EUROMET TC-M
Mass and related quantities
Annual report 2004/2005

1. General aspects

1.1. New kilogram definition

In a recent paper[1], five influential physicists have suggested that a new definition of the kilogram based on a fixed value of either the Planck constant *h* or the Avogadro constant N_A should be agreed at the CGPM 2007 meeting. The fixed value should be based on the CODATA 2006 value in order to preserve continuity of values of the fundamental constants. The authors point out correctly that today the kilogram cannot be realized with the required uncertainty from such a new definition. Therefore they suggest introducing a conventional, temporary mass unit kg_{07}, where 1 kg_{07} should be the mass of the international prototype.

Assuming that no clients really care whether mass is expressed in the SI unit or not, the short-term consequence of the suggestion would be easy to overcome: We would simply have to replace kg by kg_{07} in all practical mass measurements. On the long term, the consequences could be dramatic, however. Once the technique for realizing the kilogram with the required uncertainty is available, the relative difference between the temporary unit kg_{07} and the SI unit kg could turn out to be as large as $1 \cdot 10^{-6}$. This difference reflects the current relative discrepancy between the value of *h* determined by the NIST watt-balance experiment and the Avogadro constant N_A determined in the Avogadro project. A significant discontinuity of not only mass values, but also values of density, pressure and force could therefore occur the day the temporary unit kg_{07} were abolished and replaced by the SI unit kg.

The EUROMET TC-M has written a position paper recommending that a new definition of the kilogram based on fixed values of *h* or N_A should be postponed until at least three independent experiments (Watt-balance experiments or the Avogadro project) have provided consistent results with relative standard uncertainties of a few parts in 10^8. The position paper has been submitted to CCEM and CCM as working documents for their meetings in March and April 2005.

1.2. Research

During the last year, the EUROMET cooperation in research within the field Mass and related quantities has been focused on the following topics:

- Measurement of the density of moist air using buoyancy artifacts and comparison with the formula recommended by the BIPM (concluded 2005).
- Identification of materials most suitable for mass standards to be used in the watt-balance experiment.

[1] Ian M Mills, Peter J Mohr, Terry J Quinn, Barry N Taylor and Edwin R Williams, Redefinition of the kilogram: a decision whose time has come, *Metrologia* **42** (2005) 71–80

- Calculation of elastic distortion and associated uncertainty in high pressure piston-cylinder assemblies.
- Calculation of effective area and associated uncertainty in piston-cylinder assemblies with non-ideal geometries.
- Investigation of force balanced piston gauges (FPG's) used to measure pressure.

The research in air density measurement over the last 14 years has provided an interesting and useful result. It has been found that the air density measured using air buoyancy artifacts has a small but significant deviation from the air density calculated from the formula recommended by the CIPM. This discrepancy has now been resolved by a new measurement of the molar fraction of argon in air made by KRISS, Korea[2]. The research is now concluded, and a change in the CIPM recommended formula, which would increase the accuracy of the formula by a factor of 5, is foreseen.

1.3. EA calibration guidelines

EUROMET has agreed to take over the calibration guidelines published by EA, to the extent that the guidelines are considered technically sound. In the field of mass and related quantities, the following guides has been published by EA:

EA 10/03: Calibration of pressure balances (July 1997)

EA-10/04: Uncertainty of calibration results in force measurements (August 1996)

EA-10/14: Calibration of static torque measuring devices (June 2000)

EA-10/16: Estimation of uncertainty in hardness measurements (October 2001)

EA-10717: Calibration of electromechanical manometers (July 2002)

EA-10/18: Calibration of non-automatic weighing instruments (July 2004)

Some of these guidelines need to be revised, but the TC-M finds that they are widely used among accredited laboratories, and that it would create problems if they were suddenly withdrawn. The TC-M therefore recommends that the guidelines are transferred to the EUROMET website as they are, but with appropriate comments regarding planned revisions.

2. Meetings

The annual EUROMET TC-M contact persons meeting was held at EIM, Greece, 3 March 2005. Prior to this, meetings covering 13 EUROMET projects were held 1-2 March at the same location. More than 60 people from 35 countries took part in the meetings.

