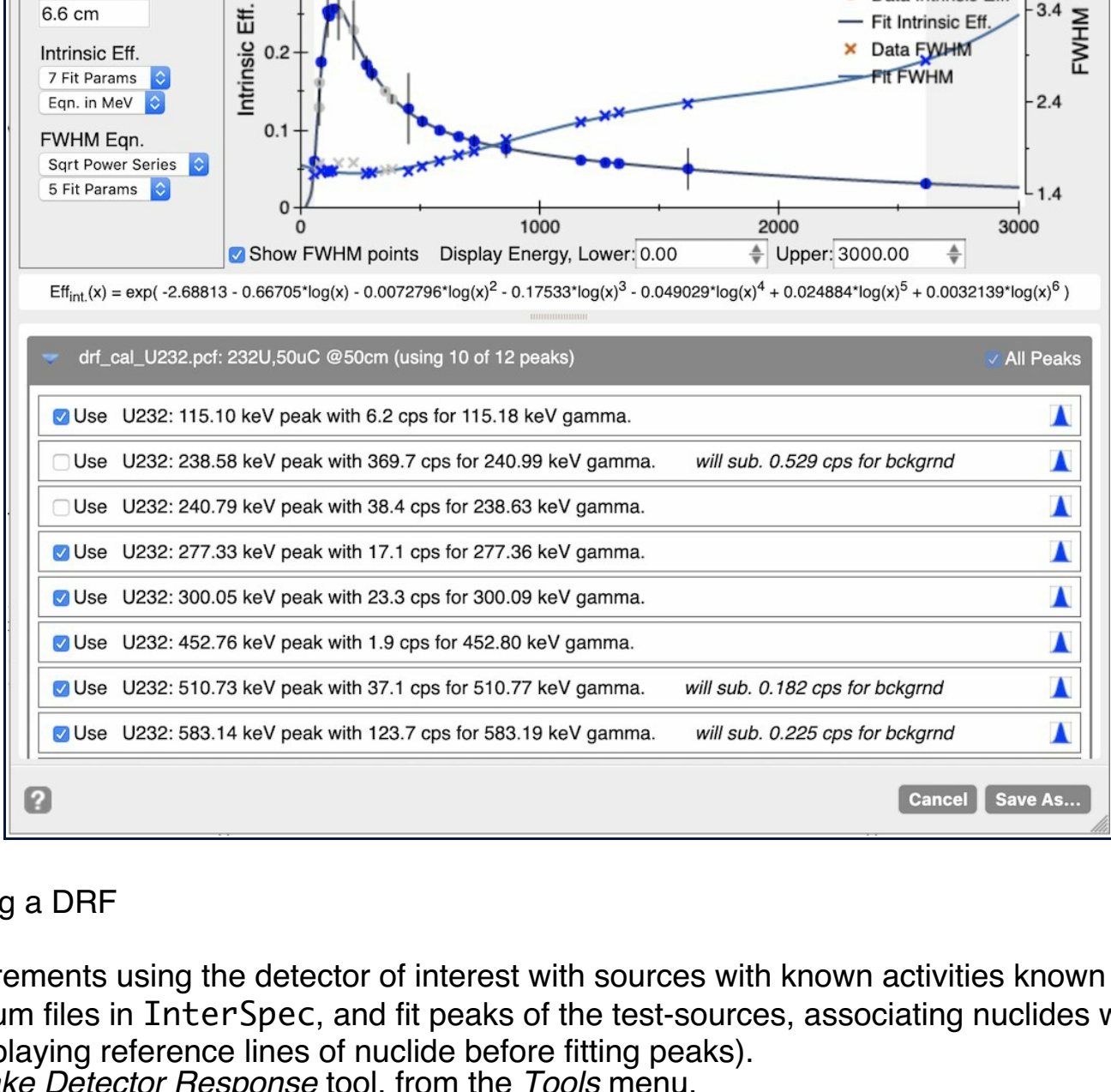


# Make Detector Response Function

To accurately determine source activities, shielding amounts, or nuclide ages, it is important to know the efficiency, as a function of energy, for a gamma incident on the detector to contribute to the full-energy photo-peak.

