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GADRAS-DRF Version 18 User's Manual

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ABSTRACT

The Gamma Detector Response and Analysis Software – Detector Response Function (GADRAS-DRF) application computes the response of gamma-ray and neutron detectors to incoming radiation and provides analysis on measured spectra. This manual provides step-by-step procedures to acquaint new users with the use of the application. The capabilities include characterization of detector response parameters, plotting and viewing measured and computed spectra, analyzing spectra to identify isotopes, estimating source energy distributions from measured spectra, and creating inject data. GADRAS-DRF can compute and provide detector responses quickly and accurately, giving users the ability to obtain usable results in a timely manner (a matter of seconds or minutes).

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
GADRAS	GAmma Detector Response and Analysis Software
GADRAS-DRF	GAmma Detector Response and Analysis Software Detector Response Function
SNM	Special Nuclear Material
1D	One Dimensional
3D	Three Dimensional
FSA	Full Spectrum Analysis
FWHM	Full-Width at Half-Maximum
keV	Kilo-electron-Volts
MeV	Mega-electron-Volts
LLD	Lower-Level Discriminator
NaI	Sodium Iodide
HPGe	High-Purity Germanium
CZT	Cadmium Zinc Telluride
PVT	Polyvinyl Toluene
AN	Atomic Number
AD	Areal Density
AC	Anti-Coincidence
Ci	Curies
Bq	Bequerels
MCNP	Monte Carlo N-Particle

1. INTRODUCTION

1.1. GADRAS Overview

GAmma Detector Response and Analysis Software (GADRAS) contains a suite of capabilities related to radiation detection [1]. Its primary function is the simulation of gamma-ray and neutron detector signals to radiation sources. It also contains various analysis tools and radiation transport.

Features in a gamma-ray detector spectrum; such as photopeaks and the Compton continuum, are derived from first-principles calculations based on interaction cross sections. Neutron detector response is computed by interpolating on a pre-computed database of thermal (^{3}He) detector responses [5] [6]. For both gamma-ray and neutron detectors, the response to radiation that scatters into the detector from the surrounding environment is determined by a combination of first-principles calculations and empirical modeling [7]. For new detectors, known detector parameters such as size and resolution are all that is necessary to compute an initial response function. This response function may be refined by measuring calibration sources and fitting the detector's parameters to match the data. After the initial characterization, GADRAS will interpolate and extrapolate the response to model different source energies, complex models, and different scattering environments.

GADRAS uses the detector response in combination with various analysis algorithms to analyze measurement data to identify sources, quantify activities, and determine shielding types and thicknesses. Because the entire spectrum is utilized, as opposed to just photopeaks, this is called full-spectrum analysis (FSA).

There are also several radiation transport methods available in GADRAS. The primary feature is one-dimensional (1D) source modeling, where users can construct nested-spherical-shells, and solve for the gamma and neutron leakage. There is support for three-dimensional (3D) models as well.

The full version of GADRAS is for official use only, export controlled, and limited to government agencies and their contractors. GADRAS-DRF (GADRAS-Detector Response Function) is a reduced capability version that is publicly available. The following key features are not available in GADRAS-DRF:

- IsotopeID – algorithm that automatically identifies the sources in a gamma spectrum
- SNMAnalysis – analysis designed to estimate isotopic composition and masses from gamma spectrum of special nuclear material (SNM)
- ModelFitFSA – algorithm that uses non-linear regression to fit the parameters of a model to match the model's simulated gamma spectrum to a measurement
- 1D Models – the model page allows users to build models and solve the radiation transport to determine leakages
- 3D Models – the effects from offsetting sources in 3D, detector collimator effects, simulating 3D models, and gamma-imager simulations

Screenshots in this manual reference the full GADRAS version; however, some depicted features and pages may not appear in the GADRAS-DRF version.

Figure 1 is a screen-capture of the GADRAS main window. The program contains eight main tabs that run across the top of the window (**Detector**, **Plot**, **Time History**, **Analyze**, **Model**, **Neutron**, **Inject**, **Tools**, and **Setup**). Each tab represents a primary function of GADRAS; these are referred to as tabs in this document (e.g. **Plot** tab). Most tab pages have a primary function initiated by clicking a large button in the bottom right corner of the screen. The title of the main window displays the current version and currently selected gamma-ray detector. GADRAS must always have a current gamma-ray detector selected, even if the current operation does not require a detector response function (e.g. plotting a measured spectrum). Neutron detectors are optional; the current neutron detector name will also appear in the main window title if selected.

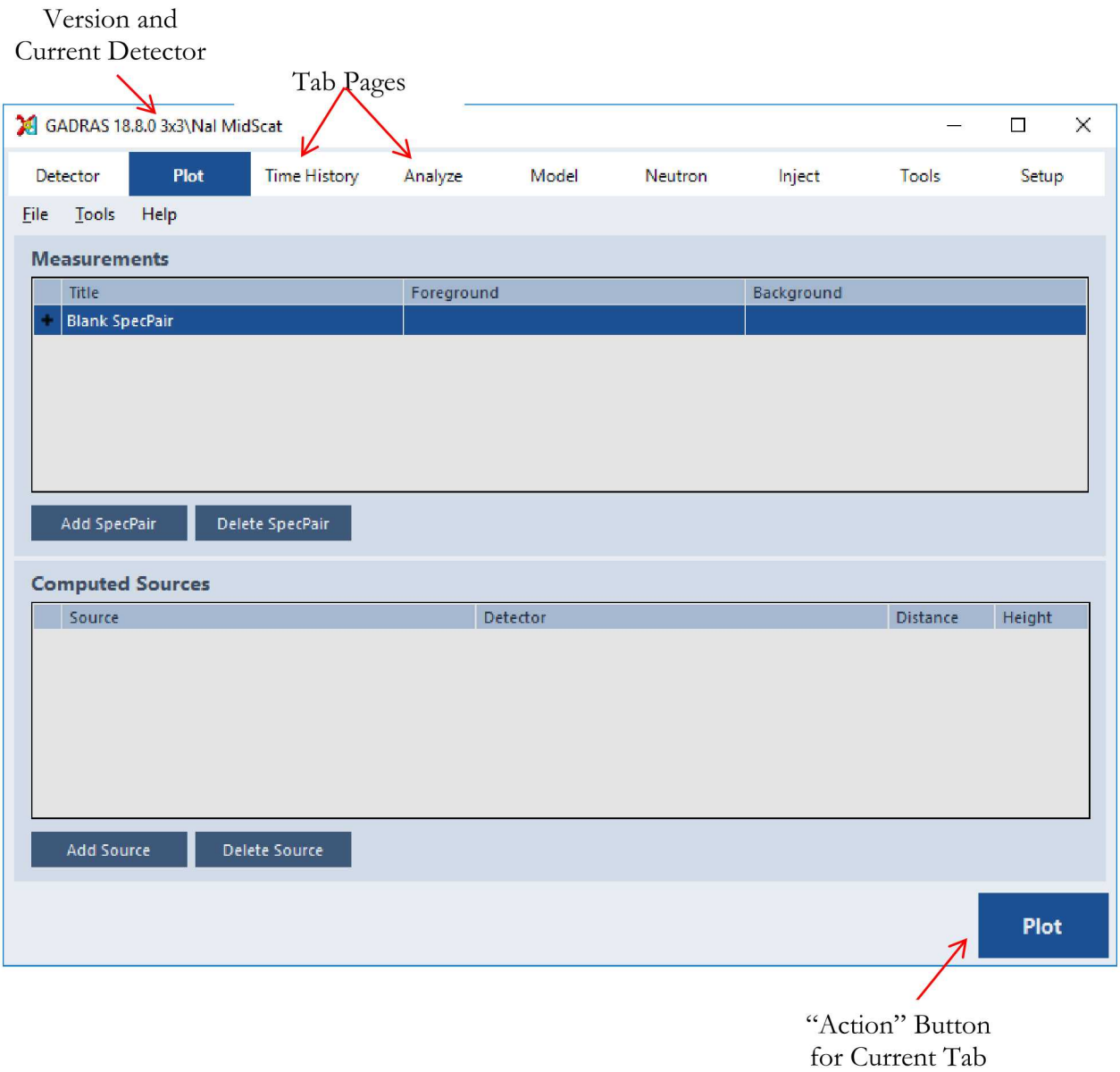

Figure 1. Overview of Main Window

1.1 Directory Structure

Within the root GADRAS directory (default is C:\GADRAS, or C:\GADRAS-DRF), there are four primary directories: (1) **Detector**, (2) **Source**, (3) **Temp**, and (4) **Program** (Figure 2).

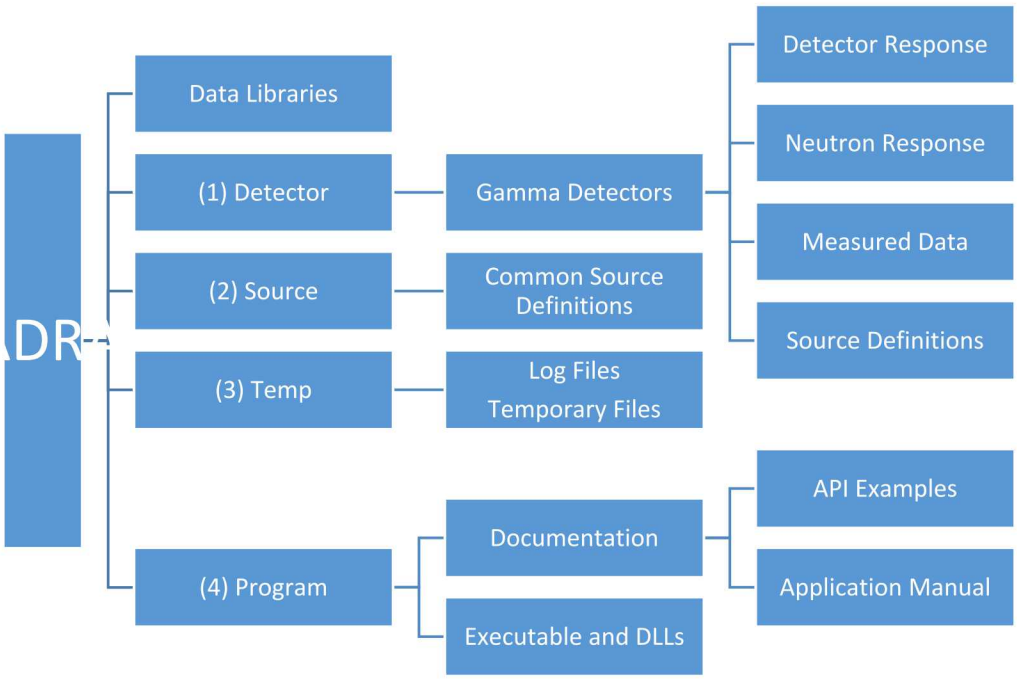

Figure 2. Overview of GADRAS Directory Structure

The **Detector** directory contains subdirectories, each for a different gamma-ray detector. The name of the subdirectory indicates the name of the detector; thus, each gamma-ray detector requires its own directory. However, multiple neutron detectors can be added to a single gamma-ray detector directory. A common practice is to use a gamma-ray detector directory as a scenario or experiment repository containing documents and measured spectra. Therefore, detector directory names are also based on experiments (e.g. "GADRAS\Detector\BeRPBall").

Common source files shared among multiple detectors are stored in the **Source** directory. Source files may be stored in individual detector directories as well.

The **Temp** directory is cleaned with each new instance of GADRAS. It contains temporary files which facilitate faster operation of the program as well as log files which record debugging information. Most users will not need to explore this directory.

The main executable is located in the **Program** directory at "GADRAS\Program\GADRAS.exe" along with associated shared libraries. This also contains a **Documentation** directory which contains this user's manual as well as example codes that utilize the GADRAS API.

2. DETECTOR RESPONSE FUNCTION

2.1. Creating New Detectors

Each detector directory contains a file named **Detector.dat**, which contains the response function parameters. Response function parameters do not normally require adjustment after initial characterization. Specific situations where parameter adjustments are necessary include:

- adjustments needed due to mechanical damage, chemical deterioration, high voltage bias change, shielding, etc. that have caused the detector to change its characteristics substantially; and
- drastic changes in the measurement environment from which the detector was characterized (e.g. moved from a room to outdoors).

2.1.1. *Using the Create New Detector Screen: Clone or Create Options*

A new detector setup within GADRAS can be created from the **Detector** tab on the main window. To create a new detector, the user selects **Create New Detector…** from the drop-down menu as shown in Figure 3 (*top*). This action opens the **Create New Detector** form shown in Figure 3 (*bottom*), which allows users to clone an existing detector or create a new detector.

The following entries are mandatory for creating new detector setups:

1) **Detector name:** Users should create a unique name for the detector.
2) **Parent directory:** The parent directory for the detector. By default, this is the main detector directory "GADRAS\Detector". Any subdirectory of the main detector directory may be used (including existing detector directories) to be the new detector's parent directory.
3) **Source-to-detector distance:** This is the distance (cm) between the detector and calibration sources. A value must be entered upon detector creation, but this value can be modified at any time if needed. The value is given in centimeters, but other units may be used (see Section 2.2).

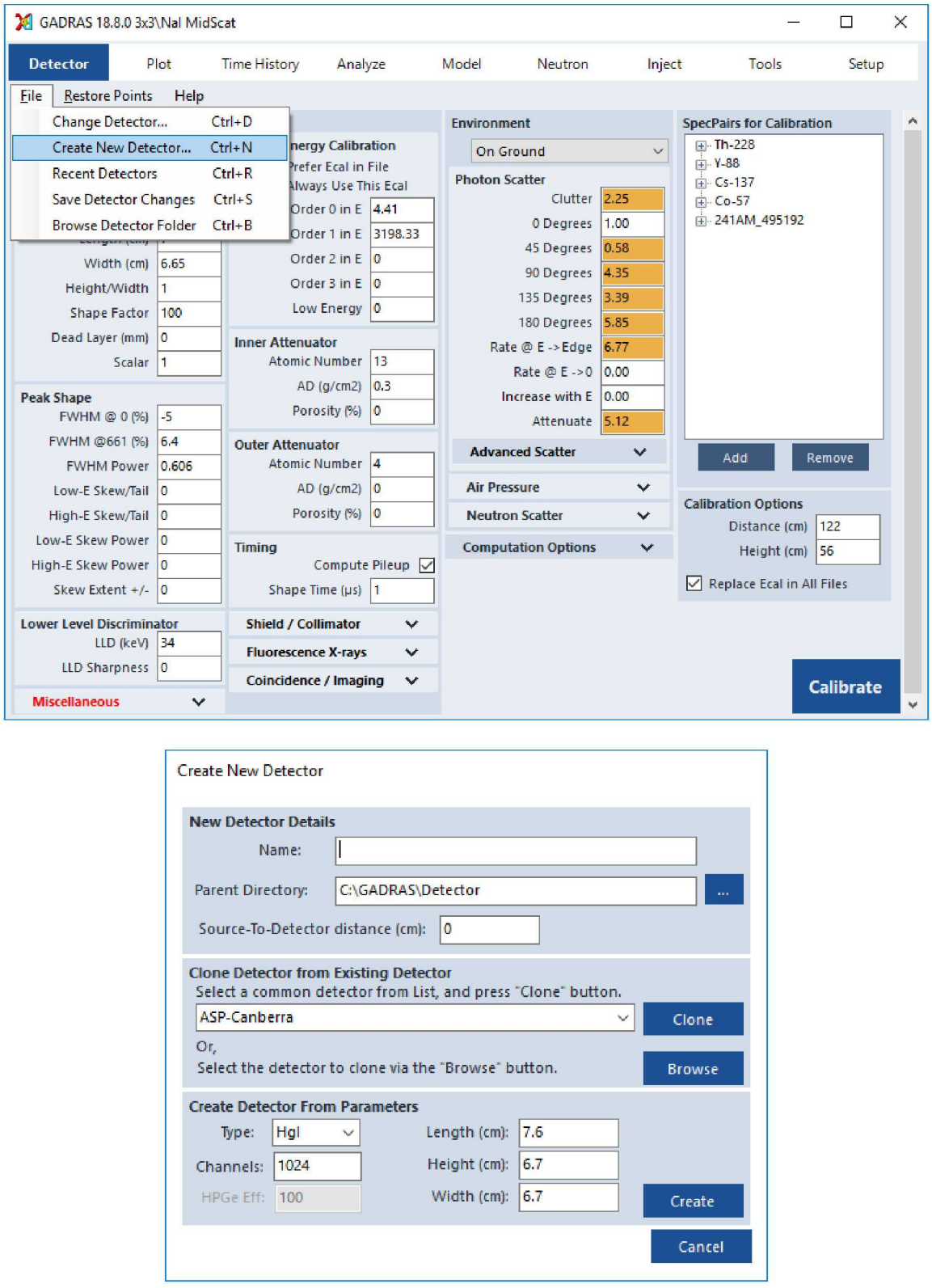

Figure 3. File Drop-down Menu (*top*) for Create New Detector Dialog (*bottom*)

New detectors may be created by clicking the **Clone** button located in the middle of the window or the **Create** button located near the bottom of the window.

1) **Clone:** An existing detector is copied using either the provided dropdown list or the **Browse** button. After choosing the appropriate detector, clicking the **Clone** button will create the new directory with the appropriate **Detector.dat** file.

2) **Create:** This option generates a new **Detector.dat** file. Select the detector type (e.g. NaI, HPGe, etc...) from the dropdown list. The number of channels and the detector efficiency or detector dimensions should be entered, depending on the type of detector. The **Length** dimension is along the line defined by the two points: (1) the center of the source and (2) the center of the front face of the detector. This is also referred to as depth. The height and width define the front face dimensions. The user can then click the **Create** button to create the new directory with the appropriate **Detector.dat** file.

   GADRAS assumes a rectangular prism for the detector shape. If the detector's front face is circular, enter the diameter in the width and height fields. With the cursor still in the fields, press the "d" key to convert each to a side length that preserves surface area.

   When creating an HPGe detector, the user can enter the relative efficiency of the detector compared to a standard 3″×3″ NaI detector at 1332.5 keV with a source-to-detector distance of 25 cm. GADRAS will subsequently assign typical physical dimensions.

   Selecting **None** for the detector type will simulate a perfect radiation detector. Computed source spectra will be composed of the leakage current from the source and the solid angle of the detector. No peak broadening or any other physics associated with a real detector are applied.

NOTE: It is advisable to always work with clones of distributed **Detector.dat** files as opposed to modifying the original. Working on original files may compromise them. Furthermore, each release and install of GADRAS will overwrite any changes to the original files.

2.2. Detector Parameters in Detector.dat Files

From the **Detector** tab, the detector response function parameters can be observed and edited. The detector response function parameters are displayed in Figure 4 for a NaI detector. For other detector types, similar screens are displayed with some detector-specific variations.

Dimensions and distances can be entered in the following units: centimeters, meters, feet, or inches. GADRAS will convert all inputs to cm when the correct conversion letter is typed in the text box. The identifiers for meters, feet, and inches are "m", "f", and "i", respectively. For example, to enter 12 inches as the distance, you would type "12i" into the distance entry box; unit conversion is performed automatically so that distance is displayed in centimeters after typing the character "i".

The following sections briefly describe the function of each field on the **Detector** tab. For more information, see reference [8].

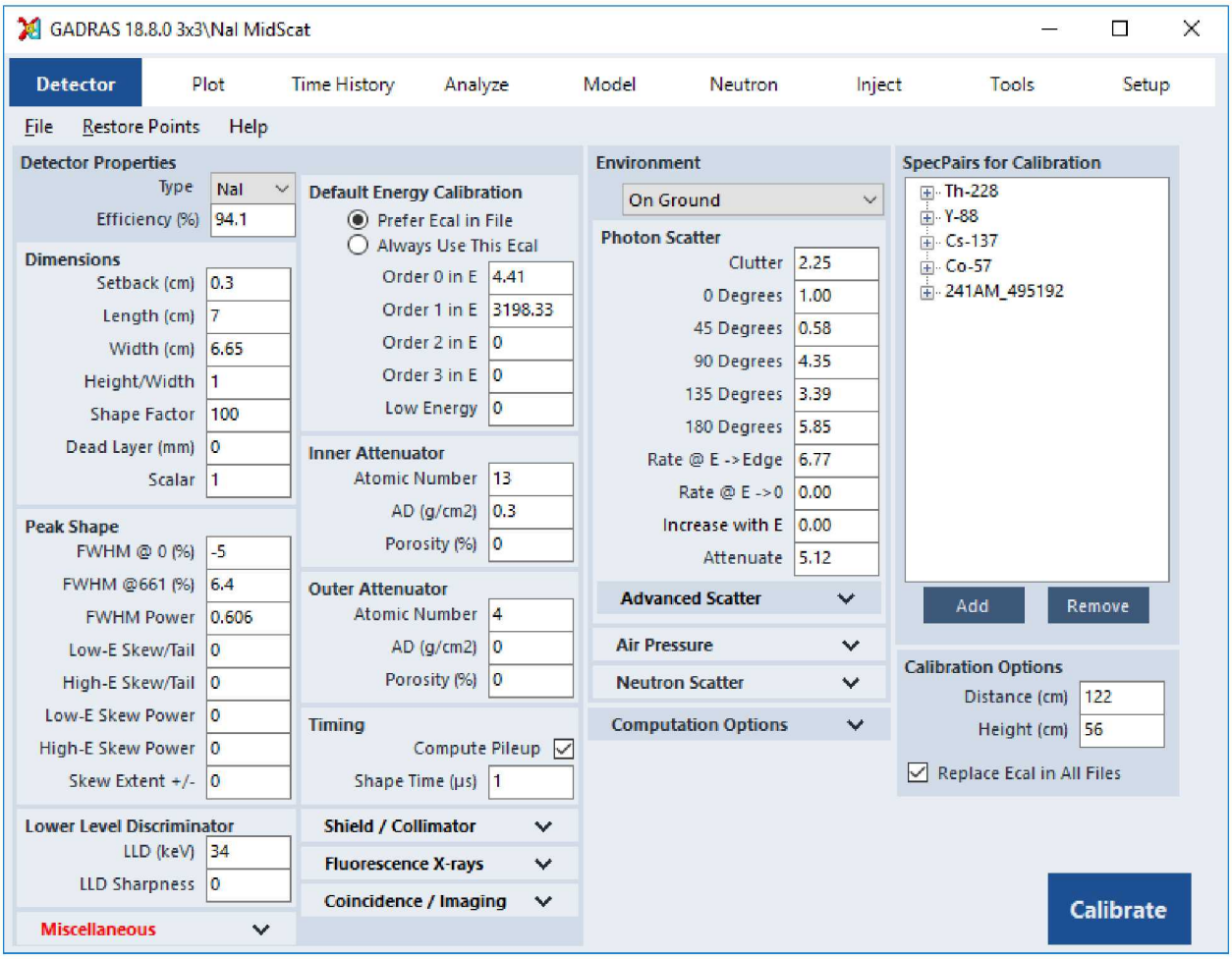

Figure 4. Example Detector Response Function Parameters for a NaI Detector

2.2.1. *Detector Dimensions*

The following parameters describe the detector dimensions:

- **Setback** is the distance in cm from the physical surface of the detector face to the active sensor element (crystal).
- **Length** is the detector length in cm measured perpendicular to the detector face and is also referred to as depth.
- **Width** is the detector width in cm measured perpendicular to the incident photon flux and parallel to the floor.
- **Height/Width** is the ratio of the two dimensions perpendicular to **Length**.

NOTE: If describing a detector system with an array of detectors and the measured spectra are simple sums of each detector's observation, the dimensions describe the size of one of the detectors. Use the **Scalar** parameter described below to add multiple detectors to a system.

Although these parameters describe a rectangular detector, other geometries can be approximated using these dimensions. For example, a cylindrical detector oriented so that the axis is pointed toward the radiation source can be approximated by a square with the same surface area as the circle (i.e., height × width = πr^2). The conversion between diameter and width can be performed by typing "d" after specifying the numerical value for the diameter.

- **Shape Factor** is a parameter describing the distribution of path lengths through which incident radiation travels as it traverses the detector. The shape factor describes a continuous function that varies from about 3 for circular cross sections (e.g. radiation enters predominantly through side of a cylindrical detector) to about 100 for flat detector profiles (e.g. radiation enters through top or bottom of cylindrical detector). Figure 5 shows detector profiles for several shape factor values. Note that the detector shape can vary depending on the orientation of the radiation source with respect to the detector. In the case of a cylindrical detector oriented so that the radiation source is located on the axis of the detector, the value of S is about 100, which describes a flat profile.

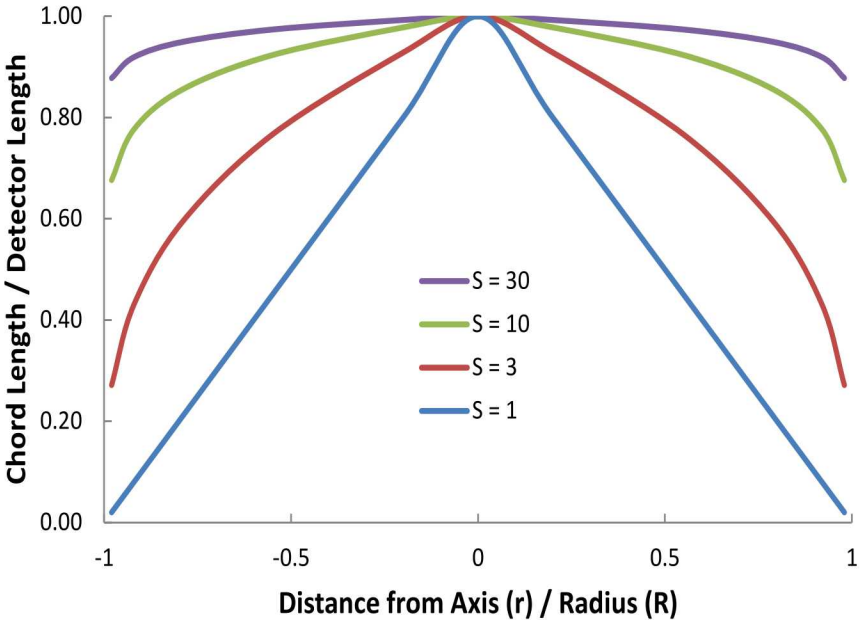

Figure 5. Detector Cross-section Profiles for Several Shape Factors

- **Dead Layer (mm)** describes the depth of the inactive region between the contacts and the semiconductor in a solid-state detector. Typical values are a less than a few millimeters, depending on the manufacturing technique employed. This primarily affects low-energy intensities such as x-rays.

- **Scalar** scales the total efficiency of the detector. This is typically used for detector system arrays. The other dimensions describe the size of one detector, and this field can be the number of detectors in the system.

2.2.2. *Peak Shape*

The full-width-at-half-maximum (FWHM) parameter describes the width of a photopeak and is commonly referred to when describing the resolution of the detector. If detector energy resolution followed Poisson statistics exactly, the FWHM of the peaks would increase as the square-root of energy. However, the resolution of scintillators is often dominated by effects associated with intrinsic nonlinearities. For semiconductor detectors, the resolution at the zero-energy FWHM asymptote is limited by dark current. GADRAS uses an empirical form of the FWHM using as few parameters as possible to describe a wide variety of detectors:

$$FWHM(E) = \begin{cases} 6.61r\left(\frac{E}{661}\right)^p & E > 661 \\ \sqrt{\left[r_0\left(\frac{661-E}{661}\right)\right]^2 + \left[6.61r\left(\frac{E}{661}\right)^p\right]^2} & E \le 661, r_0 \ge 0 \\ 6.61r\left(\frac{max(20,E)}{661}\right)^{p^{(\log(1-r_0))^{-1}}} & E \le 661, r_0 < 0 \end{cases} \quad (1)$$

where E is the photopeak energy in keV, r is the percent resolution at 661 keV, p is the FWHM energy power (unitless), and r_0 is zero-energy FWHM asymptote in keV. There is a discontinuity in the resulting FWHM from Eq. **(1)** when the zero-energy asymptote is zero. Detector response fitting will typically not cross that discontinuity and care must be taken to determine which regime (positive or negative asymptote) the detector is best suited to.

The following parameters on the **Detector** tab are used to calculate peak shape and resolution:

- **FWHM @ 0 (keV)** zero-energy asymptote of the FWHM in keV (can be negative) (r_0 in Equation 4)
- **FWHM @661 (%) (or keV @ 1332)** is the percent FWHM of the photopeak at 661 keV (or for HPGe detectors, it is displayed as the width of the photopeak at 1332 keV in keV) (r in Equation 4)
- **FWHM Power** describes the rate at which the FWHM increases as a function of energy (p in Equation 4)
- **Low-E Skew/Tail** describes the magnitude of photopeaks' low energy tails
- **High-E Skew/Tail** describes the magnitude of photopeaks' high energy tails
- **Low-E Skew Power** describes the rate at which the low-energy tail decreases
- **High-E Skew Power** describes the rate at which the high-energy tail decreases
- **Skew Extent +/-** describes additional skew range relative to the nominal range

2.2.3. *Lower Level Discriminator*

- **LLD (keV):** The lower-level discriminator of the detector (low-energy cutoff) in keV is represented by this setting.

- **LLD Sharpness:** The simulated LLD is not a step-function; the slope of the simulated spectrum at the LLD is determined by this parameter.

2.2.4. *Miscellaneous*

- **Annih. Magnitude** describes the magnitude of annihilation photons (511 keV) produced in the vicinity of the detector. Annihilation inside the active detector area is modeled explicitly. However, if high-atomic-number materials are used in the detector housing, additional annihilation photons can be modeled with this parameter.
- **Beta Magnitude** provides the ability to estimate the continuum produced by bremsstrahlung emission. A good first estimate for this parameter is 20.
- **% Holes Trapped** is used as an empirical term related to hole trapping by detectors such as CdTe. This parameter does not have quantitative significance.
- **Frisch grid %**: Frisch grids are used in conjunction with some CZT detectors. The percent of events that are recorded between Frisch grid electrodes is described by this parameter. Events recorded in this region can produce up to twice the apparent full energy because both electrons and holes are counted; whereas holes are excluded for interactions within the bulk material.

NOTE: Except for limited cases, using the bremsstrahlung parameter is neither necessary nor advised. If a more accurate representation is required, a radiation transport calculation should be performed.

2.2.5. *Default Energy Calibration*

The default energy calibration will be used when a spectral file does not explicitly define an energy calibration. Routine energy calibration is usually performed elsewhere in GADRAS. Adjusting the energy calibration is discussed in Section 0.

These parameters are typically only used when simultaneously varying the energy calibration with other detector response parameters during a characterization for plastic scintillators with no photopeak definitions (e.g. PVT).

The most common energy calibration convention is to use polynomial coefficients. These coefficients convert channel number into energy at the lower edge of the channel according to the following equation:

$$E_i = c_0 + c_1 i + c_2 i^2 + c_3 i^3 + c_4 i^4 \qquad (2)$$

where i is the channel number (starting at 0), and c_n is the n^{th} polynomial coefficient.

GADRAS uses the convention defined as the *FullRangeFraction* in ANSI N42.42-2006, which represents energy calibration as follows:

$$E_i = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + \frac{a_4}{1 + 60x} \quad (3)$$

where a_n is the n^{th} polynomial term which corresponds to c_n in Eq. (1), and x is the fractional energy of the spectral range. x ranges from 0 at the lower edge of the first channel and ends at 1 at the upper edge of the last channel. If the spectrum has uniform energy groups, $x = i/n$, where n is the total number of channels. The offset terms are identical in these definitions (i.e., $a_0 = c_0$), and the higher order parameters are related as follows:

$$a_j = n^j c_j \quad (4)$$

The final term in Eq. (3), which addresses nonlinearity in the low-energy region, does not have an equivalent term in Eq. (2). However, neither a_4 nor c_4 is often applied, so this incompatibility is rarely important.

There are a few general remarks about what values might be reasonable for the calibration of a detector.

- **Order 0 in Energy (offset)**: should a small number (<100) either positive or negative
- **Order 1 in Energy (gain)**: should be a number close to the maximum energy scale of the detector in keV
- **Order 2 in Energy (quadratic)**: should be zero unless the detector is non-linear
- **Order 3 in Energy (cubic)**: should be zero unless the detector is highly non-linear
- **Low Energy**: non-linear parameter for the low-energy region (usually zero)

In general, it is advised to initially have values only for the gain and offset. For more information on how to calibrate spectral data, see Sections 3.3.4, and 0.

2.2.6. *Inner Attenuator*

This reduces the intensity of all incident radiation, *including room scatter*, before it passes into the active detector volume. This is useful in describing detector housing.

- **Atomic Number** is the effective atomic number (AN) of the inner attenuator. This can be an average of multiple materials.
- **AD (g/cm2)** is the areal density (in g/cm^2) (density multiplied by thickness) of the attenuator
- **Porosity (%)** allows for an attenuator with incomplete coverage around the detector

2.2.7. *Outer Attenuator*

This reduces the intensity of all direct radiation, *not including room scatter*. This is useful for describing attenuation by a detection system placed in a large truck. The truck walls can be described by the outer attenuator.

- **Atomic Number** is the effective atomic number (AN) of the outer attenuator.
- **AD (g/cm2)** is the areal density (in g/cm^2) of the outer attenuator
- **Porosity (%)** allows for an attenuator with incomplete coverage around the detector

2.2.8. *Timing*

- **Compute Pileup** with this box checked, GADRAS will simulate pile-up effects from random coincidences in high-count rate simulations
- **Shape Time (μs)** is an empirical parameter to describe the shaping time of the amplifier. Since the amplifier shape time constant is generally only approximate, it is often necessary to characterize this parameter from calibration spectra. If the detector has a pileup rejecter, as most modern systems do, this field should be entered as a negative value, with a magnitude approximately equal to the shape time constant in microseconds. The value should be approximately -5 for typical HPGe detectors equipped with pileup rejection circuitry.

2.2.9. *Shield / Collimator*

These parameters describe shielding on the sides and back of the detector in addition to the attenuators. This can also be used to add a collimator to the detector.

Shielding materials are specified by specifying **Side** parameters and **Back** parameters. The **Side %** is defined as the percent of the side of the detector that is covered by the shield. This will be set to 100 if the shield completely covers the sides but does not extend past the front face of the detector. The length of the shield is described as a percent of the detector length, so collimators can be described by entering a value that is greater than 100%. For example, a value of 230 indicates that the length of the shield measured from the back of the detector to the front of the shield is 230% of the detector length (i.e., the shield extends 1.3 times the detector length in front of the detector). Similarly, **Back %** is defined as the percent of the back of the detector that is surrounded by the shield. For collimators with an aperture less than the diameter of the active detector element, the **Alt Collimator Diam** field allows specification of the aperture size. The **AN** and **AD** parameters describe the material of the side and back shields.

2.2.10. *Fluorescence X-rays*

Some detectors are constructed with high-atomic-number materials in the vicinity of the active volume which produce fluorescent x-rays in response to external radiation. This can also be used to describe the magnitude of the x-rays from a shield or collimator.

GADRAS allows for two fluorescing **Material**s with respective **Magnitude**s. An approximate energy dependence is applied for these x-rays

2.2.11. *Coincidence / Imaging*

In some detector systems, the primary detector is surrounded by another detector, called an anticoincidence (AC) shield. This reduces background by rejecting events recorded simultaneously in both detectors. AC shields reduce the Compton continuum by excluding interactions where a photon scatters between the primary detector and the AC shield. The default setting is no AC shield. The effects of AC shields can be treated by defining the parameters under the **Anti-coincidence shield** section:

- **Type**: The type of AC shield detector material (e.g. NaI)
- **Solid Angle (%)**: Solid angle percentage subtended by the AC shield from the primary detector

- **Thickness (cm)**: Thickness in cm of the AC shield
- **Dead Layer Z**: Average atomic number (AN) of the dead layer on the AC shield
- **Dead Layer AD**: Areal density of the AC dead layer in g/cm^2
- **Shield LLD (keV)**: Lower-level discriminator of the AC shield

GADRAS can support gamma-ray imaging sensors including Compton cameras, and coded-apertures with or without mask/anti-mask operation. For Compton cameras, the parameters are described by:

- **Spatial Coverage (%)** is the average percentage of photons that do not escape the material after scatter
- **Correct pixel (%)** is the percentage of Compton scatter events that are assigned to the correct pixel
- **Ang. Resolution (deg)** is the angular resolution in degrees that the imaging system can resolve an event to

For coded aperture systems, the parameters are the same for regular and mask/anti-mask systems. They are described by:

- **Focal Length (cm)** is the focal length for the system – this is usually determined during post-processing of the data
- **Mask Width (cm)** is the width of the coded aperture mask
- **Ang. Resolution (deg)** is the angular resolution in degrees that the imaging system can resolve an event to
- **Mask AN** is the atomic number of the coded aperture mask
- **Mask AD** is the aerial density of the coded aperture mask

2.2.12. *Environment*

GADRAS allows for various scattering environments that a measurement may be taken in. The following options are currently supported by GADRAS:

- **On Ground** is the most common Environment and assumes the detector is positioned horizontally
- **Aerial** is the used for high altitude detectors (such as those mounted on helicopters or airplanes); in this case, the Detector Distance is the distance between the source and the detector, and the Height is the distance above the ground that the source is located

2.2.13. *Photon Scatter*

GADRAS includes a library of scattering kernels which are used to calculate scattering contributions from any surfaces present in the environment surrounding the source and the detector. The source-to-detector distance and height determine the position of the source in a nominal room. The scattering magnitude is sensitive to height, so it is important that this parameter is accurate before attempting to adjust the Photon Scatter parameters. The **Clutter** parameter determines the average distance from the detector to the walls in the room. The following guidelines can be used when determining initial scatter parameters:

- **Outdoors/Large Room** should have a small **Clutter** term (less than 3).

- **Average Room** should have a **Clutter** term equal to 3 (indicates an average distance of 3 meters to the surrounding walls in the room).
- **Small Room** should have a **Clutter** term that is computed using the equation 900/{average distance to the walls in cm}.

The scatter parameters labeled **0 Degrees**, **45 Degrees**, **90 Degrees**, **135 Degrees**, and **180 Degrees** adjust the magnitude of the scattered radiation. The **0 Degrees** parameter corresponds to low-angle scattering within the environment, which manifests itself as continuum just below the photopeak energy. The **180 Degree** parameter corresponds to a photon which has backscattered in the environment and manifests itself in the backscatter peak. A value of 3 in these fields indicates that the observed scattering continuum in the detector is consistent with the external environment. Values may exceed 3 if additional scattering occurs within the detector housing. Setting the scatter terms to zero disables the computation of scattered radiation.

- **Rate @ E->Edge** adds or subtracts continuum just below the Compton edge (less than 3 reduces, greater than 3 adds)
- **Rate @ E->0** adds or subtracts continuum as the spectrum approaches zero energy (less than 3 reduces, greater than 3 adds)
- **Increase with E** adds or subtracts additional scatter with increasing photon energy (less than 3 reduces, greater than 3 adds)
- **Attenuate** further reduces low-energy continuum

2.2.13.1. Advanced Scatter

Some measurements can be taken in the presence of an object that produces preferential scatter features that are observable in the spectra. To account for this, the Advanced Scatter parameters can be adjusted. The parameters are described by:

- **Pref Angle (deg)** is the average preferential scatter angle in degrees
- **Pref Angle +/- (deg)** is the interval size for the preferential angle (e.g. preferential scatter from 40-50 degrees would have a Pref Angle of 45 and Pref Angle +/- of 5)
- **Pref Angle Mag** is an empirical parameter that determines how much influence the preferential scattering material has on the spectrum

2.2.13.2. Environment.dat

For special environments (e.g., source and detector are not at the same height, or placed in a corner), a user can define an **Environment.dat** file in the detector directory. An example **Environment.dat** file is located in "GADRAS\Detector\3x3\NaI AboveSource".

NOTE: The **Environment.dat** file will override the Photon Scatter parameters and the Distance and Height parameters.

2.2.14. *Air Pressure*

The air pressure defines the density of intervening air and is only significant when the source-detector distance is greater than about ten meters. Air attenuation is determined by the atmospheric pressure (**Air Pressure**) or the **Elevation** fields.

2.2.15. *Neutron Scatter*

Most gamma detectors are sensitive to neutron radiation. These parameters define the intensity of neutrons on the gamma detector:

- **Environment Drop-Down Box** describes the reflection of neutrons in the surrounding environment, also called the room return. Options are "No reflected neutrons", "Outside or large bay", "Indoors above suspended floor", and "Indoors above concrete on ground". The neutron reflection is dependent on the distance and height parameters as well.
- **Thermal Stopped %** is the percent of thermal neutrons that are stopped by exterior shielding around the detector sensor (e.g. cadmium shield)
- **Reflection Scalar** directly scales the rate of neutrons reflected by the surrounding environment uniformly across all energies

2.2.16. *Computation Options*

These control options aren't necessarily part of the detector response, but may differ between detectors.
The **Weight Range** area has two fields: **Lower Limit** and **Upper Limit**. During any analysis or fitting, GADRAS will attempt to fit only the region of the spectrum defined by these limits. Grayed-out regions in the plot indicate ignored portions of the spectrum and are not used in any analysis or fitting routine.

- **Default # Channels**: When generating synthetic spectra, this defines the number of channels in the spectra.
- **Template Error (%)** defines the assumed error with the simulated spectrum. This is used in the chi-square estimate.
- **Assume MCA Bins from Inbin:** this checkbox toggles the usage of the **Inbin.dat** file. **Inbin.dat** defines relative channel widths and is useful for detectors with non-uniform channel widths. This checkbox is only enabled if **Inbin.dat** is present in the current detector directory.
- **Collapse Spectra to Rebin:** this checkbox toggles the use of the **Rebin.dat** file. **Rebin.dat** contains a list of energy groups, usually less than the detector's total channel count, to reduce computation time for certain analyses. This checkbox is only enabled if **Rebin.dat** is present in the current detector directory (users can use Rebin tool to generate Rebin.dat).

2.2.17. *Calibration Options*

The default detector configuration with respect to the measured source is described by the following parameters:

- **Distance** is the source-to-detector distance in cm measured from the **center of the source** to the **center of the detector face**.

- **Height** is distance in cm above the ground. For most applications the detector and source are assumed to be at the same height.
- **Replace Ecal in All Files**: when the **Default Energy Calibration** parameters are varied in a detector response characterization, this box allows GADRAS to overwrite the energy calibration parameters in the files used with the default parameters.

2.3. Detector Tab Menu Items

2.3.1. *File Menu*

As seen at the top of Figure 3, the File menu allows users to save the current detector parameters or to browse the detector directory. Clicking on **Save Detector Changes** or pressing Ctrl+S will save the current detector parameters to the **Detector.dat** file. If changes are made and the user attempts to navigate away from the Detector tab or attempts to close GADRAS without saving the parameters, GADRAS will prompt the user to save the detector parameters. Users may click **Browse Detector Folder** or press Ctrl+B (on any tab) to open a new Windows Explorer window for the current detector directory. Users may click **Recent Detectors** or press Ctrl+R (on any tab) to open a form listing recently used detectors. Users may select a detector from this form to quickly change detectors.

