Bureau International des Poids et Mesures

Consultative Committee for Length (CCL)

Report of the 12th meeting
(15–16 September 2005)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Bureau
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des poids
et mesures

Organisation
intergouvernementale
de la Convention
du Mètre

<u>Note:</u>

Following a decision made by the International Committee for Weights and Measures at its 92nd meeting in October 2003, reports of meetings of Consultative Committees will henceforth be published only on the BIPM website in the form presented here.

Full bilingual printed versions in French and English will no longer appear.

A.J. Wallard,
Director BIPM,
September 2005

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR LENGTH AS OF 15 SEPTEMBER 2005

President

Dr Chung Myung Sai, member of the International Committee for Weights and Measures, University of Science and Technology, Daejeon.

Executive Secretary

Mr R. Felder, International Bureau of Weights and Measures [BIPM], Sèvres.

Members

Laboratoire National de Métrologie et d'Essais, Institut National de Métrologie [LNE-INM], Paris.

Centre for Metrology and Accreditation/Mittatekniikan Keskus [MIKES], Helsinki.

Centro Nacional de Metrología [CENAM], Querétaro.

CSIR, Division of Production Technology [CSIR-NML], Pretoria.

Czech Metrology Institute/Český Metrologický Institut [CMI], Prague.

D.I. Mendeleyev Institute for Metrology, Rostekhregulirovaniye of Russia [VNIIM], St Petersburg.

Istituto di Metrologia G. Colonnetti, Consiglio Nazionale delle Ricerche [IMGC-CNR]*, Turin.

Korea Research Institute of Standards and Science [KRISS], Daejeon.

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Boulder and Gaithersburg/Joint Institute for Laboratory Astrophysics [JILA], Boulder.

National Measurement Institute, Australia [NMIA], Lindfield.

National Metrology Institute of Japan, Advanced Institute of Science and Technology [NMIJ/AIST], Tsukuba.

National Metrology Institute of Turkey/Ulusal Metroloji Enstitüsü [UME], Gebze-Kocaeli.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

NMi Van Swinden Laboratorium/Nederlands Meetinstituut [NMi VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Slovak Institute of Metrology/Slovenský Metrologický Ústav [SMU], Bratislava.

Swiss Federal Office of Metrology/Office Fédéral de Métrologie [METAS], Bern-Wabern.

The Director of the International Bureau of Weights and Measures [BIPM], Sèvres.

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* Renamed the Istituto Nazionale di Ricerca Metrologica [INRIM], Turin, in 2006.

Observers

Centro Español de Metrología [CEM], Madrid.

Standards, Productivity and Innovation Board [SPRING], Singapore.

1 OPENING OF THE MEETING; APPOINTMENT OF RAPPORTEURS; APPROVAL OF THE AGENDA

The Consultative Committee for Length (CCL)* held its 12th meeting at the International Bureau of Weights and Measures (BIPM), Sèvres, on Thursday 15, and Friday 16 September 2005. Three sessions were held.

The following delegates were present: P. Balling (CMI), R.H. Bergmans (NMi VSL), F. Bertinetto (IMGC-CNR), N. Brown (NMIA), K. Chekirda (VNIIM), M.S. Chung (President of the CCL), J.E. Decker (NRC-INMS), C.I. Eom (KRISS), S. Gao (NIM), P. Gill (NPL), L.W. Hollberg (NIST), P. Juncar (LNE-INM), O. Kruger (CSIR-NML), A. Lassila (MIKES), A. Lewis (NPL), A. Madej (NRC-INMS), H. Matsumoto (NMIJ/AIST), A. Onae (NMIJ/AIST), J. Pekelsky (NRC-INMS), G.B. Picotto (IMGC-CNR), F. Riehle (PTB), D. Rovera (LNE-SYRTE), J. Stone (NIST), H.S. Suh (KRISS), R. Thalmann (METAS), G.-P. Vailleau (LNE), M. Viliesid (CENAM), A.J. Wallard (Director of the BIPM), G. Wilkening (PTB) and T. Yandayan (UME).

Observers: E. Prieto (CEM), S.L. Tan (SPRING).

Guests: G-S. Peng (CMS/ITRI), J.C. Oliveira (INMETRO), Y.S. Domnin (VNIIFTRI).

Also present: P. Giacomo (Director emeritus of the BIPM); E.F. Arias (BIPM), P. Espina (Executive Secretary of the JCRB), R. Felder (Executive Secretary of the CCL), R. Köhler, J. Miles, L.-S. Ma, L. Robertsson, C. Thomas (Coordinator of the KCDB), L.F. Vitushkin and M. Zucco (BIPM).

Apologies: R. Fira (SMU).

Dr Chung welcomed the participants to the 12th meeting of the Consultative Committee for Length (CCL).

Professor Wallard welcomed the participants, apologising for temporary environmental problems in the meeting room, and gave information on safety matters. He asked Mr Felder to provide some additional practical remarks.

Three guests were introduced, being new to the meeting, the remainder of the Delegates and Observers being well known to each other.

Dr Lewis was thanked for his work as Rapporteur (together with Dr Sacconi, IMGC) on the previous minutes, which were published on the BIPM website. Dr Lewis was asked if he would perform the role of Rapporteur for this meeting. There were no objections, so Dr Lewis was appointed as Rapporteur for the 12th meeting.

* For the list of acronyms, click here.

2 REPORT ON ACTIONS ARISING FROM THE SEPTEMBER 2003 MEETING

The one action from the previous meeting was that the request for CCL membership by CSIR-NML (South Africa) should be discussed at the following CIPM meeting. This had happened and CSIR-NML had become a CCL member. Therefore Dr Kruger attended this meeting of the CCL as the Delegate for CSIR-NML.

3 CREATION OF A WORKING GROUP ON CMCS

Dr Espina, the new JCRB Executive Secretary was introduced. He presented an update on the work of the JCRB. His presentation concerned current policies from the JCRB. These included: the recommendation for each Consultative Committee (CC) to have a working group (WG) on calibration and measurement capabilities (CMCs); the end of the transition period and the operation of the Quality Systems (QS); modification of published CMCs; the "Fast Track" process; and criteria for CMC acceptance.

Each of the CCs, except for the CCL, had set up its own CMC working group, though they had been given different names. The objectives of these groups were based on those set out in document JCRB 11/6(2). Several of these groups hold frequent meetings at the BIPM, where the Executive Secretary of the JCRB is always present. The actual process in each Consultative Committee is slightly different. In chemistry, for example, there is an initial review during the meeting, which then continues with a seven month schedule for further review. They operate only one review cycle per year. In ionizing radiation, there is a table of acceptable uncertainties which are accepted until key comparison results are available. Other Consultative Committees such as electricity and magnetism have procedures and guidelines for filling in CMC tables in Excel. Dr Espina mentioned that setting up such a group is not mandatory, but it is recommended.

Regarding the end of the CIPM Mutual Recognition Arrangement (MRA) transition period, at the end of 2004, various RMOs reported at the 14th meeting of the JCRB (Minsk, 12 May 2005) on their NMI Quality Systems reviews. CMCs not covered by a fully implemented Quality System were withdrawn. Because it will take several years before the first round of key comparison evidence is available, other information can be used in the meantime for the acceptance of CMCs.

Modifications of CMCs already on the BIPM key comparison database (KCDB) can be of three types: editorial changes; deletion or reduction of scope; and improved scope. In the first two cases, there is no need for approval. In the second case other RMOs need to be informed if the change is due to key comparison performance. The latter case does require formal approval, though possibly using the "Fast Track" process.

The "Fast Track" process is normally applied only for smaller numbers of CMCs. After initial acceptance from the TC chairs, e.g. by email, the files are posted directly in the approval area of the JCRB website. The approval process then often happens almost immediately using the individual RMO logons to the site, e.g. during a CMC working group review meeting. Several additional logons were available to TC chairs or their invited guests.

CMC acceptance criteria were then shown. An RMO review report is always required, and a declaration that the QS supporting the CMCs has been reviewed and approved by the RMO. Additionally, the following may be used: key comparison (KC) and supplementary comparison (SC) results, previous comparison reports (including bilaterals), on-site peer review, or technical knowledge by peers.

Dr Espina showed the status of all CMCs in length. There were no outstanding actions – a submission by SADCMET in previous years had been abandoned through lack of action.

Dr Brown and Dr Pekelsky responded to the presentation by pointing out that within CCL, and in particular within the CCL Working Group on Dimensional Metrology (WGDM), the actions required from the CMC working group had actually been started many years ago without setting up a separate group, and were performed by the WGDM. For example the so-called DimVIM was the first ever use of a CMC classification criterion within a Consultative Committee and the first specification of key topics in length was discussed in 1996. Also the so-called Joint Committee for the Regions in Length (JCRL) set up rules in July 2000 for the entry of CMCs into the KCDB and this included not only CMCs in dimensional metrology, but also services falling under the work of the Working Group on the *Mise en Pratique*.

Dr Espina thanked the WGDM for the clarification but requested that he needed to have a formal contact for such matters in the CCL. Dr Brown responded that this needed approval or clarification of the terms of reference of the WGDM, as it was felt that the WGDM had been performing this role (CMC Working Group) for several years, but this was not clear from the terms of reference. Prof. Wallard agreed that the WGDM provided these functions but Dr Espina's point was that these needed to be formalised in its terms of reference. It was unfortunate that Dr Espina had not been invited to the WGDM meeting and the CCL agreed that this would happen in the future. Dr Thalmann reminded the meeting that in the early stages of the Mutual Recognition Arrangement (MRA), the CMC review was mostly performed in the originating RMO, and the inter-RMO review was mostly a sampling, rather than a detailed review. If the inter-RMO review was now to become more formalised, this would represent a large increase in work of the CCL or the working groups. Dr Espina replied that it was the business of the CCL to conduct business as it wished, and if the inter-RMO contact within the CCL or its working groups was already sufficient, then this did not require any further formalisation of the process, or increased workload.

4 IMPLEMENTATION OF THE MRA

Mr Felder reported on recent BIPM activities carried out on behalf the CCL. All the *Mise en Pratique* files had been updated, re-arranged and placed on the BIPM website, as had the report of the 11th meeting and the latest document on the practical realization of the definition of the metre. The 2003 updated frequencies had been published in *Metrologia* (2005, **42**, 323-325). Mr Felder asked if the old references needed to be maintained or updated. Dr Gill thought that the main body of text would remain the same and only the references for the updated values needed to be updated. Dr Rovera hoped that the old references could be maintained as they provided a useful historical record.

Prof. Wallard presented several CIPM issues. The Metre Convention now has 51 Members, and there are 19 Associates of the CGPM, of which 17 have signed the MRA. Another signature is anticipated shortly, with, at least, one more next year. The last CGPM discussed the benefits of the CIPM MRA and a document has been agreed with ILAC and OIML to take the 22nd CGPM Resolution 6 (on CIPM MRA benefits) forwards to governments. Another issue discussed was circulation of artefacts across national borders. There are collaborations with the ISO Reference Materials Committee (ISO REMCO) on how best to deal with customs problems, by making a proposal to the International Customs Union.

The CIPM MRA now has a logo available for use by NMIs. Use it not obligatory. Prof. Wallard reminded the meeting of the equivalence statement that could now be used on certificates. A new SI Brochure, the supplements to the "Guide to the Expression of Uncertainty in Measurement" (the GUM) and the new "International Vocabulary of Basic and General Terms in Metrology" (the VIM) should be published in 2006.

The JCRB had set up a working group to look at the need for a modification of the definition of a CMC. Ismael Castelazo had been replaced as JCRB Executive Secretary by Pedro Espina. The JCRB is keen to see greater consistency between RMOs in their treatment of CMC evaluation and QS review. Guidance on Designated Institutes and subcontracting, had been finalized.

Some regulations specify that measurements are traceable to a particular NMI – this is a Technical Barrier to Trade. The CIPM MRA provides a framework within which there is no longer a need for requirements such as this. As an example, NIST now recommends that the Federal Aviation Authority accepts calibration certificates issued by NMIs which are signatories to the MRA – 'traceability to NIST' is no longer necessary.

The BIPM has new agreements with the WHO and the Codex Alimentarius.

Prof. Wallard introduced several key points of a forthcoming joint CIPM-ILAC statement on the roles and responsibilities of NMIs and National Accreditation Bodies (NABs). Whilst it was not up to BIPM or ILAC to tell NMIs or NABS what they should do or should not do, the aim of the statement was to encourage collaboration and give suggestions for best practice. NMIs should:

- maintain the SI and compare their realizations of the units;
- ensure international and national traceability;
- provide access to their calibration services for all users;
- maintain an overview of the whole national measurement system;
- not compete unfairly with accredited laboratories; and
- avoid conflict of interests with laboratory accreditation bodies.

Similar recommendations were directed towards NABs and to joint NMI/NAB activity.

The document will be made available through the BIPM website.

There had been some recent publications on the potential redefinition of the kilogram. The watt balance and Avogadro results currently differ by 10^{-6}. There was a slight preference at the moment for the watt balance (Planck constant) route to a future redefinition of the kilogram. Fixing the Planck constant (and thereby the Avogadro) has implications for the ampere and mole. The ampere, if based on a fixed value for the electrical charge also fixes the Josephson and von Klitzing constants, but makes ε_0 and μ_0 experimentally determined. Separately, measurements of the Boltzmann constant are approaching 2 in 10^{-6}. This could help redefine the kelvin.

It is possible that the 2011 CGPM may redefine the kilogram, the mole, the ampere, the kelvin, and the candela. Watt balances will be needed to realize the kilogram and alternative realizations of the kilogram and other base units of the SI will be dealt with by a '*Mise en Pratique*'. This would have some impact on the work of the BIPM, especially as one of its roles is to maintain the international prototype of the kilogram.

5 REPORT AND SURVEY OF WORK AT THE NATIONAL LABORATORIES (RESPONSES TO A QUESTIONNAIRE THAT WAS CIRCULATED IN ADVANCE)

Mr Felder indicated that 18 responses had been received to the questionnaire sent to the CCL members before the meeting. There had been significant work in dimensional metrology, many frequency measurements of the *Mise en Pratique*, frequency measurements of new radiations, development of new standards and much activity in femtosecond combs. Mr Felder showed a table of the most recent frequency measurements.

Dr Rovera mentioned additional good results obtained in the preceding week with strontium. There were no other recent updates since the reports had been received. Prof. Wallard welcomed receiving the reports from the laboratories as they are very useful to keep CCL members appraised of work of their peers. Other Consultative Committees provide a facility, through the BIPM website, for posting their publications. This is also available for the CCL.

6 REPORT OF THE WORKING GROUP ON DIMENSIONAL METROLOGY

Dr Brown presented his report. The Working Group on Dimensional Metrology, WGDM, had met twice since the previous CCL meeting, in Beijing in 2004 and at the BIPM in 2005. The Beijing meeting had produced several outcomes and decisions, and Dr Brown showed the most important. One issue, highlighted in Beijing, was the need to review the terms of reference of the WGDM. The WGDM had reminded key comparisons pilots of the need to have the final reports and results approved by the WGDM, for both CCL and RMO key comparisons. The process of preparing the comparison data for input to the KCDB had been improved. There was detailed guidance issued to the pilots of the new CCL RMO key comparisons to ensure they fulfilled the requirements of the MRA, as the CCL no longer routinely organizes key comparisons. The WGDM would monitor the programme of CCL RMO key comparisons, the RMO TC-Length chairpersons would have final decision on participation in the CCL RMO comparisons and inter-RMO participation would be sought for each such comparison.

One issue discussed and approved in Beijing was the exclusion of results from determining key comparisons, where the results were not from a service being offered routinely to clients.

The CMC classification scheme, the DimVIM, had been updated and translations into several other languages had been performed (Chinese, Finnish, German, Spanish).

The nanometrology discussion group moderator, Dr Vitushkin had stepped down and had been replaced by Dr Wilkening from PTB. The group had expressed its gratitude for Dr Vitushkin's work over the previous years.

There had been a guidance document issued to assist pilots of key comparisons. This included asking the pilots to provide immediate feedback to participants in the case of poor performance being identified during the circulation of the artefact, rather than waiting until draft A preparation. An NMI could therefore work on any problems and this helped ensure that correct results from calibrations were being given to NMI customers. The "poor" initial results would be reported in drafts A and B. Pilots and participants were reminded of the confidentiality of the draft A report and of the function of the report to simply summarize and agree on the results of the participants, before attempting to undertake any analysis. The use of standardized reporting was encouraged in order to minimize future workload, by re-use of previous formats. The use of Executive Reports (effectively a *précis* of the main findings) was requested to accompany each key comparison report, for ease of use of the CMC review process.

The locations of WGDM meetings had been planned over recent years to coincide where possible with the CCL meetings. The WGDM had met in San Diego in 2003 and a smaller meeting of the WGDM Executive had taken place immediately prior to the 2003 meeting of the CCL. In 2004, the WGDM met in Beijing. In 2005, the WGDM met immediately before the CCL meeting, in Paris. The 2006 WGDM meeting was planned for Mexico, returning to Paris in 2007.

Concerning the programme of key comparisons, five comparisons reports had received approval (one of which qualifies as inter-regional comparison) since the last CCL meeting and two new inter-regional comparisons had been started. Current comparison issues included the need for more activity in some regions to keep the balance of effort between the regions.

Working group membership had been discussed, as had the period of the WGDM chairmanship. It would be recommended that the WGDM chairmanship would normally last four years, and this would require approval by the CCL of a new Chairman, to start in the middle of the 2006 WGDM meeting in Mexico.

The WGDM membership needed to be flexible to be able to address not only CIPM MRA issues but those raised in new fields. The WGDM meetings were always well attended and over 50 documents had been tabled or presented at the 2005 meeting.

