GUIDE 98-1

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

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ISO/IEC Guide 98-1 was prepared by Working Group 1 of the Joint Committee for Guides in Metrology (as JCGM 104:2009), and was adopted by the national bodies of ISO and IEC.

ISO/IEC Guide 98 consists of the following parts, under the general title *Uncertainty of measurement*:

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

— *Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

The following parts are planned:

— *Part 2: Concepts and basic principles*

— *Part 4: Role of measurement uncertainty in conformity assessment*

— *Part 5: Applications of the least-squares method*

ISO/IEC Guide 98-3 has one supplement.

— *Supplement 1: Propagation of distributions using a Monte Carlo method*

The following supplements to ISO/IEC Guide 98-3 are planned:

— *Supplement 2: Models with any number of output quantities*

— *Supplement 3: Modelling*

Given that ISO/IEC Guide 98-1:2009 is identical in content to JCGM 104:2009, the decimal symbol is a point on the line in the English version.

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.

Joint Committee for Guides in Metrology

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Evaluation of measurement data — An introduction to the "Guide to the expression of uncertainty in measurement" and related documents

Évaluation des données de mesure – Une introduction au "Guide pour l'expression de l'incertitude de mesure" et aux documents qui le concernent

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Foreword

In 1997 a Joint Committee for Guides in Metrology (JCGM), chaired by the Director of the BIPM, was created by the seven international organizations that had originally in 1993 prepared the 'Guide to the expression of uncertainty in measurement' (GUM) and the 'International vocabulary of metrology – basic and general concepts and associated terms' (VIM). The JCGM assumed responsibility for these two documents from the ISO Technical Advisory Group 4 (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 GUM and to prepare Supplements and other documents for its broad application. Working Group 2, 'Working Group on International vocabulary of basic and general terms in metrology (VIM)', has the task to revise and promote the use of the VIM. For further information on the activity of the JCGM, see www.bipm.org.

The present document has been prepared by Working Group 1 of the JCGM, and has benefited from detailed reviews undertaken by member organizations of the JCGM.

This document constitutes one part in a series of JCGM documents under the generic heading *Evaluation of measurement data*. The parts in the series are

— JCGM 100:2008. Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM) (see clause 2),

— JCGM 101:2008. Evaluation of measurement data – Supplement 1 to the "Guide to the expression of uncertainty in measurement" – Propagation of distributions using a Monte Carlo method (see clause 2),

— JCGM 102. Evaluation of measurement data – Supplement 2 to the "Guide to the expression of uncertainty in measurement" – Models with any number of output quantities,

— JCGM 103. Evaluation of measurement data – Supplement 3 to the "Guide to the expression of uncertainty in measurement" – Modelling,

— JCGM 104. Evaluation of measurement data – An introduction to the "Guide to the expression of uncertainty in measurement" and related documents [this document],

— JCGM 105. Evaluation of measurement data – Concepts and basic principles,

— JCGM 106. Evaluation of measurement data – The role of measurement uncertainty in conformity assessment, and

— JCGM 107. Evaluation of measurement data – Applications of the least-squares method.

Introduction

A statement of measurement uncertainty is indispensable in judging the fitness for purpose of a measured quantity value. At the greengrocery store the customer would be content if, when buying a kilogram of fruit, the scales gave a value within, say, 2 grams of the fruit's actual weight. However, the dimensions of components of the gyroscopes within the inertial navigation systems of commercial aircraft are checked by measurement to parts in a million for correct functioning.

Measurement uncertainty is a general concept associated with any measurement and can be used in professional decision processes as well as judging attributes in many domains, both theoretical and experimental. As the tolerances applied in industrial production become more demanding, the role of measurement uncertainty becomes more important when assessing conformity to these tolerances. Measurement uncertainty plays a central role in quality assessment and quality standards.

Measurement is present in almost every human activity, including but not limited to industrial, commercial, scientific, healthcare, safety and environmental. Measurement helps the decision process in all these activities. Measurement uncertainty enables users of a measured quantity value to make comparisons, in the context of conformity assessment, to obtain the probability of making an incorrect decision based on the measurement, and to manage the consequential risks.

This document serves as an introduction to measurement uncertainty, the GUM and the related documents indicated in the Foreword. A probabilistic basis for uncertainty evaluation is used. Annex A gives acronyms and initialisms used in this document.

In future editions of JCGM 200 (VIM) it is intended to make a clear distinction between the use of the term *error* as a quantity and as a quantity value. The same statement applies to the term *indication*. In the current document such a distinction is made. JCGM 200:2008 does not distinguish explicitly between these uses.

Evaluation of measurement data — An introduction to the 'Guide to the expression of uncertainty in measurement' and related documents

1 Scope

The Joint Committee for Guides in Metrology (JCGM) has prepared this document to promote the sound evaluation of measurement uncertainty through the use of the GUM (see clause 2) and to provide an introduction to the GUM Supplements and other documents JCGM is producing: JCGM 101:2008 (see clause 2) and references [3, 4, 5, 6, 7].

