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Determination of the characteristic limits (decision threshold, detection limit and limits of the coverage interval) for measurements of ionizing radiation — Fundamentals and application —

Part 1: Elementary applications

Détermination des limites caractéristiques (seuil de décision, limite de détection et limites de l'intervalle élargi) pour mesurages de rayonnements ionisants — Principes fondamentaux et applications —

Partie 1: Applications élémentaires

Reference number
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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 ISO documents 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).

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This third edition cancels and replaces the second edition (ISO 11929-1:2019), of which it constitutes a minor revision.

The main changes are as follows:

— correction of the internal references within the text;

— correction of Formulae (3), (A.5) and (B.3);

— correction of the definitions of decision threshold (3.12) and the detection limit (3.13);

— introduction of NOTE 3 in 5.8, for clarity;

— complement of the NOTE in 9.1;

— correction of the 1st paragraph and NOTE 2 in Clause 10;

— correction of the 8th paragraph in Annex B.

A list of all the parts in the ISO 11929 series can be found on the ISO website.

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.

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Introduction

Measurement uncertainties and characteristic values, such as the decision threshold, the detection limit and limits of the coverage interval for measurements, as well as the best estimate and its associated standard measurement uncertainty, are of importance in metrology in general and for radiological protection in particular. The quantification of the uncertainty associated with a measurement result provides a basis for the trust an individual can have in a measurement result. Conformity with regulatory limits, constraints or reference values can only be demonstrated by taking into account and quantifying all sources of uncertainty. Characteristic limits provide, at the end, the basis for deciding if uncertainties have to be taken into account.

This standard provides characteristic values of a non-negative measurand of ionizing radiation. It is also applicable for a wide range of measuring methods extending beyond measurements of ionizing radiation.

The limits to be provided according to ISO 11929 series for specified probabilities of wrong decisions allow detection possibilities to be assessed for a measurand and for the physical effect quantified by this measurand as follows:

— the “decision threshold” allows a decision to be made on whether or not the physical effect quantified by the measurand is present;

— the “detection limit” indicates the smallest true quantity value of the measurand that can still be detected with the applied measurement procedure; this gives a decision on whether or not the measurement procedure satisfies the requirements and is therefore suitable for the intended measurement purpose;

— the “limits of the coverage interval” enclose, in the case of the physical effect recognized as present, a coverage interval containing the true quantity value of the measurand with a specified probability.

Hereinafter, the limits mentioned are jointly called the “characteristic limits”.

NOTE According to ISO/IEC Guide 99:2007 updated by JCGM 200:2012 the term “coverage interval” is used here instead of “confidence interval” in order to distinguish the wording of Bayesian terminology from that of conventional statistics.

All the characteristic values are based on Bayesian statistics and on the ISO/IEC 98-3 as well as on the ISO/IEC Guide 98-3:2008/Suppl 1:2008 and ISO/IEC Guide 98-3:2008/Suppl 2:2011. As explained in detail in ISO 11929-2, the characteristic values are mathematically defined by means of moments and quantiles of probability distributions of the possible measurand values.

Since measurement uncertainty plays an important part in ISO 11929, the evaluation of measurements and the treatment of measurement uncertainties are carried out by means of the general procedures according to the ISO/IEC Guide 98-3 and to the ISO/IEC Guide 98-3:2008/Suppl 1:2008; see also References [13] to [17]. This enables the strict separation of the evaluation of the measurements, on the one hand, and the provision and calculation of the characteristic values, on the other hand. The ISO 11929 series makes use of a theory of uncertainty in measurement[18] to[20] based on Bayesian statistics (e.g. see References [21] to [26]) in order to take into account those uncertainties that cannot be derived from repeated or counting measurements. The latter uncertainties cannot be handled by frequentist statistics.

Because of developments in metrology concerning measurement uncertainty laid down in the ISO/IEC Guide 98-3, ISO 11929:2010 was drawn up on the basis of the ISO/IEC Guide 98-3, but using Bayesian statistics and the Bayesian theory of measurement uncertainty. This theory provides a Bayesian foundation for the ISO/IEC Guide 98-3. Moreover, ISO 11929:2010 was based on the definitions of the characteristic values,[13] the standard proposal,[14] and the explanatory article.[15] It unified and replaced all earlier parts of ISO 11929 and was applicable not only to a large variety of particular measurements of ionizing radiation but also, in analogy, to other measurement procedures.