Dr Brown showed the work of Dr Pekelsky and the DimVIM language team, which had produced not only a comprehensive CMC categorisation list, but also translations into several languages other than English. This concept of a CMC categorisation list had been taken up by the other Consultative Committees and formed the basis of all CMC submissions.

Prof. Wallard asked if the system of the pilot alerting the participants of poor performance had been used, Dr Brown confirmed that it had on a couple of occasions but the NMI concerned had only received a request to check its data, and no information was given on the sign or size of their apparent discrepancy.

Dr Brown responded to another question from Prof. Wallard, on whether or not there was in place a mechanism for informing the WGDM pilots of updated JCRB guidance on comparisons. This was not yet in place across regions, though the regions had their own internal processes.

Clarification was made that the protocols and reports from the key comparisons were approved by the WGDM, but that a copy was always sent to the CCL President. Prof. Wallard pointed out that these approvals were formally a responsibility of the CCL but delegation to WGDM could be made if the CCL wished. If so, this responsibility should be in the WGDM's terms of reference.

The membership of the WGDM and the participation in meetings needed to be discussed and the terms of reference agreed, in order to ensure proper membership of the WGDM from CCL member laboratories, as well as by invited experts from outside the CCL.

Dr Thomas reiterated information from the comparison workshop held on the previous day, namely that the decision had been taken by the WGDM to recommend the use of the weighted mean as the preferred key comparison reference value (KCRV) determination – this was significant as this CCL was one of the first Consultative Committees to make such a particular recommendation. She also asked for confirmation that the WGDM had recommended not to run future CCL comparisons. Dr Brown responded that the CCL comparisons created a double workload for CCL members, and the solution chosen was inter-RMO participation in RMO key comparisons. This was particularly so in the case of artefacts such as gauge blocks which deteriorated in use. The WGDM's assumption was that the relative disposition and degree of equivalence of NMIs remained constant. There was still the option to run CCL comparisons in the future, where the needs of the CCL members were not being fulfilled by the CCL RMO comparisons. Ideally, the timetabling across the RMOs could improve the efficiency of the process, allowing more flexibility in participation. On the issue of recommending the weighted mean, the previous use of the simple mean was due to the desire to avoid problems of NMIs declaring quite small uncertainties, which may have too strongly influenced the KCRV. With the new analysis techniques available, this could be investigated in more detail, and the weighted mean was considered the better KCRV determinant.

Dr Pekelsky reminded the meeting that the WGDM was fortunate that the TC-Length chairpersons from all the regions were usually present at WGDM meetings, and so much of the work performed in other Consultative Committees by their CMC working group was instead handled in an efficient way directly by the WGDM.

Dr Stone commented that the new analysis procedure, set out as a recommendation from the comparison analysis workshop, was only recommended and not mandatory. Pilots and the participants were free to choose their preferred process of analysis.

7 REPORT OF THE WORKING GROUP ON THE *MISE EN PRATIQUE*

Dr Gill gave his report to the meeting. The CCL Working Group on the *Mise en Pratique* (MePWG) had a one and a half day meeting earlier in the week and there had also been a meeting of the Joint Working Group of the CCL and the CCTF. The MePWG usually only meets immediately prior to the CCL.

The CCL questionnaires had been returned and the data was thoroughly reviewed by the MePWG. This lead to the inclusion of new radiations and updates to existing radiations. The use of comb technology could lead to a proliferation of values in the *Mise en Pratique* lists, and this had to be addressed. In terms of recommended radiations, six existing radiations had been updated with new values, one new radiation had been added (atomic Sr at 698 nm), two radiations were extended in tabulated wavelengths close to the recommended radiations (acetylene at 1.54 µm, Rb 2-photon at 778 nm).

Consideration had been given to the relation between the CCL MePWG and CCL-CCTF JWG, and their respective terms of reference.

Inter-relation and combination of the results of these two working groups had been discussed and the preference was for a common list of radiations with common values and uncertainties. This lead to a consideration of the reporting schedules of the groups to their respective Consultative Committees, in order to provide timely reports to the CIPM. The logistics of publishing and updating the *Mise en Pratique* recommended radiations and Joint Working Group recommendations was also discussed, due to the need for a hardcopy publication, e.g. in *Metrologia*.

Recent femtosecond comb comparisons had been reviewed and it was thought that the need for regional dissemination was addressed using through CCL 2003 recommendations for workable comparisons.

A stabilized laser comparison within the framework of the BIPM.L-K11 key comparison was already underway. This would be presented during a later agenda item.

There was discussion of whether to include a frequency value for an un-stabilised He-Ne laser in the *Mise en Pratique* recommended radiation list. Issues raised were: the level of accuracy at which this could be possible (1 in 10^5), whether the *Mise en Pratique* publication would result in such a laser becoming a primary standard for traceability; implications for traceability (CMC statements, local calibration procedures, ISO/IEC 17025); good practice requirements; claims of traceability to national standards at the respective level; and whether He-Ne laser manufacturers could claim intrinsic traceability for their product to international standards.

There had been some discussion on the so-called ‘prudence factor’ used to multiply individual NMI uncertainties when they contribute to the overall recommended uncertainty.

MePWG proposals to the CCL

The MePWG tabled two proposals for agreement by the CCL.

CCL-MePWG-1a

The Consultative Committee for Length,

considering that:

- improved frequency values for radiations of some high-stability cold ion standards already documented in the recommended radiations list have recently become available;
- improved frequency values for the infra-red gas-cell-based optical frequency standard in the optical telecommunications region, already documented in the recommended radiations list, have been determined;
- improved frequency values for certain iodine gas-cell standard, already documented in the subsidiary recommended source list, have been determined;
- frequencies of new cold atoms, of atoms in the near-infrared region and of molecules in the optical telecommunications region have been determined by femtosecond comb-based frequency measurements for the first time;

proposes that the list of *recommended radiations* be revised to include the following:

- updated frequency values for the single trapped $^{88}Sr^{+}$ ion quadrupole transition, the single trapped $^{199}Hg^{+}$ quadrupole transition and the single trapped $^{171}Yb^{+}$ quadrupole transition;
- an updated frequency value for the Ca atom transition;
- an updated frequency value for the C_2H_2-stabilized standard at 1.54 μm;
- an updated frequency value for the I_2-stabilized standard at 515 nm;
- the addition of the ^{87}Sr atom transition at 698 nm;
- the addition of the ^{87}Rb atom two-photon transitions at 760 nm;
- the addition of the $^{12}C_2H_2$ (ν1 + ν3) band and the $^{13}C_2H_2$ (ν1 + ν3) and (ν1 + ν3 + ν4 + ν5) bands at 1.54 μm.

CCL-MePWG-1b

The Consultative Committee for Length,

considering that:

- the 2003 list of recommended radiations for the realization of the metre, including radiations of other optical frequency standards, was comprehensively reorganized and recently published in *Metrologia* 2005 and is available on the website of the International Bureau of Weights and Measures (BIPM);
- the number (six) of proposed changes to the values already contained within the list is small;
- only four new radiations are suggested;

proposes that:

- these changes be incorporated into the database' recommended radiations maintained on the BIPM website in a manner which highlights the updated values relative to the 2003 list;
- these changes also be published as a short supplementary report in *Metrologia*.

CCL-MePWG-1c

The Consultative Committee for Length **proposes** that the CIPM adopt the following updated values for existing recommended radiations:

Part I of the list

Absorbing ion $^{88}Sr^{+}$, $5s\ ^2S_{1/2} - 4d\ ^2D_{5/2}$ *transition*

The values f = 444 779 044 095 484.6 Hz

λ = 674 025 590.863 136 fm

with a relative standard uncertainty of 7×10^{-15} apply to the radiation of a laser stabilized to the unperturbed transition observed with a trapped and cooled strontium ion. The values correspond to the centre of the Zeeman multiplet.

Absorbing ion $^{199}Hg^{+}$, $5d^{10}\ 6s\ ^2S_{1/2}\ (F = 0) - 5d^9\ 6s^2\ ^2D_{5/2}\ (F = 2)$, $\Delta m_F = 0$ *transition*

The values f = 1 064 721 609 899 145 Hz

λ = 281 568 867.591 968 6 fm.

with a relative standard uncertainty of 3×10^{-15}**,** apply to the unperturbed quadrupole transition of a trapped and cooled mercury ion.

Absorbing ion $^{171}Yb^{+}$, $6s\ ^2S_{1/2}\ (F = 0, m_F = 0) - 5d\ ^2D_{3/2}\ (F = 2, m_F = 0)$ *transition*

The values f = 688 358 979 309 308 Hz

λ = 435 517 610.739 688 fm

with a relative standard uncertainty of 9×10^{-15}**,** apply to the unperturbed quadrupole transition of a trapped and cooled ytterbium ion

Absorbing atom ^{40}Ca, $^1S_0 - {}^3P_1$; $\Delta m_J = 0$ *transition*

The values f = 455 986 240 494 140 Hz

λ = 657 459 439.291 683 fm

with a relative standard uncertainty of 1.8×10^{-14}**,** apply to the radiation of a laser stabilized to Ca atoms. The values correspond to the mean frequency of the two recoil-split components for atoms which are effectively stationary, i.e. the values are corrected for the second-order Doppler shift.

Absorbing molecule $^{13}C_2H_2$ *P*(*16*) (*ν1* + *ν3*) *transition*

The values f = 194 369 569 384 kHz

λ = 1 542 383 712.38 fm

with a relative standard uncertainty of 2.6×10^{-11} apply to the radiation of a laser stabilized using the third harmonic detection technique to an external $^{13}C_2H_2$ cell within an enhancement cavity and subject to the following conditions:

- cell pressure (3 ± 2) Pa;
- frequency modulation width, peak-to-peak (1 ± 0.5) MHz; and
- one-way intracavity beam intensity of (25 ± 20) W cm^{-2}.

Part II of the list

Absorbing molecule $^{127}I_2$*, a_3 component, P*(*13*) *43-0 transition*

The values f = 582 490 603 442 kHz

λ = 514 673 466.367 fm

with a relative standard uncertainty of 8.6×10^{-12} apply to the radiation of a laser stabilized with an iodine cell external to the laser, and subject to the following conditions:

- cold point temperature (-5 ± 2) °C, corresponding to a I_2 pressure of (2.4 ± 0.5) Pa; and
- saturating beam intensity < 40 mW cm^{-2}.

CCL-MePWG-1d

The Consultative Committee for Length **proposes** that the CIPM adopt the following radiation values for addition to the list of *recommended radiations*:

Absorbing atom ^{87}Sr*, $5s^2\ ^1S_0 - 5s\ 5p\ ^3P_0$ transition*

The values f = 429 228 004 229 910 Hz

λ = 698 445 709.612 694 fm

with a relative standard uncertainty of 2×10^{-13}, apply to the radiation of a laser stabilized to Sr atoms.

Absorbing atom ^{87}Rb*, $5S_{1/2}$ (F_g = 2) – $7S_{1/2}$ (F_e = 2) two-photon transition*

The values f = 394 397 384 460 kHz

λ = 760 127 906.05 fm

with a relative standard uncertainty of 1.7×10^{-10}.

Absorbing atom ^{87}Rb, $5S_{1/2}$ $(F_g = 1) - 7S_{1/2}$ $(F_e = 1)$ *two-photon transition*

The values $f = 394\ 400\ 482\ 100$ kHz

$\lambda = 760\ 121\ 936.0$ fm

with a relative standard uncertainty of 4.5×10^{-10}.

Acetylene transitions referenced by offset from the $^{13}C_2H_2$ *P*(*16*) (*ν1* + *ν3*) *recommended transition*

$^{12}C_2H_2$, (ν1 + ν3) band at 1.54 μm

$^{13}C_2H_2$, (ν1 + ν3) and (ν1 + ν3 + ν4 + ν5) bands at 1.54 μm.

CCL-MePWG-2

The Consultative Committee for Length,

considering

- the significant advance and growth in absolute frequency values of optical frequency standards brought about by comb measurements;
- the differing accuracy requirements of the CCL length metrology community and the CCTF secondary representations criteria;

proposes that:

- the MeP-CCL list of recommended radiations and CCTF secondary representation list be combined into a single list of “Recommended frequency standard values for applications including the practical realization of the metre and secondary representations of the second”;
- the CCL-MePWG and CCL/CCTF JWG be combined into a single CCL-CCTF frequency standards working group;
- the CCL may wish to select those frequencies which it considers important to highlight for use in high accuracy length metrology;
- other frequencies be proposed, evaluated and maintained on the frequency standards list by a CCL-CCTF frequency standards WG, but not necessarily accepted as CCL-preferred radiations or CCTF-accepted representations;
- the continued maintenance of such a frequency standards “category A” list from which the CCL and CCTF accepted values would be selected, together with the “category B” list representing those radiations still available for use, but where no further improvement in values and uncertainties was deemed necessary;
- the CCTF consider, evaluate and highlight those frequencies which it wishes to accept as secondary representations of the second;
- the schedule of CCTF and CCL meetings be rationalized to take place alternately, at appropriate intervals, ideally at a time of year close to but before the CIPM date;
- a meeting of the CCL-CCTF frequency standards WG should take place prior to the respective CC meeting if appropriate, in order to update the frequency list prior to consideration by the CC;

- the frequency values list is maintained on the BIPM website with version control, and is structured at a basic level according to wavelength and frequency value, but forms a database capable of being searched by accuracy level or by frequency or by wavelength.

The two proposals from the MePWG were accepted by the meeting. They will be presented as proposals for recommendation by the CIPM in section 15 of these minutes.

The MePWG considered the following radiation values but felt they were not yet appropriate for inclusion in the list of recommended radiations:

$^{27}Al^{+}$ single ion $^{1}S_{0} – ^{3}P_{0}$, 267 nm

Since no published value was submitted at this time, it was decided that this radiation would be re-appraised at the next JWG CCL/CCTF meeting, which will be prior to the next CCTF meeting.

^{88}Sr $^{1}S_{0} – ^{3}P_{1}$ transition, 690 nm

Since only one value was available, and bearing in mind the JILA-Tokyo discrepancy on the ^{87}Sr $^{1}S_{0} – ^{3}P_{0}$ transition, 698 nm.

^{87}Rb $5S_{1/2} – 5P_{1/2}$ (F = 2) transition, 795 nm

Since there was no precedent with single photon value.

^{133}Cs $6 S_{1/2} – 6 P_{1/2}$ transitions, 895 nm

^{133}Cs $6 S_{1/2} – 6 P_{3/2}$ transitions, 852 nm

Since there was no precedent with single photon value from Cs beam and unlikely to be realized widely in this form.

^{171}Yb $(6s^{2})$ $^{1}S_{0} – (6s\ 6p)$ $^{3}P_{0}$, F = 1/2 transition, 578 nm

^{171}Yb $(6s^{2})$ $^{1}S_{0} – (6s\ 6p)$ $^{3}P_{0}$, F = 5/2 transition, 578 nm

Since the 4 kHz uncertainty was considered too preliminary at this time.

Dr Stone responded to the issue concerning the 633 nm un-stabilised laser inclusion in the *Mise en Pratique*. He gave the example of a diffraction grating being calibrated using a laser wavelength, where the laser was not calibrated. The laser wavelength is only a small part of the overall uncertainty. Inclusion in the *Mise en Pratique* may give too much confidence to the user, who may not look adequately into the other sources of uncertainty. The previous issue of a second mode at 640 nm had, according to Dr Rowley of NPL, not been seen in the last 15 years. There will always be situations where end users may abuse wavelengths in the *Mise en Pratique*, by claiming direct traceability in situations where it does not occur, and there is no way to avoid this. Dr Rovera suggested checking Section 5.6 of the document ISO/IEC 17025 to see if such a laser could be considered as a suitable standard.

Dr Bergmans gave the example of a Dutch laboratory which operated iodine-stabilised lasers and claimed direct traceability to the metre; they were operating wavelengths recommended by the *Mise en Pratique*, in accordance with the guidelines.

Dr Lewis gave the example of the spectroscopic lamps (e.g. Cd and Hg) which are used in many accredited laboratories – they are realizations listed in the *Mise en Pratique*, albeit at a higher uncertainty. The un-stabilised He-Ne laser is a simply another light source with a worse uncertainty. Dr Decker confirmed this and noted that the *Mise en Pratique* specifies the wavelengths obtainable from such lamps, and the uncertainties of these wavelengths, but also gives the very specific circumstances under which these values may be achieved. Another example is the use of a laser wavelength source in a flatness interferometer which may only measure to a few parts in 10^{-3}. The realization of the metre is attempted, using the guidance in the *Mise en Pratique*, at the uncertainty level applicable.

Whilst the majority of members felt that the un-stabilised He-Ne should be entered into the *Mise en Pratique*, perhaps as a secondary realization, it was thought that the issue needed further consideration. Dr Brown suggested that a small working group be set up to look into this matter and Dr Stone volunteered to chair it. The group would consist of Drs Rovera, Stone, Gill, Decker, Lewis, Viliesid and Juncar and correspondence would take place outside the CCL meeting.

8 REPORT OF THE JOINT WORKING GROUP CCL/CCTF

Dr Riehle presented this report to the CCL. He started by giving a brief summary of the history of the group and the reasons behind its formation, starting with the formation of the CCTF Working Group on Secondary Representations of the Second, in June 2001, and ending with the October 2001 recommendation of the CIPM to form a joint working group with the CCL. Consequences of the CIPM decision were that with a single list there will be no ambiguity in the recommended frequencies and the joint group strengthens the definition of the metre that links length and time measurements. It was left to the joint working group to take into account that some of the needs of the length and time community are orthogonal. The joint working group considered and specified two requirements for standards to be considered as secondary representations of the second:

- The SI value of the unperturbed frequency of a quantum transition suitable as a secondary representation of the second must have an uncertainty that is evaluated and documented so as to meet the requirements adopted for the primary frequency standard for use in International Atomic Time.
- This uncertainty should be no larger than about a factor of 10 of the primary standards of that date that serve as the best realisations of the second.