2.3.2. *Restore Points*

Restore points allow users to save the current detector response parameters. If users are trying to improve an existing detector response function but do not want to lose the original parameters, they may create a Restore Point. This is done by selecting **Create New** under the **Restore Points** menu item (Figure 6). If the detector parameters are adjusted incorrectly, they can be reverted to a set of previous parameters by clicking the appropriate Restore Point.

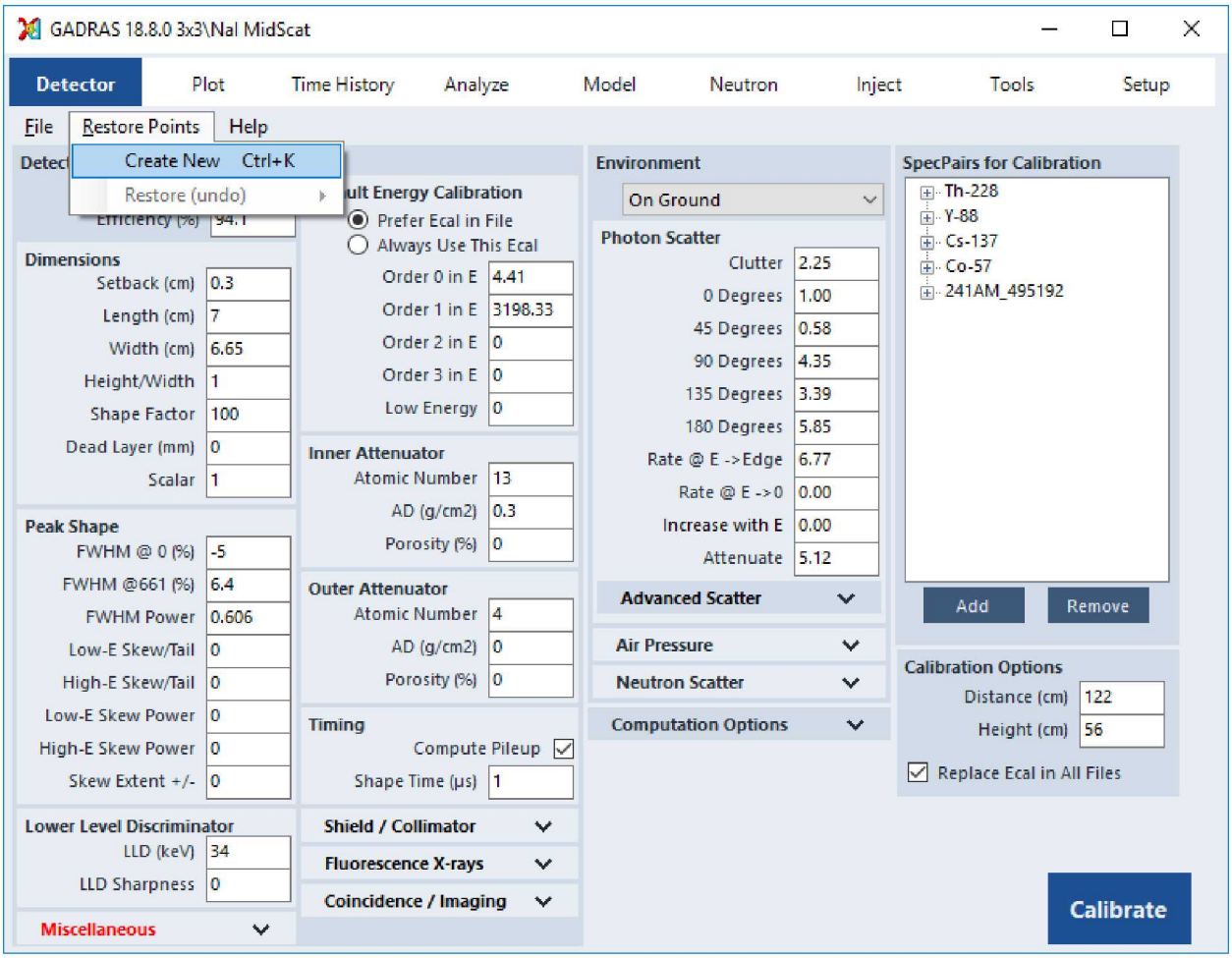

Figure 6. Restore Points Menu Item

2.4. Detector Tab Calibrate Response

To optimize detector parameters click the **Calibrate** button at the bottom right of the detector page. This adjusts the parameters that the user has selected to match measured calibration spectra to computed spectra. To select a parameter for adjustment, users should click on the label of the parameter. Parameters that are highlighted in orange have been chosen for adjustment.

Calibration spectra are added to the SpecPair tree on the detector page (Figure 7) by dragging and dropping records from the **PCF Viewer** form (Section 0) into the tree. Users can add up to eight SpecPairs to use in the calibration. Users should specify a Foreground and Background as well as a Source for the computed spectrum. GADRAS will subtract the Background from the Foreground (using count rates in each energy bin) and compare the measured spectrum to the computed spectrum for the specified source. It will do this comparison for each SpecPair specified in the Calibration form. GADRAS will then vary the adjustable parameters and find the best parameter fit through non-linear regression iterations.

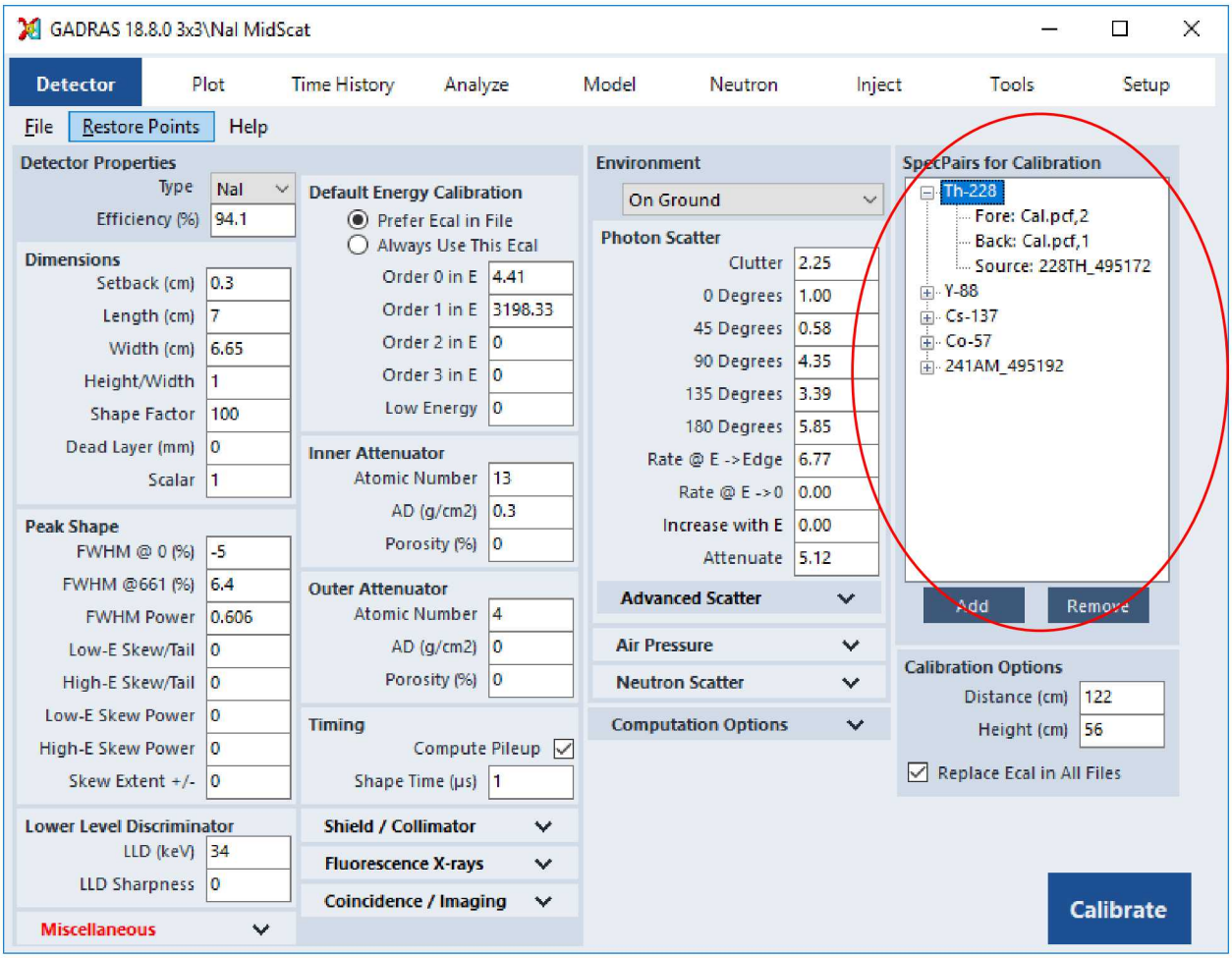

Figure 7. Detector Response Function Calibration Spectra

To effectively calibrate a new detector to measured spectra, users should first determine the energy calibration and peak resolution before varying other parameters. Users should not attempt to vary all the parameters at once, as this may lead to degenerate solutions that do not reflect the best detector response parameters for a given setup. Users should vary energy and resolution parameters first, then attenuators and scattering parameters. Some parameters may be known prior to performing the Response Function Calibration (such as Shape Time or Shield Attenuator properties). In this case, users should input these parameters before attempting any detector response function calibrations.

3. PCF FILES

3.1. PCF File Description

The main file format intrinsic to GADRAS is a binary, direct access file with a **PCF** extension. GADRAS can read many other spectral file formats (including Ortec CHN, IAEA SPE, ASC, PCC, N42, etc.) from many vendors and convert them to the GADRAS preferred PCF file format. PCF Files contain energy calibration coefficients and other supplemental information.

GADRAS generates and stores PCF files in the same file location as the **Detector.dat** file. The **Detector.dat** file must be defined prior to evaluating spectral data. Selection or creation of the detector (**Detector.dat** file) is discussed in Section 2.1. A PCF file can be created from the **Plot** tab on the main screen. To do this, the user can select **New** from the File drop-down menu, as shown in Figure 8. After the PCF file is created, the **PCF Viewer** will display a blank PCF file as shown in Figure 9.

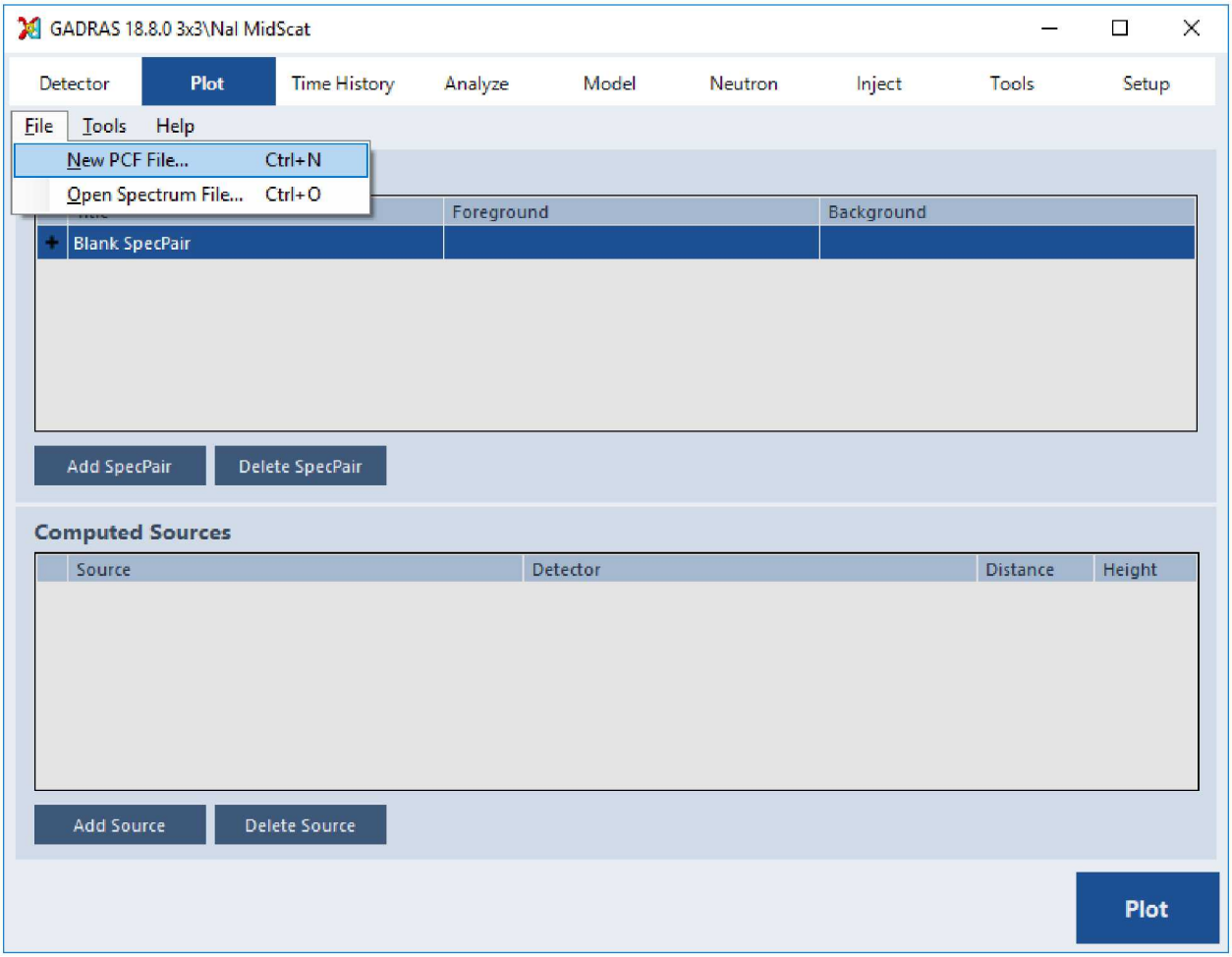

Figure 8. Creating a New PCF File From the Plot Tab Within the File Menu

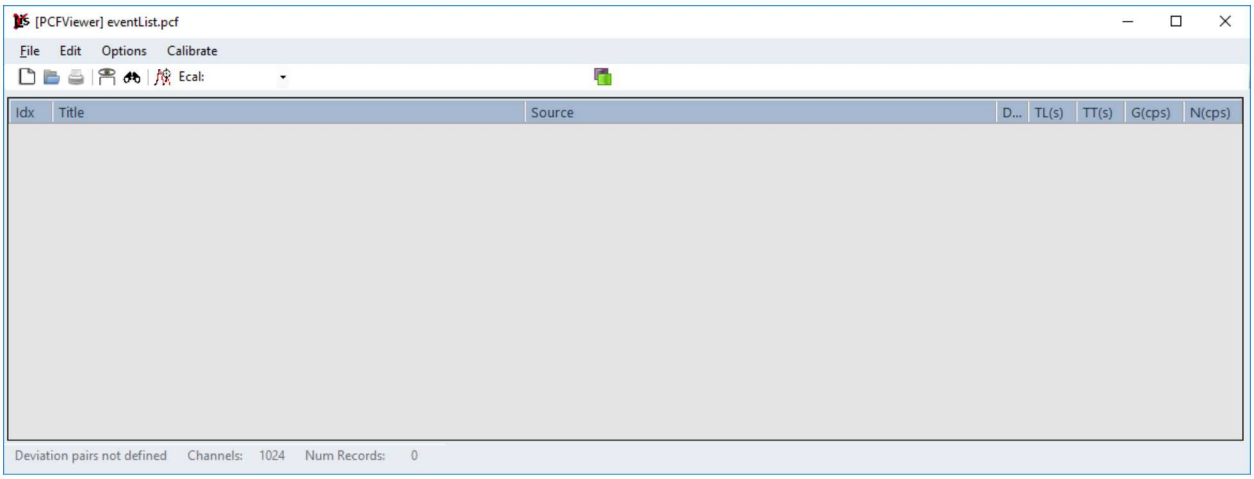

Figure 9. Newly Created PCF Shown in the PCF Viewer

Spectral files of almost any format can be added to the blank PCF by dragging and dropping the desired data file to the gray area in the **PCF Viewer**. Figure 10 shows the file list form after populating the PCF file with eight spectral entries (five calibration source spectra and three background spectra).

GADRAS can process spectral data taken at different source-to-detector distances and source/detector heights. The distances and heights can be specified in the Title field of the PCF record. To specify the source-detector distance, the "@" sign must be used, followed by the distance in cm or m. The detector height can likewise be specified with "H=". For example, a spectrum taken at a height of 20 cm and a source-detector distance of 50 cm would have "@ 50 cm H=20 cm" in the Title field.

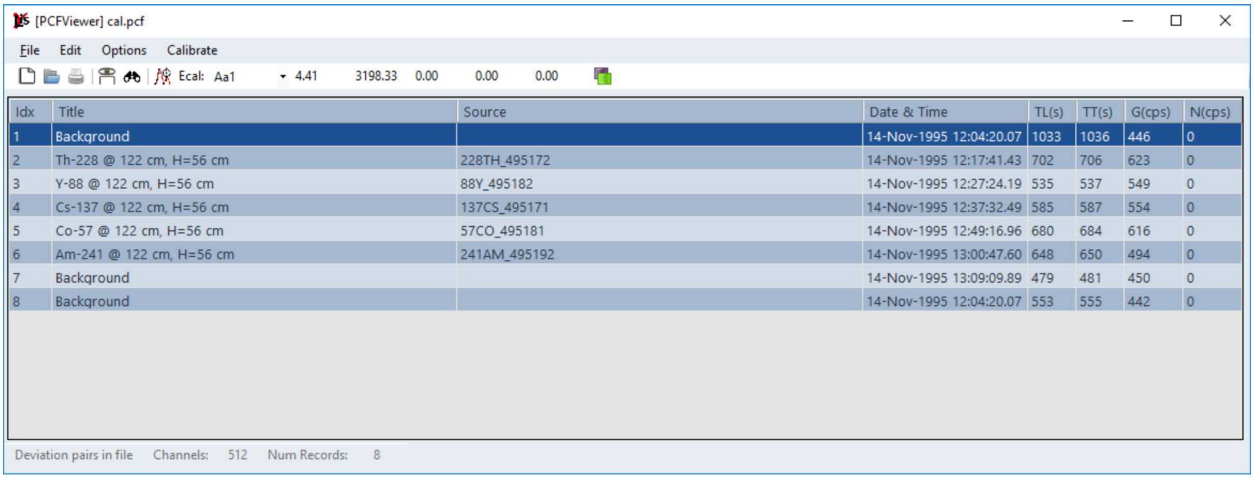

Figure 10. PCF Viewer with Spectrum Records Added

3.2. Editing PCF Files

The **PCF Viewer** edits the contents of a PCF file. Each entry or row in the **PCF Viewer** is a spectrum (record) stored in the PCF file. Editing cells in this table immediately edits and saves the contents of the PCF file. Editable fields include **Tag**, **Title**, **Source, Date & Time**, **TL** (live time),

TT (total time), **N** (neutron count rate), **Offset**, **Gain**, **Order 2**, **Order 3**, and **LowE**. Not all fields are visible by default. Users can modify which columns are visible using the **Select Columns to Display** under the **Options** menu.

The top of the **PCF Viewer** form contains shortcuts and fields with various functionality. From left to right they are:

-  Create a new PCF file
-  Open a spectrum file
-  Print record header information
-  Choose which columns are visible
-  Display spectrum preview thumbnail
-  Peak search energy calibration
- **Ecal**: This displays the energy calibration for all records in the top menu bar, if the energy calibration is the same for each detector (by default there is only one detector). If the energy calibration for one record changes, this editor will disappear.
-  Display/hide energy calibration columns

If a PCF file contains records with different energy calibration parameters, the following icon is displayed instead of the Ecal labels:

-  Overwrite all records' energy calibrations with current record's energy calibration

3.3. PCF Viewer Menu Items

3.3.1. *File Menu*

Under the **File** menu, users can create new PCF files or open existing PCF files; **Import File** will append existing files to the current PCF file (similar to drag-drop); the **Print** command sends the contents of the **PCF Viewer** window to a printer; **Export to CSV…** will export the PCF file record headers to a CSV file.

3.3.2. *Edit Menu*

Each record in the file has its own energy calibration parameters. The **Energy Calibration for All Records** (Figure 11) option allows users to modify all records simultaneously.

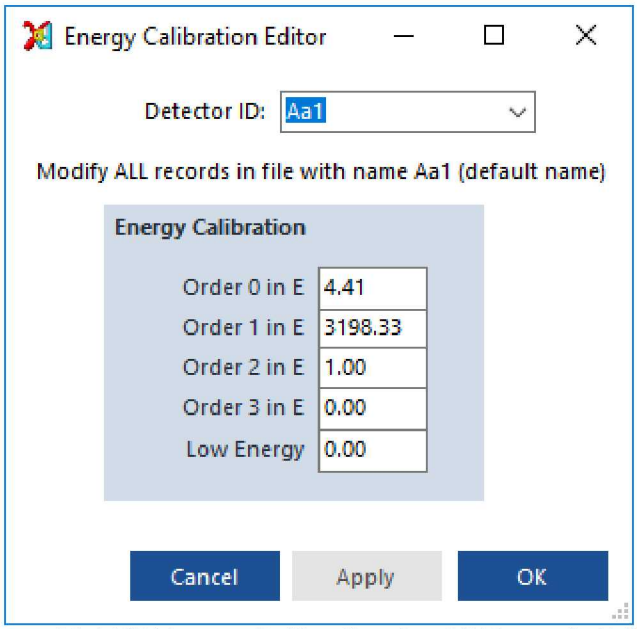

Figure 11. Edit Energy Calibration for All Records Editor

The **Deviation Pairs** menu option brings up the **Deviation Pair Editor** form, which is discussed in Section 6.3.

Reformat All Titles allows users to normalize their title formats for large files quickly. It searches for Distance, Height, and Detector Name information and reformats them to a standard.

Update with .lis file imports a file formatted in the .LIS format (normally exported header information from a PCF into the GADRAS Temp folder), and overwrites the current file's header information with information from the .LIS file.

If users inadvertently change a field in the PCF file, they can choose **Restore to Last Backup** in the **PCF Viewer**'s **Edit** menu.

3.3.3. *Options Menu*

Users can modify which columns are visible using the **Select Columns to Display** under the **Options** menu. The **Options** menu also has an option to toggle the spectrum preview window on the right side of the **PCF Viewer**.

3.3.4. *Calibrate Menu*

3.3.4.1. Peak Search Calibration All Records

Figure 12 shows the Peak Search and Manual Energy Calibration form. Users can drag-drop a record (row) from the PCF table into the blank portion of the **Peak Search** window. Users can drag right over regions of interest to zoom in. To zoom out, drag left. Clicking a peak in the spectrum will include the peak in the fitting routine. Peaks recognizable by GADRAS for this procedure are shown in *red* above a *green* continuum with the default 5 sigma peak threshold, as shown in Figure 12 *(right)*.

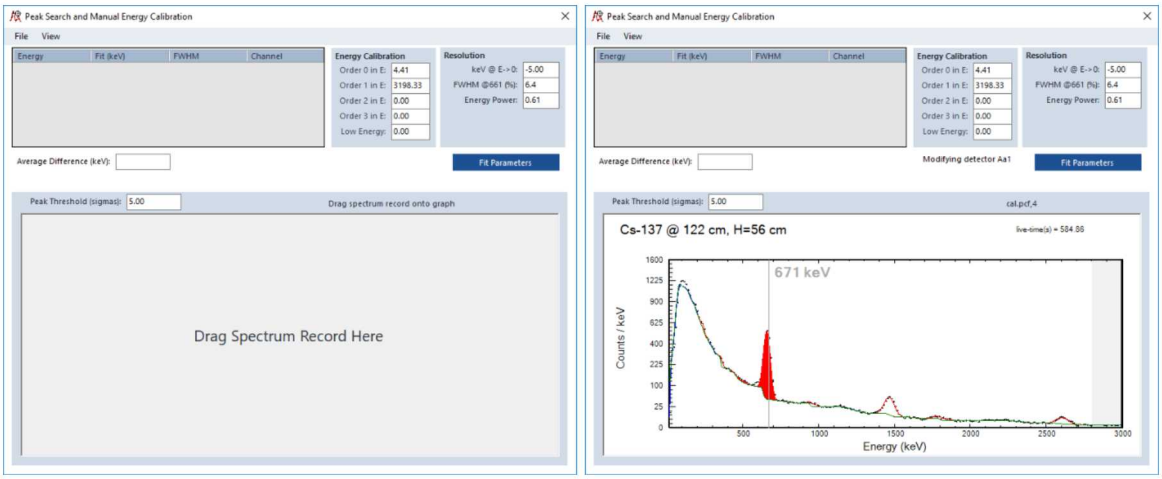

Figure 12. The Peak Search and Manual Calibration Screen is Blank When First Opened (*left*) and Populated When a Spectrum is Loaded (*right*)

The **Peak Threshold (sigmas)** option can either be lowered to recognize additional peaks or raised to recognize fewer peaks. Clicking a peak will open a window prompting the user to specify the energy of the peak as shown in Figure 13. If the centroid energy is close to a known peak for an isotope included in the GADRAS library, the isotope will be displayed along with the determined gamma-ray energy. Other peaks and energies around the determined value are also listed. The initial peak energies are based on the detector's current energy calibration parameters. Users may select the appropriate isotope and energy in the provided list, or they may manually enter the appropriate energy for the isotope. Clicking **OK** assigns the Actual Energy selected to the channel number in the spectrum. This process can be repeated for any number of available peaks in the measured spectrum as needed to complete the channel/energy table (although selected peaks should be spaced more than 200 keV apart).

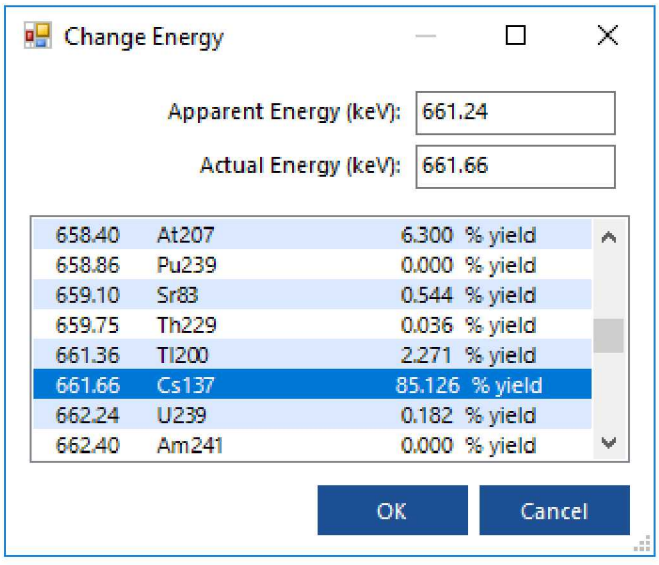

Figure 13. Users Can Select the Energy of the Peak From the Popup Window, or Manually Enter the Known Energy

After entering an appropriate number of peaks in the channel/energy table, energy calibration adjustments can be performed. The upper-left portion of Figure 14 displays the two energy peaks that were selected for energy calibration (channel/energy table) and the upper-right portion displays the **Adjust Parameters** tab. The highlighted (*orange*) parameters will be adjusted. After the peak selection process is complete and the appropriate parameters are adjusted, clicking the **Fit Parameters** button below the parameter group boxes will initiate the least-squares fit to the data.

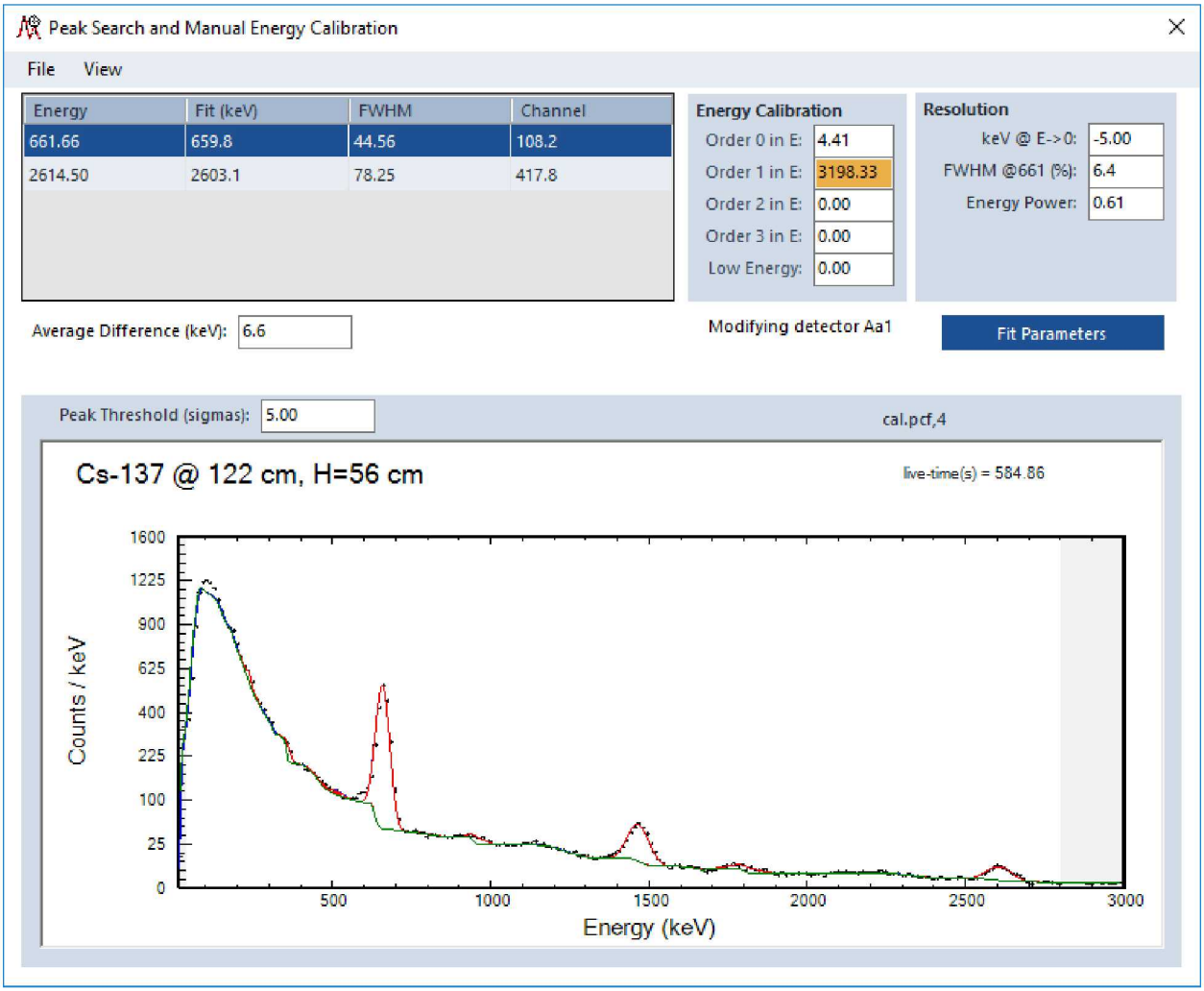

Figure 14. Energy Calibration Screen Showing the Selected Peaks and the Highlighted (*cyan*) Parameters that will be Adjusted (*center*)

To ensure a proper energy calibration, a small subset of well-known peaks should be selected. GADRAS will then properly assign energies for subsequent peak selection.

It is usually advisable to use **Order 0** and **Order 1** for an initial energy calibration, and then to include higher orders if the fits are not acceptable. The **Order 1** energy parameter should be approximately equal to the full scale energy value of spectrum in keV (e.g., 1500, 3000, 11000) depending on the detector. In general, small values are common for **Order 0**, **2**, and **3** energy parameters. Once the energy offset and gain (**Order 0 and Order 1**) parameters are adjusted correctly, the energy resolution parameters should be adjusted.

3.3.4.2. Linearize All Records

This option uses the energy calibration from each record, along with any deviation pairs defined, to determine the energy bounds for each record. It then rebins all records into a linear channel-group structure, such that the calibration is defined only with a gain term (zero offset). The deviation pairs in the file are erased.

3.3.4.3. Calibrate and Linearize All Records

This option, in addition to the linearize option, attempts to automatically calibrate each spectrum. This can be done for each record based on the 2614 keV peak, 1460 keV peak, or based on each records' **Tag** character. The following **Tag** characters are acceptable in this context:

- T only adjust gain based on 2614 keV peak
- t adjust gain and offset based on 2614 keV peak and 239 keV peak (use 583 keV peak if available)
- K only adjust gain based on 1460 keV peak

3.3.4.4. Automatic Energy Calibration Tool

This tool searches the entire spectrum for common background peaks, and fits the energy calibration parameters, resolution parameters, and skew parameters automatically. It gives users the option to write the fitted parameters to all records in the file, or just the one that was used to search for background peaks.

4. PLOTTING/VIEWING SPECTRA

4.1. Measured Spectra

Users can plot one or more gamma-ray spectra from the Plot tab (Figure 15).

A record from a PCF file can be plotted by dragging and dropping an entry from the **PCF Viewer** to the **Measurements** table. The **Measurements** table consists of four columns. The first column is the plot style for the measurement. The second column is the title of the foreground spectrum. The third column is the foreground spectrum file name and record. The fourth column specifies the background. Users can manually specify foregrounds or backgrounds by double-clicking the cell and typing into the table. The cell will suggest autocomplete values for the foreground or background using all the known spectral files in the current detector folder. The background will be time-normalized to the foreground. Clicking the **Plot** button will display the desired background-subtracted spectra. Figure 16 shows a plot of a background-subtracted ^{228}Th measurement.

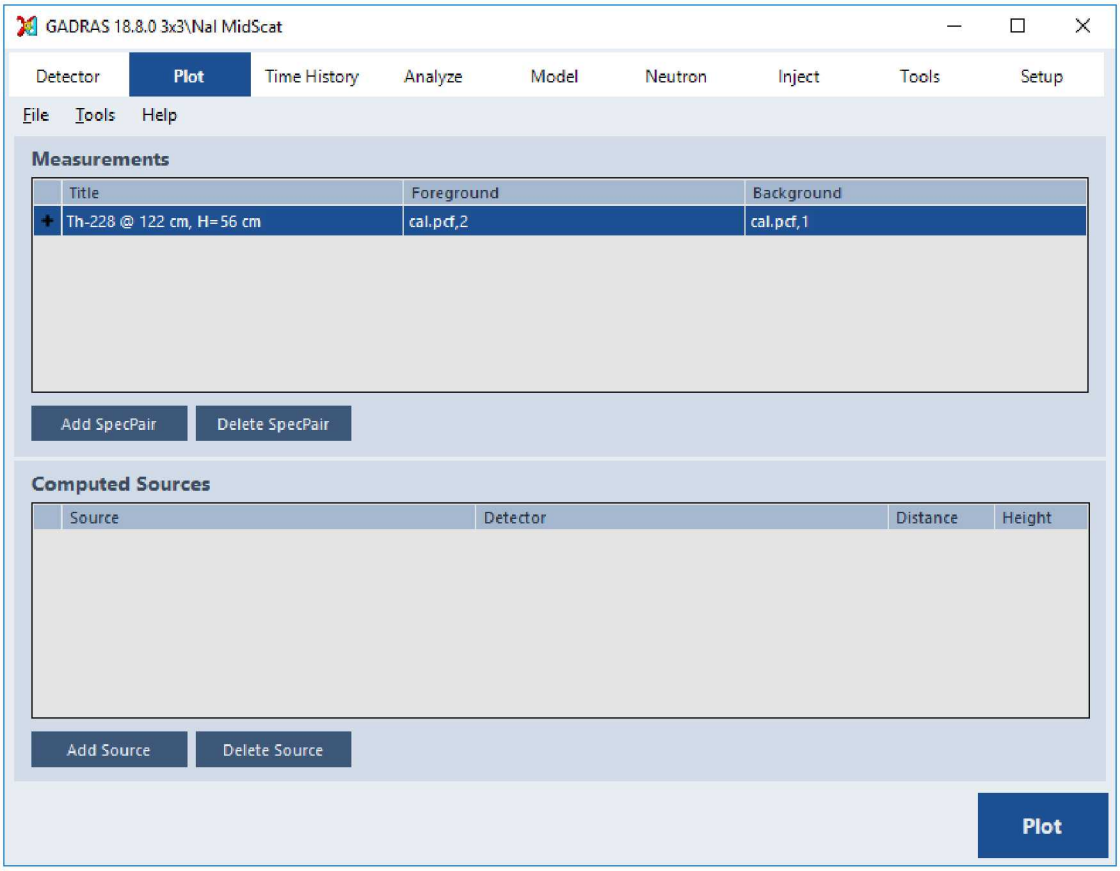

Figure 15. Plot Tab with Entries to be Plotted From the "Cal.pcf" File

The **Add SpecPair** and **Delete SpecPair** buttons in the middle of the screen are used to add or remove measured spectra from the drawn plot. When the **Add SpecPair** button is clicked, GADRAS adds the subsequent record from the current PCF file to the **Foreground** spectrum. The previous **Background** record is maintained by default. If the previous **Foreground** record was the last record in the PCF file, the same foreground is added to the table again. The plot style can be changed for a measurement by clicking on the plot style cell in the measurement table.

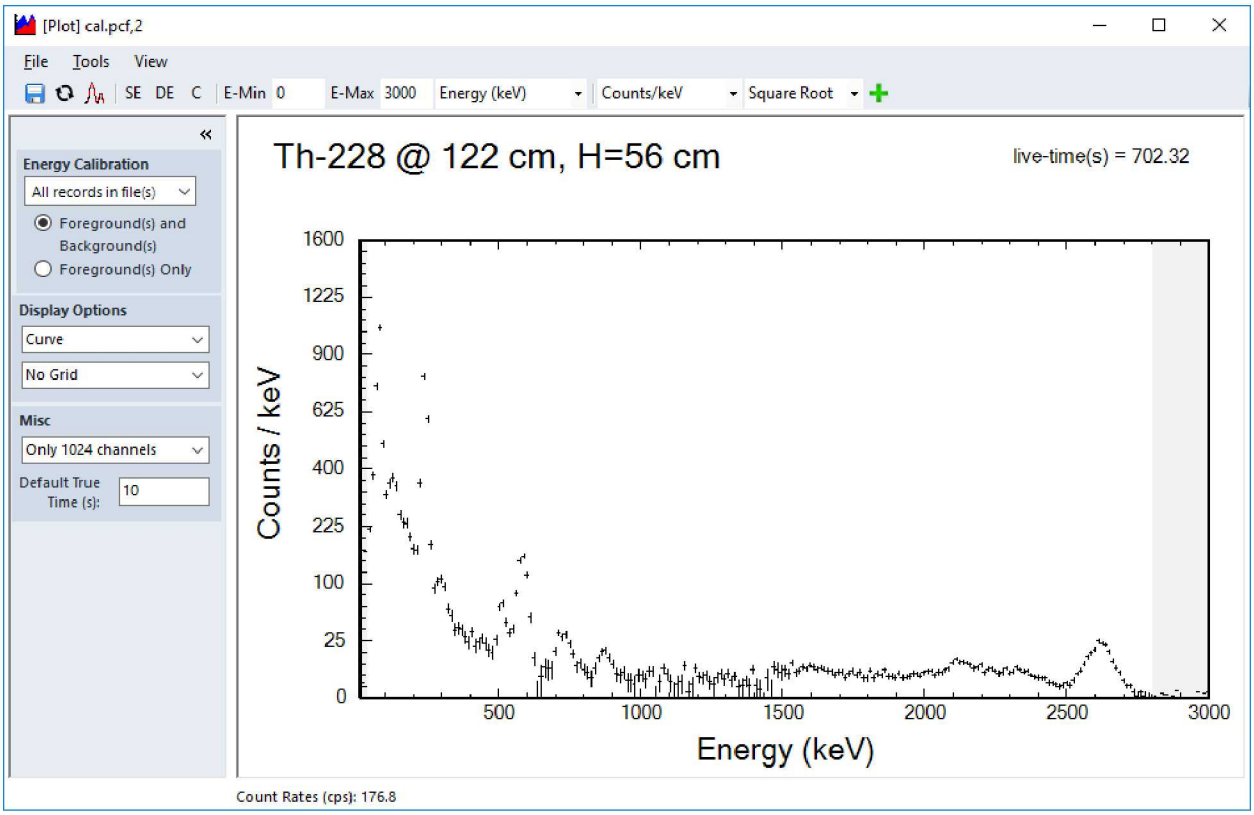

Figure 16. Plot of Background Subtracted ^{228}Th Spectrum

Figure 17 shows a plot with three spectral pairs selected for graphing. These pairs are displayed in the central white area of the **Plot** tab. Up to six spectra can be selected and displayed in a single graph.

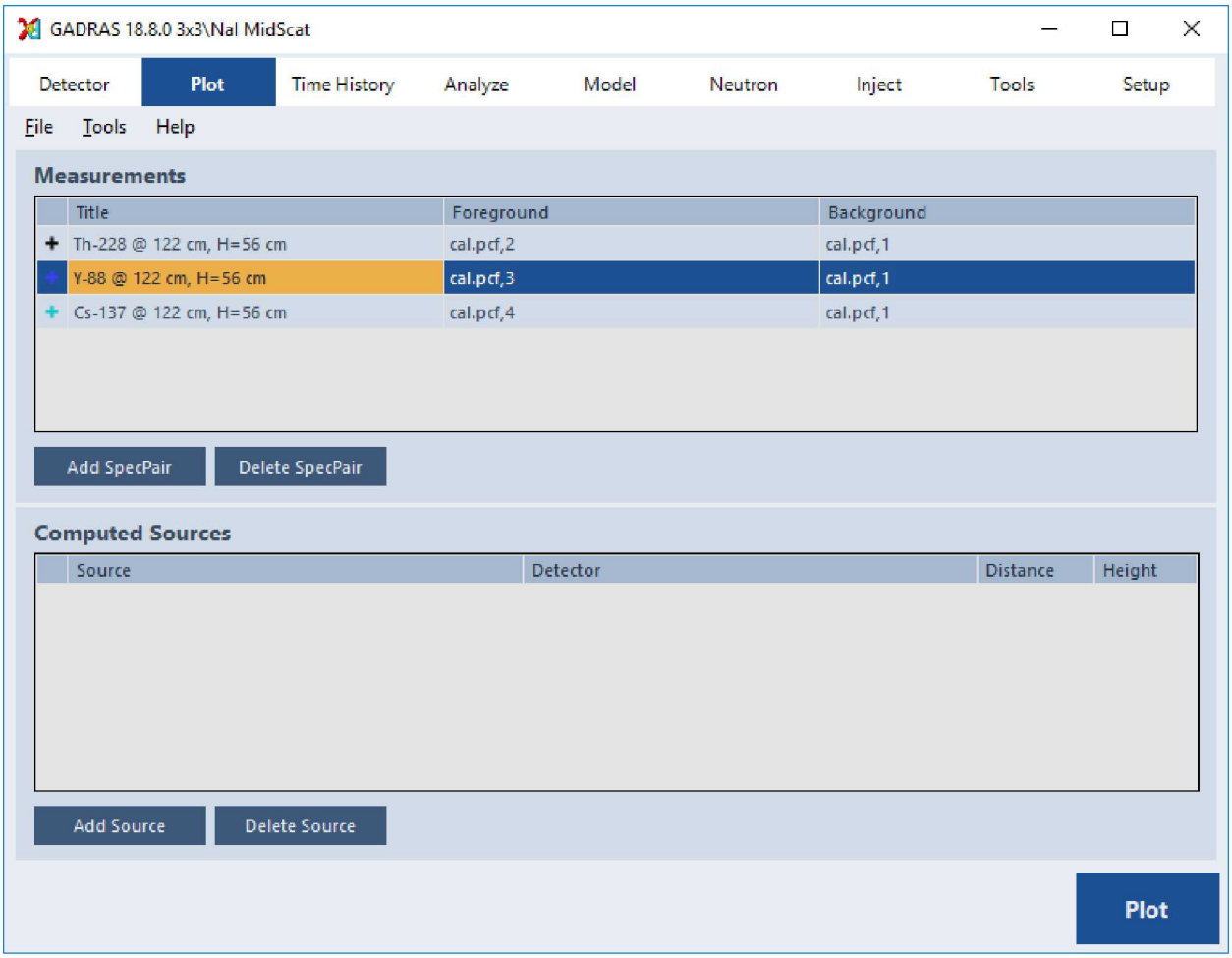

Figure 17. Plot Tab Example with Three Background-Subtracted Spectral Pairs

Figure 18 shows the graph of the three spectral pairs identified in Figure 17. The graphs are identified for each spectrum by the color selected in each style cell in the **Measurements** table.

