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

**Part 4:
Guidelines to applications**

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

Partie 4: Lignes directrices relatives aux applications





COPYRIGHT PROTECTED DOCUMENT

© ISO 2022

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

	Page
Foreword.....	vii
Introduction.....	viii
1 Scope.....	1
2 Normative references.....	2
3 Terms and definitions.....	2
4 Quantities and symbols.....	3
5 Summary of this document.....	5
5.1 Procedures according to ISO 11929 (all parts).....	5
5.2 Survey on the examples.....	5
5.3 General stipulations.....	8
6 Counting measurements with small or moderate uncertainties.....	9
6.1 Definition of the task and general aspects.....	9
6.2 Model of evaluation and standard uncertainty.....	9
6.3 Available information, input data, and specifications.....	9
6.4 Evaluation of the measurement and characteristic limits according to ISO 11929-1.....	10
6.4.1 Background effect.....	10
6.4.2 Primary result and its associated standard uncertainty.....	10
6.4.3 Standard uncertainty as a function of an assumed true value.....	10
6.4.4 Decision threshold.....	10
6.4.5 Detection limit.....	11
6.4.6 Limits of coverage intervals.....	11
6.4.7 The best estimate and its associated standard uncertainty.....	11
6.5 Documentation of the results obtained by ISO 11929-1 and ISO 11929-2.....	11
6.6 Assessment and explanations.....	13
7 Counting measurement with small count numbers.....	14
7.1 Definition of the task and general aspects.....	14
7.2 Model of evaluation and standard uncertainty.....	14
7.3 Available information, input data, and specifications.....	14
7.4 Evaluation of the measurement and characteristic limits according to ISO 11929-1.....	15
7.4.1 Background effect.....	15
7.4.2 Primary result and its associated standard uncertainty.....	15
7.4.3 Standard uncertainty as a function of an assumed true value.....	16
7.4.4 Decision threshold.....	16
7.4.5 Detection limit.....	16
7.4.6 Limits of coverage intervals.....	17
7.4.7 The best estimate and its associated standard uncertainty.....	17
7.5 Documentation of the results obtained by ISO 11929-1 and ISO 11929-2.....	17
7.6 Assessment and explanations.....	18
7.7 An alternative example of a measurement with small count numbers.....	19
7.7.1 General.....	19
7.7.2 Background effect.....	20
7.7.3 Primary result and its associated standard uncertainty.....	20
7.7.4 Standard uncertainty as a function of an assumed true value.....	20
7.7.5 Decision threshold.....	20
7.7.6 Detection limit.....	21
7.7.7 Limits of coverage intervals.....	21
7.7.8 The best estimate and its associated standard uncertainty.....	21
7.8 Documentation of the results obtained by ISO 11929-1 and ISO 11929-2.....	22
7.9 Assessment of the alternative example and explanations.....	23
8 Counting measurements with large uncertainties in the numerator of the calibration factor.....	23

8.1	Definition of the task and general aspects	23
8.2	Model of evaluation and standard uncertainty	24
8.3	Available information, input data, and specifications	24
8.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	25
8.4.1	Background effect	25
8.4.2	Primary result and its associated standard uncertainty	25
8.4.3	Standard uncertainty as a function of an assumed true value	25
8.4.4	Decision threshold	25
8.4.5	Detection limit	26
8.4.6	Limits of coverage intervals	26
8.4.7	The best estimate and its associated standard uncertainty	26
8.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	26
8.6	Assessment and explanations	28
9	Counting measurements with large uncertainties in the denominator of the calibration factor	28
9.1	Definition of the task and general aspects	28
9.2	Model of evaluation and standard uncertainty	29
9.3	Available information, input data, and specifications	29
9.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	30
9.4.1	Background effect	30
9.4.2	Primary result and its associated standard uncertainty	30
9.4.3	Standard uncertainty as a function of an assumed true value	31
9.4.4	Decision threshold	31
9.4.5	Detection limit	31
9.4.6	Limits of coverage intervals	31
9.4.7	The best estimate and its associated standard uncertainty	32
9.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	32
9.6	Assessment and explanations	33
10	Counting measurements with shielding of the background	34
10.1	Definition of the task and general aspects	34
10.2	Model of evaluation and standard uncertainty	34
10.3	Available information, input data, and specifications	34
10.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	35
10.4.1	Background effect	35
10.4.2	Primary result and its associated standard uncertainty	35
10.4.3	Standard uncertainty as a function of an assumed true value	35
10.4.4	Decision threshold	35
10.4.5	Detection limit	36
10.4.6	Limits of coverage intervals	36
10.4.7	The best estimate and its associated standard uncertainty	36
10.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	36
10.6	Assessment and explanations	38
11	Counting clearance measurement	38
11.1	Definition of the task and general aspects	38
11.2	Model of evaluation and standard uncertainty	39
11.3	Available information, input data, and specifications	39
11.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	40
11.4.1	Background effect	40
11.4.2	Primary result and its associated standard uncertainty	40
11.4.3	Standard uncertainty as a function of an assumed true value	40
11.4.4	Decision threshold	41
11.4.5	Detection limit	41
11.4.6	Limits of coverage intervals	41
11.4.7	The best estimate and its associated standard uncertainty	42
11.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	42
11.6	Assessment and explanations	43

