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eriss HPGe detector calibration

J Pfitzner

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Supervising Scientist Division

GPO Box 461, Darwin NT 0801

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Author of this report:

John Pfitzner – Environmental Research Institute of the Supervising Scientist, GPO Box 461, Darwin NT 0801, Australia.

Additional contact: Andreas Bollhöfer, Program Leader, Environmental Radioactivity, Environmental Research Institute of the Supervising Scientist, GPO Box 461, Darwin NT 0801, Australia.

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Supervising Scientist
Department of Sustainability, Environment, Water, Population and Communities
GPO Box 461, Darwin NT 0801 Australia

e-mail: publications_ssd@environment.gov.au

Internet: www.environment.gov.au/ssd (www.environment.gov.au/ssd/publications)

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Executive summary

The Environmental Radioactivity Group (EnRad) of the Supervising Scientist Division (SSD) has undertaken a comprehensive calibration of their High Purity Germanium (HPGe) gamma spectroscopy system.

Three detectors have been calibrated for five different geometries (sample types) holding sample masses of less than a gram up to 150 grams. This IR documents the calibration procedure, the methods of calculation and the results of the system calibration.

eriss HPGe detector calibration

J Pfitzner

Introduction

The Environmental Radioactivity (EnRad) Group in the Supervising Scientist Division (SSD) operates several High Purity Germanium (HPGe) detectors for the determination of radionuclide activity concentration by gamma spectroscopy analysis. Samples are analysed for naturally occurring radionuclides of the uranium and thorium decay series and ^{40}K, as well as for the nuclear bomb fallout isotope ^{137}Cs. These analyses are done for internal research projects and on a consultancy basis for external clients.

For quality assurance purposes, routine background and calibration checks are conducted to ensure that the instruments are operating within specifications, and to ensure that accurate results for these analyses are reported. Replacing hardware or making adjustments to instrument settings can cause significant changes to the calibration. Recent changes to the hardware triggered the need to do the calibration described in this document. All three detectors (detectors N, G and O) in current use were calibrated.

Samples are prepared in one of several ‘geometries’. Each geometry is assigned an identifying letter. The ‘geometries’ are designed to ensure consistentcy in the shape and quantity of sample presented to the detector. The samples are either confined within a plastic container (geometries ‘Q’ and ‘R’) or cast in polyester resin (geometries ‘A’, ‘B’ and ‘V’). The calibration was done for all five geometries for each of the three detectors.

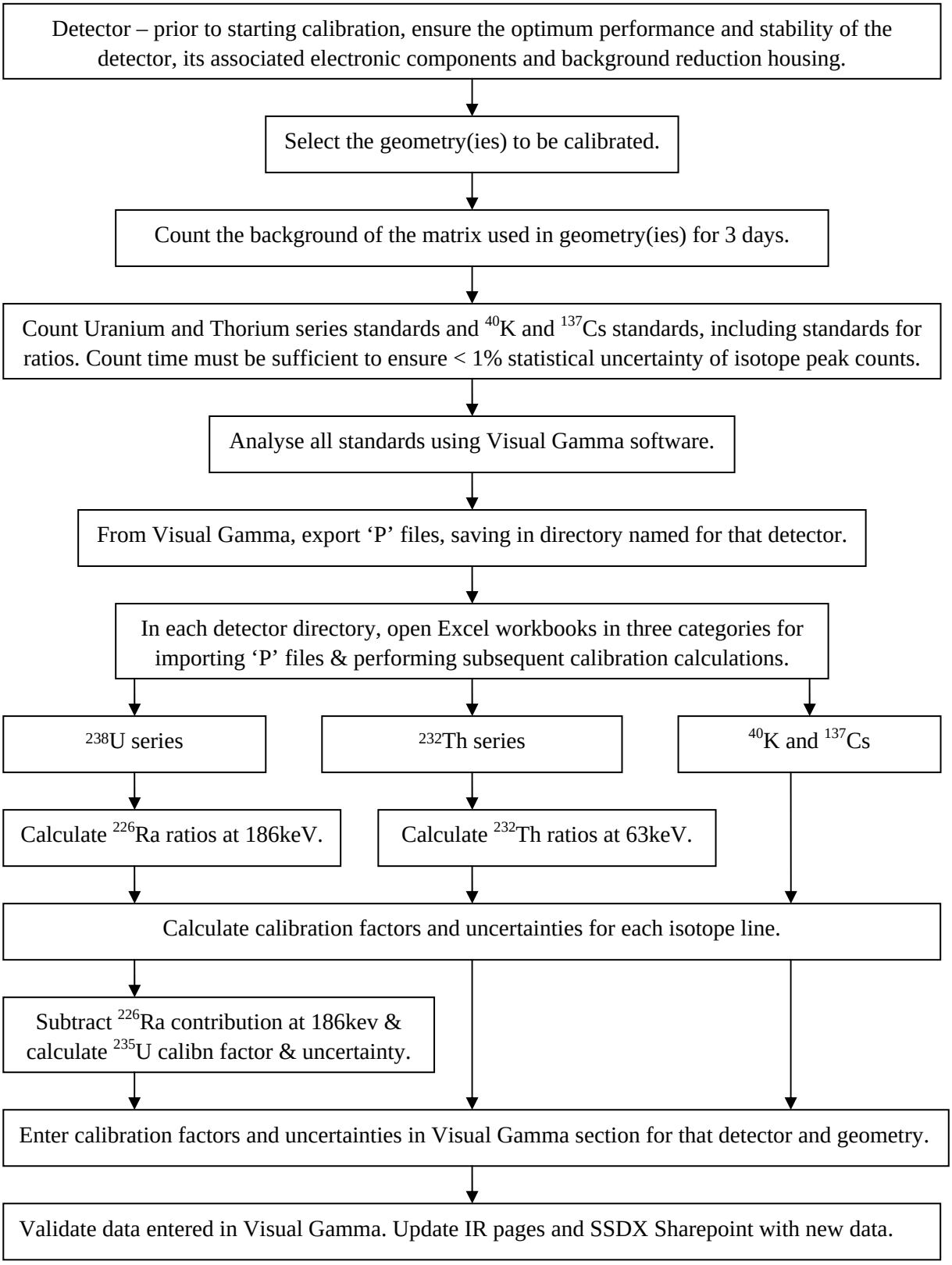
The range of geometries allows for optimisation of counting for a variety of sample sizes and types. Geometries ‘A’ and ‘V’ are ideal for organic material, such as dried or ashed leaf litter or mussel flesh. Geometries ‘B’, ‘Q’ and ‘R’ are for sediments and soils and similar inorganic materials. For a more complete description of these geometries, see Appendix 1 Table of Geometry Designations, Sizes and Sample Types.

Specific radionuclide standards are prepared for each geometry. The standards are grouped in their naturally occurring ^{238}U and ^{232}Th series. Separate standards are prepared for ^{40}K and ^{137}Cs. To reduce statistical uncertainty, the activity of the standards are such that a one day count will ensure an uncertainty of less than 1% in counting statistics alone. This level of activity also ensures that the instrument background count rate is less than 0.5% of the standard activity count rate.

Standards are prepared in batches of three, to allow measurement of systematic uncertainty. Standards are typically counted for one day, whereas backgrounds are counted for three days, usually over a weekend.

The calibration and calculation procedures

Calibration flow chart



Calculations in Visual Gamma

The program *Visual Gamma* developed in-house is used to operate the detector systems; starting and stopping counting, as well as performing the spectrum analyses. The Visual Gamma Operator's Manual (Esparon & Pfitzner 2010) describes the calculation procedures for radionuclide analysis in Appendices B: S*ources of uncertainty and propagation of uncertainty equations*, C: *Equations for the calculation of weighted average* and D: *Peak area and uncertainties by end point averaging.*

For calibration, the results of the calculation of standard and matrix and/or instrument background count rates, less continuum background, are required. At an intermediate stage of the analysis process, *Visual Gamma* produces a 'P' file which contains the desired count data, and count time in kiloseconds, for calibration calculations. Fig. 1 shows a typical 'P' file.

These 'P' files are read into an Excel spreadsheet, in which all relevant counting details are retained for Quality Assurance. Isotope line count data and associated uncertainty values are copied into the Excel sheet columns for manipulation. The copying process does not separate the 'live' count time of the standard or background from text, so this value , in ksec, must be manually entered in separate cells, identified by a label 'ksec' in an adjacent cell.

The 'P' file count data for each isotope line are :

(1) the end point averaged counts for the peak region of interest (ROI) range of channels, with the continuum, ie the average counts of the left and right background ROI channels adjacent to the peak, subtracted.

$$A = P - \frac{n}{2}\left(\frac{B_1}{n_1} + \frac{B_2}{n_2}\right)$$

where A is the end point averaged counts, P is the total counts within the peak ROI of n channels, and B_1 and B_2 are the total counts in the adjacent background ROIs of n_1 and n_2 channels respectively.

(2) the 1 standard deviation uncertainty associated with the above calculations is calculated using:

$$\sigma A = \sqrt{\left[P + \left(\frac{n}{2}\right)^2\left(\frac{B_1}{n_1^2} + \frac{B_2}{n_2^2}\right)\right]}$$

Usually three standards of each radionuclide series in each geometry are counted on each detector. In some cases there is only one standard for a particular radionuclide in that geometry, eg ^{137}Cs in A, B and V geometries.

The Excel worksheets for all the 'P' file results for one radionuclide series (U, Th, ^{40}K or ^{137}Cs) in one geometry (A, B, V, Q or R) for one detector (N, G or O) are in one Excel file. For example Det-G-Geom-Q-Th-Cal.xls contains the calibration data for detector 'G', geometry 'Q', ^{232}Th calibration. This naming convention is maintained for all detectors, geometries and radionuclides.

There are two sets of ratios calculated, the ratio of ^{232}Th in ^{234}Th at the 63 keV energy line and the ratio of ^{226}Ra in ^{235}U at the 186keV energy line. The 'P' files of ratio calculations are incorporated into the respective Th and U series Excel spreadsheets.

Latest calibration data are stored on SSDX Sharepoint in the following location: SSDX Equipment and Techniques > HPGe Gamma Spec > Calibrations > (year).

Spectrum File: ZV034o.01
Description : ZV034
Cal File : Cal9o.100
Analyst : John Pfitzner
MCB : 7
Start Time : 4/05/2010 1:13:42 PM
Live Time : 77388
Mass : 0.001996 kg

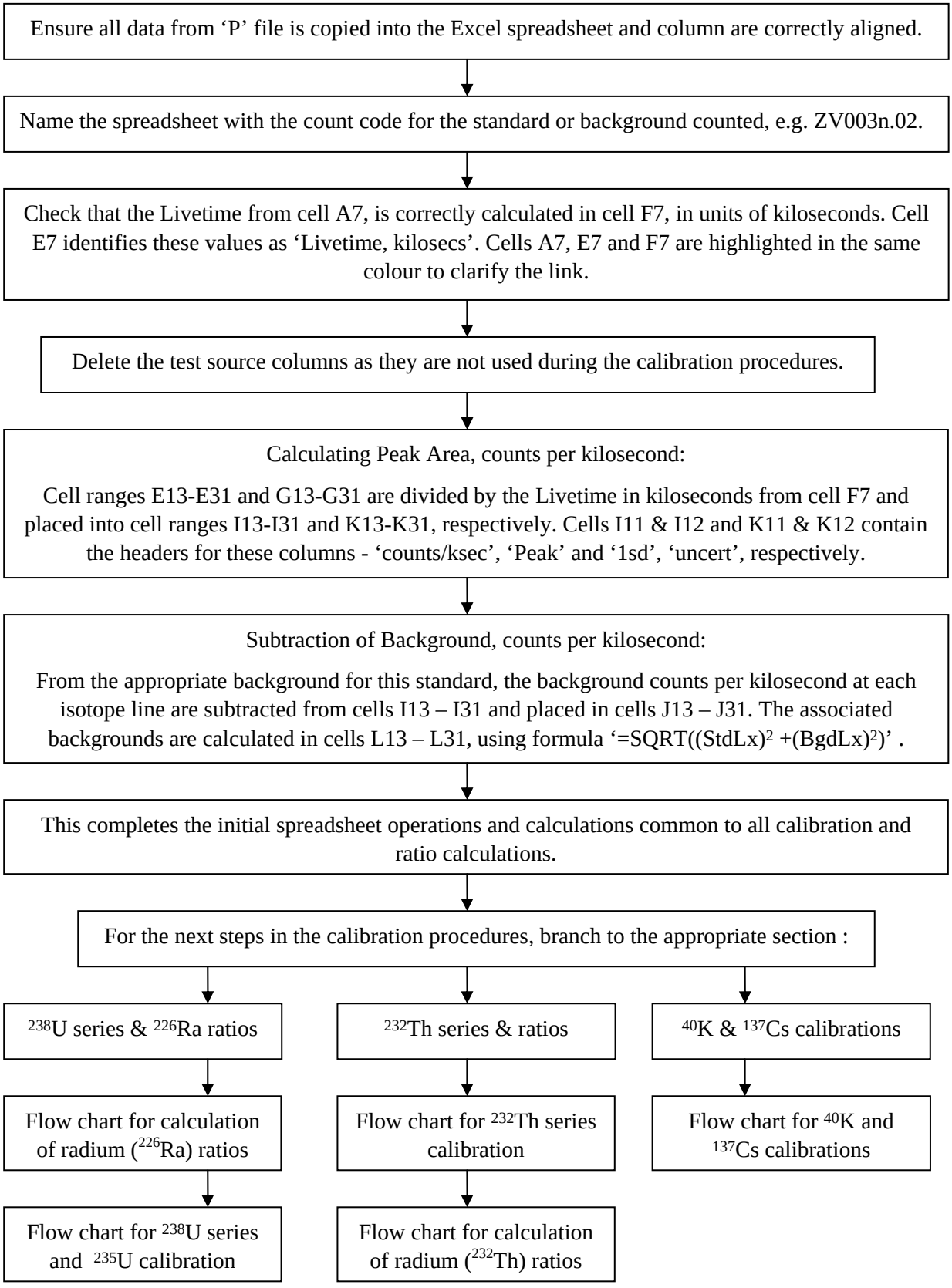
		Sample Counts		Test Source Counts	
Radio	Energy	Peak Area	1 StdDev	Peak Area	1 StdDev
Ra-223	270	217.50	78.52	733.50	40.80
Th-234	63	-65.83	112.15	65,016.50	272.16
Pa-234	1001	-31.44	35.58	3,126.50	56.42
Th-230	68	261.86	99.44	3,180.50	105.58
Ra-226	186	11,098.73	140.27	43,098.50	214.03
Pb-214	295	35,460.16	200.23	747.00	37.81
Pb-214	352	56,213.59	248.94	906.50	37.65
Bi-214	609	33,731.99	190.56	482.00	26.79
Pb-210	46	9,463.24	132.25	37,210.00	210.01
Ac-228	338	68.00	64.59	297.50	26.86
Ac-228	911	-51.17	44.85	51.50	10.52
Ac-228	969	-31.38	38.97	23.00	8.34
Ra-224	241	16,375.51	147.57	770.50	42.23
Pb-212	239	102.31	75.74	703.00	40.74
Bi-212	40	104.35	79.36	2,281.00	87.77
Tl-208	583	72.18	48.19	175.00	20.22
K-40	1461	5.18	27.41	5.00	3.94
Cs-137*	662	-25.18	45.12	143.50	19.06
Be-7	478	-68.07	51.16	174.50	23.39

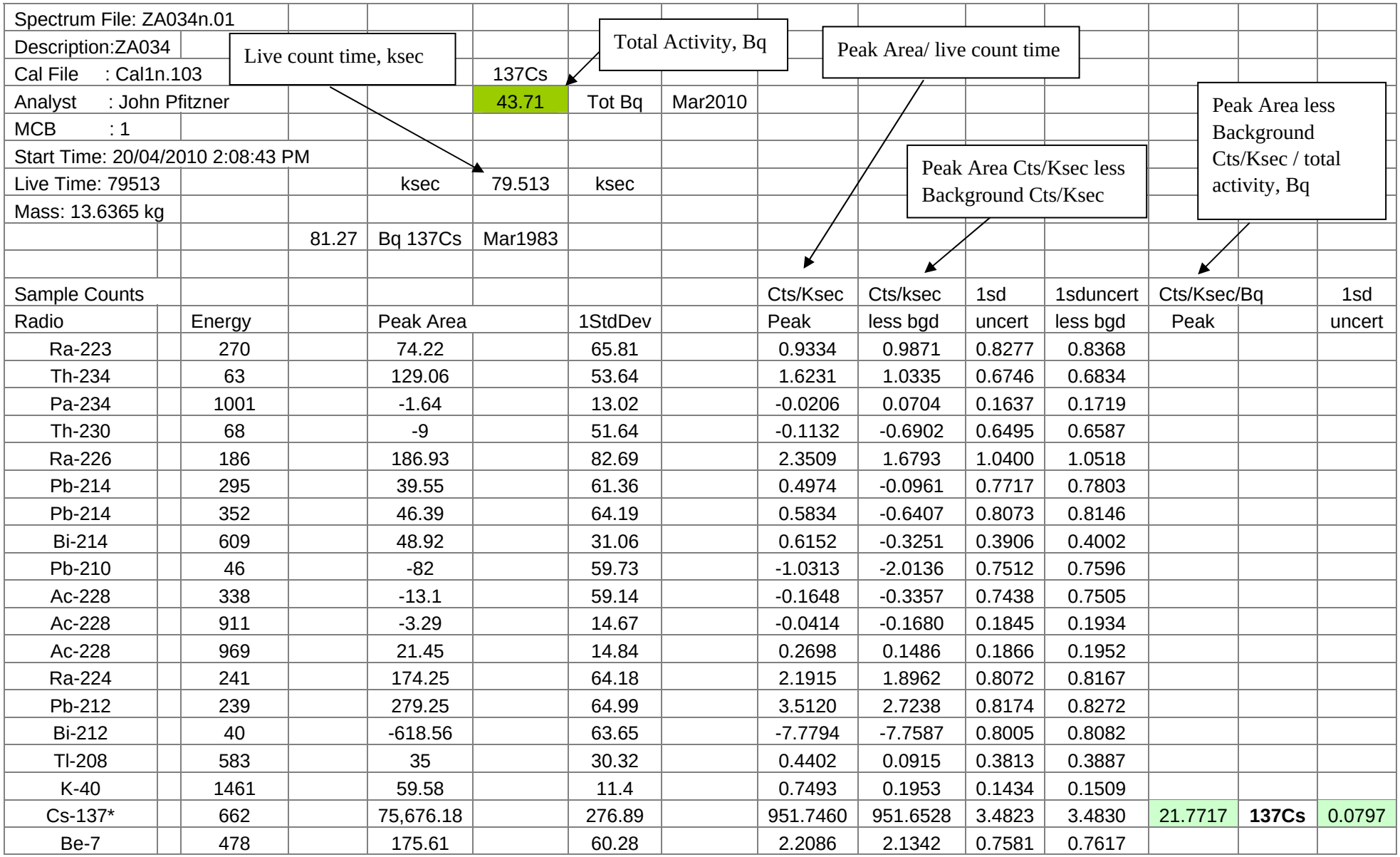
Radio	Energy	PEAK		Left Back		Right Back	
Ra-223	270	1428	1449	1418	1427	1493	1502
Th-234	63	347	360	341	346	361	367
Pa-234	1001	5328	5347	5319	5327	5372	5380
Th-230	68	371	382	364	370	383	389
Ra-226	186	1000	1016	990	999	1017	1025
Pb-214	295	1578	1596	1568	1577	1630	1638
Pb-214	352	1878	1900	1867	1877	1901	1911
Bi-214	609	3243	3267	3232	3242	3268	3279
Pb-210	46	261	273	254	260	274	279
Ac-228	338	1807	1824	1799	1806	1837	1845
Ac-228	911	4846	4871	4801	4813	4872	4883
Ac-228	969	5154	5178	5119	5131	5179	5191
Ra-224	241	1297	1313	1260	1267	1314	1322
Pb-212	239	1277	1293	1257	1264	1314	1321
Bi-212	40	224	234	217	223	235	240
Tl-208	583	3105	3127	3080	3090	3128	3138
K-40	1461	7764	7784	7753	7763	7785	7795
Cs-137*	662	3521	3544	3510	3520	3563	3574
Be-7	478	2547	2567	2535	2546	2616	2628

Figure 1 A typical ‘P’ file, for radium ratio standard SV034 counted on detector ‘O’

Flow chart of initial calculations in Excel spreadsheets on 'P' file data

The instructions flowsheet below assumes that the operator uses the template files that have been previously prepared for the calibration process. These are located on the SSDX Sharepoint path: SSDX Equipment and Techniques > HPGe Gamma Spec > Calibrations. SSDX Sharepoint is the Division's electronic document management and retrieval system (EDRMS). A typical Excel worksheet for calculation of the calibration factor, Cts/Ksec/Bq for a ^{137}Cs standard in 'A' geometry on detector 'N' is shown in Figure 2.