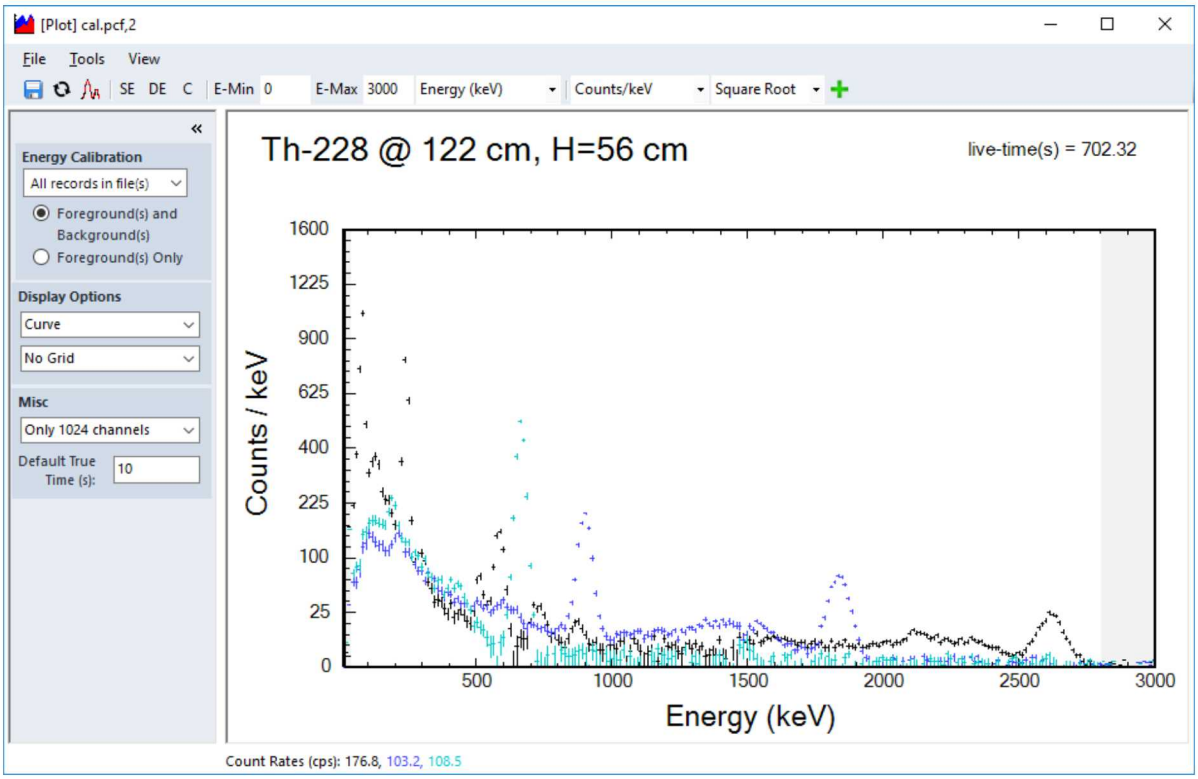

Figure 18. Plot of the Three Background-Subtracted Spectral Pairs: ^{228}Th (*black*), and ^{88}Y (*blue*), and ^{137}Cs (*cyan*).

Figure 19 shows the Plot Style selection form. From here, the color, symbol, and line style for a measurement or computed spectrum can be specified. Common presets for HPGe and NaI spectra can also be selected.

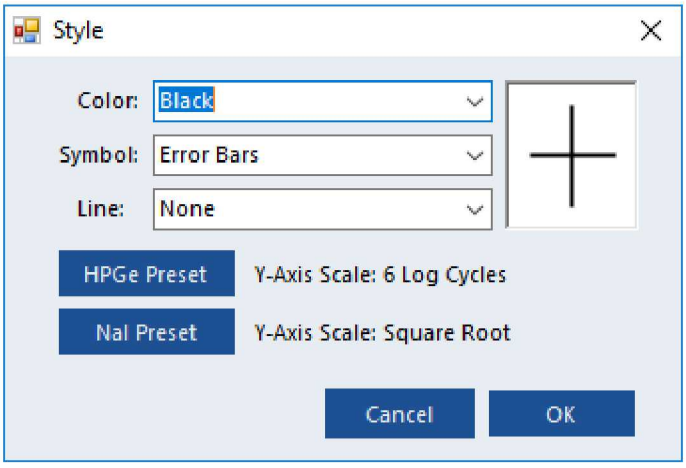

Figure 19. Plot Style Selection Window

4.2. Plotted Spectrum Window

After the plot is displayed, navigation can be done with the mouse. Drag from left to right to zoom in on a region of interest as shown in Figure 20. Dragging from right to left a small amount will partially zoom out. Dragging from the right to left a large amount will completely zoom out.

Scrolling the mouse wheel will change the number of log cycles displayed or switch between square root, linear, and logarithmic scales.

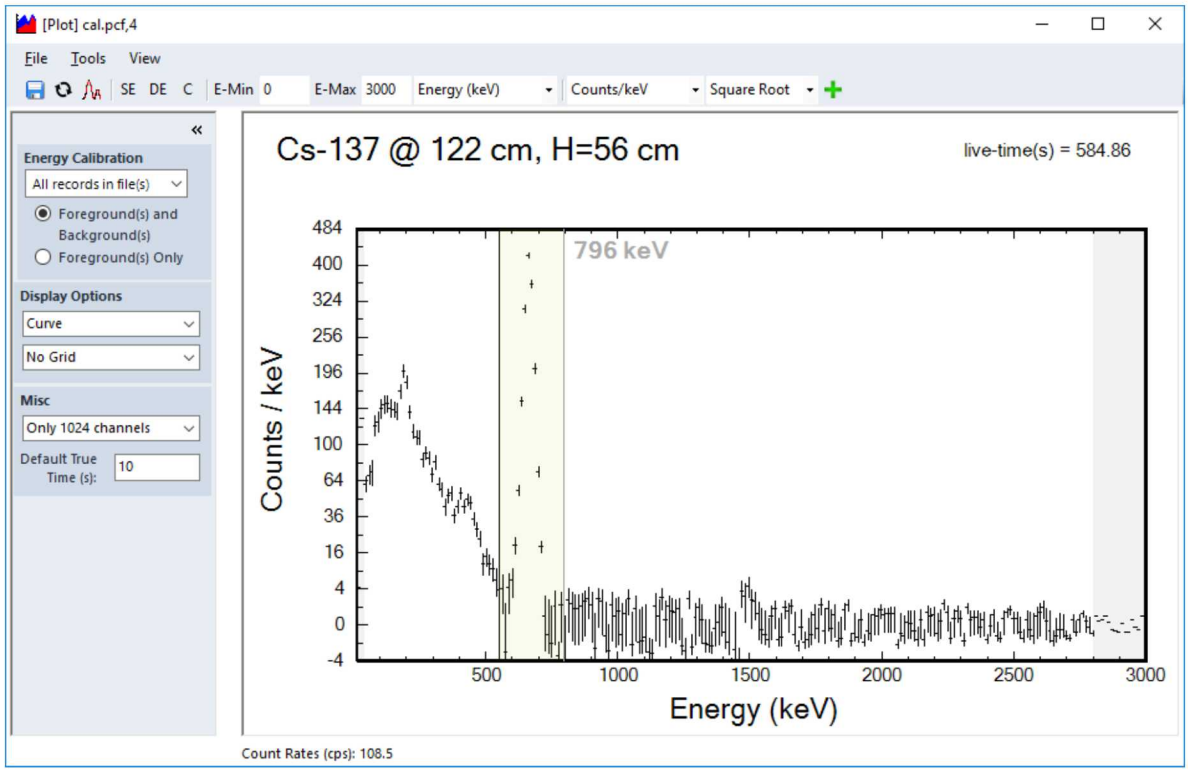

Figure 20. Zooming-in on a Plotted Spectrum

The top of the plot window shown in Figure 20 contains shortcut buttons and additional options. Starting from left-to-right, they are:

-  Save the computed spectrum to file
-  Reset the zoom (zoom out completely)
-  Enable/disable peak search mode
- **SE** Show the single-escape line (see Figure 21)
- **DE** Show the double-escape line (see Figure 21)
- **C** Show the location of the Compton edge (see Figure 21)
- **E-Min / E-Max:** These are default limits of the plot in keV.
- **Channel Number or Energy (keV):** This drop-down box allows users to view both channel number and energy, or just energy units on the x-axis
- **Counts/keV or Counts/Channel:** This drop-down box changes the normalization factor for the channel bins (normalize by energy, or normalize by channel).
- **Log Cycles or Square Root or Linear:** This drop-down changes the scale of the y-axis. This scale can also be modified with the mouse-wheel.
-  Toggle between showing positives only or showing both positive and negative values

On the left-hand side of the plot window is a collapsible panel containing additional plot options. From top-to-bottom, they are:

- **Energy Calibration:** These options modify the behavior of graphical energy calibration (see Section 6.2 for more detail on graphical energy calibration). The drop-down box specifies which spectra are to be modified (each record has its own coefficients). By default, all records from all files plotted are modified. Users can choose to only modify all the spectra that are plotted, or an individual spectrum plotted. The ability to modify the energy calibration of a single spectrum from a file is useful if there is gain or offset drift between measurements.

  Under the drop-down box there are two radio buttons to select whether the energy calibration coefficients for the foreground and subtracted background are to be modified (default), or just the foreground.

- **Display Options:** The first drop-down box has three choices to display how spectra are plotted. This only has an effect on line-style plotted spectra, not on "error-bar" style plotted spectra. The options are Curve (Default), Histogram, and Bar Chart.

  The second drop-down box controls the grid on the chart. By default, only the x-axis and y-axis at zero are plotted (Zero Crossings). Users can turn off all grid lines (No Grid), or shown them throughout the chart (Dotted Grid).

- **Misc:** The first drop-down box contains smoothing options. The default is to display at most 1024 channels. However, if a user zooms in to a region that has less than 1024 channels, no rebinning is done and all channels are displayed. Other options include 512 channels, Smooth Magic, Smooth by FWHM, No Smoothing (display all channels), and a variety of smoothing options by percent of energy. These only affect how the spectrum is viewed, not any analysis or computations.

  The default true-time is only used when only a computed source or calibration source is plotted without a foreground (from which the true-time is extracted).

4.2.1. *File Menu*

The **File** menu consists of the following options:

- **Copy to Clipboard** copies the plot screen to the clipboard as an image and can be pasted into another application
- **Write Computed Spectrum to File** saves the computed spectrum to a pcf file for future plotting
- **Save to Metafile** saves the plot screen to an image file (.emf)
- **Save to Sum Spectrum** saves Time History sum graph to separate file
- **Save Flux File** saves flux file for Compute Flux analysis on Time History spectrum
- **Print**: allows users to print the displayed graph
- **Export Plotted Spectra to CSV**: allows users to export all spectra to CSV format

4.2.2. *Tools Menu*

The Tools menu provides options for graph properties, peak lists, and count rates:

- **Zoom to Extents**: zoom the graph out to the full energy limits
- **Count Rates**: provides the count rate for each of the graphed spectra at the currently displayed energy limits
- **Peak Search Mode**: provides energy and count rates for peaks in the spectrum in graphical and list form
- **Edit Deviation Pairs**: allows the user to view and edit the deviation pairs associated with the current spectrum
- **Show Peak List**: displays a list of peaks that can be overlaid on the spectrum; by selecting an entry, all peaks from the specified source and threshold will be displayed (this option is discussed in more detail in Section 6.1.1).
- **Show Isotope DB**: displays the Isotope Database for use in analyzing displayed spectra (discussed in Section 6.1.2)

4.2.3. *View Menu*

The **View** menu allows users to display common features of a plot using the cursor. When users select any of Single Escape, Double Escape, or Compton Edge, the cursor location on the spectrum is used as a starting point and energies of the specific features are calculated and displayed on the screen (Figure 21).

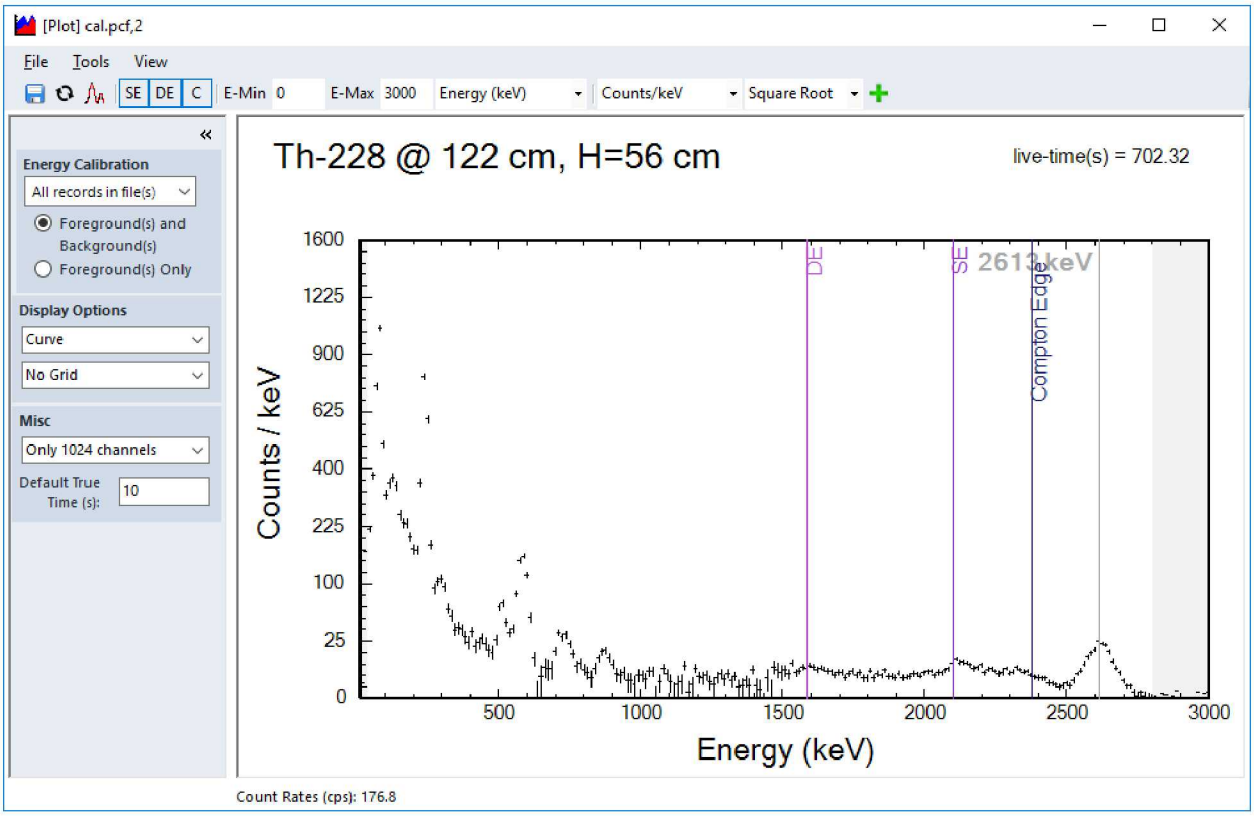

Figure 21. Spectral Features from View Menu

4.3. Computed Sources

Besides displaying measured spectra, GADRAS can also display computed spectra. Sources for computed spectra are entered in the **Computed Sources** table on the bottom of the **Plot** tab. Some measurements have computed sources already associated with them. If a foreground is added to the **Measurements** table, the associated computed source will be added to the **Computed Sources** table. Users add computed sources by clicking the **Add Source** button at the bottom of the **Computed Sources** table. There are numerous ways to specify the source, most of which are accessible by right-clicking the source cell (see Figure 22).

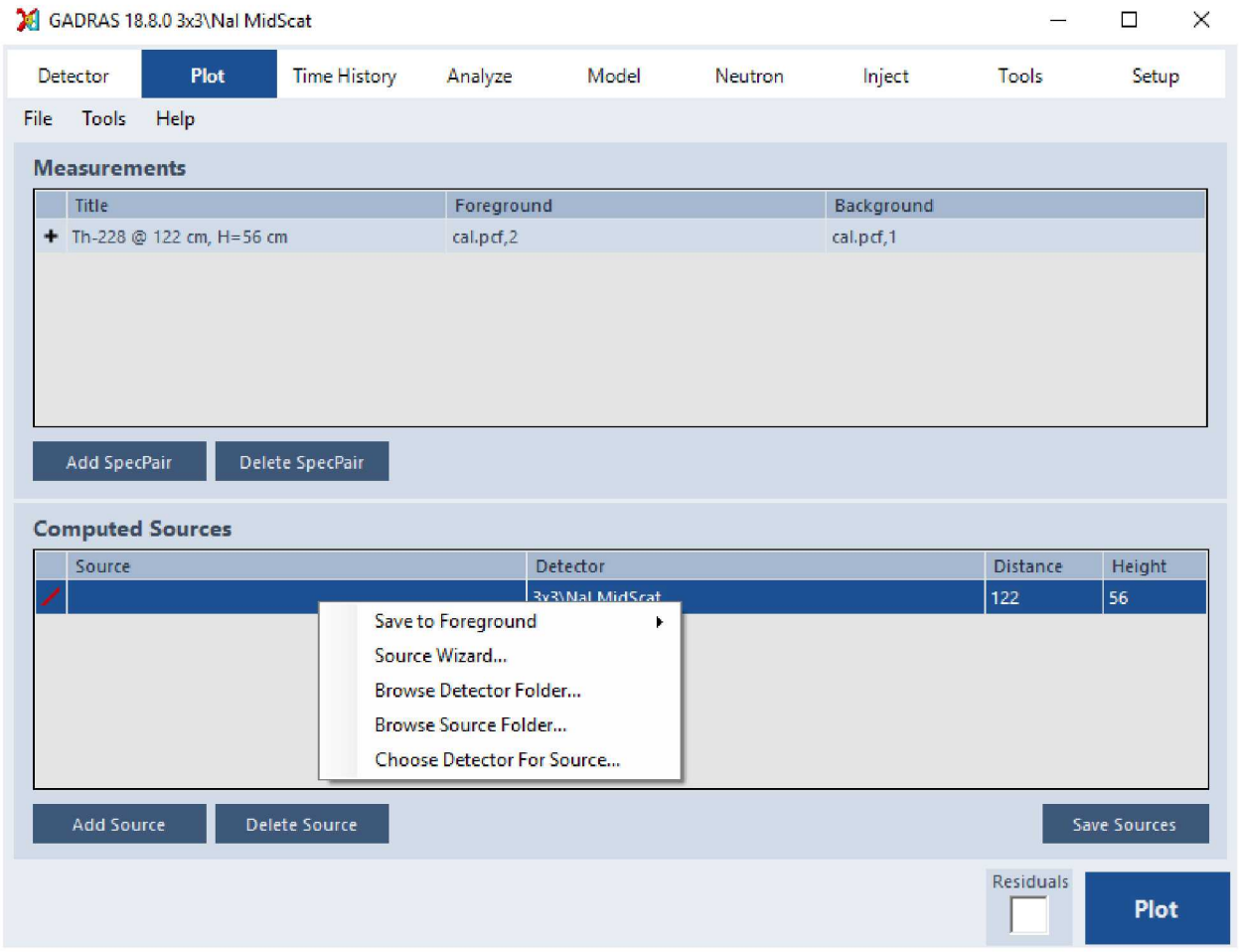

Figure 22. Right-click menu to show computed source options

4.3.1. *Source Wizard*

The **Source Wizard** option shown in Figure 22 allows users to add sources quickly and view all options for the source. The **Source Wizard** form is shown in Figure 23.

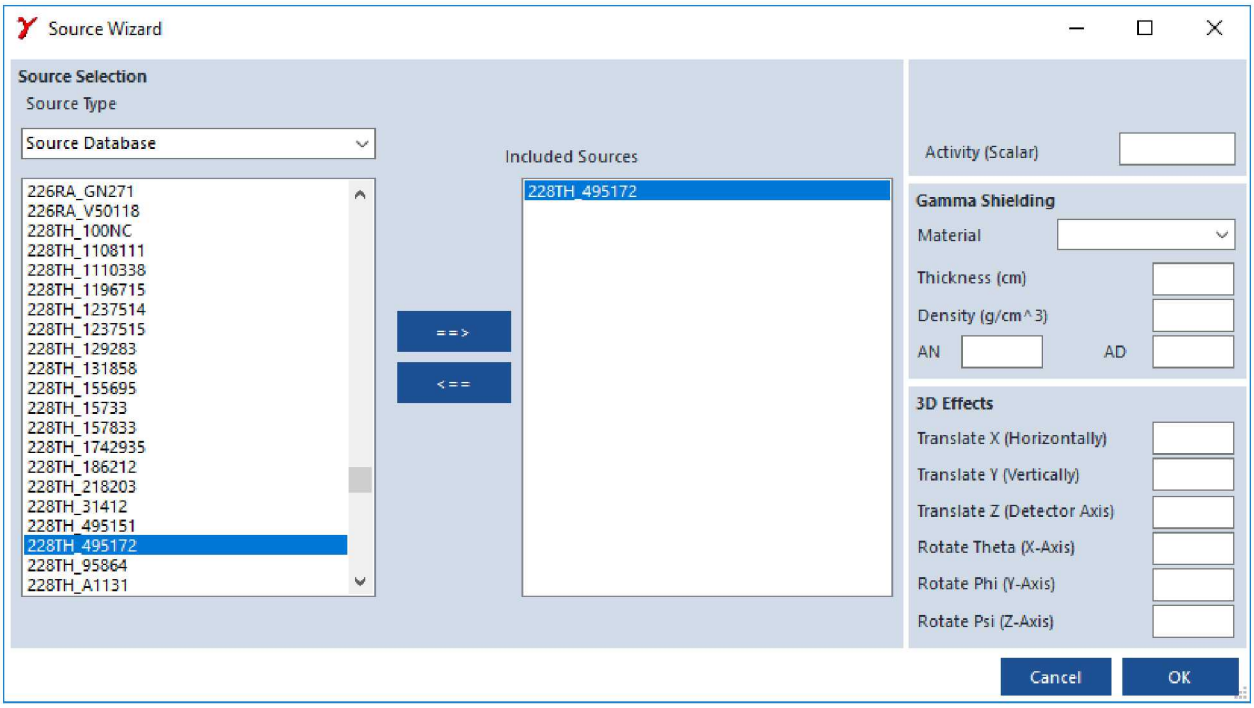

Figure 23. Source Wizard Screen

The drop-down menu in the source wizard allows users to select various types of sources, such as radionuclides and distributed GAM files. Users can use the arrows in the center of the window to add or remove sources from the current list of **Included Sources**. The third column on the far right of the Source Wizard allows users to edit the source activity, the GADRAS shorthand notation for shielding, or to apply 3D Effects. After clicking **OK**, the Source Wizard will automatically generate the GADRAS shorthand string in the Computed Spectrum text box.

4.3.2. *Browse Folder for Source*

Users may browse the current Detector folder or a subfolder of the GADRAS Source folder for computed sources. Figure 22 shows options for **Browse Detector Folder** and **Browse Source Folder**. These options will allow users to browse the selected folder for a source to plot. Users can modify the source line manually or use the Source Wizard to specify more options for the source, or to add more sources.

4.3.3. *Other Computed Source Options*

Users have the option of saving a computed source to a given measurement. Users can right-click a source and hover over the **Save to Foreground** option to list the measurements that the source can be saved to, as shown in Figure 24.

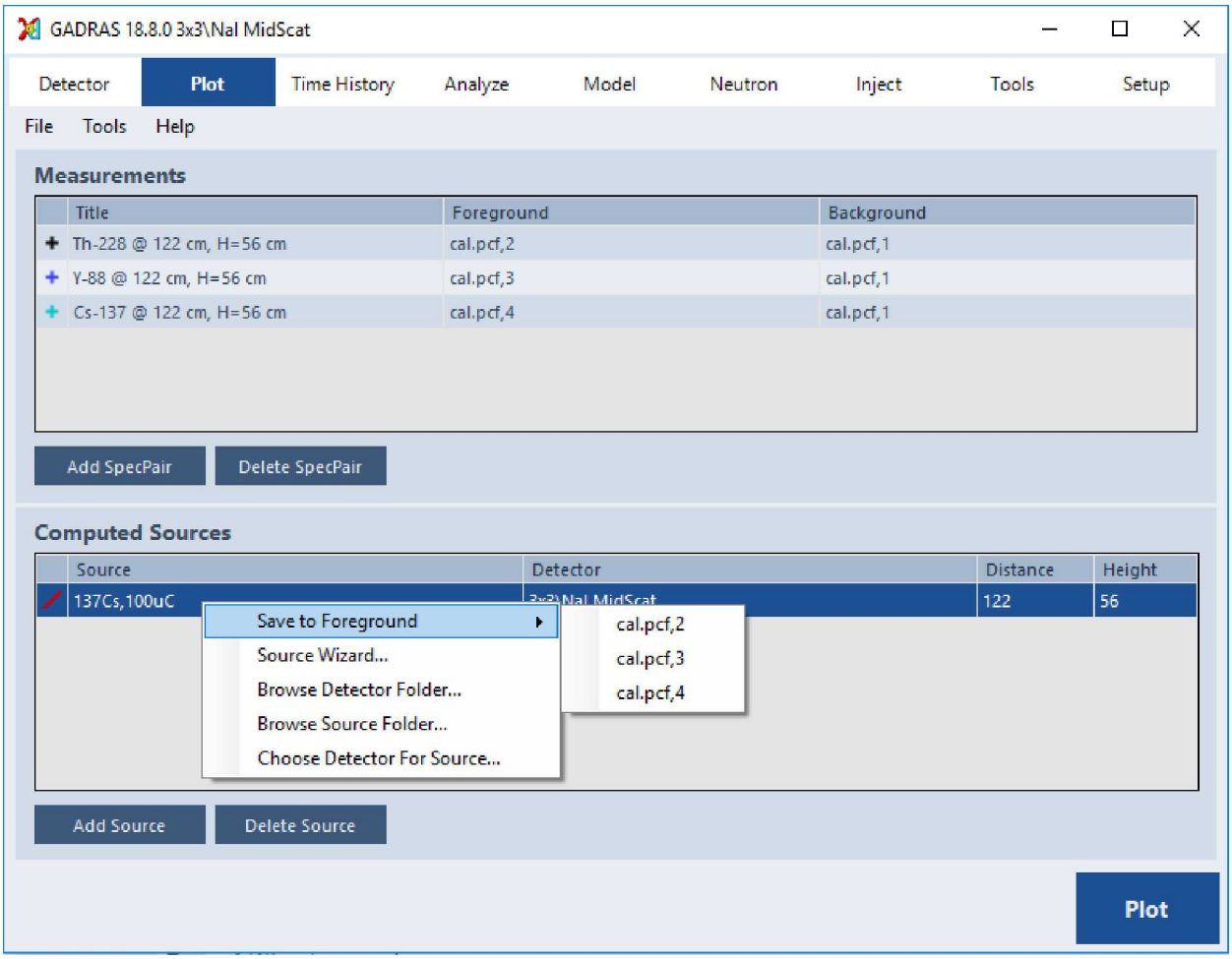

Figure 24. Users can save a computed source to a measurement

By default, the current gamma detector will be used when computed the detector response for the specified source. Users may change the detector to be used for the response if desired. This is done by selecting the **Choose Detector For Source…** option and navigating to the desired **Detector.dat** file. Alternatively, users can double-click on the detector cell and navigate to the desired **Detector.dat** file. The **Distance** and **Height** fields can be updated for the computed sources by typing in the cell.

4.3.4. *Simulated or Calibration Source*

In lieu of using the source wizard option, the user can enter source information manually in the computed source cell. To do this, highlight the cell and begin typing.

Sources may include:

- The name/serial number of a calibration source in the source library/database
- Distributed GAM files
- Isotopic designation and source strength (e.g., **232U, 1.5uC**)
- 3DM files (for 3D scenarios)
- A single-energy source (e.g. 200 keV)

- An x-ray from an element (e.g. AgXray)

Activity units for the computed spectrum are always given in Curies (shortened to "C" instead of the standard "Ci"). This unit may be prepended with the following SI prefixes (not case-sensitive):

- pC: picoCuries
- nC: nanoCuries
- uC: microCuries
- mC: milliCuries
- kC: kiloCuries

Alternatively, Becquerel units can be input using the following SI prefixes (also not case sensitive):

- kBq: kiloBecquerel
- MBq: megaBecquerel
- GBq: gigaBecquerel

Mass or activity of a source can be specified and used for plotting. The mass is converted to the proper activity prior to plotting (e.g., **239Pu, 50g** is converted to **239Pu, 3.1C**).

When **GAM** files are used, a scaling factor for the source can be applied by appending a number after a comma. For example, "example.gam,2" indicates that the source strength of example.gam should be doubled in the computed spectrum.

The simulated/computed spectrum can be a mixture or sum of several sources. The individual sources can be summed by placing a plus (+) sign between the successive sources (e.g., 232U, 1uC+40K, 25mC). Gamma-rays emitted by the specified isotopes are folded through the detector response function to compute the spectrum that would be recorded if the detector were exposed to the combination of the specified sources. If a single measurement/computed source pair is plotted, the reduced χ^2 metric for the measured and computed spectra is calculated and displayed.

4.3.5. *Viewing Spectra*

Figure 25 shows the **Plot** tab with a ^{88}Y spectrum (cal.pcf, 3) in the foreground cell and a background spectrum (cal.pcf, 1) in the background cell. The **Computed Sources** table shows that the measured spectrum is to be compared with the computed spectrum for the ^{88}Y source with serial number **495182** entered as 88Y_495182.

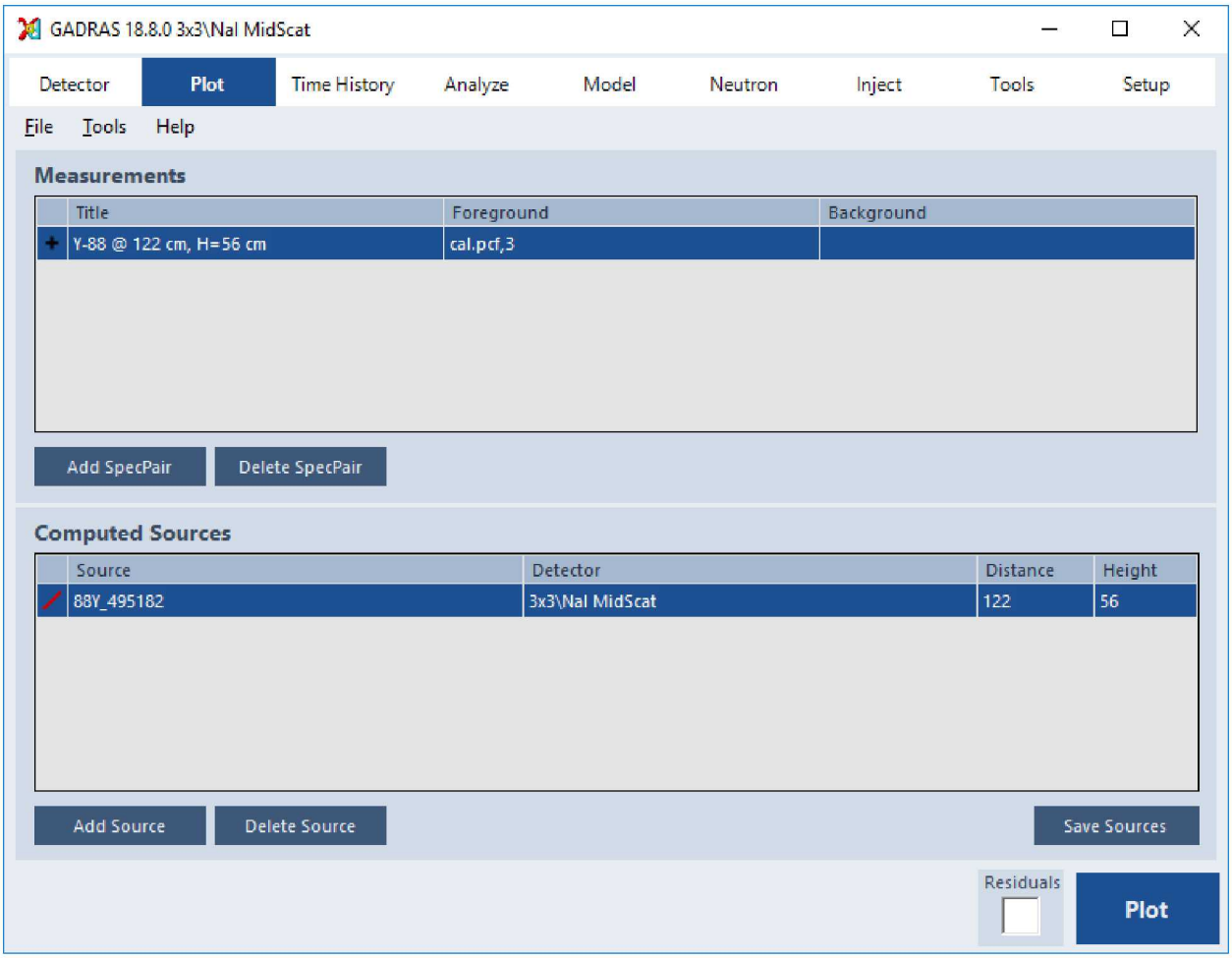

Figure 25. The Plot Tab Displaying Selections for a Foreground, Background, and Computed Spectrum

Figure 26 is generated after the **Plot** button is clicked. The measured ^{88}Y spectrum (background subtracted) is displayed in *black*, while the computed spectrum for the ^{88}Y source (ID number: 495182) from the source library is displayed in *red*. The count rate is displayed at the bottom left of the graph for all graphed spectra for the displayed energy region. The count rates are color coded to match the color of the corresponding spectrum.

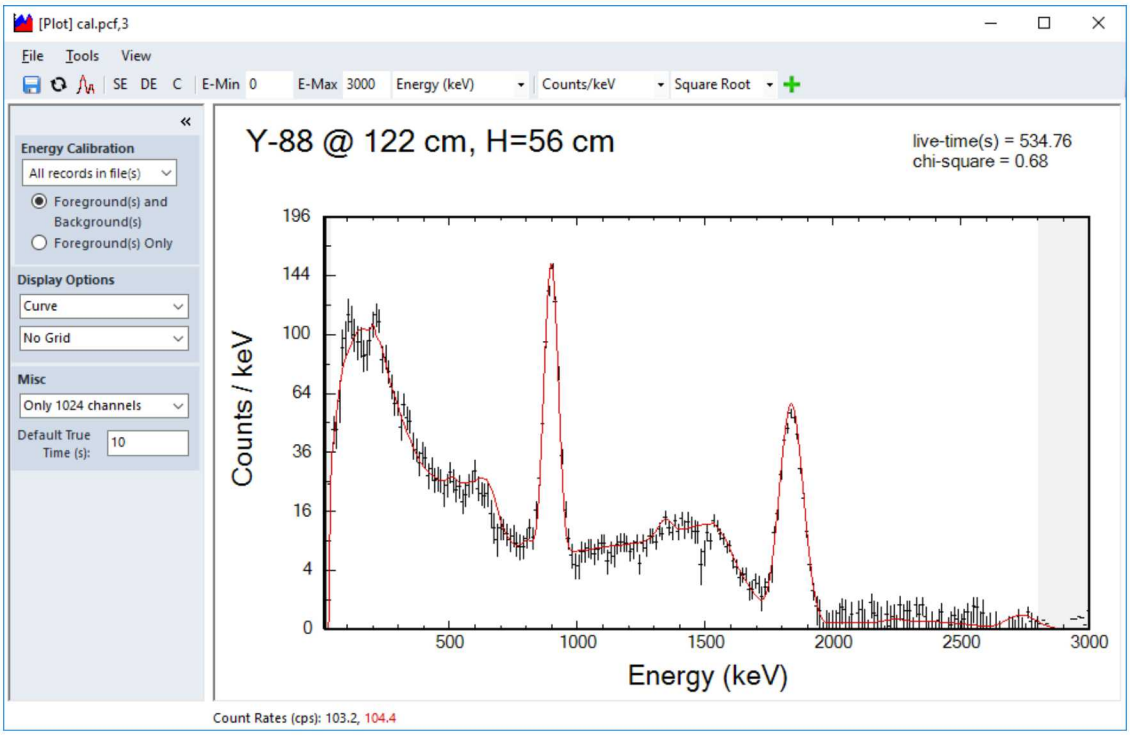

Figure 26. Plot of a Measured ^{88}Y Spectrum (background subtracted) and the Computed Spectrum from ^{88}Y Calibration Source

Computed sources may be plotted by themselves by deleting all the measurements in the **Measurements** table. If desired, effects of shielding materials can be estimated by specifying the material in the source cell. The atomic number and areal density of the absorbing material can also be entered on the input line using the following convention:

232U,10uCi {AN=26, AD=10} + 137Cs,3.2mCi {AN=13, AD=5}

In this example, 10uCi of ^{232}U is propagated through 10 g/cm^2 of iron (Z=26), and 3.2mCi of ^{137}Cs is propagated through 5 g/cm^2 of aluminum (Z=13). This functionality is also accessible from the Source Wizard form, described in Section 4.3.1.

5. COUPLING GADRAS TO EXTERNAL RADIATION TRANSPORT CODES

To accurately model very complex sources or sources in complex scattering environments using GADRAS, an external code should be used to perform the radiation transport calculations. Radiation transport codes such as the Monte Carlo N-Particle (MCNP) code, developed by Los Alamos National Laboratory, can be used to model sources and scattering environments. This section describes how users should set up external radiation transport codes (specifically MCNP but the same procedure can be generalized for use with other codes) to use with GADRAS.

GADRAS calculates the detector response for radiation directly incident on the detector as well as for radiation that has scattered in the environment before interacting with the detector. To calculate the scattered radiation, GADRAS has several scatter parameters which simulate a general scattering environment. External transport codes can be used to calculate the incident radiation instead of GADRAS. To do this, the external code should be used to model the radiation current separately on multiple facets of the detector. Using the results, GADRAS can compute gamma-ray spectra and neutron count rates for a given scenario. These results may have a higher degree of fidelity than can be obtained by applying the GADRAS's radiation transport methods. If a source cannot be approximated with a point source, an external code can be used to calculate the radiation transport from the source to the detector with a higher degree of fidelity than GADRAS alone.

The setup for the scenario should be designed to simulate the external scattering environment and tally the energy-dependent current on each surface of the modeled detector. The output files should then be converted into files that are compatible with GADRAS. These input files are called "multi-faceted GAM files." GADRAS processes these multi-faceted GAM files by calculating the detector response from the radiation that scatters within the detector housing, assuming that the external transport code has accounted for the external radiation scattering.

To correctly process multi-faceted data generated by other codes, users need to suppress GADRAS's external scatter radiation calculations by setting all of the scatter parameters to zero (Figure 27). The radiation transport code must tally photons and neutrons that scatter into the detector from the floor, walls, ceiling and any other object in the detector's vicinity; GADRAS will account for radiation scatter within the detector.

