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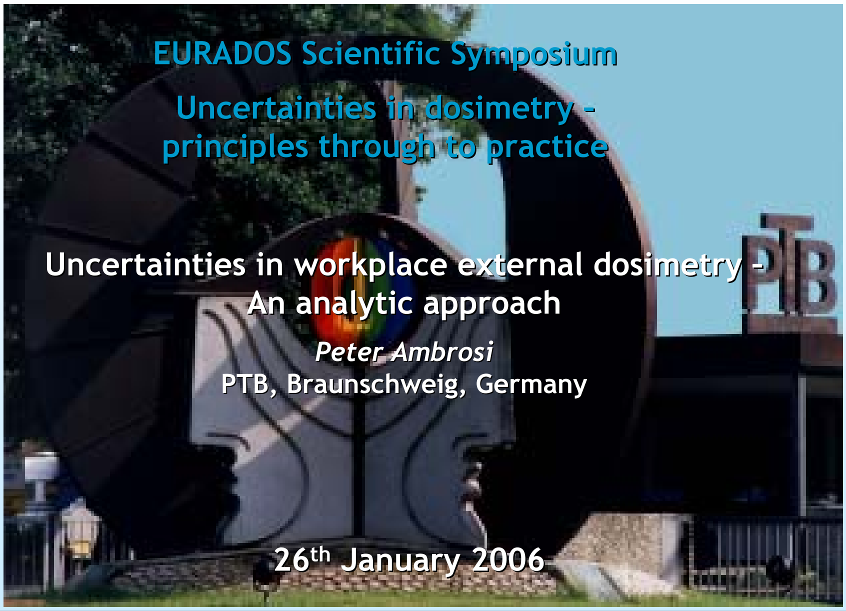

EURADOS Scientific Symposium

Uncertainties in dosimetry - principles through to practice

Uncertainties in workplace external dosimetry - An analytic approach

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Draft TR IEC 62461: INTRODUCTION: Quotation

The Guide to the Expression of Uncertainty in Measurement (GUM) is a general guide which is not easy to understand. In addition, it contains a lot of arguments why this new method is an improved approach to the determination of uncertainty. These points seem to be a barrier to many potential users. Nevertheless, it is frequently used by scientist in National Institutes of Metrology and other specialists responsible for high level calibration, but a lack of use in the field of radiation protection instrumentation must be considered. So this Technical Report shall serve as a practical introduction to the GUM with special emphasis on measurements in radiation protection.

This report cannot overcame the fact that the determination of the uncertainty requires a larger effort than performing the measurement itself. As a counterbalance the process of determining the uncertainty results not only in 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 improves also the result of the measurement.

Draft TR IEC 62461: 1 Scope and object

This Technical Report explains the principles of the GUM and the special considerations necessary for radiation protection at an example taken from individual dosimetry of external radiation, i.e. the daily measurement of the dose to the individual. In informative annexes several examples are given for the application on instruments, for which Subcommittee 45 B has developed standards.

Number of pages: 41

IEC 62461: 5 The GUM concept, 5.1 General 1/3

The GUM

- considers all available knowledge of a measurement,
- is based on the Bayes statistics,
- is internationally accepted and
- is described in many publications.

The application of the GUM method, not the justification or the mathematics behind it, will be described in a simplified example in the following.

IEC 62461: 5 The GUM concept, 5.1 General 2/3

The GUM

- supersedes the method of error analysis applied so far,
- no longer uses the term of the statistical probability exclusively,
- understands the probability in the same way as is usually done in everyday life,
- uses all relevant information available to characterise a measurement, even the experience of the person performing the measurement,
- expresses quantitatively the measurement result as a probability distribution over the possible values of the quantity ,
- uses the expectation value of the probability distribution as the measured value,
- uses the standard deviation as a measure for the ignorance of the measurand.

IEC 62461: 5 The GUM concept, 5.1 General 3/3

Complete result of a measurement:

$$M = m \pm U$$

Where M is the quantity to be measured (e.g. $H_p(10)$,
m is the best estimate of the quantity to be measured,
U is the associated or reported expanded uncertainty)

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k_{cov} = 2, which for a normal distribution corresponds to a coverage probability of approximately 95 %. The standard uncertainty of measurement has been determined in accordance with the guide to the expression of uncertainty in measurement.