Spectrum File: ZA034n.01													
Description:ZA034													
Cal File : Cal1n.103				137Cs									
Analyst : John Pfitzner				43.71	Tot Bq	Mar2010							
MCB : 1													
Start Time: 20/04/2010 2:08:43 PM													
Live Time: 79513			ksec	79.513	ksec								
Mass: 13.6365 kg													
		81.27	Bq 137Cs	Mar1983									
Sample Counts							Cts/Ksec	Cts/ksec	1sd	1sduncert	Cts/Ksec/Bq		1sd
Radio	Energy		Peak Area		1StdDev		Peak	less bgd	uncert	less bgd	Peak		uncert
Ra-223	270		74.22		65.81		0.9334	0.9871	0.8277	0.8368			
Th-234	63		129.06		53.64		1.6231	1.0335	0.6746	0.6834			
Pa-234	1001		-1.64		13.02		-0.0206	0.0704	0.1637	0.1719			
Th-230	68		-9		51.64		-0.1132	-0.6902	0.6495	0.6587			
Ra-226	186		186.93		82.69		2.3509	1.6793	1.0400	1.0518			
Pb-214	295		39.55		61.36		0.4974	-0.0961	0.7717	0.7803			
Pb-214	352		46.39		64.19		0.5834	-0.6407	0.8073	0.8146			
Bi-214	609		48.92		31.06		0.6152	-0.3251	0.3906	0.4002			
Pb-210	46		-82		59.73		-1.0313	-2.0136	0.7512	0.7596			
Ac-228	338		-13.1		59.14		-0.1648	-0.3357	0.7438	0.7505			
Ac-228	911		-3.29		14.67		-0.0414	-0.1680	0.1845	0.1934			
Ac-228	969		21.45		14.84		0.2698	0.1486	0.1866	0.1952			
Ra-224	241		174.25		64.18		2.1915	1.8962	0.8072	0.8167			
Pb-212	239		279.25		64.99		3.5120	2.7238	0.8174	0.8272			
Bi-212	40		-618.56		63.65		-7.7794	-7.7587	0.8005	0.8082			
Tl-208	583		35		30.32		0.4402	0.0915	0.3813	0.3887			
K-40	1461		59.58		11.4		0.7493	0.1953	0.1434	0.1509			
Cs-137*	662		75,676.18		276.89		951.7460	951.6528	3.4823	3.4830	21.7717	**137Cs**	0.0797
Be-7	478		175.61		60.28		2.2086	2.1342	0.7581	0.7617			

Figure 2 Worksheet for calculation of the calibration factor, Cts/Ksec/Bq for a ^{137}Cs standard in 'A' geometry on detector 'N'

Calculations in the Excel spreadsheet

The calculations described below use the 'net count rate' of the *standard*. The net rate is the difference between the counts per kilosecond of the *standard* from the 'P' file (from which the continuum background has already been subtracted) and the *background*, also in units of counts per kilosecond. The *background* may be a count of either a *matrix* material (eg Flying Fox sand or dried beef) or the *instrument* background. Matrix materials must be prepared in the same geometry and mass as the standard they represent. The 1 standard deviation (1 s.d.) uncertainty associated with this net count rate is calculated using the formula from the Visual Gamma Operator's Manual (Esparon & Pfitzner 2010) Appendix B: *Sources of uncertainty and propagation of uncertainty equations*.

$$s_y = \sqrt{a_1^2 s_{x_1}^2 + a_2^2 s_{x_2}^2}$$

where $y = a_1 x_1 - a_2 x_2$ (x_1 is uncertainty in a_1 and x_2 in a_2 and s_y is 1 s.d. uncertainty in y).

The total activity of the radionuclide in the standard is entered into a clearly labelled cell near the top of the worksheet. Particular attention must be paid to short lived isotopes, such as ^{137}Cs, where corrections for decay must be applied. Details of all ***eriss*** standards, including total activity, is maintained in the Excel spreadsheet 'All ***eriss*** gamma standards.xls', located at SSDX>Equipment and Techniques > HPGe Gamma Spec> Calibrations>Standards Listing.

If the standard is to be used only for ratios, the activity value is not used. In this case the next calculation is to select the specific cells for the ratio calculations. These are:

a) For the ratio of ^{232}Th in ^{234}Th at the 63 keV energy line the ratios used are

   63keV:338keV

   63keV:911keV and

   63keV:969keV.

b) For the ratio of ^{226}Ra in ^{235}U at the 186keV energy line the ratios used are

   186keV:295keV

   186keV:352keV and

   186keV:609keV.

The isotopes and energy lines for calibration of radionuclides in the U decay series are (see right):

^{238}U series Isotope	Line Energy (keV)
^{235}U	185.720
^{234}Th	63.300
^{234}Pa	1001*
^{230}Th	68*
^{226}Ra	186.211
^{214}Pb	295.224
^{214}Pb	351.932
^{214}Bi	609.312
^{210}Pb	46.539
^{214}Pb	241.997

(All line energies, except those marked with *, are obtained from the web site of the Nucleide Organisation, which maintains the latest updates of radionuclide data : http://www.nucleide.org/DDEP_WG/DDEPdata.htm)

The isotopes and energy lines for calibration of radionuclides in the Th-series are:

^{232}Th series Isotope	Line Energy (keV)
^{228}Ac	338.320
^{228}Ac	911.196
^{228}Ac	968.960
^{224}Ra	240.986
^{212}Pb	238.623
^{212}Bi	39.858
^{208}Tl	583.187

The isotopes and energy lines for calibration of radionuclides of the other routinely measured radionuclides are:

Nuclides Isotope	Line Energy (keV)
^{40}K	1460.822
^{137}Cs (^{m}Ba)	661.659

For each radionuclide line, the net count rate is divided by the total activty of that isotope in the standard. The result is counts per kilo second per Bq, the activity conversion factor. Uncertainties are propagated according to the formula found in the Visual Gamma Operator's Manual (Esparon & Pfitzner 2010) Appendix B. '*Sources of uncertainty and propagation of uncertainty equations*',

$$\frac{s_y}{y} = \sqrt{\left(\frac{s_{x_1}}{x_1}\right)^2 + \left(\frac{s_{x_2}}{x_2}\right)^2}$$

where $y = x_1 x_2$.

A summary worksheet contains the weighted average of the activity conversion factor for several standards (b, c, and d) of the same type in the same geometry on the same detector. The formula for calculating the weighted average, W_m, is:

$$W_m = \frac{\frac{b}{\delta b^2} + \frac{c}{\delta c^2} + \frac{d}{\delta d^2}}{\frac{1}{\delta b^2} + \frac{1}{\delta c^2} + \frac{1}{\delta d^2}}$$

where the values and their associated uncertainties are $b \pm \delta b$, $c \pm \delta c$ and $d \pm \delta d$,

and the propagated uncertainty in the weighted mean is

$$UncertW_m = \frac{1}{\sqrt{\frac{1}{\delta b^2} + \frac{1}{\delta c^2} + \frac{1}{\delta d^2}}}$$

The weighted averages and uncertainties for the isotope lines are tabulated for each radionuclide line in the series. The summary page also containes the weighted averages of the ratios for that series.

The systematic uncertainty is now added to the propagated uncertainty using the formula $s_y = \sqrt{a_1^2 s_{x_1}^2 + a_2^2 s_{x_2}^2}$ from above.

These systematic uncertainties are (Marten 1992):

Uranium (^{238}U) series	1.2%
Thorium (^{232}Th) series	1.5%
Others (^{137}Cs & ^{40}K)	2%

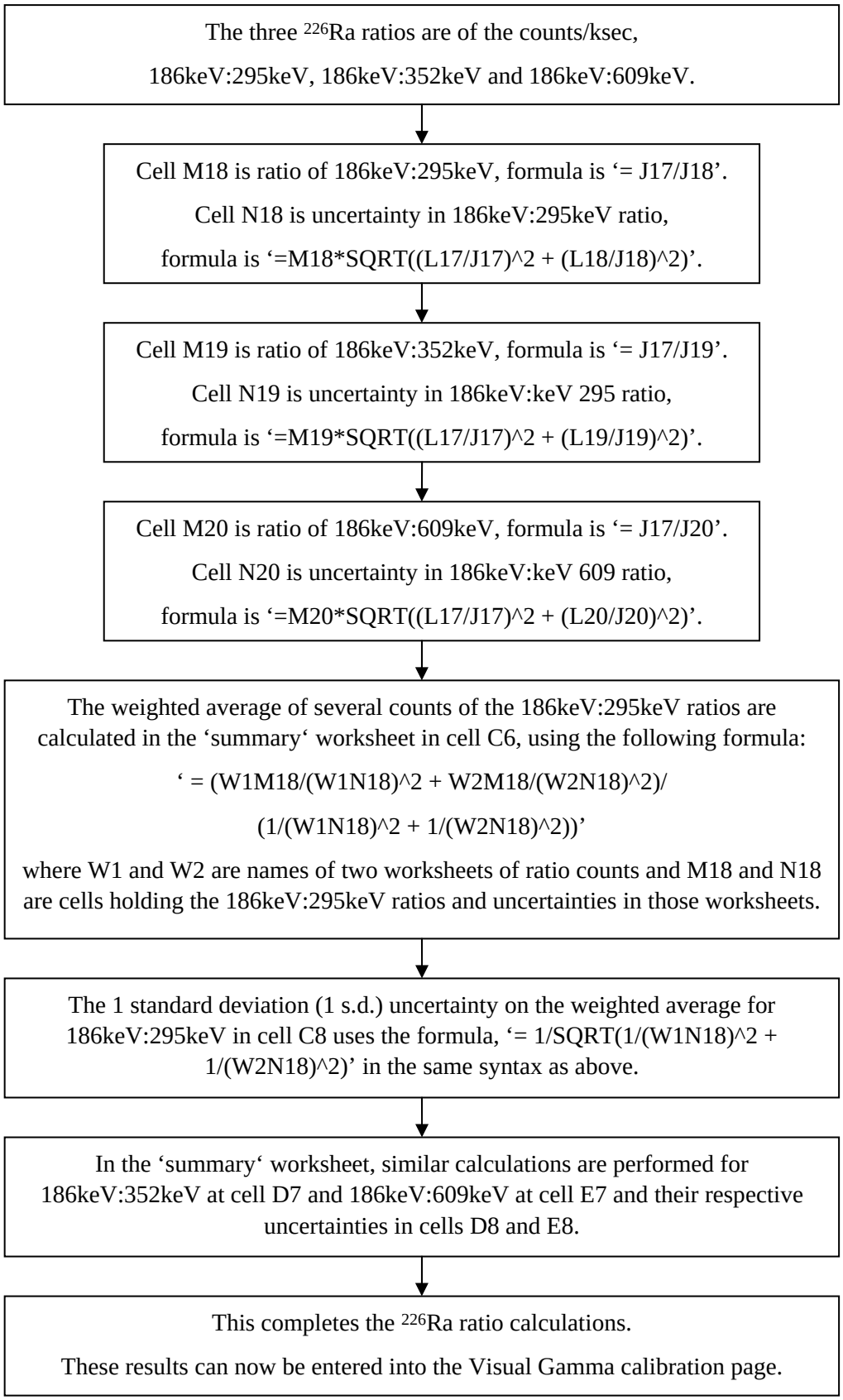
^{238}U calibration factor standards and ^{226}Ra ratio standards

eriss uses Canmet BL-5 as the standard reference material for ^{238}U series calibration. BL-5 is a uranium ore in secular equilibrium with its progeny and the activity concentration of BL-5 is accurately and precisely known.

The source material for ^{226}Ra can be one of several ^{226}Ra solutions which must not contain any ^{238}U uranium.

Flow chart of radium (^{226}Ra) ratio calculations

The ^{226}Ra ratio must be completed before calculating the ^{238}U calibration series as this ratio is used in the ^{235}U calibration at 186keV.



Flow chart of calculation for ^{238}U series and ^{235}U calibration

Details of all ***eriss*** standards, including total activity, is maintained in the Excel spreadsheet 'All ***eriss*** gamma standards.xls', located at SSDX>Equipment and Techniques > HPGe Gamma Spec> Calibrations>Standards Listing.

The total activity of the ^{238}U which is contained in the standard is entered into cells F4, in units of Bq. Cell E4 identifies these values as 'Total activity 238U, Bq'. Cells E4 and F4 are highlighted in the same colour to clarify their relationship.

The ^{235}U activity (natural activity ratio of ^{235}U:^{238}U of 0.046029 * ^{238}U) entered into cell I4, with the text, 'Total activity 235U, Bq', in cell H4 identifying the isotope. Cells H4 and I4 are highlighted in the same colour to clarify their relationship.

↓

Calculating Calibration Factor, counts per kilosecond per Bq:

Counts per kilosecond in cell ranges I13-I31 are divided by the Total Activity in Bq from cell F4 and placed into cell ranges M13-M31.

↓

Calculating Uncertainty on Calibration Factor, counts per kilosecond per Bq:

Counts per kilosecond uncertainties in cells K13-K31 are divided by the Total Activity in Bq from cell F4 and placed into cell range O13-O31.

↓

The ^{238}U series standards contains both ^{238}U and ^{235}U in their natural isotopic ratio. The only gamma emission line of ^{235}U suitable for calibration is at 185.720keV. There is no gamma emission line of ^{238}U which is suitable to use for calibration.

The 185.720keV line of ^{235}U is overlaid with counts from the 186.211keV line of ^{226}Ra, a decayed descendant of ^{238}U. Isotope peaks which are in such close proximity are beyond the resolution capacity of HPGe detectors, so an additional manual procedure is required to separate the contribution of two isotopes at the 186keV region.

Fig. 3 displays the section of an Excel spreadsheet containing the calculations for this procedure.

↓

Calculating the contribution of ^{226}Ra to the ^{235}U line at 186keV:

In the ^{238}U standard worksheet, the counts per kilosecond from cells M18, M19 and M20 are multiplied by the ratio from the 'summary' sheet cells C6, C7 and C8, and the results are placed in cells Q18, Q19 and Q20, respectively. The uncertainties are placed in cells S18, S19 and S20.

The weighted average of these contributions, in counts per kilosecond, is calculated in cell Q22 and the associated uncertainty in cell S22.

↓

Subtracting the ^{226}Ra contribution from the 186keV line:

In cell Q26, the weighted average of the ^{226}Ra contribution in cell Q22 is subtracted from the combined ^{226}Ra and ^{235}U at 186keV in cell I17 to give the ^{235}U at 186keV, all in units of counts per ksec. The associated uncertainties are calculated in cell S26, using the same units.

Calculating the calibration factor for ^{235}U at 186keV:

In cell Q30, the calibration factor for ^{235}U is calculated by dividing the counts per ksec from cell Q26 by the 'Total activity 235U, Bq' from cell H4. The associated uncertainty is calculated in cell S30 using the formula '= S26/H4'.

Calculation of ^{226}Ra calibration factor at 186keV:

In cell Q34, the calibration factor for ^{266}Ra is calculated by dividing the counts per ksec from cell Q22 by the 'Total activity 238U, Bq' from cell F4. The associated uncertainty is calculated in cell S34 using the formula '= S22/F4'.

The weighted average of the following calibration factors are calculated in the 'summary' sheet:

U-235 @ 186keV in cell D15 from cells Q30, associated uncertainty in cell E15 from cells S30

Th-63 @ 63keV in cell D16 from cells M14, associated uncertainty in cell E16 from cells O14

Pa-234 @ 1001keV in cell D17 from cells M15, associated uncertainty in cell E17 from cells O15

Th-230 @ 68keV in cell D18 from cells M16, associated uncertainty in cell E18 from cells O16

Ra-226 @ 186keV in cell D19 from cells Q34, associated uncertainty in cell E19 from cells S34

Pb-214 @ 242keV in cell D20 from cells M18, associated uncertainty in cell E20 from cells O18

Pb-214 @ 295keV in cell D21 from cells M19, associated uncertainty in cell E21 from cells O19

Bi-214 @ 609keV in cell D22 from cells M20, associated uncertainty in cell E22 from cells O20

Pb-210 @ 46keV in cell D23 from cells M21, associated uncertainty in cell E23 from cells O21

See Fig. 4

This completes the calculations for the ^{238}U series calibration.

These results can now be entered into the Visual Gamma calibration page.

	Cts/Ksec/Bq							
	Peak		uncert					
	0.739585		0.010612					
	5.459564		0.021811					
	0.152224		0.004682		From radium ratios			
	0.659348		0.01675		226Ra Contribution to 186kev			
	6.401413		0.020378		Cts/ksec		Uncert	
	11.87108		0.024049		1204.9		5.644739	
	19.21909		0.02996		1227.086		5.314179	
	11.74032		0.0232		1228.531		5.715505	
	5.481455		0.020314		Wtd Ave.			
	0.029694		0.007917		1220.392		3.204102	
	0.000369		0.005096					
	0.005775		0.004384		Net 235U at 186keV			
	5.614979		0.018243		Cts/ksec		uncert	
	0.034385		0.009511		486.2248		6.307214	
	0.049522		0.012998					
	-0.00365		0.004968		235U at 186keV			
	-0.00078		0.003335		Cts/ksec/Bq		uncert	
	0.001232		0.004804		1.823799		0.023658	
	0.006448		0.006696					
					226Ra at 186keV			
					Cts/ksec/Bq		uncert	
					4.577614		0.012018	

Figure 3 Excel worksheet showing the extra calculations required for ^{235}U calibration factor at 186keV

Det - G		Geom - Q				
	Radium Ratios:		**Combined**	**Counting**		
		wtd ave	**uncert 1sd**	**uncert 1sd**		
	186:295	0.38072	0.00161	0.00161		
	186:352	0.23949	0.00097	0.00097		
	186:609	0.39251	0.00165	0.00165		
		Using:	ZQ056g.01	ZQ055g.01	ZQ019g.01	
	Uranium Efficiencies:		**wtd ave**	**Combined**	**system**	**counting**
			Cts/ksec/Bq	**uncert 1sd**	**uncert 1.2%**	**uncert 1sd**
	U-235	**186**	41.57010	0.60936	0.49884	0.34997
	Th-234	**63**	5.41149	0.06668	0.06494	0.01515
	Pa-234	**1001**	0.15271	0.00373	0.00183	0.00324
	Th-230	**68**	0.62459	0.01377	0.00750	0.01155
	Ra-226	**186**	4.43826	0.05373	0.05326	0.00706
	Pb-214	**242**	5.45669	0.06668	0.06548	0.01260
	Pb-214	**295**	11.51723	0.13920	0.13821	0.01662
	Pb-214	**352**	18.68124	0.22513	0.22417	0.02074
	Bi-214	**609**	11.38448	0.13755	0.13661	0.01600
	Pb-210	**46**	5.43093	0.06669	0.06517	0.01414
		Using Stds:	ZQ049g.01	ZQ001g.06	ZQ003g.01	ZQ050g.01
	Updated:	235U @186 calib & uncert on 9 July 2010.				
	on:					
	Notes:					
	Systematic uncertainties (Marten 1992)					
	U: %	1.2				
	Th: %	2				
	all others %	1.5				

Figure 4 An Excel summary worksheet for U series isotopes on detector G, geometry Q. The highlighted cells are final values copied to the calibration page in Visual Gamma.

^{232}Th calibration factor standards and ratio standards

The standards for ^{232}Th ratio at 63keV must contain no uranium and the ^{232}Th series progeny must be in isotopic equilibrium for the calibration factors. The only source material currently available at ***eriss*** which contains no U is an ‘Amersham 1906 thorium nitrate’ solution. Prior to 2005, the activity concentration of this solution was considered accurately known and the solution was used for ^{232}Th series calibration factor standards as well as the ratio. Since 2005, due to a lack of confidence in the activity concentration, this solution has only been used to make ^{232}Th ratio standards. The current source material for ^{232}Th series calibration factor standards is the IAEA reference material RGTH-1 which contains a small amount of uranium and is therefore not suitable for the ^{232}Th ratios at 63keV.

Flow chart of ^{232}Th series calibration

This flow chart follows the initial calculations in the 'P' spreadsheet, see 'Flow Chart of Initial Calculations in Excel spreadsheets on 'P' file data' above.

Details of all ***eriss*** standards, including total activity, is maintained in the Excel spreadsheet 'All ERISS gamma standards.xls', located at SSDX>Equipment and Techniques > HPGe Gamma Spec> Calibrations>Standards Listing.

The total activity of the ^{232}Th which is contained in the standard is entered into cells F4, in units of Bq. Cell E4 identifies these values as 'Total activity 232Th, Bq'. Cells E4 and F4 are highlighted in the same colour to clarify their relationship.

↓

Calculating Calibration Factor, counts per kilosecond per Bq:

Counts per kilosecond in cell ranges J13 – J31 are divided by the Total Activity in Bq from cell F4 and placed into cell ranges M13 – M31.

↓

Calculating Uncertainty on Calibration Factor, counts per kilosecond per Bq:

Counts per kilosecond uncertainties in cells L13 – L31 are divided by the Total Activity in Bq from cell F4 and placed into cell range O13–O31.

↓

The weighted average of the following calibration factors are calculated in the 'summary' sheet:

^{228}Ac @ 338keV in cell D7 from cells M22, associated uncertainty in cell E7 from cells O22

^{228}Ac @ 911keV in cell D8 from cells M23, associated uncertainty in cell E8 from cells O23

^{228}Ac @ 969keV in cell D9 from cells M24, associated uncertainty in cell E9 from cells O24

^{224}Ra @ 241keV in cell D10 from cells M25, associated uncertainty in cell E10 from cells O25

^{212}Pb @ 239keV in cell D11 from cells M26, associated uncertainty in cell E11 from cells O26

^{212}Bi@ 40keV in cell D12 from cells M27, associated uncertainty in cell E12 from cells O27

^{208}Tl @ 583keV in cell D13 from cells M28, associated uncertainty in cell E13 from cells O28

See Fig. 5

↓

This completes the ^{232}Th calibration factor calculations.

