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Determination and specification of the smallest achievable measurement uncertainties in the calibration of electronic non-automatic weighing instruments

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Deutscher Kalibrierdienst (DKD) – German Calibration Service

Since its foundation in 1977, the German Calibration Service has brought together calibration laboratories of industrial enterprises, research institutes, technical authorities, inspection and testing institutes. On 3rd May 2011, the German Calibration Service was reestablished as a *technical body* of PTB and accredited laboratories.

This body is known as *Deutscher Kalibrierdienst* (DKD for short) and is under the direction of PTB. The guidelines and guides developed by the DKD represent the state of the art in the respective areas of technical expertise and can be used by the *Deutsche Akkreditierungsstelle GmbH* (the German accreditation body – DAkkS) for the accreditation of calibration laboratories.

The accredited calibration laboratories are now accredited and supervised by DAkkS as legal successor to the DKD. They carry out calibrations of measuring instruments and measuring standards for the measurands and measuring ranges defined during accreditation. The calibration certificates issued by these laboratories prove the traceability to national standards as required by the family of standards DIN EN ISO 9000 and DIN EN ISO/IEC 17025.

Contact:

Physikalisch-Technische Bundesanstalt (PTB)
DKD Executive Office

Bundesallee 100	D-38116 Braunschweig
P.O. Box 33 45	D-38023 Braunschweig
Telephone:	0049 531 5 92-8021
Internet:	www.dkd.eu

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Authors:

Dr. Klaus Fritsch, Mettler-Toledo GmbH, Greifensee, Switzerland
Otto Grunenberg, Kern & Sohn GmbH, Balingen-Frommern, Germany
Martin Häfner, Häfner Gewichte GmbH, Oberrot, Germany
Dr. Julian Haller, Sartorius Lab Instruments GmbH & Co. KG, Göttingen, Germany
Dr. Dorothea Knopf, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany
Steffen Osang, Minebea Intec Bovenden GmbH & Co. KG, Bovenden, Germany
Norbert Schnell, Bovenden-Lenglern, Germany
Dr. Olaf Schnelle-Werner, ZMK & Analytik GmbH, Bitterfeld-Wolfen, Germany

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Foreword

DKD expert reports aim to provide background information and references in connection with other DKD documents as, for example, the DKD guidelines. In some cases, they may even go far beyond these documents. They do not replace the original DKD documents but do provide a lot of supplementary information worth knowing. The expert reports do not necessarily reflect the views of the DKD's Management Board or Technical Committees in all details.

DKD expert reports are intended to present significant aspects from the field of calibration. Through publication by the DKD they are made available to the large community of calibration laboratories, both nationally and internationally.

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1 Introduction

The calibration and measurement capability (CMC) of a calibration laboratory for non-automatic electronic weighing instruments refers to the scope of accreditation of the calibration laboratory and the associated smallest achievable expanded measurement uncertainties that the calibration laboratory can achieve under defined conditions when calibrating non-automatic electronic weighing instruments. This expert report provides a description of how to determine and present the scope of accreditation and the corresponding smallest achievable expanded measurement uncertainties.

The procedure for creating CMCs described in this expert report ensures a uniform presentation of the scope of accreditation and – through the consistent use of ILAC-compliant CMCs – helps provide comparable measurement uncertainty data for accredited calibration laboratories in the field of non-automatic weighing instruments

1.1 Purpose

ILAC and BIPM have agreed to replace the term 'Best Measurement Capability' (BMC) – previously used by calibration laboratories for the smallest measurement uncertainty that can be specified within their scope of accreditation – by the term 'Calibration and Measurements Capability' (CMC) from Appendix C of the Mutual Recognition Arrangement of the International Committee for Weights and Measures (CIPM MRA [1]).

This expert report aims to provide accredited calibration laboratories with detailed guidance on how to determine and evaluate the best calibration and measurement capabilities or best measurement capabilities when calibrating non-automatic weighing instruments.

The CMC to be determined must describe the measurement uncertainty for the best available weighing instrument capable of being calibrated in such a way that the reported CMC is demonstrably achieved. Here, particular attention is paid to the term 'best available weighing instrument'. The report also aims to show which specifications and assumptions apply in order to determine the required measurement uncertainty contributions.

The best achievable measurement uncertainty defined as the CMC of the laboratory is expressed as an expanded uncertainty with a coverage probability of approximately 95%. The uncertainty must always be given in the same unit as the measurand or by a term relative to the measurand.

As a final step, a uniform and rule-compliant presentation of the CMC data (calibration and measurement capabilities) in accordance with ILAC-P14 [2] and ILAC-G18 [3] is to be derived (for example, in the appendices to the accreditation certificates).

This revised presentation may be used as a basis for future accreditations in the field of calibration of non-automatic weighing instruments as well as for presenting the measurement uncertainty associated with an actual measured value, as is required in calibration certificates.

1.2 Definitions and terms

Calibration and Measurement Capability (CMC)
(taken from ILAC-P14 [2]

Within the framework of the CIPM MRA and the ILAC Agreement, and in accordance with the joint statement by CIPM and ILAC, the following definition is agreed upon:

A CMC is a calibration and measurement capability available to customers under normal conditions:

a) according to the BIPM Key Comparison Database (KCDB) of the CIPM MRA,

or

b) as described in the scope of accreditation of the laboratory granted by a signatory to the ILAC Agreement.

Further explanations:

H1. The meanings of the terms 'Calibration and Measurement Capability' (CMC) (as used in the CIPM MRA) and 'Best Measurement Capability' (BMC) (as used in the past in connection with the uncertainties stated in the scope of accreditation of an accredited laboratory) are identical. The terms BMC and CMC should be interpreted identically and consistently in the current areas of application.

H2. Within the scope of a CMC, the measurement or calibration should:

- be carried out according to a documented procedure and have a standard uncertainty budget in accordance with the management system of the NMI or the accredited laboratory,
- be carried out regularly (including on request or at specific times of the year determined for reasons of practicability), and
- be available to all customers.

The scope of accreditation of an accredited calibration laboratory includes the calibration and measurement capability (CMC), expressed in terms of:

a) measurand or reference material,
b) calibration/measurement, method/procedure and/or type of measuring equipment/material to be calibrated/measured,
c) measuring range and, if applicable, additional parameters such as frequency of the applied voltage,
d) measurement uncertainty.

Smallest specifiable measurement uncertainty – Best Measurement Capability (BMC) (see EA-4/02 [4])

"The smallest uncertainty of measurement that a laboratory can achieve for a specific quantity under ideal measurement conditions within the scope of its accreditation."

This historical definition of the term clarifies the objective to be pursued when determining the calibration and measurement capability (CMC) of a calibration laboratory.

This characteristic value indicates the uncertainties that a laboratory can achieve when calibrating the best possible yet standard market-available weighing instrument, using the procedure commonly applied. If this information has been confirmed in an accreditation certificate, it is not permitted to indicate smaller measurement uncertainties for calibrations within the scope of accreditation. The smallest uncertainty that can be specified is a measure of a laboratory's capability.

In practice, it is not always possible to achieve the smallest specifiable uncertainties (BMCs), given that in reality the weighing instruments are not always as perfect as assumed. In addition, altered framework conditions can positively or negatively influence a measurement. Therefore, the measurement uncertainty must be re-determined individually for each calibration.

Uncertainty budget (see VIM [5] section 2.33)

Statement of a measurement uncertainty, of the components of that measurement uncertainty, and of their calculation and combination.

Note: An uncertainty budget should include the measurement model, estimates, and measurement uncertainties associated with the quantities in the measurement model, covariances, type of applied probability density functions, degrees of freedom, type of evaluation of measurement uncertainty, and any coverage factor.

Best available weighing instrument (in the sense of a "best existing device" according to ILAC-P14 [2]

Non-automatic weighing instrument with the smallest division value for a given weighing range that is commercially or otherwise actually available to a customer.

(For assumptions regarding measurement specifications see **Fehler! Verweisquelle konnte nicht gefunden werden.**).
Important information regarding the specification includes maximum load(s) $\text{Max}_{(i)}$, division value (s) $d_{(i)}$.

Technical area of competence
(see EA-4/18 G [6]

Area of competence defined by at least one measurement procedure (here: calibration of non-automatic weighing instruments in accordance with EURAMET cg-18), a property/characteristic (here: mass) and a product (here: non-automatic weighing instrument) that are related to each other.

1.3 Regulatory requirements

In addition to the documents listed in the bibliography, the following documents apply:

- DIN EN ISO/IEC 17025:2018 – General requirements for the competence of testing and calibration laboratories
- EA-2/15 M:2023 – EA Requirements for the Accreditation of Flexible Scopes

1.4 Scope of application

This report exclusively refers to calibrations of non-automatic weighing instruments and the corresponding uncertainty determination in accordance with EURAMET cg-18 [7] or the German translation of DKD-R 7-2 [8].

This also includes calibrations of non-automatic weighing instruments in which the reference loads consist partly of substitution loads (see section 7.1.2.6 in EURAMET cg-18 [7] or the German translation of DKD-R 7-2 [8], and the calibration guideline DKD-R 7-3 [9]).

Calibrations of mass comparators are also included if these are operated and/or calibrated as non-automatic weighing instruments. They are taken into account in the list of smallest possible division values (section **Fehler! Verweisquelle konnte nicht gefunden werden.** a)).

Other categories or types of weighing instruments, as for example automatic weighing instruments (AWI) or special cases, such as mass comparators designed for a very narrow weighing range (so-called window-range comparators), are expressly not described.