IEC 62461: 5.2 model function 1/3

Model function: Mathematical model of the measurement. In IEC 62461 analytical functions are considered, but it can also be a computer algorithm.

Example: direct reading individual dosemeter, reading of the dosemeter in units of the measuring quantity, e.g. µSv for the quantity $H_p(10)$.

Method to set up the model function: principle of cause and effect

Cause (and aim of the measurement) is the dose M. It produces, due to the response R, an indication of $M \cdot R$, which is increased by the zero indication G_0:

$$G = M\,R + G_0$$

Aim of the measurement is M, so the **model function** is given by

$$M = \frac{1}{R}(G - G_0)$$

Popular fallacy: starting the uncertainty analysis from the indication

IEC 62461: 5.2 model function 2/3

The inverse of the response R is given by:

$$\frac{1}{R} = N\,K$$

where N is the calibration factor and K the correction factor

Model function:

$$M = N\,K\,(G - G_0)$$

Routine measurements: $M = G$

→ No correction of measured value
→ Associated uncertainty: consider model function with all corrections

IEC 62461: 5.2 model function 3/3

Application of the GUM on the Model function $M = N\,K\,(G - G_0)$ **:**

Input quantities: N, K, G, G_0 to be replaced by **random variables**

Possible values: n^*, k^*, etc. (small letters with asterisk)

Expectation values: n, k, etc. (small letters without asterisk)

Standard uncertainty: s_n, s_k, etc. (letter s with index)

Variation of all input quantities, e.g. within $n \pm s_n$, $k \pm s_k$.

→ **Distribution of the output quantity:** m^*, m, $u(m)$ (instead of s_m)

Linearization: $m = n\,k\,(g - g_0)$

IEC 62461: 5.3 Collection of data 1/6

Methods:

1. Mathematical methods like statistical analysis
2. Other methods like collecting data from data sheets, e.g., calibration certificates, or using scientific and experimental experience.
   These other methods depend to a great extent on the experience and the knowledge of the evaluator.

Different evaluators: different information
→ different values for the uncertainty of the input quantities
→ different values for the uncertainty of the output quantity

But not: uncertainty of the uncertainty

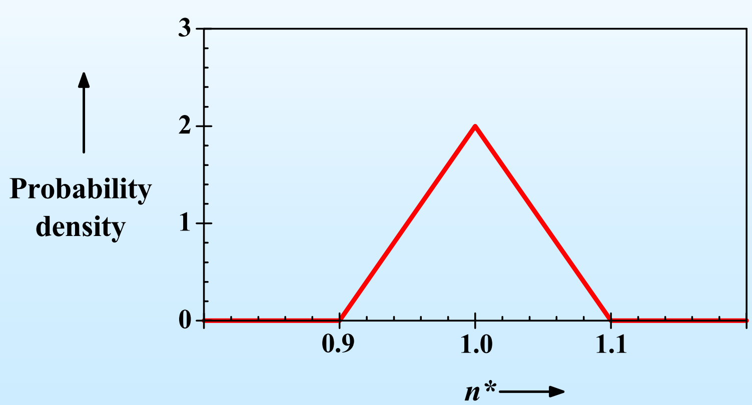
→ uncertainty analysis must be clearly documented, e.g. uncertainty budget

IEC 62461: 5.3 Collection of data 2/6

model function $M = N\,K\,(G - G_0)$

Calibration factor: $0.9 \leq n^* \leq 1.1$ with triangular probab. density distribution

→ $n = 1.0$ and $s_n = \frac{0.1}{\sqrt{6}} = 0.041$

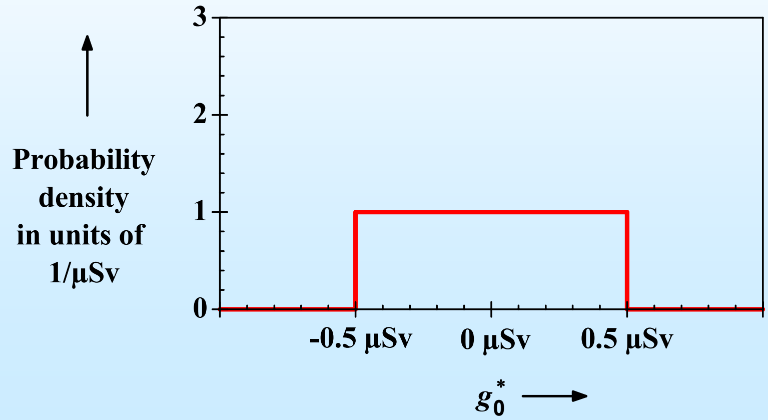


IEC 62461: 5.3 Collection of data 3/6

model function $M = N\,K\,(G - G_0)$

Zero reading: – 0.5 µSv ≤ g_0^* ≤ + 0.5 µSv with rectangular prob. dens. distribution

