Accuracy, Calibration and Type Testing

Examples

[Chapter 6 & 7 of RP 160]

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PTB

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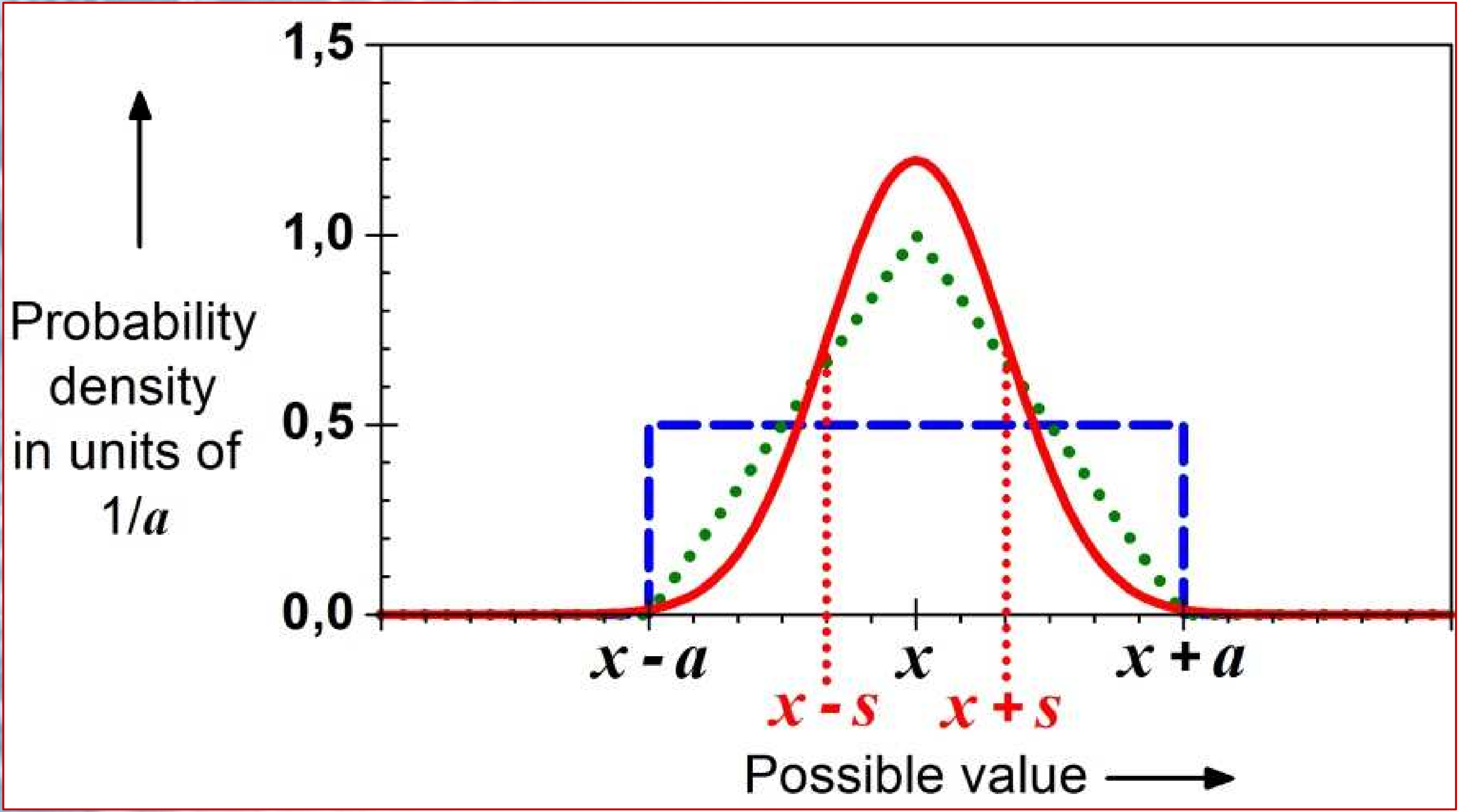
EXCEL sheet: Model function

$$M_{\mathrm{corr}} = N \times k_{E,\varphi} \times k_{\mathrm{lin}} \times (D_{\mathrm{dos}} - D_{\mathrm{zero}})$$