The JWG CCL/CCTF in its sessions on 9th and 10th September 2003 and 30th March 2004 reviewed three microwave standards and seven optical standards (most of them included in the *Mise en Pratique*).

The joint working group recommended (and CCTF adopted) that the unperturbed ground-state hyperfine quantum transition of ^{87}Rb may be used as a secondary representation of the second with a frequency of f_{Rb} = 6 834 682 610.904 324 Hz and an estimated relative standard uncertainty (1 σ) of 3×10^{-15}.

The meeting of the joint working group on 14 September 2005 adopted three optical frequency standards as secondary representations of the second: $^{199}Hg^+$ optical transition (281.6 nm), $^{88}Sr^+$ optical transition (674 nm), $^{171}Yb^+$ optical transition (435.5 nm). It was noted that these values had uncertainties in a range that was a factor of 10 worse than the best current uncertainties offered by Cs fountain experiments.

JWG CCL/CCTF proposals to the CCL

The JWG CCL/CCTF tabled two recommendations for agreement by the CCL.

CCL-JWG CCL/CCTF-1

The JWG CCL/CCTF recommends that the list of recommended radiations and CCTF´s list of secondary representations be combined into a single list of "Recommended frequency standard values for applications including the practical realization of the definition of the metre and secondary representations of the second".

CCL-JWG CCL/CCTF-2

The JWG CCL/CCTF as a majority recommends the merging of the MePWG with the CCL-CCTF Joint Working Group in order to ensure efficient consideration of the various radiations and the needs of both Consultative Committees.

However, there was some concern expressed by certain members of the joint working group that the terms of reference of the two working groups are different. Dr Gill commented that the majority of the concerns were from members who were not in the MePWG.

In conclusion, Dr Riehle summarized that the group is in a transition period and agreed that it should define the interrelation between the CCL, CCTF, MePWG and the JWG CCL-CCTF on secondary representations of the second. It might need to have new terms of references.

The next meeting of the joint working group would be on 11 September 2006 prior to the next meeting of the CCTF. Future work items would include: putting forward the recommendations to the CCTF; putting forward the recommendations of CCL and CCTF to CIPM 2006; and putting the new list of frequencies onto the web page.

It was noted that the members of the group, i.e. the NMIs had sent a number of representatives to the meetings. This was encouraged as it prevented too close a focus on the specific needs of either CCL or CCTF.

The two recommendations of the joint working group were put to the CCL. They were accepted without objection. They will be tabled for agreement by the next CCTF in September 2006.

9 SUMMARY OF WORKING GROUPS ACTIVITY AND CONCLUSION OF THE WORKSHOP ON COMPARISON REFERENCE VALUES AND THEIR ANALYSIS

[This agenda item was presented earlier in the meeting, during agenda item 6].

Dr Decker reported on a workshop on the analysis of key comparisons that had taken place on the two days before the CCL meeting. She thanked Prof. Wallard and the BIPM for making the venue available and the two experts, Dr Cox from NPL and Dr Steele from NRC who had been invited guests. She also thanked NPL for funding Dr Cox's travel. (Dr Cox is the Chairman of the BIPM advisory group on uncertainties). The first session of the workshop contained presentations of the latest reports from several CCL key comparisons. This was followed by presentations from the two statistical experts and some live demonstrations of analysis techniques using some software tools and data from CCL key comparisons.

The software tools had been shown to help solve several issues associated with decisions to be made during comparison analysis.

The workshop had been very useful, both for the dimensional metrology community, as well as for the statisticians.

Conclusions from the workshop

- Unless there are good reasons to the contrary, the recommended steps to be followed when analyzing key comparison data, are those as outlined by Dr Cox in document WGDM-0586.
- When performing analysis of dimensional metrology key comparisons, the WGDM proposes, where appropriate, the use of the Excel based 'E_n toolkit' as developed by Douglas and Steele, during and after the data acquisition phase of the comparison.

Specifically, the steps to be followed during the analysis phase of the comparison are as follows:

1. Perform an extended chi-squared (null-hypothesis) consistency check on the data submitted by the participants (result, uncertainty, degrees of freedom) based on the inverse variance weighted mean as the KCRV.
2. If the consistency check is satisfied at the 5 % level:

- proceed to use the weighted mean as the KCRV and use the formal uncertainty of the weighted mean as the uncertainty of the KCRV;
- derive unilateral and bilateral degrees of equivalence for all the participants, and publish them.

3. Otherwise (check has failed):

- determine the largest subset of participants with the lowest chi-squared, the data for which is consistent with the chi-squared null hypothesis test;
- undertake scientific dialogue with participants not in the largest subset, to try to resolve problems, where possible (blunder correction, technique differences, etc);
- set the weights of the participants not in the chosen largest subset, to zero, for the purposes of determining the KCRV and its formal uncertainty, and determine these values;
- if the largest subset is considered to be too small, consider reporting only bi-lateral degrees of equivalence (i.e. no KCRV), or performing additional modelling (e.g. drift, travelling artefact uncertainty);
- derive unilateral and bilateral degrees of equivalence (as appropriate) for all the participants, and publish.

Two software tools for comparison analysis; one from Drs Douglas and Steele, and one from Dr Cox, had been demonstrated and the tools were to be made available for WGDM use. Dr Cox was to submit his algorithm to Dr Steele for incorporation into an overall tool.

10 DISCUSSION ON NEW OPTICAL STANDARDS AND COMPARISON TECHNIQUES

Prof. Wallard introduced this agenda item by commenting that important issues were starting to arise in the use of combs and comparison of optical clocks. Prof. Wallard asked which NMIs had compared combs between each other. The PTB was interested in noise characteristics and had performed comparisons of combs within the PTB. Femtosecond PTB fibre combs had also been compared with commercial combs. Dr Hollberg commented that over long time averages, frequencies reproduce with very high accuracy. Ti-Sapphire achieved 10^{-15} with shorter times, Forsterite combs were wider in frequency (100 kHz) than Ti-Sapphire systems and were nearer to 10^{-14}. Dr Gill informed the meeting that NPL had just started comparison of Ti-Sapphire high- and low-repetition rate combs.

Dr Bertinetto reported that IMGC had just started putting its comb into action, and was just starting experiments to look for any systematic errors in their system. Prof. Wallard offered the BIPM as a host for a second workshop on femtosecond combs in 2006, if there was a need. Dr Viliesid reported that CENAM was interested in setting up a comb, but was awaiting a suitable budget. The MePWG had discussed the transfer of knowledge from established comb users to newcomers, but it was felt that it was best for the new comb user to work with an established comb and so another workshop which had the aim of “educating” new users was not the best way to achieve this aim. Dr Madej agreed with Dr Rovera that combs, if used as time standards, needed much more detailed work before they could be left operating over long periods as clocks. Ti-Sapphire combs, although expensive, are better in this respect than Forsterite combs, but still could not be used for operational periods longer than a few weeks.

Dr Gill thought that one of the commercial comb suppliers was already supplying pigtailed fibres for use in combs.

There had been plans for a fibre link between the LNE-SYRTE and the PTB in order to exchange radiations. Dr Riehle hoped to operate an 80 km fibre link; however the budget required for this was orders of magnitudes greater than the departmental budget at the PTB. However, this may be submitted as a candidate project under the EU funded iMERA project.

Dr Hollberg reported picosecond accuracy time transfer in Arizona (United States) using existing fibre networks.

Dr Arias reported on time transfer techniques presented at a recent conference, which used GPS phase and phase encoded techniques to achieve sub-nanosecond accuracies.

The CCL asked Prof. Wallard to see if the CCTF would support a joint workshop of experts concerned with the development of optical frequency standards as operational clocks.

11 PROPOSALS FOR NEW KEY COMPARISONS

The WGDM reported that it had no new proposals for key comparisons at this time (the full list of CCL key comparisons, now operated mostly as CCL RMO comparisons was presented and approved at the last CCL meeting). The MePWG also had no new proposals for key comparisons.

12 REPORT AND DISCUSSION ON THE PROGRESS OF WORK AT THE BIPM

Prof. Wallard reported that a presentation by Dr Vitushkin would be held back until the next day, as he was currently working on a gravimeter comparison. Later in the agenda (item 13), Prof. Wallard and the BIPM staff would present views and questions on the long term future of BIPM work.

Prof. Ma reported on recent work on comparing femtosecond combs. Previous work had reported differences between two combs at the 10^{-19} level (95 % confidence level). One of the combs had since been housed in an environmental chamber. The short term stability was almost ten times better. It was thought at the limit of such Ti-Sapphire combs would be reached at the 10^{-20} level. He showed a collinear self referencing setup for control of carrier envelope offset which had increased the signal over a 300 kHz bandwidth from 40 dB to 50 dB.

Dr Robertsson reported on the BIPM.L-K11 comparison. Features of the comparison were that:

- it included those wavelengths present in the list of recommended radiations in the *Mise en Pratique*, which are used in the field of dimensional metrology;
- it included absolute frequency measurements, matrix measurements as well as direct frequency heterodyne measurements;
- the measurand is the frequency of the recommended component for that wavelength, e.g. a_{16} for frequency component for 633 nm;
- BIPM was the pilot laboratory, but measurements were also made in regional laboratories (host laboratory) but with the presence of an absolutely measured standard.

Some careful analysis had been applied to the data submitted to this comparison, and sensitivity of each laser to various influences had been investigated. A weighted mean analysis had been used and uncertainties had been derived from the various estimated distributions.

In the first 1.5 years of operation, comparison BIPM.L-K11 has provided:

- a weighted average value of the $^{127}I_2$, a_{16} component, R(127) 11-5 transition at 633 nm, for the 15 lasers measured so far, equal to f = 473 612 353 604 kHz, with an uncertainty of 2 kHz (under a Birge ratio equal to one condition); i.e. a value quite compatible with that recommended;
- individual uncertainty budgets for each standard with a first consistency check;
- 20 frequency standards compared since May 2004 (-K10 compared 75 lasers in 10 years).

Dr Riehle was concerned that NMIs may not participate in such comparisons when they are able to derive absolute calibrations from their own comb systems. Dr Madej preferred to make absolute measurement rather than encounter the problems associated with transporting delicate lasers for measurements in other institutes. Dr Brown retorted that the main purpose of BIPM.L-K11, as described at the previous CCL meeting, was to test the abilities of the NMIs to calibrate lasers for customers, e.g. a classical key comparison for proficiency testing, rather than the previous style of comparison which was to facilitate the setting up and linking of national standards. Also, not all NMIs have combs, and so such a comparison fulfils the valuable role of being a continuation of the previous BIPM laser comparison.

Dr Thomas pointed out that certain data normally entered into the KCDB for key comparisons was missing from the entry for this comparison. Dr Robertsson replied that there were draft A or B reports for the various loops and these were pending approval by the CCL. Dr Thalmann indicated that if some of the work in the comparison was to be handled by the RMOs, the protocol should be seen by the TC-L Chairpersons – it was not clear whether or this had happened. Mr Felder mentioned that the protocol document and the various draft B reports had been placed on the MePWG website. Comments were requested by 16 October 2005. If there were no objections by that date, the reports would be considered approved and the data would enter the KCDB, after discussion between Mr Felder and Dr Thomas.

Dr Zucco gave a presentation on the BIPM iodine cell work. BIPM has the facilities to fill and test iodine cells used in metrology and spectroscopy. The iodine cell quality is an issue for standards operated according to method (c) of the *Mise en Pratique*. 43 cells had been sold in the last three years. Cells are tested according to two methods: frequency difference with respect to the recommended values of the *Mise en Pratique*; and laser induced fluorescence (the cell is good if the frequency difference is in the 5 kHz interval). There were some initial results with a 1.8 m length iodine cell used with a Nd:YAG laser.

Prof. Wallard pointed out that the work on iodine cells (filling process and testing) is carried out by Mr Labot, the senior technician of the Length section.

Dr Vitushkin sent apologies for not being able to present recent work on portable laser systems, due to a high workload operating a comparison of absolute gravimeters. A recent paper that he had authored was available to participants.

13 FUTURE PRIORITIES TO BE ADDRESSED BY THE BIPM

Prof. Wallard mentioned that the next CGPM would be in 2007 and the focus of this agenda item was to take the advice of the CCL on preparation of proposals for future work of the length area for submission to the CIPM and CGPM.

The 2003 CGPM had requested the CIPM and BIPM Director to provide with clear criteria for setting the BIPM work programme. The CGPM had endorsed the BIPM's mission as set out in the "*Kaarls Report"* and this was taken as a basis.

The CIPM in 2004 endorsed the general criteria as presented to the CGPM but asked for more details. The CIPM in 2005 will take papers on the criteria used to set the technical programme as well as those used to define priorities for international coordination work. Prof. Wallard and the Section Heads at the BIPM have prepared 10 year plans based on 'bottom up' scientific requirements expressed by the Consultative Committees as a framework for the usual 4 year programme of work to be presented to the CGPM in 2007.

The broad mission of the BIPM is summarized succinctly: worldwide uniformity of measurement. However, in practice this extends to a wide range of activities, which Prof. Wallard summarized:

- maintaining and extending the SI;
- carrying out basic scientific tasks e.g. TAI, future measurement standards;
- supporting NMIs through comparisons, calibrations, technology transfer, staff exchanges;
- coordinating metrology worldwide e.g. the CIPM MRA, Committee Secretariats;
- collaborating internationally with other bodies e.g. OIML, WHO, WMO, WTO etc; and
- spreading information about metrology.

Whilst these are quite general topics, they had been presented in more detail by Prof. Wallard to the previous CGPM. In detail, the highest priority activities for the next few years are:

- maintain explicit commitments: TAI, the kilogram;

- provide calibration services which would offer better value for money than if done by individual NMIs: SIR, femtosecond comb validation, Josephson and QHR systems, ozone spectrophotometers;
- maintain an ability through unique facilities to pilot comparisons and to act as a project coordinator: stabilised laser under BIPM.L-K11, capacitance, gravimeters;
- workshops and best practice; CCQM, CCTF, CCRI, CCL workshops, (another BIPM Summer School is planned for 2008);
- *Metrologia*: editorial functions and coordination of special editions;
- authoritative publications: SI brochure, VIM, GUM…;
- visits and publications;
- BIPM's new website;
- KCDB;
- international collaboration with ILAC, WHO, WMO...;
- Joint Committees; and
- extending the CIPM MRA.

In terms of what this means for the length group, Prof. Wallard presented several slides showing various boundary conditions on the future work of the length section at BIPM:

- the CIPM has asked that the group closes in 2006 but the CCL had made a strong representation that parts of the work should be retained, e.g. comb based calibration facilities linked with -K11, but RMO services will generally replace them over 5-10 years;
- several members of staff will retire in the next 5 years;
- optical clocks are just around the corner and need addressing in the context of time measurements;
- the need to maintain a core competency in optical interferometry for use in project such as the watt balance.

The BIPM will propose to the CIPM to:

- concentrate on red lasers and combs as an operational facility;
- stop the methane work;
- stop green laser development;
- look briefly as gas lensing in iodine cells;
- validate and implement zero dead time counting techniques;
- retain cell filling and characterisation services;
- continue with compact lasers for interferometry;
- continue gravimetry;
- merge remaining members of the optical frequency/laser group with the Time section, but to retain the identity of 'length' at BIPM.

Prof. Wallard welcomed comments on these proposals and asked if there were areas where initial topics were not yet covered, but where the NMIs may wish the BIPM to become involved, e.g. nanotechnology.

Dr Rovera commented that there would probably be significant overlaps in spectroscopy techniques between the molecular chemistry/bio-metrology areas and the spectroscopic work performed previously in the Length section, including work with methane stabilized lasers. Prof. Wallard said this was true but depended on the extend to which the CIPM/CGPM supported new projects in chemical metrology.

Dr Eom asked if the Length section would disappear as an entity or might return in the near future. Prof. Wallard was keen that the concept of a ‘length’ area be maintained.

Dr Hollberg mentioned recent work in Japan which used a comb system to perform multi-wavelength measurements of distance. However, if such work were to be performed at the BIPM, it would need to be focused on a final goal, and it was not clear what a goal would be for such research at the BIPM, unless perhaps it would solve some problems in nanometrology.

Dr Madej supported retaining the comb work and could foresee future uses related to TAI, whereby certain restrictions of the current time comparison methods may be removed. Prof. Wallard thought that it would be difficult for the BIPM to propose a large research project on optical clocks and combs when several NMIs were already active in this area.

Dr Brown was concerned that the detailed knowledge in operation of high specification lasers or lower specification combs was being lost from the length area and whilst the CCTF was not too concerned with these, there was a danger that the knowledge in these areas would be lost from the length community, especially from the smaller laboratories which would no longer have access to pools of expertise previously held within the BIPM. Many NMIs were now dependent on very few commercial suppliers and if these were to go out of business, there was no alternative available.

Dr Riehle suggested that the competencies that would be required in the future would be concerned with the operation of compact combs, and expertise or knowledge of this should be available within the time and frequency area. There was no need to develop a transportable comb because recent commercially available combs sent to PTB were operable within half a day. There was no reason to believe that a small group at the BIPM would provide better transportable combs than the larger community of commercial comb manufacturers.

Dr Pekelsky countered with an example from the dimensional metrology area. In 1992 the CCDM had taken the decision to no longer maintain a competence in gauge block metrology and this had caused concern. However, in the time since that decision was taken, the NMI community had taken on the experience and responsibility of gauge block metrology, and the community of NMI users of these services had no been unduly affected.

Prof. Wallard welcomed these comments which, he felt, broadly supported the proposed BIPM strategy.

