INTERNATIONAL STANDARD

ISO 11929-5

First edition
2005-02-15

Determination of the detection limit and decision threshold for ionizing radiation measurements —

Part 5: Fundamentals and applications to counting measurements on filters during accumulation of radioactive material

Détermination de la limite de détection et du seuil de décision des mesurages de rayonnements ionisants —
Partie 5: Principes fondamentaux et leurs applications aux mesurages par comptage réalisés sur filtres lors d'une accumulation de radioactivité

Reference number
ISO 11929-5:2005(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 11929-5 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

ISO 11929 consists of the following parts, under the general title *Determination of the detection limit and decision threshold for ionizing radiation measurements*:

— *Part 1: Fundamentals and application to counting measurements without the influence of sample treatment*

— *Part 2: Fundamentals and application to counting measurements with the influence of sample treatment*

— *Part 3: Fundamentals and application to counting measurements with high resolution gamma spectrometry, without the influence of sample treatment*

— *Part 4: Fundamentals and applications to measurements by use of linear-scale analogue ratemeters, without the influence of sample treatment*

— *Part 5: Fundamentals and applications to counting measurements on filters during accumulation of radioactive material*

— *Part 6: Fundamentals and applications to measurements by use of transient mode*

— *Part 7: Fundamentals and general applications*

— *Part 8: Fundamentals and applications to unfolding of spectrometric measurements without the influence of sample treatment*

Introduction

This part of ISO 11929 gives basic information on the statistical principles for the determination of the detection limit, of the decision threshold and of the limits of the confidence interval for nuclear radiation measurements when monitoring the concentration of aerosols in exhaust gas, air or waste water.

ISO 11929-1 and ISO 11929-2, respectively, deal with integral counting measurements with or without consideration of the sample treatment. High-resolution spectrometric measurements are covered in ISO 11929-3. ISO 11929-4 deals with measurements using linear-scale analogue ratemeters, ISO 11929-6 with measurements using a transient measuring mode, ISO 11929-7 with general applications and ISO 11929-8 with unfolding of spectrometric measurements.

Whereas the earlier arts 1 to 4 were elaborated for special measuring tasks in nuclear radiation measurements based on the principles defined by Altschuler and Pasternack [1], Nicholson [2], Currie [3], this restriction does not apply to this part, or to parts 6 to 8. The determination of the characteristic limits mentioned above is separated from the evaluation of the measurement. Consequently this part of ISO 11929 is generally applicable and can be applied to any suitable procedure for the evaluation of a measurement. Since the uncertainty of measurement plays a fundamental role in this part of ISO 11929, evaluations of measurements and the determination of the uncertainties of measurement have to be performed according to the Guide for the expression of uncertainty in measurement.

This part, as well as parts 6, 7 and 8, of ISO 11929 is based on methods of Bayesian statistics part of ISO 11929 [4] to [6] in the Bibliography in order to be able to account also for uncertain quantities and influences which do not behave randomly in repeated or counting measurements.

For this purpose, Bayesian statistical methods are used to specify the following statistical values, called “characteristic limit.”

- The *decision threshold*, which allows a decision to be made for a measurement with a given probability of error as to whether the result of the measurement indicates the presence of the physical effect quantified by the measurand.
- The *detection limit*, which specifies the minimum true value of the measurand which can be detected with a given probability of error using the measuring procedure in question. This consequently allows a decision to be made as to whether or not a measuring method checked using this part of ISO 11929 satisfies certain requirements and is consequently suitable for the given purpose of measurement.
- The *limits of the confidence interval*, which define an interval which contains the true value of the measurand with a given probability, in the case that the result of the measurement exceeds the decision threshold.

This part of ISO 11929 concerns the monitoring of the volume concentration and of the increase or decrease of the volume concentration of radioactive particles in exhaust air, gas or (waste) water by multiple counting measurements during accumulation of the particles on a filter. It is assumed that dead-time losses are negligible. Wherever activities, activity concentrations or specific activities are to be determined, it is assumed that the factors for the conversion of pulse rates into activities, activity concentrations or specific activities have to be determined with sufficient accuracy to ignore the influence of their uncertainty in the measurement. The exhaust air, gas or water flow rate and the background are considered to be constant during the measurements.