D_{dos}	:= Indiation of the dosemeter in mSv
D_{zero}	:= Deviation due to zero indiation of the dosemeter in mSv
N	:= Calibration factor
$k_{E,\varphi}$	:= Correction factor for rad. energy and direction of rad. incidence
k_{lin}	:= Correction factor for linearity
a	:= Half-width of the interval for possible values of the quantity
s	:= Standard deviation/uncertainty

GUM: Basics of distributions

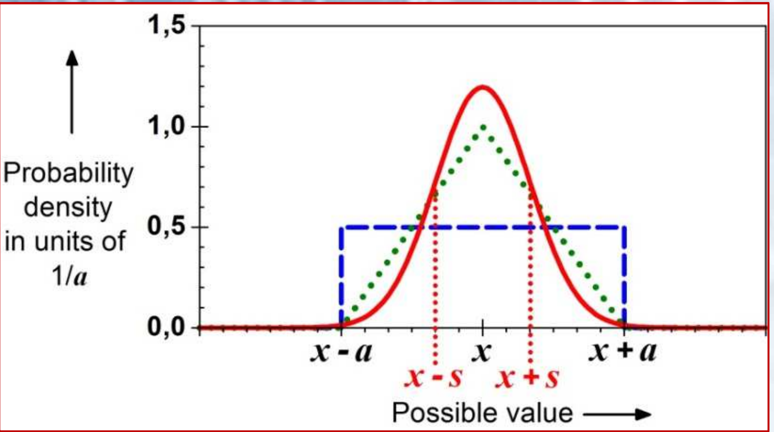


x := Best estimate

a := Half-width of the interval for possible values of the quantity

s := Standard deviation or standard uncertainty

GUM: Distribution → Std. uncertainty s_i



a := Half-width of the interval for possible values of the quantity

u := Standard uncertainty (67 % of all possible values are within the interval from s_- to s_+)

Calculation of standard uncertainty s_i from the half-width a_i

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_+

EXCEL sheet: Absolute std. uncertainty s_i

$$M_{corr} = N \times k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

D21

Quantity	Best estimate	Absolute value of *a* or *s*	Distribution	Absolute std. uncertainty, *s*	Sensitivity coefficient, *c*	Uncertainty contribut., *u*	Rel. uncert. contribution
N	1	0,03	Std. deviation	0,030	5,24 mSv	0,157 mSv	39,7%
$k_{E,\varphi}$	1,08	0,1	Triangular	0,041	4,85 mSv	0,198 mSv	50,0%
k_{lin}	0,97	0,05	Rectangular	0,029	5,40 mSv	0,156 mSv	39,3%
D_{dos}	5 mSv	0,25 mSv	Std. deviation	0,250 mSv	1,05	0,262 mSv	66,1%
D_{zero}	0 mSv	0,02 mSv	Rectangular	0,012 mSv	-1,05	0,012 mSv	3,1%
M_{corr}	5,238 mSv			0,396 mSv			8%

D26 = D21*D22*D23*(D24-D25)

EXCEL sheet: Absolute std. uncertainty s_i

$$M_{corr} = N \times k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

=IF(H22="Rectangular";F22/SQRT(3);
IF(H22="Triangular";F22/SQRT(6);
IF(H22="Gaussian";F22/3;F22)))

F22 H22

Quantity	Best estimate	Absolute value of *a* or *s*	Distribution	Absolute std. uncertainty, *s*	Sensitivity coefficient, *c*	Uncertainty contribut., *u*	Rel. uncert. contribution
N	1	0,03	Std. deviation	0,030	5,24 mSv	0,157 mSv	39,7%
$k_{E,\varphi}$	1,08	0,1	Triangular	0,041	4,85 mSv	0,198 mSv	50,0%
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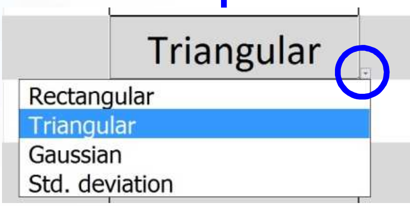
M_{corr}	**5,238 mSv**			**0,396 mSv**			**8%**



