International comparison protocol for the key comparison of 1 kg stainless steel standards.

Organized by the Working Group on Mass Standards of the Consultative Committee for Mass and related Quantities (CCM)

CCM.M-K4

Pilot Laboratory (PL) : Bureau International des Poids et Mesures
Pavillon de Breteuil
92312 Sèvres cedex
FRANCE

Contact person: Alain Picard
email: apicard@bipm.org
Tel: +33 1 45 07 70 28,
Fax: +33 1 45 34 20 21.

Steering committee:

The steering committee is composed of the contact persons at the NIST, NMIJ and PTB. Its role is to assist the PL in decision making to solve problems encountered during the process of the KC or for compiling the draft A and draft B reports.

1. Outline

The scope of the comparison is to demonstrate the coherency of the calibration of 1 kg stainless steel mass standards as realized in the participating institutes.

This comparison is being undertaken by the Consultative Committee on Mass and Related Quantities (CCM) and is based on a decision taken at the 13th CCM meeting held in May 2011. The protocol follows the rules of the "Measurement comparisons in the CIPM MRA" [1].

Each participating NMI is asked to determine the mass of two 1 kg stainless steel travelling standards.

The previous comparison (CCM.M-K1) was carried out between 1995 and 1998 and registered in the BIPM KCDB appendix B.

2. Purpose of this document

The purpose of this document is:

- To define the organization of the comparison
- To provide instructions for participants on the transport and handling of the transfer standards
- To explain the method of reporting results.

[1] http://www.bipm.org/utils/common/CIPM_MRA/CIPM_MRA-D-05.pdf

It is important to remember, however, that the purpose of a key comparison is to compare the standards as realized in the participating institutes, not to require each participant to adopt precisely the same conditions of realization. Therefore, this protocol specifies the procedures necessary for the comparison, but not the procedures used for the measurements.

3. Timetable for the comparison

Table 1. Timetable for the comparison.

Activity	**Deadline ***
Questionnaire and Protocol agreed	June 2011
Measurements at the pilot laboratory	August 2011
Circulation and measurements by participants	September 2011
Return to pilot laboratory and control measurements	January 2012
Receipt of the last measurement results reported by participants	February 2012
Analysis of results reported by participants	April 2012
Elaboration of Draft A	June 2012
Circulation of Draft A for comments/corrections	September 2012
Elaboration of Draft B	December 2012
Circulation of Draft B for comments/corrections	January 2013
Final report	February 2013

*The deadline corresponds to the end of the month shown in table 1.

4. Travelling standards

Eight 1 kg stainless steel travelling standards will be used for this comparison. Four were provided by the PTB named C1, C2, D1 and D2 and four by the BIPM named B5, B6, B7 and B8. The PTB standards are marked on the top surface. The BIPM standards are marked on the cylindrical surface. The standards provided by the BIPM were obtained specifically for CCM.M-K4. Details of each mass standard are listed in table 2.

The participants will be supplied with the following data:

- Volume of each cylinder at 20 °C (supplied by the PTB (Germany) for its standards and by CEM (Spain) for the BIPM standards).
- Coefficient of cubical expansion (supplied by the PTB for its standards and by the manufacturer Zwiebel for the BIPM standards).
- Height of each cylinder (supplied by the PTB and the BIPM for their respective standards).

- The magnetic properties of all travelling standards as the volume magnetic susceptibility and the magnetic polarization. These have been determined by the PTB and by the BIPM for their respective standards.

Table 2. Information on the eight travelling standards.

Identification	Volume at 20 °C /cm^3	Standard uncertainty /cm^3	Coefficient of cubical expansion /10^{-6} °C^{-1}	Height /mm	Volume magnetic susceptibility	Magnetic polarization /µT
C1	128.765 5	0.001 0	45.6	58.5	0.0026	≤ 0.12
C2	128.766 5	0.001 0	45.6	58.5	0.0027	≤ 0.12
D1	126.268 0	0.001 0	45.6	57.5	0.0026	< 0.10
D2	126.268 2	0.001 0	45.6	57.5	0.0025	< 0.10
B5	125.128 7	0.000 61	47.7	55	0.0033	< 0.10
B6	125.128 8	0.000 61	47.7	55	0.0033	< 0.10
B7	125.127 6	0.000 61	47.7	55	0.0033	< 0.10
B8	125.128 6	0.000 61	47.7	55	0.0033	< 0.10

The mass stability of these eight standards has been regularly monitored by comparison with two BIPM stainless steel standards since 2002 at the BIPM by using two mass comparators (HK1000 and METROTEC). No cleaning has been carried out since 2002 (except the B6 standard that was cleaned on its top surface with ethanol/ether mixture in 2009) and the standards are stored under glass bell jars. A smooth evolution of mass within 0.030 mg has been observed over the period 2002-2011.

5. Participants

Following approval of the draft protocol, interest in the Key Comparison will be assessed from each member of the CCM through a questionnaire (see annex 1).

All NMIs that have sufficient capabilities to contribute meaningfully to the Key Comparison Reference Value KCRV will be considered when deciding the final participation. Preference will be given to full members of the CCM and CCM-WG Mass Standards. Participants will also be chosen to achieve sufficient geographical representation to link this CIPM key comparison to future RMO KCs. These decisions will be made by the Chairman of the CCM-WG-Mass Standards.

In a decision by the CCM at its 12th meeting in 2010, laboratories which have had stainless steel kilograms calibrated at the BIPM during the 12 months before the comparison will be excluded from participating.

A total of 12 to 16 participants can be accommodated depending on how many participants can be included in one petal. The participating laboratories are listed in table 3.

Table 3. Institutes participating in the comparison.

