IEC TR 62461

Edition 2.0 2015-01

TECHNICAL REPORT

Radiation protection instrumentation – Determination of uncertainty in measurement

colour inside

IEC TR 62461:2015-01(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 13.280 ISBN 978-2-8322-2216-4

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RADIATION PROTECTION INSTRUMENTATION –
DETERMINATION OF UNCERTAINTY IN MEASUREMENT

FOREWORD

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IEC 62461, which is a technical report, has been prepared by subcommittee 45B: Radiation protection instrumentation, of IEC technical committee 45: Nuclear instrumentation.

This second edition of IEC TR 62461 cancels and replaces the first edition, published in 2006, and constitutes a technical revision. The main changes with respect to the previous edition are as follows:

– add to the analytical method for the determination of uncertainty the Monte Carlo method for the determination of uncertainty according to supplement 1 of the Guide to the Expression of uncertainty in measurement (GUM S1), and
– add a very simple method to judge whether a measured result is significantly different from zero or not based on ISO 11929.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
45B/783/DTR	45B/813/RVD

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

The ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)* as well as its Supplement 1:2008, *Propagation of distributions using a Monte Carlo method* (GUM S1), are general guides to assess the uncertainty in measurement. This Technical Report lays emphasis on their application in the area of radiation protection and serves as a practical introduction to the GUM and its supplement 1 (GUM S1).

The process of determining the uncertainty delivers not only a numerical value of the uncertainty; in addition it produces the best estimate of the quantity to be measured which may differ from the indication of the instrument. Thus, it can also improve the result of the measurement by using information beyond the indicated value of the instrument, e.g. the energy dependence of the instrument.

RADIATION PROTECTION INSTRUMENTATION – DETERMINATION OF UNCERTAINTY IN MEASUREMENT

1 Scope

This Technical Report gives guidelines for the application of the uncertainty analysis according to ISO/IEC Guide 98-3:2008 (GUM describing an analytical method for the uncertainty determination) and its Supplement 1:2008 (GUM S1 describing a Monte Carlo method for the uncertainty determination) for measurements covered by standards of IEC Subcommittee 45B. It does not include the uncertainty associated with the concept of the measuring quantity, e. g., the difference between $H_\mathrm{p}(10)$ on the ISO water slab phantom and on the person.

This Technical Report explains the principles of the ISO/IEC Guide 98-3:2008 (GUM),its Supplement 1:2008 (GUM S1) and the special considerations necessary for radiation protection at an example taken from individual dosimetry of external radiation. In the informative annexes, several examples are given for the application on instruments, for which SC 45B has developed standards.

This Technical Report is supposed to assist the understanding of the ISO/IEC Guide 98-3:2008 (GUM), its Supplement 1: 2008 (GUM S1), and other papers on uncertainty analysis. It cannot replace these papers nor can it provide the background and justification of the arguments leading to the concept of the ISO/IEC Guide 98-3:2008 (GUM) and its Supplement 1:2008 (GUM S1).

Finally, this Technical Report gives a very simple method to judge whether a measured result is significantly different from zero or not based on ISO 11929.

For better readability the correct terms are not always used throughout this technical report. For example, instead of “random variables of a quantity” only the “quantity” itself is stated.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts): *International Electrotechnical Vocabulary* (available at http://www.electropedia.org)

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

ISO/IEC Guide 98-3, Supplement 1:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995) – Propagation of distributions using a Monte Carlo method*

3 Terms and definitions

For the purposes of this document, the technical terms of IEC 60050-151 [1], and IEC 60050-311 [2] as well as the following definitions taken from the ISO/IEC Guide 98-3:2008 (GUM), and its Supplement 1:2008 (GUM S1) apply[1].

3.1
calibration factor
N
quotient of the true value of a quantity and the indicated value for a specified reference radiation under specified reference conditions

3.2
conformity test
test for conformity evaluation

[SOURCE: IEC 60050-151:2001,151-16-15]

3.3
complete result of a measurement
set of values attributed to a measurand, including a value, the corresponding uncertainty and the unit of measurement

Note 1 to entry: The central value of the whole (set of values) can be selected as *measured value* and a parameter characterising the dispersion as *uncertainty*.

Note 2 to entry: The result of a measurement is related to the *indication given by the instrument* and to the values of correction obtained by calibration and by the use of a *model*.