14 CCL MEMBERSHIP AND MEMBERSHIP OF WORKING GROUPS; TERMS OF REFERENCE OF WORKING GROUPS; FORMALISATION OF THE WGDM

There had been no new requests for membership of the CCL. It would be necessary to discuss the terms of reference of the working groups, prior to formalizing their membership.

14.1 Terms of reference and formalisation of the WGDM

Dr Brown made a presentation on the history of the WGDM, referring to the minutes of the CCDM meeting of 1992 on the setting up of the WGDM:

> "The precise membership of the working group was not decided during the session, as delegates needed to consult with their laboratories. It was agreed that the membership would be determined by correspondence through the BIPM. Members of the working group need not be actual members of the CCDM, but should be nominated through the national laboratories of Member States of the Convention du Mètre. It was hoped that one member would be proposed from each regional organization. Mr Pekelsky was proposed as Chairman, and indicated his assent. Messrs Brown, Sacconi and Zhao Kegong also indicated their willingness to participate."

and also to the initial terms of reference given to the WGDM by the CCDM:

> "To maintain links with the regional metrological cooperation organizations, seeking to ensure the involvement of the BIPM or member laboratories of the CCDM in major comparisons, thereby providing the means for assuring world-wide traceability of measurements at the highest levels of accuracy.
>
> To make recommendations to the CCDM on the needs and priorities for additional international comparisons under the auspices of the CCDM.
>
> To act as a focus for information exchange on international comparisons of dimensional metrology standards and techniques.
>
> Note: The term 'dimensional metrology' is taken to include the measurement of length, displacement, angle, form and deformation, and also those quantities and physical properties involved in their measurement such as the refractive index of air and the thermal expansion coefficient of standards."

Since that time, the RMOs had all formed Length Technical Committees and the chairpersons from these committees attend the WGDM meetings, so these requirements were being addressed already by the WGDM.

Dr Brown proposed a revision to the terms of reference (changes in bold font):

> To maintain links with the regional metrological cooperation organizations, seeking to ensure the involvement of the BIPM or member laboratories of the CCL in major comparisons **in dimensional metrology**, thereby providing the means for assuring worldwide traceability of measurements **in dimensional metrology** at the highest levels of accuracy.

To make recommendations to the CCL on the needs and priorities for additional international comparisons **in dimensional metrology** under the auspices of the CCL.

To act as a focus for information exchange on international comparisons of dimensional metrology standards and techniques, **through the use of suitable Discussion Groups.**

To facilitate the inter-regional CMC review process.

He requested clarification be formalized on the membership of the WGDM:

- WGDM Chair appointed by the CCL for a normal period of 4 years (can be re-appointed);
- full voting members nominated by the NMI members of the Metre Convention, non-voting members invited by the WGDM, through the Chair;
- the WGDM Chair to determine when meetings are required and to appoint a Rapporteur for each meeting.

Dr Brown also requested formalisation of authorities recently conferred on the WGDM:

- approval of dimensional metrology key comparison reports.

He reported that if this was accepted, his own period as WGDM Chairman would end in 2006 and he recommended that Dr Thalmann from METAS be appointed as the next WGDM Chairman in time for the next WGDM meeting.

Dr Brown then requested that the terms of reference of the WGDM be further extended to take into account the work that it performs already as the *de facto* CMC Working Group of the CCL:

To facilitate the Inter-regional CMC Review Process, by:

a) establishing and maintaining lists of service categories, and where necessary rules for the preparation of CMC entries;

b) agreeing on detailed technical review criteria;

c) coordinating and where possible conducting inter-regional reviews of CMCs submitted by RMOs for posting in Appendix C of MRA;

d) providing guidance on the range of CMCs supported by particular key and supplementary comparisons;

e) identifying areas where additional key and supplementary comparisons are needed;

f) coordinating the review of existing CMCs in the context of new results of key and supplementary comparisons.

and to formally request the WGDM to address future needs in new topics by suitable means:

To establish and operate Discussion Groups in areas of new technology, in which there are needs for dimensional metrology, with the aim of assuring worldwide traceability of measurements at the highest levels of accuracy.

Prof. Wallard reported that a paper had been prepared at the bureau of the CIPM to formalize the aims and terms of reference for CIPM Consultative Committees. The items listed in the document were examined and compared with the proposed terms of reference of the WGDM. Prof. Wallard was concerned that there was no explicit mention of reporting issues back to the CCL, but Dr Pekelsky gave examples from the previous CCL meeting where the WGDM had made some quite detailed reports and recommendations to the CCL. The WGDM did not want an explicit reporting route to the CCL on new technologies, as it was felt that this was the job of the CCL itself – the WGDM was the forum for the discussions, and the NMIs were free to raise the issues themselves at CCL meetings – many of the WGDM members are present as Delegates at the CCL meeting. The CCL should initiate more requests for information if it were felt that new areas were not adequately addressed. The previous day's discussion on the inclusion of un-stabilised lasers in the *Mise en Pratique* highlighted this – simply tabling a report on the matter would not have been sufficient; it would have excluded or minimized the detailed discussion between the differing views of the two working groups.

Dr Brown wished to have clarification on the membership of the WGDM. Items 10 and 11 of the document "*CIPM Consultative Committees: General rules and policy"* indicated that the members of the WGDM were individual experts, rather than the NMIs. This was confirmed. The flexibility requested by the WGDM was enshrined in this document. After a short discussion, it was agreed that the current members of the WGDM who come from NMI members of the CCL would automatically be approved for continued membership. However, the WGDM Chairman should invite non CCL members who wished to attend, and have these members approved by the CCL. The WGDM Chairman always had the ability to invite experts as guests.

The CCL formally approved the appointment of Dr Thalmann as the next Chairman of the WGDM, to take office at the meeting in 2006. As the current Chairman would step down before the next meeting of the CCL, the CCL President thanked, on behalf of the CCL, Dr Brown for his work as WGDM Chairman. The meeting applauded its agreement.

14.2 Terms of reference of the MePWG

The MePWG was set up between 1992 and 1997 to take over the role previously undertaken by small sub-groups that used to meet during sessions of the CCDM. It was not clear whether the MePWG had been issued formal terms of reference.

14.3 Terms of reference of the future JWG CCL/CCTF on reference frequencies

Yesterday, the CCL approved the change in structure of the MePWG and the merging with the CCTF working group. It was felt that such a group should be organized such that members coming from the two disciplines (CCL, CCTF) could attend only the sessions in which they had the appropriate expertise.

Dr Riehle reported that after yesterday's approval by CCL (and after subsequent approval by CCTF) it had been suggested that the joint working group resulting from the merging of the MePWG and the Joint Working Group of CCL/CCTF on Secondary Representations of the Second, should be called the "Joint Working Group of the CCL/CCTF on Reference Frequencies*"*.

Provisional terms of reference of this new group (JWG-CC-RF) were suggested:

1. to make recommendations to the CCL for radiations to be used for the realization of the definition of the metre and to make recommendations to the CCTF for radiations to be used as secondary representations of the second;

2. to maintain the list of recommended frequency standard values and wavelength values for applications including the practical realisation of the definition of the metre and secondary representations of the second;
3. to ask BIPM to discuss these provisional terms of reference with CCTF and if necessary to add further terms of reference which again should be communicated to CCL for its approval.

Dr Hollberg recommended the formation of this single group but wished to see the proposed terms of reference widened somewhat. Prof. Wallard asked which of the two working groups, WGDM or JWG-CC-RF would be responsible for any issues concerned with CMC review as it was possible that the WGDM did not contain the relevant experts. Dr Madej responded that NRC recently had to document, in Quality System terms, the operation of their comb system to be able to offer a calibration service – CMCs would probably follow (PTB and NPL were doing or had already done likewise). It was concluded that the logical place for this CMC-related activity was within the new working group. The terms of reference of the new group should be amended to include responsibilities on CMCs in laser frequency/wavelength. The CMC classification for these services was within the DimVIM and some cooperation might be needed to ensure the DimVIM categories were suitably amended when the JWG-CC-RF wished to enter new categories of CMCs. Dr Pekelsky offered to update the DimVIM at the request of the JWG-CC-RF, as necessary.

The CCL decided it wished to have CMCs for NMIs which offer comb-based calibrations of lasers.

The Joint WG was asked to define a service category for DimVIM and invite CMC proposals.

It was also proposed that each working group have the Chairman of the other group as an *ex officio* member of the group, i.e. the WGDM Chairman is an *ex officio* member of the JWG-CC-RF. The responsibility for BIPM.L-K11 was discussed. The approval of BIPM.L-K11 would reside, alongside the CMCs in this area, in the JWG-CC-RF. Dr Madej quoted the minutes of the previous CCL which mandated the MePWG to organize the CMCs and key comparisons in the area of laser frequencies.

Dr Eom asked what was the role of the CCL now that most of the detailed work was handled by its working groups? He thought the CCL should strengthen its position to become something more than the sum of the two groups. Dr Pekelsky responded that a strength of the CCL was as a meeting point and discussion forum between the two working groups; as evidenced by the previous day's discussion on un-stabilised lasers.

15 RECOMMENDATIONS TO THE CIPM AND DECISIONS OF THE CCL

Dr Gill presented proposals from the MePWG, for CCL approval, to be put to the CIPM. These were examined and corrections were made before the meeting.

The approved text is given at the end of the report (see Recommendation CCL 1, on the revision of the *Mise en Pratique* list of recommended radiations, and Recommendation CCL 2, on recommended frequency standard values for applications including the practical realisation of the metre and secondary representations of the second).

16 OTHER BUSINESS

Dr Suh asked if it would be possible for the BIPM to make and supply a comb system for an NMI, if so requested? This would be discussed outside the meeting as the BIPM would need to make a detailed consideration.

Dr Pekelsky mentioned that there had been some discussion in the WGDM meeting regarding the inclusion of the silicon lattice spacing as an item in the *Mise en Pratique*. The issue was quite detailed and Dr Pekelsky suggested the NANO Discussion Group might wish to look into this in more detail. Dr Chung agreed and asked the WGDM to ask the NANO Discussion Group to look into this matter and present a report to the next CCL.

Prof. Wallard asked the working group Chairmen to consider which of their submitted papers should be brought to the open access part of the website. Dr Pekelsky suggested that when the WGDM members submitted their documents for the next meeting, they number them with an asterisk to indicate that they were suitable for putting onto the open access website.

17 NEXT MEETING OF THE CCL

Prof. Wallard asked whether the CCL wished to maintain its usual September timetable for future meetings. The meeting agreed and asked Prof. Wallard to reserve a complete week for the next meeting. If the eventual timing of the CGPM in 2007 permitted, the next meeting of the CCL would take place at the BIPM, during September 2007, at a date to be confirmed.

The meeting thanked the staff of the BIPM for managing the meeting and for providing the IT infrastructure.

The Chairman thanked all participants for a lively and very productive meeting and the meeting was closed.

Dr A. Lewis, Rapporteur

Recommandations du

Comité consultatif des longueurs

présentées au

Comité international des poids et mesures

RECOMMANDATION CCL 1 (2005) : Révision de la liste des radiations recommandées pour la mise en pratique de la définition du mètre

RECOMMANDATION CCL 1a (2005)*

Le Comité consultatif des longueurs,

considérant que

- l'on dispose de meilleures valeurs des fréquences des radiations de certains étalons à ion ou à atomes refroidis très stables, déjà publiées dans la liste des radiations recommandées ;
- l'on a déterminé de meilleures valeurs des fréquences des étalons de fréquence optique, fondés sur des cuves à gaz, dans le domaine des télécommunications optiques, dans l'infrarouge, valeurs déjà publiées dans la liste des radiations recommandées ;
- l'on a déterminé de meilleures valeurs des fréquences de certains étalons fondés sur des cuves à iode, valeurs déjà publiées dans la liste complémentaire des sources recommandées ;
- l'on a effectué pour la première fois des mesures de la fréquence de nouveaux atomes refroidis, d'atomes dans la région de l'infrarouge proche et de molécules dans le domaine des télécommunications optiques, à l'aide de peignes à impulsions femtosecondes ;

propose que la liste des radiations recommandées soit révisée pour y inclure :

- les valeurs mises à jour des fréquences des transitions quadripolaires de l'ion piégé de $^{88}Sr^+$, de l'ion piégé de $^{199}Hg^+$ et de l'ion piégé de $^{171}Yb^+$;
- la valeur mise à jour de la fréquence de la transition de l'atome de calcium ;
- la valeur mise à jour de la fréquence de l'étalon asservi sur l'acétylène à 1,54 μm ;
- la valeur mise à jour de la fréquence de l'étalon asservi sur l'iode à 515 nm ;
- la fréquence de la transition de l'atome de ^{87}Sr à 698 nm ;
- les fréquences des transitions de l'atome de ^{87}Rb autour de 760 nm ;
- les fréquences des transitions de la bande ($\nu 1 + \nu 3$) de $^{12}C_2H_2$, et des bandes ($\nu 1 + \nu 3$) et ($\nu 1 + \nu 3 + \nu 4 + \nu 5$) de $^{13}C_2H_2$, autour de 1,54 μm.

* Cette recommendation a été adoptée par le CIPM comme Recommandation 3 (CI-2005) lors de sa 94e session en octobre 2005.

RECOMMANDATION CCL 1b (2005)

Le Comité consultatif des longueurs,

considérant que

- la liste de 2003 des radiations recommandées pour la mise en pratique de la définition du mètre, qui comprend aussi d'autres radiations d'étalons de fréquence optique, a été entièrement réorganisée et publiée dans *Metrologia* en 2005 ainsi que sur le site Web du Bureau international des poids et mesures (BIPM) ;
- le nombre (six) de changements proposés aux valeurs déjà publiées dans la liste est restreint ;
- seulement quatre radiations nouvelles sont proposées ;

propose que

- ces changements soient intégrés dans la base de données sur les radiations recommandées, placée sur le site Web du BIPM, en mettant en évidence les valeurs mises à jour depuis la liste de 2003 ;
- ces changements soient aussi publiés sous forme d'un bref rapport dans *Metrologia*.

RECOMMANDATION CCL 1c (2005)

Le Comité consultatif des longueurs **propose** au Comité international des poids et mesures d'adopter les valeurs mises à jour des radiations recommandées suivantes :

Partie I de la liste

Ion absorbant $^{88}Sr^+$*, transition* $5s\ ^2S_{1/2} - 4d\ ^2D_{5/2}$

Les valeurs f = 444 779 044 095 484,6 Hz

λ = 674 025 590,863 136 fm

avec une incertitude-type relative de 7×10^{-15}, s'appliquent à la radiation d'un laser asservi sur la transition non perturbée que l'on observe à l'aide d'un ion de strontium piégé et refroidi. Les valeurs correspondent au centre du multiplet Zeeman.

Ion absorbant $^{199}Hg^+$*, transition* $5d^{10}\ 6s\ ^2S_{1/2}\ (F = 0) - 5d^9\ 6s^2\ ^2D_{5/2}\ (F = 2),\ \Delta m_F = 0$

Les valeurs f = 1 064 721 609 899 145 Hz

λ = 281 568 867,591 968 6 fm

avec une incertitude-type relative de 3×10^{-15}, s'appliquent à la transition quadrupolaire non perturbée d'un ion de mercure piégé et refroidi.

Ion absorbant $^{171}Yb^{+}$, transition 6s $^{2}S_{1/2}$ (F = 0, m_F = 0) – 5d $^{2}D_{3/2}$ (F = 2, m_F = 0)

Les valeurs f = 688 358 979 309 308 Hz

λ = 435 517 610,739 688 fm

avec une incertitude-type relative de 9×10^{-15}, s'appliquent à la transition quadrupolaire non perturbée d'un ion d'ytterbium piégé et refroidi.

Atome absorbant ^{40}Ca, $^{1}S_0 - {}^{3}P_1$, transition $\Delta m_J = 0$

Les valeurs f = 455 986 240 494 140 Hz

λ = 657 459 439,291 683 fm

avec une incertitude-type relative de $1,8 \times 10^{-14}$, s'appliquent à la radiation d'un laser asservi sur des atomes de calcium. Les valeurs correspondent à la fréquence moyenne des deux composantes de recul d'atomes réellement stationnaires, c'est-à-dire qu'elles sont corrigées pour tenir compte du déplacement Doppler de second ordre.

Molécule absorbante $^{13}C_2H_2$, transition P(16) ($\nu_1 + \nu_3$)

Les valeurs f = 194 369 569 384 kHz

λ = 1 542 383 712,38 fm

avec une incertitude-type relative de $2,6 \times 10^{-11}$, s'appliquent à la radiation d'un laser asservi à l'aide de la technique de détection du troisième harmonique, avec une cuve à $^{13}C_2H_2$ située à l'extérieur du laser dans une cavité à absorption renforcée, lorsque les conditions suivantes sont respectées :

- pression d'acétylène (3 ± 2) Pa ;
- largeur de modulation de fréquence, crête à creux (1 ± 0,5) MHz ;
- puissance surfacique transportée par le faisceau dans un seul sens à l'intérieur de la cavité (25 ± 20) W cm^{-2}.

Partie II de la liste

Molécule absorbante $^{127}I_2$, composante a_3, transition P(13) 43-0

Les valeurs f = 582 490 603 442 kHz

λ = 514 673 466,367 fm

avec une incertitude-type relative de $8,6 \times 10^{-12}$, s'appliquent à la radiation d'un laser asservi à l'aide d'une cuve à iode située à l'extérieur du laser, lorsque les conditions suivantes sont respectées :

- point froid à la température de (–5 ± 2) °C, correspondant à une pression d'iode de (2,4 ± 0,5) Pa ;
- intensité du faisceau saturant < 40 mW cm^{-2}.

