

Interactive Web Accessible Gamma-Spectrum Generator & EasyMonteCarlo Tools



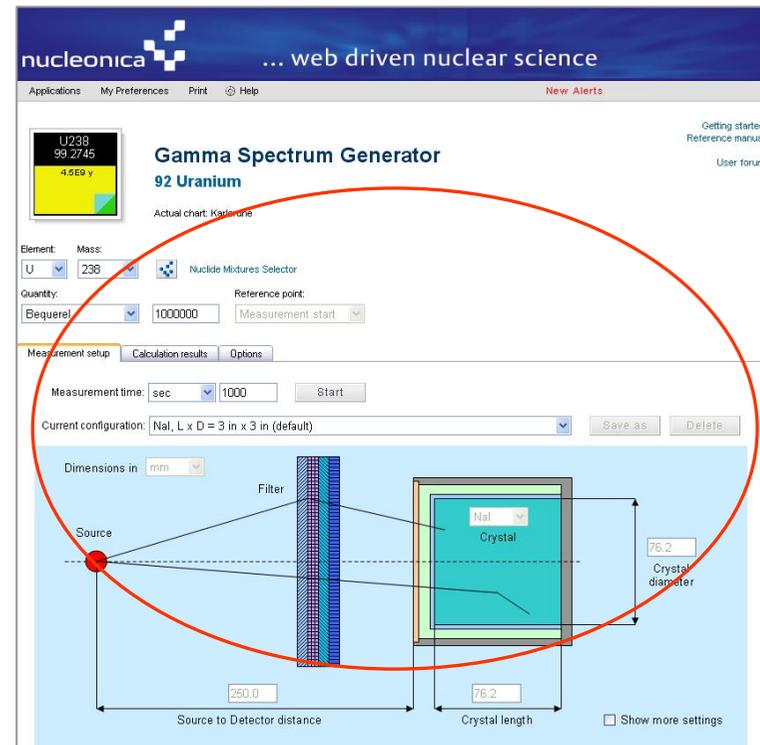
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Karlsruhe - Germany

<http://itu.jrc.ec.europa.eu/>

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Gamma Spectrum Generator
92 Uranium
Actual chart: Karlsruhe

Element: U Mass: 238 Nuclide Mixtures Selector

Quantity: Bequerel 1000000 Reference point: Measurement start

Measurement setup Calculation results Options

Measurement time: sec 1000 Start

Current configuration: NaI, L x D = 3 in x 3 in (default) Save as Delete

Dimensions in mm

Source Filter NaI Crystal

Crystal diameter 76.2

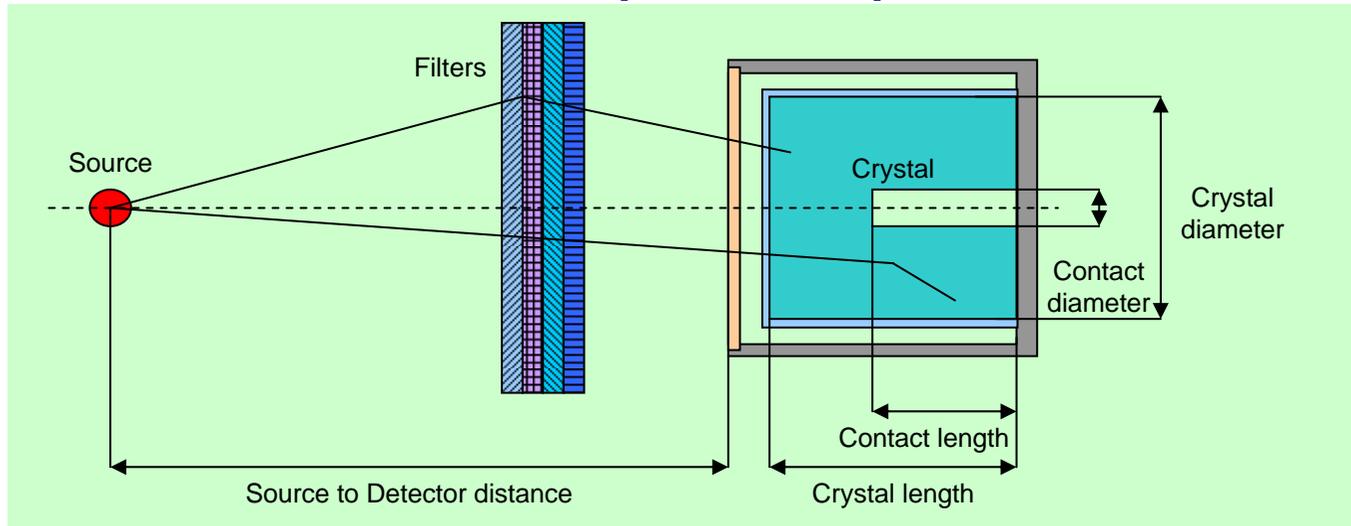
Source to Detector distance 250.0 Crystal length 76.2

