Making the CIPM MRA sustainable: An approach for CIPM MRA Phase II

Ch. Bock, R. Edelmaier. R. Lapuh, M.-L. Rastello, I. Severn, I. Urdea Marcus, R. Wynands

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E-Mail: christian.bock@metas.ch

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Abstract. Now reaching its 16th year, the Mutual Recognition Arrangement of the CIPM (CIPM MRA) has been a resounding success. It has fostered trust by demonstrating competence among the participating metrological institutions and in this way forms the basis for the quasi-worldwide acceptance of metrological certificates by all relevant authorities. However, the strong growth since its inception has brought the system to a point where it is becoming less practical and difficult to manage. It is therefore the time to take the CIPM MRA forward from its start-up phase into the next phase: maturity. We propose steps to be taken to ensure a successful and sustainable future for the CIPM MRA.

1. Introduction

An important basis for free trade is the removal of unnecessary technical barriers. One such barrier is the requirement of traceability of measurements to one specific national metrology system, typically that of the importing country. This requires exporters to have their tools and products calibrated in the importing country, or at least to have an additional infrastructure in their home country that can perform these special calibrations against standards of the importing country.

The removal of this technical barrier was one motivation for the drafting of the Arrangement on mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes (CIPM MRA, or MRA in short) [1]. Its objectives were to provide a mechanism that allows customers and authorities alike to trust the calibration and measurement certificates of institutions participating in the MRA, allowing them to recognize those certificates. This can be summed up in the phrase “calibrated once, accepted everywhere”. In that respect the MRA has been a complete success. Not only has it removed metrological barriers to free trade but also has it greatly contributed to the uniformity of the international measurement system. A number of examples for the success of the MRA have been presented, for instance, in 2009 in a symposium organized at BIPM on the occasion of the tenth anniversary of the MRA [2] and in a summary by the former BIPM director [3].

The representatives of 38 national measurement systems signed the MRA on October 14, 1999. Since then, more institutions have acceded to the MRA, with a total of 98 signatories as of March 2015 covering an additional 152 institutions. The corresponding countries represent 94 % of the world's economic power. Among those countries and organizations, it is no longer necessary to document the traceability of measurements to one specific national metrology institute (NMI). It is sufficient to document traceability to an NMI that is a signatory of the MRA, or to one of its designated institutes (DIs).

The MRA has caused quality systems to be introduced in all participating NMIs and DIs, either through formal accreditation or self-declaration, both based on peer-reviews. This alone is a huge success of the MRA and has had, in our view, a direct effect on the quality of metrology.

However, this success comes at a price. With so many institutions participating, the MRA and its associated mechanisms are becoming more and more strained. It is now necessary to think about what the future of the MRA might look like, in particular the management of its processes.

A particular issue to be borne in mind is that there have emerged other uses of the MRA, some foreseen, some perhaps not (an example is the use of the number of CMCs for the justification of the funding-level of an NMI or as an indicator for development). From the point of view of the highest metrological authorities, the NMIs and their DIs, the key comparison mechanism of the MRA and the underlying quality system are the formal basis for the establishment of the degree of equivalence of national measurement standards, maintained by these institutions. Based on this degree of equivalence, measurement uncertainties claimed by the institutions can be assessed and trusted at the demonstrated level.

Trust among NMIs existed prior to the MRA. The technical experts in these institutions have always used instruments like measurement comparisons, technical discussions in publications and at conferences, exchange of scientists and guest researchers, and review visits by peers, in order to assess each other's technical capabilities and to establish trust in them. The MRA provided a formal framework for the process of establishing trust, in a way that can also be understood and trusted by authorities that are not technical experts. In our opinion this is the main success of the MRA, a success that must not be jeopardized by action (or inaction) now and in the future.

Resolution 5 of the 25th General Conference on Weights and Measures (25th meeting, 18-20 November 2014) "On the importance of the CIPM Mutual Recognition Arrangement" [4] goes into the same direction.

2. Mechanisms behind the MRA

To achieve the goal of the MRA it is imperative to generate and maintain trust by regulatory authorities (customs officials, health and safety authorities, etc.), accreditors, certification bodies, trading partners and end customers of metrological services or devices in the validity of calibration certificates and other metrological documents. They need to be convinced that

"foreign" metrological institutions are working correctly so that their certificates can be trusted. One of the main drivers of the MRA is decentralized production of high-end products. In this field, the acceptance of certificates at the highest level of accuracy is essential. It is important to note that, strictly speaking, it is not required for NMIs of different countries to trust each other – the targets really are the end-users, regulatory authorities and accreditors: It is they who need to trust "foreign" certificates.

To achieve this goal the MRA established procedures that regulatory authorities find convincing, even though perhaps they are not metrological experts. At the same time, processes were implemented that ensure that the proper procedures are followed by all participating metrological institutions. Finally, a database was set up that provides a public record of the quality-checked and internationally agreed-upon calibration and measurement capabilities (CMC) of each participant in the MRA [5]. The database is publicly accessible via a web interface, free of charge and free of bureaucratic barriers like user registration.

