM standards for exceptional use



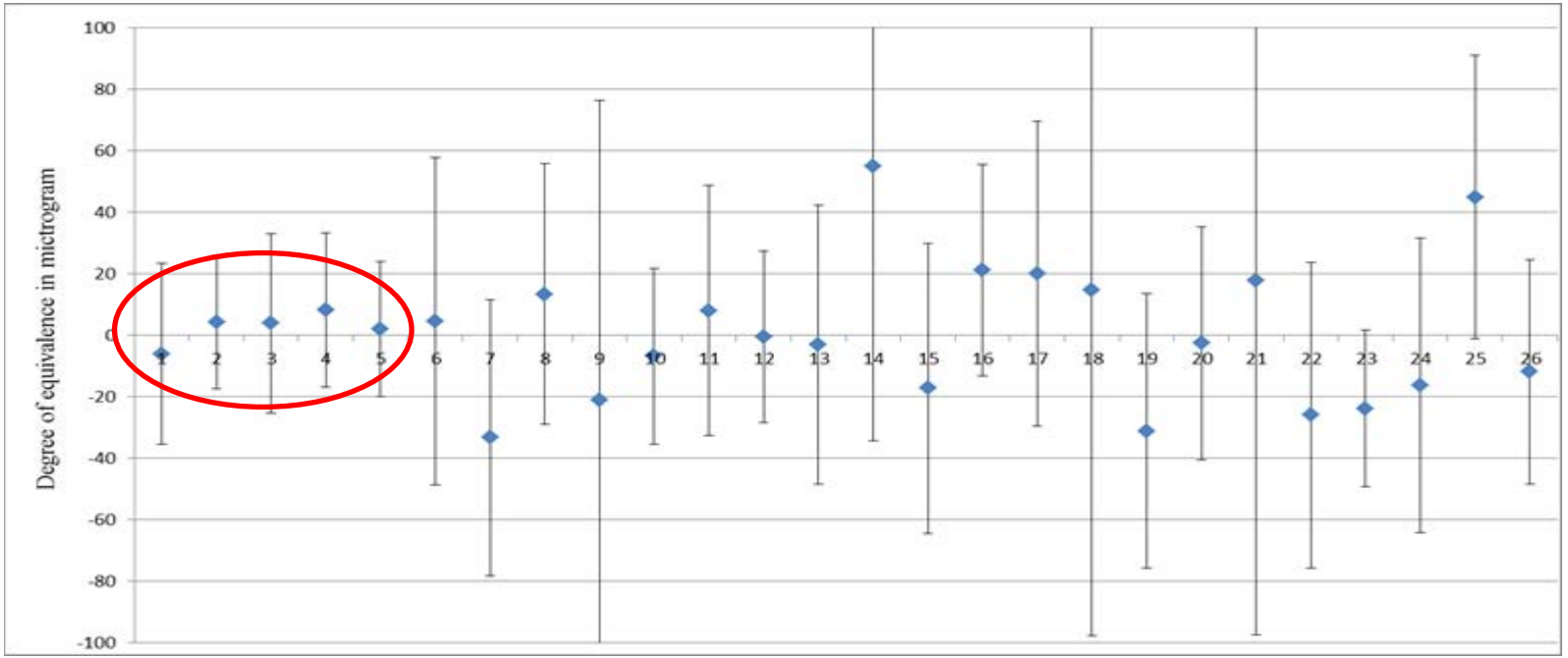
Mass evolution of the working standards for current use



Bureau International des Poids et Mesures


Mass evolution of the working standards for current use
[77]
[88]
[63]
[103]
[97]
[42']
0.0030
0.0020
0.0010
0.0000
-0.0010
-0.0020
-0.0030
-0.0040
-0.0050
-0.0060
-0.0070
-0.0080
-0.0090
-0.0100
-0.0110
01/01/2015
01/01/2016
31/12/2016
01/01/2018
01/01/2019
Drift from 5 March 2015 / mg
Time
Present calibration uncertainty 5.5 µg
First use of working standards for exceptional use (preliminary results)

EURAMET.M.M-K4 – 1 kg stainless steel standards



- BIPM participated as link laboratory to CCM.M-K4
- Very good agreement with the other four link labs