Show more settings

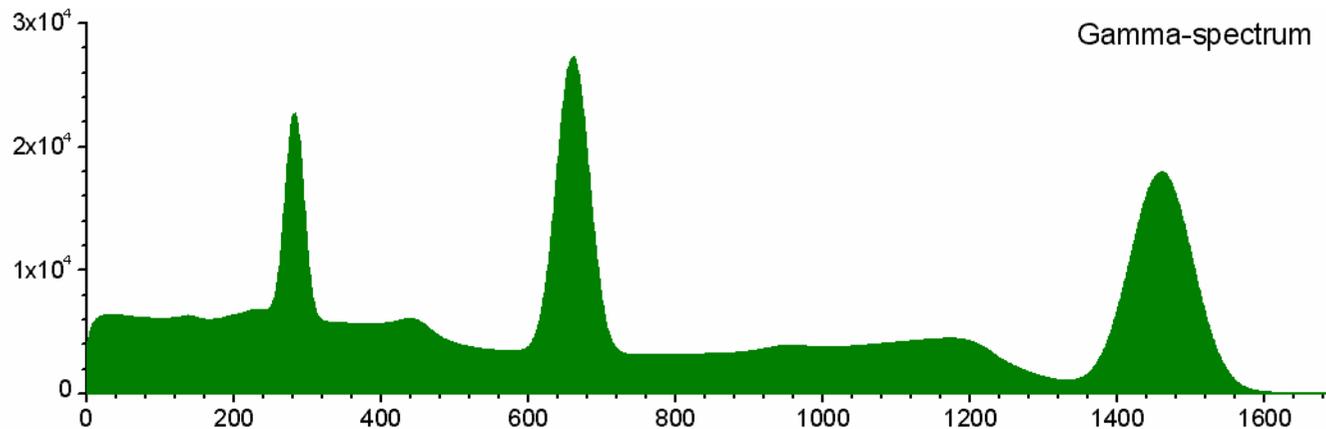
Outline

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

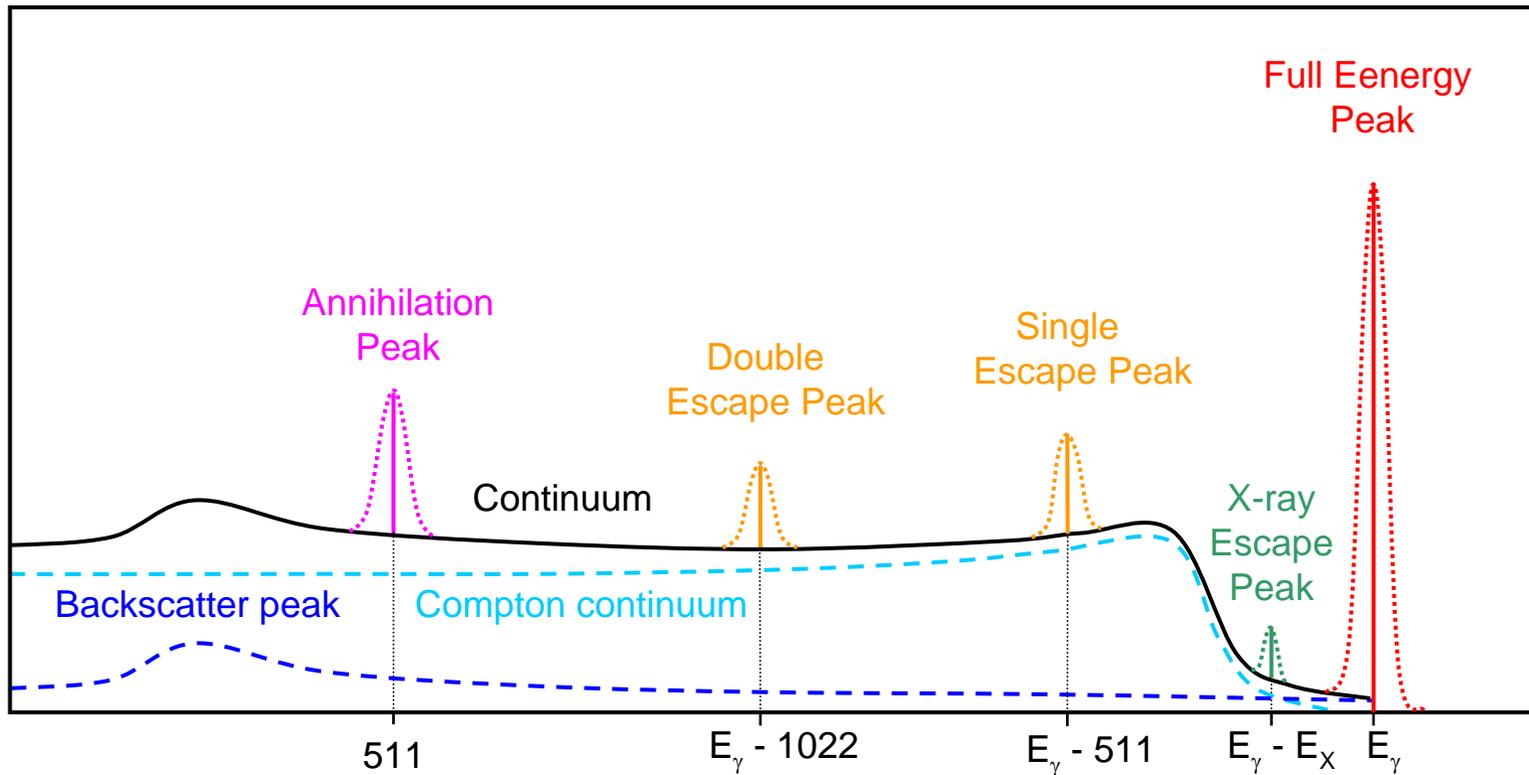
Measurement setup model implemented:



Spectrum modeling procedure:



Detector response profile model:



Detector Reference Response Profile DATABASE:

Method:

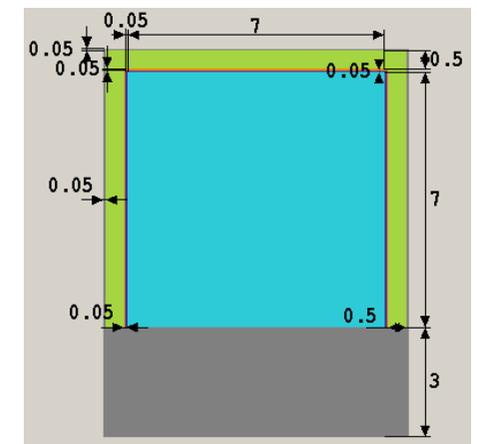
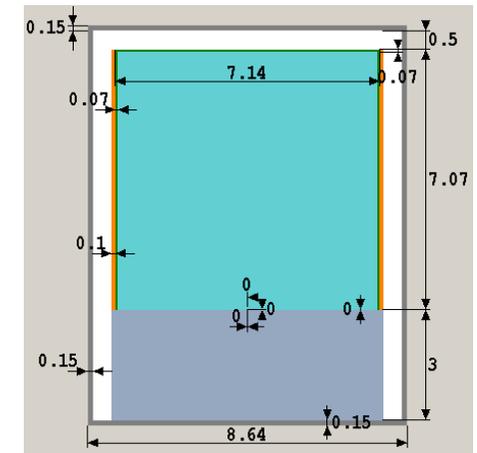
- **Monte Carlo** simulation using specially developed and validated program – DRGen (*Detector Response Generator*)

Content:

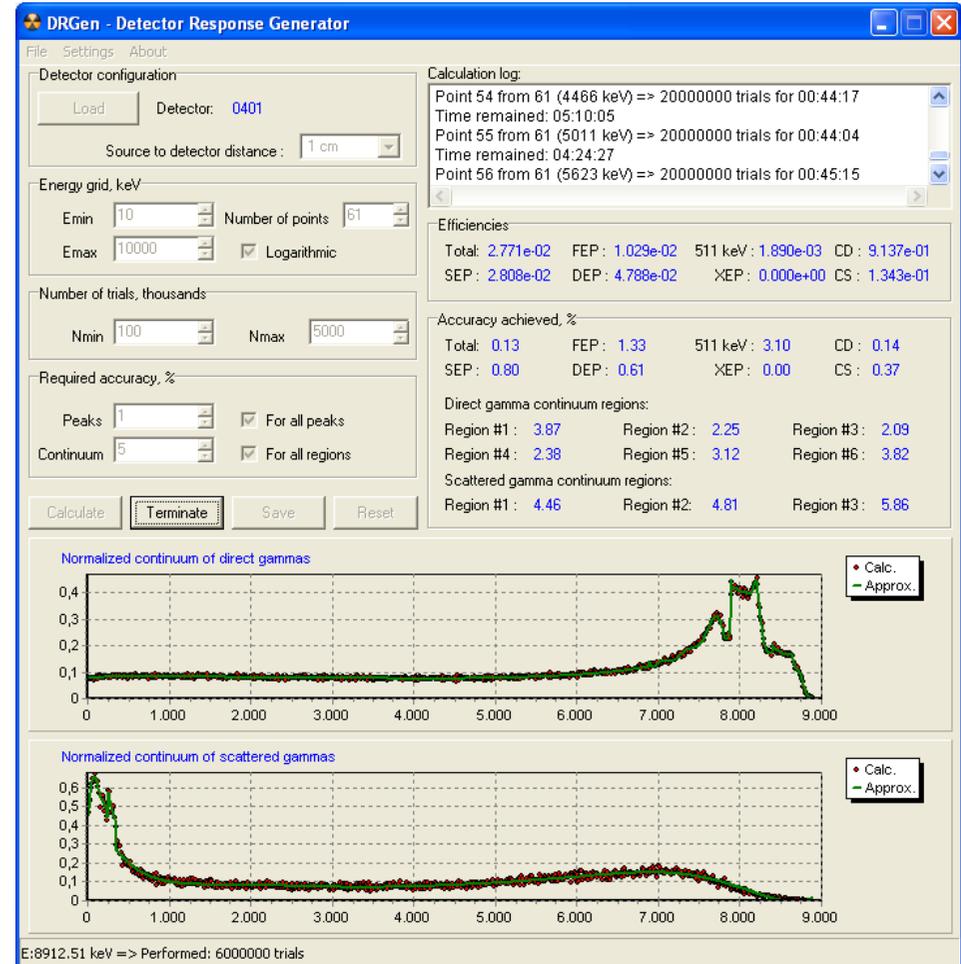
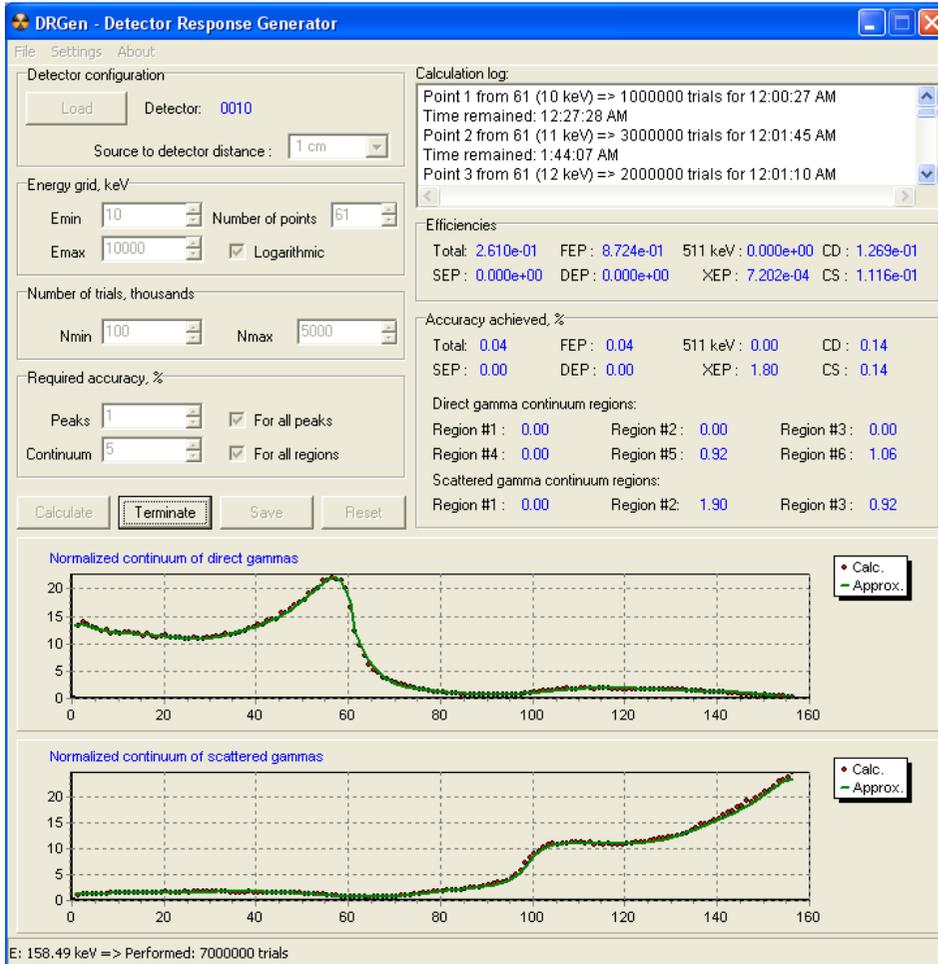
- Peak-to-Total efficiency ratios for FEP, SEP, DEP, XEP, and 511 keV annihilation peak
- Continuum-to-Total efficiency ratios for Compton continuum and Backscatter „peak“ distribution
- Parameterized shapes of Compton continuum and Backscatter „peak“ distribution

