Director's Report on the Activity and Management of the International Bureau of Weights and Measures

Supplement: Mass Department

(1 January 2014 – 31 December 2014)

March 2015

Bureau International des Poids et Mesures

BIPM Mass Department

Interim Director: M. Stock[1]

(1 January 2014 to 31 December 2014)

1. Measurement services

1.1 Calibrations

1.1.1 Extraordinary calibrations with respect to the IPK in anticipation of the redefinition of the kilogram (P. Barat, M. Milton, E. de Mirandés, M. Stock)

In December 2013 the Mass Department started a campaign of calibrations with respect to the International Prototype of the Kilogram (IPK) in anticipation of the planned redefinition of the kilogram (*Extraordinary Calibrations*). This campaign will meet one of the prerequisites for the redefinition of the kilogram requested by the Consultative Committee for Mass and Related Quantities (CCM). It will enable the mass standards used in the watt balance and X-ray crystal density (XRCD) experiments, which will contribute to fixing the numerical value of the Planck constant, to be compared as directly as possible with the IPK. This is essential to ensure continuity from the present definition of the kilogram (based on the IPK) to the future definition (based on the numerical value of the Planck constant). Another objective of this campaign is to recalibrate the BIPM reference and working standards with respect to the IPK. At the beginning of this campaign, the traceability of the BIPM working standards to the IPK depended on measurements made in the context of the 3rd Periodic Verification (3rd PV) of National Prototypes, carried out from 1988 to 1992.

In the first phase of the Extraordinary Calibrations, the six official copies of the IPK and the BIPM working standards have been compared with the IPK for the first time since the 3rd PV. The definition of the kilogram was realized according to the procedure outlined in the 8th Edition of the SI Brochure. Thus, the IPK and its six official copies have been cleaned and washed following the BIPM procedure. The cleaning of the IPK resulted in a mass loss of 17 µg, after 22 years since the last cleaning and washing. The average mass loss of the six official copies was 15 µg, with the individual mass losses ranging from 13 µg to 17 µg.

The differences in mass between the IPK and the official copies, after cleaning and washing, have changed on average by only 1 µg since the 3rd PV. These results do not confirm the trend for the masses of the six official copies to diverge from the mass of the IPK that was observed during the 2nd and 3rd PVs. In the present calibration campaign, the IPK and its six official copies have behaved as a consistent set of mass standards. During the same period prototype n° 34 of the French Academy of Sciences, which had not been used since the 3rd PV, was calibrated. Its mass was found to be 1 µg lower than its mass observed during the 3rd PV.

All BIPM working standards have been calibrated with respect to the IPK and they were all found to have lower masses than when they were calibrated during the 3rd PV. As a consequence, the BIPM 'as-maintained' mass unit has been found to be offset by 35 µg with respect to the IPK. Mass calibrations based on the 'as-maintained' BIPM mass unit resulted in values which were 35 µg higher than those based on the IPK.

To understand how the offset of 35 µg in 2014 has evolved over time, extensive mathematical modelling has been carried out. The results of all mass comparisons between the BIPM working standards that were carried out between the 3rd PV and now have been used as input data. Different deterministic models were tested against these data and we have identified the model that describes the data most satisfactorily. The phenomena included in this model are: the mass increase of a standard after cleaning and washing, and mass changes proportional to the number of weighings in the two comparators used most often during this time. As a consequence of this, it is

[1] A. Picard (Director of the Mass Department) was absent in 2014 due to ill health

planned that the BIPM's mass comparators will be investigated for eventual anomalous wear. As boundary conditions, the model assumes that the mass of the IPK was exactly 1 kg after cleaning and washing in 1992 and in 2014. This model allows retrospective calculation of revised mass values for previous calibrations. The correction is below 5 µg for calibrations carried out before 2003. The correction increases up to about 35 µg in 2010 and remains constant during the following years. The uncertainty of the revised mass values has been estimated as 3 µg. The NMIs involved in accurate determinations of the Planck or the Avogadro constant have been informed of the revised mass values for previous mass calibrations. This has allowed them to recalculate their results, where the effect of the correction was significant, and to submit revised values for the 2015 CODATA fundamental constants adjustment.