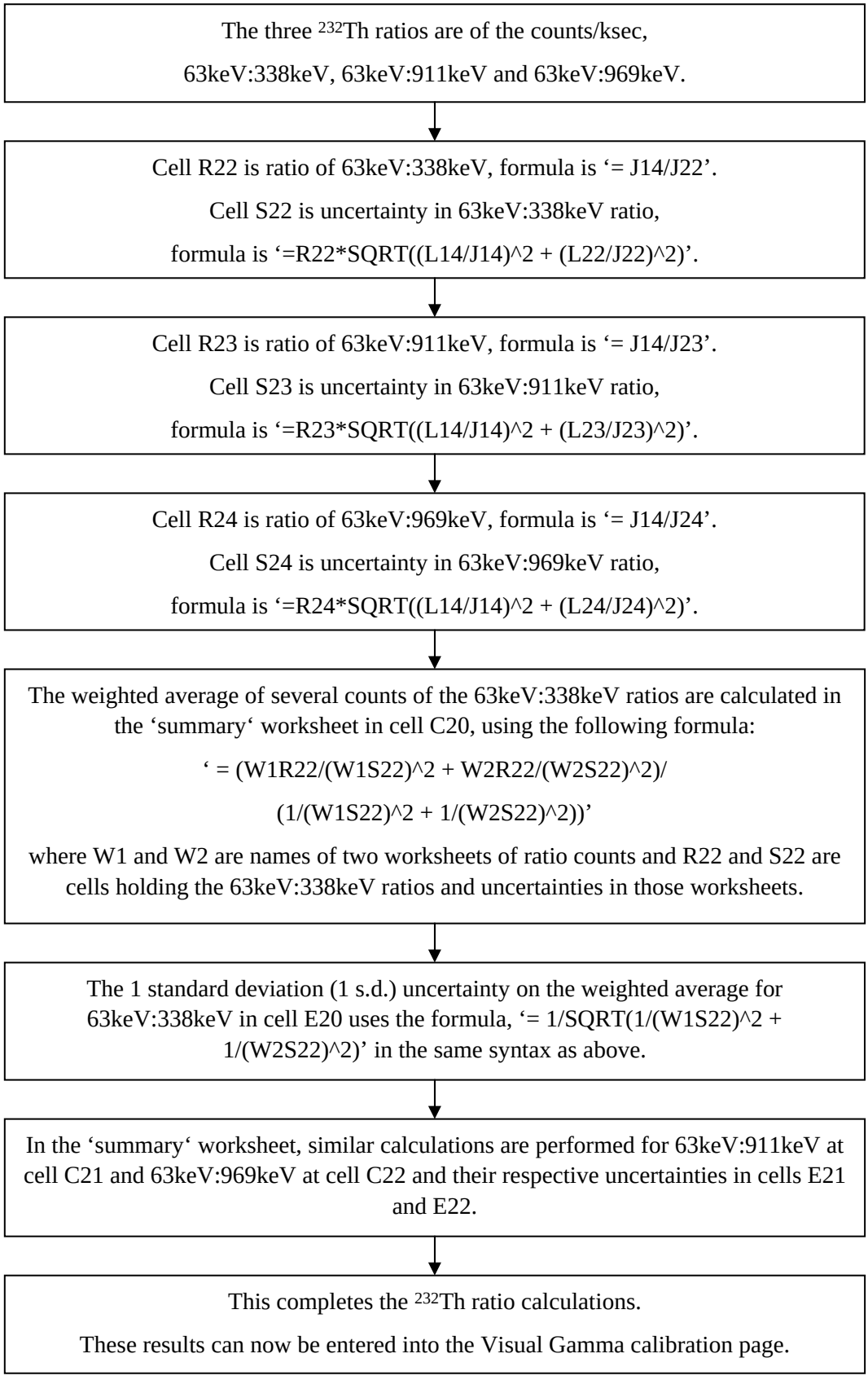
These results can now be entered into the Visual Gamma calibration page.

Det - G		**Geom - Q**				
Thorium calibration						
			Wtd ave	**Combined**	**counting**	**system**
	Isotope	**line keV**	**cts/ksec/Bq**	**uncert 1sd**	**uncert 1sd**	**err 2%**
	Ac-228	**338**	6.30702	0.12691	0.01399	0.12614
	Ac-228	**911**	5.32166	0.10709	0.01182	0.10643
	Ac-228	**969**	3.09670	0.06259	0.00907	0.06193
	Ra-224	**241**	3.26282	0.06627	0.01154	0.06526
	Pb-212	**239**	34.71357	0.69493	0.03029	0.69427
	Bi-212	**40**	1.22936	0.02659	0.01011	0.02459
	Tl-208	**583**	7.99019	0.16050	0.01497	0.15980
		Using:	ZQ008g.01&2	ZQ005g.01&2	ZQ054g.01	ZQ065g.01
	Ratios		**Combined**	**counting**		
		Wtd ave	**uncert 1sd**	**uncert 1sd**		
	63:338	0.05677	0.00192	0.00192		
	63:911	0.06732	0.00228	0.00228		
	63:969	0.11558	0.00392	0.00392		
			Using:	ZQ008g.01&2	ZQ005g.01&2	
	Updated:					
	on:					
	Notes:					
	Systematic uncertainties (Marten 1992)					
	U: %	1.2				
	Th: %	2				
	all others %	1.5				

Figure 5 An Excel summary worksheet for ^{232}Th series isotopes on detector G, geometry Q. The highlighted cells are final values copied to the calibration page in Visual Gamma.

Flow chart for ^{232}Th ratios at 63keV

This flow chart follows the initial calculations in the ‘P’ spreadsheet, see ‘Flow Chart of Initial Calculations in Excel spreadsheets on ‘P’ file data’ above.



Flow chart for ^{40}K and ^{137}Cs calibration

Typically separate standards are made for ^{40}K and ^{137}Cs. There are several choices of source material for ^{40}K as it is naturally occurring in potassium at the isotopic concentration of 0.001167%. Anatytical grade potassium salts, such as potassium sulphate and potassium nitrate are suitable sources. ^{137}Cs, on the other hand, is a product of the nuclear testing during the period 1950 – 1990 and has been deposited in varying concentrations all over the earth's terrestrial and aquatic surface. For ^{137}Cs a source solution with a certified activity concentration must be obtained from a reputable supplier, such as United Nuclear, GE Lifesciences or Oak Ridge National Lab. Nuclear Science & Technology Division.

Details of all ***eriss*** standards, including total activity, is maintained in the Excel spreadsheet 'All ERISS gamma standards.xls', located at SSDX>Equipment and Techniques > HPGe Gamma Spec> Calibrations>Standards Listing.

The total activity of the ^{40}K or ^{137}Cs which is contained in the standard is entered into cells F4, in units of Bq. Cell E4 identifies these values as 'Total activity 40K (or 137Cs), Bq'. Cells E4 and F4 are highlighted in the same colour to clarify their relationship.

↓

Calculating Calibration Factor, counts per kilosecond per Bq:

Counts per kilosecond in cell ranges J29 - J30 are divided by the Total Activity in Bq from cell F4 and placed into cell ranges M29 - M30.

↓

Calculating Uncertainty on Calibration Factor, counts per kilosecond per Bq:

Counts per kilosecond uncertainties in cells L29 - L30 are divided by the Total Activity in Bq from cell F4 and placed into cell range O29-O30.

↓

The weighted average of the following calibration factors are calculated in the 'summary' sheet:

^{40}K @ 1461keV in cell D6 from cells M29, associated uncertainty in cell E6 from cells O29

^{137}Cs @ 661keV in cell D7 from cells M30, associated uncertainty in cell E7 from cells O30

See Fig. 6

↓

This completes the ^{40}K & ^{137}Cs calibration factor calculations.

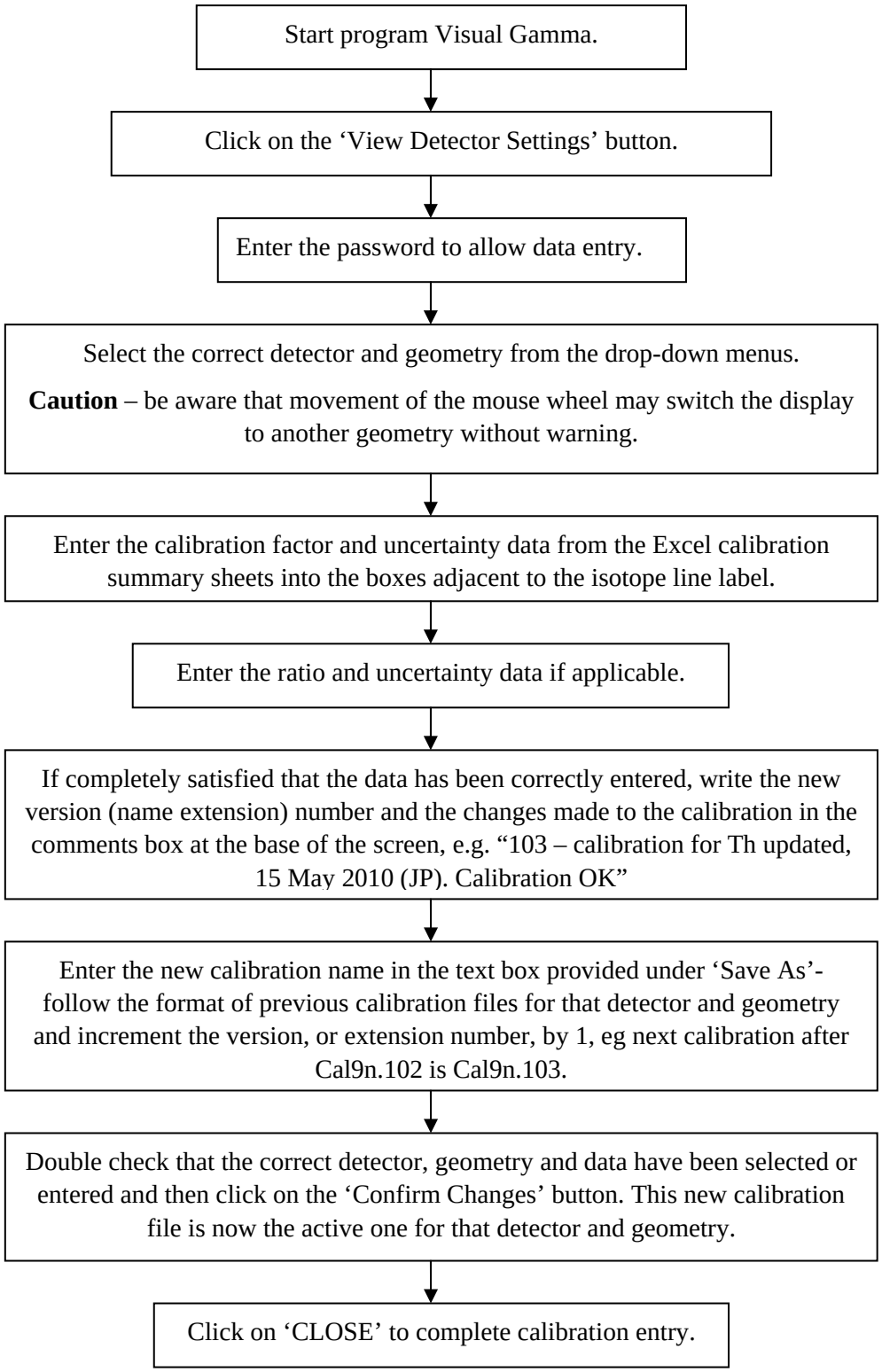
These results can now be entered into the Visual Gamma calibration page.

Det - G		**Geom - Q**				
40K & 137Cs calibration						
			wtd ave	**combined**	**counting**	**System**
	Isotope	**line keV**	**cts/ksec/Bq**	**uncert 1sd**	**uncert 1sd**	**err 1.5%**
	K-40	**1461**	1.38204	0.03483	0.02799	0.0207306
	Cs-137	**662**	17.88292	0.28395	0.09314	0.2682438
			Using :	ZQ058g.02	ZQ057g.01	ZQ052g.01
	Entered:					
	on:					
	Notes:	included systematic uncertainties from Marten 1992				
	Systematic uncertainties (Marten 1992)					
	U: %	1.2				
	Th: %	2				
	all others %	1.5				

Figure 6 Excel spreadsheet of Detector G, Geometry Q, summary sheet for ^{40}K and ^{137}Cs calibration

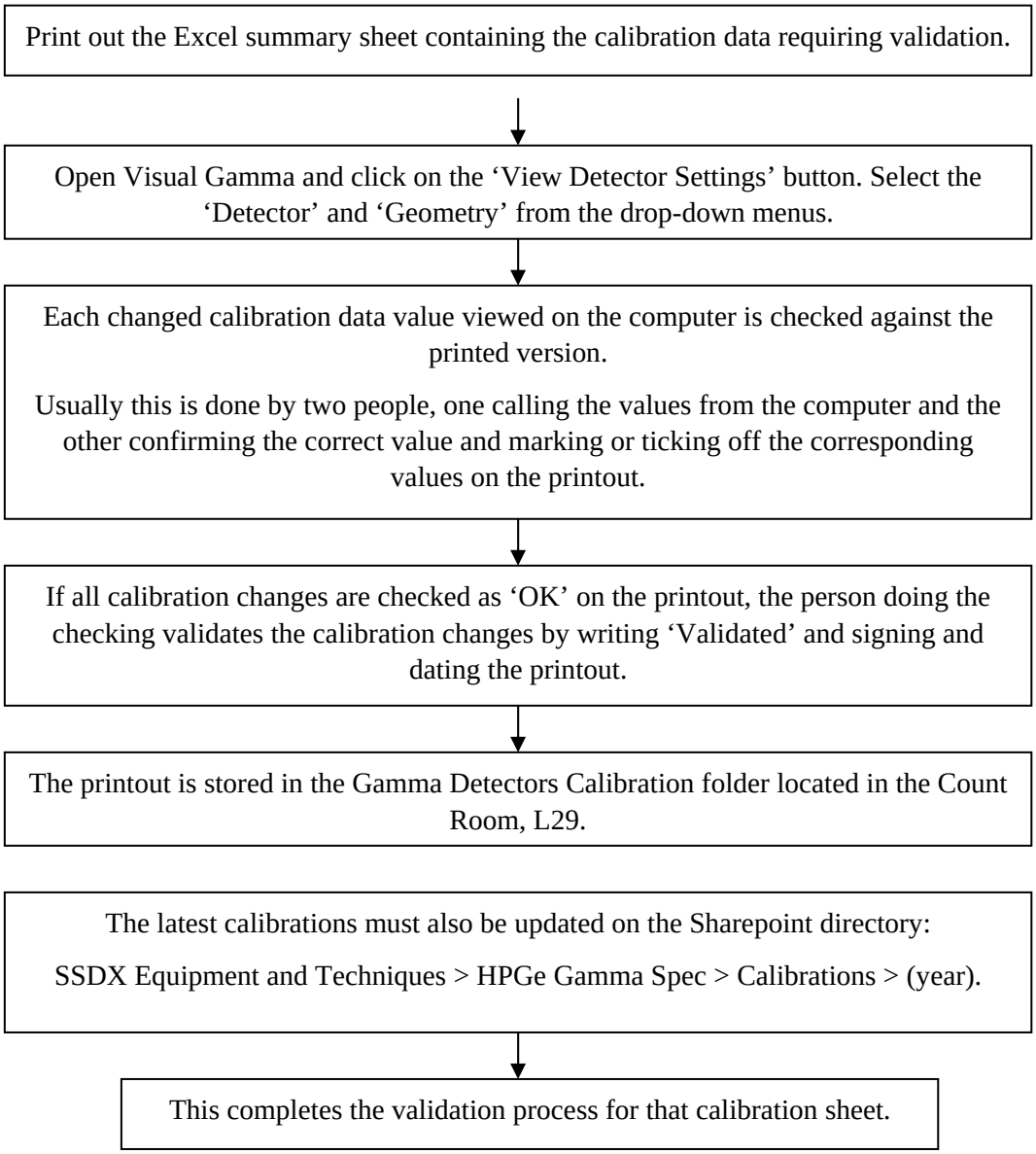
Entering calibration data into Visual Gamma

The following describes the step-by-step process of entering the calibration data into *Visual Gamma*. Copies of these calibration data pages are in Appendix 1. *Current Calibration Data*.



Validation procedure

The validation procedure is an assurance check that the appropriate spectrum files have been used and calculations and data entry have been done correctly.



Other quality assurance procedures

The International Atomic Energy Agency conducts intercomparison excercises where laboratories are invited to participate in the radionuclide determination of specially prepared samples of environmental water, sediments or biota, with the aim of assessing the ability of each laboratory to accurately measure specific radionuclide activity concentrations. ***eriss*** have participated in several of these excercises during the past 20 years and have always achieved excellent accuracy and precision with their reported results. Following these intercomparison excercises, the sample material, with certified radionuclide concentrations, is made available for purchase as reference materials. Several of these reference materials are routinely analysed on the HPGe detectors to provide independent quality assurance of the ***eriss*** gamma spectroscopy calibrations and analytical procedures. The result of several years of counting these reference materials will be the subject of a separate Internal Report.

References

Esparon A & Pfitzner J (in press) Visual Gamma – Gamma Analysis Manual. Internal Report 539, Supervising Scientist, Darwin.

Canberra Industries Product Catalogue, Edition twelve, p25.

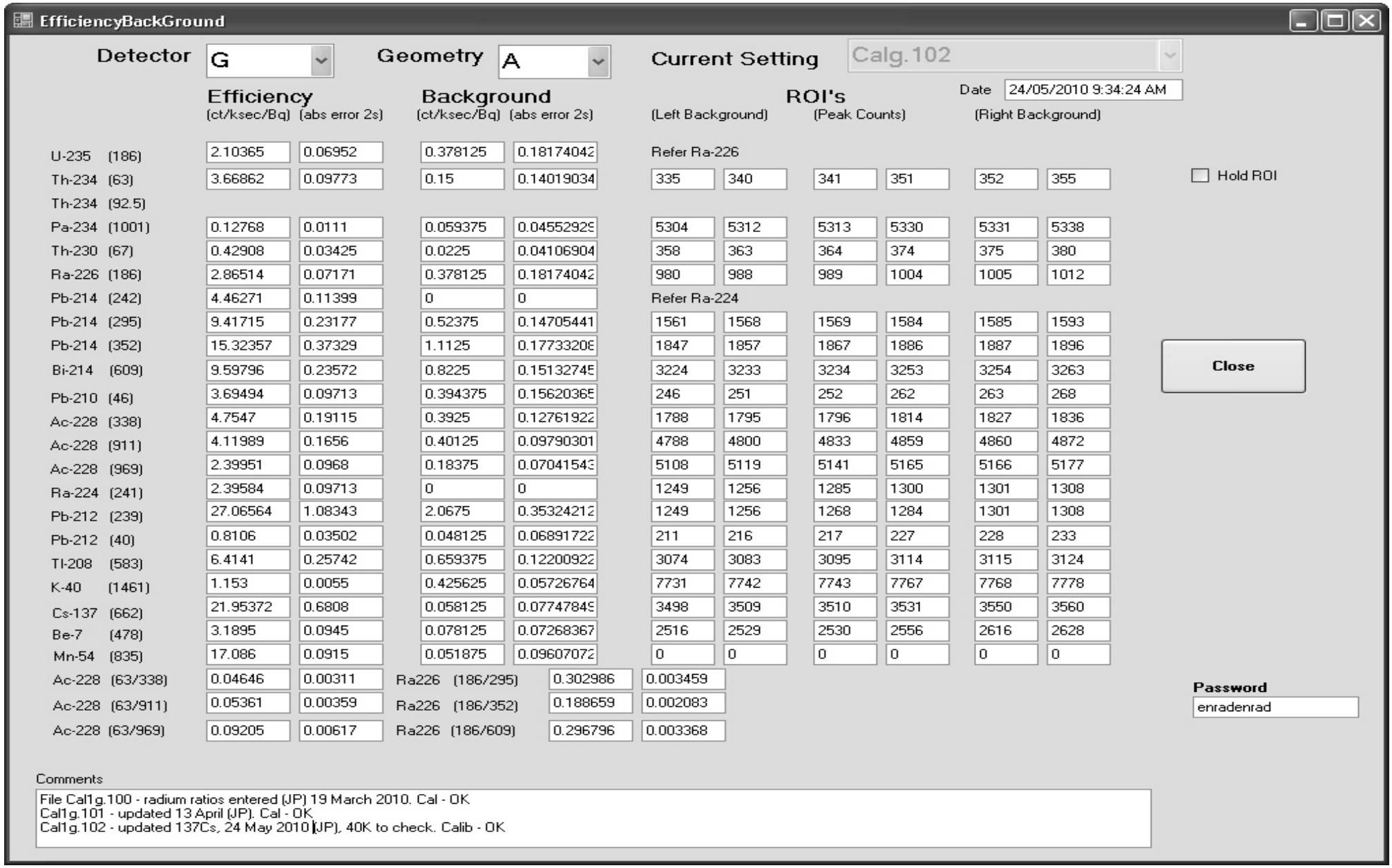
Marten R 1992. Procedures for routine analysis of naturally occurring radionuclides in environmental samples by gamma-ray spectrometry with HPGe detectors. Internal report 76, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Appendix 1 Table of geometry designation, size, containment material, sample type and sample weight range