→ $g_0 = 0$ µSv and $s_{g_0} = \frac{0.5\,\mu Sv}{\sqrt{3}} = 0.29\,\mu Sv$

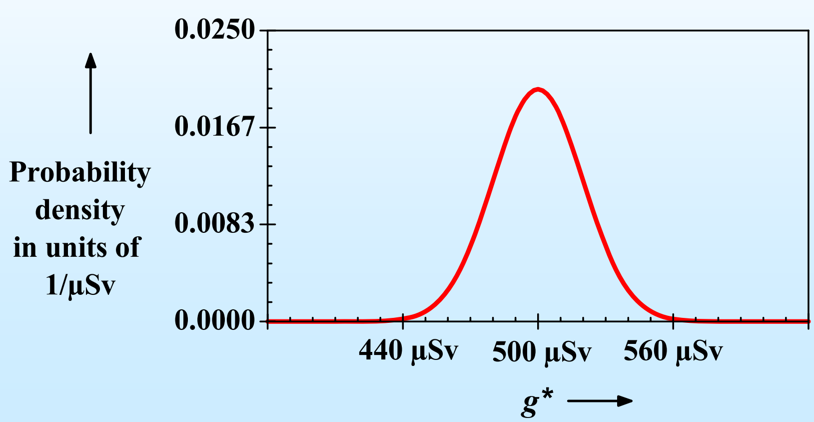


IEC 62461: 5.3 Collection of data 4/6

model function $M = N\,K\,(G - G_0)$

Reading: g = 500 µSv, s_g = 4 % with normal probability distribution

→ $s_g = 0.04 \cdot 500$ µSv = 20 µSv



IEC 62461: 5.3 Collection of data 5/6

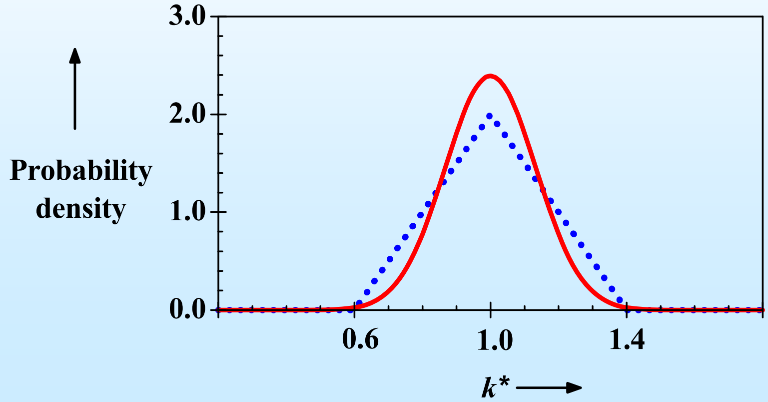
model function $M = N\,K\,(G - G_0)$

Correction factor (low level of consideration of workplace conditions):

IEC 61526: $0.71 \leq r^* \leq 1.67$ → $0.6 \leq k^* \leq 1.4$

Assumption: Normal distribution due to movement and broad spectra

→ $k = 1.0$ and $s_k = \frac{0.4}{3} = 0.133$



IEC 62461: 5.3 Collection of data 6/6

model function $M = N\,K\,(G - G_0)$

Correction factor (high level of consideration of workplace conditions):

X-ray testing equipment: $0.71 \leq r^* \leq 1.0$ → $1.0 \leq k^* \leq 1.4$

Assumption: Normal distribution due to movement and broad spectra

→ $k = 1.2$ and $s_k = \frac{0.2}{3} = 0.067$

IEC 62461: 5.4 Calculation 1/5

The calculation of the result of a measurement and the associated uncertainty according to the model function is done using established mathematical methods and may, therefore, also be performed by software.