The *Make Detector Response Function* tool allows you to use measurements of known sources to determine the *Intrinsic* efficiency (i.e., the probability that if a gamma of a given energy is incident on the detector face, that its full energy will be absorbed, and it will contribute to the photo-peak) of a detector. Usually the detector response function (DRF) will only have to be determined once for a given system, and often detectors of the same model can use the same response function.



## Overview of creating a DRF

- Take measurements using the detector of interest with sources with known activities known distances.
- Open spectrum files in InterSpec, and fit peaks of the test-sources, associating nuclides with the peaks (most easily by displaying reference lines of nuclide before fitting peaks).
- Open the *Make Detector Response* tool, from the *Tools* menu.
- Inside the *Make Detector Response* tool, the fit peaks of each open spectrum file will be shown. Select the peaks you would like to use to determine detector efficiency.
- When peaks are selected to use, an area to enter source information will appear; enter source information
- Enter detector face diameter, select number of fit parameters, and the type of equation to fit for FWHM, and other options.
- Save the DRF into the InterSpec's internal database for future use, and/or choose to download a CSV for use on other devices, or to use in other programs.

## DRF Basics

InterSpec will help you to determine the *Intrinsic Efficiency* (i.e., probability of full-energy detection of gammas incident on the detector) by fitting your collected data to an equation of the form:

$$Eff_{pred}(x) = \exp( C_0 + C_1 * \log(x) + C_2 * \log(x)^2 + C_3 * \log(x)^3 + \dots )$$

Where x is energy in keV or MeV.

The number of gammas at a given energy incident on the detector is determined by the source activity, the gamma line branching ratio, source to detector distance, the surface area of the detectors face, and live-time of the measurement.

$$FractionSolidAngle = (1 - (Dist/\sqrt{Dist^2 + DetRad^2}))^2$$
$$Eff_{obs}(x_i) = PeakArea(x_i) / (Activity * Br(x_i) * LiveTime * FractionSolidAngle)$$

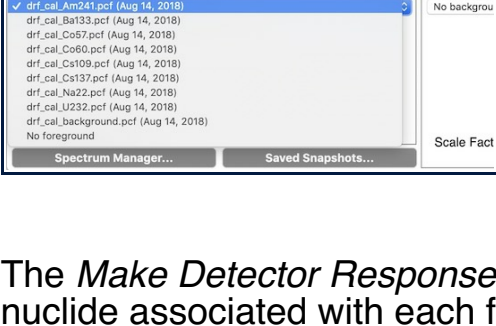
Where x<sub>i</sub> is the energy if the i<sup>th</sup> gamma/photo-peak of the source.

The coefficients of the equation is fit using x<sup>2</sup> minimization, where uncertainties for each peak are propagated from the peak fit, as well as any uncertainty you entered for the source.

Some comments on taking test-source data:

- It is important that the peaks you use from the test-sources at least span the energy range you will use the DRF for. Extrapolation outside the test-source energy range will often be drastically incorrect.
- Commonly used test-sources include: Am-241 (59.5 keV), Cd-109 (88.0 keV), Co-57 (122.0 and 136.5 keV), Ba-133 (81.0, 276.4, 302.9, 356.0, 383.9 keV), Y-88 (898.0, 1836.1 keV), Cs-137 (661.7 keV), Co-60 (1173.2, 1332.5 keV), Na-22 (511, 1274.5 keV) and Th-228, U-232, or Th-232 (238.6, 583.2, 1620.5, 2614.5 keV).
- If any of your test-sources have peaks that overlap with background peaks, or the detectors seed-source (if it has one), then a background spectrum is also needed.
- Photo-peaks from the test-sources should have plenty of statistics and be substantially above background. For many sources and detectors the sources generally need to be in the 10's of micro-Curie range at 25 cm to 100 cm, and for between 5 and 30 minutes dwell time.
- Dead time should not be too high, as this can cause peak-distortions and other effects. Very roughly, scintillating detectors (NaI, LaBr, etc) should probably have less than about 20% dead-time, while HPGe should have less than about 50% dead-time, although acceptable levels will be system dependant.
- Test-sources should be at least 25 cm away from the detector so that gammas striking the detector are about parallel.
- Test-sources should be lined up with the detector so that source gammas will be perpendicular to the detector face.
- Shielding should be eliminated or minimized.
- It is preferred to measure each source separately. However, especially higher resolution detectors, it may be fine to measure multiple sources at a time, as long as their photo-peaks will be of comparable statistics.

