More in-depth InterSpec

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Todays goals:

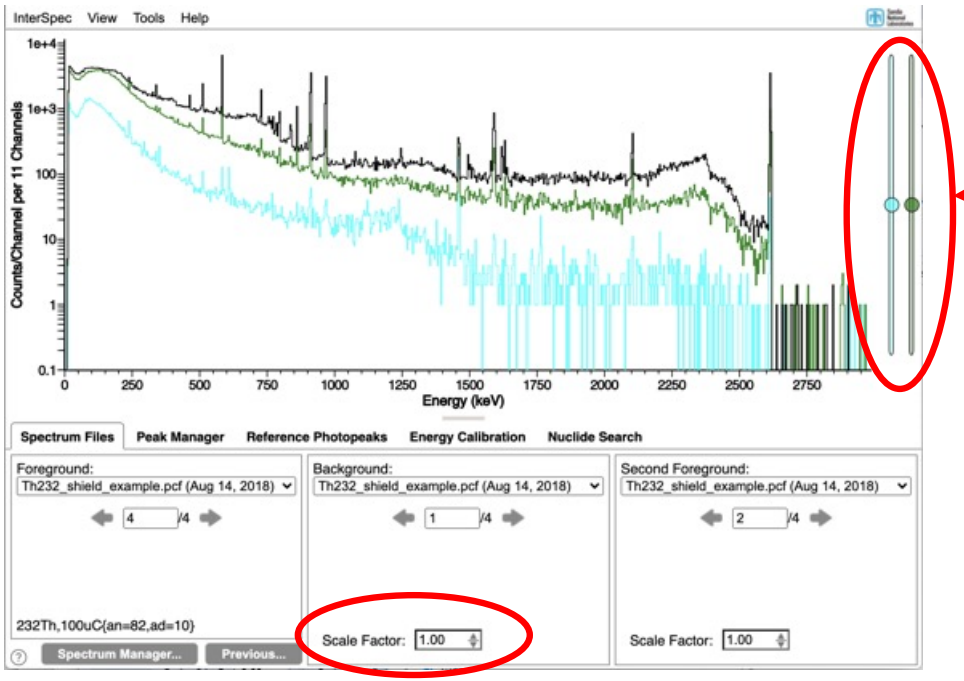
- Get you ready, and give you practice, really doing analysis in InterSpec
- Useful smaller-features
- Energy Calibration
- Nuclide ID – will use Trinitite spectrum as example
- Fitting nuclide activities, shielding, and ages with of point-sources (more Trinitite ex.)
  - We'll talk about limitations, etc
  - Surface contamination and volumetric (trace) source activities
- Detector response functions: creating your own vs using existing ones
- Viewing search-mode or portal data
- Other calculations: nuclide decay, dose, cross-section, …

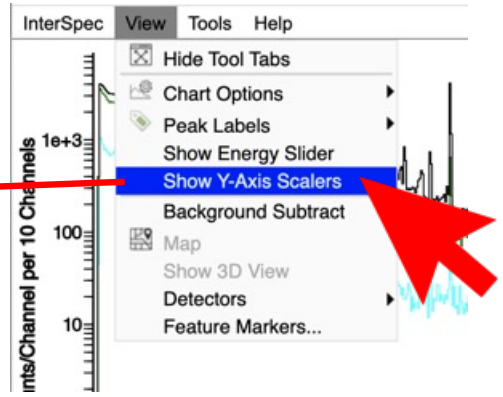
Please work-along, or tinker around with InterSpec as we go along today

The example spectrum files at https://sandialabs.github.io/InterSpec/tutorials/

Useful smaller-features

Scaling spectra





The "Y-Axis Scalers" should show up by default when you display multiple spectra, but you can show/hide them from the "View" menu

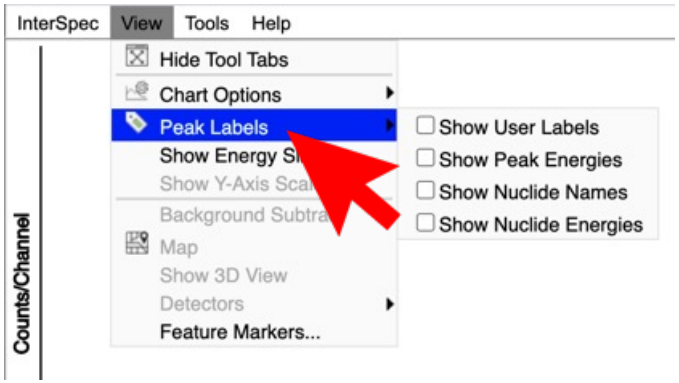
By default, InterSpec will live-time normalize the background and secondary spectrum to the foreground

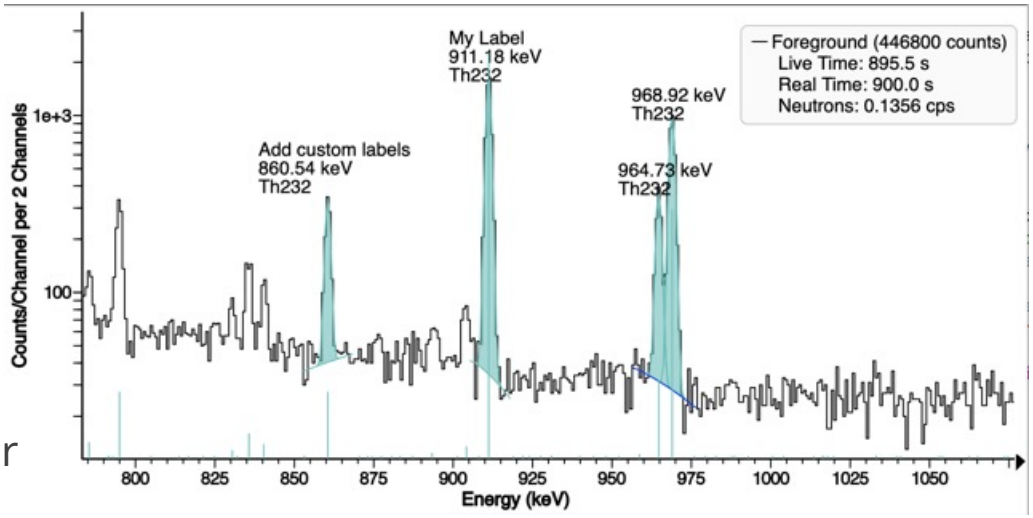
- You can manually enter the scale factor you want on the "Spectrum Files" tab

You can also drag the "Y-Axis" scalers to adjust the background/secondary normalization

- Particularly useful for comparing spectra against reference spectra

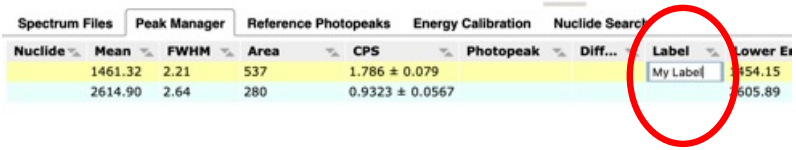
More Display Options – peak labels

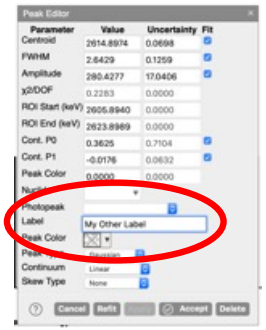




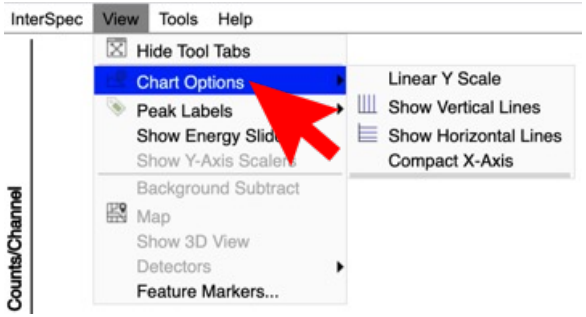
You can choose to show peak energy, nuclide, gamma, and/or a user label for each peak

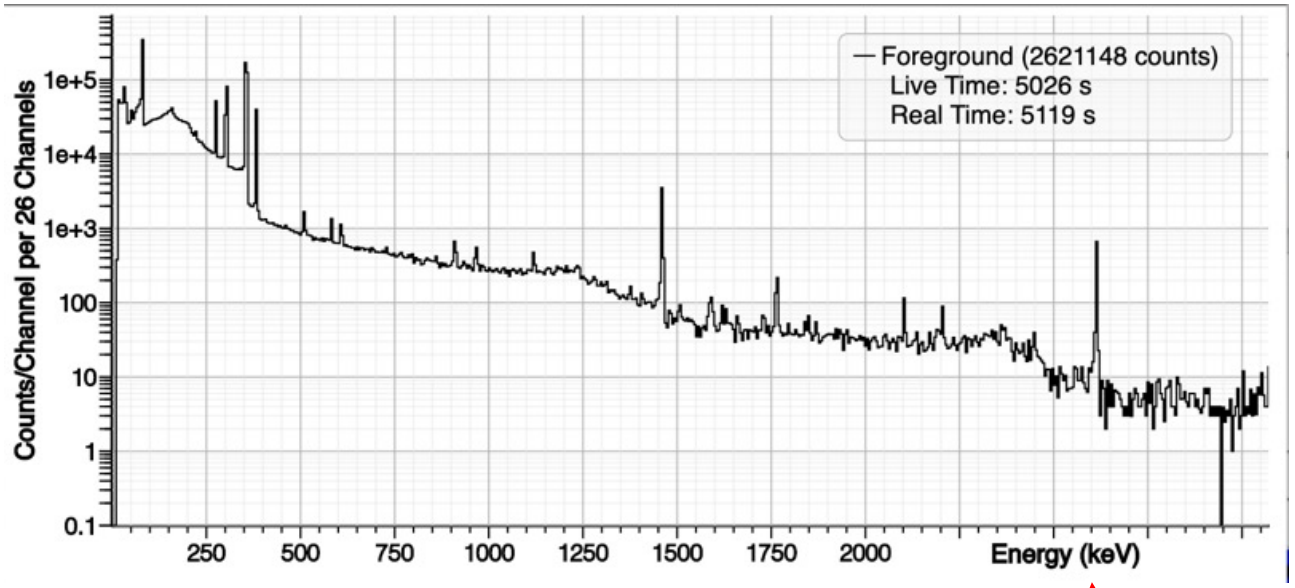
You can add or edit the user label using the "Peak Manager" tab, or the "Peak Editor"





More Display Options – chart options





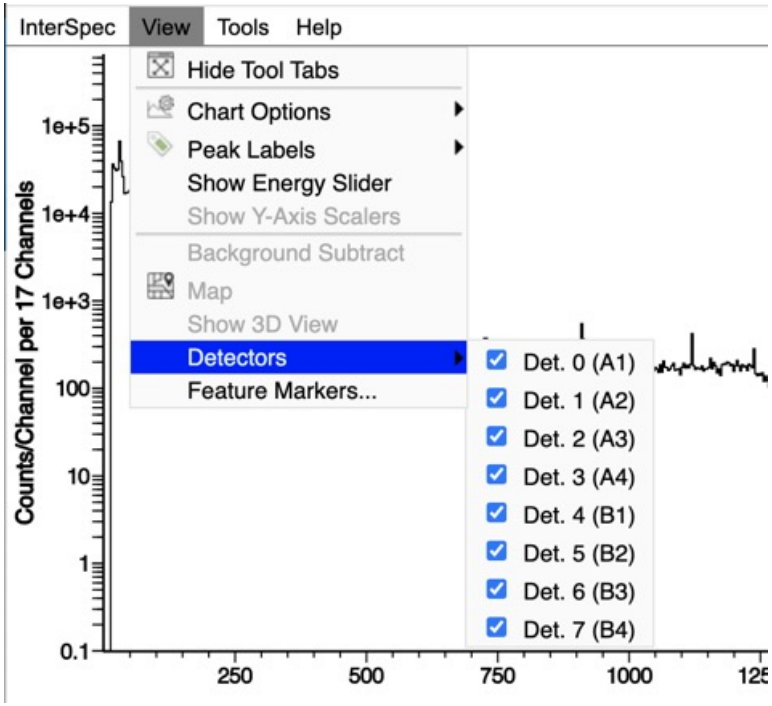
Linear Y Scale: occasionally useful when squinting at tiny peaks or features.
"Ctrl-L" will toggle between log/linear

Vertical/Horizontal Lines: sometimes useful for reports or HPGe spectra

Compact X-Axis: good for screens with limited real-estate

Hide Tool Tabs: entire screen becomes spectrum; the tabs contents become available in the "Tools" menu

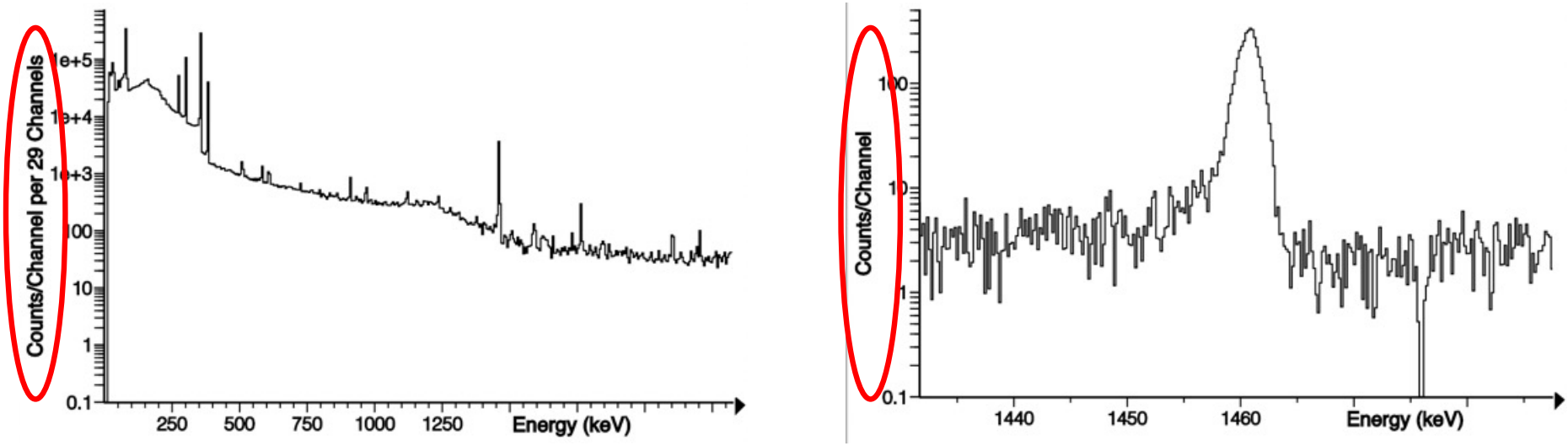
More Display Options – multiple detectors



If the spectrum file contained multiple detectors, you can control which ones the data is displayed from “View” -> “Detectors”

- Can be useful to isolate left/right side of portal monitors, or to energy calibrate sub-set of detectors

A note about the spectrum display:



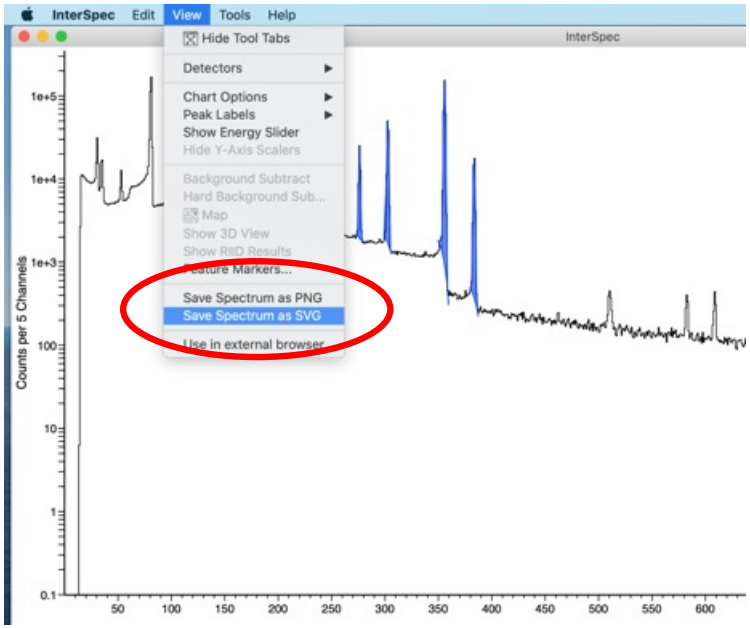
When there are more spectrum channels than pixels, multiple channels are summed together for display.

As you zoom in and out, this is dynamically adjusted.

The time-history plot does the same thing, but can also be turned off.

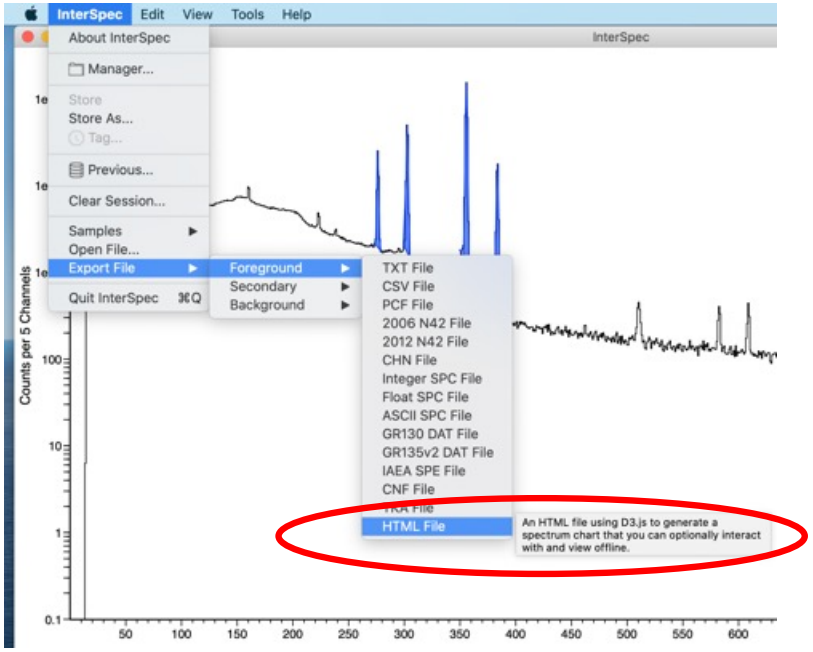
Seems to be the least-misleading way to display the data in discernable way.

Saving screen-shots



You can save a screenshot of the spectrum as either a PNG or SVG file

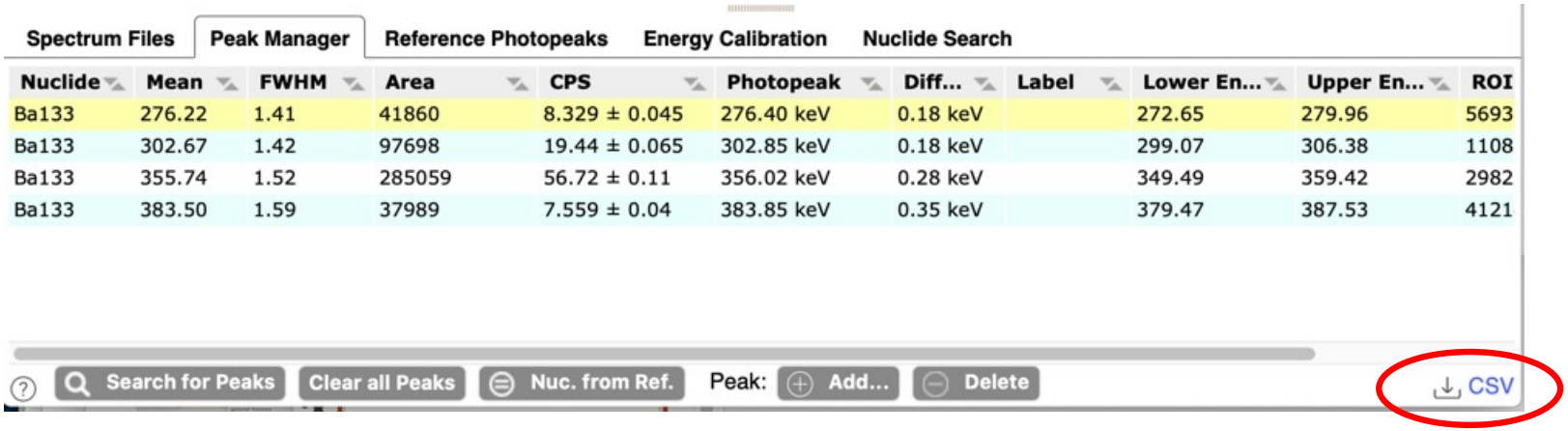
The picture will be the same size as is currently displayed – but of course SVG is a vector format so can be rescaled well.



You can also export the current spectrum as an HTML file, that will have an interactive spectrum embedded into it, with similar controls as inside InterSpec.

Will have peaks, reference lines, etc

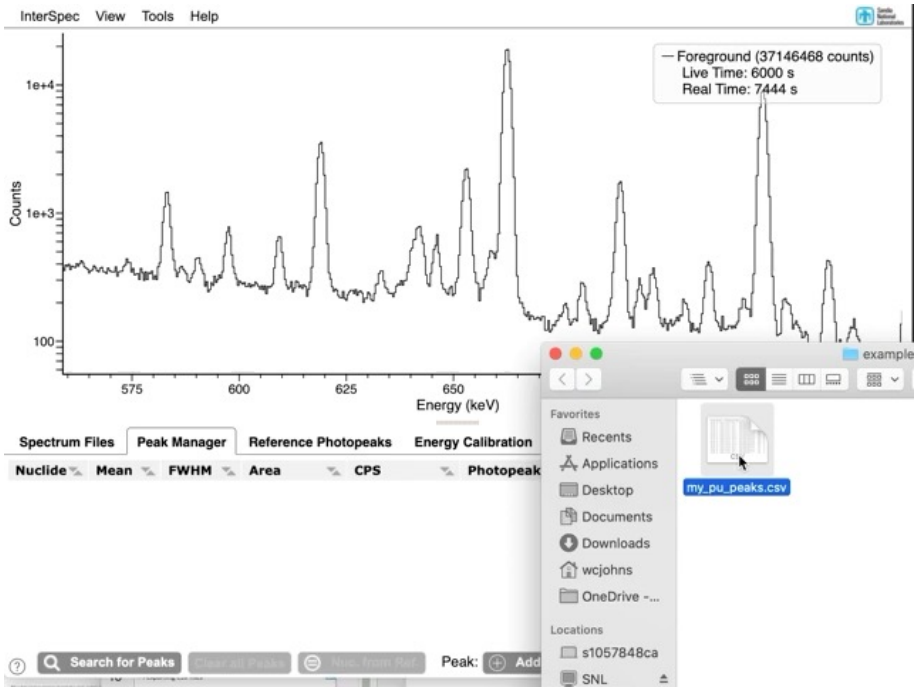
Exporting CSV files



A lot of places throughout the app you'll see little links to download things – these export text-based files useful for getting information into other applications.

- Peak information, nuclide decay info, energy calibration, detector response function, etc.

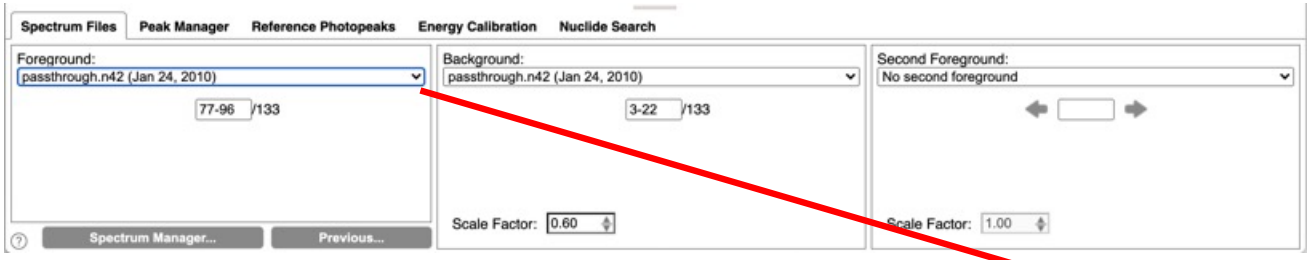
Using the CSV files

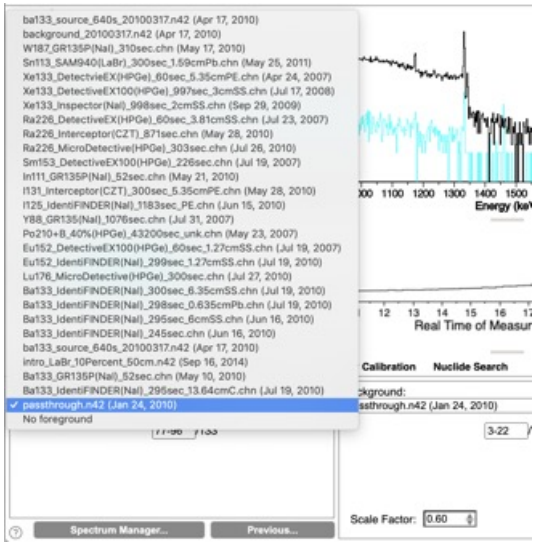


For a number of these files, you can drag-n-drop them back into InterSpec.