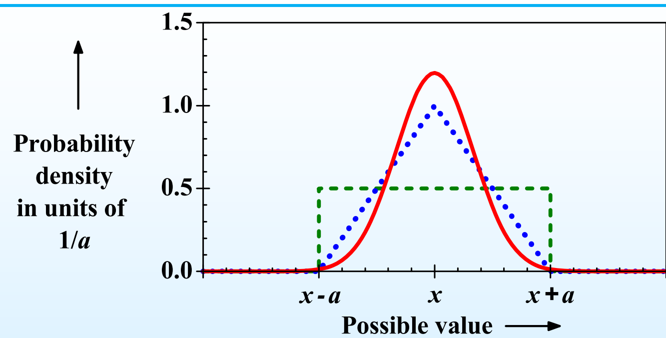
Repetition of Basics:

Type A methods: statistics as before

Type B methods: other (new) methods

Distribution: best estimate, x,
limits of the distribution a_- and a_+ must be symmetrical to x
→ $a_- = x - a$ and $a_+ = x + a$

IEC 62461: 5.4 Calculation 2/5



Type of distribution	standard uncertainty	remark
Rectangular	$\frac{a}{\sqrt{3}}$	100 % of all possible values are within the interval from a_- to a_+
Triangular	$\frac{a}{\sqrt{6}}$	100 % of all possible values are within the interval from a_- to a_+
Gaussian	$\frac{a}{3}$	99.7 % of all possible values are within the interval from a_- to a_+

IEC 62461: 5.4 Calculation 3/5

Aim: measured value m and standard uncertainty, $u(m)$

$m = n\,k\,(g - g_0)$

$u(m) = u(s_n, s_k, s_g, s_{g0}) = ???$

$u_n(m)$ = "extent", by which m is influenced by variations of the input quantity n

$u_n(m) = c_n \cdot s_n$ with c_n := **sensitivity coefficient**

$$c_n = \frac{\partial m}{\partial n} = \left.\frac{\partial M}{\partial N}\right|_{N=n,\,K=k,\,G=g,\,G_0=g_0} = k\,(g - g_0)$$

$$u(m) = \sqrt{(c_n \cdot s_n)^2 + (c_k \cdot s_k)^2 + (c_g \cdot s_g)^2 + (c_{g_0} \cdot s_{g_0})^2}$$

IEC 62461: 5.4 Calculation 4/5

Uncertainty budget for the example and low level of consideration of workplace conditions

Quantity	Best estimate	Standard uncertainty	Distribution	Sensitivity coefficient	Uncertainty contribution to output quantity
N	1.0	$\frac{0.1}{\sqrt{6}} = 0.041$	Triang.	500 µSv	0.041 x 500 µSv = 20.5 µSv
K	1.0	$\frac{0.4}{3} = 0.133$	Gauss	500 µSv	0.133 x 500 µSv = 66.5 µSv
G	500 µSv	0.04 x 500 µSv = 20 µSv	Gauss	1.0	20 µSv x 1.0 = 20 µSv
G_0	0 µv	$\frac{0.5\,\mu Sv}{\sqrt{3}} = 0.29\,\mu Sv$	Rect.	- 1.0	0.29 µSv x |-1.0| = 0.29 µSv
M	**500 µSv**	**72 µSv** (15 %)			

M = 500 µSv ± 145 µSv (k_{cov} = 2)

IEC 62461: 5.4 Calculation 5/5

Uncertainty budget for the example and **high** level of consideration of workplace conditions

Quantity	Best estimate	Standard uncertainty	Distribution	Sensitivity coefficient	Uncertainty contribution to output quantity
N	1.0	$\frac{0.1}{\sqrt{6}} = 0.041$	Triang.	600 µSv	0.041 x 600 µSv = 24.6 µSv
K	1.2	$\frac{0.2}{3} = 0.067$	Gauss	500 µSv	0.067 x 500 µSv = 33.5 µSv
G	500 µSv	0.04 x 500 µSv = 20 µSv	Gauss	1.2	20 µSv x 1.2 = 24 µSv
G_0	0 µv	$\frac{0.5\,\mu Sv}{\sqrt{3}} = 0.29\,\mu Sv$	Rect.	- 1.2	0.29 µSv x |-1.2| = 0.35 µSv
M	**600 µSv**	**48 µSv** (8 %)			

M = 600 µSv ± 96 µSv (k_{cov} = 2)

The two intervals overlap, thus these results are consistent.

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