COOMET	COOMET Recommendation	**COOMET** R/GM/21:2024
	Use of concepts «error of Measurement» and «uncertainty of measurements». General principles	

Approved in 21st the meeting of COOMET Committee (27–28 April 2011, Yerevan, Armenia)
Clarified and supplemented: at the __ meeting of the COOMET Committee (______________________)

1. SCOPE OF APPLICATION

This recommendation is intended for use in the development of documentation of all types, scientific and technical, educational and reference literature on metrology used in the performance of work in the field of legislative and applied metrology and standardization.

In this document concepts «error of measurement» and «uncertainty of measurement» are analyzed, and recommendations about logically consistent joint application of these concepts of various metrological problems are made. As the basic terminological documents, [1 – 3] are accepted.

Terminological articles in these recommendations, repeating terminological articles of [2], are represented by thin lines.

The previous version of the recommendation (COOMET R/GM/21:2011) was developed on the basis of RMG 91-2009 and updated by updating and supplementing the "Bibliography" [1-11] with new significant documents (publications) and correcting bibliographic references in the text with local notes.

In [1] basic distinction of concepts «error of measurement» and «uncertainty of measurements» is underlined, but possibility use of concept «error» is not excluded. Thus, it is meant that the concrete error always has a certain sign (positive or negative). Application of concept «true value of the measured quantity» instead of concept «reference quantity value» in error definition in [2] it does not change its sense. By definition, unlike «error» concept, «uncertainty» characterizes dispersion of values which could be attributed to the measured quantity.

The incorrectness of application of concept «error» is indicated in its mixing with the concepts different by implication, such as «measurement result error characteristics», «error confident limits». The error of a certain result of measurement is evinced in the considered experiment with a certain copy of a measuring instrument, and during the evaluation of «error characteristics» a set of possible values of errors in virtual or real experiments with various copies of measuring instruments of the given type at admissible variation of measurement conditions is used. Therefore the standard evaluation of the standard deviation, non-excluded systematic error and confident limits of a set of errors of measurement results do not correspond any more to initial definition of an error. Actually, these evaluations characterize not an error, but a dispersion of values attributed to the measured quantity on the basis of the used information, i.e. similar uncertainty.

Concepts «error of measurement» and «uncertainty of measurement» should be applied according to their definitions, without error substitution by evaluation parameter and components of measurement results dispersion.

2. TERMS AND DEFINITIONS

The following terms with their respective definitions and comments are used in these recommendations:

2.1

measurement error (error of measurement, error): measured quantity value minus a reference quantity value N o t e 1: The concept of 'measurement error' can be used both: a) when there is a single reference quantity value to refer to, which occurs if a **calibration** is made by means of a **measurement standard** with a **measured quantity value** having a negligible **measurement uncertainty**, or if a **conventional quantity value** is given, in which case the measurement error is known, and b) if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, which case the measurement error is not known. N o t e 2: Measurement error should not be confused with production error or mistake. [2, article 2.16]

Comment: True value of a quantity cannot be defined. This concept applies only in theoretical researches. In practice, they use reference quantity value X_o (see 4.2), and a error of measurement Δ is defined according to formula:

$\Delta = X_m - X_o$,

where X_m – the value of quantity received by measurement (result of measurement [2, article 2.9]);

X_o – the value attributed to concrete quantity and accepted, often under the agreement, as a value, which has an uncertainty acceptable for the given purpose [2, article 2.12].

Thus, by definition, concept «the measurement error» concerns only the certain result of measurement received with the use of a certain copy of a measuring instrument. The error of measurement is a certain positive or a negative number. There are no bases to assign to this concept a sense of statistical parameter of any set of real or guess values. «Error of measurement» and «uncertainty of measurement» represent different concepts; they should not be confused with each other or used in the wrong way [1, point 3.2.2].

2.2.

reference quantity value (reference value): **quantity value** used as a basis for comparison with values of **quantities** of the same **kind** N o t e 1: A reference quantity value can be a **true quantity value** of a **measurand**, in which case it is unknown, or a **conventional quantity value**, in which case it is known. N o t e 2: A reference quantity value with associated **measurement uncertainty** is usually provided with reference to: a) a material, e.g. **certified reference material**, b) a device, e.g. stabilized laser, c) a **reference measurement procedure**, d) a comparison of **measurement standards.** [2, article 5.18]

C o m m e n t: Concept «conventional quantity value» [2, article 2.12] covers the concept «the real value of quantity» («the conventional true quantity value») — the value of quantity received experimentally and being so close to the true value, that in the put measuring problem it can be used instead of that.