National Metrology Institute Delivery address	Acronym	Technical Contact
Bureau International des Poids et Mesures, Pavillon de Breteuil, 92312 Sèvres Cedex, FRANCE	BIPM	Alain Picard apicard@bipm.org Phone: +33 1 45 07 70 28 Fax: +33 1 45 34 20 21
Bundesamt für Eich- und Vermessungwesen, Mass and related quantities Arltgasse 35, A 1160 Wien, AUSTRIA	BEV	Zoltan Zelenka Christian Buchner christian.buchner@bev.gv.at Phone: +43 1 211 10 6361 Fax: +43 1 211 10 6000
Centro Español de Metrología, Area de masa Calle del Alfar n° 2 28760 Tres Cantos-Madrid SPAIN	CEM	Nieves Medina/Angel Lumbreras mnmedina@cem.mityc.es Phone: +34 91 807 47 89 Fax: +34 91 807 48 07
Centro Nacional de Metrología, Mass and density division km 4.5 Carretera a los Cués, municipio El Marqués Querétaro, MEXICO C.P. 76246 MEXICO	CENAM	Luis Omar Becerra lbecerra@cenam.mx Phone: +52 442 2 11 05 73 Fax: +52 442 2 11 05 68
Istituto Nazionale di ricerca metrologica Strada delle cacce 91 10135 Torino ITALY	INRIM	Andrea Malengo a.malengo@inrim.it Phone: +39 011 3919 944 Fax: +39 011 3919 937
Korea Research Institute of Standards and Science Centre of mass and related quantities 267 Gajeong-ro, Yuseong-gu, Daejeon 305-340 REPUBLIC OF KOREA	KRISS	Jin Wan Chung jwchung@kriss.re.kr Phone: +82 42 868 5111 Fax: +82 42 868 5012
Laboratoire National de Métrologie et d'Essais Département Masse-Volume-Masse volumique-Viscosité, DMSI 25, avenue Albert Bartholomé 75724 Paris Cedex 15 FRANCE	LNE	Paul-André Meury paul-andre.meury@lne.fr Phone: +33 1 40 43 38 86 Fax: +33 1 40 43 37 37
Bundesamt für Metrologie METAS Labor Masse und Dichte Lindenweg 50, CH-3003 Bern-Wabern SWITZERLAND	METAS	Peter Fuchs peter.fuchs@metas.ch Phone: +41 31 32 33 204 Fax: + 41 31 32 33 210

National Institute of Metrology, Mechanics and acoustics division No.18,Bei San Huan Dong Lu, Chaoyang Dist,Beijing,100013 CHINA	NIM	Wang Jian wjian@nim.ac.cn Phone: +86 10 6452 4609 Fax: + 86 10 6421 8628
National Institute of Standards and Technology Physical Measurement Laboratory, Quantum Measurement division, Mass and Force group, 100 Bureau Drive, MS 8221 Maryland 20899-8221, Gaithersburg UNITED STATES	NIST	Zeina J. Kubarych zeina.kubarych@nist.gov Phone: + 1 301 975 6624 Fax: + 1 301 417 0514
National Measurement Institute, Bradfield Road, P.O. Box 264 West Lindfield NSW 2070 AUSTRALIA	NMI-A	Dr. John Man john.man@measurement.gov.au Phone: +61 2 8467 3513 Fax: +61 2 8467 3752 Ms. Kitty Fen kitty.fen@measurement.gov.au
National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology Mechanical metrology division AIST Tsukuba Central 3, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8563 JAPAN	NMIJ/AIST	Shigeki Mizushima s.mizushima@aist.go.jp Phone: +81 29 861 4352 Fax: +81 29 861 4399
National Metrology Institute of South Africa Mass, density and small volume laboratory CSIR campus Building 5n Meiring Naudé Road Brummeria, Pretoria 0002 SOUTH AFRICA	NMISA	Ronél Steyn rsteyn@nmisa.org Phone: +27 12 841 3508 Fax: +27 12 841 4458 Thomas Mautjana tmautjana@nmisa.org
National Physical Laboratory Mass group, engineering measurement division Hampton Road,Teddington, TW11 0LW UNITED KINGDOM	NPL	Stuart Davidson stuart.davidson@npl.co.uk Phone: +44 208 943 6224 Fax: +44 208 614 0535
National Physical Laboratory Mass standards Dr.K. S. Krishnan Road New Delhi-110 012 INDIA	NPLI	Anil Kumar anil_apirl27@yahoo.co.in Phone: +91 11 4560 8348 Fax: +91 11 4560 9310
National Research Council of Canada-Institute for National Measurement Standards Mass standards 1200, Montréal road, M-36 Ottawa (Ontario) K1A 0R6 CANADA	NRC-INMS	Claude Jacques Claude.Jacques@nrc-cnrc.gc.ca Phone: +1 613 993 9330 Fax: +1 613 952 1394

Physikalisch-Technische Bundesanstalt 1.11 Darstellung Masse Bundesallee 100 D-38116 Braunschweig GERMANY	PTB	Michael Borys michael.borys@ptb.de Phone: +49 531 592 1110 Fax: +49 531 592 69 1110

6. Plan of the comparison

Two 1 kg cylinders will be sent to each participating institute. The Key Comparison will be organized in four simultaneous "petals". Each participant within a petal will receive the same two travelling standards as follow.

Petal 1	B5:C1
Petal 2	B6:C2
Petal 3	B7:D1
Petal 4	B8:D2

Each petal should have three or four participants. The BIPM will carry out a comparison among these standards before the comparison and after the conclusion of work within each petal.
Three weeks will be allowed for the laboratory comparisons and one week for transport between participants.

In case of unexpected delays, the institute involved must give details to the PL as soon as possible about the cause and expected duration of the delay. If the delay is considered too long, the PL will try to reschedule the institute in question by replacing its turn with another institute. Each participant will be expected to report its results to the PL within 4 weeks of completing its measurements.