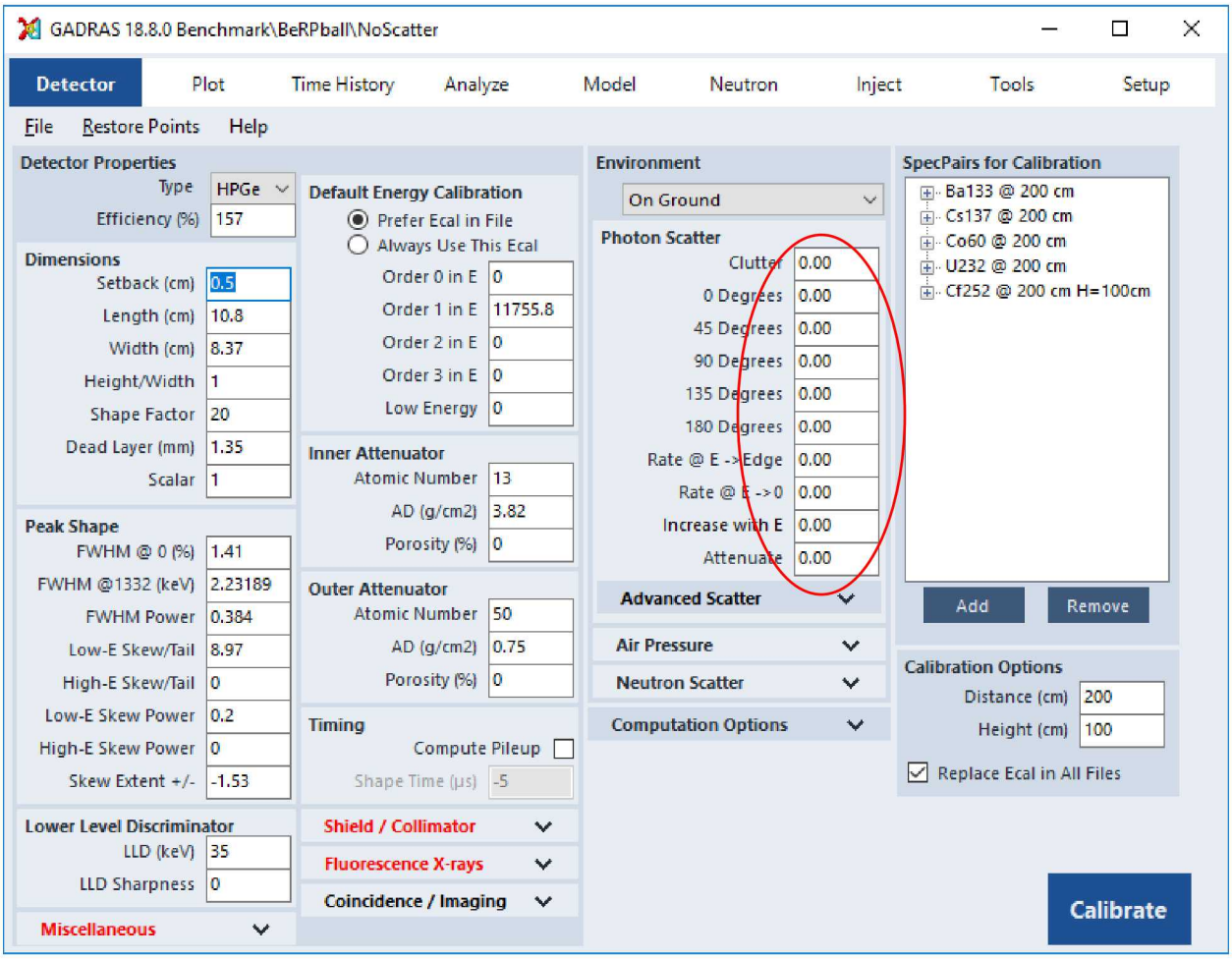

Figure 27. Set all Scatter Parameters to 0 When Using Multi-faceted GAM Files

5.1. MCNP Methodology

To compute the detector surface currents for a given scenario, the MCNP model should contain a cylindrical volume representing the detector. The cylinder should be positioned at the detector location with dimensions similar to those of the detector. The current tally (F1) should be used to tally the photons and neutrons that cross each individual surface (front, back, sides). The pulse-height tally (F8) is not appropriate for use with GADRAS, as this tally represents the detector response function generated by MCNP and cannot be readily converted to a format that is usable by GADRAS. The current tally should be generated with the energy bin structure provided with the GADRAS distribution in the "MCNP-photon-tally-bins.dat" file (usually in **C:\GADRAS\Program\Documentation\CouplingExternalTransportCodes**). Figure 28 below shows a simple example of a ^{127}Cs source 1 meter away in air. A photon importance of zero in the detector cell ensures that the tally does not double-count particles that pass through the detector volume.

```
Simple Example Input Deck
1 0 -1 imp:p=0 $ detector volume
2 1 -0.0012 -2 1 imp:p=1 $ surrounding air
3 0 2 imp:p=0

1 rcc 100 0 0  10 0 0  10 $ detector surfaces
2 so 1000 $ universe sphere

mode p
sdef par=p pos=0 0 0 erg=0.6617
m1   7014 -75 $ air
     8016 -25
f1:p 1.1  $ side of cylinder, side of detector
f11:p 1.2 $ bottom of cylinder, front face of detector
f21:p 1.3 $ top of cylinder, back face of detector
e0 {insert values from MCNPbins.dat}
```

Figure 28. A Simple MCNP Input Deck

The MCNP output file needs to be converted into a format usable by GADRAS. The tally from MCNP should be converted into surface current density (particles/m^2s) for each energy bin. To do this, the source activity, particles per decay, and detector facet surface areas must be known. Figure 29 below shows an example of the necessary unit conversion for a 1 uCi ^{137}Cs source counted with a cylindrical detector (r=10cm, l=10cm). Once converted to the appropriate units (particles/m^2s), the current densities can be incorporated into the GADRAS multi-faceted GAM file.

$$\{\text{front current density}\} = \left\{\frac{\text{front current}}{\text{source particle}}\right\} * \frac{(1\times10^{-6}\ Ci)\left(3.7\times10^{10}\frac{Bq}{Ci}\right)\left(1\frac{1/s}{Bq}\right)}{\pi(10\ cm)^2\left(\frac{1\ m}{100\ cm}\right)^2}$$

$$\{\text{side current density}\} = \left\{\frac{\text{side current}}{\text{source particle}}\right\} * \frac{(1\times10^{-6}\ Ci)\left(3.7\times10^{10}\frac{Bq}{Ci}\right)\left(1\frac{1/s}{Bq}\right)}{2\pi(10\ cm)(10\ cm)\left(\frac{1\ m}{100\ cm}\right)^2}$$

$$\{\text{back current density}\} = \left\{\frac{\text{back current}}{\text{source particle}}\right\} * \frac{(1\times10^{-6}\ Ci)\left(3.7\times10^{10}\frac{Bq}{Ci}\right)\left(1\frac{1/s}{Bq}\right)}{\pi(10\ cm)^2\left(\frac{1\ m}{100\ cm}\right)^2}$$

Figure 29. Pseudo-code for Scaling MCNP Surface Current Outputs to Units Suitable for use with GADRAS

Figure 30 below shows an example of a multi-faceted GAM file with current densities for the three facets of a detector. GADRAS represents detectors as if they are symmetric normal to the detector axis, so there is no distinction between the top, bottom, left, and right sides. The average current over all the lateral sides of the detector should be specified as the third parameter on each line.

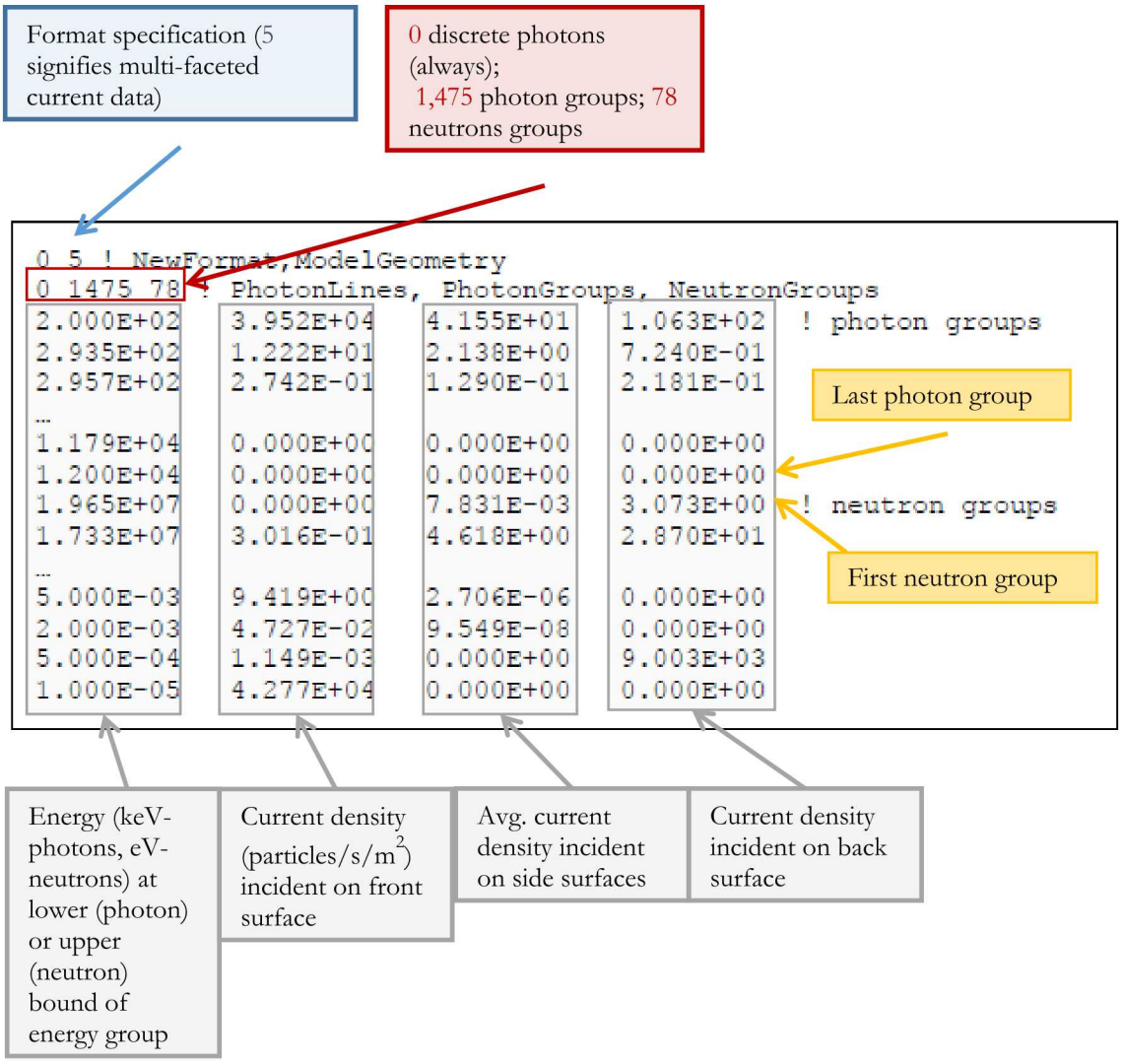

Figure 30. Multi-faceted GAM File Example

In Figure 30 above there are NG + 1 lines for the photon groups and NN + 1 lines for the neutron groups where NG and NN are the number of photon and neutron groups respectively. For multi-faceted GAM files, there are always 0 discrete photons specified. The leakage values are specified in units of inbound current density (particles/m^2s, current divided by surface area) on each detector surface. GADRAS accounts for the surface area of each detector facet when the response function is computed for a given detector. As a result, the same GAM file may be used to compute a response function for a different detector if it is situated at the same height and distance to a radiation source.

The multi-faceted GAM file should be saved as <*filename*>.GAM, where <*filename*> is the user's chosen file name. This file can then be included on the computed source line for plotting.

5.2. Automatic Conversion from MCNP Output to GADRAS Input

GADRAS is distributed with python scripts that will convert MCNP output files into GADRAS input files. These scripts are located in the external transport codes documentation folder (usually

C:\GADRAS\Program\Documentation\CouplingExternalTransportCodes), and are called "mfgf.py" and "mcnpfunc.py". Users can view and modify "mcnp_example.py" to use these scripts properly. Currently only photons are included in the mcnp_example.py file.

To use these scripts, the MCNP model must be configured to create a MCTAL file as part of its output. To do this, the line "PRDMP J J -1" must be included in the data card of the MCNP file. The python scripts need several inputs to properly generate a multi-faceted GAM file for use with GADRAS. Users must supply:

- MCNP MCTAL file
- Source activity (in Bq)
- Source yield (particles per decay)
- Area of face of detector in MCNP model (in m^2)
- Area of side of detector in MCNP model (in m^2)

Users must also install python on their computer and make sure the numpy library is present. To run the script, users should type "python mcnp_example.py" into the command prompt.

6. SPECTRUM ENERGY CALIBRATION

There are a variety of methods in GADRAS for energy-calibration. Section 3.3.4 covers how to calibrate from the **PCF Viewer** by automatic methods as well as peak-search methods. The most common method to quickly calibrate a spectrum is through the **Plot** window.

6.1. Helpful Tools for Energy Calibration and Peak Analysis

6.1.1. *Photopeak List*

To aid in performing an energy calibration or in determining a peak's energy in a spectrum, the **PhotoPeak List** library can be used. This list can be accessed:

- From the **Tools** tab on the main GADRAS window
- Using the mouse (shift+left mouse click (*holding down the shift key while clicking the* ***left mouse button***)) on a peak of interest in a displayed spectrum
- From the graph display form under the **Tools** menu, **Show Peak List**
- Pressing Ctrl+L on graph display form

The **PhotoPeak List** library is shown in Figure 31. The blue highlighted entry corresponds to the gamma-ray automatically selected by GADRAS based on its proximity to the selected energy location on the current plot (*shift-left click* location). The selection also takes into account the relative importance of the gamma-ray to the observable spectral features.

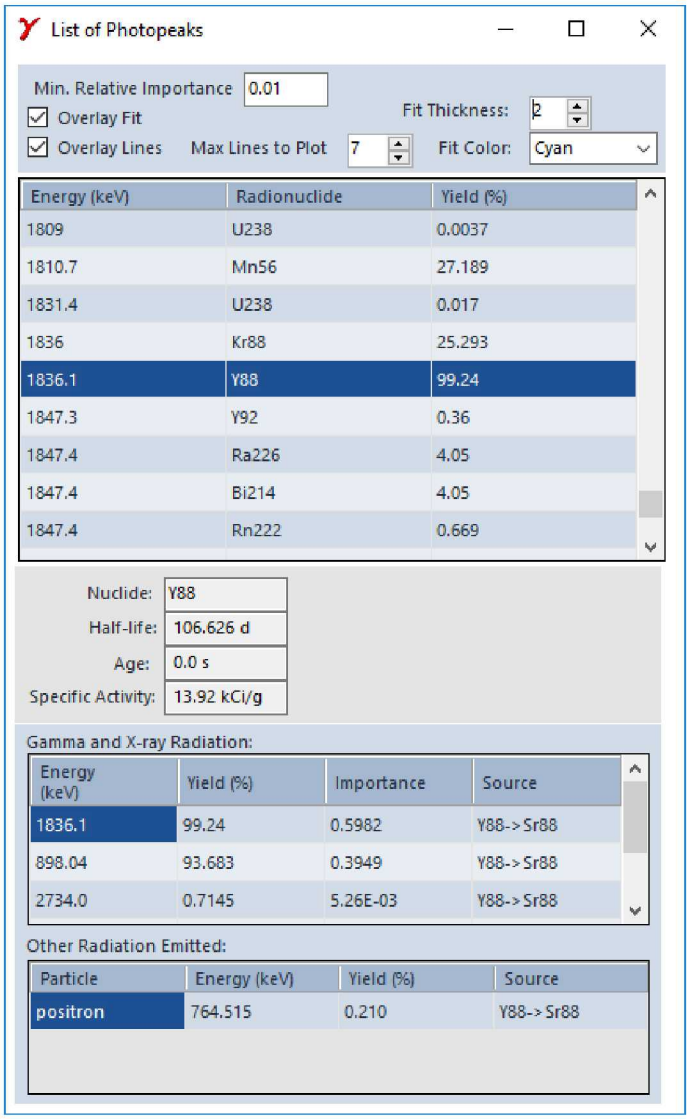

Figure 31. PhotoPeak List Library with ^{88}Y Highlighted and Both Overlay Options Boxes Checked

At the top left of the **PhotoPeak List** library screen are two check boxes for overlay options. The overlay fit check box when selected will generate a spectral overlay fit for the selected isotope (a single regression fit using one isotope). The spectral overlay displays the source activity and shielding configuration estimated to provide the best fit to the measured spectrum. The overlay lines check box overlays vertical lines at the appropriate energy locations for the selected isotope on the measured spectrum utilizing the **Max Lines to Plot** selection. The displayed overlay can be changed to display another isotope simply by selecting and highlighting another gamma-ray line in the **PhotoPeak List**, allowing for rapid examination of many isotopes in the library. The color and line thickness of the overlaid spectrum can be changed using the options at the top of the library window. The selections displayed in the **PhotoPeak List** in Figure 31 are shown in the displayed graph in Figure 32.

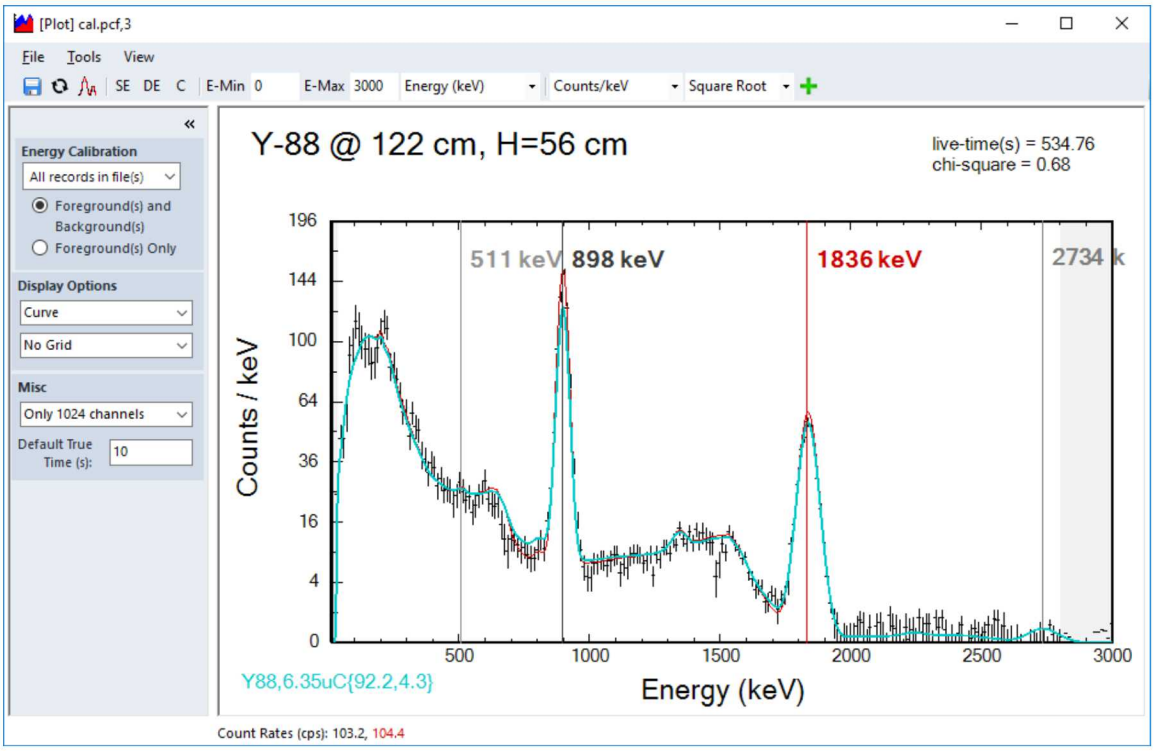

Figure 32. Graph Displays the Measured ^{88}Y Spectrum (black) with Both Overlay Options

The graph in Figure 32 displays the measured ^{88}Y spectrum (black) along with both overlay options. The overlay fit option generates a spectrum which is cyan and has a thickness value of two. The overlay lines option displays the lines and their energies.

6.1.2. *Isotope List*

Another useful tool when graphically calibrating is the **Isotope Database** tool (shown in Figure 33). The drop-down menu at the top of the form allows users to choose a radionuclide from the list. This can also be used as a reference for emitted radiation from common radionuclides.

The graph in the center of the form shows the locations of the main photopeaks for the selected isotope. The center of the window displays properties for the selected isotope such as isotope designation, half-life, age, and specific activity. It also specifies if the nuclide is assumed to be in prompt or secular equilibrium with its daughters. The bottom of the window displays characteristic gamma-ray energies sorted by intensity multiplied by the square-root of the energy.

Users can display overlays of the nuclide on the current plot using the two **Overlay** checkboxes located at the top of the **Isotope Database** form. The first checkbox overlays a graphical fit of the selected isotope by automatically calculating the activity and shielding to best match the measured spectrum. The overlaid spectrum is generated using the detector response function parameters found in the **Detector.dat** file. The user may also change the color and line thickness of the overlaid fit. The second checkbox overlays vertical lines on the plotted spectrum, which correspond to the major energy lines of the selected isotope. The number of lines to display can be changed by the user.

GADRAS lists gamma-ray emissions from daughter radionuclides in the gamma-ray emission list for a given parent. This occurs if the daughter radionuclide is usually observed to be in equilibrium with the parent. For example, gamma-ray emissions arising from the decay of ^{208}Tl are also listed under ^{232}Th. The origin of a gamma-ray can be observed in the **Source** column of the table.

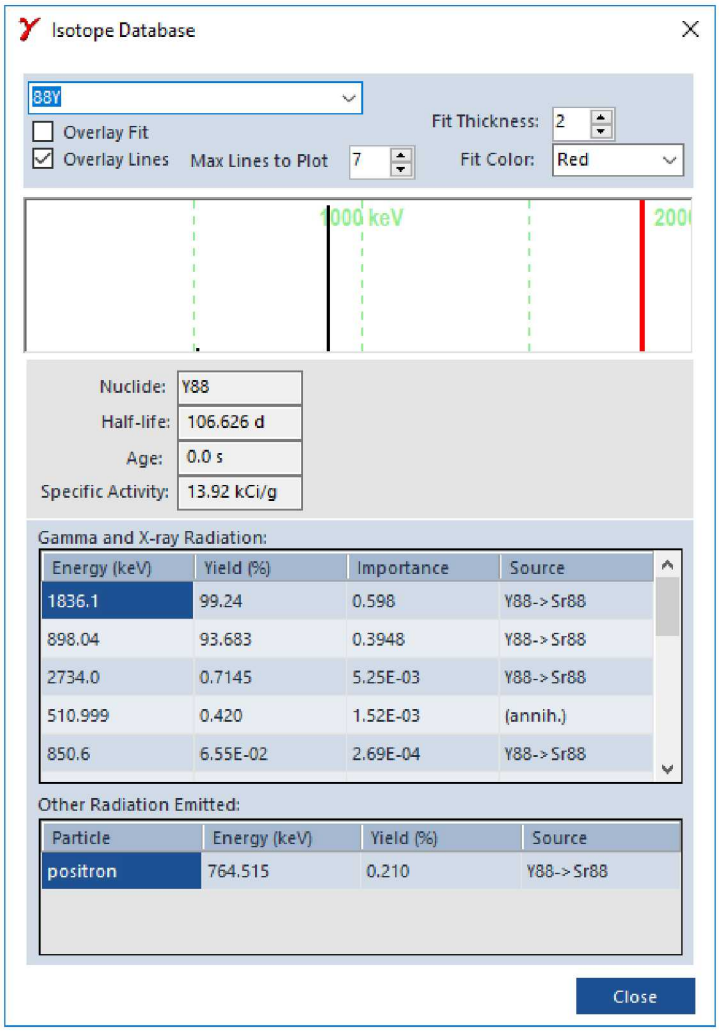

Figure 33. Isotope Database Form

6.2. Graphical Energy Calibration

Graphical calibration is an alternative method to using the Peak Search and Manual Energy Calibration process (see Section 3.3.4.1). Graphical calibration can be used for the adjustment of the gain and offset (**Order 0 and Order 1**) of the spectrum. This method uses a graph of the measured spectrum and an overlaid spectrum from the **PhotoPeak list** or **Isotope Database** library (or a specified computed source). Figure 34 (top) shows a measured ^{137}Cs spectrum (*black*) and a library ^{137}Cs spectrum (*red*). This plot is zoomed in to the region around the primary ^{137}Cs peak at 662 keV. The measured spectrum *(black)* does match the computed spectrum *(red)*. This implies that an energy calibration of the measurement is needed.

To calibrate the measured spectrum correctly, the measured peak (*black*) should be adjusted to match the computed spectrum (*red*). To make this adjustment, users can right-click-drag the peak in the measured spectrum to the correct energy (the centroid of the peak in the computed spectrum). After right-clicking the plot window will be outlined in red as shown in Figure 34 to indicate energy calibration mode. Figure 34 (bottom) shows what the plot looks like after dragging the measured spectrum to the left (while still holding down the right-mouse-button).

Release the right-mouse-button to complete the action (or press escape to cancel it). Once this action has been performed, the energy calibration window shown in Figure 35 will appear for the selection of the appropriate calibration parameter (offset or gain). The user will need to confirm the adjustment before the energy calibration parameter will be changed.

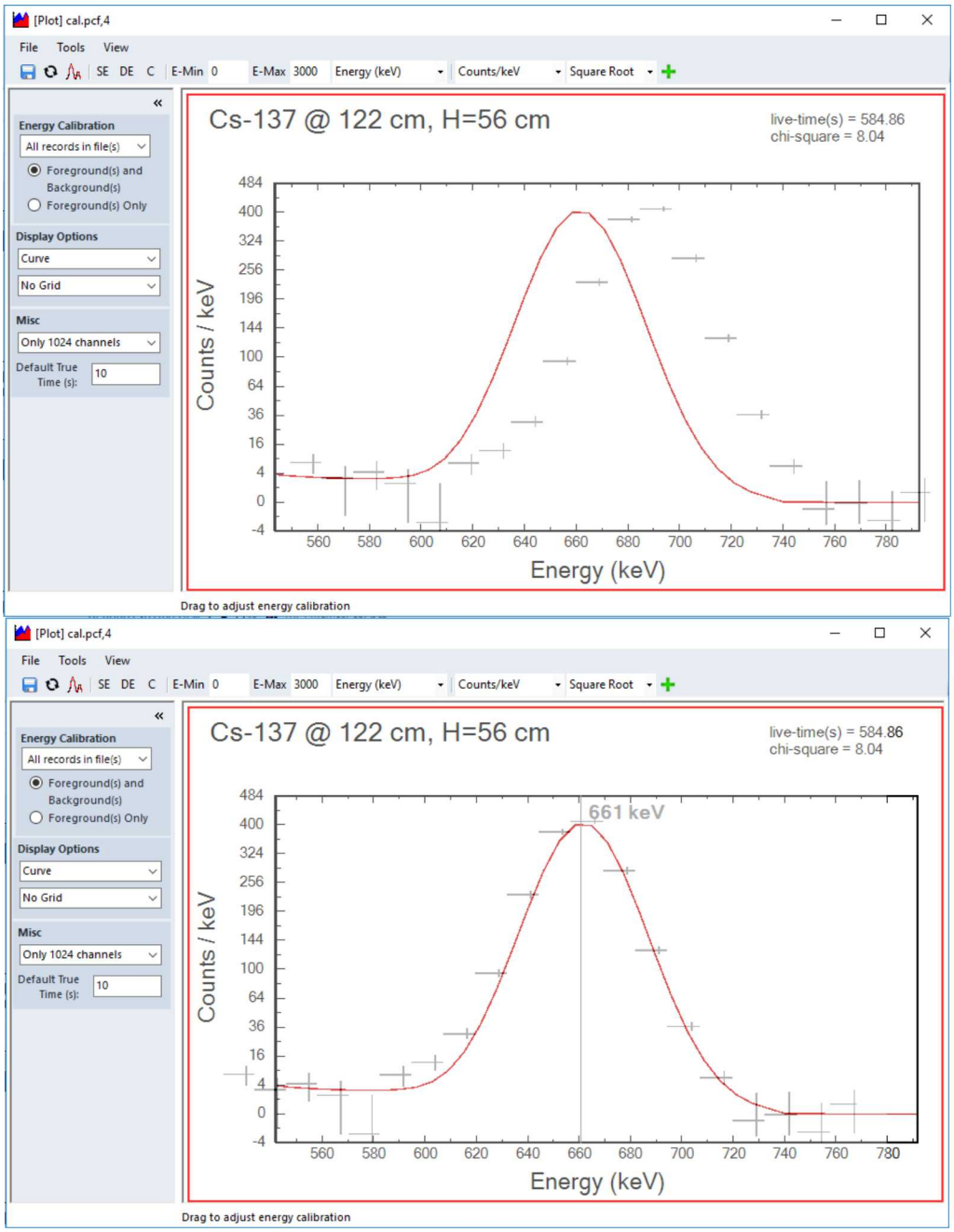

Figure 34. Graphical Energy Calibration Example

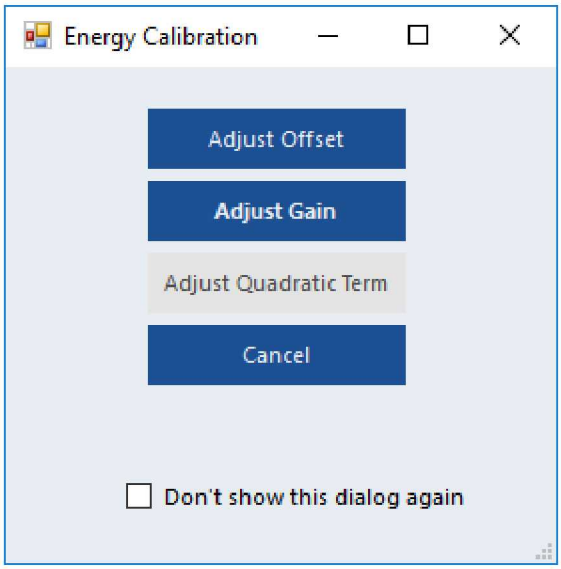

Figure 35. Graphical Energy Calibration Confirmation Window

Due to the potential for inadvertent changes to calibration parameters, GADRAS requests confirmation for the parameters to be adjusted when graphical calibration is used. If a gain adjustment is made within thirty seconds of an offset adjustment, GADRAS will use both changes simultaneously to fit the gain and offset. The quadratic option is only available once the following criteria have been met:

1. Successful gain adjustment within 30 seconds
2. Successful offset adjustment within 30 seconds
3. The third adjustment energy is greater than 400 keV
4. The adjustment energy is greater than 0.4 times the full-energy-range away from the energy used to adjust the offset
5. The adjustment energy is greater than 0.4 times the full-energy-range away from the energy used to adjust the gain

For example, if calibrating a background spectrum and the 239 keV peak (Th chain), 1460 keV peak (K-40), and 2614 keV peak (Th chain) are visible, users can drag the measured spectrum at 239 keV to adjust the offset, the 2614 keV to adjust the gain, and then the 1460 keV to adjust the quadratic term. However, if the user tries to use the 583 keV peak (Th chain), GADRAS will not allow a quadratic adjustment because it is too close to the 239 keV peak.

If all the criteria are met, GADRAS will utilize all three energy adjustments to determine the offset, gain, and quadratic terms.

Figure 36 displays the successful completion of the graphical energy calibration for the measured ^{137}Cs spectrum to the computed spectrum.

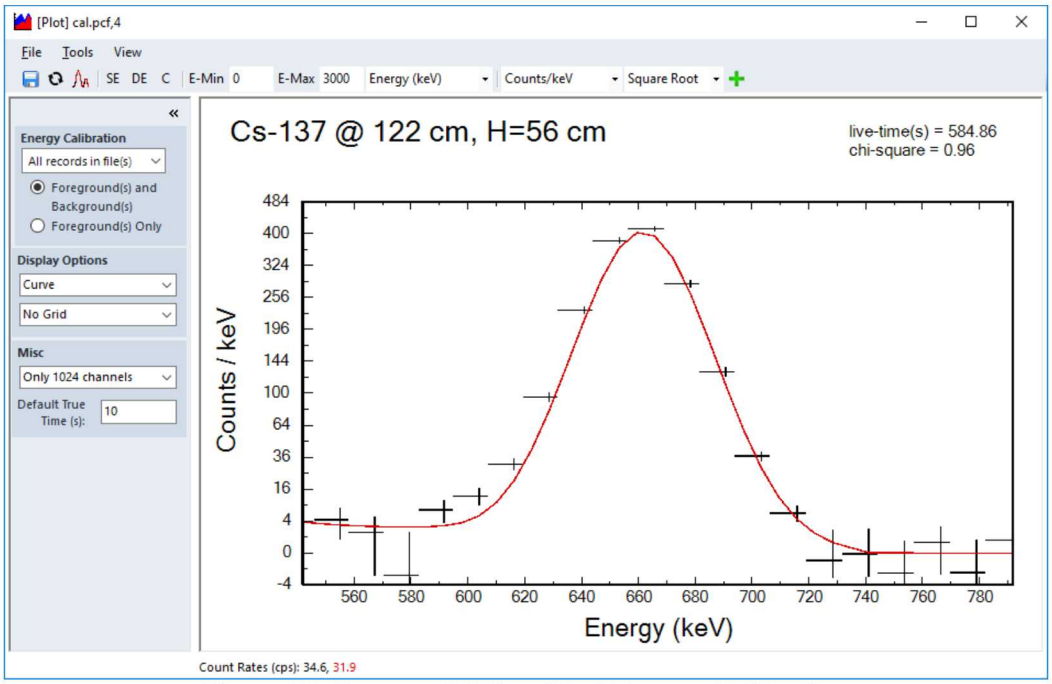

Figure 36. Successful Graphical Energy Calibration

6.3. Deviation Pairs Energy Calibration

Scintillator detectors are often non-linear in their energy calibration and require more than two terms to describe the relationship between channels and energy. Some may require third- and fourth-order polynomials, but still have substantial error in the energy calibration. Deviation pairs are a method to describe highly non-linear detectors or to describe the energy calibration exactly for detailed analyses.

Deviation pairs can be thought of as a supplement to a linear energy calibration. An ideal detector would follow this linear calibration across all energies of interest; however, this is not always the case. Deviation pairs can describe the detector's deviation from linearity as a set of energies paired with the amount of deviation (in energy). GADRAS fits a cubic spline through the deviation pairs to determine a continuous function of deviation across the entire energy range.

NOTE: Deviation pairs can also be applied to quadratic, or higher-order polynomial fits, but is not recommended except for advanced users.

The primary benefit of deviation pairs is the level of accuracy that can be obtained without the artifacts introduced by large coefficients in higher-order polynomials. In addition, the deviation pairs for a given detector appear to be *constant*. Thus, even with gain and offset drifting, as long as the gain and offset can be established with occasional calibration (or automatic calibration), the same deviation pairs can be applied (without modification) to achieve a high degree of accuracy in energy-calibration. A further explanation of deviation pairs can be found in Reference [8].

Deviation pairs are stored in a PCF file (but can also be written to the detector folder to **Deviation.dat** for reuse). The current deviation pairs can be accessed in multiple ways. From the **PCF Viewer** window under **Edit->Deviation Pairs**, from the **Tools** tab, and from the **Plot** window under **Tools->Edit Deviation Pairs**. The only requirement is that there is a spectrum file currently open and editable.

NOTE: The presence of deviation pairs is indicated in the bottom status bar of the PCF Viewer window.

For this example, we will use the **3x3\NaI MidScat** detector's Cal.pcf, which has deviation pairs defined. After opening the Cal.pcf file in the **PCF Viewer**, the **Edit->Deviation Pairs** option brings up the **Deviation Pairs Editor** window as shown in Figure 37. The deviation pairs in a PCF file can be different for multiple detectors in a single system (for more information on multiple detectors and naming convention, see Section 0). The editor allows the user to choose which **Detector ID** to view/edit. For this file, there is only one detector (Aa1). The deviation pairs are listed in two columns in the text box. The first column is the deviation point (usually a photopeak energy) in keV. Those are paired with the second column, which is the amount of deviation from linearity in keV.

Deviation pairs should be reasonably spaced in energy. Placing deviation pairs close together can cause erratic behavior. They should also be smoothly decreasing or increasing across the deviation points. Oscillating deviations is an indication of improper use.

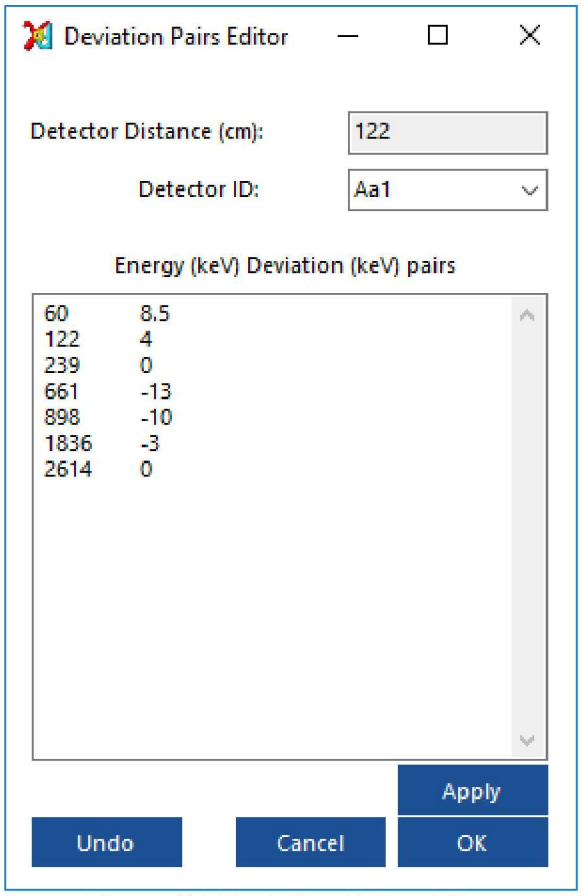

Figure 37. Deviation Pairs Editor

Figure 38 shows the ^{228}Th measured spectrum (background subtracted) and its matching calibration source. The gain looks approximately correct, but mid-range photopeaks are not matched well. This is a typical starting point for a new detector without any deviation pairs defined. Deviation pairs can be defined by the following procedure:

- Erase all deviation pairs in the deviation pairs editor and click Apply.
- Ensure there are no third- or higher-order terms in the PCF file by asserting zeros in the **PCF Viewer** energy calibration coefficients at the top of the window.
- Plot a measurement which provides good high-energy and low-energy peaks to establish the gain and offset.
- Using the graphical energy calibration method (Section 6.2), adjust the calibration for gain and offset. The two peaks used for this are called "anchor points". Insert the anchor point energies in the **Deviation Pairs Editor** window with zero deviation and click apply.
- Plot spectra and add deviation pairs as needed.

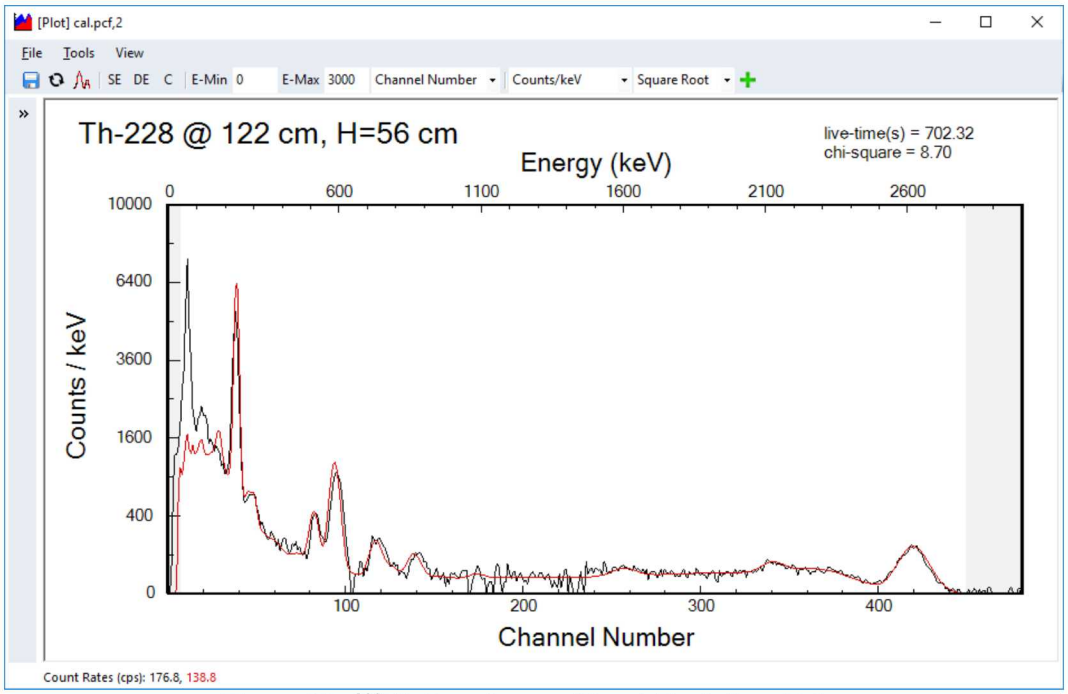

Figure 38. ^{228}Th Spectrum without Deviation Pairs

After determining the anchor points (e.g. 239 keV and 2614 keV from ^{228}Th), open the **Deviation Pairs Editor,** set their deviations to zero, and click apply (see Figure 39). The plot window shows vertical blue dashed lines to indicate the location of deviation points. Because these are anchor points (with zero deviation), the energy calibration is still linear.

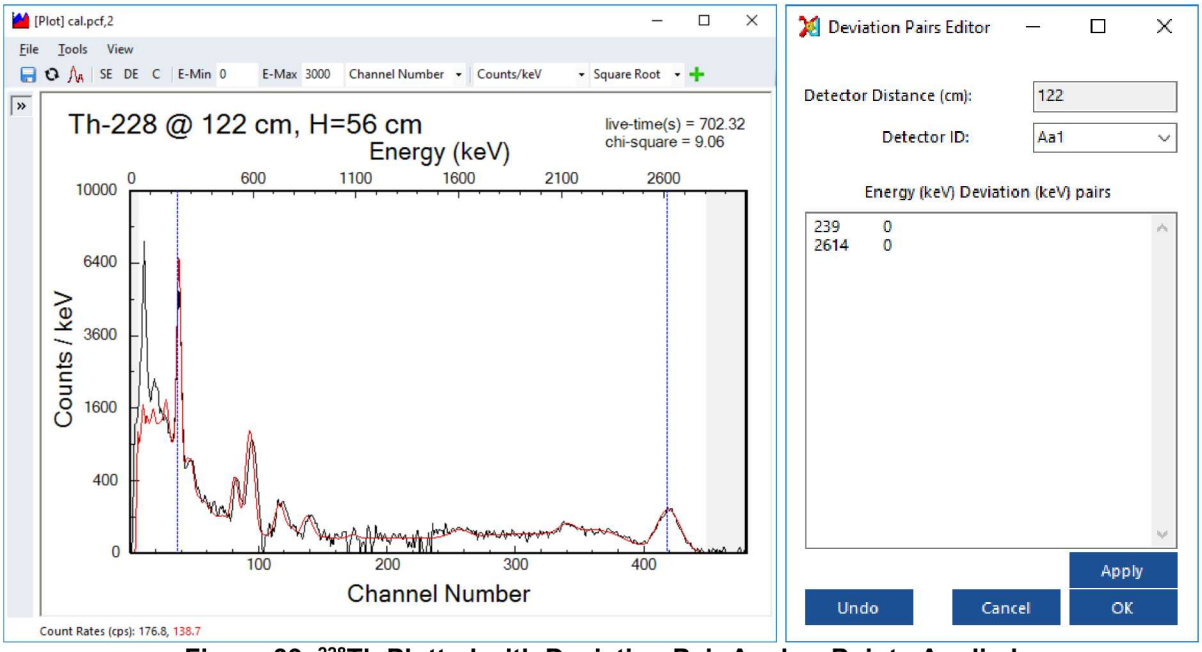

Figure 39. ^{228}Th Plotted with Deviation Pair Anchor Points Applied

The deviation for 583 keV can be set by right-click-dragging the measured 583 keV photopeak. Figure 40 shows how the plot window looks when this is done. The plot window is outlined in

purple indicating deviation pair adjustment. The deviation pair is set by right-click-dragging the measured photopeak (black) to the simulated photopeak (red). GADRAS will regenerate the spectrum with the new deviation pair, and the deviation will be added to the deviation editor. Figure 41 shows the resulting plot and deviation pair editor. This process can be repeated by plotting multiple calibration sources, and adding deviation pairs as needed. Users can manually edit the numbers to tweak the deviation pairs after adding them graphically or to add new ones.