2.3

relative error: Ratio Δ/X_o error of measurement Δ to reference quantity value X_o.

C o m m e n t: It is not recommended to replace in this respect the reference quantity value by the result of measurement, as it contradicts the concept of «error of measurement» definition.

2.4.

systematic measurement error (systematic error of measurement, systematic error): component of **measurement error** that in replicate **measurements** remains constant or varies in a predictable manner N o t e 1: A **reference quantity value** for a systematic measurement error is a **true quantity value**, or a **measured quantity value** of a **measurement standard** of negligible **measurement uncertainty**, or a **conventional quantity value**. N o t e 2: Systematic measurement error, and its causes, can be known or unknown. A **correction** can be applied to compensate for a known systematic measurement error. N o t e 3:Systematic measurement error equals measurement error minus **random measurement error**. [2, article 2.17]

C o m m e n t: It is necessary to keep in mind that at definition of a difference of the specified errors, each of the errors is taken with the positive or negative sign.

2.5.

random measurement error (random error of measurement, random error): component of **measurement error** that in repeated **measurements** varies in an unpredictable manner N o t e 1: A **reference quantity value** for random measurement error is the average that would ensue from an infinite number of replicate measurements of the same **measurand.** N o t e 2: Random measurement errors of a set of replicate measurements form a distribution that can be summarized by its expectation, which is generally assumed to be zero, and its variance. N o t e 3: Random measurement error equals measurement error minus systematic measurement error. [2, article 2.19]

C o m m e n t: It is necessary to keep in mind that at definition of a difference of the specified errors, each of the errors is taken with the positive or negative sign

2.6.

measurement uncertainty (uncertainty of measurement, uncertainty): Non-negative parameter characterizing the dispersion of the **quantity values** attributed to a **measurand**, basis on the information used N o t e 1: Measurement uncertainty includes components arising from systematic effects, such as components associated with **corrections** and the assigned quantity values of **measurement standards**, as well as the **definitional uncertainty.** Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated. N o t e 2: The parameter may be, for example, a standard deviation called **standard measurement uncertainty** (or a specified multiple of it), or the half-width of an interval, having a stated **coverage probability**. N o t e 3: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by **Type A evaluation of measurement uncertainty** from the statistical distribution of the quantity values from series of **measurements**, and can be characterized by standard deviations. The other components, which may be evaluated by **Type B evaluation of measurement uncertainty**, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information. N o t e 4: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty [2, article 2.26]

C o m m e n t: The value said in the note 4 is the best estimation of value of the measurand,

and all components of uncertainty, including the components caused by systematic effects, for example, connected with corrections and standards, lead to dispersion [1, point 2.2.3, Notes 1- 3].

Quantitatively, «uncertainty of measurement» (as a rule) can be characterized by «standard uncertainty of measurement» – uncertainty of result of the measurement expressed as a standard deviation, or «the expanded measurement uncertainty» [1, points 2.3.1, 2.3.4 and 2.3.5].

Thus, «uncertainty of measurement» as the parameter, characterizes the dispersion of a set of measurement results possible values in a considered measuring situation, but not an error of concrete result of measurement. For example, a case is possible, when the result of measurement has negligibly small error with large uncertainty [1, point 3.3.1, the note].

2. RECOMMENDATIONS FOR THE CORRECT APPLICATION OF THE CONCEPTS OF «MEASUREMENT ERROR» AND «MEASUREMENT UNCERTAINTYS»

3.1 Application of concepts «error of measurement» and «uncertainty of measurement» in concrete metrological situations

3.1.1 Result of measurement is the value of quantity received by its measurement and uncertainty of measurement . Concrete results of measurements in any metrological situations unequivocally can and should be characterized by uncertainty. Application of concept error of measurement result, which is essentially unknown and is specifically indefinable, is possible only in theoretical reasoning concerning measurement results. Error concept is supposed to be used during measuring instrument calibration and verification (see point 4.1, note 1, enumeration a).

3.1.2 Results of experiments, which are carried out during national standards comparisons (key, regional, international) according to the Arrangement [4], are represented with the detailed data about evaluation of uncertainty. Here, the errors characteristics of standards, which are stated in registration certificates for national standards, can be used for evaluation of uncertainty of comparison results.