Table 4. Timetable for the circulation of standards.

Petal	NMI	Date of arrival	Date of departure	Date of sending results
Petal 1 Masses B5 & C1	PTB*	3rd October 2011	24th October 2011	21st November 2011
	CENAM	31st October 2011	21st November 2011	19th December 2011
	NRC-INMS	28th November 2011	19th December 2011	16th January 2012
	NIST	9th January 2012	27th January 2012	24th February 2012
Petal 2 Masses B6 & C2	NMI-A	3rd October 2011	24th October 2011	21st November 2011
	NMIJ/AIST	31st October 2011	21st November 2011	19th December 2011
	NIM	28th November 2011	19th December 2011	16th January 2012
	KRISS	26th December 2011	23rd January 2012	20th February 2012

Petal 3 Masses B7 & D1	CEM	3rd October 2011	24th October 2011	21st November 2011
	INRIM	31st October 2011	21st November 2011	19th December 2011
	LNE*	28th November 2011	19th December 2011	16th January 2012
	NMISA	26th December 2011	23rd January 2012	20th February 2012
Petal 4 Masses B8 & D2	NPL*	3rd October 2011	24th October 2011	5^{th} December 2011
	METAS	31st October 2011	21st November 2011	19th December 2011
	BEV	28th November 2011	19th December 2011	16th January 2012
	NPLI	26th December 2011	23rd January 2012	20th February 2012

* PTB, LNE and NPL should send back the traveling standards to the BIPM and not to the next laboratory.

7. Transport and handling of the travelling standards

Each participating institute has the responsibility to deliver the travelling standards to the next participant or to the BIPM.

Each participating institute is responsible for its own costs for the measurements, transport and any customs charges as well as any damage that may occur within its country. The overall costs of organizing the comparison, including the supply of the transfer devices, are normally borne by the pilot institute.

Insurance of transfer devices is decided by agreement among the participants, taking account of the responsibility of each participant for any damage that occurs within its country.

In case of failure of a travelling standard, the institute sending the standard must report to the PL as soon as possible the cause of the transportation failure, the expected delay or the eventual damage to the standard. The institute sending the standard and the institute receiving the standard must strive to resolve the transportation failure in order to minimize its impact on the running of the comparison. In case of damage to the standard, the institute sending it must return the standard to the PL for expert advice.

Remark: a test between the BIPM and NIST was carried out in 2008 by using an ATA Carnet for shipping. No Customs problems were reported and the mass difference before and after the transfer to the NIST was within 0.002 mg.

7.1. Sending the travelling standards

A) The travelling standards are to be carried by hand between institutes. 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 Carrier Company, which can deal with customs formalities, can be used in exceptional circumstances.

B) Necessary customs formalities will be handled through an ATA Carnet provided by the BIPM. 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 an ATA Carnet is valid for one year and that forms must be filled in each time a frontier is crossed. Depending on participants, an ATA Carnet or temporary importation form will be used to deal with Customs formalities.

C) Detailed arrangements for each time the standards are transported will be made between the sending institute, the receiving institute and the PL. Email information should contain: the method of transportation of the weights (carried by hand or carrier company), date the standards left the country and the expected date of entry into the country of the next participant.

D) The travelling standards are housed in separate travelling containers. These have been designed to protect the standards from contamination and damage. The containers with a red plastic interior were supplied by the PTB for their four standards. The containers with white Delrin interiors are copies made by the BIPM for its four standards. Figures 2 and 3 in annex 2 show the travelling containers. The two standards are packed into a suitcase (figure 1 annex 2).

E) The BIPM will provide photographs of the open containers so that customs and airport security will be able to visualize the contents (annex 3). In addition, the sending institute, the receiving institute and the PL will collaborate to supply a short document describing the standards and their metrological importance. The document should be written in the language of the customs and security officers and should be typed on official institute stationery (see example in annex 4).

F) In the event that the containers must be opened for inspection: Place the container on a table or counter. Remove the top of the container as described in annex 5. Replace the top as soon as possible. The person transporting the standards should practice opening and closing the case before removing the standards from the sending institute so that this operation can be carried out efficiently, if required. A brief message should be sent to the PL and the receiving institute if any problems occur during transport (customs, airport security or other).

7.2. Receiving the travelling standards

A) The receiving institute should remove the standards from their containers for visual inspection by following the procedure given in annex 5.

B) The travelling standards should be inspected visually. The standards must be placed on stable table covered by new lens cleaning tissues provided by the PL (figure 6 and 7 annex 2). Any scratches, stains, surface contamination or other damage should be noted. The travelling standard visual inspection form, shown in annexes 6.1 and 6.2 must be completed during the inspection and sent to the PL before measurements.

C) In case of dust on the surface of the standard, use only the brush provided by the PL in order to remove the visible particles. DO NOT CLEAN THE TRANSFER STANDARDS.

D) If the standard is not placed into the balance after inspection, the standard should be placed on the lens cleaning tissues and covered by a bell jar in the safe cabinet (figure 8 annex 2).

7.3. Packaging and sending the travelling standards

A) The institute sending the standards should package the standards in good condition before transfer by following the procedure given in annex 7.
B) The institute sending the standards must follow the instructions in section 7.1 for the preparation and transfer of the travelling standards.

8. Determining the mass of the standards

The goal is to compare the absolute mass value of the masses that each participating institute would assign to the two 1 kg stainless steel travelling standards. Each participating institute will be asked to determine the mass in air of two travelling standards. The mass must not include any visible dust on the travelling standards. Any dust should be removed by using a clean brush provided by the PL. The mass must not include any invisible surface films or contamination. Visible surface contamination must be reported immediately to the PL.