During the second phase of the *Extraordinary Calibrations,* transfer standards from NMIs involved in determinations of the Planck or the Avogadro constant, will be calibrated (see section 1.1.2).

The results of this calibration campaign have been discussed with a Support Group of mass experts, which was set up by the CCM. The results will be presented and discussed in detail at the CCM meeting in February 2015. Following this meeting, all mass calibration customers will be informed of the results.

1.1.2 *Calibration of 1 kg Pt-Ir prototypes and stainless steel standards* (P. Barat)

The mission of the BIPM is to ensure and promote the global comparability of measurements. In the field of mass measurements, the Mass Department is in charge of providing mass calibrations to Member States that are traceable to the IPK.

Since the 3rd Periodic Verification of the National Prototypes of the Kilogram (1988-1992), the mass unit of the BIPM was maintained by means of the BIPM working standards in platinum-iridium, which were directly calibrated with respect to the IPK in 1992.

The establishment of improved traceability to the International System of Units (SI) by making use of the IPK is considered to be an essential step toward the planned redefinition of the kilogram by the CCM. The BIPM therefore started with the first phase of the "Extraordinary calibrations with respect to the IPK for the redefinition of the kilogram" in December 2013 (see section 1.1.1).

Under the framework of the extraordinary calibrations only a selection of 1 kg mass standards, used by NMIs that contribute to the redefinition of the kilogram, could be calibrated as close as possible with respect to the IPK. These NMIs are: LNE (France), METAS (Switzerland), MSL (New Zealand), NIM (China), NIST (USA), NMIJ/AIST (Japan), NRC (Canada) and PTB (Germany). The extraordinary calibrations of the 1 kg mass standards belonging to these NMIs, for a total of eleven standards, started in December 2014 and will be completed in January 2015, except for one standard which is expected to arrive at the BIPM at the end of January.

To ensure the global comparability of mass measurements, the BIPM provides 1 kg mass prototypes to Member States. During 2014 five new 1 kg mass prototypes, which were manufactured at the BIPM in 2013, have been calibrated: Nos. 102, 104 and 105 for the NIST, No. 106 for the NRC and No. 103 for the BIPM. Prototype No. 12 of the Russian Federation has been recalibrated. The calibration of the prototype No. 93, reallocated to Saudi Arabia (SASO), is also ongoing and will be completed in early 2015.

The Mass Department has issued certificates for the calibration of stainless steel standards from the LATU (Uruguay), the IPQ (Portugal) and the VSL (The Netherlands).

1.1.3 *Air-to-vacuum transfer characterizations* (P. Barat)

The realization of the new kilogram definition by watt balance or x-ray crystal density experiments must be made under vacuum. As a consequence, the laboratories involved in these experiments are required to evaluate the amount of water desorbed from the test artefacts when they are transferred from air to vacuum. The amount of desorbed water can be deduced using sorption artefacts composed of one 1 kg mass prototype (a cylinder) and one 1 kg stack of discs made of the same material.

The BIPM has provided the NIST and the NRC with such artefacts made of platinum-iridium:

- for the NRC: a new stack of discs (F18) with one of the new prototypes (No. 106) fabricated in 2013.
- for the NIST: an already existing stack of discs (C18) and two of the three new prototypes belonging to the NIST and fabricated in 2013 (Nos. 104 and 105).

The BIPM has characterized the mass changes following air-to-vacuum transfers of these five artefacts.

1.1.3 *Mass determinations of the AVO28 spheres* (P. Barat, M. Stock)

In order to reduce the uncertainty of the Avogadro constant (and of the Planck constant which can be derived from it), the Avogadro consortium is carrying out a new determination with the re-polished spheres AVO28-S5 and AVO28-S8, made of isotopically pure ^{28}Si, and an improved apparatus for the determination of the other parameters. The BIPM is responsible for coordinating the determination of the sphere masses, which is being carried out at the BIPM, the NMIJ and the PTB.