In 2008 the ISO/IEC Guide 98-3:2008/Suppl 1:2008 has been published, dealing comprehensively with a more general treatment of measurement uncertainty using the Monte Carlo method in complex measurement evaluations. This provided an incentive for writing a corresponding Monte Carlo supplement[16] to ISO 11929:2010 and to revise ISO 11929:2010. The revised ISO 11929 is also essentially founded on Bayesian statistics and can serve as a bridge between ISO 11929:2010 and the ISO/IEC Guide 98-3:2008/Suppl 1:2008. Moreover, more general definitions of the characteristic values (ISO 11929-2) and the Monte

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Carlo computation of the characteristic values make it possible to go a step beyond the present state of standardization laid down in ISO 11929:2010 since probability distributions rather than uncertainties can be propagated. It is thus more comprehensive and extending the range of applications.

The revised ISO 11929, moreover, is more explicit on the calculation of the characteristic values. It corrects also a problem in ISO 11929:2010 regarding uncertain quantities and influences, which do not behave randomly in measurements repeated several times. Reference [17] gives a survey on the basis of the revision. Furthermore, in ISO 11929-3, it gives detailed advice how to calculate characteristic values in the case of multivariate measurements using unfolding methods. For such measurements, the ISO/IEC Guide 98-3:2008/Suppl 2:2011 provides the basis of the uncertainty evaluation.

Formulae are provided for the calculation of the characteristic values of an ionizing radiation measurand via the "standard measurement uncertainty" of the measurand (hereinafter the "standard uncertainty") derived according to the ISO/IEC Guide 98-3 as well as via probability density functions (PDFs) of the measurand derived in accordance with the ISO/IEC Guide 98-3:2008/Suppl 1:2008. The standard uncertainties or probability density functions take into account the uncertainties of the actual measurement as well as those of sample treatment, calibration of the measuring system and other influences. The latter uncertainties are assumed to be known from previous investigations.

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Determination of the characteristic limits (decision threshold, detection limit and limits of the coverage interval) for measurements of ionizing radiation — Fundamentals and application —

Part 1: Elementary applications

1 Scope

The ISO 11929 series specifies a procedure, in the field of ionizing radiation metrology, for the calculation of the "decision threshold", the "detection limit" and the "limits of the coverage interval" for a non-negative ionizing radiation measurand when counting measurements with preselection of time or counts are carried out. The measurand results from a gross count rate and a background count rate as well as from further quantities on the basis of a model of the evaluation. In particular, the measurand can be the net count rate as the difference of the gross count rate and the background count rate, or the net activity of a sample. It can also be influenced by calibration of the measuring system, by sample treatment and by other factors.

ISO 11929 has been divided into four parts covering elementary applications in this document, advanced applications on the basis of the ISO/IEC Guide 3-1 in ISO 11929-2, applications to unfolding methods in ISO 11929-3, and guidance to the application in ISO 11929-4.

This document covers basic applications of counting measurements frequently used in the field of ionizing radiation metrology. It is restricted to applications for which the uncertainties can be evaluated on the basis of the ISO/IEC Guide 98-3 (JCGM 2008). In Annex A, the special case of repeated counting measurements with random influences is covered, while measurements with linear analogous ratemeters are covered in Annex B.

ISO 11929-2 extends the former ISO 11929:2010 to the evaluation of measurement uncertainties according to the ISO/IEC Guide 98-3:2008/Suppl 1:2008. ISO 11929-2 also presents some explanatory notes regarding general aspects of counting measurements and on Bayesian statistics in measurements.

ISO 11929-3 deals with the evaluation of measurements using unfolding methods and counting spectrometric multi-channel measurements if evaluated by unfolding methods, in particular, for alpha- and gamma-spectrometric measurements. Further, it provides some advice on how to deal with correlations and covariances.

ISO 11929-4 gives guidance to the application of the ISO 11929 series, summarizes shortly the general procedure and then presents a wide range of numerical examples. Information on the statistical roots of ISO 11929 and on its current development may be found elsewhere[33][34].

The ISO 11929 series also applies analogously to other measurements of any kind especially if a similar model of the evaluation is involved. Further practical examples can be found, for example, in ISO 18589[1], ISO 9696[2], ISO 9697[3], ISO 9698[4], ISO 10703[5], ISO 7503[6], ISO 28218[7] and ISO 11665[8].

NOTE A code system, named UncertRadio, is available for calculations according to ISO 11929-1 to ISO 11929-3. UncertRadio[31][32] can be downloaded for free from https://www.thuenen.de/en/institutes/fisheries-ecology/fields-of-activity/marine-environment/coordination-centre-of-radioactivity/uncertradio. The download contains a setup installation file which copies all files and folders into a folder specified by the user. After installation one has to add information to the PATH of Windows as indicated by a pop-up window during installation. English language can be chosen and extensive "help" information is available.