RECOMMANDATION CCL 1d (2005)

Le Comité consultatif des longueurs **propose** au Comité international des poids et mesures d'adopter les nouvelles radiations recommandées suivantes :

Atome absorbant ^{87}Sr*, transition* $5s^2\ ^1S_0 - 5s\ 5p\ ^3P_0$

Les valeurs $f = 429\ 228\ 004\ 229\ 910$ Hz

$\lambda = 698\ 445\ 709{,}612\ 694$ fm

avec une incertitude-type relative de 2×10^{-13}, s'appliquent à la radiation d'un laser asservi sur des atomes de strontium.

Atome absorbant ^{87}Rb*, transition* $5S_{1/2}\ (F_g = 2) - 7S_{1/2}\ (F_e = 2)$ *à deux photons*

Les valeurs $f = 394\ 397\ 384\ 460$ kHz

$\lambda = 760\ 127\ 906{,}05$ fm

avec une incertitude-type relative de $1{,}7 \times 10^{-10}$.

Atome absorbant ^{87}Rb*, transition* $5S_{1/2}\ (F_g = 1) - 7S_{1/2}\ (F_e = 1)$ *à deux photons*

Les valeurs $f = 394\ 400\ 482\ 100$ kHz

$\lambda = 760\ 121\ 936{,}0$ fm

avec une incertitude-type relative de $4{,}5 \times 10^{-10}$.

Fréquence des transitions de l'acétylène mesurées par référence à la transition recommandée $P(16)\ (\nu1 + \nu3)$ *de* $^{13}C_2H_2$

- bande $(\nu1 + \nu3)$ de $^{12}C_2H_2$, autour de 1,54 µm ;
- bandes $(\nu1 + \nu3)$ et $(\nu1 + \nu3 + \nu4 + \nu5)$ de $^{13}C_2H_2$, autour de 1,54 µm.

RECOMMANDATION CCL 2 (2005) :
Valeurs recommandées des fréquences étalons destinées à la mise en pratique de la définition du mètre et aux représentations secondaires de la seconde

Le Comité consultatif des longueurs (CCL),

considérant

- les progrès considérables et le nombre croissant des valeurs absolues des fréquences des étalons optiques de fréquence résultant des mesures réalisées au moyen des peignes ;

- les besoins différents en matière d'exactitude requise pour la communauté de la métrologie des longueurs représentée par le CCL d'une part et pour les représentations secondaires de la seconde du Comité consultatif du temps et des fréquences (CCTF) d'autre part ;

propose que

- la liste des radiations recommandées par le Groupe de travail du CCL sur la mise en pratique de la définition du mètre et la liste des représentations secondaires de la seconde du CCTF soient fusionnées dans une seule liste de « valeurs recommandées des fréquences étalons destinées à la mise en pratique de la définition du mètre et aux représentations secondaires de la seconde » ;
- le Groupe de travail du CCL sur la mise en pratique de la définition du mètre et le Groupe de travail commun au CCL et au CCTF sur les représentations secondaires de la seconde soient fusionnés en un seul groupe de travail commun au CCL et au CCTF sur les étalons de fréquence ;
- le CCL puisse choisir dans cette liste les fréquences qu'il considère importantes pour la métrologie des longueurs d'exactitude élevée ;
- d'autres fréquences soient proposées, évaluées et maintenues dans la liste des fréquences étalons par un groupe de travail commun au CCL et au CCTF sur les étalons de fréquence, sans qu'elles soient nécessairement approuvées comme radiations préférées par le CCL ou comme représentations approuvées par le CCTF ;
- l'on maintienne une liste des fréquences étalons de « catégorie A » à partir de laquelle les valeurs approuvées par le CCL et par le CCTF seront choisies, ainsi qu'une liste de « catégorie B » représentant les radiations disponibles, mais dont il n'est pas nécessaire d'améliorer les valeurs et les incertitudes ;
- le CCTF examine, évalue et mette en évidence les fréquences qu'il souhaite approuver comme représentations secondaires de la seconde ;
- les réunions du CCL et du CCTF soient rationalisées et se tiennent en alternance, à des intervalles de temps appropriés, juste avant, ou à une date proche de la réunion du CIPM ;
- le Groupe de travail commun au CCL et au CCTF sur les étalons de fréquence se réunisse préalablement aux réunions du CCL et du CCTF, si nécessaire, afin de mettre à jour la liste des fréquences proposées, pour examen, au Comité consultatif approprié ;
- la liste des valeurs des fréquences soit maintenue sur le site Web du BIPM* avec un contrôle des versions, et qu'elle soit organisée en fonction de la valeur de la longueur d'onde et de la fréquence, dans une base de données dans laquelle il soit possible d'effectuer des recherches par niveau d'exactitude, par fréquence, ou par longueur d'onde.

* http://www.bipm.org/fr/committees/cc/ccl/mep.html

Recommendations of the
Consultative Committee for Length

submitted to the
International Committee for Weights and Measures

RECOMMENDATION CCL 1 (2005): Revision of the *Mise en Pratique* list of recommended radiations

RECOMMENDATION CCL 1a (2005)*

The Consultative Committee for Length,

considering that:

- improved frequency values for radiations of some high-stability cold ion standards already documented in the recommended radiations list have recently become available;
- improved frequency values for the infra-red gas-cell-based optical frequency standard in the optical telecommunications region, already documented in the recommended radiations list, have been determined;
- improved frequency values for certain iodine gas-cell standard, already documented in the subsidiary recommended source list, have been determined;
- frequencies of new cold atoms, of atoms in the near-infrared region and of molecules in the optical telecommunications region have been determined by femtosecond comb-based frequency measurements for the first time;

proposes that the list of *recommended radiations* be revised to include the following:

- updated frequency values for the single trapped $^{88}Sr^+$ ion quadrupole transition, the single trapped $^{199}Hg^+$ quadrupole transition and the single trapped $^{171}Yb^+$ quadrupole transition;
- an updated frequency value for the Ca atom transition;
- an updated frequency value for the C_2H_2-stabilized standard at 1.54 µm;
- an updated frequency value for the I_2-stabilized standard at 515 nm;
- the addition of the ^{87}Sr atom transition at 698 nm;
- the addition of the ^{87}Rb atom two-photon transitions at 760 nm;
- the addition of the $^{12}C_2H_2$ (ν1 + ν3) band and the $^{13}C_2H_2$ (ν1 + ν3) and (ν1 + ν3 + ν4 + ν5) bands at 1.54 µm.

* This recommendation was adopted as Recommendation 3 (CI-2005) by the CIPM at its 94th meeting in October 2005.

RECOMMENDATION CCL 1b (2005)

The Consultative Committee for Length,

considering that:

- the 2003 list of recommended radiations for the realization of the metre, including radiations of other optical frequency standards, was comprehensively reorganized and recently published in *Metrologia* 2005 and is available on the website of the International Bureau of Weights and Measures (BIPM);
- the number (six) of proposed changes to the values already contained within the list is small;
- only four new radiations are suggested;

proposes that:

- these changes be incorporated into the database' recommended radiations maintained on the BIPM website in a manner which highlights the updated values relative to the 2003 list;
- these changes also be published as a short supplementary report in *Metrologia*.

RECOMMENDATION CCL 1c (2005)

The Consultative Committee for Length **proposes** that the CIPM adopt the following updated values for existing recommended radiations:

Part I of the list

Absorbing ion $^{88}Sr^{+}$, $5s\ ^2S_{1/2} – 4d\ ^2D_{5/2}$ *transition*

The values f = 444 779 044 095 484.6 Hz

λ = 674 025 590.863 136 fm

with a relative standard uncertainty of 7×10^{-15} apply to the radiation of a laser stabilized to the unperturbed transition observed with a trapped and cooled strontium ion. The values correspond to the centre of the Zeeman multiplet.

Absorbing ion $^{199}Hg^{+}$, $5d^{10}\ 6s\ ^2S_{1/2}\ (F = 0) – 5d^9\ 6s^2\ ^2D_{5/2}\ (F = 2)$, $\Delta m_F = 0$ *transition*

The values f = 1 064 721 609 899 145 Hz

λ = 281 568 867.591 968 6 fm

with a relative standard uncertainty of 3×10^{-15}**,** apply to the unperturbed quadrupole transition of a trapped and cooled mercury ion.

Absorbing ion $^{171}Yb^+$, 6s $^2S_{1/2}$ (F = 0, m_F = 0) – 5d $^2D_{3/2}$ (F =2, m_F = 0) transition

The values f = 688 358 979 309 308 Hz

λ = 435 517 610.739 688 fm

with a relative standard uncertainty of 9×10^{-15}, apply to the unperturbed quadrupole transition of a trapped and cooled ytterbium ion.

Absorbing atom ^{40}Ca, $^1S_0 - ^3P_1$; $\Delta m_J = 0$ transition

The values f = 455 986 240 494 140 Hz

λ = 657 459 439.291 683 fm

with a relative standard uncertainty of 1.8×10^{-14}, apply to the radiation of a laser stabilised to Ca atoms. The values correspond to the mean frequency of the two recoil-split components for atoms which are effectively stationary, i.e. the values are corrected for the second-order Doppler shift.

Absorbing molecule $^{13}C_2H_2$ P(16) (ν1 + ν3) transition

The values f = 194 369 569 384 kHz

λ = 1 542 383 712.38 fm

with a relative standard uncertainty of 2.6×10^{-11} apply to the radiation of a laser stabilized using the third harmonic detection technique to an external $^{13}C_2H_2$ cell within an enhancement cavity and subject to the following conditions:

- cell pressure (3 ± 2) Pa;
- frequency modulation width, peak-to-peak (1 ± 0.5) MHz;
- one-way intracavity beam intensity of (25 ± 20) W cm^{-2}.

Part II of the list

Absorbing molecule $^{127}I_2$, a_3 component, P(13) 43-0 transition

The values f = 582 490 603 442 kHz

λ = 514 673 466.367 fm

with a relative standard uncertainty of 8.6×10^{-12} apply to the radiation of a laser stabilized with an iodine cell external to the laser, and subject to the following conditions:

- cold point temperature (-5 ± 2) °C, corresponding to a I_2 pressure of (2.4 ± 0.5) Pa;
- saturating beam intensity < 40 mW cm^{-2}.

RECOMMENDATION CCL 1d (2005)

The Consultative Committee for Length **proposes** that the CIPM adopt the following radiation values for addition to the list of *recommended radiations*:

Absorbing atom ^{87}Sr, $5s^2\ {}^1S_0 - 5s\ 5p\ {}^3P_0$ *transition*

f = 429 228 004 229 910 Hz

λ = 698 445 709.612 694 fm

with a relative standard uncertainty of 2×10^{-13}**,** apply to the radiation of a laser stabilised to Sr atoms.

Absorbing atom ^{87}Rb, $5S_{1/2}\ (F_g = 2) - 7S_{1/2}\ (F_e = 2)$ *two-photon transition*

f = 394 397 384 460 kHz

λ = 760 127 906.05 fm

with a relative standard uncertainty of 1.7×10^{-10}.

Absorbing atom ^{87}Rb, $5S_{1/2}\ (F_g = 1) - 7S_{1/2}\ (F_e = 1)$ *two-photon transition*

f = 394 400 482 100 kHz

λ = 760 121 936.0 fm

with a relative standard uncertainty of 4.5×10^{-10}.

Acetylene transitions referenced by offset from the $^{13}C_2H_2$ *P*(*16*) (*ν1+ ν3*) *recommended transition*

$^{12}C_2H_2$, (ν1 + ν3) band at 1.54 μm

$^{13}C_2H_2$, (ν1 + ν3) and (ν1 + ν3 + ν4 + ν5) bands at 1.54 μm.

RECOMMENDATION CCL 2 (2005)
Recommended frequency standard values for applications including the practical realisation of the metre and secondary representations of the second

The Consultative Committee for Length,

considering

- the significant advance and growth in absolute frequency values of optical frequency standards brought about by comb measurements;
- the differing accuracy requirements of the CCL length metrology community and the CCTF secondary representations criteria;

proposes that:

- the MeP-CCL list of Recommended Radiations and CCTF Secondary Representation list be combined into a single list of "Recommended frequency standard values for applications including the practical realisation of the metre and secondary representations of the second";
- the CCL-MePWG and CCL/CCTF JWG be combined into a single CCL-CCTF frequency standards working group;
- the CCL may wish to select those frequencies which it considers important to highlight for use in high accuracy length metrology;
- other frequencies be proposed, evaluated and maintained on the frequency standards list by a CCL-CCTF frequency standards WG, but not necessarily accepted as CCL-preferred radiations or CCTF-accepted representations;
- the continued maintenance of such a frequency standards "category A" list from which the CCL and CCTF accepted values would be selected, together with the "category B" list representing those radiations still available for use, but where no further improvement in values and uncertainties was deemed necessary;
- the CCTF consider, evaluate and highlight those frequencies which it wishes to accept as secondary representations of the second;
- the schedule of CCTF and CCL meetings be rationalised to take place alternately, at appropriate intervals, ideally at a time of year close to but before the CIPM date;
- a meeting of the CCL-CCTF frequency standards WG should take place prior to the respective CC meeting if appropriate, in order to update the frequency list prior to consideration by the CC;
- the frequency values list is maintained on the BIPM website* with version control, and is structured at a basic level according to wavelength and frequency value, but forms a database capable of being searched by accuracy level or by frequency or by wavelength.

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* http://www.bipm.org/en/committees/cc/ccl/mep.html

Appendix L 1.
Working documents submitted to the CCL at its 12th meeting

Working documents submitted to the CCL at its 12th meeting are on restricted access.

APPENDIX L 2.
Report of the meeting of the *Mise en Pratique* Working Group
BIPM, Sèvres, 12-13 September 2005

The following reports the discussion and outcomes of the meeting of the CCL *Mise en Pratique* Working Group (MePWG) held at the BIPM on 12-13 September 2005.

The following were present: P. Balling (CMI), F. Bertinetto (IMGC-CNR), M.S. Chung (President of the CCL), P. Gill (NPL, Chairman of the MePWG), R. Hamid (UME), L.W. Hollberg (NIST), F.-L. Hong (NMIJ), A. Madej (NRC), H.S. Margolis (NPL), M. Merrimaa (MIKES), A. Onae (NMIJ), F. Riehle (PTB), D. Rovera (BNM-SYRTE), H. Suhng Suh (KRISS), J.-P. Wallerand (LNE-INM).

Also present: R. Felder (Executive Secretary of the CCL), L.-S. Ma, L. Robertsson, A.J. Wallard (Director of the BIPM), M. Zucco (BIPM).

The meeting was attended by 15 MePWG delegates, together with members of the BIPM, and presided over by the President of the CCL, Dr Myung Sai Chung, and the Director of the BIPM. The MePWG Chairman was Dr Patrick Gill of the NPL.

Executive Summary

At the opening of the meeting, Delegates were welcomed and the proposed agenda (see above) was approved.

The meeting began with a review by Raymond Felder (BIPM) of the returned questionnaires, which highlighted recent changes to the values and uncertainties of some of the radiations in the CCL recommended radiation list, and which identified new radiations where absolute frequency measurements had been made. From the measurements reported in 23 questionnaires returned, there were proposals for:

- six existing radiations to be updated with new values; and
- 11 new radiations to be considered for inclusion.

At the conclusion of the meeting, the result was as follows:

- six existing radiations were updated ($^{88}Sr^+$ ion at 674 nm, $^{171}Yb^+$ ion at 436 nm, $^{199}Hg^+$ ion at 282 nm, ^{40}Ca at 657 nm, $^{13}C_2H_2$ at 1.54 µm, $^{127}I_2$ at 514 nm);
- one new radiation was added (Sr neutral at 698 nm); and
- two radiations were extended in respect of tabulated wavelengths close to the recommended radiation (acetylene at 1.54 µm, Rb 2-photon at 761 nm).

The other radiations were considered not appropriate for inclusion in the MeP list, either on account of there being too little published data for consideration at this time or because of the considered likely general applicability of the radiation in the experimental arrangement presented.

The relationship between the CCL MeP recommended radiation list and the CCL/CCTF JWG secondary representation list was considered. A proposal was drawn up to co-ordinate the construction of a single list of recommended frequency values, whereby the CCL could select radiations it considered appropriate for the practical realization of the metre, and where the CCTF would highlight radiations it would accept as secondary representations of the second. To aid this proposal, it was also proposed to combine the CCL MePWG and the CCL/CCTF JWG. These proposals were taken forward both to the JWG and subsequently the CCL.

A short review of comb measurement capability was given by L.-S. Ma, highlighting the influence of environmental fluctuations; e.g. in air paths when looking to achieve comparison uncertainties at the 10^{-19} level. The need for general comb comparisons involving, e.g. iodine-stabilized lasers was considered, and the consensus was that adequate arrangements were in place through regional activities, or by comb calibrations at BIPM. Rather, the importance of training courses for comb operation was considered more relevant.

There was a preliminary discussion of issues surrounding the possible inclusion of an un-stabilized 633 nm He-Ne laser frequency in the recommended radiation list, prior to being taken forward to the following CCL meeting.

Updated radiations:

$^{88}Sr^+$ strontium ion $^2S_{1/2} - {}^2D_{5/2}$ quadrupole transition at 674 nm

Two recent measurements of the $^{88}Sr^+$ quadrupole transition were reported by H.S. Margolis (NPL) and A. Madej (NRC). The values were:

NPL:	444 779 044 095 484.6 (1.5) Hz	Margolis *et al., Science,* 2004, **306,** 1355.
NRC:	444 779 044 095 484 (15) Hz	Madej *et al., Phys. Rev. A,* 2004, **70,** 012507.
		Dubé *et al., Phys. Rev. Lett.,* 2005, **95,** 33001.

The weighted mean of these two values gives the current CCL value. Given the very good agreement (to 0.6 Hz) between laboratories, and with the previous values, the MePWG decided to adopt an uncertainty equal to the NPL uncertainty multiplied by a factor of two (3 Hz or 7×10^{-15}).

