

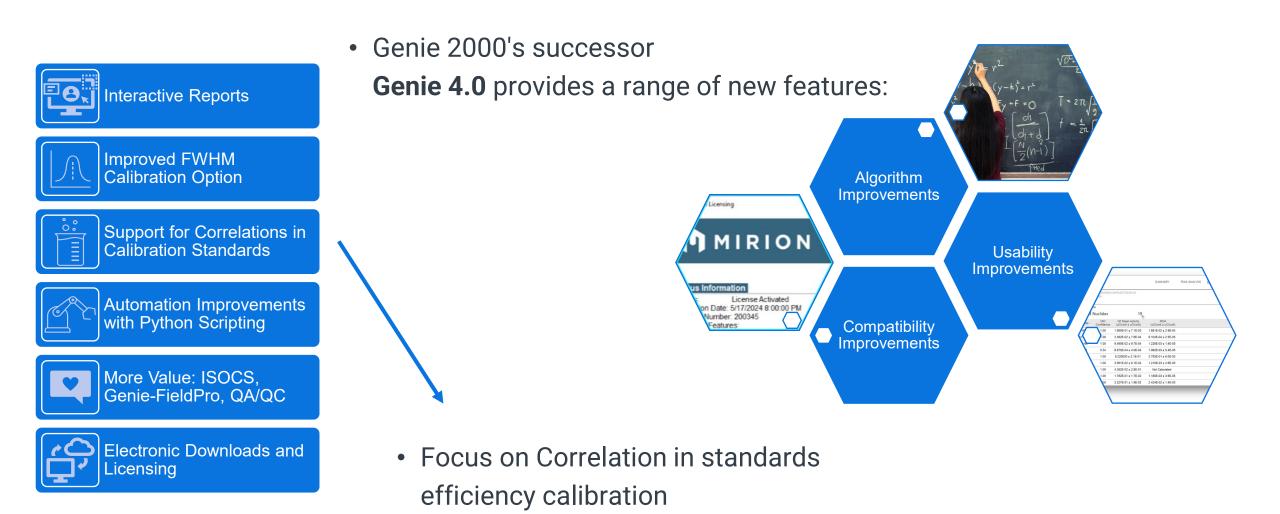
Improving the accuracy of uncertainty calculations with Genie 4.0

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28 September 2023 Helsinki



Genie 4.0 Introduction



Genie 2000 / Genie 4.0

Uncertainty management

- Efficiency calibration Uncertainty
 - Certificate used
 - Rate uncertainty •

(combine Abundance uncertainty and Nuclide Activity Uncertainty)

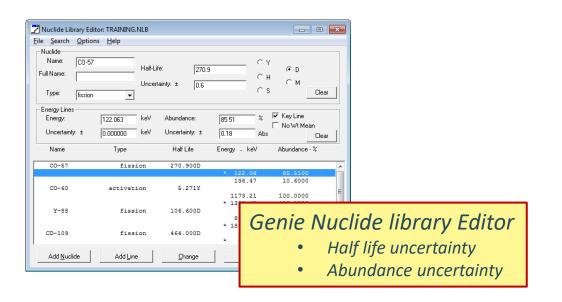
Net peak area



Quantity: 1 unit(s) Assay date: 1/1/2011 at 120000 Disjinal Certificate Bit	
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CO-60 1173.210 6303.0000 4.0000 5.27	
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106.66	0
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Genie Certificate Editor	
Activity uncertainty for k=1	
V_{CT}	

Activity Uncertainty

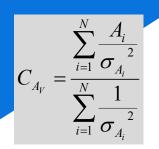
- Net peak area •
- Efficiency
- Energy line Abundance
- Nuclide Half life •
- Sample quantity
- Random (facultative) ۰
- Systematic (facultative) ۲



Genie 2000 /Genie 4.0

Uncertainty management

Activity



Formula used for Weighted mean Activity Multi-line nuclide

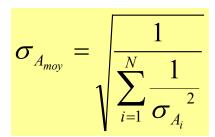
• The calculation of the uncertainty on the activity is given by the following formula

$$\sigma_{C} = C \cdot \sqrt{\left(\frac{\sigma_{R}}{100}\right)^{2} + \left(\frac{\sigma_{S}}{S}\right)^{2} + \left(\frac{\sigma_{V}}{V}\right)^{2} + \left(\frac{\sigma_{\varepsilon}}{\varepsilon}\right)^{2} + \left(\frac{\sigma_{y}}{y}\right)^{2} + \left(\frac{\sigma_{K}}{K}\right)^{2}}$$