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: $2 \times 121 \times 61 \times 4 = 59048$



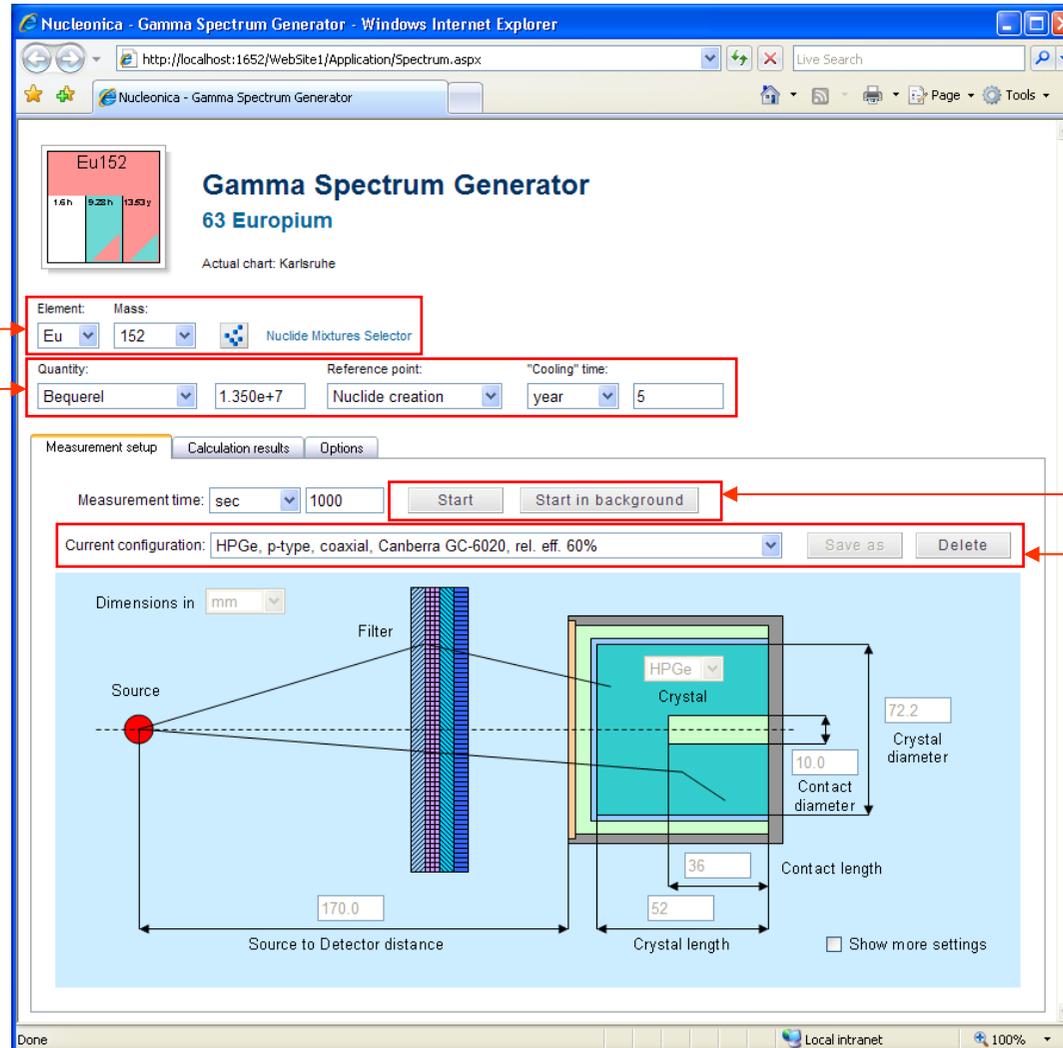
DRGen (Detector Response Generator): creating the Detector Reference Response Profile Database



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.



The screenshot displays the 'Gamma Spectrum Generator' interface for 63 Europium. It includes a 'Measurement setup' section with the following fields:

- Element: Eu, Mass: 152, Nuclide Mixtures Selector
- Quantity: Bequerel, 1.350e+7
- Reference point: Nuclide creation
- "Cooling" time: year, 5
- Measurement time: sec, 1000
- Buttons: Start, Start in background
- Current configuration: HPGe, p-type, coaxial, Canberra GC-6020, rel. eff. 60%
- Buttons: Save as, Delete

The schematic diagram shows the detector geometry with dimensions in mm:

- Source to Detector distance: 170.0
- Crystal length: 52
- Contact length: 36
- Contact diameter: 10.0
- Crystal diameter: 72.2