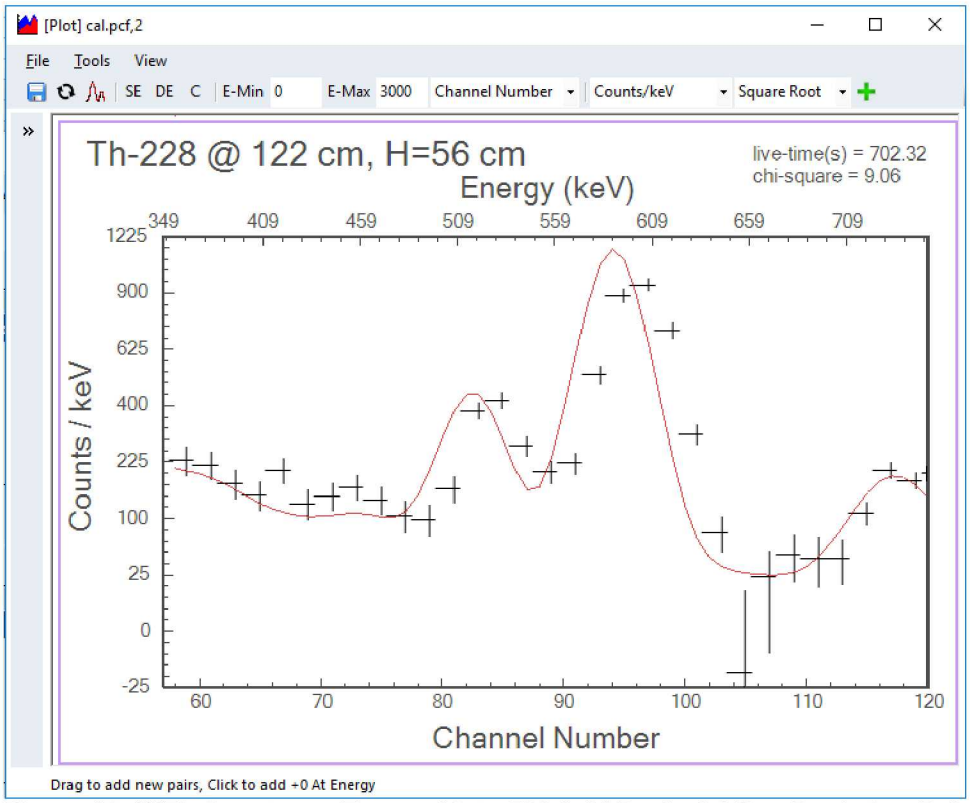

Figure 40. ^{228}Th Spectrum, Zoomed into 583 keV Peak, Adding Deviation Pair

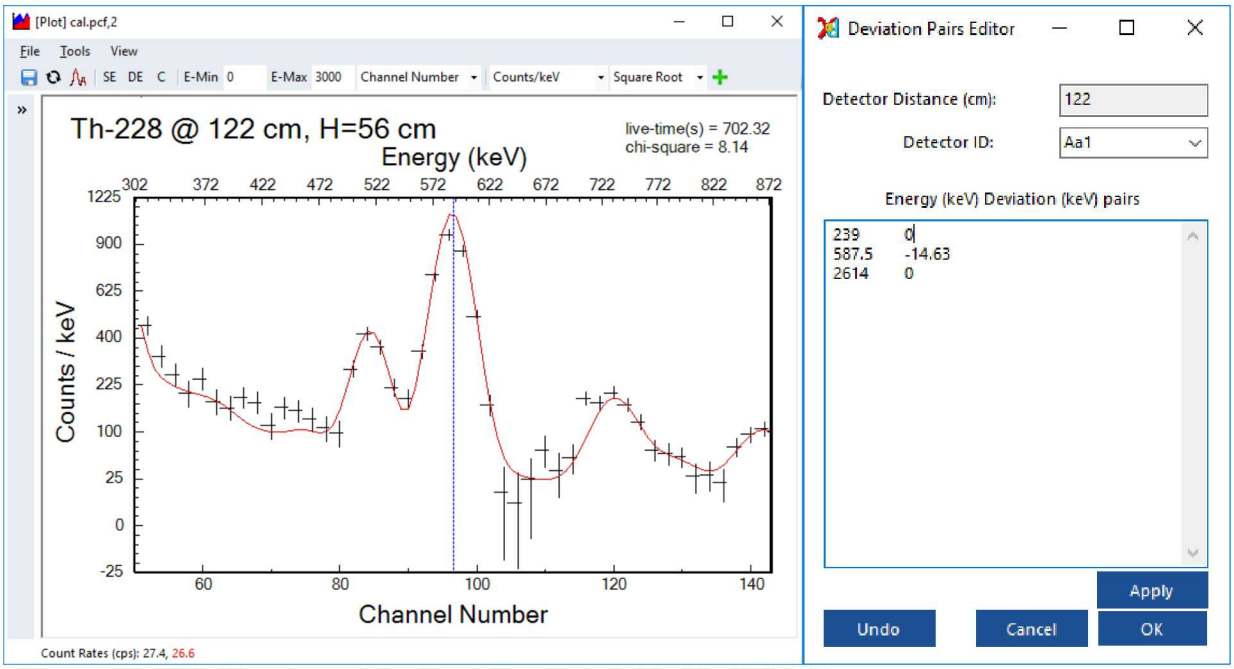

Figure 41. ^{228}Th Spectrum After Deviation Pair Added to 583 keV

7. TIME HISTORY

Some detector systems have the capability of taking multiple spectra over a period of time in order to create a time-segmented series of spectra. By summing spectra over a specified time period, users can gain insight into a time-dependent scenario that would not otherwise be attainable with conventional spectra. The **Time History** tab allows users to plot and manipulate these types of spectral records. Upon opening the **Time History** tab, users are presented with a screen involving several input fields as shown in Figure 42. Users may specify the following:

- **File**: The file containing the time history spectra
- **Foreground Time Segment** (optional): Time in seconds to sum over (default: 0 s to end of file)
- **Background Time Segment** (optional): Time in seconds to sum over for background-subtraction (default: none)
- **Plotted Particle**: The particle(s) of interest to display (default: Photons)
- **Plot Styles**: specify the plot style for the spectrum types
- **Detectors**: If there are multiple detectors specified in the file, this panel box specifies which detectors to display the data from (default: all detectors)
- **Plot Computed Time History**: Specify if a computed spectrum should be displayed on the Time History graph display

Figure 42 shows the file as "SearchData.n42". N42 is a common search-file format, which GADRAS internally converts to the PCF file format. Users can either type the name of the file in (must be in current detector folder); or open a search file using the **PCF Viewer** and drag one of the records into the **File** field.

Once the file is specified, GADRAS searches for all detector names in the file and displays them on the right side of the **Time History** tab as shown in Figure 42. The convention for naming detectors follows the convention for naming portal detectors:

[A-H][a-d][1-8][N (optional)]

where the first field [A-H] is the "panel", [a-d] is the "column" within the "panel", [1-8] is the multi-channel analyzer (MCA) within the "column", and [N] is an optional character indicating it is a neutron detector. This allows for complex detection systems with many detectors to share the same spectral file, as their energy calibration coefficients may be different. The simplest example is a detection system with one detector (which has the name "Aa1"). The example file shown in Figure 42 has eight detectors. They are arranged graphically that is typical of portals. Panels A, B, C, D are on either side of the inspected vehicle or cargo, panel E is below the vehicle, and panel F is above (E and F not shown).

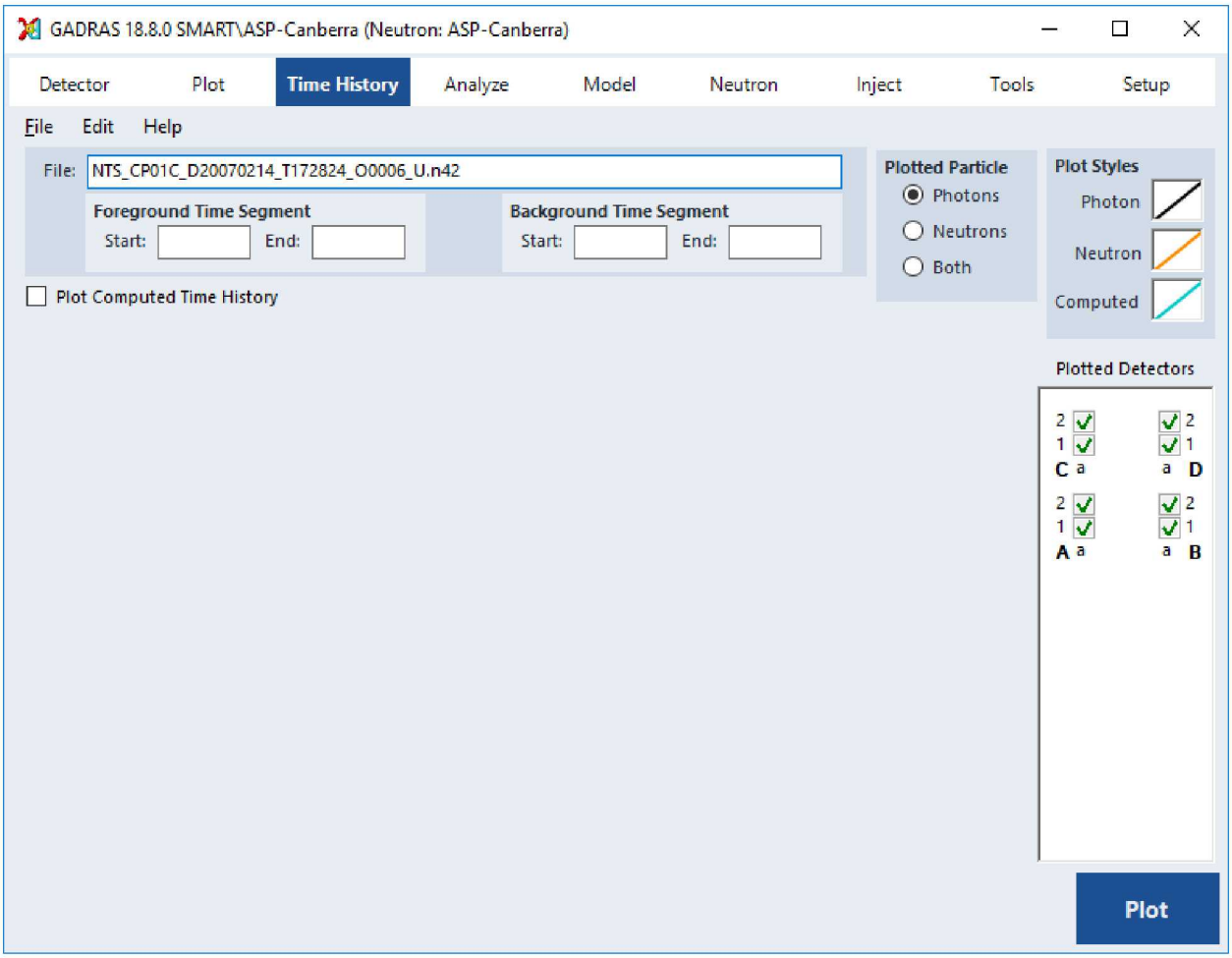

Figure 42. Time History Page

7.1. Plotting Time History Spectra

By default, GADRAS will use all detectors in the Time History plot. Users can check or uncheck detectors from the **Time History** tab. After specifying a file and any desired options, the user may click **Plot** to display the time history spectrum graph. GADRAS generates two plots as shown in Figure 43. The first display shows the time history data where the x-axis is the time in seconds since the data collection started and the y-axis is the total count rate per detector. The second display is the sum of all spectra contained in the specified time period. By default, the second display shows the summed spectrum across the entire collection time (in this case, 12 detectors multiplied by 429 seconds each, equals 5148 total time). The right side of the Time History display gives several options for manipulating the displays. By default, **Zoom** is selected, which allows users to zoom in and out of the Time History graph without affecting the sum display. This action is performed by dragging across the display, similar to normal graph displays.

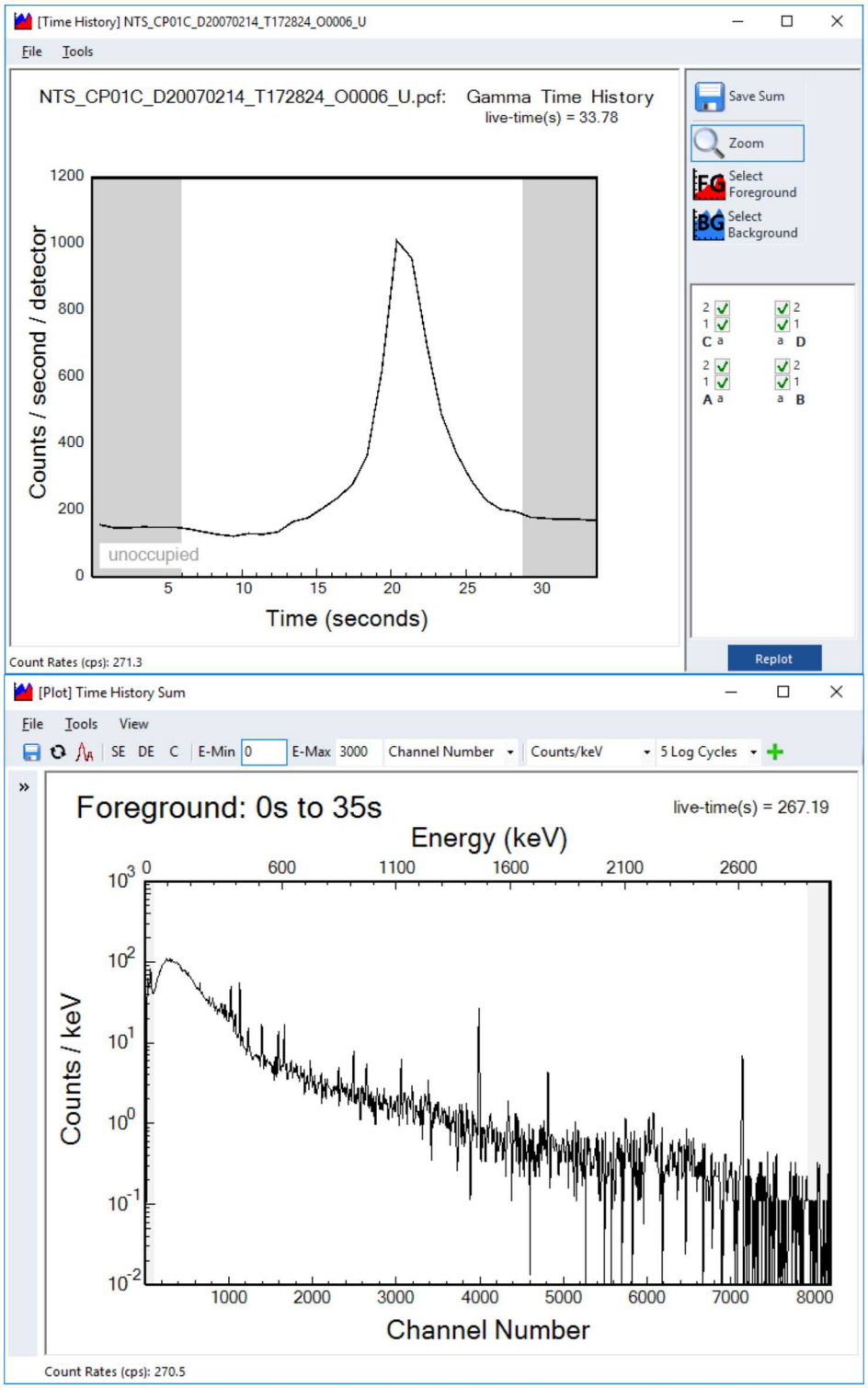

Figure 43. Time History Display (top) and Sum Spectrum (bottom)

Select Foreground allows users to select a portion of the Time History display to sum across. When this option is selected, dragging will generate a red rectangle which indicates the portion of the spectrum that is being summed (Figure 44).

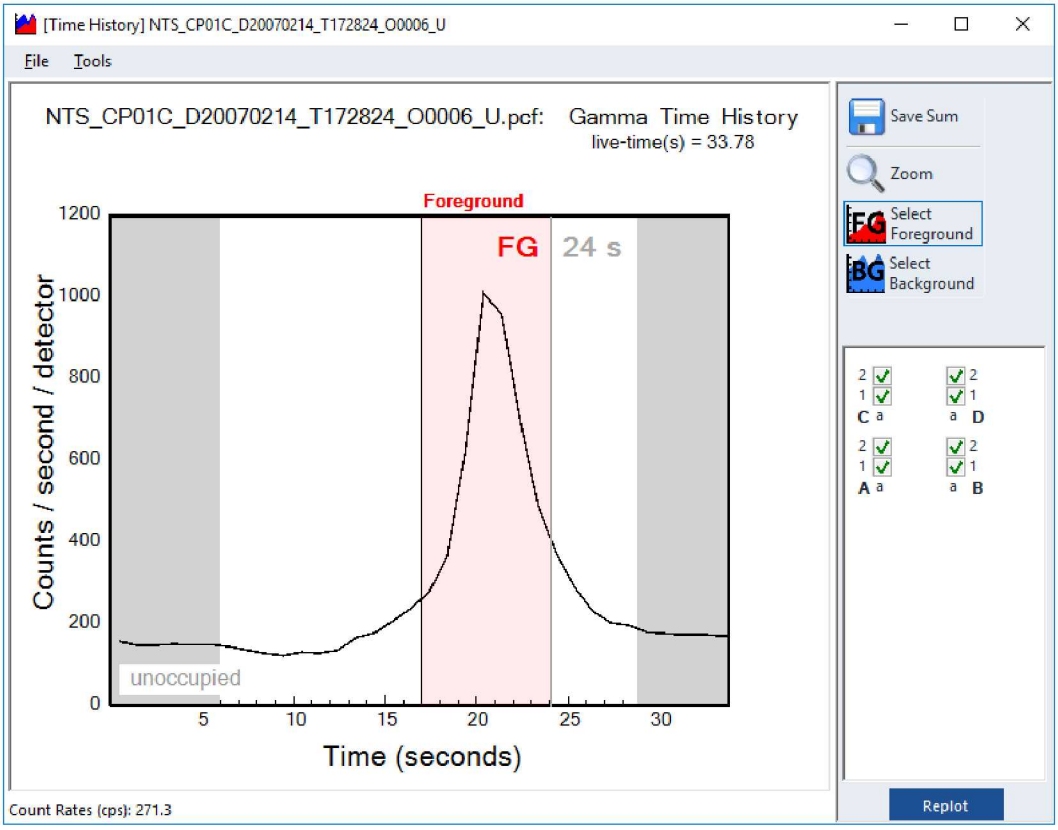

Figure 44. Selecting a Foreground to Sum Over

Upon selection of a foreground, the Time History Sum display updates automatically to display the sum over the selected time region (Figure 45). As shown, the title of the spectrum reflects the specified time interval ("Foreground: 273s to 299s").

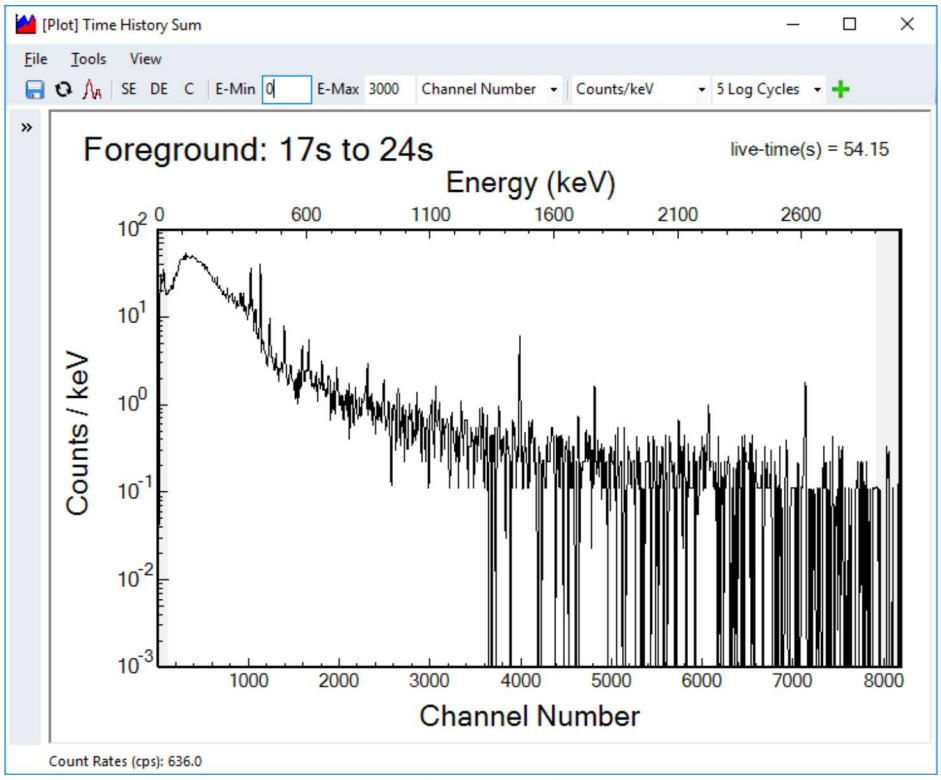

Figure 45. Time History Sum over Selected Time Interval

Users may elect to display a background-subtracted spectrum. To do this, the user should click **Select Background** and select the portion of the Time History display corresponding to the background. Dragging will generate a blue rectangle, which indicates the portion of the spectrum to sum over and use as the background as shown in Figure 46. Note that the summed foreground and background spectra will be normalized by time and thus display the background-subtracted count rate for the selected regions. The resulting background subtracted spectrum is shown in Figure 47.

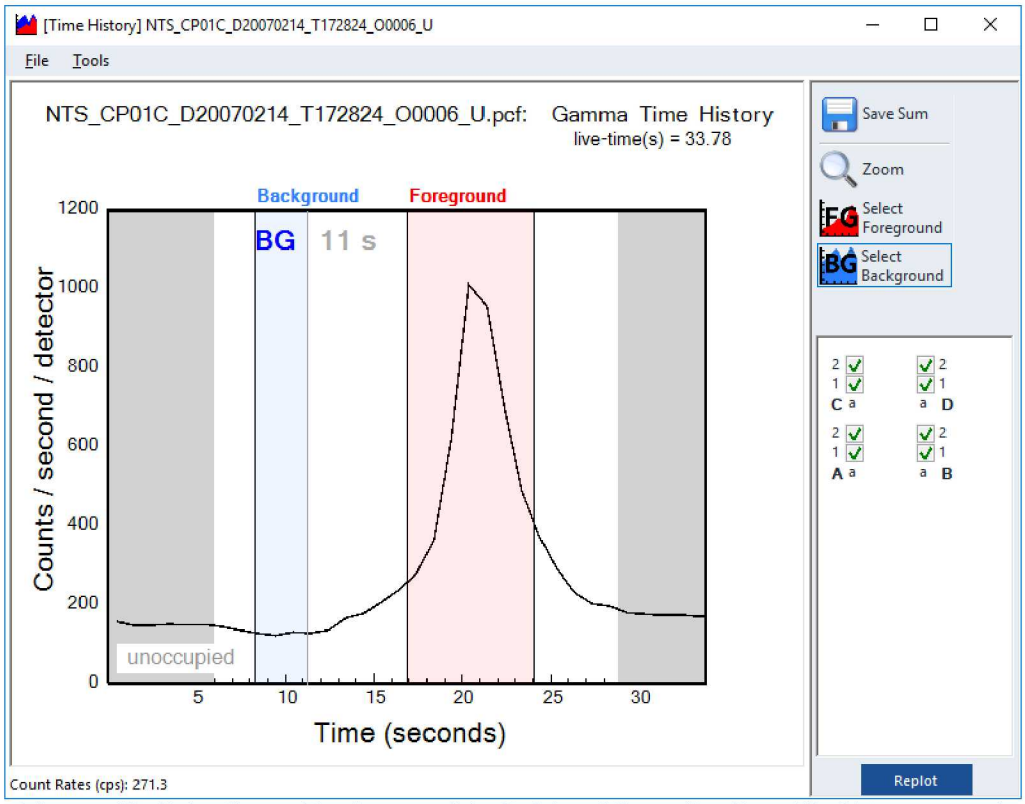

Figure 46. Selecting a Background to Subtract from the Specified Foreground

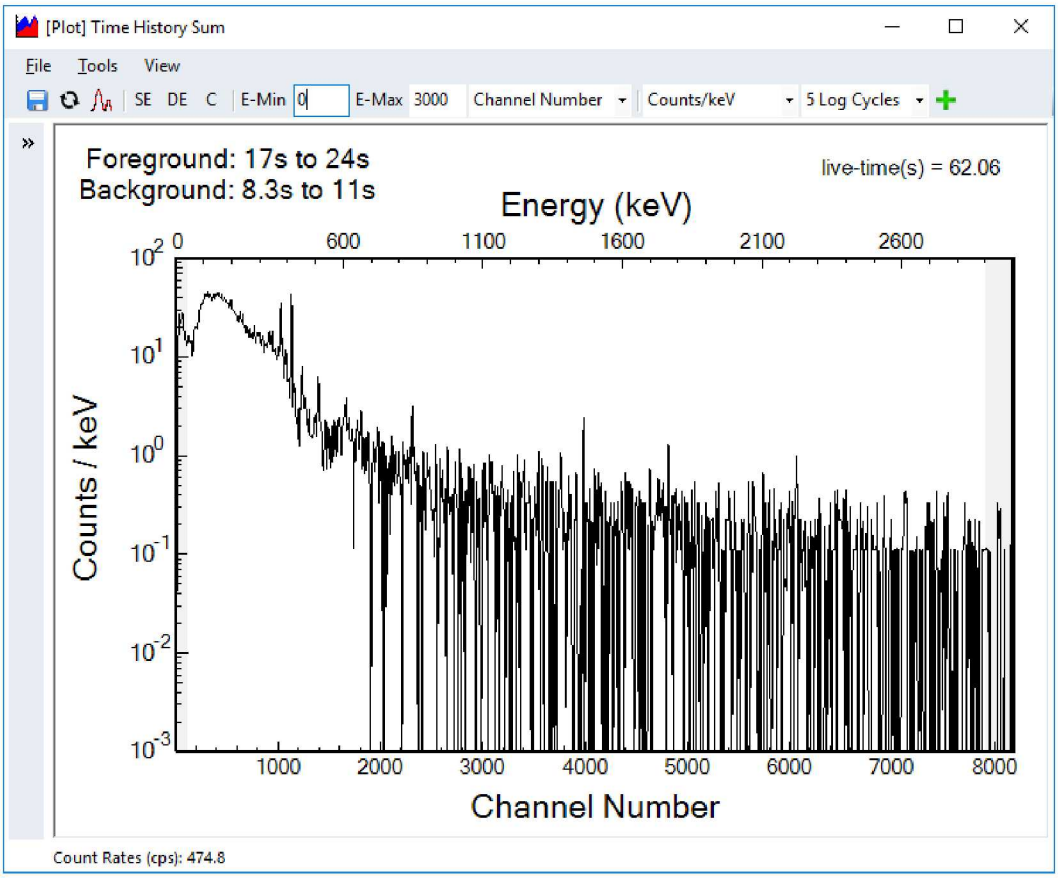

Figure 47. Background-Subtracted Spectrum

When the user specifies a foreground or background on the Time History graph display, the main page is being updated with this information, as shown in Figure 48. The user may specify the foreground or background on this page and click **Plot** to update the graph display forms appropriately.

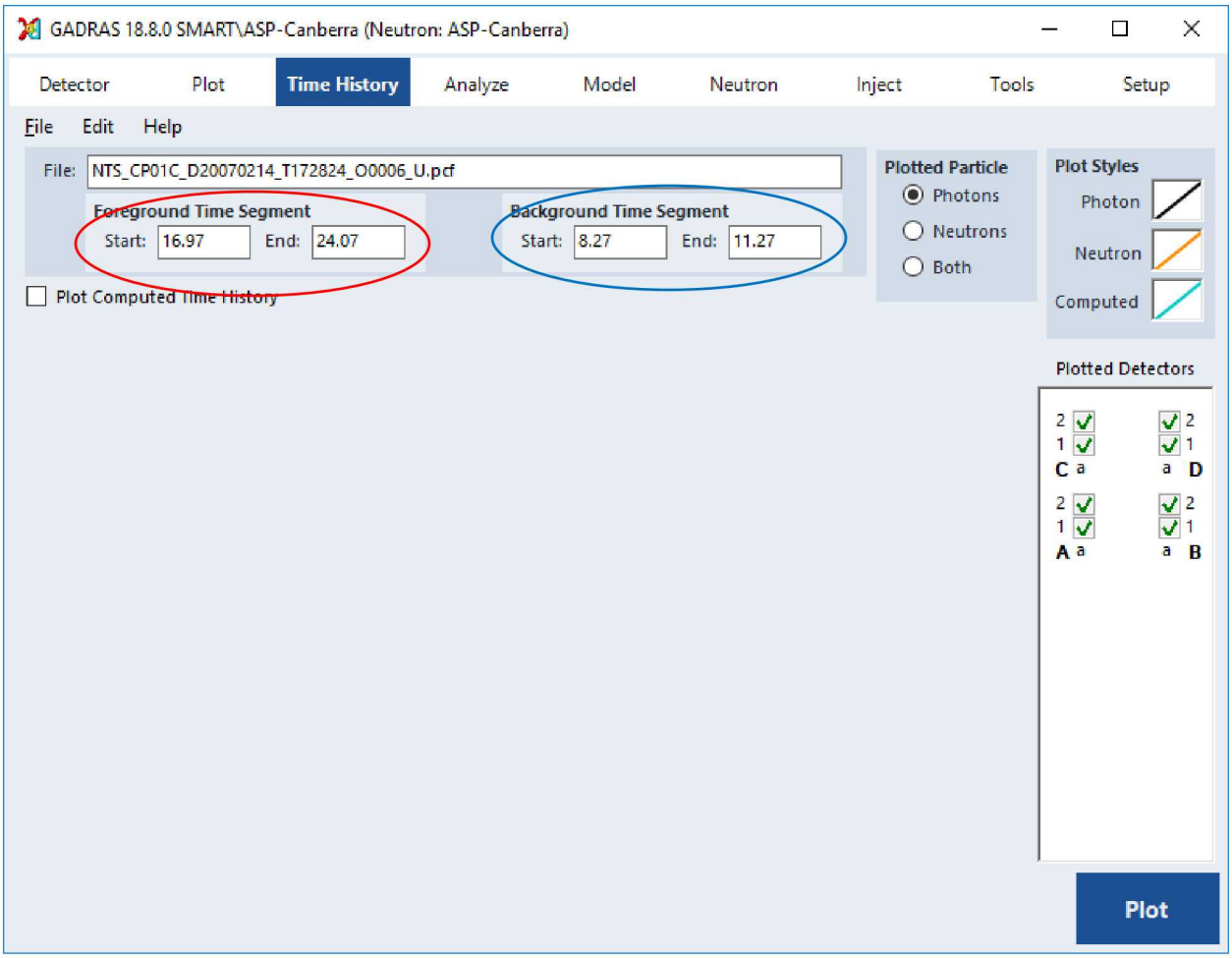

Figure 48. Foreground and Background Time Periods Are Updated on the Main Display

In addition to dragging across the spectrum or manually specifying the times on the main form, there are several ways to specify the foreground and background time segments. If the segments are already displayed on the time history display form, users can drag the edge of the rectangle to move the boundary to a different time position. The time sum spectrum will automatically update when the boundary position is selected. The user may also right-click inside the rectangle and choose to delete the selection or manually specify the boundaries for the selection. The final way to change the time selection is to right-click drag the time selections. Doing this preserves the time duration, but changes its start/end time.

7.2. Saving Time History Spectra

Users may save time history selections for future plotting or analysis routines by clicking **Save Sum** in the top-right corner of the Time History display form. Doing so will initiate the Save Sum Spectrum form as shown in Figure 49. For most situations, the default values will suffice for the user, but there may be some scenarios in which the user may want to deviate from the defaults. Users can specify the following fields:

- **File**: The name of the file to save the summed spectrum to
- **Start Record**: This field generally increments as users save spectra to the file; users may change this to overwrite previous records or start saving future records
- **Foreground Title**: The title of the foreground record; default is "Foreground <start time> to <end time>"
- **Include background in output file**: If a background is selected in the Time History display form, the background selection will be saved when this is selected; it will be saved as a separate record from the foreground
- **User defined background**: If the user has defined a background, this selection will be saved
- **Background from file (if present)**: If the file has a background record associated, this record will be saved as the background in the new file
- **Calibrate and Rebin Spectra**: During the summation, GADRAS will attempt to shift the gains for each detector individually as a function of time to match common background peaks, and then rebin the spectra into a linear energy structure defined by the **Offset** and **Full-scale energy**
- **Rebin Spectra**: GADRAS will rebin the spectra into a linear energy structure defined by the **Offset** and **Full-scale energy**
- **Offset (keV)**: The 0^{th} order parameter of the new energy calibration used for rebinning
- **Full-scale energy (keV)**: The 1^{st} order parameter of the new energy calibration used for rebinning
- **Combine spectra or keep the separate?**: This group box will be enabled if there are multiple detectors displayed in the Time History display form
- **Output only sum spectrum for all detectors** (default): Sums spectra for all detectors and combines them into one record
- **Write separate sum spectrum for each detector**: Writes the sum spectrum for each detector as its own record (foreground and background)

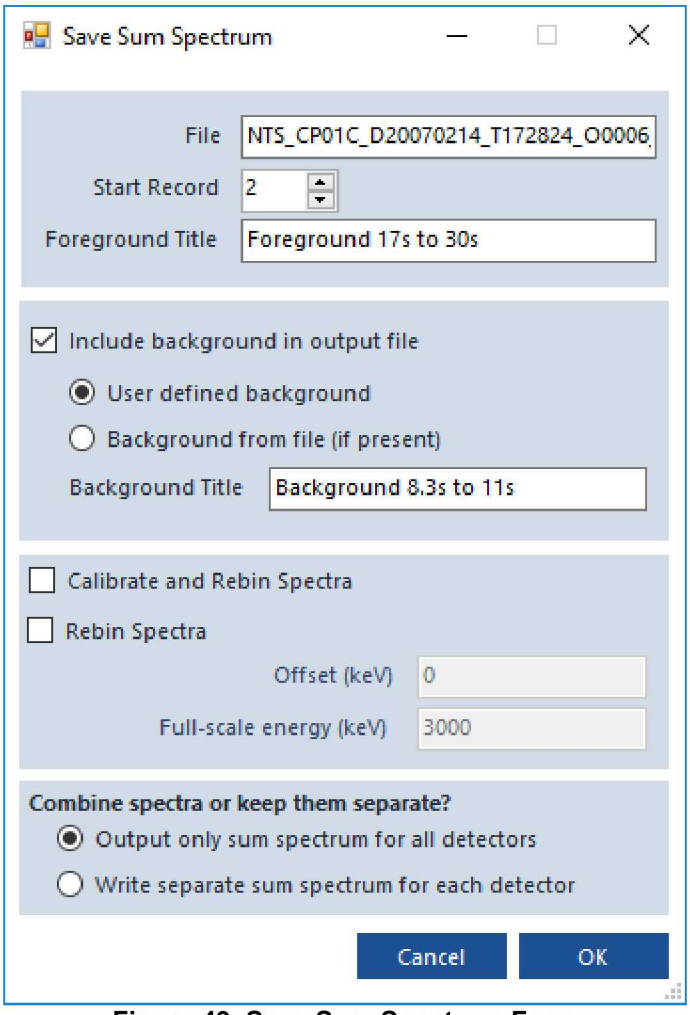

Figure 49. Save Sum Spectrum Form

7.3. Computed Time History

GADRAS can compute a time history spectrum and either display it individually or overlay it on a measured time history spectrum. Checking the **Plot Computed Time History** checkbox, the computed spectrum parameters appear along with several options near the bottom of the page (Figure 50). Users may choose to specify parameters for photons or neutrons, indicated by the selected tab at the top of the computed spectrum parameters. The computed spectrum calculations assume that the source is passing by the detector at a constant speed. If there are multiple sources, the calculations assume that all sources pass by the detector at the same speed. The parameters are defined as follows:

- **Rel. speed (m/s)**: The speed at which the source(s) pass by the detector face
- **Min. distance (m)**: The minimum distance from the detector that the source(s) are relative to the detector face
- **Bkg. count rate**: The background count rate across the entire time history spectrum; assumed to be constant across the entire contents of the file
- **Time to src 1(s)**: The time in seconds until the first source is in front of the detector
- **Peak cps 1**: The maximum count rate the detector sees for the first source

- **Length src 1 (m)**: The length of the first source in meters
- **Separation n (m)**: Separations 2-10 indicate the distance between the current source and the previous source
- **Peak cps n**: The peak count rate for source n
- **Length src n (m)**: The length of source n
- **Cos power #1, Cos power #2, Fraction #2 power**: Parameters for manipulating the shape of the peaks (defined further below)
- **% Template error**: Chi-square is calculated based on statistics in spectrum plus an overall factor defined by this parameter (generally ~10%)
- **Chi-square for fit**: Statistical parameter defining how well the fit adheres to the measured spectrum
- **Average error (%)**: The average amount the fitted spectrum is off of the measured spectrum
- **Peak / average**: Factor defining how far the peaks are above the overall average spectrum count rate

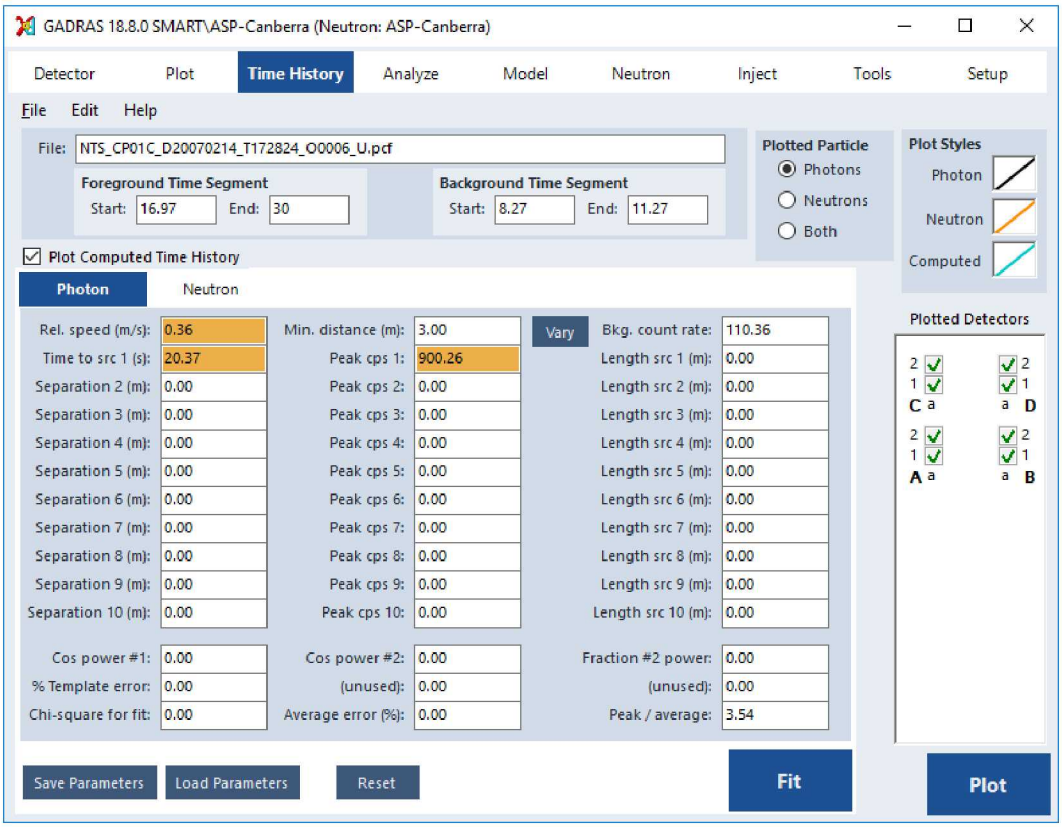

Figure 50. Time History Page with Computed Spectrum Options

Save To File will write the specified parameters to a file for future use. Photon parameters are saved to a file with extension **PAS**, and neutron parameters are saved to a file with extension **NAS**. Similarly, **Load From File** loads previously saved parameters from a file and populates the appropriate fields.

GADRAS can fit a computed spectrum to a measured time history file. Users can select any property to vary by clicking the label of the parameter. Clicking the label of a parameter will highlight the parameter's text box, as shown in Figure 50. Any parameters that are highlighted will vary when the user clicks **Fit Data**. The computed spectrum before and after fitting the peak count rates is shown in Figure 51.

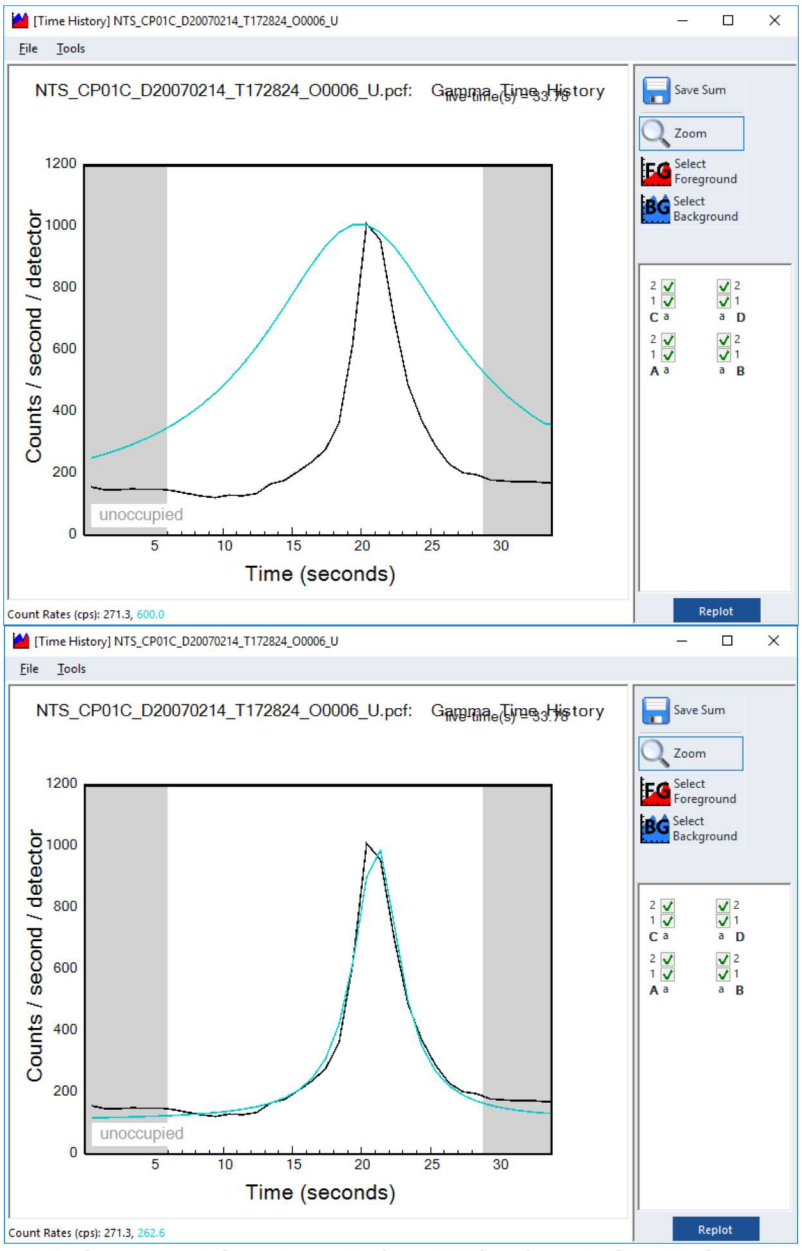

Figure 51. Computed Spectrum before Fit (top) and after Fit (bottom)

The parameters Cos power #1, Cos power #2, and Fraction #2 power determine the shape of the peaks for the source objects. If a bare spherical source passes by a bare detector, the source will have the same shape at all points in time, and thus the Cos power #1, Cos power #2, and Fraction #2 power will all be 0. However, if the detector or source is shielded on the sides, the source will

appear differently at different positions. The equation for the rate at different locations take the form

$$R = R_0\left[(1 - Frac)cos^{P1}\theta + (Frac)cos^{P2}\theta\right] \quad (5)$$

where θ is the horizontal angle from the source to the detector, R is the count rate at angle θ, R_0 is the count rate of the source when the source is directly in front of the detector (θ=90 degrees), and *Frac*, *P1*, and *P2* are empirical parameters to be fit to the measurement. In the above equation, *P1* corresponds to Cos power #1, *P2* corresponds to Cos power #2, and *Frac* corresponds to Fraction #2 power.

