Technical Protocol for the Pilot Study of 1 kg mass standards calibrated with relation to primary realization experiments for the unit of mass

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Steering committee:

The steering committee for this Pilot Study comprises Horst Bettin (PTB, Chair CCM Working Group on the realization of the kilogram), Chris Sutton (MSL, Chair CCM Working Group on the dissemination of the kilogram), and Michael Stock (BIPM). The role of the steering committee is to assist with the key decisions regarding the protocol for the Pilot Study, to advise regarding problems encountered during the comparison process and to review and advise on the production of the final report.

1. Background

The CIPM proposes to change the definitions of four of the SI base units ("New SI"). The new definition of the unit of mass, the kilogram, will be based on a fixed numerical value of the Planck constant, *h*. The CCM roadmap towards the redefinition of the kilogram [1] was approved by the CIPM in 2013. It anticipates that the new definition could be accepted by the 26th CGPM in 2018. As one of the preparatory steps it foresees the implementation of a Pilot Study.

The Pilot Study should compare realizations of the unit of mass at the level of 1 kilogram obtained with the primary realization experiments which are capable of determining mass at an appropriate level of uncertainty (a relative standard uncertainty of less than or equal to 2 parts in 10^7) at the time of the Pilot Study.

The BIPM is establishing an Ensemble of Reference Mass Standards (ERMS) in order "to facilitate the dissemination of the unit of mass when redefined" (CGPM Resolution 1 of 2011 [2]). A linking of the "Ensemble" to the primary realization experiments will provide a first calibration of the ensemble in terms of the new primary realizations.

2. Aims of the Pilot Study

The purpose of this Pilot Study is to check the realization and dissemination of the new kilogram as described in the *mise en pratique* [3]. The two main objectives are:

- to test the uniformity of kilogram realizations based on different primary realization experiments
- to test the agreement between the kilogram realized according to the future definition and according to the present definition.

Both objectives are complementary. The first is to test if the future primary realization experiments realize the same mass unit (uniformity). The second is to test if the future realizations agree with the present one based on the IPK (continuity). The protocol has been designed so that primary realizations of the kilogram obtained by different primary realization experiments may be compared as directly as possible.

The Pilot Study will also be used to link the BIPM Ensemble of Reference Mass Standards to the primary realization experiments as starting point for the future ongoing BIPM key comparison BIPM.M-K1 and for the future dissemination of the mass unit from the BIPM, for NMIs which do not possess a primary realization. The technical protocol and the experience gained from the Pilot Study can help to formulate the technical protocol for BIPM.M-K1. The outcome of this study may result in an update of the *mise en pratique*.

The Pilot Study will check whether the CCM recommendation G1 (2013) [4] is fulfilled, with regard to the validation of procedures for the future realization and dissemination of the kilogram. The results of the Pilot Study shall be available for discussion at the 16th CCM meeting in May 2017, which will be the last CCM meeting before sending the Convocation for the 26th CGPM.

3. General Principle of the Pilot Study

The Pilot Study will be carried out by using two independent sets of 1 kg travelling standards (provided by each participant) to be calibrated by the participants as follows:

Set 1: 1 Pt-Ir standard and optionally 1 standard of the participant's choice (e.g. Si-sphere, tungsten cylinder, second Pt-Ir standard), to be calibrated as directly as possible with the primary realization experiment (in general under vacuum);

Set 2: 2 stainless steel standards, to be calibrated in air, traceable to the primary realization experiment.

Each participant shall calibrate its travelling standards assigning to each of them a mass and an uncertainty (assuming a common exact value of the Planck constant, see section 9). The BIPM will afterwards collect the travelling standards from all participants and carry out mass comparisons among all of them. Results from these comparisons will be confronted with the mass and uncertainties claimed by the participants. This will assess the capability of future primary realizations to realize and disseminate worldwide the same unit of mass (uniformity). The traceability of the BIPM working standards to the IPK, re-established in 2014, will allow to investigate the agreement between kilogram realizations based on the future and the present definition of the kilogram (continuity).

Using two sets of standards both the primary realization of the unit (Set 1) and its subsequent dissemination (from vacuum to air and from primary standard to stainless steel standard, Set 2) will be evaluated as part of this study.

Since it is the objective of the Pilot Study to compare the mass units as realized and disseminated in practice by the participating institutes, the participants shall use those procedures for the calibration of both sets of standards which they plan to apply after the redefinition. A detailed description of the procedures for the realization and the dissemination shall be provided together with the calibration results.

4. Purpose of this document

The purpose of this document is to define the organisation of the comparison, to provide instructions for participants on the transport and handling of the travelling standards and to outline the method of reporting results.