The scope of application for the calibration of non-automatic weighing instruments constitutes a separate area of technical competence according to EA-4/18 G [6] (see DKD-R 0-1 [10]).

2 Framework conditions for determining CMCs

The expanded measurement uncertainty of a calibration is determined by several influencing factors:

- the calibration item itself,
- the capabilities of the calibration laboratory,
- the environmental conditions during calibration,
- and by the coverage factor k.

The smallest achievable expanded measurement uncertainty represents the best possible calibration for the calibration laboratory.

The following sections define the framework conditions under which the best available weighing instrument (see Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**) is calibrated with the reference weights available in the calibration laboratory (see Chapter 2.2) under defined environmental conditions (see Chapter 2.3).

To determine the smallest achievable measurement uncertainty of a calibration laboratory, the following presentation focuses on the influence quantities for determining the measurement uncertainty of the calibration in accordance EURAMET cg-18 [7], Chapter 7.1.3.

When using only the substitution load method for a specific calibration range, the smallest achievable measurement uncertainty increases accordingly due to the influence of the substitution load.

If different measurement uncertainties arise due to different framework conditions during calibration, these must be taken into account in a separate presentation of the CMC. The same rules apply respectively, in accordance with Chapters **Fehler! Verweisquelle konnte nicht gefunden werden.** to 2.3.

2.1 Framework conditions for taking into account the specifications of the best available weighing instrument

The weighing instrument must be physically available and fall within the laboratory's scope of calibration (calibration task).

For the best available weighing instrument, the following specifications are assumed:

a) Assumptions for rounding error:
- The smallest available division values d depending on the load are to be used in accordance with Appendix A. Appendix A reflects the current state of the art, i.e. these values may be adopted without further consideration as division values d_0 and d_L in accordance with Section 7.1.1, or as d_T in accordance with Section 4.4.2 of EURAMET cg-18 [7].
- Smaller values are possible if a corresponding weighing instrument actually exists.

b) Assumption for repeatability:
- The standard deviation of the repeatability measurement is zero
  $s = 0$

c) Assumption for the maximum deviation due to off-centre loading:
- The weighing instrument has no deviation due to off-centre loading
  $|\Delta I_{ecci}|_{max} = 0$

2.2 Framework conditions for taking into account the reference loads

The best possible weighing instrument is calibrated with the laboratory's best reference weights. The following assumptions apply:

a) The reference weights are actually available to the laboratory for each specified load range.

b) Either the calibration uncertainty of the weights as provided by the laboratory in accordance with its documentation ($U_{95\%}$) or the maximum permissible tolerance (*mpe*) of the accuracy class of a standard or guideline (e.g. OIML R111 [11]) of the best reference weights available and used applies.

c) The change in the reference weights over the period of use (Drift D) is determined in accordance with EURAMET cg-18 [7], Chapter 7.1.2.3 with, for example, $k_D = 1$, provided that the laboratory can prove this. Otherwise, the value achievable by the laboratory is applicable for k_D.

2.3 Framework conditions for taking into account the environmental conditions

With regard to the influence of environmental conditions on the best possible calibration of a weighing instrument, the following assumptions apply:

a) Assumptions regarding the influence of convection on the reference weights Δm_{conv} :

- The table in EURAMET cg-18 [7] Appendix F2.1 applies, subject to the condition that the smallest temperature difference between reference weight and ambient air is ΔT = 1 K.
- The table in EURAMET cg-18 [7] Appendix F2.1 does not list any values for the influence of convection on reference weights smaller than 10 g – for loads < 10 g the influence may therefore be assumed to be zero (Δm_{conv} [< 10 g] = 0).
- The table in EURAMET cg-18 [7] Appendix F2.1 also does not list any values for the influence of convection on reference weights greater than 50 kg – for loads > 50 kg the laboratory must therefore demonstrate plausible apparent mass changes (e.g. by an estimated continuation of the columns in Table F2.1).

Note: If the laboratory can demonstrate temperature differences smaller than 1 K, e.g. by extending the acclimatisation period, smaller apparent mass changes for the reference weights can be used in the determination of convection.

b) Assumption regarding the influence of the air buoyancy of the reference weights Δm_B:

- The weighing instrument is adjusted immediately before calibration. Accordingly, the following applies:
- $u_{\text{rel},B} = mpe / (4 m_N \sqrt{3})$ according to EURAMET cg-18 [7], Eq. 7.1.2-5c

Note: According to EURAMET cg-18 [7], Eq. 7.1.2-5a and Eq. 7.1.2-5b, smaller values are also possible if the laboratory knows the material density and uncertainty of the reference weights, and if the air density and its uncertainty are determined in a verifiable manner.

3 Characteristics of the measurement uncertainties in the calibration of weighing instruments

The measurement uncertainty of calibrations of weighing instruments according to EURAMET cg-18 [7] shows several characteristics that must be taken into account for a compliant and correct representation of the CMCs:

If, as specified in Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**, the uncertainty contributions for repeatability and off-centre loading are assumed to be zero, the measurement uncertainty is dominated by two contributions – the contribution for digital rounding errors (unloaded and loaded) and the contribution for the reference weight.

The characteristics of the two contributions typically behave as follows:

- The relative contributions of the reference weight (at least when using weights of an accuracy class according to OIML R111 [11]) are typically constant above approximately 100 g and increase significantly below approximately 100 g towards small loads.
- Using the highest-resolution weighing instruments for the respective nominal values that are currently available on the market we find the following behaviour: up to approximately 10 g, the relative contribution of digital rounding errors decreases with increasing load; between 10 g and approximately 50 kg, it remains roughly constant; and above 100 kg, it increases disproportionately to the load.

It should also be noted that even when using weights with a high accuracy class (e.g. E_2) up to approximately 1 kg, the contribution of the reference weight clearly predominates, and only above approximately 1 kg does the contribution of the digital rounding errors become of the same order of magnitude.

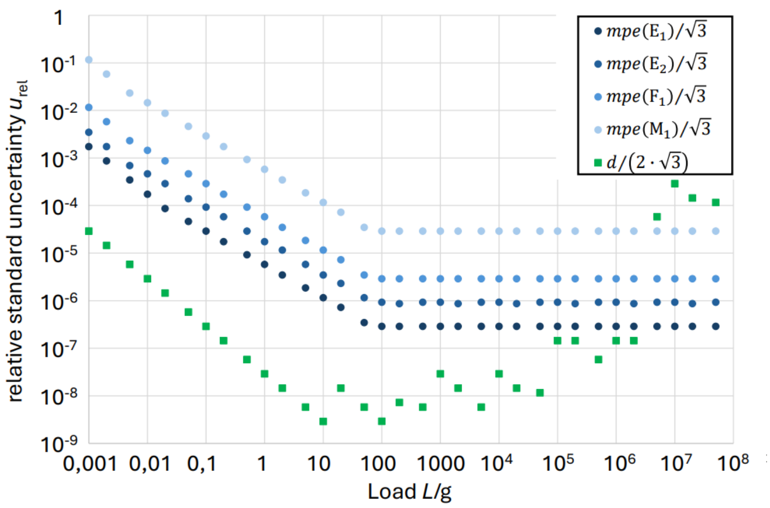

Figure 1: Comparison of the magnitude of typical uncertainty contributions of reference weights of different accuracy classes (dots, calculated as $\boldsymbol{mpe/\sqrt{3}}$) and the uncertainty contribution for a digital rounding error (squares, calculated as $\boldsymbol{d/(2 \cdot \sqrt{3})}$).

Regardless of the individual details (i.e. which accuracy class a laboratory uses for which loads and which drift factor k_D a laboratory uses for the change in weights), there is typically a characteristic behaviour of the measurement uncertainty in such a way that the relative measurement uncertainty decreases for increasing loads from 1 mg to about 100 g, is approximately constant between 100 g and 50 kg or 100 kg (depending on the individual details), and increases for increasing loads above that.

Note: The above description and the uncertainty contributions of the reference weights shown in Figure 1 were calculated based on the maximum permissible errors according to formula 7.1.2-3 of the EURAMET Calibration Guideline cg-18 [7]. If the actual calibration uncertainties U_{95} of the reference weights are used according to formula 7.1.2-2, or weights from other standards/guidelines and/or with free nominal values, a different curve may result. However, the general characteristics, particularly the increase in relative measurement uncertainties for small loads, as well as the general order of magnitude of the values, remain the same in these cases.

Furthermore, the following fundamental aspects regarding the characteristics of measurement uncertainties in the calibration of non-automatic weighing instruments must be taken into account:

I. While ‘zero’ is often not accepted as a valid measuring point (e.g. due to national regulations) and/or no measurement uncertainty is assigned to it, the EURAMET Calibration Guideline cg-18 [7] explicitly mentions ‘zero’ as a valid measuring point (Section 5.2). In the examples in Appendix H, a measurement uncertainty is calculated for the "zero" measuring point in each case.
Whether the smallest possible measurement uncertainty for the ‘zero’ measuring point should be specified in the CMCs may be handled differently at national level – however, if it is specified, this must be done as an absolute value (while a relative value is preferred for all other measuring points, see Point 2 in Section 5).

II. As a rule, weighing instruments are calibrated using standard weights that correspond to the permissible nominal values specified in OIML R111 [11]. Hence it is possible to create any reference load by combining weights. Even with just a few weights (e.g. 10), more than 1,000 reference loads can be realised. It is therefore neither sensible nor feasible to calculate the smallest achievable measurement uncertainty for all possible reference loads. Instead, it is recommended that CMCs only be calculated for ‘single piece’ measuring points (and, if necessary, other appropriately selected points of support). Combining several weights between these points may result in greater uncertainties.