The peaks CSV is the most useful: when you drag the CSV onto the app, the peaks will be refit, so count-rates or exact resolution doesn't need to match – useful if you work with similar spectra a lot.

Having multiple files open

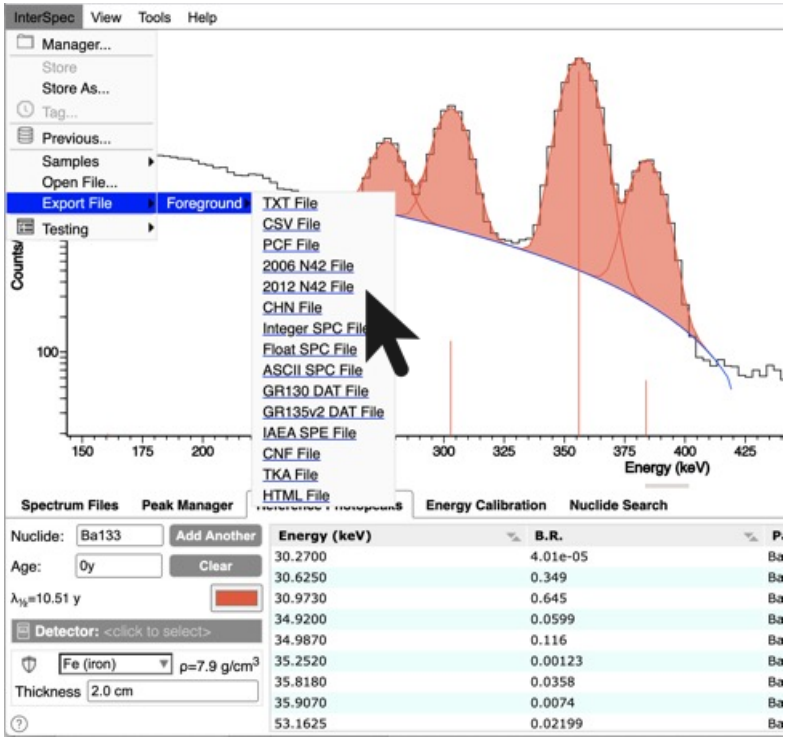




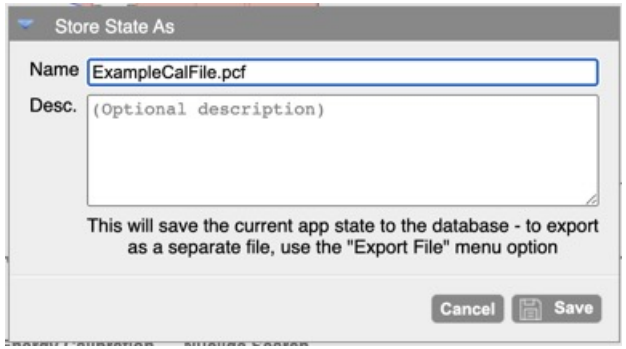
When you open a new spectrum file, all your previous files get kept in memory and any work done on previous spectra is not lost, until you close InterSpec

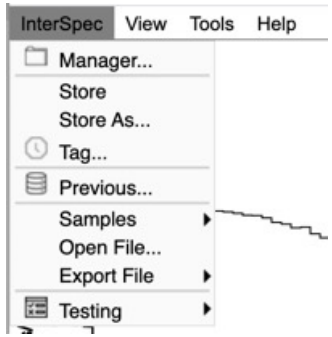
You can go back to any of the previous spectra easily

Saving your work



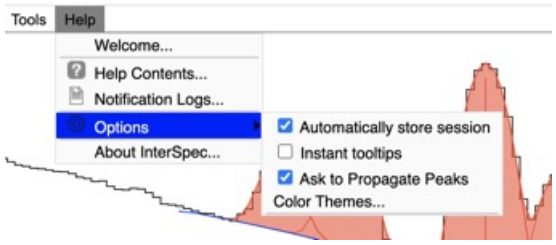
If you export to a N42-2012 file, then all of your peaks, DRF, and fit activities/shielding will be saved inside the file and restored when you load back into InterSpec.





Or you can store everything in InterSpecs' internal database.

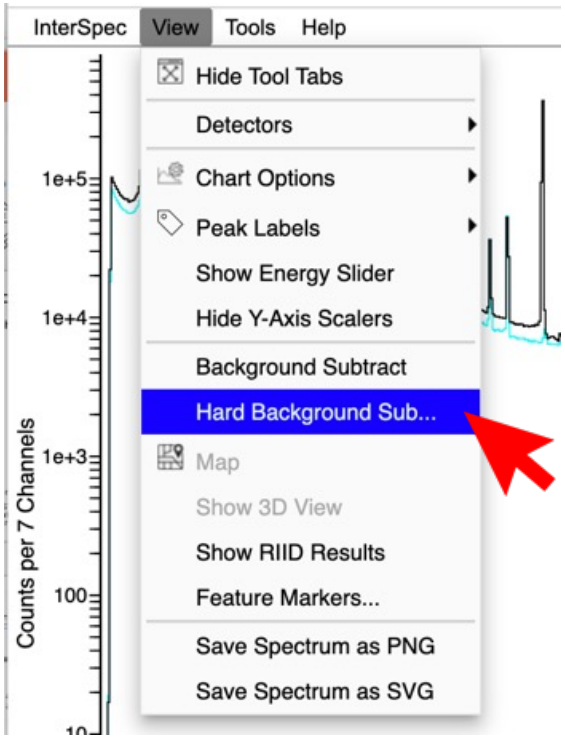
- If you do this you can "Tag" snapshots of your work, or if you load the original spectrum some time later, you will be let known you can pickup where you left off before



There is also an option to store your session when you quit InterSpec, or switch spectrum files

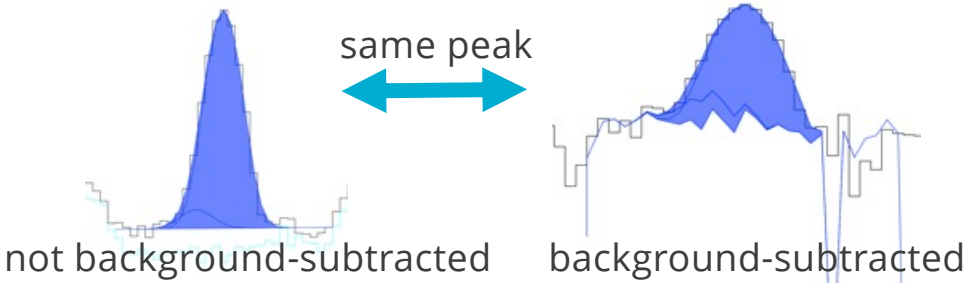
- You cant currently access these auto-saved spectra via the GUI, but if you load the same spectrum file later, a dialog will come up asking if you want to pick up where you left off

Background Subtraction



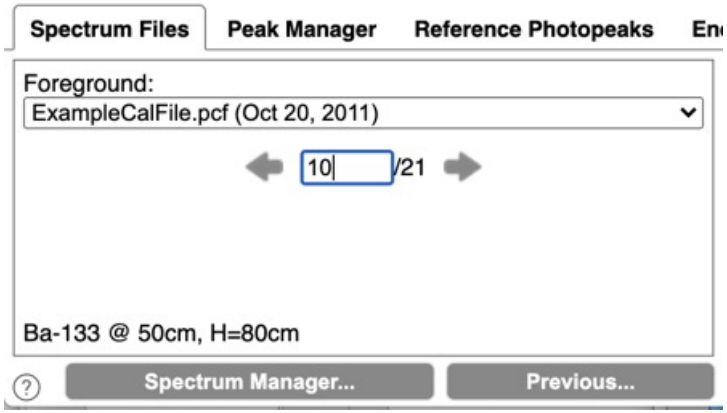
InterSpec has two background subtraction options:

- "Background Subtract" – a visual subtraction for plotting only
  - Can cause display affects to the peak continuum



- "Hard Background Sub…" – background counts are subtracted from foreground to make a new spectrum
  - This is what most people are used to
  - I personally prefer to avoid this, but in practice its probably what works best

Files with multiple samples

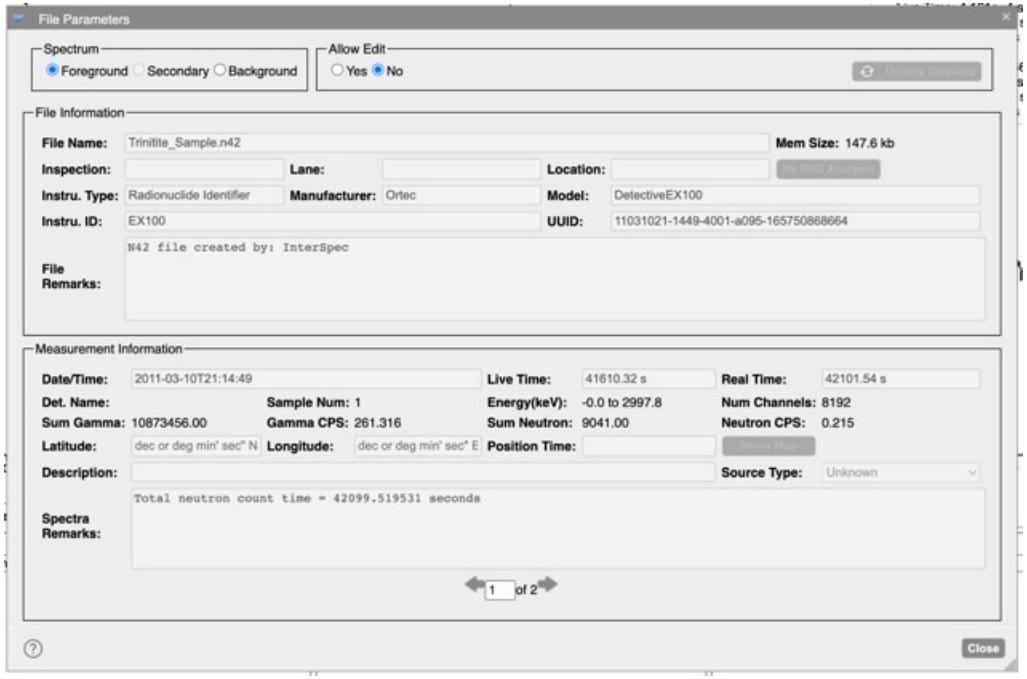


If a file has multiple measurements inside of it, you can also select which samples you want to display

- If you want to use multiple samples summed, you can enter text like:
  - "1-10" to sum samples 1 through 10
  - "2,3,5-7" to sum samples two, three, and five through seven
- If you need to sum samples across files, see the "Spectrum Manager…" to create new files with all the samples you want
- For search-mode or portal data there will be a time-chart to let you do this summing easily

Inspecting spectrum file contents

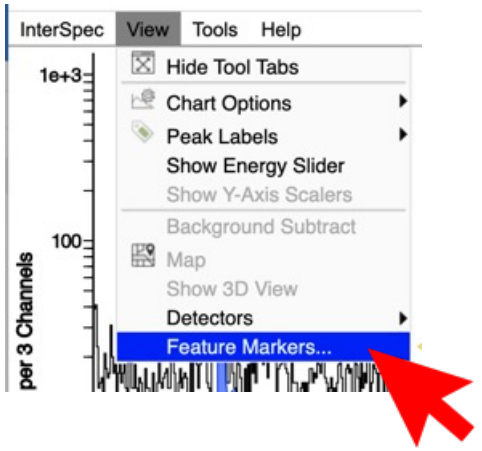
Tools -> “File Parameters”

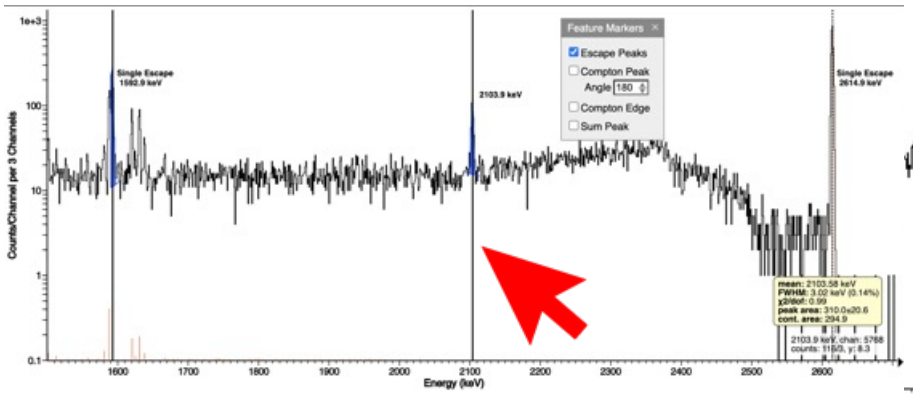


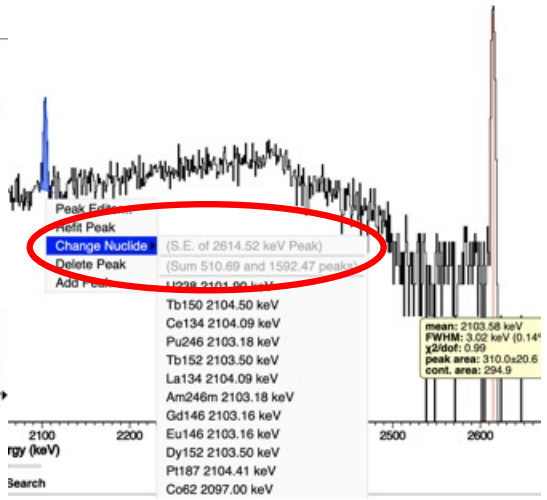
The “File Parameter” tool lets you look at, and edit information in spectrum files.

Sometimes spectrum files contain “meta” information that turns out to be useful, that will show up here; if you didn’t take the measurement, it may be worth checking this out to make sure you aren’t missing something (it can also be useful to open the file up in a text-editor as well)

Feature Markers







Not all peaks and features in a spectrum are caused by full-energy absorption of a gamma/x-ray

- Escape peaks fall 511 keV and 1022 keV bellow the full energy peak
- Sum peaks at double the actual energy
- Compton peaks or Compton edges can be confused for peaks, or scatter angle can be important to figure out

As you move the mouse on the spectrum, lines will be drawn on left and right to show where the source peak and feature peak would be for the current mouse position

You can also try right-clicking on a peak and InterSpec will let you know about sum and escape peak possibilities

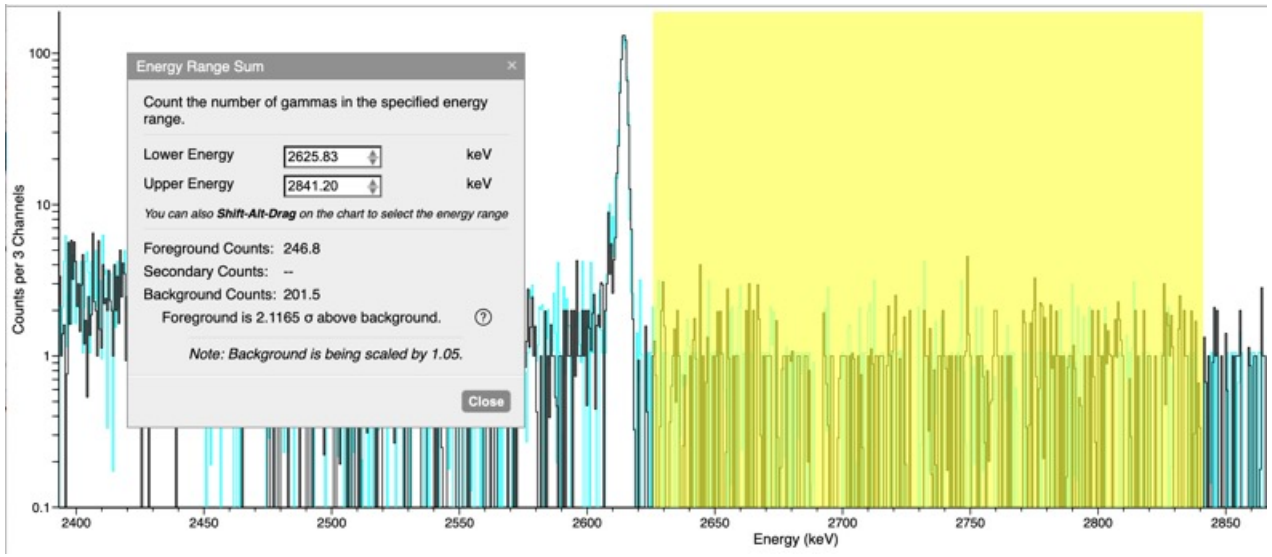
- Uses both the peaks you've fit, as well as the automated peak search results, so it works pretty well

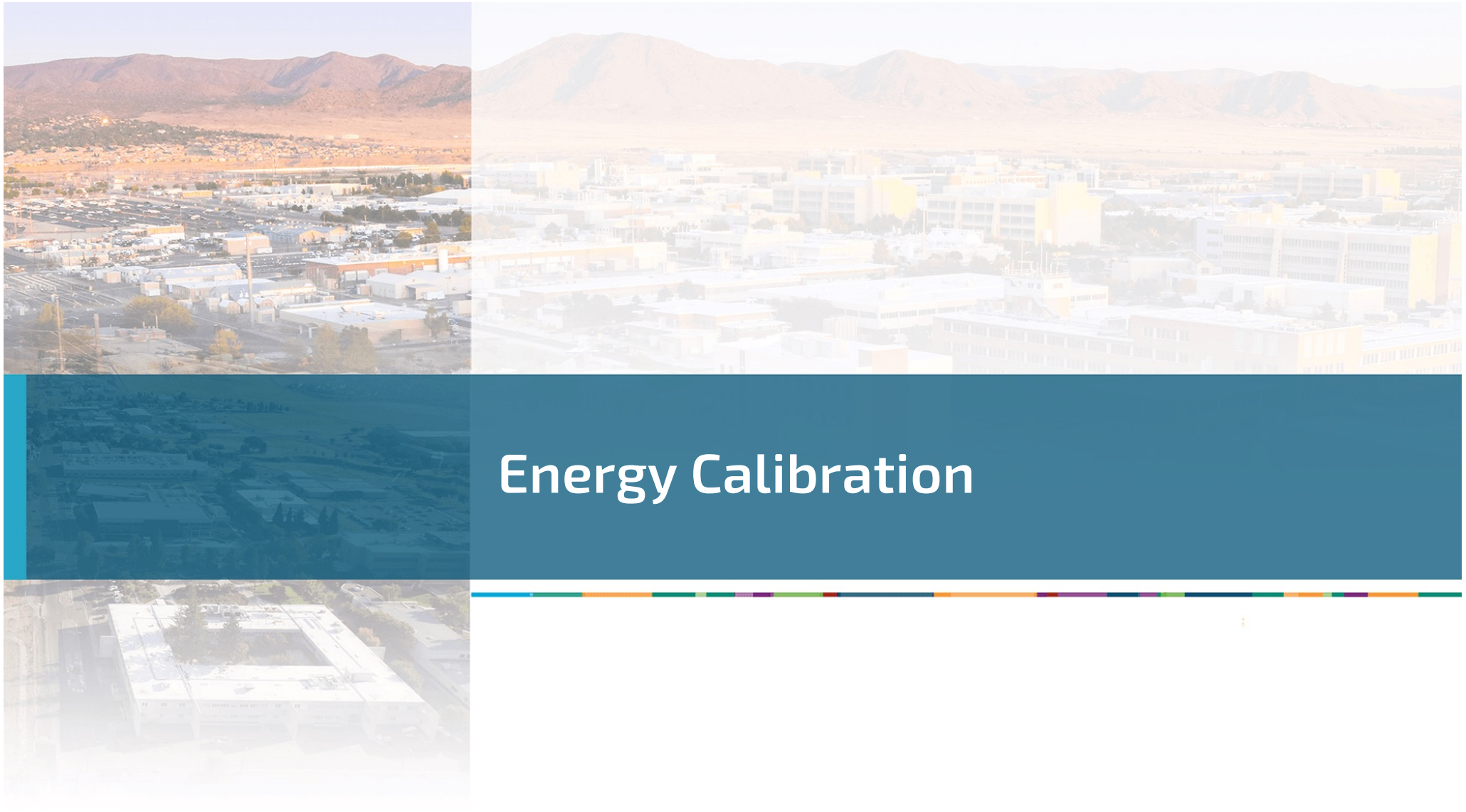
If there are some peaks left in the spectrum that you cant identify, this tool is worth a try, especially for HPGe

Comparing counts in an energy range

The “Energy Range Sum” tool lets you compare count rates between foreground and background/secondary spectra

- You can access via “Tools -> Energy Range Sum” menu, or “shift + alt + mouse-drag”
- A common use-case is comparing continuum counts above the 2614 keV peak to check if neutrons are present





Energy Calibration

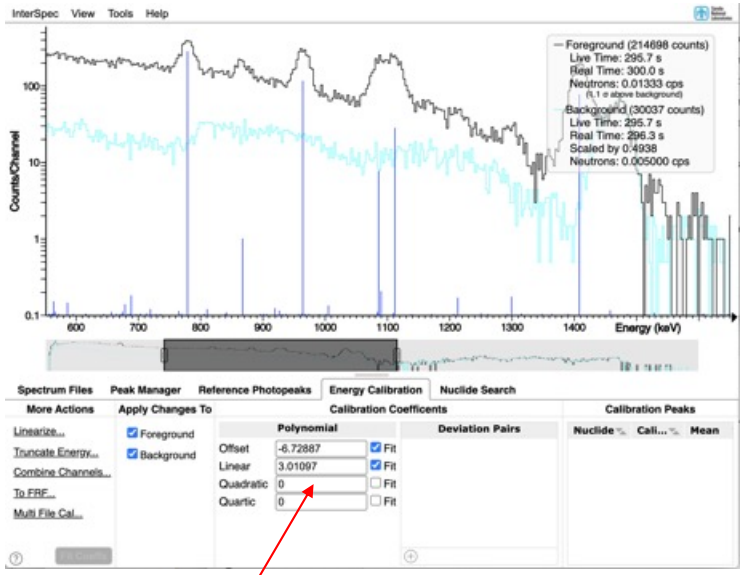
Energy Calibration – a primer

Almost all spectrum files use one of:

- Polynomial:
  - The energy of channel i is: $E_i = c_0 + c_1 \times i + c_2 \times i^2 + c_3 \times i^3 + \ ...$
  - Spectrum file gives the coefficients c_j, usually 2 or 3 of them, but sometimes up to ~5.
  - c_0 is often times called offset, c_1 is gain, c_2 quadratic
  - The most common energy calibration form
- Full Range Fraction (FRF):
  - The energy of channel i is: $let\ x_i = \frac{i}{\#channels}$ then $E_i = c_0 + c_1 x_i + c_2 x_i^2 + c_3 x_i^3 + \frac{c_4}{1+60 x_i}$
  - Primarily used in PCF files (GADRAS and related), but also in some N42-2006 files.
- Lower Channel Energies:
  - The lower energy of each channel is given.
  - Sometimes the upper energy of last channel is also given
  - Common in CSV or simple ASCII files, but can also be in N42 and PCF files

A detectors calibration may not always be great, so sometimes adjustments to the coefficients of polynomial or FRF coefficients may be necessary before analyzing data – there are a few ways to do this in InterSpec

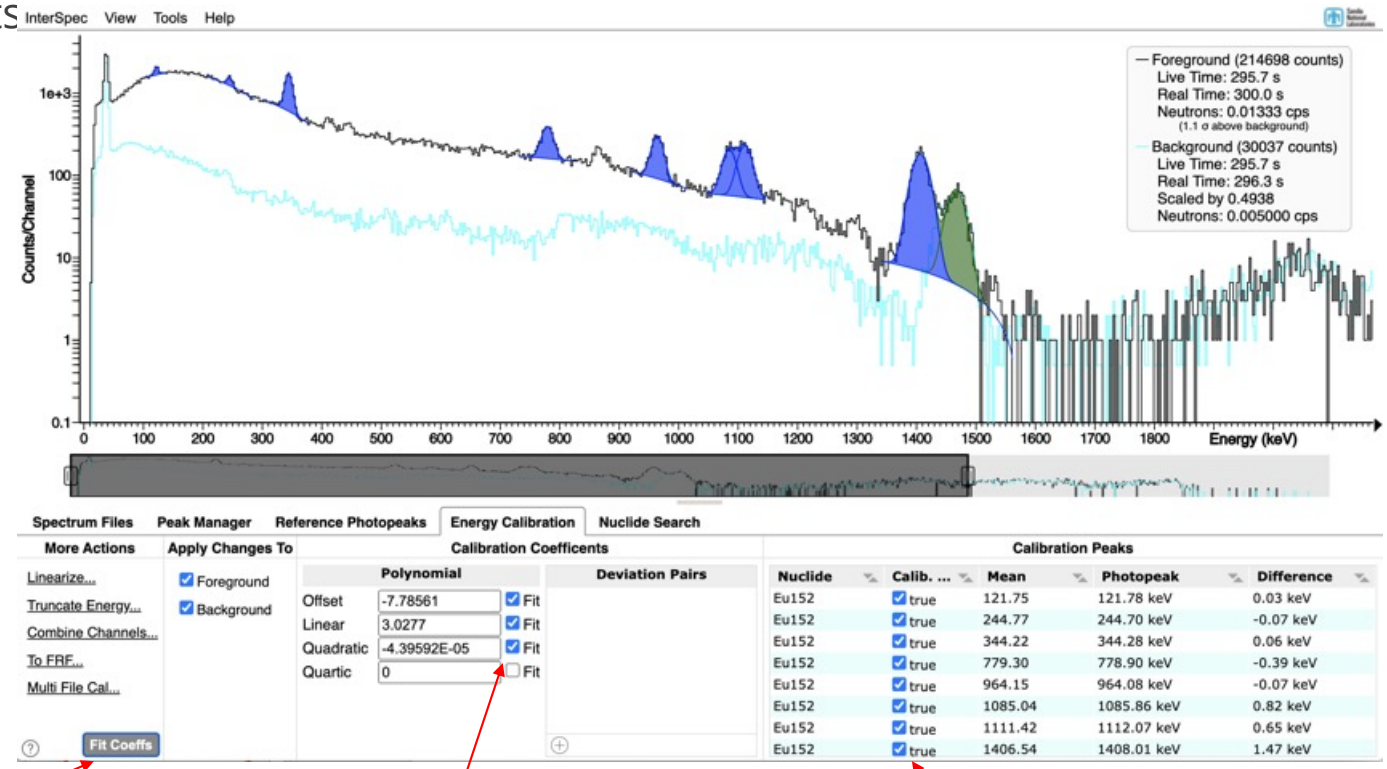
Energy Calibration (cont.)



