

Gamma Spectrometer

Manual

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A – Hardware

1 – Overall system description

The gamma spectrometer consists of two parts:

- 1) Scintillation detector (5185.00), which registers each incoming gamma quantum, delivering an electrical pulse, ideally of a size proportional to the energy of the gamma quantum.
- 2) Multichannel analyzer (5180.00), which sorts the incoming pulses in a large number of intervals ("channels") and counts the number of pulses in each of these.

The accompanying software should also be considered as an integral part of the multichannel analyzer.

Multichannel analyzer – see paragraph A.2

The multichannel analyzer has 1024 channels.

The multichannel analyzer is powered via the USB connection from the PC. It is important that the USB port used can deliver full power as specified in the USB standard. There may be e.g. laptops that do not live up to this.

SiPM detector – see paragraph A.3

The detector is suitable for measuring the gamma and x-rays down to 30-50 keV.

The detector is based on a silicon photomultiplier. As a scintillator, Cs (TI) is used, i.e. a thallium-activated caesium iodide crystal. Both the light output of the scintillator and the gain of the photomultiplier is a bit temperature dependent, which is compensated by varying the bias voltage to the SiPM.

The detector is powered from the MCA 5180.00 and cannot be used without this.

Other scintillation detectors – see paragraph A.4

Multichannel may be used in combination with other detectors.

Two inputs are provided: one is used with the detector SIPM 5185.00, the other can be connected to the anode signal from a conventional photomultiplier. Switching between the two inputs happens automatically, depending on whether power is drawn by the 5185.00 or not.



2 – Multichannel analyzer

Connections

The multichannel analyzer (and eventually the detector) is powered via the USB connection from the PC. An LED indicates when USB power is present. It is important that the USB port used can deliver full power as specified in the USB standard.

A power supply for the associated scintillation detector 5185.00 is build into the unit. The detector needs multiple voltages, including a bias voltage to the silicon photomultiplier. See details in the following section.

Note: Connect the detector to the multichannel analyzer *before* the USB cable is connected to the PC. Do not disconnect the detector as long as the USB cable is connected to the PC.

There are two inputs to the device. If a 5185.00 detector is connected to the *Detector Power*, the input marked *Detector* is activated – otherwise *Aux (PM Anode)* is active. Use of the *Aux* input is detailed in Section A.4.

The active input is indicated by an LED on the front panel.



The *Detector* input is a voltage input, ground referenced. It is terminated with 50 Ω . The signal from the detector is assumed to be positive pulses.

The *Aux (PM Anode)* input is a current input, accepting negative pulses from a high-impedance output. This input is adapted the anode signal from a traditional vacuum photomultiplier. The signal at this input is inverted before it is digitized.

Signal processing

Pulses from the detector are amplified by a selectable factor (*Gain*). (This parameter – like the following – is controlled from the program *GaSp*.)

Next, the signal is digitized. The appearance of the pulses can be examined in the program. It is advisable to gain experience of how impulses from e.g. a Cs-137 source look at this point in the signal chain. See Section B.2.

Pulses that exceed a certain size (*Trigger Level*) will be integrated into a selectable time interval (Integration Time) – that is, the area between the signal and the idling voltage is determined. This area expresses the pulse size.

The idle voltage is automatically detected when no signals arrive at the detector. The processing waits the *Time To Baseline* before the idle voltage is measured.

Pulses with a deviant appearance are assumed to be due to pile up, i.e. two independent particles detected shortly after each other, where the first pulse hasn't ended before the next arrives. Such pulses are rejected electronically. The program has the parameter Pile Up Time, which controls this.

Signal analysis

The size of an "approved" pulse now determines which of the analyzer channels is to be incremented by one. The sorting is scaled by a compression factor (a power of 2).

Ideally, there is proportionality throughout the signal chain: Energy of the gamma quantum – the light flash in the scintillator crystal – the size of the pulse from the detector – the channel number.

In the program, the channel number is represented by the x axis of the spectrum, the channel counts as the y axis. The resulting curve therefore depicts (again: ideally) the statistical distribution of the energy of the gamma quanta hitting the detector.

(In reality, the spectrum doesn't look as simple as suggested here. Even a mono-energetic gamma radiation will not only provide counts in a single channel.

This is due to the interaction between a gamma quantum and the scintillation crystal. In brief, some of the gamma energy does not always result in emission of light. The details will be discussed in Appendix C.4.)

3 – SiPM detector

Description

The detector 5185.00 must be connected to the multichannel analyzer with two cables: a power cable with RJ45 modular connector (same connector as in computer networks) – and a signal cable with BNC connectors. The cables are connected to resp. *Detector Power* and *Detector*. The input is activated when current is drawn from the power supply. This is indicated by an LED on the front panel.



Note: Connect the detector to the multichannel analyzer *before* the USB cable is connected to the PC. Do not disconnect the detector as long as the USB cable is connected to the PC.

The scintillation crystal is behind a 0.5 mm thick aluminium cap, which partly serves as light barrier and partly provides protection against mechanical damage. The relatively thin material is obviously a bit fragile – treat the detector accordingly. Compared with conventional photomultiplier tubes it is nevertheless quite rugged.

One can assume that the crystal starts approx. 1.5 mm behind the surface of the hood.

For measurements of approximate point sources, the detector must "point" at the source, as this optimizes efficiency.

The detector uses a 6 x 6 x 15 mm Cs I(Tl) crystal as a scintillator. The crystal is glued to a silicon photomultiplier (SiPM) with a sensitive area of 6 x 6 mm. The output current from the SiPM is integrated and pulse shapes in an amplifier circuit in the detector housing.

Output pulses are unipolar – positive – almost without negative overshoot. The amplitude is somewhat smaller than that of traditional nuclear instrumentation amplifiers. The multichannel analyzer input circuits (*Detector* input) takes this into account.

Temperature compensation

The detector is equipped with a temperature sensor that through the multichannel analyzer can be read by the included program *GaSp*. The program regulates the bias voltage to the SiPM, so the overall energy calibration is kept fairly constant despite changes in temperature.

The power cable to the detector must be connected to multichannel analyzer – which must be under program control – before the output delivers valid pulses.

The output signal can easily be connected to e.g. an oscilloscope – the output signal is not used in temperature stabilization. Further details of temperature compensation: Paragraph B.2

Bias adjustment

The bias voltage is most conveniently adjusted in software – see paragraph B.2.

4 – Other scintillation detectors

When no detector is plugged in to the *Detector Power* connector, the *Aux input (PM Anode)* is activated. This will also be marked by an LED on the front panel.

The input is adapted to the anode signal from a traditional vacuum photomultiplier. The tube must be powered from a separate voltage source. Follow the photomultiplier vendor's instructions regarding the recommended voltage.

The input is AC coupled and terminated with 50 Ω (AC-wise). This means that the photo multiplier circuitry must provide a (high impedance) DC path to ground for the anode current.

The MCA unit can be changed to DC coupling by modifying the circuit board. In this case the open circuit voltage is some hundreds of millivolts. The detector circuitry must leave this resting level unchanged as any shift is amplified and transferred through the analog part of the MCA.

The NaI detector to the left in the photo below is an example of an old detector that can gain a second life with our multichannel analyzer.



B – Software

1 – Overall system description

The software consists of two parts: The files *GaSp.exe* and *FMCA.dll*, comprising the program itself – and the files *libusb0.dll* and *libusb0.sys*, which constitutes the driver for the handling of USB communication. The program files can easily be moved and copied, while the driver must be installed properly on the computers you want to connect to the gamma spectrometer. For installation details, refer to Appendix 1.

The program can be used without spectrometer, if you want to use it for the analysis of already collected data.

Hardware control – see paragraph B.2

The gain in the multichannel analyzer and a variety of other parameters are controlled from the program. Initially, a number of standard values are selected for the matching detector 5,185.00, so you can be fairly sure that you will get a spectrum on the screen when you hold a gamma source next to the detector. There are shortcut buttons to restore this initial setting and to set reasonable parameters for a NaI detector. The parameters are remembered from time to time.

Experiments – see paragraph B.3

Data acquisition in *GaSp* is centred on the *experiment* concept. An experiment can have one of the types *free*, *spectrum* or *decay*. These types are described briefly below and in more detail in a later section.

A *free experiment* is created automatically when you open the program and start the data collection. It is characterized by unrestrained starting and stopping, and allows changing the hardware parameters along the way. The resulting data can be stored manually during or after data collection.

A *spectrum experiment* is set up for a fixed duration. The experimental parameters are locked while the experiment is running, but you can course monitor and analyze the data along the way.

A *decay experiment* also has a fixed duration, but along the way the spectrum is stored in individual files at fixed time intervals. This allows for an analysis of how the number of counts in a given energy region evolves as a function of time.