Note 3 to entry: In this Technical Report, the "measured value", see Note 1 above, is abbreviated by M.

Note 4 to entry: In this Technical Report, the "indication given by the instrument", see Note 2 above, is abbreviated by G, and called "indicated value".

Note 5 to entry: In this Technical Report, the "model", see Note 2 above, is called "model function", see 3.10 and 5.2.

[SOURCE: IEC 60050-311:2001, 311-01-01, modified]

3.4
correction factor
K
factor to the indicated value to correct for deviation of measurement conditions from calibration conditions

3.5
coverage factor
k_{cov}
numerical factor used as a multiplier of the (combined) standard uncertainty in order to obtain an expanded uncertainty

Note 1 to entry: A coverage factor k_{cov} is typically in the range of 2 to 3.

[SOURCE: GUM:2008, 2.3.6]

1 Numbers in square brackets refer to the bibliography.

3.6
decision threshold
m*
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, one decides that the physical effect is present

Note 1 to entry: The decision threshold is defined such that in cases where the measurement result, m, exceeds the decision threshold, m^*, the probability that the true value of the measurand is zero is less or equal to a chosen probability, α.

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

[SOURCE: ISO 11929:2010]

3.7
deviation
D
difference between the indicated values for the same value of the measurand of an indicating measuring instrument, or the values of a material measure, when an influence quantity assumes, successively, two different values

Note 1 to entry: This definition is applicable to all measuring instruments and influence quantities, but it should mainly be used in those cases, where this deviation is independent of the indicated value.

[SOURCE: IEC 60050-311:2001, 311-07-03, modified[2]]

3.8
distribution function
***F*(*x*)**
a function giving, for every value x, the probability that the random variable X be less than or equal to x: $F(x) = \Pr(X \leq x)$

[SOURCE: GUM:2008, C.2.4; GUM S1:2008, 3.2]

3.9
expanded uncertainty
U
quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

Note 1 to entry: The expanded uncertainty is obtained by multiplying the (combined) standard uncertainty by a coverage factor.

[SOURCE: GUM:2008, 2.3.5]

3.10
indicated value
G
quantity value provided by a measuring instrument or a measuring system

Note 1 to entry: An indication is often given by the position of a pointer on the display for analogue outputs, a displayed or printed number for digital outputs, a code pattern for code outputs, or an assigned quantity value for material measures.

3.11
influence quantity
quantity that is not the measurand but that effects the result of the measurement

2 Original term “variation (due to an influence quantity)”.

Note 1 to entry: For example, temperature of a micrometer used to measure length.

[SOURCE: GUM:2008, B.2.10]

3.12
measured value
M
value determined from the indicated value, G, by applying the model function for the measurement

Note 1 to entry: An example of a model function is given below. The calibration factor N, a deviation D, and a correction factor K are applied:

$$M = N \times K \times (G - D)$$

The calculations according to this model function are not always performed. One main purpose of this model function of the measurement is, that it is necessary for any determination of the uncertainty according to the GUM (see GUM, 3.1.6, 3.4.1 and 4.1; see also 5.2 of this Technical Report).

Note 2 to entry: In the GUM the *measured value* is called *value of the measurand*.

3.13
probability density function <for a continuous random variable>
$f(x)$
the derivative (when it exists) of the distribution function: $f(x)=\mathrm{d}F(x)/\mathrm{d}x$

Note 1 to entry: $f(x)\cdot\mathrm{d}x$ is the "probability element": $f(x)\cdot\mathrm{d}x=\Pr(x<X<x+\mathrm{d}x)$; in general: $\Pr(a < X < b) = \int_a^b f(x)\mathrm{d}x$.

[SOURCE: GUM:2008, C.2.5; GUM S1:2008, 3.3, modified by adding "in general"]

3.14
reference conditions
set of specified values and/or ranges of values of influence quantities under which the uncertainties, or limits of error, admissible for a measuring instrument are the smallest

[SOURCE: IEC 60050-311:2001, 311-06-02]

3.15
reference response
R_{ref}
response of the assembly under reference conditions to unit reference dose (rate) or activity and is expressed as:

$$R_{\mathrm{ref}} = \frac{G}{M_{\mathrm{c}}}$$

where G is the indicated value of the equipment or assembly under test and M_{c} is the true value of the reference source

3.16
relative response
R_{rel}
quotient of the response and the reference response under specified conditions

Note 1 to entry: For the specified reference conditions, the response is the reciprocal of the calibration factor.