You can manually adjust parameter until the photopeak's line up with where they “should” be

Energy Calibration (cont.)

You can fit for peaks associated with nuclides, and use those to "fit" for the best coefficients

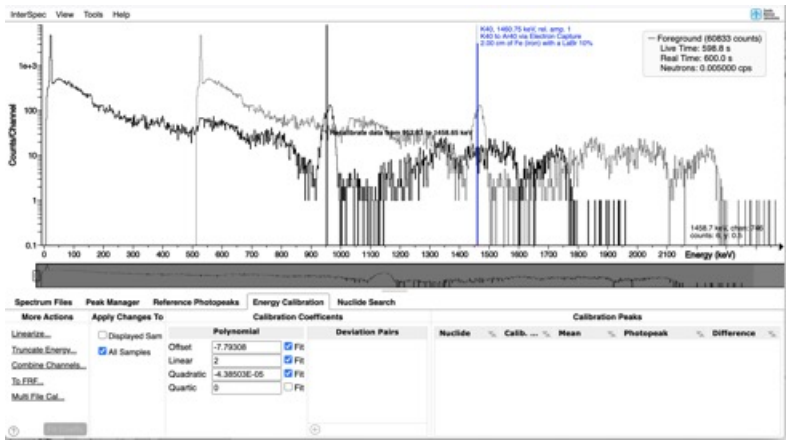


3) Push "Fit Coeffs"

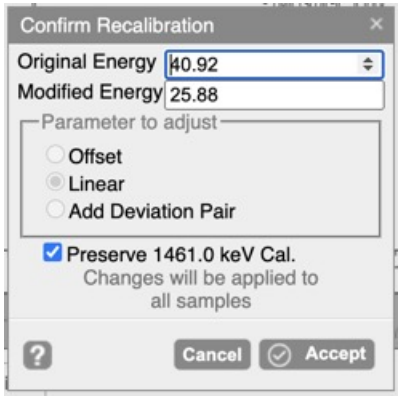
2) Select which order coefficients you want to fit for

1) Select the peaks you want to use for the fit

Energy Calibration (cont.)



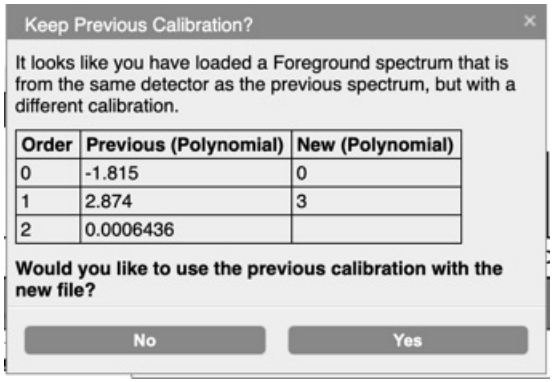
You can graphically recalibrate by holding Ctrl+Alt and dragging the spectrum to where you want



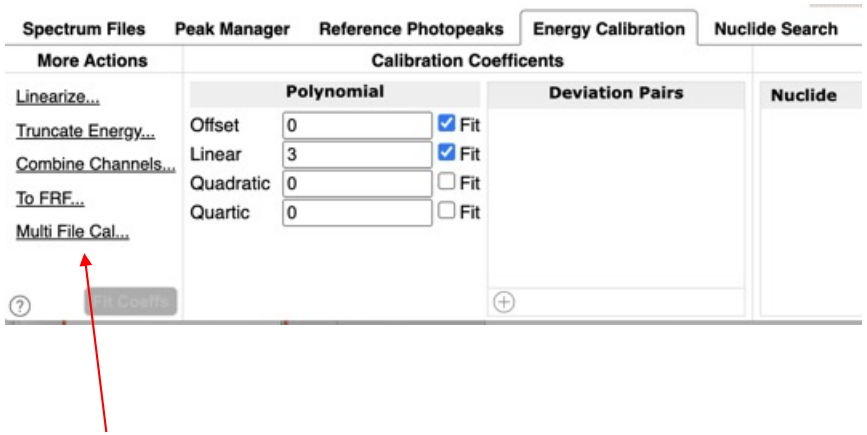
If Ctrl+Alt+drag again within 2 minutes, one of the options will be to preserve your last calibration

- This is useful to adjust both the gain and offset using a low and high energy peak; when you do the second calibration this option will keep your previous peak at the same location you drug it to

Energy Calibration (cont)



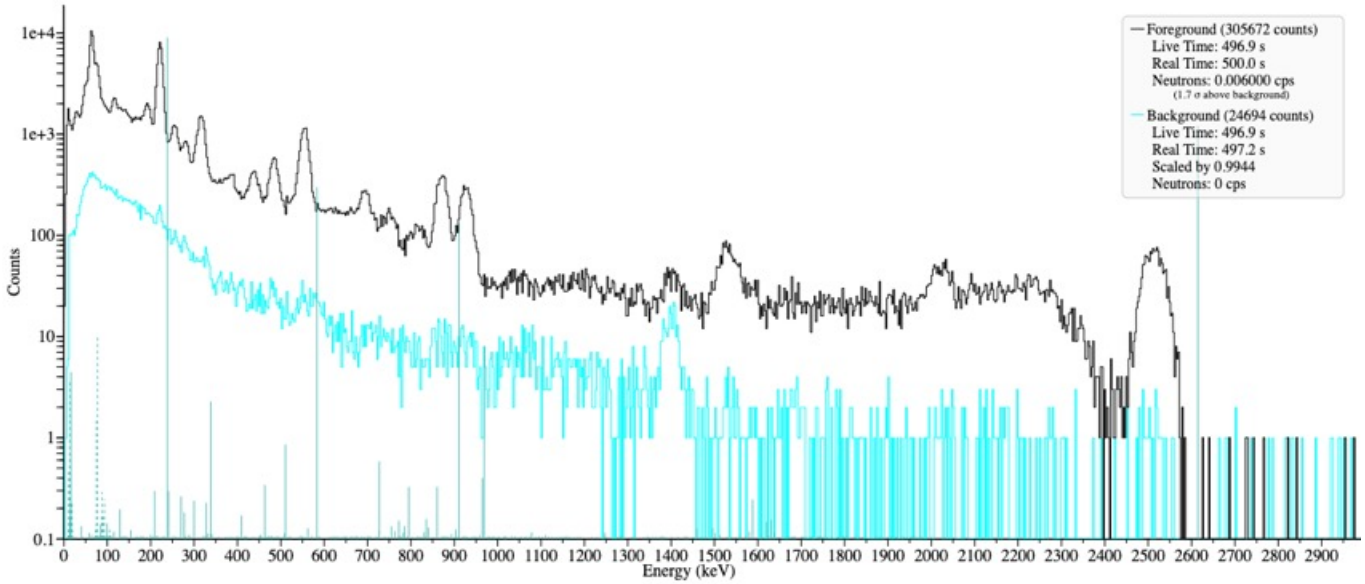
When you load a new spectrum, and its from the same detector as your previous spectrum, and the energy calibrations are different, you will be asked if you want to keep the previous calibration



Further options having to do with energy calibrations will appear in the Energy Calibration tab depending on context

Energy calibration practice

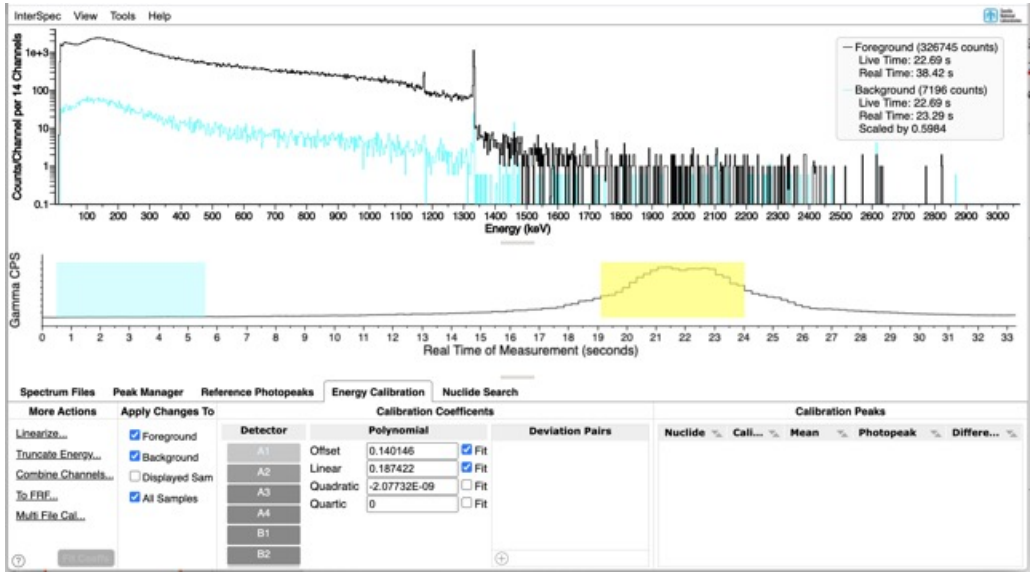
The file “th232_energy_cal_practice.n42” was generated without an energy calibration – please try to determine it



You can assume you need at least a quadratic equation.

The truth answer will be given in about 10 minutes – if you are not a power energy calibration user, feel free to ignore this next 10 minutes, and instead determine the energy calibration

Energy Calibration - complications

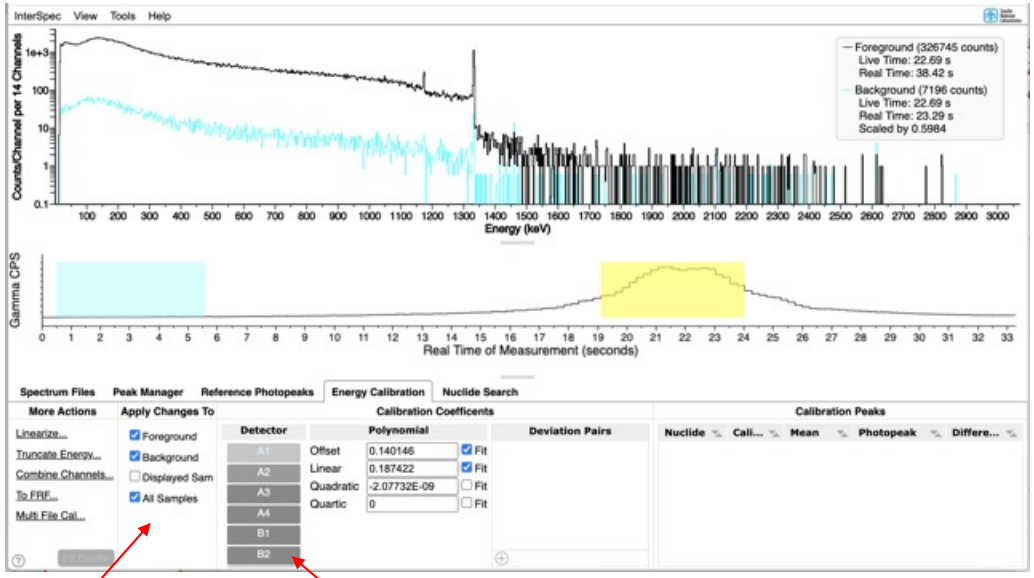


Some detection systems have multiple physical detectors, and/or may provide many different measurements all within the same file

- Each detector may have a different energy calibration
- The energy for a given detector may change for each sample

In these cases you will have to select how you want the changes applied

Energy Calibration – complications (cont.)



You can select which detectors, samples, and files to apply the changes to here

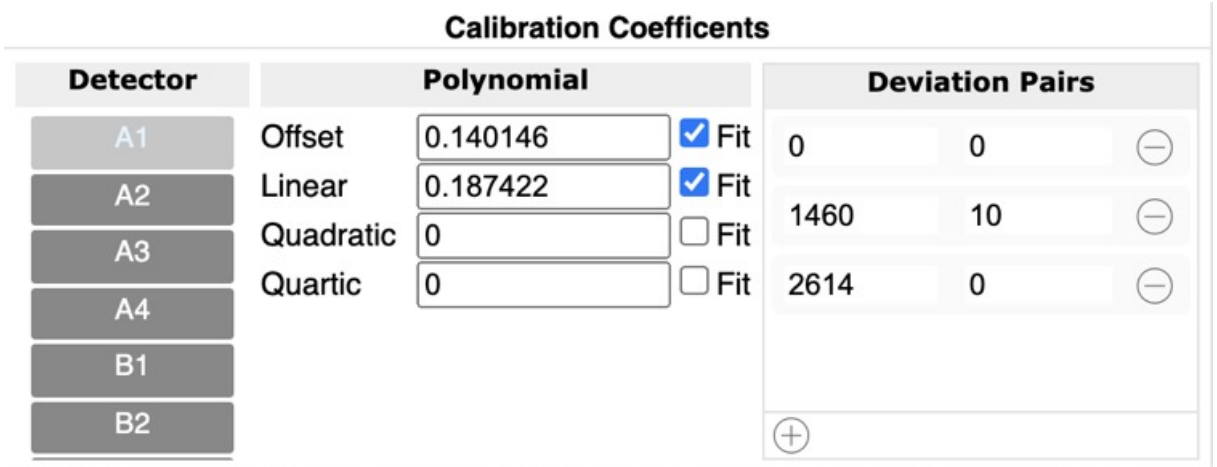
You can see the calibrations for each detector using this menu, which will appear when you load a spectrum with multiple detectors

Energy Calibration – complications (cont.)

For multiple detector systems, or where calibration changes throughout file:

- If you manually change a coefficient, the effect of that change is applied to all the other calibrations in the file
  - E.g., the peaks for all detectors will move the same amount
  - This isn't as straight forward as changing the coefficients of each calibration by the same amount, but InterSpec takes care of the math
- If you want to adjust the calibration of just one detector, use the "View" → "Detectors" menu to change which detectors are being shown, to just that one detector
- Options also appear on the GUI to let you apply changes to just the visible samples, or all the samples, or just the foreground/background/secondary spectrum
  - Changes are not applied to other files you may have open, but aren't being displayed; use the "Multi File Cal..." option for that, or after an adjustment, change back to the other file you want, and you should be prompted if you would like to use the new calibration

Energy Calibration – nonlinear deviation pairs



Non-Linear deviation pairs are typically used to account for intrinsic non-linearities not captured by a lower-order polynomial

- Non-linear deviation pairs are typically static over time and temperatures and wont need to be adjusted after initial characterization

The deviation pairs are actually the nodes of a cubic spline that specifies a change to add on-top of the polynomial or FRF calibration

An example use is:

- Use the 239 keV and 2614 keV peak to determine offset and gain
- Then if the 1460 keV K-40 peak is at 1450 keV, you would a deviation pair with energy of 1460 and offset of 10
- You would also add a deviation pair with offset 0 at 0 keV, and one with offset of 0 at 2614 keV

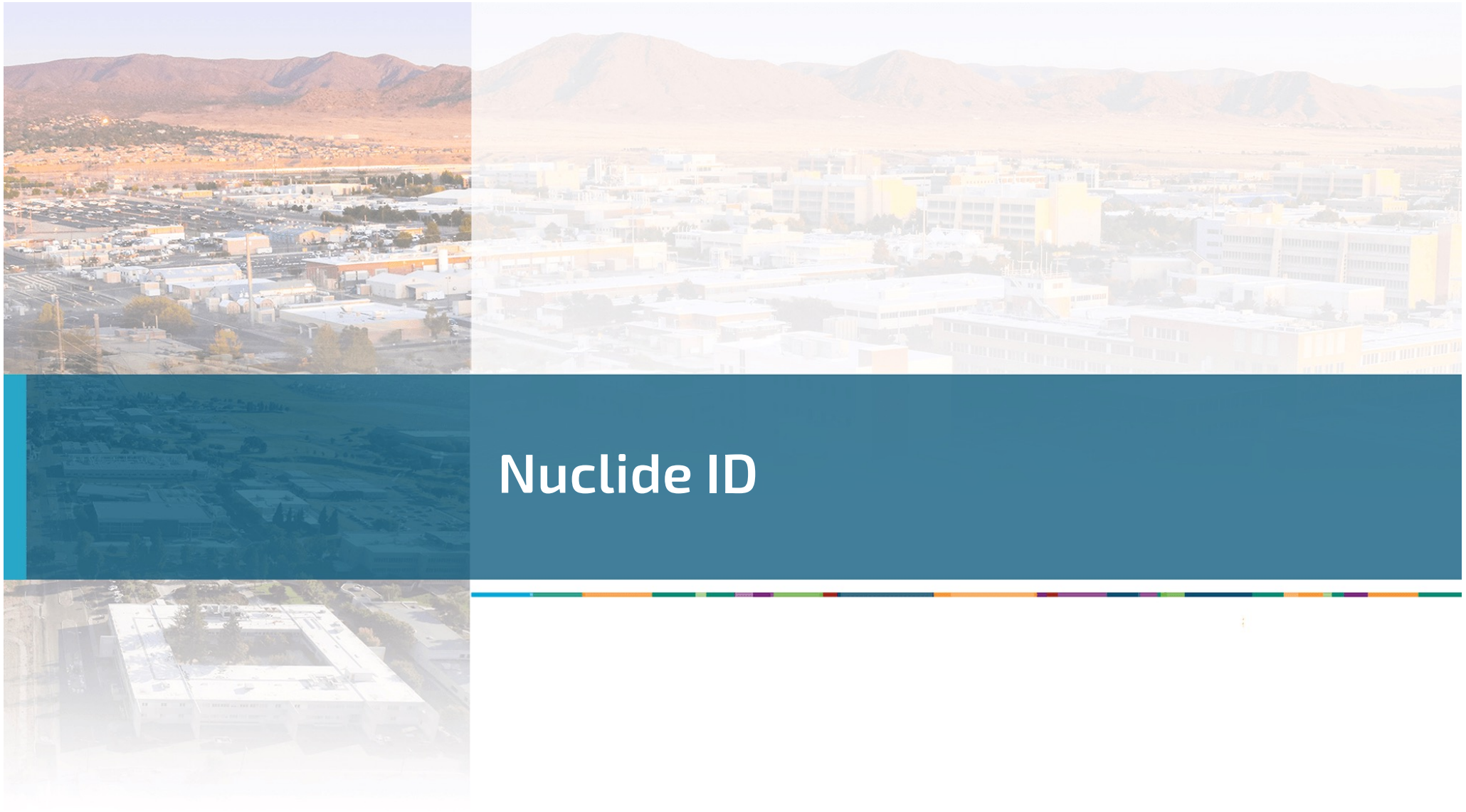
Practically, if you are trying to use a quartic or above calibration, you should consider non-linear deviation pairs

Energy calibration practice - Answer

Truth answer:

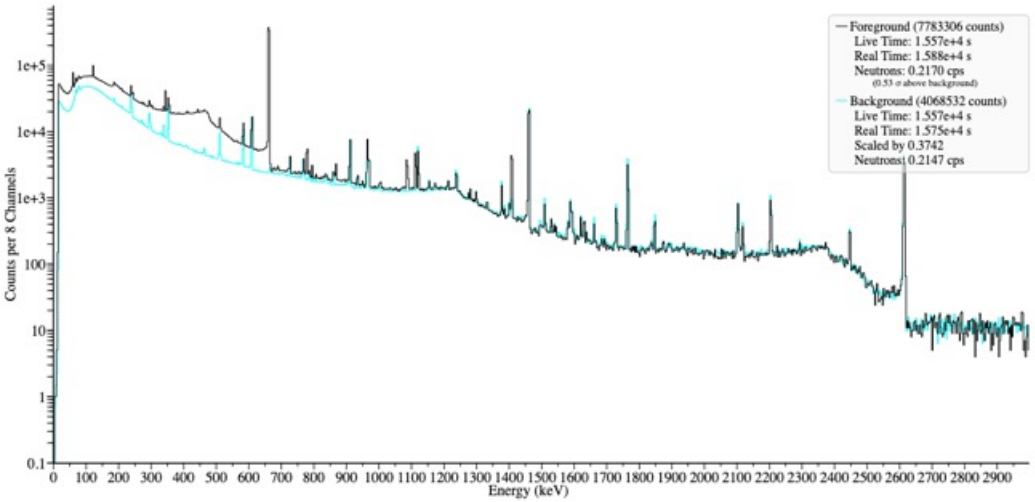
Polynomial		
Offset	10	☑ Fit
Linear	3.02832	☑ Fit
Quadratic	9.53674E-06	☑ Fit
Cubic	1.86265E-09	☑ Fit

However, we probably don't have enough power with this lower resolution spectrum to get the small cubic parameter.