Analysis of data – see paragraph B.4 and B.5

In a spectrum, you are often interested in the total counts in one or more energy ranges – typically representing photo tops. Data in such an area can be fitted to various mathematical functions – or the counts can just be summed.

In a decay experiment you can again define one or more areas of the spectrum whose count rates you wish to examine as a function of time. You can here choose the fitted data rather than the counts – e.g. the area under a Gaussian function with background subtracted.

The sequence can also be fitted to a theoretical function – e.g. an exponentially decreasing function.

Spectrum arithmetic – see paragraph B.9

Often you want to subtract a background radiation spectrum from the raw data before analyzing the spectrum. The program can of course handle this. The normal situation is to store the spectra as individual data sets, although they may be stored together in a single experiment file.

In certain situations, however, you may wish to add or subtract two spectra and save the resulting spectrum. The program handles these tasks, adjusting uncertainties properly, and tags the resulting spectrum to indicate that it no longer contains raw data.

2 – Hardware control

Testing the USB connection

The multichannel analyzer must be connected to the USB port, before starting the program. Contact is only established at the start.

When the program successfully connects to the multichannel analyzer the status bar on the left will say "Live Data". Otherwise the text "Not connected" is displayed in red.

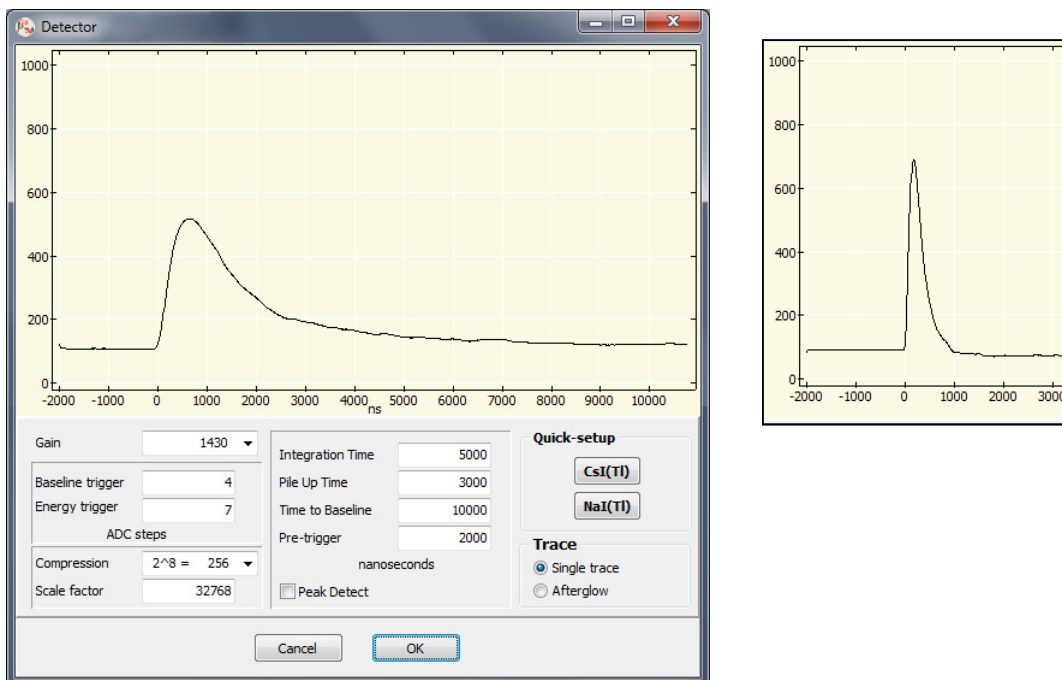
The connection may be lost – e.g. due to a loose cable. It will during an experiment be revealed by a constantly growing number of timeouts appearing in the status bar. Save any valuable data and restart the program.



The program can run perfectly well without a connection to the MCA – meaning that existing data files can be analyzed.

Checking the pulse shape

Select the menu item *Hardware / Detector*. This brings up the dialog box shown below. Note that it is not necessary to close the box to return to the main program.



The pulse shape shown (large picture) is typical of the matching CsI(Tl) detector. The small picture shows the significantly shorter pulse from a NaI(Tl) detector.

Time is measured in nanoseconds; the y axis goes from 0 to 1023, where each step corresponds approximately to 1 mV after amplification. (The screen is not updated for every pulse recorded!)

Gain and trigger level

These parameters are controlled via the menu item *Hardware / Detector*.

(These parameters will be blocked from editing during spectrum and decay experiments, and when data is loaded from a file. The dialog box will be active again when you press the *Reset* button.)

The analog gain can be selected from a list. Set this so that the largest pulse you are interested in slip through without "hitting its head against the ceiling."

Occasionally, cosmic rays etc. will arrive which give a very strong pulse that is clipped severely at the top. It's no problem – it will simply not appear in the spectrum. If you are not sure that all desired pulses slip through, you can test it with a Peak Detect spectrum. This is discussed below.

The pulses which are to be further processed must exceed the *Energy trigger* level, measured from the base level. If no sensible pulses can be seen it may be caused by setting the *Energy trigger* too low, constantly triggering on noise. *Energy trigger* must typically follow the gain when it is increased or decreased.

The electronics calculates the base level as an average in the absence of a pulse. A pulse is considered completed when the voltage reaches the value of *Baseline trigger* (again calculated from the initial resting level). *Baseline trigger* is normally set between 3 and 5.

When a pulse is accepted, its area is determined (see next section). It is this area which is a measure of the registered gamma energy. Before the area becomes a part of the spectrum, it is scaled digitally. First, it is compressed with a power of 2, determined by the *Compression* parameter. Next, it is multiplied by the *Scale factor* and divided by 32768. Since the pulses are counted in channels with integer numbers, the result is rounded before it is included in the spectrum.

Rounding to integers can result in strange spectra when the scale factor is close to, but different from 32768. Then, for example, every other channel can be a little too high and the rest a little too low. Usually it is recommended to keep the scale factor = 32768.

Integration time etc.

These parameters are controlled via the menu item *Hardware / Detector*.

(These parameters will be blocked from editing during spectrum and decay experiments, and when data is loaded from a file. The dialog box will be active again when you press the *Reset* button.)

These parameters can easily be set to a reasonable starting point for the two typical types of detectors by clicking on the shortcut buttons *CsI(Tl)* or *NaI(Tl)*.

Integration Time determines how much of the pulse that should be included in the area calculation.

Pile Up Time is set to the pulse half width – a little more than half of the integration time. It is used internally to reject useless, misshaped pulses, which occurs when one pulse starts on top of the previous one. The mechanism can be disabled by selecting the value 0.

Time to Baseline sets a forced downtime, so the idle level can be restored before the next pulse is treated.

Pre-trigger is not essential for recording spectra. It simply indicates how much of the curve that appears before the pulse in this dialog box.

Peak Detect

This parameter is controlled via the menu item *Hardware / Detector*.

(This parameter will be blocked from editing during spectrum and decay experiments, and when data is loaded from a file. The dialog box will be active again when you press the *Reset* button.)

If this box is checked, integration and digital scaling are disabled, and the spectrum is recorded with the pulse peak values instead. Note that this will deteriorate the energy resolution – use *only* for control of the gain selection.

Note: Changing this parameter will only take effect after clicking *Start* or *Reset*. (This behaviour differs from that of the other fields in the dialog box.)

With *Peak Detect* activated you can easily see if the spectrum is cut at high energies. The maximum occurring channel number in the spectrum will be equal to the difference between the base level and 1023. As a rule of thumb, you can assume that all interesting peaks in the peak spectrum must be below channel 800.

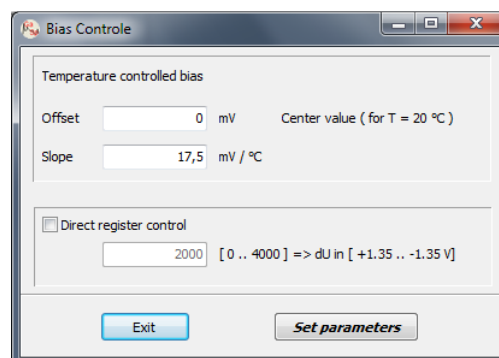
Do not forget to uncheck the *Peak Detect* before recording real spectra.

Bias

Scintillationsdetektoren 5185.00 is based on a solid state photomultiplier, which gets its bias voltage from the multichannel analyzer.

The menu item *Hardware / Bias* allows you to control this. Changes are not activated until you click *Set parameters*. The values are remembered the next time you start the program.

(Editing the bias parameters is blocked during spectrum and decay experiments, and when the data is loaded from a file. The dialog box will be active again when you press the *Reset* button.)



There is no guarantee that the silicon photomultiplier used always comes with the same requirements for bias voltage. Therefore both the detector and the multichannel analyzer come with a slip of paper showing the bias voltage. A possible difference can be entered in the *Offset* field.