By-products of this trust-building and trust-maintaining infrastructure geared towards the needs of regulatory authorities are a deeper knowledge of NMIs about the capabilities of the other NMIs, a deeper trust in each others' metrological capabilities, increased cooperation among NMIs, and finally a metrologically sound determination of the degree of equivalence of national standards. This last point is sometimes touted as the essence of the MRA. However, we would like to point out again that for the target group of the MRA – the regulatory authorities in the field of metrology and the customers of metrological services and devices – the degree of equivalence of national standards is not of particular interest in itself; what they need is the information on CMCs in the database, in particular the measurement ranges and their associated uncertainties. Or to put it more bluntly: Most users want to know that the uncertainty of the national standards in question meet their requirements, and that the calibration certificates issued by different institutes for the same device agree within the stated uncertainties.

3. Maintenance cost as a threat to the MRA

There are now 24,000 entries in the CMC database. In theory, all principal techniques in a specific field should be covered by a key comparison that is not older than a specified number of years, for instance five to ten or fifteen (for an overview about KCs *cf.* appendix 3). Currently, this is definitively not the case. One reason is that the cost in terms of time and manpower is becoming too high for all metrological parties concerned. There are just too many key comparisons in need of updating and too many new key comparisons needed to support new CMC entries.

Some technical committees in the regional metrology organizations have basically become administrative bodies for CMC review, to the point that it becomes difficult to find chairs for these committees because nobody wants to be burdened with all the administrative work. The original purpose of these committees as *fora* for technical discussions and decision-making is receding into the background.

The large number of CMCs has gradually created another issue. The user interface for the database is no longer suitable for finding the desired information in a huge quantity of data. Each CMC has its own range of measurement quantities and associated parameters, all specified in great detail. This is understandable because everybody wants their database entries to reflect their true (*i. e.* best) capabilities. However, this makes it exceedingly hard to compare different entries because in general at least one parameter is different.

A further problem with the database is the lack of an integrated thesaurus in the search engine. For instance, at the time of writing this paper, a search for "Gaussmeter" yields 8 hits, whereas a search for "Teslameter" results in 7 entries – and only one single entry appears in both lists. Furthermore, a search for "Magnetometer" results in 32 entries, while searching for "magnetic field" results in 175 hits [5]. Also, it is not possible to search for a given target uncertainty, for instance in order to find an institution that can provide a calibration at just the right level of uncertainty.

It is clear that the MRA processes have become difficult to manage and that the MRA's sustainability and even its very survival is jeopardized if no reform of its processes can be implemented.

One possible path is a simplification of and reduction of the number of CMCs. This route was followed in the past by the electricity community by making CMCs clearer, more readable and reducing the number of entries by the use of matrices and formulas.

However, we think that this obvious solution might not be a solution for the overall problems with the MRA. This is because there are three types of incentives for a large or increasing number of CMC entries for a given institution:

- In some countries a large number of CMCs is seen as a sign of quality and of relevance of an NMI/DI. There is the worry that a reduction in this number, or a restriction to reach an internal "threshold number" of CMCs, might lead to financial or political problems for that institution.
- Increasingly, customers become aware of the value of a calibration certificate with the MRA logo, and ask their NMI/DI to include it in the certificate. This is only possible when a proper CMC entry exists. For example, about 65 % of all calibration certificates PTB issued in 2014 carried the MRA logo while the others were based on services where no CMC had been obtained yet. Those "non-CMC" services for the most part are unique capabilities or recently improved ones with respect to uncertainty or value range. To serve customers' interest, CMC entries should be sought for those services, too.
- NMIs that are not accredited use CMCs as one way to demonstrate their competence and for accredited NMIs the scope of accreditation is often identical with their CMCs.

Therefore, in addition to an increased efficiency a solution must be found that keeps the MRA manageable even when the number of CMC entries keeps growing.

4. The proposed solution: MRA Phase II

We propose to move the MRA forward and to make it sustainable by reforming the internal processes and procedures (there are, indeed, alternatives to reforming the MRA; *cf*. appendix 1 for more details). It is absolutely mandatory that the original goals are kept and the level of trust reached over the last 16 years is not jeopardized. While making the MRA sustainable is the main goal of the reform, it is desirable to keep as many of the side benefits as possible.