Thus the values $f = 444\ 779\ 044\ 095\ 484.6$ Hz

$\lambda = 674\ 025\ 590.863\ 136$ fm

with a relative standard uncertainty of 7×10^{-15}, apply to the radiation of a laser stabilized to the unperturbed transition observed with a trapped and cooled strontium ion. The values corresponds to the centre of the Zeeman multiplet.

$^{171}Yb^+$ ytterbium ion, $^2S_{1/2}$ (F = 0, m_F = 0) – $^2D_{5/2}$ (F = 2, m_F = 0) quadrupole transition at 436 nm

A new measurement of the $^{171}Yb^+$ 436 nm quadrupole transition, reported by F. Riehle (PTB), gives the value:

PTB: 688 358 979 309 307.65 (2.14) Hz Riehle, doc. CCL/MePWG/05-22.PTB

The value agrees with the previous PTB 2001 measurement to within the 1 σ uncertainty of that measurement. For the recent measurement, a full uncertainty budget was being prepared for submission to the CCL/CCTF JWG. The blackbody shift correction was not included in this uncertainty budget. The largest contribution to the uncertainty was the Cs fountain reference at just under 2 Hz. The contribution from the Yb^+ standard was less than 1 Hz. Further, two independent traps had been operated with the same cooling and probe lasers, and demonstrated differences of ~4 parts in 10^{16}. However, given that only one laboratory contributed a measurement of this transition, the MePWG decided it was prudent to round the PTB value to the nearest Hz to obtain the CCL value, and increase the stated uncertainty by a factor of three, and then rounded, to give 6 Hz total uncertainty.

The values f = 688 358 979 309 308 Hz

λ = 435 517 610.739 687 fm

with a relative standard uncertainty of 9×10^{-15}**,** apply to the unperturbed quadrupole transition of a trapped and cooled ytterbium ion.

$^{199}Hg^+$ mercury ion, $^2S_{1/2}$ (F = 0, m_F = 0) – $^2D_{5/2}$ (F = 2, m_F = 0) quadrupole transition at 282 nm

Since 2001, L. Hollberg reported that there had been some ten measurements made of the Hg^+ quadrupole transition, with a conservative uncertainty level assumed in the region of 10 Hz in order to account for the lack of characterization of the quadrupole shift. During the last two years, this had been shown to be much smaller and consistent with theoretical calculations. The most recent value for the quadrupole transition was

NIST: 1 064 721 609 899 144.98 (0.94) Hz Bergquist *et al*, submitted to *Nature.*

In view of there only being one laboratory's measurement of this transition, the MePWG considered it prudent to round the NIST value to the nearest Hz, and adopt an uncertainty of three time the quoted 0.94 Hz NIST uncertainty and rounded to 3 Hz or 3×10^{-15}.

Thus the values f = 1 064 721 609 899 145 Hz

λ = 281 568 867.591 968 6 fm

with a relative standard uncertainty of 3×10^{-15}**,** apply to the unperturbed quadrupole transition of a trapped and cooled mercury ion.

Neutral atom ^{40}Ca $^1S_0$ – $^3P_1$ Δm_J = 0 transition at 657 nm

Two new measurements were reported by Riehle (PTB) and Hollberg (NIST). The publication of the PTB measurement (from 2003) was in process, subsequent to referees' comments. The value had been corrected for chirp, in contrast to ealier measurements. The NIST measurement had not yet been submitted for publication. The largest systematic uncertainty (2.2 Hz) was that due to the residual collisional shift with hot atoms from the oven. The reported values are:

PTB: 455 986 240 494 144 (5.3) Hz Degenhardt *et al., Phys. Rev. A* (accepted).

NIST: 455 986 240 494 135.8 (3.4) HzUncertainty budget not yet published.

The MePWG reached the decision to recommend CCL adoption of the unweighted mean of the two values, with an uncertainty of 8 Hz, equal to the difference between the values.

Thus the values f = 455 986 240 494 140 Hz

λ = 657 459 439.291 683 fm

with a relative standard uncertainty of 1.8×10^{-14}**,** apply to the radiation of a laser stabilized to Ca atoms. The values correspond to the mean frequency of the two recoil-split components for atoms which are effectively stationary.

Acetylene $^{13}C_2H_2$ $(\nu_1 + \nu_3)$ *P*(*16*) *transition at 1542 nm*

Recent measurements for the acetylene P(16) transition were reported by four laboratories (CMI, NMIJ, NPL, NRC). A Madej noted that measurements at NRC had agreed to within 500 Hz over two years, indicating good reproducibility for a gas cell standard, where the NRC cells were pumped out everyday to the µPa level and refilled with acetylene. P. Balling described the CMI system which operated with more relaxed conditions, making use of a much lower power density with a single retro-reflection through the acetylene cell. In general, the reproducibility observed between systems with different acetylene cells were in the region of 1 kHz at the various laboratories. A. Madej commented that in general acetylene systems seemed better behaved than iodine systems, with better reproducibility, less sensitivity to re-alignment and impurity shifts.

The measurements reported were:

CMI: 194 369 569 384.875 (2.8) kHz Balling *et al., Opt. Express,* 2005, submitted.

NMIJ: 194 369 569 383.5 (1.3) kHz Jang *et al., Opt. Express,* 2005, **13**,1958.

NPL: 194 369 569 386.4 (1.1) kHz Edwards *et al., App. Phys. B,* 2005, **80,** 977.

NRC: 194 369 569 384 (2.5) kHz Czajkowski *et al., App. Phys. B,* 2004, **79,** 45.

However, these measurements were carried out with a variety of acetylene cell pressures (i.e. CMI 2 Pa, NMIJ 4 Pa, NPL 1 Pa and NRC 3 Pa). In order to combine these measurements, the values were converted to a common 3 Pa cell pressure by use of the pressure shift coefficients measured for the particular system (-0.3 kHz/Pa for CMI, 327 Hz/Pa for NMIJ, -503 Hz/Pa for NPL) giving rise to values at 3 Pa of :

CMI: 194 369 569 384.6 (2.8) kHz

NMIJ: 194 369 569 383.3 (1.3) kHz

NPL: 194 369 569 385.5 (1.1) kHz

NRC: 194 369 569 384 (2.5) kHz

The unweighted mean of these values gave 194 369 569 384.3 kHz. Given the good agreement between the different laboratories, the MePWG reduced the uncertainty from the 10 kHz 2003 value to 5 kHz, which corresponds to the quadrature sum of the quoted uncertainties, then rounded up. After due consideration, led by A. Madej, of the various operating conditions, and associated modulation, power and pressure shift coefficients measured for the various systems, the range of operating parameters were specified.

Thus the values f = 194 369 569 384 kHz

λ = 1 542 383 712.37 fm

with a relative standard uncertainty of 2.6×10^{-11}**,** apply to the radiation of a laser stabilized using the third harmonic detection technique to an external $^{13}C_2H_2$ cell within an enhancement cavity and subject to the following conditions:

- cell pressure 3 ± 2 Pa;
- frequency modulation width, peak-to-peak (1.5 ± 1) MHz; and
- one-way intracavity beam intensity of (25 ± 20) W cm^{-2}.

Iodine $^{127}I_2$ molecule, a_3 component, 43-0 P(13) transition at 515 nm

J.-P. Wallerand (LNE-INM) described the improved correspondence between values for the a_3 component from LPL Villateneuse and NIST/JILA Boulder. There was now good agreement to 0.5 kHz, bearing in mind that the iodine cell arrangement was significantly different for each case. The JILA sytem incorporates a sealed iodine cell, whereas the LPL arrangement uses a low pressure flowing gas cell. The LPL value was 582 490 603 42.6 (0.4) kHz. This represented the value corresponding to an effective iodine cold finger temperature of –5 °C. To achieve this, the actual value obtained using the very low iodine pressure in the flowing gas apparatus was corrected by 4.7 kHz using pressure shift data from previous works. The MePWG recommended value was the mean of the two values, with an uncertainty reduced from 10 kHz in 2003 to 5 kHz.

Thus the values f = 582 490 603 442.2 kHz

λ = 514 673 466.367 fm

with a relative standard uncertainty of 8.6×10^{-12} apply to the radiation of a laser stabilized with an iodine cell external to the laser, having an equivalent standard cell cold-finger temperature of (-5 ± 2) °C, corresponding to a pressure of (2.4 ± 0.5) Pa; with a saturating beam intensity < 40 mW cm^{-2}.

New radiations

^{87}Sr neutral atom, $^1S_0 - {}^3P_0$ transition at 698 nm

Two measurements (from University of Tokyo and JILA) were reported by F.L. Hong (NMIJ) and L. Hollberg, for the ^{87}Sr neutral atom $^1S_0 - {}^3P_0$ transition at 698 nm in a 1-dimensional lattice. These results were:

Tokyo: 429 228 004 229 952 (15) Hz Takamoto *et al., Nature,* 2005, **435**, 321.

JILA : 429 228 004 229 867 (20) Hz Ludlow *et al.,* ArXiv:physics, 2005, 0508041.

The two results thus differed by 85 Hz, which was considered to be significant, given the stated uncertainties from both institutes. As a result, the value recommended by the MePWG was the unweighted mean of these two values, with an adopted uncertainty equal to the discrepancy between measurements, corresponding to a square distribution.

Thus the values f = 429 228 004 229 910 Hz

λ = 698 445 709.612 694 fm

with a relative standard uncertainty of 2×10^{-13}, apply to the radiation of a laser stabilized to Sr atoms.

Extension of tabulated values for existing radiations

The CCL MePWG also proposes the addition of the following radiations to the supplementary tables of the recommended radiation list:

^{87}Rb $5S_{1/2} - 7\,S_{1/2}$ 2-photon transitions at 761 nm

$f = 2$ $\qquad f = 394\ 397\ 384\ 460\ (65)$ kHz

$\lambda = 760\ 127\ 906.4$ fm

with a relative standard uncertainty of 1.7×10^{-10}

$f = 1$ $\qquad f = 394\ 400\ 482\ 100\ (180)$ kHz

$\lambda = 760\ 121\ 936.4$ fm

with a relative standard uncertainty of 4.5×10^{-10}.

Acetylene at 1.54 μm (v1 + v3) band of $^{13}C_2H_2$

Results were reported from three laboratories (NMIJ/AIST, NPL and NRC). Values for the particular lines were determined from the unweighted mean of values from the three laboratories, where available, or from NPL and NRC for those lines where only these labs supplied values. The uncertainties were determined from the square root of the quadrature sum of individual line uncertainties divided by the number of labs contributing. The MeP data set for the $^{13}C_2H_2$ ($v_1 + v_3$) band, complete with rounded frequency values and uncertainties, is given later in draft recommendation CCL-WGMeP-2.

The source references for these tabulated values are:

NPL: Edwards *et al.* *Appl. Phys. B*, 2005, **80,** 977-983.

NRC: Madej *et al.* *JOSA B*, 2006, **23,** 741-749.

NMIJ: NMIJ/AIST response to 2005 CCL questionnaire

Line	Mean frequency offset from P(16) [kHz]	Uncertainty [kHz]
P31	-1 236 727 330.20	5.10
P30	-1 149 564 561.88	3.57
P29	-1 063 105 009.44	3.33
P28	-977 244 287.55	3.14
P27	-892 105 380.22	1.22
P26	-807 638 069.61	0.85
P25	-723 847 083.93	1.36
P24	-640 721 966.91	0.83
P23	-558 275 720.97	0.96
P22	-476 502 654.26	0.69
P21	-395 402 886.51	0.65
P20	-314 976 290.43	0.73
P19	-235 222 731.30	0.60
P18	-156 142 105.73	0.66
P17	-77 734 397.08	0.66
P16	–	–
P15	77 063 007.11	0.75
P14	153 451 226.21	0.74
P13	229 165 963.63	0.63
P12	304 206 524.34	0.97
P11	378 572 272.08	0.95
P10	452 257 031.84	0.73
P9	525 279 211.62	0.63
P8	597 619 759.46	0.86
P7	669 287 336.85	0.64
P6	740 285 115.99	0.65
P5	810 618 380.24	0.74
P4	880 294 497.67	0.82
P3	949 322 303.60	0.71
P2	1 017 710 756.54	0.67
P1	1085467073.04	1.11
R0	1 219 093 121.98	0.80
R1	1 284 956 011.47	0.92
R2	1 350 174 197.69	0.82
R3	1 414 736 583.69	0.73
R4	1 478 632 192.36	0.92
R5	1 541 851 516.94	0.73
R6	1 604 387 135.95	0.85
R7	1 666 233 736.01	0.78
R8	1 727 380 518.76	0.73
R9	1 787 844 397.35	0.71
R10	1 847 604 826.32	0.71
R11	1 906 665 847.46	0.70
R12	1 965 025 955.80	0.94
R13	2 022 683 713.90	0.71
R14	2 079 635 679.90	0.73
R15	2 135 883 115.73	0.86
R16	2 191 421 970.08	0.75
R17	2 246 250 501.89	1.00
R18	2 300 366 566.67	1.09

R19	2 353 767 927.71	0.91
R20	2 406 452 321.11	0.70
R21	2 458 417 491.85	0.80
R22	2 509 661 431.50	0.82
R23	2 560 176 323.61	1.10
R24	2 609 973 043.93	1.05
R25	2 659 039 015.41	1.27
R26	2 707 376 844.07	1.27
R27	2 754 934 186.51	1.27
R28	2 801 831 907.74	2.12
R29	2 847 963 516.42	2.12

($v_1 + v_2 + v_4 + v_5$) band of $^{13}C_2H_2$

Results were reported from one laboratory (NPL).

The source data is published in Edwards *et al.* *Appl. Phys. B, 2005,* **80,** 977-983.

Line	Frequency/kHz	u_c/kHz
	194 307 400 766.8	0.8
P(21)	194 387 420 759.6	2.3
P(20)	194 466 700 976.9	1.7
P(19)	194 545 255 870.8	4.8
P(18)	194 623 100 111.2	2.6
P(17)	194 700 248 978.2	1.0
P(16)	194 776 717 968.1	1.0
P(15)	194 852 522 484.8	2.7
P(14)	194 927 677 581.2	1.2
P(13)	195 002 197 738.0	1.6
P(12)	195 076 096 694.2	0.6
P(11)	195 149 387 299.6	0.7
P(10)	195 222 081 408.7	1.7
P(9)	195 294 189 794.0	1.1
P(8)	195 365 722 096.2	1.6
P(7)	195 436 686 781.0	1.7
P(6)	195 507 091 119.7	3.6
P(5)	195 576 941 186.7	3.3
P(4)	195 646 241 846.7	2.3
P(3)	195 714 996 769.2	1.1
P(2)	195 783 208 425.6	1.7
P(1)	195 850 878 106.6	4.3
R(0)	195 984 590 790.5	0.8
R(1)	196 050 630 476.3	1.9
R(2)	196 116 121 548.2	0.7
R(3)	196 181 059 389.5	1.7
R(4)	196 245 438 196.5	1.0
R(5)	196 309 250 959.4	1.4
R(6)	196 372 489 470.8	0.8
R(7)	196 435 144 317.1	1.9
R(8)	196 497 204 894.6	1.4
R(9)	196 558 659 425.1	2.4
R(10)	196 619 494 998.4	1.0
R(11)	196 679 697 623.3	2.2
R(12)	196 739 252 313.1	1.8
R(13)	196 798 143 194.5	1.2
R(14)	196 856 353 649.9	1.1
R(15)	196 913 866 493.5	1.1
R(16)	196 970 664 189.8	1.8
R(17)	197 026 729 109.6	3.0
R(18)	197 082 043 836.1	3.0
R(19)	197 136 591 575.5	3.0
R(20)	197 190 355 743.3	3.0

To incorporate these absolute frequencies as tabulated values within the MeP recommended radiation list, their uncertainties are multiplied by a factor 3 in order to take account of one laboratory only contributing. However, where this increased uncertainty is less than the 2.6×10^{-11} uncertainty associated with the (ν1 + ν3) P(16) reference transition, this latter value is quoted. The MeP data set for the $(\nu_1 + \nu_2 + \nu_4 + \nu_5)$ band, complete with increased uncertainties and rounded frequency values, is given in draft resolution CCL-WGMeP-2 later in this report.

(v_1 + v_3) band of $^{12}C_2H_2$

Results were reported from one laboratory (NPL).

The source data is published in: Edwards *et al.* *J. Mol. Spectr.*, 2005, **234,** 143-148.