[2] A Picard, H Fang and M Gl¨aser, Discrepancies in air density determination between the thermodynamic formula and a gravimetric method: evidence for a new value of the mole fraction of argon in air, *Metrologia* **41** (2004) 396–400

3. Projects

There are currently 28 agreed projects in the field of Mass and related quantities. Since the last General Assembly, 4 projects have been completed. Additionally 4 projects are currently proposed. The 36 projects are listed in Annex 1 sorted after the subfields *Mass*, *Density*, *Pressure*, *Force*, *Viscosity*, and *Hardness*. The distribution of the 36 projects over type of collaboration and over current status is shown in table 1. The distribution of the projects over the subfields is shown in figure 1. The trend in the number of projects sorted after type of collaboration is shown in figure 2.

Note that the increase in comparison projects and corresponding decrease in cooperation projects, which started three years ago, continues. The numbers of traceability and consultation projects are stable, but relatively small.

	Completed	**Agreed**	**Proposed**	**Total**
Cooperation	2 projects No.144, 740	11 projects No. 113, 351, 402, 463, 499, 509, 519, 534, 734; 803, 837	0 projects	13 projects
Comparison	0 projects	13 projects No. 439, 442, 445, 461, 505, 510, 518, 535, 627, 702, 788, 832, 834	4 projects No. 769, 786, 838, 839	17 projects
Traceability	1 project No. 138	3 projects No. 005, 285, 286	0 projects	4 projects
Consultation	1 projects No. 675	1 project No. 697	0 projects	2 projects
Total	4 projects	28 projects	4 projects	36 projects

Table 1. *Status on EUROMET Mass & RQ projects as per 2005-05-01. The projects are grouped according to the project status (Completed, agreed, proposed) and type of collaboration (Cooperation in research, comparison of measurement standards, traceability, consultation on facilities). The completed projects include only those that were active in 2004/2005.*