To begin with, the following sections explain two common types of CMC presentation for the calibration of weighing instruments. This is followed by a proposal for a presentation that takes into account the special requirements for measurement uncertainties in the calibration of weighing instruments and complies with the specifications of Section 4.3 of ILAC-P14 [2].

4 Currently used formats for the presentation of CMCs in the calibration of weighing instruments

4.1 Discrete representation for selected nominal values

At present, a common way of presenting CMCs is to use a tabular overview that specifies the smallest possible absolute measurement uncertainty for the nominal values of OIML R111 [11] (or ASTM E617 [12]) across the entire scope of accreditation, for example in the form shown in Table 1:

Calibration and measurement capabilities (CMCs)				
Measurand / calibration item	Measuring range / measuring span	Measurement conditions / procedure	Expanded measurement uncertainty	Remarks
Weighing instruments Non-automatic electronic weighing instruments	1 mg	EURAMET Calibration Guide No. 18, Version 4.0	4,2 µg	
	2 mg		4,2 µg	
	5 mg		4,2 µg	
	…more lines…		…	
	1 t		510 g	
	2 t		900 g	
	5 t		2,3 kg	

Table 1: Specification of CMCs as absolute measurement uncertainty for discrete nominal values according to OIML R111 [11] and/or ASTM E617 [12]

A major disadvantage of this presentation is the large number of entries required – in the case shown above with an accreditation scope of up to 5 t, this results in at least 30 lines, for example.

Another disadvantage is that, in the above form, only the listed nominal values would be formally permitted, but no intermediate values. This could be solved with an interval-based representation, which, however, has certain disadvantages depending on the implementation:

a) In the case of an interval-based implementation in which the next largest uncertainty would have to be taken above a nominal value (Table 2), in many cases a significantly greater measurement uncertainty would have to be specified for the intermediate values than would actually be achievable. In the case shown in Table 2, for example, a measurement uncertainty of 0,87 mg (when calculated according to Example B1 in Appendix B) would always have to be specified for the usual measuring points 220 g | 250 g | 300 g | 320 g | 350 g | 400 g | 450 g even though significantly smaller values would be achievable (namely 0,42 mg | 0,44 mg | 0,51 mg | 0,59 mg | 0,62 mg | 0,66 mg | 0,77 mg, see Table 3).

Nominal value	Smallest achievable absolute measurement uncertainty
...	...
100 g < m_N ≤ 200 g	0,33 mg
200 g < m_N ≤ 500 g	0,87 mg
...	...

Table 2: Specification of CMCs as absolute measurement uncertainty of an interval between two discrete nominal values, values calculated according to example B1 in Appendix B

a) Alternatively, common measuring points could be explicitly shown in the CMC table – however, this would multiply the number of lines required (Table 3). In addition, for other intermediate values not explicitly listed, the problem from a) would still exist, namely that the next largest measurement uncertainty would have to be applied.

Nominal value	Smallest achievable absolute measurement uncertainty
...	...
150 g < m_N ≤ 200 g	0,23 mg
200 g < m_N ≤ 220 g	0,42 mg
220 g < m_N ≤ 250 g	0,44 mg
250 g < m_N ≤ 300 g	0,51 mg
300 g < m_N ≤ 320 g	0,59 mg
320 g < m_N ≤ 350 g	0,62 mg
350 g < m_N ≤ 400 g	0,66 mg
400 g < m_N ≤ 450 g	0,77 mg
450 g < m_N ≤ 500 g	0,63 mg
...	...

Table 3: Specification of CMCs as absolute measurement uncertainty at discrete nominal values, including common measuring points, values calculated according to example B1 in Appendix B

4.2 Interval representation with constant relative measurement uncertainty

Another common type of presentation currently used is the representation by intervals. In this case, the smallest achievable relative measurement uncertainty is specified for each range in which a certain accuracy class is used. This is done, for example, in the following form:

Calibration and measurement capabilities (CMCs)				
Measurand / calibration item	Measuring range / measuring span	Measurement conditions / procedure	Expanded measurement uncertainty	Remarks
Weighing instruments Non-automatic electronic weighing instruments	up to 10 kg	EURAMET Calibration Guide No. 18, Version 4.0	$1 \cdot 10^{-6}$	with weights according to OIML R 111-1:2004 according to class E_2
	up to 305 kg		$1 \cdot 10^{-5}$	with weights according to OIML R 111-1:2004 according to class F1
	up to 5 t		$1 \cdot 10^{-4}$	with weights according to OIML R 111-1:2004 according to class M1

Table 4: Specification of CMCs as relative measurement uncertainty for ranges in which a specific weight class is used

Although this type of presentation is very clear, it has one significant disadvantage: Only the smallest achievable measurement uncertainty is specified for each range, although for individual measuring points in this range, the actual achievable measurement uncertainty (and that specified by laboratories in practice in calibration certificates) can sometimes be many times greater (e.g. for 1 mg, the typical calibration uncertainty for a 1 mg weight of class E_2 results in an uncertainty of 3 µg, i.e. $3 \cdot 10^{-3}$ instead of the stated $1 \cdot 10^{-6}$). This means that it is not at all clear to users what uncertainty they can expect at best for a given nominal value.

5 Uniform presentation of CMCs for weighing instrument calibrations

Given the respective advantages and disadvantages of the representations described in the previous two sections, the following compromise is proposed here, which, in the authors' view, represents the best possible compromise between "correct" and "understandable":

Specifically, the following procedure is proposed here:

1. The measurement uncertainty is calculated for all nominal values of OIML R111 [11] ('support points') and, if applicable, at 0 and other points of support where a significant change in the measurement uncertainty budget occurs, in particular due to a change in the general conditions or a significant change in the uncertainty of the reference weights (e.g. due to a change in the weight class).).
2. The measurement uncertainty is generally specified as a relative quantity. The only exception is the measurement uncertainty at 0, which is specified as an absolute measurement uncertainty (unless 0 is generally excluded as a measuring point by national regulations). To avoid a mixture of relative and absolute values, the relative values are multiplied by m_N.
3. The ranges in which the relative measurement uncertainty can be assumed to be almost constant over several support points are identified – these ranges are entered into the CMC table as corresponding lines with the largest relative uncertainty determined at a support point within the range.
4. The uncertainty for the remaining points of support is specified in a separate interval or line in the CMC table.
5. In each line, the largest value calculated at one of the support points is specified as the smallest achievable uncertainty for the range.

The CMCs are then presented in the form shown in Table 5 (values correspond to those in example B1, Appendix B):

Calibration and measurement capabilities (CMCs)				
Measurand / calibration item	Measuring range / measuring span	Measurement conditions / procedure	Expanded measurement uncertainty	Remarks
Weighing instruments Non-automatic electronic weighing instruments	0 g	EURAMET Calibration Guide No. 18, Version 4.0	$5{,}8 \cdot 10^{-8}$ g	
	1 mg		$6{,}4 \cdot 10^{-3} \cdot m_N$	
	2 mg ≤ m_N < 5 mg		$3{,}2 \cdot 10^{-3} \cdot m_N$	
	5 mg ≤ m_N < 10 mg		$1{,}3 \cdot 10^{-3} \cdot m_N$	
	10 mg ≤ m_N < 20 mg		$8{,}5 \cdot 10^{-4} \cdot m_N$	
	20 mg ≤ m_N < 50 mg		$5{,}3 \cdot 10^{-4} \cdot m_N$	
	50 mg ≤ m_N < 100 mg		$2{,}5 \cdot 10^{-4} \cdot m_N$	
	100 mg ≤ m_N < 200 mg		$1{,}7 \cdot 10^{-4} \cdot m_N$	
	200 mg ≤ m_N < 500 mg		$1{,}1 \cdot 10^{-4} \cdot m_N$	
	500 mg ≤ m_N < 1 g		$5{,}3 \cdot 10^{-5} \cdot m_N$	
	1 g ≤ m_N < 2 g		$3{,}2 \cdot 10^{-5} \cdot m_N$	
	2 g ≤ m_N < 5 g		$2{,}1 \cdot 10^{-5} \cdot m_N$	
	5 g ≤ m_N < 10 g		$1{,}1 \cdot 10^{-5} \cdot m_N$	

	$10\ g \leq m_N < 20\ g$		$6{,}5 \cdot 10^{-6} \cdot m_N$	
	$20\ g \leq m_N < 50\ g$		$4{,}3 \cdot 10^{-6} \cdot m_N$	
	$50\ g \leq m_N < 100\ g$		$2{,}2 \cdot 10^{-6} \cdot m_N$	
	$100\ g \leq m_N < 200\ g$		$1{,}8 \cdot 10^{-6} \cdot m_N$	
	$200\ g \leq m_N \leq 10\ kg$		$1{,}7 \cdot 10^{-6} \cdot m_N$	
	$10\ kg < m_N \leq 300\ kg$		$1{,}2 \cdot 10^{-5} \cdot m_N$	
	$300\ kg < m_N \leq 3\ t$		$1{,}5 \cdot 10^{-4} \cdot m_N$	
	$300\ kg < m_N \leq 3\ t$		$1{,}5 \cdot 10^{-4} \cdot m_N$	

Table 5: Recommended way of specifying CMCs

Appendix B shows the procedure proposed here using a number of specific examples

Note: It should be emphasised once again that the CMCs are specified for nominal values. These nominal values can be grouped into ranges to which a specific measurement uncertainty is assigned. Ranges should therefore not be understood as the available weighing ranges of certain categories of weighing instruments (characterised, for example, by the division value *d*), to which a single measurement uncertainty is assigned that covers the entire weighing range.