In counting measurements on filters during accumulation of radioactive material, the measurement in question is evaluated with respect to two measurands:

- the radioactivity per unit volume (activity concentration);
- the variation of the radioactivity per unit volume (variation of activity concentration).

Determination of the detection limit and decision threshold for ionizing radiation measurements —

Part 5: Fundamentals and applications to counting measurements on filters during accumulation of radioactive material

1 Scope

This part of ISO 11929 specifies suitable statistical values which allow an assessment of the detection capabilities in ionizing radiation measurements and of the physical effect quantified by the measurand. For this purpose, Bayesian statistical methods are used to specify characteristic limits.

This part of ISO 11929 deals with fundamentals and applications to counting measurements on filters during accumulation of radioactive material.

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.

ISO 11929-7:2005, *Determination of the detection limit and decision threshold for ionizing radiation measurements — Part 7: Fundamentals and general applications*

BIPM/IEC/IFCC/ISO/IUPAC/OIML, *Guide to the Expression of Uncertainty in Measurement*, *Geneva, 1993*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
measuring method
any logical sequence of operations, described generically, used in the performance of measurements

NOTE 1 Adapted from the International Vocabulary of Basic and General Terms in Metrology:1993.

NOTE 2 A method as defined for the purpose of this part of ISO 11929 shall be an integral, a dual channel or a spectrometric counting measurement under specified conditions during accumulation of particles on a filter.

3.2
measurand
particular quantity subject to measurement

[International Vocabulary of Basic and General Terms in Metrology:1993]

NOTE 1 Measurand in this part of ISO 11929 is non-negative and quantifies a nuclear radiation effect. The effect is not present if the value of the measurand is zero.

NOTE 2 In this standard, two measurands are distinguished, namely the radioactivity per unit volume (activity concentration) and the variation of the radioactivity per unit volume (variation of the activity concentration). For both measurands the characteristic limits are specified.

3.3
uncertainty (of measurement)
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

[Guide for the Expression of Uncertainty in Measurement:1993]

NOTE The uncertainty of a measurement derived according to the Guide for the Expression of Uncertainty in Measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. The other components, which also can be characterized by standard deviations, are evaluated from assumed or known probability distributions based on experience and other information.

3.4
mathematical model of the evaluation
a set of mathematical relationships between all measured and other quantities involved in the evaluation of the measurement

3.5
decision quantity
random variable for the decision whether or not the physical effect to be measured is present

3.6
series of measurements
number of independent measurement cycles following one another giving information about the volume concentration of radioactivity and about the trend of the results versus time.

NOTE Each new result will be checked to decide whether it is in the trend or it is significantly different from the expected value.

3.7
decision threshold
fixed value of the decision quantity by which, when exceeded by the result of an actual measurement of a measurand quantifying a physical effect, one decides that the physical effect is present

NOTE The decision threshold is the critical value of a statistical test to decide between the hypothesis that the physical effect is not present and the alternative hypothesis that it is present. When the critical value is exceeded by the result of an actual measurement this is taken to indicate that the hypothesis should be rejected. The statistical test will be designed such that the probability of wrongly rejecting the hypothesis (error of the first kind) is equal at most to a given value α.

3.8
detection limit
smallest true value of the measurand which is detectable by the measuring method

NOTE 1 The detection limit is the smallest true value of the measurand which is associated with the statistical test and hypotheses according to 3.7 by the following characteristics: if in reality the true value is equal to or exceeds the detection limit, the probability of wrongly not rejecting the hypothesis (error of the second kind) will be at most equal to a given value β.

NOTE 2 The difference between using the decision threshold and using the detection limit is that measured values are to be compared with the decision threshold, whereas the detection limit is to be compared with the guideline value.

3.9
confidence limits
values which define confidence intervals to be specified for the measurand in question which, if the result exceeds the decision threshold, includes the true value of the measurand with the given probability $(1-\gamma)$

3.10
sample
radioactive material accumulated on a filter absorbed from the whole amount of exhausted gas, air or water or an aliquot of it in a bypass and measured in a particular cycle

3.11
background counting rate
measured counting rate without radioactivity of interest

NOTE This is the counting rate caused by external sources, and radioactivity in detector and shielding and detector noise.