## Fitting Peaks of Calibration Data

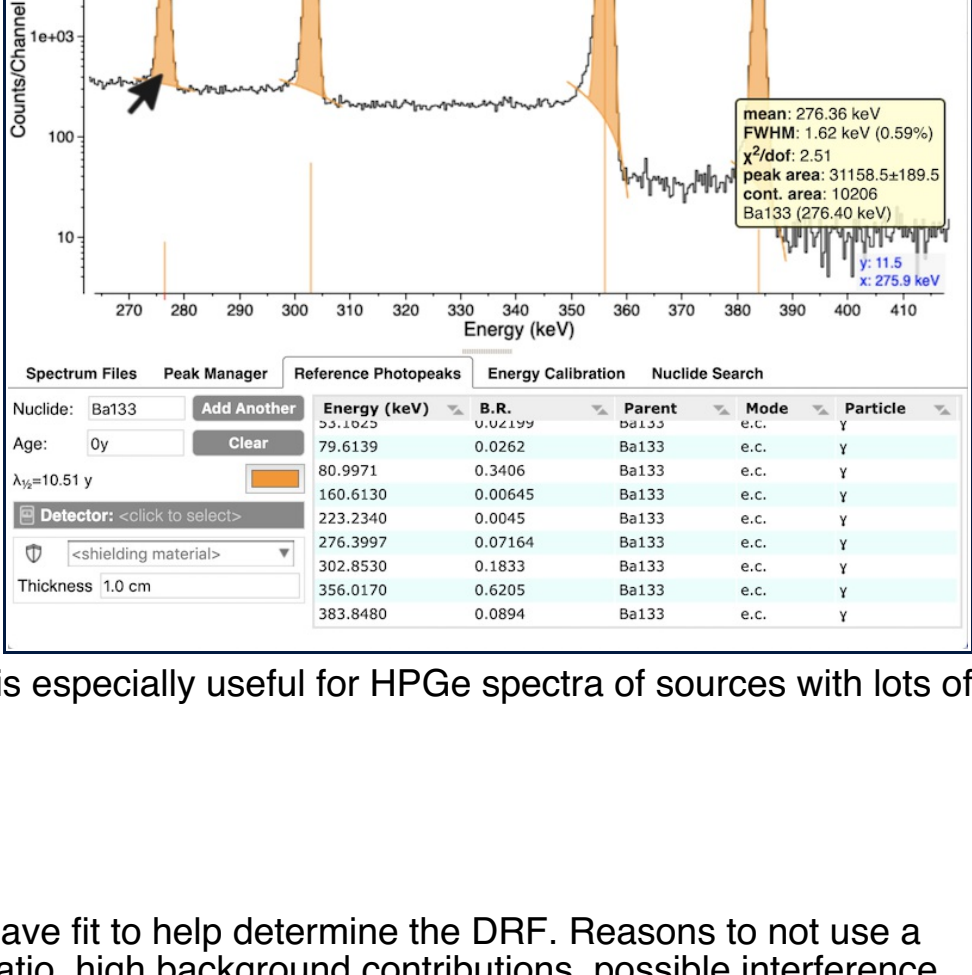


If your calibration data spans multiple spectrum files, you will need to load, and fit peaks for all of the files in the same session of InterSpec. That is, on the "Spectrum Manager" tab, when you are done fitting peaks for all of your spectra, you should be able to see each of the files available in the drop-down, as shown on the left. The *Make Detector Response* tool will allow you to select peaks from all of the files from your current session. If you want to fit peaks across multiple sessions, you can always fit the peaks and either save the results to InterSpec's internal database, or export to N42-2012 files, which will save the peaks you fit.

The *Make Detector Response* tool needs to know the nuclide associated with each fit peak; there are several ways to accomplish this. To do this easily, show reference lines, as demonstrated in the screenshot on the right, before fitting the peaks; then when you fit the nuclide and specific gamma will be automatically associated with the peak. You can also make this association by right-clicking on a peak, and either choosing a new nuclide from the list of suggested nuclides, or opening the *Peak Editor* and entering a nuclide. The *Peak Manager* also lets you set the nuclide and specific gamma line of a peak.