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_+

GUM: Sensitivity coefficient c_i

$$M_{corr} = N \times k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

$$c_N = \frac{\partial M_{corr}}{\partial N} = k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

$$c_{k_{E,\varphi}} = \frac{\partial M_{corr}}{\partial k_{E,\varphi}} = N \times k_{lin} \times (D_{dos} - D_{zero})$$

$$c_{k_{lin}} = \frac{\partial M_{corr}}{\partial k_{lin}} = N \times k_{E,\varphi} \times (D_{dos} - D_{zero})$$

$$c_{D_{dos}} = \frac{\partial M_{corr}}{\partial D_{dos}} = -N \times k_{E,\varphi} \times k_{lin}$$

$$c_{D_{zero}} = \frac{\partial M_{corr}}{\partial D_{zero}} = N \times k_{E,\varphi} \times k_{lin}$$

EXCEL sheet: Sensitivity coefficient c_i

$$M_{corr} = N \times k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

$$c_{k_{E,\varphi}} = \frac{\partial M_{corr}}{\partial k_{E,\varphi}} = N \times k_{lin} \times (D_{dos} - D_{zero})$$

D21 D23

=D21*D23*(D24-D25)

Quantity	Best estimate	Absolute value of *a* or *s*	Distribution	Absolute std. uncertainty, *s*	Sensitivity coefficient, *c*	Uncertainty contribut., *u*	Rel. uncert. contribution
N	1	0,03	Std. deviation	0,030	5,24 mSv	0,157 mSv	39,7%
$k_{E,\varphi}$	1,08	0,1	Triangular	0,041	4,85 mSv	0,198 mSv	50,0%
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M_{corr}	5,238 mSv			0,396 mSv			8%

D24 D25

GUM: Uncertainty contribution u_i

$$M_{\text{corr}} = N \times k_{E,\varphi} \times k_{\text{lin}} \times (D_{\text{dos}} - D_{\text{zero}})$$

$$u_N = |c_N \times s_N|$$

$$u_{k_{E,\varphi}} = \left|c_{k_{E,\varphi}} \times s_{k_{E,\varphi}}\right|$$

$$u_{k_{\text{lin}}} = \left|c_{k_{\text{lin}}} \times s_{k_{\text{lin}}}\right|$$

$$u_{D_{\text{dos}}} = \left|c_{D_{\text{dos}}} \times s_{D_{\text{dos}}}\right|$$

$$u_{D_{\text{zero}}} = \left|c_{D_{\text{zero}}} \times s_{D_{\text{zero}}}\right|$$

EXCEL sheet: Uncertainty contribution u_i

$$M_{\text{corr}} = N \times k_{E,\varphi} \times k_{\text{lin}} \times (D_{\text{dos}} - D_{\text{zero}})$$

$$u_{k_{\text{lin}}} = \left| c_{k_{\text{lin}}} \times s_{k_{\text{lin}}} \right|$$

I22 K22 =ABS(I22*K22)

Quantity	Best estimate	Absolute value of *a* or *s*	Distribution	Absolute std. uncertainty, *s*	Sensitivity coefficient, *c*	Uncertainty contribut., *u*	Rel. uncert. contribution
N	1	0,03	Std. deviation	0,030	5,24 mSv	0,157 mSv	39,7%
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M_{corr}	5,238 mSv			0,396 mSv			8%

GUM: Standard uncertainty of $u(M_{corr})$

$$M_{corr} = N \times k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

$$u(M_{corr}) = \sqrt{{u_N}^2 + {u_{k_{E,\varphi}}}^2 + {u_{k_{lin}}}^2 + {u_{D_{dos}}}^2 + {u_{D_{zero}}}^2}$$

EXCEL sheet: Std. uncertainty of $u(M_{corr})$

$$M_{corr} = N \times k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

D21 | M21

Quantity	Best estimate	Absolute value of *a* or *s*	Distribution	Absolute std. uncertainty, *s*	Sensitivity coefficient, *c*	Uncertainty contribut., *u*	Rel. uncert. contribution
N	1	0,03	Std. deviation	0,030	5,24 mSv	0,157 mSv	39,7%
$k_{E,\varphi}$	1,08	0,1	Triangular	0,041	4,85 mSv	0,198 mSv	50,0%
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M_{corr}	5,238 mSv			0,396 mSv			8%