All measurements at the BIPM were carried out using the Sartorius CCL 1007 mass comparator. Before weighing, the two spheres were cleaned three times, using the cleaning procedure that was recommended by the National Metrology Institute of Australia (NMIA). A set of air buoyancy artefacts made of stainless steel, consisting of a tube (Cp) and a hollow cylinder (Cc), was used to determine the air density, for the buoyancy correction. A set of sorption artefacts made of Pt-Ir, consisting of a cylinder (A0) and a stack of 8 disks (A18), was used to establish the link between masses in air and vacuum. The masses in air were determined during three periods from 18 February to 18 March 2014, with weighings made in-between in vacuum. The relative humidity during the measurements in air was 45 % on average. The vacuum pressure was 2 mPa. After each change of condition, a period of at least 3 days was allowed for stabilization before the start of the measurements.

The two spheres were weighed directly after the first phase of the Extraordinary Calibrations. The spheres were compared in air with BIPM working standard No. 77, which itself had been weighed against working standards Nos. 91 and 650. The latter two working standards had been compared directly with the IPK, in air. The values for the masses under vacuum determined by the three institutes agree well within the uncertainties. The weighted mean has an uncertainty of 3.5 µg, corresponding to a relative uncertainty of 3.5 parts in 10^9. A publication on the new determination of the Avogadro constant has been submitted by the consortium.

The NMIs contributing to the mass determinations of the ^{28}Si spheres used for the previous determination of the Avogadro constant in 2011 have been informed of the estimated offsets of the 'as-maintained' BIPM mass unit at the time of their previous BIPM mass calibrations. This has allowed them to calculate revised sphere masses, which are required for a revised value of the Avogadro constant. The revised result of the previous determination has been included in the new publication.

A study was undertaken at the BIPM to determine the mass of the chemisorbed water layer present on the surface of a natural silicon sphere. Two methods were applied: baking the sphere under vacuum and immersing the sphere in bi-distilled water. For both methods, the chemical adsorption coefficient was obtained by determining the mass difference under vacuum conditions (to reduce the uncertainty) prior to and after placing the sphere in air, in order to reintroduce the chemisorbed water on the surface of the sphere. The mean chemical adsorption coefficient thus obtained was 0.026 µg cm^{-2} with a standard uncertainty (k = 1) of 0.012 µg cm^{-2}. The BIPM results confirm those obtained by the NMIJ/AIST (Japan) which had measured the adsorption isotherms on SiO_2/Si(100) plane surfaces.

1.1.3 *Mass determinations for the BIPM Ensemble of Reference Mass Standards* (P. Barat)

The four prototypes which are part of the BIPM Ensemble of Reference Mass Standards have been calibrated in the framework of the extraordinary calibrations (section 1.1.1). Their masses are now linked as closely as possible to the IPK.

The calibration of the 1 kg mass standards in stainless steel will be carried out in early 2015 as soon as the calibration of the selected NMI standards is completed (1.1.2).

1.1.4 *Volume calibrations of mass standards* (D. Bautista[2], H. Fang, C. Goyon-Taillade[3])

A newly hired technician, Mr Bautista, was trained by Dr Fang in the density and volume determination of mass standards ranging from 200 g to 1 kg, including mass prototypes. This training was validated by the density determination of a 1.02 kg platinum-iridium cylinder (JM57), which was used as travelling density standard for a bilateral comparison with the PTB in 2009. The difference between the new determination and the one carried out during the previous comparison is consistent, at the 95 % level of confidence with the uncertainties, and proves the validity of our new measurements. Density determinations of three new 1 kg prototypes have been carried out.

Mr Bautista has taken over the ongoing work to improve the hydrostatic weighing facility. The aim is to replace distilled water as the density reference with two 500 g cylinders of single-crystal silicon in a transfer liquid (Fluorinert Electronic Liquid FC40). The use of this liquid instead of water should lead to a significant simplification in the determination of the density of "stacks", made up of several disks separated by spacers. These stacks play an important role in the air-to-vacuum transfer process, which is needed for the future realizations of the kilogram (section 1.1.3). To this end, and with a view to reducing operator interventions, modifications have been made to the control and data acquisition software.

1.1.5 *Pressure calibrations* (F. Idrees)

Calibrations of BIPM manometers, with respect to the pressure balance maintained by the Mass Department, were carried out during two campaigns in 2014. Sixteen internal certificates were issued.