Where
$$C = \frac{S}{V.\varepsilon.y.T_1.K_C.K_W}$$

$$\sigma_R$$
: Random uncertainty

- σ_s : Net peak area uncertainty
- σ_V : Sample quantity uncertainty
- σ_{ε} : Efficiency uncertainty
- σ_y : peak Abundance Uncertainty
- $\sigma_{\scriptscriptstyle K}\,$: Nuclide Half life Uncertainty
- The uncertainty calculated for the nuclide average activity will be given by the formula



Genie 2000 / Genie 4.0

Uncertainty management

ISO 11929 MDA

ISO11929 MDA formula, where measurement Uncertainty

is part of MDA calculation

ISO11929 formula for decision threshold

$$c_A^* = k_{1-\alpha} \cdot \frac{w}{t_g} \sqrt{n_{b, E} + u^2_{(nb, E)}}$$

ISO11929 MDA formula

 $c_{A}^{\#} = \frac{2.c_{A}^{*} + (k^{2}.w) / t_{g}}{1 - k^{2}.u_{rel}^{2}(w)}$

Detection Limit (MDA)

Measurement uncertainty

Decision thresold

 $c_A^{\#}$

 c^*_A

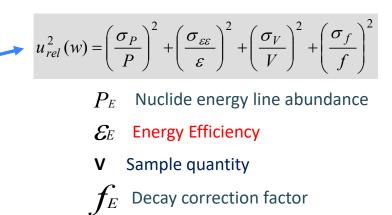
 $u_{rel}^2(w)$

$$w = \frac{1}{P_{E}.\varepsilon_{E}.V.f_{E}}$$

Where:

*	
\mathcal{C}_A	Decision threshold
k_{1-lpha}	Confidence factor
	1.645 for 95%, 1.96 for 97.5%
$n_{b, E}$	Integral of the region
$u^{2}_{(n_{b}, E)}$	Integral Uncertainty
t_{g}	Active count time

Where:



Correlations in Calibration Standards

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Support for Correlations in Calibration Standards



Automation Improvements w Python Scripting

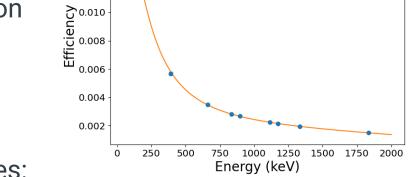


More Value: ISOCS Genie-Fieldpro, QA



Electronic Download and Licensing

- The uncertainty in an efficiency calibration is propagated to the uncertainty of the unknown sample activity.
- Uncertainty propagation is different for correlated values than independent values:



0.016

0.014

0.012

Efficiency calibration

Fit Tit Data

- Generally additional independent measurements improve the knowledge of the detector efficiency response, driving down the final activity uncertainty.
- Additional fully-correlated measurements *do not* improve the knowledge of the detector efficiency response, and the final activity uncertainty may be higher than with values treated independently.
- Uncertainty propagation and management is a topic of focus by regulators and the scientific community

Correlations in Calibration Standards



Improved FW/HM

Calibration Optio



Support for Correlations in Calibration Standards

mprovements wi Python Scripting

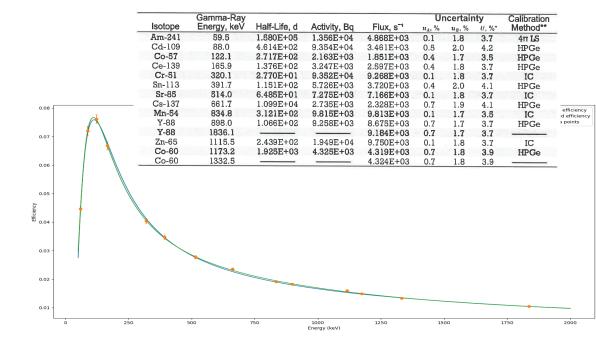
More Value: ISOCS, Genie-Fieldpro, QA/0



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Definitions:

- Two vales are "correlated" if there is a relationship between the measurements
- Two values are independent if there is no information gained



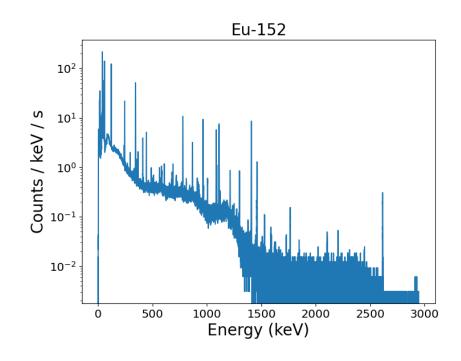
about one measurement from the other measurement

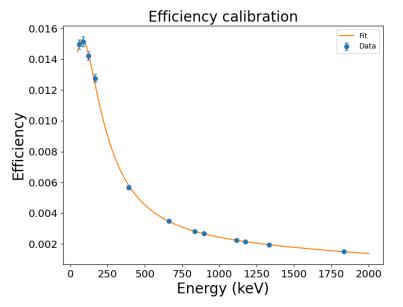
In our application:

- In Gamma Spectroscopy and Efficiency Calibrations, the item being "measured" is the true efficiency of the detector at various energies.
- The measurement values are the calculated "efficiency triplets" from the emission lines of the calibration standard.

Genie 4.0 Correlation improvement Introduction

- For high precision gamma spectrometry, the uncertainty from efficiency calibration is often dominating
- Quantities in gamma spectrometry can be determined using multiple measurements
 - Efficiency as a function of Energy, weighted mean activity of radionuclides
- When these measurements are independent the uncertainty is reduced when more measurements are added
- This leads to uncertainties from the efficiency fit to be lower than the uncertainty of the individual points unless correlations between data points are accounted for



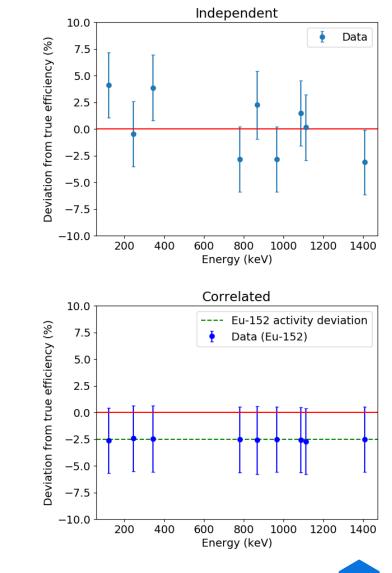


Genie 4.0 Correlation

- Correlations are relations in data that varies together in a way not expected from chance alone
- The emission rate for lines from a multiline radionuclide
- Changes the least squares fit

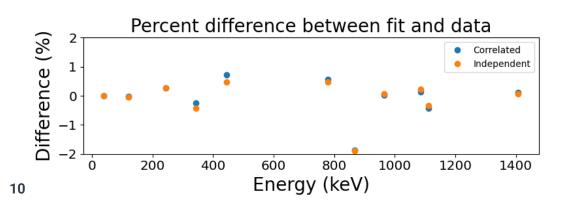
$$\chi^{2} = \sum_{i=1}^{n} \frac{(y_{i} - f(x))^{2}}{\sigma_{y_{i}}^{2}} \to \chi^{2} = (y - f(x))^{T} V^{-1} (y - f(x))$$

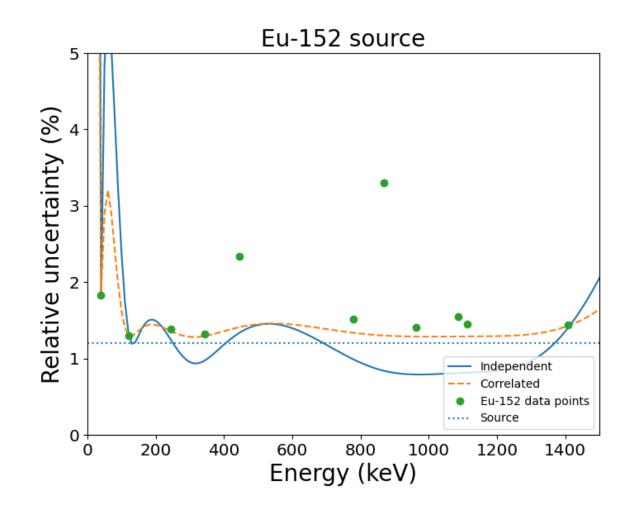
- This has consequences for efficiency calibration, weighted mean activity and interference correction of activities*
- But also for MDA ISO11929 calculation