3.1.3 Calibration and measuring capabilities of national metrological institutes, according to Appendix C of Agreement [4], are represented with indication expanded uncertainty of measurement results and coverage factor. Here, it is obligatory to indicate data about metrological traceability under transfer of appropriate measurement scale or size of measurement unit.

3.1.4 In measurement procedure, operation and calculus complex is described; its fulfillment provides obtaining of the measurement result with the established indices of accuracy.

Results of measurement according to measurement procedure are recommended to be accompanied by uncertainty of measurement evaluations. Measurement procedure may include information about target uncertainty of measurement [2, point 2.34]. Standardized (certified) measurement procedure may maintain other established indices of accuracy measurements, for example by [5], corresponding of concrete setting and aria of its application.

3.1.5 At calibration of measuring instruments, they establish, under certain conditions, the proportion between values of quantity according to indications of measuring instrument and appropriate values realized using the standard. According to calibration results, corrections to measuring instruments indications may be made or values realized by measuring instruments may be made more exact. As it is specified in Appendix C to Agreement [4], only uncertainty can be a calibration accuracy characteristic. The same concerns the results of measuring instruments graduation in the course of calibration.

3.1.6 Measuring instruments metrological characteristics are standardized using the concept «error» or «accuracy class». Here, permissible error limits for measuring instruments of a given type are used.

3.1.7 Measuring instruments verification consists in establishing of measuring instrument (MI) suitability to application on the basis of experimental definition of metrological characteristics and acknowledgement of their conformity specified requirements. At verification, measurement standards are used.

MI verification may consist in the following:

a) Determination of MI suitability to application with rejection of those MI, whose error exceeds limits of the assumed error, established for MI of a given type;

b) Establishing of conventional true values or gauging characteristics of the MI brought for verification (including the way of corrections application);

c) Determination of MI suitability to application according to norms of their stability (with rejection of those MI, whose change of the conventional true value or gauging characteristics exceeded permissible instability limit established for MI of a given type for inter-verification interval), and establishing of the conventional true values or gauging characteristics of the other MIs.

At verification, norms of measuring instruments error limits are operated. Therefore, in verification it is assumed to specify, in what proportion should be the expanded uncertainty of procedures verification and limits of errors of measuring instruments of the given confirmed type, and also to specify criteria of measuring instruments validity taking into account uncertainty of results at verification (see Appendix A). Here, general principles taking into account uncertainty of measurements in procedure evaluation of conformity with specified requirements may be used [6, 9-11].

3.1.8 In construction of a verification chain, accuracy of unit size transfer method may be characterized by uncertainty of measurement.

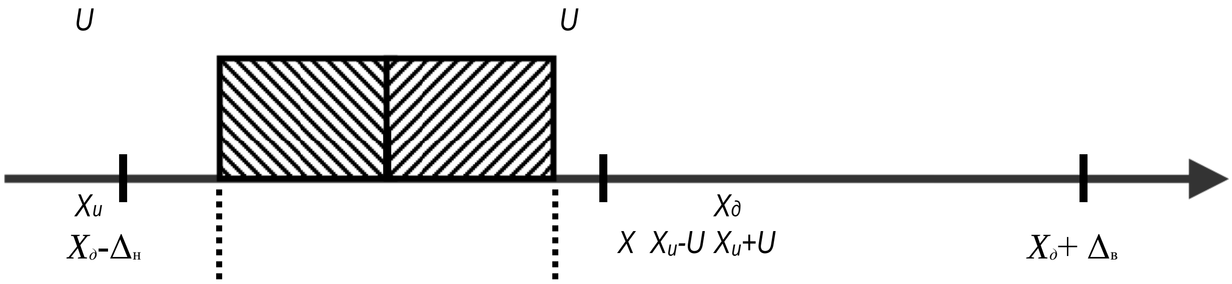
3.2 General recommendation.

On the basis of the considered metrological situations, it is possible to assume the general rule: in the most metrological situations, measurement results are characterized by uncertainty, and accuracy of measuring instruments are characterized by error limits. Concept «error» is used at comparison with reference quantity value, and evaluation errors are obtained at calibration or verification of measuring instruments. Thus, concepts "uncertainty" and "error" are recommended to be used harmoniously, without mutual contraposition and exclusion of one of them.