Determine the mass of the travelling standards to the best of your ability. There are few requirements that must be followed, although sufficient data must be taken to complete the reports shown in annexes 8, 9 and 10.

The participants must follow these guidelines:

- Balance comparisons should be made between the travelling standards and your secondary standards. Do not compare directly to your national prototypes.
- Always use the gloves provide by the PL or forceps if the gloves are not suitable for your hands.
- The absolute mass has to be determined in air ($h \approx 0.5$, $t \approx 20$ °C and $p \approx 1000$mbar).
- In order to achieve a good mass stability, it is recommended that the mass is placed into the balance and allowed to stabilize for one full day before carrying out the first measurements in air.
- The effective measurements could be carried out over a few days (depending on the stability of the results) after the delay mentioned above.
- For participants who have enough positions in their balance to accommodate the two travelling mass standards at the same time, it would be interesting to carry out, simultaneously, the mass measurements of the two travelling standards in order to determine the mass difference between them, as well as the sum of their masses in the same weighing sequence.
- For institutes with air buoyancy artefacts, it is recommended that the air density is determined by means of both methods (CIPM-2007 formula [2] and air buoyancy artefacts), with simultaneous acquisition of data.
- Do not check the magnetic properties of the travelling standards.
- Use the brush provided to remove any visible dust from the surface of the standard.

[2] Revised formula for the density of moist air (CIPM-2007); *Metrologia* **45** (2008) 149-155.

9. Results report

Each participant will determine the mass of the travelling standards with respect to its own working standards in stainless steel.

- Each participant will be expected to report its results to the PL within 4 weeks of completing its measurements.
- Each participant will supply the PL with the general information requested on the form in annex 8.
- Institutes should report their results in air, traceable to the International Prototype of the Kilogram, in annex 9 and calculate their uncertainties in a coherent way in annex 10.
- A complete table of uncertainties (including estimated degrees of freedom) is requested. The uncertainty must include traceability links to the International Prototype of the Kilogram. All uncertainties should be reported in accordance with the Guide to the expression of uncertainty in measurement [3] using a coverage factor of unity (k = 1).

The four items listed above will help monitor the stability of the travelling standards. If it can be shown that one of the two travelling standards was unstable, it may be possible to obtain the necessary data from a single travelling standard. In such cases, the steering committee will be consulted for advice.

10. Key Comparison Reference Value (KCRV) and degrees of equivalence

In an initial analysis, the results of each participant are linked to the results of the PL. We thus produce a set of mass *differences* between the PL and each participant. The uncertainties of these differences are calculated as in CCM.M-K1 [4].

An initial reference value for these differences, $diffRV_0$ is then calculated. Various calculation methods will be compared: weighted mean, median, simple mean etc. Normally, the weighted mean is used. However, the "best" method for calculating $diffRV_0$ will be decided by consensus of the participants and will be based on whether the assumptions behind the weighted mean are justified by the results of the comparison.

All results obtained in the Key Comparison will then be adjusted by $diffRV_0$ so that the definitive reference value of the *differences* is zero: $diffRV = 0$.

Degrees of equivalence for each participant with respect to $diffRV$ will be calculated.
Degrees of equivalence between any two participants will also be calculated.

---

[3] JCGM 100:2008, Evaluation of measurement data - Guide to the expression of uncertainty in measurement, 2008. http://www.bipm.org/en/publications/guides/gum.html
[4] Final report on CIPM key comparison of 1 kg standards in stainless steel (CCM.M-K1), *Metrologia*, 2004, **41**,*Tech. Suppl*., 07002. http://iopscience.iop.org/0026-1394/41/1A/07002/

For ease in reporting the KCRVs, as defined in the CIPM MRA, it will be assumed that the KCRV = 1 kg exactly. This does not affect the degrees of equivalence calculated in the previous step [5].

[5] Assuming that the performance of each participant would be essentially unchanged if the travelling standards had a mass of exactly 1 kg and a density at 20 °C sufficiently close to 8000 $kg \cdot m^{-3}$.

ANNEX 1

Questionnaire for potential participants:
(Please reply before 30 June 2011)

NMI:
Contact person:

a) Interest in participating.

b) Traceability chain [as for CMCs].

c) Balance to be used [as for CMCs].

d) Expected standard uncertainty for the measurand [as for CMCs].

e) Periods available to measure.

f) Periods not available.

g) Preferred method of transportation (carry by hand; other).

h) ATA Carnet or temporary import/export form.

