UKAS

A world of confidence

LAB 45

Edition 5 June 2023

Schedules of accreditation for calibration laboratories

Contents

Changes since last edition

References updated and other minor editorial changes made for improved clarity.

1. Introduction

1.1 The definitive statement of the accredited scope of a calibration laboratory is the UKAS Schedule of Accreditation which should be viewed after checking that the laboratory concerned is presently accredited by reference to www.ukas.com. The Schedule of Accreditation defines the measurement capabilities, ranges and boundaries of the calibration activities for which the organisation holds accreditation. It is therefore important that the Schedule of Accreditation is presented in a manner that is scientifically meaningful and presents unambiguous information in a manner that will be readily understood by the target audience.

1.2 This publication provides guidance on the format, presentation and content of Schedules of Accreditation for UKAS accredited calibration laboratories. It is primarily aimed at UKAS Assessment Managers and Technical Assessors but may also be of use to laboratories when applying for accreditation or when researching calibration schedules in support of obtaining traceability of measurement. Use of this guidance will assist in the production of consistent and meaningful schedules and will minimise the risk of customers and readers being misled.

2. Calibration schedules - permanent laboratories

2.1 The first page of a Schedule of Accreditation for permanent laboratories normally contains the following details:

a) Name of the accredited entity, as stated in the associated Accreditation Certificate.

b) Contact details, including name, telephone number, email address and web site details. These details are intended to assist the laboratory's customers and therefore may be different to those of the primary UKAS contact shown in our database.

c) Statements to the effect that the organisation is accredited to ISO/IEC 17025 and that calibration is performed at the given address only.

d) The UKAS calibration accreditation symbol with the organisation's accreditation number.

2.2 An example is shown below.

Schedule of Accreditation

issued by

United Kingdom Accreditation Service

2 Pine Trees, Chertsey Lane, Staines-upon-Thames, TW18 3HR, UK

<table>
<tr><td rowspan="2">UKAS CALIBRATION
0000

Accredited to
ISO/IEC 17025:2017</td><td colspan="2">NiceCal UK Limited

Issue No: 001 Issue date: 1 April 2021</td></tr>
<tr><td>Calibration Laboratory
High Street
Feltham
Middlesex
TW13 4UN</td><td>Contact: Mr S I Unit
Tel: +44 (0) 1784 429000
E-Mail: si.unit@nicecal.com
Website: www.nicecal.com</td></tr>
<tr><td colspan="3">Calibration performed at the above address only</td></tr>
</table>

CALIBRATION AND MEASUREMENT CAPABILITY (CMC)

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks

First page details for permanent laboratories

3. Calibration schedules - multi-site laboratories

3.1 The first page of a Schedule of Accreditation for multi-site laboratories normally contains the following details:

a) Name of the accredited entity, as stated in the associated Accreditation Certificate.

b) Contact details, including name, telephone number, email address and web site details. These details are intended to assist the laboratory's customers and therefore may be different to those of the primary UKAS contact shown in our database. There may be different contact details for each site, if appropriate.

Statements to the effect that the organisation is accredited to ISO/IEC 17025 and that calibration is performed at the given address, at specified sites, or both. There will inevitably be restrictions on the type of customer sites at which calibrations can be performed - these are due to, for example, the suitability of the environmental conditions, the space or facilities available and safety-related issues. This may therefore be a consideration when phrasing the description of the types of site. The UKAS calibration accreditation symbol with the organisation's accreditation number.

c) A location code or identifier that indicates in subsequent pages where particular calibrations may be performed.

