Interactive Web Accessible Gamma-Spectrum Generator & EasyMonteCarlo Tools

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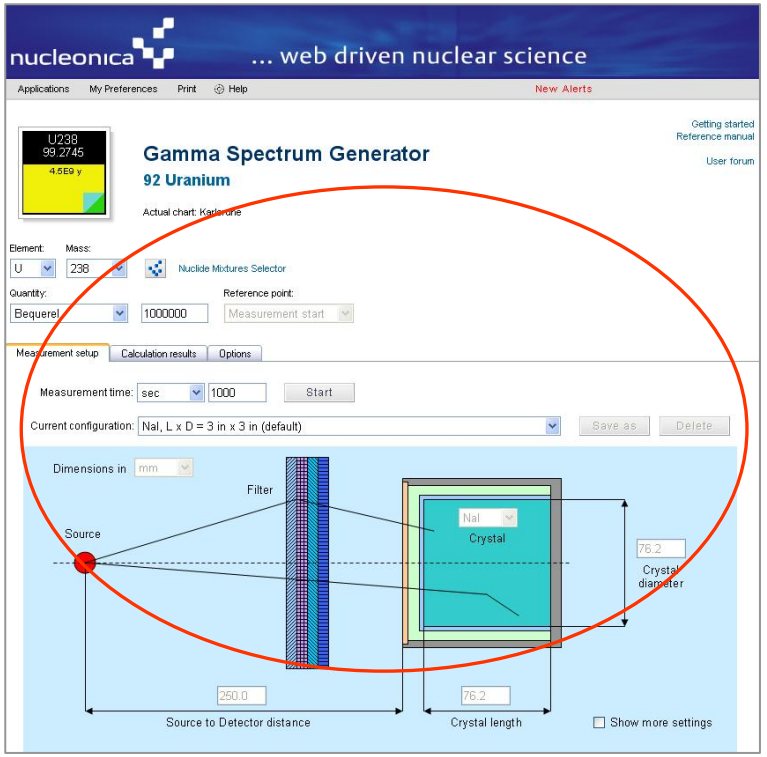
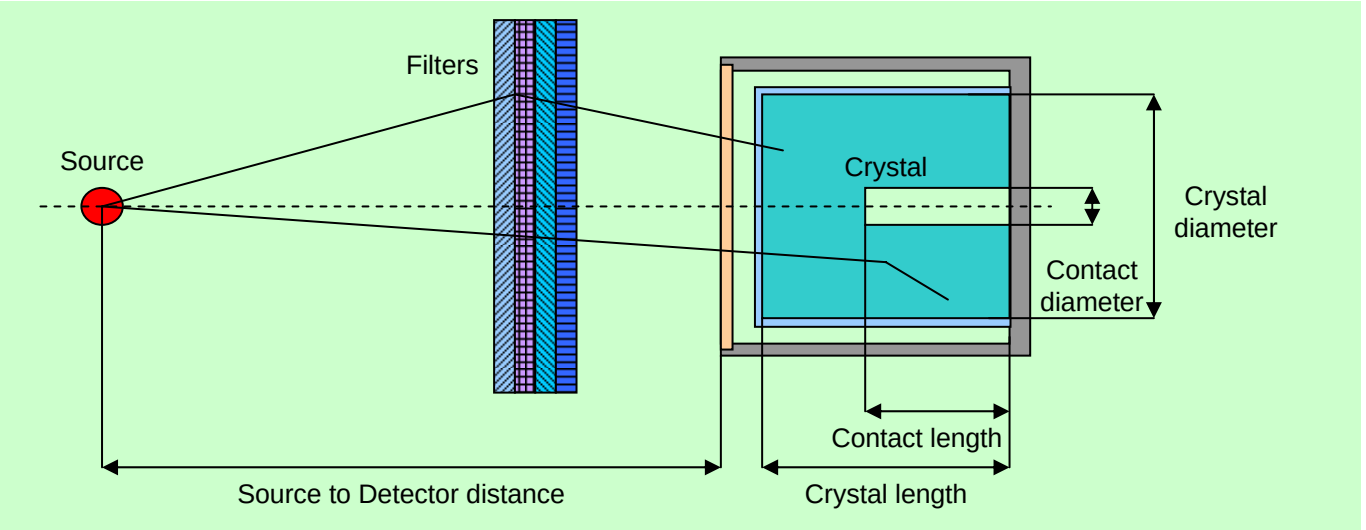


Outline

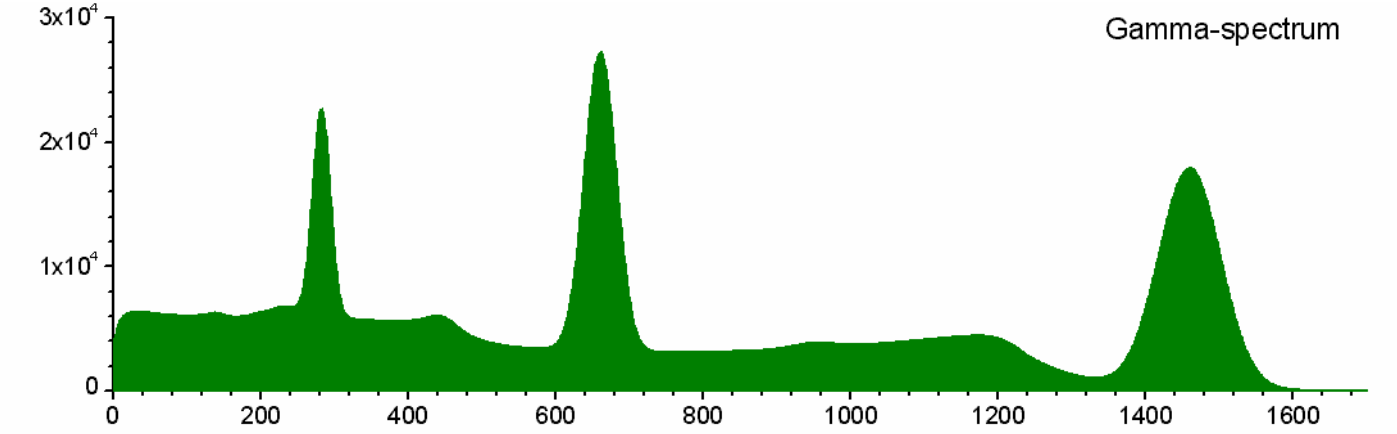
- Simulation approach
- Features implemented
- Some examples
- Future work
- Exercises