It is important to note, however, that the purpose of this Pilot Study is to compare the measurements as realized and disseminated in the participating institutes, not to require each participant to adopt precisely the same conditions of realization and dissemination. Therefore, this protocol specifies the procedures necessary for the comparison, but not the procedures used for the measurements.

5. Timetable for the comparison

The Pilot Study will be performed using travelling standards provided by the participating laboratories. Table 1 shows the comparison timetable including the transportation of the travelling standards and the preparation of the report. More details of the actual measurements required to be undertaken by the participants and the pilot laboratory are given in sections 9 and 10.

Table 1: Timetable for the Pilot Study

January 2014	Questionnaire circulated
April 2014	Main points of technical protocol: travelling standards etc. decided
November 2014	Draft outline for comparison developed
February 2015	Draft protocol presented at 15th CCM meeting
June-July 2015	Protocol agreed by potential participants
Aug-Dec 2015	Travelling standards selected and characterized by participants
Jan-March 2016	Calibration of travelling standards by the participants (Section 9)
March 2016	Transport of all travelling standards to the pilot laboratory
April 2016	Results sent to pilot laboratory within four weeks of measurements
April – June 2016	Comparison of travelling standards at the pilot laboratory (Section 10)
July 2016	Return of all travelling standards to the participants
July-Sept 2016	Re-calibration of travelling standards by the participants (Section 9)
Oct 2016	Measurements completed
Oct-Nov 2016	Results sent to pilot laboratory within four weeks of measurements
Dec 2016	Draft A report
Feb 2017	Draft B report
March 2017	Final report
May 2017	16th CCM meeting
June 2017	Publication of final report

6. Travelling Standards

All the travelling standards will be provided by the participating NMIs. Each NMI should provide one platinum-iridium kilogram standard and optionally a kilogram standard of their choice for Set 1. If an NMI wants to use a kilogram standard of their choice, they shall inform the BIPM well before the start of the comparison, to verify the feasibility. Two stainless steel one kilogram standards shall be provided for Set 2. The mass of all standards shall be close to nominally 1 kg, ideally well within 100 mg.

The travelling standards selected should be fit for purpose and well characterized with regard to their mass stability. This is particularly important for the behaviour of the standards of Set 1 under air-to-vacuum transfer. The NMI shall verify that the travelling standards are stable (within the uncertainties) under repeated air-to-vacuum transfers.

For each of the travelling standards the participants must supply the following data as early as possible after approval of the protocol and before the beginning of the comparison measurements (Annex 1):

- Weight manufacturer
- Type / construction
- Nominal dimensions
- Volume at 20 °C (and associated uncertainty)
- Coefficient of cubic thermal expansion
- Magnetic properties (volume magnetic susceptibility and magnetic polarization)

Additional information (e.g. surface roughness) may also be provided if available.

7. Participants

The participants in the Pilot Study consist of all NMIs with primary realization methods of the mass unit which are able to produce results at the level of 1 kg at an appropriate level of uncertainty. The relative standard uncertainty should not be larger than 2 parts in 10^7, that is 200 µg at 1 kg.

Possible methods are currently: watt balance, joule balance and XRCD. For the XRCD method, institutes that can determine surface layer and volume of the ^{28}Si spheres were approached to participate. Published values for molar mass, lattice parameter and point defects of the ^{28}Si crystal may be used. Similarly the ratio of Planck constant and mass of a ^{28}Si atom may be calculated from recognised published values.

Table 2: Participant details

Institute	Contact	Primary realization method	Estimated uncertainty of realization / µg	Other information

8. Transport and handling of the travelling standards

Each participating institute is responsible for the delivery of the travelling standards to the pilot laboratory and collection of the travelling standards from the pilot laboratory. Since the integrity of the comparison is reliant, to a large extent, on the pilot laboratory being able to make a direct comparison of travelling standards from all the participating institutes, the participants must ensure that the travelling standards are available to the pilot laboratory during the period outlined in the comparison timetable.

It is the responsibility of the participating institutes to provide suitable transport containers for the travelling standards. Details of the containers together with a comprehensive description of their assembly/disassembly must be provided to the pilot laboratory.

Each participating institute is responsible for its own costs for their measurements, transport of the travelling standards and any customs charges as well as any damage that may occur within its country or while in transit. The overall costs of organizing the comparison will be borne by the pilot laboratory. Insurance of travelling standards will be decided by the participants, taking account of the responsibility of each participant for its own standards. In the case of delay with respect to the schedule, the institute sending the standard must report to the pilot laboratory as soon as possible the cause of the delay and its expected duration. The institute sending the standard must strive to resolve any transportation failure in order to minimize its impact on the running of the comparison. In case of damage to a standard during transport, the receiving institute should report details to the sending institute and a judgement should be made on the continued suitability of the standards for the purpose of the comparison and an appropriate course of action decided on.