3.17
response
R
ratio of the quantity measured under specified conditions by the equipment or assembly under test and the true value of this quantity

3.18
standard uncertainty
standard deviation associated with the measurement result or an input quantity

Note 1 to entry: See GUM:2008, 2.3.4.

Note 2 to entry: The standard uncertainty of the measurement result is sometimes called “combined standard uncertainty”.

Note 3 to entry: The quotient of the standard uncertainty and the measurement result is called “relative standard uncertainty” and sometimes given as percentage.

3.19
type test
conformity test made on one or more items representative of the production

[SOURCE: IEC 60050-151:2001, 151-16-16]

3.20
uncertainty
uncertainty of measurement
parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand

Note 1 to entry: The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence (coverage probability).

[SOURCE: GUM:2008, 2.2.3]

4 List of symbols

Table 1 gives a list of the symbols (and abbreviated terms) used in the main text of this Technical Report (excluding annexes).

Table 1 – Symbols (and abbreviated terms) used in the main text (excluding annexes)

Symbol	Meaning	Unit (dose measurement)
a	Half-width of an interval for possible values of a quantity	As quantity
a_-	Lower limit of an interval for possible values of a quantity	As quantity
a_+	Upper limit of an interval for possible values of a quantity	As quantity
α	Probability to detect an effect (state a result above zero) although in reality no effect is present (the true value is zero) also called “probability of false positive decision”	–
c_k	Sensitivity coefficient for the input quantity K	Sv
c_m	Sensitivity coefficient for the input quantity M	–
c_{m0}	Sensitivity coefficient for the input quantity M_0	–
c_n	Sensitivity coefficient for the input quantity N	Sv
$F(x)$	Distribution function	–

Symbol	Meaning	Unit (dose measurement)
$f(x)$	Probability density function (for a continuous random variable) PDF	Inverse of quantity
G	Indicated value, for example, reading of the dosemeter in units of $H_p(10)$	Sv
$\hat{g}$	Best estimate of G	Sv
g	Possible value (estimate) of G	Sv
G_0	Zero reading	Sv
$\hat{g}_0$	Best estimate of G_0	Sv
g_0	Possible value (estimate) of G_0	Sv
$h(x)$	Model function, see Note 1 to 3.12	As output quantity
$H_p(10)$	Personal dose equivalent at a depth 10 mm	Sv
i	Running index (integer)	–
j	Running index (integer)	–
K	Correction factor, for example, for energy and angle of radiation incidence	–
$\hat{k}$	Best estimate of K	–
k	Possible value (estimate) of K	–
$k_{1-\alpha}$	quantile of the standardized normal distribution for a given probability α	–
k_{cov}	Coverage factor	–
L	Number of Monte Carlo trials	–
M	Measured value, for example, personal dose equivalent $H_p(10)$	Sv
M_c	True value of a reference source	Sv
$\hat{m}$	Best estimate of M	Sv
m	Possible value (estimate) of M	Sv
m^*	Decision threshold of M	Sv
N	Calibration factor	–
$\hat{n}$	Best estimate of N	–
n	Possible value (estimate) of N	–
p	Coverage probability	–
Q	Distribution function for the output quantity	–
q	Arbitrary integer	–
R_{abs}	Absolute response	–
R_{rel}	Relative response	–
$s_{\hat{g}}$	Standard deviation of the distribution of the g-values	Sv
$s_{\hat{g}0}$	Standard deviation of the distribution of the g_0-values	Sv
$s_{\hat{k}}$	Standard deviation of the distribution of the k-values	–
$s_{\hat{n}}$	Standard deviation of the distribution of the n-values	–
T	Number of input quantities	–
U	Expanded uncertainty	Sv
$u(\hat{m})$	Standard uncertainty associated with the best estimate of the measurement result, $\hat{m}$	Sv
$u_g(\hat{m})$	Uncertainty contribution to u of the input quantity G associated with the best estimate of the measurement result, $\hat{m}$	Sv
$u_{g0}(\hat{m})$	Uncertainty contribution to u of the input quantity G_0 associated with the best estimate of the measurement result, $\hat{m}$	Sv
$u_k(\hat{m})$	Uncertainty contribution to u of the input quantity K associated with the best estimate of the measurement result, $\hat{m}$	Sv