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2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 3534-1, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

ISO 80000-1, *Quantities and units — Part 1: General*

ISO 80000-10, *Quantities and units — Part 10: Atomic and nuclear physics*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 98-3:2008/Suppl 1:2008, *Evaluation of measurement data — Supplement 1 to the "Guide to the expression of uncertainty in measurement" — a Propagation of distributions using a Monte Carlo method, JCGM 101:2008*

ISO/IEC Guide 98-3:2008/Suppl 2:2011, *Evaluation of measurement data — Supplement 2 to the "Guide to the expression of uncertainty in measurement" — Models with any number of output quantities, JCGM 102:2011*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 80000-1, ISO 80000-10, ISO/IEC Guide 98-3, ISO/IEC Guide 98-3:2008/Suppl 1:2008, ISO/IEC Guide 98-3:2008/Suppl 2:2011, ISO/IEC Guide 99 and ISO 3534-1 and the following apply.

3.1
quantity value
value of a quantity
value
number and reference together expressing magnitude of a quantity

[SOURCE: JCGM 200:2012, 1.19]

3.2
measurement
process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity

[SOURCE: JCGM 200:2012, 2.1]

3.3
measurand
quantity intended to be measured

[SOURCE: JCGM 200:2012, 2.3]

3.4
coverage interval
interval containing the set of true quantity values of a measurand with a stated probability, based on the information available

[SOURCE: JCGM 200:2012, 2.36]

Note 1 to entry: A coverage interval does not need to be centred on the chosen measured quantity value (see JCGM 101:2008).

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Note 2 to entry: A coverage interval should not be termed “confidence interval” to avoid confusion with the statistical concept.

3.5
measurement method
method of measurement
generic description of a logical organization of operations used in a measurement

[SOURCE: JCGM 200:2012, 2.4]

3.6
measurement procedure
detailed description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result

[SOURCE: JCGM 200:2012, 2.6]

3.7
measurement result
result of measurement
set of quantity values being attributed to a measurand together with any other available relevant information

[SOURCE: JCGM 200:2012, 2.9]

3.8
measured quantity value
value of a measured quantity
measured value
quantity value representing a measurement result

[SOURCE: JCGM 200:2012, 2.10]

3.9
true quantity value
true value of a quantity
true value
quantity value consistent with the definition of a quantity

[SOURCE: JCGM 200:2012, 2.11]

Note 1 to entry: In the error approach to describing measurement, a true quantity value is considered unique and, in practice, unknowable. The uncertainty approach is to recognize that, owing to the inherently incomplete amount of detail in the definition of a quantity, there is not a single true quantity value but rather a set of true quantity values consistent with the definition. However, this set of values is, in principle and in practice, unknowable. Other approaches dispense altogether with the concept of true quantity value and rely on the concept of metrological compatibility of measurement results for assessing their validity.

Note 2 to entry: When the definitional uncertainty associated with the measurand is considered to be negligible compared to the other components of the measurement uncertainty, the measurand may be considered to have an “essentially unique” true quantity value. This is the approach taken by the ISO/IEC Guide 98-3 and associated documents, where the word “true” is considered to be redundant.

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3.10
measurement uncertainty
uncertainty of measurement
uncertainty
non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

[SOURCE: JCGM 200:2012, 2.26]

Note 1 to entry: 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.

Note 2 to entry: 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.

Note 3 to entry: 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.

Note 4 to entry: 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.

3.11
model of evaluation
set of mathematical relationships between all measured and other quantities involved in the evaluation of measurements

Note 1 to entry: The model of evaluation does not need to be an explicit function; it can also be an algorithm realized by a computer code.

3.12
decision threshold
value of the estimator of the measurand, which, when exceeded by the result of an actual measurement using a given measurement procedure of a measurand quantifying a physical effect, is used to decide that the physical effect is present

Note 1 to entry: In cases where the measurement result, y, exceeds the decision threshold, y^*, it is decided to conclude that the physical effect is present. The probability of making an erroneous decision in this case is equal to-the pre-selected probability α. An incorrect decision means assuming a physical effect, even though it is, in fact, absent.

Note 2 to entry: If the result, y, is below the decision threshold, y^*, it is decided to conclude that the result cannot be attributed to the physical effect; nevertheless, it cannot be concluded that it is absent.

Note 3 to entry: The probability α is the probability that a measured value exceeds the decision threshold and is accepted as indicator for a non-zero true value although it is, in fact, zero. In this case, the conclusion $\tilde{y} > 0$ would be a wrong decision.