8.1 Sending the travelling standards

[A] The institute sending the standards should package the standards in good condition before transfer to the pilot laboratory.

[B] The travelling standards shall be inspected visually before sending them. Any scratches, stains, surface contamination or other damage shall be noted. The travelling standard visual inspection form, shown in Annex 3.2 shall be completed during the inspection and sent to the receiving institute.

[C] The travelling standards are to be carried preferentially by hand to and from the BIPM. If the cost of transfer by hand is not acceptable to the sending institute the option of shipping the travelling standards by using a safe courier company, which can deal with customs formalities, can be used in exceptional circumstances.

[D] Necessary customs formalities will be handled through an ATA Carnet or temporary importation form provided by the participant. It will be necessary for the person carrying the travelling standards to take them safely through customs and (if travelling by air) airport security. Remember that in general an ATA Carnet is valid for one year and that forms must be filled in each time a frontier is crossed.

[E] Detailed arrangements will be made for the transfer of the standards in close consultation between the participant and the BIPM. E-mail information should contain: the method of transportation of the weights (carried by hand or the name of the courier company and any tracking information) and dates for arrival/collection of the standards at the pilot laboratory.

[F] The travelling standards should be housed in separate travelling containers. These should be designed to protect the standards from contamination and damage.

[G] The participating laboratory should provide photographs of the open containers so that customs and airport security will be able to visualize the contents. In addition, the participating laboratory should supply a short document describing the standards and their metrological importance. The document should be written in English and the language of the customs and security officers and should be typed on official institute stationery (see example in Annex 2).

[H] In the event that the containers must be opened for inspection the person transporting the standards should carry out all handling operations using appropriate gloves provided by the participating institute. During transportation the travelling standards should not be handled unless absolutely necessary.

[I] The pilot laboratory (with assistance from a representative from the participating laboratory where appropriate) will similarly follow the procedure on the use of the transport containers when returning the standards to the participant.

8.2 Receiving the travelling standards

[A] The pilot laboratory will remove the standards for visual inspection by following the procedures provided by the participants.

[B] The travelling standards shall be inspected visually as soon as they arrive at the receiving institute (BIPM or NMI) after transport. Any scratches, stains, surface contamination or other damage shall be noted. The travelling standard visual inspection form, shown in Annex 3.1 shall be completed during the inspection and sent to the sending laboratory before measurements are started.

9. Determining the mass of the standards at the participating NMIs

Each participating institute is required to determine the mass of two sets of travelling standards. The standards should be free from contamination. Any dust should be removed by using a clean brush. Apart from this, in general the travelling standards should not be cleaned with solvents etc. during the Pilot Study. If a participant recommends to clean the optional standard of Set 1 (e.g. a Si sphere), the pilot laboratory shall be informed at the time of sending the form in Annex 1. Visible surface contamination which cannot be easily removed must be reported immediately to the pilot laboratory, or the NMI, as appropriate.

The travelling standards of Set 1 should be calibrated as directly as possible with the participating institute's primary realization experiment. Ideally this should involve a measurement (under vacuum) of the travelling standards on the watt or joule balance apparatus or a direct comparison under vacuum against one or more ^{28}Si spheres. If it is necessary to take traceability to the primary realization experiment via an interim mass standard the comparison with the travelling standard must be performed under vacuum. In the exceptional case that the primary realization experiment operates in air, the travelling standard shall be calibrated in air. The aim of this part of the comparison is to compare, as directly as possible, the primary realization experiments. These measurements need to be made only once, before sending the travelling standards to the pilot laboratory.

The mass values attributed to the standards of Set 1 shall be calculated assuming an exact value of the Planck constant of

$$h = 6.626\,070\,040 \times 10^{-34}\ \text{Js}$$

which is the value provided by the 2014 CODATA fundamental constants adjustment. This value for *h* shall be assumed as exact, and its uncertainty, determined by CODATA, shall not be included in the uncertainty budgets for the Pilot Study. This value is traceable to the IPK. Agreement between the comparison reference value and the IPK would therefore indicate continuity between realizations based on the present and the new definition (see section 12).