nucleonica

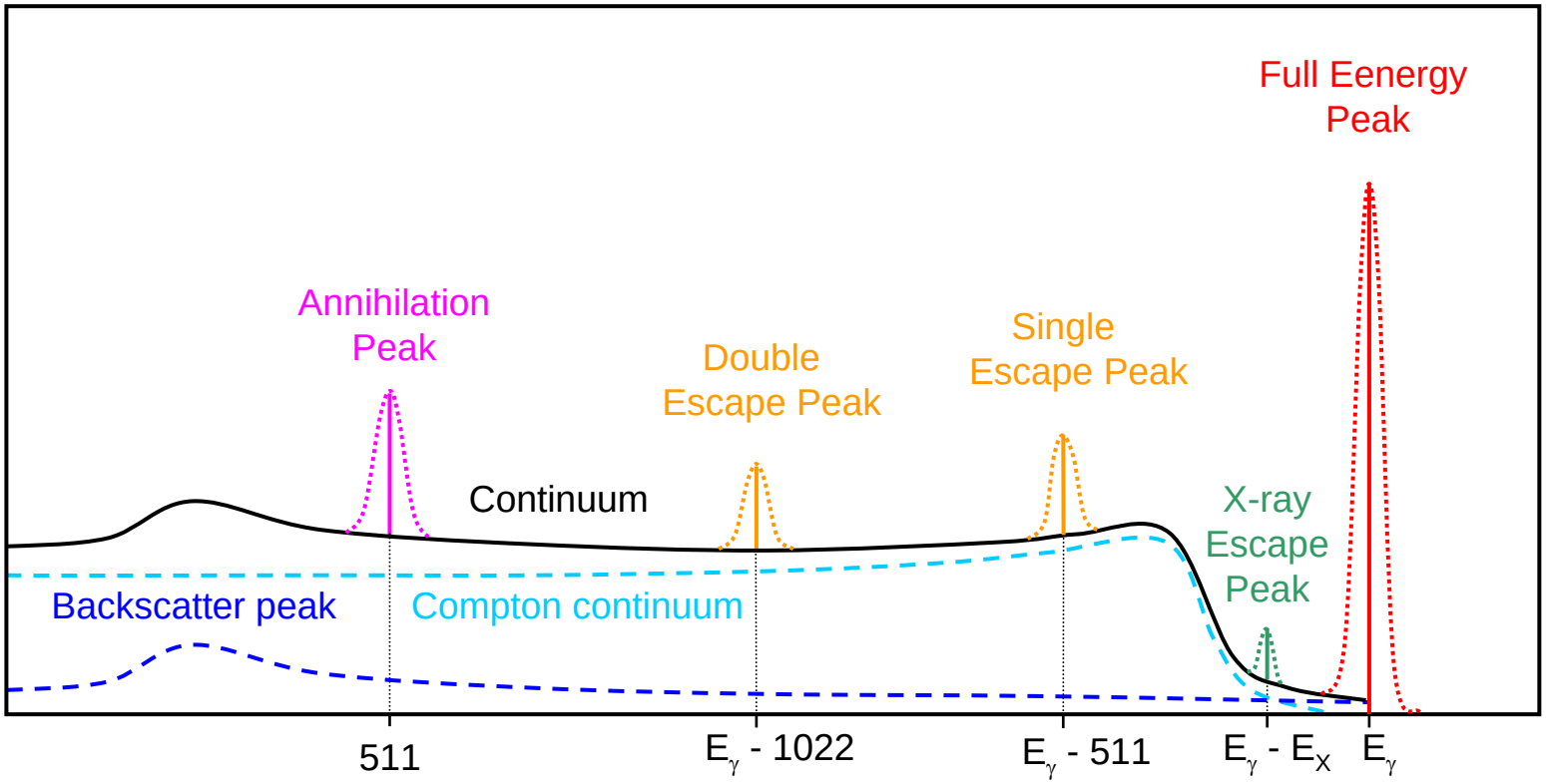
Measurement setup model implemented:



Spectrum modeling procedure:



Detector response profile model:



Detector Reference Response Profile DATABASE:

Method:

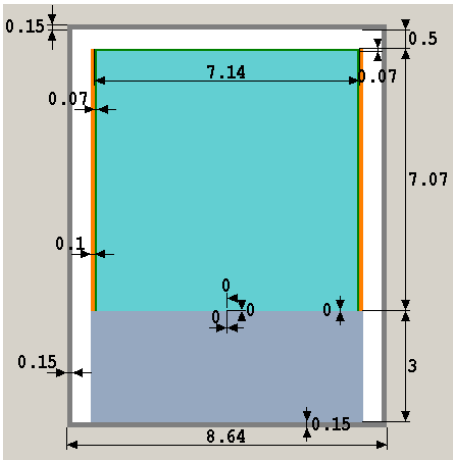
- Monte Carlo simulation using specially developed and validated program – DRGen (*Detector Response Generator*)

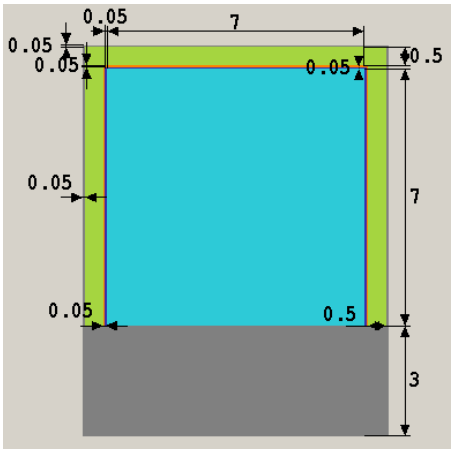
Content:

- Peak-to-Total efficiency ratios for FEP, SEP, DEP, XEP, and 511 keV annihilation peak
- Continuum-to-Total efficiency ratios for Compton continuum and Backscatter „peak“ distribution
- Parameterized shapes of Compton continuum and Backscatter „peak“ distribution

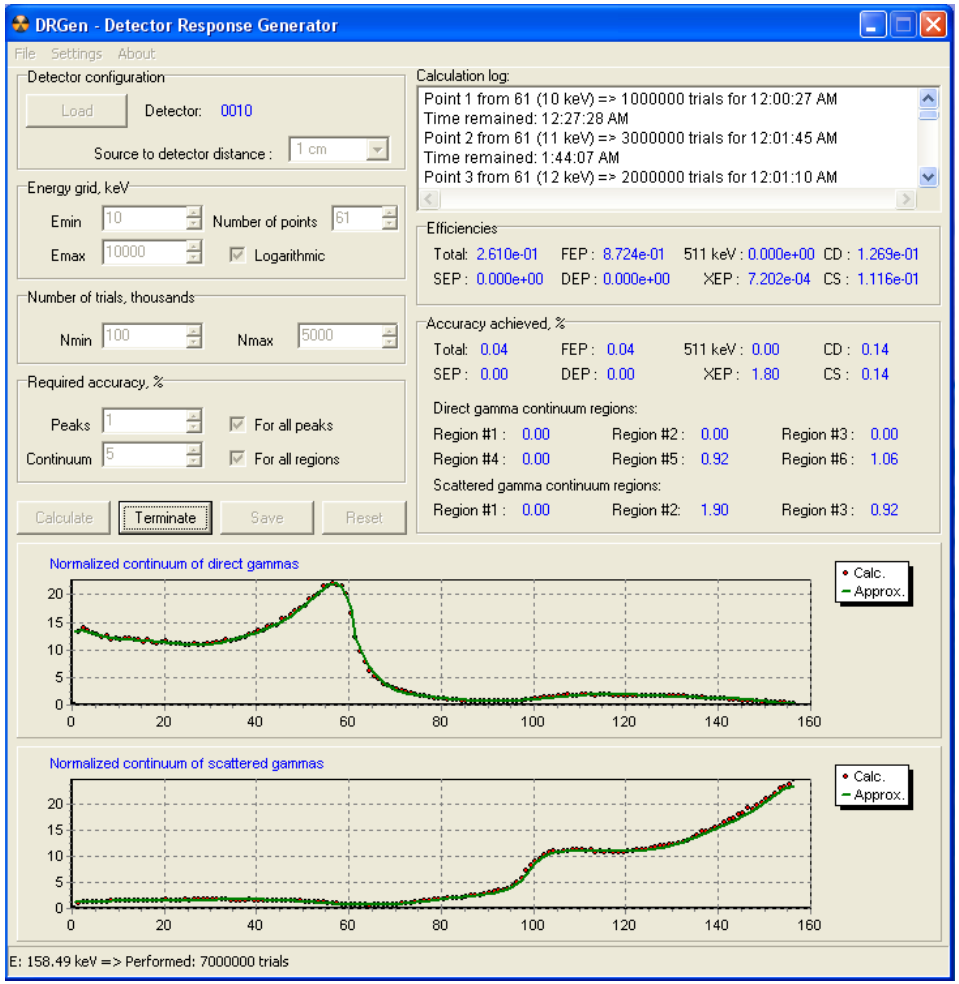
Scope:

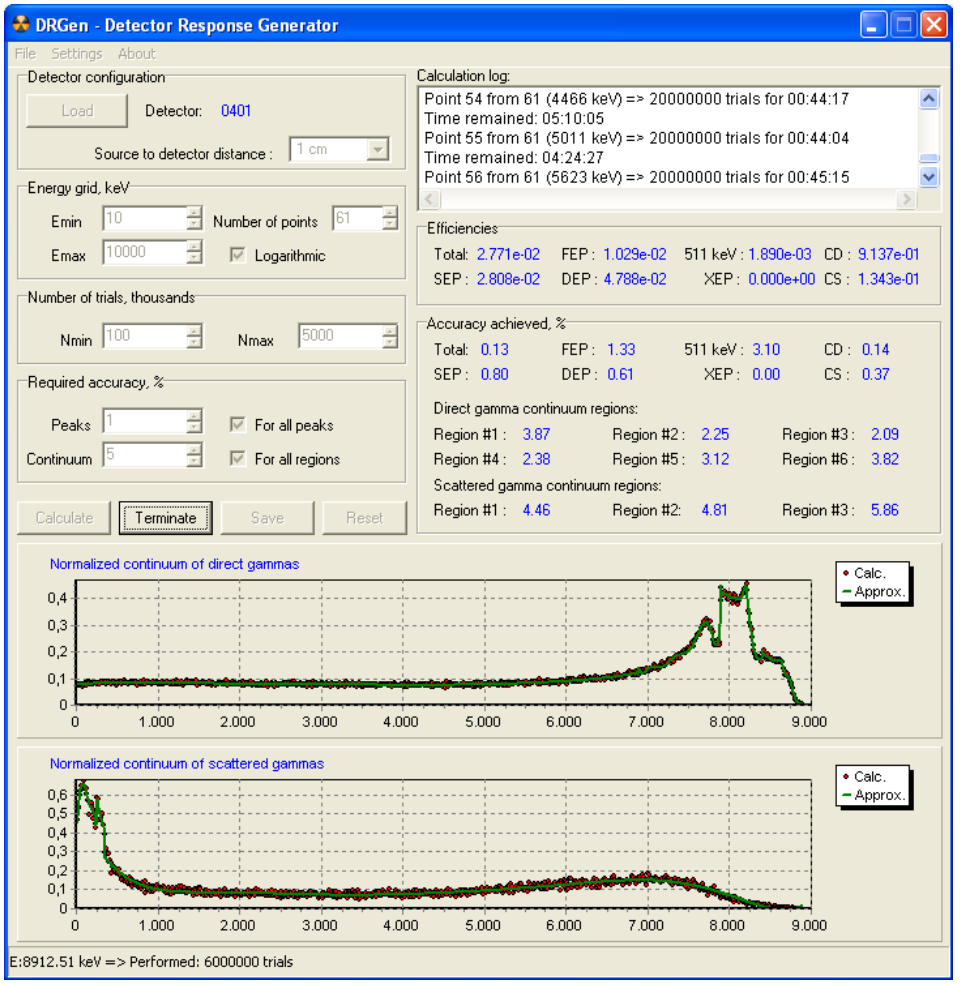
- Detectors: NaI and High Pure Ge (HPGe)
- Crystal length and diameter grid: 20 mm – 120 mm with 10 mm step
- Photon energy grid: 61 points, 10 keV – 10 MeV
- Source-to-detector distance grid: 0 mm, 10 mm, 50 mm, 250 mm
- Total number of profiles generated: 2 x 121 x 61 x 4 = 59048





DRGen (Detector Response Generator): creating the Detector Reference Response Profile Database

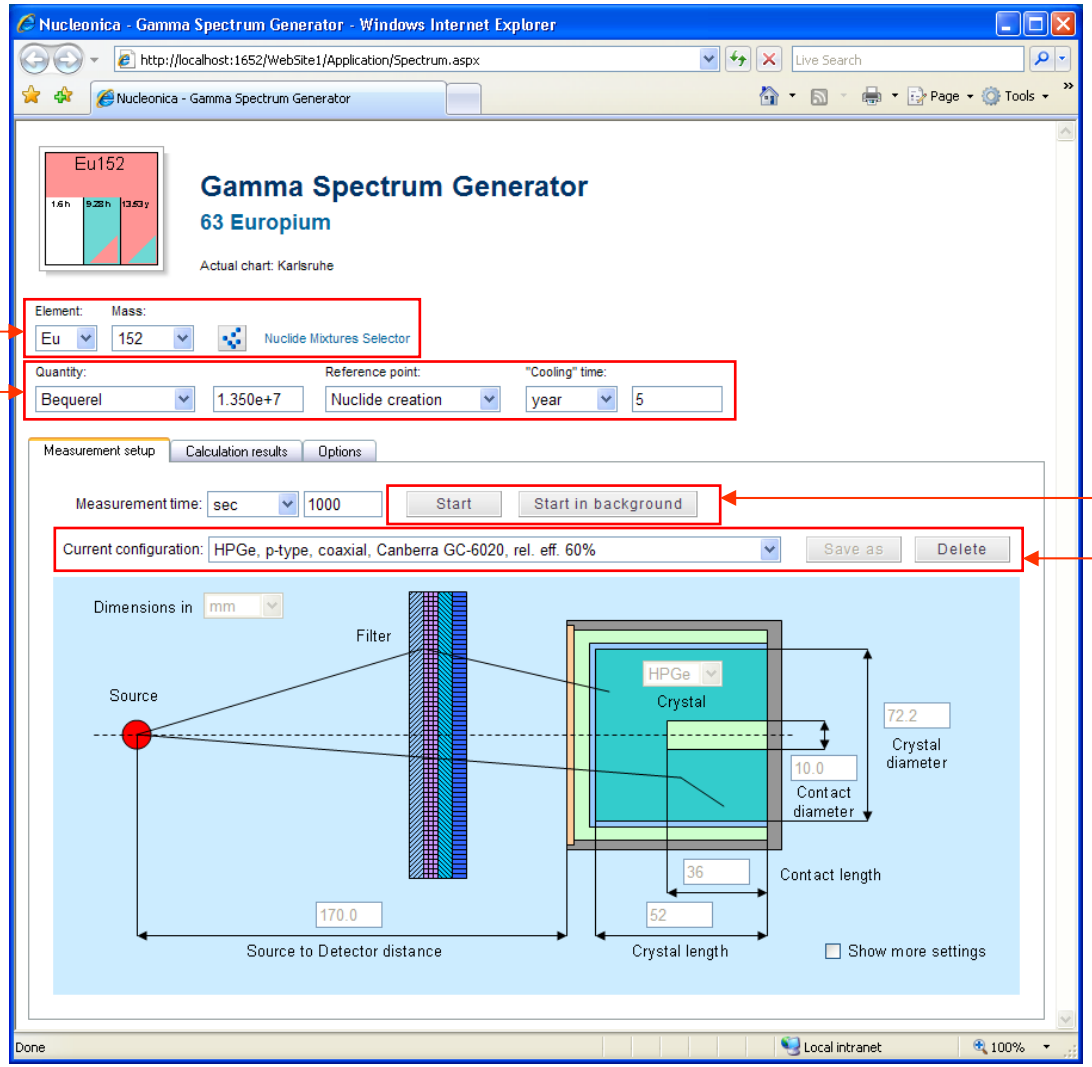




Features implemented: Measurement setup

An arbitrary individual nuclide or a pre-defined mixture of nuclides can be selected as a radiation source

The quantity (activity, mass or number of atoms) of a nuclide or a mixture can be specified either at the moment of its production or at the spectrum measurement starting point of time. In the former case controls for specifying duration of a source cooling time interval become available.