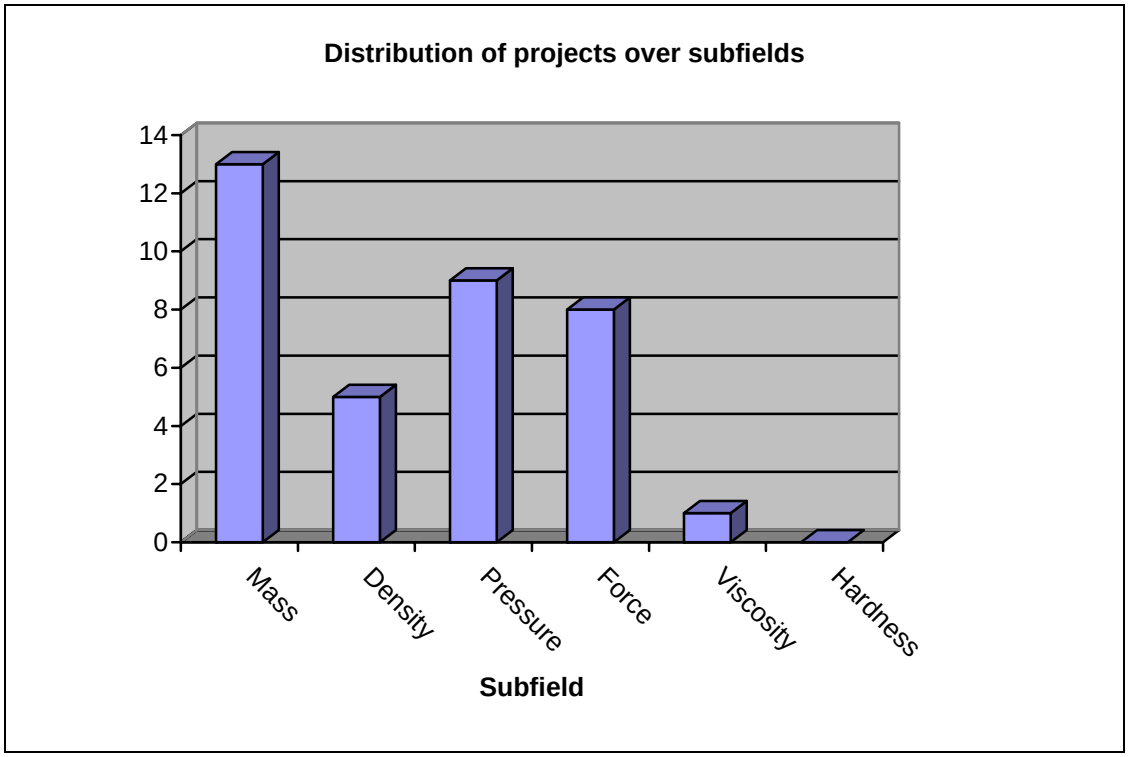

Figure 1. *Distribution of EUROMET Mass & RQ projects over subfields*

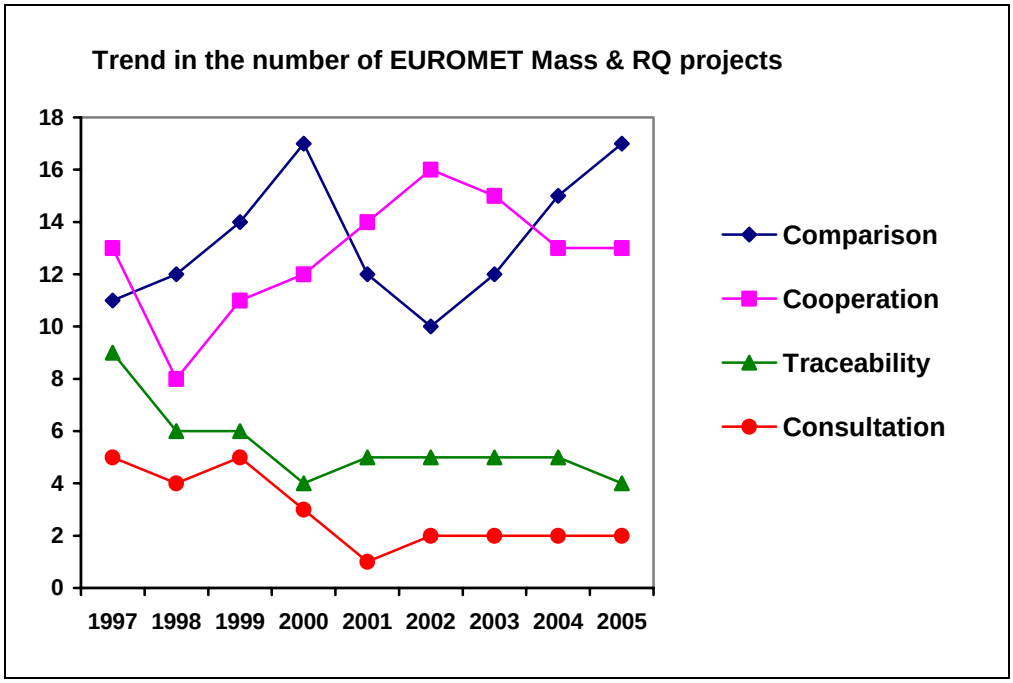

Figure 2. *Trend in the number of EUROMET Mass & RQ projects sorted after type of collaboration.*

4. Mutual Recognition Arrangement

4.1 Key and supplementary comparisons

Like last year, the BIPM Key Comparison Database contains 57 CIPM Key Comparisons and 6 CIPM Supplementary Comparisons. The distribution of these comparisons over subfields is shown in table 2. The numbers of comparisons in which EUROMET is represented are shown in brackets. In general, the number of EUROMET participants in CIPM comparisons is sufficient to provide a strong link between EUROMET and CIPM comparisons.

In addition, EUROMET is represented in two inter-RMO bilateral key comparisons and one inter-RMO trilateral key comparison registered in the database. These three comparisons are all in the field of pressure. As for the CIPM comparisons, there are no EUROMET projects associated with the inter-RMO comparisons.

	Mass	Density	Pressure	Force	Viscosity	Hardness
No. of KC's	5 (5)	4 (4)	13 (13)	26 (22)	5 (5)	4 (4)
No. of SC's	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	6 (6)

Table 2. *The number of CIPM key (KC) and supplementary (SC) comparisons in the different subfields. The numbers in brackets are the number of comparisons in which EUROMET is represented.*

There is a total of 19 EUROMET Key Comparisons and 6 EUROMET Supplementary Comparisons registered in the key comparison database. These comparisons are listed in table 3 and 4. Since last year two comparisons has been initiated (EUROMET.M.M-K2.1, EUROMET.M.P-S1).

During the last year, only one additional key comparison (EUROMET.M.P-K1.b) has reached the final stage "Approved for equivalence". The linking of EUROMET comparisons to CIPM comparisons still causes delays in the final stage, as there is no agreed way of doing so.