Should this note be lost, the following procedure is followed.

If you use the default setup (click on *CsI(Tl)* under *Hardware / Detector*), the top photo in a Cs-137 spectrum lie near channel 400 Differences can be compensated by changing the parameter *Offset*. A higher bias voltage will provide increased gain. The default is 0.

The value of the *Slope* indicates the temperature dependency of the bias voltage. It compensates primarily for the so-called breakdown voltage of the photomultiplier which increased by approx. 20 mV per degree, but the default value 17.5 is chosen to keep the gain of the whole detector constant in a range around room temperature.

Direct register control is used for testing and adjustment purposes. Should not be selected.

Testing for offset problems

This test uses the menu item *Hardware / detector*.

The detector 5185.00 and the multichannel analyzer are DC coupled to each other and although the multichannel analyzer is adjusted during production, one can imagine that an unfortunate combination can cause problems with offset errors. It is demonstrated by marked base level jumps when the gain is changed. Checks are carried out as follows:

Remove any sources from the detector. Adjust *Energy trigger* to a low value as 0 or 1, to trigger constantly on noise near the resting level (the curve changes appearance constantly).

Start with a low gain like 430 or 1100 in order to see where the rest level is. It should typically be slightly above 100 on the y axis.

Now, increase the gain incrementally, and observe if the resting level is changing too much.

If the level drops down to 0, it means trouble. The system can only work with a correct determination of the base level. If the level is changed upwards, you will lose some dynamic range, which is not nearly as problematic.

3 – Experiments

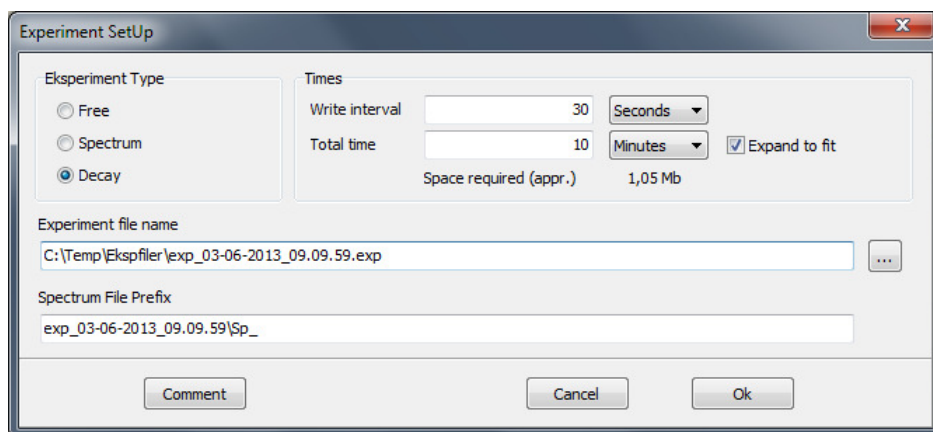
Setting up an experiment

To switch between different types of experiment and to select the duration, file names, etc., select the menu item *File / Setup experiment*.

Note that the dialog box for this menu item is set inactive when data collection is started, and after loading a spectrum from a file. It is only activated again by pressing the *Reset* button.

If you set up a spectrum or decay experiment, data is stored automatically. The current spectrum, and all settings can always be saved by choosing *File / Experiment / Save as Spectrum Exp*. The spectrum is stored as a spectrum experiment with the current live time as total time.

Below, the different types of experiments are described in detail.



Free experiment

When the program is first launched, it is set up as a *free experiment*.

This means that parameters such as gain can be varied freely, and that data collection can be started and stopped at any time.

Spectrum experiment

A spectrum experiment is set up to run for a certain *Total time* after which the result is stored in a file. Along the way, accidental changes to the hardware parameters (gain, integration etc.) are blocked.

A filename based on the current date and time is proposed, but this can of course be changed to something more sensible. The path name is easily changed by using the "..." button to the right, which opens a usual Windows *Save As* dialog.

A backup of the temporary data is stored at the specified *Interval*; circulating between three files, overwriting the oldest. The three files will be located in a subfolder of the location of the file named *Temp*. If *Interval* is set to 0 in a spectrum experiment, no backup is performed.

The *Total time* of the experiment will under normal circumstances always be chosen as a multiple of the *Interval* parameter. However, this can be turned off by unchecking *Expand to fit*.

The *Control* panel is minimized during a spectrum experiment to prevent accidentally pressing *Pause*. If you want to stop a running spectrum experiment, simply open the panel. In this case the spectrum is *not* stored automatically, it must be done manually.

Decay experiment

As for the actual data collection, the decay experiment resembles a spectrum experiment a lot. Data is stored whenever the time *Interval* has elapsed – only now it is done in individual, systematically named files, to allow the timing to be re-established.

Interval should not be chosen too short – that will only stress the hard drive and increase the uncertainties per measurement. But if set to a too large value, you will lose details in the data series.

Since it is possible subsequently to skip measuring points, it is best to choose this time, so it with certainty is not too long.

Expand to fit should always be checked for a decay experiment.

Just as in the spectrum experiment, a file name is suggested which can be changed if desired. The file specified for the experiment contains only setup parameters. The spectra are usually put in a subfolder. The names of the spectra begin with a prefix, containing the name of the folder. A consecutive number is appended.

If you want to copy a decay experiment, be sure to copy both the experiment file *and* the folder containing the corresponding spectra.

The spectra are stored as cumulative spectra – the program calculates the desired difference spectra as required.

In a decay experiment, you can switch to the *Decay* view, which shows the time evolution of the number of counts in one or more energy regions. This is discussed in more detail below in section B.5.

The *Control* panel is minimized during a decay experiment to avoid accidental pressing *Stop*.

If you want to stop a running decay experiment, simply open the panel and click *Stop*.

Experiment file will already exist. The same applies to the spectra that have been written to disk during the experiment. The last spectrum which does not correspond to a complete interval is not automatically saved; it will rarely make sense to save it manually.

The background spectrum

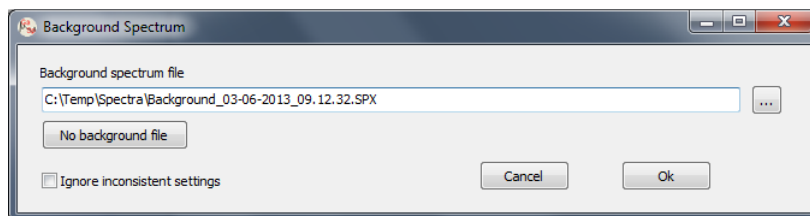
A background spectrum is made by first going through the hardware setup of the "actual" experiment and then removing the radiation source again. Record the spectrum with suitable long measurement time. When enough data has been collected it is saved as a spectrum (*File / Spectrum / Save as Spectrum*).

Next, the background spectrum can be used in conjunction with measurements with identical hardware setup.

This enables you to view the current spectrum with the background spectrum subtracted. The calculations take differences in live time into account.

It will usually be a prerequisite for applying this technique that the background spectrum has the same hardware parameters etc. as the current experiment.

Select the menu item *File / Background Spectrum*



Specify the file name of the background spectrum – or search by clicking on the button "..." to the right.

The background spectrum is removed from the experiment by pressing the *No background file* button.

It is possible (but rarely sensible) to use a background spectrum from a different hardware configuration. If tried, it will result in a flashing red spot and strikethrough text in the *Spectrum* panel, but the crossed out options can still be selected. If you wish to disable this warning, you must check *Ignore inconsistent settings*.