1.2 Comparisons (P. Barat, A. Picard[4], M. Stock, S. Davidson[5])

The BIPM has piloted the key comparison of stainless steel 1 kg mass standards, CCM.M-K4. The final report was published in the BIPM key comparison database (KCDB) in 2014. This comparison had 16 participants, each of which had to measure two 1 kg mass standards. The measurements were made between August 2011 and May 2012. The stability of the mass standards was monitored by the BIPM. The key comparison reference value was calculated by a General Linear Least Squares method. The result obtained by one participant was considered to be an outlier, all other results agree within their uncertainties.

The BIPM will act as the pilot laboratory for the planned pilot study of primary realizations of the kilogram. The purpose of this comparison is to check the realization and the dissemination of the new kilogram, as described in the *mise en pratique* for the definition of the kilogram. A draft technical protocol was developed during the secondment of Dr Davidson (NPL).

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[2] Since 1 July 2014
[3] Until 28 February 2014
[4] A. Picard was absent in 2014 due to ill health
[5] On secondment from NPL (16 June – 25 July, 22 September – 31 October 2014)

1.3 Maintenance of the mass comparators (P. Barat)

In cooperation with the BIPM workshop, some improvements have been made to the Vacuum Transfer System (VTS) which equips the Sartorius CCL1007 mass comparator. The hanging system that allows the bell of the containers to be attached has been completely modified. The transfer of standards from BIPM containers, manufactured for the Ensemble of Reference Mass Standards (ERMS), and those made by Sartorius for the VTS can now be carried out securely for both types of container.

2. **Manufacturing 1 kg artefacts in Pt-Ir for NMIs** (F. Boyer - BIPM Workshop, P. Barat)

Three new 1 kg mass prototypes are being manufactured at the BIPM: one for Pakistan and two that have yet to be allocated.

3. **Ensemble of Reference Mass Standards** (P. Barat, F. Idrees and E. de Mirandés)

In 2014, work on the BIPM Ensemble of Reference Mass Standards focused on daily maintenance and data analysis. No major development work has been carried out due to the high work load that the Extraordinary Calibrations involving the IPK has imposed on the staff responsible for the ensemble. It is expected that the activities related to the ensemble will resume in 2015.

4. **Watt balance** (F. Bielsa[6], R. Chayramy, A. Dupire, H. Fang, A. Kiss, T. Lavergne, Y. Lu[7], E. de Mirandés, L. Robertsson, S. Solve and M. Stock)

A watt balance is being developed at the BIPM to enable the realization of the expected new definition of the kilogram in terms of the Planck constant. Preparations are under way for a new version of the apparatus with the objective of reducing measurement uncertainties, in particular the type B uncertainty due to misalignment. The new apparatus will comprise several new and improved measurement facilities.

Some elements of the new apparatus have already been assembled for testing *in situ*, most importantly a dynamic alignment mechanism that is based on four pairs of push-pull piezo-elements. The mechanism allows dynamic correction of the coil trajectory during its travel whilst in working mode. It also helps to align the coil with respect to the magnetic field. The performance of the system has been successfully validated under real working conditions. All five undesirable degrees of freedom of the coil (horizontal translations in two directions and rotations around all three axes) were servo-controlled via a closed loop. The rotation around the vertical axis was controlled by means of electrostatic actuators. The horizontal translation of the freely moving coil of up to 120 µm was reduced to almost zero, with some residual deviations up to 10 µm due to the low bandwidth of the servo-control loop below one hertz. Concerning the rotation, a small deviation of 15 µrad was corrected and the residual noise was of a few µrad. A second method is based on a correction of the coil trajectory which is deduced from the highly reproducible coil motion. This method avoids problems due to oscillations, a characteristic of closed-loop operation, and is easier to operate. The noise from the feedback was thus minimized and the remaining noise was limited by electric and vibrational noise intrinsic to the system. Additional modifications to further facilitate the operation and improve the reliability of the system are anticipated.