Example: According to Appendix A, commercially available ultra-micro balances with d = 0,1 µg are available up to a maximum load of 10,1 g. Accordingly, the CMCs can be calculated for all nominal values up to 10 g using the digital rounding error based on d = 0,1 µg. If the measurement uncertainties of adjacent nominal values are very similar, they can be combined into ranges. The range is therefore not defined as the weighing range of ultra-micro balances from 0 g to 10 g to which a single measurement uncertainty is assigned.

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7 History of changes

Revision	Date	Changes
0	12/2025	First version

Appendix A List of the smallest possible division values

Nominal value m_N /g	Division value d /g	
0	$1 \cdot 10^{-7}$	Ultra-micro balances with d=0,1 µg are commercially available up to a maximum load = 10,1 g
$1 \cdot 10^{-3}$	$1 \cdot 10^{-7}$	
$2 \cdot 10^{-3}$	$1 \cdot 10^{-7}$	
$5 \cdot 10^{-3}$	$1 \cdot 10^{-7}$	
$1 \cdot 10^{-2}$	$1 \cdot 10^{-7}$	
$2 \cdot 10^{-2}$	$1 \cdot 10^{-7}$	
$5 \cdot 10^{-2}$	$1 \cdot 10^{-7}$	
0,1	$1 \cdot 10^{-7}$	
0,2	$1 \cdot 10^{-7}$	
0,5	$1 \cdot 10^{-7}$	
1	$1 \cdot 10^{-7}$	
2	$1 \cdot 10^{-7}$	
5	$1 \cdot 10^{-7}$	
10	$1 \cdot 10^{-7}$	
20	$1 \cdot 10^{-6}$	Micro balances with d=1 µg available up to maximum load = 111 g
50	$1 \cdot 10^{-6}$	
$1 \cdot 10^{2}$	$1 \cdot 10^{-6}$	
$2 \cdot 10^{2}$	$5 \cdot 10^{-6}$	up to 220 g
$5 \cdot 10^{2}$	$1 \cdot 10^{-5}$	up to 610 g
$1 \cdot 10^{3}$	$1 \cdot 10^{-4}$	up to 5100 g
$2 \cdot 10^{3}$	$1 \cdot 10^{-4}$	
$5 \cdot 10^{3}$	$1 \cdot 10^{-4}$	
$1 \cdot 10^{4}$	$1 \cdot 10^{-3}$	up to 41 kg
$2 \cdot 10^{4}$	$1 \cdot 10^{-3}$	
$5 \cdot 10^{4}$	$2 \cdot 10^{-3}$	up to 64 kg
$1 \cdot 10^{5}$	$5 \cdot 10^{-2}$	up to 150 kg
$2 \cdot 10^{5}$	0,1	up to 600 kg
$3 \cdot 10^{5}$	0,1	
$5 \cdot 10^{5}$	0,1	
$1 \cdot 10^{6}$	0,5	up to 1100 kg
$2 \cdot 10^{6}$	1	up to 2500 kg
$5 \cdot 10^{6}$	$1 \cdot 10^{3}$	up to 5400 kg
$1 \cdot 10^{7}$	$1 \cdot 10^{3}$	
$2 \cdot 10^{7}$	$1 \cdot 10^{4}$	up to 30 t
$5 \cdot 10^{7}$	$2 \cdot 10^{4}$	
$1 \cdot 10^{8}$	$5 \cdot 10^{4}$	

Appendix B Examples

Example B1

Laboratory requirements:

For nominal loads up to 10 kg, the laboratory uses the conventional weighed value for weights of class E_2 according to OIML R111 [11]. Typically, the weights are calibrated with a calibration uncertainty corresponding to the respective *mpe* of the next higher class E_1, i.e. $U = mpe(\mathrm{E1})$ ($\approx mpe(\mathrm{E}_2)/3$). Based on statistical observations, the laboratory assumes a value of k_D = 2,5 for the change in weights.

For nominal loads between 10 kg and 300 kg, the laboratory uses the nominal value for weights of class F_1 according to OIML R111 [11], with $U = mpe/\sqrt{3}$. Based on statistical observations, the laboratory assumes a value of k_D = 1,5 for the change in weights.

For nominal loads between 300 kg and 3 t, the laboratory uses the nominal value for weights of class M_1 according to OIML R111 [11], with $U = mpe/\sqrt{3}$. Based on statistical observations, the laboratory assumes a value of k_D = 2 for the change in weights.

In addition to the nominal values specified in OIML R111 [11], the laboratory identifies the values 300 kg (as the framework conditions change significantly there due to the use of a different weight class) and 3 t (as this represents the upper end of the scope of accreditation) as support points. Taking into account the above conditions as well as the framework conditions specified in **Fehler! Verweisquelle konnte nicht gefunden werden.** and 2.2, we get the following smallest achievable uncertainties for these support points:

