JOINT COMMITTEE FOR GUIDES IN METROLOGY (JCGM)

› Composed of eight international organizations working in the field of metrology: BIPM, ISO, IEC, IUPAC, IUPAP, OIML, ILAC and IFCC

› In charge of maintaining, developing and promoting international guidance documents addressing the metrological needs, operating with two groups:
  – JCGM-WG1 for the Guide to the expression of Uncertainty in Measurement (GUM)
  – JCGM-WG2 for the International Vocabulary of basic and general terms in Metrology (VIM)
JCGM-WG1

› Meets twice a year
› The group is currently composed of approximately 20 members appointed by the members’ organizations
› The group took the responsibility of developing the GUM that was previously published
› Several documents, supplements and guides were then developed by this group to complement the GUM
The JCGM 100, is currently known as the GUM. **Under the new perspective « the GUM » becomes the whole suite of documents published by the JCGM-WG1**

The goal of this new perspective is to broaden the scope of the GUM, to provide different levels of complexity depending on the readership and its needs.

Existing documents will be updated and renumbered as parts of the suite. New documents will be developed to address the various needs in metrology.

Part 1 Introduction (revised edition of JCGM 104)
Part 2 Concepts (ex JCGM 105)
Part 3 Current ‘grandfathered’ GUM (ex JCGM 100)
Part 4 Role of measurement uncertainty in conformity assessment (ex JCGM 106)
Part 5 Examples of uncertainty evaluation (ex JCGM 110)
Part 6 Developing and using measurement models (ex JCGM 103)
Part 7 Propagation of distributions using a Monte Carlo method (ex JCGM 101)
Part 8 Extension to any number of output quantities (ex JCGM 102)
Part 9 Statistical models and data analysis for interlaboratory studies (ex JCGM 109)
Part 10 Least squares methods (ex JCGM 107)
Part 11 Bayesian methods (ex JCGM 108)
Part 12 Basic method for uncertainty propagation
The introduction is the overarching document in the suite.

To introduce the suite and provide guidance towards the relevant parts depending on the interest of the reader.

This document will replace the existing JCGM 104.

The document will be concise, contain no mathematics and should be accessible to a large readership without specific background in metrology or statistics.

A draft was circulated for comments among National Metrology Institutes and members organizations. Feedback was globally positive. The final version is now circulating for approval by the members’ organizations. Publication is expected in 2023.
The first document published as part of the GUM under the new perspective

This part provides guidance on developing and using a measurement model and deals with the assessment of model adequacy

The document contains a significant number of small examples illustrating specificities of measurement models

The document deals with measurement models based on physical principles but also statistical models or hybrid ones. Bayesian modelling is also considered

ISO publication under the name ISO/IEC Guide 98-6:2021
UNCERTAINTY OF MEASUREMENT EVALUATION SCHEMA

Stage 1: Analysis of the Measurement Process

- **Uncertain Input Quantities**: $x_i$
- **Mathematical Model of the Measurement Process**: $f(X_1,\ldots,X_n)$
- **Measurand**: $Y = f(X_i)$

Stage 2: Quantification of the sources of uncertainty of the $x_i$
- Standard Uncertainty or distribution

Stage 3: Propagation of Uncertainty (LPU, MCM)

Stage 4: Final Expression of the Result $y \pm U$

Feedback
A measurement model relating a single output \( Y \) to the input quantities \( X_1, \ldots, X_N \) is termed univariate and explicit. Simplest models handled by provisions of JCGM 100 or JCGM 101.

A measurement model taking the form:

\[
Y_1 = f_1(X_1, \ldots, X_N), \ldots, Y_m = f_m(X_1, \ldots, X_N)
\]

where \( Y_i \) are \( m \) output quantities and \( f_i \) denote the \( m \) measurement functions is termed multivariate and explicit. This form of model can be handled by the provisions of JCGM 102.

Example: JCGM 100 H:2  resistance \( R \) and reactance \( X \) of a circuit are obtained by:

\[
R = \frac{V}{I} \cos \phi, X = \frac{V}{I} \sin \phi \quad \text{where } V \text{ denotes potential difference, } I \text{ current and } \phi \text{ phase angle}
\]

A measurement model taking the form:

\[ h(Y, X_1, \ldots, X_N) = 0 \]

is termed univariate and implicit. Generally it is solved numerically and can be handled by the provisions of JCGM 102.
Steps included in the process of building a measurement model (stage 1):
› Select and specify the measurand
› Model the measurement principle, thus providing a basic model for this purpose, choosing an appropriate mathematical form
› Identify effects involved in the measurement
› Extend the basic model as necessary to include terms accounting for these effects
› Assess the resulting measurement model for adequacy
MEASURAND DEFINITIONS

The choice of the measurand depends on the purpose of the measurement and may take into account of a target measurement uncertainty. What is the measurement for?