Alignment techniques for the coil and the magnetic field continue to be refined. A new optical bench has been designed and prepared to improve the alignment accuracy of 150 µrad achieved so far on a test coil. This consists of two spatially separated alignment systems which allow the alignment the two orthogonal axes of the coil at the same location, inside the uniaxial magnetic field produced by a horizontally aligned precision solenoid. The coil, once horizontally aligned, will allow the alignment of the magnetic field of the watt balance

[6] Since 15 July 2014
[7] On secondment from NIM, China, since 1 September 2014

magnet. In parallel, a new method based on a rotating Hall probe has been developed to independently align the magnetic field. The technique consists of the alignment of the magnetic field orthogonally to a Hall probe, vertically aligned, at several locations inside the air gap of the magnetic circuit. The vertical reference is the axis of a rotation stage, which is aligned vertically by means of a tiltmeter. The directional Hall probe is mounted on the axis of the rotating stage so that it rotates around itself at each chosen location in the air gap of the magnetic circuit. The probe output as a function of the rotation angle is mainly composed of a sum of harmonics. The DC component represents the tilt of the magnetic field. The first harmonic contains information about the misalignment of the probe. Higher order harmonics are due to parasitic effects such as the planar Hall effect and default of centring of the probe. In practice, careful alignment of the probe is required in order to reduce any bias due to these unwanted effects. Measurements carried out on the simple magnetic circuit used for the first version of the watt balance showed an alignment resolution better than 50 µrad. The technique will soon be applied on the definitive magnetic circuit. To adapt the alignment set-up on this magnet, various mechanical support components and adjustable mounts have been designed. It is expected that the results obtained by both alignment methods will be compared.

The BIPM watt balance experiment requires the simultaneous operation of two Josephson voltage standards (JVSs), one for the measurement of the induced voltage and one for the measurement of the current. A new 1 V SNS programmable array for the voltage measurement was delivered by NIST in June 2014 to replace a previous chip for which the array carrier (NIST *flexboard*) was damaged as a consequence of it undergoing too many temperature cycles between liquid He temperature and laboratory temperature. This array is based on a newly designed board and will be tested in the future. The development work has focused on the assembly and testing of the JVS dedicated to the measurement of the current. Once assembled, the JVS was compared to the BIPM JVS primary reference maintained in the Electricity Department and a relative voltage difference of a few parts in 10^{11} was achieved. As a second step, the capabilities of the JVS in operation were investigated: it was connected in series opposition to a resistor coupled to commercial current source, simulating its use in the watt balance. The system produced very satisfactory results and was transferred to the watt balance laboratory for the final validation step (more details are available in the Electricity Department report). The JVS was successfully tested on the watt balance apparatus. The short-term noise of the current source could be evaluated as 50 nV (using a digital voltmeter with an integration time of 4 s). This noise includes a significant contribution from the digital voltmeter. Further tests will allow the assignment of a numeric value to each contribution.

Development of a new interferometer has advanced well. It has been carefully designed to allow for a small non-linear error, high signal-to-noise ratio and high phase resolution. The new interferometer is based on space-separated heterodyning techniques. It uses non-polarizing elements and has a minimal number of optical surfaces. The interferometer signals are differential outputs with a "common mode" reference signal. The laser source is based on a commercial Nd:YAG laser with a useful power of at least 35 mW at a wavelength of 532 nm. The frequency of this laser has been stabilized on a hyperfine-line of iodine by the saturated absorption technique. The whole set-up is installed on a portable optical table for easy implementation. Three outputs via optical fibres are used, two to feed light into the interferometers and one for the calibration of the laser frequency. The mounting and alignment of the optical set-up of three interferometers is being tested. Set-ups for signal conditioning and phase detection are in progress.

A new support structure for the watt balance has been designed in order to facilitate the alignment of the apparatus. The new structure has an open design that allows easy access to all key components of the watt balance. In addition to being rigid and stable for a total load of around 50 kg, the new structure has been designed to avoid low frequency resonance peaks, especially at frequencies present in the environment. It is composed of three stages of a symmetric pentapod structure. Finite elements analysis showed that only three eigenfrequencies below 200 Hz exist for the new support structure, compared to five frequencies in the present one. A new compact mass loading and exchange system has been designed in order to make space for the installation and alignment of the interferometers. The mechanism is based largely on a translation arm which can move horizontally and vertically. The loading of the test mass on the weighing pan is ensured by the vertical motion of the translation arm, while the transfer between the weighing pan and the mass storage carrousel is done by combing both horizontal and vertical motions. Both the new support structure and the new mass exchanger are being fabricated. The two lower stages of the new structure will allow the installation of the mechanical set-up for the alignment of the magnetic circuit.