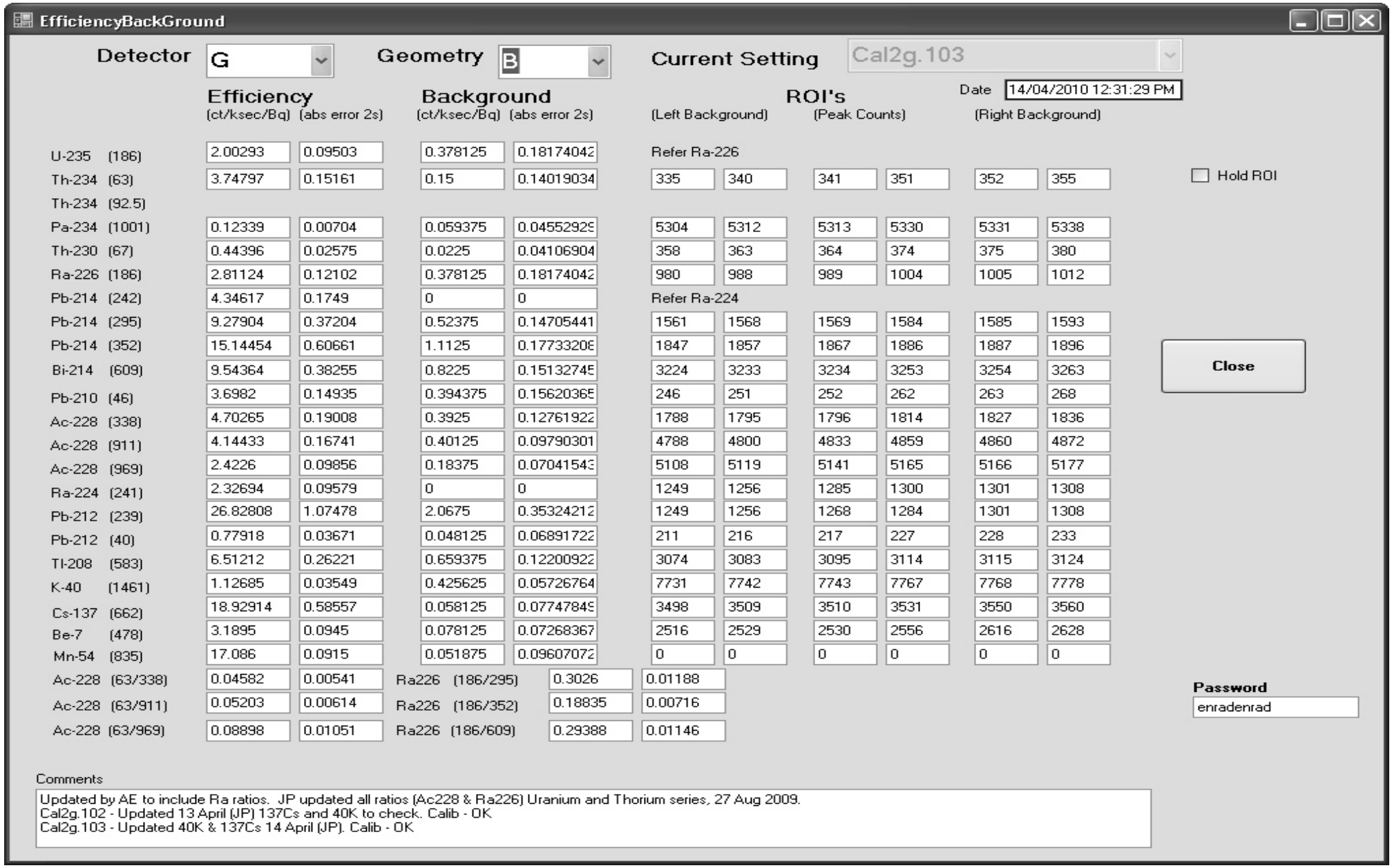
Geometry Designation	Size height (mm) x radius (mm)	Containment material	Sample type	Sample weight range (g)
A	10 x 65	polyester resin	organic	0 – 30
B	10 x 65	polyester resin	mineral	10 – 30
Q	4 x 45	acrylic	mineral	5 – 7
R	20 x 75	acrylic	mineral	120 – 180
V	5 x 40	polyester resin	organic	0 – 3