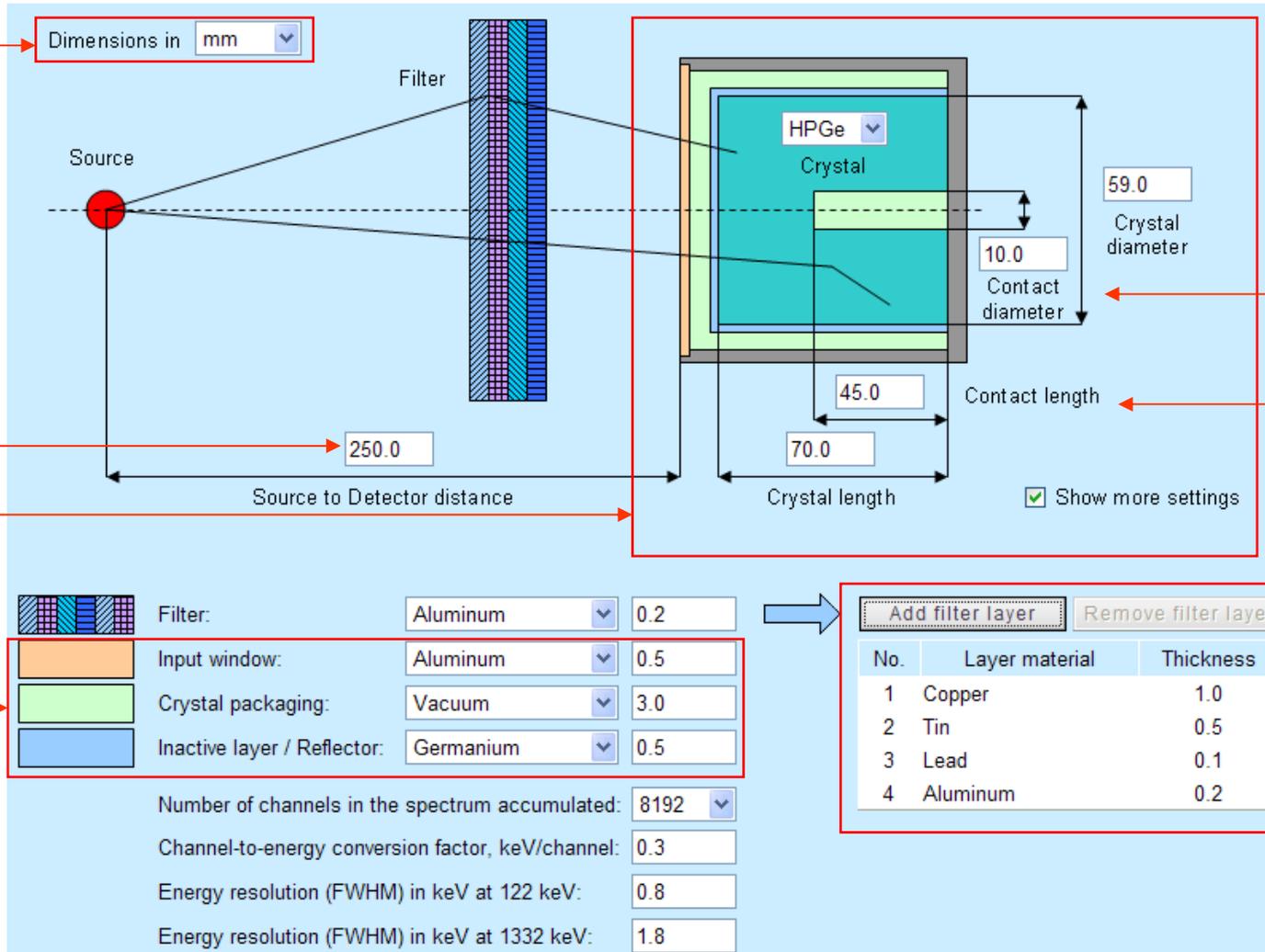
Calculations can be started on-line or in a background mode

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 ($\text{\O}3'' \times 3''$ and $\text{\O}2'' \times 1''$). 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.