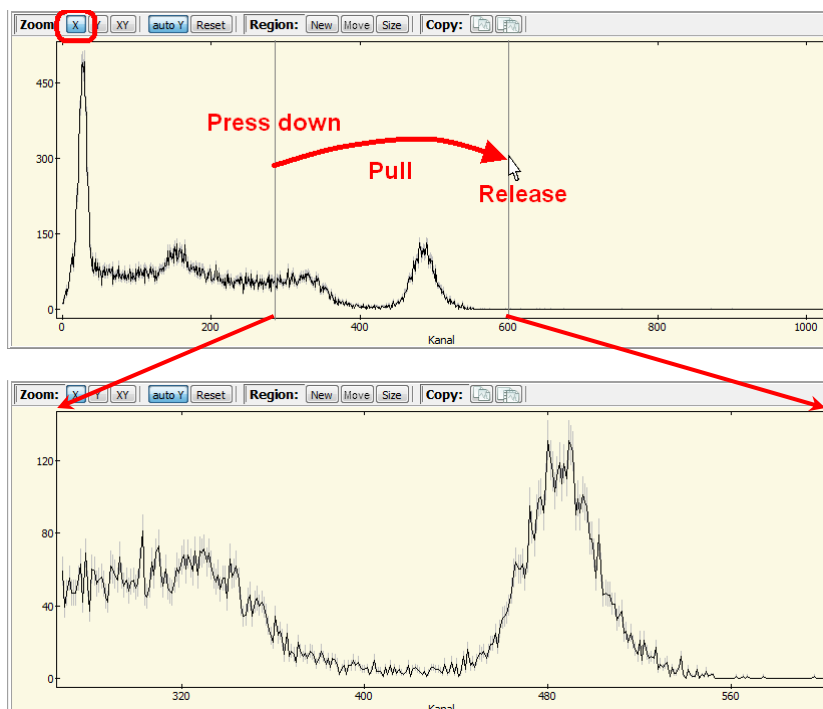
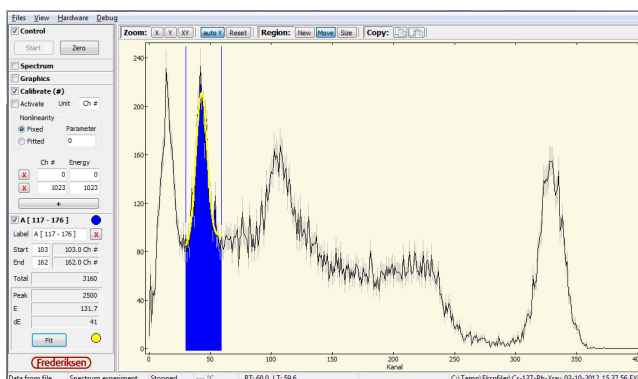
When you store a spectrum as a spectrum experiment, the background is included in the experiment file. Eventual warnings about inconsistent hardware setup are not recorded in this file.

4 – Spectrum view

The graph area

The large pane to the right shows the spectrum and is constantly updated. The x axis reflects the current calibration; the y axis is always counts.

It is possible to zoom in on details in the spectrum with the mouse. First select X, Y or XY and drag the mouse from start point to end point with the mouse button pressed.



When *Auto Y* is active, the y axis is always scaled so that all data (and possibly uncertainties) is visible in the selected channel range.

The zoom *Reset* button brings the view back to the full spectrum.

Regions to be analyzed in more detail can be created and customized with the buttons *New*, *Move* and *Size*. Again, this is done by dragging with the mouse - see "Panels for regions" below.

There is also a pair of buttons to copy either the spectrum alone or the whole application window. The image can subsequently be inserted into a document or saved via an image processing program.

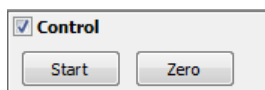
Panels to the left

These panels are presented separately below.

A common behaviour is that they are unfolded or minimized, depending on the presence of a "v" tick in the box. You can for simplicity minimize the panels you do not use.

If you have defined a few regions, the panels can easily fill more than the height of the program window. In this case a scroll bar shows up, allowing you to reach them all.

Control panel



When the experiment is set up as described in Section B.3, the recording of a spectrum is started by pressing the *Start* button. The button changes to become a *Stop* button.

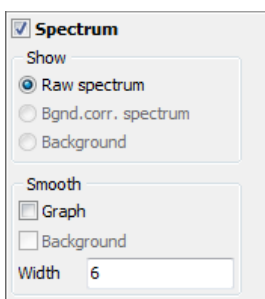
The first press on the *Start* button will zero and start both the *real time* and *live time* clocks. Live time is continuously adjusted for dead time.

Both times stops when you click on *Stop*. If you press *Start* again, real time and live time clocks proceed.

In a free experiment, you can at any time click *Zero*, which resets both the spectrum and the timing.

The actual time that has elapsed while collecting data is called *Real Time* (RT) in the status bar; the time the system has been ready to accept new pulses is called *Live Time* (LT). The difference is the cumulative dead time.

Spectrum panel



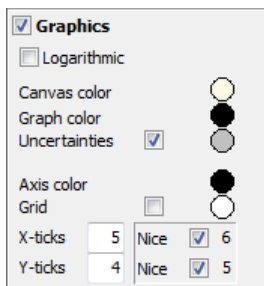
In this panel, the displayed spectrum can be manipulated. If a background spectrum is defined in the experiment setup, you can choose to display the measured spectrum with background subtracted. You can also choose to see the background spectrum itself.

Both the background spectrum as the displayed spectrum can be smoothed. Each channel of the smoothed spectrum is a weighted average of an interval around the channel. The weights are Gaussian distributed with adjustable standard deviation.

Usually, little is gained by smoothing the displayed spectrum. However, it may be good sense to smooth the background spectrum before subtraction – unless there are sharp details in the background, which aren't due to statistical chance.

If the top right panel shows a red circle, it is signalling that the foreground and background spectra do not use the same hardware parameters. This usually means that it makes no sense to subtract them. (See also the section *The background spectrum* in B.3 above.)

Graphics panel



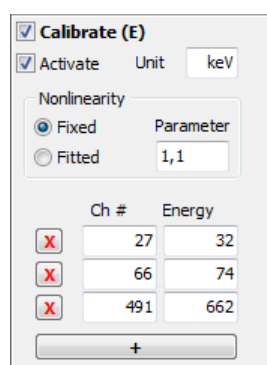
In this panel, the appearance of the graph pane (to the right) is controlled.

You can choose colours for each element, error bars can be turned on and off, and you can insert a grid in the background.

For the y axis you can choose between a normal linear scale and a logarithmic scale.

The divisions of the x and y axes can be specified individually, including if the divisions should be spaced evenly on the axis, or rounded to "nice" numbers.

Calibrate panel



If the gamma energies of a few photo tops and the corresponding channel numbers are known, you can calibrate the x axis, so that it directly indicates the gamma energy (for example in keV), rather than just the channel number. A precise determination of the channel number is best performed by fitting a Gaussian function to a region of the spectrum. This is described in the next section.

A tip: If you want more photo peaks with known energies, a radioactive mineral sample can often supplement your standard sources with single isotopes.

Calibration is active when the *Activate* box is checked. The checkmark disappears every time there is a change in the panel (except for the *Unit* field). The reason is that the points are fitted with a second degree polynomial, which happens when the box is checked again. While setting up the calibration, you have to work with the raw channel numbers from the fittede photo peaks.

The *Calibrate* panel starts with only two times two fields at the bottom for calibration. If you want a point more, click on the large, elongated "+" button below. An item can be deleted again by clicking the corresponding button with a red "X".

Points are fitted to a quadratic polynomial with a very small second-order term – the function is "almost linear". The relationship between second and first degree coefficients are corrected for gain and compression and multiplied by a constant factor. The result is a "non-linearity parameter", which mainly depends on the used detector. It is this parameter that occurs in the panel.

If you have many photo peaks for calibration, check the option *Fitted* to make the quadratic function adapt freely to data.

If you have fewer points, you can choose to lock the non-linearity parameter on a "typical value" – preferably one you have achieved in the past. It will usually give a much better match than a linear fit.

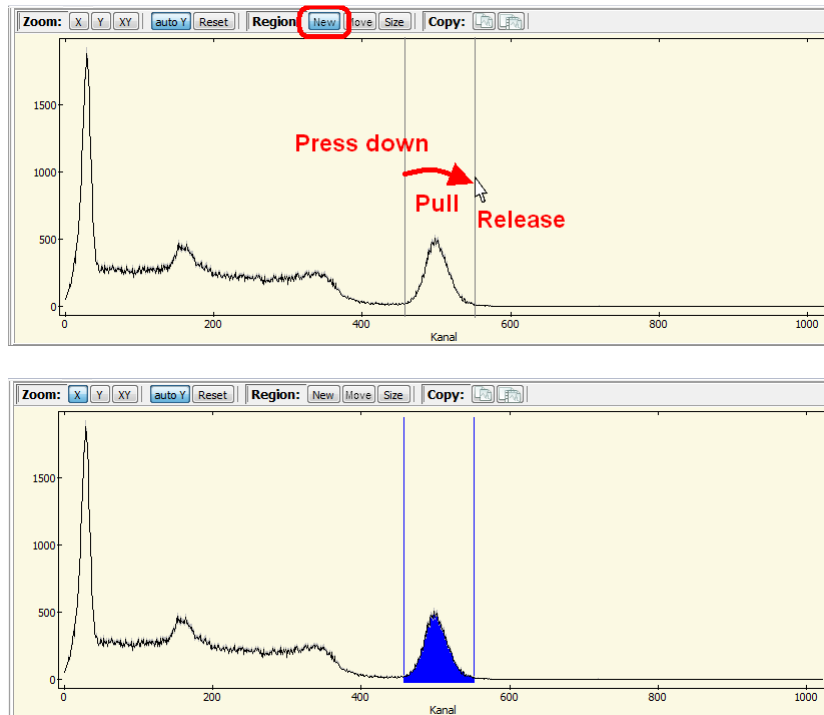
If you want a pure linear calibration function, simply fix the non-linearity parameter at 0.