In addition, the NMIs shall determine, just before shipment to the pilot laboratory, the mass of the standards of Set 1 *in air* with respect to their national prototype, traceable to the IPK. The purpose of this auxiliary measurement is to allow a verification of the mass stability during transport by comparing with the mass obtained by the pilot laboratory, just after reception of the travelling standards, in air, also traceable to the IPK. If both results deviate significantly, this would indicate a change of mass during transport. These additional measurements shall be made twice: just before sending the standards to the pilot laboratory and just after receiving them back. Comparison of these two sets of results will also allow to determine the stability of the travelling standards during the whole duration of the comparison to a suitable level of uncertainty.

The second set of travelling standards will consist of a pair of stainless steel travelling standards, the mass of which in air shall be traceable to the primary realization experiments. The aim of this part of the comparison is to assess the worldwide uniformity of the dissemination of the unit of mass from the primary realization experiment, which will include the transfer of the traceable mass standard(s) from vacuum to air, by the technique chosen by the participant.

The detailed list of the results to be sent to the pilot laboratory is shown in annexes 4 to 6.

As an example, the measurements may consist of the following stages. Other schemes are possible, since each participant shall apply its own techniques. For example, for the exceptional case of a watt balance operating in air, step S1.2 would not be needed.

<u>Set 1, travelling standards calibrated using primary method:</u>

S1.1 Mass of travelling standard (in vacuum) calibrated traceable to primary realization experiment

S1.2 Transfer to air

S1.3 Mass of travelling standard (in air) calibrated with respect to platinum-iridium reference standard (traceable to IPK), for check of stability during transportation

S1.4 Standard transferred (in air) to the BIPM

S1.5 All travelling standards compared in air with BIPM working standards (traceable to the IPK), for check of stability under transportation

S1.6 All travelling standards compared under vacuum (and also compared with BIPM air-to – vacuum transfer standards). If an NMI carries out a primary realization in air, BIPM will use a vacuum-to-air transfer for comparison with the other travelling standards

S1.7 All travelling standards re-compared in air with BIPM working standards (traceable to the IPK), for check of stability under transportation

S1.8 Standards returned (in air) to participating NMIs

S1.9 Mass of travelling standard (in air) calibrated with respect to platinum-iridium reference standard (traceable to IPK), for check of stability under transportation

S1.10 Stability of standard during transfer process assessed

Set 2, stainless steel travelling standards:

S2.1 Travelling standards compared in air with NMI (stainless steel) standards which are directly traceable to the primary realization experiment.

S2.2 *If necessary stability checks made against additional stainless steel standards*[1]

S2.3 Standard transferred (in air) to the BIPM

S2.4 All travelling standards will be compared directly and against BIPM stainless steel standards traceable to the IPK.

S2.5 Standards returned (in air) to participating NMIs

S2.6 Stability checks repeated if necessary

S2.7 Travelling standards re-compared in air with NMI (stainless steel) standards which are directly traceable to the primary realization experiment.

The participants must follow these guidelines:

- The absolute mass of the travelling standards has to be determined in vacuum (where possible, 0.001 Pa < p < 0.1 Pa) for the standards of Set 1 and in air for the stainless steel standards of Set 2.
- In order to achieve a good mass stability, the travelling standards should be placed into the primary realization apparatus or mass comparator for an appropriate period prior to carrying out the first measurements. The period should make allowance for thermal stabilisation and desorption from the surface of the standards.

It is the responsibility of the participating NMIs to provide all the relevant data on the travelling standards necessary for their comparison at the pilot laboratory (see annexes 4 to 6).

10. Measurements at the BIPM

10.1 Standards of Set 1

The standards of Set 1 will be directly compared with each other and also with BIPM air-to-vacuum transfer standards (sorption artefacts) under vacuum. The air-to-vacuum transfer standards allow to establish a link to the BIPM working standards, held in air. The BIPM working standards are traceable

[1]This stage (and stage S2.6) only needs to be performed if the stability over the duration of the comparison of the stainless steel standards used in stage S2.1 (and stage S2.7) is inadequate to characterise the stability of the travelling standard before and after transport to the pilot laboratory. It is not necessary to determine an absolute mass value, just a value relative to a reference standard which is supposed to be stable or the drift rate of which is supposed to be known.

to the IPK and therefore allow to test the continuity of the present and the future mass units. The working standards will also be used shortly after the measurements for the Pilot Study to calibrate standards from the Ensemble of Reference Mass Standards with respect to the primary realizations. In the exceptional case that an NMI calibrates its travelling standards of Set 1 in air, those will be compared with the travelling standards under vacuum of the other participants via the BIPM air-to-vacuum transfer standards.

