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Fastlæggelse af karakteristiske grænser til måling af ioniserende stråling (beslutningsgrænse, detektionsgrænse og grænser for dækning) – Grundprincipper og anvendelse – Del 3: Anvendelser til udfoldningsmetoder

Determination of the characteristic limits (decision threshold, detection limit and limits of the coverage interval) for measurements of ionizing radiation – Fundamentals and application – Part 3: Applications to unfolding methods

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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 3: Applications to unfolding methods

*Détermination des limites caractéristiques (seuil de décision, limite de détection et extrémités de l'intervalle élargi) pour mesurages de rayonnements ionisants — Principes fondamentaux et applications —
Partie 3: Applications aux méthodes de déploiement*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by This document was prepared by ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

This second edition of [ISO 11929-3](#) together with [ISO 11929-1](#), [ISO 11929-2](#), cancels and replaces [ISO 11929:2010](#) which have been technically revised, specifically with reference to the type of statistical treatment of the data and extended with respect to the methodology of uncertainty assessment from the [ISO/IEC Guide 98-3:2009](#), to the [ISO/IEC Guide 98-3-1:2008](#).

A list of all the parts in the [ISO 11929 series](#) can be found on the ISO website.

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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 under uncertainty.

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 the [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](#) Guide to the Expression of Uncertainty in Measurement as well as on the [ISO/IEC Guide 98-3-1](#) and [ISO/IEC 98-3-2](#). 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 98-3-1](#); see also References [9] to [13]. 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 [14] to [16] based on Bayesian statistics (e.g. [17] to [22]) in order to allow to take into account also 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^[9], the standard proposal^[10], and the introducing article^[11]. 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.

Since the [ISO/IEC Guide 98-3-1](#) has been published, dealing comprehensively with a more general treatment of measurement uncertainty using the Monte Carlo method in complex measurement

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evaluations. This provided an incentive for writing a corresponding Monte Carlo supplement^[12] 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 98-3-1](#). Moreover, more general definitions of the characteristic values ([ISO 11929-2](#)) and the Monte 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 [\[13\]](#) gives a survey on the basis of the revision. Furthermore, this document gives detailed advice how to calculate characteristic values in the case of multivariate measurements using unfolding methods. For such measurements, the [ISO/IEC Guide 98-3-2](#) provides the basis of the uncertainty evaluation.

Formulas 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 [ISO/IEC Guide 98-3-1](#). 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 3: Applications to unfolding methods

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 [ISO 11929-1](#), advanced applications on the basis of the [ISO/IEC Guide 98-3-1](#) in [ISO 11929-2](#), applications to unfolding methods in this document, and guidance to the application in [ISO 11929-4](#).

[ISO 11929-1](#) 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 of [ISO 11929-1:2019](#), the special case of repeated counting measurements with random influences is covered, while measurements with linear analogous ratemeters, are covered in Annex B of [ISO 11929-1:2019](#).

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

This document 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.

[ISO 11929](#) Standard 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](#)^[7], [ISO 9696](#)^[2], [ISO 9697](#)^[3], [ISO 9698](#)^[4], [ISO 10703](#)^[5], [ISO 7503](#)^[1], [ISO 28218](#)^[8], and [ISO 11665](#)^[6].

NOTE — A code system, named UncertRadio, is available for calculations according to [ISO 11929-1](#) to [ISO 11929-3](#). UncertRadio^[35]^[36] can be downloaded for free from <https://www.thuenen.de/en/fi/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 1: Guide to the expression of uncertainty in measurement, JCGM 100:2008*

[ISO/IEC Guide 98-3-1](#), *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 98-3-2](#), *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)*