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Calculation of the detection limits by explicit expressions

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Content

With the detection limit we express the smallest true value of the measurand, which can be detected with a predefined probability. It is calculated by [1]

$y\# = y^* + k1\text{-}\beta \cdot u(y\#)$, (1)

where k1-β denotes the quantile of the standardized normal distribution corresponding to the predefined probability β and y* the decision threshold, i.e the value of the measurand for which when exceeded the probability, that the true value of the measurand is zero, is less than a predefined probability α

$y^* = k1\text{-}\alpha \cdot u(0)$. (2)

Here u(0) denotes the null-measurement uncertainty, i.e. the uncertainty of the observed value of the measurand equal to zero. The equation (1) is an implicit equation, which can be, in general, solved by iteration [1].

In radiation measurements the measuring function is [1]

$y = w \cdot nn$, (3)

where nn is the net indication and w denotes the conversion factor converting the net indication into the observed value of the measurand. Since

$u(y)^2 = w^2 \cdot u(nn)^2 + nn^2 \cdot u(w)^2$, (4)

it follows from equation (1)

$nn\# = nn^* + k1\text{-}\beta' \cdot u(nn\#)$, (5)

where nn# and nn* are the indications corresponding to the detection limit and the decision threshold and k1-β' denotes

$k1\text{-}\beta'^2 = k1\text{-}\beta^2 \cdot [1 + u(w)^2/w^2 \cdot nn\#^2/u(nn\#)^2]$. (6)

This quantile corresponds to the probability β' of the indication, which takes into account the uncertainty of the conversion factor and in Eq. (5) replaces the quantile corresponding to the predefined probability β. It is obvious from the Eq. (6) that the quantile in the net indication is proportional to the quantile in the measurand and that the factor of proportionality is given by the relative uncertainties of the conversion factor and the indication corresponding to the detection limit.

It is clear that also Eq. (6) presents an implicit equation for k1-β', since the relative uncertainty nn#/u(nn#) depends on it. However, in case when the uncertainty of the background dominates the uncertainty budget of the net indication, the uncertainty of the net indication does not depend on the value of the net indication, i.e. u(nn=0) = u(nn#). Then Eq. (6) simplifies to

$k1\text{-}\beta'^2 = k1\text{-}\beta^2 \cdot [1 + u(w)^2/w^2 \cdot (k1\text{-}\alpha + k1\text{-}\beta')^2]$, (7)

from where

$k1\text{-}\beta' = [k1\text{-}\beta^2 \cdot k1\text{-}\alpha \cdot u(w)^2/w^2 + k1\text{-}\beta \cdot \mathrm{sqrt}(1 + (k1\text{-}\alpha^2 - k1\text{-}\beta^2) u(w)^2/w^2)] / (1 - k1\text{-}\beta^2 \cdot u(w)^2/w^2)$ (8)

follows. Then, according to Eqs. (3) and (5), the detection limit is

$y\# = w \cdot u(nn=0) \cdot (k1\text{-}\alpha + k1\text{-}\beta')$. (9)

Eq. (9) shows that in the case when the uncertainty of the background dominates in the uncertainty budget of the net indication, the decision threshold could be expressed in a closed form. In the contribution numerical examples of calculation of decision threshold for various relative uncertainties of the indication will be presented. It will be demonstrated that the described method is useful when the uncertainty of the conversion factor is large, because then the successive approximations yielded by the iteration process slowly converge. When the series of successive approximations does not converge, i.e. when $u(w)/w > 1/k1\text{-}\beta$, also Eq. (8) yields a negative value for k1-β', which can't be interpreted statistically.

Reference: [1] ISO 11929(2010): Determination of the characteristic limits (decision threshold, detection limit and limits of the confidence interval) for measurements of ionizing radiation – Fundamentals and application, ISO, 2010.

About the Presenter

Matjaz Korun:
Since 35 years I am engaged in gamma-ray spectrometric measurements of environmental samples. During this time I developed gamma-ray spectrometers with the aim of decreasing the detection limits. I developed also methods for efficiency calculations, coincidence summing corrections, characterization of backgrounds and calculations of decision thresholds and detection limits. In the field of quality assurance I was active in the areas where the metrological approach is relevant: traceability of results, calculation of characteristic limits, assessment of uncertainties, assessment of correlation coefficients and assessment of reliability of peak analysis results. In last years the focus of my research is on the reliability of measurement outcomes near the decision threshold. In this field I have published 15 articles in last four years. My motivation for this work is to decrease the systematic influences on the doses, assessed from gamma-ray spectrometric results of environmental samples, where the outcomes near the decision threshold are abundant.

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