3.12
gross counting rate
measured counting rate due to both the radioactivity on the filter (sample contribution) and the background counting rate

3.13
net counting rate(1)
difference between the gross counting rate of the first measuring cycle and the background counting rate

3.14
net counting rate(2)
difference between the gross counting rates of two consecutive measurements

3.15
guideline value
value which corresponds to scientific, legal or other requirements for which the measuring procedure is intended to assess

EXAMPLE Activity, specific activity or activity concentration, surface activity, or dose rate

4 Quantities and symbols

$\hat{\xi}$ Random variable as an estimator for a non-negative measurand quantifying a physical effect

ξ Value of the estimator $\hat{\xi}$; true value of the measurand

X Random variable as decision quantity; estimator of the measurand

x Result of a measurement of the decision quantity X

$u(x)$ Standard uncertainty of the measurand associated with the measured result x of a measurement

$\tilde{u}(\xi)$ Standard uncertainty of the decision quantity X as a function of the true value ξ of the measurand

z Best estimate of the measurand

$u(z)$ Standard uncertainty of the measurand associated with the best estimate z

x^* Decision threshold for the measurand

ξ^* Detection limit for the measurand

ξ_l, ξ_u Respectively the lower and upper limit of the confidence interval for the measurand

α Probability of the error of the first kind; the probability of rejecting the hypothesis if it is true

β Probability of the error of the second kind; the probability of accepting the hypothesis if it is false

$1 - \gamma$ Probability attributed to the confidence interval of the measurand; probability that the true value of the measurand is included by the confidence interval

k_p Quantiles of the standardized normal distribution for the probability p (see Table 1); $p = 1 - \alpha$, $1 - \beta$, $1 - \gamma/2$

Y_k Output quantity Y_k derived from the measured results; ($k = 1, ..., n$)

y_k Estimate of an output quantity Y_k; ($k = 1, ..., n$)

$u(y_k)$ Standard uncertainty associated with y_k

G_k Function of the input quantities X_i; ($i = 1, ..., m$); model of the evaluation

X_i Input quantities; ($i = 1, \ldots, m$)

x_i Estimate of an input quantity; ($i = 1, \ldots, m$)

$u(x_i, x_j)$ Covariance associated with x_i and x_j; ($i, j = 1, \ldots, m$)

E Operator for the formation of the expectation of a random variable

Var Operator for the formation of the variance of a random variable

κ Parameter

A_V Activity concentration

α_V True value of the activity concentration

A^*_V Decision threshold of the activity concentration

α^*_V Detection limit of the activity concentration

ΔA_V Variation of the activity concentration

$\Delta\alpha_V$ True value of the variation of the activity concentration

ΔA^*_V Decision threshold of the variation of the activity concentration

$\Delta\alpha^*_V$ Detection limit of the variation of the activity concentration

$N_{g,i}$ Gross number of events counted in the i-th measuring cycle of duration t

t Duration of each measurement cycle

$R_{g,i}$ Gross counting rate during i-th measuring cycle

ε Detection efficiency

V Volume of gas or water passing the filter during a measuring cycle

R_0 Background count rate during the first measuring cycle

$R_{n,i}$ Net counting rate, difference of gross counting rate of measuring cycles i and i–1; $R_{n,i} = R_{g,i} - R_{g,i-1}$

$\overline{R_{n,i}}$ Mean net counting rate averaged over k measuring cycles preceding the i-th measuring cycle

A_i Activity collected on the filter during the i-th measuring cycle

$\overline{A}$ Average activity collected during k measuring cycles

$\Phi(t)$ Distribution function of the standardized normal distribution

$\varphi(z)$ Standardized normal distribution

5 Statistical values and confidence interval

5.1 Principles

5.1.1 General aspects

For a particular task involving nuclear radiation measurements, first the particular physical effect which is the objective of the measurement has to be described. Then a non-negative measurand has to be defined which quantifies the physical effect and which assumes the value zero if the effect is not present in an actual case.