Line	Frequency/kHz	type A u_c/kHz	combined u_c/kHz
P(31)	194 018 374 094.1	7.6	12.6
P(30)	194 111 459 728.8	18.3	20.9
P(29)	194 203 815 942.5	1.8	10.2
P(28)	194 295 440 627.0	2.8	10.4
P(27)	194 386 332 292.8	3.5	10.6
P(26)	194 476 488 872.9	0.8	10.0
P(25)	194 565 910 200.2	3.4	10.6
P(24)	194 654 593 138.9	4.8	11.1
P(23)	194 742 536 730.3	2.5	10.3
P(22)	194 829 739 424.6	2.0	10.2
P(21)	194 916 199 708.2	3.2	10.5
P(20)	195 001 916 082.3	3.5	10.6
P(19)	195 086 887 070.5	2.8	10.4
P(18)	195 171 111 213.5	3.2	10.5
P(17)	195 254 587 071.2	1.5	10.1
P(16)	195 337 313 215.0	2.2	10.2
P(15)	195 419 288 238.9	2.6	10.3
P(14)	195 500 510 747.7	1.1	10.1
P(13)	195 580 979 371.1	2.0	10.2
P(12)	195 660 692 745.2	3.1	10.5
P(11)	195 739 649 524.7	1.0	10.0
P(10)	195 817 848 382.3	3.2	10.5
P(9)	195 895 288 001.6	2.6	10.3
P(8)	195 971 967 085.9	1.5	10.1
P(7)	196 047 884 350.2	2.8	10.4
P(6)	196 123 038 521.4	2.3	10.3
P(5)	196 197 428 345.7	2.1	10.2
P(4)	196 271 052 581.9	2.4	10.3
P(3)	196 343 910 000.6	7.8	12.7
P(2)	196 415 999 399.1	2.9	10.4
P(1)	196 487 319 567.0	1.9	10.2
R(0)	196 627 647 488.1	2.1	10.2
R(1)	196 696 652 920.3	0.9	10.0
R(2)	196 764 884 471.3	1.0	10.0
R(3)	196 832 341 013.2	2.7	10.4
R(4)	196 899 021 431.4	1.2	10.1
R(5)	196 964 924 627.6	1.1	10.1
R(6)	197 030 049 517.7	2.7	10.4
R(7)	197 094 395 033.3	2.7	10.4
R(8)	197 157 960 120.5	2.7	10.4
R(9)	197 220 743 737.0	2.7	10.4

A conservative correction of +10 kHz is included in the frequencies given in the table, to take into account the presence of contaminants in the particular $^{12}C_2H_2$ cell used (see Edwards *et al., J. Mol. Spectr., 2005,* **234,** 143-148 for the method used). The combined uncertainty is obtained by combining the type A uncertainty with the type B uncertainty (10 kHz for all lines) in quadrature. The MeP data set for the $^{12}C_2H_2$ ($\nu_1 + \nu_3$) band, complete with rounded frequency values and uncertainties, is given in draft resolution CCL-WGMeP-2 later in this report.

Radiations not recommended by the MePWG at this time

$^{27}Al^+$ aluminium ion $^1S_0 - {}^3P_0$ transition at 267 nm

A recent measurement of this ultra-narrow (~ mHz theoretical linewidth) transition had been made at NIST relative to the Hg^+ ion standard, giving the value 1 121 015 393 207 857.4 (1.1) Hz. However, this result had not been fully evaluated at this time and no formal report was provided to the working group. As a result, it was considered too early to make serious consideration of this transition, and further discussion of the transition was postponed to the following CCL/CCTF JWG.

^{88}Sr neutral atom, $^1S_0 - {}^3P_1$ transition at 690 nm

A measurement of this transition had been made at JILA (ref) and gave the value :

434 829 121 312 334 (39) Hz.

This had been carried in a free space geometry, and the 39 Hz stated uncertainty was considered "ambitious" in view of the correction applied. In view of the 85 Hz discrepancy observed between the Tokyo and JILA ^{87}Sr neutral atom, $^1S_0 - {}^3P_0$ transition at 698 nm, it was felt that more work was needed before considering this transition further.

^{171}Yb and ^{173}Yb neutral atom $^1S_0 - {}^3P_0$ transitions at 578 nm

Preliminary values for the ^{171}Yb F = 1/2 and ^{173}Yb F = 5/2 transitions had been measured at NIST in laser cooled trapped Yb atoms, with quoted uncertainties of 4.4 kHz. Given the narrow theoretical linewidth of these transitions, it was considered too early to make serious consideration of these wavelengths, and inappropriate to add them to the recommended list

^{133}Cs, 895 nm, 6 $S_{1/2}$ — 6 $P_{1/2}$ transitions

^{133}Cs, 852 nm, 6 $S_{1/2}$ — 6 $P_{1/2}$ transitions

L. Hollberg reported comb measurements of these single photon transitions in a cold Cs beam, with uncertainties of 2.4 kHz and 5.1 kHz. Whilst these uncertainties are significantly lower than previous measurements, there was no precedent for inclusion of single photon data from orthogonally-probed atomic beams, and it was unlikely for such a radiation to be realized widely in this form. Thus, although the importance of Cs D1 line in determination of *h*/*m* Cs (and hence α) was recognized, the transitions were considered not to be practically useful for length metrology at present.

^{87}Rb, $5S_{1/2}$ — $5P_{1/2}$ ($F = 2$) transition at 795 nm

A value for this single photon transition had been determined from direct comb spectroscopy, yielding an uncertainty of 180 kHz. In view of this large uncertainty, and the unlikelihood of its widespread use in this single photon form, it was not considered appropriate for inclusion.

Iodine $^{127}I_2$ molecule, a_7 component, 62-0 R(26) transition at 502 nm

J.-P. Wallerand reported a measurement of this iodine transition with an Ar^+ ion laser and continuously pumped iodine cell. A measurement uncertainty of 0.85 kHz was quoted, but a discrepancy of 17 kHz existed with previous high-accuracy measurement of hyperfine splittings by Camy. This transition was potentially of metrological interesting from the view that the hyperfine components have natural linewidths of only 20–30 kHz, a good deal narrower than most iodine transitions.

However, further discussion was not considered necessary until the discrepancy had been resolved

Evolution of the MeP list of recommended radiations and inter-relation with the list of secondary representations of the second

The observation was made that there was a significantly increased number of radiations/ measurements reported, brought about primarily by the advance of comb technology. This was considered likely to contribute to difficulties arising from proliferation of the recommended radiation list in the longer term, and ways to deal with this were desirable. Consideration was also given to the question of sub-division of the list into various categories such as those wavelengths for the realization of the metre, for use in telecomms traceability, and for use as secondary representations of the second. There was strong and almost unanimous agreement that there should be only one list, primarily to avoid the possibility of the same radiation having values and uncertainties adopted that were different depending on consideration by the MePWG or the CCL/CCTF Joint Working Group (JWG) on Secondary Representations of the Second. With a single recommended radiation list, sub-sets of radiations could be identified; e.g. for MeP use, telecomms use and secondary representation use. The list should be web-based, evaluated and maintained by the MePWG and CCL/CCTF JWG. This could enable the CCL and CCTF to ratify particular radiations that conformed to the respective criteria; e.g. for practical realization of the metre or for secondary representation of the second. It was recognised that the CCL and CCTF were responsible only for ratifying those radiations appropriate to their respective applications (e.g. for practical length metrology or for secondary representations). It was accepted that a future recommended radiation list would have a greater extent than the totality of highlighted subsets, but this would enable access by the wider community to a properly maintained reference list. There was some discussion as to the merits of extending the list to include microwave standards, but no firm conclusion reached here.

With the development of a single unified list of radiations, it was considered that a new name was desirable, such as “Recommended frequency standard values for applications including the practical realization of the metre and secondary representations of the second”. In parallel with this development, it was felt by the WG that the MePWG and the CCL/CCTF JWG should be combined into a single WG taking responsibility for the maintenance of the list. It was suggested that a new combined WG should meet prior to every CCL and CCTF to propose additions and changes. However it was noted that ratification of particular proposals by the appropriate CC might have to wait for periods up to 2 years, given the non-synchronisation of the CCL and CCTF meetings.

Femtosecond comb comparisons

L.-S. Ma (BIPM) gave a short introduction to this item, describing the improvements in the highest accuracy comb comparisons that had taken place since 2003 at the NIST. In 2003, the comparison of a number of combs from the NIST, BIPM and East China National University, all locked to the same 657 nm diode laser, demonstrated a mean difference between systems of 1.1×10^{-20} with an uncertainty of $\pm 1.4 \times 10^{-19}$. In 2004, this had given a weighted mean difference of $(0.55 \pm 1.1) \times 10^{-19}$. Environmental conditions had been found to be very important, with problems induced due to the fluctuating air paths between two combs on the same optical table.

Following this, there was general discussion of the need for comb comparisons. L.-S. Ma commented that the important issues in ensuring good comb measuring accuracy was to have a god knowledge of the reference performance, phase locks and synthesiser performance. F. Riehle commented that he didn't see the need for a programme of comb comparisons, rather he felt there was a need for training of new personnel in the use of combs, and asked if BIPM could offer this. L. Robertsson (BIPM) commented that this was a perfectly good suggestion to propose to the CIPM.

A suggestion was made for the use of a portable stabilized laser to be circulated between labs to enable comb comparisons to be undertaken, perhaps in a similar manner to the way BIPM-4 had been employed in BIPM.L-K10 laser international comparisons. P. Gill commented that a methodology had been established at the last CCL, whereby BIPM would only be involved in the highest accuracy comb comparisons at NMIs. Typically these would involve high stability lasers associated with cold atom and ion frequency standards. For the provision of traceability to gas cell stabilized systems such as iodine-stabilized lasers, there were options available to take the laser to a regional NMI with a high accuracy comb capability, or to the BIPM directly. A number of NMIs with the high accuracy capability commented that they planned to offer comb-based calibration services. In addition the BIPM.L-K11 protocol for the intercomparison of stabilized lasers allows the use of comb based measurements as well as standard matrix measurement and acousto-optic heterodyne techniques. BIPM have already hosted comb measurements under the -K11 protocol.

BIPM.L-K11 comparisons

L. Robertsson (BIPM) felt that discussion of activity under this category should be postponed until the CCL, and this was accepted.

Unstabilized He-Ne lasers

In anticipation of expected discussion within the CCL of a possibility to include a value for an unstabilized He-Ne laser in the MeP recommended radiation list, the MePWG discussed some of the issues which might arise in this instance. These included:

- The level of accuracy for which this might be safe to do? (1 in 10^5?)
- Would MeP publication result in an unstabilized laser becoming a "primary standard" for traceable metrology?
- Were there any implications for traceability (e.g. requirements for conformance to ISO 17025, local calibration procedure eg UKAS, CMC statements)? Was there a requirement for an associated good practice guide and need for diagnostic tests in some applications?
- Were there likely to be any product specification issues, whereby manufacturers of Nd:YAG and diode lasers would seek endorsement by inclusion in the list?

Further discussion of this topic was postponed until the CCL, where the views of the WGDM would be presented.

Draft recommendations for presentation to the CCL

CCL-MePWG-1

The Consultative Committee for Length **proposes** that the CIPM adopt the following updated values for existing recommended radiations:

Absorbing ion $^{88}Sr^+$*, 5s* $^2S_{1/2}$ *– 4d* $^2D_{5/2}$ *transition*

The values f = 444 779 044 095 484.6 Hz

λ = 674 025 590.863 136 fm

with a relative standard uncertainty of 7×10^{-15}, apply to the radiation of a laser stabilized to the unperturbed transition observed with a trapped and cooled strontium ion. The values correspond to the centre of the Zeeman multiplet.

Absorbing ion $^{199}Hg^+$*,* $5d^{10}6s\,^2S_{1/2}$ $(F = 0, m_F = 0) – 5d^9 6s^2\,^2D_{5/2}$ $(F = 2, m_F = 0)$ *transition*

The values f = 1 064 721 609 899 145 Hz

λ = 281 568 867.591 968 6 fm

with a relative standard uncertainty of 3×10^{-15}**,** apply to the unperturbed quadrupole transition of a trapped and cooled mercury ion.

Absorbing ion $^{171}Yb+$*, 6s* $^2S_{1/2}$ $(F = 0, m_F = 0) – 5d\,^2D_{5/2}$ $(F = 2, m_F = 0)$ *transition*

The values f = 688 358 979 309 308 Hz

λ = 435 517 610.739 687 fm

with a relative standard uncertainty of 9×10^{-15}**,** apply to the unperturbed quadrupole transition of a trapped and cooled ytterbium ion

Absorbing atom ^{40}Ca, $^1S_0 - {}^3P_1$; $\Delta m_J = 0$ transition

The values $f = 455\ 986\ 240\ 494\ 140$ Hz

$\lambda = 657\ 459\ 439.291\ 683$ fm

with a relative standard uncertainty of 1.8×10^{-14}**,** apply to the radiation of a laser stabilized to Ca atoms. The values correspond to the mean frequency of the two recoil-split components for atoms which are effectively stationary.

Absorbing molecule $^{13}C_2H_2$ P(16) ($\nu 1 + \nu 3$) transition

The values $f = 194\ 369\ 569\ 384$ kHz

$\lambda = 1\ 542\ 383\ 712.37$ fm

with a relative standard uncertainty of 2.6×10^{-11} apply to the radiation of a laser stabilized using the third harmonic detection technique to an external $^{13}C_2H_2$ cell within an enhancement cavity and subject to the following conditions:

- cell pressure (3 ± 2) Pa;
- frequency modulation width, peak-to-peak (1.5 ± 1) MHz; and
- one-way intracavity beam intensity of (25 ± 20) W cm^{-2}.

Absorbing molecule $^{127}I_2$, a3 component, P(13) 43-0 transition

The values $f = 582\ 490\ 603\ 442$ kHz

$\lambda = 514\ 673\ 466.367$ fm

with a relative standard uncertainty of 8.6×10^{-12}**,** apply to the radiation of a laser stabilized with an iodine cell external to the laser, having an equivalent standard cell cold-finger temperature of (-5 ± 2) °C, corresponding to a pressure of (2.4 ± 0.5) Pa; with a saturating beam intensity < 40 mW cm^{-2}.

CCL-MePWG-2

The Consultative Committee for Length **proposes** the following recommended radiation values for addition to the recommended radiation list:

Absorbing atom ^{87}Sr, $5s^2\ {}^1S_0 - 5s5p\ {}^3P_0$ transition

$f = 429\ 228\ 004\ 229\ 910$ Hz

$\lambda = 698\ 445\ 709.612\ 694$ fm

with a relative standard uncertainty of 2×10^{-13}**,** apply to the radiation of a laser stabilized to Sr atoms.

The CCL also proposes the addition of the following radiations to the supplementary tables of the recommended radiation list:

Absorbing atom ^{87}*Rb*, $5S_{1/2}$ $(F = 2) – 7S_{1/2}$ $(F = 2)$ *2-photon transition*

f = 394 397 384 460 kHz

λ = 760 127 906.4 fm

with a relative standard uncertainty of 1.7×10^{-10}.

Absorbing atom ^{87}*Rb*, $5S_{1/2}$ $(F = 1) – 7S_{1/2}$ $(F = 1)$ *2-photon transition*

f = 394 400 482 100 kHz

λ = 760 121 936.0 fm

with a relative standard uncertainty of 4.5×10^{-10}.

Acetylene transitions within the following bands:

$^{13}C_2H_2$, *1.54 µm, (v1 + v3) bands, referenced by offset from the P(16) (v1+ v3) reference transition:*

Line	Mean frequency offset from P(16) [kHz]	Uncertainty [kHz]
P31	-1 236 727 330	5
P30	-1 149 564 562	4
P29	-1 063 105 009	3
P28	-977 244 288	3
P27	-892 105 380	1
P26	-807 638 070	1
P25	-723 847 084	1
P24	-640 721 967	1
P23	-558 275 721	1
P22	-476 502 654	1
P21	-395 402 887	1
P20	-314 976 290	1
P19	-235 222 731	1
P18	-156 142 106	1
P17	-77 734 397	1
P16	–	–
P15	77 063 007	1
P14	153 451 226	1
P13	229 165 964	1
P12	304 206 524	1
P11	378 572 272	1
P10	452 257 032	1
P9	525 279 212	1
P8	597 619 759	1
P7	669 287 337	1

P6	740 285 116	1
P5	810 618 380	1
P4	880 294 498	1
P3	949 322 304	1
P2	1 017 710 757	1
P1	1 085 467 073	1
R0	1 219 093 122	1
R1	1 284 956 011	1
R2	1 350 174 198	1
R3	1 414 736 584	1
R4	1 478 632 192	1
R5	1 541 851 517	1
R6	1 604 387 136	1
R7	1 666 233 736	1
R8	1 727 380 519	1
R9	1 787 844 397	1
R10	1 847 604 826	1
R11	1 906 665 847	1
R12	1 965 025 956	1
R13	2 022 683 714	1
R14	2 079 635 680	1
R15	2 135 883 116	1
R16	2 191 421 970	1
R17	2 246 250 502	1
R18	2 300 366 567	1
R19	2 353 767 928	1
R20	2 406 452 321	1
R21	2 458 417 492	1
R22	2 509 661 432	1
R23	2 560 176 324	1
R24	2 609 973 044	1
R25	2 659 039 015	1
R26	2 707 376 844	1
R27	2 754 934 187	1
R28	2 801 831 908	2
R29	2 847 963 516	2

Offset values from P(16) for the particular lines were determined from the unweighted mean of values from the different source data. The uncertainties were determined from the square root of the quadrature sum of individual line uncertainties divided by the number of laboratories contributing, with values and uncertainties rounded to the nearest kHz. To determine absolute frequency values for a particular line, it is necessary to add in quadrature the 2.6×10^{-11}**.** CIPM uncertainty (5 kHz) of the P(16) reference transition.

$^{13}C_2H_2$, 1.54 µm, (*v1+ v3+ v4+ v5*) *bands*

Line	Frequency/kHz	u_c/kHz
P(22)	194 307 400 767	5
P(21)	194 387 420 760	7
P(20)	194 466 700 977	5
P(19)	194 545 255 871	14
P(18)	194 623 100 111	8
P(17)	194 700 248 978	5
P(16)	194 776 717 968	5
P(15)	194 852 522 485	8
P(14)	194 927 677 581	5
P(13)	195 002 197 738	5
P(12)	195 076 096 694	5
P(11)	195 149 387 300	5
P(10)	195 222 081 409	5
P(9)	195 294 189 794	5
P(8)	195 365 722 096	5
P(7)	195 436 686 781	5
P(6)	195 507 091 120	11
P(5)	195 576 941 187	10
P(4)	195 646 241 847	7
P(3)	195 714 996 769	5
P(2)	195 783 208 426	5
P(1)	195 850 878 107	13
R(0)	195 984 590 791	5
R(1)	196 050 630 476	6
R(2)	196 116 121 548	5
R(3)	196 181 059 390	5
R(4)	196 245 438 197	5
R(5)	196 309 250 959	5
R(6)	196 372 489 471	5
R(7)	196 435 144 317	6
R(8)	196 497 204 895	5
R(9)	196 558 659 425	7
R(10)	196 619 494 998	5
R(11)	196 679 697 623	7
R(12)	196 739 252 313	5
R(13)	196 798 143 195	5
R(14)	196 856 353 650	5
R(15)	196 913 866 494	5
R(16)	196 970 664 190	5
R(17)	197 026 729 110	9
R(18)	197 082 043 836	9
R(19)	197 136 591 576	9
R(20)	197 190 355 743	9

Since there was only one laboratory supplying data for this band (C.S. Edwards *et al., App. Phys. B,* 2005, **80,** 977), the uncertainties quoted there are increased by a factor 3. In cases where this increased value is less than the 2.6×10^{-11} uncertainty (5 kHz) of the P(16) (ν1 + ν3) reference transition, this 5 kHz uncertainty is quoted instead.

