Implementing combined uncertainty according to ISO/GUM into a commercial gamma spectrometric software

FOI Umeå & SSM:

H. Ramebäck, A. Tovedal, U. Nygren, P. Lagerkvist, J. Boson, E. Johansson, J. Johansson

NKS/GammaSem Sep. 2009

or

How we forced ISO/GUM into GammaVision!

Why measurement uncertainty?

- Decisions are often based on measurements
- Therefore, measurement results need a quality statement
- **The measurement uncertainty is this quality statement!**
- Keep the traceability chain
- But, uncertainty calculations on individual measurements cannot be applied in routine situations!

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Why measurement uncertainty?

- Bad uncertainty estimations may leed to wrong decisions…
- …because too much, or too low, trust will be assigned to a measurement result
- The uncertainty estimation shall not be over- or underestimated!

Uncertainty sources in gamma spectrometry

- Counting statistics
- Calibrations
- Geometry
- (Mass meaurements)
- Physical data
- (Sampling)
- (Chemical yields)
- Corrections: coincidence summing, decay, density correction, volume, etc.

Uncertainty sources

- For a fixed calibrated measurement system all input quantities are constant beside the uncertainty in the measured signal
- We can therefore beforehand model our measurement system with respect to measurement uncertainty
- The combined uncertainty of any measurement on a particular sytem will then consist of the uncertainty in the signal (**Type A**) and the combined uncertainty of all other input quantities (**Type B**)

The measurement model

The measurand *A* [Bq/kg] is calculated from a set of equations, the measurement model:

$$A = \frac{R_E - R_{BG.E}}{\Psi_{E2} \cdot \gamma_E \cdot m_{sample}}$$

$$R_E = {}^{N_E}\!\big/\!{}_{t_{LT}}$$

$$R_{BG.E} = {}^{N_{BG.E}}\!\big/\!{}_{t_{LT.BG}}$$

GV polynomial: $\Psi_E = \exp(a_1 \cdot E^1 + a_2 \cdot E^0 + a_3 \cdot E^{-1} + a_4 \cdot E^{-2} + a_5 \cdot E^{-3} + a_6 \cdot E^{-4})$

$$\Psi_{E2} = \Psi_E \cdot k_{Source} \cdot k_{Fit} \cdot k_{Geo.reporo} \cdot k_\rho \cdot k_V \cdot \prod k_i$$

k_i: Any additional uncertainty source arising from e.g. decay correction, counting loss for coincidence summing etc.

Input quantities (Example: Cs-137)

Input quantity	**Value**	**Standard uncertainty u_i**	**Explanation**
m_{Sample}	0.0600 kg	0.000001 kg	From balance certificate, rectangular distribution (**Type B**)
N_{E}	*Varied*	*Varied*	Poisson statistics (**Type A**)
N_{BGE}	19	47	From background measurement (**Type A or B**)
t_{LT}	1000 s	0 s	From GEDCKE (**Type B**)
t_{LTBG}	250000 s	0 s	From GEDCKE (**Type B**)
γ_{E}	0.85100	0.00116	From ENSDF (**Type B**)
Ψ_{E}	0.02079	--	From the calibration
k_{Fit}	1.000	0.008	From the calibration (**Type B**)
k_{Source}	1.000	0.015	From the calibration certificate (**Type B**)
$k_{\mathrm{Geo.repro}}$	1.000	0.018	Evaluated from repeated measurements (**Type B**)

Results

- **Two extreme situations:**
  -The uncertainty in the measured signal is low (<1-2%)# ➔Uncertainty limited by other input quantities, e.g. calibration
  -The uncertainty in the measured signal is high (>3-4%)# ➔Uncertainty is limited by counting statistics in the actual measurement.

#*For the detector system studied in this work! Will depend on calibration and geometry related uncertainties.*

Result: Uncertainty budgets

The uncertainty budget reveals the contribution from the different input quantities to the combined uncertainty.
➔Important tool if uncertainty needs to be lowered!

Measure longer!
Perform new calibration and/or improve geometry!