12	Gamma-spectrometry of Uranium-235 with interference by Radium-226	44
12.1	Definition of the task and general aspects	44
12.2	Model of evaluation and standard uncertainty	45
12.3	Available information, input data, and specifications	46
12.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	47
12.4.1	Background effect	47
12.4.2	Primary result and its associated standard uncertainty	47
12.4.3	Standard uncertainty as a function of an assumed true value	48
12.4.4	Decision threshold	49
12.4.5	Detection limit	49
12.4.6	Limits of coverage intervals	49
12.4.7	The best estimate and its associated standard uncertainty	50
12.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	50
12.6	Assessment and explanations	51
13	Black box measurements	52
13.1	Definition of the task and general aspects	52
13.2	Model of evaluation and standard uncertainty	52
13.3	Available information, input data, and specifications	53
13.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	53
13.4.1	Background effect	53
13.4.2	Primary result and its associated standard uncertainty	54
13.4.3	Standard uncertainty as a function of an assumed true value	54
13.4.4	Decision threshold	54
13.4.5	Detection limit	55
13.4.6	Limits of coverage intervals	55
13.4.7	The best estimate and its associated standard uncertainty	55
13.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	56
13.6	Assessment and explanations	57
14	Counting measurements with unknown random influence of sample treatment	57
14.1	Definition of the task and general aspects	57
14.2	Model of evaluation and standard uncertainty	58
14.3	Available information, input data, and specifications	58
14.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	59
14.4.1	Background effect	59
14.4.2	Primary result and its associated standard uncertainty	59
14.4.3	Standard uncertainty as a function of an assumed true value	60
14.4.4	Decision threshold	60
14.4.5	Detection limit	61
14.4.6	Limits of coverage intervals	61
14.4.7	The best estimate and its associated standard uncertainty	61
14.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	61
14.6	Assessment and explanations	63
15	Counting measurement with known influence of sample treatment	63
15.1	Definition of the task and general aspects	63
15.2	Model of evaluation and standard uncertainty	64
15.3	Available information, input data, and specifications	65
15.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	66
15.4.1	Determination of the relative uncertainty of the sample treatment	66
15.4.2	Background effect	66
15.4.3	Primary result and its associated standard uncertainty	66
15.4.4	Standard uncertainty as a function of an assumed true value	67
15.4.5	Decision threshold	67
15.4.6	Detection limit	68
15.4.7	Limits of coverage intervals	68
15.4.8	The best estimate and its associated standard uncertainty	68
15.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	68
15.6	Assessment and explanations	70