Example 1 - Single radionuclide calibration

- Eu-152 calibration
 - Point source at 30 cm
 - 20% rel eff p-type detector
 - Multiple emission lines with correlation from the radionuclide activity
- Activity has a relative uncertainty of 3.1% at 99% CL

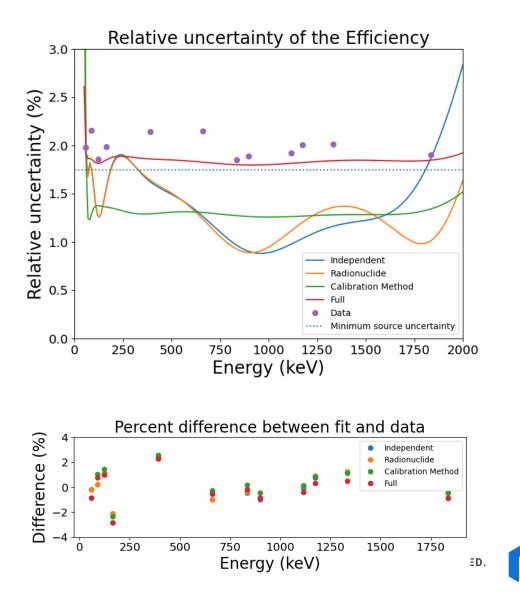




Example 2 - Mixed gamma source

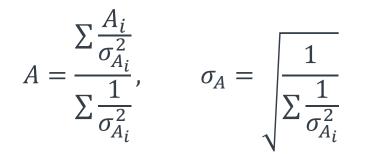
- Multi-radionuclide calibration source
- The level of correlation depends on the assumptions
 - All points independent
 - · Points from same radionuclide correlated
 - Points using the same calibration method correlated
 - All points correlated
- For the most conservative assumption the relative uncertainty will be slightly above the lowest relative uncertainty from the certificate.

	Gamma-Ray				Ur	certair	nty	Calibration
Isotope	Energy, keV	Half-Life, d	Activity, Bq	Flux, s⁻¹	$u_A, \%$	$u_B, \%$	U, %*	Method**
Am-241	59.5	1.580E+05	1.358E+04	4.875E+03	0.1	1.8	3.7	4π LS
Cd-109	88.0	4.614E+02	9.367E+04	3.466E+03	0.5	2.0	4.2	HPGe
Co-57	122.1	2.717E+02	2.165E+03	1.854E+03	0.4	1.7	3.5	HPGe
Ce-139	165.9	1.376E+02	3.251E+03	2.601E+03	0.4	1.8	3.7	HPGe
Cr-51	320.1	2.770E+01	9.365E+04	9.281E+03	0.1	1.8	3.7	IC
Sn-113	391.7	1.151E+02	5.733E+03	3.725E+03	0.4	2.0	4.1	HPGe
Sr-85	514.0	6.485E+01	7.285E+03	7.175E+03	0.1	1.8	3.7	IC
Cs-137	661.7	1.099E+04	2.739E+03	2.331E+03	0.7	1.9	4.1	HPGe
Mn-54	834.8	3.121E+02	9.828E+03	9.826E+03	0.1	1.7	3.5	IC
Y-88	898.0	1.066E+02	9.270E+03	8.686E+03	0.7	1.7	3.7	HPGe
Y-88	1836.1			9.196E+03	0.7	1.7	3.7	-
Zn-65	1115.5	2.439E+02	1.951E+04	9.763E+03	0.1	1.8	3.7	IC
Co-60	1173.2	1.925E+03	4.331E+03	4.324E+03	0.7	1.8	3.9	HPGe
Co-60	1332.5	<u> </u>		4.330E+03	0.7	1.8	3.9	



Weighted mean activity

• Independent weighted mean



• New Correlated weighted mean algo

$$A = \frac{\sum_{i,j} V_{ij}^{-1} A_j}{\sum_{i,j} V_{ij}^{-1}}, \qquad \sigma_A = \sqrt{\frac{1}{\sum_{i,j} V_{ij}^{-1}}}$$

