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Guide to the expression of uncertainty in measurement —

Part 1:
Introduction

Guide pour l'expression de l'incertitude de mesure —

Partie 1: Introduction

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives or www.iec.ch/members_experts/refdocs).

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This document was prepared by Working Group 1 of the Joint Committee for Guides in Metrology (as GUM 1:2022) and was adopted by the national bodies of ISO and IEC.

This second edition cancels and replaces the first edition (ISO/IEC Guide 98-1:2009), which has been technically revised.

The main changes are as follows:

— the document has been redrafted as an introduction to the revised ISO/IEC Guide 98 series;

— most conceptual and technical aspects have been removed.

A list of all parts in the ISO/IEC Guide 98 series can be found on the ISO and IEC websites.

Given that this document is identical in content to GUM 1:2022, the decimal symbol is a point on the line.

Annex ZZ has been appended to provide a list of corresponding ISO/IEC Guides and JCGM guidance documents for which equivalents are not given in the text.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html and www.iec.ch/national-committees

Contents

Foreword

In 1997 a Joint Committee for Guides in Metrology (JCGM), chaired by the Director of the Bureau International des Poids et Mesures (BIPM), was created by the seven international organizations that had originally in 1993 prepared the 'Guide to the expression of uncertainty in measurement' and the 'International vocabulary of basic and general terms in metrology'. The JCGM assumed responsibility for these two documents from the Technical Advisory Group 4 of the International Organization for Standardization (ISO/TAG4).

The Joint Committee is formed by the BIPM with the International Electrotechnical Commission (IEC), the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC), the International Laboratory Accreditation Cooperation (ILAC), the International Organization for Standardization (ISO), the International Union of Pure and Applied Chemistry (IUPAC), the International Union of Pure and Applied Physics (IUPAP), and the International Organization of Legal Metrology (OIML).

JCGM has two Working Groups. Working Group 1, 'Expression of uncertainty in measurement', has the task to promote the use of the 'Guide to the expression of uncertainty in measurement' and to prepare documents for its broad application. Working Group 2, 'Working Group on International vocabulary of basic and general terms in metrology', has the task to revise and promote the use of the 'International vocabulary of basic and general terms in metrology' (the 'VIM').

In 2008 the JCGM made available a slightly revised version (mainly correcting minor errors) of the 'Guide to the expression of uncertainty in measurement', labelling the document 'JCGM 100:2008'.

In 2017 the JCGM rebranded the documents in its portfolio that have been produced by Working Group 1 or are to be developed by that Group: the whole suite of documents is now known as the 'Guide to the expression of uncertainty in measurement' or 'GUM', and is concerned with the evaluation and expression of measurement uncertainty, as well as its application in science, trade, health, safety and other societal activities.

This part of the suite introduces the processes involved and the subsequent parts in this suite giving specific guidance on these processes. This document replaces JCGM 104:2009.

This document has been prepared by Working Group 1 of the JCGM, and has benefited from detailed reviews undertaken by member organizations of the JCGM and National Metrology Institutes.

Guide to the expression of uncertainty in measurement — Part 1: Introduction

1 Scope

The 'Guide to the expression of uncertainty in measurement' (GUM) establishes general rules for evaluating and expressing uncertainty in measurement from the shop floor to fundamental research. Therefore, the principles of this suite of documents are intended to be applicable to a broad spectrum of measurements and their applications. An overview of the parts of the GUM is given in table A.1 in Annex A.

NOTE Where the acronym GUM is used in this document, it refers to the suite of documents. For an individual part (for example part 3) of the GUM, this is referred to as JCGM GUM-3.

This document gives a rationale for evaluating, expressing and using measurement uncertainty (Clause 2). A brief introduction is given to measurement (Clause 3) and to the decisions involved when evaluating measurement uncertainty (Clause 4). In Clause 5, a brief description of the contents of the parts of the GUM is given. In each of these clauses, the relevant parts of the GUM are identified for further guidance.