Nuclide ID

Nuclide-ID practice



Please load the “trinitite_sample_b.n42” and “trinitite_sample_b_background.n42” files available from Tutorials section of https://sandialabs.github.io/InterSpec/

- Measurement is from Dave Mercer of Los Alamos National Laboratories
- This is sample “B” in “Gamma and Decay Energy Spectroscopy Measurements of Trinitite” – available at https://arxiv.org/abs/2103.06240 (an excellent discussion and analysis!)
- 125.6 grams of typical green-glass pieces

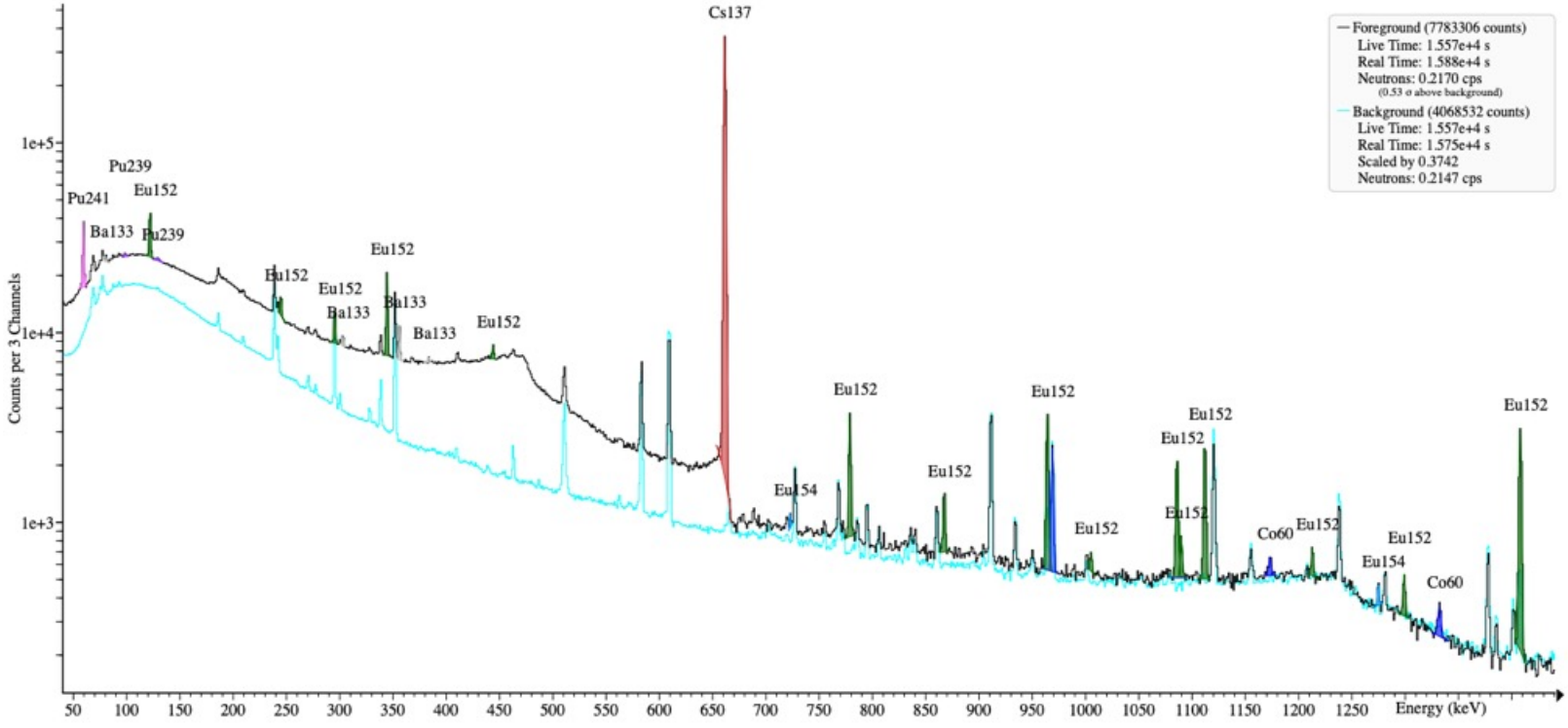
Lets take 15 minutes to do nuclide ID (or take a break)

Please fit, and associate the nuclides for as many non-background peaks as you can.

Later today we will fit for activities, and then back-decay them to time of detonation, and then compare to the paper.

Results

Co-60, Ba-133, Cs-137, Eu-152, Eu-154, Pu-239, Pu-241



Fitting activity and shielding

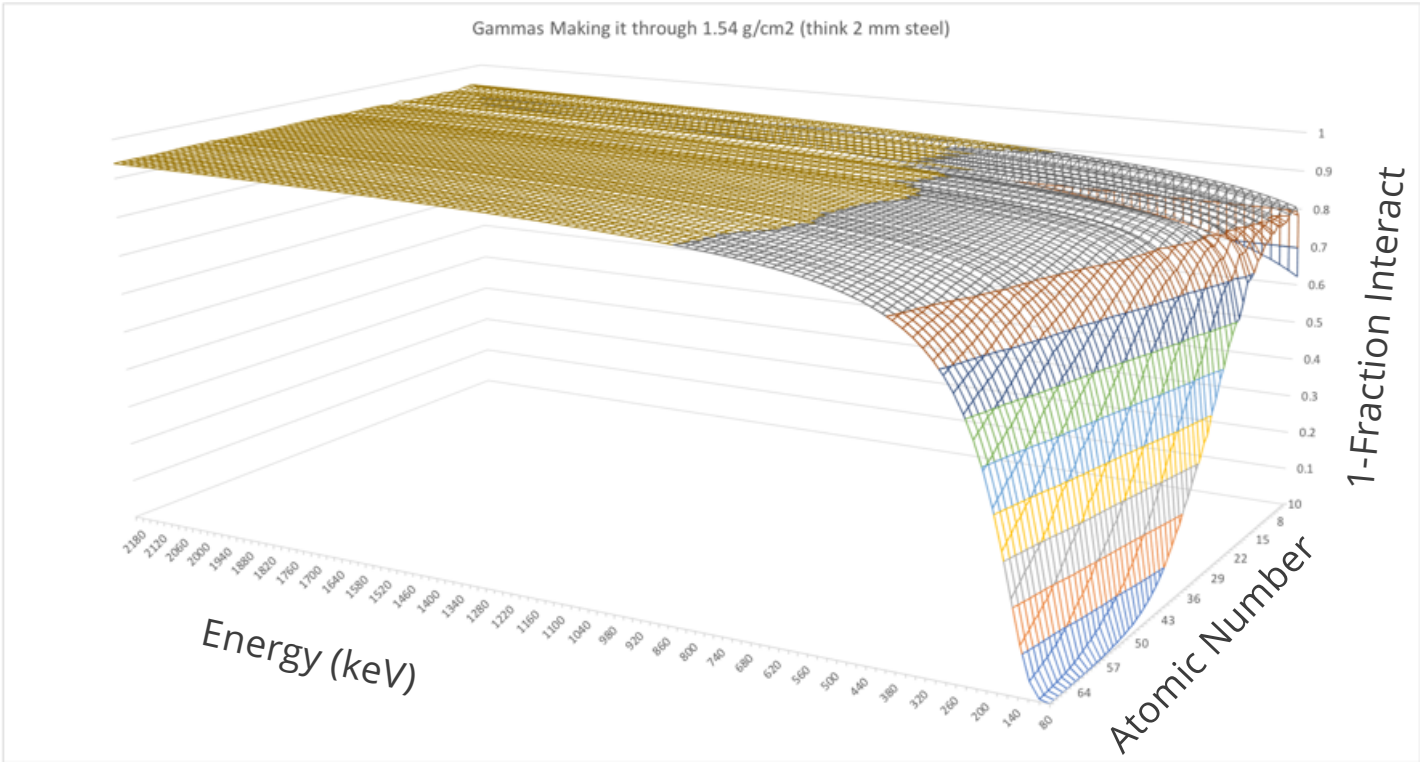
Peak-Based Differential Attenuation Analysis

Goal: Take gamma spectrum of radioactive source, and from the spectrum potentially determine:

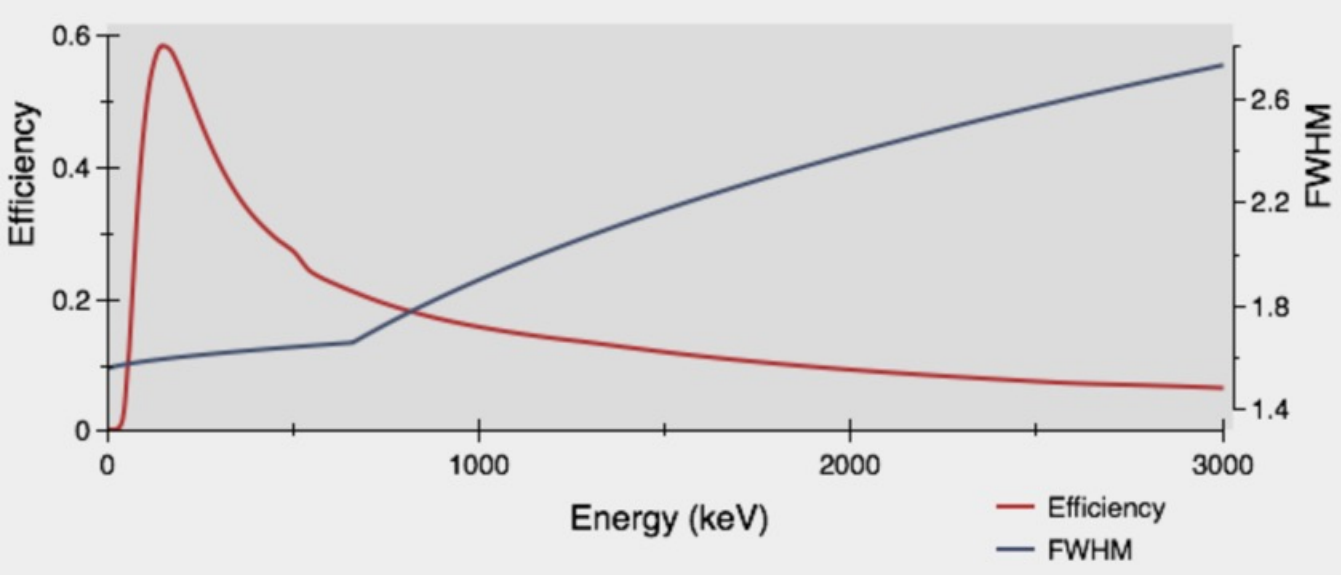
1. The amount of shielding
2. The effective atomic number of shielding
3. The source activity
4. Isotopics of material
5. The source Age

Differential Attenuation – Pretty Basic Stuff

The photon cross-section with matter varies by both photon energy and material atomic number



Detector Response Function



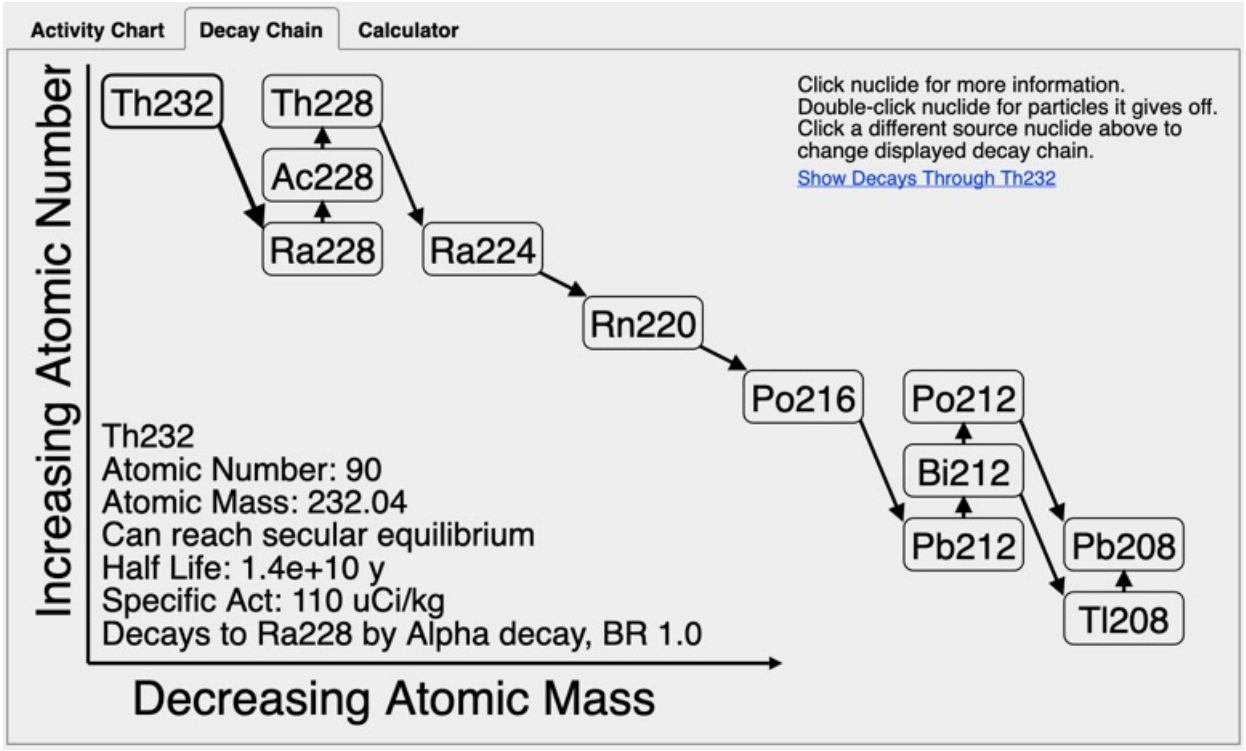
For peak-based spectroscopy, we care about the efficiency of detecting the full-energy of incoming gammas – i.e., efficiency to see peaks in the spectrum.

The efficiency is commonly given as either:

- Intrinsic: A function describing the fraction of gammas striking the detector face, who's full energy will be absorbed
- Absolute: The fraction of full-energy absorptions , for a source at a given distance

Usually given in a form like: exp(-343.63 + 269.10*log(x) -83.80*log(x)^2 + 13.0*log(x)^3 -1.01*log(x)^4 + 0.03*log(x)^5)

Source Gamma Intensities:



ENSDF gives us the energy and intensity of gammas for each nuclide

The Bateman equations let us determine these probabilities for decay chains as a function of time

Putting it together:

We know a nuclides output gamma spectrum (as a function of age)

We know the gamma attenuation (as a function of energy and atomic number)

We know the efficiency for a gamma to end up in a photopeak (as a function of energy, source to detector distance, and detector face size/shape)

We can fit photopeak's in spectra to determine their area

Its now just χ^2 or -log(likelihood) fit to figure out the the unknowns

Comparison of Peak-Based analysis to Full Spectrum analysis

Advantages of peak-based:

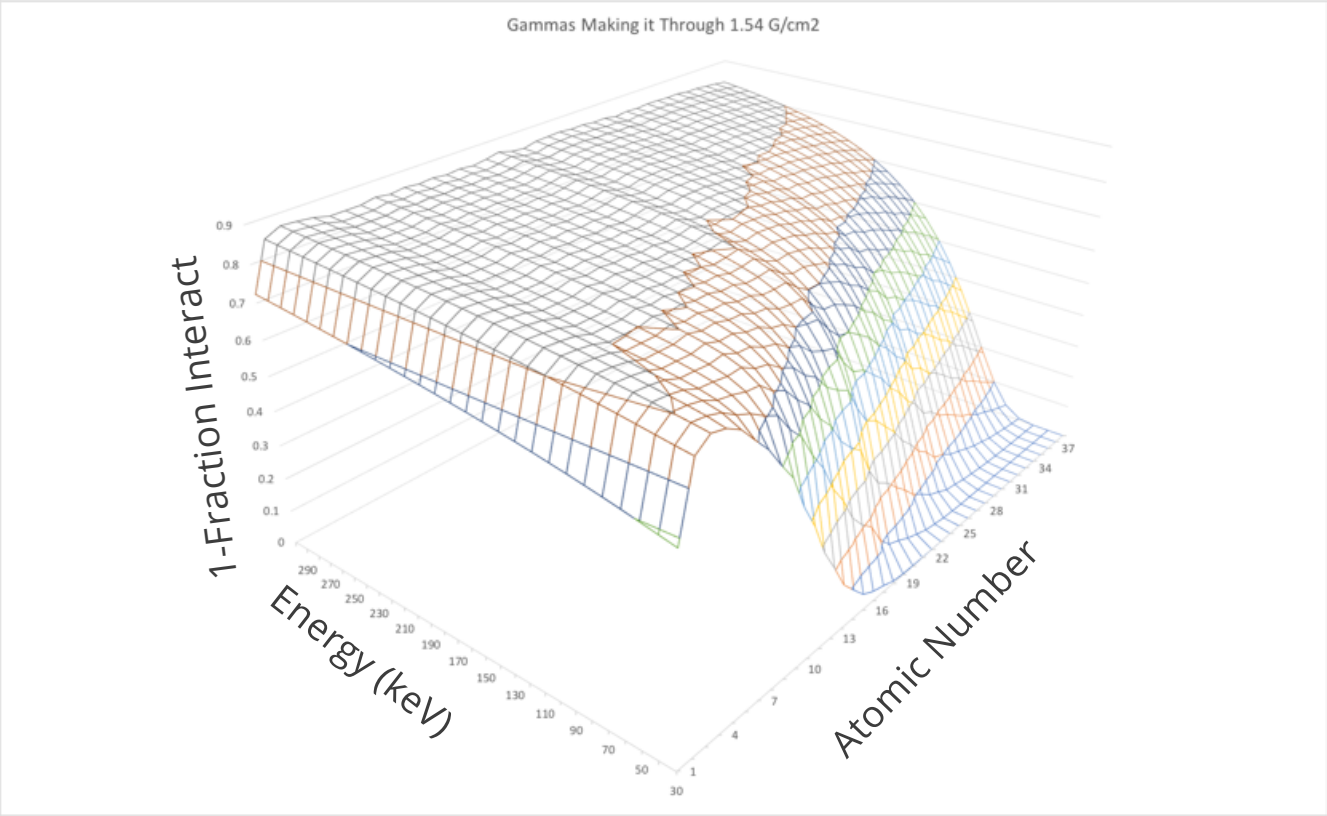
- No background is needed (unless you want to use source peaks that overlap with background peaks)
- Does not depend on scattering of your environment.
  - For full spectrum you need to characterize the DRF to your environment, ex. concrete floor, 1m high, how big the room is, etc.
- Detector characterization much simpler (either do by measuring a couple check sources, or a simple GEANT/MCNP calc can be good enough)
- Gamma transport through material is trivial; doesn't really depend on geometry
- Peaks and spectral features from nuisance sources only effect you if they also have a gamma line overlapping a peak you want to use of the isotope of interest

Disadvantages of peak-based:

- You need at least as many peaks in your spectrum as quantities you want to fit
  - The broader energy range, the better (see next slide)
  - E.x. To fit for activity and shielding thickness, you need at least two peaks (three or more is better) – full spectrum analysis can fit for atomic number, areal density, and activity of single-peak sources like Cs-137
- You are not using spectral information outside of the peaks
- You aren't extracting information about scattering environment
- Full-spectrum analysis uses more information, so can give better results, but can also give worse results if scattering environment is not well characterized

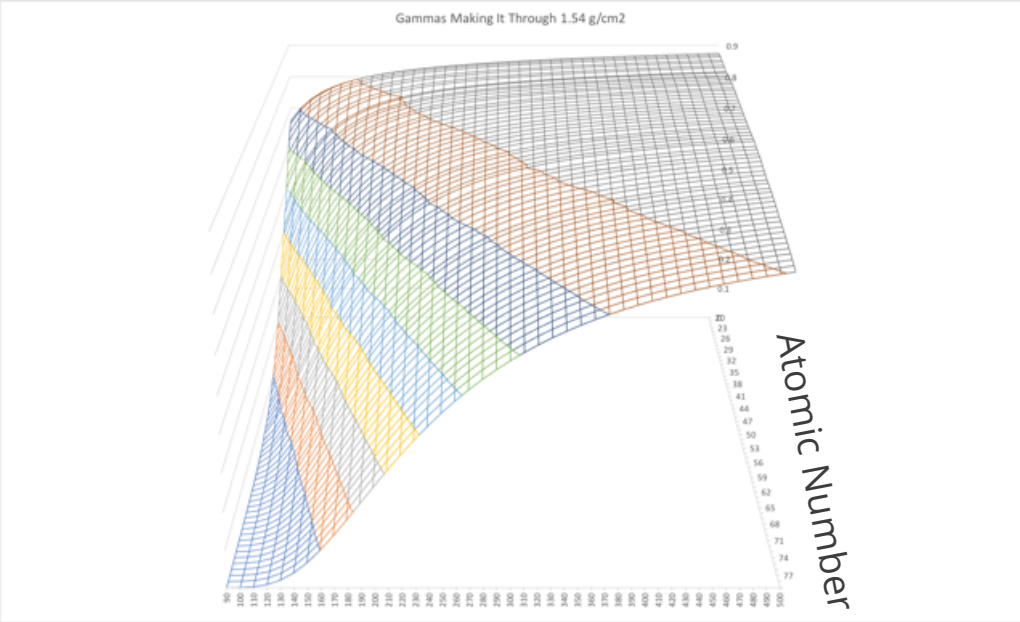
Finding shielding atomic number:

For energies ≳ 300 keV fitting for both atomic number, and amount of shielding becomes degenerate – so you really want at least one peak bellow 300 keV (preferably a few)



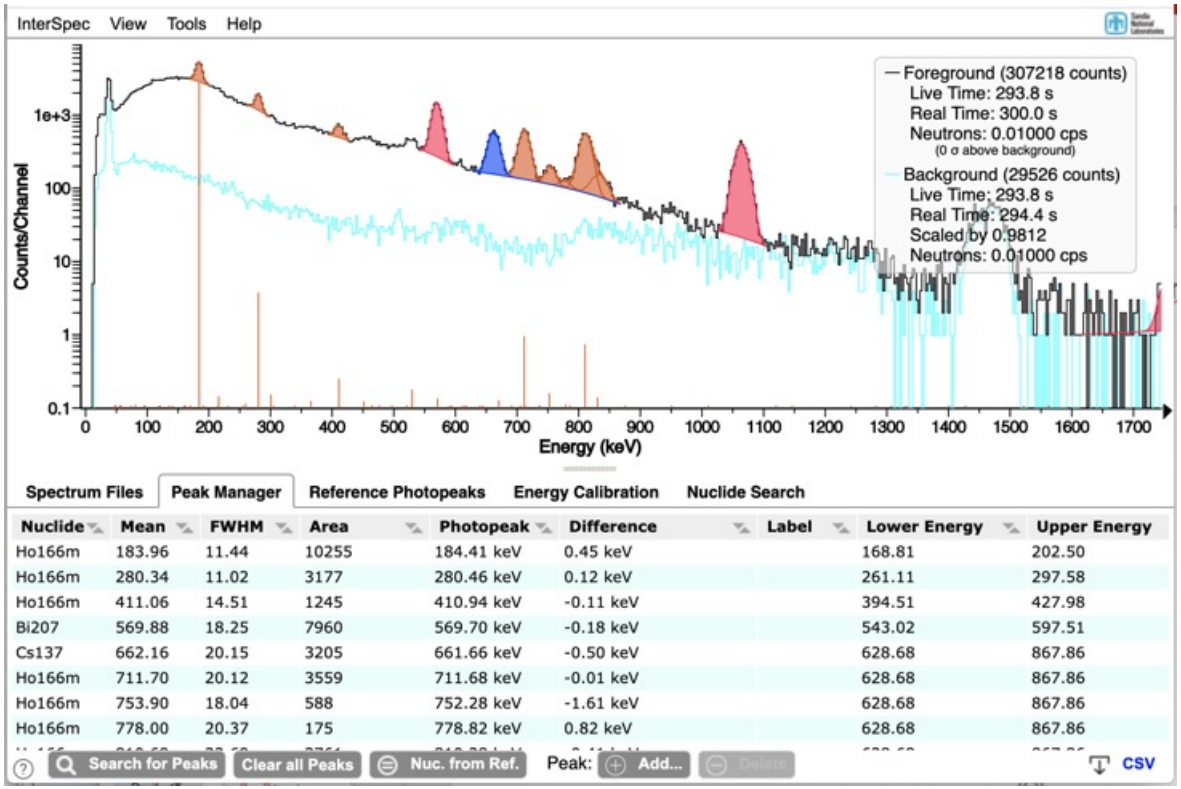
Finding shielding atomic number (cont):

Atomic Numbers > 20
80 to 500 keV



Bottom line: if you want to determine the both effective atomic number, and amount of shielding, using a peak-based approach, you want at least one peak below 300 keV, and preferable a few