Directly after reception and before sending them back, the BIPM will compare the travelling standards of Set 1 with its own working standards in air. Together with the measurements made at the NMIs in air (steps S1.3 and S1.9 in the above scheme) this will allow to detect any mass changes during transport. Combining the results obtained in air and under vacuum could also allow to identify problems and instabilities related to the air-to-vacuum transfer of the travelling standards.

10.2 Standards of Set 2

The stainless steel standards of set 2 will be directly compared with each other and also with BIPM working standards in stainless steel in air. The BIPM working standards are traceable to the IPK in 2014.

11. Reporting the results

Each participant will determine the mass of the selected travelling standards with respect to its own primary realization experiment.

- Each participant will be expected to report the results of the first measurement series, before BIPM, and the second series, after BIPM, within 4 weeks of completing each series.
- Each participant will supply the pilot laboratory with the general information requested on the form in Annex 4.
- All results should be reported on a true mass basis.
- Institutes should report their results in vacuum (where possible) for the platinum-iridium standards and optional standards of Set 1 (S1.1) and in air for the stainless steel standards (S2.1, S2.7). Both sets of results should be traceable to the NMI's primary realization experiment. For the standards of Set 1 they should also report the mass values in air, traceable to the IPK (S1.3, S1.9) as a check of mass stability during transportation. Results should be reported on the forms given in Annexes 5 and 6.
- Uncertainties should be reported on the forms given in Annexes 5 and 6. A detailed table of uncertainty contributions is requested.
- The uncertainty must include traceability links to the NMI's primary realization experiment. This is particularly important for the stainless steel standards where the dissemination of the primary realization is being assessed.
- All uncertainties should be reported in accordance with the Guide to the Expression of Uncertainty in Measurement [5] using a coverage factor of unity (k = 1).
- A detailed description of the traceability path shall be provided.

12. Evaluation and publication of the results

For both sets of travelling standards the results of the Pilot Study will be presented in such a way as to provide information relevant to the two main objectives stated in section 2: (1) to test the uniformity of kilogram realizations based on different primary realization experiments and (2) to test the continuity between kilogram realizations based on the future definition and on the present definition.

The uniformity can be evaluated by combining the calibration results provided by the participants with the results of the direct comparison of the travelling standards with each other at the BIPM.

The continuity can be evaluated by comparing the suitably averaged "mean kilogram" of the participants with the IPK. In practice this can be done by calibrating a BIPM working standard against all travelling standards, and by comparing the mean of the results ("reference value") with a calibration against the IPK. The choice between the simple mean and the weighted mean will depend on the level of agreement between the participants' results, that is their uniformity. If the participants' results agree within their uncertainties, a weighted mean would be the best choice. Otherwise an estimator which does not rely on the uncertainties will be chosen, for example the simple mean. In calculating the reference value any significant correlation between participants' uncertainties will be taken into account, in particular for the common use of ^{28}Si spheres. Known significant correlations shall be indicated in the uncertainty budgets provided by the participants.

Since this work is done in the form of a Pilot Study, the results will not be published in the Key Comparison Database (KCDB). However, the preparation of the report on this comparison will follow the CCM process for key comparisons, that is a Draft A report will be submitted to the participants and a Draft B report to the CCM Working Group on the Realization of the Kilogram, WGR-kg. It is planned to publish the final report in a peer-reviewed journal, with co-authors from all participating institutes.

References

[1] CCM Roadmap towards a redefinition of the kg http://www.bipm.org/utils/en/pdf/CCM-strategy-document.pdf (page 21)

[2] Resolution 1 of the 24th CGPM (2011): http://www.bipm.org/en/CGPM/db/24/1/

[3] *Mise en pratique* of the definition of the kilogram (draft version 9.0).

[4] CCM recommendation G1 (2013): Report on the 14th meeting of the CCM (2013), page 36, http://www.bipm.org/en/committees/cc/ccm/publications-cc.html

[5] JCGM 100:2008 Guide to the expression of uncertainty in measurement http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

Annex 1: Properties of the travelling standards

Institute:

Identification of standard	Manufacturer	Type / construction	Approximate deviation from 1 kg / mg	Nominal dimensions (dia x ht) / mm	Volume at 20 °C [2] / cm^3	Volume unc. (k=1) / cm^3	Coeff. of cubic expansion / $°C^{-1}$	Magnetic susceptibility	Magnetic polarization /µT
Set 1 - to be calibrated as directly as possible with the primary realization experiment (under vacuum)									
<Pt-Ir>									
<optional>									
Set 2 - to be calibrated in air, traceable to the primary realization experiment									
<stainless steel 1>									
<stainless steel 2>									

The masses of all standards shall be 1 kg within 100 mg.

