Guidelines for Submission and Review of Calibration and Measurement Capabilities (CMCs)

Consultative Committee for Mass and Related Quantities (CCM) Working Group on Mass (CCM-WGM)

1 Introduction

This document gives guidelines to readers both on the submission and on the review of calibration and measurement capabilities (CMCs) in the field of Mass.

This guide is intended to give detailed guidance on the submission and review of CMCs in the technical area of Mass which cover the calibration of mass standards. By following the guidelines outlined here, a consistency of CMC entries between NMIs and a uniform application of the review process can be achieved.

For the submission of CMCs there is a three point checklist provided in the KCDB [1]. This outlines the need for a Quality Management System for the submitting institute, Technical Evidence and Metrological Traceability.

Furthermore, Section 3 of CIPM MRA-G-13 [2] specifies four criteria that need to be fulfilled for acceptance of CMCs into the BIPM Key Comparison database (KCDB). These are:

- Metrological traceability of the national standard
- Metrological traceability of supporting measuring instruments that contribute to the measurement uncertainty
- Technical evidence
- Ensuring the validity of results

Within the "Technical evidence" section, it is specified that the range and measurement uncertainty of the CMCs should be consistent with information from at least some of the following sources:

- Results of Key and Supplementary comparisons (draft B or published)
- Publicly available information on technical activities, including publications
- Onsite peer assessment reports, including those from accreditation assessment with appropriate technical peers
- Active participation in RMO projects
- Other evidence of knowledge and experience, as agreed by the appropriate Consultative Committee

It goes on to state that, while Key and Supplementary comparison results are the ideal supporting evidence, the other specified sources may all be considered to underpin CMCs, and that Consultative Committees are responsible for providing specific guidance on the required technical evidence.

This document aims to give specific guidance on the submission and subsequent review of CMCs in the area of Mass. It details the required technical evidence to support CMCs following a risk-based approach in which additional evidence is required to support more technically-challenging claims.

A programme of digitalisation of the KCDB is being undertaken by the BIPM. This will facilitate the searching and retrieval of the CMC records. It does not directly affect the process of CMC submission and updates but highlights the need for consistent and concise use of formatting during these processes.

2 Summary of Published CMC Status

As of March 2025, there are 865 Mass CMC lines within the CIPM MRA database (KCDB), representing the capability of 74 NMIs. CMCs cover a range of nominal mass values from 0.05 mg (NPL, UK) to 27 tonnes (NIST, US).

CMCs should be clear and structured in such a way that the number of entries is meaningfully minimised (taking onto account usability). This can be achieved by, for example, expressing the CMCs in decade (or larger) ranges. For this to be achievable uncertainties should approximately scale with the value of the measurand (as a rule of thumb a tolerance of up to 5% of the uncertainty value can be allowed).

3 CMC Template

To get a PHYSICS CMC import template from the KCDB, you need to access the KCDB website and use the direct entry form for new submissions, as Excel file imports are no longer supported for submissions under KCDB 2.0. You can also export a draft CMC to an Excel file, which can then be used as a template to create new entries for import into the system (further guidance is available from the KCDB).

4 Guidance on CMC formatting

A major consideration when submitting a set of CMCs is to minimise the number of rows required to summarise the institute's calibration capability as recommended by the CCM, "Strategy 2022-2032", Version 1.8, March 2022 [3].

Below is a sample row, given in three parts, illustrating a typical mass CMC submission.

Country code	Institute	Quantity	Instrument or Artifact under study	Instrument type or method applied	International standard	Parameters
GB	NPL	Mass	Mass standard	Comparison in air		

Measurand Minimum value	Measurand Maximum value	Unit	Expanded uncertainty Minimum value	Expanded uncertainty Maximum value	Unit	Coverage factor	Level of Confidence in %	Type of uncertainty	Uncertainty Equation	Comment Uncertainty Equation	Uncertainty Matrix Label
0.1	1.0	kg	6.0	46.0	µg	2.0	95.0	Absolute			

Comments	Approval date	NMI Service Identifier	Link for NMI Service Identifier
Uncertainty scales with measurand level, The volume of the mass standards is known, following the CCM decision on the implementation of the redefinition of the kg.	2021-02-28	NPL/MM01	

Figure 1: Typical Mass CMC submission, covering the range 100 g to 1 kg (given in three parts).