3.2 An example is shown below.

Schedule of Accreditation
issued by
United Kingdom Accreditation Service
2 Pine Trees, Chertsey Lane, Staines-upon-Thames, TW18 3HR, UK

<table>
<tr><td rowspan="2">UKAS CALIBRATION
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Tel: +44 (0) 1784 429000
E-Mail: si.unit@nicecal.com
Website: www.nicecal.com</td></tr>
<tr><td colspan="3">**Calibration performed at the locations specified below**</td></tr>
</table>

Locations covered by the organisation and their relevant activities

Laboratory locations:

Location details		Activity	Location code
Address High Street Feltham Middlesex TW13 4UN	**Local contact** Mr S I Unit Tel: +44 (0) 20 8917 8400 Email: si.unit@nicecal.com Website: www.nicecal.com	Electrical calibration	P

Site locations:

Location details		**Activity**	**Location code**
The location must be suitable for the nature of the particular calibrations undertaken and will be the subject of contract review arrangements between the laboratory and the customer	**Local contact** Professor W K Heisenberg Tel: +44 (0) 20 8917 8400 Email: uncertainty@nicecal.com Website: www.nicecal.com	Quantum Physics	S

First page details for multi-site laboratories

CALIBRATION AND MEASUREMENT CAPABILITY (CMC)

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks	Location code

Second page details for multi-site laboratories

4. Flexible scopes

4.1 It is often considered that Calibration Schedules of the style used by UKAS are already inherently flexible as they typically describe the boundaries of the accreditation in terms of parameters and ranges, rather than solely by specification. This usually obviates any need to consider further the matter of flexible scopes for calibration laboratories.

4.2 This method of presentation imparts flexibility as the laboratory can, in many cases, calibrate various types of equipment where the measurements lie within the stated parametric boundaries.

4.3 However, should it be necessary to provide a schedule that specifically addresses Flexible Scopes for calibration laboratories, the following statement is suggested, either for the first page or in the part of the schedule where Flexible Scopes have been agreed:

The laboratory is accredited to ISO/IEC17025 for calibration activities in accordance with the details listed in this schedule. This may also include calibrations on the same or similar products against standards, laboratory developed procedures or customer-specified methods that are not specifically listed in this Schedule, providing that:

(1) The method, procedure or standard does not introduce new principles of measurement.

(2) The method, procedure or standard does not require measurements to be made outside the parametric boundaries defined in this Schedule.

Information about flexible scopes of accreditation is available in UKAS document GEN 4 and EA document EA-2/15.

5. Opinions and interpretations

5.1 In cases where it has been agreed that the expression of Opinions and Interpretations is included in a calibration laboratory's Schedule of Accreditation, the following statement is suggested for inclusion in that Schedule:

Opinions regarding the results and interpretations of those results may be provided for the measurements indicated.

5.2 It should be noted that assessment of conformity with specification does not require Opinions and Interpretations to be included in the Schedule of Accreditation. This is because conformity assessment is based on stated and objective criteria, normally those presented in Appendix M of M3003 [A1].

6. Calibration and measurement capabilities

6.1 The capabilities provided by accredited calibration laboratories are described by the Calibration and Measurement Capability (CMC), which expresses the lowest uncertainty of measurement that can be achieved during a calibration. The CIPM-ILAC definition [A2] of the CMC is as follows:

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

(a) as published in the BIPM key comparison database (KCDB) of the CIPM MRA; or

(b) as described in the laboratory's scope of accreditation granted by a signatory to the ILAC Arrangement.

6.3 The CMC is normally used to describe the uncertainty that appears in an accredited calibration laboratory's schedule of accreditation and is the uncertainty for which the laboratory has been accredited using the procedure that was the subject of assessment. The measurement uncertainty should be calculated according to the procedures given in M3003 [A1] and should normally be quoted as an expanded uncertainty at a coverage probability of 95%, which usually requires the use of a coverage factor of $k = 2$.

6.4 The measurement uncertainty may be described using various methods in the Schedule of Accreditation:

a) As a single value that is valid throughout the range.