From covariance matrix
$$V = \begin{pmatrix} \frac{\sigma_{\varepsilon_1}^2}{\varepsilon_1^2} & \dots & V_{1n} \\ \dots & \dots & \dots \\ V_{n1} & \dots & \frac{\sigma_{\varepsilon_n}^2}{\varepsilon_n^2} \end{pmatrix}$$

Energy (keV)	Eff:Corr WtM:Corr	Eff:Corr WtM:Indep	Eff:Indep WtM:Corr	Eff:Indep WtM:Indep
121.8	1.39 %	1.39 %	1.39 %	1.39 %
244.7	1.52 %	1.52 %	1.42 %	1.42 %
344.3	1.41 %	1.41 %	1.12 %	1.12 %
444.0	2.47 %	2.47 %	2.43 %	2.43 %
778.9	1.62 %	1.62 %	1.35 %	1.35 %
867.4	3.33 %	3.33 %	3.18 %	3.18 %
964.1	1.48 %	1.48 %	1.08 %	1.08 %
1085.9	1.62 %	1.62 %	1.27 %	1.27 %
1112.1	1.52 %	1.52 %	1.15 %	1.15 %
1408.0	1.63 %	1.63 %	1.61 %	1.61 %
Wt Mean	1.25 %	0.52 %	0.55 %	0.44 %

Relative uncertainty of Eu-152 source 1.20 %

Correlations are supported in Genie 4.0

• Primary User Focus: Updated

Certificate File Editor (see right).

This is where the user defines how the calibration source standard emission lines are correlated.

• Transparent for the user

Genie algorithms updated for efficiency calibration fits and nuclide identification with interference correction engine (now called w/ Correlations") "NID

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Use for C Nuclide CD-109 CO-57 CE-139 HG-203	alib/Init Activity (Bq) 14247.100 1068.310 690.209 2134.180	Unce %Uncert 3.023 1.700 4.000 2.495	rtainty: Energy (keV) 88.034 122.061 165.853 279.197	100 decays) 3.6100 85.9000 79.8860 81.4600	0.1 Uncertainty (per 100) 0.1000 1.2000 0.0150 0.1300	& Uncert Rate (s ⁻¹ unit ⁻¹) 514.3203 917.6783 551.3803 1738.5029	*ainty: %Uncert 4.1000 2.2000 4.0000 2.5000	Half-life 462.90 D 271.80 D 137.64 D 46.61 D	Uncertainty	Clear Current Rate (s ⁻¹ unit ¹) 1.65e-15 4.98e-33 5.74e-101	
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✓ Use for C Nuclide CD-109 CO-57 CE-139 HG-203	alib/Init Activity (Bq) 14247.100 1068.310 690.209 2134.180	Unce %Uncert 3.023 1.700 4.000 2.495	rtainty: Energy (keV) 88.034 122.061 165.853 279.197	100 decays) 3.6100 85.9000 79.8860 81.4600	0.1 Uncertainty (per 100) 0.1000 1.2000 0.0150 0.1300	& Uncert Rate (s ⁻¹ unit ⁻¹) 514.3203 917.6783 551.3803 1738.5029	*ainty: %Uncert 4.1000 2.2000 4.0000 2.5000	Half-life 462.90 D 271.80 D 137.64 D 46.61 D	Uncertainty	Clear Current Rate (s ⁻¹ unit ¹) 1.65e-15 4.98e-33 5.74e-101	

Conclusion

- Taking correlations into account for efficiency calibration and activity calculations in gamma spectrometry can increase the uncertainty of the radionuclide activities when the efficiency data points are correlated.
- Uncertainties in the independent variable, intensities, are necessary when performing interference correction when the relative uncertainty in the decay data is comparable or large compared to other uncertainties.
- Nuclide Activity Uncertainty Results <u>may</u> increase by 1-3%

Included in Genie 4.0



Genie 4.0 webinar presentation available on our website

Latest in Gamma Spectroscopy: New Genie[™] 4.0 Software (on24.com)

Thank you

Special thank to our scientist team Henrik Persson, Troy Anderson, John M Kirkpatrick, Kara Phillips