More in-depth, mass specific, guidance on individual entries is given below.

4.1 Country Code and Institute

These can be found here List of country codes by alpha-2, alpha-3 code (ISO 3166)

4.2 Quantity

Here “Mass” should be entered.

4.3 Instrument or Artifact under study

Here “Mass standard” should be specified. As the artifact under study will almost always be a stainless steel (or similar) standard, it is not necessary to specify anything else. This will make the KCDB entries clearer and assist with future digitalisation and interoperability.

4.4 Instrument type or method applied

Instrument type is not relevant here.

The most likely method of measurement is “comparison in air”. Please use this exact phrase. The comparison is with standards of known mass and density, but this does not need to be specified.

Other methods may be employed, such as comparison in vacuum, but are not widely used for the routine calibration of weights. Additional calibration methods may be adopted in future (for example once individual dissemination from kilogram realisation experiments is adopted) and then the formal should follow that of “comparison in air” as closely as possible.

4.5 International standard

It is not necessary to use this column for standard mass calibration procedures since no recognised international standards exist for these calibrations. The specific method used by the NMI does not need to be described as it does not affect the result provided, as described by the CMC.

It is assumed that the traceability is to the consensus value of the kilogram until such time that sovereign realisations are allowed (Phase 3 of the transition from the IPK to independent NMI realizations of the unit of mass [4]).

4.6 Parameters

It is not necessary to specify additional measurement parameters (such as temperature, pressure and humidity) and these do not (significantly) affect the uncertainty of the calibration result as provided to the customer.

4.7 Measurand values (Measurand)

As noted, the total number of CMCs for each NMI in the KCDB in a given technical area should consist of as few entries as possible to fully cover the range being declared. The total number of CMCs for each NMI should be kept to a minimum while still ensuring full coverage of the declared range. Measurand ranges should not overlap except at the boundaries of the range. Measurand units can be mg, g or kg depending on the nominal values (it is generally not necessary to use tonnes, but this is not specifically precluded).

In general, reporting CMCs by decade will cover the range adequately.

Quantity	Instrument or Artifact under study	Instrument type or method applied	Measurand Minimum value	Measurand Maximum value	Unit	Expanded uncertainty Minimum value	Expanded uncertainty Maximum value	Unit	Coverage factor	Level of Confidence in %	Type of uncertainty
Mass	Mass standard	Comparison in air	0.001	1	g	0.4	0.4	µg	2	95	Absolute
Mass	Mass standard	Comparison in air	1	10	g	0.4	1.5	µg	2	95	Absolute
Mass	Mass standard	Comparison in air	10	100	g	1.5	6	µg	2	95	Absolute
Mass	Mass standard	Comparison in air	0.1	1	kg	6	46	µg	2	95	Absolute
Mass	Mass standard	Comparison in air	1	10	kg	46	570	µg	2	95	Absolute
Mass	Mass standard	Comparison in air	10	20	kg	0.57	1.1	mg	2	95	Absolute
Mass	Mass standard	Comparison in air	20	100	kg	1.1	6	mg	2	95	Absolute

Figure 2: Mass CMC illustrating typical ranges for measuring to minimise number of entries.

Figure 2 illustrates a well scoped CMC submission where the number of lines used to define the full scope of the NMI is minimised. Points to note are;

- Scope from 1 mg up to 1 g (three decades) has been covered by one entry (and the uncertainty is the same for all nominal values in this range). This will often be the case as uncertainties here are generally dominated by the weighing process (type A).
- Where different equipment or measuring processes are used across a decade it will usually be necessary to use separate entries, this can be seen for the entries between 10 kg and 100 kg.