2 Rationale

2.1 Measurement [12, Definition 2.1] is one of the most common processes in human activity. Measured values of quantities [12, Definition 2.10] are required for a diverse range of applications and, for each of these values, a statement is needed about its credibility. Such a statement is usually expressed in terms of measurement uncertainty [12, Definition 2.26]. The two components, the measured value and the associated uncertainty, together constitute the most common way of reporting a measurement result [12, Definition 2.9]. In cases where values for more than one quantity are provided by the measurement, a more elaborate statement of the uncertainty is often required (Clause 5.5; see also Clause 3.1).

2.2 Measurements are performed in many branches of society for widely different purposes. Many measurements performed on a daily basis, often in automated processes, concern trade and commerce. Reliable measurement results are also needed for making informed decisions in for example health, safety, weather forecasts, law enforcement and science. Measurements are performed by for example greengrocers, technicians, engineers, laboratory staff, health care professionals, scientists and individuals at home, in very different contexts.

2.3 Many measurements are made for the purpose of comparison of results with specifications. Such a comparison can be made for widely different purposes. This activity is generally known as conformity assessment [3, Definition 4.1] [10, Definition 3.3.1]; see also Clause 5.2.

2.4 Comparison of measurement results is an essential activity in science, calibration and testing. Compatibility of measurement results [12, Definition 2.47] is the basis for being able to reproduce scientific findings, performing quality assurance and quality control, and providing the interpretation of measurement results and informed decision making. Many standards that set requirements for demonstrating competence in measurement require evaluating measurement uncertainty and identifying the major sources of uncertainty, for example ISO/IEC 17025 (calibration and testing laboratories) [4], ISO 17034 (reference material producers) [5], ISO/IEC 17043 (proficiency testing) [6] and ISO 15189 (medical laboratories) [2].

2.5 Measurement uncertainty is of importance in various situations, including but not limited to

— comparison of measurement results,
— comparison of a measured value with specification limits (conformity assessment),
— establishing metrological traceability [12, Definition 2.41],
— applying a decision rule [10, Definition 3.3.12],
— calculating risks and risk assessment,
— comparison of model outputs and experiments,
— evaluating the validity of models,
— setting limits for the values of physical quantities,
— validating or developing scientific theories, and
— propagation of uncertainty from one measurement to another.

2.6 The GUM substantially contributes to the harmonization of methods for the evaluation, expression and use of measurement uncertainty. It supports the mutual recognition of calibration certificates and laboratory accreditations. The principles and methods of the GUM have been adopted in many documentary standards of ISO, IEC and other standardization organizations. Much software used by laboratories worldwide is based on the provisions of the GUM.

3 Measurement

3.1 The quantity intended to be measured is called the measurand [12, Definition 2.3]. A measurement can have the objective of determining values and associated uncertainties for a set of output quantities in a measurement model [12, Definition 2.51], rather than a single quantity. Then the measurand is said to be multivariate. The measurement result is represented by the measured values and the measurement uncertainty.

3.2 Measurement [12, Definition 2.1] can be described as an experimental or computational process that, by comparison with a measurement standard [12, Definition 5.1], produces an estimate of the true value [12, Definition 2.11] of a property, together with a statement of the uncertainty associated with that estimate, and intended for use in support of decision making. This property can be of a material or virtual object or collection of objects, or of a process, event or series of events [18].

NOTE The GUM takes a broad view of 'measurement' in that it recognises that there are instances where the process concerned is essentially computational or where the measurement result is of a conceptual or theoretical nature [7, Clause 1.3].

3.3 In the description of 'measurement' (see Clause 3.2), an estimate [1, Definition 1.31] is an approximation of the true value [12, Definition 2.11] of the property of interest. Another term sometimes used for estimate is measured value [12, Definition 2.10]. By 'comparison with a measurement standard' (see 3.2), it is meant that somewhere in the process a measurement standard is used to obtain an estimate that is metrologically traceable to the relevant measurement unit [12, Definition 1.9].