D24 | M25

=D21*D22*D23*(D24-D25)

=SQRT(M21*M21+M22*M22+M23*M23+M24*M24+M25*M25)

$$u(M_{corr}) = \sqrt{u_N{}^2 + u_{k_{E,\varphi}}{}^2 + u_{k_{lin}}{}^2 + u_{D_{dos}}{}^2 + u_{D_{zero}}{}^2}$$

Example 1: Dosemeter shown yesterday

- **Model function for external correction**

$$M_{\mathrm{corr}} = N \times k_{\mathrm{lin}} \times k_{E,\varphi} \times (D_{\mathrm{dos}} - D_{\mathrm{zero}})$$

see also **IEC TR 62461:2015-01**
Radiation protection instrumentation – Determination of uncertainty in measurement

M_{corr} = 5.0 mSv ± 1.7 mSv
(k = 2)
(within rated ranges)

- **No information/consideration of workplace conditions**
  - take value of indication D_{dos} (= 5 mSv)
  - assume D_{zero} = 0 mSv and $k_{E,\varphi} = k_{\mathrm{lin}} = N = 1.0$

  ➔ $M_{\mathrm{corr}} = D_{\mathrm{dos}}$

- **Perform uncertainty calculation**
  - take values of standard uncertainties of D_{dos} ; D_{zero} ; $k_{E,\varphi}$; k_{lin} and N from type test results for entire rated range

Example 1: Dosemeter shown yesterday

➢ Model function for external correction

$$M_{\text{corr}} = N \times k_{\text{lin}} \times k_{E,\varphi} \times (D_{\text{dos}} - D_{\text{zero}})$$

No information/consideration of workplace conditions

- $N = 1.0$; $s_N = 3\ \%$ (Standard uncertainty; std. deviation)
- $k_{E,\varphi} = 1.0$; $a_{E,\varphi} = 0.4$ (Gaussian distribution)
- $k_{\text{lin}} = 1.0$; $a_{\text{lin}} = 0.15$ (Rectangular distribution)
- $D_{\text{dos}} = 5$ mSv ; $s_{\text{dos}} = 5\ \%$ (Standard deviation)
- $D_{\text{zero}} = 0$ mSv ; $a_{\text{zero}} = 20\ \mu$Sv (Rectangular distribution)

M_{corr} = 5.0 mSv ± 1.7 mSv
(k = 2)
(within rated ranges)

➢ Compare with your EXCEL sheet result

Example 1: Dosemeter shown yesterday

- **Model function for external correction**

$$M_{corr} = N \times k_{lin} \times k_{E,\varphi} \times (D_{dos} - D_{zero})$$

see also **IEC TR 62461:2015-01**
Radiation protection instrumentation – Determination of uncertainty in measurement

M_{corr} = 5.2 mSv ± 0.8 mSv
(k = 2)
(X-rays, $k_{E,\varphi} = 1.08$
$k_{lin} = 0.97$)

- **Use (Consider) information of workplace conditions**
  - take value of indication D_{dos} (= 5 mSv)
  - take values of D_{zero} = 0 mSv; $k_{E,\varphi}$ = 1.08; k_{lin} =0.97 and N = 1.0 for workplace conditions and this measurement
  ➔ $M_{corr} = 1.048 \times D_{dos}$
- **Perform uncertainty calculation**
  - take values of standard uncertainties of D_{dos} ; D_{zero} ; $k_{E,\varphi}$; k_{lin} and N from type test results for workplace conditions and this measurement