Appendix A
(reference)

Explanations to the use of concept «uncertainty of measurements» during verification

In the international document OIML D 8 [7], the concept «uncertainty of measurement during verification of measuring instruments» is used without this provision concretization. Different versions of its realization are possible due to the diversity of real situations in correlation of error limits of verified measuring instruments and standards used for that, in correlation of type A and type B evaluated uncertainties. For example, if the expanded uncertainty of measurements at verification (coverage factor 2) does not exceed 1/3 of limits of error, uncertainty is ignored. The other possible versions of measuring instruments (MI) suitability criteria on verification results are: MI evaluated error doesn't exceed difference limit of error and expanded measurements uncertainty during verification (see, for example [8]); MI evaluated error does not exceed square root from difference of squares limit of error and expanded measurements uncertainty during verification. Such criteria of suitability may be used, in particular, during verification of MI representing the measures, for which the error is «difference between nominal values of measures and real values of quantities reproduced by them». The sense of uncertainty account during verification is explained by the graph in Figure A.1. The versions represented in this Appendix explain only the principles of concept «error» and «uncertainty» use, but they are not preferably recommended and don't cover all the diversity of possible situations.



$X_д$ – reference (real) value (of standard);

X_u –indication of tested measuring instrument;

$\Delta_н$, $\Delta_в$ – upper and lower limits of error, according to normative document for measuring instruments to be tested (usually $\Delta_н = \Delta_в = \Delta$);

U – expanded uncertainty.

Figure A.1 – Diagram of uncertainty taking into account at confirmation of conformity of tested measuring instrument to limits of error.

The options given in this appendix only explain the principles of using the concepts of "error" and "uncertainty", but are not primarily recommended and do not cover the full variety of possible situations. The role of measurement uncertainty in making decisions on conformity assessment is described in detail in international guidelines and standards [9-11].

The updated recommendation RMG 91-2019 [3] contains additional Appendices: Appendix A (reference) "Classification of concepts and terms related to the keywords "error" and "uncertainty"; Appendix B (reference) "Explanations for the use of the concept of "measurement uncertainty" during verification".

The classification of concepts in Appendix A contains detailed comments on their application options, and in Appendix B the explanations are supplemented with specific recommendations for determining the width of the "protective strip" when confirming the conformity of the verified measuring instrument.

Bibliography

[1] ISO/IEC Guide 98-3:2008, Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995).

[2] JCGM 200:2008 (E/F). International vocabulary of metrology – Basic and general concepts and associated terms (VIM).

[3] РМГ 91-2019. Государственная система обеспечения единства измерений. Использование понятий «погрешность измерения» и «неопределённость измерений». Общие принципы. (State system for ensuring the uniformity of measurements. Use of concepts «error of measurement» and «uncertainty of measurements». General principles).

[4] Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes , Paris, 14 October 1999.

[5] ISO 5725-1:1994. Accuracy (trueness and precision) of measurement methods and results. Part 1: General principles and definitions.

[6] ISO 10576-1:2003. Statistical methods. Guidelines for the evaluation of conformity with specified requirements. Part 1. General principles.

[7] International Document OIML D 8, Edition 2004. Measurement standards. Choice, recognition, use, conservation and documentation.

[8] OIML R 111-1-2004. Weights of classes E1, E2, F1, F2, M1, M1-2, M2, M2-3, M3. Part 1: Metrological and technical requirements.

[9] JCGM 106:2012. Evaluation of measurement data - The role of measurement uncertainty in conformity assessment.

[10] Guide OIML G19:2017. The role of measurement uncertainty in conformity assessment decisions in legal metrology.

[11] CISPR 16-4-2:2003, MOD. Electromagnetic compatibility of technical equipment. Specification for radio disturbance and immunity measuring apparatus and methods. Part 4-2. Uncertainties, statistics and limit modelling. Measurement instrumentation uncertainty.

Information data

1. Coordinating organization: «NATIONAL SCIENTIFIC RESEARCH INSTITUTE FOR PHYSICOTECHNICAL AND RADIO ENGINEERING MEASUREMENTS».

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4. Information about application of the document in organizations – members of COOMET.

The updated version of the Recommendation was developed taking into account RMG 91-2019 "State system for ensuring the uniformity of measurements. The use of the concepts of "measurement error" and "measurement uncertainty". General Principles", International Dictionary of Metrology. Basic and general concepts and relevant terms (VIM 3), international documents, materials of publications: Doynikov A. S. Lectures on metrology, 2nd edition, Mendeleevo: FSUE "VNIIFTRI". 2021, 376 p., etc.

Recommended conceptually-terminological system and general principles are intended for use in legislative and applied metrology.

Contents