m_N /g	$u(\delta I_{dig0})$ /g	$u(\delta I_{digL})$ /g	$u(\delta m_c)$ /g	$u(\delta m_B)$ /g	$u(\delta m_D)$ /g	$u(\delta m_{conv})$ /g	$u(m_N)$ /g	$U(m_N)$ /g	$U_{rel}(m_N)$ /g
0	$2,9\cdot10^{-8}$	0	0	0	0	0	$2,9\cdot10^{-8}$	$5,8\cdot10^{-8}$	---
$1\cdot10^{-3}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,0\cdot10^{-6}$	8,7·107	$2,9\cdot10^{-6}$	0,0	$3,2\cdot10^{-6}$	$6,4\cdot10^{-6}$	$6,4\cdot10^{-3}$
$2\cdot10^{-3}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,0\cdot10^{-6}$	8,7·107	$2,9\cdot10^{-6}$	0,0	$3,2\cdot10^{-6}$	$6,4\cdot10^{-6}$	$3,2\cdot10^{-3}$
$5\cdot10^{-3}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,0\cdot10^{-6}$	8,7·107	$2,9\cdot10^{-6}$	0,0	$3,2\cdot10^{-6}$	$6,4\cdot10^{-6}$	$1,3\cdot10^{-3}$
$1\cdot10^{-2}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,3\cdot10^{-6}$	$1,2\cdot10^{-6}$	$3,8\cdot10^{-6}$	0,0	$4,2\cdot10^{-6}$	$8,5\cdot10^{-6}$	$8,5\cdot10^{-4}$
$2\cdot10^{-2}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,7\cdot10^{-6}$	$1,4\cdot10^{-6}$	$4,8\cdot10^{-6}$	0,0	$5,3\cdot10^{-6}$	$1,1\cdot10^{-5}$	$5,3\cdot10^{-4}$
$5\cdot10^{-2}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$2,0\cdot10^{-6}$	$1,7\cdot10^{-6}$	$5,8\cdot10^{-6}$	0,0	$6,4\cdot10^{-6}$	$1,3\cdot10^{-5}$	$2,5\cdot10^{-4}$
0,1	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$2,7\cdot10^{-6}$	$2,3\cdot10^{-6}$	$7,7\cdot10^{-6}$	0,0	$8,5\cdot10^{-6}$	$1,7\cdot10^{-5}$	$1,7\cdot10^{-4}$
0,2	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$3,3\cdot10^{-6}$	$2,9\cdot10^{-6}$	$9,6\cdot10^{-6}$	0,0	$1,1\cdot10^{-5}$	$2,1\cdot10^{-5}$	$1,1\cdot10^{-4}$
0,5	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$4,2\cdot10^{-6}$	$3,6\cdot10^{-6}$	$1,2\cdot10^{-5}$	0,0	$1,3\cdot10^{-5}$	$2,6\cdot10^{-5}$	$5,3\cdot10^{-5}$
1	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$5,0\cdot10^{-6}$	$4,3\cdot10^{-6}$	$1,4\cdot10^{-5}$	0,0	$1,6\cdot10^{-5}$	$3,2\cdot10^{-5}$	$3,2\cdot10^{-5}$
2	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$6,7\cdot10^{-6}$	$5,8\cdot10^{-6}$	$1,9\cdot10^{-5}$	0,0	$2,1\cdot10^{-5}$	$4,2\cdot10^{-5}$	$2,1\cdot10^{-5}$
5	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$8,3\cdot10^{-6}$	$7,2\cdot10^{-6}$	$2,4\cdot10^{-5}$	0,0	$2,6\cdot10^{-5}$	$5,3\cdot10^{-5}$	$1,1\cdot10^{-5}$
10	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,0\cdot10^{-5}$	$8,7\cdot10^{-6}$	$2,9\cdot10^{-5}$	$5,8\cdot10^{-6}$	$3,2\cdot10^{-5}$	$6,5\cdot10^{-5}$	$6,5\cdot10^{-6}$
20	$2,9\cdot10^{-7}$	$2,9\cdot10^{-7}$	$1,3\cdot10^{-5}$	$1,2\cdot10^{-5}$	$3,8\cdot10^{-5}$	$5,8\cdot10^{-6}$	$4,3\cdot10^{-5}$	$8,5\cdot10^{-5}$	$4,3\cdot10^{-6}$
50	$2,9\cdot10^{-7}$	$2,9\cdot10^{-7}$	$1,7\cdot10^{-5}$	$1,4\cdot10^{-5}$	$4,8\cdot10^{-5}$	$1,7\cdot10^{-5}$	$5,6\cdot10^{-5}$	$1,1\cdot10^{-4}$	$2,2\cdot10^{-6}$
$1\cdot10^{2}$	$2,9\cdot10^{-7}$	$2,9\cdot10^{-7}$	$2,7\cdot10^{-5}$	$2,3\cdot10^{-5}$	$7,7\cdot10^{-5}$	$2,9\cdot10^{-5}$	$9,0\cdot10^{-5}$	$1,8\cdot10^{-4}$	$1,8\cdot10^{-6}$
$2\cdot10^{2}$	$1,4\cdot10^{-6}$	$1,4\cdot10^{-6}$	$5,0\cdot10^{-5}$	$4,3\cdot10^{-5}$	$1,4\cdot10^{-4}$	$4,6\cdot10^{-5}$	$1,7\cdot10^{-4}$	$3,3\cdot10^{-4}$	$1,7\cdot10^{-6}$
$5\cdot10^{2}$	$2,9\cdot10^{-6}$	$2,9\cdot10^{-6}$	$1,3\cdot10^{-4}$	$1,2\cdot10^{-4}$	$3,8\cdot10^{-4}$	$9,8\cdot10^{-5}$	$4,3\cdot10^{-4}$	$8,7\cdot10^{-4}$	$1,7\cdot10^{-6}$
$1\cdot10^{3}$	$2,9\cdot10^{-5}$	$2,9\cdot10^{-5}$	$2,7\cdot10^{-4}$	$2,3\cdot10^{-4}$	$7,7\cdot10^{-4}$	$1,7\cdot10^{-4}$	$8,7\cdot10^{-4}$	$1,7\cdot10^{-3}$	$1,7\cdot10^{-6}$
$2\cdot10^{3}$	$2,9\cdot10^{-5}$	$2,9\cdot10^{-5}$	$5,0\cdot10^{-4}$	$4,3\cdot10^{-4}$	$1,4\cdot10^{-3}$	$2,9\cdot10^{-4}$	$1,6\cdot10^{-3}$	$3,2\cdot10^{-3}$	$1,6\cdot10^{-6}$
$5\cdot10^{3}$	$2,9\cdot10^{-5}$	$2,9\cdot10^{-5}$	$1,3\cdot10^{-3}$	$1,2\cdot10^{-3}$	$3,8\cdot10^{-3}$	$6,3\cdot10^{-4}$	$4,3\cdot10^{-3}$	$8,6\cdot10^{-3}$	$1,7\cdot10^{-6}$
$1\cdot10^{4}$	$2,9\cdot10^{-4}$	$2,9\cdot10^{-4}$	$2,7\cdot10^{-3}$	$2,3\cdot10^{-3}$	$7,7\cdot10^{-3}$	$1,1\cdot10^{-3}$	$8,6\cdot10^{-3}$	$1,7\cdot10^{-2}$	$1,7\cdot10^{-6}$
$2\cdot10^{4}$	$2,9\cdot10^{-4}$	$2,9\cdot10^{-4}$	$5,8\cdot10^{-2}$	$1,4\cdot10^{-2}$	0,10	$2,0\cdot10^{-3}$	0,12	0,23	$1,2\cdot10^{-5}$
$5\cdot10^{4}$	$5,8\cdot10^{-4}$	$5,8\cdot10^{-4}$	0,14	$3,6\cdot10^{-2}$	0,25	$4,5\cdot10^{-3}$	0,29	0,58	$1,2\cdot10^{-5}$
$1\cdot10^{5}$	$1,4\cdot10^{-2}$	$1,4\cdot10^{-2}$	0,29	$7,2\cdot10^{-2}$	0,50	$9,0\cdot10^{-3}$	0,58	1,2	$1,2\cdot10^{-5}$
$2\cdot10^{5}$	$2,9\cdot10^{-2}$	$2,9\cdot10^{-2}$	5,	0,14	1,0	$1,8\cdot10^{-2}$	1,2	2,3	$1,2\cdot10^{-5}$
$3\cdot10^{5}$	$2,9\cdot10^{-2}$	$2,9\cdot10^{-2}$	0,87	0,22	1,5	$2,7\cdot10^{-2}$	1,7	3,5	$1,2\cdot10^{-5}$
$5\cdot10^{5}$	$2,9\cdot10^{-2}$	$2,9\cdot10^{-2}$	14	3,6	33	$4,5\cdot10^{-2}$	37	73	$1,5\cdot10^{-4}$
$1\cdot10^{6}$	0,14	0,14	29	7,2	67	$9,0\cdot10^{-2}$	73	$1,5\cdot10^{2}$	$1,5\cdot10^{-4}$
$2\cdot10^{6}$	0,29	0,29	58	14	$1,3\cdot10^{2}$	0,18	$1,5\cdot10^{2}$	$2,9\cdot10^{2}$	$1,5\cdot10^{-4}$
$3\cdot10^{6}$	2,9	2,9	87	22	$2,0\cdot10^{2}$	0,27	$2,2\cdot10^{2}$	$4,4\cdot10^{2}$	$1,5\cdot10^{-4}$

Table 6: Uncertainty contributions for calculating the smallest achievable uncertainties for Example 1. Contributions are designated as in EURAMET cg-18 [7] and DKD-R 7-2 [8]. The individual uncertainty contributions are rounded to 2 significant digits. The unrounded values were used to calculate the expanded measurement uncertainty.

Note 1: The table in EURAMET cg-18 [7] Appendix F2.1 does not list any values for taking into account possible convection effects for nominal values greater than 50 kg. The values ≤ 50 kg exhibit exponential behaviour but were extrapolated for nominal values > 50 kg as a conservative estimate, in this case linearly from the value for m_N = 50 kg.

Note 2: For smaller nominal values up to approximately 100 g, the non-linear behaviour of the calibration uncertainty above the nominal values means that it makes a significant difference whether single-piece loads are assumed or whether, for example, 50 g is formed by a combination of "20 g + 20 g + 10 g". Typically, however, it can be assumed in this range that a laboratory has the appropriate single-piece loads and does use them.

For larger loads, however, practical reasons often lead to the use of multi-piece loads (combined weights) (e.g., a combination of ‘20 kg + 20 kg + 10 kg’ instead of a single 50 kg weight). In this range, however, the calibration uncertainties of the weights are typically proportional to the nominal value, so that only negligible differences arise here. An exception here are the weight baskets with free nominal value commonly used in the high-load range and for which the calibration uncertainty and the *mpe* of the next higher nominal value are often specified. For a standard high-load weight set of class $_{M1}$ with a basket of 60 kg (for which the calibration uncertainty U = 1,6 g and the *mpe* = 5 g of the next higher nominal value of 100 kg are assumed) and 22*20 kg (each with U = 0,30 g und *mpe* = 1 g), we get, for example

$$mpe = 5\text{ g} + 22 * 1\text{ g} = 27\text{ g and } U = 1{,}6\text{ g} + 22 * 0{,}30\text{ g} = 8{,}2\text{ g},$$

whereas for a single-piece 500 kg weight we get

$$mpe = 25\text{ g and } U = 8{,}0\text{ g}$$

or, similarly, for 10 individual 50 kg weights

$$mpe = 10 * 2{,}5\text{ g} = 25\text{ g and } U = 10 * 0{,}80\text{ g} = 8{,}0.$$

The relative total uncertainty is then $1{,}6\cdot10^{-4}$ instead of $1{,}5\cdot10^{-4}$ as stated in Table 6. However, this simplification in the calculation of the CMCs is permissible, i.e. weight baskets do not have to be considered separately, and the assumption of single-piece weights is also accepted in this case.

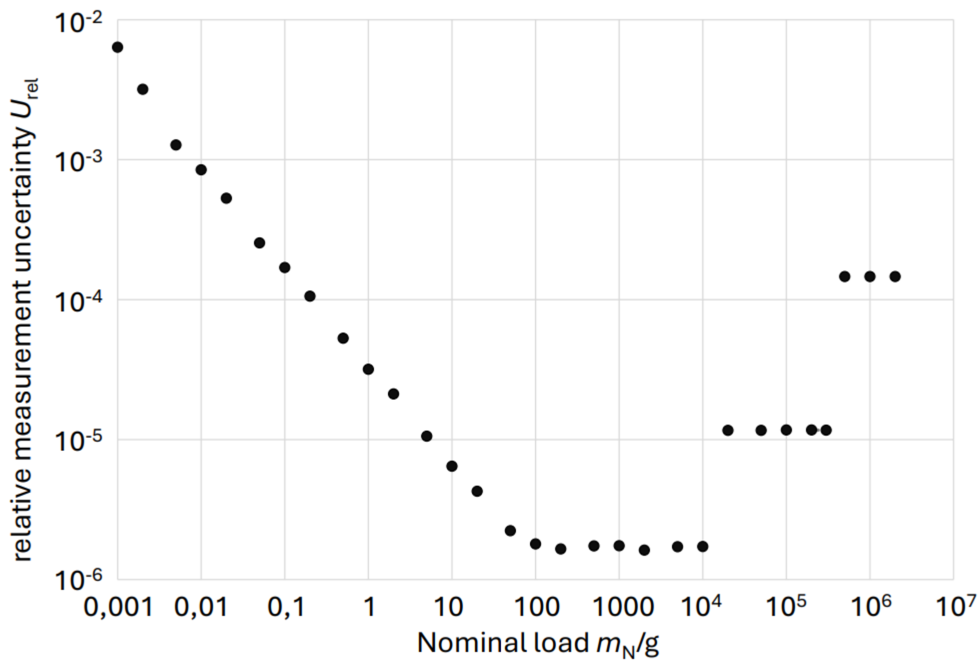

Figure 2: Representation of the smallest achievable uncertainties for example B1

Table 6 and Figure 2 clearly show that there are three ranges in which the smallest achievable relative measurement uncertainty can be considered constant. The differences within these ranges are so small that they are no longer discernible when expressed with two significant digits. Accordingly, only one value for the smallest achievable uncertainty can be specified for each of these ranges, see Table 7.