Example 1: Dosemeter shown yesterday

➢ Model function for external correction

$$M_{corr} = N \times k_{lin} \times k_{E,\varphi} \times (D_{dos} - D_{zero})$$

Use (Consider) information of workplace conditions

- $N = 1.0$; $s_N = 3$ % (Standard uncertainty; std. deviation)
- $k_{E,\varphi} = 1.08$; $a_{E,\varphi} = 0.1$ (Triangular distribution)
- $k_{lin} = 0.97$; $a_{lin} = 0.05$ (Rectangular distribution)
- $D_{dos} = 5$ mSv ; $s_{dos} = 5$ % (Standard deviation)
- $D_{zero} = 0$ mSv ; $a_{zero} = 20$ µSv (Rectangular distribution)

$M_{corr} = 5.2$ mSv ± 0.8 mSv

($k = 2$)

(X-rays, $k_{E,\varphi} = 1.08$

$k_{lin} = 0.97$)

➢ Compare with your EXCEL sheet result

Example 2: Active area dosemeter

IEC 60846-1

Edition 1.0 2009-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Radiation protection instrumentation – Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation – Part 1: Portable workplace and environmental meters and monitors

- Portable dose equivalent rate meter according to IEC 60846-1:2009
- Dosemeter just fulfills minimal requirements for all influence quantities

Example 2: Requirements of IEC 60846-1

Table 6 (excerpt) – Radiation characteristics of ambient dose equivalent (rate) meters

Characteristic under test or influence quantity	(Minimum) rated range of influence quantity	Limits of variation of the relative response
Linearity	Three orders of magnitude including 10 µSv h^{-1} and 100 µSv	– 15 % to + 22 %
Statistical fluctuation: dose equivalent rate	$\dot{H} < \dot{H}_0$ [a] $\dot{H}_0 \leq \dot{H} < 11\ \dot{H}_0$ $\dot{H} \geq 11\ \dot{H}_0$	15 % (16 –$\dot{H}/\dot{H}_0$) % 5 %
X and gamma radiation energy and angle of incidence	80 keV to 1,5 MeV or 20 keV to 150 keV and 0° to ± 45° from reference direction	– 29 % to + 67 %

[a] H_0 and $\dot{H}_0$ are the lower limits of the measuring range of dose equivalent and dose equivalent rate.
[b] At least maximum value of measuring range of dose rate.

Example 2: Calc. of *a* or *s* and distribution

Table 6 (excerpt) – Radiation characteristics of ambient dose equivalent (rate) meters

Characteristic under test or influence quantity	(Minimum) rated range of influence quantity	Limits of variation of the relative response	Absolute *a* or *s* value	Distribution
Linearity	Three orders of magnitude including 10 μSv h^{-1} and 100 μSv	– 15 % to + 22 %	1/0.85 = 1.18 1/1.22 = 0.82 ➔ *a* = 0.18	
Statistical fluctuation: dose equivalent rate	$\dot{H} < \dot{H}_0$ [a] $\dot{H}_0 \leq \dot{H} < 11\ \dot{H}_0$ $\dot{H} \geq 11\ \dot{H}_0$	15 % (16 – $\dot{H}/\dot{H}_0$) % 5 %	$\dot{H}_0$ = 0.1 mSv/h and $\dot{H}$ = 0.3 mSv/h ➔ s_{rel} = 13 % ➔ *s* = 0.039 mSv/h	
X and gamma radiation energy and angle of incidence	80 keV to 1,5 MeV or 20 keV to 150 keV and 0° to ± 45° from reference direction	– 29 % to + 67 %	1/0.71 = 1.4 1/1.67 = 0.6 ➔ *a* = 0.40	

[a] H_0 and $\dot{H}_0$ are the lower limits of the measuring range of dose equivalent and dose equivalent rate.

[b] At least maximum value of measuring range of dose rate.