8. ANALYZING SPECTRA

8.1. Graphical Analysis Using Plot Overlays from Library

The GADRAS plot window allows for some primitive spectral analysis. Energies from measurement peaks can be compared with library spectra from the **Isotope Database** or the **PhotoPeak List**.

The left side of Figure 52 shows an example where the **PhotoPeak List** form is used to overlay a computed spectrum for ^{88}Y (cyan) with the measured spectrum. This display is presented after shift+clicking on the 1836 keV peak. The activity of ^{88}Y in this sample is estimated to be 8.63 uCi shielded by 11.9 g/cm^2 of material with atomic number 94. The PhotoPeak list is shown on the right side of Figure 52. If the overlay does not match, another peak may be chosen for comparison with the measured spectrum.

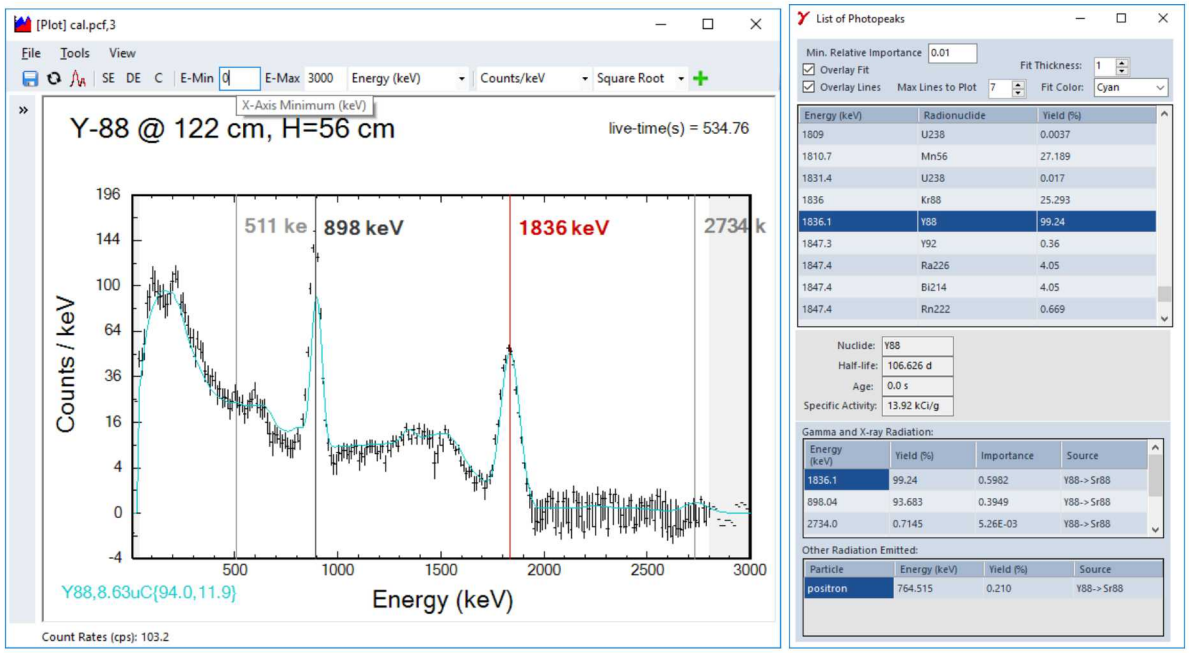

Figure 52. Graph of Measured Spectrum with Overlay (*left*); Photopeak List with Displayed Isotope Highlighted (*right*)

8.2. Numerical Spectral Analysis

GADRAS is designed to perform robust full-spectrum analysis. Once a detector calibration has been performed, various analysis techniques can be used to identify peaks and estimated source information. The **Analyze** tab on the main window provides options for numerical analysis options, which include:

- Single Regression
- Multiple Regression
- ComputeFlux

The Analyze tab shown in Figure 53 contains a table with measurement information, similar to the **Plot** tab. Display options for the analysis output are located on the bottom of the **Analysis** tab. The ensuing plot will only subtract the background if the **Strip background** option is selected. If no background is specified, GADRAS will attempt to estimate the background based on features in the measurement.

For the analysis algorithms to function properly, the distance from the front face of the detector to the center of the source must be known or assumed to correctly calculate the intensity of the source.

There is also an option to perform an analysis routine on a time history file by clicking the **Time History** button. This will perform the analysis on the time-summed spectrum. If the user updates the foreground or background time segments, the analysis routine will automatically perform a new analysis, unless the analysis takes a long time (e.g. ComputeFlux). In this case, after the user selects the foreground and background segments, they may click **Analyze** on the Time History display form.

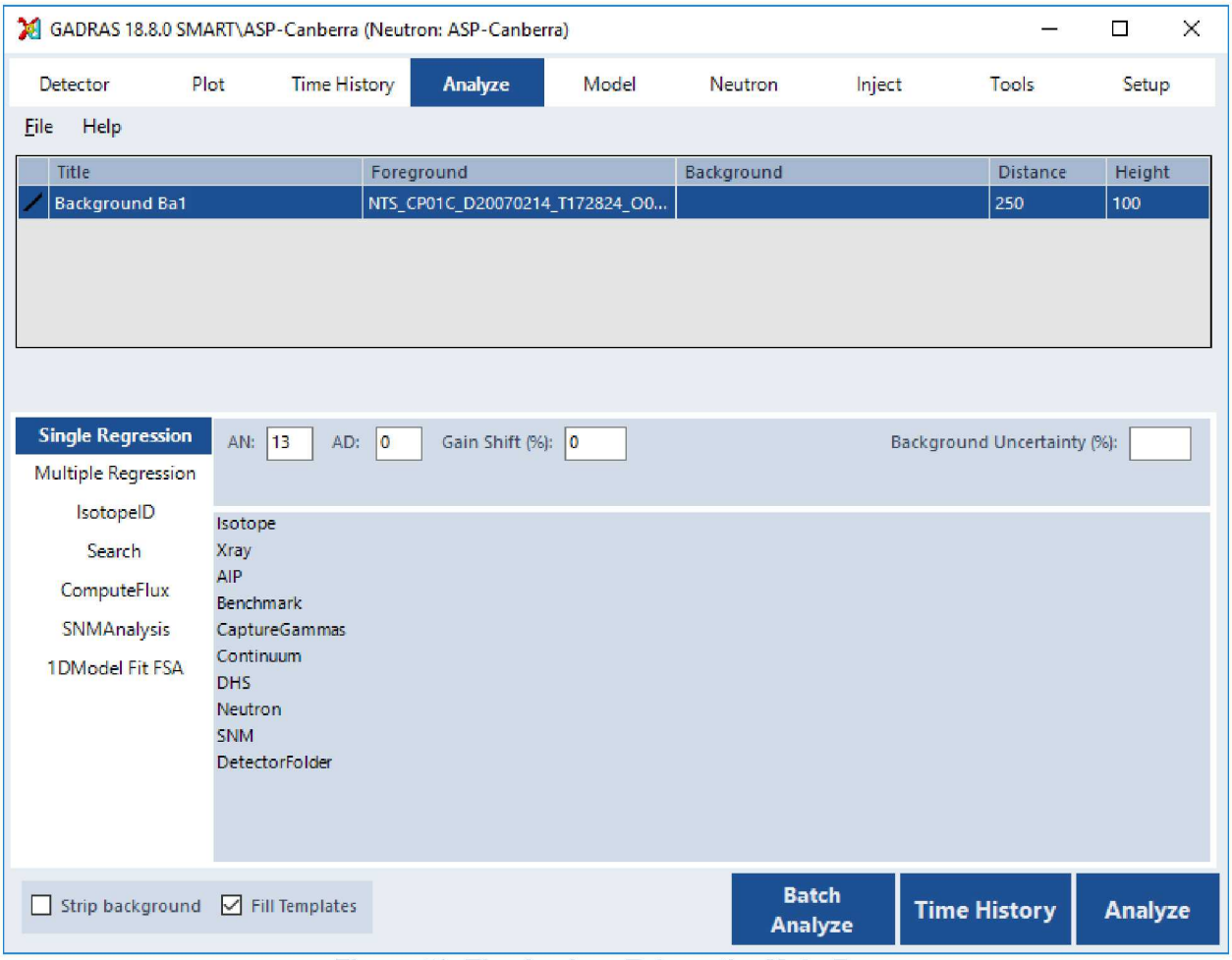

Figure 53. The Analyze Tab on the Main Form

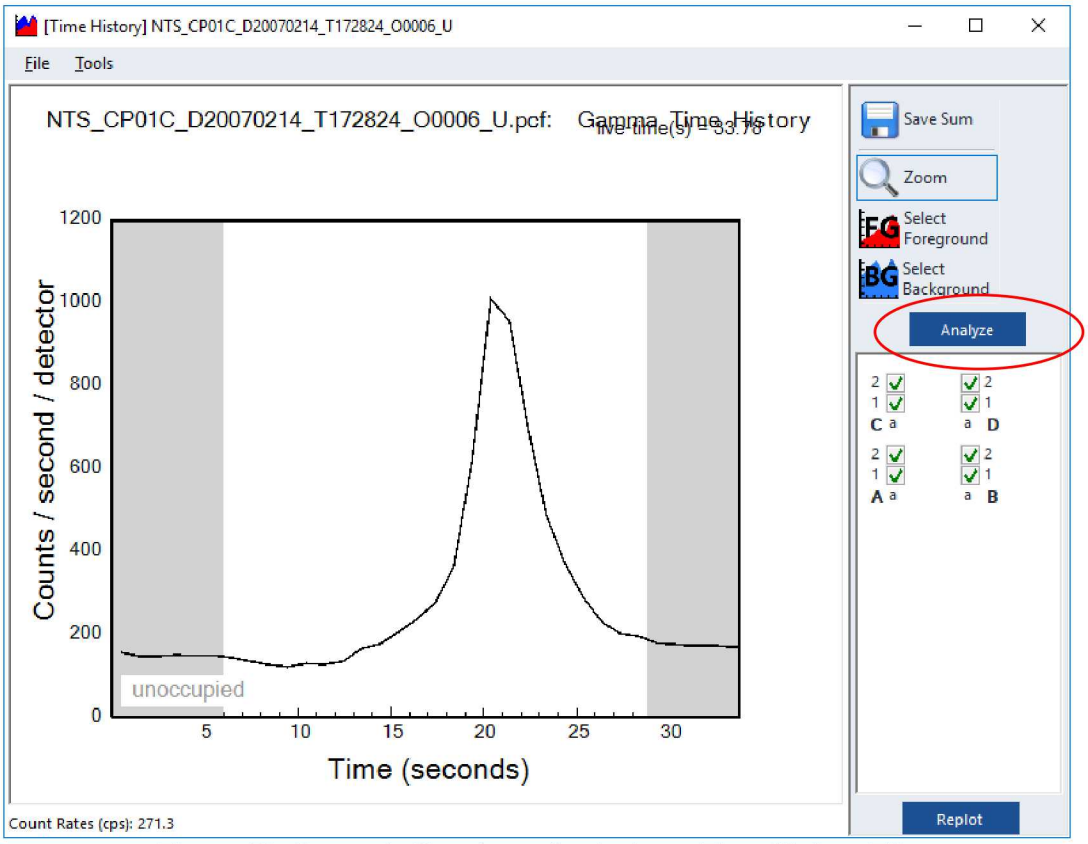

Figure 54. Compute Spectrum Analysis on Time History File

8.2.1. *Source Libraries*

Several source libraries are generally available for inclusion in regression analysis, shown in Figure 53.

The available source libraries are:

- Isotope
- Xray
- AIP
- Benchmark
- CaptureGammas
- Continuum
- DHS
- Neutron
- SNM
- DetectorFolder

Most of these libraries match the subfolders of the Source directory (usually located in **C:\GADRAS\Source**). Other libraries can be created by the user by making new subdirectories

under **C:\GADRAS\Source**. Each library/directory contains files that define emission rates of gamma-rays or neutrons.

Within each library is a list of sources that can be selected for use in the current analysis. Sources can be selected by clicking on the source. Multiple Regression analysis allows for multiple sources to be included in the analysis results.

The most commonly used library in a typical analysis is the Isotope library. Figure 55 shows the Isotope library window with several isotopes selected (*orange*). Users may select various groups of isotopes in the Group Selection Options portion of the window. The group selection capability is provided only to save time in selecting an isotopic group. The groups include:

- **Fission** – common fission daughter products
- **Natural** – naturally occurring isotopes commonly found in measurements
- **Medical** – typical isotopes used as radiopharmaceuticals and sources for imaging and therapeutic use
- **Calibration** – isotopes often used as laboratory calibration sources
- **SNM** – isotopes typical of uranium and plutonium
- **Automatic** – automatically chooses potential isotopes from the library based on a simple peak identification algorithm

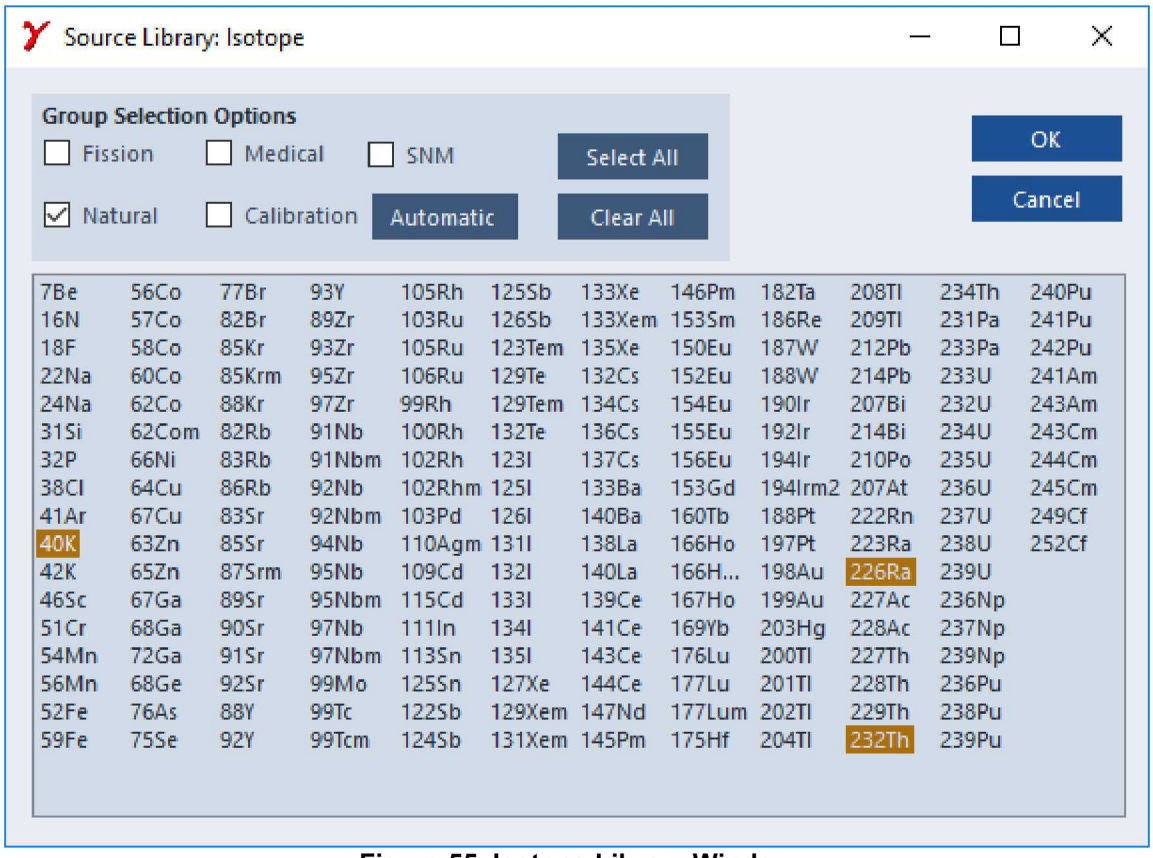

Figure 55. Isotope Library Window

Fitting the continuum caused by the presence of a neutron source cannot be done by selecting a neutron emitter (e.g., ^{252}Cf) from the gamma-ray **Isotope** library. Instead, it must be done with an appropriate selection from the **Neutron** library.

8.2.2. *Introduction to Linear Regression Analysis*

GADRAS contains two linear regression analysis routines. The two routines, located on the **Analysis** screen, have the same user interface and analysis approach, but are used for different purposes.

- **Single Regression** performs a chi-square (χ^2) analysis to rank individual gamma-ray sources to a radiation measurement. This option should be used when it is anticipated that only one source heavily dominates the spectrum.
- **Multiple Regression** performs a chi-square (χ^2) analysis with the assumption that several gamma-ray sources are contributing to a measurement. For example, in the case of a radioactive fallout measurement, several radionuclides will be present and should be included in the analysis.

Both analysis routines report a χ^2 metric, which indicates the deviation between the measured data and the fit (relative to estimated uncertainties in the two sets). If the data is of good quality, has a good energy-calibration, and the detector-response function is good, the value of χ^2 should be near 1.0 if the fit matches the data.

The spectrum to be analyzed is determined by the what is included in the measurement table at the top of the **Analyze** page. Shielding parameters can be estimated to characterize effects associated with intervening materials. The shielding parameters describe intervening materials by an effective atomic number (**AN**) and areal density (**AD**). Selected sources are ranked for consistency with the measurements when **Single Regression** is performed and more than one source is selected. **Multiple Regression** finds the combination of selected sources and associated activities that gives the best fit to the spectrum. Parameters associated with intervening materials can be varied for the best fit by clicking on the **AN** and **AD** labels (clicking these labels highlights the adjacent boxes, turning them orange). There is also a check box for the option of allowing independent shielding for each radioactive source in the measured spectrum (only for use in **Multiple Regression**).

8.2.2.1. Single Regression Analysis

The **Single Regression** option ranks individual gamma-ray sources for their similarity (χ^2) to a radiation measurement. It is used when it is anticipated that one source heavily dominates the spectrum. Any combination of sources can be selected by the user from the available source libraries (see Section 8.2.1). Figure 56 shows the **Single Regression** tab with selected sources. Clicking the **Analyze** button will perform the analysis.

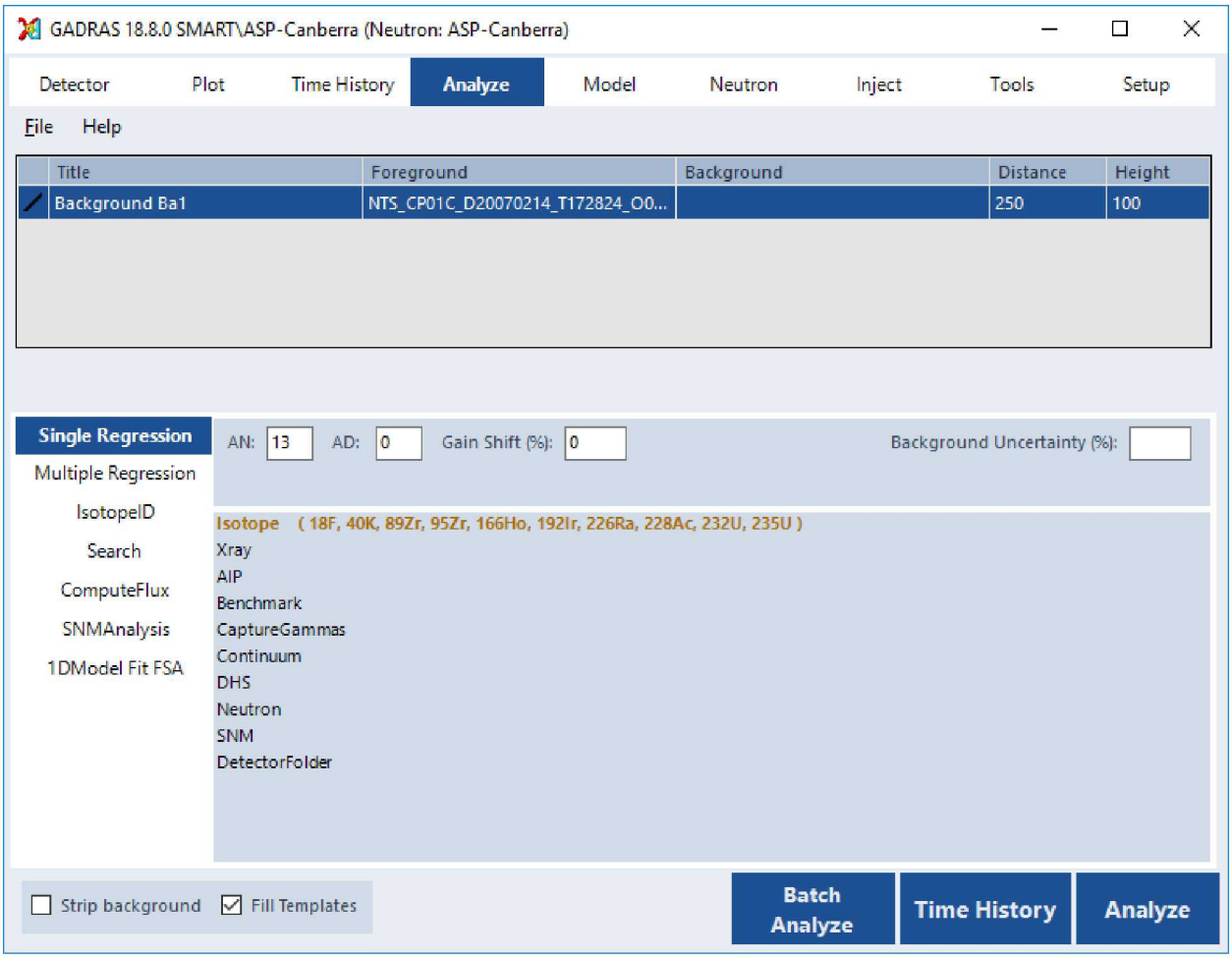

Figure 56. Single Regression Analysis Tab

Single Regression analysis generates a plot of the single nuclide that best fits the data and a summary page. The best fit is plotted as shown in Figure 57, and the summary page (Figure 58) ranks the selected isotopes based on similarity to the measurement using the reduced chi-square (χ^2).

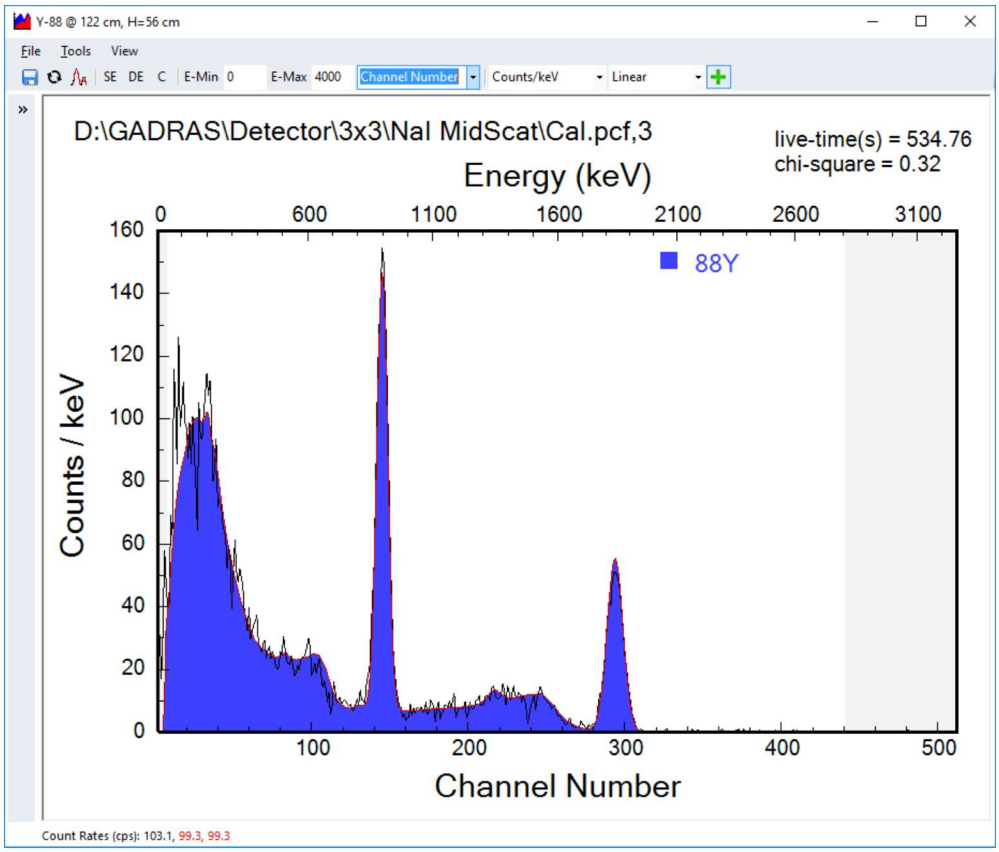

Figure 57. Single Regression Analysis Results of Unshielded 88Y Spectrum

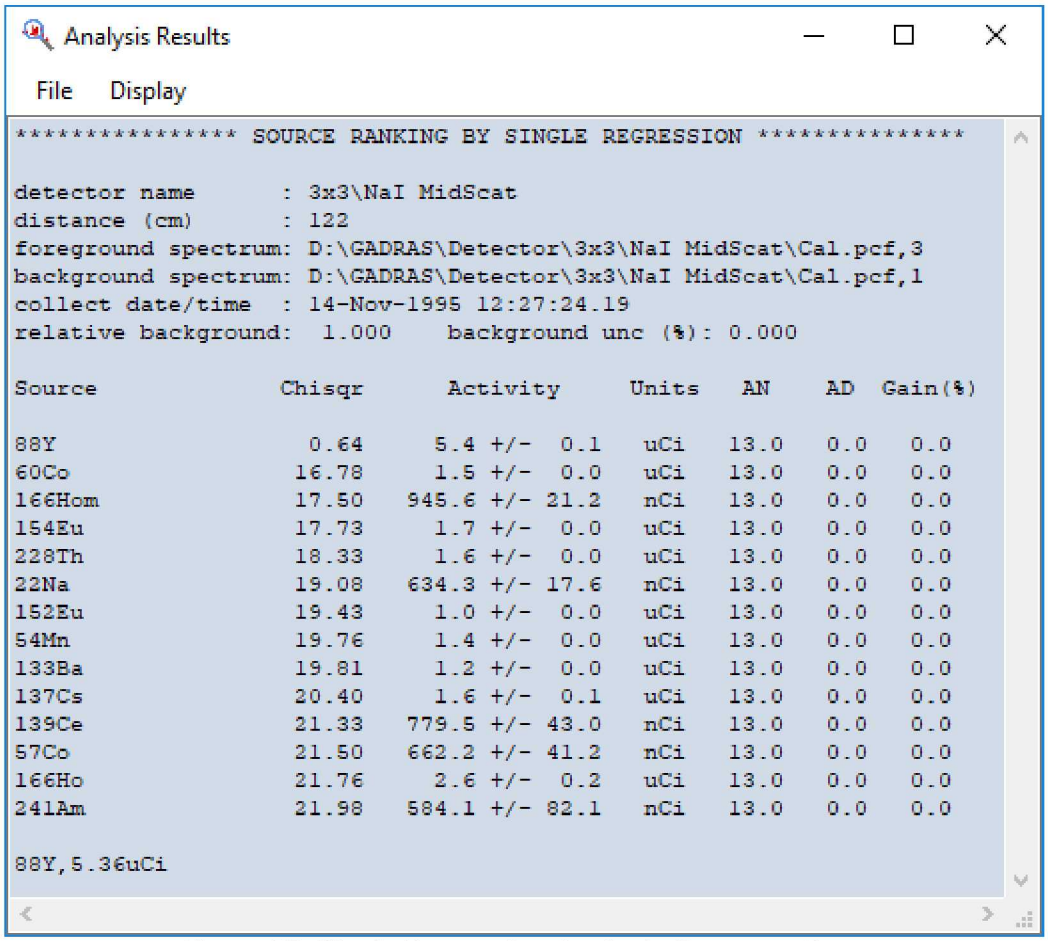

Figure 58. Single Regression Analysis Summary Page

8.2.2.2. Multiple Regression Analysis

The **Multiple Regression** analysis algorithm finds the combination of sources that gives the best fit to the measured spectrum. A reverse regression technique is used in which a combination of all spectral templates is utilized. Subsequent iterations gradually remove sources that do not contribute to the fit.

When performing this procedure, users have the option to allow an intervening, adjustable absorber/shield to obtain the best fit. This is done by activating the boxes labeled **AN** and **AD**. Calculations can take several minutes if many sources are selected, especially if the shielding can vary.

Figure 60 shows the Multiple Regression tab with the same 88Y spectrum in the foreground, except we have now also removed the background subtraction to allow the multiple regression to fit the background components. We have also allowed the shielding AN/AD to vary, as well as allow independent shielding for each radionuclide.

The **Multiple Regression** analysis routine generates a single graph of the group of nuclides that best fits the data and a summary page. The graph will indicate the relative effects of each isotope in the overall fit if the **Fill Templates** option has been selected**.** The graph shown in Figure 60 displays each selected source's contribution. The summary of the multiple regression analysis results shown in Figure 61 displays the analysis results in text form (isotope list, activities, weights, and shielding information). The text string found at the bottom of the summary page can be copied and pasted to the source line (Source for Computed Spectrum) on the **Plot** tab for plotting as an overlay for comparison with measured data.

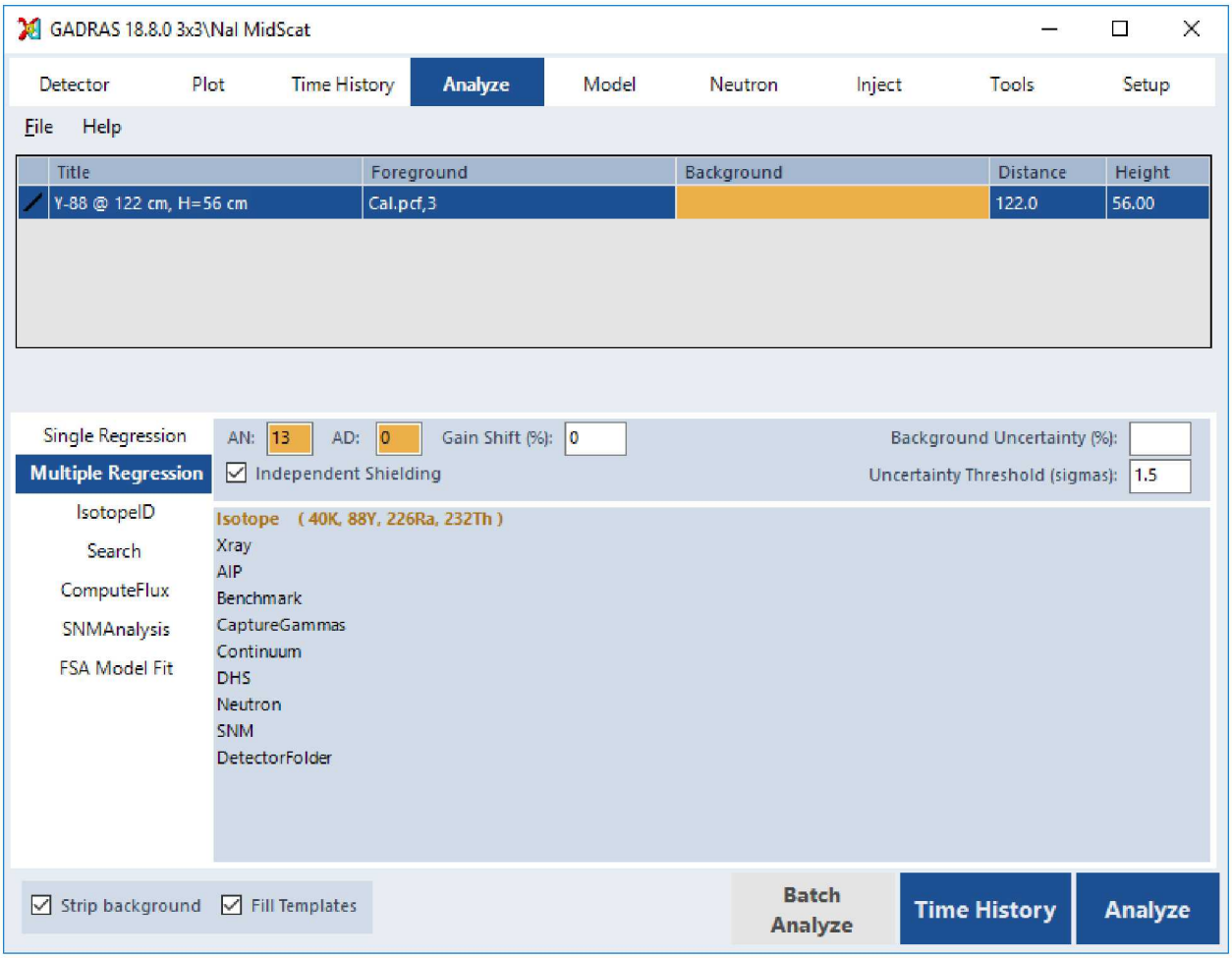

Figure 59. Multiple Regression Analysis Tab

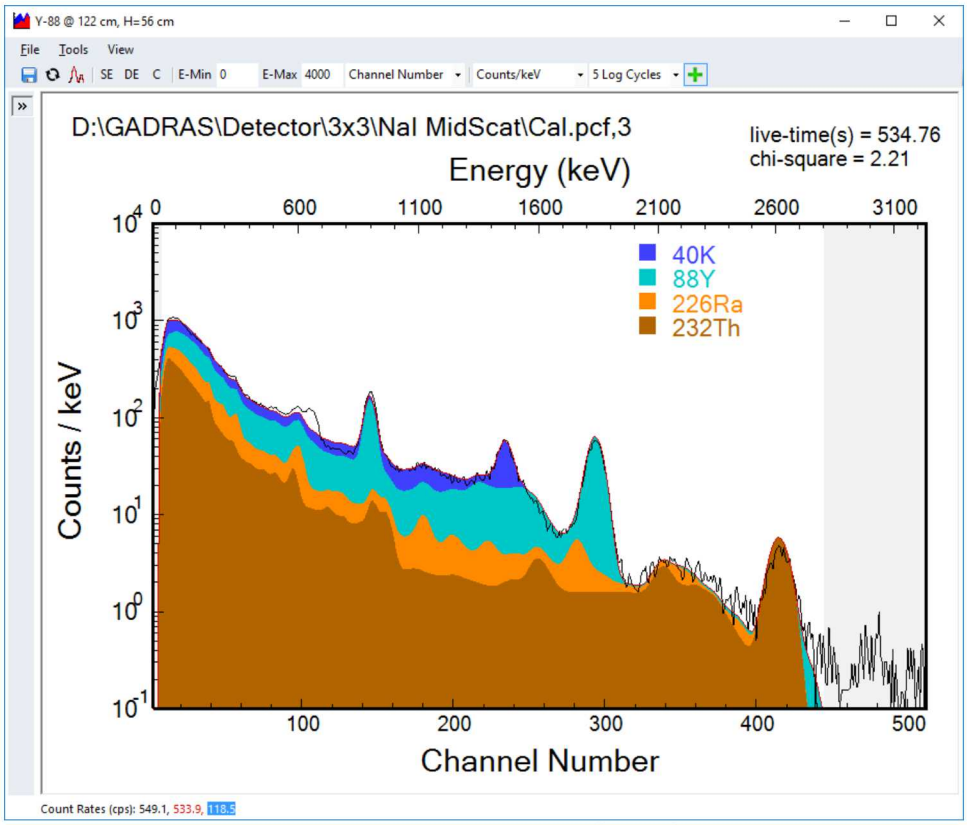

Figure 60. Multiple Regression Analysis Results of 88Y Spectrum and Background

Analysis Results

File Display

```
*************** MULTIPLE LINEAR REGRESSION ANALYSIS ***************

detector name       : 3x3\NaI MidScat
distance (cm)       : 122
foreground spectrum: D:\GADRAS\Detector\3x3\NaI MidScat\Cal.pcf,3
background spectrum:
collect date/time   : 14-Nov-1995 12:27:24.19
reduced chi-square :  4.413     weight range (keV): 36-2796
relative background:  1.000     background unc (%): 0.000
mult-regres. coeff.:  0.498     template error (%): 5.000
GainShift (%)       :  0.000

Source                  Activity(uCi)      Weight(gm)     AN     AD

40K                 128      +/-  3          1.79E+01      6.0   28.4
88Y                   9.88   +/-  0.09       7.10E-10     18.0   12.6
226Ra                 4.5    +/-  0.1        4.63E-06     17.5   21.6
232Th                 6.9    +/-  0.1        6.35E+01      9.9   25.0

40K,127uCi{6.0,28.4}+88Y,9.89uCi{18.0,12.6}+226Ra,4.58uCi{17.5,21.6}+232Th,7.00uCi{9.9,25.0}
```

Figure 61. Multiple Regression Analysis Summary Page

8.2.3. *Compute Flux*

The **ComputeFlux** algorithm can be selected as shown in Figure 62. The **ComputeFlux** tool estimates the incident flux from the measured spectrum by performing nonlinear regression analysis. Prior to analysis, the user should select the appropriate spectral files for the foreground and background. A graphic plot of the results displays peak and continuum terms as shown in Figure 63. The flux profile is also saved in a file with a **GAM** extension.

Normally, the radiation is assumed to be going through the front of the detector. The **Compute flux as background** option will assume the radiation enters all facets of the detector.

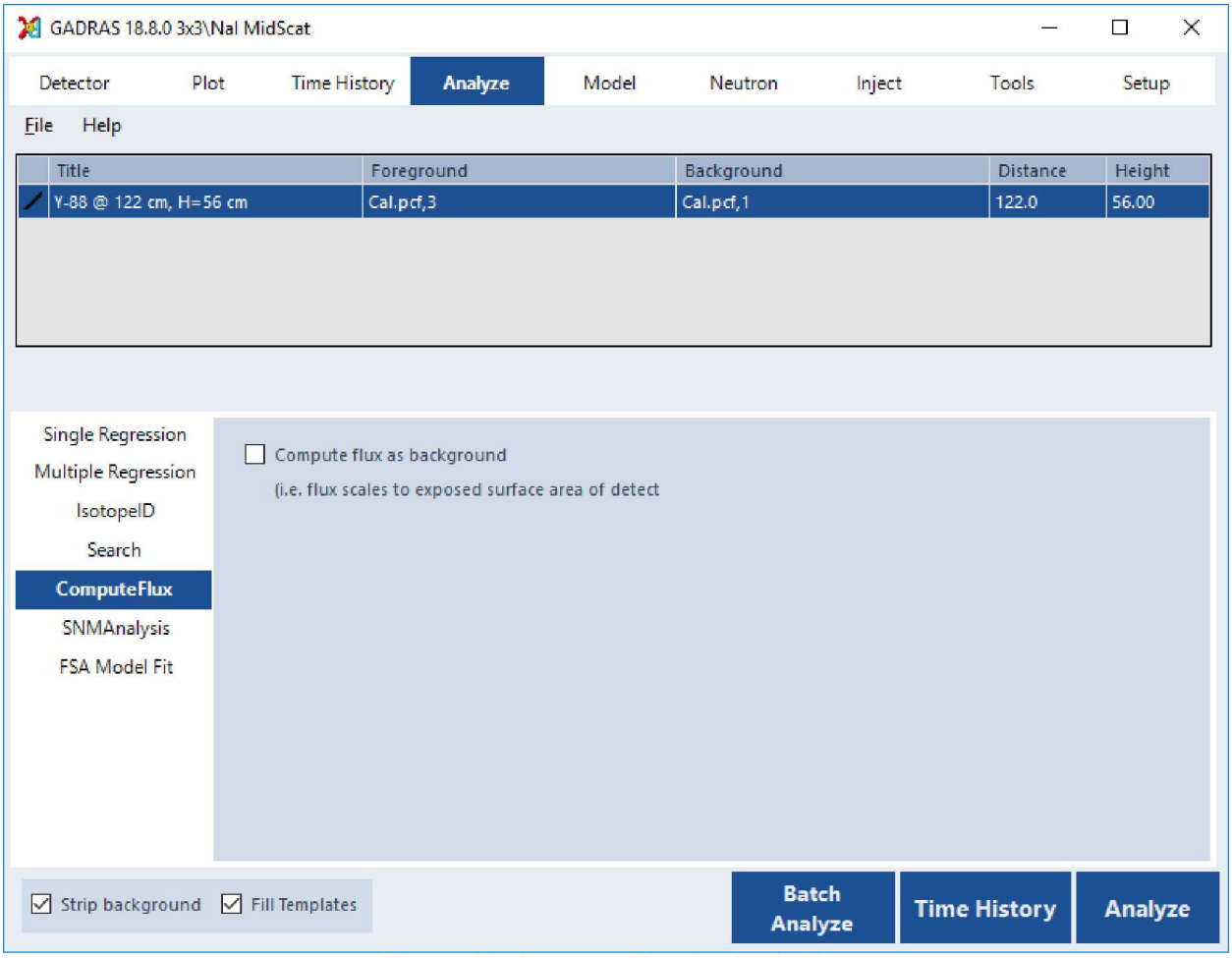

Figure 62. ComputeFlux Analysis Tab

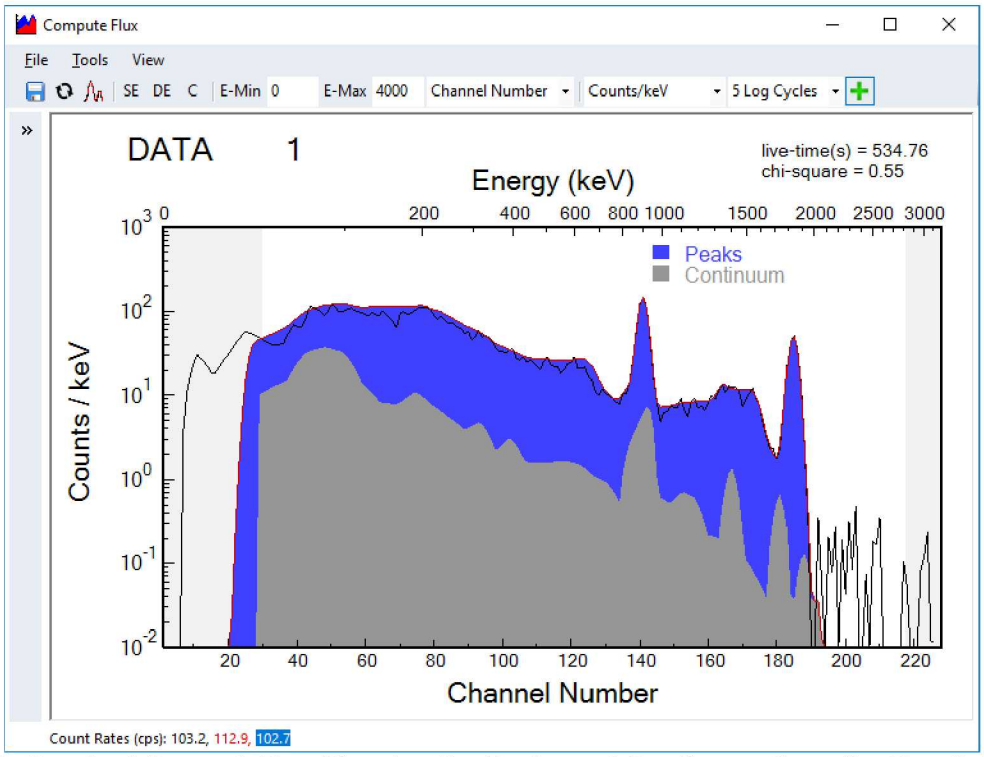

Figure 63. Graph of ComputeFlux Showing the Peaks and Continuum from the Flux Calculation

9. NEUTRON DETECTORS

The **Neutron** tab allows users to model neutron detectors. Neutron detector response information is stored in files named **Neutron$XX.gadras**, where "XX" is the name of the neutron detector. Neutron detector files must be stored in a gamma detector directory and thus be associated with a gamma detector. If a scenario arises in which no gamma detector was used, users must create a "dummy" gamma detector before they can access the **Neutron** tab. Doing this will not affect the neutron detector results. If no neutron detector is associated with the current gamma detector setup, the **Neutron** tab will look like Figure 64.