1) Distance between the centre and the upper side of the gauge and the plan to which it adheres, at 20°C and at a vertical position.

2) Distance between the two centres of the sides of the gauge, at 20°C. The gauge is at a horizontal position.

3) Distance between two parallel plans, at 20°C. The gauge is at a horizontal position.
GUM-6: MODELLING THE MEASUREMENT PRINCIPLE

› The measurement principle enables a basic model, often based on a scientific law, to be established.

› A *theoretical measurement model* is based on scientific theory that describes how the output quantities in the measurement relate to the input quantities.

› Sometimes the measurement principle can only be formulated in terms of an *empirical model*. The measurand would then be expressed in terms of mathematical functions such as polynomials. These models are expressed as statistical models, e.g. calibration functions.

› Most measurement *models are hybrid*, they combine aspects of theoretical and empirical models.

Example: spectral irradiance of a lamp: combination of the Planck function $L$ and a correction factor $G$ in a form of a polynomial model of parameters $a$, where $\lambda$ denotes the wavelength and $T$ the temperature:

$$F(\lambda, T, a_1, \ldots, a_p) = L(\lambda, T)G_p(\lambda, a_1, \ldots, a_p)$$
GUM-6: CHOOSING THE FORM OF THE MEASUREMENT MODEL

Same measurement principle can rise to different models

A measurement model should be capable of accounting for all information that is relevant and available, following aspects should be taken into consideration:

› Availability of a reliable theoretical form
› Target measurement uncertainty, related to the appropriate degree of approximation
› Simplicity, implementation with a minimal effort
› Relevance, interpretation of the parameters in terms of physical quantities
› Parsimony, not exceeding number of parameters in statistical models
› Available information
› Numerical accuracy, “ill-posed” problem and computational issues
› Solution stability
› Computational costs

These aspects are often mutually incompatible. Choice is a balance depending on local priorities. Main concern remains whether the model is capable of providing a valid estimate and associated uncertainty
The basic model describing the measurement principle holds in ideal conditions. The model should usually be extended to cover effects arising in the practical implementation of the measurement.

One of the most demanding tasks is the construction of a fit-for-purpose model.

The effects are not necessarily independent.

Effects involved in the measurement can be well or poorly understood but in anyway they need to be included in the measurement model using a correction and an associated uncertainty.

Contributions from following effects:

- Realization of the specification of the measurand,
- Approximations in modelling the measurement,
- Drift of the measuring system,
- Sampling,
- Calibration,
- System resolution,
- Sample preparation,
- Environmental influences,
- Zeroing of an instrument,
- Instability of the artefact,...
Identifying influences on measurement result can be facilitated by the use of cause-and-effect diagrams.
Comparative Measurement

The Mathematical Model

\( l \): measurand, length of an unknown gauge block at a 20°C temperature

\( L \): length of a standard gauge

\[
l_{20} = L_{20} + \Delta l + \text{corrections}
\]

\[
l_{20} = L_{20} + (l_{\text{ct}2} - l_{\text{ct}1}) + \text{corrections}
\]
• Measurement Method

1 – Quantification Corrections
\[ \text{lect}_1 \Rightarrow C_{q1} \quad \text{lect}_2 \Rightarrow C_{q2} \]

2 – Trueness Corrections
\[ \text{lect}_1 \Rightarrow C_{j1} \quad \text{lect}_2 \Rightarrow C_{j2} \]

\[ l_{20} = L_{20} + (\text{lect}_2 - \text{lect}_1) + \text{corrections} \]

\[ l_{20} = L_{20} + \text{lect}_2 + C_{q2} + C_{j2} - (\text{lect}_1 + C_{q1} + C_{j1}) + \text{corrections} \]
• The Standard Gauge Block

3 – Calibration Correction

\[ L_{20} = L_{\text{nom}} + C_e \]

\[ l_{20} = L_{20} + l_{\text{ect}2} + C_{q2} + C_{j2} - (l_{\text{ect}1} + C_{q1} + C_{j1}) + \text{corrections} \]

\[ l_{20} = L_{\text{nom}} + C_e + l_{\text{ect}2} + C_{q2} + C_{j2} - (l_{\text{ect}1} + C_{q1} + C_{j1}) + \text{corrections} \]
MEASUREMENT BY COMPARISON TO A STANDARD