ANNEX 2

Transport containers

Figure 1

Figure 3

Figure 2

Figure 4

Figure 5

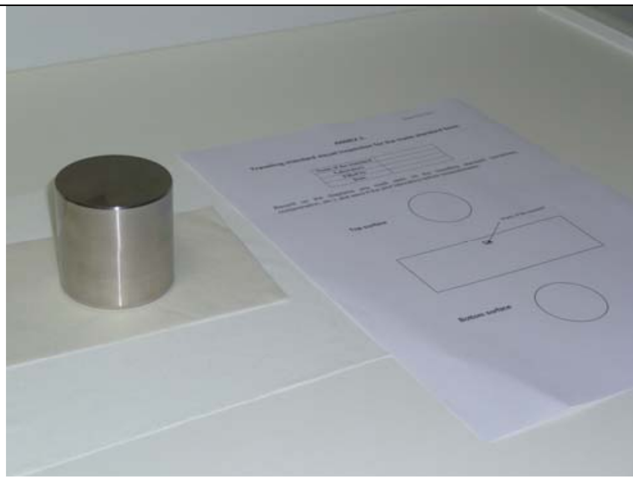


Figure 7

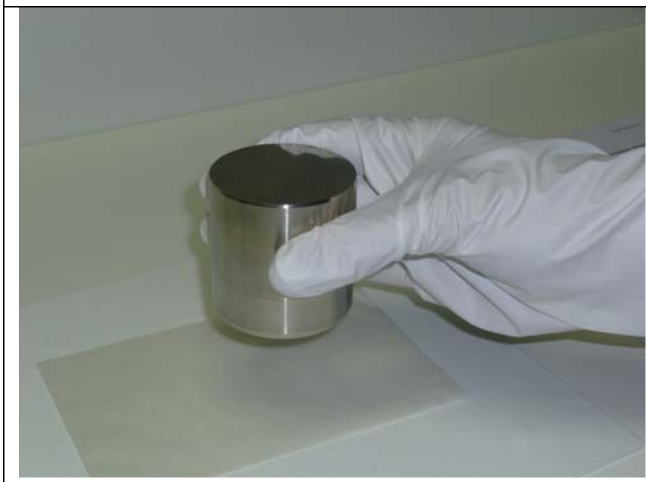


Figure 6

Figure 8

ANNEX 3

List of contents of the suitcase

- **Two containers**

- **Two 1 kg stainless steel travelling standards**

- Duraclean Lycra **Glove** size XL.
  (Six pairs for each participant)

- **Lens cleaning tissues** WHATMAN for the **top** of both containers.
  (Four tissues for each participant)

- **Lens cleaning tissues** WHATMAN for the **bottom** of both containers.
  (Four tissues for each participant)

- **Lens cleaning tissue** WHATMAN sheet of 200 x 300 mm to place under the standards
  (Four sheets for each participant)

- **Lens cleaning tissue** WHATMAN sheet of 100 x 150 mm
  (Six sheets for each participant)

- **One brush**
  (Please keep it clean as it is the same for all participants)

- **One pair forceps** with protection to handle the standards
  (Please keep it clean as it is the same for all participants)

- **Colrings** to close the suitcase before to send it to the next participant
  (Two for each participant)

- **Inspection forms for both standards.**
  (Made by the BIPM before the standards be sent to the first participant)

ANNEX 4

Example form for security control

Example of a form for security purposes when the masses are carried by hand in an aircraft. Additional forms can be provided (in the language of the sender's country) to the person who will have to assure the mass transfer. This model must be adapted in accordance with the people and NMIs involved in the transfer.

………………

DD MM YYYY, at Sèvres

I the undersigned, Alain Picard, Director of the Mass Department of the International Bureau of Weights and Measures (BIPM), certify that Dr. YYY, is carrying two stainless steel 1 kg mass standards from the Bureau International des Poids et Mesures (International Bureau of Weights and Measures) in Sèvres, France, to the National Metrology Institute of Japan (NMIJ) National Institute of Advanced Industrial Science and Technology AIST
Central 3, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8563, Japan
TEL: +81-298-61-4316 or 4062

These mass standards, made of stainless steel, are of enormous scientific value. They are very fragile and must not be manipulated by unauthorized persons. Improper handling during transportation would render them useless. The container has 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. They are safe and do not pose any risk to the health and safety of passengers travelling on the same flight.

A. Picard

Director of the Mass Department
BIPM, France

ANNEX 5

Procedure for removing the travelling standards

A) Take the suitcase into the mass laboratory. Cut the two colrings.

B) Prepare a clean table surface, including the large lens cleaning tissues (supplied by the pilot laboratory) and two bell jars.

C) Check the contents list of the package (annex 3).

D) Remove a container from the suitcase and place it on the table (figure 2 annex 2).

E) Unscrew the upper clamp; be sure that the upper clamp is at its highest level (1 cm unscrewed).

F) Unscrew the upper part of the container, while supporting the lower part. Remove the upper part as shown in figure 3 annex 2. Unscrew the three base clamps in order to release the standard.

G) Wearing gloves (supplied by the pilot laboratory), remove the filter paper above the standard (figure 4 annex 2).

H) Using the gloves or the forceps (if the gloves do not fit), the standard should be placed on lens cleaning tissues (supplied by the pilot laboratory) and covered with a bell jar (figures 6 and 8 annex 2).

I) Follow the same procedure from D for the second standard.

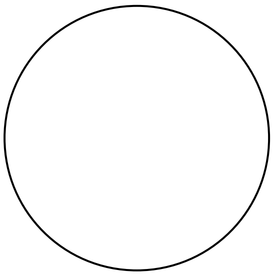
ANNEX 6.1

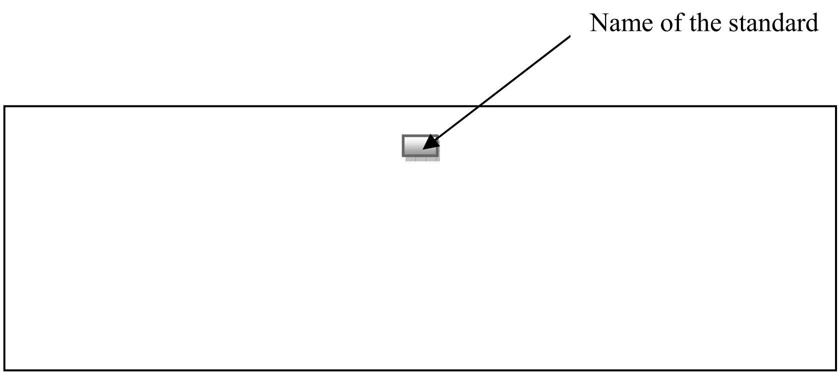
Travelling mass standard visual inspection form.
For the standards B5, B6, B7 and B8

Name of the standard	
Institute	
Completed by	
Date	

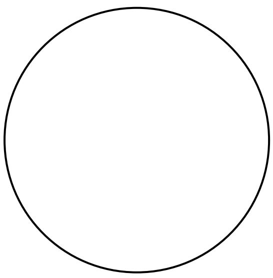
Record on the diagrams any mark(s) seen on the travelling standard (scratches, contamination, etc.), and send it to the PL before starting measurements.