Range	Expanded measurement uncertainty
200 g ≤ m_N ≤ 10 kg	$1{,}7 \cdot 10^{-6} \cdot m_N$
10 kg < m_N ≤ 300 kg	$1{,}2 \cdot 10^{-5} \cdot m_N$
300 kg < m_N ≤ 3 t	$1{,}5 \cdot 10^{-4} \cdot m_N$

Table 7: Ranges with the smallest relative measurement uncertainty assumed to be constant for example B1

For all smaller loads, the relative measurement uncertainty between two points of support changes so significantly that these must be specified as separate intervals, see Table 8.

Range	Expanded measurement uncertainty
0 g	$5{,}8 \cdot 10^{-8}$ g
1 mg	$6{,}4 \cdot 10^{-3} \cdot m_N$
2 mg ≤ m_N < 5 mg	$3{,}2 \cdot 10^{-3} \cdot m_N$
5 mg ≤ m_N < 10 mg	$1{,}3 \cdot 10^{-3} \cdot m_N$
10 mg ≤ m_N < 20 mg	$8{,}5 \cdot 10^{-4} \cdot m_N$
20 mg ≤ m_N < 50 mg	$5{,}3 \cdot 10^{-4} \cdot m_N$
50 mg ≤ m_N < 100 mg	$2{,}5 \cdot 10^{-4} \cdot m_N$
100 mg ≤ m_N < 200 mg	$1{,}7 \cdot 10^{-4} \cdot m_N$

200 mg ≤ m_N < 500 mg	$1{,}1 \cdot 10^{-4} \cdot m_N$
500 mg ≤ m_N < 1 g	$5{,}3 \cdot 10^{-5} \cdot m_N$
1 g ≤ m_N < 2 g	$3{,}2 \cdot 10^{-5} \cdot m_N$
2 g ≤ m_N < 5 g	$2{,}1 \cdot 10^{-5} \cdot m_N$
5 g ≤ m_N < 10 g	$1{,}1 \cdot 10^{-5} \cdot m_N$
10 g ≤ m_N < 20 g	$6{,}5 \cdot 10^{-6} \cdot m_N$
20 g ≤ m_N < 50 g	$4{,}3 \cdot 10^{-6} \cdot m_N$
50 g ≤ m_N < 100 g	$2{,}2 \cdot 10^{-6} \cdot m_N$
100 g ≤ m_N < 200 g	$1{,}8 \cdot 10^{-6} \cdot m_N$

Table 8: Ranges in which the smallest relative measurement uncertainty cannot be assumed to be constant, calculated for example B1

All in all, for the present example, this results in the following suggestion for presenting the CMCs:

Calibration and measurement capabilities (CMCs)				
Measurand / Calibration item	Measuring range / Measuring span	Measurement conditions / Procedure	Expanded measurement uncertainty	Remarks
Weighing instruments Non-automatic electronic weighing instruments	0 g	EURAMET Calibration Guide No. 18, Version 4.0	$5{,}8 \cdot 10^{-8}$ g	
	1 mg		$6{,}4 \cdot 10^{-3} \cdot m_N$	
	2 mg ≤ m_N < 5 mg		$3{,}2 \cdot 10^{-3} \cdot m_N$	
	5 mg ≤ m_N < 10 mg		$1{,}3 \cdot 10^{-3} \cdot m_N$	
	10 mg ≤ m_N < 20 mg		$8{,}5 \cdot 10^{-4} \cdot m_N$	
	20 mg ≤ m_N < 50 mg		$5{,}3 \cdot 10^{-4} \cdot m_N$	
	50 mg ≤ m_N < 100 mg		$2{,}5 \cdot 10^{-4} \cdot m_N$	
	100 mg ≤ m_N < 200 mg		$1{,}7 \cdot 10^{-4} \cdot m_N$	
	200 mg ≤ m_N < 500 mg		$1{,}1 \cdot 10^{-4} \cdot m_N$	
	500 mg ≤ m_N < 1 g		$5{,}3 \cdot 10^{-5} \cdot m_N$	
	1 g ≤ m_N < 2 g		$3{,}2 \cdot 10^{-5} \cdot m_N$	
	2 g ≤ m_N < 5 g		$2{,}1 \cdot 10^{-5} \cdot m_N$	
	5 g ≤ m_N < 10 g		$1{,}1 \cdot 10^{-5} \cdot m_N$	
	10 g ≤ m_N < 20 g		$6{,}5 \cdot 10^{-6} \cdot m_N$	
	20 g ≤ m_N < 50 g		$4{,}3 \cdot 10^{-6} \cdot m_N$	
	50 g ≤ m_N < 100 g		$2{,}2 \cdot 10^{-6} \cdot m_N$	
	100 g ≤ m_N < 200 g		$1{,}8 \cdot 10^{-6} \cdot m_N$	
	200 g ≤ m_N ≤ 10 kg		$1{,}7 \cdot 10^{-6} \cdot m_N$	
	10 kg < m_N ≤ 300 kg		$1{,}2 \cdot 10^{-5} \cdot m_N$	
	300 kg < m_N ≤ 3 t		$1{,}5 \cdot 10^{-4} \cdot m_N$	

Example B2

Laboratory requirements:

For nominal loads up to 200 g, the laboratory uses the conventional weighed value for weights of class E_2 according to OIML R111 [11]. Typically, the weights are calibrated with a calibration uncertainty of U = mpe/4. Based on statistical observations, the laboratory assumes a value of k_D = 1,5 for the change in weights.

For nominal loads between 200 g and 20 kg, the laboratory uses the conventional weighed value for weights of class E_2 according to OIML R111 [11]. Typically, the weights are calibrated with a calibration uncertainty of U = mpe/5. Based on statistical observations, the laboratory assumes a value of k_D= 1 for the change in weights.

For nominal loads between 20 kg and 500 kg, the laboratory uses the conventional weighed value for weights of class F_1 according to OIML R111 [11]. Typically, the weights are calibrated with a calibration uncertainty of U = mpe/5. Based on statistical observations, the laboratory assumes a value of k_D= 2 for the change in weights.

For nominal loads between 500 kg and 100 t, the laboratory uses the nominal value for weights of class M_1 according to OIML R111 [11], with U = mpe/√3. Based on statistical observations, the laboratory assumes a value of k_D = 2 for the change in weights.

In addition to the nominal values specified in OIML R111 [11], the laboratory identifies the values 200 g and 100 t as support points. The former because the framework conditions change significantly when a different weight class is used, and the latter because it represents the upper limit of the scope of accreditation. Taking into account the above conditions as well as the framework conditions specified in **Fehler! Verweisquelle konnte nicht gefunden werden.** and 2.2 we get the following smallest achievable uncertainties for these support points (Table 9):