Appendix 2 Current calibration data

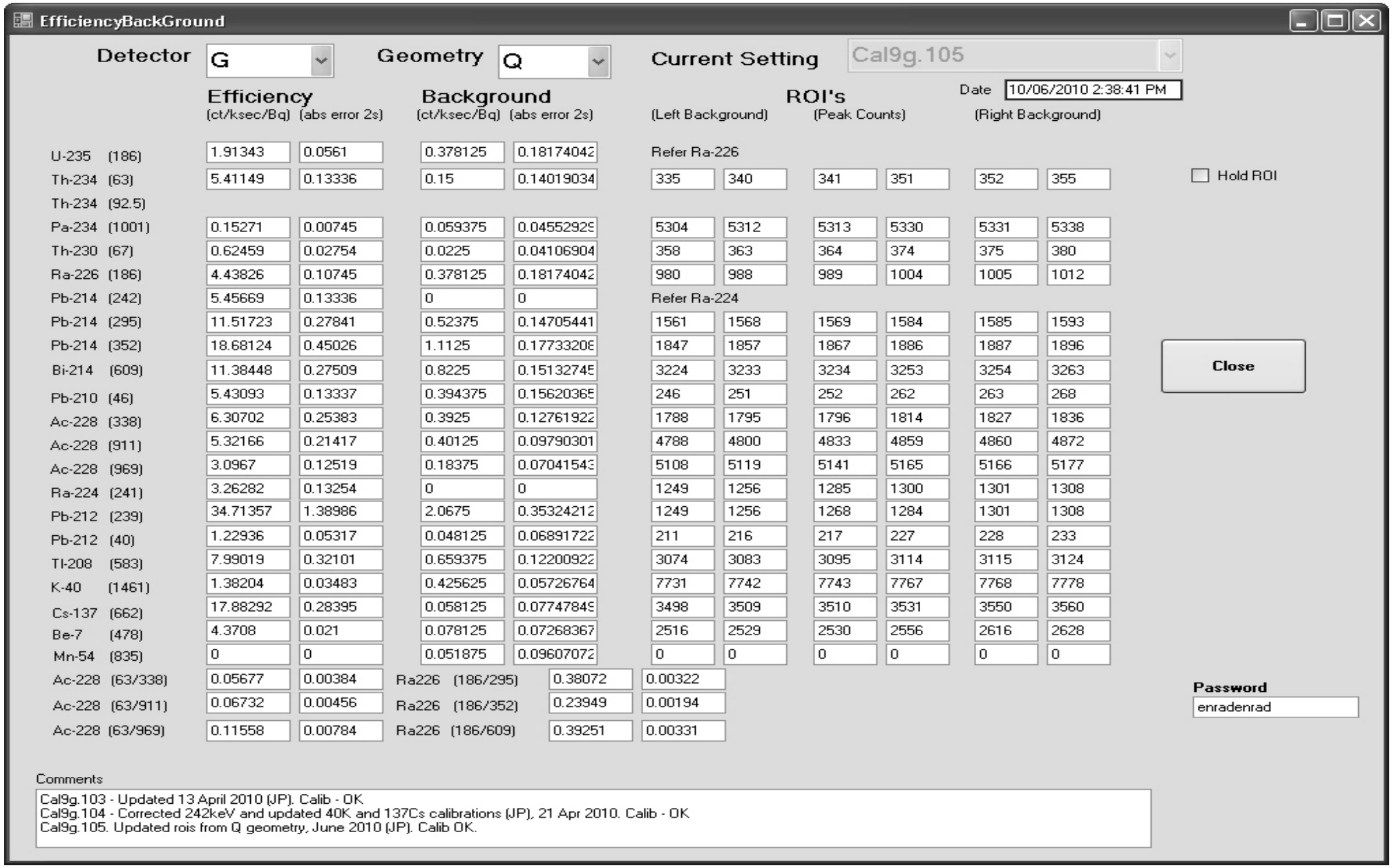
Detector G, Geometry A



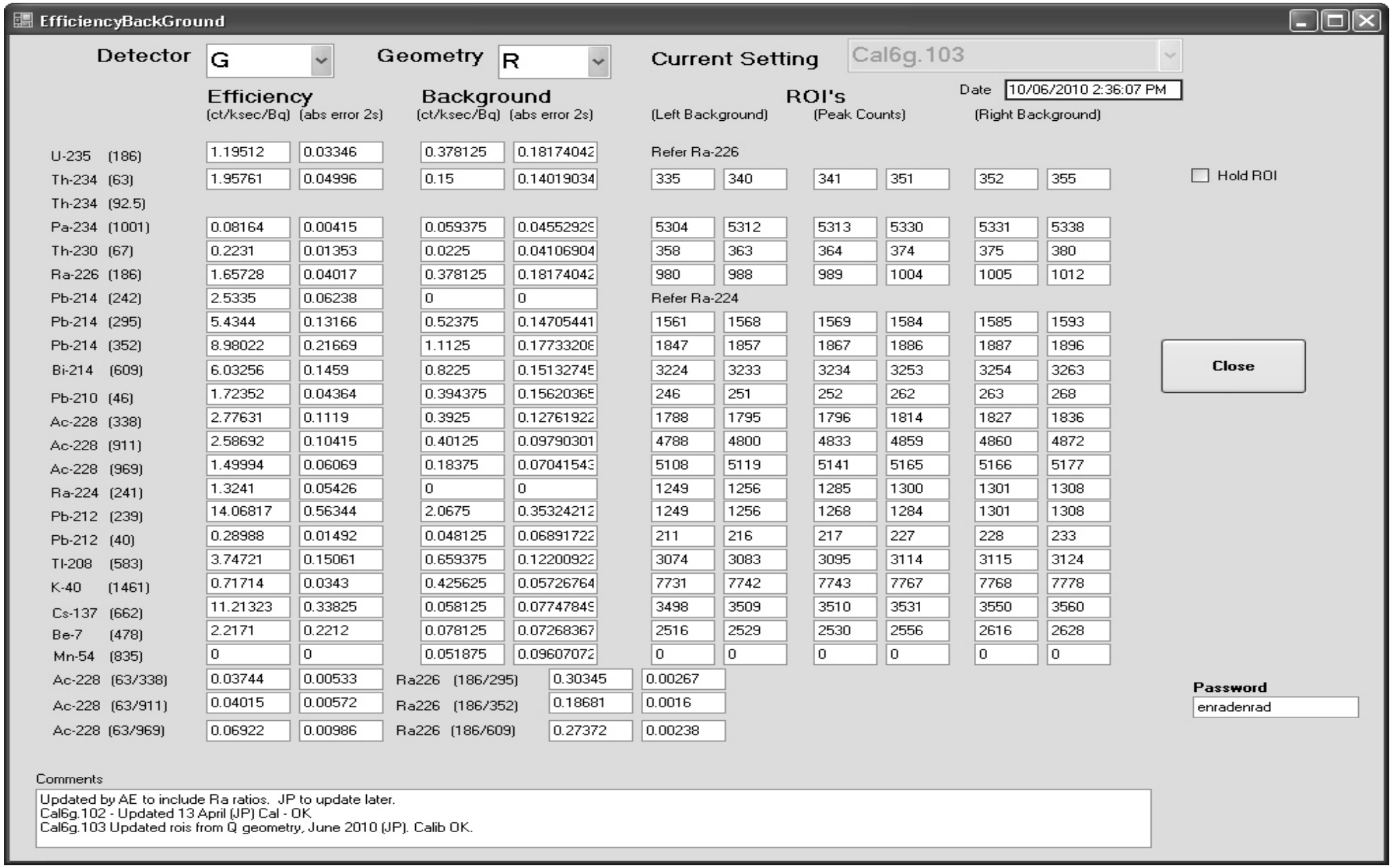
Detector G, Geometry B



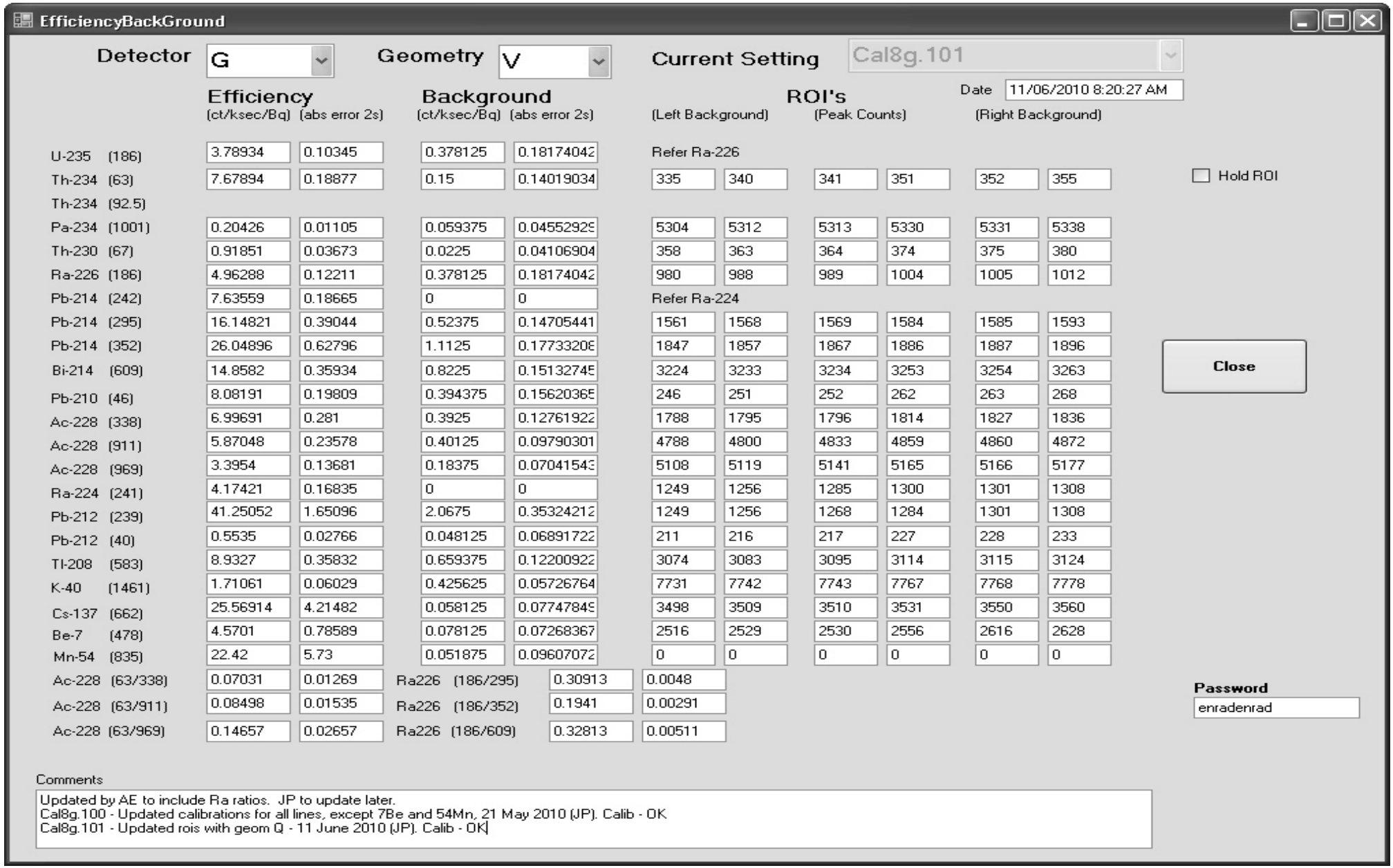
Detector G, Geometry Q



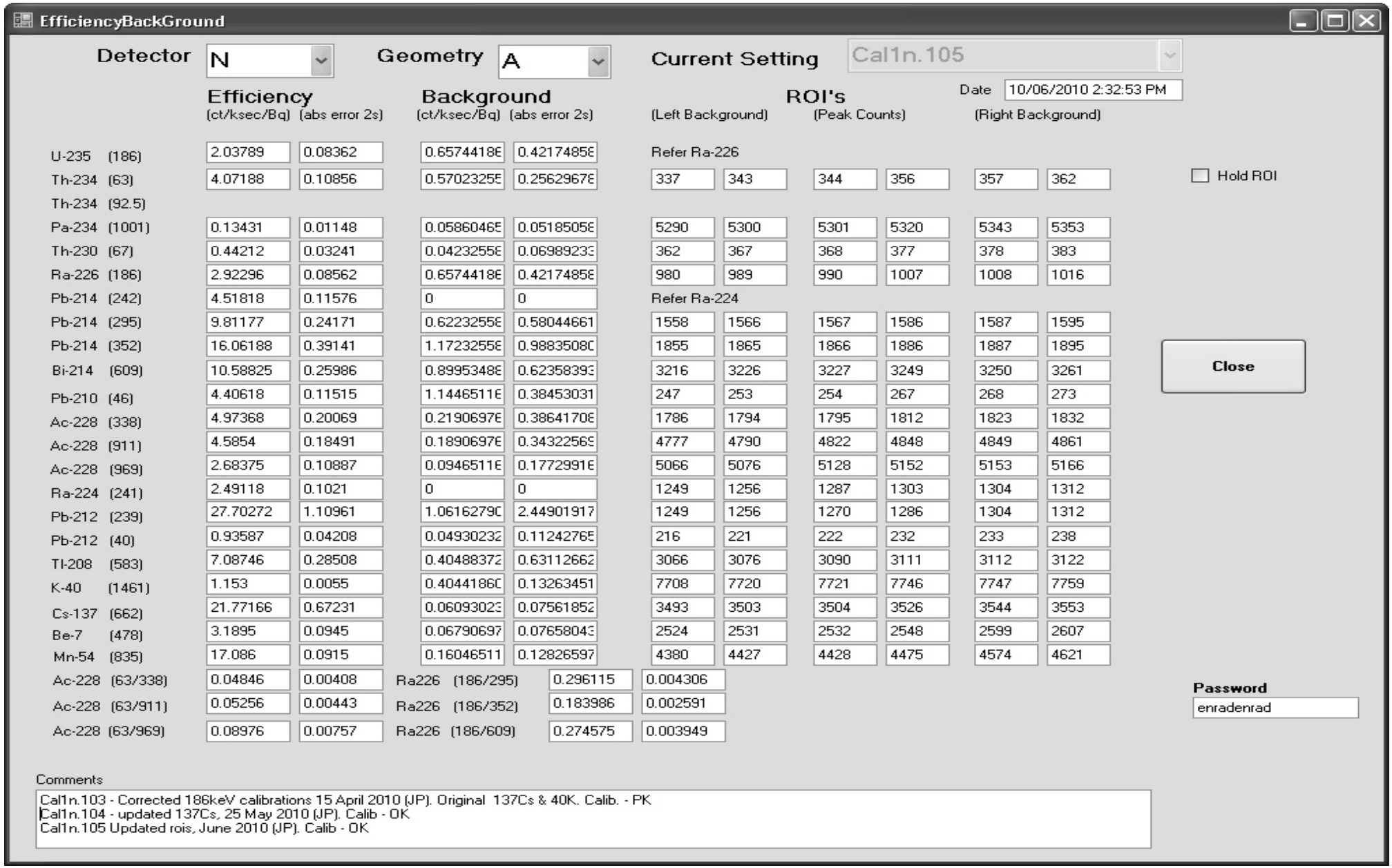
Detector G, Geometry R



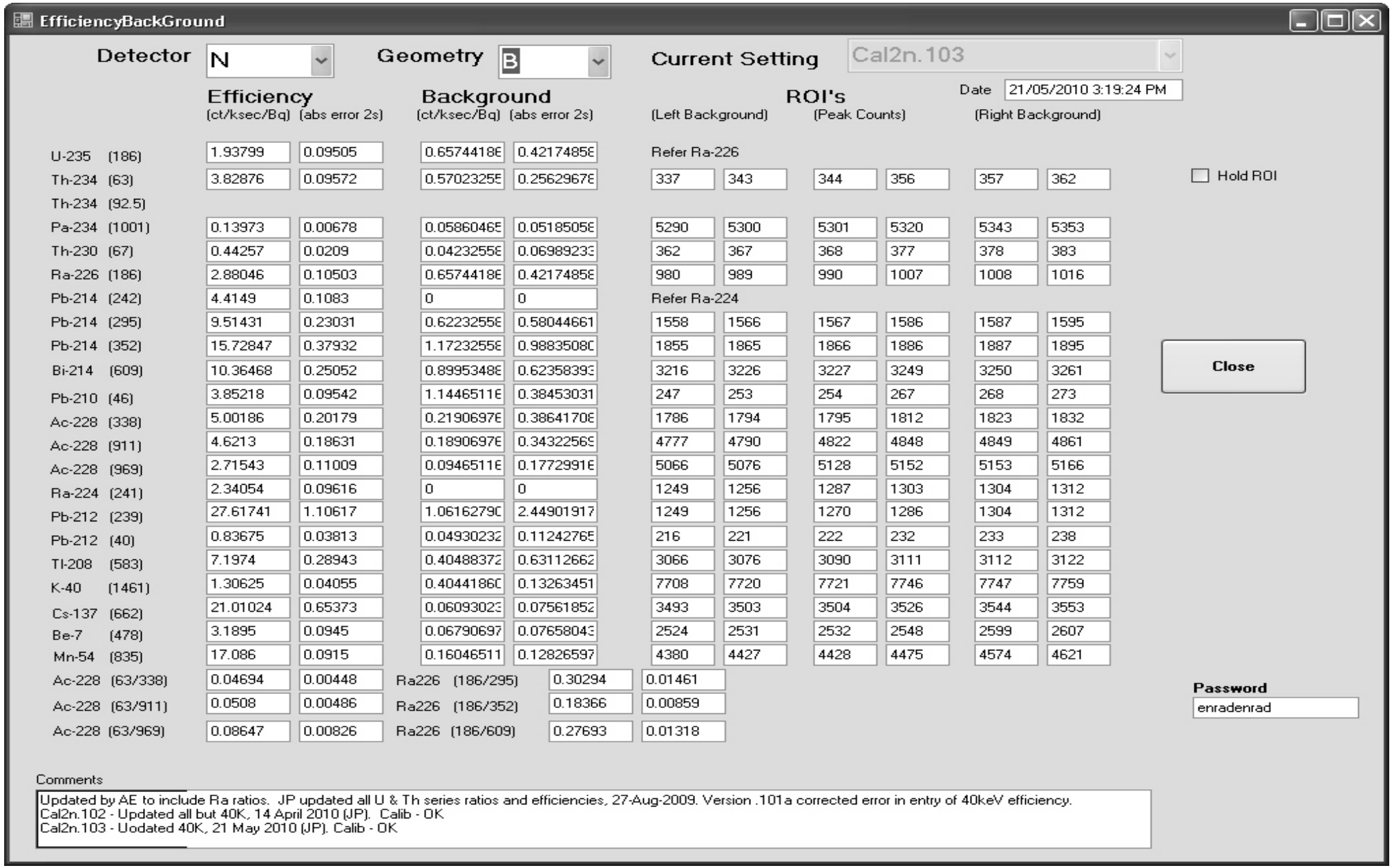
Detector G, Geometry V



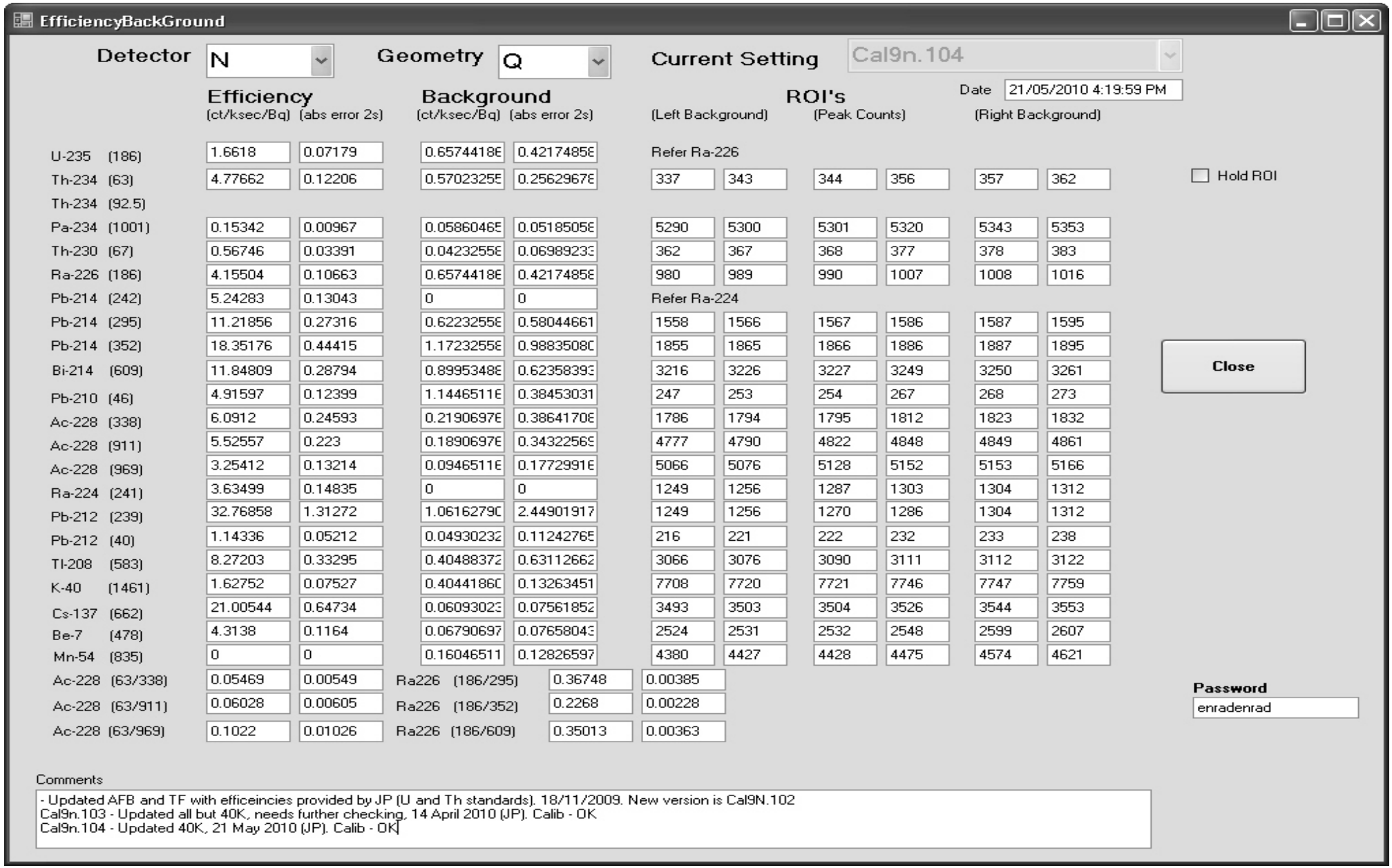
Detector N, Geometry A



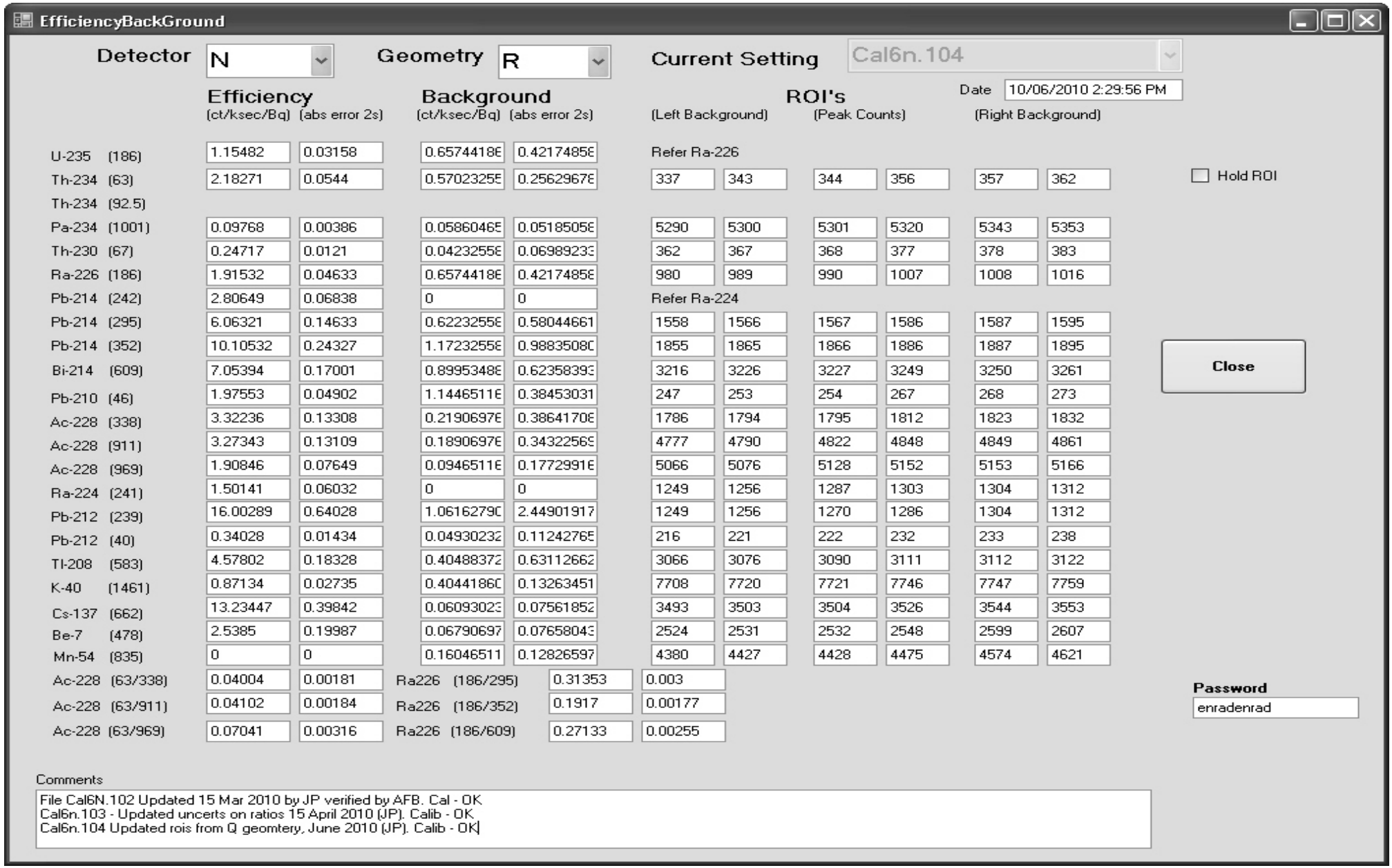
Detector N, Geometry B



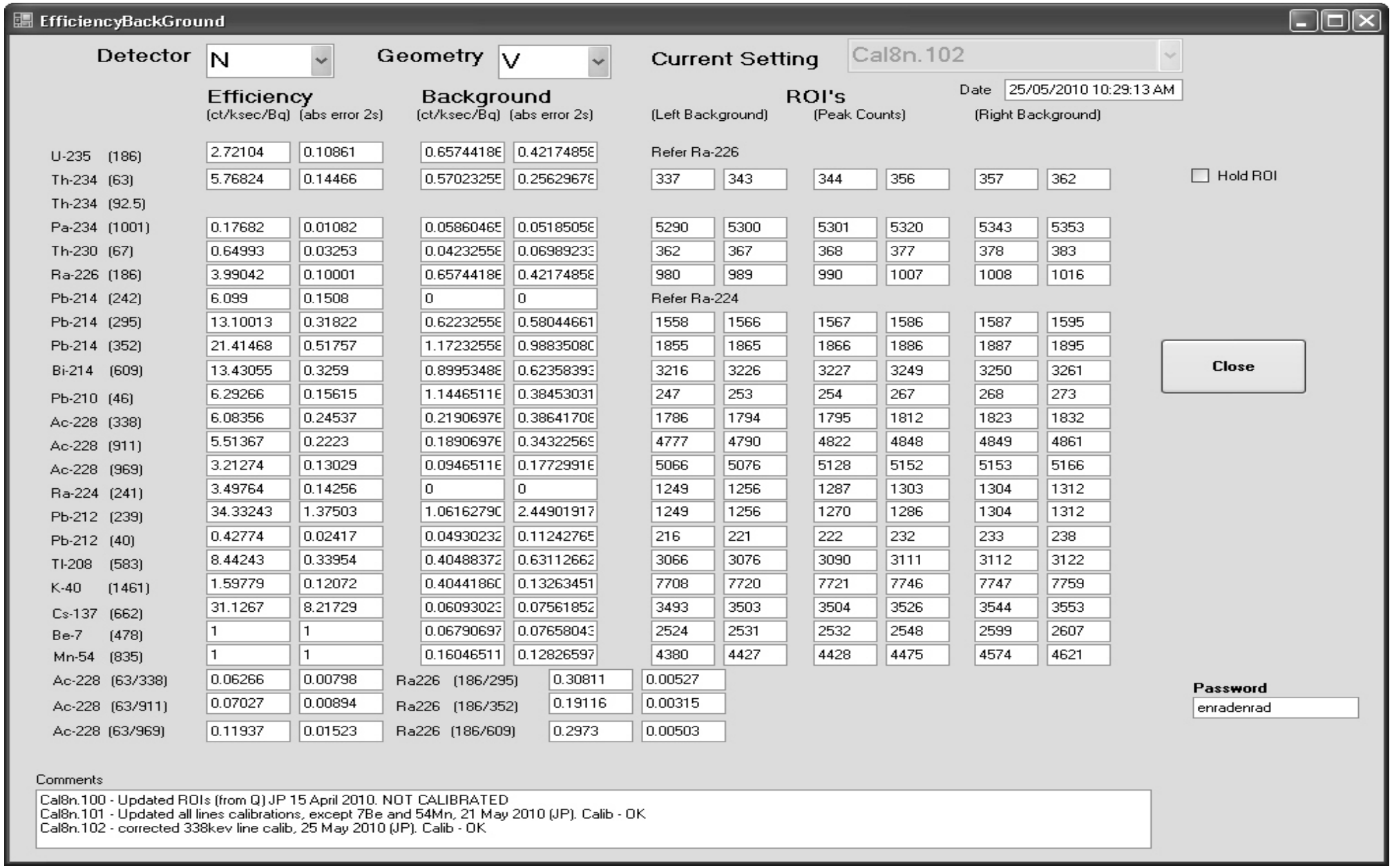
Detector N, Geometry Q



Detector N, Geometry R



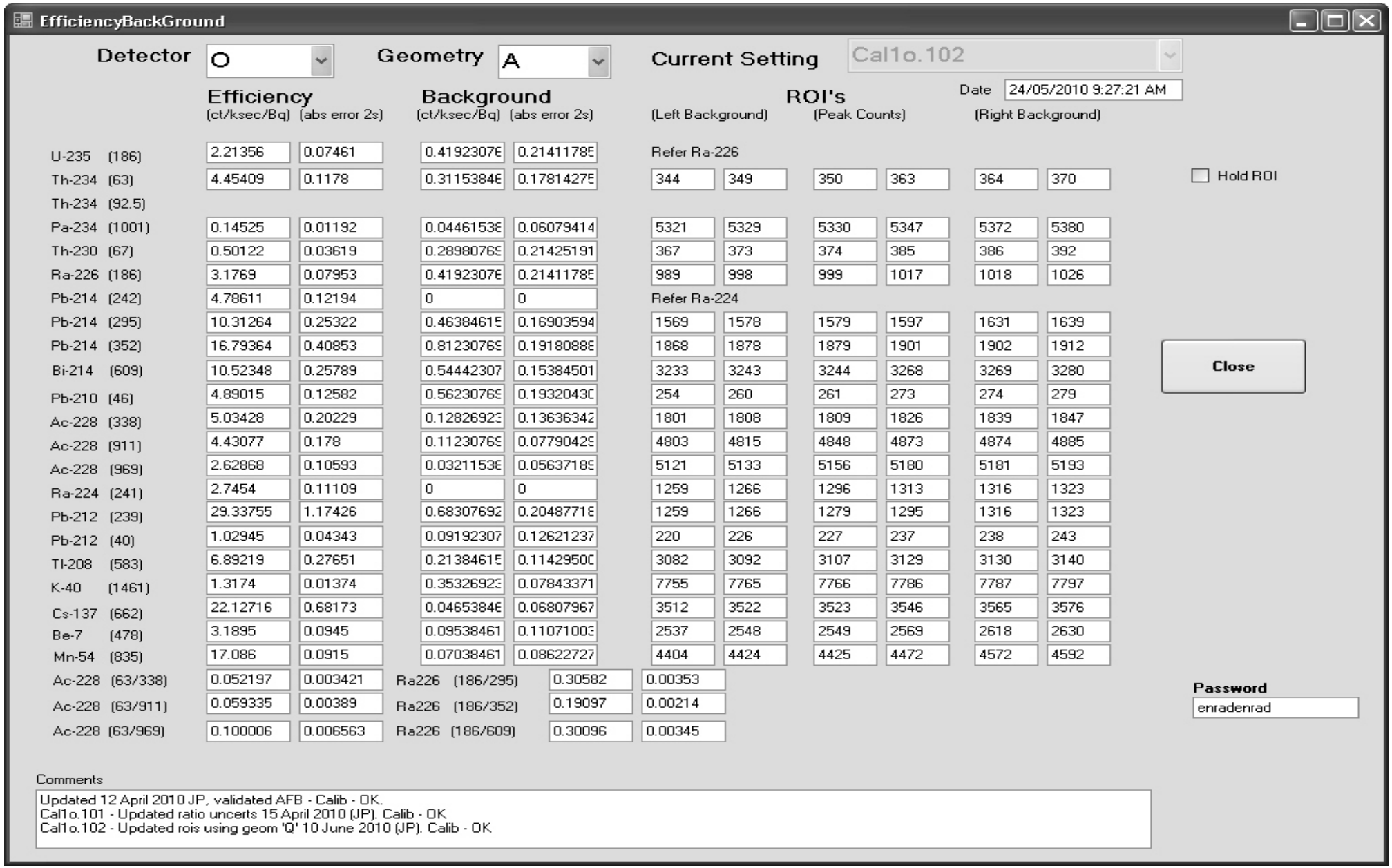
Detector N, Geometry V



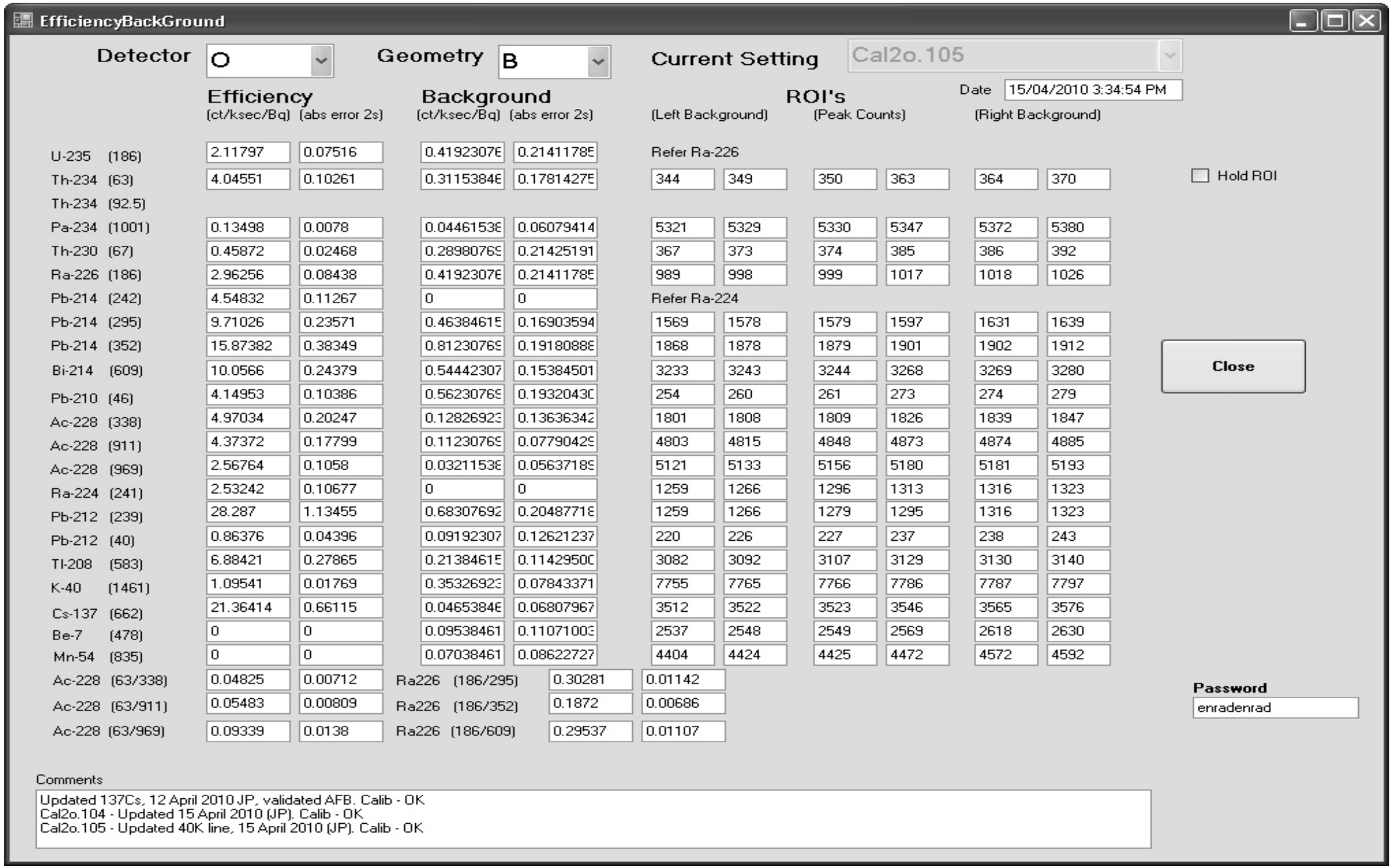
U-235	(186)	2.72104	0.10861	0.6574418E	0.4217485E	Refer Ra-226					
Th-234	(63)	5.76824	0.14466	0.5702325E	0.2562967E	337	343	344	356	357	362
Th-234	(92.5)										
Pa-234	(1001)	0.17682	0.01082	0.0586046E	0.0518505E	5290	5300	5301	5320	5343	5353
Th-230	(67)	0.64993	0.03253	0.0423255E	0.0698923E	362	367	368	377	378	383
Ra-226	(186)	3.99042	0.10001	0.6574418E	0.4217485E	980	989	990	1007	1008	1016
Pb-214	(242)	6.099	0.1508	0	0	Refer Ra-224					
Pb-214	(295)	13.10013	0.31822	0.6223255E	0.58044661	1558	1566	1567	1586	1587	1595
Pb-214	(352)	21.41468	0.51757	1.1723255E	0.9883508C	1855	1865	1866	1886	1887	1895
Bi-214	(609)	13.43055	0.3259	0.8995348E	0.6235839E	3216	3226	3227	3249	3250	3261
Pb-210	(46)	6.29266	0.15615	1.1446511E	0.38453031	247	253	254	267	268	273
Ac-228	(338)	6.08356	0.24537	0.2190697E	0.3864170E	1786	1794	1795	1812	1823	1832
Ac-228	(911)	5.51367	0.2223	0.1890697E	0.3432256E	4777	4790	4822	4848	4849	4861
Ac-228	(969)	3.21274	0.13029	0.0946511E	0.1772991E	5066	5076	5128	5152	5153	5166
Ra-224	(241)	3.49764	0.14256	0	0	1249	1256	1287	1303	1304	1312
Pb-212	(239)	34.33243	1.37503	1.0616279C	2.44901917	1249	1256	1270	1286	1304	1312
Pb-212	(40)	0.42774	0.02417	0.0493023E	0.1124276E	216	221	222	232	233	238
Tl-208	(583)	8.44243	0.33954	0.4048837E	0.6311266E	3066	3076	3090	3111	3112	3122
K-40	(1461)	1.59779	0.12072	0.4044186C	0.13263451	7708	7720	7721	7746	7747	7759
Cs-137	(662)	31.1267	8.21729	0.0609302E	0.0756185E	3493	3503	3504	3526	3544	3553
Be-7	(478)	1	1	0.0679069E	0.0765804E	2524	2531	2532	2548	2599	2607
Mn-54	(835)	1	1	0.1604651I	0.1282659E	4380	4427	4428	4475	4574	4621