Bureau International des Poids et Mesures

BIPM ensemble of reference mass standards: initial concept

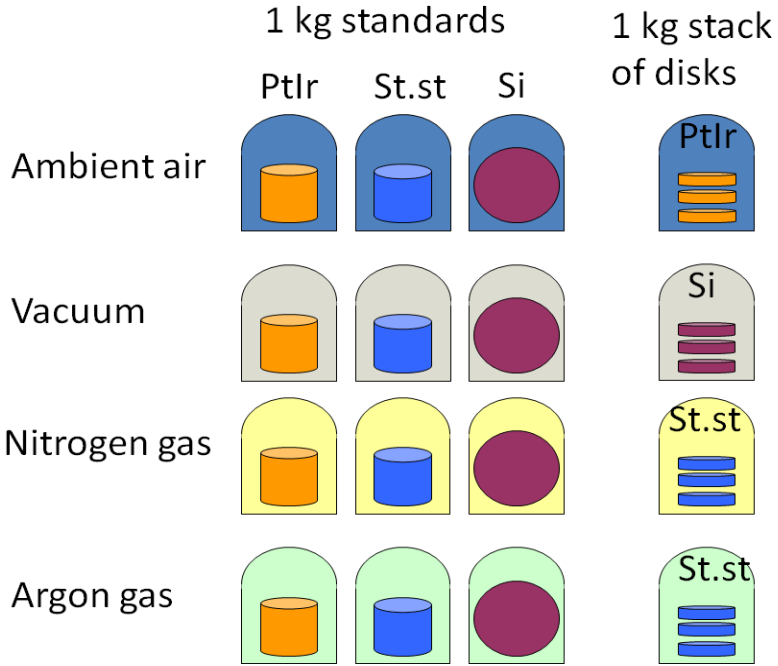
Main concern around 2010:

- Unexplained mass changes of Pt-Ir prototypes in the past, thought to be due to contamination (CCM workshop 2012)
- Common drift of Pt-Ir standards could not be detected

Solution:

- Standards of 3 different materials stored in 4 different environment

Initial configuration of Ensemble



Bureau International des Poids et Mesures

BIPM ensemble of reference mass standards: lessons learned

- Extraordinary calibration campaign in 2014 led to conclusion that mass change of prototypes is due principally to wear, not to contamination (at BIPM, where prototypes are used intensively)
- Recent experience with BIPM standards and national prototypes shows that contamination rates are typically ≤ 1 µg/year
- In 2015, BIPM introduced a change in the use of its working standards:
    - Strong reduction of usage to reduce wear
    - Hierarchical levels of standards with very different levels of usage

Good experience with this scheme until now, good control of mass of standards

BIPM ensemble of reference mass standards: new approach

Recent change of strategy for use of the Ensemble:

- Pt-Ir standards will be used for comparisons and calibrations
  - used according to a strict hierarchical scheme
  - long history and well understood
- Some recent studies show that storage under inert gas is not advantageous compared to air
- Storage under inert gas or vacuum requires more complicated manipulation and could lead to more wear
- Storage under permanent gas flow has a high cost

During 2019 standards of the Ensemble will be brought into air

Bureau International des Poids et Mesures

BIPM ensemble of reference mass standards: new approach

- Standards are traceable to the IPK (2014)
- Standards are traceable to the realization experiments participating in Pilot Study (2016)
- They should be included into the weighing scheme for each key comparison to contribute to providing a solid link between comparisons, and not be used in-between

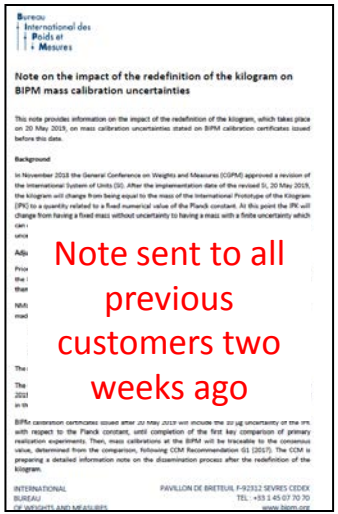
Impact of the kg redefinition on past BIPM calibrations

- Prior to the redefinition, all NMIs took traceability, directly or indirectly, from the IPK
- This will continue to be the case immediately after 20 May 219
- The mass of the IPK will then have an uncertainty of 10 µg

For use of past BIPM calibration certificates for measurements made after 20 May, NMIs have to review their uncertainty budgets by:

- adding 10 µg in quadrature to the uncertainty on the BIPM certificate
- updating their internal uncertainty budgets accordingly
- potentially revising their published CMCs (CCM should provide guidance)

The mass values on the BIPM certificates remain valid


Bureau International des Poids et Mesures

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

This note provides information on the impact of the redefinition of the kilogram, which takes place on 20 May 2019, on mass calibration uncertainties stated on BIPM calibration certificates issued before this date.