<u>Example:</u>

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty ($k = 2$)	Remarks
Gas pressure (Gauge)	0 Pa to 500 Pa	0.10 Pa	

b) As an explicit function of the measurand or of a parameter. Where the function includes quadrature addition in the measurement uncertainty statements, the notation Q[a, b] stands for the root-sum-square of the terms between brackets: $Q[a, b] = [a^2 + b^2]^{1/2}$

<u>Example:</u>

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty ($k = 2$)	Remarks
Gas pressure (gauge), P	100 kPa to 1 MPa	Q [10 Pa, 0.0040 % x P]	

c) As a range of values. In such cases, the laboratory shall have procedures for determining the uncertainty at any given point within the range. Furthermore, the range should be sufficiently restricted that the customer could make a reasonable estimate of the likely uncertainty at any point within the range. Where a continuous range has been broken down into sub-ranges for this purpose, the measurement uncertainty should match at the break points.

Example:

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks
AC POWER FACTOR	0.5 to 0.9 *At 50 Hz*	0.0075 to 0.0036	Maximum voltage 500 V Maximum current 25 A For Power Factor Meters

As a matrix or table where the measurement uncertainty depends on the values of the measurand and a further parameter.

Example:

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks
AC VOLTAGE			For AC Voltmeters by comparison

Voltage range	Calibration and Measurement Capability in % of value for AC voltages over the frequency ranges shown				
	10 Hz to 100 Hz	*100 Hz to 30 kHz*	*30 kHz to 200 kHz*	*200 kHz to 500 kHz*	*500 kHz to 1 MHz*
1 mV to 3.3 mV	0.15	0.13	0.19	0.35	0.70
3.3 mV to 10 mV	0.048	0.030	0.069	0.20	0.47
10 mV to 33 mV	0.038	0.023	0.050	0.15	0.36
33 mV to 100 mV	0.029	0.014	0.027	0.080	0.21

d) In graphical form, providing there is sufficient resolution on each axis to obtain at least two significant figures for the measurement uncertainty.

6.5 Open intervals (e.g. ">*x*") are not permitted in the expression of CMCs.

6.6 It is sometimes the case that a laboratory may wish to be accredited for a measurement uncertainty that is larger than it can actually achieve. If the principles of M3003 [A1] are followed when constructing the uncertainty budget, the resulting expanded uncertainty should be a realistic representation of the laboratory's measurement capability. If this is smaller than the uncertainty the laboratory wishes to be accredited for and report on their certificates of calibration, the implication is that the laboratory is uncomfortable in some way about the magnitude of the expanded uncertainty. If this is the case, then the contributions to the uncertainty budget should be reviewed and re-evaluated not arbitrarily expanded for a 'safe' or 'conservative' estimate as this is not consistent with the GUM.

6.7 In cases where specific conditions are required in order to obtain the CMC, these conditions should be described in the Schedule of Accreditation, normally in the Remarks column.

Example:

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks
RF Attenuation	*0.3 MHz to 3 GHz* 0 dB to 40 dB 40 dB to 62 dB 62 dB to 80 dB	 0.047 dB 0.092 dB 0.90 dB	For Attenuators 7 mm 50 Ω coaxial line fitted with GPC 7 or Type N connectors. The uncertainty is for devices with input and output VRC not exceeding 0.2.

6.8 The CMC should always be stated numerically and not exclusively by reference to a standard or other document that describes the measurements undertaken.

Incorrect Example:

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks
Non automatic weighing machines	Up to 1000 kg	Uncertainties quoted will depend on the performance of the weighing machine under calibration, and will not be less than the uncertainty of calibration of the weights used for the calibration.	Weights are available in OIML Class E2 from 10 mg to 200 g, Class F1 from 10 mg to 10 kg and class M1 from 1 kg to 20 kg, 2 x 200 kg and 2 x 500 kg, to a total of 1000 kg

Correct Example:

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks
Non automatic weighing machines using OIML methods	10 mg to 10 g 10 g to 50 g 50 g to 30 kg 30 kg to 1000 kg	0.025 mg 2.0 mg/kg 10 mg/kg 100 mg/kg	Weights are available in OIML Class E2 from 10 mg to 200 g, Class F1 from 10 mg to 10 kg and class M1 from 1 kg to 20 kg, 2 x 200 kg and 2 x 500 kg, to a total of 1000 kg

6.9 It should be particularly noted that relative expressions, such as percentages, are not permissible when the range of the quantity values includes, or is close to, zero. Under such conditions, an absolute term must also be present; either on its own or in conjunction with the relative term.