Fitting activity, shielding, and age in InterSpec

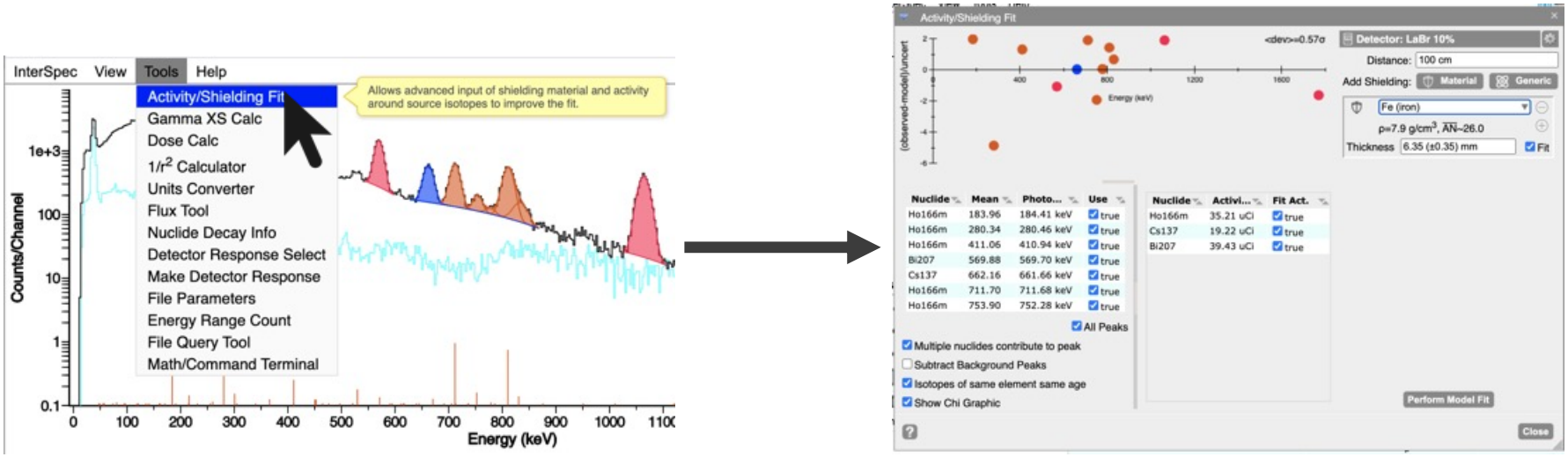


Nuclide	Mean	FWHM	Area	Photopeak	Difference	Label	Lower Energy	Upper Energy
Ho166m	183.96	11.44	10255	184.41 keV	0.45 keV		168.81	202.50
Ho166m	280.34	11.02	3177	280.46 keV	0.12 keV		261.11	297.58
Ho166m	411.06	14.51	1245	410.94 keV	-0.11 keV		394.51	427.98
Bi207	569.88	18.25	7960	569.70 keV	-0.18 keV		543.02	597.51
Cs137	662.16	20.15	3205	661.66 keV	-0.50 keV		628.68	867.86
Ho166m	711.70	20.12	3559	711.68 keV	-0.01 keV		628.68	867.86
Ho166m	753.90	18.04	588	752.28 keV	-1.61 keV		628.68	867.86
Ho166m	778.00	20.37	175	778.82 keV	0.82 keV		628.68	867.86

First: fit peaks, associating them with nuclides

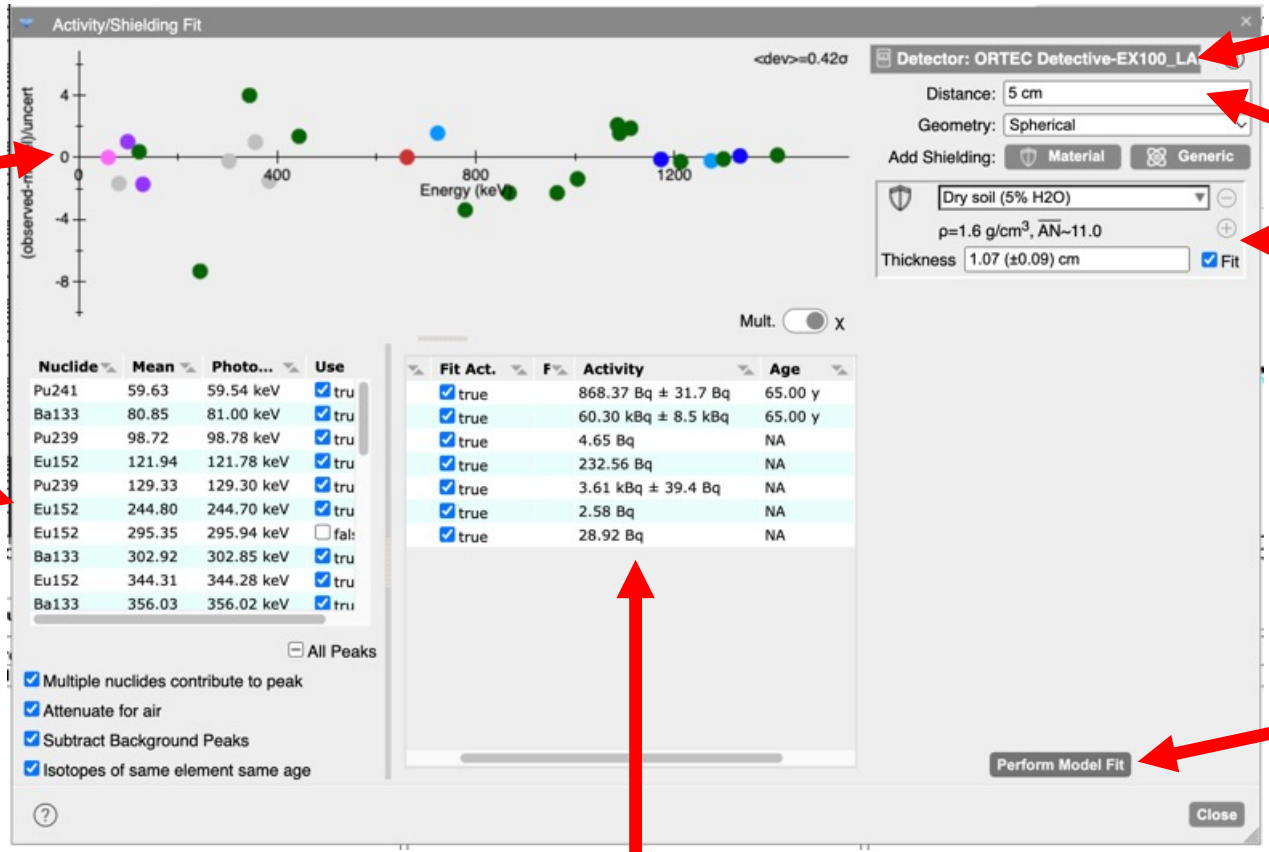
- Peaks that are in both the background and foreground do not need to be fit. Or if a peak is for a nuclide you don't care about you can skip it
- If you have lots of peaks for a nuclide, like a HPGe spectrum of Ra-226, you can maybe fit for just the larger ones

Fitting activity, shielding, and age in InterSpec (cont.)



From the “Tools” menu, select “Activity/Shielding Fit”

Activity/Shielding Fit Tool



Get an idea of how good the fit is

You can select peaks to use in the fit

Some options

Select DRF

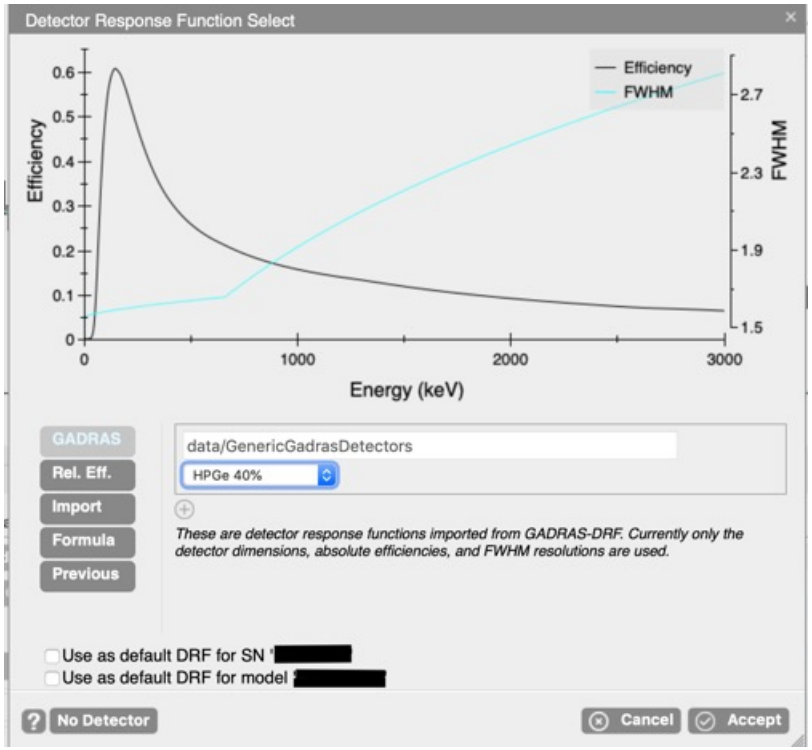
Enter distance

Select shielding(s)

Fit for the quantities you want

Decide if you want activity and/or age fixed for each nuclide

Activity/Shielding Fit Tool (DRF)



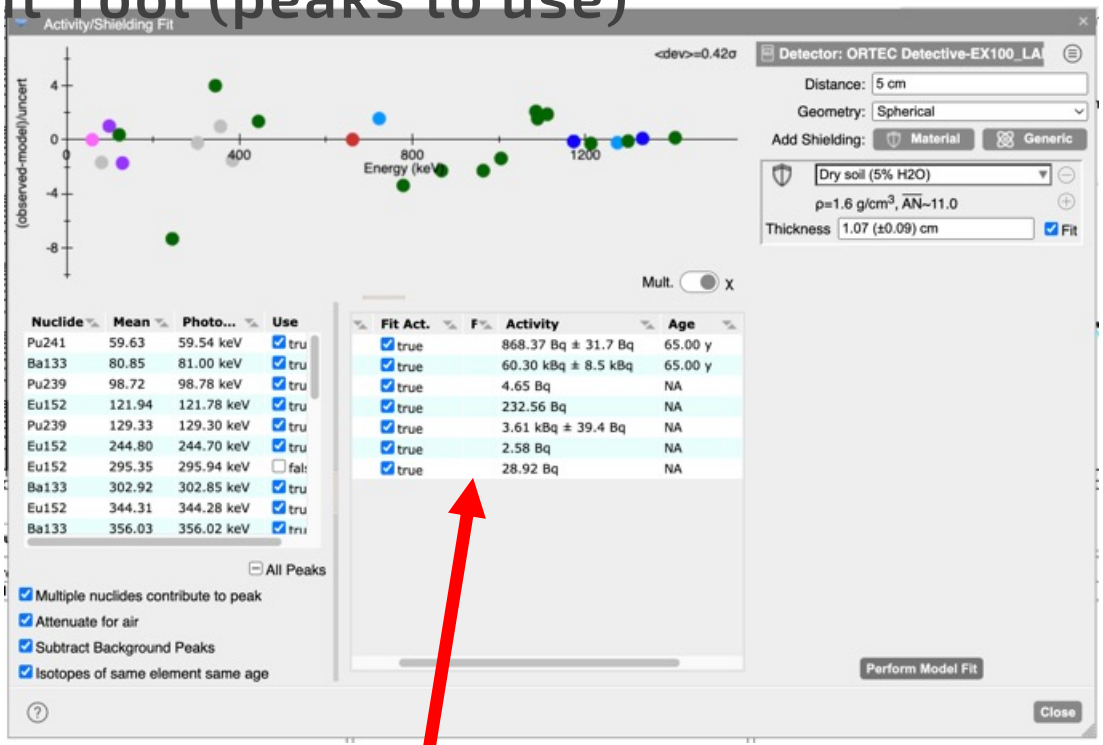
If you click/tap on the detector area, it will bring up this dialog

- We'll cover DRFs later, but this dialog lets you choose from some DRFs that come with InterSpec, enter your own DRF equation, upload a DRF, or select from previous DRFs

Activity/Shielding Fit Tool (peaks to use)

All of the peaks you have fit for the foreground will appear in this list.

- You can choose if a peak should participate in the fitting process.
- We'll cover strategies for deciding if a peak should be included during exercises

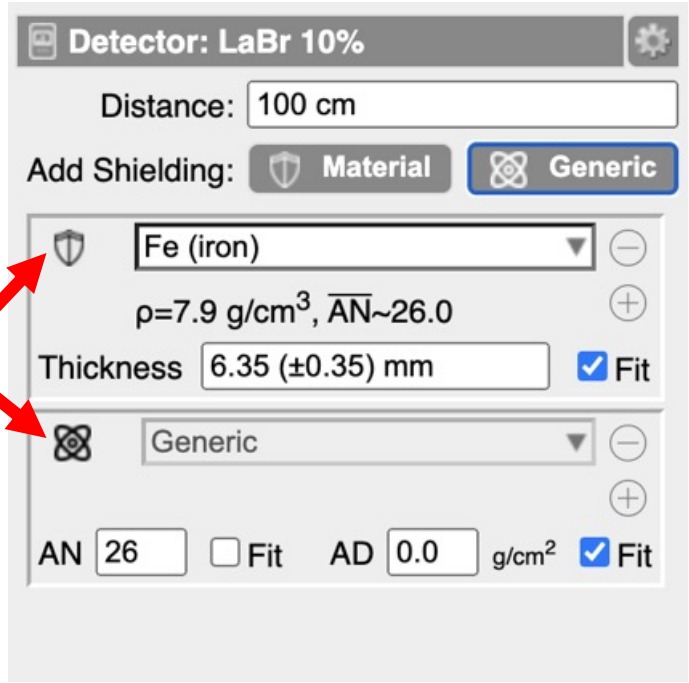


Any nuclides associated with the peaks you have selected, will appear here

- You can manually edit an activity, and choose not to fit it, if you happen to know it, but not the shielding
- Age of nuclides is also editable, or fittable for applicable nuclides

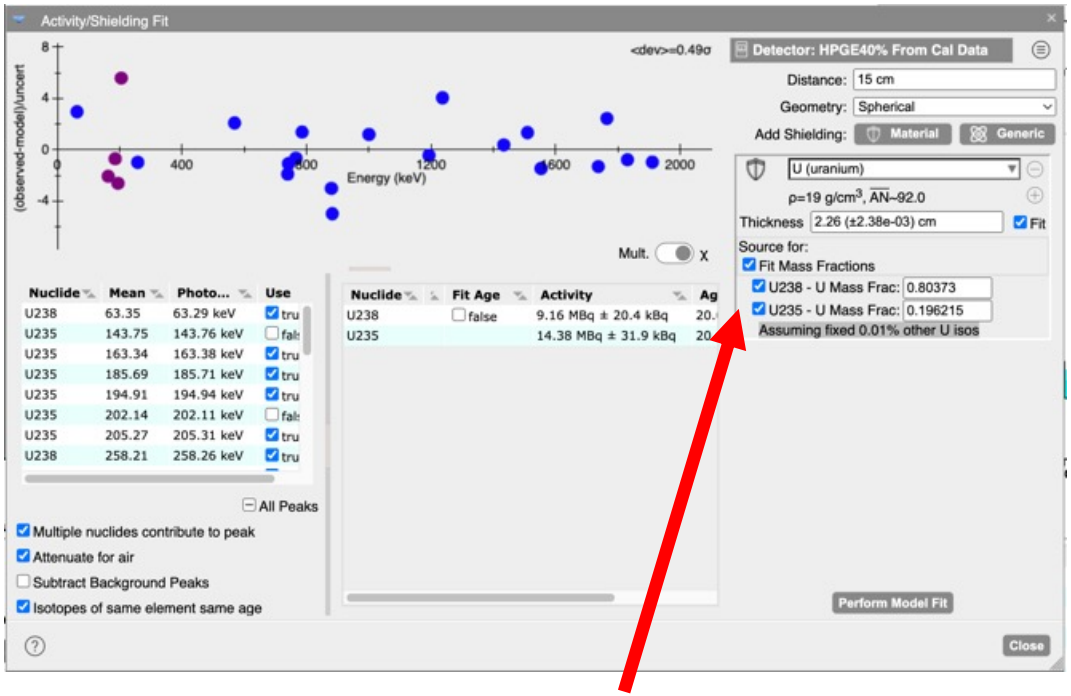
Activity/Shielding Fit Tool (shielding)

Clicking on these icons will toggle between shielding types



- The shielding can be either a specific type of material from InterSpecs database, or it can be a generic material where you specify the atomic number (AN) and areal density (AD), or you can enter a chemical formula and density.
  - You can choose to fit for, or fix, thickness, AN, and AD
- You can have multiple shielding's, but of course this can get degenerate to fit for multiple of them, especially if they have similar effective atomic numbers

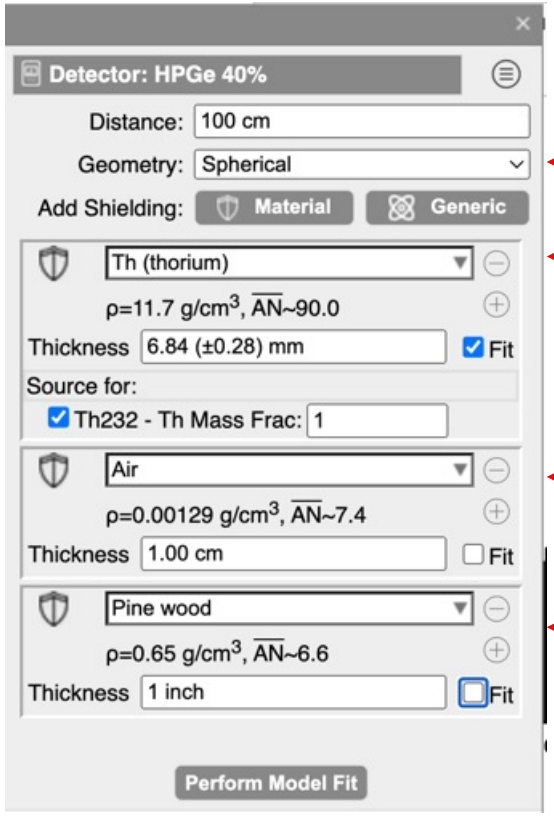
Activity/Shielding Fit Tool (shielding cont.)



If your shielding contains the same element as one or more of the nuclides you are fitting for, you will be given the option to have the shielding become the source term

- In this case self-attenuation is taken into account; especially useful in high-Z materials (W, Th, U, Pu, etc)
  - InterSpec uses an adaptive quadrature based ray-tracing algorithm to account for self-attenuation and geometric effects
- If there are multiple nuclides composing the shielding you can fit for the isotopics as well

Activity/Shielding Fit Tool (shielding cont.)



Inner shell

Outer shell

Spherical geometry

6.84 mm solid sphere of Thorium metal

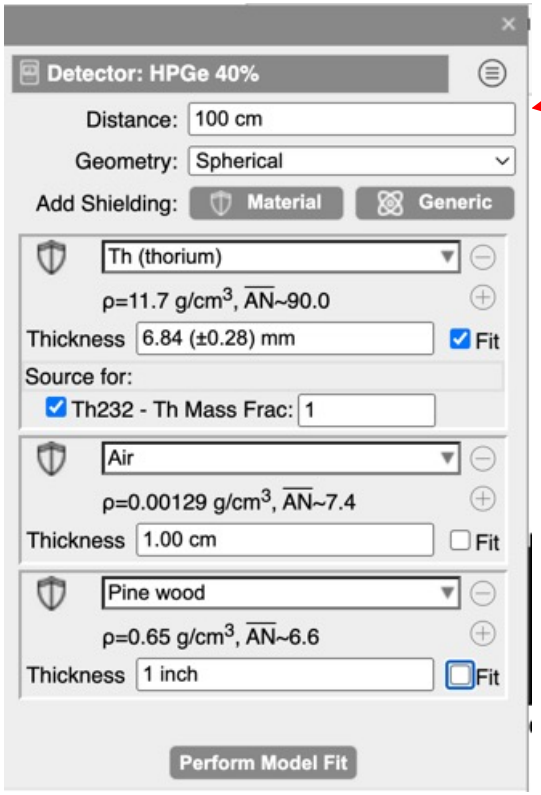
A 1 cm gap outside the Thorium

A 1 inch shell of wood

InterSpec uses a spherical geometry when self-attenuating sources are used

Nuclides that aren't part of shielding's are point-sources at the center of all shieldings

Activity/Shielding Fit Tool (distance)

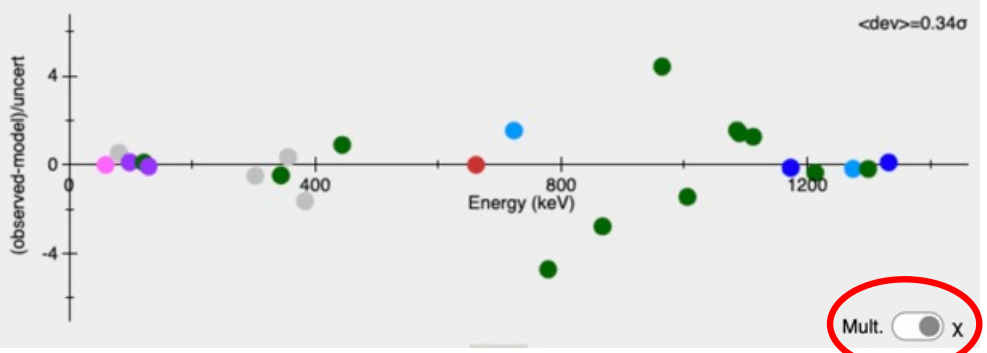


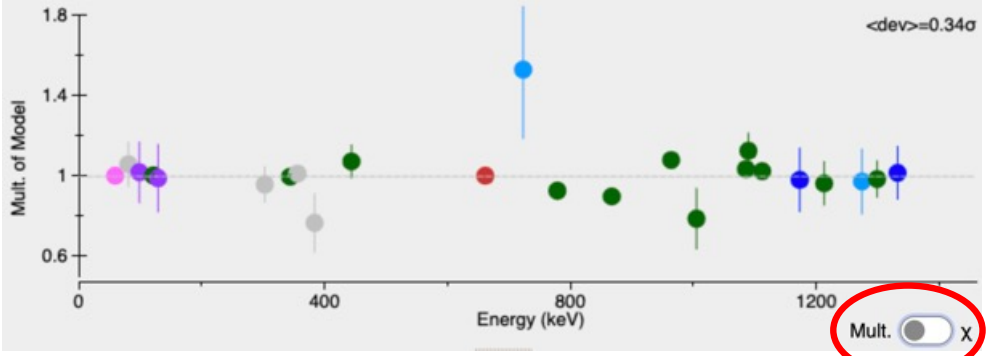
The distance is from the detector face, to the center of shielding

Distance, like times, can be entered in fairly flexible formats; the following are all valid distances:

"1.2cm", "1ft", "1 ft 13 in", "1' 13"", "3 m", "3 meters", "3.6E-2 m", etc

Activity/Shielding Fit Tool - graphic



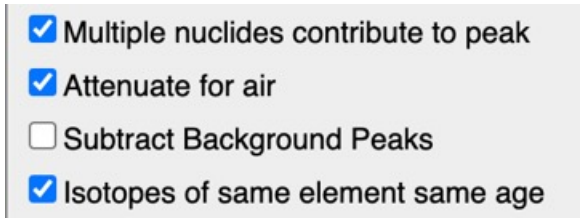


The graphic in this tool is to help provide you an idea of how well the data lines up to the model

- Left: chart shows you how many statistical deviations each peak is away from the model
- Right: chart shows you the multiple of how far away from the model each peak-area is. The error bars are 1-sigma statistical uncertainties.
  - E.x., if the dot corresponding to a peak is at 2.0, that indicates that peak would give double the activity that is currently showing

Generally, if after doing a "Perform Model Fit," a peak is greater than maybe 5-or-so-sigma away from the nominal value, you should consider removing that peak from the fit, or checking that its associated with the correct gamma line, or that there isn't an interfering nuclide that you aren't currently fitting for

Activity/Shielding Fit Tool (options)



- **Multiple nuclides contribute to peak**: if two or more nuclides being fit for contribute to a peak, allow all of them to contribute to calculating the expected peak area, not just the nuclide assigned to the peak
- **Attenuate for air**: Adds attenuation from the air; between the detector and the outside of the shielding
- **Subtract Background Peaks**: useful if background peaks contribute to your isotope of interest. To enable this option you must have a background spectrum loaded, and you must have the background peaks fit in it
  - To fit the peaks in a background spectrum, first load it as a foreground spectrum, fit the peaks, then load your foreground of interest file, and from the "File Manager" tab select the first file as background
  - Background peaks do not need nuclides associated with them; matching of which peaks to subtract from which is based on energy
- **Isotopes of same element same age**: If you are fitting for the age of a material, like Th, U, Pu, etc, and you want to constrain all isotopes for an element to be the same age, select this option

Activity/Shielding Fit Tool (more...)