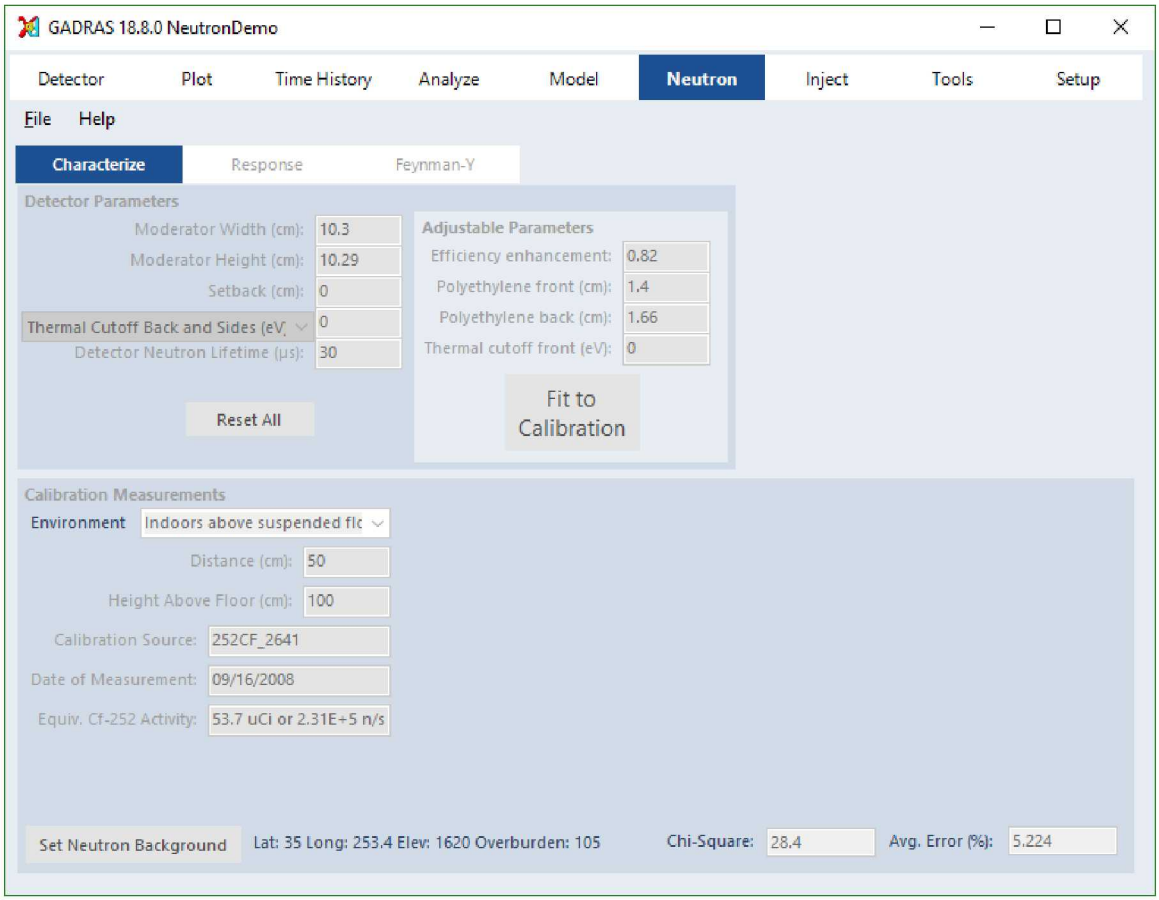

Figure 64. Neutron Tab without Selected Neutron Detector

9.1. Creating a New Neutron Detector

Users can create a new neutron detector by clicking on the **File** menu, then **Create New Neutron Detector**. A new form will appear prompting the user to input parameters to create a new neutron detector (Figure 65). Users must enter a name for the detector, the source-to-detector distance in cm, and the height of the detector in cm. Users may then either choose to clone a common detector, clone an existing detector, or create a new detector from known parameters.

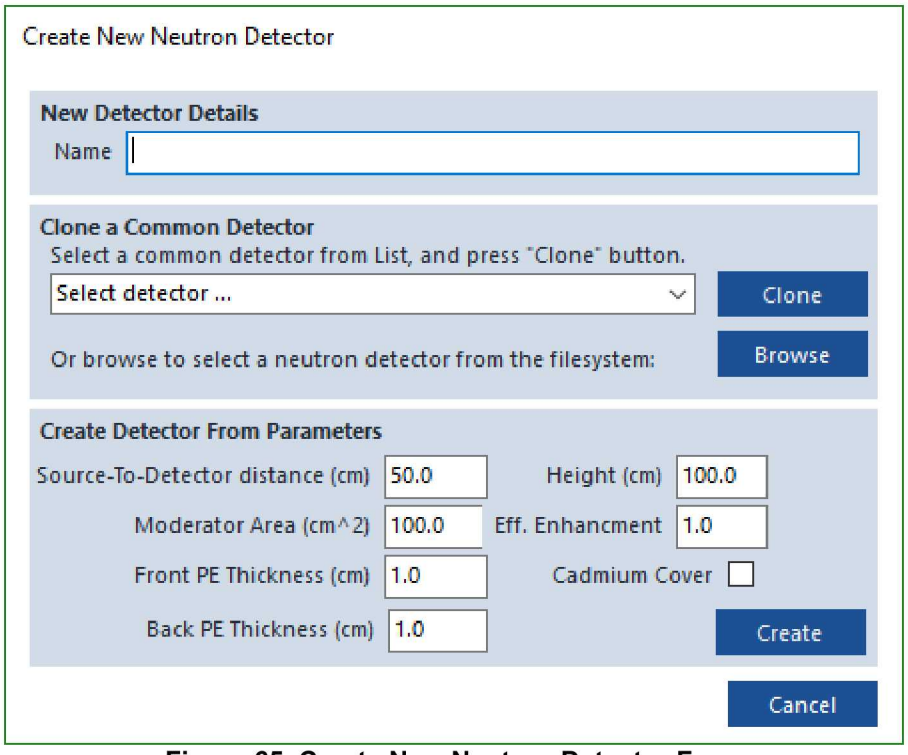

Figure 65. Create New Neutron Detector Form

To clone a common detector, users can select a detector from the drop-down list and click **Clone**. To copy an existing detector, users can click **Browse** and navigate to the existing detector file (**Neutron$*.gadras**). This detector file can be in another directory. This is useful when the same neutron detector is used with multiple gamma detectors.

To create a detector from existing parameters, fill out the bottom portion of the form (Figure 65). The required parameters are:

- **Moderator Area (cm^2)**: the surface area of the moderator surrounding the detector as seen by the source
- **Front PE Thickness (cm):** the thickness of polyethylene in front of the detector as seen by the source
- **Back PE Thickness (cm)**: the thickness of polyethylene behind the detector as seen by the source
- **Eff. Enhancement**: used to resolve differences between observed and computed efficiencies
- **Cadmium Cover**: checked if the detector is surrounded by cadmium

After specifying the parameters, click the **Create** button to create a new neutron detector.

9.2. Neutron Detector Characterization

After creating a neutron detector, the parameters on the **Neutron** tab are activated and the initial settings are filled in. Users can then fill in more information about the neutron detector:

- **Moderator Height (cm)**: the vertical height of the moderator
- **Moderator Width (cm)**: the horizontal width of the moderator
- **Setback (cm)**: the distance from the front face of the detector to the moderator face
- **Thermal Cutoff Back and Sides** or **% Covered by Cadmium**: the energy at which neutron are killed if they enter from the back or sides of the detector housing, or the percent of the detector covered by cadmium
- **Detector Neutron Lifetime (μs)**: the average lifetime of a neutron in the detector in microseconds

After the initial detector parameters are input, the **Calibration Measurements** section can be completed. The first drop-down menu describes the overall scattering environment for the calibration measurements. The following options are available:

- **No reflected neutrons**: the environment does not scatter any neutrons into the detector
- **Outside or large bay**: the environment scatters neutrons only from the floor
- **Inside above suspended floor**: neutrons are scattered from the walls and floor; the floor is assumed to be above ground and thin
- **Inside above concrete on ground**: neutrons are scattered from the walls and floor; the floor is assumed to be infinitely thick

The following parameters should be filled in before attempting to characterize the detector:

- **Distance (cm)**: The distance from the center of the source to the detector face
- **Height Above Floor (cm)**: the height of the detector above the floor

Once the parameters are filled in, characterization measurements using ^{252}Cf should be recorded. The calibration source should be in the source database (see Section 11.1.1). The name of the source is 252CF_*serialNumber* where *serialNumber* is the identifying serial number of the ^{252}Cf source. The date of the measurements should be recorded. Once this information is present, GADRAS_DRF will calculate the activity of the source during the measurements and display the information in the corresponding textbox. Alternatively, users can input a known activity of ^{252}CF (e.g. "252CF,100uC") into the name field; however, this is not recommended.

A range of moderated ^{252}CF sources is required for GADRAS to determine the proper energy-dependent response function of the neutron detector. Measurement information for each moderated source is recorded in the table on the bottom of the form. The source configuration can be selected from the following:

- **Background**: measurement taken with no source
- **Cf252-Bare**: measurement taken with bare ^{252}Cf source (no shielding or moderator on source)
- **Cf252-*XX*cm-PE**: measurement taken with *XX* cm of polyethylene surrounding the source
- **Cf252-*XX*cm-BPE**: measurement taken with *XX* cm of borated polyethylene surrounding the source

For each measurement, the **Live Time** and the total number of counts should be recorded in the table. The net count rate will be computed automatically. The computed count rate will be computed based on the parameters entered in the form. The **Neutron Background** button will bring up the Neutron Background form (Figure 66). This form determines the cosmic flux that can be expected during the count. Users can select a pre-defined location from the dropdown list, or they can input the latitude, longitude, and elevation themselves. Users should specify whether the experiment was taken in a building below multiple floors, or they can specify the areal density themselves. The reference date can be changed to match when the measurement was taken. As a reference, the cosmic neutron rate relative to the average rate New York City is given.

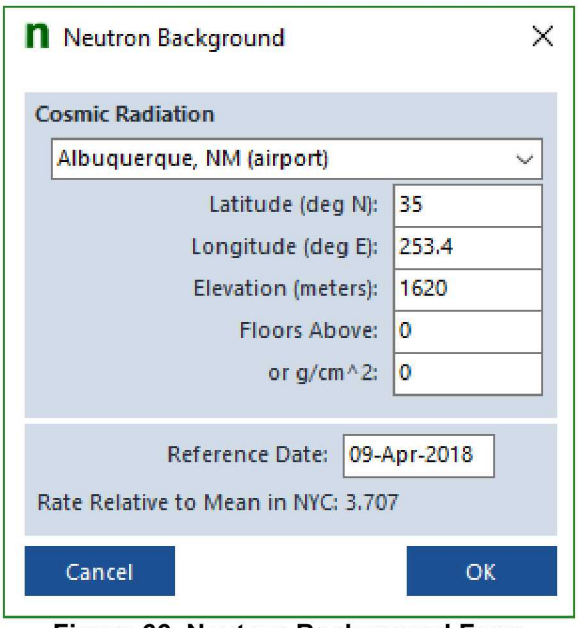

Figure 66. Neutron Background Form

The **Adjustable Parameters** box holds parameters that can be optimized to improve the neutron detector model. By clicking the label of the adjustable parameter, users can specify whether they want the parameter to be adjusted. By clicking the **Fit** button, GADRAS will optimize the highlighted parameters using an iterative non-linear regression algorithm. The computed count rate in the measurement table will be updated with the optimized parameters. Clicking the **Clear** button will reset all parameters on the form.

9.3. Neutron Response

The response function of the neutron detector to any measurement scenario (different from the calibration measurement scenario) can be analyzed in the **Response** tab. Users can see the efficiency of the detector plotted in red. Users can specify the measurement environment, the distance, and the height for the measurement.

Once a source GAM file (or ^{252}Cf activity) is specified in the **GAM/3DM File** field, the leakage from the source will be plotted in blue. For SNM radionuclides like ^{240}Pu, this does not include any shielding or potential multiplication from fission. To include these effects, users must have a GAM

file derived from a model. The units for neutron leakage are changed in the **Plot Options** box. The choices are:

1. **Diff. Neutron Leakage (n/eV/s)**: this is the neutron group leakage into 4π, with each group divided by the group-width in eV
2. **Neutron Leakage (energy * diff. leakage (n/s))**: this is the differential leakage as described above, multiplied by the average energy of each group (default)

In addition to the plot, the leakage from the source, estimated multiplication, detector count rate, intrinsic efficiency and absolute efficiency fields are populated. Here, intrinsic efficiency is defined as the percentage of neutrons that are detected, given they strike the neutron detector. The absolute efficiency is defined as the percentage of neutrons that are detected that leak from the source.

There is also a **Quick Source Activity Estimate** box which allows users to input a recorded count-rate from a detector. GADRAS will estimate the equivalent bare and moderated ^{252}CF activity at the specified distance/height/measurement environment.

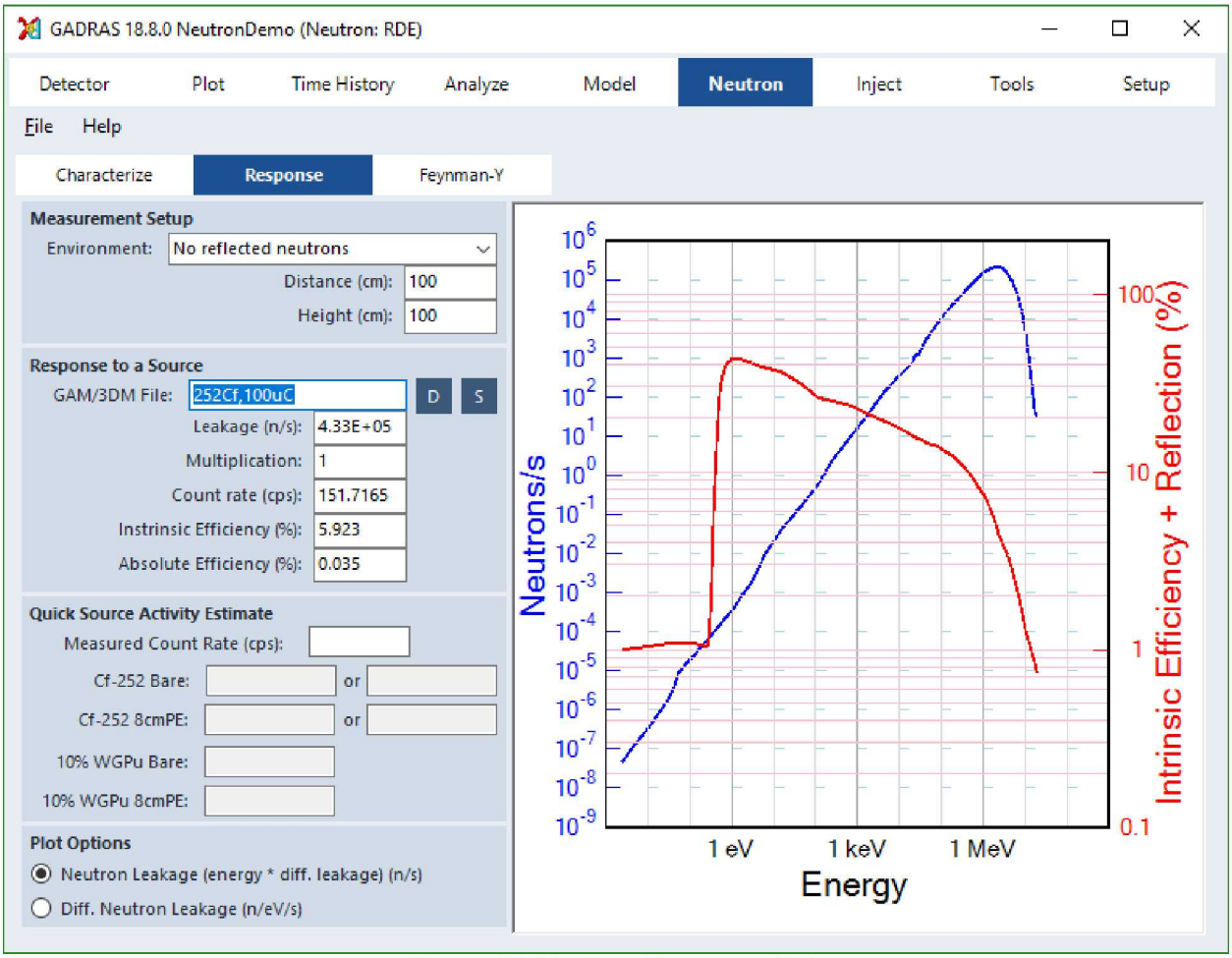

Figure 67. Neutron Response Tab

9.4. Neutron Feynman-Y

GADRAS can analyze and compute Feynman-Y plots. Figure 68 shows the Feyman-Y tab on the GADRAS Neutron page. Users can display a multiplicity measurement using the Measurement text box. Users can also calculate the Feynman-Y distribution from a 1-D model by using the Calculation text box.

Figure 68. Neutron Feynman-Y Page

10. INJECT CALCULATIONS

10.1. Creating Inject Data

GADRAS has the capability of synthesizing spectra and save them to a file. The results of these computations are called inject spectra and can be used for a variety of purposes, including training, sensitivity analysis, and minimum detectable activity tests. The main sections in the Inject page are general settings, neutron settings, detector settings, and background settings. The inject page is shown in Figure 69.

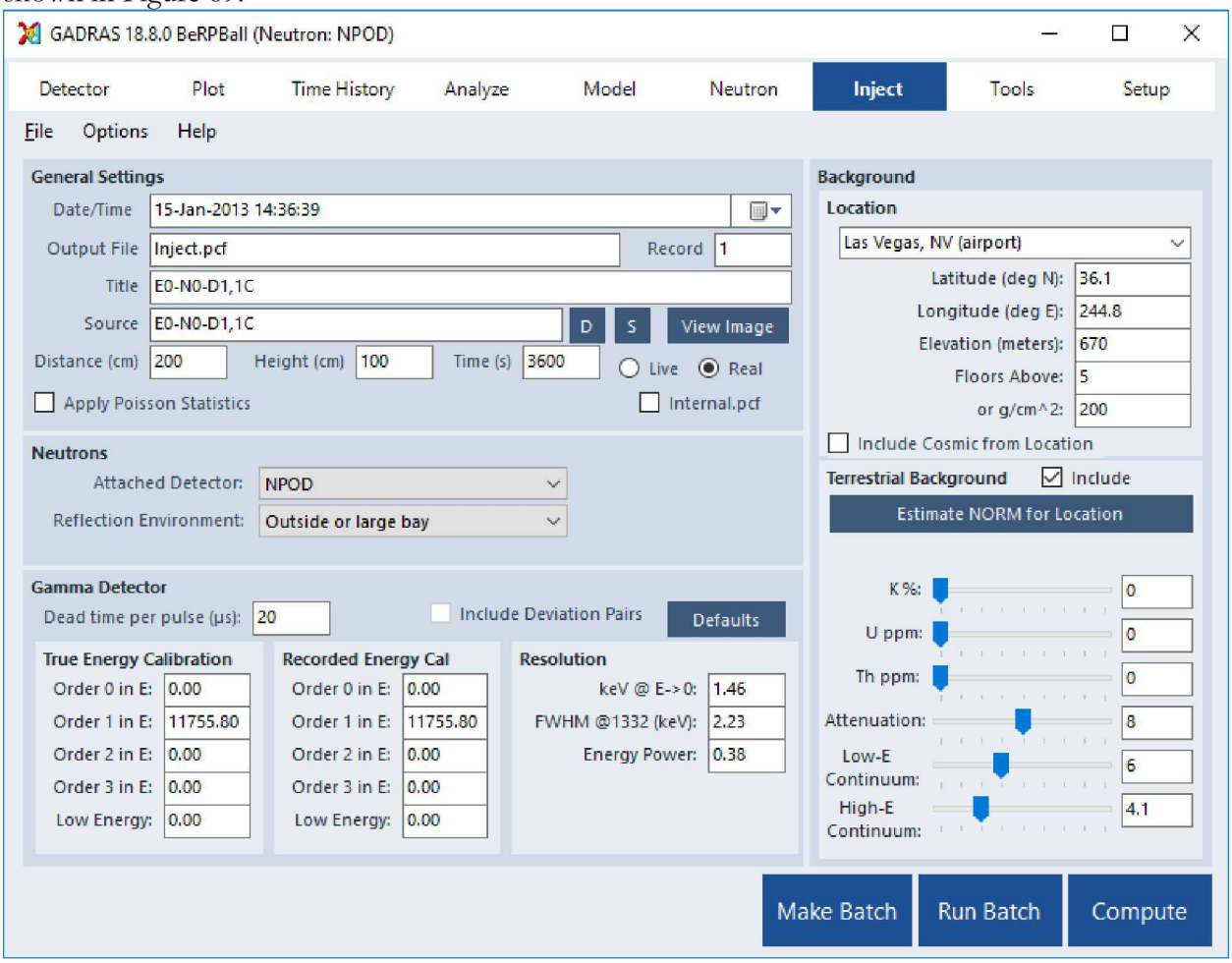

Figure 69. Inject Page

10.1.1. *General Settings*

Users may specify a variety of properties when creating inject data. The general settings include:

- **Date/time**: The timestamp that should be assigned to the spectrum; users may type in a date and time or select one from the calendar icon
- **Output File**: The file to write the inject data to
- **Record**: The record in the file to write the inject run to
- **Title**: The title of the run

- **Source** (optional): The source information to include in the inject data; this field is similar to the Computed Spectrum table on the **Plot** page (Section 4)
- **Distance (cm)**: The distance between the source and the detector face
- **Height (cm)**: The height of the detector above the floor for this scenario
- **Time (s)**: The amount of time that should be simulated for the run; users may also specify whether this is Live time or Real time
- **Apply Poisson Statistics**: When this box is checked, the inject data will have a Poisson distribution which simulates real measurement data; when unchecked, the data will be perfectly conformed to theoretical calculations
- **Internal.pcf**: If the detector has internal radioactive components (e.g. LaBr) or calibration sources attached to the detector, there may be a file called *Internal.pcf* in the detector folder, which contains the spectrum associated with the internal source; this checkbox allows this spectrum to be included in the inject data file

10.1.2. *Neutrons*

Some detectors have neutron detectors attached to them. This section allows a user to also compute the count-rate from the neutron detector and embed that information into the spectrum file. For a neutron detector to be available, the neutron detector file must be present in the current detector folder.

The **Reflection Environment** is also important for gamma detectors measuring neutron sources, as it will change the rate of incident neutrons on the gamma detector, and thus the observable neutron interactions in the gamma detector. This is described in more detail in Section 9.2

10.1.3. *Gamma Detector*

Users may desire to change the detector settings from the default settings (imported from the current **Detector.dat** file).

- **Dead time per pulse** affects the recorded live-time of the simulation. Typical values are between 10 and 20 microseconds.
- **True Energy Calibration** is the energy calibration parameters used to determine the channel group structure for the simulated spectrum. This can also be used to change the full-energy-range of the detector by changing the **Order 1** to the full energy in keV.
- **Recorded Energy Cal** is what is recorded in the spectrum file. This may be different than the true calibration to simulate uncalibrated or poorly calibrated spectra.
- **Resolution** parameters allow users to simulate subtle differences between different detectors of the same type, which have different resolution, or may have resolution changes with time or temperature.

Clicking the **Defaults** button will adjust the energy calibration and resolution parameters back to the default parameters assigned to the detector.

10.1.4. *Background Settings*

Background radiation primarily comes from two sources: cosmic and terrestrial. Cosmic radiation contribution to the spectrum is determined by the latitude, longitude, elevation, and solar cycle (date

and time provided). In addition, the user can specify how many building floors are above the detector (or equivalent areal density of shielding material) which also affects the cosmic radiation. Terrestrial background is mostly composed of ^{40}K, the uranium decay chain, and the thorium decay chain. The following settings can be specified regarding background:

- **Location** (dropdown menu): The latitude, longitude, and elevation for many cities across the world are stored in GADRAS; selecting an option from this dropdown menu will automatically fill these fields in the location info
- **Latitude (deg N)**: Latitude of the simulated measurement
- **Longitude (deg E)**: Longitude of the simulated measurement
- **Elevation (meters)**: The elevation of the simulated measurement
- **Floors Above or g/cm^2**: Users may specify the aerial density of the material above the detector if it is known; otherwise, users may specify the *Floors Above* parameter and the aerial density will be estimated; this is used to generate the cosmic background attributed for the simulated spectrum
- **Include** (terrestrial background checkbox): Specifies whether terrestrial background calculations should be included in the simulated spectrum
- **K%**: The weight percentage of potassium in the soil; for reference, 1% corresponds to 7.8 g of ^{40}K (54.47 μCi) in a 1 meter radius sphere
- **U ppm**: Amount of uranium in soil in parts per million; for reference, 1 ppm corresponds to 2.236 μCi ^{238}U, 2.236 μCi ^{226}Ra, and 104.2 nCi ^{235}U
- **Th ppm**: Amount of thorium in soil in parts per million; for reference, 1 ppm corresponds to 6.7 g ^{232}Th (732.3 nCi) in a 1 meter radius sphere
- **Attenuation**: Amount of attenuation the terrestrial background goes through before encountering the detector
- **Low-E Continuum**: Amount of low-energy continuum the terrestrial background will contribute; this can be based on materials between the soil and the detector or how much soil is present near the detector
- **High-E Continuum**: Amount of high-energy continuum the terrestrial background will contribute
- **Include Cosmic**: Specifies whether cosmic background calculations should be included in the simulated spectrum, this is the primary source of neutron background for the calculations

Users may click the **Estimate NORM for location** button to estimate the naturally occurring radioactive material (K, U, and Th) for the location specified in the *Location* dropdown menu.

NOTE: The terrestrial NORM estimation only works for cities in the U.S., but there are additional cities listed to get the correct latitude/longitude for cosmic radiation.

Once all the settings have been specified, clicking the **Compute** button will generate the output. The **PCF Viewer** window will open and be populated with the file specified in the **Output File** text box. The graph display will also appear and display the simulated inject data. The settings will all be saved in a .inj file, which has a default file name format of <outputFileName>-<RecordNumber>.inj. Users may choose to save the settings without running the inject using the

Save As inject file… option in the **File** menu. The auto-save feature can be disabled from the **Options** menu. Users may also populate the settings from an inject file by selecting **Open inject file…** from the **File** menu.

10.2. Batch Inject

Users may need to generate a large amount of inject data. This can become a tedious process if done in the traditional way. GADRAS allows users to perform batch inject calculations using a series of .inj files. Users may create these text-based files themselves, provided they follow the correct format. To perform a batch inject calculation, users should click the **Batch** button on the inject page. This will bring up the batch inject form as shown in Figure 70.

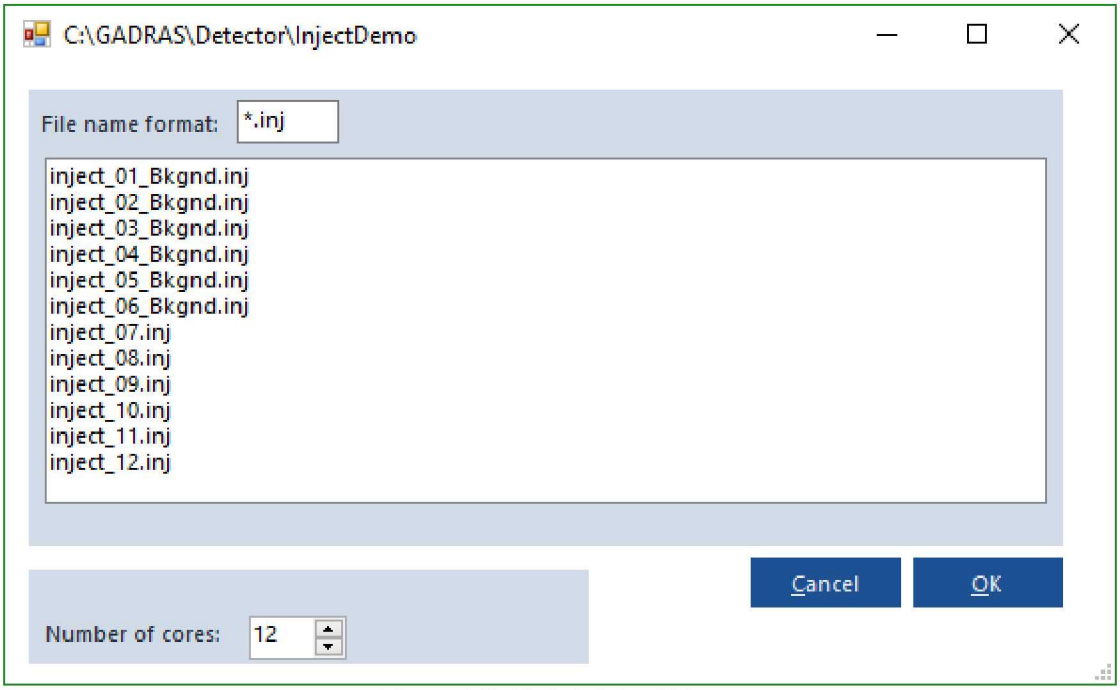

Figure 70. Batch Inject Form

To perform a batch inject calculation, the user selects the desired files to perform the inject calculations with. If none of the files are highlighted, all the displayed inject files will be included in the batch calculation. The *File name format* text box can be used to populate the form with different files. Files do not need the .inj extension to be used in batch calculations. The user can also specify the number of cores to use for the selected batch calculations.

10.3. Batch Inject Setup

Manually generating inject files for large batch runs can be tedious and error prone. The **Batch Inject Setup** tool enables the user to readily generate batch inject data by a varying a subset of the available inject variables, such as source, counting time, and detector distance. The tool is accessed via the **Make Batch** button on the inject page. There are two modes on the **Batch Inject Setup** form: **Batch** and **Pass By**, each accessed by their own tab, as seen in Figure 71.

The **Batch Inject Setup** page is populated with the current configuration on the **Inject Page**, including the settings that cannot be changed on the **Batch Inject Setup** form, such as the background and detector settings. These settings can be changed by either returning to the **Inject Page** or by loading the inject configuration from another inject file via **Load Inject Template…**from the **File** menu. One can also load the inject settings and the entire **Batch Inject Setup** configuration via **Load Setup…** from the **File** menu, for both **Batch** and **Pass By** modes via the ".bis" file.

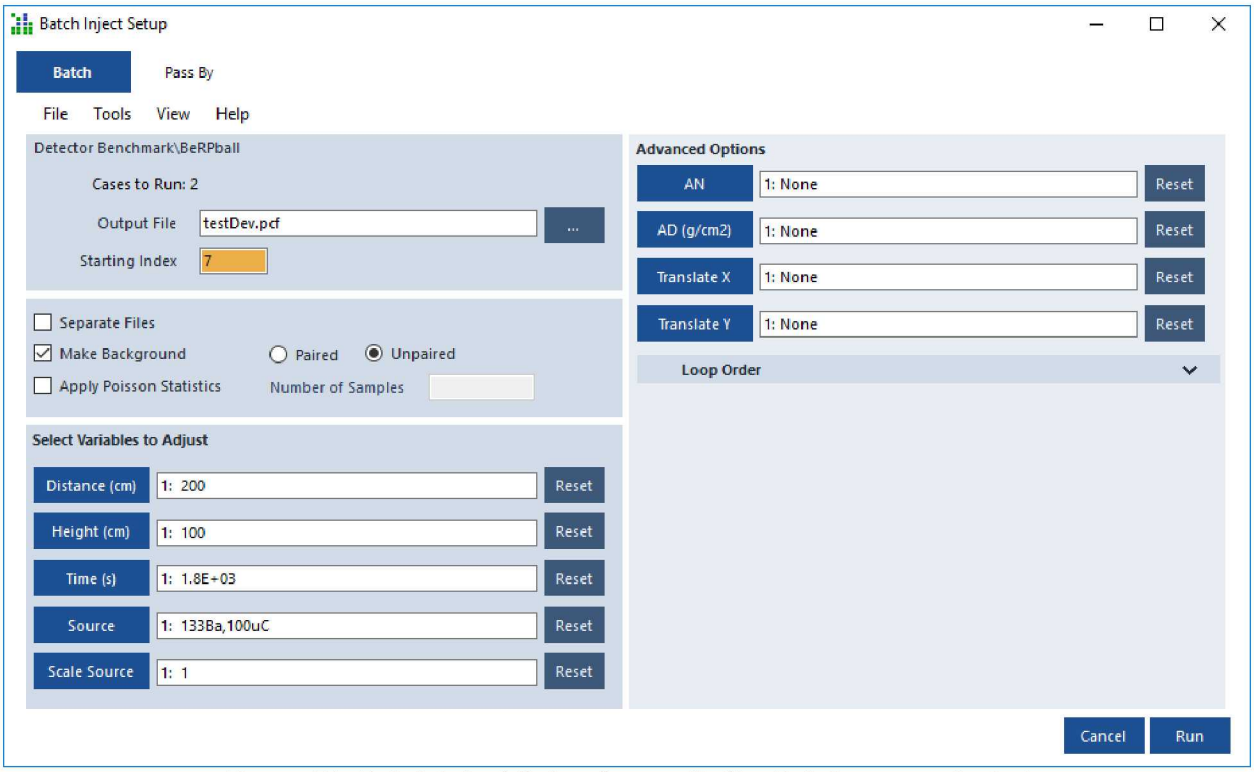

Figure 71. Batch Inject Setup form with the Batch page selected

10.3.1. *Batch*

The **Batch** mode is used to generate inject data by adjusting a subset of the available inject variables, e.g. distance and source. Before adjusting variables, there are a set of parameters that must be set in the top two boxes.

- **Output File:** the name of the spectral file where all the resulting inject data will be stored. Must be either a ".pcf "or ".n42" file
- **Starting Index:** This is the index the inject data will be appended at. It is automatically set to the next free record, if the file already exists
- **INJ Output Directory:** The **Batch Inject Setup** can create a multitude of files in the detector directory, which can be automatically moved to this directory after the **Batch** run completes
- **Save INJ Files After Run:** If not selected, the inject files generated are deleted.
- **Separate Files:** Writes a single inject spectrum to a file, such that each spectral file contains one record
- **Make Background:** If selected, background inject records will be made. **Paired** background gives a background with every source containing record. **Unpaired** generates all the background first, and then the source records follow.
- **Apply Poisson Statistics:** When this box is checked, the inject data will have a Poisson distribution which simulates real measurement data; when unchecked, the data will be perfectly conformed to theoretical calculations. **Number of Samples** is the number of Poisson samples taken of the inject data.

There are two categories of variables: **Select Variables to Adjust** and **Advanced Options**, the former requires a value to generate inject data and the latter are optional. For all variables, the **Reset** button restores the variable to its original data, and the button with the variable name launches a new input form, seen in Figure 72 .

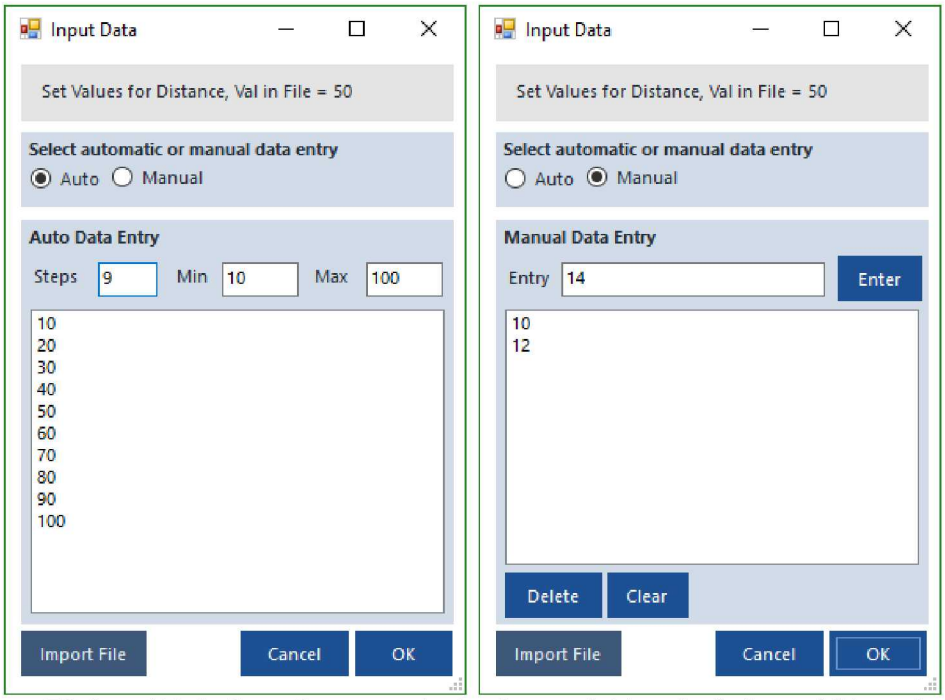

Figure 72. Input Data form for numerical value variables, in Auto and Manual mode

There are three ways to enter the values for a variable. First is **Auto**, where the user specifies the number of uniform sized **Steps** to generate values between **Min** and **Max**, including the limits. Next, is **Manual** where numbers are simply entered. The **Delete** button allows the user to remove selected values and **Clear** removes all entered values. Finally, **Import File** allows the user to load a text file, with a single number on each line, as the values for the selected variable.
The **Source** variable has a special input form, as seen in Figure 73. There are five ways to enter sources. The buttons **D** and **S**, open a file browser for sources in the detector and source folders, respectively. The **CSV** button allows the user to select sources from a user generated ".csv" file that contains the gam file name and a description column. The remaining methods of entry, are **Manual Data Entry**, where you simply type source and by **Import File**, which obeys the same rules as the numerical value input form.

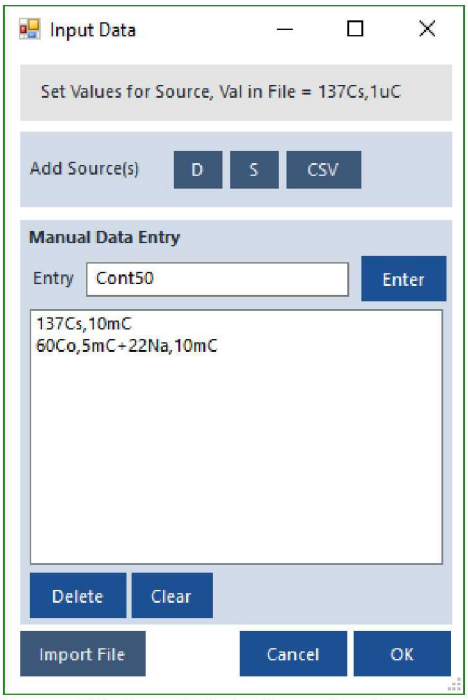

Figure 73. Input Data form for Sources

The normally collapsed section on the **Batch Inject Setup** form, called **Loop Order**, is an advanced option, that allows the user to set the order the variables will be displayed in the spectral record. For example, one could vary **Distance** before **Height**, or vice versa. The data would be the same, but the order of the inject data would change.

Once all variables have been set, one can either write the inject files without running them using the **Write** button or perform the inject calculations by using the **Run** button, where the files are saved or not depending on the state of the **Save INJ Files After Run**. After a **Write**, **Run,** or **File->Save Setup As…** a ".bis" file is generated that saves the current setup of the **Batch** tab. If a **Run** or **Write** is performed a csv file is generated that maps the spectral record to the inject configuration.

10.3.2. *Pass By*

The **Pass By** tab, as seen in Figure 74 , allows users to simulate a source and detector moving relative to each other. Most page behavior is the same as the **Batch** tab. One can no longer write a single spectral record to its own file, but can write paths to their own file by selecting **Separate Files for Each Path.** The **Make Background** box now requires one to enter a **Count Time(sec)** for all backgrounds, which are always at the beginning of the spectral record.