m_N /g	$u(\delta I_{dig0})$ /g	$u(\delta I_{digL})$ /g	$u(\delta m_c)$ /g	$u(\delta m_B)$ /g	$u(\delta m_D)$ /g	$u(\delta m_{conv})$ /g	$u(m_N)$ /g	$U(m_N)$ /g	$U_{rel}(m_N)$ /g
0	$2,9\cdot10^{-8}$	0	0	0	0	0	$2,9\cdot10^{-8}$	$5,8\cdot10^{-8}$	---
$1\cdot10^{-3}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$7,5\cdot10^{-7}$	$8,7\cdot10^{-7}$	$1,3\cdot10^{-6}$	0	$1,7\cdot10^{-6}$	$3,5\cdot10^{-6}$	$3,5\cdot10^{-3}$
$2\cdot10^{-3}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$7,5\cdot10^{-7}$	$8,7\cdot10^{-7}$	$1,3\cdot10^{-6}$	0	$1,7\cdot10^{-6}$	$3,5\cdot10^{-6}$	$1,7\cdot10^{-3}$
$5\cdot10^{-3}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$7,5\cdot10^{-7}$	$8,7\cdot10^{-7}$	$1,3\cdot10^{-6}$	0	$1,7\cdot10^{-6}$	$3,5\cdot10^{-6}$	$6,9\cdot10^{-4}$
$1\cdot10^{-2}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,0\cdot10^{-6}$	$1,2\cdot10^{-6}$	$1,7\cdot10^{-6}$	0	$2,3\cdot10^{-6}$	$4,6\cdot10^{-6}$	$4,6\cdot10^{-4}$
$2\cdot10^{-2}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,3\cdot10^{-6}$	$1,4\cdot10^{-6}$	$2,2\cdot10^{-6}$	0	$2,9\cdot10^{-6}$	$5,8\cdot10^{-6}$	$2,9\cdot10^{-4}$
$5\cdot10^{-2}$	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$1,5\cdot10^{-6}$	$1,7\cdot10^{-6}$	$2,6\cdot10^{-6}$	0	$3,5\cdot10^{-6}$	$6,9\cdot10^{-6}$	$1,4\cdot10^{-4}$
0,1	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$2,0\cdot10^{-6}$	$2,3\cdot10^{-6}$	$3,5\cdot10^{-6}$	0	$4,6\cdot10^{-6}$	$9,2\cdot10^{-6}$	$9,2\cdot10^{-5}$
0,2	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$2,5\cdot10^{-6}$	$2,9\cdot10^{-6}$	$4,3\cdot10^{-6}$	0	$5,8\cdot10^{-6}$	$1,2\cdot10^{-5}$	$5,8\cdot10^{-5}$
0,5	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$3,1\cdot10^{-6}$	$3,6\cdot10^{-6}$	$5,4\cdot10^{-6}$	0	$7,2\cdot10^{-6}$	$1,4\cdot10^{-5}$	$2,9\cdot10^{-5}$
1	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$3,8\cdot10^{-6}$	$4,3\cdot10^{-6}$	$6,5\cdot10^{-6}$	0	$8,7\cdot10^{-6}$	$1,7\cdot10^{-5}$	$1,7\cdot10^{-5}$
2	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$5,0\cdot10^{-6}$	$5,8\cdot10^{-6}$	$8,7\cdot10^{-6}$	0	$1,2\cdot10^{-5}$	$2,3\cdot10^{-5}$	$1,2\cdot10^{-5}$
5	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$6,3\cdot10^{-6}$	$7,2\cdot10^{-6}$	$1,1\cdot10^{-5}$	0	$1,4\cdot10^{-5}$	$2,9\cdot10^{-5}$	$5,8\cdot10^{-6}$
10	$2,9\cdot10^{-8}$	$2,9\cdot10^{-8}$	$7,5\cdot10^{-6}$	$8,7\cdot10^{-6}$	$1,3\cdot10^{-5}$	$5,8\cdot10^{-6}$	$1,8\cdot10^{-5}$	$3,7\cdot10^{-5}$	$3,7\cdot10^{-6}$
20	$2,9\cdot10^{-7}$	$2,9\cdot10^{-7}$	$1,0\cdot10^{-5}$	$1,2\cdot10^{-5}$	$1,7\cdot10^{-5}$	$5,8\cdot10^{-6}$	$2,4\cdot10^{-5}$	$4,8\cdot10^{-5}$	$2,4\cdot10^{-6}$
50	$2,9\cdot10^{-7}$	$2,9\cdot10^{-7}$	$1,3\cdot10^{-5}$	$1,4\cdot10^{-5}$	$2,2\cdot10^{-5}$	$1,7\cdot10^{-5}$	$3,4\cdot10^{-5}$	$6,7\cdot10^{-5}$	$1,3\cdot10^{-6}$
$1\cdot10^{2}$	$2,9\cdot10^{-7}$	$2,9\cdot10^{-7}$	$2,0\cdot10^{-5}$	$2,3\cdot10^{-5}$	$3,5\cdot10^{-5}$	$2,9\cdot10^{-5}$	$5,5\cdot10^{-5}$	$1,1\cdot10^{-4}$	$1,1\cdot10^{-6}$
$2\cdot10^{2}$	$1,4\cdot10^{-6}$	$1,4\cdot10^{-6}$	$3,8\cdot10^{-5}$	$4,3\cdot10^{-5}$	$6,5\cdot10^{-5}$	$4,6\cdot10^{-5}$	$9,8\cdot10^{-5}$	$2,0\cdot10^{-4}$	$9,8\cdot10^{-7}$
$5\cdot10^{2}$	$2,9\cdot10^{-6}$	$2,9\cdot10^{-6}$	$8,0\cdot10^{-5}$	$1,2\cdot10^{-4}$	$9,2\cdot10^{-5}$	$9,8\cdot10^{-5}$	$1,9\cdot10^{-4}$	$3,9\cdot10^{-4}$	$7,8\cdot10^{-7}$
$1\cdot10^{3}$	$2,9\cdot10^{-5}$	$2,9\cdot10^{-5}$	$1,6\cdot10^{-4}$	$2,3\cdot10^{-4}$	$1,8\cdot10^{-4}$	$1,7\cdot10^{-4}$	$3,9\cdot10^{-4}$	$7,8\cdot10^{-4}$	$7,8\cdot10^{-7}$
$2\cdot10^{3}$	$2,9\cdot10^{-5}$	$2,9\cdot10^{-5}$	$3,0\cdot10^{-4}$	$4,3\cdot10^{-4}$	$3,5\cdot10^{-4}$	$2,9\cdot10^{-4}$	$7,0\cdot10^{-4}$	$1,4\cdot10^{-3}$	$7,0\cdot10^{-7}$
$5\cdot10^{3}$	$2,9\cdot10^{-5}$	$2,9\cdot10^{-5}$	$8,0\cdot10^{-4}$	$1,2\cdot10^{-3}$	$9,2\cdot10^{-4}$	$6,3\cdot10^{-4}$	$1,8\cdot10^{-3}$	$3,6\cdot10^{-3}$	$7,2\cdot10^{-7}$
$1\cdot10^{4}$	$2,9\cdot10^{-4}$	$2,9\cdot10^{-4}$	$1,6\cdot10^{-3}$	$2,3\cdot10^{-3}$	$1,8\cdot10^{-3}$	$1,1\cdot10^{-3}$	$3,7\cdot10^{-3}$	$7,4\cdot10^{-3}$	$7,4\cdot10^{-7}$
$2\cdot10^{4}$	$2,9\cdot10^{-4}$	$2,9\cdot10^{-4}$	$3,0\cdot10^{-3}$	$4,3\cdot10^{-3}$	$3,5\cdot10^{-3}$	$2,0\cdot10^{-3}$	$6,7\cdot10^{-3}$	$1,3\cdot10^{-2}$	$6,7\cdot10^{-7}$
$5\cdot10^{4}$	$5,8\cdot10^{-4}$	$5,8\cdot10^{-4}$	$2,5\cdot10^{-2}$	$3,6\cdot10^{-2}$	$5,8\cdot10^{-2}$	$4,5\cdot10^{-3}$	$7,3\cdot10^{-2}$	0,15	$2,9\cdot10^{-6}$
$1\cdot10^{5}$	$1,4\cdot10^{-2}$	$1,4\cdot10^{-2}$	$3,0\cdot10^{-2}$	$4,3\cdot10^{-2}$	$6,9\cdot10^{-2}$	$9,0\cdot10^{-3}$	0,10	0,21	$2,1\cdot10^{-6}$
$2\cdot10^{5}$	$2,9\cdot10^{-2}$	$2,9\cdot10^{-2}$	$5,0\cdot10^{-2}$	$7,2\cdot10^{-2}$	0,12	$1,8\cdot10^{-2}$	0,18	0,36	$1,8\cdot10^{-6}$
$5\cdot10^{5}$	$2,9\cdot10^{-2}$	$2,9\cdot10^{-2}$	0,10	0,14	0,23	$4,5\cdot10^{-2}$	0,31	0,63	$1,3\cdot10^{-6}$
$1\cdot10^{6}$	0,14	0,14	14	3,6	33	$9,0\cdot10^{-2}$	37	73	$7,3\cdot10^{-5}$
$2\cdot10^{6}$	0,29	0,29	29	7,2	67	0,18	73	$1,5\cdot10^{2}$	$7,3\cdot10^{-5}$
$5\cdot10^{6}$	$2,9\cdot10^{2}$	$2,9\cdot10^{2}$	58	14	$1,3\cdot10^{2}$	0,45	$1,1\cdot10^{3}$	$2,2\cdot10^{3}$	$4,4\cdot10^{-4}$
$1\cdot10^{7}$	$2,9\cdot10^{3}$	$2,9\cdot10^{3}$	$1,4\cdot10^{2}$	36	$3,3\cdot10^{2}$	0,90	$1,1\cdot10^{4}$	$2,2\cdot10^{4}$	$2,2\cdot10^{-3}$
$2\cdot10^{7}$	$2,9\cdot10^{3}$	$2,9\cdot10^{3}$	$2,9\cdot10^{2}$	72	$6,7\cdot10^{2}$	1,8	$1,1\cdot10^{4}$	$2,2\cdot10^{4}$	$1,1\cdot10^{-3}$
$5\cdot10^{7}$	$5,8\cdot10^{3}$	$5,8\cdot10^{3}$	$5,8\cdot10^{2}$	$1,4\cdot10^{2}$	$1,3\cdot10^{3}$	4,5	$2,2\cdot10^{4}$	$4,3\cdot10^{4}$	$8,7\cdot10^{-4}$
$1\cdot10^{8}$	$1,4\cdot10^{4}$	$1,4\cdot10^{4}$	$2,9\cdot10^{3}$	$7,2\cdot10^{2}$	$6,7\cdot10^{3}$	9,0	$5,4\cdot10^{4}$	$1,1\cdot10^{5}$	$1,1\cdot10^{-3}$

Table 9: Uncertainty contributions for calculating the smallest achievable uncertainties for example B2. Contributions are designated as in EURAMET cg-18 [7] and DKD-R 7-2 [8]. The individual

uncertainty contributions are rounded to 2 significant digits. The unrounded values were used to calculate the expanded measurement uncertainty.