Clicking on the gear icon brings up a menu that lets you:

- See a log of calculations, which has a whole bunch of details about what exactly went into the calculations
- You can save, export, import, or load a previous model. Useful if your model is complex.
  - If you export the foreground to a N42-2012 file, or store it in InterSpecs internal database, your model will be saved along with the foreground

Activity/Shielding Fit Tool (general notes)

This tool requires use of *your* critical thinking and spectroscopy knowledge – you can do things that don't make sense

- E.x., if you try to fit for atomic number of shielding using two close-together peaks, or two high-energy peaks, you will get a nonsense answer (but you should also get a large error as well). Or if you fit for the age of a nuclide that has already reached equilibrium, you might get a really large age (but also hopefully large uncertainty)
- InterSpec doesn't currently do a great job of detecting and notifying you of degeneracies being fit for
  - Large uncertainties are a "smell" of these

You can only fit for as many quantities as you have peaks for

If you are fitting for the effective atomic number of your shielding, having one or more peaks below 300 keV is usually necessary.

Always ask yourself if the results make sense.

Uncertainties given are only statistical. Uncertainties about your DRF, peak-skew, distance, material conmposition, or other factors may dwarf the statistical uncertainties

Lets fit activity of the Trinitite Sample

Some additional information you need:

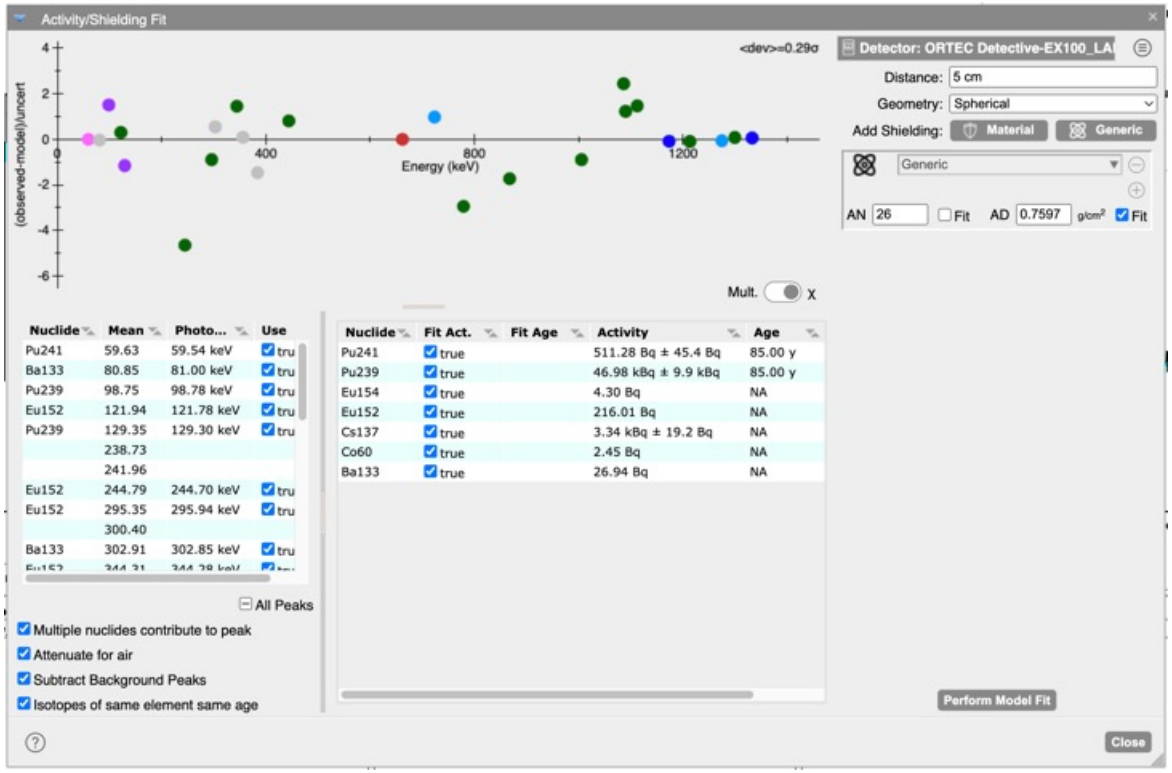
Lets take 15 minutes to fit activities, and/or as a break.

If you didn't previously ID as many nuclides as you would like, you can start from my fit peaks using the file "Trinitite_Sample_B_peaks_fit.n42" file available from the "Tutorials" section of https://sandialabs.github.io/InterSpec/

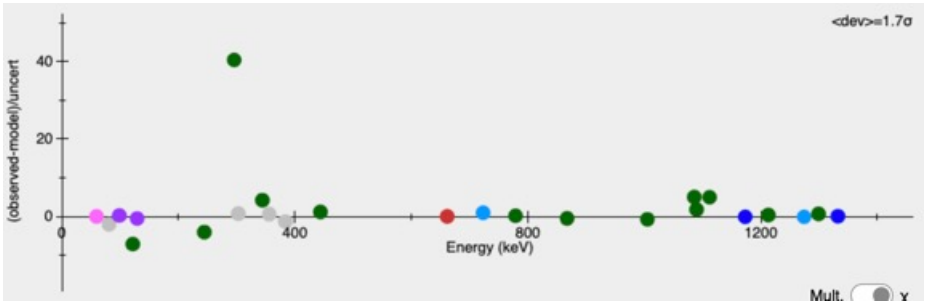
Additional information that may be useful:

- The trinity detonation happened 07/16/1945
- The date of the measurement can be found in the "File Parameters" tool
- The detector used is an EX-100 – if you have InteSpec v1.0.9 or less, there is a "common_drfs.tsv" file on the Tutorial page that has the DRF. InterSpec v1.0.10_rc3 and above will automatically load the DRF
- You can assume a (roughly estimated) distance of 5 cm from the sample –the distance isn't known well

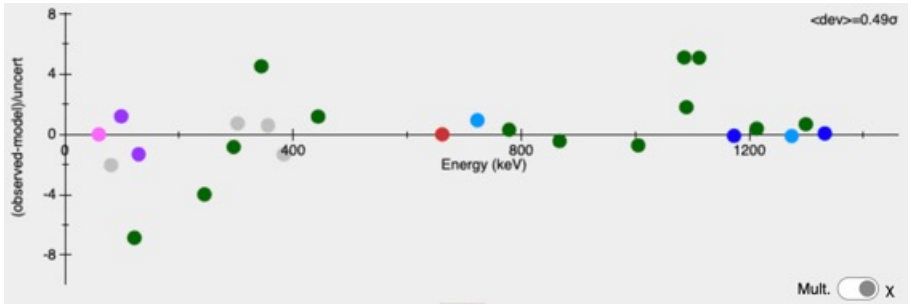
Trinity Sample Activities



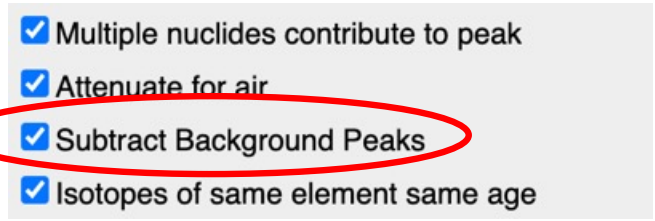
Trinity Sample Activities (cont):



No background-peak subtraction



With background peak subtraction



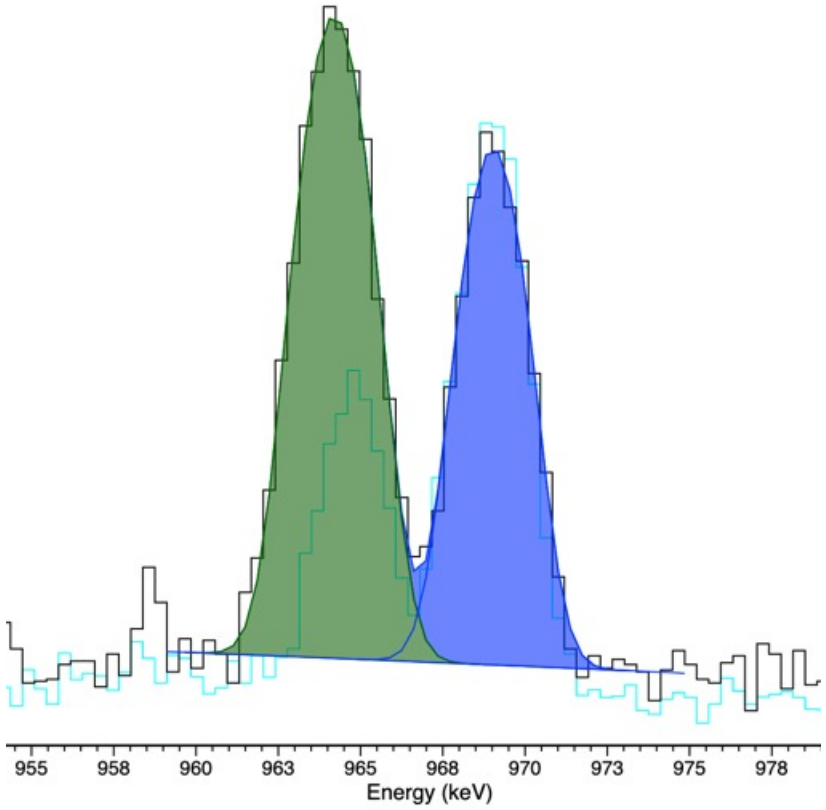
A few of the Eu152 peaks overlap with NORM background peaks, so we need to account for this.

- I loaded the background spectrum as a foreground, used the automated peak-search function, and then quickly cleaned up a few peak fits – did not assign nuclides to background peaks

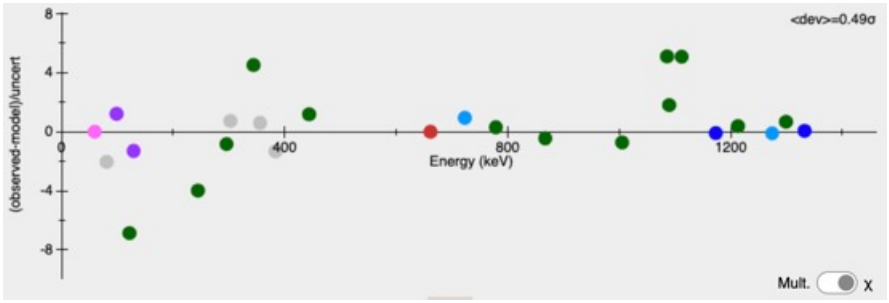
Trinity Sample Activities (cont):

Some peaks of interest have background peaks that either partially overlap, or totally overlap. Shown here:

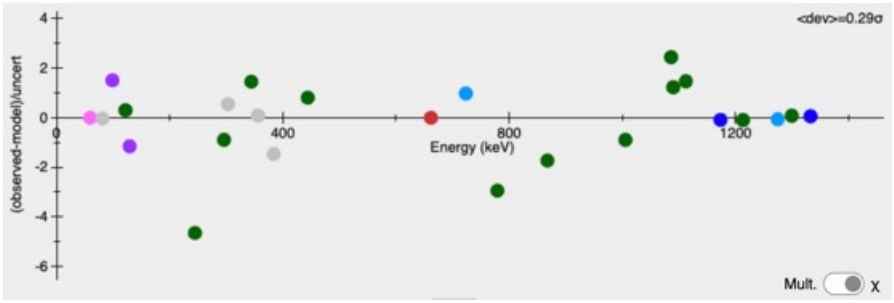
- The 969 keV background peak had to be fit so the 964.1 keV Eu-152 peak would be fit well.
- There is a background peak at 964.8 keV (from Th232) that totally overlaps with the Eu-152 peak – this needed to be fit in the background spectrum in order to account for it in fitting activity



Trinity Sample Activities (cont):



No Shielding

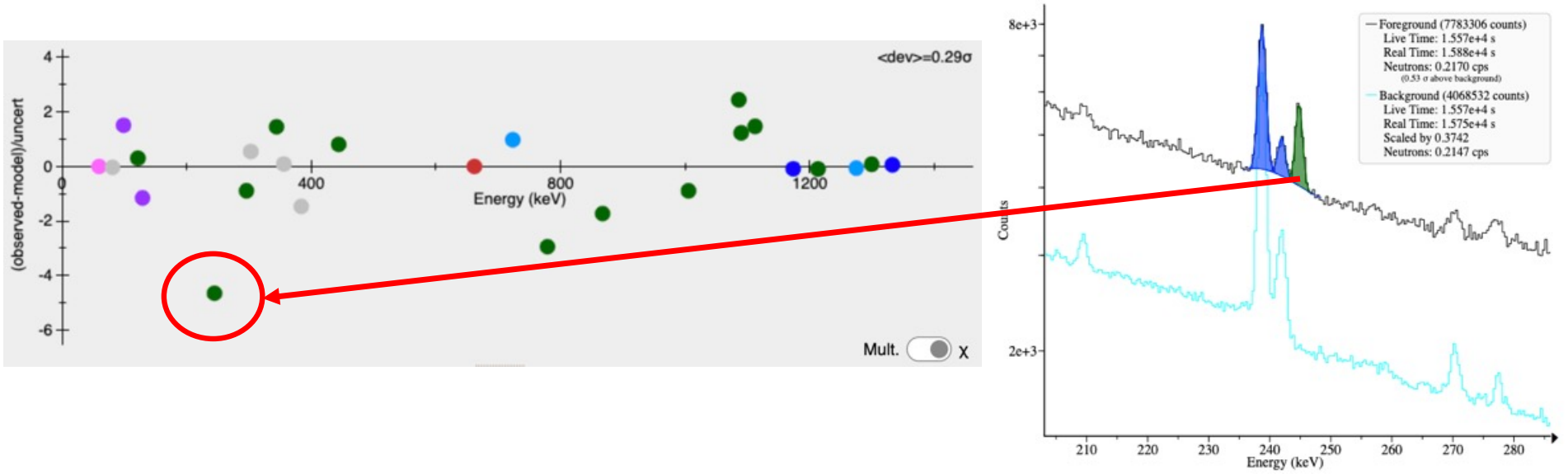


A little bit of shielding fit for

Adding a shielding, and allowing its thickness to be fit for helped improve the fit.

- This is mostly to account for the self-attenuation of the sample itself
- The *type* (i.e., the effective atomic number) of shielding doesn't matter much, we don't have the statistics to differentiate much
- If we take the shielding to be iron, it fits for about 1 mm – so not much

Trinity Sample Activities (cont):



The Eu-152 peak at 244.7 keV appears to be a bit of an outlier

- It has ~5 sigma fewer counts than the other Eu-152 peaks would predict
  - (The 5 sigma is statistical only, and doesn't account for systematic errors that like the quality of the peak fit might contribute to)
- If you wanted, you could remove the peak from the activity fit, or you could go back to the spectrum and see if maybe a different continuum model would work better
- I choose to leave it in – 5 sigma is about my personal comfort level to leave peaks in

Trinity Sample Activities (cont):

Nuclide	Fit Act.	Fit Age	Activity	Age
Pu241	true		1.35 kBq ± 119.6 Bq	65.00 y
Pu239	true		46.99 kBq ± 9.9 kBq	65.00 y
Eu154	true		4.30 Bq	NA
Eu152	true		216.01 Bq	NA
Cs137	true		3.34 kBq ± 19.2 Bq	NA
Co60	true		2.45 Bq	NA
Ba133	true		26.94 Bq	NA

Nuclide	Fit Act.	Fit Age	Activity	Age
Pu241	true		17.36 kBq ± 2.6 kBq	20.00 y
Pu239	true		47.00 kBq ± 9.9 kBq	20.00 y
Eu154	true		4.30 Bq	NA
Eu152	true		215.97 Bq	NA
Cs137	true		3.34 kBq ± 31.9 Bq	NA
Co60	true		2.45 Bq	NA
Ba133	true		26.94 Bq	NA

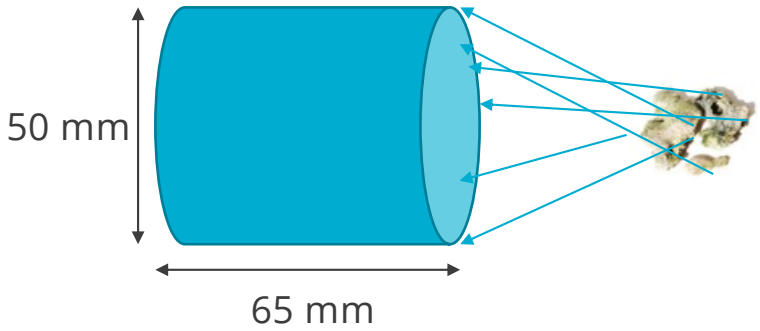
Age matters for the Pu-241 activity

- We actually see the 59 keV peak from Am-241. If we had assigned the 59 keV peaks as Am-241, then the age wouldn't matter
- For most of the isotopes in this spectrum, the relative intensities of the peaks don't really change over time.
- For Pu-239 and Pu-241, we don't have peaks from multiple progeny isotopes, so the option to fit the ages is not given to us

Trinity Sample Activities (cont):

The distance was 5 cm - this is closer than the DRF approximation is valid for

Detective-EX100 detection element is 65 mm x 50 mm



InterSpec models the detector as a flat-disk.

I.e., the gamma-rays coming in from the source are all parallel.

I.e., distance between the source and the detector is much larger than the size of the source or detector

This approximation starts becoming valid when distance between source and detector is much larger than the detectors diameter, or source size

Also, the DRF we have is probably not from the same detector used, so this could be up to maybe 20% difference

Trinity Sample Activities (cont):

Nuclide	Fit Act.	Activity	Age	Mass
Pu241	true	1.35 kBq ± 119.5 Bq	65.00 y	351.059 pg
Pu239	true	47.08 kBq ± 9.9 kBq	65.00 y	20.512 ug
Eu154	true	4.30 Bq	NA	0.430 pg
Eu152	true	216.05 Bq	NA	33.591 pg
Cs137	true	3.34 kBq ± 19.2 Bq	NA	1.041 ng
Co60	true	2.45 Bq	NA	0.058 pg
Ba133	true	26.97 Bq	NA	2.848 pg

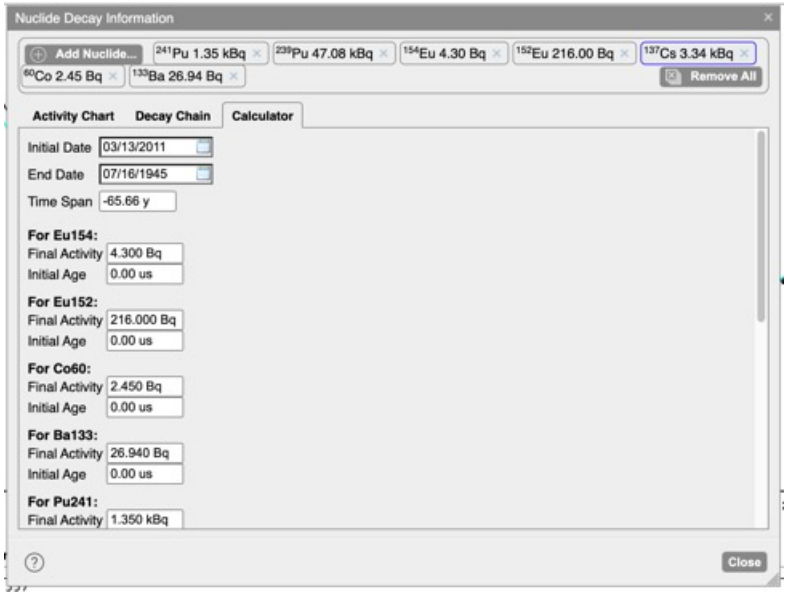
Radio-nuclide	Trinitite Green B (This Work)
^{60}Co	65.7 ± 15.1
^{133}Ba	11.3 ± 0.6
^{137}Cs	81.1 ± 3.1
^{152}Eu	35.7 ± 1.4
^{154}Eu	8.2 ± 1.7
^{155}Eu	–
^{237}Np	–
^{239}Pu	317 ± 144
^{241}Am[b]	2.5 ± 0.2
^{241}Pu[b]	82.9 ± 6.6

https://arxiv.org/abs/2103.06240

However, Mercer, *et al* list the activities in Bq/gram, at date of detonation

To compare we need to back-decay these activities to 1945

Trinity Sample Activities (cont):



Before 65.66 y:

Nuclide	Activity	Mass
Pu241	32.62 kBq	8.50 ng
Pu239	47.17 kBq	20.55 ug
Eu154	854.05 Bq	85.48 pg
Eu152	6.23 kBq	968.75 pg
Cs137	15.16 kBq	4.72 ng
Ba133	2.05 kBq	216.12 pg
Co60	13.77 kBq	328.84 pg

The “Nuclide Decay Info” tool can help us.

On the “Calculator” tab, if the “End Date” is before the “Initial Date”, then things will be back-calculated

- This is only true for InterSpec ≥v1.0.10_rc3 – before that you’ll have to have to have the “End Date” after “Initial Date” and manually do the extra multiplication

I used the “Math/Command Terminal” to divide original activities by 126.6 grams

Trinity Sample Activities (cont):

Nuclide	InterSpec	Mercer, et al
Co60	109.6	65.7 ± 15.1
Ba133	16.32	11.3 ± 0.6
Cs137	120.7	81.1 ± 3.1
Eu152	49.6	35.7 ± 1.4
Eu154	6.8	8.2 ± 1.7
Pu239	375	317 ± 144
Am241	7.36	2.5 ± 0.2
Pu241	259	82.9 ± 6.6

Activity in Bq/gram of ”Sample B”, decay corrected to date of detonation
(except Am-241, its activity is at date of measurement)

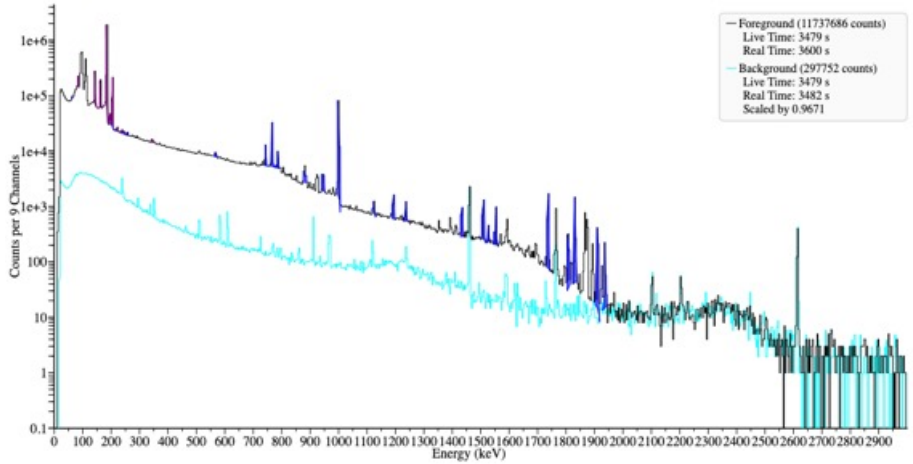
For most of the nuclides, we are ~50% high, except Pu241/Am241, we’re off by a factor of 3

- If we drop the shielding from the fit (ex., ~1 mm Fe), then Pu241/Am241 activity drops by a factor of ~2.5, bringing us inline with other estimates

The distance and/or DRF is likely a little off – but overall not to bad

Enrichment Calculations

Enrichment Calculations



As mentioned earlier, if your shielding contains the same element as one of your source nuclides, an options will appear to make it a self-attenuating source

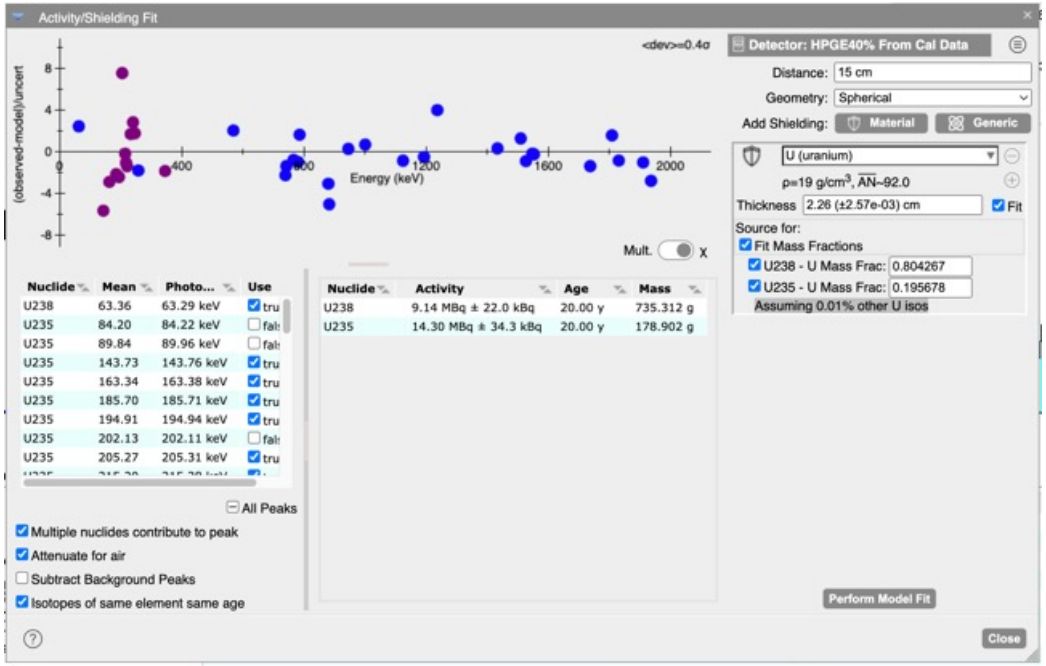
- This uses a ray-trace algorithm to integrate over the source volume, and correct for self attenuation

Please load “uranium_40%_HPGe_15cm_peaks_fit.n42”; it contains the DRF, peaks have been fit for, with nuclides assigned, and is ready for you to fit the activity/mass to.