Additional information (e.g. special cleaning procedure for optional standard of Set 1):

[2] If other reference temperature, please specify.

Annex 2: Example of a letter for airport security authorities

Example of a form for security purposes when the transfer standards are hand carried by air. Additional forms should be provided in the language of the sender's country to the person who will be responsible for the mass transfer. This wording of the model must be adapted in accordance with the people and NMIs involved in the transfer. The document should be typed on official institute stationery.

……

DD MM YYYY, at Sèvres

I the undersigned, <Michael Stock, acting Director of the Mass Department of the International Bureau of Weights and Measures (BIPM)>, certify that <*name of transporting person*>, is carrying two platinum-iridium and two stainless steel 1-kilogram mass standards from the Bureau International des Poids et Mesures (International Bureau of Weights and Measures) in Sèvres, France, to the <*Name and address of NMI*> as part of an international comparison of mass standards.

These standards are of large scientific importance. They are very fragile and must not be handled by unauthorized persons. Improper handling during transportation would render them useless. The containers have been designed to protect the masses during their transport so that they remain clean.

It is essential that they travel in the cabin as hand luggage and NOT in the baggage hold since they are sensitive to changes in atmospheric pressure. The standards are safe and do not pose any risk to the health and safety of passengers travelling on the same flight.

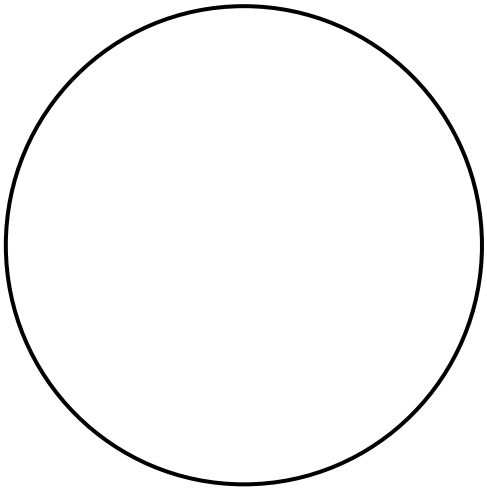
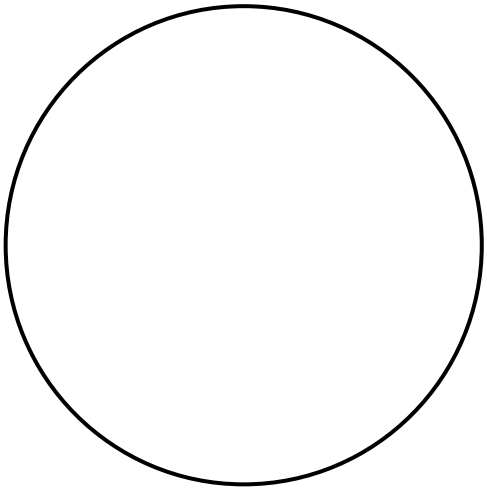
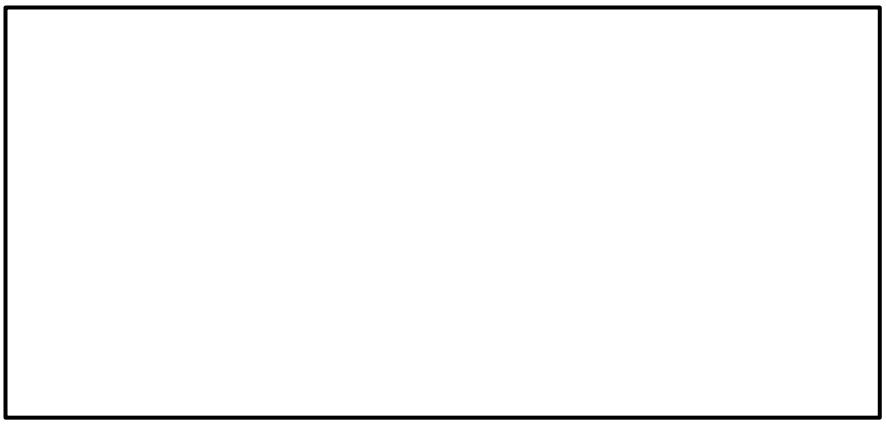
<Michael Stock
Acting Director of the Mass Department
BIPM, France>

Annex 3.1: Travelling standard visual inspection form

Arrival

Standard I/D	
Institute	
Inspected by	
Date	

Record any mark(s) seen on the travelling standard (scratches, contamination, etc.), sign the form and return the form to the sending institute before starting measurements.