Dimensions in

Source

Filter

HPGe
Crystal

250.0
Source to Detector distance

70.0
Crystal length

45.0
Contact length

10.0
Contact diameter

59.0
Crystal diameter

Show more settings

Filter: Aluminum 0.2

Input window: Aluminum 0.5

Crystal packaging: Vacuum 3.0

Inactive layer / Reflector: Germanium 0.5

Number of channels in the spectrum accumulated: 8192

Channel-to-energy conversion factor, keV/channel: 0.3

Energy resolution (FWHM) in keV at 122 keV: 0.8

Energy resolution (FWHM) in keV at 1332 keV: 1.8

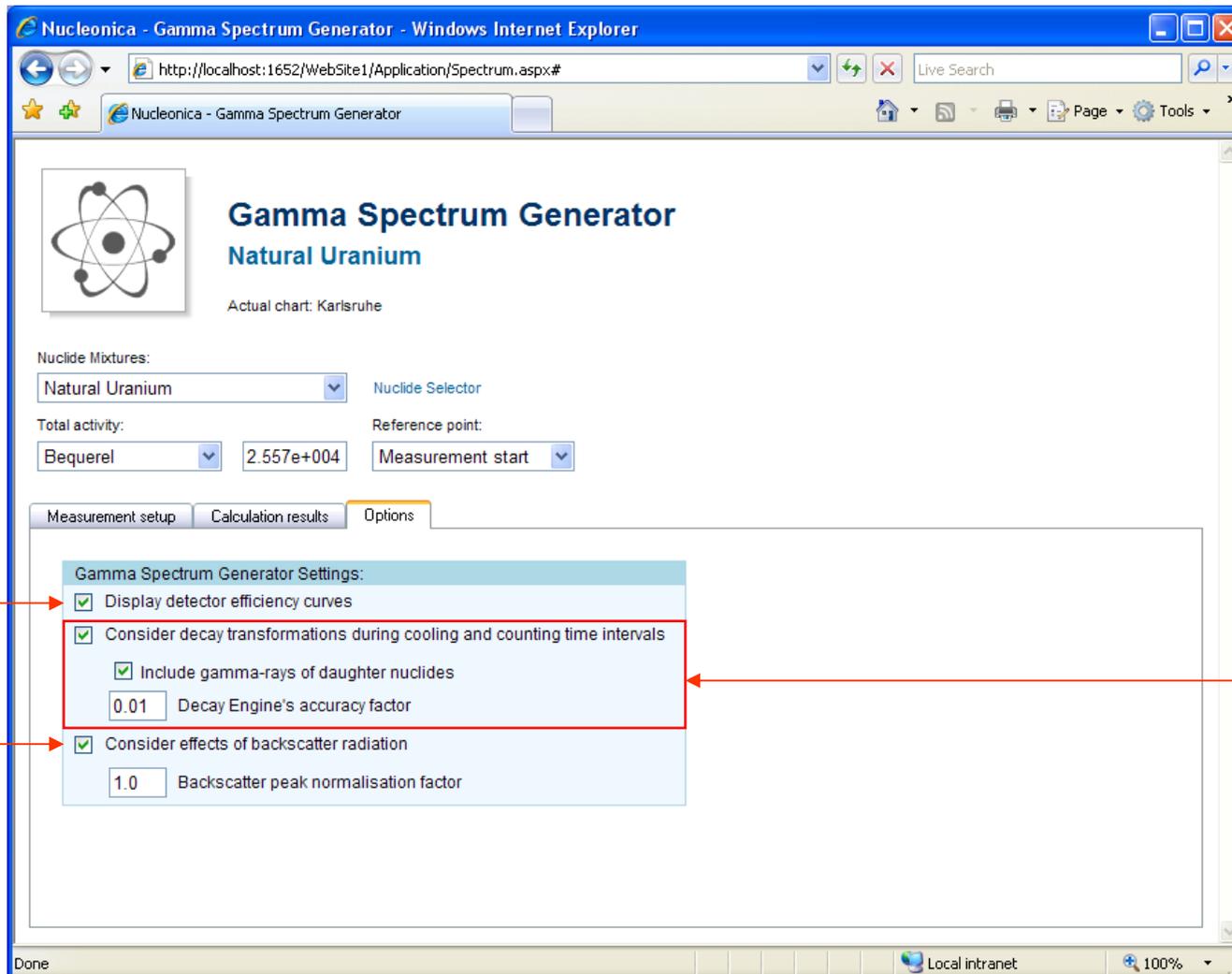
Add filter layer Remove filter layer

No.	Layer material	Thickness
1	Copper	1.0
2	Tin	0.5
3	Lead	0.1
4	Aluminum	0.2

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

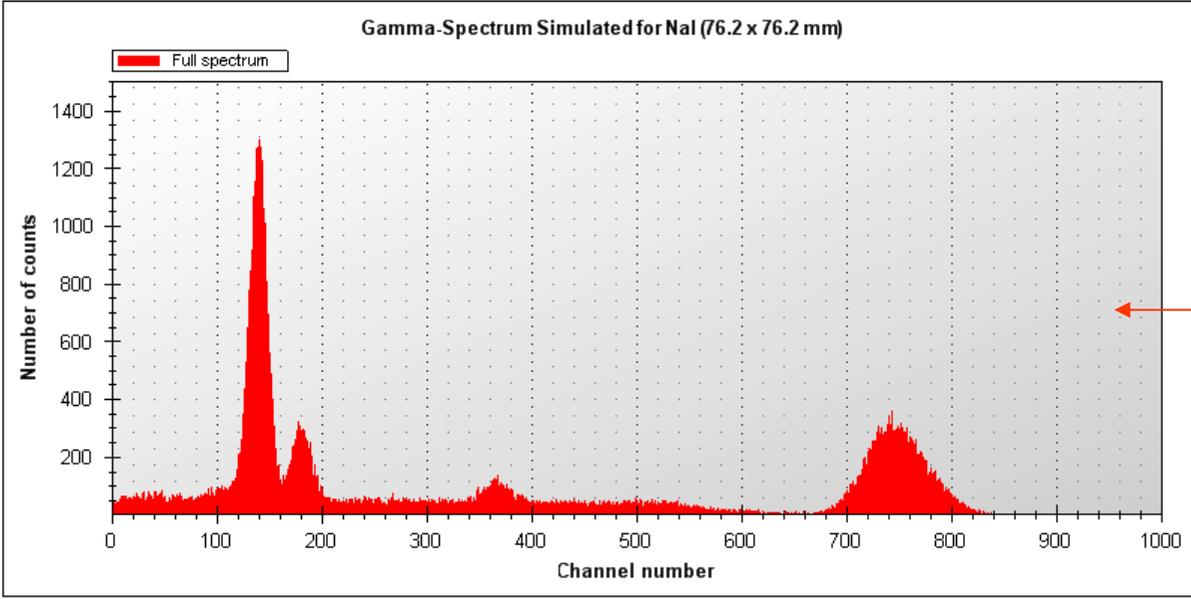
Decay calculations can be enabled that will allow contributions from decay products, being accumulated during source cooling and spectrum measurement time intervals

Features implemented: Calculation results

Measurement setup | **Calculation results** | Options

Data displayed: Statistical number of counts

Gamma-Spectrum Simulated for NaI (76.2 x 76.2 mm)



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	<input type="checkbox"/>
2	43 Tc 99	6.70E-15	6.79E-15	0.00E+00	<input type="checkbox"/>
3	43 Tc 99m	2.69E+01	2.68E+01	2.70E+04	<input type="checkbox"/>
Total		8.92E+01	8.90E+01	8.97E+04	

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

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

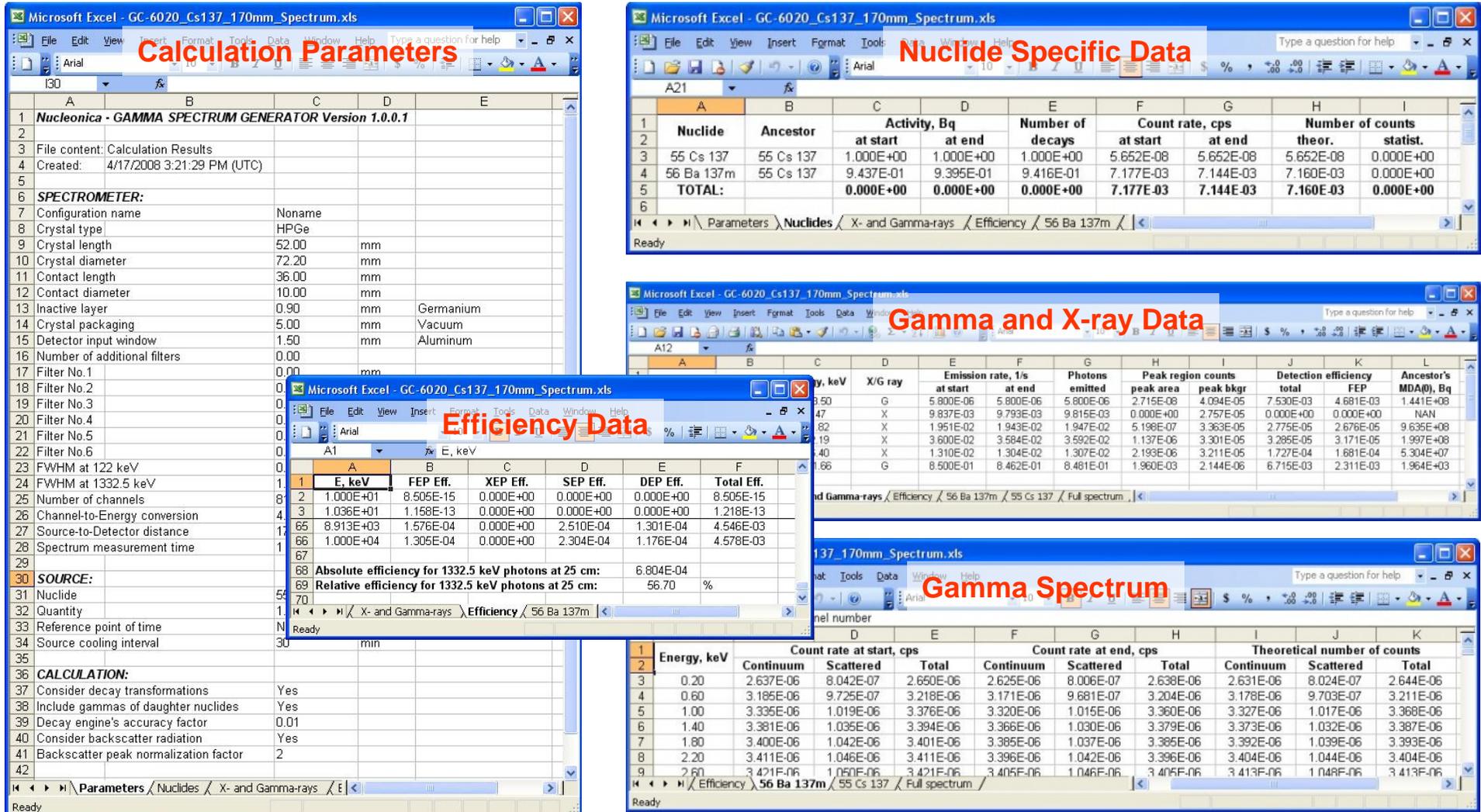
Right click within the graph area enables a context menu, from which one can print or download the spectrum graph

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 Parameters

Nucleonica - GAMMA SPECTRUM GENERATOR Version 1.0.0.1			
File content:	Calculation Results		
Created:	4/17/2008 3:21:29 PM (UTC)		
SPECTROMETER:			
Configuration name	Noname		
Crystal type	HPGe		
Crystal length	52.00	mm	
Crystal diameter	72.20	mm	
Contact length	36.00	mm	
Contact diameter	10.00	mm	
Inactive layer	0.90	mm	Germanium
Crystal packaging	5.00	mm	Vacuum
Detector input window	1.50	mm	Aluminum
Number of additional filters	0.00		
Filter No.1	0.00		
Filter No.2	0.00		
Filter No.3	0.00		
Filter No.4	0.00		
Filter No.5	0.00		
Filter No.6	0.00		
FWHM at 122 keV	0.00		
FWHM at 1332.5 keV	0.00		
Number of channels	81		
Channel-to-Energy conversion	4.00		
Source-to-Detector distance	17.00		
Spectrum measurement time	28.00		
SOURCE:			
Nuclide	55 Cs 137		
Quantity	1.00		
Reference point of time	N		
Source cooling interval	30 min		
CALCULATION:			
Consider decay transformations	Yes		
Include gammas of daughter nuclides	Yes		
Decay engine's accuracy factor	0.01		
Consider backscatter radiation	Yes		
Backscatter peak normalization factor	2		