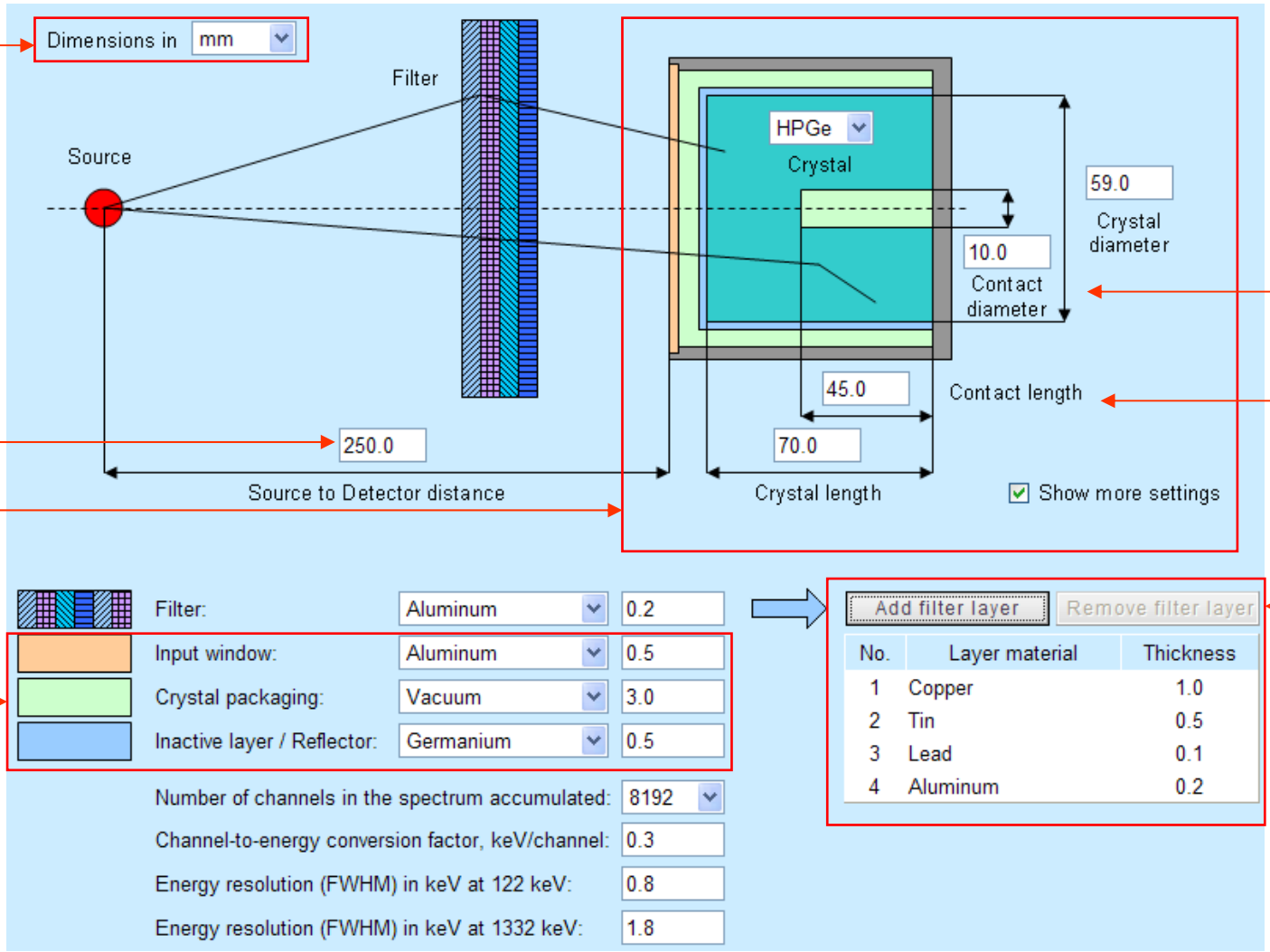


Calculations can be started on-line or in a background mode

A suitable γ-spectrometer can be chosen from 6 pre-defined configurations, which include 2 coaxial HPGe (50% and 150%) detectors, low-energy (LEGe) and broad-energy (BEGe) HPGe detectors, and 2 NaI detectors (∅3″×3″ and ∅2″×1″). In addition, user's specific configurations can be managed.

Features implemented: Measurement setup

Dimensions can be entered in “mm”, “cm” or “inch” units

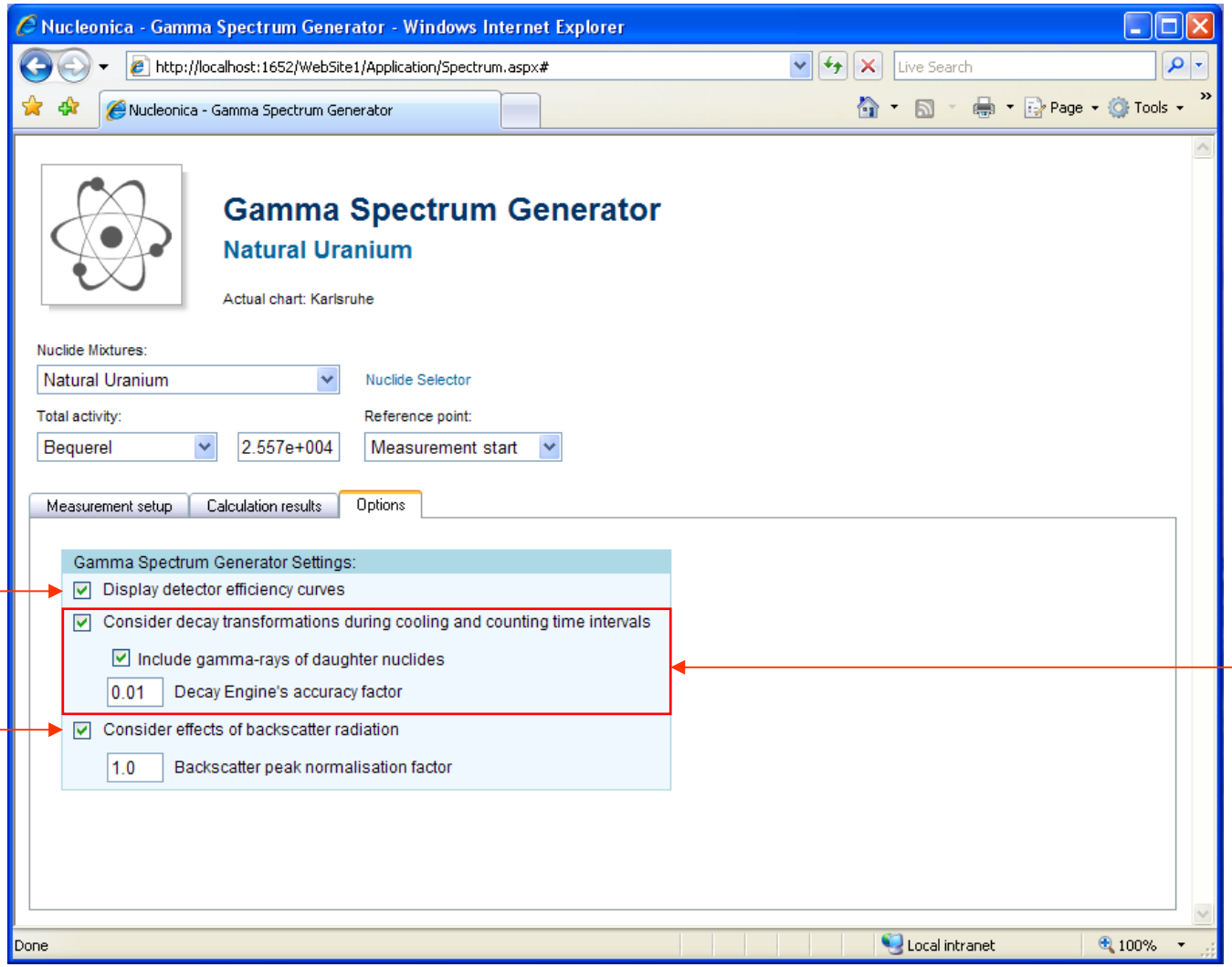


The configurable parameters include the source-to-detector distance, as well as dimensions and materials of the detector construction elements.