Example 2: Calc. of *a* or *s* and distribution

Table 6 (excerpt) – Radiation characteristics of ambient dose equivalent (rate) meters

Characteristic under test or influence quantity	(Minimum) rated range of influence quantity	Limits of variation of the relative response	Absolute *a* or *s* value	Distribution
Linearity	Three orders of magnitude including 10 µSv h^{-1} and 100 µSv	– 15 % to + 22 %	1/0.85 = 1.18 1/1.22 = 0.82 ➔ a = 0.18	Rectangular
Statistical fluctuation: dose equivalent rate	$\dot{H} < \dot{H}_0$ [a] $\dot{H}_0 \leq \dot{H} < 11\ \dot{H}_0$ $\dot{H} \geq 11\ \dot{H}_0$	15 % $(16 - \dot{H}/\dot{H}_0)$ % 5 %	$\dot{H}_0$ = 0.1 mSv/h and $\dot{H}$ = 0.3 mSv/h ➔ s_{rel} = 13 % ➔ s = 0.039 mSv/h	Std. deviation
X and gamma radiation energy and angle of incidence	80 keV to 1,5 MeV or 20 keV to 150 keV and 0° to ± 45° from reference direction	– 29 % to + 67 %	1/0.71 = 1.4 1/1.67 = 0.6 ➔ a = 0.40	Triangular

[a] H_0 and $\dot{H}_0$ are the lower limits of the measuring range of dose equivalent and dose equivalent rate.
[b] At least maximum value of measuring range of dose rate.

Calibration factor $N = 1.0$, $s_N = 0.06$

Example 2: Calc. of uncertainty (EXCEL)

$$M_{corr} = N \times k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

Quantity	Best estimate		Absolute value of *a* or *s*		Distribution	Absolute std. uncertainty, *s*		Sensitivity coefficient, *c*		Uncertainty contribut., *u*		Rel. uncert. contributio
N	1		0,06		Std. deviation	0,060		0,30	mSv	0,018	mSv	24,6%
$k_{E,\varphi}$	1		0,4		Triangular	0,163		0,30	mSv	0,049	mSv	67,0%
k_{lin}	1		0,18		Rectangular	0,104		0,30	mSv	0,031	mSv	42,6%
D_{dos}	0,3	mSv	0,039	mSv	Std. deviation	0,039	mSv	1,00		0,039	mSv	53,3%
D_{zero}	0	mSv	0,02	mSv	Rectangular	0,012	mSv	-1,00		0,012	mSv	15,8%
M_{corr}	**0,3**	**mSv**				**0,073**	**mSv**					**24%**

$\dot{H}_{corr}$ = (0.3 ± 0.15) mv/h ➔ 0.15 mSv/h ≤ $\dot{H}_{corr}$ ≤ 0.45 mSv/h

The uncertainty stated is the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the coverage factor *k* = 2. It has been determined in accordance with the “Guide to the Expression of Uncertainty in Measurement (GUM)”. The value of the measurand then normally lies, with a probability of approximately 95 %, within the attributed coverage interval.

Example 3: Your dosimetry system

$$M_{corr} = N \times k_{E,\varphi} \times k_{lin} \times (D_{dos} - D_{zero})$$

Quantity	Best estimate	Absolute value of *a* or *s*	Distribution	Absolute std. uncertainty, *s*	Sensitivity coefficient, *c*	Uncertainty contribut., *u*	Rel. uncert. contributio
N	1	0,06	Std. deviation	0,060	0,30 mSv	0,018 mSv	24,6%
$k_{E,\varphi}$	1	0,4	Triangular	0,163	0,30 mSv	0,049 mSv	67,0%
k_{lin}	1	0,18	Rectangular	0,104	0,30 mSv	0,031 mSv	42,6%
D_{dos}	0,3 mSv	0,039 mSv	Std. deviation	0,039 mSv	1,00	0,039 mSv	53,3%
D_{zero}	0 mSv	0,02 mSv	Rectangular	0,012 mSv	-1,00	0,012 mSv	15,8%
M_{corr}	0,3 mSv			0,073 mSv			24%

M_{corr} = (   ) mSv

The uncertainty stated is the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the coverage factor k = 2. It has been determined in accordance with the “Guide to the Expression of Uncertainty in Measurement (GUM)”. The value of the measurand then normally lies, with a probability of approximately 95 %, within the attributed coverage interval.

You should now know

- The model function of the dosemeter is the key element of any measurement
- The knowledge influences not only the uncertainty but also the best estimate of the measurement
- For dosemeters fulfilling International Standards their maximum uncertainty can be calculated without additional knowledge

Thank you for your attention

Questions ??

EURADOS

Physikalisch-Technische Bundesanstalt

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