Top surface





Bottom surface



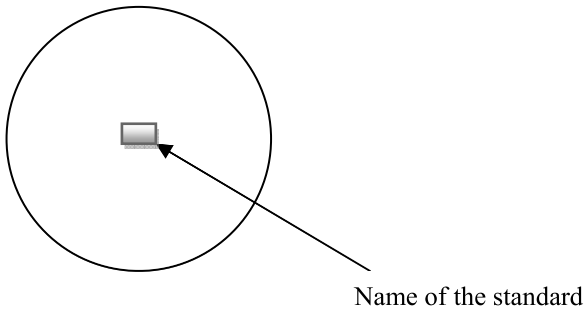
ANNEX 6.2

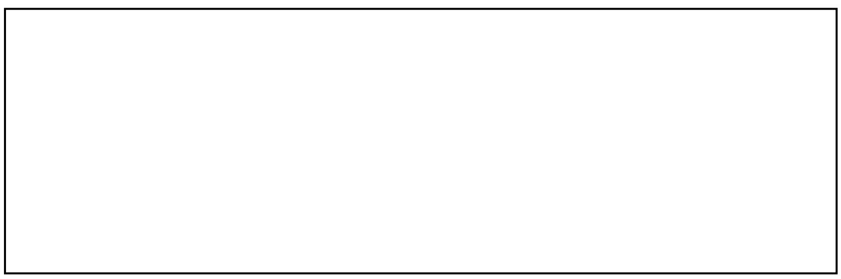
Travelling mass standard visual inspection form.
For the standards C1, C2, D1 and D2

Name of the standard	
Institute	
completed by	
Date	

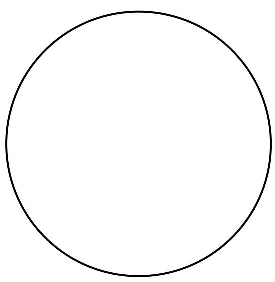
Record on the diagrams any mark(s) seen on the travelling standard (scratches, contamination, etc.), and send it to the PL before starting measurements.

Top surface





Bottom surface



ANNEX 7

Procedure for packaging the standards into the container

A) Place two lens cleaning tissues (supplied by the pilot laboratory) at the bottom of the container (figure 5 annex 2). Please use new ones.

B) Using gloves or the forceps (supplied by the pilot laboratory), place the standard on top of the tissues (figure 4 annex 2).

C) Gently tighten the three base clamps in order to hold the standard. Place two lens cleaning tissues (supplied by the pilot laboratory) on top of the standard (figure 3 annex 2).

D) Check that the upper clamp is at its highest position i.e. 1 cm unscrewed.

E) Screw the upper part of the container onto the lower part, while holding the lower part, to close the container.

F) Gently tighten the upper clamp in order to hold the standard (figure 2 annex 2).

G) Follow the same procedure for the second standard.

H) Place the two containers, the brush, the forceps and envelopes for other participants inside the suitcase (figure 1 annex 2).

I) Close the suitcase and add the two colrings.

ANNEX 8

Form for reporting general information about the institute laboratory.

(Please complete the form for each travelling standard)

The information requested will (a) help insure that results from different institutes are reported coherently and (b) help determine whether differences in results for each travelling mass standard are correlated with the experimental conditions.

Name of the institute: ……………………………………………………
Name of the travelling standard: …………………………………..........
Date travelling standard was received: ………………………………….
Date travelling standard was placed in balance: ....
Date(s) measurements were made: ....

<u>Characterisation of the balance:</u>

Manufacturer and model no. of balance used ....
Standard deviation of balance (for one comparison weighing) ....mg
Please supply a short document indicating how this standard deviation is computed.
Nominal mass of sensitivity weight used to determine
the value of a balance division ....mg

Exchanger position error corrections:

Position:	correction	uncertainty
1	……. mg	…… mg
2	……. mg	…… mg
3	……. mg	…… mg
4	……. mg	…… mg
5	……. mg	…… mg
6	……. mg	…… mg

<u>Characteristics of the masses involved:</u>

a) Mass and density (at 20 °C) of the standard(s) used to determine the mass of the travelling standard:

Standard	Name	Mass (kg)	Density ($kg \cdot m^{-3}$)
1	....	....	....
2	....	....	....
3	....	....	....
4	....	....	....

b) Air buoyancy artefacts (at 20 °C) used to determine air density.

Standard	Name	Volume (cm^3)	Surface (cm^2)	Shape
1	……….	……….	……….	……….
2	……….	……….	……….	……….

c) Indicate the nominal mass (in mg) of any small weights that were added to your standards or to the travelling mass standards during the measurements.

Standards	added weight
1	………..
2	………..

d) Indicate the gravitational gradient ($\partial g/\partial h$) in your institute : .... (s^{-2})
(by convention, the gradient is negative for acceleration g decreasing with height h)

For measurements:

- Atmospheric conditions during measurements

Range and mean value of air pressure (Pa): ....

Range and mean value of temperature (°C): ....

Range and mean value of relative humidity (parts in 10^2): ....

or

Range and mean value of dew points (°C): ....

Range and mean value of carbon dioxide in air (parts in 10^6): ....
measured ___ ? assumed ___ ? (mark as appropriate)

- Range and mean value of air density by using:

a) CIPM-2007 formula ($kg \cdot m^{-3}$) ....

b) Air buoyancy artefacts ($kg \cdot m^{-3}$) ....

Date of the first measurements ……………..

Number of series† ……………….

Date of the last measurements……………..

† The term 'series' is the number of individual measurements for each travelling standard mass which is then averaged to give the mean value.