If you usually use the same sources for calibration, it is convenient to store the calibration data using the menu item *File / Calibration / Save as CAL file*. Then you don't need to enter the table values but only the correct channel numbers.

If you are very optimistic, you can even just re-use the calibration from the file.

Panels for *regions* – fitting of Peaks

A "Region Of Interest" (ROI) – is a channel interval. A region is created with a mouse drag on the graph after clicking the *New* button at the top of the graph pane. At the same time, a corresponding panel is created in the left column. (See next page.)



Each region is defined by its start and end channel. These are also part of the initial name of the region, but the name can be changed as needed ("Photo peak" and "X-rays" might be appropriate names).

☒ **A [4 - 47]**
X

Label: A [4 - 47]

Start: 8 3.5 keV
 End: 41 46.0 keV

Total: 1715

Peak: 708
 E: 23.6 keV
 dE: 17 keV

●

The region can be deleted by clicking the red "X".

The region is associated with the colour that appears at the top. Click to edit.

The total counts for all channels in the region can be seen in the panel: *Total*.

For each region, you can define a theoretical function that is continuously fitted to data – frequently this is a Gaussian function. Details of the setup are accessed by a click of the button *Fit*. This opens a dialog box which is discussed shortly.

The graph of the fitted function is coloured as shown in the lower circle. This colour can also be edited.

The lower part of the panel shows the results of the fit. The example in the figure above is for a Gaussian function with linear background: *Top* shows the number of counts above the background, *E* is the peak position (as energy or channel number), and *dE* is the associated uncertainty, understood as the peak's half width at full maximum (FWHM).

The types of functions, you can choose from, are either "none" – i.e. simple summation – or an expression of the form:

$$f(x) = a \cdot (x - c) + b + P \cdot \exp\left(\frac{(x - E)^2}{s^2}\right)$$

This is a Gaussian function with a linear "background". By locking some of the parameters at 0, the various options are achieved. For fitting of photo peaks in a gamma spectrum, the full expression (Gauss + lin.) will normally be the one to choose.

Please note that the parameter *s* is not the standard deviation of the Gaussian, but $\sqrt{2}$ times the standard deviation. The number *c* is a constant = midpoint of the region.

All of the parameters in this formula are related to the channel numbers.

Fitting a region is activated via the button *Fit*. This opens a dialog box as shown on the right.

If you just want to activate a standard Gaussian + lin. fit, it is enough to click OK – provided that the peak roughly fills the region (more on this later).

The types of functions you can choose from are listed in the drop-down menu *Fit Mode*.

When a new fit mode is selected, the parameters are assigned "sensible" initial values. The button *Guess* repeats this setting of initial values.

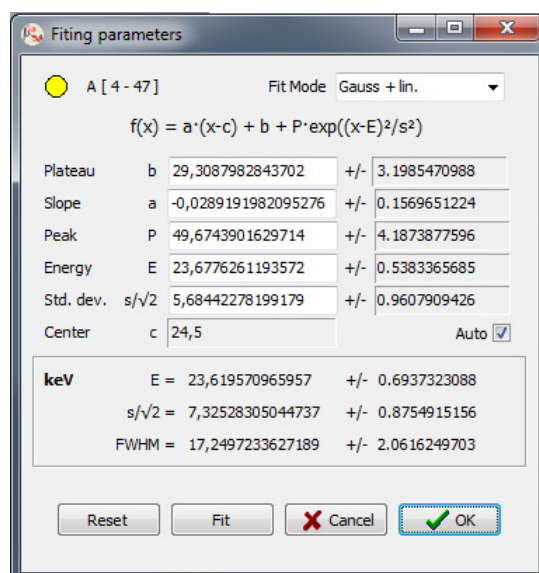
In the case of one of the Gaussian fits, the position is set to the region's centre, and the width of the peak to about half of the width of the region. Therefore, you should define the regions to have the top roughly in the middle,

and with a width that fits the peak. Once the fitting procedure has got a hold, change the width or location of the region in small steps. Major changes will force a new guess of initial values.

Fit provides a single pass of the fit procedure. A "v" in the box *Auto* causes continuous fitting to the data as the spectrum accumulates. The "Auto fitting" does not start until you have clicked OK.

Everything in the upper section of the dialog box applies to channel numbers. The values in the frame at the bottom will reflect any energy calibration.

NOTE: If the fitting procedure gets stuck in impossible parameters, you can "shake" it by forcing a new guess.



Sorting the region panels

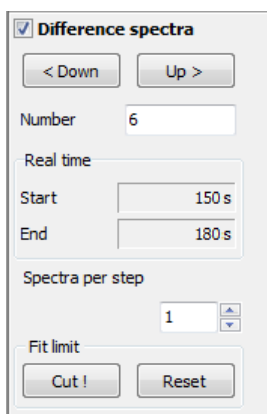
If you have created several panels of regions, these can be sorted through the menu item *View / Sort ROIs*. Regions can be sorted by start or end channel, or by name. The symbol "/" means in increasing order, whereas "\" refers to decreasing.

By Start /
By Start \
By End /
By End \
By Label /
By Label \

The regions' panels are minimized by sorting.

(If you jump directly from editing of a region name to sorting by name, the old name will be used for sorting. Finish editing with the Enter key before sorting.)

Difference spectra panel



When a decay experiment is selected, this panel pops up in the left column. It can be activated the first time a spectrum is written to disk.

This panel is a bit different from the other, as the checkmark "v" both controls whether the panel is unfolded and whether the graph pane shows the difference spectra rather than the cumulative spectrum:

When the panel is active, the cumulative spectrum is no longer shown, but instead the increase of the spectrum in a time interval. The two buttons *< Down* and *Up >* moves the interval start time. The interval length can be chosen as a multiple of the time that elapses between writing data to the disk.

If you have selected some areas for fitting with a Gaussian function, the difference spectra will be fitted with the same function, just with fixed position and width of the top.

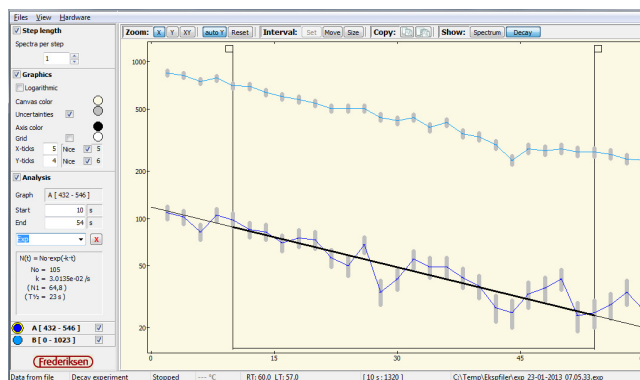
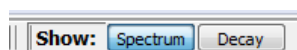
This means that you usually need to disable the *Difference spectra* panel and first fit the total spectrum; when these parameters are established, you can follow the peak development in the difference spectra.

If a peak cannot be fitted in a difference spectrum, you can choose to abandon fitting the rest of the time evolution by clicking *Cut!* (starting with the displayed spectrum).

Another option is to increase the range of the intervals. This will often reduce the statistical uncertainty sufficiently to fit the spectrum. The parameter *Spectra per step* controls how many time intervals that must be aggregated in a difference spectrum. (The length of the basic time intervals were defined during setup of the experiment - see section B.3.)

5 – Decay view

In a decay experiment you can switch between the two views *Spectrum* and *Decay*. Switching is performed via the *View* menu or with the buttons above the graph.



The graph pane

The large pane to the right shows the time evolution of each of the selected regions and is updated when data is saved to disk. If no region is selected when switching to *Decay* view the entire spectrum is used.

As in the *Spectrum* view, you can zoom both the x and the y axis.

A time interval can be specified for one of the graphs to be analyzed – this is described below.

Panels to the left

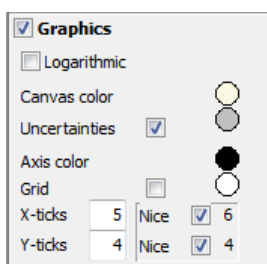
These panels act in the same manner as in the *Spectrum* view: they are unfolded or minimized, depending on whether the box is checked or not. You can for better overview minimize the panels you do not use.

Step length panel



This panel controls the parameter *Spectra per step* like in the *Difference spectra* panel in *Spectrum* view.

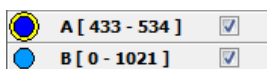
Graphics panel



The *Graphics* panel is also very similar to the corresponding panel in *Spectrum* view.

The colour of the graph cannot be changed; it is set by the colour of the corresponding region of the screen spectrum.

Panels for each region



These small panels control whether the time evolution of a region should be drawn in the graph pane. This is selected by a "v" in the box.