Ac-228	(63/338)	0.06266	0.00798	Ra226	(186/295)	0.30811	0.00527
Ac-228	(63/911)	0.07027	0.00894	Ra226	(186/352)	0.19116	0.00315
Ac-228	(63/969)	0.11937	0.01523	Ra226	(186/609)	0.2973	0.00503

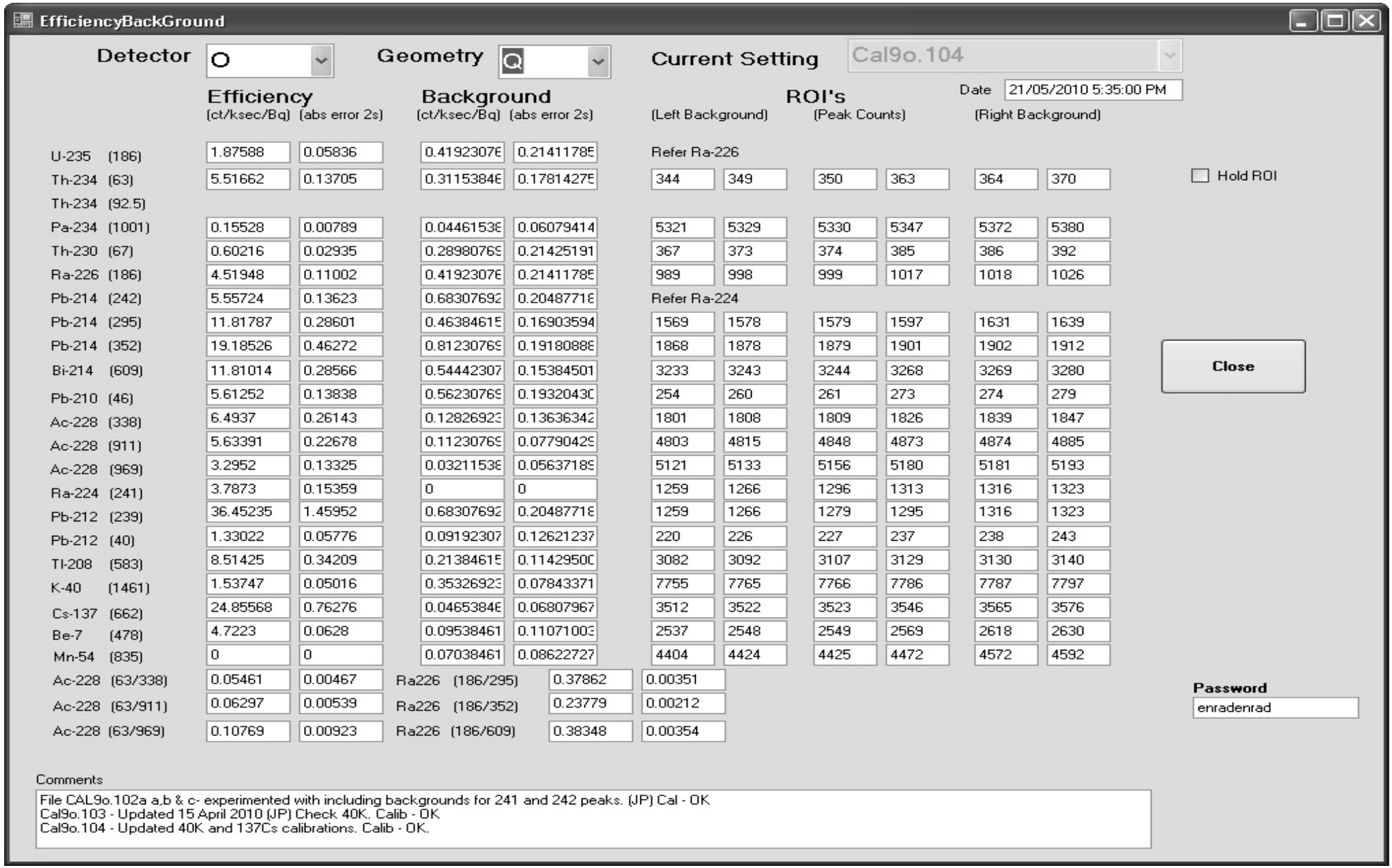
Detector O, Geometry A



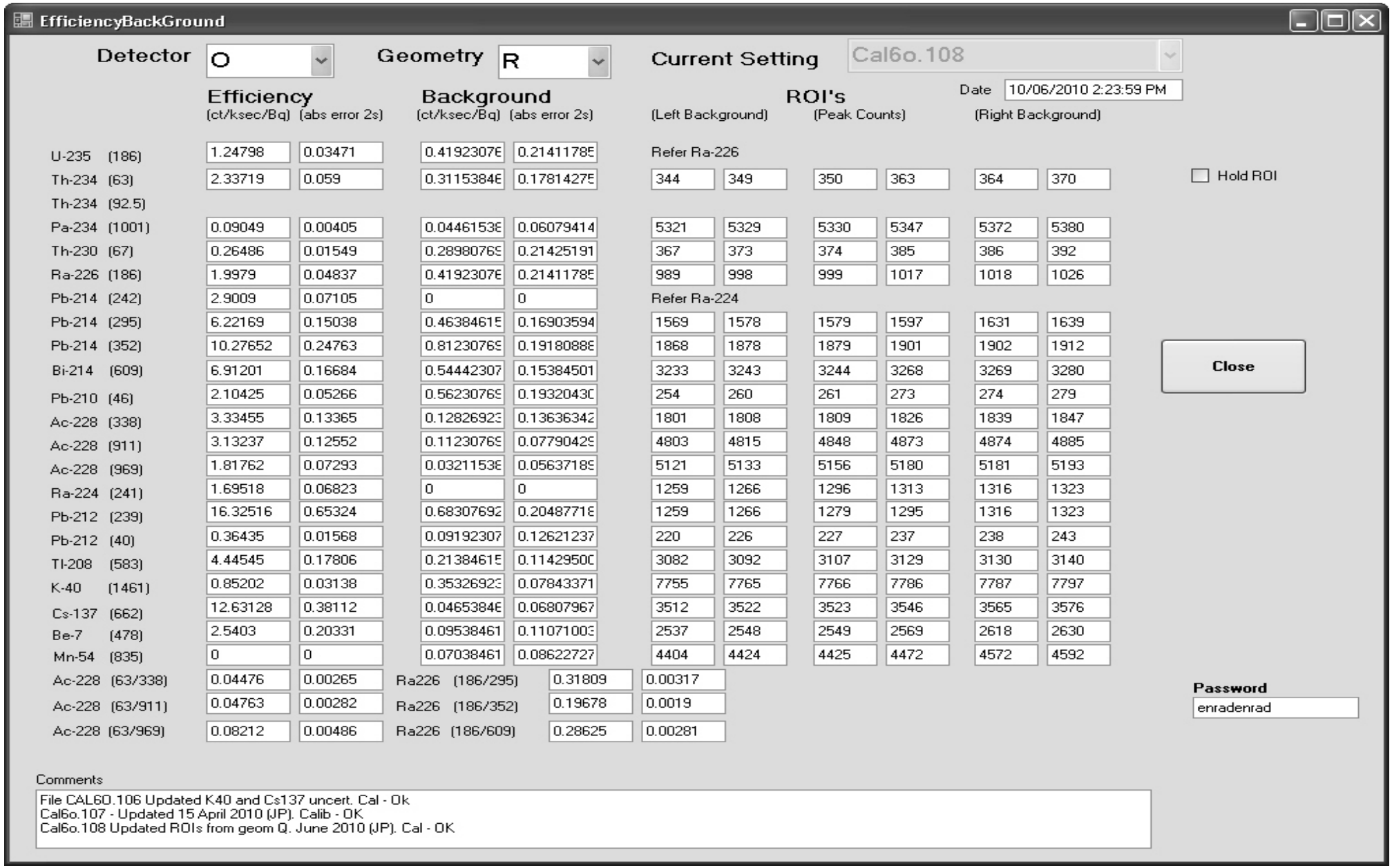
Detector O, Geometry B



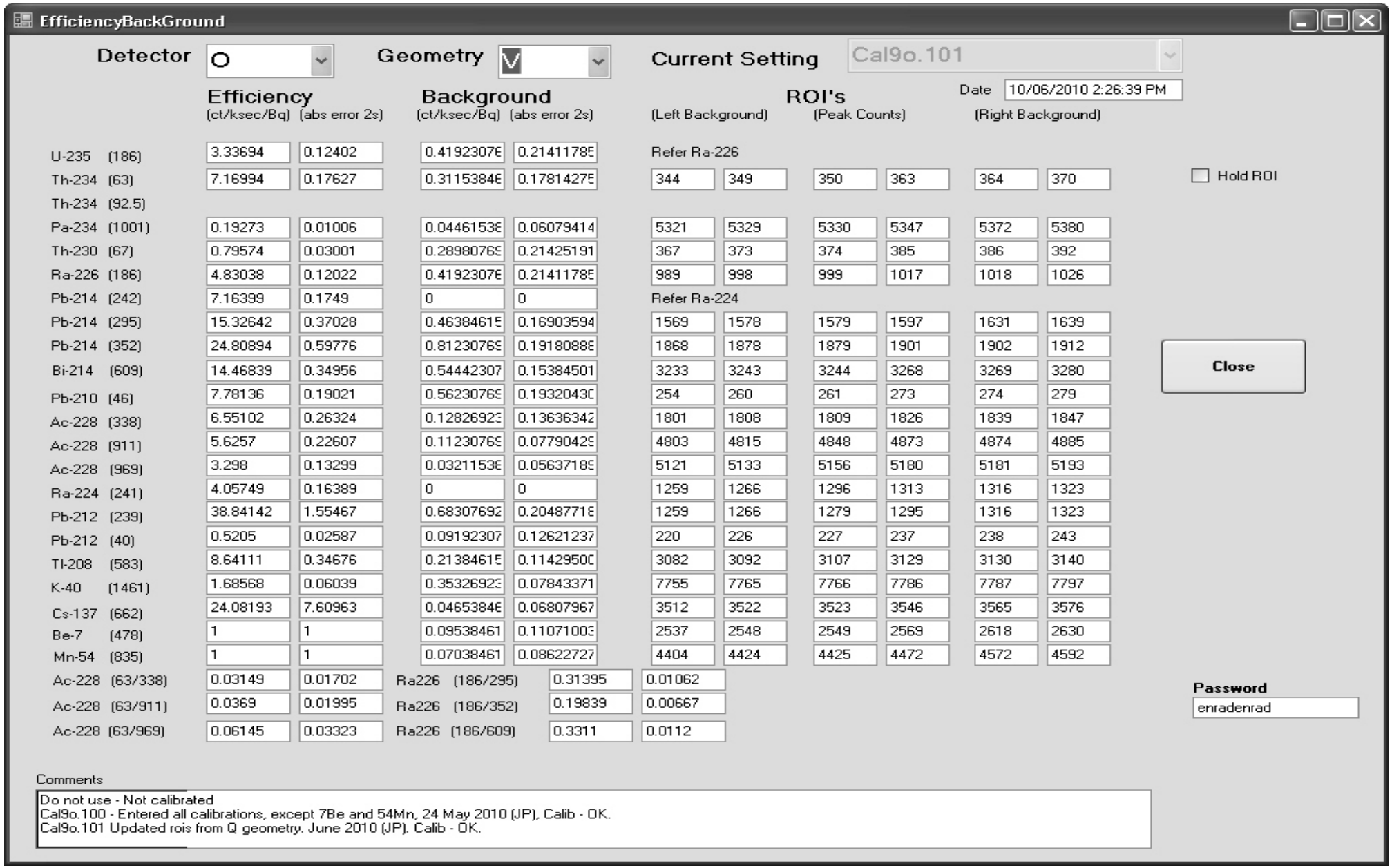
Detector O, Geometry Q



Detector O, Geometry R

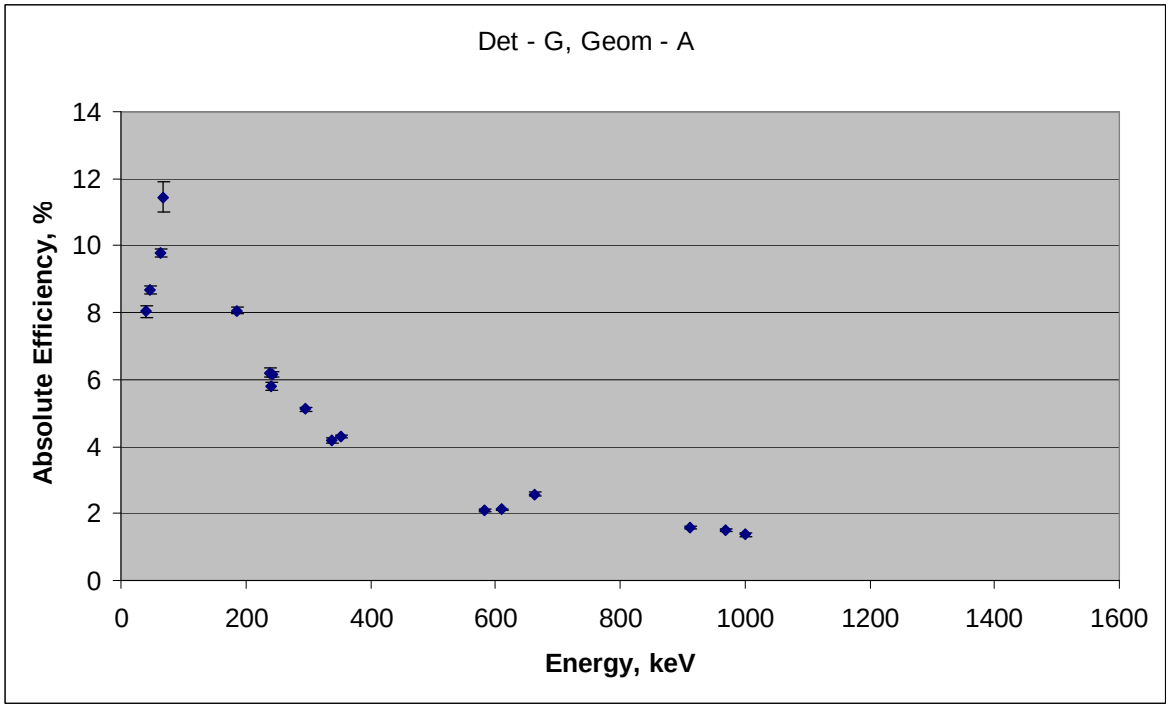


Detector O, Geometry V

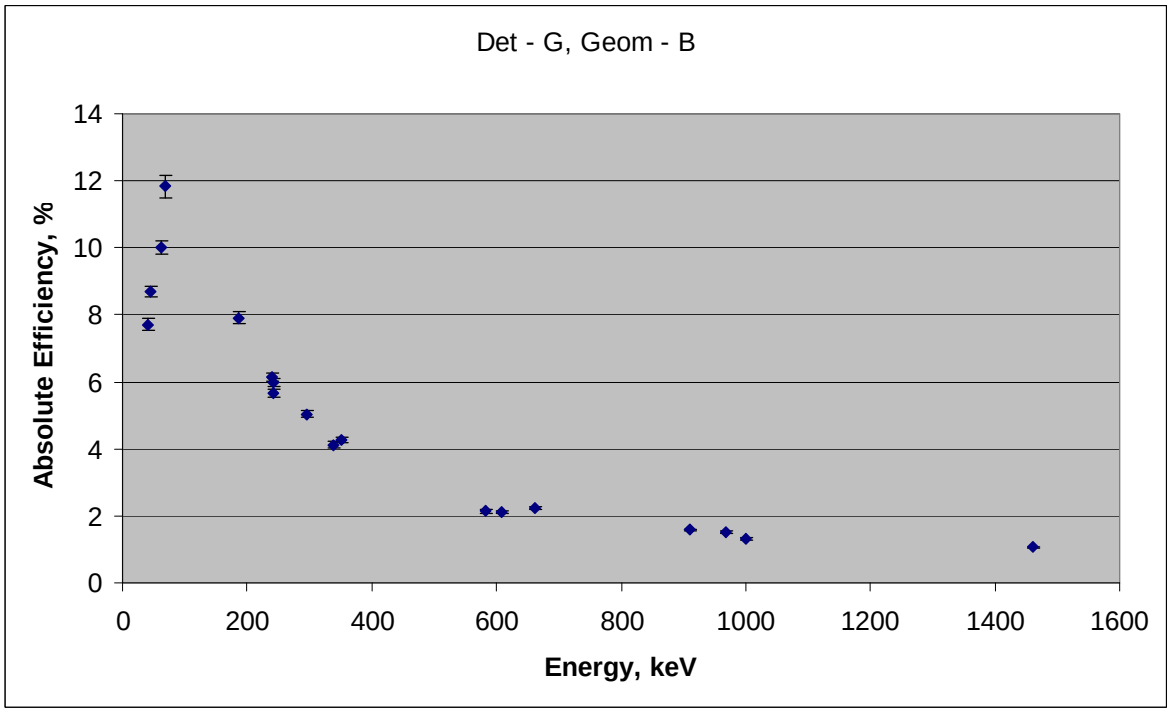


Appendix 3 Plots of absolute efficiencies for Detectors G, N and O

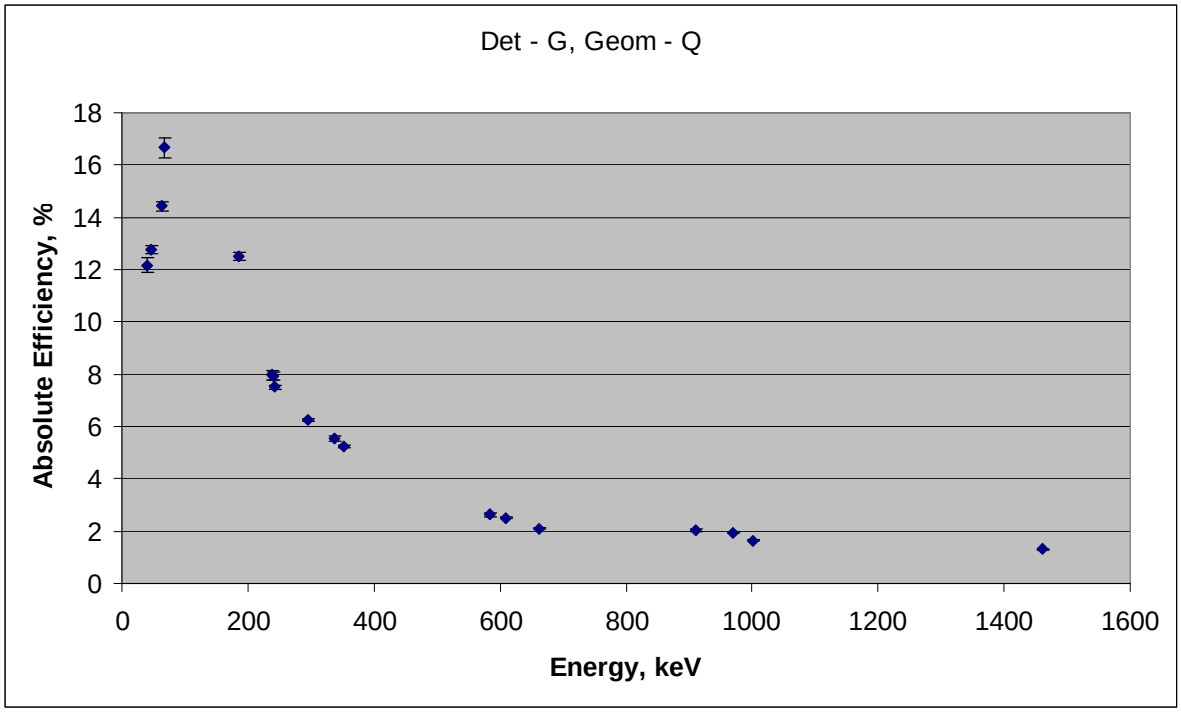
Detector G, Geometry A



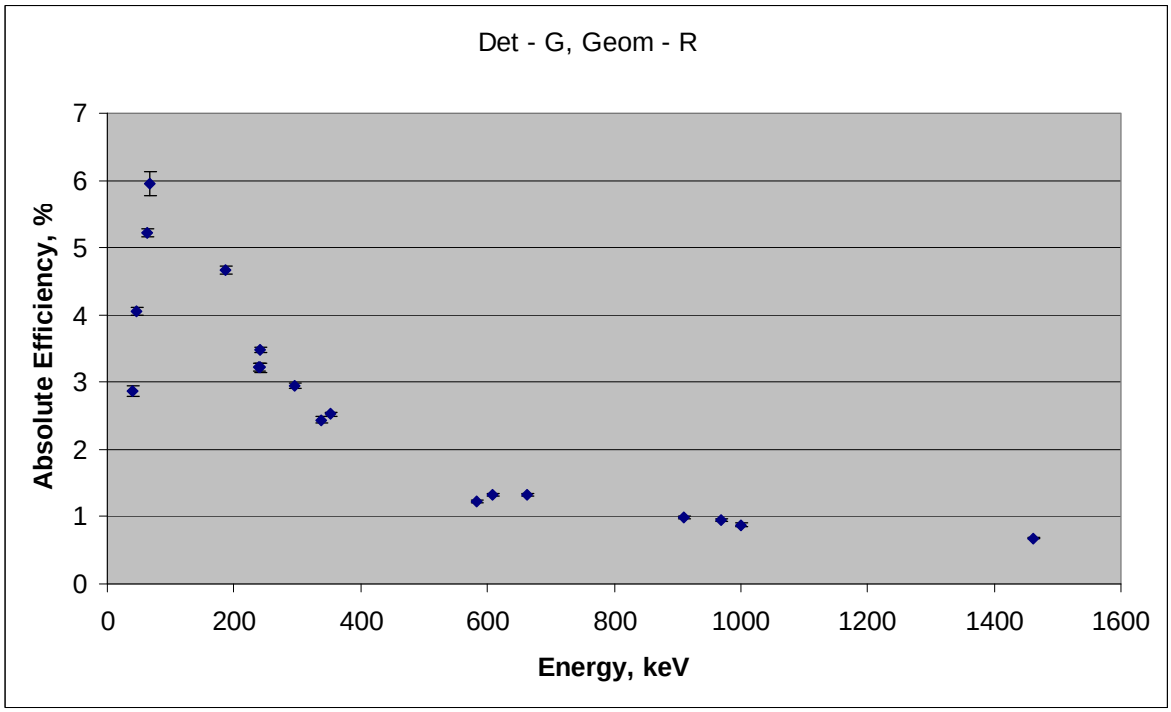
Detector G, Geometry B



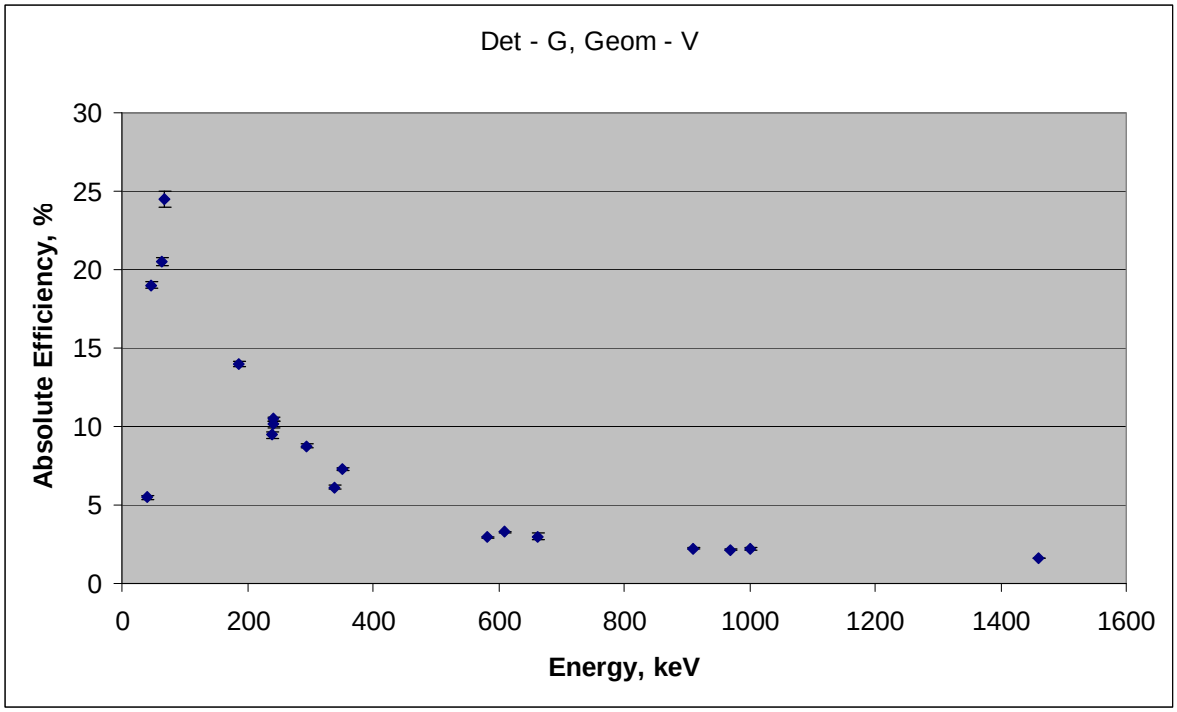
Detector G, Geometry Q



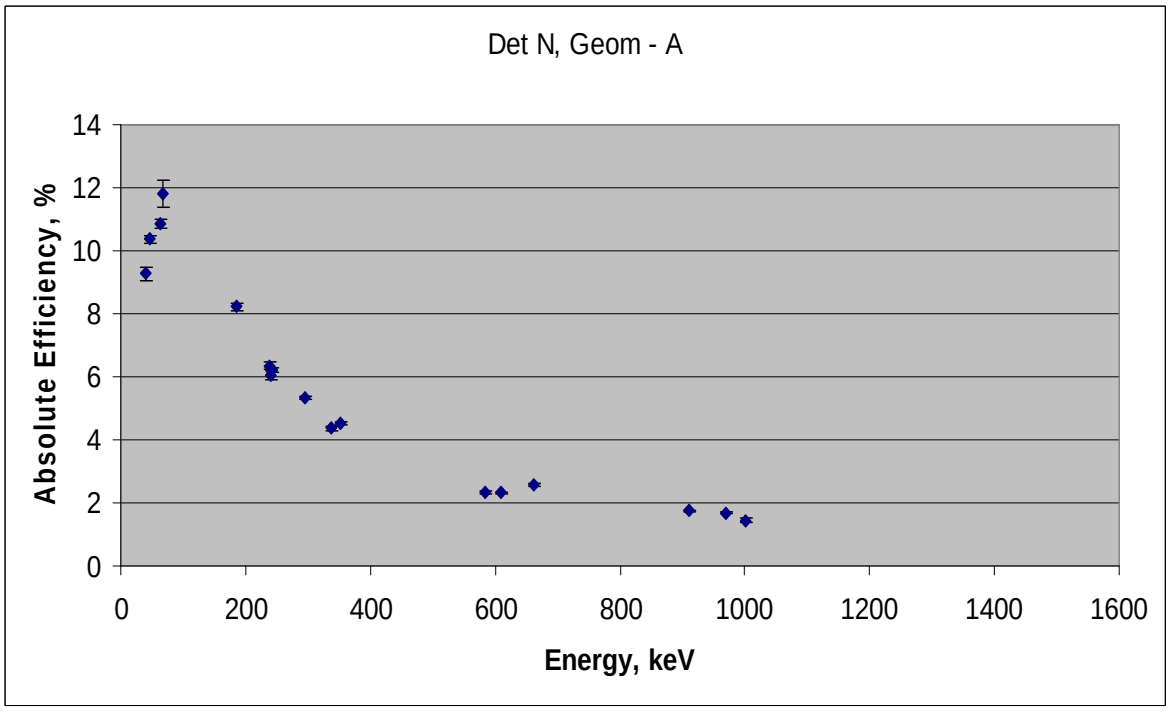
Detector G, Geometry R



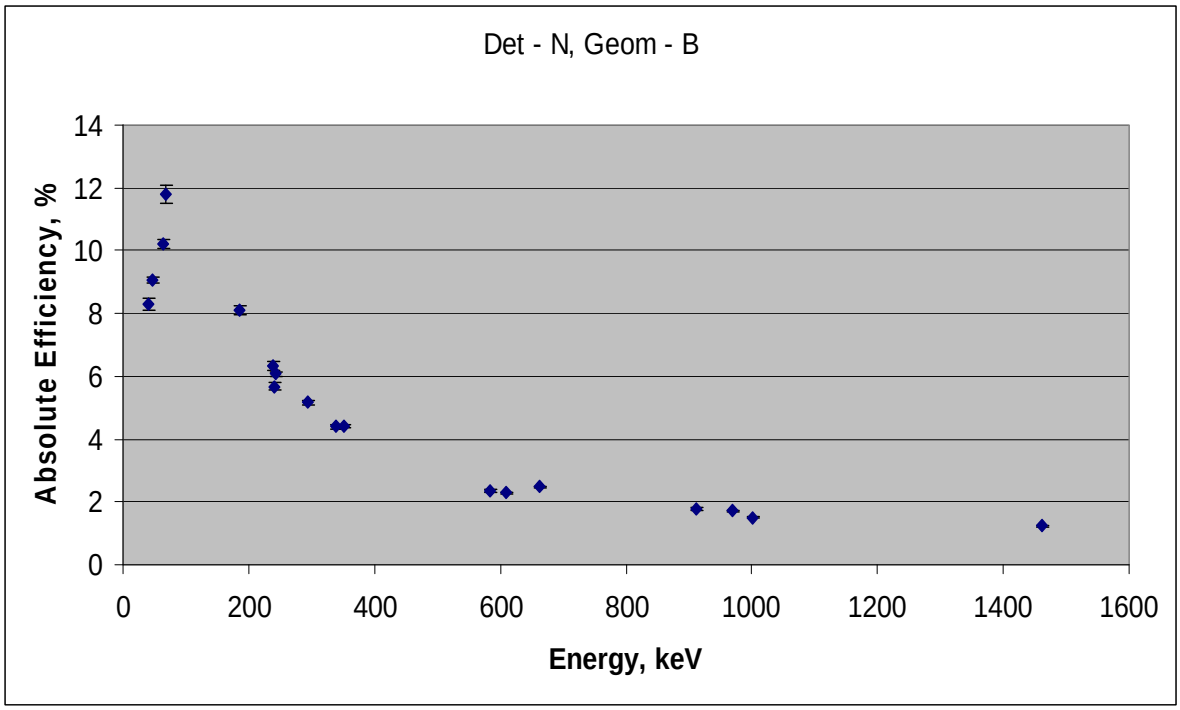
Detector G, Geometry V



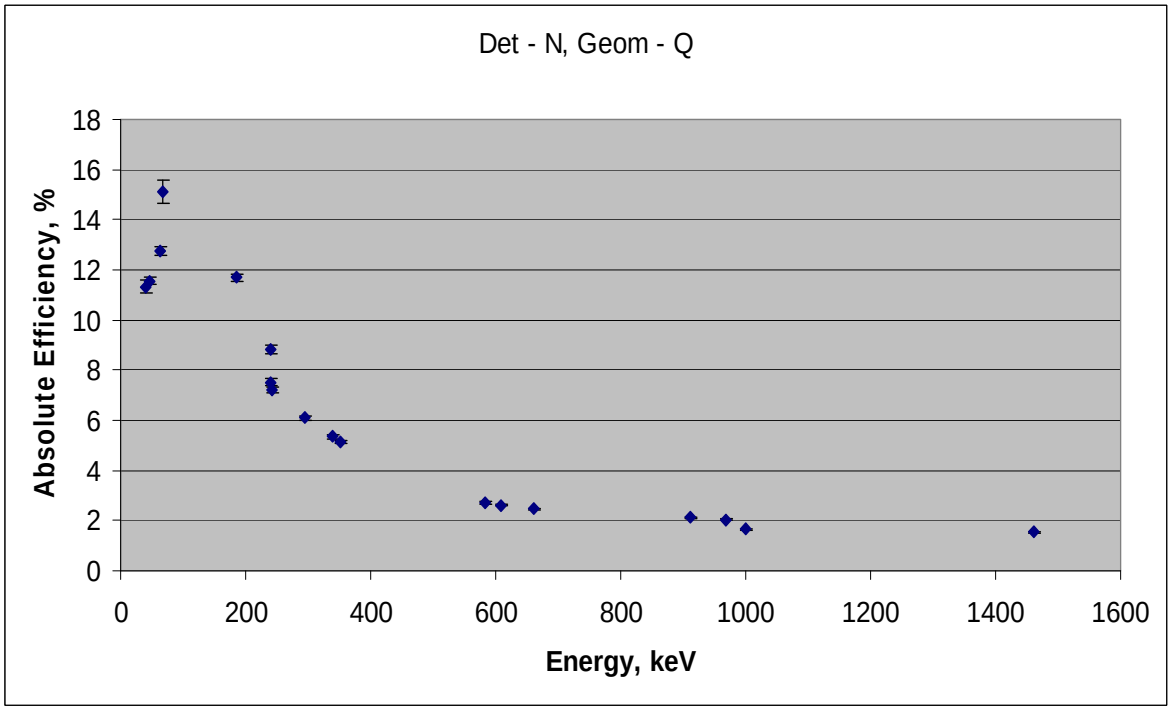
Detector N, Geometry A



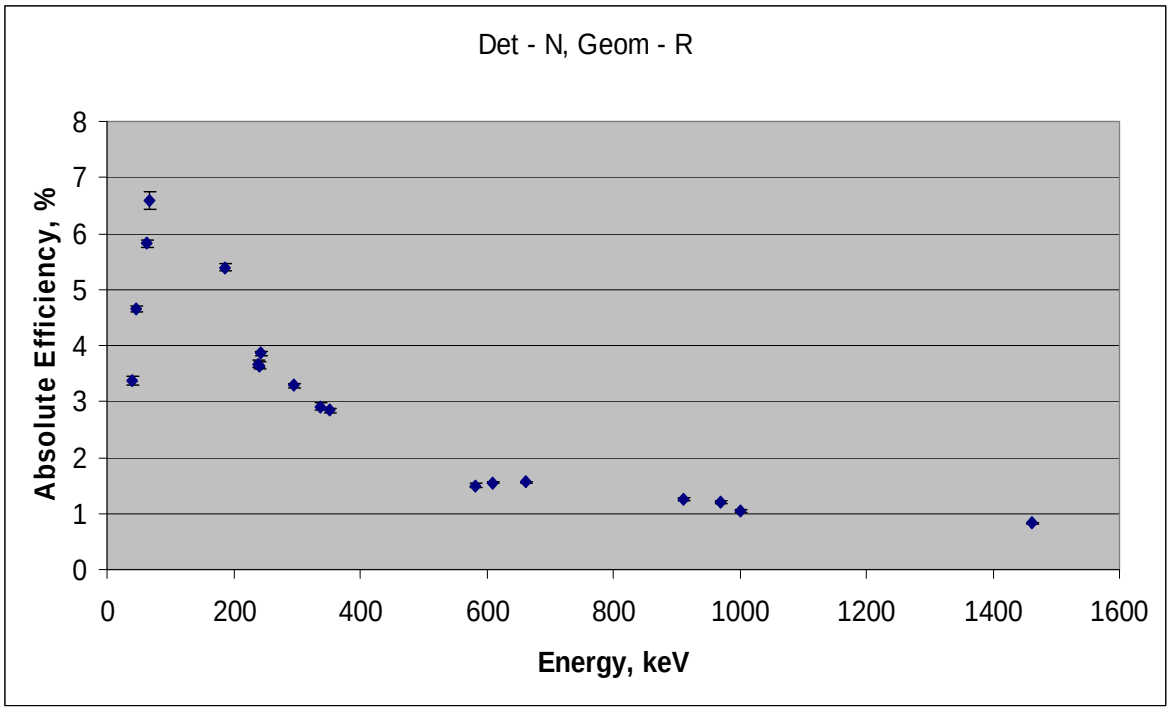
Detector N, Geometry B



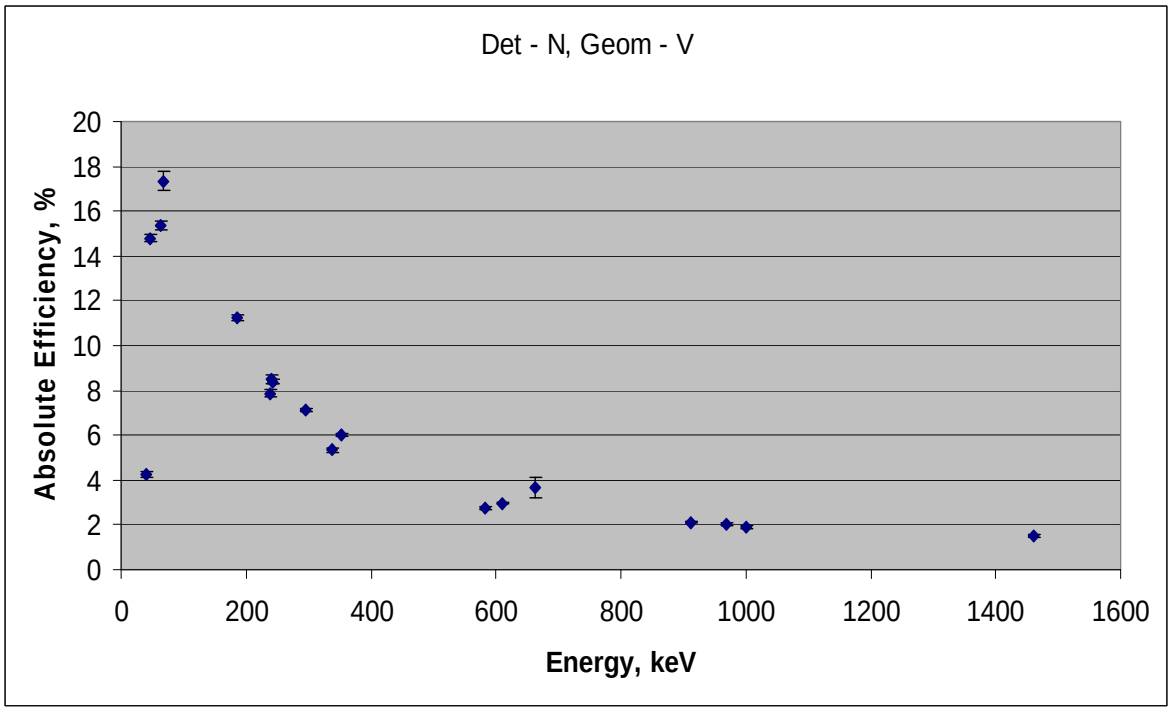
Detector N, Geometry Q



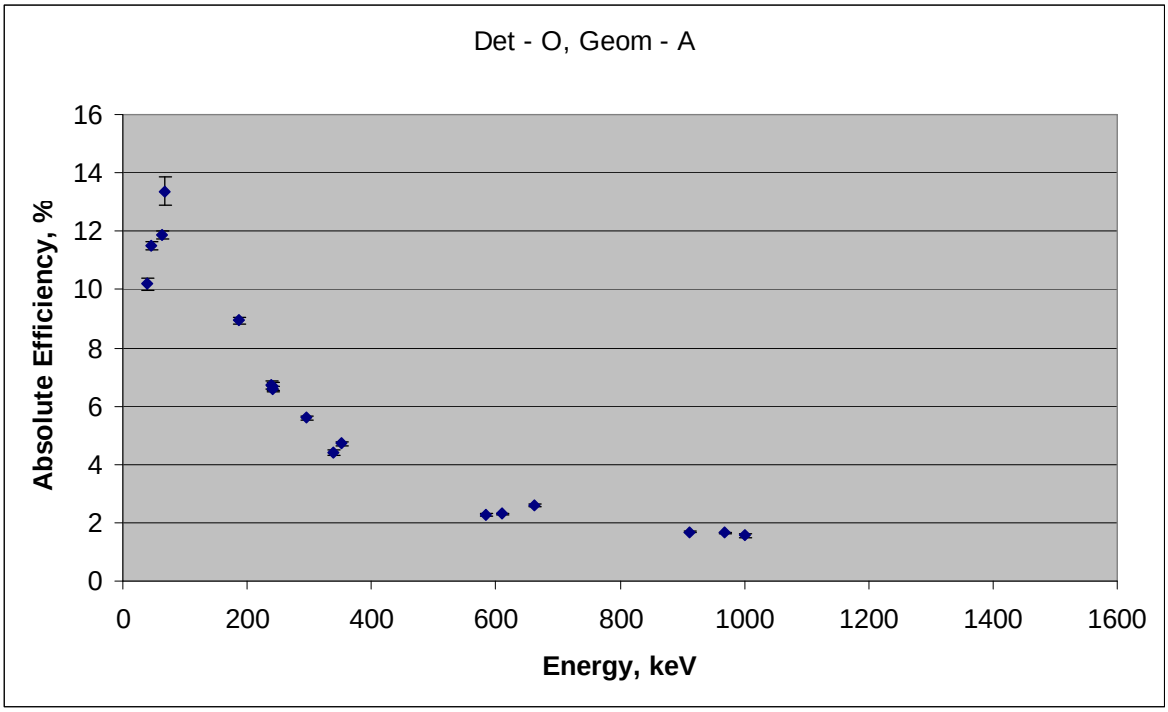
Detector N, Geometry R



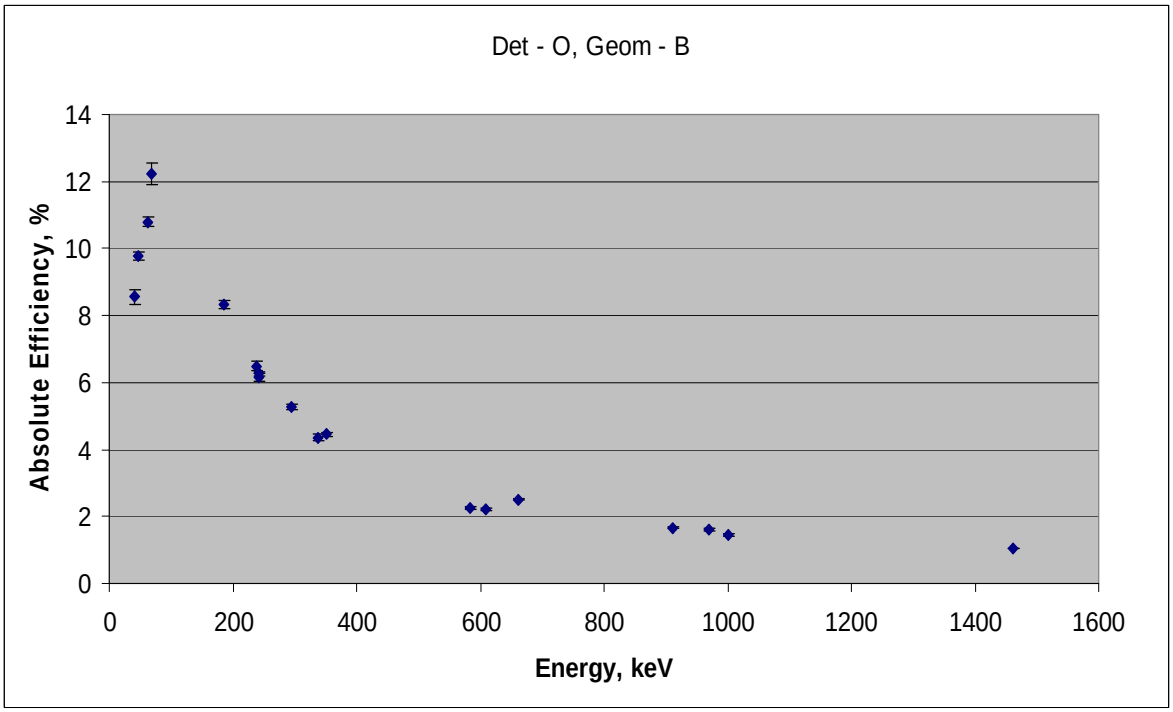
Detector N, Geometry V



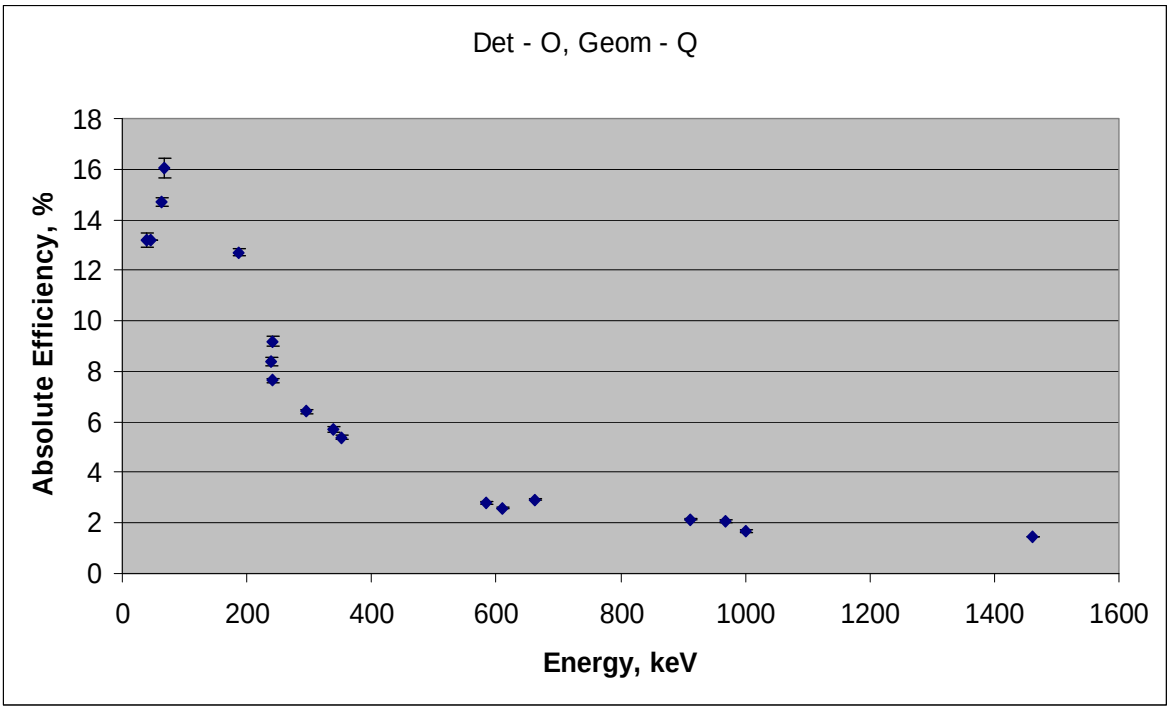
Detector O, Geometry A



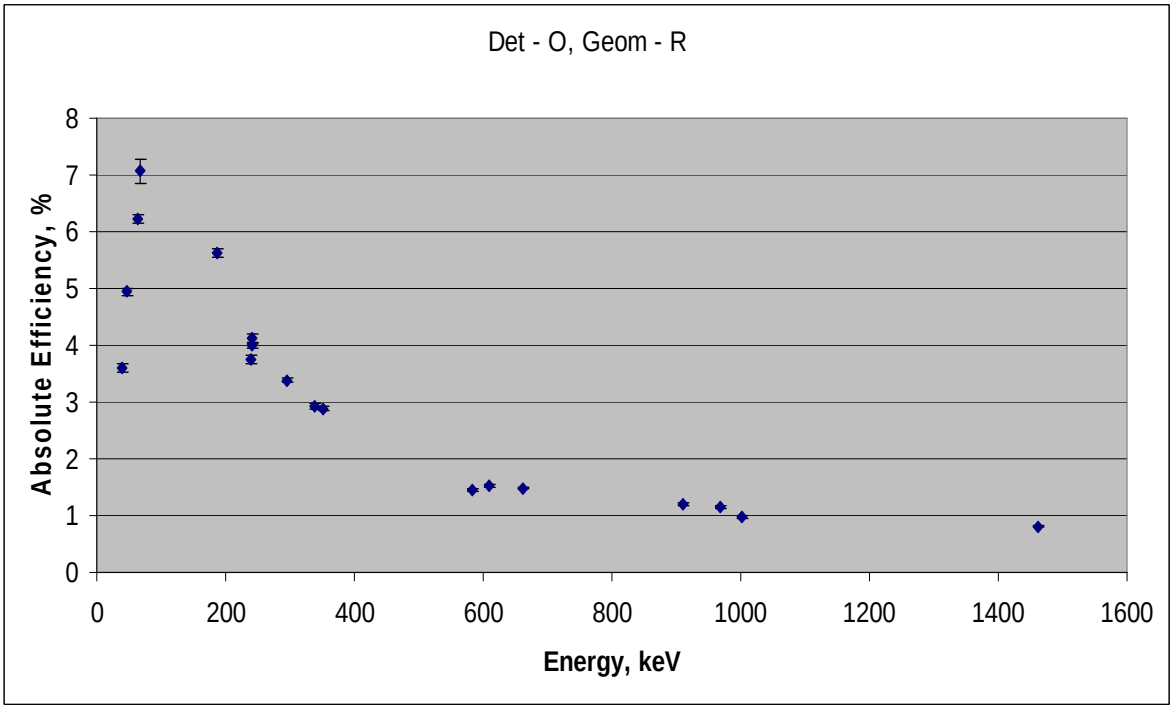
Detector O, Geometry B



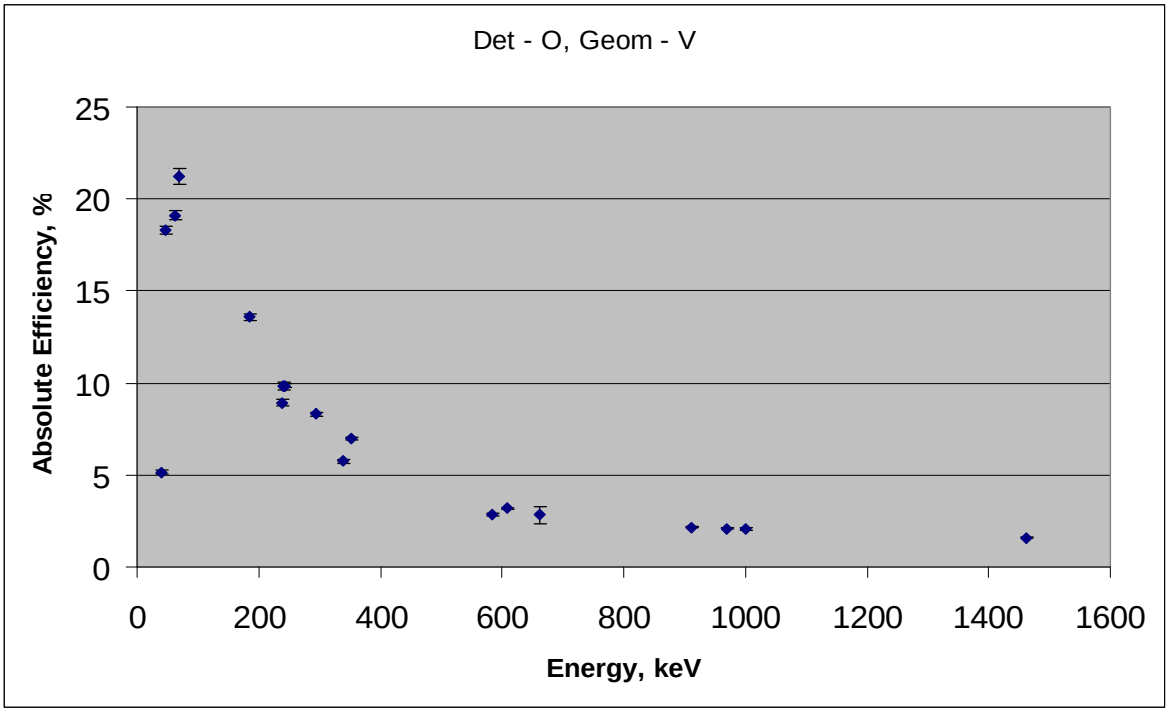
Detector O, Geometry Q



Detector O, Geometry R



Detector O, Geometry V



Appendix 4 Tables of absolute efficiency values for detectors G, N and O

Detector G, Geometry A, B & Q

Det - G		Geom - A	Geom - A	Geom - B	Geom - B	Geom - Q	Geom - Q
		absolute	Efficiency	absolute	Efficiency	absolute	Efficiency
Isotope	keV	efficiency %	uncert 1sd	efficiency %	uncert 1sd	efficiency %	uncert 1sd
U-235	**186**	0.36906	0.00610	0.35139	0.00834	0.33569	0.00492
Th-234	**63**	9.78298	0.13031	9.99460	0.20214	14.43063	0.17782
Pa-234	**1001**	1.37543	0.05980	1.32921	0.03790	1.64507	0.04013
Th-230	**68**	11.44211	0.45664	11.83883	0.34333	16.65582	0.36725
Ra-226	**186**	8.05946	0.10086	7.90786	0.17021	12.48457	0.15113
Pb-214	**242**	6.14021	0.07842	5.97987	0.12032	7.50783	0.09175
Pb-214	**295**	5.11412	0.06293	5.03912	0.10102	6.25460	0.07560
Pb-214	**352**	4.30437	0.05243	4.25408	0.08520	5.24754	0.06324
Bi-214	**609**	2.10991	0.02591	2.09796	0.04205	2.50263	0.03024
Pb-210	**46**	8.68988	0.11422	8.69755	0.17563	12.77264	0.15684
Ac-228	**338**	4.17079	0.08384	4.12513	0.08337	5.53247	0.11133
Ac-228	**911**	1.57248	0.03160	1.58180	0.03195	2.03117	0.04087
Ac-228	**969**	1.50913	0.03044	1.52365	0.03099	1.94761	0.03937
Ra-224	**241**	5.81515	0.11787	5.64790	0.11625	7.91946	0.16085
Pb-212	**239**	6.20771	0.12425	6.15323	0.12325	7.96183	0.15939
Bi-212	**40**	8.02577	0.17339	7.71466	0.18172	12.17189	0.26322
Tl-208	**583**	2.10298	0.04220	2.13512	0.04299	2.61973	0.05262
K-40	**1461**			1.06810	0.01682	1.30999	0.01651
Cs-137	**662**	2.58279	0.04005	2.22696	0.03445	2.10387	0.01670