Nuclide Specific Data

Nuclide	Ancestor	Activity, Bq		Number of decays	Count rate, cps		Number of counts	
		at start	at end		at start	at end	theor.	statist.
55 Cs 137	55 Cs 137	1.000E+00	1.000E+00	1.000E+00	5.652E-08	5.652E-08	5.652E-08	0.000E+00
56 Ba 137m	55 Cs 137	9.437E-01	9.395E-01	9.416E-01	7.177E-03	7.144E-03	7.160E-03	0.000E+00
TOTAL:		0.000E+00	0.000E+00	0.000E+00	7.177E-03	7.144E-03	7.160E-03	0.000E+00

Gamma and X-ray Data

Energy, keV	X/G ray	Emission rate, 1/s		Photons emitted	Peak region counts		Detection efficiency total	Ancestor's MDA(0), Bq
		at start	at end		peak area	peak bkg		
350	G	5.800E-06	5.800E-06	5.800E-06	2.715E-08	4.094E-05	7.530E-03	4.681E-03
47	X	9.837E-03	9.793E-03	9.815E-03	0.000E+00	2.757E-05	0.000E+00	NAN
82	X	1.951E-02	1.943E-02	1.947E-02	5.198E-07	3.363E-05	2.775E-05	2.676E-05
119	X	3.600E-02	3.584E-02	3.592E-02	1.137E-06	3.301E-05	3.285E-05	3.171E-05
140	X	1.310E-02	1.304E-02	1.307E-02	2.193E-06	3.211E-05	1.727E-04	1.681E-04
186	G	8.500E-01	8.462E-01	8.481E-01	1.960E-03	2.144E-06	6.715E-03	2.311E-03

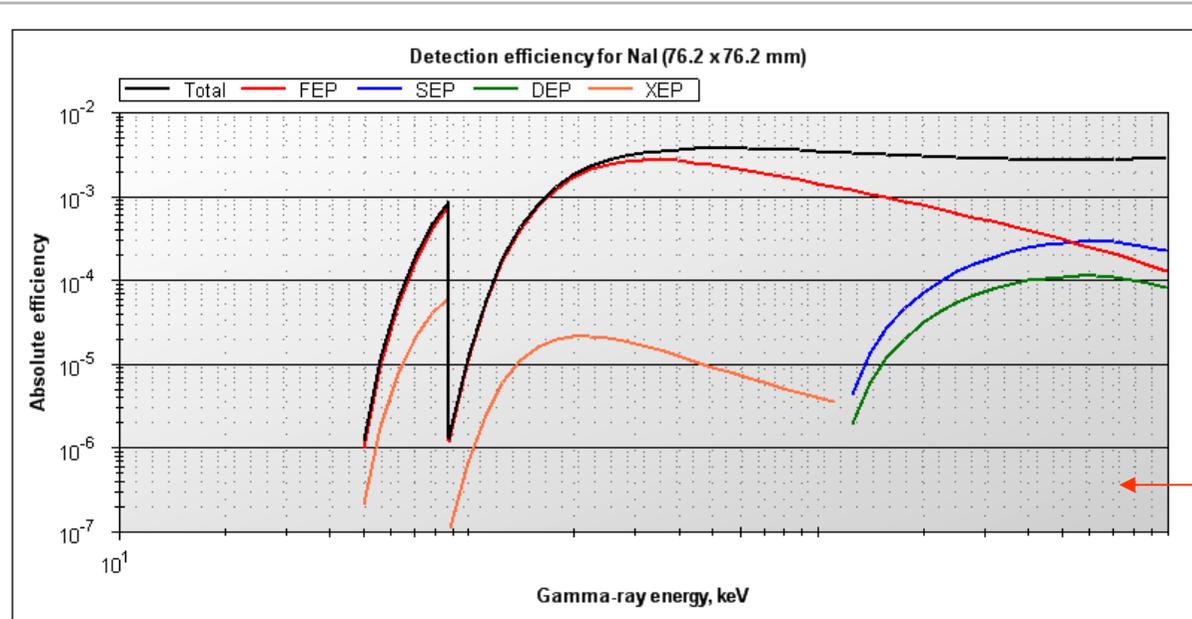
Efficiency Data

E, keV	FEP Eff.	XEP Eff.	SEP Eff.	DEP Eff.	Total Eff.
1.000E+01	8.505E-15	0.000E+00	0.000E+00	0.000E+00	8.505E-15
1.036E+01	1.158E-13	0.000E+00	0.000E+00	0.000E+00	1.218E-13
85.8913E+03	1.576E-04	0.000E+00	2.510E-04	1.301E-04	4.546E-03
1.000E+04	1.305E-04	0.000E+00	2.304E-04	1.176E-04	4.578E-03
Absolute efficiency for 1332.5 keV photons at 25 cm:					6.804E-04
Relative efficiency for 1332.5 keV photons at 25 cm:					56.70 %

Gamma Spectrum

Energy, keV	Count rate at start, cps			Count rate at end, cps			Theoretical number of counts		
	Continuum	Scattered	Total	Continuum	Scattered	Total	Continuum	Scattered	Total
0.20	2.637E-06	8.042E-07	2.650E-06	2.625E-06	8.006E-07	2.638E-06	2.631E-06	8.024E-07	2.644E-06
0.60	3.185E-06	9.725E-07	3.218E-06	3.171E-06	9.681E-07	3.204E-06	3.178E-06	9.703E-07	3.211E-06
1.00	3.335E-06	1.019E-06	3.376E-06	3.320E-06	1.015E-06	3.360E-06	3.327E-06	1.017E-06	3.368E-06
1.40	3.381E-06	1.035E-06	3.394E-06	3.366E-06	1.030E-06	3.379E-06	3.373E-06	1.032E-06	3.387E-06
1.80	3.400E-06	1.042E-06	3.401E-06	3.385E-06	1.037E-06	3.385E-06	3.392E-06	1.039E-06	3.393E-06
2.20	3.411E-06	1.046E-06	3.411E-06	3.396E-06	1.042E-06	3.396E-06	3.404E-06	1.044E-06	3.404E-06
2.60	3.421E-06	1.050E-06	3.421E-06	3.405E-06	1.046E-06	3.405E-06	3.413E-06	1.046E-06	3.413E-06

Calculation results : Detection Efficiency



Update efficiency graph

Efficiencies displayed: Full Energy Peak (FEP) Single Escape Peak (SEP) Total
 X-ray Escape Peak (XEP) Double Escape Peak (DEP) More graph options

X-axis settings:		Y-axis settings:	
Scale	Tick steps	Scale	Tick steps
<input checked="" type="checkbox"/> Auto <input checked="" type="checkbox"/> Log	<input checked="" type="checkbox"/> Auto	<input checked="" type="checkbox"/> Auto <input checked="" type="checkbox"/> Log	<input checked="" type="checkbox"/> Auto
Minimum: 10	Major step: 1000	Minimum: 0	Major step: 0.01
Maximum: 10000	Substeps No: 5	Maximum: 1.00	Substeps No: 5
Grid lines	Ticks	Grid lines	Ticks
<input checked="" type="checkbox"/> Major <input checked="" type="checkbox"/> Minor	<input checked="" type="checkbox"/> In <input checked="" type="checkbox"/> Out <input checked="" type="checkbox"/> Labels	<input checked="" type="checkbox"/> Major <input checked="" type="checkbox"/> Minor	<input checked="" type="checkbox"/> In <input checked="" type="checkbox"/> Out <input checked="" type="checkbox"/> Labels