Note 4 to entry: The probability β is hereby the probability that a measured value lies below the decision threshold and the result is therefore not attributed to the physical effect although the true value equals the detection limit $y^\#$. In this case, the conclusion $\tilde{y} = 0$ would be a wrong decision.

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3.13
detection limit
smallest true value of the measurand which ensures a specified probability of being detectable by the measurement procedure

Note 1 to entry: The detection limit, $y^{\#}$, is the smallest true value for which the probability that the measured value-y falls below the decision threshold according to 3.12 is the pre-selected probability β. If a measured value falls below the decision threshold, it is decided to conclude that there is no physical effect, although, in fact, it exists. This would result in a wrong decision being made with the probability β. The probability of making the correct decision is consequently (1-β).

Note 2 to entry: The terms detection limit and decision threshold are used in an ambiguous way in different standards (e.g. standards related to chemical analysis or quality assurance). If these terms are referred to one has to state according to which standard they are used.

3.14
probabilistically symmetric coverage interval
coverage interval for a quantity such that the probability that the quantity is less than the smallest value in the interval is equal to the probability that the quantity is greater than the largest value in the interval

[SOURCE: JCGM 101:2008, 3.15]

3.15
shortest coverage interval
coverage interval for a quantity with the shortest length among all coverage intervals for that quantity having the same coverage probability

[SOURCE: JCGM 101:2008, 3.16]

3.16
limits of the coverage interval
values which define a coverage interval

Note 1 to entry: A coverage interval is sometimes known as a credible interval or a Bayesian interval. Its limits are calculated in the ISO 11929 series to contain the true value of the measurand with a specified probability $(1 - \gamma)$.

Note 2 to entry: The definition of a coverage interval is ambiguous without further stipulations. In this standard two alternatives, namely the probabilistically symmetric and the shortest coverage interval are used.

3.17
best estimate of the true quantity value of the measurand
expectation value of the probability distribution of the true quantity value of the measurand, given the experimental result and all prior information on the measurand

Note 1 to entry: The best estimate is the one among all possible estimates of the measurand on the basis of given information, which is associated with the minimum uncertainty.

3.18
guideline value
value which corresponds to scientific, legal or other requirements with regard to the detection capability and which is intended to be assessed by the measurement procedure by comparison with the detection limit

Note 1 to entry: The guideline value can be given, for example, as an activity, a specific activity or an activity concentration, a surface activity or a dose rate.

Note 2 to entry: The comparison of the detection limit with a guideline value allows a decision on whether or not the measurement procedure satisfies the requirements set forth by the guideline value and is therefore suitable for the intended measurement purpose. The measurement procedure satisfies the requirement if the detection limit is smaller than the guideline value.

Note 3 to entry: The guideline value shall not be confused with other values stipulated as conformity requests or as regulatory limits.

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3.19
background effect
measurement effect caused by radiation other than that caused by the object of the measurement itself

Note 1 to entry: The background effect can be due to natural radiation sources or radioactive materials in or around the measuring instrumentation and also to the sample itself (for instance, from other lines in a spectrum).

3.20
background effect in spectrometric measurement
number of events of no interest in the region of a specific line in the spectrum

3.21
net effect
contribution of the possible radiation of a measurement object (for instance, of a radiation source or radiation field) to the measurement effect

3.22
gross effect
measurement effect caused by the background effect and the net effect

3.23
shielding factor
factor describing the reduction of the background count rate by the effect of shielding caused by the measurement object

3.24
relaxation time constant
duration in which the output signal of a linear-scale ratemeter decreases to 1/e times the starting value after stopping the sequence of the input pulses

4 Quantities and symbols

The symbols for auxiliary quantities and the symbols only used in the annexes are not listed. Physical quantities are denoted by upper-case letters but shall be carefully distinguished from their values, denoted by the corresponding lower-case letters.

NOTE In this document, a quantity is considered to have a true value which is unknown and unknowable. In some applications, one needs to assume a true value.

m	number of input quantities
X_i	input quantity $(i = 1, \ldots, m)$
x_i	estimate of the input quantity X_i
$u(X_i)$	standard uncertainty of the input quantity X_i associated with the estimate x_i
W	calibration factor
w	estimate of the calibration factor
$u_{\mathrm{rel}}(W)$	relative standard uncertainty of a quantity W associated with the estimate w
G	model function
Y	non-negative measurand, which quantifies the physical effect of interest
Y_0	random variable serving as an estimator of Y without taking into account that Y is non-negative
Y_1	random variable serving as an estimator of Y taking into account that Y is non-negative

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