Example:

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks
~~DC Voltage~~	~~0 V to 1 V~~	~~25 ppm~~	~~Incorrect~~
DC Voltage	0 V to 1 V	Q [25 μV/V, 5.0 μV]	Correct Using a comparison meter
DC Current	0 mA to 20 mA	2.5 μA	Correct Using a shunt and voltmeter

6.10 Particular care should be taken when the unit itself is normally expressed in percentage terms; examples are relative humidity (%rh) and amplitude modulation (% AM). For example,

50 %rh ± 10 %rh means the boundaries are 40 %rh and 60 %rh, whereas
50 %rh ± 10 % means the boundaries are 45 %rh and 55 %rh.

Under circumstances of this nature the presentation of the CMCs must be such that there is no ambiguity in interpretation.

6.11 Mathematical functions should not be used when the measurand is a single, specific value, rather than a range of values. Rather, the expression should be evaluated, and a single value of measurement uncertainty stated.

Example:

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks
~~DC Resistance (specific value)~~	~~100 Ω~~	~~Q [25 µΩ/Ω, 3.0 mΩ]~~	~~Incorrect~~
DC Resistance (specific value)	100 Ω	39 mΩ	For Resistors Using a bridge Correct

6.12 The number of figures in a measurement uncertainty declaration should always reflect practical measurement capability. In view of the process for estimating uncertainties it is seldom justified to present more than two significant figures. Using less than two significant figures can, however, introduce unacceptably large rounding errors. The measurement uncertainty should therefore be stated to two significant figures, using the normal rules of rounding, unless there are valid technical reasons for doing otherwise.

Examples:

Incorrect	Correct
~~2 µm~~	2.0 µm
~~0.1 MPa~~	0.098 MPa
~~5 mg~~	4.7 mg
~~7.17 nA~~	7.2 nA

When the measurement uncertainty value is provided by a function, the coefficients should have no more significant figures than are required for the calculation to be accurate when rounded to two significant figures.

6.13 It is frequently the case that a measurement capability is broken down into ranges corresponding to those available on the measuring instrument upon which the capability is based. Under such circumstances, the ranges described in the Schedule of Accreditation should correspond to the nominal range change points, as in the example below.

Correct		Incorrect	
Measured Quantity Instrument or Gauge	Range	Measured Quantity Instrument or Gauge	Range
DC Voltage	0 mV to 200 mV 200 mV to 2 V 2 V to 20 V 20 V to 200 V 200 V to 1000 V	DC Voltage	For voltmeters by comparison 0 mV to 200 mV > 200 mV to 2 V > 2 V to 20 V > 20 V to 200 V > 200 V to 1000 V 0 mV to 200 mV 201 mV to 2 V 2 .01V to 20 V 20.1 V to 200 V 201 V to 1000 V

6.14 The rationale behind this reasoning is as follows:

a) The intermediate ranges contain values that are repeated in the previous and subsequent ranges. So the question arises: “What is the measurement uncertainty at these repeated points?”

b) The exact stimulus required to switch between ranges on any instrument will depend on the particular calibration characteristics of each range of the instrument, *including the measurement uncertainty*. That stimulus can, therefore, never be truly known. Hence, there is no point in attempting to avoid the repetition; for example, by use of the “>” symbol or by leaving small gaps in the capability.

c) The laboratory’s procedures or records should contain sufficient information to define the range that was used in a particular calibration and hence the correct uncertainty, corresponding to that range, may be reported.