4.8 Uncertainties

The uncertainties should normally be given in mass units, usually µg, mg or g, and expressed to 2 significant figures. Uncertainties should (approximately) scale with the value of the measurand for each entry, and the listed uncertainty should correspond to that of the of the listed measurand value. Some deviation from linearity (as a guide, typically less than ± 5 %) is allowed here to facilitate simplification of the entries (a guide to the rationalisation of CMC entries is in preparation where further guidance will be given). The general guiding principle is that the uncertainties should be listed such that the reader of the CMC entry can determine the uncertainty at any value in the listed measurand range, solely from the content of the CMC listing.

It is usual that there is continuity at the boundaries of adjacent CMC ranges, so that the uncertainty at the maximum of the range of one CMC, is the same as the minimum uncertainty in the next higher range. However, often, under certain circumstances this may not be possible, for example if different balances are used for adjacent ranges where the associated relative uncertainties do not scale. This is often due a significant difference in balance resolutions across a range boundary. In this case a comment should be included for the affected CMC entries.

There is no standard format specified for the uncertainties (or the measurand) but for clarity it makes sense to vary the unit prefix/suffix to optimise the format of the value (see Figure 2 example). Scientific notation should be avoided as this generally makes the published CMCs less easy to read.

The uncertainty covered by the CMC shall be expressed as the expanded uncertainty having a specific coverage probability of approximately 95 %, i.e. the reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor such that the coverage probability corresponds to approximately 95 %.

4.9 Comments

To clarify the entries, it is preferable that a comment is added to give details of how the uncertainty varies with measurand level and significant additional requirements needed to achieve the stated uncertainty. For example: *"Uncertainty scales with measurand level. The volume of the mass standards is known."*

If there are discontinuities at the range boundary of adjacent CMCs, a note clarifying which CMC covers which boundary point should be added. Do this by eliminating the value associated with the higher uncertainty from the rage listed in the CMC. An example is given in Figure 3.

Measurand	Uncertainty	Comments
[10 , 50] kg	[10 , 50] mg (Absolute)	Uncertainty scales with measurand level. The volume of the mass standards is known.
[50, 100] kg	[0.5, 1.0] g (Absolute)	Uncertainty scales with measurand level. The volume of the mass standards is known. **CMC range down to but not including the lower boundary value**.

Figure 3: Example of explanatory comment to explain discontinuity in CMC entries.

5 Guidance on reviewing CMCs

The CCM Strategy Document for 2022-2032 [3] states that, to support and simplify the process of CMC review, "specific guidance on criteria for a risk-based approach in each mass related quantity will be established by the relevant CCM Working Group".

It is the responsibility of the NMI submitting the CMC to ensure that the required technical evidence to support the CMC is made available. The purpose of the review is to ensure that the submitted technical evidence fully supports the proposed CMCs.

5.1 Technical evidence

As per CCM strategy a two tier risk-based approach to CMC review will be adopted in the mass area. CMCs at uncertainties at OIML Class E_2 level and better will require a more comprehensive set of supporting evidence.

5.1.1 Uncertainties at OIML Class E_2 level and better

For uncertainties at the level of OIML Class E_2 [5] equivalent or better (where expanded uncertainty ≤ 1/3 tolerance) a full review of CMC proposals must be undertaken. The following evidence will be required;

- Results of Key or Supplementary comparison
- Onsite peer assessment reports

Additional evidence such as;

- Fully documented uncertainty budgets
- Equipment lists and performance values (standard deviation at max load as a minimum)

may be requested particularly where uncertainty are particularly low or to confirm "how far the light shines" (See CCQM/18-03), a concept attempting to define the level of evidence needed to support a range of CMCs from demonstration of equivalence for a single calibration.