We are not pretending to have invented the following measures here. There are many initiatives within CCs, TCs etc. to adjust the processes connected to the MRA in its current phase. The purpose of the proposals below is to bring greater consistency across CCs. In a sense this can be seen as a "toolbox" of measures to transition from an MRA growth phase, "Phase I", to a mature phase, "Phase II", of the MRA. Time is ripe for such a transition:

- One has to realize that the number of CMCs by itself is not a problem; in principle there could be many entries in the database, as long as they can be found with a search interface adapted to the current users' need. It is only the amount of work required to quality-check a new entry and to keep existing entries up-to-date and quality-assured that is causing the sustainability problems.
- One must acknowledge that we can now look back on 16 years of building trust within the MRA formalism (not counting the decades of collaboration before the MRA). In all those years, in the established areas of metrology, very few problems were encountered, and they were detected and remedied in most cases in a robust way.
- It is therefore obvious that the solution is to transition from a system of 100 % checking and double-checking to a system that is building upon the verifiable trust generated in Phase I of the MRA. After all, how can we claim that we build trust with our system if we do not trust ourselves even after such a long period of successful trust-building exercises?

We therefore propose the following changes to the rules of the MRA for the mature "Phase II":

- New CMC entries will only be discussed and quality-checked within the Regional Metrology Organisation (RMO) of origin, so there will be no more inter-RMO reviews before CMCs are entered into the database.
- Once an RMO has approved a new CMC it is entered into the database without additional quality control steps.
- To complement this simplified, trust-based system a strong "appeals mechanism" is implemented. There will be a temporally unrestricted right for each RMO or signatory of the MRA to challenge a CMC entry. Measures to resolve the issue could range from a simple exchange of letters providing additional information to on-site visits (especially to cope with problems concerning the quality management system) or even bilateral or multilateral measurement comparisons. An outline of such an "appeals procedure" can be found in appendix 2.
- An alerting mechanism is implemented that provides "What's new in the database" information, perhaps sorted by CCs or technical fields and published at a suitable interval. In this way all RMOs know when new CMC entries have been added by another RMO.
- The search engine of the KCDB should be improved.

- To reduce the number of CMC entries and to improve readability of the remaining ones it is suggested to follow the approach currently being taken by some CCs, where entries are grouped in matrices or uncertainties are given by formulas, instead of in many individual entries.
- To reduce the number of key comparisons (KC) each CC defines a set of "core competences" or "anchor points", where comparisons are still performed. An institute that has participated successfully in such a KC would then be trusted with other measurements within a certain range around the anchor point, or, in chemistry, with certain different combinations of matrix and species of interest. This process has already been started by several CCs.
- The number of participants in KCs is reduced so that comparisons are finished in a more timely manner. For instance, one could require that only laboratories with a primary realization participate in comparisons at the most demanding level of metrology and that appropriate comparisons are arranged for secondary realization. Also, one can restrict participation to that subset of laboratories that will be able to reach a measurement uncertainty not worse by more than a factor of 5 (or 3, or 10?) compared to the second-best laboratory.
- Strict deadlines are set and enforced for each participant's contribution to a KC. The participants have to commit to follow the time schedule (including reporting) agreed upon before the start of the comparison. It is the responsibility of each participating laboratory that their infrastructure and documentation is up-to-date and the necessary resources are dedicated to the comparison (which should not be a big challenge as these are services which are available to customers on a regular basis).
- One could think about adapting the concept of an "on-going comparison", as it is implemented by CCTF for the calibration of TAI and CCL for the comparison of optical frequency and wavelength standards (K11), also for other KCs. In this way, it would be possible for an institution to drop out of a KC when problems occur (major equipment failure, flooding of the lab, …) in order not to delay the KC, and at a later date to contribute an additional data point to the KC even once it has already been concluded.
- As a supporting measure, the Technical Committees (TCs) of the RMOs are asked to review existing CMCs as to whether they are still needed, still valid, and consistent with other TC's approaches.

All rules and procedures relating to quality and quality systems are in our opinion functioning rather well and need no change.

A problem that has not been elaborated further here is the difficulty of finding NMIs or DIs that are ready to take the burden of acting as the pilot laboratory for a comparison. There is an overlap between this challenge and the scope of this paper (administrative burdens, respecting of deadlines, workload, …).

It is our conviction that the most important step is a change in philosophy after the first sixteen years of successful implementation and development of the MRA: We can forego the 100 %-checking mentality and put more emphasis on trust instead. Some of these changes can simply be implemented by a new interpretation or even application of existing documents.

5. Implementation

To implement the measures proposed here it is not necessary to modify the MRA itself. The abolishment of the inter-RMO review only needs a change to the "Guide to the implementation of the CIPM MRA" [6], which would require a decision by the CIPM after consultation with the NMI directors. The same is true for the implementation of the appeals mechanism. All other measures fall within the technical authority of the CCs to adopt and adapt, perhaps to be decided by the JCRB.

Within the rules for Phase II of the MRA there is no real need for special consideration of the transitional period. Each CC can implement the new regime whenever their next meeting is taking place. The same goes for the changes to the Technical Supplement of the MRA that need to be adopted by the CIPM during one of its next sessions.

Unlike in Phase I of the MRA, we suggest to have a review of the new regulations after a certain time, say, three years. If it turns out then – or even before that – that there are unforeseen and grave consequences of the regulations in the new phase it will always be possible to revert to the old regime. This will be formally easy to do since the MRA document itself does not have to be changed in order to transition from Phase I to Phase II.

