SAND2015-5176

SANDIA REPORT

SAND2014-20625 Revision 1
Unlimited Release
Printed December 2014
Revised June 2015

GADRAS-DRF 18.5 User's Manual

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GADRAS-DRF 18.5 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. 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, and estimating source energy distributions from measured spectra. 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).

ACKNOWLEDGMENTS

This project was funded by the U.S. Department of Energy's Office of Proliferation Detection, the U.S. Department of Homeland Security's Domestic Nuclear Detection Office, and the U.S. Department of Defense's Defense Threat Reduction Agency.

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1 INTRODUCTION

1.1 GADRAS-DRF Overview

GAmma Detector Response and Analysis Software – Detector Response Function (GADRAS-DRF) contains a suite of capabilities related to radiation detection. Its primary function is the simulation of gamma-ray and neutron detector signals to radiation sources. It also contains limited analysis functionality. GADRAS-DRF is the public version of the full version of GADRAS [1] with capabilities such as radiation transport [2] [3] and advanced analyses [4] removed.

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-principals 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.

Figure 1 is a screen-capture of the GADRAS-DRF main window. The program contains eight main tabs that run across the top of the window (**Detector**, **Plot**, **TimeHistory**, **Analyze**, **Neutron**, **Inject**, **Tools**, and **Setup**). Each tab represents a primary function of GADRAS-DRF; 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-DRF 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 detector name will also appear on the main window title if selected.