They also control which graph is targeted by the *Analysis* panel (see below). Click on the coloured circle to select. The active graph is marked with yellow ring.

Analyse panel – fitting in a time interval



☒ **Analysis**

Graph: A [4 - 47]

Start: 16 s

End: 48 s

Exp

$N(t) = N_0 \cdot \exp(-k \cdot t)$

$N_0 = 105$
 $k = 3.0135e-02 /s$
 $(N_1 = 64,8)$
 $(T_{1/2} = 23 s)$

A time interval can be defined in which one of the region series can be fitted to a theoretical function. The interval is selected by clicking the *Set* button and dragging horizontally with the mouse on the graph – exactly as you zoom or select regions.

When the interval is chosen, it can be moved by clicking *Move* and dragging the small square on the interval boundary in the graph pane.

Similarly, the width of the interval is adjusted by clicking *Width*.

Click on the red cross to delete the interval.

You can choose between four options:

- An exponential function, with or without a constant background

$$f(t) = N_0 \cdot \exp(-k \cdot t) + B$$

- A function that increases towards a saturation value

$$f(t) = N_{\infty} - (N_{\infty} - N_0) \cdot \exp(-k \cdot t)$$

- A linear function

$$f(t) = a \cdot t + N_0$$

The parameters of the function can be read at the bottom of the panel. The upper parameters are included directly in the fitting procedure; those at the bottom are calculated like this:

N_1 designates the function value at the start point of the interval, while $T_{1/2} = \frac{\ln(2)}{k}$ (the same expression is used for the saturation function).

6 – File menu

The items *Set Up Experiment* and *Background Radiation* are discussed in Section B.3 – *Experiments*.

Except for the item *Exit* which exits the program, each of the remaining items open up a submenu for typical file processing.

Save and fetch data

The four file types that the program uses for data are

- **Calibration files**
Hardware parameters (see B.2), unit for energy, the list of calibration points (see B.4)
- **ROI files**
Definition, colour choices and fit mode for the regions you have defined. (See B.4)
- **Spectrum files**
Calibration, timing and data for the **displayed** spectrum. If the spectrum is displayed with background subtracted (or if the background is displayed), you get a warning that you are not saving the raw data.
- **Experiment files**
The contents depends on whether a *Spectrum* or a *Decay* experiment is saved – see B.3
If you save a *Spectrum* experiment, it will (unlike the case for spectrum files) always store the foreground spectrum.

(The file formats are described in detail in Appendix C.2, if you need this information.)

There is some overlap between the different file types. For example, you can read the calibration section from a spectrum file – without reading the spectrum. You can also read the spectrum or even the background spectrum from an experiment file for a *Spectrum* experiment.

This is reflected in the menu's many "Read from ..." items.

If you can remember that you previously used a radioactive mineral sample for energy calibration in a *Spectrum* experiment, you can thus easily load the old calibration in the new experiment. Although the channel numbers may be different, the table values for the energies could be reused.

However, each file type understandably has only one way to save data.

Spectrum arithmetic

The submenu for spectrum files has some items for performing calculations on the spectra. They are described in a separate section (B9 – Spectrum arithmetic).

7 – View menu

The item *Sort ROIs* is described in paragraph B.4.

Language

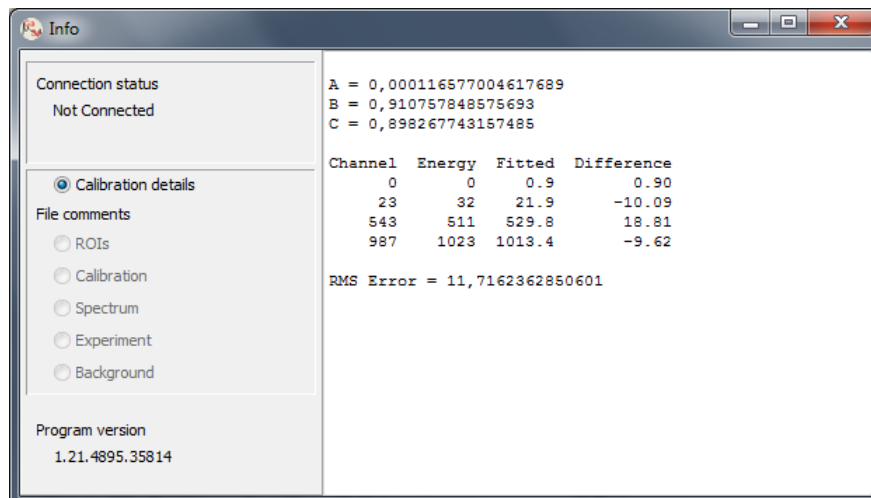
The item *Language* can be used to switch to another language – presently there is a choice between *Danish* and *English*.

Language choice follows the regional settings (or "locale") that is set up in Windows, but you can here change the selection manually.

Info

The item *Info* displays a dialog box with information on (among other things)

- Serial number of the hardware
- Eventual comments associated with the files that has been read
- Details on the energy calibration (fit parameters)



8 – *Hardware* menu

The two most important items – *Detector* and *Bias* – are described in paragraph B.2 – Hardware control.

Simulated data

In very specific situations – e.g. for instructional or demonstration purposes – it can be useful to show the facilities of the program, even if you do not have the hardware. In those cases, you can activate a simulated experiment.

Three different simulations are built-in:

- A Cs-137 source with constant activity
- A Ba-137m source (exponential decay)
- Background radiation (slightly exaggerated)

The simulated sources are selected via the menu item *Hardware / Simulate*.

Not every recess of the program is included in the simulation. For example, the *Hardware / Detector* dialog box always shows the same pulses regardless of the gain, and the spectrum is completely insensitive to integration time etc. Another part that is without function is the detector bias settings page.

However, since most settings are remembered the next time the program starts, you are advised not to mess too much!

9 – Spectrum arithmetic

You may need to add two spectra if you under otherwise identical conditions repeat or continues an experiment.

A spectrum is added to the current one using the menu item *File / Spectrum / Add to current*.

Data are added channel by channel. The uncertainties are recalculated.

Similarly, one may wish to subtract two spectra from each other. However, it is not quite as unambiguous how this should be done. The program implemented two options:

The simplest process can be considered as an "undo" operation to the above. It is found as the menu item *File / Spectrum / Raw subtract*.

Data are subtracted channel by channel, and uncertainties are reduced, so an *Add* and a *Raw subtract* will cancel each other – except perhaps for rounding errors on the uncertainties.

If instead you want a subtraction that is relevant in the sense of nuclear physics, chose instead the item *File / Spectrum / Subtract from current*.

The idea is that it is actually count *rates* and not cumulative *counts* that you want to subtract. Therefore, the counts in the spectrum that is to be subtracted from the current on are adjusted by the ratio between the live times of the two spectra.

The uncertainties of the result are calculated correctly (and will always be greater than the uncertainties in the two spectra separately).

You can easily save a spectrum that is manipulated in this way, but the file will be tagged, so you have a chance to notice it later. (See also Appendix C.2 for details.)

When a spectrum is loaded, information on previous calculations can be studied under the item *View / Info*. The descriptions are as follows:

<i>Add</i>	The spectrum is the result of one or more additions: $(x+y)$
<i>Sub</i>	The spectrum is the result of a subtraction: $(x-y)$
<i>SubAdd</i>	A spectrum with an <i>Add</i> tag has been subtracted: $(x-(y+z))$
<i>MixCalc</i>	"Dubious" operations like $(x+(y-z))$ or $(x-(y-z))$, where x is not a difference by itself

Absurd results are easily obtained, but these small warning flags should make it possible to avoid them.

The tags are accumulative – if one of them is set, it cannot be reset, no matter which further manipulation the spectrum undergoes.

10 – Exporting data and graphs

If the raw spectrum data are needed outside the program, you can make use of the fact that spectrum files (file type .spx) are pure text files. The same applies to experiment files (.exp) for spectrum experiments, whereas decay experiments store data outside the experiment file.

In Excel you import spectrum files as character-delimited text with the equal sign ("=") as separator.

A spectrum file comprises a lot of different lines with meta-information.

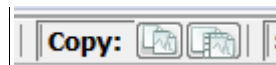
The spectrum itself starts in the line beginning with "D0 =" and continues with one channel per line the next several lines.

In the case of a calculated spectrum, the corresponding uncertainties may follow after the channel counts. The first of these lines begins with "U0 =".

For further details, refer to Appendix C.2.

Often you will want to copy the spectrum as an image into a text document. This is done via the clipboard in Windows:

Click one of the *Copy* buttons above the graph.



The button to the left copies only the graph pane while the one to the right includes panels. Switch to the document and paste the image. (Right click and select Paste - or press Ctrl and V simultaneously.)

If you need the graph as a separate graphic file, the process is the same, just insert the copy in a graphics program (such as Paint), and save it from there.