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References

[1] http://www.bipm.org/en/cipm-mra/mra_online.html; accessed in March 2015.

[2] http://www.bipm.org/en/events/10-year_symposium; accessed in March 2015.

[3] M. Kühne, A. Henson, C. Thomas, Ö. Altan, "The CIPM MRA", Proc. of the International School of Physics "Enrico Fermi", Course 185 "Metrology and Physical Constants", edited by E. Bava, M. Kühne and A. M. Rossi, (IOS, Amsterdam; SIF Bologna) 2013, pp. 29-44.

[4] http://www.bipm.org/en/CGPM/db/25/5/; accessed in March 2015.

[5] http://kcdb.bipm.org; accessed in March 2015.

[6] http://www.bipm.org/utils/common/documents/CIPM-MRA/CIPM-MRA-G-01.pdf; accessed in March 2015.

[7] http://www.euramet.org/index.php?id=tc-projects; accessed in March 2015.

Appendix 1: Ways to change the MRA rules

There are several formal options for how to overcome the problems with the existing MRA. In this part we want to list and evaluate them.

A1.1 Revision of the MRA

After an initial period of four years the MRA may be changed by the signatories at meetings organized by the CIPM of directors of the NMIs.[1] Any change of the MRA needs the unanimous support of all signatories, *i.e.* any signatory has a *de facto* veto right.

In 2011 the CIPM intended to change the MRA. This change never came into force as some signatories refused to sign or simply never replied.

The requirement of unanimity gives the MRA a high legitimacy but on the other hand allows every signatory to block any change of the MRA even though the reasons are not directly related with the MRA.

From a theoretical point of view, a formal revision of the existing MRA would be the best solution for overcoming any weaknesses of the MRA. In reality, however, such a change will be a very cumbersome and long process which no guarantee of success.

A1.2 "MRA 2.0"

Another solution is to conclude a new MRA (here referred to as "MRA 2.0"). Both MRAs would coexist in parallel. A "safeguard clause" in the "MRA 2.0" would stipulate that in case an NMI is member of the MRA and the "MRA 2.0" only the latter would apply. A "MRA 2.0" would allow those NMIs who are willing (or able) to revise the MRA to actually do so ("two-speed MRA"). Signatories who are not willing could not block the "MRA 2.0" and would remain signatories to the old MRA.

Despite its intellectual elegance this option has some severe drawbacks: like any revision of the MRA it would take a long time. In 1999 it was possible for most signatories to sign the arrangement[2] of the MRA without governmental approval. One can expect that any "MRA 2.0" today would need explicit approval by Government or even Parliament.[3] Such a "MRA 2.0" would also ignore the principle of equal treatment of NMIs. We would end up with a "two-class system" where some NMIs are bound by the old MRA and some by the new "MRA 2.0". This could have some unwanted (political) side-effects.

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1 Article 11.4 MRA.

2 For the reason why the MRA is an "arrangement" and not an "agreement" *cf.* T. Quinn, *"From Artefacts to Atoms"* (Oxford University Press, New York) 2012, p 338.

3 For a Swiss perspective on the MRA *cf.* L. Caflisch, "La pratique suisse en matière de droit international public", RSDIE **22** (2010), pp. 109-10.

A1.3 Revision of secondary MRA documents

The MRA consists of a large set of documents that are divided into the following categories:[4]

- policy documents
- guidance documents on CMCs
- guidance documents on comparisons
- complementary information documents.

Those documents are understood here as *secondary documents* (the MRA being the primary document). Secondary documents are either approved by the CIPM, by the JCRB or the RMOs. Secondary documents do not need the same approval process as the MRA. They can be enacted either by the CIPM, by the JCRB or by the relevant RMO according to the applicable rules of procedure.

The advantage is that changes can be made quickly. As all bodies are internationally represented and consist of well renowned specialists in metrology their acceptance is high. Nevertheless there are some shortfalls: they can not change the MRA itself and changes which are of high importance (*i.e.* that they should be part of the MRA) cannot be introduced.

Secondary documents are the best target for technical changes by specialists.

A1.4 Actions by CCs

The CCs have to contribute to the implementation and maintenance of the MRA. This includes *inter alia* the identification of KCs, the approval of the organisation of KCs, their results and final reports.[5] Many of the problems with the actual MRA and its application could be solved by the CCs.

Since 2013 the CIPM has initiated a new strategic planning process of the CCs. This process consists of three phases:

- In phase 1 a CC strategy document is elaborated by the relevant CC;
- phase 2 starts with comments from NMI directors and Member States representatives on the strategy documents and ends with a CIPM reflection document which includes strategic priorities for the CCs and the BIPM laboratory document;
- in phase 3 the document is (again) reviewed, commented and consulted with NMI directors and Member States representatives. After this consultation the consensus strategy is published.

Through this strategy process, actions by the meeting of NMI directors (which was introduced by the MRA and was not implemented in the original Metre Convention) can influence the MRA work of the CCs.