6.15 In the example above, the ranges designated in multiples of “2” are nominal, as the theoretical change over point is 1 least significant digit lower. For example, the 200 mV range actually has a full-scale value of 199.9999 mV. However, there is no point in stating the capability to such a degree of resolution, for the reasons stated in b) above.

6.16 When a normative standard defines an “uncertainty” calculation methodology which differs from measurement uncertainty, for example the “test value uncertainty” defined for the verification of callipers to ISO 13385-1, the test value uncertainty will be reported along with a comment that explains what has and has not been included in the analysis, in line with the definition provided by the standard. For example, “the test value uncertainty has been evaluated in accordance with the relevant ISO standard… calliper resolution and measurement repeatability are not included in the test value uncertainty”.

6.17 In dimensional calibration, the schedules of accreditation for the calibration of basic dimensional measuring tools and equipment have historically reported a CMC for parameters most relevant to end users. This method however does not provide transparency with regards to auxiliary measurements such as flatness and parallelism of micrometer measuring faces etc. These additional measurement techniques shall be listed on the schedule of accreditation along with the corresponding measurement uncertainty.

6.18 The measurement uncertainty should where practicable be expressed in terms of the measurand, however for calibrations in which various measurands s are possible depending upon the nature of the response x from the calibrated item, the CMC may be stated as the equivalent uncertainty expressed in the units of the reference quantity q, rather than in terms of the measurand $s = s(x, q)$, such that

$$u(q) = \left|\frac{\partial q}{\partial s}\right| u(s).$$

For example, suppose that the calibration of a flow sensor at flowrate F establishes an output frequency f and this is usually reported in terms of a meter factor $h = \frac{F}{f}$.

The CMC can be reported in terms of the reference quantity F (rather than the measurand h) by calculating

$$u(F) = \left|\frac{\partial F}{\partial h}\right| u(h) = f \times u(h)$$

6.19 Testing laboratories, in most cases, conduct their tests against internationally published standards and the associated testing schedule will contain references to these standards. Most calibration activities are conducted using documented in-house methods that have been demonstrated to provide the stated CMCs by means of uncertainty analysis. Consequently, there is, in most cases, no requirement to list normative references in calibration schedules. However, where such standards are used, they should be included in the Remarks column as in the following example:

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (k = 2)	Remarks
RELATIVE MAGNETIC PERMEABILITY, μ_r			
For low magnetic permeability materials	(μ_r - 1) from 0.001 to 1.5 (DC)	0.20 %	In accordance with BS 5884:1987

7. Symbols and units

7.1 It is recommended that only units of the SI and those units recognised for use with the SI should be used to express the values of quantities and of the associated measurement uncertainty. Nevertheless, other common units may be used where considered necessary for the intended audience, provided that the relationship between the chosen unit and the corresponding SI unit is stated.

7.2 ILAC P14 4.3 states “Because of the ambiguity of definitions, the use of terms “PPM” and “PPB” are not acceptable”. Therefore, the terms “ppm” and “ppb” should not be used. These terms can be replaced by a ratio of engineering units e.g., µV/V which would have the same numeric value as ppm, or through the use of “%” or parts in 10^6.

7.3 There are also units that are not part of the SI system but the use of which may be necessary for historical purposes or for calibration of instruments that are scaled in such units. For example, many dimensional measuring instruments are available that are scaled in inch units, although the SI definition of length relates to the metre. In such circumstances, the Schedule of Accreditation should use the correct SI unit but with a note such as “All linear calibrations may be given in inch units”.

7.4 One specific unit that is not mentioned in the SI system is relative humidity. It is recommended that the expression “%rh” be used for this quantity. Similarly, revolutions per minute is recommended to be shortened to “rpm”. Other commonly encountered units that are not defined in the SI system relate to units of time, in particular days, hours and minutes. The following are recommended for use in Schedules of Accreditation:

Name	Symbol	Value in SI units
minute (time)	min	1 min = 60 s
hour	h	1 h = 60 min = 3600 s
day	d	1 d = 24 h = 86 400 s

7.5 Abbreviations such as sec, cc, or mps are to be avoided and only standard unit symbols, prefix symbols, unit names, and prefix names should be used.