- Use a distance of 15 cm
- Assume a solid sphere
- No need for shielding outside the Uranium

Enrichment Calculations

1. After loading the spectrum, to to the “Activity/Shielding Fit” tool
2. Enter distance, and add a Uranium shielding
3. Select peaks you want to use
   - Some of the U235/U238 peaks have x-ray interferences, you probably don’t want to use these
4. A “Source for” box should appear in the shielding, and you can select to use the shielding for U235 and U238; you can then choose to “Fit Mass Fractions”

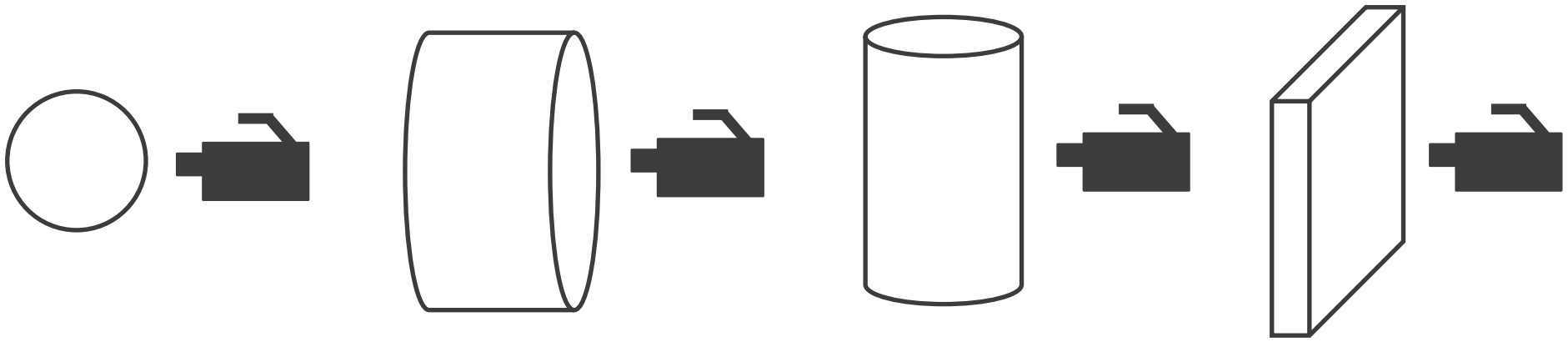


Real answer: 1 kg, 20% enriched sphere
Fit answer: 915 g, 19.6% enriched

Contamination Calculations

InterSpec for soil and other contamination analysis

InterSpec supports determining contamination
via adding trace sources to a shielding



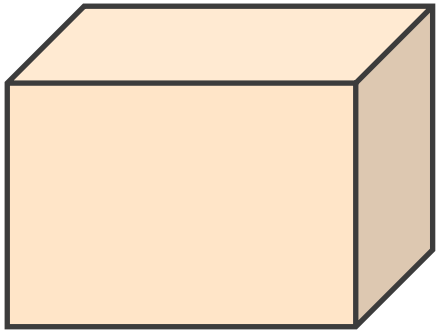
Spherical | End-on Cylinder | Side-on Cylinder | Rectangular

Homogenous and exponentially distributed trace sources

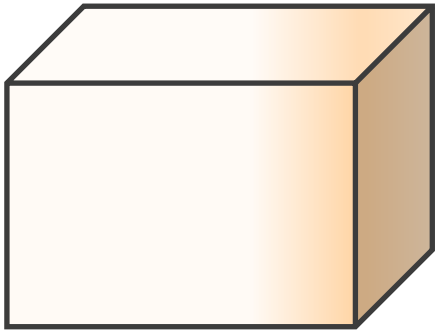
Trace sources can either be

a) uniform: determined as activity per cm^3, total activity, or activity per gram
b) Exponentially distributed sources, starting from surface facing the detector

Trace sources are volumetric source-terms in the shielding's – they do not affect the attenuation of the shielding



Uniform trace source distribution



Exponential

$$f(z) = \frac{S_0}{L} e^{-z/L}$$

$S_0 = total\ activity\ (\frac{Bq}{m^2})$

$L = relaxation\ length\ (cm)$

63% of activity is within one relaxation length of the surface

Basic idea for analyzing soil measurements in InterSpec

In the “Activity/Shielding Fit” tool, use a shielding composed of soil that is effectively “infinitely large” with one or more trace sources

- The dimension along detector axis should be many attenuation lengths of highest energy peak used for analysis

  For 2614 keV, 2 meters in soil would attenuate 99.999% of gammas

- The radial (cylindrical) or width/height (rectangular) dimensions should be large enough to cover the detector’s field of view

  For detector 1-meter from ground, needed radius ranges from 15 m (homogeneous), to 210 m (pure surface)

- Increasing dimensions beyond the effectively infinitely large dimensions wont change answers

  i.e., for soil contamination, using cylinder with height 2 m, and radius 225 m is a good default to use

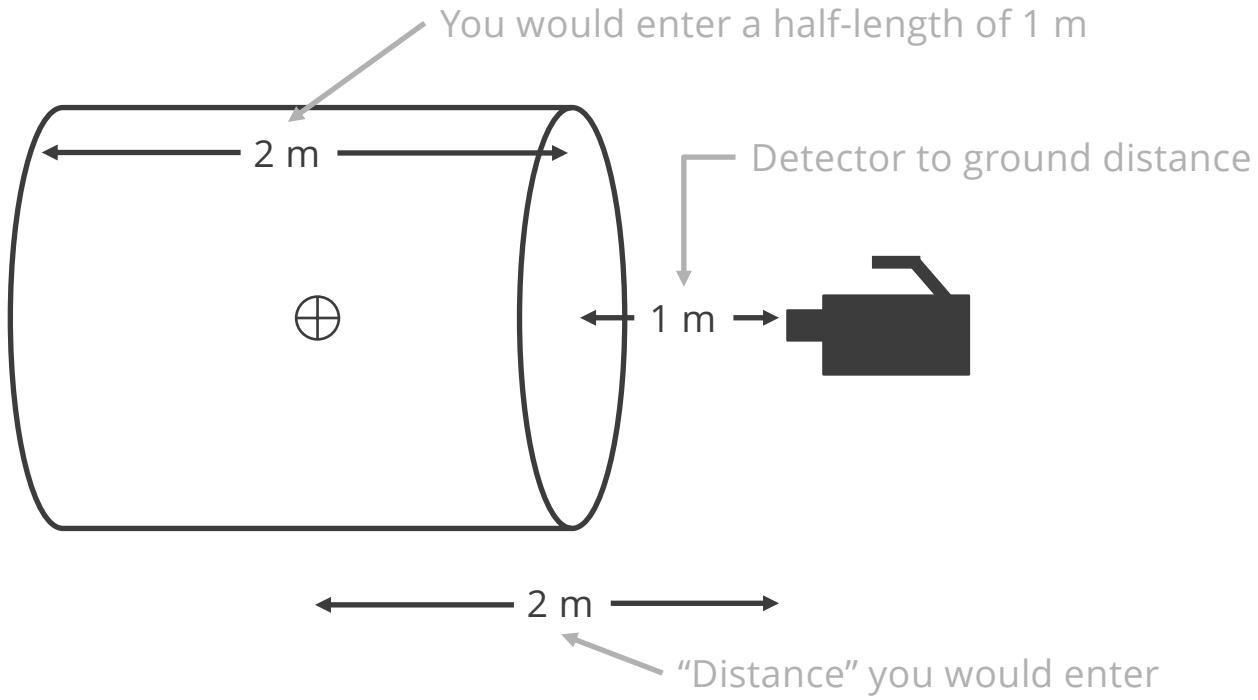
  Also, when an exponential distribution is selected, dimensions to use will be suggested

You will then fit for trace-source activitie(s)

Shielding geometries and distances in InterSpec

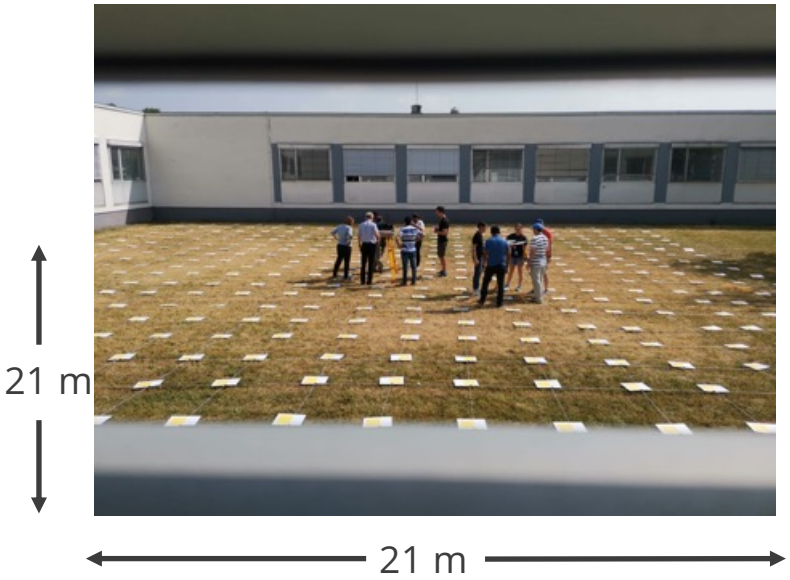
The “Distance” entered in the “Activity/Shielding Fit” tool is from the center of the shielding to the detector

Example: if you want to represent soil as 2 meter thick, end-on cylinder, with detector 1 meter from the ground:



Case-study: Eu152 surface contamination (cont)

Paper coated with Eu152 were distributed over a 21m x 21m area to simulate fresh fallout. A Micro-Detective was used to measure contamination 1m above the ground, pointing down.

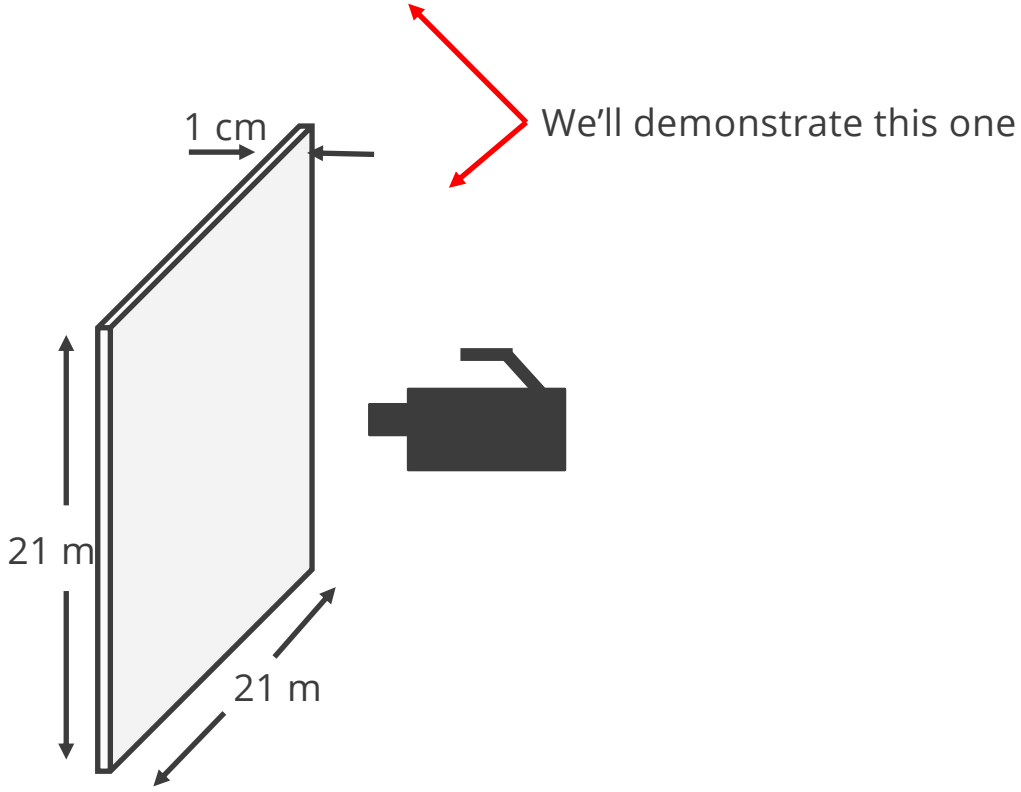


This measurement was performed by P. SLADEK and group of Nuclear Science and Instrumentation Laboratory (NSIL), Physics Section Division Physical & Chemical Sciences, IAEA.
This and similar measurements were discussed on an IAEA webinar presented 20211117, and is available at https://elearning.iaea.org/m2/course/view.php?id=1224

Case-study: Eu152 surface contamination (cont)

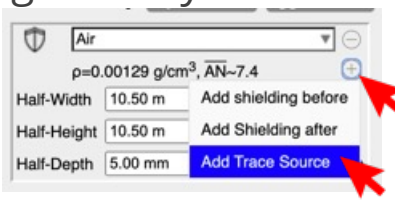
There are a couple ways you could represent this scenario

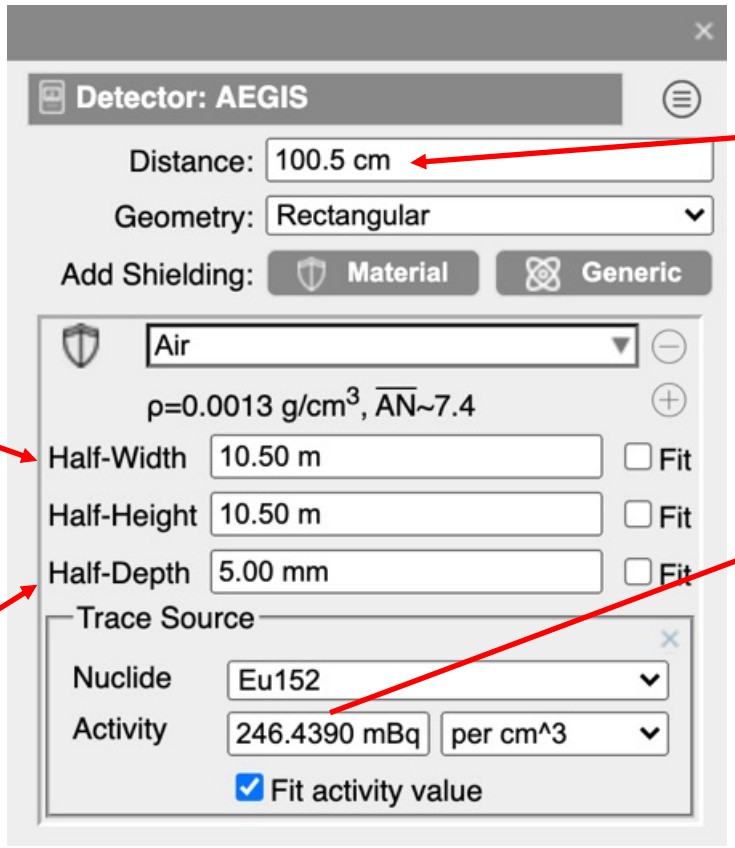
1. As an exponential surface contamination, with very short relaxation length
2. As a thin “air” volume, with uniform trace-source distribution



Case-study: Eu152 surface contamination (cont)

The steps for analysis is similar to before, but this time choose a rectangular geometry of air, set the dimensions, and click on the "+" button to add a trace-source





Add 0.5 cm to distance to make up for 1 cm thickness

"Width" and "Height" are entered as half-values – this makes things easier when there are multiple layers

Choose a total thickness of 1 cm, for convenience

Multiplying by 1 cm, gives surface contamination of 246 mBq/cm^2
(known value: 252 mBq/cm^2)

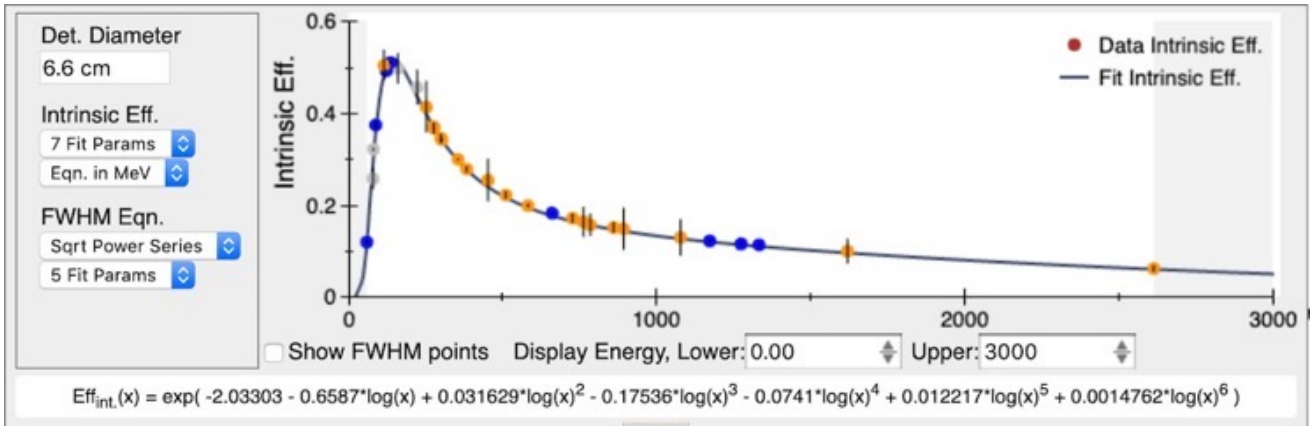
Warnings about volumetric-source calculations in InterSpec

- The angular response of the detectors is not taken into account.
  - Not typically a large effect (think 10%), but has not been rigorously evaluated
  - This is expected to be added in the future
- There are likely to be larger systematic uncertainties to consider
- There are a lot of things to consider about the sampling that aren't covered here

Detector Response Functions

Detector Response Functions

To determine an unknown source's activity, or unknown shielding, or nuclide age you usually need to know the photo-peak detection efficiency of the detector.



You either need to determine your own detector response function (DRF) using known check-sources, and the "Make Detector Response" tool

- See tutorial dated 20190619 on the InterSpec tutorial site for how to do this

Or you can use a DRF supplied with InterSpec, or by some-one else

- Usually this is for a detector of the same model – and is close enough

Detector Response Functions – supplied by others

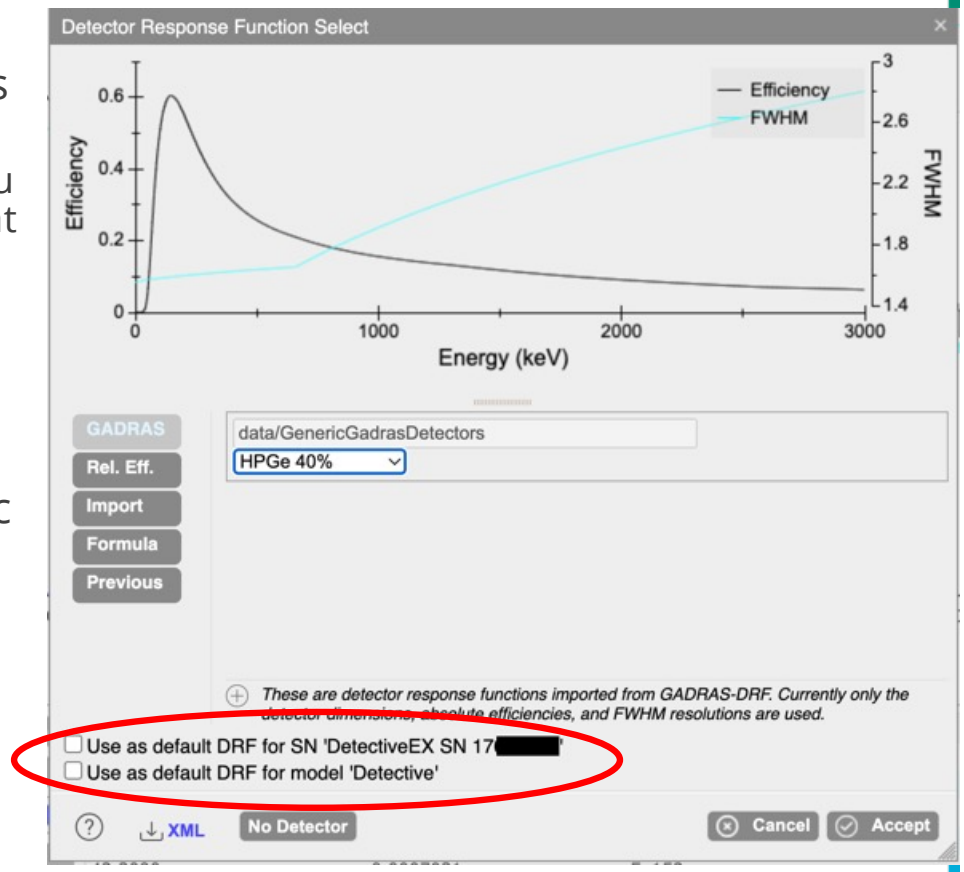
As of version 1.0.10_rc3, InterSpec includes a number of common detector response functions

- If InterSpec detects a file loaded from a detector it has the DRF from, it will prompt you if you would like to use the default DRF for that model always

Or you can import DRFs in various CSV formats, as a mathematical formula, from GADRAS Detector.dat and Efficicency.csv files

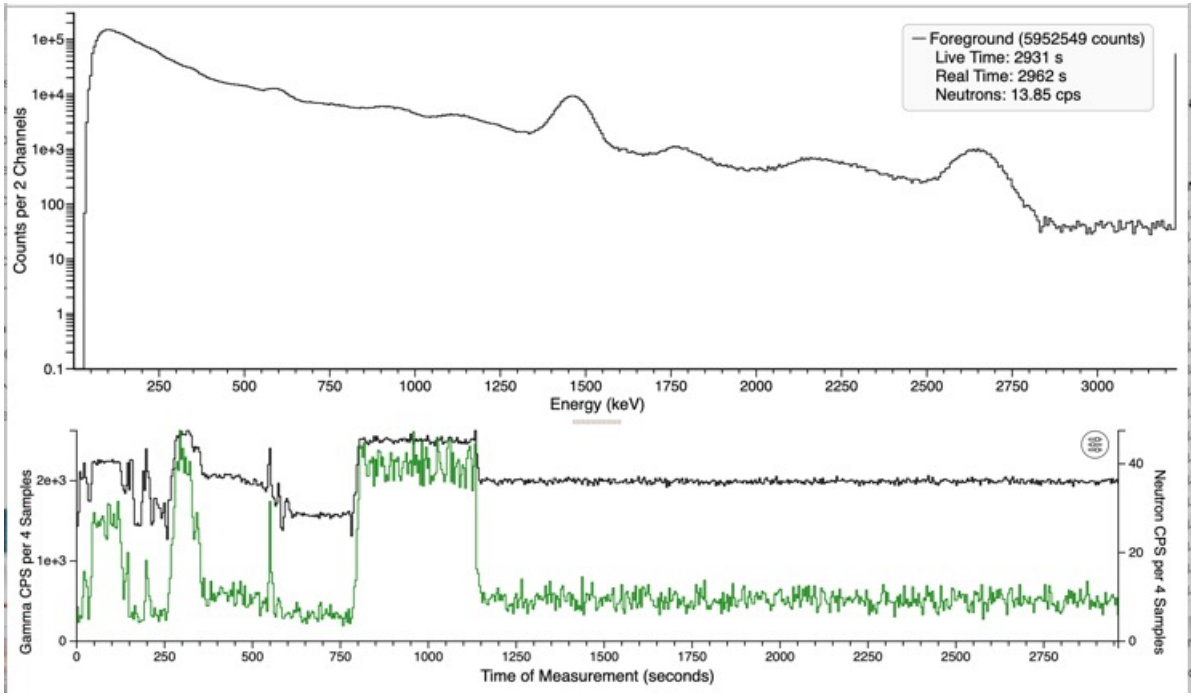
You can also have InterSpec always use a specific DRF for either a specific serial-numbered detector, or for a given model