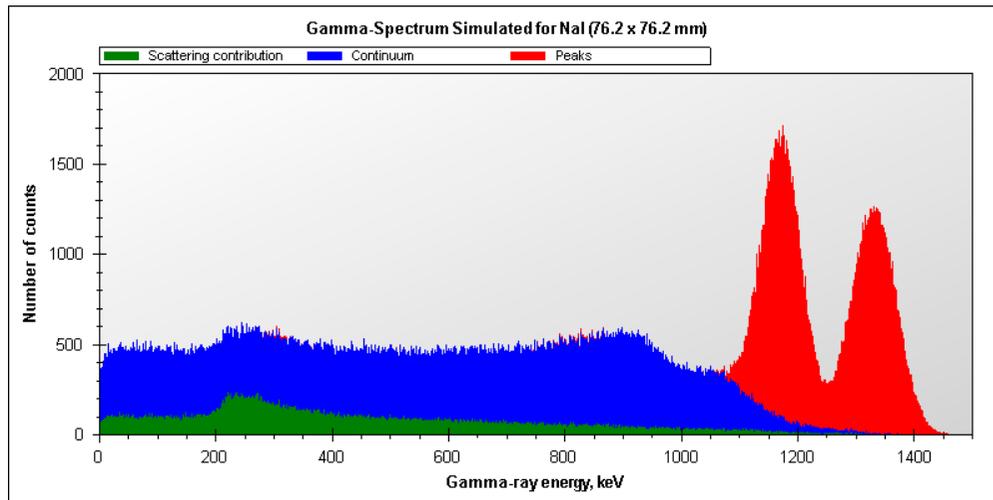
Select efficiency data to be displayed on the graph

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

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

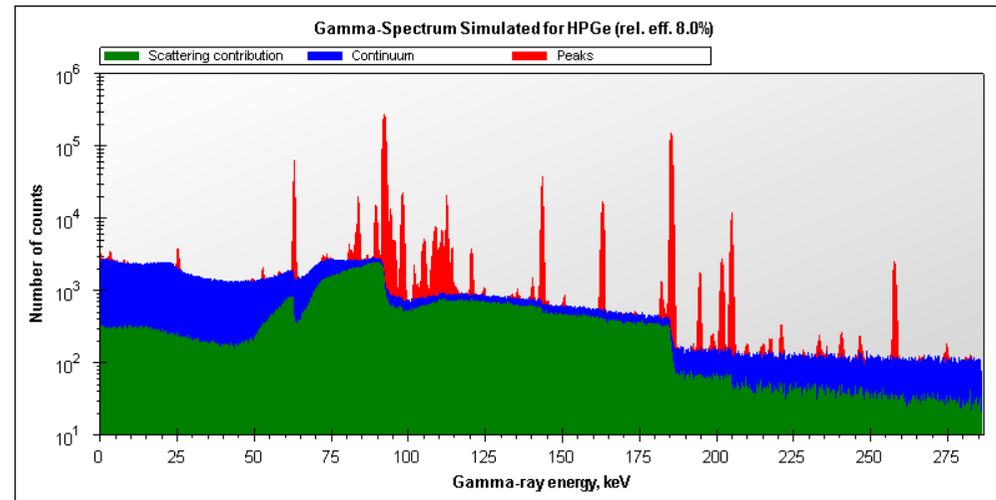
Examples:

100 kBq ^{60}Co



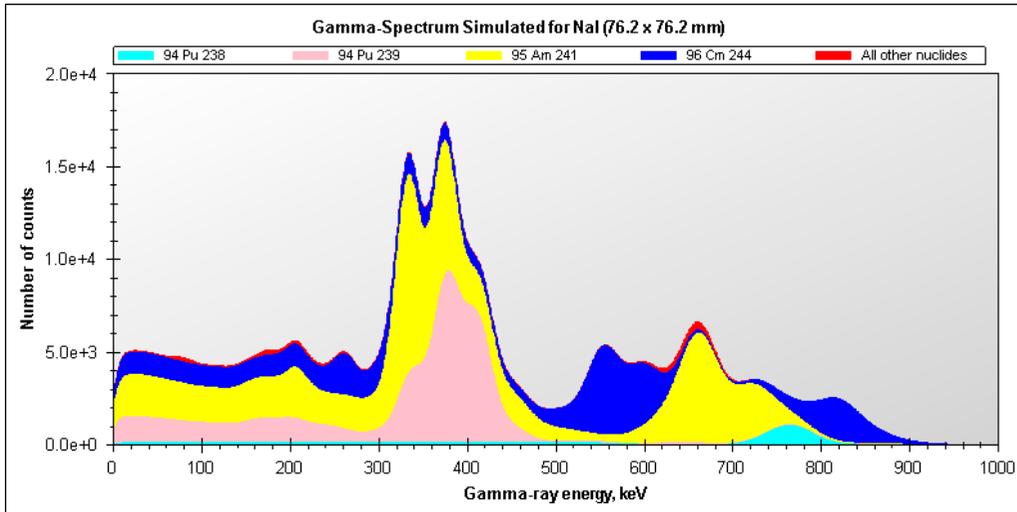
Detector - NaI ($\varnothing 3'' \times 3''$)
Source-to-detector distance - 25 cm
Measurement time - 1000 s

1 g Nat U (2 years after separation)

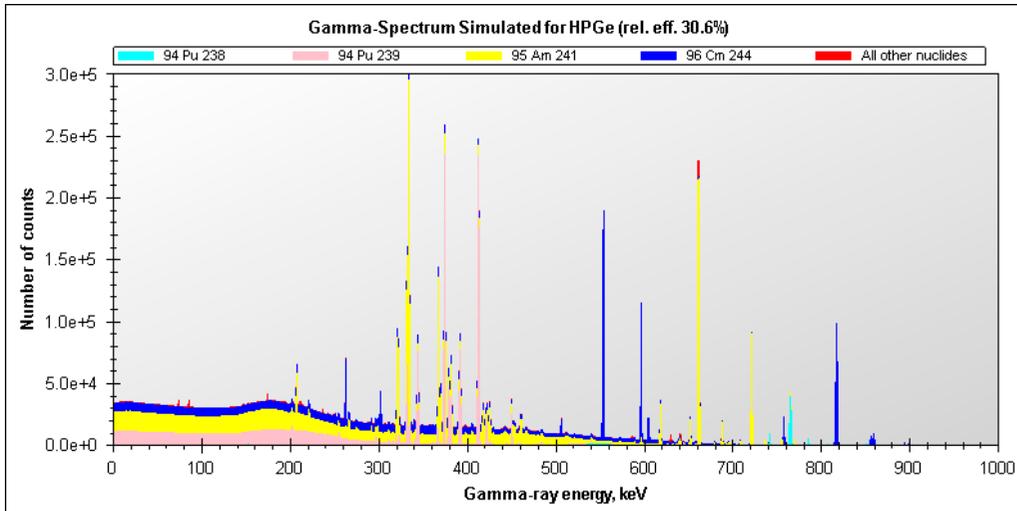


Detector – LEGe (20 mm \times 2800 mm²)
Source-to-detector distance – 25 mm
Filter – 0.5 mm Sn
Measurement time - 10^5 s

Examples:



Detector – NaI (Ø3"×3")
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

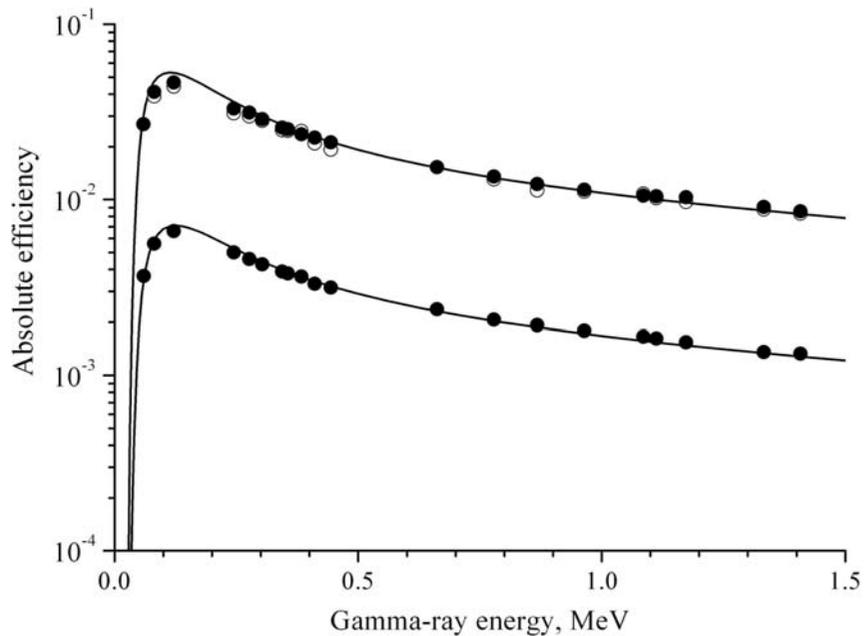


Actinides extracted from 1 kg 6-year-aged PWR spent fuel. Activity - 5.25 TBq

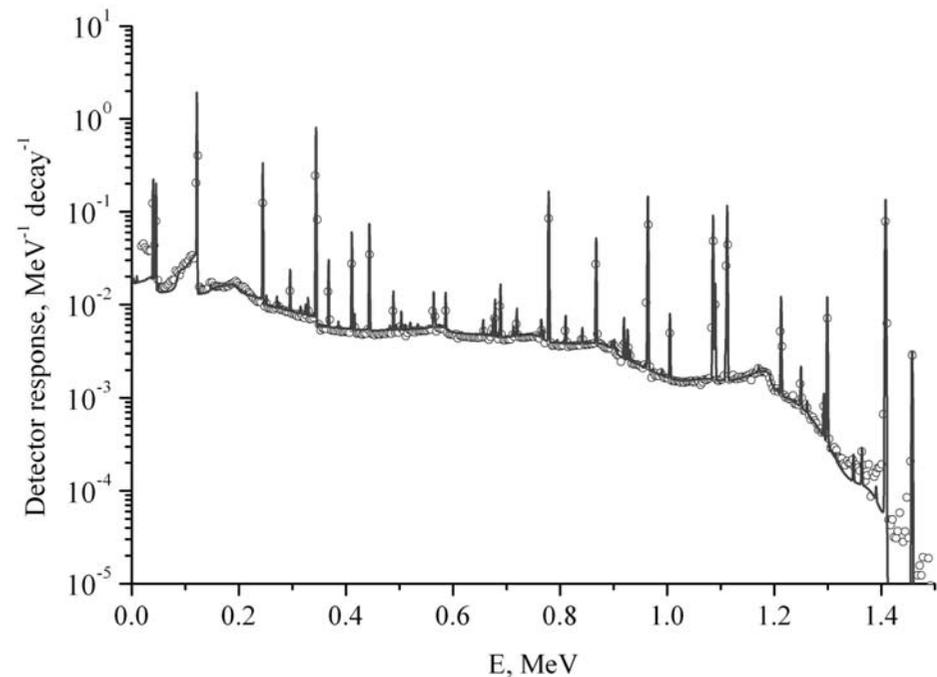
Detector – BEGe (30% rel. eff.)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

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

Co60

10.47 m 5.27 y

easyMonteCarlo

27 Cobalt

Actual chart: Karlsruhe

Dosimetry & Shielding with Neutrons & Gammas

Version: 2008.09.24 07:05:08

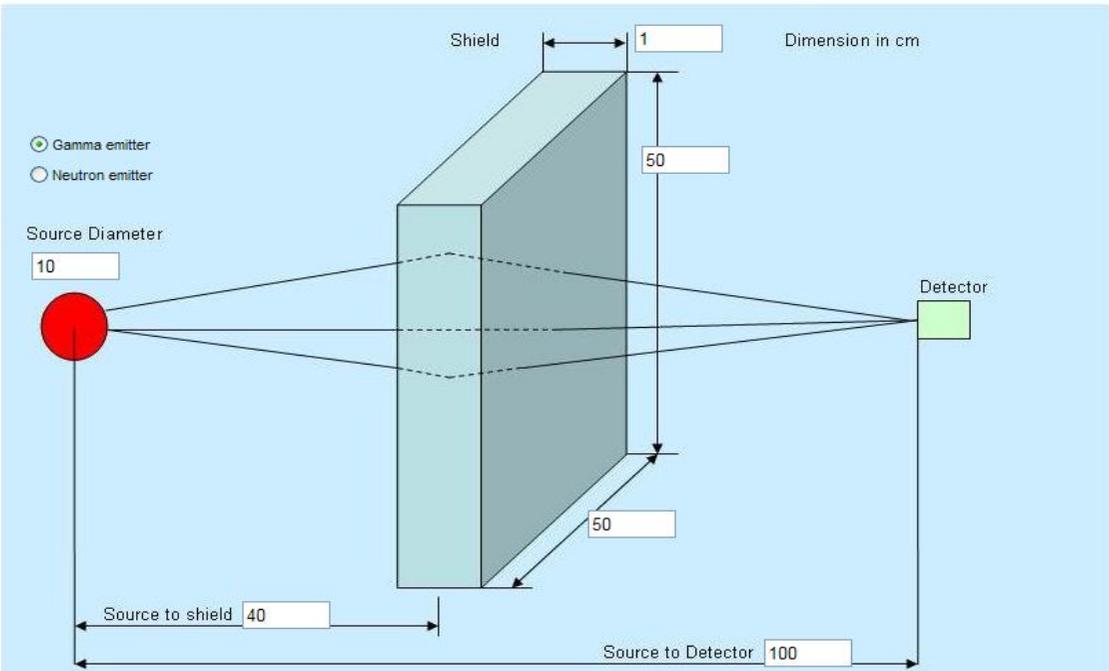
Element	Co	Mass	60	Mixture selector		Shield		Detector	
	<input type="text" value="Co"/>		<input type="text" value="60"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="radio"/> Compound	<input type="text" value="Paraffin"/>	<input type="radio"/> Particle flux	<input type="radio"/>
	<input type="text" value="1E+06"/>		<input type="text" value="1E+06"/>	<input type="checkbox"/>	<input checked="" type="radio"/> Element	<input type="radio"/>	<input type="text" value="Pb"/>	<input checked="" type="radio"/> Dose rate	<input type="radio"/>

Geometry
Source Options
Results
Input Parameters
Service Output

Gamma emitter

Neutron emitter

Source Diameter



Shield 1 Dimension in cm

50

50

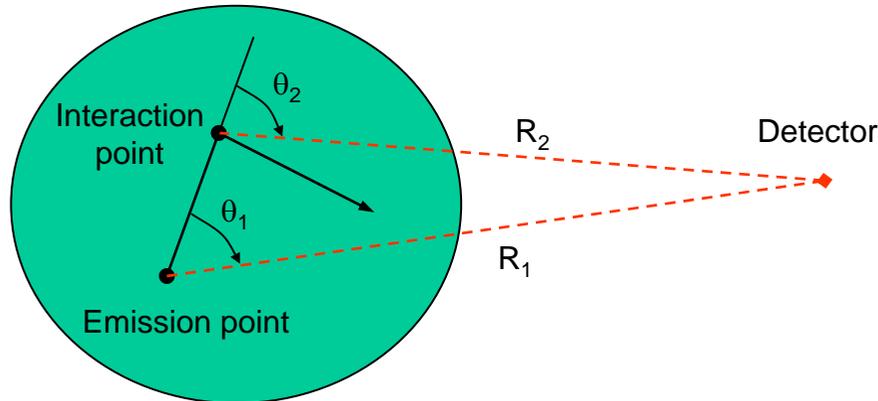
Source to shield 40

Source to Detector 100

Detector

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.



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**.

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

$p(\mu)$ – 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.



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 LaBr₃ 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 !

nucleonica 