Examples:

Correct: s or second; cm^3 or cubic centimetre; ms^{-1}, m/s or metre per second
Incorrect: sec; cc; mps

7.6 Unit symbols are unaltered in the plural.

Example:

Correct: *l* = 75 cm
Incorrect: *l* = 75 cms

7.7 Unit symbols (or names) are not to be modified by the addition of subscripts or other information. The following form, for example, is used instead.

Correct: V_{max} = 1000 V
Incorrect: *V* = 1000 V_{max}

7.8 The dash (-) should not be used to indicate a range of values, due to ambiguity with the negative operator (minus sign). The word "to" should be used instead.

Example:

Correct: 0.8 g/ml to 1.0 g/ml
Incorrect: 0.8 g/ml - 1.0 g/ml

7.9 The unit should be repeated for each quantity value, either explicitly or by the use of parentheses.

Example:

Correct: 20 ˚C to 30 ˚C, *or* (20 to 30) ˚C
Incorrect: 20 to 30 ˚C

7.10 There is a space between the numerical value and unit symbol, even when the value is used in an adjectival sense, except in the case of superscript units for plane angle.

Examples:

Correct: a 25 kg mass	Incorrect: a 25-kg mass
Correct: 100 mV	Incorrect: 100mV
Correct: an angle of 2˚ 3' 4"	Incorrect: an angle of 2 ˚ 3 ' 4 "
Correct: 100 ˚C	Incorrect: 100˚C
Correct: 0.25 %	Incorrect: 0.25%

7.11 In cases where a number is not used as part of an expression, there is no space between mathematical operators (such as "+" or "-" signs) and the associated number. (This is known as a *monadic operator*.)

Examples:

Correct: -20 ˚C	Incorrect: - 20 ˚C
Correct: -100 mV to +100 mV	Incorrect: - 100 mV to + 100 mV

NOTE: the absence of a "+" or "-" sign implies that the value is positive, however the use of the "+" sign is encouraged where negative values are also possible, as in the second example above.

7.12 However, if the number and symbol are part of an expression (e.g. *a* + *b*), then spaces should be used. (This is known as a *dyadic operator*.)

8. Inclusion of reference to method or procedure and to equipment to be calibrated

8.1 If the descriptions in the other columns of the Schedule do not include a reference to the method or procedure used; then such a description shall be placed in the Remarks column. This is required to comply with ISO/IEC 17011:2017 so that the reader may appreciate the nature of the calibration or may enquire further about the reference given.

8.2 This reference may be in the form of the principle deployed, or the equipment used, or a reference to a documented procedure: For example:

By calibration against a pressure balance

By comparison with a voltage reference source

Methods consistent with EURAMET CG18

8.3 If the wording in the other columns does not describe the type of equipment or material to be calibrated, then this must be added to the Parameter or the Remarks column when this is required for the interpretation of the capability. For laboratories with multiple parameters per equipment this may be provided in the equipment list presented in the schedule preview pane of those laboratories on the UKAS website.

9. Final page of schedule

9.1 In order to assist laboratories' customers with the interpretation of the information provided in calibration schedules, the information presented below should be included as the final page. This information is a short summary of the recommendations of this document, LAB 45.