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4 http://www.bipm.org/en/cipm-mra/documents; accessed in May 2014.

5 Rules of Procedure for the Consultative Committees (CCs) created by the CIPM, CC working groups and CC workshops (CIPM-D-01), 2012.

A1.5 Actions by MRA signatories

Except from pressure by peers and/or higher authorities there is no necessity for NMIs to have a certain number of CMCs. Thus, the problem of an increasing burden of participation in comparisons is in essence homemade. Representatives of an NMI in a CC or a technical committee are – in most cases – collaborators of an NMI and therefore bound by instructions.

A1.6 Memorandum-of-understanding between MRA signatories

Several NMIs or Member States could combine or coordinate their individual actions (*cf.* A1.5) based on a memorandum-of-understanding (MoU) type agreement. Such a group could be identical with the members of a RMO. With such a MoU the peer-pressure for more CMCs and KCs could be reduced.

Such an option has some drawbacks: it could result in a "game of power" between NMIs or RMOs, as NMIs with many CMCs could use their bargaining power in order to guide the MRA through such MoUs into a direction they want. Also it would change the principle that the same MRA applies for all signatory.

A1.7 Conclusion

In our opinion any option which can have unexpected side-effects should be avoided. We think that the existing MRA is powerful enough to overcome the existing deficiencies (if this is not the case other solutions could be sought in a second step). Therefore, the focus should be on the revision of secondary MRA documents (*cf.* A1.3) and actions by CCs (*cf.* A1.5). The MRA has given rise to the annual meeting of NMI directors[6]. This body should also be used with care to determine the strategic direction of the MRA.

6 Quinn, note 2, p. 335.

Appendix 2: Proposal for an Appeals Procedure for CMCs in the KCDB

One of our main suggestions is to reserve key and supplementary comparisons for special CMCs which need strong support and evidence. All other CMCs should be based on the alternative (but equally valid) procedures. Additionally, CMCs should be declared much more rapidly and directly with a streamlined acceptance procedure.

There is an interrelation between *ex ante* and *ex post* procedures: the more comprehensive the first one is, the less the latter needs to be, and vice versa. If the *ex ante* procedure is reduced or reserved only for selected CMCs we need an effective *ex post* appeals procedure.

The filing of CMCs and the appeals procedure must be aligned. A system where it is easy to file a CMC should be accompanied by a system where it is also easy to file an appeal. Having an easy appeal system in place will keep the risk small that a signatory of the MRA will file CMCs carelessly or an RMO will review them too superficially.

The new appeals procedure should be

- open for MRA signatories and RMOs
- transparent (the procedure and all related documents should be published on-line)
- quick (in our understanding a decision should be taken within a couple of months)
- effective (it can end with greying-out or removing of CMCs)
- not be restricted in time (it is applicable for all CMCs, no matter how long ago they were entered in to the database)
- led by a newly created JCRB Appeals Group, which would seek technical advice from the respective CC.

Typically, an appeal will be based on doubts about claimed uncertainties. The doubts can be dispelled by providing (more) detailed uncertainty budgets in a form that can be verified by technical experts. This might require additional measurements and crosschecks, analogous to the standard procedures when peer-reviewing scientific manuscripts before publication.

In a clear case the JCRB can decide immediately after hearing the “owner” of the CMC. If additional information is necessary it can ask the responsible bodies (NMI, DI, RMO, CC) and/or the CMC holder or the appealing party for clarification. If this information arrives it can decide either to reject the appeal, to grey-out the CMC or to remove it from the database altogether. Its decision should be final. The responsible NMI has the possibility to file the same CMC again with a better documentation.

Appendix 3: Some Statistics on Comparisons

As of February 2014, in the Key Comparison Database (KCDB) of the BIPM there are 872 key comparisons recorded where 88 of them correspond to exercises prior to the implementation of the MRA and were chosen as "Approved for provisional equivalence". Additionally, there are 380 supplementary comparisons recorded in the KCDB. All of them but 21 are conducted by the RMOs.

A3.1 Number of Key and Supplementary Comparisons

From the KCDB we can derive the following *overview about Key and Supplementary Comparisons*:

Key Comparisons	AUV	EM	IR	L	M	PR	TF	T	QM
BIPM/CC	16	60	128	10 + 1	97	19	1	20	163
AFRIMETS	0	0	0	0	1	0	0	0	1
APMP	8	18	17	12	37	7	0	15	10
COOMET	5	5	4	1	12	1	0	6	5
EURAMET	8	25	9	19	36	17	0	16	8
SADCMET	0	0	0	0	1	0	0	0	0
SIM	4	16	3	6	13	4	0	5	2
Total	41	124	161	48 + 1	197	48	1	62	189