16	Dose measurement using an active personal dosimeter	70
16.1	Definition of the task and general aspects	70
16.2	Model of evaluation and standard uncertainty	70
16.3	Available information, input data, and specifications	71
16.4	Evaluation of the measurement and characteristic limits according to ISO 11929-1	71
16.4.1	Background effect	71
16.4.2	Primary result and its associated standard uncertainty	72
16.4.3	Standard uncertainty as a function of an assumed true value	72
16.4.4	Decision threshold	72
16.4.5	Detection limit	73
16.4.6	Limits of coverage intervals	73
16.4.7	The best estimate and its associated standard uncertainty	74
16.5	Documentation of the results obtained by ISO 11929-1 and ISO 11929-2	74
16.6	Assessment and explanations	75
17	Dose rate measurement using a neutron area monitor	76
17.1	Definition of the task and general aspects	76
17.2	Model of evaluation and standard uncertainty	77
17.3	Available information, input data, and specifications	78
17.4	Evaluation of the measurement and characteristic limits	80
17.4.1	Background effect	80
17.4.2	Primary result and its associated standard uncertainty	80
17.4.3	Standard uncertainty as a function of an assumed true value	80
17.4.4	Decision threshold	81
17.4.5	Detection limit	82
17.4.6	Limits of coverage intervals	82
17.4.7	The best estimate and its associated standard uncertainty	83
17.5	Documentation of the results	83
17.6	Assessment and explanations	84
	Annex A (informative) Determination of a calibration factor	85
	Annex B (informative) Calculations according to ISO 11929-2	90
	Bibliography	93

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 on 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 the following URL: www.iso.org/iso/foreword.html.

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

This third edition of ISO 11929-4 cancels and replaces the second edition (ISO 11929-4:2020), of which it constitutes a minor revision.

The main changes are as follows:

— Editorial changes were done in text and formulae

A list of all parts of ISO 11929 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.

Introduction

Measurement uncertainties and characteristic values, i.e. characteristic limits 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.

NOTE 1 Conformity with regulatory limits, constraints or reference values can only be demonstrated taking into account and quantifying all sources of uncertainty. Characteristic limits provide – in the end – the basis for deciding accepting results under uncertainty.

ISO 11929 (all parts) provides characteristic values of a non-negative measurand of ionizing radiation. It is applicable for a wide range of measuring methods extending beyond measurements of ionizing radiation.

The limits to be provided according to ISO 11929 (all parts) 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 and allows for 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 “characteristic limits”.

NOTE 2 According to ISO/IEC Guide 99 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 Guide 98-3 as well as on the ISO/IEC Guide 98-3:2008/Suppl.1 and ISO/IEC Guide 98-3:2008/Suppl.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 role in all parts of 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; see also References [21] to [25]. 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. ISO 11929 (all parts) makes use of a theory of uncertainty in measurement[26] to [28] based on Bayesian statistics (e.g. References [29] to [36]) in order to allow taking 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 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[21], the standard proposal[22], and the introducing article[23]. 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. Some

explanatory material about the basics of ISO 11929 (all parts), in general, and its application in has been published elsewhere^{[42][43]}.

Since the ISO/IEC Guide 98-3:2008/Suppl.1 has been published, the Monte Carlo method has been used to deal comprehensively with a more general treatment of measurement uncertainty in complex measurement evaluations. This development provided an incentive for writing a corresponding Monte Carlo supplement^[24] to ISO 11929:2010. The revised ISO 11929 (all parts) is also essentially founded on Bayesian statistics and can serve as a bridge between documents ISO 11929:2010 and the ISO/IEC Guide 98-3:2008/Suppl.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 (all parts), moreover, is more explicit on the calculation of the characteristic values. Reference ^[25] gives a survey on the basis of the revision. Further, 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 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 “standard uncertainty”) derived according to the ISO/IEC Guide 98-3 as well as via probability density functions (PDFs) of the measurand derived on the basis of the ISO/IEC Guide 98-3:2008/Suppl.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.

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

Part 4: Guidelines to applications

1 Scope

This document 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 98-3:2008/Suppl.1 in ISO 11929-2, applications to unfolding methods in ISO 11929-3, 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 ISO 11929-1:2019, Annex A the special case of repeated counting measurements with random influences and in ISO 11929-1:2019, Annex B, measurements with linear analogous ratemeters are covered.

ISO 11929-2 extends ISO 11929-1 to the evaluation of measurement uncertainties according to the ISO/IEC Guide 98-3:2008/Suppl.1. ISO 11929-2 also presents some explanatory notes regarding general aspects of counting measurements and 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, alpha- and gamma-spectrometric measurements. Further, it provides some advice how to deal with correlations and covariances.

ISO 11929-4 gives guidance to the application of ISO 11929 (all parts), summarizing shortly the general procedure and then presenting a wide range of numerical examples. The examples cover elementary applications according to ISO 11929-1 and ISO 11929-2.