7. Activities related to the work of Consultative Committees (R. Davis and A. Picard[8])

A. Picard is Executive Secretary of the CCM (until the end of 2014) and the Consultative Committee for Thermometry (CCT) and is a member of several working groups (WGs) and task groups (TGs) of these Consultative Committees (CCs).

R. Davis is the Interim Acting Executive Secretary of the CCM (until the end of 2014) and has provided support to the new CCM President, P. Richard (METAS) since his appointment in late 2012. Of particular note, R. Davis is the co-editor with H. Bettin (PTB) of the *mise en pratique* of the (new) definition of the kilogram being drafted within the CCM. H. Fang has been nominated as Executive Secretary of the CCM from January 2015.

8. Activities related to external organizations (E. de Mirandés, M. Stock)

M. Stock acted as the BIPM liaison with the International Avogadro Coordination project, the EURAMET Technical Committee of Mass and Related Quantities (TC-M) and for the European Metrology Research Programme (EMRP) joint research projects SIB-05 (NewKILO) and SIB-03 (kNOW). On 8 October 2014 a NewKILO progress meeting was held at the BIPM.

E. de Mirandés is member of the CODATA Task Group on Fundamental Constants.

9. Publications

1. Fang H., Kiss A., Picard A., Stock M., A watt balance based on a simultaneous measurement scheme, *Metrologia*, **51**, S80-S87.
2. Fang H. *et al*., Recent progress on the BIPM watt balance, *EPJ Web of Conferences*, 2014, **77**, 00023.
3. Becerra L.O., *et al*., Final report on CCM.M-K4: Key comparison of 1 kg stainless steel mass standards, *Metrologia*, 2014, **51**, *Tech. Suppl*., 07009.
4. Davis R.S., Milton M.J.T., The assumption of the conservation of mass and its implications for present and future definitions of the kilogram and the mole, *Metrologia*, 2014, **51**(3), 169-173.
5. Fang H., Kiss A., Lavergne T., Robertsson L., de Mirandés E., Solve S., Picard A., Stock M., Update from the BIPM Watt Balance, *Proc. 2014 Conference on Precision Electromagnetic Measurements (CPEM)*, 2014, 710-711.
6. Azuma Y., Barat P., et al., An improved result on the measurement of the Avogadro constant from a 28Si crystal *Metrologia* **52** (2015) 360 –375.
7. Stock M., Barat P., Davis R., Picard A., Milton M., Calibration campaign against the International Prototype of the kilogram: Part I: comparison of the International Prototype with its official copies, *Metrologia* **52** (2015) 2010-316.
8. Barat P., Mémoire d'ingénieur Cnam, "Projet international Avogadro: Détermination de la masse de la couche d'eau chimisorbée à la surface d'une sphère en silicium naturel", 2015

[8] A. Picard was absent in 2014 due to ill health

10. Travel (conferences, lectures and presentations, visits)

M. Stock to:

- LNE, Trappes (France), 2-3 April 2014, to attend the EURAMET TC-PR meeting and to present information from the CCPR and the JCRB;
- Brno (Czech Republic), 9-11 April 2014, to attend the EMRP NewKILO project meeting and the EURAMET TC-M meeting and to present BIPM activities related to the planned kilogram redefinition;
- Rio de Janeiro (Brazil), 22-28 August 2014, to attend the CPEM conference and CCEM and CCM satellite meetings, and to present the results of the *Extraordinary Calibrations*;
- PTB, Berlin (Germany), 1 December 2014, to give a lecture on determinations of the Planck constant at a PTB seminar.

P. Barat to:

- NMIJ/AIST, Tsukuba (Japan), 26-28 March 2014, to deliver the ^{28}Si Avogadro spheres and to give a presentation about BIPM activities in mass.

R. Davis to:

- LNE, Paris (France), 31 March 2014, to participate in the mid-term review of EMRP projects funded from the 2011 SI Broader Scope call;
- NMC A*STAR (Singapore), 27-28 October 2014 for a peer review of mass calibration services and 29-30 October for consultations on wider mass issues.

H. Fang to:

- Rio de Janeiro (Brazil), 23-28 August 2014, to attend the CPEM conference and the CCEM WGkg (monitoring the kilogram) meeting, and to give two oral and one poster presentation on the BIPM watt balance.