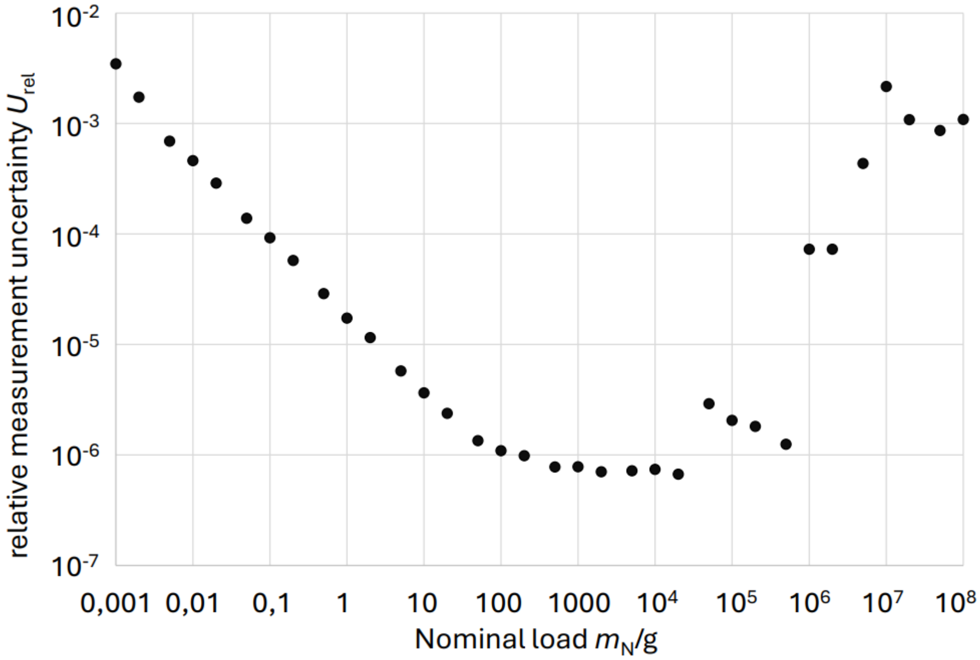

Figure 3: Representation of the smallest achievable uncertainties for example B1

Contrary to example B1, in this example it is no longer entirely obvious which ranges can be assumed to have a constant relative measurement uncertainty. For this example, the ranges shown in Table 10 are selected:

Range	Expanded measurement uncertainty
500 g ≤ m_N ≤ 20 kg	$7{,}8 \cdot 10^{-7} \cdot m_N$
1 t ≤ m_N ≤ 2 t	$7{,}3 \cdot 10^{-5} \cdot m_N$
20 t ≤ m_N ≤ 100 t	$1{,}1 \cdot 10^{-3} \cdot m_N$

Table 10: Ranges where the minimum relative measurement uncertainty can be assumed to be constant for example B2

Note 1: Since no specification has been made here as to which fluctuations within a range are to be "assumed to be constant", the laboratory could also define the ranges differently – e.g. by splitting the first range as shown in Table 10. The advantage of this would be that for 20 kg, the uncertainty would not have to be artificially raised from the actual value $U = 6{,}7 \cdot 10^{-7}$ (= 13,4 mg) to the specified value of the range of $U = 7{,}8 \cdot 10^{-7}$ (= 15,6 mg). In principle, however, the aim of achieving clearer scopes of accreditation should take precedence.

Range	Expanded measurement uncertainty
500 g ≤ m_N ≤ 10 kg	$7{,}8 \cdot 10^{-7} \cdot m_N$
10 kg < m_N ≤ 20 kg	$6{,}7 \cdot 10^{-7} \cdot m_N$

Table 11: Alternative splitting of the first range with the smallest relative measurement uncertainty assumed to be constant from Table 10.

Note 2: Since the second range listed in Table 10 only comprises two support points, the savings compared to listing the two support points separately are very small.

For all smaller loads, the relative measurement uncertainty between two support points changes so significantly that they must be specified as separate intervals:

Range	Expanded measurement uncertainty
0 g	$5{,}8 \cdot 10^{-8}$ g
1 mg	$3{,}5 \cdot 10^{-3} \cdot m_N$
2 mg ≤ m_N < 5 mg	$1{,}7 \cdot 10^{-3} \cdot m_N$
5 mg ≤ m_N < 10 mg	$6{,}9 \cdot 10^{-4} \cdot m_N$
10 mg ≤ m_N < 20 mg	$4{,}6 \cdot 10^{-4} \cdot m_N$
20 mg ≤ m_N < 50 mg	$2{,}9 \cdot 10^{-4} \cdot m_N$
50 mg ≤ m_N < 100 mg	$1{,}4 \cdot 10^{-4} \cdot m_N$
100 mg ≤ m_N < 200 mg	$9{,}2 \cdot 10^{-5} \cdot m_N$
200 mg ≤ m_N < 500 mg	$5{,}8 \cdot 10^{-5} \cdot m_N$
500 mg ≤ m_N < 1 g	$2{,}9 \cdot 10^{-5} \cdot m_N$
1 g ≤ m_N < 2 g	$1{,}7 \cdot 10^{-5} \cdot m_N$
2 g ≤ m_N < 5 g	$1{,}2 \cdot 10^{-5} \cdot m_N$
5 g ≤ m_N < 10 g	$5{,}8 \cdot 10^{-6} \cdot m_N$
10 g ≤ m_N < 20 g	$3{,}7 \cdot 10^{-6} \cdot m_N$
20 g ≤ m_N < 50 g	$2{,}4 \cdot 10^{-6} \cdot m_N$
50 g ≤ m_N < 100 g	$1{,}3 \cdot 10^{-6} \cdot m_N$
100 g ≤ m_N < 200 g	$1{,}1 \cdot 10^{-6} \cdot m_N$
200 g ≤ m_N < 500 g	$9{,}8 \cdot 10^{-7} \cdot m_N$
20 kg < m_N < 50 kg	$2{,}9 \cdot 10^{-6} \cdot m_N$
50 kg ≤ m_N < 100 kg	$2{,}9 \cdot 10^{-6} \cdot m_N$
100 kg ≤ m_N < 200 kg	$2{,}1 \cdot 10^{-6} \cdot m_N$
200 kg ≤ m_N < 500 kg	$1{,}8 \cdot 10^{-6} \cdot m_N$
500 kg ≤ m_N < 1 t	$7{,}3 \cdot 10^{-5} \cdot m_N$
2 t < m_N < 5 t	$4{,}4 \cdot 10^{-4} \cdot m_N$

5 t ≤ m_N < 10 t	$2{,}2 \cdot 10^{-3} \cdot m_N$
10 t ≤ m_N < 20 t	$2{,}2 \cdot 10^{-3} \cdot m_N$

Table 12: Ranges in which the smallest relative measurement uncertainty cannot be assumed to be constant, calculated for example B2.

All in all, for the present example, this results in the following suggestion for presenting the CMCs:

Calibration and measurement capabilities (CMCs)				
Measurand / Calibration item	Measuring range / Measuring span	Measurement conditions / Procedure	Expanded measurement uncertainty	Remarks
Weighing instruments Non-automatic electronic weighing instrument	0 g	EURAMET Calibration Guide No. 18, Version 4.0	$5{,}8 \cdot 10^{-8}$ g	
	1 mg		$3{,}5 \cdot 10^{-3} \cdot m_N$	
	2 mg ≤ m_N < 5 mg		$1{,}7 \cdot 10^{-3} \cdot m_N$	
	5 mg ≤ m_N < 10 mg		$6{,}9 \cdot 10^{-4} \cdot m_N$	
	10 mg ≤ m_N < 20 mg		$4{,}6 \cdot 10^{-4} \cdot m_N$	
	20 mg ≤ m_N < 50 mg		$2{,}9 \cdot 10^{-4} \cdot m_N$	
	50 mg ≤ m_N < 100 mg		$1{,}4 \cdot 10^{-4} \cdot m_N$	
	100 mg ≤ m_N < 200 mg		$9{,}2 \cdot 10^{-5} \cdot m_N$	
	200 mg ≤ m_N < 500 mg		$5{,}8 \cdot 10^{-5} \cdot m_N$	
	500 mg ≤ m_N < 1 g		$2{,}9 \cdot 10^{-5} \cdot m_N$	
	1 g ≤ m_N < 2 g		$1{,}7 \cdot 10^{-5} \cdot m_N$	
	2 g ≤ m_N < 5 g		$1{,}2 \cdot 10^{-5} \cdot m_N$	
	5 g ≤ m_N < 10 g		$5{,}8 \cdot 10^{-6} \cdot m_N$	
	10 g ≤ m_N < 20 g		$3{,}7 \cdot 10^{-6} \cdot m_N$	
	20 g ≤ m_N < 50 g		$2{,}4 \cdot 10^{-6} \cdot m_N$	
	50 g ≤ m_N < 100 g		$1{,}3 \cdot 10^{-6} \cdot m_N$	
	100 g ≤ m_N < 200 g		$1{,}1 \cdot 10^{-6} \cdot m_N$	
	200 g ≤ m_N < 500 g		$9{,}8 \cdot 10^{-7} \cdot m_N$	
	500 g ≤ m_N ≤ 20 kg		$7{,}8 \cdot 10^{-7} \cdot m_N$	
	20 kg < m_N < 50 kg		$2{,}9 \cdot 10^{-6} \cdot m_N$	
	50 kg ≤ m_N < 100 kg		$2{,}9 \cdot 10^{-6} \cdot m_N$	
	100 kg ≤ m_N < 200 kg		$2{,}1 \cdot 10^{-6} \cdot m_N$	
	200 kg ≤ m_N < 500 kg		$1{,}8 \cdot 10^{-6} \cdot m_N$	
	500 kg ≤ m_N < 1 t		$7{,}3 \cdot 10^{-5} \cdot m_N$	
	1 t ≤ m_N ≤ 2 t		$7{,}3 \cdot 10^{-5} \cdot m_N$	
	2 t < m_N < 5 t		$4{,}4 \cdot 10^{-4} \cdot m_N$	
	5 t ≤ m_N < 10 t		$2{,}2 \cdot 10^{-3} \cdot m_N$	
	10 t ≤ m_N < 20 t		$2{,}2 \cdot 10^{-3} \cdot m_N$	
	20 t ≤ m_N ≤ 100 t		$1{,}1 \cdot 10^{-3} \cdot m_N$	

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