As in the GUM, this document is primarily concerned with the expression of uncertainty relating to the measurement of a well-defined quantity—*the measurand* [JCGM 200:2008 (VIM) 2.3]—that can be characterized by *an essentially unique true value* [JCGM 200:2008 (VIM) 2.11 NOTE 3]. The GUM provides a rationale for not using the term 'true', but this term will be kept in this document when there is otherwise a possibility for ambiguity or confusion.

The purpose of the GUM Supplements and the other documents produced by the JCGM is to help with the interpretation of the GUM and enhance its application. The GUM Supplements and the other documents are together intended to have a scope that is considerably broader than that of the GUM.

This document introduces measurement uncertainty, the GUM, and the GUM Supplements and other documents that support the GUM. It is directed predominantly at the measurement of quantities that can be characterized by continuous variables such as length, temperature, time, and amount of substance.

This introductory document is aimed at the following, including but not limited to

— scientific activities and disciplines in general,

— industrial activities and disciplines in general,

— calibration, testing and inspection laboratories in industry, and laboratories such as those concerned with health, safety and environment, and

— evaluation and accreditation bodies.

It is hoped that it will also be useful to designers, because a product specification that takes better account of inspection requirements (and the associated measurement) can result in less stringent manufacturing requirements. It is also directed at academia, with the hope that more university departments will include modules on measurement uncertainty evaluation in their courses. As a result, a new generation of students would be better armed to understand and provide uncertainty statements associated with measured quantity values, and thus gain an improved appreciation of measurement.

This introductory document, the GUM, the GUM Supplements and the other documents should be used in conjunction with the 'International Vocabulary of Metrology—Basic and general concepts and associated terms' and all three parts of ISO 3534 cited in clause 2, which define statistical terms (used in statistics and probability, including applied statistics and design of experiments), and express them in a conceptual framework in accordance with normative terminology practice. The last consideration relates to the fact that the theoretical background of evaluation of measurement data and evaluation of the uncertainty of measurement is supported by mathematical statistics and probability.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

JCGM 100:2008. Evaluation of measurement data — Guide to the expression of uncertainty in measurement (GUM). Joint Committee for Guides in Metrology.

JCGM 101:2008. Evaluation of measurement data — Supplement 1 to the "Guide to the expression of uncertainty in measurement" — Propagation of distributions using a Monte Carlo method. Joint Committee for Guides in Metrology.

JCGM 200:2008. International Vocabulary of Metrology—Basic and general concepts and associated terms, 3rd Edition. Joint Committee for Guides in Metrology

ISO 3534-1:2006. Statistics – Vocabulary and symbols – Part 1: General statistical terms and terms used in probability.

ISO 3534-2:2006. Statistics – Vocabulary and symbols – Part 2: Applied statistics.

ISO 3534-3:1999. Statistics – Vocabulary and symbols – Part 3: Design of experiments.

3 What is measurement uncertainty?

3.1 The purpose of measurement is to provide information about a quantity of interest—a *measurand* [JCGM 200:2008 (VIM) 2.3]. The measurand might be the volume of a vessel, the potential difference between the terminals of a battery, or the mass concentration of lead in a flask of water.

3.2 No measurement is exact. When a quantity is measured, the outcome depends on the measuring system [JCGM 200:2008 (VIM) 3.2], the measurement procedure, the skill of the operator, the environment, and other effects [1]. Even if the quantity were to be measured several times, in the same way and in the same circumstances, a different *indication value* [JCGM 200:2008 (VIM) 4.1] (measured quantity value [JCGM 200:2008 (VIM) 2.10]) would in general be obtained each time, assuming that the measuring system has sufficient resolution to distinguish between the indication values. Such indication values are regarded as instances of an indication quantity.

3.3 The *dispersion* of the indication values would relate to how well the measurement is made. Their *average* would provide an *estimate* [ISO 3534-1:2006 1.31] of the *true quantity value* [JCGM 200:2008 (VIM) 2.11] that generally would be more reliable than an individual indication value. The dispersion and the number of indication values would provide information relating to the average value as an estimate of the true quantity value. However, this information would not generally be adequate.

3.4 The measuring system may provide indication values that are not dispersed about the true quantity value, but about some value offset from it. The difference between the offset value and the true quantity value is sometimes called the *systematic error value* [JCGM 200:2008 (VIM) 2.17]. Take the domestic bathroom scales. Suppose they are not set to show zero when there is nobody on the scales, but to show some value offset from zero. Then, no matter how many times the person's mass were re-measured, the effect of this offset would be inherently present in the average of the indication values. In general, a systematic error, regarded as a quantity, is a component of error that remains constant or depends in a specific manner on some other quantity.

3.5 There are two types of measurement error quantity, *systematic* and *random* [JCGM 200:2008 (VIM) 2.19]. A systematic error (an estimate of which is known as a *measurement bias* [JCGM 200:2008 (VIM) 2.18]) is associated with the fact that a measured quantity value contains an offset. A random error is associated with the fact that when a measurement is repeated it will generally provide a measured quantity value that is different