Detector G, Geometry R & V

Det - G Isotope	 keV	Geom - R absolute efficiency %	Geom - R Efficiency uncert 1sd	Geom - V absolute efficiency %	Geom - V Efficiency uncert 1sd
U-235	**186**	0.20967	0.00294	0.66480	0.00907
Th-234	**63**	5.22030	0.06661	20.47718	0.25169
Pa-234	**1001**	0.87941	0.02237	2.20036	0.05949
Th-230	**68**	5.94932	0.18047	24.49370	0.48972
Ra-226	**186**	4.66184	0.05649	13.96028	0.17175
Pb-214	**242**	3.48583	0.04292	10.50576	0.12840
Pb-214	**295**	2.95124	0.03575	8.76953	0.10602
Pb-214	**352**	2.52253	0.03043	7.31712	0.08820
Bi-214	**609**	1.32613	0.01604	3.26626	0.03950
Pb-210	**46**	4.05344	0.05132	19.00732	0.23294
Ac-228	**338**	2.43536	0.04908	6.13764	0.12325
Ac-228	**911**	0.98738	0.01988	2.24064	0.04500
Ac-228	**969**	0.94336	0.01908	2.13547	0.04302
Ra-224	**241**	3.21384	0.06585	10.13159	0.20430
Pb-212	**239**	3.22664	0.06461	9.46113	0.18933
Bi-212	**40**	2.87008	0.07388	5.48017	0.13693
Tl-208	**583**	1.22860	0.02469	2.92875	0.05874
K-40	**1461**	0.67975	0.01626	1.62143	0.02858
Cs-137	**662**	1.31920	0.01990	3.00813	0.24793

Detector N, Geometry A, B & Q

Det - N		Geom - A	Geom - A	Geom - B	Geom - B	Geom - Q	Geom - Q
		absolute	Efficiency	absolute	Efficiency	absolute	Efficiency
Isotope	keV	efficiency %	uncert 1sd	efficiency %	uncert 1sd	efficiency %	uncert 1sd
U-235	186	0.3575	0.0073	0.3400	0.0083	0.2915	0.0063
Th-234	63	10.8583	0.1448	10.2100	0.1276	12.7357	0.1627
Pa-234	1001	1.4469	0.0618	1.5052	0.0365	1.6456	0.0521
Th-230	68	11.7898	0.4321	11.8018	0.2787	15.1126	0.4520
Ra-226	186	8.2221	0.1204	8.1026	0.1477	11.6879	0.1500
Pb-214	242	6.2165	0.0796	6.0744	0.0745	7.2126	0.0897
Pb-214	295	5.3284	0.0656	5.1669	0.0625	6.0920	0.0742
Pb-214	352	4.5118	0.0550	4.4181	0.0533	5.1548	0.0624
Bi-214	609	2.3276	0.0286	2.2785	0.0275	2.6044	0.0316
Pb-210	46	10.3626	0.1354	9.0597	0.1122	11.5599	0.1458
Ac-228	338	4.3629	0.0880	4.3876	0.0885	5.3432	0.1079
Ac-228	911	1.7502	0.0353	1.7639	0.0356	2.1090	0.0426
Ac-228	969	1.6879	0.0342	1.7078	0.0346	2.0466	0.0416
Ra-224	241	6.0466	0.1239	5.6809	0.1167	8.8228	0.1800
Pb-212	239	6.3538	0.1272	6.3343	0.1269	7.5157	0.1505
Bi-212	40	9.2660	0.2083	8.2847	0.1888	11.3204	0.2580
Tl-208	583	2.3238	0.0467	2.3598	0.0474	2.7121	0.0546
K-40	1461			1.2382	0.0192	1.5427	0.0357
Cs-137	662	2.5614	0.0395	2.4718	0.0385	2.4712	0.0381

Detector N, Geometry R & V

Det - N		Geom - R absolute	Geom - R Efficiency	Geom - V absolute	Geom - V Efficiency
Isotope	**keV**	**efficiency %**	**uncert 1sd**	**efficiency %**	**uncert 1sd**
U-235	**186**	0.2026	0.0028	0.4774	0.0095
Th-234	**63**	5.8205	0.0725	15.3820	0.1929
Pa-234	**1001**	1.0523	0.0208	1.9048	0.0583
Th-230	**68**	6.5913	0.1614	17.3315	0.4338
Ra-226	**186**	5.3877	0.0652	11.2248	0.1407
Pb-214	**242**	3.8614	0.0470	8.3916	0.1037
Pb-214	**295**	3.2927	0.0397	7.1142	0.0864
Pb-214	**352**	2.8386	0.0342	6.0154	0.0727
Bi-214	**609**	1.5507	0.0187	2.9524	0.0358
Pb-210	**46**	4.6461	0.0576	14.7993	0.1836
Ac-228	**338**	2.9143	0.0584	5.3365	0.1076