A random variable, called a decision quantity X, has to be attributed to the measurand. It is also an estimator of the measurand. It is required that the expectation value EX of the decision quantity X equals the true value ξ of the measurand. A value x of the estimator X derived from measurements is a primary estimate of the measurand. The primary estimate x of the measurand, and its associated standard uncertainty $u(x)$, have to be calculated as the primary complete result of the measurement, according to the Guide for the Expression of Uncertainty in Measurement, by evaluation of measured quantities and of other information using a mathematical model of the evaluation which takes into account all relevant quantities. Generally, the fact that the measurand is non-negative will not be explicitly made use of. Therefore, x may become negative, in particular, if the true value of the measurand is close to zero.

NOTE The model of the evaluation of the measurement need not necessarily be given in the form of explicit mathematical formulas. It can also be represented by an algorithm or a computer code [see Equation (2)].

For the determination of the decision threshold and the detection limit, the standard uncertainty of the decision quantity has to be calculated, if possible, as a function $\tilde{u}(\xi)$ of the true value ξ of the measurand. In the case that this is not possible, approximate solutions are described below.

ξ is the value of another, non-negative estimator $\hat{\xi}$ of the measurand. The estimator $\hat{\xi}$, in contrast to X, makes use of the knowledge that the measurand is non-negative. The limits of the confidence interval to be determined refer to this estimator $\hat{\xi}$ (compare 5.4). Besides the limits of the confidence interval, the expectation value E$\hat{\xi}$ of this estimator as best estimate z of the measurand, and the standard deviation $[\mathrm{Var}(\hat{\xi})]^{1/2}$ as a the standard uncertainty $u(z)$ associated with the best estimate z of the measurand, have to be calculated (see 6.3).

For the numerical calculation of the decision threshold and the detection limit, the function $\tilde{u}(\xi)$ is needed, which is the standard uncertainty of the decision quantity X as a function of the true value ξ of the measurand. The function $\tilde{u}(\xi)$ generally has to be determined by the user of this part of ISO 11929, in the course of the evaluation of the measurement according to the Guide for the Expression of Uncertainty in Measurement. For examples see Annex A. This function is often only slowly increasing. Therefore, it is justified in many cases to use the approximation $\tilde{u}(\xi) = u(x)$.This applies, in particular, if the primary estimate x of the measurand is not much larger than its standard uncertainty $u(x)$ associated with x. If the value x is calculated as the difference (net effect) of two approximately equal values y_1 and y_0 obtained from independent measurements, that is $x = y_1 - y_0$, one gets $u^2(\xi) = u^2(y_1) + u^2(y_0)$ with the standard uncertainties $u(y_1)$ and $u(y_0)$ associated with y_1 and y_0, respectively.

If only $\tilde{u}(0)$ and $u(x)$ are known, an approximation by linear interpolation is often sufficient for $x > 0$ according to:

$$\tilde{u}^2(\xi) = \tilde{u}^2(0) \cdot (1 - \xi / x) + u^2(x) \cdot \xi / x \tag{1}$$

NOTE In many practical cases, $\tilde{u}^2(\xi)$ is a slowly increasing linear function of ξ. This justifies the approximations above, in particular, the linear interpolation of $\tilde{u}^2(\xi)$ instead of $\tilde{u}(\xi)$ itself.

For setting up the mathematical model of the evaluation of the measurement, one has to distinguish two types of physical quantities, input and output quantities. The output quantities Y_k ($k = 1, ..., n$) are viewed as measurands (for example, the parameters of an unfolding or fitting procedure) which have to be determined by the evaluation of a measurement. The decision quantity X is one of them. They depend on the input quantities x_i ($i = 1, ..., m$) which are the quantities obtained by repeated measurements, influence quantities and results of previous measurements and evaluations. (Compare chapter 4.1.2 of the ISO Guide for the Expression of Uncertainty in Measurement:1993.) One has to calculate the estimates y_k of the output quantities (measurands) as the results of the measurement and the standard uncertainties $u(y_k)$ associated with y_k.