- I use the defaults on a per-model basis, so rarely have to manually load DRFs



Viewing Portal/Search-mode data

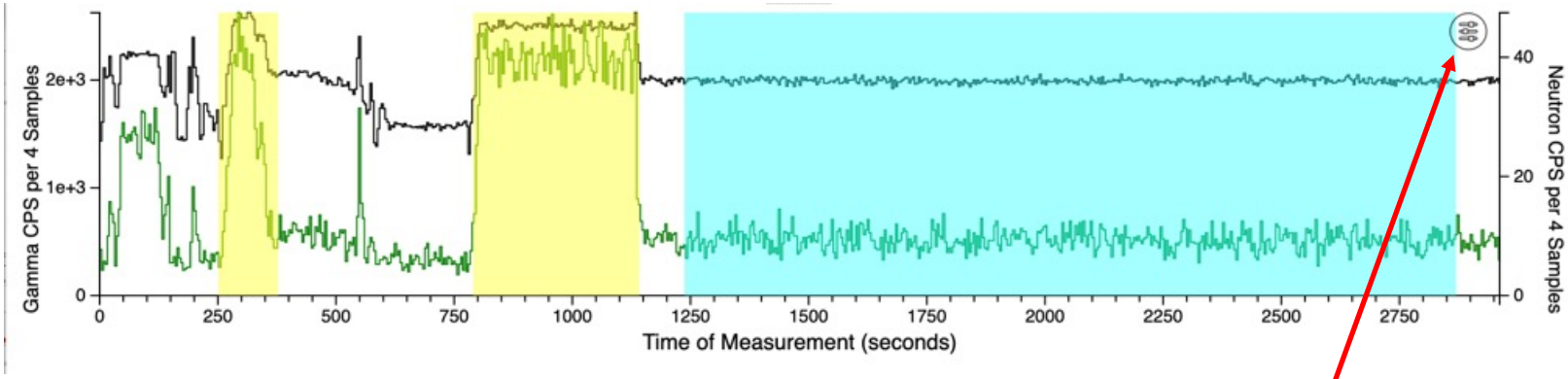
Portal/Search-mode data



RPM Portal and search-mode systems often record data at regular short-intervals (e.g., one spectrum every 0.1 seconds)

When you load one of these files in InterSpec, a time-history chart will appear

Portal/Search-mode data (cont)



You can click-and-drag on the time chart to select which samples to sum to make the foreground

Holding shift and dragging will add additional samples

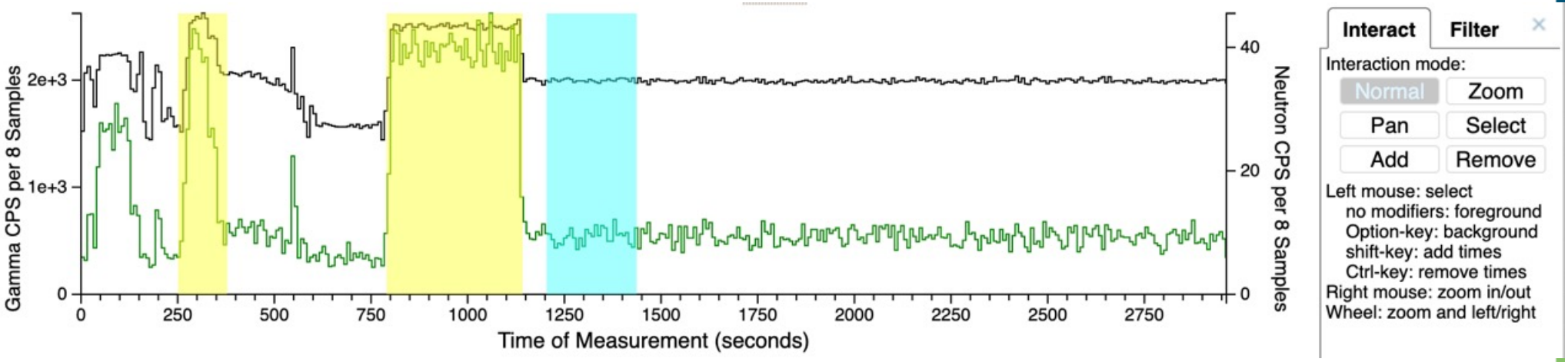
Holding “option” key and dragging will select background samples; option-shift will add background samples

Hitting escape while dragging will cancel current operation

Right mouse-button, or mouse-wheel will zoom-in-out

+ more action… but I don’t even remember all these – so click on

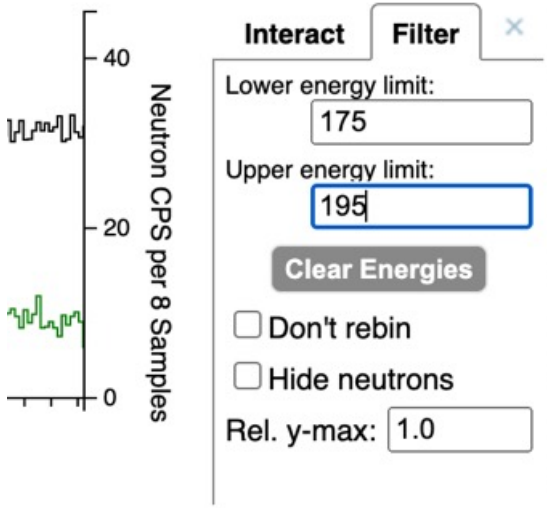
Portal/Search-mode data (cont)



In this “settings” panel, you can just select the operation you want to do.

It also reminds you of the short-cuts if you are a power-user

Portal/Search-mode data (cont)



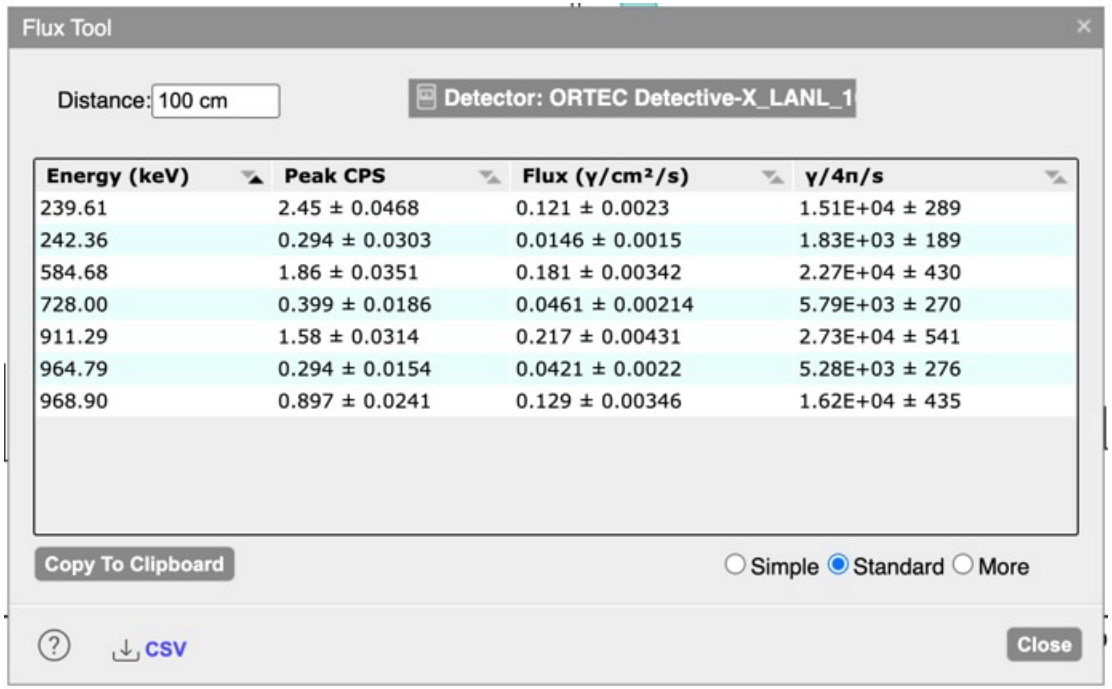
You can also choose to filter the time chart to just be the sum of counts in a given energy range

And there are some display options

- "Don't rebin": this is when there are more tiem-samples than pixels on your screen – instead of summing time-samples for a pixel, it will plot the max counts during the time intervals of that pixel – useful for long measurements with only short blips of signal
- "Hide neutrons": sometimes the neutrons are just noise for your problem; you can hide them
- "Rel. y-max": poorly named, but a value <1 emphasizes neutrons on the chart, while values >1 emphasize gammas. Keeps neutrons or gammas on the chart, but will lower the line you are not as interested in so the measurement type you do want, pops out a bit more

Other calculations

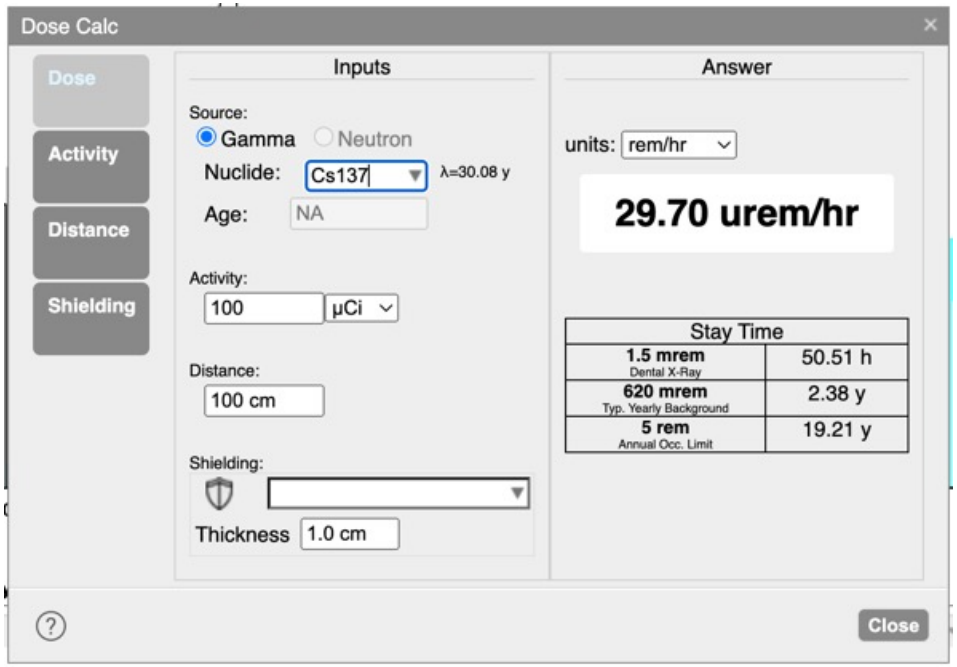
Flux Tool



Converts your peaks count rate into gammas into 4 pi steradians

- Has a few different format tables to accommodate different use cases
- You can copy results to the clipboard, or download as a CSV file

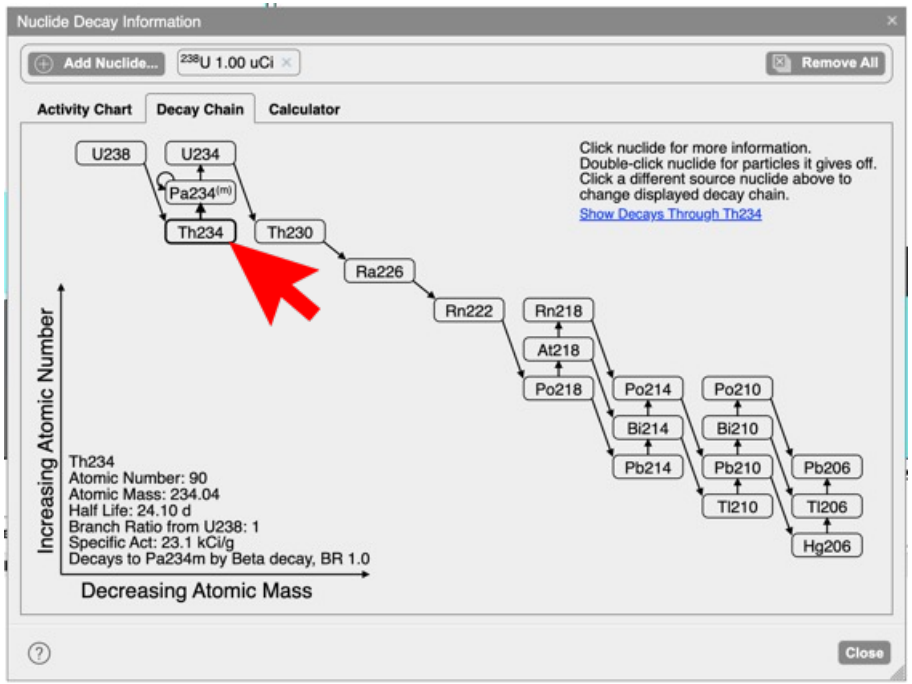
Dose Calc

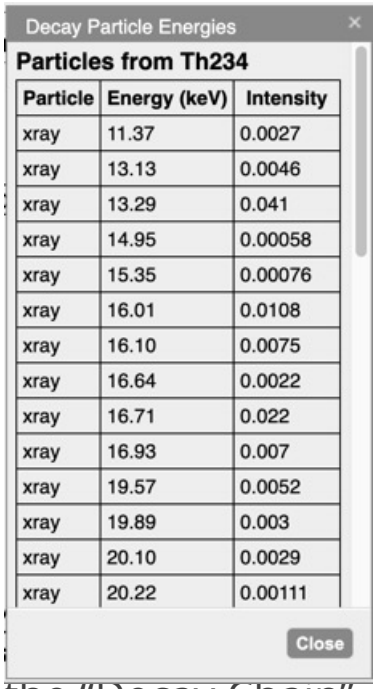


Calculates the dose from **gamma** sources

- Accounts for scattering of gammas in shielding and air (i.e., full spectrum)
- Always adds in shielding due to air
- Provides a quick/handy reference table to put the dose rates in context
- Or if you measured a dose, lets you easily go from that to source strength/shielding/distance

Nuclide Decay



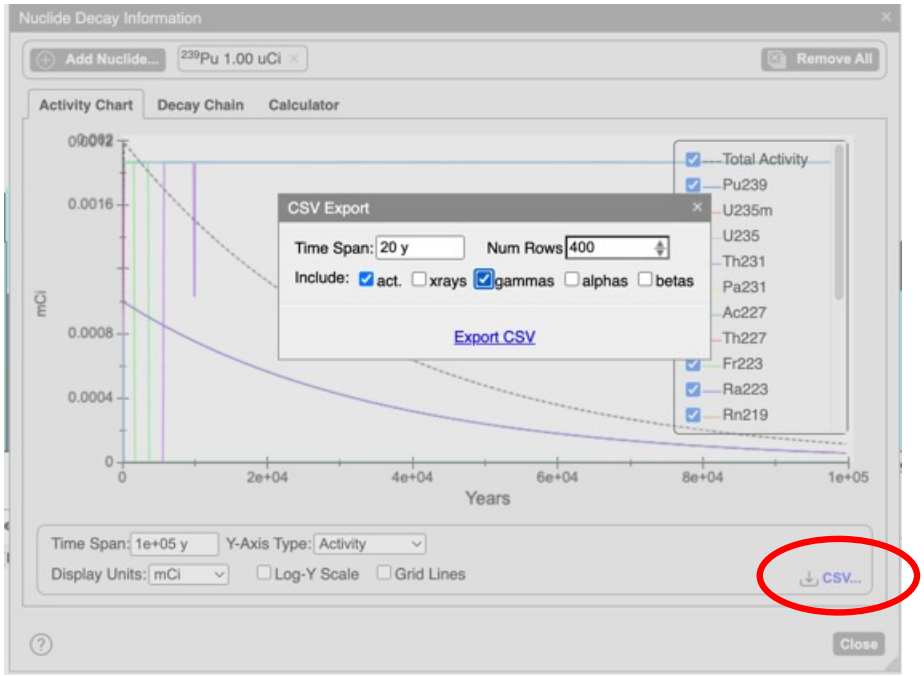


Particle	Energy (keV)	Intensity
xray	11.37	0.0027
xray	13.13	0.0046
xray	13.29	0.041
xray	14.95	0.00058
xray	15.35	0.00076
xray	16.01	0.0108
xray	16.10	0.0075
xray	16.64	0.0022
xray	16.71	0.022
xray	16.93	0.007
xray	19.57	0.0052
xray	19.89	0.003
xray	20.10	0.0029
xray	20.22	0.00111

We already used this tool a bit, but a few things to mention about the "Decay Chain"

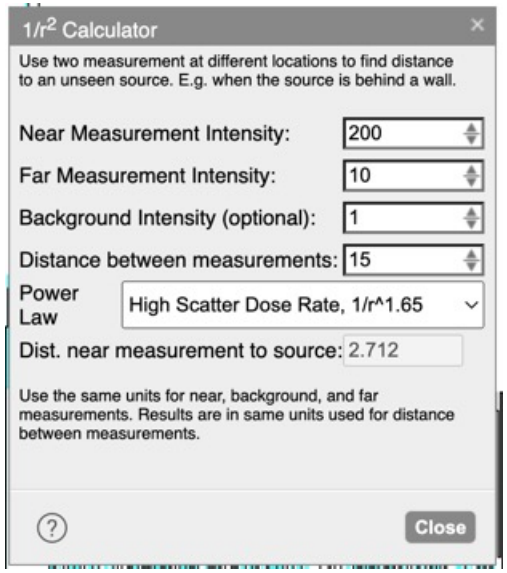
- You can click on an nuclide to get further information about the nuclide
- You can double-click on a nuclide to get a list of decay products when it decays (only includes products from that parent nuclide, not further prodigeny)
- The "Show Decays Through…" feature is also useful to find other potential parent nuclides
  - E.x. If you are seeing gammas from Tl-208, you might want to check where the Tl-208 is coming from

Nuclide Decay – CSV export



If you want to plot a gamma intensity, progeny activity, ratio of activities, or other quantities over time, there is a CSV download option on the “Activity Chart” tab

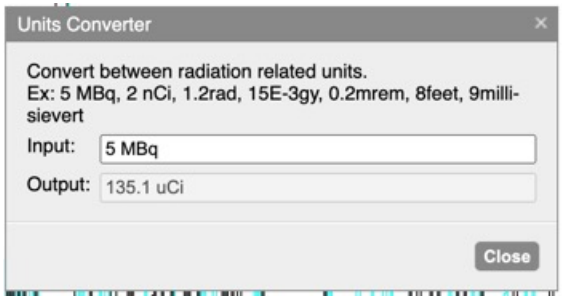
1/r2 Calculator

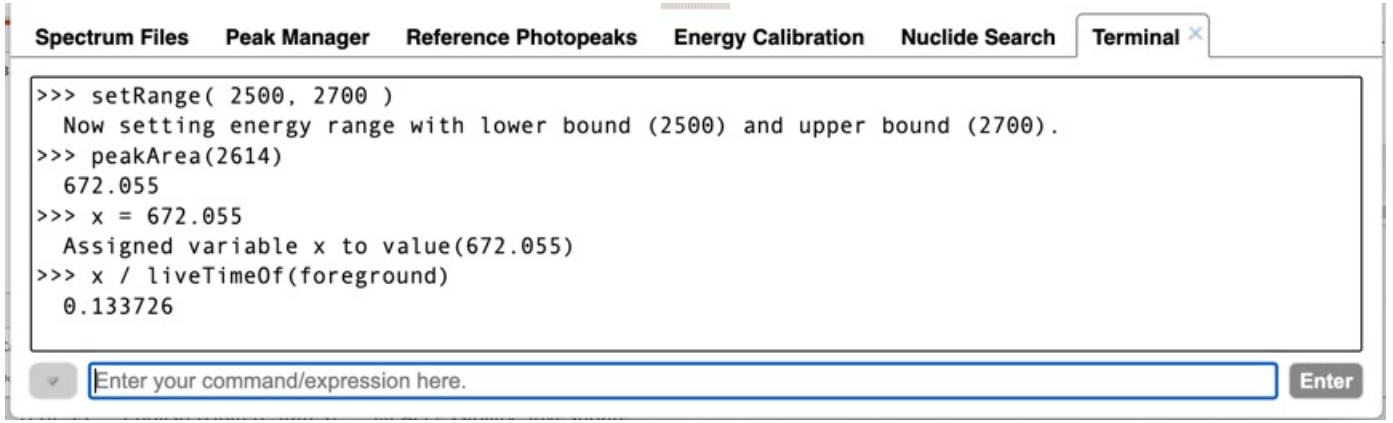


Fairly standard $1/r^2$ calculator, but does give you the option of high, medium, or low scatter

- If you can use a peak area, this is best – and would be using the “Low” scatter option

Terminal and Units Converter





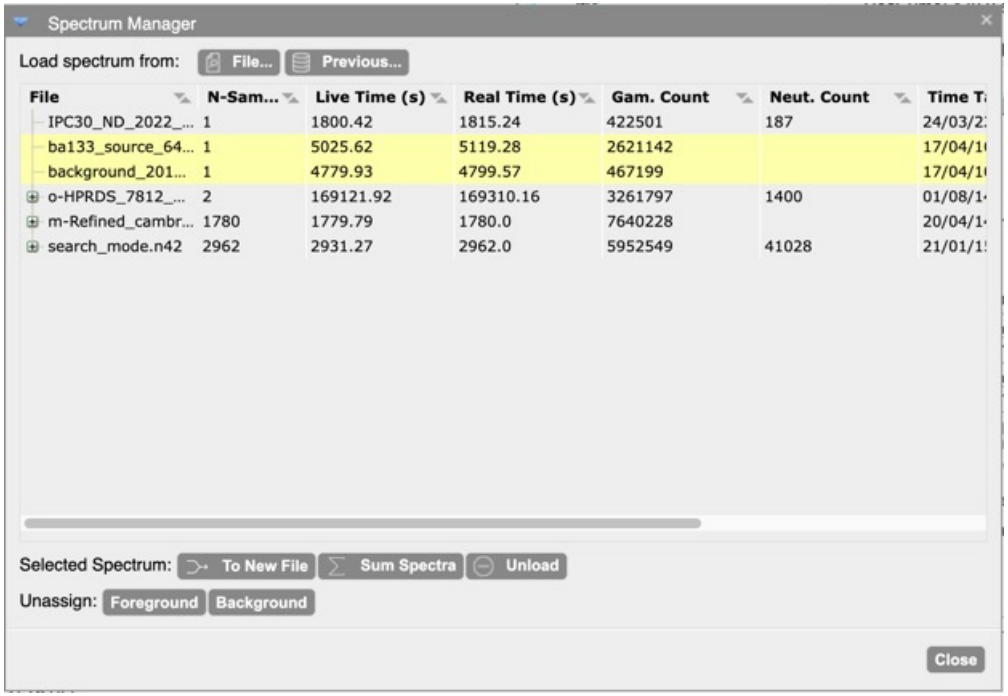
There is a radiation-analysis related units converter tool.

- Useful for going between Bq and Ci, or meters and feet, etc

There is also a “Math/Command Terminal” tool that lets you programmatically access some quantities, as well as lets you do some simple algebra and math

- I find this easier than using the Windows/macOS calculator a lot of times
- A few users have reported using this as a “macro” type language and have requested additional functionality

Spectrum Manager



The “Spectrum Manager” can be used to more-fine-grained control which spectra are currently displayed

Also can be used to sum spectra, or combine multiple spectra in a new file (e.g., put separate CHN foreground and background files into a single N42).

Backup slides

Case study: Chernobyl measurements

Do same steps as previous examples, but:

- fit peaks for Eu154, Cs137, Co60, and Cs134
- Use a end-on cylindrical, or rectangular geometry, with sufficiently large dimensions
- Add a trace source for each of the four nuclides
- Select "**per m^2 exp**" activity type – this will cause a "Relaxation Distance" enter form to appear
- Enter "3 cm" for relaxation distance

Chernobyl - Point 1

Nuclide	Activity
Eu154	6.24 ± 0.15 kBq/m²
Cs137	1.43 ± 0.01 MBq/m²
Co60	206.9 ± 14.2 Bq/m²
Cs134	368.78 ± 38.7 kBq/m²