You do not need to fit background peaks for your test-source spectra. If any of your test-sources have peaks that you would like to use and that overlap with background peaks, and that you would like to use, you should use a background spectrum with its peaks fit; you do not need to associate nuclides with the peaks of the background spectrum. The background peak rates will be subtracted from the test-source peak rates during DRF fitting.

The "Search for Peaks" button/tool in the *Peak Manager* tab can be used to automate the peak fitting process. This is especially useful for HPGe spectra of sources with lots of gamma-lines or the background.



## Selecting Peaks to Use, and Entering Source Information

You may choose to either use, or not use, peaks that you have fit to help determine the DRF. Reasons to not use a peak include: not from a source of interest, low branching ratio, high background contributions, possible interference from other sources, poor peak fit, or a peak may just visually deviate from the reasonable range for the efficiency curve. For this latter case, it may be worth checking that the correct gamma-line is associated with the peak using the *Peak Manager* or *Peak Editor*; usually InterSpec correctly picks the correct gamma-line to associate with peaks, but occasionally a correction needs to be done.

drf\_cal\_Cs137.pdf: 137Cs,50uCi @50cm (using 1 of 1 peaks)

☒ Use Cs137: 661.61 keV peak with 309.5 cps for 661.66 keV gamma.

☐ Is Background?

Cs137, A<sub>0</sub>=30.08 y

Distance: 50.00 cm

Activity: 100 uCi

Act. Uncert: 0.0 %

☐ Age? ☐ Shielded?

When you select a peak to use to help determine the DRF equation, a source box will appear under all the peaks of that file. Here you can enter the source distance from the detector face, the source activity, and an activity uncertainty. If a single spectrum has multiple sources, you must enter the distance separately for each source. If more than one source nuclide will contribute to a peak, InterSpec will take this into account, for all sources being used for that spectrum.

If you only know the source activity at a previous date, you can select the "Age?" checkbox, which will allow you to enter the assay date; the entered activity will then be decayed to the date given in the spectrum file (which you can also change here). If it is a source where the gamma spectrum appreciable changes with age, you will also be given a chance to enter age at assay date.

drf\_cal\_Cs137.pdf: 137Cs,50uCi @50cm (using 1 of 1 peaks)

☒ Use Cs137: 661.61 keV peak with 309.5 cps for 661.66 keV gamma.

☐ Is Background?

Cs137, A<sub>0</sub>=30.08 y

Distance: 50.00 cm

Activity: 50 uCi

Act. Uncert: 0.0 %

Assay Date: 19/06/2016

Spec. Date: 14/08/2018

Aging Rate: 47.6 uCi

☐ Age? ☐ Shielded?

You can also choose to enter a shielding between the test-source and detector. This is primarily useful to account for the source container or for self-attenuating sources. Shielding should be avoided or minimized when making characterization measurements.

drf\_cal\_Cs137.pdf: 137Cs,50uCi @50cm (using 1 of 1 peaks)

☒ Use Cs137: 661.61 keV peak with 309.5 cps for 661.66 keV gamma.

☐ Is Background?