Uncertainty

All uncertainties should be reported in accordance with ISO guidelines using a coverage factor of unity (k = 1).

a) Air density (CIPM-2007 formula)

Quantity		Uncertainty
Pressure	$u(p)$	................Pa
Temperature	$u(t)$	................°C
Relative Humidity	$u(h)$	....
or		
Dew Point	$u(t_r)$	................°C
Carbon dioxide	$u(\chi_{co2})$	..............parts in 10^6

c) Air density (air buoyancy artefacts)

Quantity	Uncertainty
Volume difference* (in air temperature)	…………cm^3
Apparent mass difference* (in air)	…………mg
Mass difference* in vacuum	…………mg
Exchanger position error artefact 1	…………mg
Exchanger position error artefact 2	…………mg
Water sorption correction between artefacts	…………mg

* The difference is between the two air buoyancy artefacts used to determine the air density.

d) Balance

Quantity	Uncertainty
Linearity	…………..mg
Sensitivity	…………..mg
Balance reading	…………..mg

ANNEX 9

Results reporting form

(Please complete the form for each travelling standard)

The corrections due to the gravitational gradient ($\partial g/\partial h$) and the exchanger position corrections should be applied in the final results. The results obtained should be reported for each travelling mass standard as follows:

First travelling standard m_1:

Name of the travelling standard: ……………..

Corrected value by air buoyancy using:

a) CIPM-2007 formula ....kg combined uncertainty: …………………..mg
degrees of freedom† ν : …………………..…..
effective degrees of freedom* ν_{eff} : ....
scheme of weighing**: ………………....….

b) Air buoyancy artefacts..................kg combined uncertainty : …………………..mg
degrees of freedom ν: ……………………...
effective degrees of freedom ν_{eff}: ....
scheme of weighing: ……………….………

† See, JCGM 100:2008, Guide to the expression of uncertainty in measurement, 2008.Section G.3.
* See, JCGM 100:2008, Guide to the expression of uncertainty in measurement, 2008.Section G.4.
** Scheme of weighing for example 6 × ABBA cycles per series.

Second travelling standard m_2:

Name of the travelling standard: ……………..

Corrected value by air buoyancy using:

a) CIPM-2007 formula ....kg combined uncertainty: …………………..mg
degrees of freedom ν : …………………...…
effective degrees of freedom ν_{eff} : ....
scheme of weighing: ……………….……...

b) Air buoyancy artefacts..................kg combined uncertainty : …………………..mg
degrees of freedom ν : ……………………..
effective degrees of freedom ν_{eff}: ....
scheme of weighing: ……………………..…..

Mass difference between the first and the second travelling standards

$\Delta m = m_1 - m_2$ and $u_c\ (\Delta m)$

Corrected value by air buoyancy using:

a) CIPM-2007 formula ....mg combined uncertainty: ………...mg

b) Air buoyancy artefacts..................mg combined uncertainty : ....mg

Average mass of both travelling standards

$m = 0.5(m_1 + m_2)$ and $u_c\ (m)$

Corrected value by air buoyancy using:

a) CIPM-2007 formula ....kg combined uncertainty: …………..mg

b) Air buoyancy artefacts...................kg combined uncertainty : ....mg

On separate files (exclusively MS Word or Excel), please provide (see example in annex 10):

1. A detailed summary of your calculation of the combined uncertainty.

2. The traceability route between the final results and your national prototype. Please indicate when your secondary standards were cleaned and when they were last calibrated with respect to your national prototype. In addition, please state whether you have (a) cleaned your national prototype since the 3rd Verification; (b) taken the mass of your national prototype to be different from that on the Certificate of the 3rd Verification (ageing correction) or (c) taken the uncertainty of your national prototype to be larger than that given on the Certificate of the 3rd Verification (ageing correction uncertainty).

3. All additional information that you consider might help the PL in comparing your results with those of the other participants.

ANNEX 10

Form for reporting uncertainty budget

(Please complete the form for each travelling standard)

Traceability route between final results and national prototype

Primary standards*:
- Name of your national prototype: …………..
- Last cleaning date of your national prototype:…………
- Date of last calibration of your national prototype: …………
- Ageing correction in mg: …………
- Uncertainty on the ageing correction in mg: ………..

Secondary standards*:
- Name of your secondary standard: …………
- Last cleaning date of your secondary standard: …………
- Date of last calibration of your secondary standard…….against standard No.......

***** If more than one primary standard or secondary standard are involved in this comparison, please mention their traceability.

Summary of calculation of the combined uncertainty

Air density uncertainty by using buoyancy artefacts

Uncertainty of the air buoyancy artefacts mass difference under vacuum:

Input Quantity X_i	$u_i(x_i)$/mg in vacuum	$u_i(x_i)$/mg in air
Standard uncertainty of mass/weighing difference	……….	……….
Uncertainty of drift since last vacuum weighing	……….	……….
Influence of mass position	……….	……….
…………………………………………	……….	………..
$u_c(\Delta m)$	X	Y

Uncertainty of the air buoyancy artefact's mass difference in air:

Input Quantity X_i	Standard uncertainty $u(x_i)$		Rel. sensitivity coefficient $\lvert c_i \rvert/\rho$		Rel. uncertainty contribution $u_i(\rho)/\rho$
Mass difference in vacuum	….X….	mg	………	mg^{-1}	………
Weighing difference in air	….Y….	mg	………	mg^{-1}	………
Sorption correction	…..…..	mg	………	mg^{-1}	………
Volume difference	………	cm^3	………	cm^{-3}	………
………………………………	….…..	…..	………	….	………
$u(\rho)/\rho$					Z1

Air density uncertainty by CIPM-2007 formula

The density of moist air is evaluated using the revised formula for the density of moist air (CIPM-2007); *Metrologia* **45** (2008) 149-155.