Comparison ID	Project no.	Subfield	No. of part.	Pilot	Status	Years
EUROMET.M.M-K1	215 C	Mass	10	NPL	Report in progress, Draft B	1992-1999
EUROMET.M.M-K2	445 A	Mass	25	SP	Report in progress, Draft A	2001-2003
EUROMET.M.M-K2.1	786 A	Mass	5	SP	Protocol complete	2004-
EUROMET.M.M-K4	510 A	Mass	26	NPL	Report in progress, Draft A	1999-2003
EUROMET.M.D-K1	339 C	Density	12	METAS	Provisional equivalence	1998-1999
EUROMET.M.D-K2.Prev	236 C	Density	5	IMGC	Provisional equivalence	1993-1994
EUROMET.M.D-K2	627 A	Density	8	PTB	Report in progress, Draft B	2001-2002
EUROMET.M.D-K4	702 A	Density	11	IMGC	In progress	2003-
EUROMET.M.P-K1.a	442 A	Pressure	10	BNM-LNE	Report approved, Draft B	1999-2002
EUROMET.M.P-K1.b	442 A	Pressure	7	BNM-LNE	Approved for equivalence	2000-2002
EUROMET.M.P-K2	305 C	Pressure	6	PTB	Approved for equivalence	1994-1995
EUROMET.M.P-K3.a	439 A	Pressure	8	LNE/NPL	Report in progress, Draft B	1999-2001
EUROMET.M.P-K3.b	439 A	Pressure	13	NPL	Report in progress, Draft A	1999-2001
EUROMET.M.P-K4	389 C	Pressure	14	NPL	Report in progress, Draft B	1998-1999
EUROMET.M.P-K5	045 C	Pressure	7	BNM-LNE	Provisional equivalence	1993-1995
EUROMET.M.P-K6	110 C	Pressure	6	BNM-LNE	Provisional equivalence	1992-1994
EUROMET.M.F-K1	535 A	Force	9	MIKES	Report in progress, Draft A	2002-2004
EUROMET.M.F-K2	518 A	Force	10	NPL	Planned	2006-2008
EUROMET.M.F-K3	505 A	Force	11	PTB	Planned	2005-2007

Table 3. *EUROMET key comparisons*

Comparison ID	Project no.	Subfield	No. of partic.	Pilot	Status	Years
EUROMET.M.V-S1	273 C	Viscosity	4	PTB	Published	1992-1993
EUROMET.M.V-S2	303 C	Viscosity	5	PTB	Published	1993-1996
EUROMET.M.V-S3	415 C	Viscosity	12	PTB	Published	2000
EUROMET.M.V-S4	415 C	Viscosity	8	PTB	Published	1997
EUROMET.M.M-S1	461 A	Mass	15	CMI	Report in progress, Draft A	2001-2005
EUROMET.M.P-S1	788 A	Pressure	2	METAS	Report in progress, Draft A	2004-2005

Table. 4 *EUROMET supplementary comparisons*

4.2 Calibration and measurement capabilities

The status of the interregional review of CMC tables is shown in table 5. Since the last EUROMET GA, APMP have made three CMC submissions (APMP.M.7.2005, APMP.M.8.2005, APMP.M.10.2005), whereas COOMET and SIM have made one submission each (COOMET.M.4.2005 and SIM.M.3.2004). Except for the latest submission (APMP.M.10.2005), EUROMET has reviewed all the CMC's submitted by the other RMOs.

In November 2004, EUROMET submitted a set of new or modified CMC tables from 11 countries. The tables were reviewed by COOMET 2005-01-13, SIM 2005-03-21 and APMP 2005-04-01. SADCMET have indicated that they will review before 2005-03-31 but have not yet submitted a review report. The result of the SIM review was not very clear as the conclusion "Abstain" was given to several CMC entries, where a reviewer felt he had too little prior information about the laboratory in question. APMP also had some reservations expressed by question marks to some of the claimed uncertainties. EUROMET has therefore submitted a response to the reviews with information that hopefully increases the confidence of the RMOs in the CMCs submitted by EUROMET. As there are no time limits specified for the RMO interactions after the first reviews have been posted and until the revised CMC tables are posted for approval, it is unclear when EUROMET.M.4.2004 will be published in the KCDB.