Supplementary Comparisons	AUV	EM	IR	L	M	PR	TF	T	QM
BIPM/CC	1	2	14	4	0	3	0	3	0
AFRIMETS	3	0	1	2	3	0	0	4	0
APMP	1	16	7	6	12	10	0	12	7
COOMET	2	17	5	12	11	7	0	0	4
EURAMET	2	37	22	26	38	6	0	3	8
SADCMET	1	0	0	0	1	0	0	0	0
SIM	1	11	1	7	37	1	0	5	4
Total	11	83	50	57	102	27	0	27	23

Broken down by type and CC:

Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV) Members/Observers 17/14			
Comparison activity	**Completed**	**In progress**	**Planned**
CCAUV KCs (& CC Supplementary)	9	3 + (1)	15
RMO KCs (& SCs)	19 + (3)	3 + (7)	no data
BIPM comparisons (all on-going)	0	0	0
CC Pilot studies	1	0	5
CMCs	1071 CMCs in 51 service categories		

Consultative Committee for Electricity and Magnetism (CCEM) Members/Observers 23/0			
Comparison activity	**Completed**	**In progress**	**Planned**
CCEM KCs (& CC Supplementary)	26 + (2)	8	20
RMO KCs (& SCs)	35 + (40)	16 + (28)	no data
BIPM comparisons (all on-going)	9	0	10
CC Pilot studies	0	1	2
CMCs	7062 CMCs in 194 service categories		

Consultative Committee for Length (CCL) Members/Observers 25/1			
Comparison activity	**Completed**	**In progress**	**Planned**
CCL KCs (& CC Supplementary)	8 + (4)	2	9
RMO KCs (& SCs)	18 + (23)	12 + (23)	3 + (no data)
BIPM comparisons (all on-going)	2	0	0
CC Pilot studies	4 (later ugraded to SC)	0	2
CMCs	1341 CMCs in 102 service categories		

Consultative Committee for Mass and Related Quantities (CCM) Members/Observers 23/4			
Comparison activity	**Completed**	**In progress**	**Planned**
CCM KCs (& CC Supplementary)	47	19	30
RMO KCs (& SCs)	48 + (44)	39 + (37)	8 + (13)
BIPM comparisons (all on-going)	no data	no data	no data
CC Pilot studies	6	0	0
CMCs	2785 CMCs in 34 service categories		

Consultative Committee for Photometry and Radiometry (CCPR) Members/Observers 12/4			
Comparison activity	**Completed**	**In progress**	**Planned**
CCPR KCs (& CC Supplementary)	16	5	7
RMO KCs (& SCs)	12 + (10)	17 + (11)	0 + (2)
BIPM comparisons (all on-going)	0	0	0
CC Pilot studies	4	0	0
CMCs	1224 CMCs in 84 service categories		

Consultative Committee for Amount of Substance – Metrology in Chemistry (CCQM) Members/Observers 27/11			
Comparison activity	**Completed**	**In progress**	**Planned**
CCQM KCs (& CC Supplementary)	113 + (0)	125 + (0)	no data

Consultative Committee for Amount of Substance – Metrology in Chemistry (CCQM) Members/Observers 27/11			
Comparison activity	**Completed**	**In progress**	**Planned**
RMO KCs (& SCs)	14 + (10)	no data	no data
BIPM comparisons (all on-going)	1	1	no data
CC Pilot studies	115	66	no data
CMCs	5360 CMCs in 67 service categories		

Consultative Committee for Ionizing Radiation (CCRI) Members/Observers: Section I: 18/9, Section II: 20/8, Section III: 11/3			
Comparison activity	**Completed**	**In progress**	**Planned**
CCRI KCs (& CC Supplementary)	16 + (7)	17 + (6)	4/year
RMO KCs (& SCs)	20 + (21)	8 + (13)	3
BIPM comparisons (all on-going)	64 + (1)	11	21/year
CC Pilot studies	0	0	0
CMCs	3903 CMCs in 79 service categories		

Consultative Committee for Thermometry (CCT) Members/Observers 23/1			
Comparison activity	**Completed**	**In progress**	**Planned**
CCT KCs (& CC Supplementary)	11	6	5
RMO KCs (& SCs)	17 + (8)	15 + (8)	no data
BIPM comparisons (all on-going)	0	0	0
CC Pilot studies	4	0	no data
CMCs	2064 CMCs in 46 service categories		

Consultative Committee for Time and Frequency (CCTF) Members/Observers 29/3			
Comparison activity	**Completed**	**In progress**	**Planned**
CCTF UTC (on-going, monthly or more frequently)	1	1	1
RMO KCs (& SCs)	0	0	0
BIPM comparisons (all on-going)	0	0	0
CC Pilot studies	0	0	0
CMCs	667 CMCs in 19 service categories		

In addition, there is a large number of bilateral comparisons.

A3.2 Strategies developed by the Consultative Committees of the BIPM

Recently strategy documents have been developed by the Consultative Committees for Acoustics, Ultrasound and Vibration (CCAUV), for Electricity and Magnetism (CCEM), for Length (CCL), for Mass and Related Quantities (CCM), for Photometry and Radiometry (CCPR), for Amount of Substance – Metrology in Chemistry (CCQM), for Ionizing Radiation (CCRI), for Thermometry (CCT) and for Time and Frequency (CCTF). Here, we collect these strategies for easier reference.