Cs137, A<sub>0</sub>=30.08 y

Distance: 50.00 cm

Activity: 50 uCi

Act. Uncert: 0.0 %

Shielding: Fe (iron) p=7.9 g/cm<sup>3</sup>

Thickness: 1.0 cm

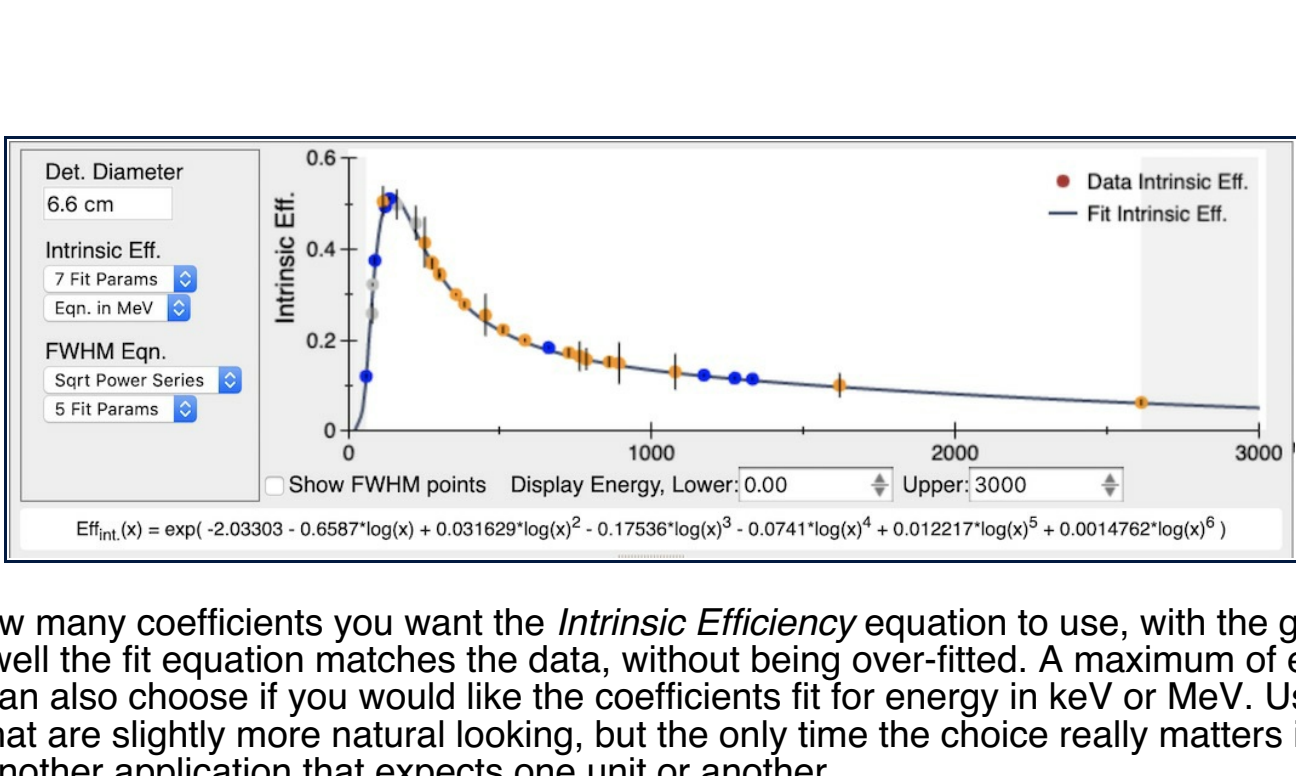
☐ Age? ☒ Shielded?

If the "Is Background?" checkbox is selected, then all peaks of that measurement will be assumed to be background peaks. InterSpec will automatically correct test-source peaks for background peaks if there is any overlap; this correction will be indicated in text by the test-source peak being corrected.

If you do not want to associate a nuclide with a peak, you can still use the peak for determining the DRF; when the peak is selected to use, an entry form will appear to enter the branching ratio of this peak, and a generic source will also be shown to enter the activity and distance. This feature is useful if you think the nuclide library has an error, or you are determining the DRF based on a simulation with arbitrary gamma sources.

☒ Use 238.63 keV peak - no nuc. associated BR= 1.00

## Fitting Options:



You can choose how many coefficients you want the *Intrinsic Efficiency* equation to use, with the guiding criteria usually being how well the fit equation matches the data, without being over-fitted. A maximum of eight coefficients can be used. You can also choose if you would like the coefficients fit for energy in keV or MeV. Usually MeV gives coefficient values that are slightly more natural looking, but the only time the choice really matters is if you want to use the coefficients in another application that expects one unit or another.

The detector Full Width Half Maximum (FWHM) as a function of energy is also fit at the same time as the *Intrinsic Efficiency*. However, since InterSpec does not really use this information, it is not emphasized in the user interface, but the information is saved as part of the DRF, and is also written to the CSV file available from the "Save As..." dialog.