CMC identifier	Description	Status	Date
APMP.M.1.2001	Mass, force, pressure, density, and hardness from 7 APMP members	Published	2002-03-27
APMP.M.2.2002	Mass and pressure from Malaysia	Published	2002-06-10
APMP.M.3.2001	Mass, force and pressure from Japan	Published	2002-08-12
APMP.M.4.2002	Mass, force, pressure and hardness from Japan	Published	2004-04-26
APMP.M.5.2002	Mass, pressure and hardness from Chinese Taipei	Published	2003-10-21
APMP.M.7.2005	Correction of density entry from New Zealand	Published	2005-04-15
APMP.M.8.2005	Force from India	Reviewed	2005-04-18
APMP.M.10.2005	Mass, pressure from Thailand	To be reviewed	2005-06-30
COOMET.M.1.2001	Mass, force and pressure from Russia	Published	2002-09-25
COOMET.M.2.2001	Viscosity from Russia	Published	2002-09-15
COOMET.M.3.2001	Force from Russia	Published	2002-09-25
COOMET.M.4.2005	Hardness from Russia	Reviewed	2005-02-22
EUROMET.M.1.2001	Mass, density, pressure, force, torque, viscosity, and gravimetry from 21 countries	Published	2002-06-26
EUROMET.M.3.2003	Modification of viscosity from 9 countries	Published	2003-12-11
EUROMET.M.4.2004	New or modified entries from 11 countries	Inter-RMO review	2004-11-15
SADCMET.M.1.2001	Mass and density from South Africa	Published	2003-10-09
SADCMET.M.2.2001	Pressure from South Africa	Published	2004-04-19
SADCMET.M.3.2001	Force, torque, and hardness from South Africa	Published	2004-05-14
SIM.M.1.2001	Mass, force, torque, hardness, pressure, and density from 6 countries	Published	2002-06-18
SIM.M.2.2003	Mass and force from Chile	Published	2004-01-21
SIM.M.3.2004	Viscosity from 4 countries	Disapproved	2005-04-14

Table 5. *Status on the interregional review of CMC tables for appendix C of the MRA*

Appendix 1. List of EUROMET Mass & RQ projects sorted after subfields

Subfield: Mass

Project no.	Coordinator	Title and participants	Report
351 A Type: Cooperation	Gosset (FR)	Workshop on "Secondary & reference mass standards" CZ, DE, DK, ES, FI, FR, GB, IT, NL, NO, SE, TR, BIPM	Ongoing 2004-03-08
402 A Type: Cooperation	Spurný (SK)	Mass measurement (Guide to the mass determination) CZ, DK, ES, FI, FR, GB, IT, NL, NO, SE, SK, TR	Ongoing 2000-02-11
445 A Type: Comparison	Jacobsson (SE)	Comparison of mass standards in multiples and sub-multiples of the kilogram BE, ES, IE, FI, IS, DK, DE, FR, GB, IT, SE, NO, PT, NL, CH, PL, HU, CZ, SK, LT, AT, SL, GR, TR, RO, BG, LV, EE	Ongoing 2004-03-03
461 A Type: Comparison	Kriz (CZ)	Comparison of 500 kg mass standard weight AT, BE, CH, CZ, DK, ES, FI, GB, GR, HU, IT, IE, NO, SE, SI, TR	Ongoing 2005-04-08
509 A Type: Cooperation	Davidson (GB)	Intercomparison of Pt-Ir kilogram standards AT, BIPM, BE, CH, CZ, DE, DK, ES, FI, FR, GB, HU, IT, NO, PL, SE, SI, SK, TR	Ongoing 2004-02-20
510 A Type: Comparison	Davidson (GB)	Comparison of mass standards of the kilogram (stainless steel) AT, BE, CH, CZ, DE, DK, ES, FI, FR, GB, HU, IE, IS, IT, NL, NO, PT, SI, SK, TR	Ongoing 2004-02-20
519 A Type: Cooperation	Khelifa (FR)	Correlations between air humidity & abnormal dispersion of refractive index of air BIPM, DE, DK, FR, GB, IT, SE	Ongoing 2001-12-10
697 A Type: Consultation	Bartolo (MT)	Setting up a mass lab from 1 mg to 10 kg at E1 level IT, MT	Ongoing 2004-02-14
734 A Type: Consultation	Pinot (FR)	Study of materials for the realization of mass standards BIPM, CH, FR, SE	Ongoing 2005-02-21
839 P Type: Comparison	Kriz (CZ)	Comparison of stainless steel 500 kg mass standard CZ, HU, PL, RO, PT, AT, SK, MT	Starting 2005-04-15