Recommendations in CIPM MRA-G-11 suggest that Key and Supplementary Comparison define the CMC range(s) which will be covered; this should be based on the nominal values of the weight(s) being used. It is technically justified to propose that CMCs can be supported by a comparison using a transfer standard at any point within each decade as long as the uncertainties scale linearly within that decade, and for which the same measurement equipment is used. Masses from 1 mg to 100 mg (or even to 1 gram) could be covered by one CMC entry, and therefore by one nominal value within a comparison, since NMI performance in this range is generally limited by balance resolution and repeatability.

Other supporting evidence such as;

- Documented results of past CC, RMO or other comparisons (including bilateral)
- Knowledge of technical activities by other NMIs, including publications
- Active participation in RMO projects
- Other available knowledge and experience

may also be provided.

5.1.2 Uncertainties larger than OIML Class E_2 level

For less demanding uncertainty levels the submission of Key or Supplementary Comparison results (and peer assessment reports) is still recommended. However, other suitable comparison data or supporting evidence may also be accepted, for example comparison which have not been registered in the KCDB. Such comparison should have been undertaken follow the protocols recommended by the CIPM [4]. This approach to CMC review follows the recommendation of the CCM to implement a risk based review procedure in order to simplify and speed up the CMC review process.

6 Internal NMI CMC review

It is NMI responsibility to Internally review all CMC on a 5 year cycle (or in line with the review cycle of the national accreditation body if relevant). This need not be a specific exercise; it can be part of other quality procedures. The review needs to be checked for:

- Metrological validity
- Technical support (supporting comparisons)
- Quality system support

All non-editorial changes need to go through full review process.

7 KC reports and review of participants CMCs

As noted, the protocols for Key and Supplementary Comparison should define the CMC range which will be covered by the comparison. This should generally be one transfer artefact within each decade supported by the comparison.

After completion of the comparison, final publication or Draft B comparison report may be used as evidence to support CMC. Older comparison results should not be used to support CMC submission where a newer comparison covering the same range of mass has been undertaken (the suggested period for the repeat of a Key Comparison being 10-15 years).

When using the results of Key Comparisons to support new CMCs or in review of existing ones, the results of the comparison should not be discrepant with the KCRV within the expanded uncertainty of the reported measurement [6, 7, 8]. Specifically: "*a result should be considered discrepant when the degree of equivalence represented by the difference* $d_i = x_i - x_{KCRV}$ *and the expanded measurement uncertainty* $U(di) = k \cdot u(di)$ *do not fulfil the condition* $|di| < U(di)$" [7]. It should be noted that issues such as the suitability and stability of the transfer standards need to be considered when reviewing the uncertainty claimed by participants in a comparison in comparison with their CMCs.

8 References

[1] CMC Checklist

[2] CIPM MRA-G-13, "Calibration and measurement capabilities in the context of the CIPM MRA – Guidelines for their review, acceptance and maintenance", Version 1.2, July 2022

[3] CCM, "Strategy 2022-2032", Version 1.8, March 2022

[4] CCM detailed note on the dissemination process after the redefinition of the kilogram

[5] OIML R 111-1 Edition 2004 (E), Weights of classes E1, E2, F1, F2, M1, M1–2, M2, M2–3 and M3

[6] Measurement comparisons in the CIPM MRA guidelines for organizing, participating and reporting CIPM MRA-G-11 Version 1.1 18/01/2021

[7] EURAMET Procedures and Review Criteria for CMCs, EURAMET Guide No. 3 Version 3.0 (02/2023)

[8] ILAC-P14/20120 ILAC Policy for Uncertainty in Calibration

Document History

Version	Date	Approval	Remarks
1.0	16 Jul 2024		Draft document produced by CCM WGM Chair and Vice-Chair
1.1	15 Apr 2025		Updated draft issued to WG Mass members for comment
1.2	26 Jun 2025	CCM WG Mass	Updated based on comments from WG and discussion at CCM WG Mass meeting 24 June 2025
1.3	3 Oct 2025		Final comments from WG Mass
1.4	9 Oct 25		Updated to remove references to CCM guide on CMC review