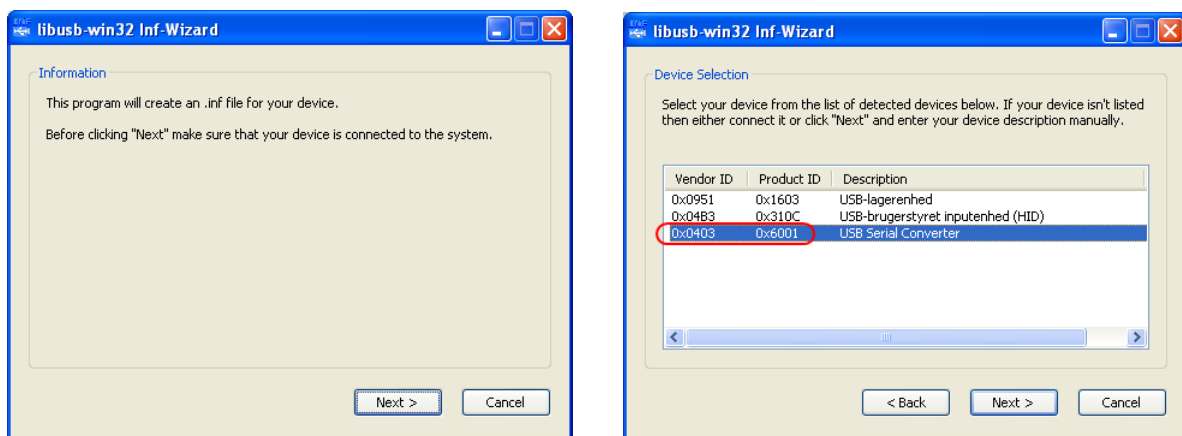
C – Appendix

1 – Installation

a) Driver installation

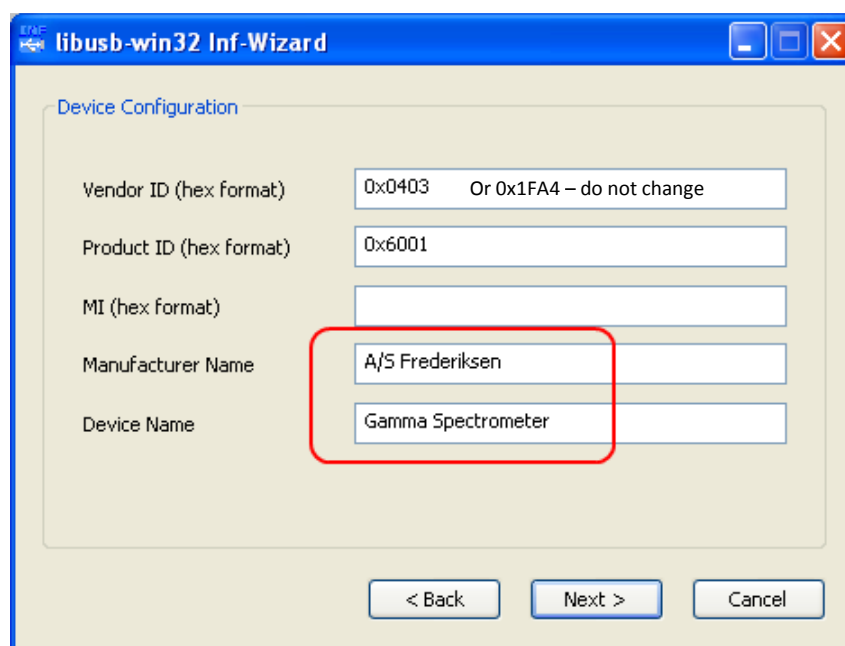
Connect the multichannel analyzer to a USB port on the PC. Wait about half a minute.
If the usual Plug'n'Play installation procedure is carried out automatically – ignore it.
If the automatic installation starts asking questions – shut it down.

The CD contains a shortcut to the *USB Install* program. Double-click to start. From the first screen view you just click *Next*.



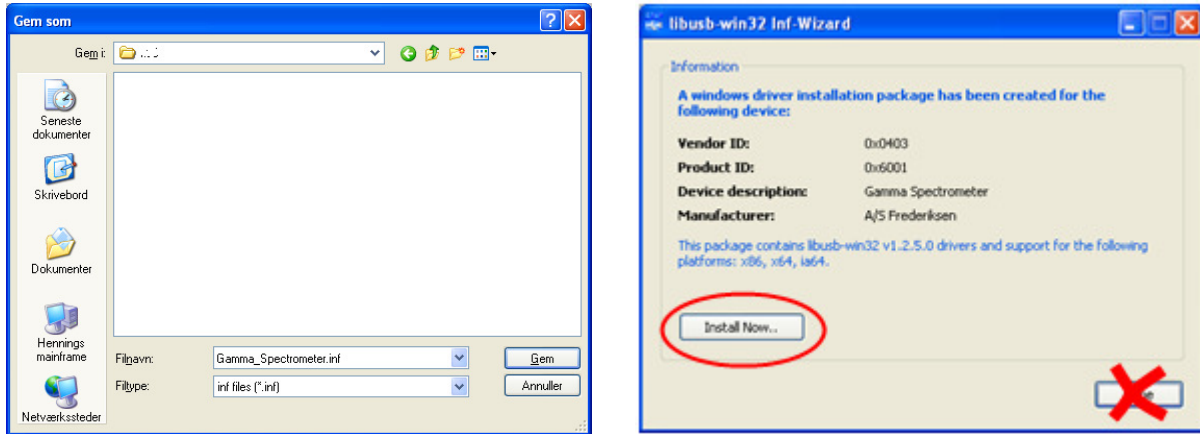
In the next dialog box, highlight the line that has **Vendor ID 0x0403 or 0x1FA4** and *Product ID 0x6001*, before clicking *Next*.

Fill out the next dialog box as follows and click *Next*:

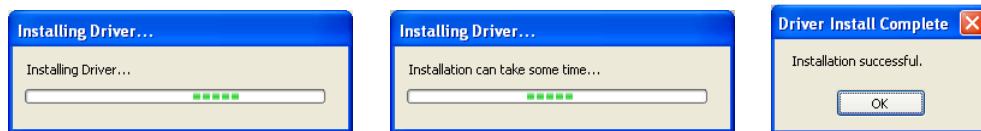


Now the installation will produce a so-called INF file that we do not actually need. Specify a location for it; it is OK to delete it again afterwards.

On the next screen, select *Install Now ...* (do **not** click *Done!*).



Wait for these boxes:



Now, the driver installation process is completed.

b) Installation of GaSp

The CD contains the program itself, consisting of the two files:

GaSp.exe

FMCA1.dll

Copy these two files manually to an appropriate folder using Windows Explorer.

On a **Windows 7** PC this could be

C:\Program files(x86)\Frederiksen\GaSp

Likewise on a **Windows XP** PC:

C:\Program files\Frederiksen\GaSp

Copy a shortcut to GaSp.exe to the desktop:

Right-click GaSp.exe, select *Copy*

Right-click the desktop, select *Paste Shortcut*

2 – File formats

All files are text files, split in sections (as “INI files”).

The files can be edited with, for example, Notepad – and the relevant parts can be copied into a spreadsheet.

The sections are preceded by a line with the section name in [square brackets].

In each section, the order of lines is unimportant.

Format of each line: <field name>=<value>

Calibration files

File Extension: .cal

[Calibration]

The first group of parameters corresponds to the *Detector* dialog box.

Next group is the contents of the Calibrate panel. C-lines are channel numbers, E-lines corresponding energies.

Fields:

Gain	Integer	(index in the dropdown menu)
Compression	Integer	(index in the dropdown menu)
Scaling	Integer	
BaselineTrigger	Integer	
EnergyTrigger	Integer	
Integration	Integer	
PileUp	Integer	
TimeToBase	Integer	
PreTrigger	Integer	
EnergyUnit	Text	
UnLinParm	Floating point number	
Number	Integer	
C1	Floating point number	
E1	Floating point number	
C2	Floating point number	
E2	Floating point number	
...		
C<number>	Floating point number	
E<number>	Floating point number	

[Comment]

Contains the comment field of the file

Fields:

Number	Integer
L1	Text
L2	Text
...	
L<Number>	Text

ROI (Regions Of Interest) files

File Extension: .roi

[ROIinfo]

Contains a single parameter: the number of ROIs defined

Fields:

Number	Integer
--------	---------

[ROI-1]

These values reflect the fields in the first ROI panel – likewise for the following sections.

Fields:

Name	Text
Start	Integer
Stop	Integer
RoiColor	Hex number
FitColor	Hex number
FitMode	Integer (index in the dropdown menu)
Show	0 / 1 (0: The panel is minimized)

[ROI-2]

...

[ROI-<Number>]

- Fields as in [ROI-1]

[Comment]

- Fields as in a calibration file.