Project no.	Coordinator	Title and participants	Report
786 P Type: Comparison	Jacobsson (SE)	Comparison of mass standards in multiples and sub-multiples of the kilogram II SE, UK, IT, MA, NL and others	Starting 2004-12-01
832 A Type: Comparison	Riski (FI)	Comparison of 50 kg weights FI, EE, LV	Starting 2004-12-01
837 A Type: Cooperation	Fuchs (CH)	Surface effects on mass standards CH, FR, ES, GB, TR	Starting 2005-03-03

Subfield: Density

Project no.	Coordinator	Title and participants	Report
138 C Type: Traceability	Bettin (DE)	Calibration of master hydrometers DE, GB	Final Report 2004-11-17
144 C Type: Cooperation	Gläser (DE)	Measurement of air density using specially designed masses BIPM, DE, GB, SE	Final report 2005-03-17
627 A Type: Comparison	Bettin (DE)	Comparison of density determinations of liquid samples DE, FI, FR, HU, IT, PL, ZA	Ongoing 2004-03-15
675 C Type: Consultation	Verbeek (NL)	Validation of facilities for density determinations of solids NL, EE	Final report 2005-03-11
702 A Type: Comparison	Lorefice (IT)	Comparison of high resolution hydrometers for liquid density determination IT, AT, DE, FI, FR, HU, PL, PT, RU, SL, TR	Starting 2003-07-01

Subfield: Pressure

Project no.	Coordinator	Title and participants	Report
439 A Type: Comparison	Severn (GB)	Pressure standard comparisons, gas media and gauge mode from 50 kPa to 7 MPa AT, BG, CZ, DE, DK, ES, FI, FR, GB, HU, IE, IT, NL, PL, PT, RU, SE, SK, TR, ZA	Ongoing 2003-03-17

Project no.	Coordinator	Title and participants	Report
442 A Type: Comparison	Legras (FR)	Comparison in the low pressure range 0,1 mPa to 1000 Pa BE, BG, CZ, DE, ES, FI, FR, GB, HU, IT, LT, NL, SE, SI, SK, TR	Ongoing 2001-12-10
463 A Type: Cooperation	Sabuga (DE)	Calculation of elastic distortion and associated uncer-tainty in piston-cylinders operating up to 1 GPa DE, FR, GB, IT, SK, TR	Ongoing 2005-02-25
499 A Type: Cooperation	Verbeek (NL)	Bulletin-board of concerns, problems and experiences BE, CH, DE, DK, ES, FI, FR, GB, GR, HU, IE, IT, NL, NO, PL, PT, SE, TR, ZA	Ongoing 2005-03-08
534 A Type: Cooperation	Tesar (CZ)	Low pressure digital piston manometer with nominal ef-fective area 100 cm² CZ, DE, GB, IE, SE	Ongoing 2002-02-17
740 C Type: Cooperation	Molinar (IT)	Effective area calculation, uncertainty evaluation and studies for piston-cylinder units of non-ideal geometries used in PB's IT, DE, TR, SK, NL, FR, UK	Final report 2005-03-04
788 A Type: Cooperation	Wüthrich (CH)	Pressure measurements and calculation of the effective area of a piston-cylinder assembly from 0.05 to 1 MPa CH, CZ	Starting 2004-03-20
803 A Type: Cooperation	Rantanen (FI)	FPG-type digital piston manometer – exchange of ex-periences FI, CZ, FR, SE	Ongoing 2005-03-13
834 A Type: Comparison	Kocas (TR)	Bilateral comparison in the field of pressure measure-ment TR, RO	Starting 2005-03-10

Subfield: Force

Project no.	Coordina-tor	Title and participants	Report
113 A Type: Cooperation	Ferrero (IT)	Force multi-component DE, FI, FR, GB, IT, PT, TR	Ongoing 2000-04-03
285 A Type: Traceability	Kumme (DE)	Calibration of precision force measuring devices and transfer standards of the capacities up to 16,5 MN DE, DK, FI, GB, IT, SE, TR, AT	Ongoing 2000-12-11