Ad-hoc WGs were established in quite different ways:

CCAUV	1 working group Key Comparison (CCAUV-KCWG)
CCEM	2 working groups on Key Comparisons, one for low frequency quantities (WGLF), one for radio frequency and microwave (GTRF)
CCL	1 working group on MRA WG MRA
CCM	1 working group on Strategy (WGS)—in 2013 includes KC and CMC functions
CCPR	2 working groups on CMCs (WG-CMC) and Key Comparisons (WG-KC)
CCQM	1 working group on both Key Comparisons and CMCs (KCWG)
CCRI	3 working groups on Key Comparisons, 1 for each section
CCT	2 working groups: on Key Comparisons (WG7) and on CMCs (WG8)
CCTF	1 working group on the CIPM MRA (WG MRA).

The resources for piloting KCs are again quite different among different CCs:

CCAUV	Varies from about 3.5 PM to about 12 PM but typically around 6 PM.
CCEM	Resources to pilot a comparison vary greatly. Averaged piloting is about 6 PM and participation per lab about 1.2 PM per comparisons.
CCL	Piloting 1.0 PM, Participation 0.14 PM. Values given are minimal, for repeating a well-established comparison with no unusual problems/measurement requirements, and with much overhead at the time of the KC assigned not to the KC but to maintenance of the quality system.
CCM	Piloting varies from about 1 PM to over 30 PM. Mean around 3 PM. Participation estimated at around 0.5 PM.
CCPR	Historical piloting workload, mean is around 20 PM, one 70 PM, participation typically 4 PM.
CCQM	Resources vary significantly by group particularly for preparation of study samples (from a minimum of 0.5 PM to a maximum of 24 PM). Coordination is typically a minimum of 3 to 6 PM and a maximum of around 12 PM. Participation minimums are around 1 PM and maximums around 12 PM.
CCRI	(no declaration).
CCT	Piloting ranges from 2 PM to 24 PM in two populations, participation typically 2 or 3 PM.

CCTF Comparison conducted monthly or more frequently, best estimate of resources per comparison is: Pilot (BIPM): 8 PM, Participation: about 200 PM distributed in 72 contributing laboratories.

A3.3 The Strategy for KCs

CCAUV 20 KCs/Pilot studies with proposed dates established running through to 2023, covering the four areas (6 sound in air, 5 ultrasound, 4 vibration, 5 underwater acoustics).

The extension of the NMI community active in AUV is a major factor, newly participating NMIs requesting comparison activity to underpin their CMCs.

Thorough strategic planning is undertaken in terms of KC selection, and by default the original stated idea for repeat comparisons on a 5 – 7 year timescale has not been followed.

CCEM The importance of KCs will not diminish. In the low frequency range it is planned to repeat KCs during the next 10 years. Completed RF/MW comparisons will not be repeated unless new techniques or problems emerge, due to limited resources and the needs for comparisons at higher frequencies.

A total of 10 new RF KCs and 2 Pilot Studies are planned to 2023 in the existing seven Key Quantities required at higher frequencies, as the importance of higher frequencies increases and more laboratories acquire measurement capabilities at higher frequencies. For LF: repeat each existing comparison during the next 10 years with minor modifications to parameters.

CCL Currently 7 comparisons test the 7 basic techniques (gauge blocks, angle standards, cylindrical diameter, step gauges, line scales, surface texture and laser wavelength). The set may evolve but no plans to reduce the scope, it is considered a minimum set needed to test basic measurement techniques.

8 of the tentatively planned KCs are repeats only. Thus if the discussed new technologies do indeed lead to the need for comparisons, the list may grow but the resources needed to participate in comparisons are relatively modest. Needs for new comparisons might be particularly anticipated in nanometrology and 3D flexible CMMs.

With a set list supporting the basic techniques, possible increase in the workload depends on whether potential new measurement areas develop in the NMIs, requiring new comparisons.

Lengthening the time between comparisons would in principle have little adverse effect, provided the quality system is working properly.

There is already a lack of support in the NMIs for taking on the burden of piloting (and the associated purchase of the required artefacts, which are often unusable after comparison circulation).

CCM The agreed repeat frequency at the CCM level is generally 10 years (15 years for force). The CCM seems to have a sufficient number of KCs to cover the declared CMCs.

The mean time for completion of a CCM KC is >5 years. For the pilot laboratory, the labour is >100 man-days and equipment and transport costs are > Euros 25,000. This cost demonstrably decreases when KCs are repeated, especially as we learn which transfer standards offer the best performance. Further efficiency can be gained by developing validated data reduction spreadsheets and protocol and report templates, by increasing time between recurring KCs, by reducing the total duration of KCs and by covering more CMCs with less KCs.