Spectrum files

File Extension: .spx

[Calibration]

- Fields as in a calibration file.

[Comment]

- Fields as in a calibration file.

[Spectrum]

StartTime and EndTime are specified as absolute time.

RealTime and LiveTime are specified in seconds.

Fragments denotes the number of times that the data acquisition has been started.

Add / Sub / SubAdd / MixCalc – described in paragraph B.9 – Spectrum arithmetic

The spectrum is defined by the number of channels and a line for each channel with the number of counts, possibly followed by the uncertainties (*) if Sub, SubAdd or MixCalc is 1

Fields:

StartTime	Text	(dd-mm-yyyy hh:mm:ss)
EndTime	Text	(dd-mm-yyyy hh:mm:ss)
RealTime	Floating point number	
LiveTime	Floating point number	
Fragments	Integer	
Add	0 / 1	
Sub	0 / 1	
SubAdd	0 / 1	
MixCalc	0 / 1	
Channels	Integer	
D1	Integer	
D2	Integer	
...		
D<Channels>	Integer	
U1	Integer	(*)
U2	Integer	(*)
...		
U<Channels>	Integer	(*)

Experiment files

File Extension: .exp

An experiment can be a single spectrum or a decay series. In the case of a single spectrum, this will be contained in the file itself. Decay series will always be placed as a number of spectra in a folder.

[Control]

Fields:

StartTime	Text	dd-mm-yyyy hh:mm:ss
BgInFile	0 / 1	(1: The section Background is present in the file)
SpcInFile	0 / 1	(1: The section Spectrum is present in the file)
Prefix	Text	Path (relative to the exp file) and prefix for the spectra

[Calibration]

- Fields as in a calibration file.

[ROIinfo]

[ROI-1]

[ROI-2]

...

[ROI-<number>]

- Fields as in a ROI file.

[Comment]

- Fields as in a calibration file.

[Background]

- Fields as in a spectrum file.

[Spectrum]

- Fields as in a spectrum file.

3 – Setup files

The norm would be that GaSp uses the Windows Registry to store parameters from time to time. Should this option be closed, alternatively, two old-fashioned INI files can be used, one read only, while the other must be both readable and writeable by the program. The first file points to the position of the second.

Algorithm for determining the location of the saved parameters

First GaSpIni.ini is looked for in the same folder as GaSp.exe.

If this file exists, it is read in order to find the file containing the actual parameters: GaSp.ini - to be open in R/W mode.

If not GaSpIni.ini exists, it is assumed that the program can operate with the registry as a storage space for parameters.

If this key does not exist in the registry database, it is created:

```
HKEY_CURRENT_USER\Software\Frederiksen\GaSp
```

If write access to this key is not granted, you will get an error message.

GaSpIni.ini

Used for instance if you can not or will not use Windows' registry. In this case, this file must be found in the same folder as GaSp.exe. The file **must** contain the following section:

[IniFile]

This section **must** contain one of two value:

WriteableDir	Folder with write access, where GaSp.ini is placed. (Full Path specified.)
UseRegistry	=1 if registry should be used (GaSp.ini is not used)

GaSpIni.ini can also be used to restrict certain parts of the user interface.

For this use the file can contain the following section:

[Restrictions]

This section can contain the following values:

HideLiveTime	=1, if live time should not be displayed in the status line
HideTimeToBaseline	=1, to hide the "Time to Baseline" field in the Detector dialog
LockTimeToBaseline	= Integer (time in ns). Time to Baseline is locked at this value

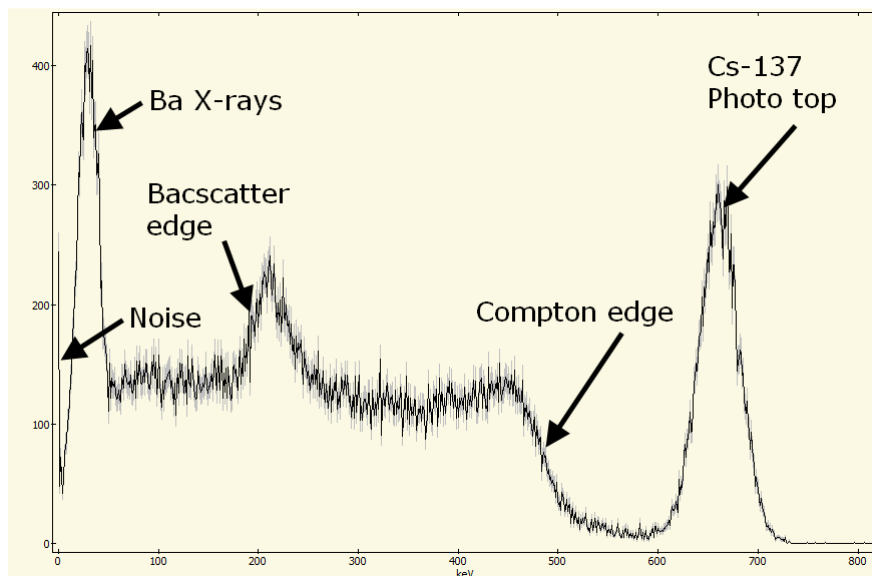
Example of a complete Gasplni.ini:

```
[IniFile]
WriteableDir=N:\temp\GaSp
```

4 – Details of the spectrum

The spectrum from a scintillation detector shows not only the energy of the gamma quanta as emitted from the source.

Details of the spectrum testify collision processes between gamma quanta and electrons.



If the full gamma energy is deposited in the scintillation crystal, a count in the photo top is registered. The top has a certain width, because the transformation of gamma energy into a certain number of visible photons and the following electronic registration of these is of a stochastic nature.

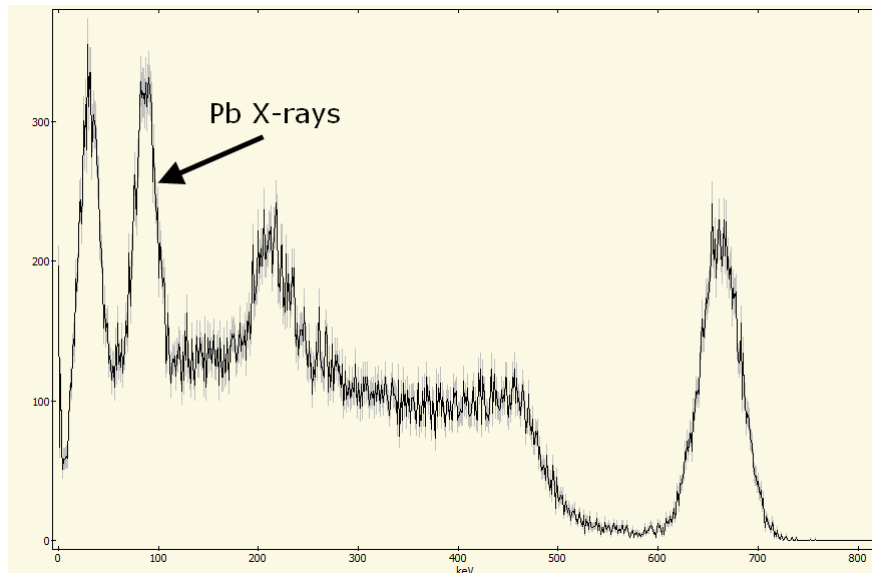
Often a gamma quantum collides with a loosely bound electron in the detector so that a part of the energy is transferred to this. Such Compton scattered gamma quanta has a high probability to continue out of the detector, so their share of the energy is lost. On the other hand, the energy of the recoiling electron is registered with high probability. Due to momentum conservation, there is an upper limit to the amount of energy that can be transferred to the electron. This upper limit is called the Compton edge.

The reverse situation is also possible: A gamma quantum first collides with an electron outside the detector and is then registered with the energy it has left. The energy of the scattered gamma quanta have (compare the previous section) a lower limit, called the backscatter edge.

Calculations on these collision processes are an excellent chance to apply the special theory of relativity!

Note that you, for example with our set for Compton scattering (5190.00), will see the photo top shifted towards lower values. Here we measure basically mono-energetic gamma quanta, Compton scattered with a well-defined scattering angle, external to the detector. The situation should not be confused with the presence of the Compton edge. The spectrum of the scattered gamma quanta has its own Compton edge.

In the spectrum you will often be able to observe X-rays from the daughter nucleus. If you irradiate a lead foil with a Cs-137 source, you will also be able to detect X-ray fluorescence from lead.



In addition to gamma radiation from the nucleus, you can often identify a peak at 511 keV, corresponding to a rest mass of an electron. This comes from the annihilation of positrons and electrons.

The top can of course be seen in particular when directly dealing with a positron emitter as Na-22. But also in the case of very high energy gamma quanta, you will see traces of pair production with subsequent annihilation.