The dimensions of a cylindrical contact at the rear side of the crystal (a construction feature of conventional coaxial HPGe detectors) can be specified

Up to 6 additional absorbing filters made of Al, Cu, Fe, Pb, Sn, or polyethylene can be placed between source and detector

Features implemented: Options



Efficiency Graph can be activated in the Calculation Results output

The backscatter peak simulation can be switched on/off, and its contribution to the spectrum can be adjusted

Decay calculations can be enabled that will allow contributions from decay products, being accumulated during source cooling and spectrum measurement time intervals

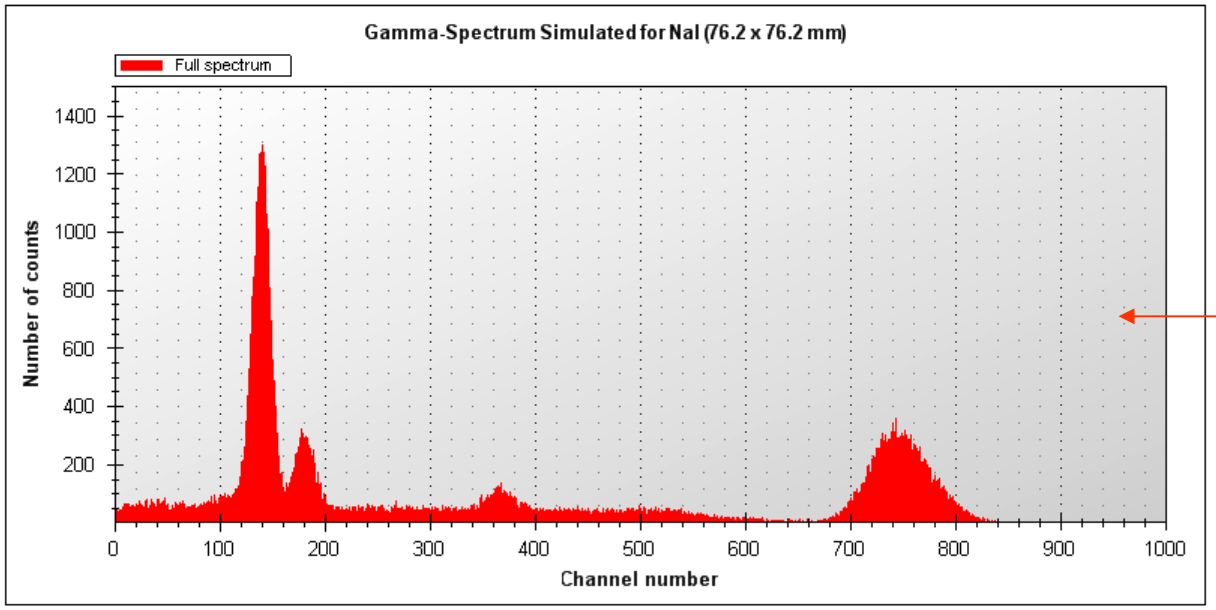
Features implemented: Calculation results

Measurement setup | Calculation results | Options

Statistical number of counts
Count rate at start
Count rate at end
Theoretical number of counts
Statistical number of counts

Data displayed: Statistical number of counts

View/Save results in Text or Excel format



Update spectrum graph

Display: Energy scale | Spectrum continuum | Contribution of scattered photons | More graph options

No.	Nuclide	Count rate at start, cps	Count rate at end, cps	Spectrum counts	Display
1	42 Mo 99	6.23E+01	6.22E+01	6.26E+04	☐
2	43 Tc 99	6.70E-15	6.79E-15	0.00E+00	☐
3	43 Tc 99m	2.69E+01	2.68E+01	2.70E+04	☐
	Total	**8.92E+01**	**8.90E+01**	**8.97E+04**	

Complete set of spectral information can be downloaded as a text or Excel spreadsheet file

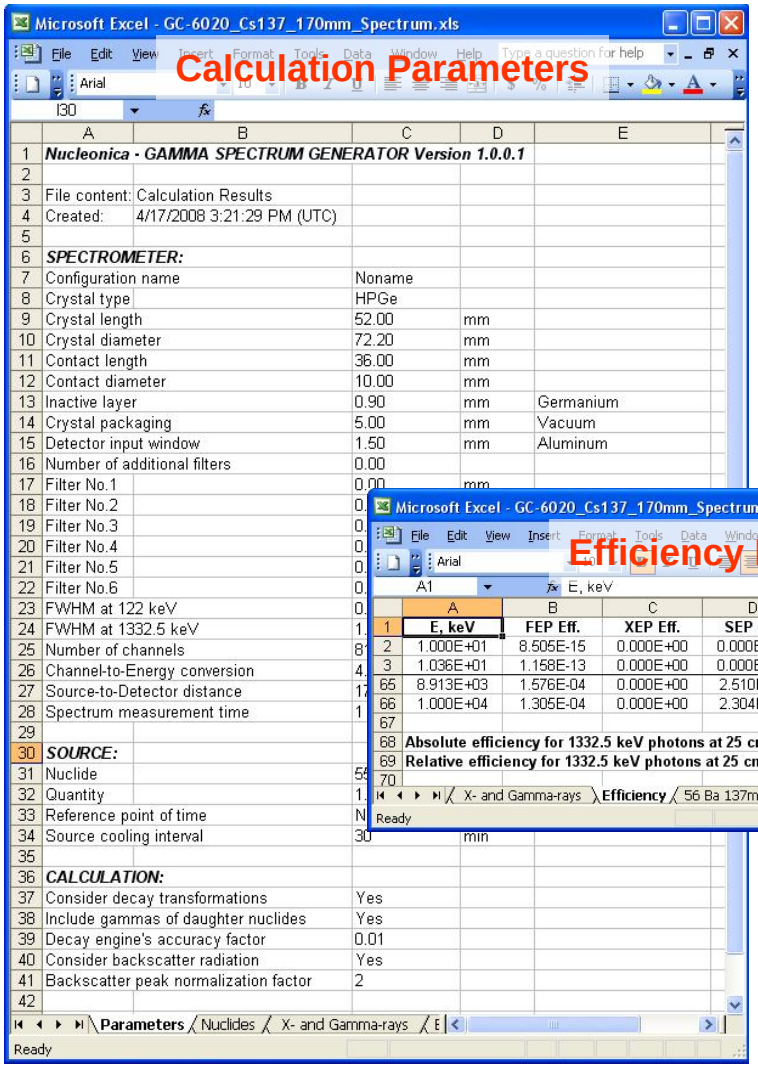
Right click within the graph area enables a context menu, from which one can print or download the spectrum graph

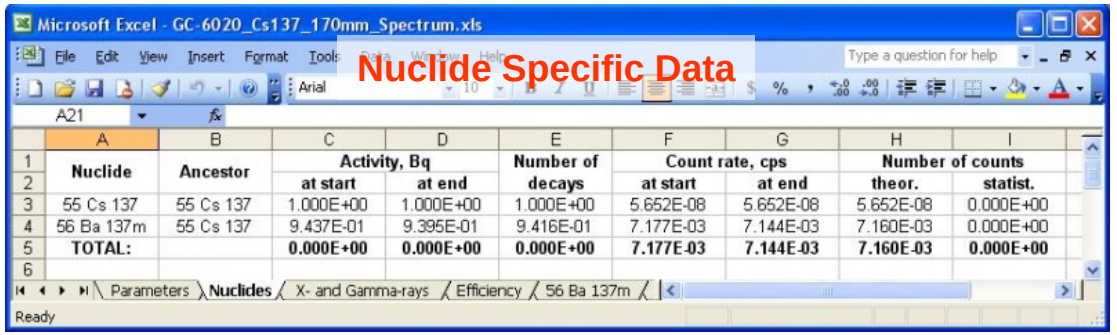
Additional options allow to customize appearance of the graph to meet one's needs and requirements