Many measurands are having difficulty finding NMIs to volunteer as pilots. Generally, the larger NMIs are repeatedly serving as pilots because small NMIs cannot afford the cost. Some KCs have successfully shared shipping costs. Mechanisms for cost sharing to better distribute the cost of transfer standard equipment should be considered, perhaps via a general fund administered by the BIPM.

Finally, the CCM wants to:

- Simplify, standardise and accelerate all steps of KCs (from the protocol to the publication of results),
- Use common resource for KCs and streamlining (protocols, data analysis, reporting) at least within each WGs,
- Share validated calculation tools,
- Encourage common views across the CCs to analyse KC data and aim at an improved coordination work across the CCs.

CCPR Ten-year cycle. Second round CCPR KCs (2013-2023) are nearly identical to those carried out in the first round with six core quantities (luminous intensity, luminous flux, spectral irradiance, spectral responsivity, spectral regular transmittance and spectral diffuse reflectance) – and a consequent set of 10 KCs.

Consideration as to the need for key comparison in extended wavelengths and for other materials would depend upon the closeness in the relationship for the measurement methodologies and artefacts for these measurement capabilities. Pilot studies currently being undertaken or investigated within the CCPR include: Fiber optic properties, specifically OTDR length; THz radiometry, regular spectral transmittance in the UV.

Criteria to manage workload at CC level developed for the second round with participation limited to CCPR members with independent scale realization and CMC

coverage of the quantity over the whole wavelength range, and limitations on number of participants.

CCQM The scope of this CC is very diverse and complex and should provide for evolving and expanding measurement service needs. Specific examples of important issues and trends in various sectors that are likely to drive the development of NMI services are given. Future CCQM comparisons would then be selected to establish the international equivalence of these measurement standards and services for Healthcare, Food safety and nutrition, Environment, Energy, Advanced materials, New technological requirements.

CCQM WGs have developed a "core capability" approach to the organization of KCs in order to maintain the total number of KCs and pilot studies constant while increasing their scope and impact.

CCRI CCRI developed a strategy in 2009, ahead of this current exercise, including prioritization and specific actions.

CCRI comparisons for dosimetry are based on the BIPM on-going comparisons, which include 3 new comparisons planned for high dose rate (HDR) ^{192}Ir sources (using transfer instruments) in 2013-2015 and to reconvene in 2015 the planning for low dose rate (LDR) ^{125}I seeds-based comparisons.

The removal of the need to calculate pair-wise degrees of equivalence in comparison reports has greatly streamlined the reporting process, and revisions to the 10-year plan for radioactivity comparisons have improved coverage of the Measurement Methods Matrix (MMM) to fully support CMCs. CCRI-specific planned comparisons include 1 nuclide/year for the MMM system, among them ^{68}Ge/^{68}Ga, ^{137}Cs, ^{222}Rn, ^{35}S, ^{109}Cd, ^{229}Th, ^{123m}Te and ^{133}Xe until/by 2020.

CCT In total 6 KCs are expected to cover all temperature ranges. First repeat of CCT-K9 is in progress, but the frequency for the others not yet decided. It is already clear that a KC at high temperature is urgent as claimed CMCs cannot be substantiated. A KC above the silver point is planned from around 2015.

CCT SCs, or RMO or pilot studies, may be organized for thermophysical quantities such as thermal expansion coefficient; thermal diffusivity and specific heat capacity of thin films; thermal conductivity of bulk materials and insulation materials; combustion enthalpy of fuels; thermal resistance of vacuum insulation panels.

CCTF Comparison of clock readings conducted monthly or more frequently, as an "ongoing" comparison, in order to calibrate TAI.

Appendix 4: Abbreviations

BIPM:	Bureau International des Poids et Mesures
CC:	Consultative Committee of the CIPM
CCAUV:	Consultative Committee for Acoustics, Ultrasound and Vibration
CCEM:	Consultative Committee for Electricity and Magnetism
CCL:	Consultative Committee for Length
CCM:	Consultative Committee for Mass and Related Quantities
CCPR:	Consultative Committee for Photometry and Radiometry
CCQM:	Consultative Committee for Amount of Substance – Metrology in Chemistry
CCRI:	Consultative Committee for Ionizing Radiation
CCT:	Consultative Committee for Thermometry
CCTF:	Consultative Committee for Time and Frequency
CIPM MRA:	Mutual Recognition Arrangement of the CIPM
CIPM:	Comité international des poids et mesures
CMC:	Calibration and Measurement Capability
DI:	Designated Institute
JCRB:	Joint Committee of the Regional Metrology Organizations and the BIPM
KC:	Key Comparison
KCDB:	Key Comparison Data Base
MRA:	See CIPM MRA
NMI:	National Metrology Institute
PM:	person months
RMO:	Regional Metrology Organisation
SI:	Système international d'unités
TAI:	International Atomic Time
TC:	Technical Committee
WG:	Working Group