Background

In November 2018 the General Conference on Weights and Measures (CGPM) approved a revision of the International System of Units (SI). After the implementation date of the revised SI, 20 May 2019, the kilogram will change from being equal to the mass of the International Prototype of the Kilogram (IPK) to a quantity related to a fixed numerical value of the Planck constant. At this point the IPK will change from having a fixed mass without uncertainty to having a mass with a finite uncertainty which

Note sent to all previous customers two weeks ago

BIPM calibration certificates issued after 20 May 2019 will include the 10 µg uncertainty of the IPK with respect to the Planck constant, until completion of the first key comparison of primary realization experiments. Then, mass calibrations at the BIPM will be traceable to the consensus value, determined from the comparison, following CCM Recommendation G1 (2017). The CCM is preparing a detailed information note on the dissemination process after the redefinition of the kilogram.

INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES

PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX
TEL : +33 1 45 07 70 70
www.bipm.org

Bureau International des Poids et Mesures

Impact of the kg redefinition on future BIPM calibrations

- Calibration certificates established after 20 May 2019 will include the 10 µg uncertainty of the IPK wrt Planck constant (5.5 µg -> 12 µg)

- Calibrations made after the first key comparison of kg realizations (2020) will be traceable to the “consensus value” (unc. approx. 20µg)

Technical Protocol for 1. key comparison - proposal

- **Conditions for participation**
  - Best uncertainties will be 10-15 µg (10-15 ppb)
  - Allowing a ratio of 1:10 would lead to a threshold of about 150 µg (150 ppb)
  - 200 ppb proposed in CCM Extended Note on phases of kg dissemination, would allow 1 or 2 more participants
  - New realization since participation in Pilot Study (ideally close to time of comparison)
  - Published result in peer reviewed journal incl. detailed uncertainty budget and evidence of long-term stability of experiment (?) (could exclude new experiments)

Technical Protocol for 1. key comparison - proposal

- **Measurand**
    - In the Pilot Study the comparison of vacuum masses and air masses gave very similar results (but increased the work load)
    - Buoyancy corrections are tested in CCM.M-K4 (comp. of stainless steel masses at 1 kg)
    - Proposal: limit key comparison to vacuum masses
    - Participants shall characterize repeatability of vacuum mass after exposure to air

Technical Protocol for 1. key comparison – proposal

- **Transfer standards**
  - In Pilot Study Pt-Ir showed better stability than stainless steel (smaller surface ?)
  - But: stainless steel standards could be shipped by freight: easier logistics

  - Proposal: 2 standards (1 kg) provided by the participant
    - 1 Pt-Ir (if available)
    - 1 standard of the participant's choice (Pt-Ir, stainless steel, Si-sphere, …)
    - Mass stability to be checked by participant (weighing before & after BIPM)

Technical Protocol for 1. key comparison – proposal

- **Starting date**
  - CCM Strategy: “immediately after the redefinition”
  - May 2019, CCM Agreement on comparison scheme
  - June/July 2019 Technical Protocol
  - Sept – Oct 2019 Measurement of transfer standards at NMIs using realization experiment (earlier realization can be accepted)
  - Nov – Jan 2019 Comparison measurements at BIPM, incl. link with IPK
  - Feb 2020 NMIs check stability of transfer standards (no new realization)
  - Draft A April 2020
  - Draft B May 2020

Survey amongst NMIs with realization experiments

(N)MI	Timetable (Start Sep-Oct 19)	Uncertainty	Standards (1 kg unless stated)	Other comments
BIPM	Yes	100 µg	PtIr	
NIST	Yes	15 µg	PtIr	
METAS	Potentially (TBA)	50 µg	Au Plated Cu or SS	
LNE	Jan 2020	50 µg	PtIr	
PTB	Yes (or later)	15 µg	PtIr + nat. Si sphere	
NRC	Yes	12 µg	PtIr	
NMIJ	Jan-Feb 2020	24 µg	2 x PtIr	
NIM	Yes	50 ppb	1 kg & 500 g SS	
KRISS	Yes	200 µg	PtIr + SS	
UME	Hopefully	<200 µg	E0 SS	
NPL	End 2020	50 ppb	100 g W sphere	1 kg by build-up

6 NMIs ready for start in Sept/Oct 2019
2 NMIs ready for Jan/Feb 2020
2 NMIs depending on progress
1 NMI ready end 2020

Points for discussion - Summary

- **Limiting uncertainty:** 200 ppb
- **Comparison of vacuum masses, air masses, or both :** vacuum
- **Choice of travelling standards (1 kg):** 1Pt-Ir + 1 (Pt-Ir, st.st., Si, …)
- **When:** travelling standards at BIPM in
  - Nov 2019 (Draft A in April 2020)
  - March 2020 (Draft A in August 2020)
- **Support group?**