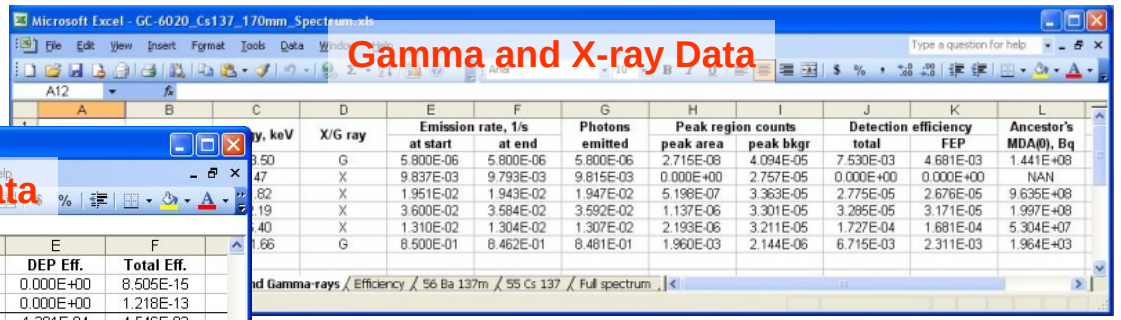
Switch between channel number and energy scale; show peak, continuum and backscatter peak contributions to the full spectrum

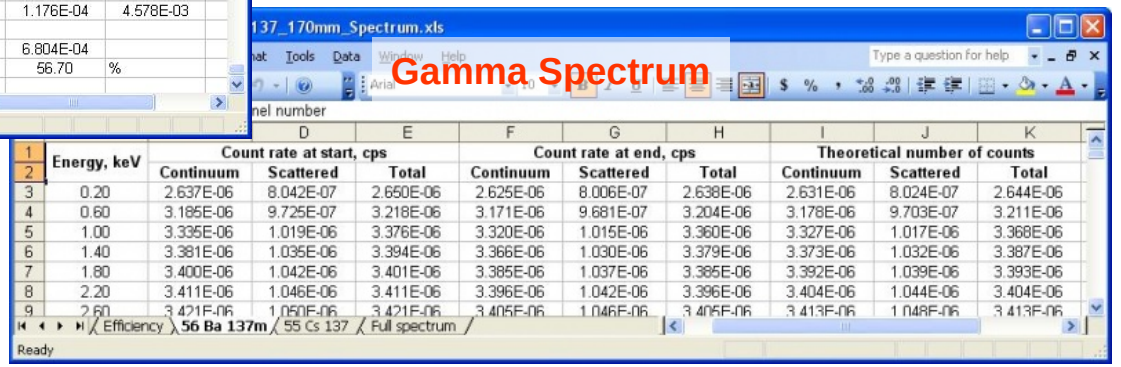
Display nuclide specific contributions to the full spectrum

Calculation results : Detailed Spectral Data in Excel Spreadsheet









Calculation results : Detection Efficiency

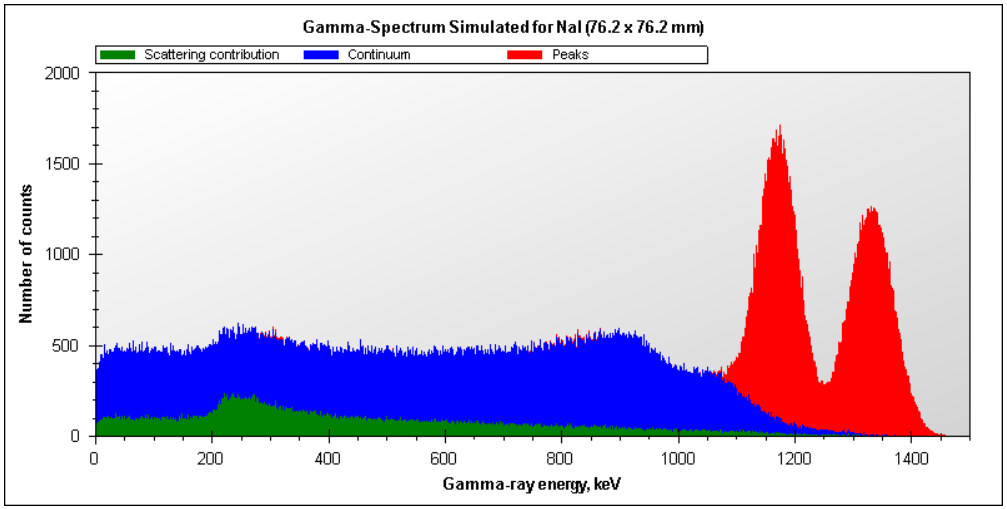
Right click within the graph area enables a context menu, from which one can print or download the efficiency graph

Select efficiency data to be displayed on the graph

Additional options allow to tailor the efficiency graph to one's needs and requirements

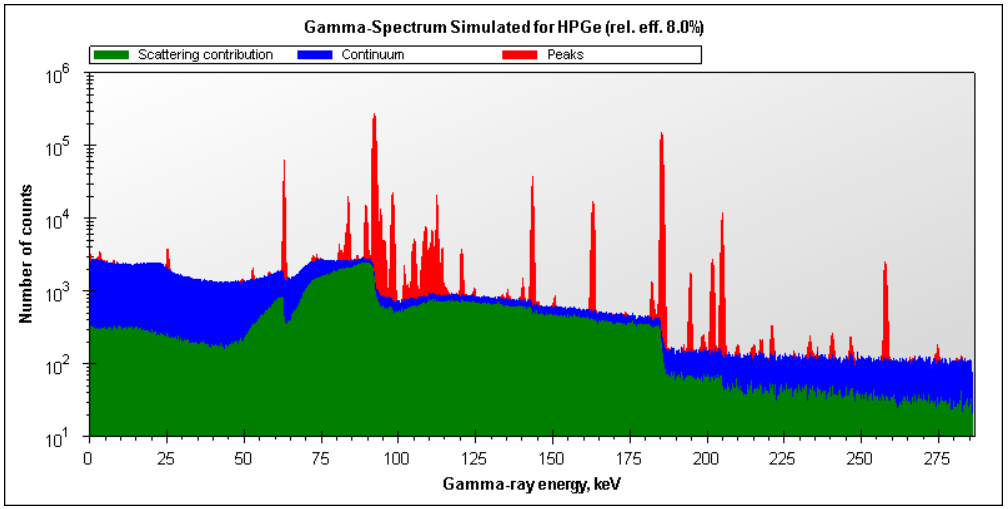
Examples:

100 kBq ^{60}Co



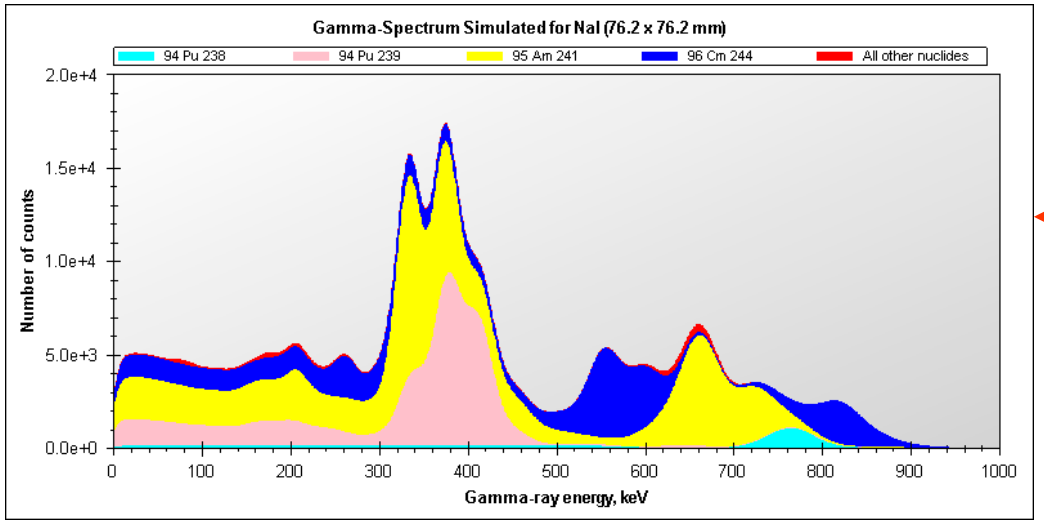
Detector - NaI (∅3″×3″)
Source-to-detector distance - 25 cm
Measurement time - 1000 s

1 g Nat U (2 years after separation)



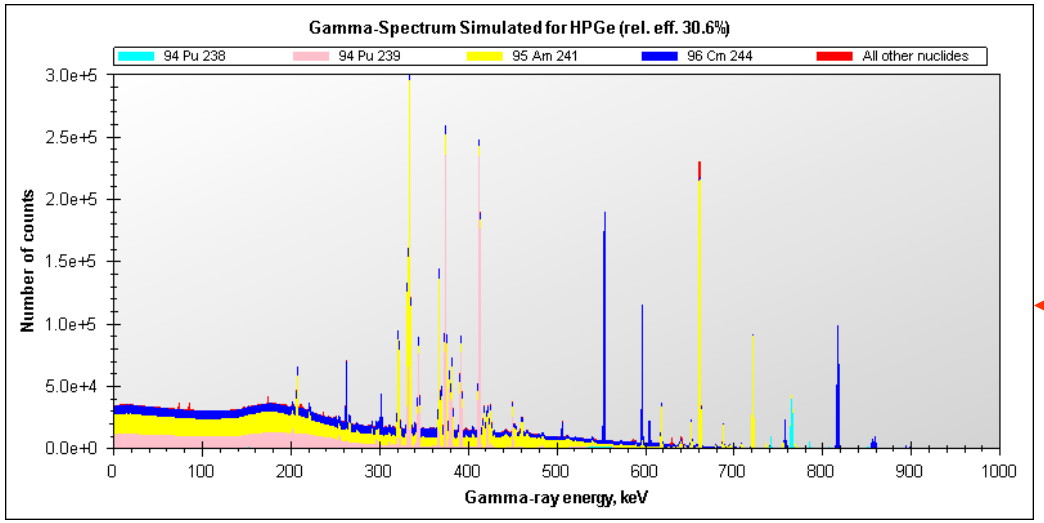
Detector – LEGe (20 mm × 2800 mm^2)
Source-to-detector distance – 25 mm
Filter – 0.5 mm Sn
Measurement time - 10^5 s

Examples:



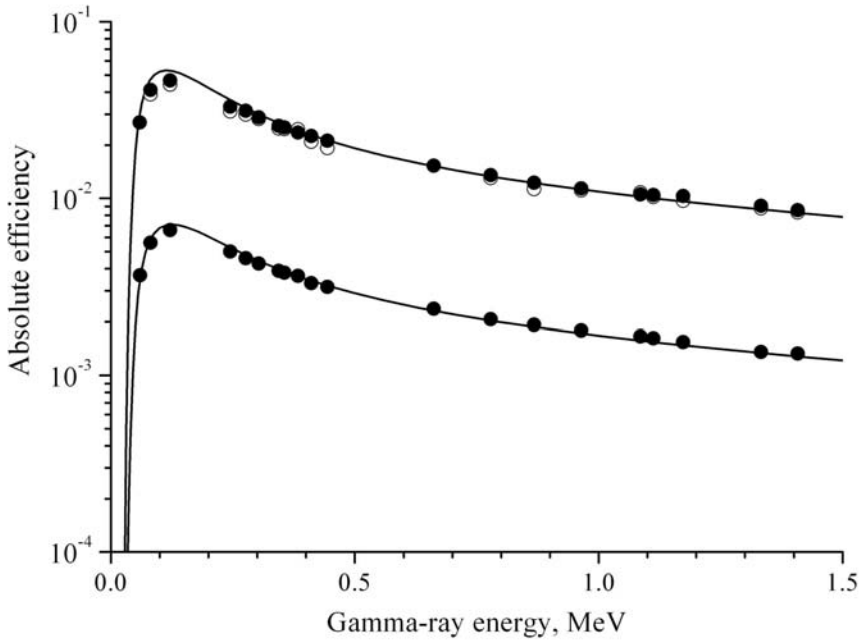
Detector – NaI (∅3″×3″)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

Actinides extracted from 1 kg 6-year-aged PWR spent fuel. Activity - 5.25 TBq

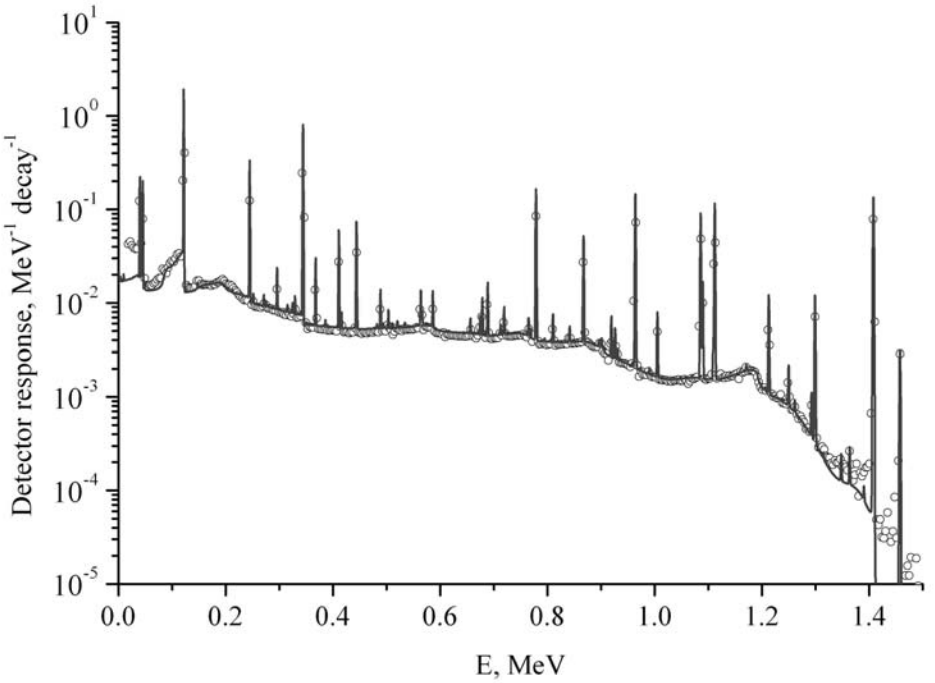


Detector – BEGe (30% rel. eff.)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