$$\rho_{\mathrm{a}} = \frac{pM_{\mathrm{a}}}{ZRT}\left[1 - x_{\mathrm{v}}\left(1 - \frac{M_{\mathrm{v}}}{M_{\mathrm{a}}}\right)\right]$$

where the quantities and units are:

p/Pa :	pressure
t/°C :	air temperature
T/K :	thermodynamic temperature = 273.15 + t/°C
x_{v} :	mole fraction of water vapour
$M_{\mathrm{a}}/(\mathrm{g{\cdot}mol^{-1}})$:	molar mass of dry air
$M_{\mathrm{v}}/(\mathrm{g{\cdot}mol^{-1}})$:	molar mass of water
Z :	compressibility factor
$R/(\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}})$:	molar gas constant

In addition to the CIPM-2007 relative formula for uncertainty ($u(\rho_{\mathrm{a}})/\rho_{\mathrm{a}}) = 22 \times 10^{-6}$) there are additional instrumental uncertainties due to the measured input pressure, p, temperature, T, and dew-point temperature, t_{d} (or relative humidity, h) and mole fraction of carbon dioxide, $x_{\mathrm{CO_2}}$. These must be added in quadrature by users of the CIPM-2007 equation. The appropriate influence factors are given as (see chapter 2.2 of the CIPM-2007 formula).

Input Quantity X_i	Standard uncertainty $u(x_i)$		Rel. sensitivity coefficient $\lvert c_i\rvert/\rho$		Rel. uncertainty contribution $u_i(\rho)/\rho$
Pressure $u(p)$	……….	Pa	1×10^{-5}	Pa^{-1}	………
Temperature $u(T)$	……….	K	-4×10^{-3}	K^{-1}	………
Relative humidity $u(h)$†	…..…..		-9×10^{-3}		………
Dew point temperature $u(t_r)$	………	K	-3×10^{-4}	K^{-1}	………
Carbon dioxide content $u(\chi_{CO2})$	………		0.4		………
Formula					22×10^{-6}
………………………………………	....	….	………….	….	………
$u(\rho)/\rho$					Z2

† report either the relative humidity or the dew point temperature.

If the mole fraction of carbon dioxide in air x_{CO_2} is not measured but instead is assumed to be equal to 400 μmol·mol^{-1} (or any other reference value), an uncertainty component must be added to account for this assumption. The average mole fraction of carbon dioxide and its dispersion within a laboratory may vary greatly from the assumed value. It is therefore advisable for users of the CIPM-2007 equation to base their assumed value for the average mole fraction of carbon dioxide and its dispersion on a survey of the laboratory.

Mass determination for a secondary standard used for the comparison.

Parameter X_i	Standard uncertainty $u(x_i)$		Sensitivity coefficient $\lvert c_i\rvert$		Uncertainty contribution $u_i(m)$/mg
Mass of the national prototype	……..	mg	1	…….	…….
Instability of the national prototype	……..	mg	1	…….	…….
Ageing of the national prototype	……..	mg	1	…….	…….
Volume of the national prototype	……..	cm^3	…….	$mg\cdot cm^{-3}$	…….
Volume secondary standard	……..	cm^3	…….	$mg\cdot cm^{-3}$	…….
Air density*	Z1 or Z2	$mg\cdot cm^{-3}$	…….	cm^3	…….
Balance linearity	……..	mg	1	…….	…….
Balance sensitivity	……..	mg	1	…….	…….
Balance reading (display resolution)	……..	mg	1	…….	…….
Weighing difference	……..	mg	1	…….	…….
Error of mass position	……..	mg	1	…….	…….
Small mass added on mass compared	……..	mg	1	…….	…….
Gradient of gravitational acceleration	……..	s^{-2}	…….	$g\cdot s^2$	…….
Centre of gravity	……..	m	…….	$g\cdot m^{-1}$	…….
……………………………………..	……..	…	…….	……	…….
Mass secondary standard $u(m)$					…….

*Report the most accurate uncertainty between Z1 and Z2.

Mass determination for a travelling standard.

Parameter X_i	Standard uncertainty $u(x_i)$		Sensitivity coefficient $\|c_i\|$		Uncertainty contribution $u_i(m)$/mg
Mass of the national prototype	……..	mg	1	…….	…….
Instability of the national prototype	……..	mg	1	…….	…….
Ageing of the national prototype	……..	mg	1	…….	…….
Volume of the national prototype	……..	cm^3	…….	$mg \cdot cm^{-3}$	…….
Volume travelling standard	……..	cm^3	…….	$mg \cdot cm^{-3}$	…….
Air density*	Z1 or Z2	$mg \cdot cm^{-3}$	…….	cm^3	…….
Balance linearity	……..	mg	1	…….	…….
Balance sensitivity	……..	mg	1	…….	…….
Balance reading (display resolution)	……..	mg	1	…….	…….
Weighing difference	……..	mg	1	…….	…….
Error of mass position	……..	mg	1	…….	…….
Small mass added on mass compared	……..	mg	1	…….	…….
Gradient of gravitational acceleration	……..	s^{-2}	…….	$g \cdot s^2$	…….
Centre of gravity	……..	m	…….	$g \cdot m^{-1}$	…….
………………………………………	……..	….	…….	…….	…….
Mass travelling standard $u(m_i)$					…….

*Report the most accurate uncertainty between Z1 and Z2.

Mass difference between the first and the second travelling standards

$$u(\Delta m) = u(m_1 - m_2) = \ldots\ldots\ldots \text{mg}$$

Average mass of both travelling standards

$$u(\overline{m}) = u\{0.5(m_1 + m_2)\} = \ldots\ldots\ldots \text{mg}$$