11. Visitors

- L.F. Vitushkin, VNIIM (Russian Federation), to collect prototype No. 12 following calibration, 6 February 2014;
- H. Bettin, PTB (Germany), to deliver the ^{28}Si Avogadro spheres for mass measurements and to work on the *mise en pratique* of the (new) definition of the kilogram, 9-10 February 2014;
- D. Arneson, Professional Instruments Company (USA), and E. Marsh, Penn State University (USA), to visit the watt balance, 24 March 2014;
- M. Götz, PTB (Germany), to visit the watt balance, 3 April 2014;
- O. Zakaria, NML-SIRIM (Malaysia), to collect two 1 kg mass standards in stainless steel following calibration, 9 April 2014;
- C. Bock and M. Hirayama, METAS (Switzerland), to visit the watt balance, 15 May 2014;
- G. Tsorbatzoglou and H. Al Kaabi, ADQCC - Emirates Metrology Institute, EMI (Abu Dhabi) accompanied by J. Lüscher, Mettler-Toledo AG (Switzerland), to visit the mass laboratories and to make a presentation on their NMI, 16 May 2014;
- F. Kelly, Christ's College, Cambridge, (UK) and T. Quinn, to visit the watt balance, 21 May 2014;
- P. Taquet, President Académie des Sciences (France), to visit the watt balance, 13 June 2014;
- P. Richard, METAS (Switzerland), to discuss results of Phase 1 of the Extraordinary Calibrations and to discuss CCM matters, 25 June 2014;

- J. Bienfang, NIST (USA), to collect new mass standards, 4 July 2014;
- C. Müller-Schöll, Mettler-Toledo (Switzerland), for general discussions, 15 July 2014;
- J. Pratt, NIST (USA), to visit the watt balance, 4 September 2014;
- D. Rovera, SYRTE (France), to visit the watt balance, 25 September 2014;
- M. Borys, PTB (Germany), to deliver prototype No. 55 for phase 2 of the Extraordinary Calibrations, 7 October 2014;
- I. Rahneberg, Ilmenau University (Germany), to visit the watt balance, 8 October 2014;
- S. Mizushima, NMIJ/AIST (Japan), to deliver prototype No. 94 and 1 kg mass standard in platinum-iridium E59 for Phase 2 of the Extraordinary Calibrations, 10 October 2014;
- F. Nez, LKB (France) and F. Piquemal, LNE (France), to visit the watt balance, 3 November 2014;
- B. Wood, NRC (Canada), to visit the watt balance, 5 November 2014;
- P. Richard, METAS (Switzerland) to complete plans for next CCM meeting, 14 November 2014;
- J. Champagne, Canadian Embassy in France (Canada), to deliver prototype No. 74 for Phase 2 of the Extraordinary Calibrations, 24 November 2014;
- S. Akretche, B. Harchaoui, A. Cheblal, K. Bey Benagliz (all NAFTAL, Algeria), M. Bekhadda (Embassy, Algeria) and J-F. Lipskier (LNE) to visit the BIPM laboratories, 27 November 2014.
- K. Chesnutwood, NIST (USA), to deliver prototypes Nos. 20 and 79 for Phase 2 of the Extraordinary Calibrations, 2 December 2014;
- X. Ni and J. Wang, NIM (China), to deliver prototype No. 60 for Phase 2 of the Extraordinary Calibrations and to visit the watt balance, 3 December 2014;
- Journalists, Le Journal du Dimanche (France), to visit the watt balance, 3 December 2014;
- M. Mecke, PTB (Germany), to collect prototype No. 55 following calibration, 4 December 2014;
- P. Otal and P. Pinot, LNE (France), to deliver prototype No. 17 and 1 kg mass standard in platinum-iridium JM15 for Phase 2 of the Extraordinary Calibrations, 5 December 2014;
- X. Ni and J. Wang, NIM (China), to collect prototype No. 60 following calibration, 10 December 2014;
- J. Champagne, Canadian Embassy in France (Canada), to collect prototype No. 74 following calibration and new 1 kg mass prototype No. 106 and new 1 kg stack of discs F18, 17 December 2014;
- K. Chesnutwood, NIST (USA), to collect prototypes Nos. 20 and 79 following calibration, 19 December 2014.