Appendix - Calibration and Measurement Capabilities
Introduction The definitive statement of the accreditation status of a calibration laboratory is the Accreditation Certificate and the associated Schedule of Accreditation. This Schedule of Accreditation is a critical document, as it defines the measurement capabilities, ranges and boundaries of the calibration activities for which the organisation holds accreditation. **Calibration and Measurement Capabilities (CMCs)** The capabilities provided by accredited calibration laboratories are described by the Calibration and Measurement Capability (CMC), which expresses the lowest measurement uncertainty that can be achieved during a calibration. If a particular device under calibration itself contributes significantly to the uncertainty (for example, if it has limited resolution or exhibits significant non-repeatability) then the uncertainty quoted on a calibration certificate will be increased to account for such factors. The CMC is normally used to describe the uncertainty that appears in an accredited calibration laboratory's schedule of accreditation and is the uncertainty for which the laboratory has been accredited using the procedure that was the subject of assessment. The measurement uncertainty is calculated according to the procedures given in the GUM and is normally stated as an expanded uncertainty at a coverage probability of 95 %, which usually requires the use of a coverage factor of $k = 2$. An accredited laboratory is not permitted to quote an uncertainty that is smaller than the published measurement uncertainty in certificates issued under its accreditation. **Expression of CMCs - symbols and units** It should be noted that the percentage symbol (%) represents the number 0.01. In cases where the measurement uncertainty is stated as a percentage, this is to be interpreted as meaning percentage of the measurand. Thus, for example, a measurement uncertainty of 1.5 % means 1.5 × 0.01 × *q*, where *q* is the quantity value. The notation Q[a, b] stands for the root-sum-square of the terms between brackets: $Q[a, b] = [a^2 + b^2]^{1/2}$

<u>Last page details for calibration schedules</u>

Appendix A - References

A1 United Kingdom Accreditation Service, M3003, *The Expression of Uncertainty and Confidence in Measurement*, Edition 5, September 2022.

A2 Joint BIPM/ILAC Working Group, CIPM 2007-11, *Calibration and Measurement Capabilities*, 7 September 2007.

Appendix B - Example schedule entries

Ideally the schedule should identify the measurand and the range of the reference quantity (or quantities) for which it can be established. The measurement uncertainty should where practicable be expressed in terms of the measurand, however for calibrations in which various measurands s are possible depending upon the nature of the response x from the calibrated item, the CMC may be stated as the equivalent uncertainty expressed in the units of the reference quantity q, rather than in terms of the measurand $s = f(x, q)$, such that $u(q) = \left|\frac{\partial q}{\partial s}\right| u(s)$. For example, suppose that a transducers output x corresponds to current i and the measurand is current sensitivity $s = i/q$. The uncertainty in the measurand $u(s)$ may be expressed in terms of the reference quantity q through the relation $u(q) = \left|\frac{\partial q}{\partial s}\right| u(s) = \frac{i}{s^2} u(s)$

A selection of examples is given below demonstrating various ways in which the CMC may be presented.

Measured Quantity Instrument or Gauge	**Range**	**Expanded Measurement Uncertainty (*k* = 2)**	**Remarks**
Pressure error, e at pressure p	p from $100\ \mathrm{kPa}$ to $1\ \mathrm{MPa}$ <u>or alternatively</u> $100\ \mathrm{kPa} \le p \le 1\ \mathrm{MPa}$ <u>or alternatively</u> $100 \le \frac{p}{\mathrm{kPa}} \le 1000$	$U(e) = 0.66\ \mathrm{Pa}$	
Pressure error, e at pressure p	$1\ \mathrm{kPa} \le p \le 110\ \mathrm{kPa}$	$U(e) = Q[a, b]$ $a = 0.42\ \mathrm{Pa}$ $b = 0.23\ p$	
Pressure error, e at pressure p	$1\ \mathrm{kPa} \le p \le 110\ \mathrm{kPa}$	$U(e) = Q[0.42\ \mathrm{Pa}, 0.23\ p]$	
Pressure ratio, f at pressure p	p from $10\ \mathrm{Pa}$ to $500\ \mathrm{Pa}$	$U(f) = Q[a, b]$ $a = 0.042$ $b = 2.4 \times 10^{-4}\ p/\mathrm{Pa}$	
Pressure error, e at differential pressure Δp and line pressure p	$1\ \mathrm{kPa} \le \Delta p \le 110\ \mathrm{kPa}$ $1\ \mathrm{MPa} \le p \le 100\ \mathrm{MPa}$	$U(e) = Q[a, b, c]$ $a = 51\ \mathrm{Pa}$ $b = 0.0023\ \Delta p$ $c = 1.1 \times 10^{-6}\ p$	