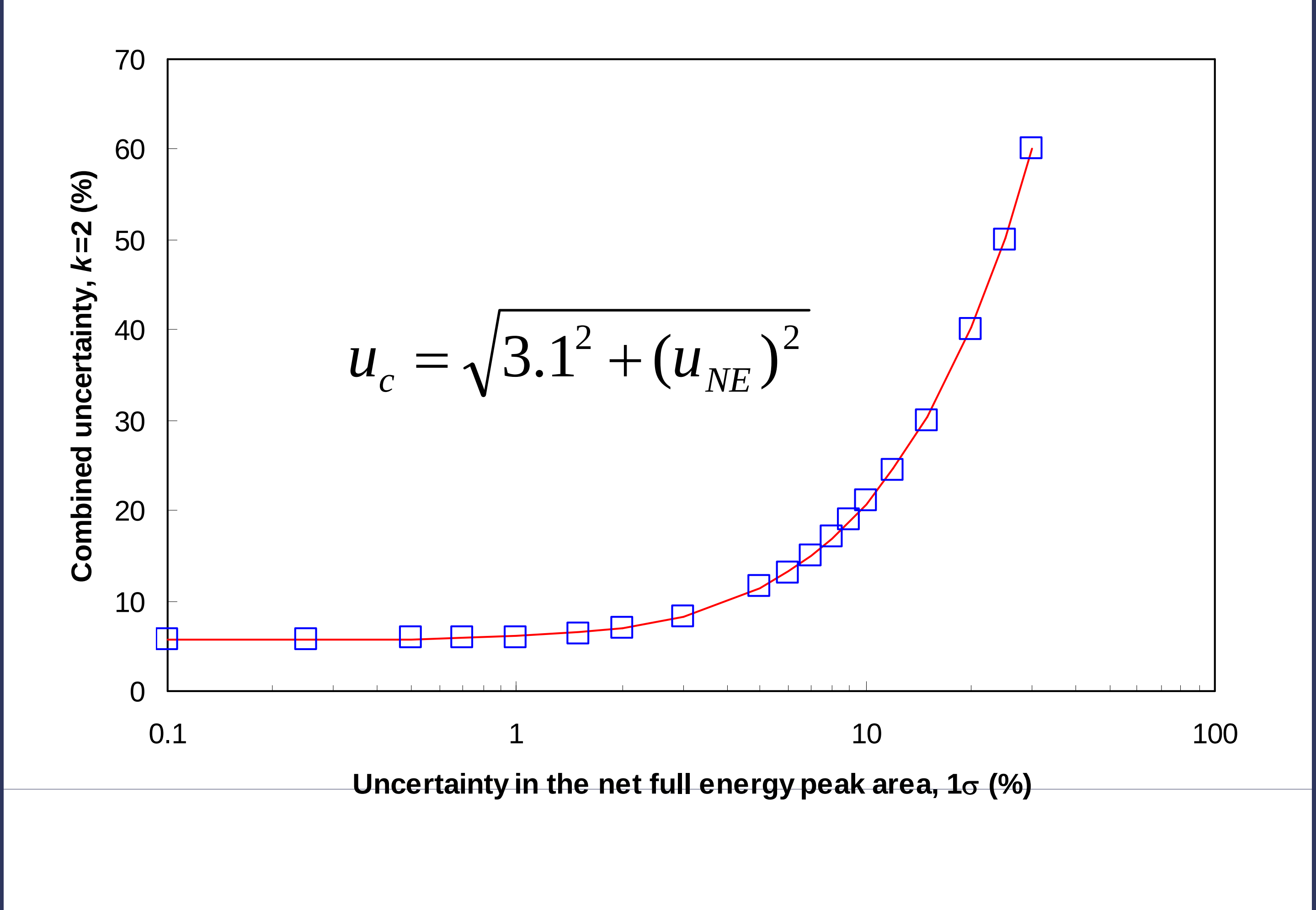
I. Limited by counting statistics (Type A, 5% unc):

Input quantity	**Variance contribution**
m_{Sample}	0.0 %
γ_{E}	0.0 %
N_{E}	80.3 %
t_{LT}	0.0 %
N_{EBG}	0.0 %
t_{LTBG}	0.0 %
k_{Fit}	2.1 %
k_{source}	7.2 %
k_{geom}	10.4 %

II. Limited by Type B sources:

Input quantity	**Variance contribution**
m_{Sample}	0.0 %
γ_{E}	0.3 %
N_{E}	0 %
t_{LT}	0.0 %
N_{EBG}	0.0 %
t_{LTBG}	0.0 %
k_{Fit}	10.4 %
k_{source}	36.6%
k_{geom}	52.7%

Results: Uncertainty modelling



$$u_c = \sqrt{3.1^2 + (u_{NE})^2}$$

Result: Implementation

- **Some of the uncertainty sources considered in Gammavision 6.01:**
  -Counting (sample, not PBC!)
  -Physical data (if correct in library)
  -Fitting of efficiency function
  -Calibration source (measurement standard)
  Beware!!!
- **Additonal? Identify and evaluate the magnitude of additional uncertainties!**

Result: Implementation

- Evaluate a measurement using Gammavision with an additional uncertainty set to zero!
- Evaluate the combined uncertainty ”off-line” according to ISO/GUM
- The difference can then by brought into Gammavision as an additional uncertainty!

$$u_{c.GUM} = \sqrt{u_{c.GV}^{2} + u_{add}^{2}}$$

- In the example an additional uncertainty of 2.5% (*k*=1) should be introduced into Gammavision

Conclusions

- *Of course*: The uncertainty is an important part of the measurement result!
- For a few measurements the uncertainty calculation can be individually calculated. This is hard in routine situations.
- Here, we have presented a method which, at the end, gives ISO/GUM-compliant uncertainty statements in the measurement report from a measurement system!
- The measurement model has proved to be *fit-for-purpose* in proficiency tests, i.e. the measurement is under statistical control!

Thank you for your attention!