The FWHM can be fit using either the square root of a power series in energy:

$$FWHM(energy) = \sqrt{A_0 + A_1 * energy + A_2 * energy^2 + A_3 * energy^3 + \dots} \text{ [energy in MeV]}$$

Or using the FWHM equation used by GADRAS-DRF:

```
def getFWHM( energy ) :  
    //P6----> resolution @ E=0 (energy in keV)  
    //P7----> % FWHM @ 661 keV  
    //P8----> resolution power  
    if energy >= 661 or P6=0  
        return 6.61*P7*(energy/661)P8  
    if P6 < 0.0  
        var p = p81.0/Log(1.0-P6)  
        return 6.61*P7*(energy/661)p  
  
    if P6 > 6.61*P7  
        return P6;  
  
    var p = sqrt((6.61*P7)2-P62)/6.61;  
    return sqrt(P62+(6.61*p*(energy/661)P8)2)
```

You can also choose to show this fit and peak FWHM data on the chart by selecting the "Show FWHM points" checkbox.

## Save As Dialog:

Store/Export DRF

Name: My Acme DRF

Description: green lab HPGe characterized on 20190615.

☐ Make default DRF for model number 'Serial #1XXX'

☐ Make default DRF for serial number 'Acme HPGe 40%'

[Export data as N42-2012 file.](#)

[Export DRF as CSV.](#)

Cancel Save

When saving the DRF it gets saved into InterSpec's internal database and can be retrieved in the "Previous" tab of the *Detector Response Select* tool.

The name you assign can not have symbols commonly prohibited in filenames such as slashes, backslashes, quotes, commas, semi-colons, and question marks. The description field is to make any notes about the DRF you may want to recall in the future.

Clicking on the "Export data as N42-2012 file" option will combine all spectra used into a single N42 file. This N42 file can be opened in other programs, but if opened in InterSpec, all of the fit peaks, as well as the DRF will be retained.

The "Export DRF as CSV" option creates a CSV with the *Intrinsic Efficiency* coefficients, *Relative Efficiency* (i.e., efficiency at 25 cm) coefficients, peak areas, gamma counts from isotopes, efficiencies and FWHM at 25 keV energy intervals, x<sup>2</sup> of fits, and some other information.

You can also select to have this DRF automatically loaded whenever you load data from either this specific detector (as determined by the serial number in the spectrum file), or this model of detector (as determined by the spectrum file).

Hovering the mouse, or tapping, the ⓘ icon will display additional tips for each item in this dialog.

## Miscellaneous Information:

- The *Create Detector Response Function* tool can be used with any detector type you can fit peaks for, including CsI, NaI, LaBr3, CZT, and HPGe.
- The error bars shown on the data points of the *Intrinsic Efficiency* chart are 1-sigma uncertainties based on the statistical uncertainties of the peak fit, the background peak fit (if applicable), and entered source activity uncertainty.
- The efficiency chart defaults to showing the energy range of the spectrum files, but the areas above the highest energy peak used and below the lowest energy peak are slightly greyed out to indicate the DRF is not valid in those regions.
- Background peak rates are subtracted from a test-source peak rate if the fit background peak is within 1.5 peak-sigmas of the fit test-source peak, or if the background peak is assigned a nuclide and its source line is within 1 keV of the test-source line.
- If a spectrum has multiple sources associated with it, then for each peak used, not only will the primary nuclide associated with that peak be used to calculate the incident photons on the detector at that energy, but if any of the other sources have gamma rays within 1.25 peak sigmas of the primary nuclides line, it will be used as well. However, the effect of this is not currently displayed to the user.
- If the spectrum file contains source information such as activity or distance, this info may get pre-populated in the tool. A common way this is indicated is if the spectrum title (or remark that starts with "Source:") is formatted similarly to "57Co,75uCi @50cm", where this indicates the Co-57 was 75uCi, and the source to detector distance is 50 cm.
- The fits to efficiency and square-root power series (FWHM) are performed by transforming the data and equations to a form suitable for least squares fitting via linear algebra techniques. However, since the uncertainties are no longer approximately Gaussian distributed after the transformation, the answer will be biased. Therefore InterSpec uses the least squares result as a starting point for a numerical-based steepest decent approach on the non-transformed data and equation to find the actual solution and errors presented by the tool.
- Clicking on the ⬆ icon next to each peak will show you a preview of that peak if you want to check the fit quality of that peak.