Example:
Results of the experimental validation with 60% HPGe coaxial detector

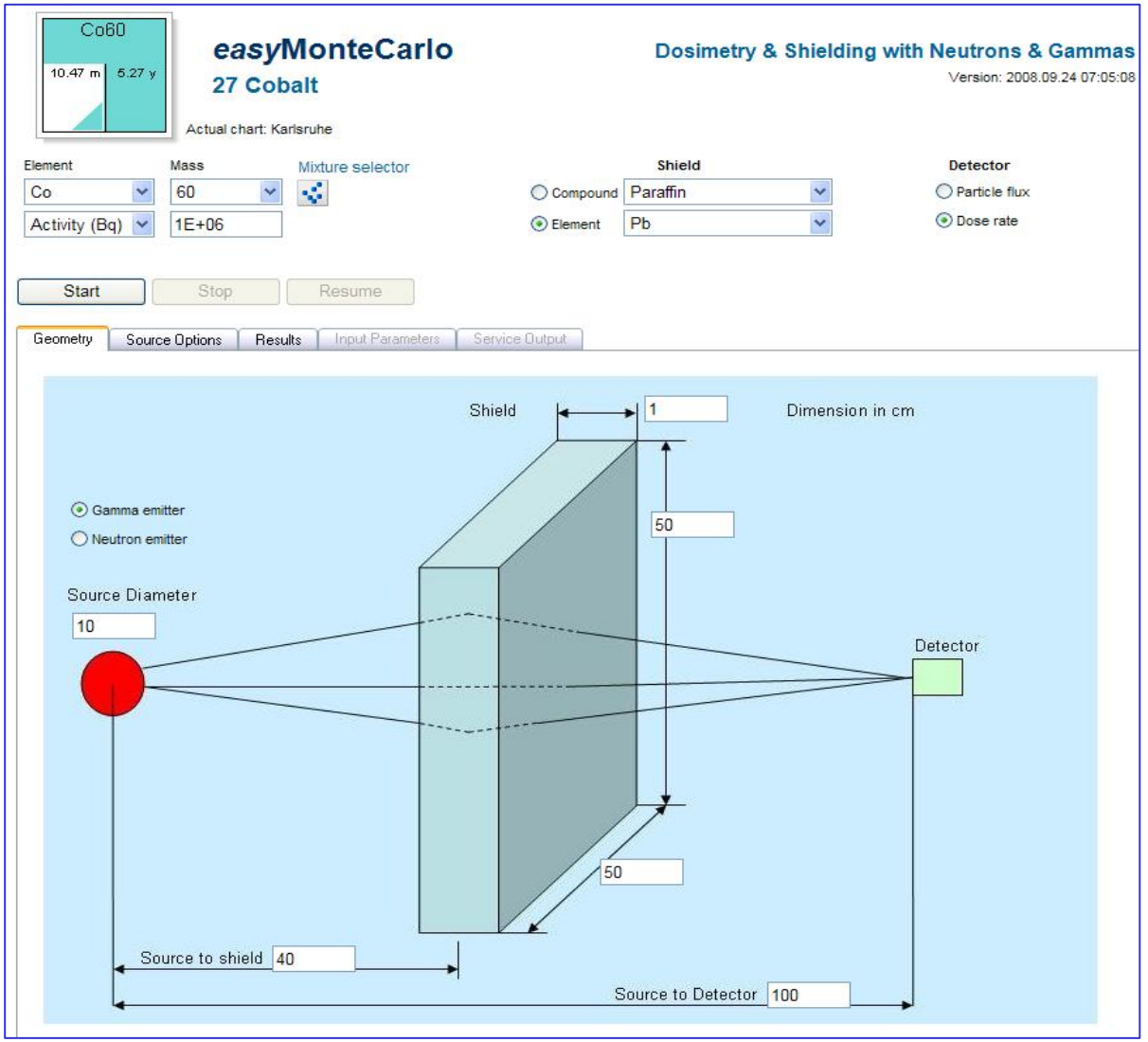


Full Energy Peak efficiency as a function of the photon energy: circles – experimental values, curve – calculated. Two sets of data refer to the source location at 5 cm and 17 cm distances from the detector end cap.



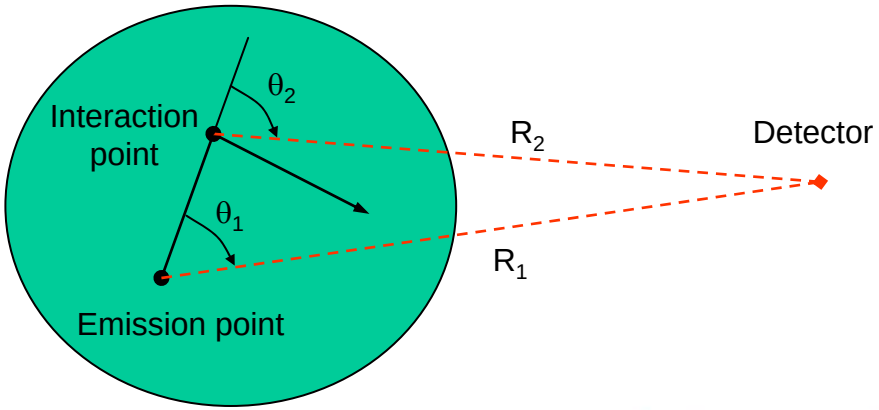
Calculated (curve) and experimental (circles) detector responses for ^{152}Eu source at 17 cm distance from the detector end cap.

Nucleonica : Easy Monte Carlo for Gamma & Neutron Dosimetry & Shielding Calculations through Web



Variance Reduction Example: Point Detector Tally

For very small volumes and heavily shielded sources it can be almost impossible to get either a track-length or surface crossing estimate because of the low probability of crossing into the small volume or because of the very low particle flux outside a heavily shielded object. In such cases the use of the **Point Detector Tally** (one of the **Variance Reduction Techniques**) can provide much greater efficiency (FOM) of the calculation.



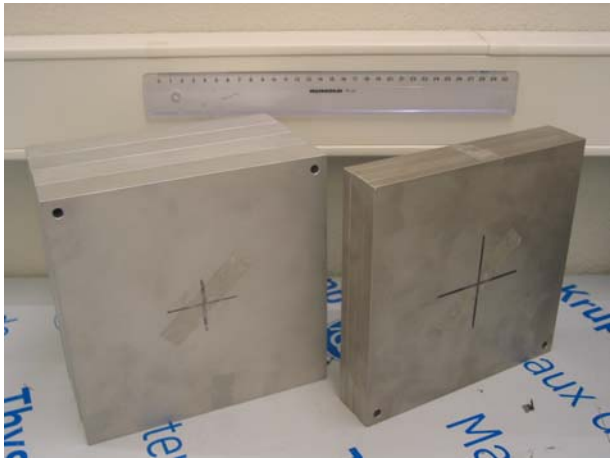
$$\Phi = \sum_j p(\mu_j) \frac{e^{-\lambda_j}}{2\pi R_j^2}$$

In the **Point Detector** approach the tally is scored, first, when particles emitted from the source, and, then, after each interaction of primary particles, by calculating the probability for all secondary particles to be emitted or scattered directly to the detector.

The approach therefore is also frequently called as the **Next Event Estimator**.

$p(\mu)$ – probability density function for a particle to be emitted / scattered into detector,
μ - cosine of angle between particle trajectory and detector,
R – distance to detector,
λ - total mean free path to detector.

NUCLEONICA: GSG & EMC Validation



Future work:

- Include simulation of the spectrum distortion effects (e.g. due to coincidence summing and energy resolution deterioration), which may appear in measurements involving elevated count rates and small source-to-detector distances.
- Extend the detector response profile database to include $LaBr_3$ scintillators that, because of their much superior energy resolution, start to replace traditional NaI crystals in many applications.
- Include self-attenuation effects (by combining GSG and EMC modules), which would allow more realistic simulation of gamma-spectra from voluminous sources.
- Include background gamma spectrum from naturally occurring radionuclides, which will make the spectrum shape and MDA evaluations more realistic.

Thanks for your attention !