Project no.	Coordinator	Title and participants	Report
286 A Type: Traceability	Kumme (DE)	Traceability in force measurement at national laboratory level in range up to 2MN DE, FI, SE, TR, AT	Ongoing 2000-12-11
505 A Type: Comparison	Kumme (DE)	Comparison of force standards from 500 kN to 4 MN BE, CH, CZ, DE, ES, FI, GB, HU, IT, PL, SE, TR	Ongoing 2000-12-13
518 A Type: Comparison	Knott (GB)	An intercomparison of force standards at 50 kN and 100 kN AT, CH, CZ, DE, GB, GR, HU, NL, PL, PT	Starting 2003-01-01
535 A Type: Comparison	Pusa (FI)	Intercomparison of force standards at 5 kN and 10 kN CH, CZ, DE, FI, HU, IT, PL, PT, SE	Starting 2002-01-01
769 P Type: Comparison	Averlant (FR)	Bi-lateral comparison of torque at 1 kN.m FR, ES	Starting 2004-03-08
838 P Type: Comparison	Fank (TR)	Bilateral Comparison of Force Standard Machines TR, RO	Starting 2005-06-20

Subfield: Viscosity

Project no.	Coordinator	Title and participants	Report
5 A Type: Traceability	Wolf (DE)	Viscosity measurement services DE, GB	Ongoing 2005-01-12

Subfield: Hardness

Project no.	Coordinator	Title and participants	Report

Subfield: Others

Project no.	Coordinator	Title and participants	Report

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Position of the EUROMET TC-M on the paper:

Redefinition of the kilogram: A decision whose time has come[1]

The EUROMET TC-M recognizes that the current definition of the kilogram in terms of the international prototype is not satisfactory, as the mass of the prototype is believed to change as a function of time.

In recent years, members of EUROMET, as well as the BIPM and NIST, have initiated new or improved Watt-balance experiments in order to determine the Planck constant h with a relative standard uncertainty of a few parts in 10^8 that is necessary for monitoring the foreseen change in mass of the prototype over a period of several years. These experiments are expected to deliver results within the next 5-10 years that might change the current value of h in terms of the kilogram at its present definition based on the international prototype.

In parallel, a significant effort is being put into the Avogadro project in order to measure the Avogadro constant N_A with the required relative standard uncertainty of a few parts in 10^8. As a result, an improved value of N_A is expected to be available within the next 5-10 years as well.

Currently, there is a relative discrepancy of 10^{-6} between the prototype-based values of h and N_A. If the kilogram would be defined by fixing the value of h or N_A today, the mass of the prototype, $m(\mathcal{K})$ could therefore be expected to change by 1 mg or more within the next 5-10 years, as the results of the new experiments become available. In other words, the relative difference between the SI unit kg and the temporary conventional unit kg_{07}, being defined in the paper as the mass of the kilogram prototype, could well amount up to 10^{-6}. For comparison, the relative expanded uncertainty ($k = 2$) claimed by a typical NMI is $5 \cdot 10^{-8}$ at the 1 kg level, whereas the relative maximum permissible error for commercial OIML class E_1 weights larger than 50 g is $5 \cdot 10^{-7}$.

A relative difference of 10^{-6} between the SI unit kg and the conventional unit kg_{07} would create a number of problems at NMIs, at industrial calibration laboratories and at verification offices the day the conventional unit kg_{07} were abolished:

- All values assigned to high accuracy weights, weighing instruments and density standards would have to be updated from one day to the next.
- Most of the classified OIML class E_1 weights would have to be replaced.
- Density tables used in volume and density measurements would have to be updated.
- The impact on all instruments measuring quantities derived from the kilogram, such as force, torque and pressure, would have to be evaluated.

[1] Ian M Mills, Peter J Mohr, Terry J Quinn, Barry N Taylor and Edwin R Williams, Redefinition of the kilogram: a decision whose time has come, *Metrologia* **42** (2005) 71–80

In order to avoid such problems, the relative difference between the new SI unit kg and the mass of the international prototype of the kilogram should not be larger than $2 \cdot 10^{-8}$. Therefore, the EUROMET TC-M recommends that a new definition of the kilogram based on fixed values of h or N_A should be postponed until at least three independent experiments (Watt-balance experiments or the Avogadro project) have provided consistent results with relative standard uncertainties of a few parts in 10^8.

Agreed by EUROMET TC-M at its meeting 2005-03-03 in Thessalonica