Ac-228	**911**	1.2494	0.0250	2.1045	0.0424
Ac-228	**969**	1.2003	0.0241	2.0206	0.0410
Ra-224	**241**	3.6442	0.0732	8.4894	0.1730
Pb-212	**239**	3.6704	0.0734	7.8744	0.1577
Bi-212	**40**	3.3691	0.0710	4.2351	0.1197
Tl-208	**583**	1.5010	0.0300	2.7680	0.0557
K-40	**1461**	0.8259	0.0130	1.5145	0.0572
Cs-137	**662**	1.5570	0.0234	3.6620	0.4834

Detector O, Geometry A, B & Q

Det - O		Geom - A	Geom - A	Geom - B	Geom - B	Geom - Q	Geom - Q
		absolute	Efficiency	absolute	Efficiency	absolute	Efficiency
Isotope	keV	efficiency %	uncert 1sd	efficiency %	uncert 1sd	efficiency %	uncert 1sd
U-235	186	0.38834	0.00655	0.37157	0.00659	0.32910	0.00512
Th-234	63	11.87757	0.15706	10.78802	0.13681	14.71099	0.18274
Pa-234	1001	1.56469	0.06422	1.45407	0.04202	1.67273	0.04250
Th-230	68	13.36576	0.48257	12.23260	0.32910	16.05772	0.39140
Ra-226	186	8.93643	0.11185	8.33350	0.11868	12.71301	0.15474
Pb-214	242	6.58518	0.08389	6.25801	0.07751	7.64617	0.09372
Pb-214	295	5.60044	0.06876	5.27330	0.06400	6.41787	0.07766
Pb-214	352	4.71732	0.05738	4.45894	0.05386	5.38912	0.06499
Bi-214	609	2.31336	0.02835	2.21073	0.02680	2.59621	0.03140
Pb-210	46	11.50083	0.14795	9.75901	0.12213	13.19971	0.00413
Ac-228	338	4.41603	0.08872	4.35995	0.08880	5.69479	0.11463
Ac-228	911	1.69113	0.03397	1.66936	0.03397	2.14976	0.04327
Ac-228	969	1.65326	0.03331	1.61487	0.03327	2.07190	0.04189
Ra-224	241	6.66358	0.13482	6.14666	0.12958	9.18799	0.18630
Pb-212	239	6.72880	0.13466	6.48784	0.13011	8.35880	0.16734
Bi-212	40	10.19262	0.21502	8.55209	0.21763	13.17269	0.28598
Tl-208	583	2.25974	0.04533	2.25712	0.04568	2.79084	0.05607
K-40	1461			1.03830	0.00838	1.45732	0.02377
Cs-137	662	2.60320	0.04010	2.51343	0.03889	2.92420	0.04487

Detector O, Geometry R & V

Det - O		Geom - R	Geom - R	Geom - V	Geom - V
		absolute	Efficiency	absolute	Efficiency
Isotope	keV	efficiency %	uncert 1sd	efficiency %	uncert 1sd
U-235	186	0.21894	0.00304	0.58543	0.01088
Th-234	63	6.23251	0.07867	19.11985	0.23503
Pa-234	1001	0.97483	0.02181	2.07615	0.05417
Th-230	68	7.06288	0.20657	21.21962	0.40013
Ra-226	186	5.61996	0.06803	13.58757	0.16909
Pb-214	242	3.99134	0.04888	9.85690	0.12032
Pb-214	295	3.37878	0.04083	8.32324	0.10054
Pb-214	352	2.88666	0.03478	6.96880	0.08396
Bi-214	609	1.51946	0.01834	3.18056	0.03842
Pb-210	46	4.94884	0.06192	18.30047	0.22367
Ac-228	338	2.92505	0.05862	5.74651	0.11546
Ac-228	911	1.19556	0.02395	2.14722	0.04314
Ac-228	969	1.14315	0.02293	2.07421	0.04182
Ra-224	241	4.11451	0.08281	9.84828	0.19890
Pb-212	239	3.74430	0.07491	8.90858	0.17829
Bi-212	40	3.60747	0.07762	5.15345	0.12805
Tl-208	583	1.45752	0.02919	2.83315	0.05685
K-40	1461	0.80760	0.01487	1.59780	0.02862
Cs-137	662	1.48603	0.02242	2.83317	0.44763

Appendix 5 Listing of gamma spectroscopy standards used for calibration

An up-to-date listing of all gamma spectroscopy standards is maintained in the file ‘All-ERISS-standards.xls’ on Sharepoint directory :

SSDX > Equipment and Techniques > HPGe Gamma Spec > Calibrations > Standards Listing