Top	**Base**
	
Side	
	

Additional remarks:

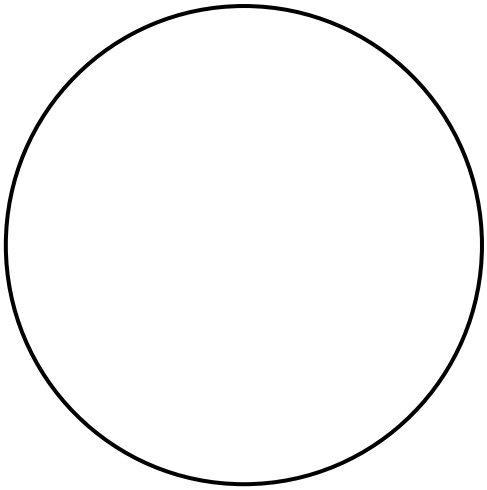
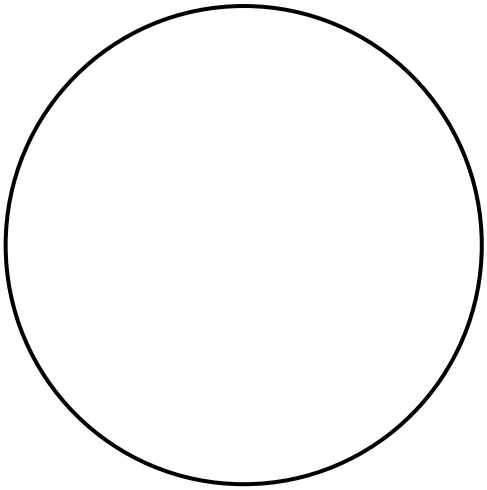
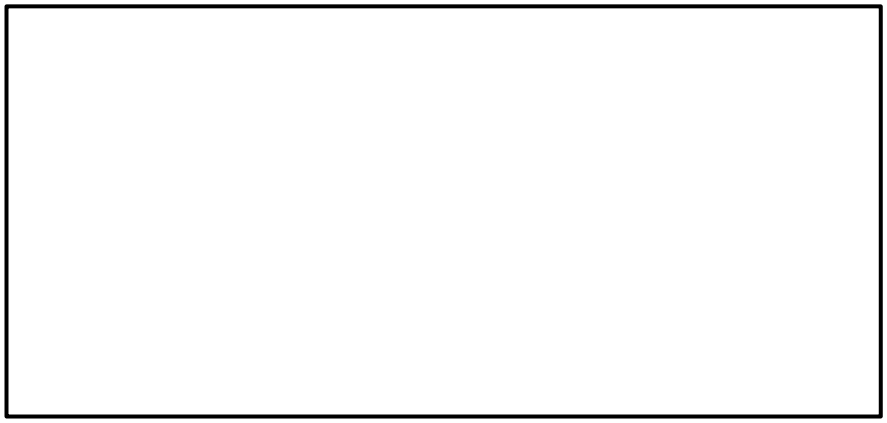
Signed: _____

Annex 3.2: Travelling standard visual inspection form

Departure

Standard I/D	
Institute	
Inspected by	
Date	

Record any mark(s) seen on the travelling standard (scratches, contamination, etc.), sign the form and return the form to the receiving institute.

Top	**Base**
	
Side	
	

Additional remarks:

Signed: _____

Annex 4: Description of the primary realization experiment and the measurement procedures

Institute: Date:

The purpose of this annex is to provide detailed background information on the primary realization experiment.

Background - Published material on primary realization experiment

Author(s)	Title	Reference

Latest values for Planck or Avogadro constant

	Value	Standard uncertainty
Latest estimate of value		
Most recent published value		
Reference		

Traceability from $h_{CODATA,2014}$ to the mass unit under vacuum

List detailed traceability chain from primary realization experiment (using the value for $h_{CODATA,2014}$, provided in this protocol) to the travelling standards of Set 1 (mass values under vacuum). Identify - where applicable - all intermediate mass standards and mass comparators used. Indicate the period of operation of the primary realization experiment relevant for the Pilot Study:

Annex 5.1: Results of calibration of standards of Set 1 under vacuum

Provide in this annex the measurement results and the detailed uncertainty budgets for the calibration of the travelling standard(s) of Set 1 under vacuum, using the primary realization experiment and value of *h* provided by the technical protocol.

• Standard 1, identifier:

date(s) of measurement	
measured vacuum mass	
estimated standard uncertainty	
average vac. pressure during cal.	