3.4 Measurement uncertainty is the doubt about the true value of the measurand that remains after making a measurement. Measurement uncertainty can be expressed in various ways. Commonly used ways include

- a standard uncertainty [12, Definition 2.30],
- an expanded uncertainty [7, Definition 2.3.5] with a coverage factor [7, Definition 2.3.6],
- a coverage interval [12, Definition 2.36] with a stated coverage probability [9, Definition 3.25], or
- a probability distribution describing the knowledge about the measurand [8, Definition 3.1], often expressed as a probability density function [8, Definition 3.3].

3.5 A measurement result should be presented in a way that is understandable and usable by its recipient. The measurement result should therefore include all information needed for its intended use [7, Clause 7]. The information available depends on whether the law of propagation of uncertainty (section 5.1), the propagation of distributions (section 5.4), or another method [11, Clause 11] has been used for the evaluation of measurement uncertainty.

4 Guidance on evaluating measurement uncertainty

4.1 The evaluation of measurement uncertainty is neither a routine task nor a purely mathematical one. It depends on detailed knowledge of the nature of the measurand and the measurement. The quality and utility of the measurement result therefore ultimately depend on the understanding, critical analysis, and diligence of those who contribute to that result [7, Clause 3.4.8].

4.2 In selecting a method of uncertainty evaluation that suits the current needs, the user should consider the following:

1. the information available,
2. the assumptions to be made,
3. the nature of the results required (see Clause 4.3),
4. the extent to which use is to be made of the information available.

4.3 Alongside the estimate of the output quantity or measurand, results required from the uncertainty propagation comprise some or all of

1. standard uncertainty associated with the estimate,
2. coverage interval for the measurand for a stated coverage probability,
3. probability distribution for the measurand.

NOTE 1 The probability distribution for the measurand in Clause 4.3 bullet 3 is the most complete description of the output quantity in terms of the information used. The estimate and the items 1 and 2 can be obtained from it.

NOTE 2 The propagation of distributions (see Clause 5.5) provides the probability distribution for the measurand [8, 9].

NOTE 3 In the case of a multivariate measurand, Clause 4.3 bullets 1 and 2 are generalized: see also Clause 5.5.

4.4 The following information is required for uncertainty propagation:

— A measurement model (mathematical or algorithmic) suitable for the current application, containing input quantities [12, Definition 2.50] of which the user has knowledge and an output quantity (measurand) for which results are required [11],

— Either

  * an estimate of each input quantity – from statistical analysis of observations or provided by other means, and
  * the standard uncertainty associated with each estimate and, when appropriate, the degrees of freedom [1, Definition 2.54] and correlations [1, Definition 2.44] between estimates.

— or a joint probability distribution for the input quantities.

NOTE 1 Guidance on quantifying correlation is given in [7, Clause 5.2] and [11, Clause 10.5].

NOTE 2 Probability distributions for the input quantities are often specified in uncertainty budgets [12, Definition 2.33].

NOTE 3 Guidance on obtaining probability distributions for the input quantities is given in [8, clause 6].

NOTE 4 Guidance on degrees of freedom in the simplest case of uncorrelated repeated observations of an input quantity is given in [7, Annex G] and [9, Clause 6.5.3] for a set of quantities.

4.5 To propagate measurement uncertainty using a measurement model (see also section 5.3), it is important to consider what information is available and what is required [11, Clauses 5.1, 5.3, 5.8 and 5.9]. Also the resources necessary to take account of the information are important. Such resources include, for example, human effort, mathematical or similar skills, and computational capabilities. Finally, consideration should be given to how the evaluated uncertainty will be used [11, Clauses 12 and 13].

4.6 Taking account of all available knowledge might require the services of a professional statistician, a data scientist or the use of sophisticated software. By contrast, an adequate account of information might only require a spreadsheet calculation and relatively simple calculations. The uncertainty evaluation should be rigorous enough to ensure that measurement results are delivered to the satisfaction of the recipient. Some guidance is given in this document, further elaborated in the other parts of the GUM [7, Clause 3.4] [11, Clauses 6-10], to reach an appropriate balance between effort and outcome.