The model of the evaluation is given by a set of functional relationships:

$$Y_k = G_k(x_1, ..., X_m); (x = 1, ..., n) \tag{2}$$

Estimates of the measurands Y_k, denoted y_k, are obtained from Equation (2) using input estimates $x_1, ..., x_m$ for the values of the m quantities $X_1, ..., X_m$. Thus, the output estimates y_k and the standard uncertainties $u(y_k)$ associated with y_k are given by

$$y_k = G_k(x_1, ..., x_m); (k = 1, ..., n) \tag{3}$$

$$u(y_k, y_l) = \sum_{i,j=1}^{m} \frac{\partial G_k}{\partial X_i} \cdot \frac{\partial G_l}{\partial X_j} \cdot u(x_i, x_j); (k, l = 1, ..., n) \tag{4}$$

where x_i and x_j are the estimates of X_i and X_j and $u(x_i, x_j) = u(x_j, x_i)$ are the estimated covariances associated with x_i and x_j. The standard uncertainty $u(y_k)$ is given by:

$$u^2(y_k) = u(y_k, y_k) \tag{5}$$

In cases when the partial derivatives are not explicitly available, they can be numerically approximated in a sufficiently exact way using the standard uncertainty $u(x_k)$ as an increment of x_k by

$$\frac{\partial G_k}{\partial X_i} \approx \frac{1}{u(x_i)} \left\{ G_k \left[x_1, ..., x_i + u(x_i)/2, ..., x_m \right] - G_k \left[x_1, ..., x_i - u(x_i)/2, ..., x_m \right] \right\} \tag{6}$$

5.1.2 Model

When evaluating any measurements of filters during accumulation of radioactive material, an output quantity Y will be calculated from input data X_i using the general model

$$Y = G(X_1, ..., X_n) \tag{7}$$

The general model of Equation (7) will be specified in this part of ISO 11929. Determine the values of two measurands:

a) the concentration of radioactivity per unit volume of gas or liquid A_V; and

b) the variation of the concentration of radioactivity per unit volume of gas or liquid ΔA_V.

The measurements are performed as follows. A volume V of a gas or liquid is flowing through a filter during a time t. During the accumulation of radioactive materials on the filter, cyclic counting measurements are performed. Each measuring cycle i has a duration t during which a gross number of events $N_{g,i}$ is counted. The values of both measurands A_V and ΔA_V are to be determined from these measurements taking into account a calibration factor ε. For the sake of simplicity it is assumed that the calibration factor ε and the volume V can be determined with negligible uncertainties.

For the evaluation of the measurements with respect to the two measurands, one needs two different models of evaluation which are described in 5.1.2.1 and 5.1.2.2.

5.1.2.1 Model for the measurement of concentration of radioactivity

The measurand in this counting measurement is the activity concentration A_V calculated from the difference between the gross counting rates of two consecutive measurements:

$$A_V = \frac{R_{g,i} - R_{g,i-1}}{\varepsilon \cdot V} = \frac{N_{g,i} - N_{g,i-1}}{\varepsilon \cdot V \cdot t} \tag{8}$$

where

$R_{g,i}$ is the i-th gross counting rate;

$R_{g,i-1}$ is the (i–1)-th gross counting rate;

$N_{g,i}$ are the gross pulses counted in the i-th measuring cycle of duration t;

$N_{g,i-1}$ are the gross pulses counted in the (i–1)-th measuring cycle of duration t;

t is the duration of each measurement;

ε is the detection efficiency;

V is the volume of gas or water passing the filter while the measurement is running.

Ignoring the uncertainty of t, and for simplicity, those of ε and V, the standard uncertainty $u(A_V)$ associated with A_V is given by:

$$\tilde{u}^2(A_V) = \frac{N_{g,i} + N_{g,i-1}}{(\varepsilon \cdot V \cdot t)^2} \tag{9}$$

For the calculation of the decision threshold A^*_V, one needs the standard uncertainty $\tilde{u}(0)$ of A_V for a true value $\alpha_V = 0$. For $\alpha_V = 0$, one expects $N_{g,i} = N_{g,i-1}$. This yields:

$$\tilde{u}^2(0) = \frac{2 \cdot N_{g,i-1}}{(\varepsilon \cdot V \cdot t)^2} \tag{10}$$

$\tilde{u}^2(0)$ depends on $N_{g,i-1}$ which increases with increasing radioactivity on the filter. The smallest value of $\tilde{u}^2(0)$ is:

$$\tilde{u}^2(0) = \frac{2 \cdot N_0}{(\varepsilon \cdot V \cdot t)^2} = \frac{2 \cdot R_0}{(\varepsilon \cdot V)^2 \cdot t} \tag{11}$$

with N_0 being the measured counts using a fresh filter.