Detailed uncertainty budget for calibration of Standard 1 of Set 1 under vacuum, for all steps of the traceability chain described in annex 4. Please provide information on the estimated vacuum mass stability following air-vacuum transfers (standard shipped in air!). Identify known significant correlations with other participants' uncertainties.

source of uncertainty	standard uncertainty
primary realization experiment (mass unit wrt to $h_{CODATA,2014}$)	
…	
…	

• Standard 2, identifier:

date(s) of measurement	
measured vacuum mass	
estimated standard uncertainty	
average vac. pressure during cal.	

Detailed uncertainty budget for calibration of Standard 2 of Set 1 under vacuum, for all steps of the traceability chain described in annex 4. Please provide information on the estimated vacuum mass stability following air-vacuum transfers (standard shipped in air!). Identify known significant correlations with other participants' uncertainties.

source of uncertainty	standard uncertainty
primary realization experiment (mass unit wrt to $h_{CODATA,2014}$)	
…	
…	

Annex 5.2: Results of calibration of standards of Set 1 in air

The calibration of the standard(s) of Set 1 in *air*, in terms of the *present definition* of the kilogram, when combined with the equivalent calibrations at the BIPM, will allow to check the mass stability during transport. This measurement shall be carried out twice: before sending the standards to the BIPM and after receiving them back from the BIPM.

- **Standard 1, identifier:**

Results

date(s) of measurement	
measured mass in air	
estimated standard uncertainty	

Environmental conditions

Pressure range	
Temperature range	
Humidity range (RH or DP)	
Air density range	
Air density determination method (artefact/CIPM-2007)	

Balance details

Balance model	
Typical standard deviation (1 kg load)	
Constant pressure/vacuum chamber	
Other details	

Traceability

	Value	Unc.
National prototype		
Date of last calibration		
Ageing model applied since last calibration		

Describe traceability chain from national prototype to travelling standard:

Detailed uncertainty budget for calibration of Standard 1 of Set 1 in air:

source of uncertainty	standard uncertainty
national prototype	
ageing model	
…	
…	

- **Standard 2, identifier:**

Results

date(s) of measurement	
measured mass in air	
estimated standard uncertainty	

Environmental conditions

Pressure range		
Temperature range		
Humidity range (RH or DP)		
Air density range		
Air density determination method (artefact/CIPM-2007)		

Balance details

Balance model		
Typical standard deviation (1 kg load)		
Constant pressure/vacuum chamber		
Other details		

Traceability

	Value	Unc.
National prototype		
Date of last calibration		
Ageing model applied since last calibration		

Describe traceability chain from national prototype to travelling standard:

Detailed uncertainty budget for calibration of Standard 2 of Set 1 in air:

source of uncertainty	standard uncertainty
national prototype	
ageing model	
…	
…	

Annex 6: Results of calibration of standards of Set 2 in air (based on primary realization experiment)

Provide in this annex the measurement results and the detailed uncertainty budgets for the calibration of the travelling standards of Set 2 in air, traceable to the primary realization experiment. Please adapt the form if necessary.

- **Standard 1 (Set 2), identifier:**

Results

Measured mass	
Estimated standard uncertainty	
Nominal date of measurement	

Environmental conditions

Pressure range	
Temperature range	
Humidity range (RH or DP)	
Air density range	
Buoyancy correction	
Air density determination method (artefact/CIPM-2007)	

Balance details

Balance model	
Typical standard deviation (1 kg load)	
Constant pressure/vacuum chamber	
Other details	

Traceability

Describe traceability chain from primary realization experiment to travelling standard:

Air-vacuum transfer

Detailed description of the procedure used for dissemination of the mass unit from vacuum to air:

Mass standards used for air-to -vacuum transfer		
Vacuum pressure		
Air pressure		
Air temperature		
Humidity		
Sorption correction		
Source of sorption correction		

Uncertainty budget

Detailed uncertainty budget for calibration of Standard 1 of Set 2 in air:

source of uncertainty	standard uncertainty
…	
…	

- **Standard 2 (Set 2), identifier:**

Results

Measured mass	
Estimated standard uncertainty	
Nominal date of measurement	

Environmental conditions

Pressure range	
Temperature range	
Humidity range (RH or DP)	
Air density range	
Buoyancy correction	
Air density determination method (artefact/CIPM-2007)	

Balance details

Balance model	
Typical standard deviation (1 kg load)	
Constant pressure/vacuum chamber	
Other details	

Traceability

Describe traceability chain from primary realization experiment to travelling standard:

Uncertainty budget

Detailed uncertainty budget for calibration of Standard 2 of Set 2 in air:

source of uncertainty	standard uncertainty
…	
…	