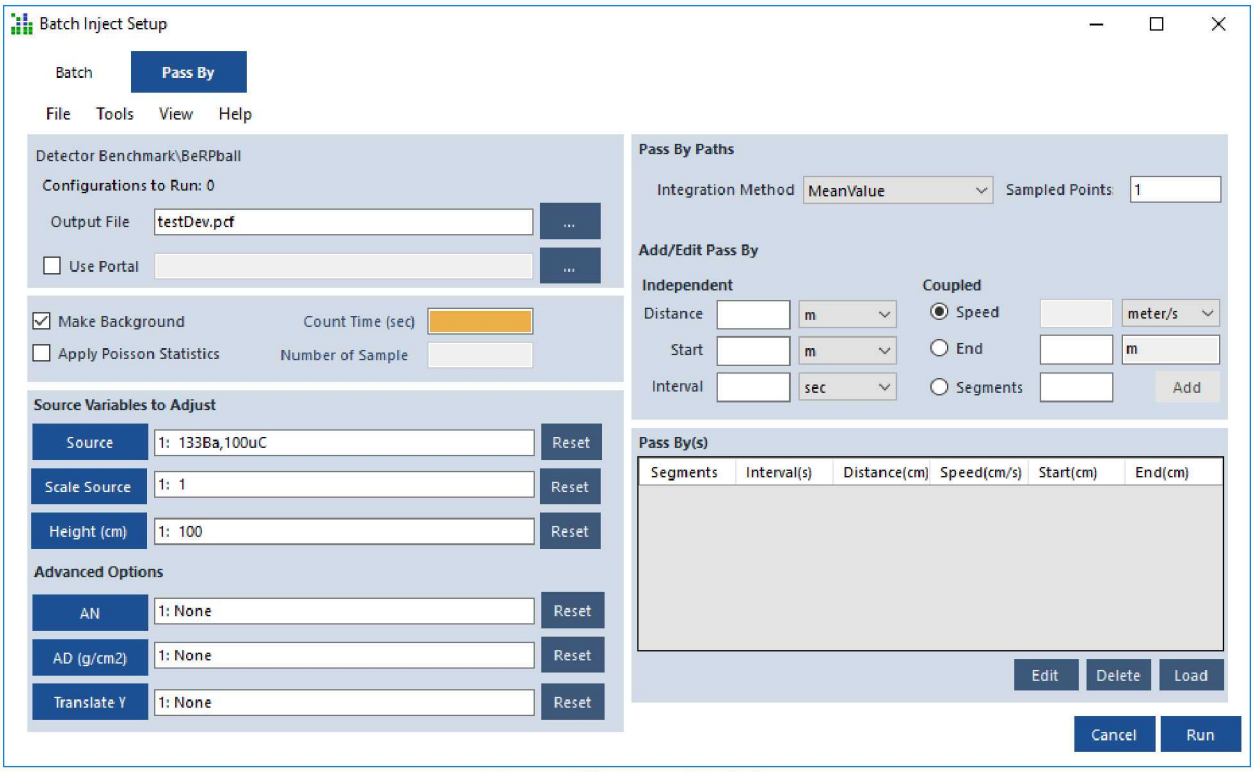

Figure 74. Pass By tab

The **Source Variables to Adjust** and **Advanced Options** buttons behave exactly as they do in the **Batch** tab. The **Pass By Paths** button launches a new form, as seen in Figure 75, to define the relative motion between the source and detector. Each field must be completed and each input supports multiple units, selected in the adjacent dropdown.

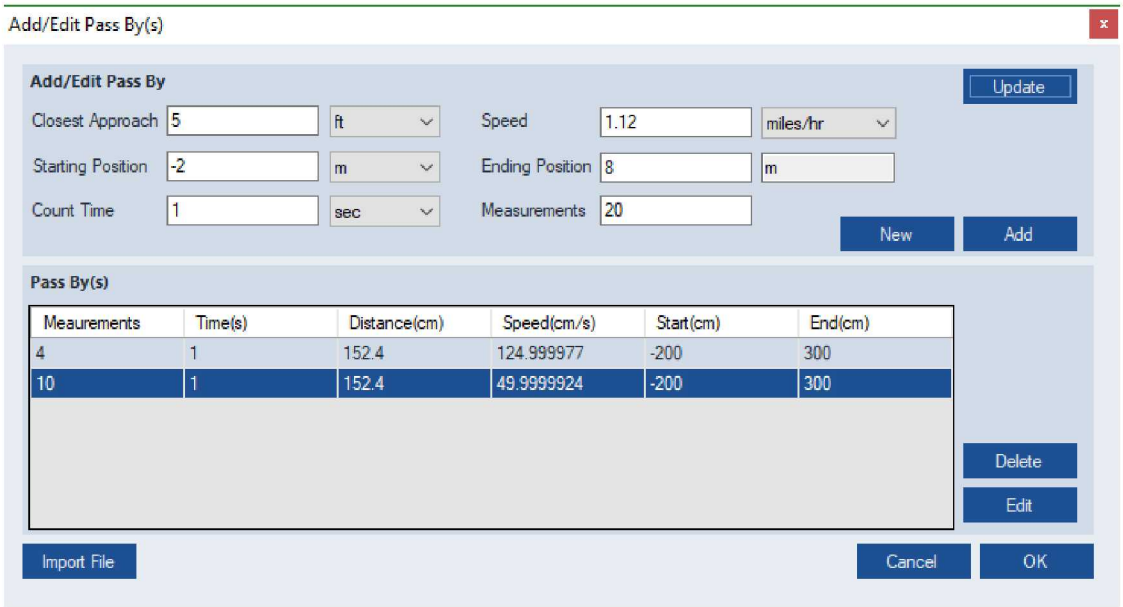

Figure 75. Add/Edit Pass By(s)

There are two types of variables to set in the **Add/Edit Pass By** form: fixed and complimentary variables. Fixed variables are set by the user and complimentary variables are those that the program may vary to insure an integer number of **Measurements**. The fixed variables are in the left column and complimentary are the variables in the right column. The top section of the form is the **Add/Edit Pass By(s)** section, where paths are defined. The **Pass By(s)** table stores all the paths to be used in the inject calculations. The path values are displayed in the units used by GADRAS but when edited display the units used to define the path.

- **Closest Approach:** (Fixed) The minimum distance between the source and the detector. The point of closest approach is fixed at x=0, usually between the **Starting Position** and **Ending Position**.
- **Starting Position:** (Fixed) The initial position of the "Pass By", relative to x=0, as defined by the distance of **Closest Approach.** The **Starting Position** can be positive or negative, allowing for left-to-right and right-to-left paths
- **Count Time:** (Fixed) The time for a single measurement. Multiple measurements are taken along the path, each with a duration of **Count Time**
- **Speed:** (Complimentary) The speed the source and detector move relative to each other between **Starting Position** and **Ending Position**. Must be a positive number, the direction of travel between the source and detector is determined by the **Starting Position** and **Ending Position.** Must have units defined to use **Update** to set a value.
- **Ending Position:** (Complimentary) The end of the path, as defined relative to x=0, as defined by the distance of **Closest Approach**. Does not have a unit drop down, because it has the same units as **Starting Position**
- **Measurements:** (Complimentary) The number of measurements that will be taken along the path. This value must be an integer.
- **Update:** This button becomes active when all fixed variables have been assigned values and units, and two out of three complimentary variables have been completed. Pressing **Update** will autocomplete the remainder of the form or ask which complementary variable should be adjusted to ensure **Measurements** is an integer.
- **New:** Sets all the fields in the **Add/Edit Pass By** section to empty.
- **Add:** Will become active only when the all path criteria have been satisfied, such as values, units, and an integer number of **Measurements**. Pressing **Add** will save the current path to the **Pass By(s)** table and clear the **Add/Edit Pass By(s)** section.
- **Delete:** Removes the path selected in the table
- **Edit:** Copies the path selected in the table to the **Add/Edit Pass By** section of the form, where the path can be modified. The original path used for **Editing** will remain unchanged, and a modified/copy of the path can be added.
- **Import File:** Allows the user to load a text file of paths, where each path is defined on its own line. The format for a path is that used by the ".bis" file for saving the **Batch** configuration.

The next options to consider are the **Integration Method** and **Sampled Points.** The **Integration Method** determines how each measurement along a path accounts for the relative motion of the source and detector, which can be crucial is the source-to-detector distance varies significantly along the path. The path integration along a subsegment of a path, where we count for a single **Count Time**, sums a set of point(s) along the path to yield a single measurement. The **Sampled Points**

field determines the number of subintervals utilized by an **Integration Method.** There are two **Integration Methods:**

- **Uniform:** Uses the midpoint of each uniformly spaced interval, defined by the number of **Sampled Points**, to calculate spectra that are summed over the entire path. This method requires more **Sampled Points**, the more the source-to-detector distance varies along a path subsegment.
- **MeanValue:** Uses the mean value theorem of definite integrals to find the point along a path subsegment that preserves the total count rate, if we moved along the subsegment accounting for geometric attenuation (inverse square law). In most conditions a **Sampled Points** equal to one is sufficient but in high count rate environments the modeling of pileup effects may require more **Sampled Points.**

The final consideration is the **Loop Order**, which behaves just identically to the **Loop Order** on the **Batch** tab. The paths do not appear as a **Loop Order** option, because all variations of the variables to adjust occur within a path configuration. Additionally, there is no **Write** option, as on the **Batch** tab, because **Pass By** relies on the summation of multiple injects for each path. However, the **Pass By** setup can be saved to a ".bis" file and is automatically generated when the pass by is **Run.**

11. GADRAS TOOLS

11.1. GADRAS Editors and Libraries

Editors for various libraries and properties can be found under the **Tools** menu option on the main window, as shown in Figure 76. Editor options include:

- **Deviation Pairs** (discussed in Section 6.3)
- **Isotope DB** (discussed in Section 6.1.2)
- **PhotoPeak List** (discussed in Section 6.1.1)
- **Source DB** (Source database)

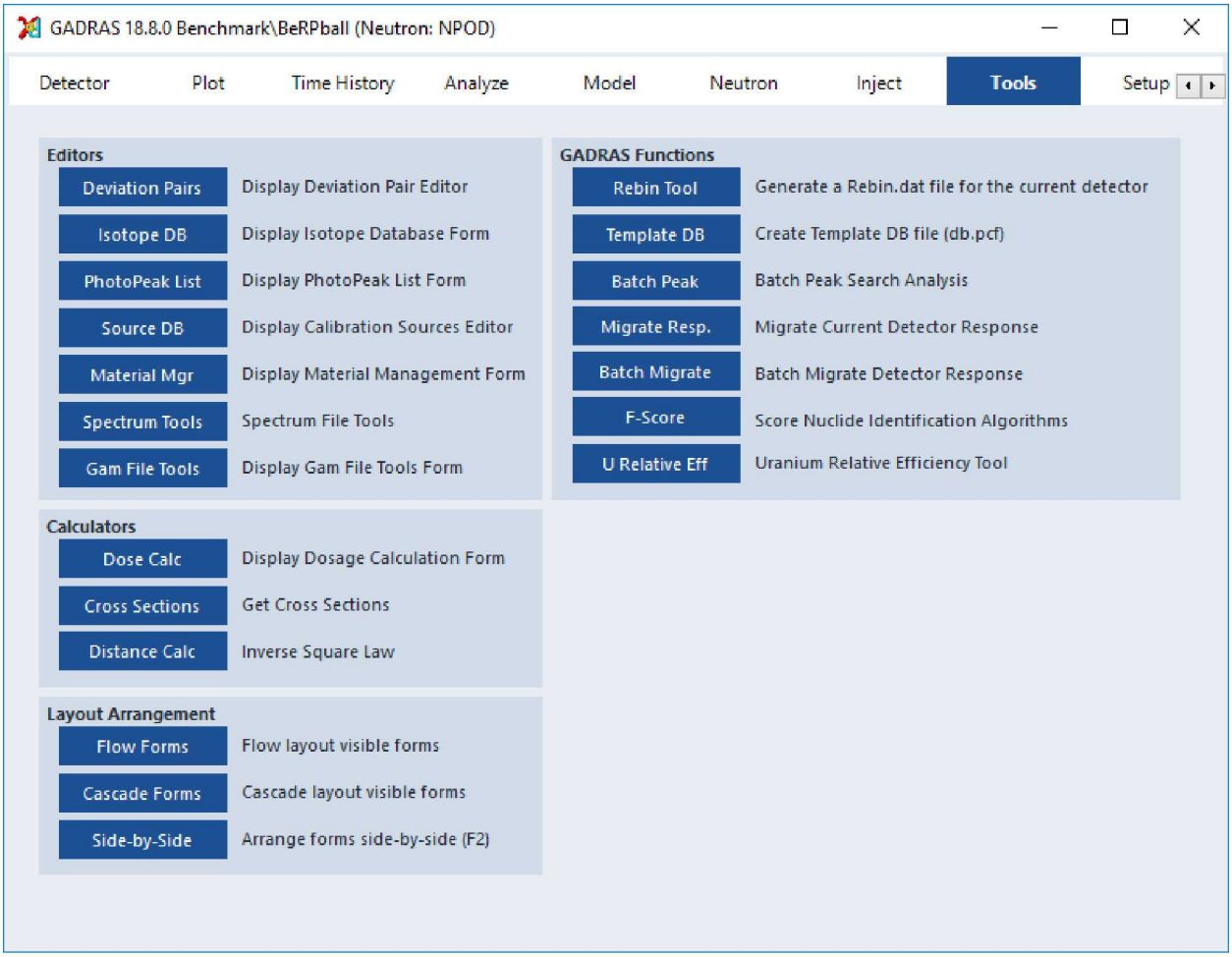

Figure 76. Tools Tab

11.1.1. *(Calibrated) Source Database (DB)*

Users can access the **Source DB** form from the **Tools** tab on the main window. This form displays a database of known calibration sources with various properties. The source list is located in the **Source.lib** file in the root GADRAS directory. When GADRAS is updated to a new version, user-

added sources are automatically retained. Sources are added and identified according to their unique **Source ID.**

Source DB includes the following information for each calibration source:

- **Source ID** —Naming convention: atomic weight followed by the elemental symbol (e.g., 109Cd) + underscore + alphanumeric information (i.e., serial number or other identifying information).
- Original Calibrated Activity
- Original Calibration Date
- Location

Calibration sources are grouped by radionuclide on the **Source DB** form. Clicking the tree-expand button (the **+** to the left of each isotope name) allows the user to view all calibration sources for that radionuclide. Users may edit or delete existing sources or add new sources using this form.

When computed spectra are compared with measurements, activities for stored calibration sources are decay-corrected based on the **Calibration Date**, the **Calibrated Activity**, and the measurement date of the plotted spectrum. An activity calculator is provided at the bottom of the window for users to obtain decay-corrected activities for each source. Figure 77 illustrates a listing of calibration sources for ^{109}Cd and the activity calculator.

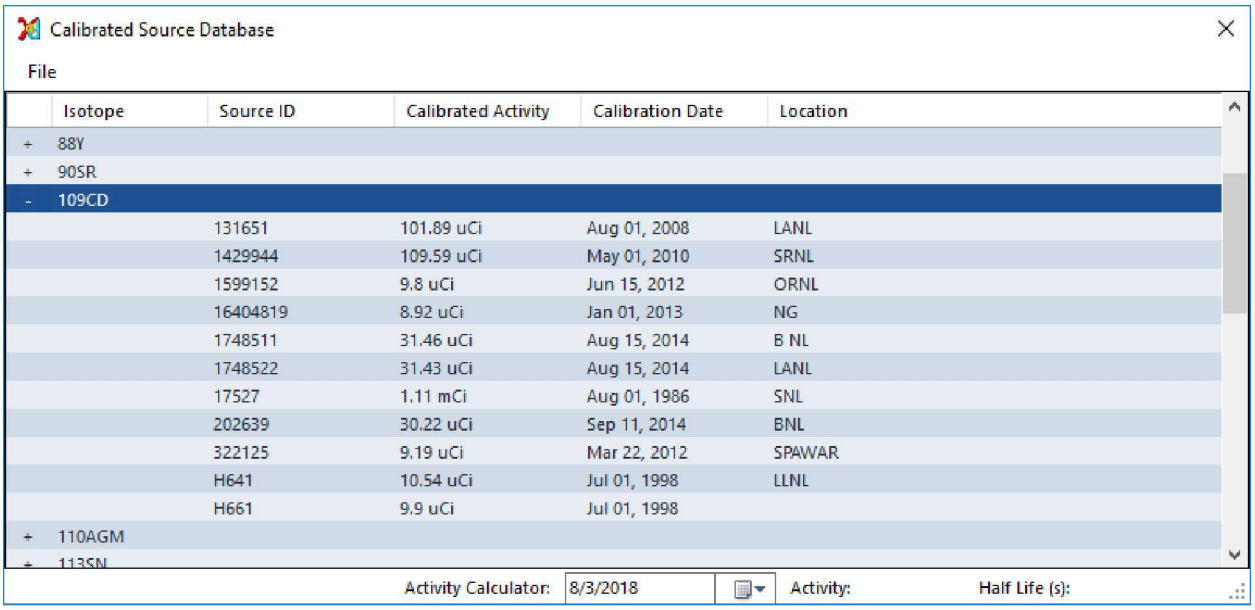

Figure 77. Source DB Tool with a ^{109}Cd Source Highlighted

11.1.2. *Spectrum File Tools*

GADRAS has the capability of manipulating spectra to perform desired tasks or calculations. This may include adding or subtracting spectra, scaling a spectrum, applying Poisson statistics to a record, or other calculations. The Spectrum Tools form is shown in Figure 78.

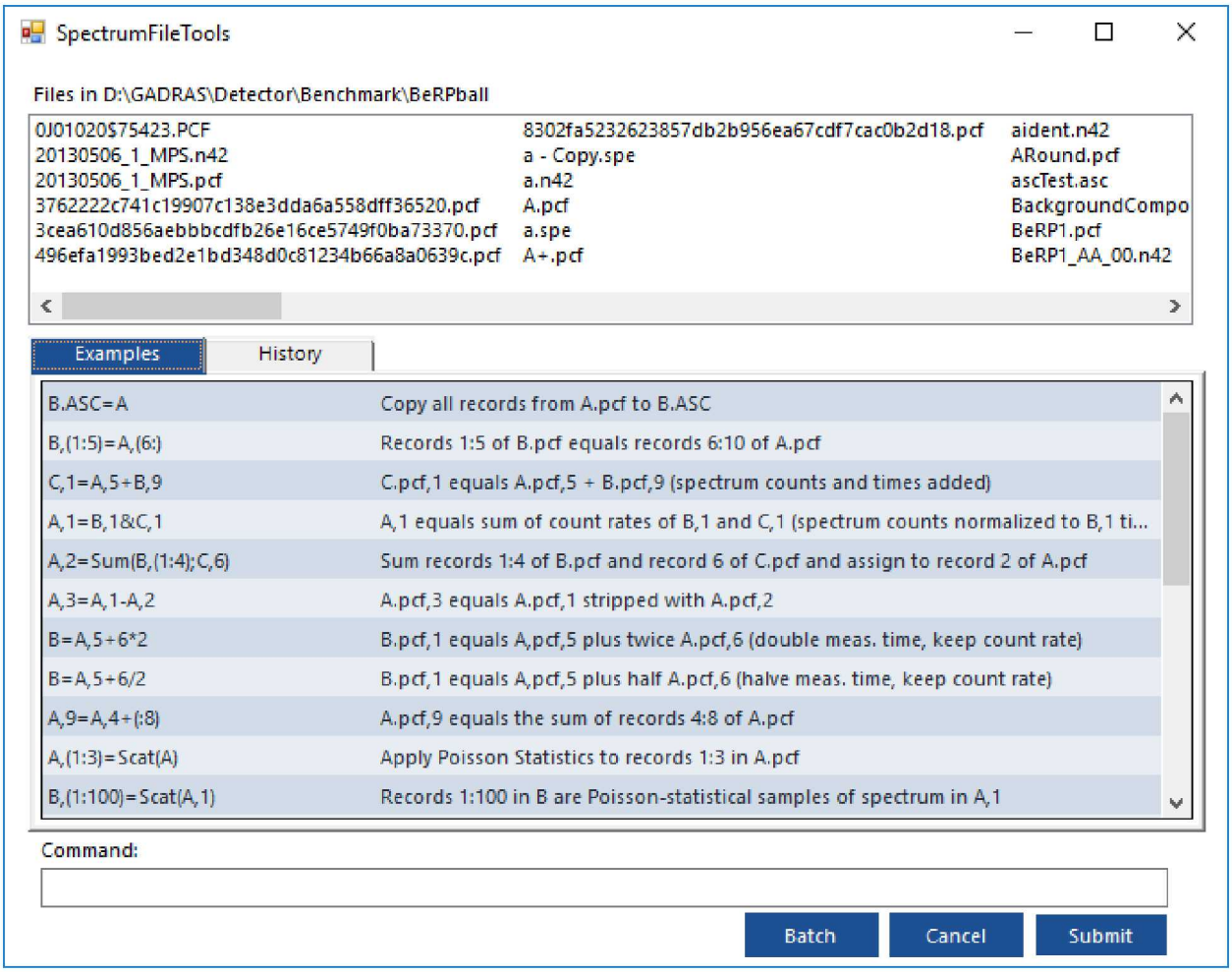

Figure 78. Spectrum Tools Form

The Examples tab demonstrates the available functions in the spectrum tools form. To type a file name at the current cursor location, the user may click the filename from the list box or manually type the file. If a file name includes special characters such as spaces or operators (e.g. +, -, /, *), the file name should be put in quotes (e.g. "my+spectrum.pcf"). This ensures the file name is not misinterpreted as an operation. Clicking **Submit** sends the command to GADRAS. If it is a valid command, it will appear in the History tab, otherwise, GADRAS will warn the user that the command is invalid. Users can repeat a command by clicking on the command in the History tab. To clear the History, the user may click **Clear**. Users may perform batch operations by writing multiple commands on separate lines in a text file. When the user clicks **Batch**, they should select the file with the commands. GADRAS will perform the commands sequentially. If one of the commands is invalid, GADRAS will inform the user which of the commands was invalid and which commands were executed successfully. GADRAS will also inform the user if all the commands were executed successfully.

11.2. Calculators

11.2.1. *Dose Calculation*

The expected dose (exposure) rate from almost any source can be calculated using GADRAS. This calculation is independent of detector characteristics. However, GADRAS does compensate for attenuation and scattering by intervening air. Based on methods specified in ANSI/ANS-6.1.1-1991, "Neutron and Gamma-Ray Fluence-to-Dose Factors," effective dose equivalent rates for an anthropomorphic representation of the human body can be calculated.

The **Dose Calc** button is located under the **Tools** tab on the main form. The radionuclide source strength can be provided as activity (Curies) or mass (grams). Information needed for a dose calculation includes the following:

- **Preferred dose units:** Select output units via drop-down menu (Rem or Sievert)
- **Source (radionuclide and source strength):** Radioactive source information (e.g., "137Cs, 100uC"; a known source from **Source DB**; or a model file name)
- **Distance:** source-to-detector distance (cm)
- **Gamma Energy Threshold (optional):** any gamma emissions below the specified threshold energy (keV) are excluded when the gross leakage is tallied. This only affects the gross leakage, not the computed dose.

The following calculated rates are shown in Figure 79:

- Gamma Dose
- Neutron Dose
- Total Dose
- Gross Leakage (gamma)
- Gross Leakage (neutron)

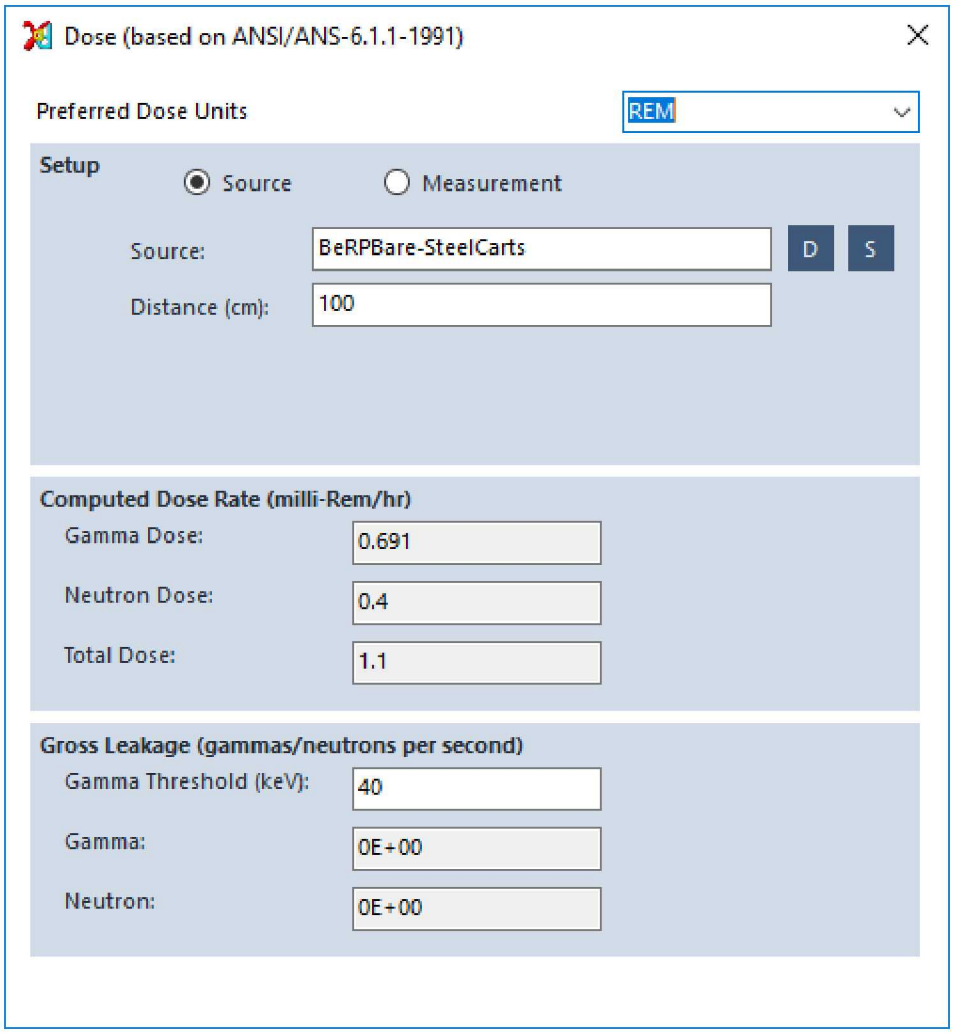

Figure 79. Dose Calculation Tool

11.2.2. *Distance Calculator*

The distance calculator uses dose rates taken at two different positions to estimate the distance to the source. This can be useful if the source is inside a large container and the exact position is unknown. This form uses ratios of dose rates and distances, so units are arbitrary as long as they are consistent. An example of the form can be seen in Figure 80.

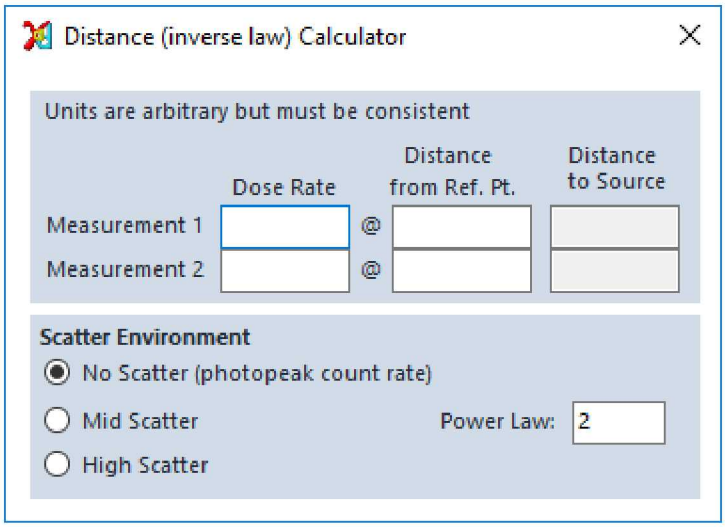

Figure 80. Distance Calculator Tool

The **Distance from Ref. Pt.** should be entered as a distance from a consistent position that is in line with the source (i.e. the source and the two measurements should form a line and the distances should be entered from an arbitrary point on the line). One caveat is that if the source is not in line with the two measurement points, the resulting position may not be accurate.

The scatter environment can impact the dose rate measurements. Because of this, the distance calculator gives users the option to estimate the scatter environment. Most of the time, users should use the **Mid Scatter** option (Power Law: 1.85). **Low Scatter** (Power Law: 2.0) should be used when the floor is very thin or non-existent and there are no walls nearby. **High Scatter** (Power Law: 1.65) should be used when the measurement is taken in a compact area, such as a vehicle. Users also have the option of specifying their own **Power Law** if this value is known.

11.3. Other Tools

11.3.1. *Rebin Tool*

The rebin tool creates a file called Rebin.dat for a particular detector. This tool should be used when users want to rebin a spectrum into a specific energy bin structure. The form can be seen in Figure 81.

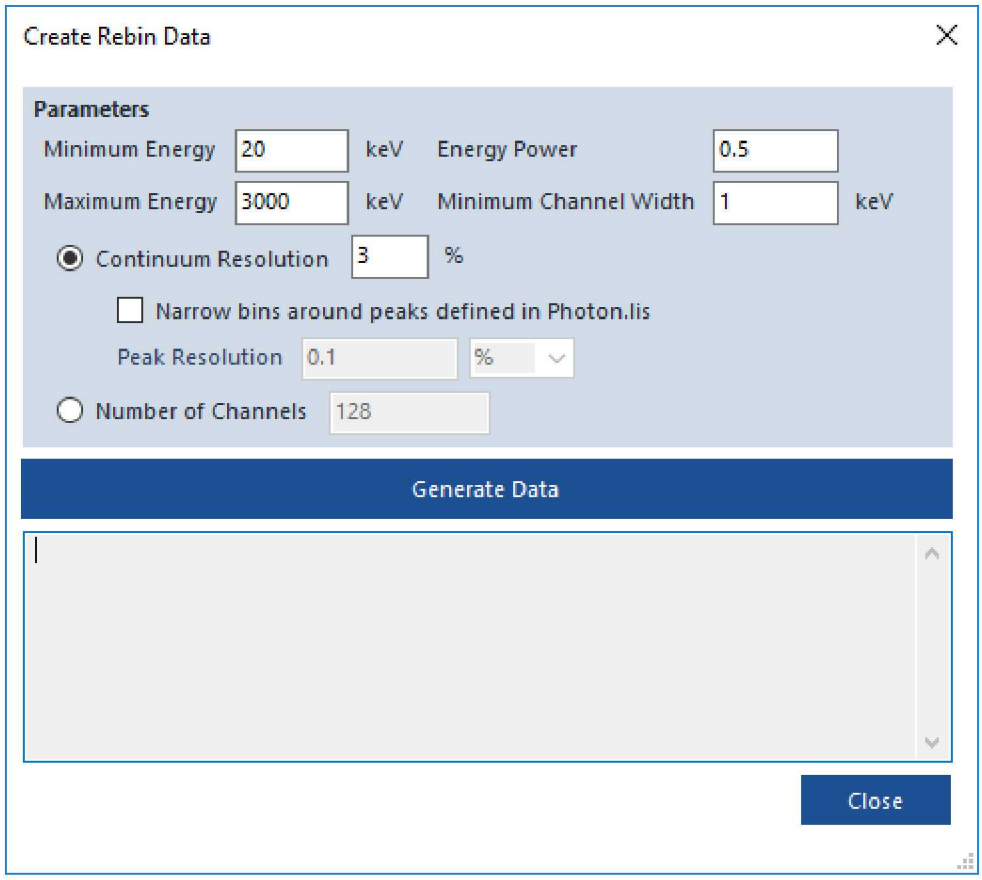

Figure 81. Rebin Tool

The **Minimum Energy** should be the energy of the low edge of channel 0. **Maximum Energy** should be the energy of the upper edge of the maximum channel. The **Energy Power** and **Zero Intercept** fields are used to determine the bin width as a function of energy. To have uniform bins in the continuum, the **Energy Power** should be 0. The bin width will be determined by the minimum and maximum energies, as well as the number of channels. In Figure 81, the bin width will increase as the square root of the energy, and the channel corresponding to 0 keV will have a bin width of 1 keV.

Users may define the number of channels in two ways. By selecting the **Number of Channels** option, users can define the total number of channels to use. The continuum and peaks will have the same binning structure. If **Continuum Resolution** is selected, users can specify separate bin widths for the continuum and the peaks. The **Continuum Resolution** textbox defines the bin width as a percentage of energy at 661 keV. The bin width ΔE (keV) for the continuum is determined using

$$\Delta E = C^{1-p} E^p + E_0,$$

where E is the bin lower energy bound in keV, C is the **Continuum Resolution** (at 661 keV) in keV, p is the **Energy Power**, E_0 is the **Zero Intercept** in keV. For example, in Figure 81, the **Zero Intercept** is 1 keV, the **Energy Power** is 0.5, and the **Continuum Resolution** is 3%. Therefore, at 1000 keV, the bin width is 25.4 keV. By default, the continuum resolution is also used for energy bins containing peaks. If the "Narrow bins around peaks defined in Photon.lis" checkbox is

checked, users can define a different bin structure around peaks. **Photon.lis** is stored in the root **GADRAS** data directory (default is C:\GADRAS) and is universal for all detectors. Users can modify this file to include peaks they wish to have more bins in or remove peaks they wish to ignore. An example of the **Photon.lis** file can be seen in Figure 82.

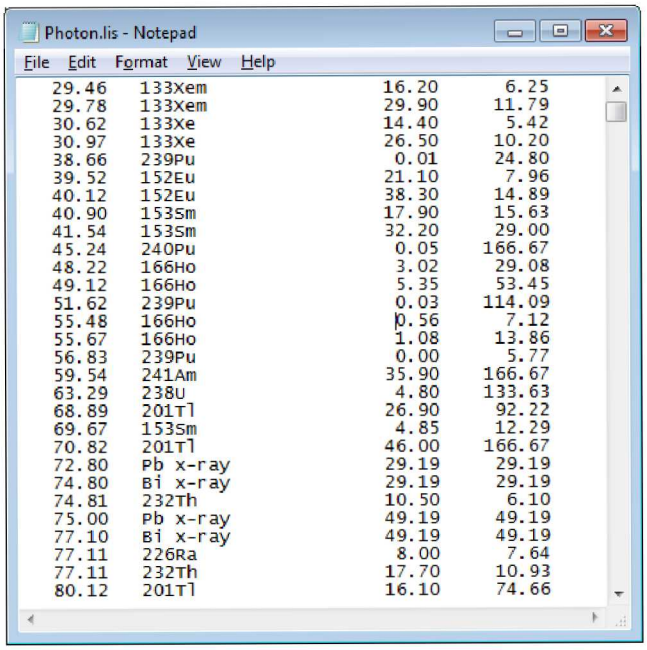

Figure 82. Photon.lis File

To modify this file, users can input the energy in the first column, the nuclide name in the second column, the absolute yield (%) in the third column, and the detectability (based on energy and yield) in the fourth column. The **Rebin** tool only reads the first column; the rest of the columns are ignored. Only peaks within the specified energy range will be used. The default file is sorted by energy, but users may input peaks in any order. Users may select a constant bin width for peaks, or may use the percent of the peak's energy as the bin width basis. The **Rebin** tool will assign one bin to the peak with a width corresponding to the specified energy or percentage of peak energy. If the annihilation peak at 511 keV is specified, the bin width is extended by 3 keV due to Doppler broadening of the peak.

Once the parameters are filled in, users can click the **Generate Data** button to create the **Rebin.dat** file. The information textbox will be populated (Figure 83). The number of channels will be displayed first, followed by the energy bins. This information is recorded in **Rebin.dat**. When the **Rebin.dat** file is present in the detector directory, the **Rebin** checkbox on the **Detector** tab will be enabled. Users can choose whether they want the plotted spectrum to be rebinned according to the **Rebin.dat** file by checking this box.

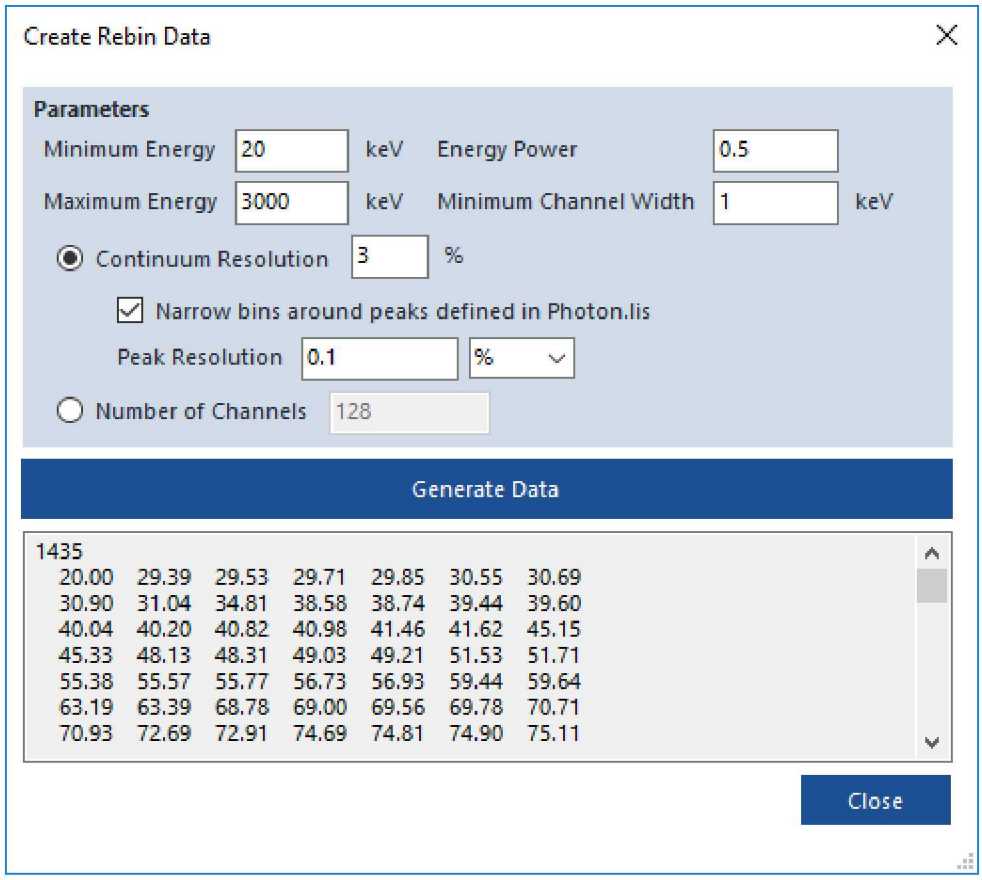

Figure 83. Rebin Data Tool with Data Generated

11.3.2. *Batch Peak Search*

Users can perform a peak search on multiple files by using the **Batch Peak Search** tool (Figure 84). Users can select which files they want to analyze by clicking the **Choose Files** button. In Figure 84, all files in the current detector directory ending in .pcf will be analyzed. The **Threshold (Sigmas)** textbox defines how far above the continuum a peak must be to be included in the results. After the files are chosen and the threshold is specified, clicking OK will start the analysis.

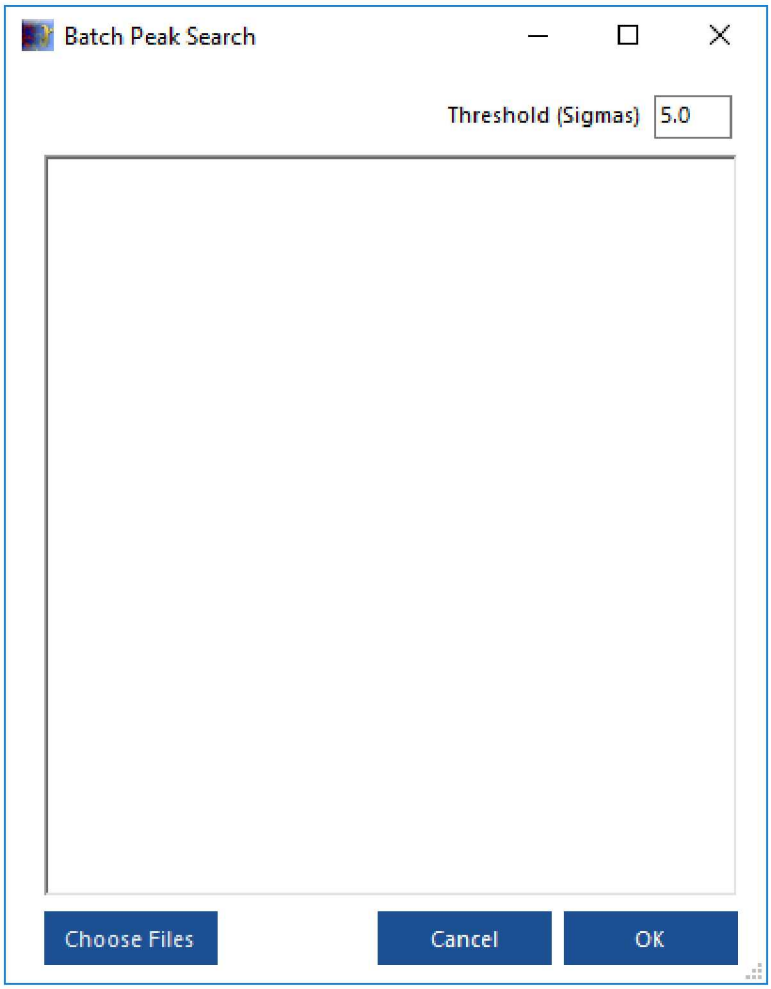

Figure 84. Batch Peak Search Tool

The tool will sequentially analyze all spectra in each of the files specified by the filter. The results will be stored in .csv files which are located in the **Temp** directory (default is C:\GADRAS\Temp). These files can be opened in Excel. The following data is stored in the csv file:

- Energy (keV)
- Energy uncertainty (sigma)
- Count Rate (counts per second)
- Count Rate uncertainty (sigma)
- Full-Width at Half Max (keV)
- FWHM uncertainty (sigma)
- Leakage (photons per second)

12. GADRAS SETTINGS

GADRAS has some settings that users can modify to customize the user interface. These options consist of:

- Change plot options on detector change (default on): GADRAS will change the plot style of the first spectrum depending on if the detector is high resolution (e.g. HPGe) or low resolution (e.g. NaI)
- Automatically update plot when fields change (default off): with this turned on, users can update the spectrum viewer automatically when they change any field on the Plot tab (Foreground, Background, Compute Source term)
- Don't show energy calibration dialog (default off): when doing the graphical energy calibration (Section 6.2), this option determines whether GADRAS will automatically ask which calibration parameter to adjust
- Adjust plot scale with mouse wheel (default on): if selected, the mouse wheel will adjust the y-axis scale on the spectrum viewer; if not selected, the mouse wheel will zoom in
- Animate zoom (default on): if selected, the spectrum viewer will zoom in with an animation
- Open ROI in new window (default off): if selected, zooming in will open a new spectrum viewer with the zoomed spectrum; otherwise, the zoom will remain on the same window
- Reset Dialogs button: when pressed, this reset the GUI to show all dialog boxes until user checks the option to not show the dialog again
- Save DLL Log button: if GADRAS functions incorrectly, this button can be used to save the error to a file
- Exit splash screen upon load (default off): checking this will exit the initial GADRAS splash screen as soon as GADRAS is ready for user interaction, otherwise it will stay visible for a full three seconds
- Turn off autocomplete (default off): the Computed Source line on the **Plot** tab has an autocomplete feature; if desired, this functionality can be turned off
- Rebin spectra when inserting to files (default off): if checked, spectra will be rebinned according to the Rebin.dat file structure (Section 11.3.1) whenever they are added to a PCF file via the **PCF Viewer**

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