• Environment

4 – Temperature Corrections

\[ l = l_{20} \left(1 + \alpha \left(T_{\text{cale}} - 20\right)\right) \]
\[ L = L_{20} \left(1 + \alpha \left(T_{\text{étalon}} - 20\right)\right) \]

\[ l_{20} = L_{\text{nom}} + C_e + l_{\text{ect}2} + C_{q2} + C_{j2} - (l_{\text{ect}1} + C_{q1} + C_{j1}) \]
\[ + L_{\text{nom}}\alpha \left(\Delta T_e - \Delta T_{\text{cale}}\right) + \text{corrections} \]
MEASUREMENT BY COMPARISON TO A STANDARD

The measurement model:

\[ l_{20} = L_{nom} + C_e + l_{ect2} + C_{q2} + C_{j2} - (l_{ect1} + C_{q1} + C_{j1}) \]

\[ + L_{nom\alpha} \left( \Delta T_e - \Delta T_{cale} \right) \]
DIRECT MEASUREMENT

- **Measurand:**
  
  length of standard gauge block at 20° C (the same)

- **Measurement method:**
  
  direct measurement of the gauge block height with a comparator once it is reset

- **Measurement model:**

  \[ l_{20} = \text{reading} + \text{corrections} \]
DIRECT-measurement correction

Measurement model:

\[ l_{20} = \text{reading} + \text{corrections} \]

- quantification corrections
- trueness corrections
- temperature corrections

\[ L_{20} = \text{reading} + Cq_i + Ct + l \alpha \Delta T \]

The two different measurement models represent different measurement procedures and have then different mathematical expressions.
GUM-6: REPRODUCIBILITY STUDIES

› When examining the **repeatability and reproducibility of a measurement procedure**, small number of random effects associated with the measurand combine essentially all random variation effects.

› These models focus on random variation in the measurand without separating the effects associated with individual quantities.

› This model is widely used in testing and under the “top-down” approach. It is based on the principle that the reproducibility standard deviation obtained in a collaborative study is valid for uncertainty evaluation.

\[
Y = m + B + E
\]

where \( m \) is the ‘general mean’ of \( Y \), \( B \) is the laboratory error under repeatability conditions and \( E \) the random error under repeatability conditions.

› In some collaborative studies the measurement model is extended to:

\[
Y = \mu + \delta + B + E
\]

where \( \delta \) is the bias of the measurement method, resulting uncertainty:

\[
u^2(y) = u^2(\mu) + u^2(\delta) + S_R^2
\]

› In practice some important effect might be missing from the collaborative study, a more general form including \( X \), additional input quantities describing effects on which the measurand depends:

\[
Y = \mu + \delta + f(X_1, \ldots, X_n) + B + E
\]
GUM–5 EXAMPLES OF UNCERTAINTY EVALUATION

› Specific part of the suite that should illustrate various methods of uncertainty evaluation, LPU, Monte Carlo,..

› This document will be updated more regularly, allowing the addition of new examples when available

› The examples come from various areas of measurement and should contain enough information to be self-supporting and reproducible

› A first working draft of 16 examples is at an advanced stage within the group

› Several of the examples are coming from the EMPIR EMUE project coordinated by Maurice Cox (NPL), supported by EMN Mathmet, that publically delivered a compendium of 36 examples, available here:

http://empir.npl.co.uk/emue/publications-and-presentations/
ADDITONNAL WORK: DEFINITIONS

Definitions prepared by JCGM-WG1 and proposed to WG2 (not current official ones):

› **measurement uncertainty**

*uncertainty of measurement*

doubt about the true value of the measurand that remains after making a measurement

*NOTE 1* Measurement uncertainty can be described fully and quantitatively by a probability distribution on the set of possible values of the measurand. It can be described summarily and approximately by a quantitative indication of the dispersion (or scatter) of such distribution

› **Standard measurement uncertainty**

*measurement uncertainty expressed as a standard deviation*
FURTHER INFORMATION

› Priority is given next to revision of Part 7 and 8 known as supplements 1 and 2

› JCGM-WG1 has established a cooperation with the Expert Team on Measurement Uncertainty (ET-MU) of the World Meteorological Organisation (WMO). A joint online workshop on MU in meteorology and climatology was held in 2022 and several members participated at the BIPM-WMO joint workshop on Metrology for Climate Action in September 2022

Thank you for your attention