Measured Quantity Instrument or Gauge	Range	Expanded Measurement Uncertainty (*k* = 2)	Remarks
pH, h	h from -5 to 5	$U(h) = 0.11 + 0.021\ h$	Measurement uncertainty is a linear fit to U vs h
Resistance, R	$R\ =\ 1\ \mathrm{k\Omega} \pm 50\ \Omega$	$U(R) =\ 0.12\ \mathrm{m\Omega}$	
Flowrate transducer sensitivity, s at flowrate q	q from $1\ \mathrm{ml/s}$ to $20\ \mathrm{ml/s}$	$U(s) = Q[a,b]$ $a = 0.012\ \mathrm{mA\ \cdot s/ml}$ $b = 0.0021\ i\ \mathrm{s/ml}$	$s\ =\ i/q$ for transducer current i and flowrate q
Flowrate meter factor, s at flowrate q	q from $1\ \mathrm{ml/s}$ to $20\ \mathrm{ml/s}$	$U(s) = Q\left[0.14, 0.0012\ \frac{f}{\mathrm{Hz}}\right]\mathrm{litre}^{-1}$	$s\ =\ f/q$ for meter frequency f and flowrate q
Flowrate meter error, e at flowrate q for meter with current output i	q from $20\ \mathrm{l/s}$ to $1000\ \mathrm{l/s}$ T between $0\ \mathrm{°C}$ to $30\ \mathrm{°C}$	$U(e) = Q[a,b]$ $a\ =\ 0.012\ \mathrm{l/s}$ $b\ =\ 0.0021\ q$	$e\ = q - \ q_{\mathrm{calc}}$ where $q_{\mathrm{calc}} = f(i)$ and function f and its coefficients are fixed. Calibration can be performed with other electrical outputs at equivalent measurement uncertainty
Flowrate q for meter with output voltage signal, v	q from $10\ \mathrm{l/s}$ to $2000\ \mathrm{l/s}$	$U(q) = Q[a,b]$ $a\ =\ 0.12\ \mathrm{l/s}$ $b\ =\ 0.021\ q_v$ $q_v = v \times 200\ \mathrm{ls^{-1}V^{-1}}$	Measurement uncertainty expressed in equivalent flowrate units for purposes of CMC schedule.
Coefficients (α, β) of linear calibration function for pH, h	$-5\ \leq h \leq\ 5$	$V(\alpha,\beta) = \begin{bmatrix} 0.281 & -0.082 \\ -0.082 & 0.032 \end{bmatrix}$	Calibration function: $h\ = \alpha\ +\ \beta . h_{\mathrm{obs}}$ h_{obs} is the observed value $V(\alpha,\beta)$ is the covariance matrix for coefficients (α,β)

Measured Quantity Instrument or Gauge	**Range**	**Expanded Measurement Uncertainty (*k* = 2)**	**Remarks**
Coefficients (α, β) of linear calibration function for mass flowmeter with output current i	Mass flowrate q from $0 \text{ slm to } 100 \text{ slm}$	$V(\alpha,\beta) = \begin{bmatrix} u_\alpha^2 & u_{\alpha\beta} \\ u_{\alpha\beta} & u_b^2 \end{bmatrix}$ $u_a^2 = 0.0042 \text{ slm}^2$ $u_\beta^2 = 0.0024 \text{ (slm/mA)}^2$ $u_{\alpha\beta} = 0.000032 \text{ slm}^2\text{/mA}$	Calibration function: $q = \alpha + \beta . i$ $V(\alpha,\beta)$ is the covariance matrix for coefficients (α, β) 1 slm = 1 litre/min at 20 °C

END