Infrastructure Commission (INFCOM)

Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)

Expert Team on Quality, Traceability and Calibration (ET-QTC)

Calibration and Measurement Uncertainty

Part-1: Definition and Importance of Uncertainty

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Content

Uncertainty:

a logical doubt

about our limits

to know the truth

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Why worry about uncertainty?

- Every measurement is subject to some level of uncertainty.
- A measurement result is incomplete without a statement of the uncertainty.
- Understanding measurement uncertainty is the first step to reducing it.
- Good measurement practice can help reduce uncertainties.

Why we need to evaluate uncertainty

- Allows us to assess methods and results against data quality requirements.
- Fitness for purpose of a measurement method (do we meet target uncertainties?).
- Provides an understanding of which parameters should be given most consideration.
- Informs method optimisation and improvement.
- Interpretation and application of results.
- Equivalence of different results.
- Comparability of measurements.

- Uncertainty is a **property of a measurement result**

- Indicates the likely range within which we think the ‘true’ value of a measured quantity lies, **given all the information we have;**

- Measurement uncertainty is a **single value**, expressed in terms of the measurement result either;

  - as a percentage (relative uncertainty)

  or

  -in units of the measurand (absolute uncertainty).

The uncertainty is not the error!

They are not synonyms, but represent completely different concepts; they should not be confused with one another or misused.

Errors can be (partially) **corrected.**
Uncertainties can be (partially) **reduced.**

Uncertainties are not mistakes:
they represent our limit to exactly know a *measurement* value.

The uncertainty is not the error!

If I have a cheaper or low performance instrument than someone else, I do not make a mistake or an error: I will just have larger uncertainties.

But if I do not correct the readings of my instrument by applying the calibration curve, then I will introduce errors in my measurement results.

JCGM 100:2008 Evaluation of measurement data – Guide to the expression of uncertainty in measurement

(*aka the “GUM”*)

The "GUM" is now a whole suite of documents.
The legacy GUM is just one among many

Free download at
https://www.bipm.org/en/committees/jc/jcgm/publications

Charter
Joint Committee for Guides in Metrology (JCGM)

From the GUM

3.3 Uncertainty: dispersion of the values that could reasonably be attributed to the measurand.

3.3.1 The uncertainty of the result of a measurement reflects the lack of exact knowledge of the value of the measurand (see 2.2).

The result of a measurement after correction for recognized systematic effects is still only an *estimate of the true value of the measurand because of the uncertainty arising from random effects and from imperfect correction of the result* for systematic effects.

Thus the uncertainty of the result of a measurement should not be confused with the remaining unknown error.

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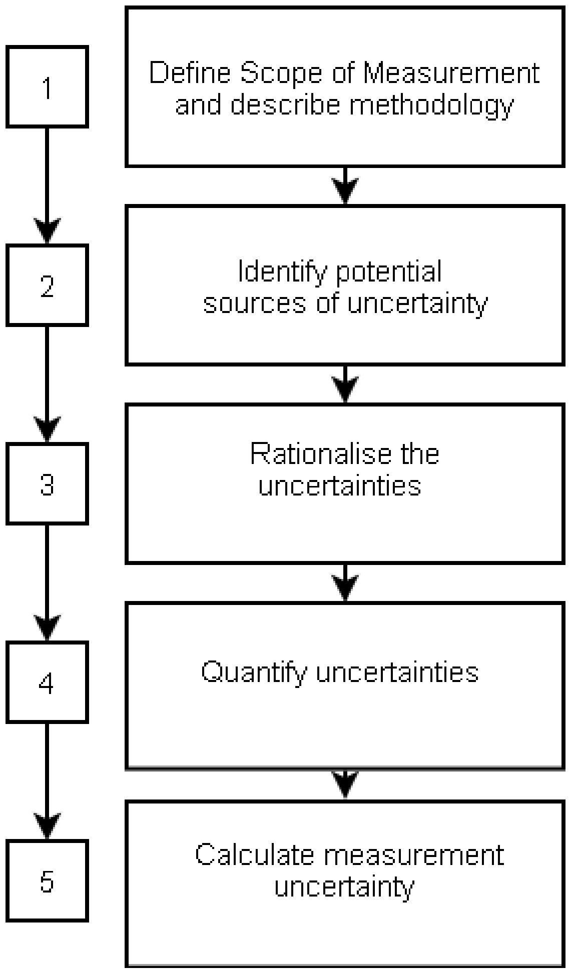
Guide to the Expression of Uncertainty in Measurement (GUM)

- The GUM has been adopted as an overarching methodology
- Approach can be summarised as:
  - Describe measurement steps.
  - Identify uncertainties associated with these and all inputs.
  - Combine them.
  - Assign known level of confidence to this uncertainty.



GUM approach to determining uncertainty

1. **Define** the measurement process
   In principle we should know the **'measurement equation'**

$$Y = f(X_1, X_2..X_N)$$

2. **Quantify** uncertainties of each X_i (input quantities) these as standard uncertainties (in units of measurand)
   - Statistical, by repeated measurement - Type A
   - by estimation (non statistical - instrumental) - Type B
   - Insignificant contributions may be ignored.

3. **Combine** these source uncertainties as square root of the sum of the variances – for random uncorrelated sources.

4. **Expand** the combined uncertainty to give an estimate of the uncertainty with a required level of confidence by multiplying be a coverage factor.

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- The uncertainty arises from numerous causes and we try to evaluate it in two quite distinct ways:
  - **Type A** estimates are made by analyzing the statistics of repeated measurements.
  - **Type B** estimates are made by using prior knowledge about factors affecting the measurement, such as calibration certificates, or known sensitivities to confounding factors.
- There may be multiple sources of uncertainty in each category.
- These uncertainties are then combined into an uncertainty budget to calculate a standard uncertainty

STANDARD MEASUREMENT UNCERTAINTY (2.3.1)

measurement uncertainty expressed as a standard deviation

RELATIVE STANDARD MEASUREMENT UNCERTAINTY

standard measurement uncertainty divided by the absolute value of the **measured quantity value**

COMBINED STANDARD MEASUREMENT UNCERTAINTY (2.3.4)

standard measurement uncertainty that is obtained using the individual standard measurement uncertainties associated with the **input quantities in a measurement model**

EXPANDED UNCERTAINTY (2.3.5)

product of a **combined standard measurement uncertainty** and a factor larger than one, to cover larger probability that the measured value and the expanded uncertainty range include the true value

By combining all the statistical and systematic (instrumental) components, the uncertainty is evaluated by completing the uncertainty budget

x_i		$u(x_i)$ [°C]	
		HMP 155	**HMP 45 AC**
Components derived from the reference thermometer		$5.12 \cdot 10^{-3}$	$5.02 \cdot 10^{-3}$
Components derived from measurement system		$1.27 \cdot 10^{-2}$	$1.27 \cdot 10^{-2}$
Components derived from meteorological thermometer	repeatibility	$3.47 \cdot 10^{-2}$	$2.06 \cdot 10^{-2}$
	resolution	$4.04 \cdot 10^{-3}$	$2.89 \cdot 10^{-3}$
	reproducibility	$1.40 \cdot 10^{-2}$	$5.00 \cdot 10^{-4}$
	hysteresis	$2.00 \cdot 10^{-2}$	$1.73 \cdot 10^{-3}$
$u(x) = (\sqrt{\sum u^2(x_i)})^{1/2}$		$4.45 \cdot 10^{-2}$	$2.50 \cdot 10^{-2}$
$\boldsymbol{U(x) = 2 \cdot u(x)}$		**0.090 °C**	**0.050 °C**

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Thank you.

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