$^{12}C_2H_2$, 1.54 µm, (v1 + v3) band

Line	Frequency/kHz	u_c/kHz
P(31)	194 018 374 094	13
P(30)	194 111 459 729	21
P(29)	194 203 815 943	10
P(28)	194 295 440 627	10
P(27)	194 386 332 293	11
P(26)	194 476 488 873	10
P(25)	194 565 910 200	11
P(24)	194 654 593 139	11
P(23)	194 742 536 730	10
P(22)	194 829 739 425	10
P(21)	194 916 199 708	11
P(20)	195 001 916 082	11
P(19)	195 086 887 071	10
P(18)	195 171 111 214	11
P(17)	195 254 587 071	10
P(16)	195 337 313 215	10
P(15)	195 419 288 239	10
P(14)	195 500 510 748	10
P(13)	195 580 979 371	10
P(12)	195 660 692 745	11
P(11)	195 739 649 525	10
P(10)	195 817 848 382	11
P(9)	195 895 288 002	10
P(8)	195 971 967 086	10
P(7)	196 047 884 350	10
P(6)	196 123 038 521	10
P(5)	196 197 428 346	10
P(4)	196 271 052 582	10
P(3)	196 343 910 001	13
P(2)	196 415 999 399	10
P(1)	196 487 319 567	10
R(0)	196 627 647 488	10
R(1)	196 696 652 920	10
R(2)	196 764 884 471	10
R(3)	196 832 341 013	10
R(4)	196 899 021 431	10
R(5)	196 964 924 628	10
R(6)	197 030 049 518	10
R(7)	197 094 395 033	10
R(8)	197 157 960 121	10
R(9)	197 220 743 737	10

The uncertainty quoted in the source data to account for the presence of contaminants in the particular $^{12}C_2H_2$ cell used (see Edwards *et al., J. Mol. Spectr*., 2005) is considered to be sufficiently conservative such that a further multiplier of the uncertainty is not required. This is also confirmed from comparison with recent unpublished results from NRC.

CCL-MePWG-3

The Consultative Committee for Length,

considering

- the significant advance and growth in absolute frequency values of optical frequency standards brought about by comb measurements,
- the differing accuracy requirements of the CCL length metrology community and the CCTF secondary representations criteria,

proposes that

- the MeP-CCL list of recommended radiations and CCTF secondary representation list be combined into a single list of “Recommended frequency standard values for applications including the practical realization of the metre and secondary representations of the second”,
- the CCL-MePWG and CCL/CCTF JWG be combined into a single CCL-CCTF frequency standards working group,
- the CCL may wish to select those frequencies which it considers important to highlight for use in high accuracy length metrology,
- the CCTF consider, evaluate and highlight those frequencies which it wishes to accept as secondary representations of the second,
- other frequencies be proposed, evaluated and maintained on the frequency standards list by a CCL-CCTF frequency standards WG, but not necessarily accepted as CCL-preferred radiations or CCTF-accepted representations,
- the continued maintenance of such a frequency standards “category A” list from which the CCL and CCTF accepted values would be selected, together with the “category B” list representing those radiations still available for use, but where no further improvement in values and uncertainties was deemed necessary,
- the schedule of CCTF and CCL meetings be rationalised to take place alternately, at appropriate intervals, ideally at a time of year close to but before the CIPM date,
- a meeting of the CCL-CCTF frequency standards WG should take place prior to the respective CC meeting if appropriate, in order to update the frequency list prior to consideration by the CC,
- the frequency values list is maintained on the BIPM website with version control, and is structured at a basic level according to wavelength and frequency value, but forms a database capable of being searched by accuracy level.

APPENDIX L 3.
REPORT OF THE MEETING OF WORKING GROUP ON DIMENSIONAL METROLOGY TO THE 12TH MEETING OF THE CCL
BIPM, 12-13 SEPTEMBER 2005

Since the last CCL meeting (CCL 10), we have held two working group meetings; WGDM 9 at the NIM, Beijing, China (27-28 September 2004) and WGDM 10 at the BIPM, at Sèvres (12-13 September 2005). Our policy of moving the focus of our activities towards the regions continues with our next meeting in 2006 to be held in Mexico.

A full set of documents from these meeting can be obtained from the BIPM website so this is a summary of the key points.

SUMMARY OF THE TWO MEETINGS

WGDM 9 – 27-28 September 2004, China

The meeting followed the normal format with regional reports presented from the APMP, COOMET, EUROMET, SADCMET and SIM. These were followed by reports on the key comparison programme, reviewing the progress of comparisons in progress and reports on completed comparisons.

Future directions in nano-metrology were discussed. While nano-technology is clearly developing into a major driver of future industrial development and many NMIs are developing measurement capabilities on the nano-scale, there has been almost no demand for traceable dimensional measurements from industry. Investment in these instruments is very costly so we are keeping a close watch on developments. Dr Vitushkin stepped down as moderator of the nano-metrology discussion group and he was thanked for running a very active programme and series of pilot studies. Dr Wilkening (PTB) has now taken on this role.

CIPM MRA activities were discussed with a review of the WGDM standardized service categories (DimVIM) which have now been translated into a number of languages to promote its use throughout the regions. It has already been adopted by some accreditation services. The procedures to be followed by comparison pilots were reviewed and a concise "Advice to KC pilots" approved.

A workshop was conducted on the CCL RMO key comparisons proposed by the WGDM and adopted at CCL 10. Some ground rules were developed to establish responsibilities and the best procedure to be followed.

WGDM 10 – 12-13 September 2005, BIPM

This meeting kept the normal reporting on regional activities, key comparisons and discussion group activities to the first day. On the first session of the second day the terms of reference for the working group were discussed. The rest of this day was then dedicated to an analysis of comparison data. This included a workshop on key comparison analysis which was organized by Dr Jennifer Decker with special guests Dr Maurice Cox and Dr Alan Steele. A smaller group, which included our guests, met again on the third day (14 September) to produce a set of recommendations on key comparison analysis to be presented to CCL 12 on the following day.

MEETING RECOMMENDATIONS IN MORE DETAIL

WGDM 9

The following list is a summary of the major decisions and recommendations made at the 9th meeting in China (WGDM 9). The minutes give a more comprehensive account. Items are numbered according to the minutes.

General items

1 -2. Distribution of documents before WGDM meetings:

Send them to the WGDM website well in advance.

3. Membership of the WGDM:

WGDM membership to be decided by CCL. Current mailing list to be defined by delegates who were at the most recent meeting, plus those that apologized for absence from that meeting. The WGDM Chairman will email all recipients as to whether or not they wish to remain on the mailing list.

Items relating to key and supplementary comparison results and reports

4.-8. The meeting reviewed the reporting process for key comparisons and emphasized the key role played by the WGDM in reviewing all reports of comparisons before they are entered in the KCDB.

9. Use of non-CMC services and equipment in key comparisons:

Only those services for which there are, or will be, a corresponding CMC entry may contribute to the KCRV and may be entered into the KCDB list of results.

Results obtained from other services or instruments may be reported in the Final Report but will not form part of the KCRV calculations nor be part of the Appendix to the report which calculates degrees of equivalence.

10. CCL RMO key comparisons:

In respect of the new style of CCL RMO key comparisons, it was decided that:

- the CCL/WGDM will monitor the programme;
- the RMO TCLs should have the final decision on who participates in their comparisons;
- RMO TCLs should send their key comparison schedule to the WGDM for distribution to all RMO TCLs;
- participants must apply through their RMO-TCL if they wish to participate in comparisons in other regions;

- RMO TCLs must send key comparison technical protocols (at the start of the comparison) and final reports to the CCL/WGDM for comment.

Items relating to key and supplementary comparison results and reports

11. EUROMET.L-K5.2004 CCL RMO key comparison:

The WGDM reviewed the protocol and participant list for this first CCL RMO key comparison and gave its approval to the pilot.

Items relating to MRA appendix C

12. Updated and translated DimVIM: The latest English language version of the DimVIM (3 August 2003) plus recent translations into Finnish, German and Spanish were approved by the WGDM for the Chairman to send to the BIPM WGDM document website.

Items relating to Discussion Groups

13. Nanometrology discussion group: Following the request by Dr Vitushkin to step down from moderating DG7, the WGDM welcomed the nomination of Dr Wilkening from PTB and, following further email correspondence confirmed Dr Wilkening was appointed as DG7 moderator.

WGDM 10

Comparison programme

5 report approvals (one qualifies as inter-regional).

2 new inter-regional comparisons started.

Issues: Need more activity in some regions to balance the regions so inter-regional participation isn't all one way. Rules need to be developed.

Working group membership

It was pointed out that responsibilities, terms of reference and membership of CCL working groups is a matter for CCL12. New roles were being proposed for working groups so there was a need for a better definition of the WGs. Also, the term of office for the Chairman should be defined. Given that the CCL is responsible for appointing the chair; if a 4 year term is appropriate, a new appointments need to be made at every second CCL meeting. The new chair could take over during/after the non-CCL WG meeting.

The meeting recommended that membership should be flexible to adjust to new technologies, but may need two membership types; those that represent CCL member laboratories for voting on comparison reports, and an open membership for expanding our horizons, running comparisons, etc.

Recommendations of the workshop on key comparison analysis

Basic recommendation:

Unless there are good reasons to the contrary, the recommended steps to be followed when analysing key comparison data, are those as outlined by Dr Cox in document WGDM-05-86.

Outline:

This is based on using of the Excel based 'En toolkit' as developed by Douglas and Steele, during and after the data acquisition phase of the comparison.

Specifically, the steps to be followed during the analysis phase of the comparison are as follows:

1. Perform an extended chi-squared (null-hypothesis) consistency check on the data submitted by the participants (result, uncertainty, degrees of freedom) based on the inverse variance weighted mean as the KCRV
2. If the consistency check is satisfied at the 5 % level:
    - use the weighted mean as the KCRV and use the formal uncertainty of the weighted mean as the uncertainty of the KCRV;
    - derive unilateral and bilateral degrees of equivalence for all the participants, and publish.
3. If the consistency check fails at the 5 % level:
    - determine the largest subset of participants which is consistent with the chi-squared null hypothesis test;
    - alert participants not in the largest subset that there may be problems with their data. Try and find reasons for inconsistent data (blunder correction, technique differences, etc);
    - set the weights of the participants not in the chosen subset to zero, only for determining the KCRV and its formal uncertainty;
    - if the largest subset is considered to be too small, consider reporting only bi-lateral degrees of equivalence (i.e. no KCRV); ***or***
    - perform additional modelling (e.g. drift, travelling artefact uncertainty);
    - derive unilateral and bilateral degrees of equivalence (as appropriate) for <u>all</u> the participants, and publish.

Membership

The meeting agreed that as the WGDM has been asked to manage more work on behalf of the CCL, the *ad hoc* arrangement for defining WGDM membership needs to be changed to a more formal one which guarantees a similar balance to the CCL membership. It is on the Agenda for CCL 12 to decide the responsibilities, terms of reference and membership of CCL working groups. Our aim is to maintain the very broad and inclusive membership regime we have operated with in the past, but we may have to restrict voting rights to CCL member laboratories when we are approving reports on behalf of the CCL. But issues of political fairness should not prevent us welcoming technical opinions from non-CCL members, so we may have to establish a non-voting guest membership.

Recently the JCRB has asked CCs to establish working groups to facilitate the Inter-regional CMC Review Process. The WGDM has managed this in the past by establishing a standard set of services (DimVIM), produced a set of recommendations on running key comparisons and reviewing CMCs. We did this to promote a uniform approach across the regions and our recommendations have been adopted in the APMP, EUROMET and the SIM. We felt there was little to be gained by establishing a separate working group to continue this work. The working group was surprised and concerned that this work was not recognised by the JCRB secretariat, given their claim that the CCL had not done this. It would appear that we have no advocate on the JCRB.

The terms of reference proposed to the CCL by WGDM 10

General

- To maintain links with the regional metrological cooperation organizations, seeking to ensure the involvement of the BIPM or member laboratories of the CCL in major comparisons *in dimensional metrology,* thereby providing the means for assuring world-wide traceability of measurements *in dimensional metrology* at the highest levels of accuracy.
- To make recommendations to the CCL on the needs and priorities for additional international comparisons *in dimensional metrology* under the auspices of the CCL.
- To act as a focus for information exchange on international comparisons of dimensional metrology standards and techniques, *through the use of suitable Discussion Groups.*
- *To facilitate the Inter-regional CMC Review Process.*

Membership of the WGDM

- Chair appointed by the CCL for a normal period of 4 years (can be re-appointed).
- Full voting members nominated by the NMI members of the Convention, non-voting members invited by the WGDM, through the Chair.
- The WGDM chair to determine when meetings are required and to appoint a rapporteur for each meeting.

Authorities conferred on the WGDM by the CCL

Approval of dimensional metrology key comparison reports.

Discussion groups

To establish and operate Discussion Groups in areas of new technology, in which there are needs for dimensional metrology, with the aim of assuring world-wide traceability of measurements at the highest levels of accuracy.

Expansions on the terms of reference to facilitate the Inter-regional CMC Review Process

a) establishing and maintaining lists of service categories, and where necessary rules for the preparation of CMC entries;

b) agreeing on detailed technical review criteria;

c) coordinating and where possible conducting inter-regional reviews of CMCs submitted by RMOs for posting in Appendix C of MRA;

d) providing guidance on the range of CMCs supported by particular key and supplementary comparisons;

e) identifying areas where additional key and supplementary comparisons are needed;

f) coordinating the review of existing CMCs in the context of new results of key and supplementary comparisons.

Prof. Wallard expressed a concern that the proposed terms of reference for the WGDM did not adequately cover the terms of reference for CIPM Consultative Committees. It was agreed that some further work would be done to consider this issue.

The Chairman of the WGDM has discussed this issue within the WGDM and has produced a proposal which is attached as Appendix A.

Nick Brown

Chairman WGDM

8 June 2006

APPENDIX A
PROPOSED REVISED TERMS OF REFERENCE OF THE CCL WORKING GROUP ON DIMENSIONAL METROLOGY (CCL-WGDM)

Preamble

The terms of reference for the CCL-WGDM were originally set out in 1992 in the report to the CIPM of the 8th meeting of the CCDM. The 10th meeting of the CCL-WGDM in 2005 agreed that the original terms of reference needed updating to include work related to the operation of the CIPM MRA. Additionally, it was agreed by the 10th meeting of the CCL-WGDM that the membership of the WGDM needed to be clarified and that period of office of the Chairperson should be limited to 4 years, when appointment of a new Chairperson would be made by the CCL. Taking the above into account, the WGDM proposes to the CCL that the terms of reference of the CCL-WGDM be amended to the following.

Terms of reference of the CCL-WGDM

The CCL **requests** the CCL-WGDM

- **to maintain links** with the regional metrology organizations (RMOs) to promote key and supplementary comparisons and pilot studies in dimensional metrology, thereby providing the means for assuring world-wide traceability of measurements in dimensional metrology at the highest levels of accuracy,
- **to advise the CCL**, and through it the CIPM,
  a) on the technical needs of the key areas in dimensional metrology, by establishing and operating Discussion Groups, particularly in areas of new technology;
  b) on future BIPM scientific programmes required in dimensional metrology;
- **to facilitate** the Inter-regional CMC Review Process, by:
  a) establishing and maintaining lists of service categories, and where necessary rules for the preparation of CMC entries;
  b) agreeing on detailed technical review criteria to be used by RMOs in reviewing CMCs;
  c) coordinating, and where possible conducting, inter-regional reviews of CMCs submitted by RMOs for posting in Appendix C of the CIPM MRA;
  d) providing guidance on the range of CMCs supported by particular key and supplementary comparisons;
  e) identifying areas where additional key and supplementary comparisons are needed;
  f) identifying the optimum frequency of comparisons needed to validate CMCs during their regular reviews;
  g) coordinating the review of existing CMCs in the context of new results of key and supplementary comparisons;
- **to approve**, on behalf of the CCL, final reports of CCL and RMO key comparisons in dimensional metrology for onward submission to the BIPM's key comparison database.

The CCL **confirms**

- that the current members of the CCL-WGDM which are experts coming from NMI members of the CCL **are automatically approved** for continued membership;
- that the CCL-WGDM Chairperson **could invite** non CCL members to attend in conformity with the CIPM document on Consultative Committee Rules and Policy;
- and that the Chairmanship of the CCL-WGDM shall normally be for a period of four years, with the possibility of re-appointment.

The CCL **requests** the CCL-WGDM Chairperson

- **to determine** when meetings of the CCL-WGDM are required;
- **to appoint** a rapporteur for each meeting;
- **to inform** the CCL, in advance, of the need to appoint any new CCL-WGDM Chairperson, such that the CCL may make this appointment in good time before the changeover of Chairperson.