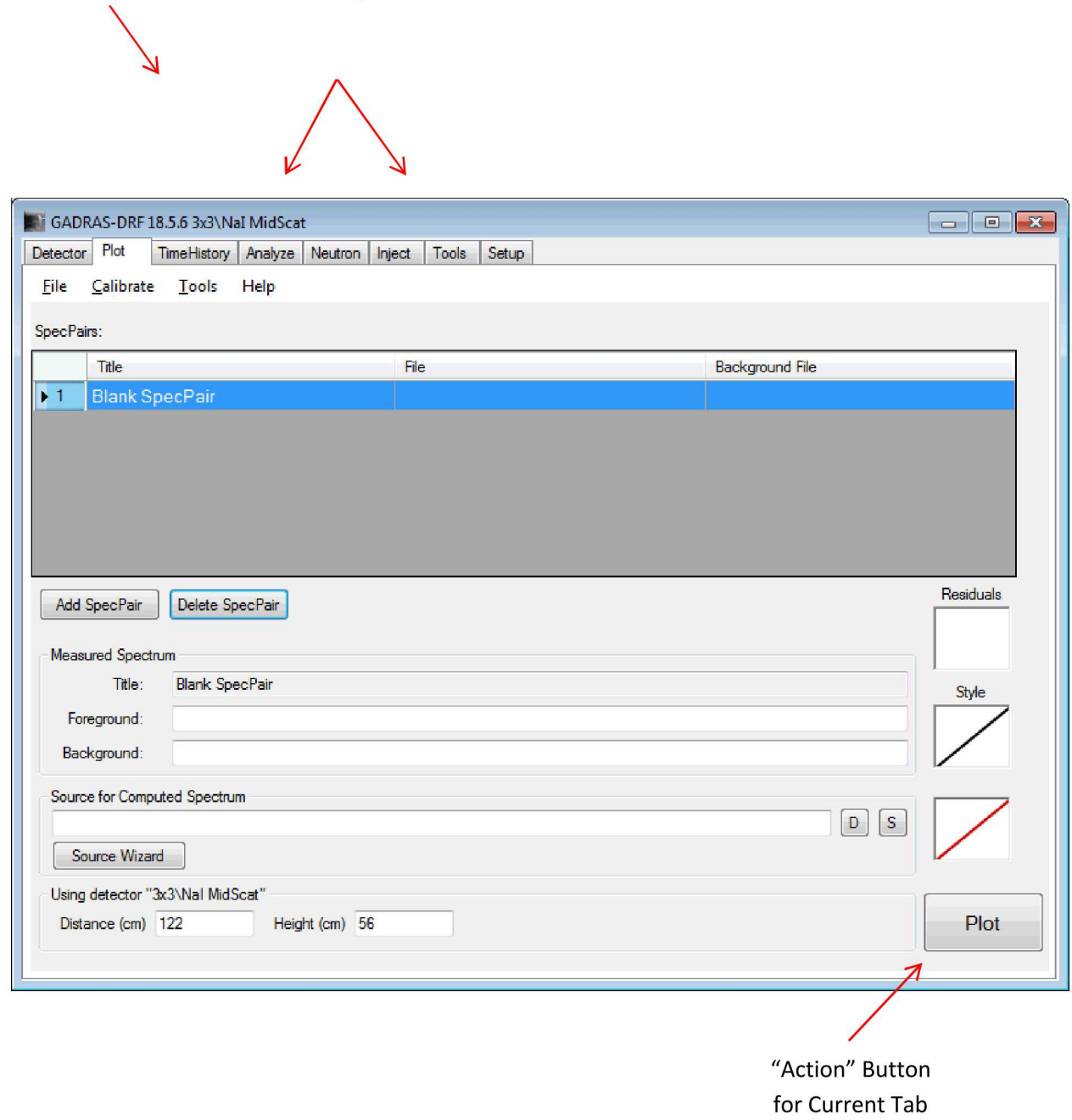

Figure 1: Overview of Main Window

1.2 Directory Structure

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

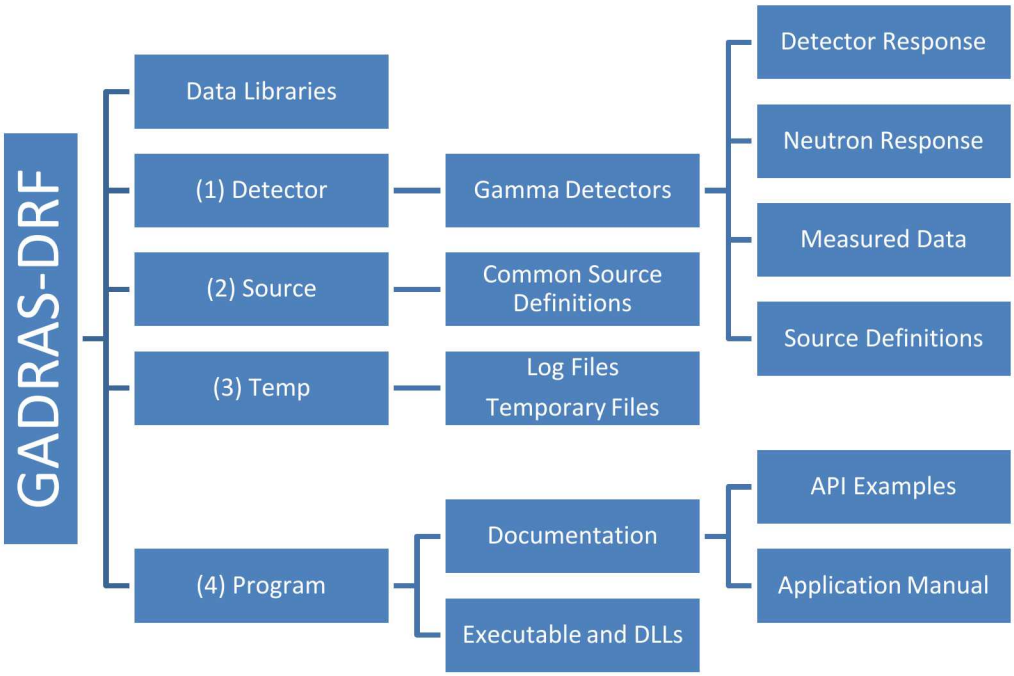

Figure 2: Overview of GADRAS-DRF Directory Structure

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-DRF\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-DRF. 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-DRF\Program\GADRAS-DRF.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-DRF 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:

- Occasional adjustments for energy calibration drift;
- Change in source-to-detector distance or height from the floor;
- 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
- Changes in the experimental environment.

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

A new detector setup within GADRAS-DRF can be created from the **Detector** tab on the main window. To create a new setup, the user must select **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-DRF\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:** 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).

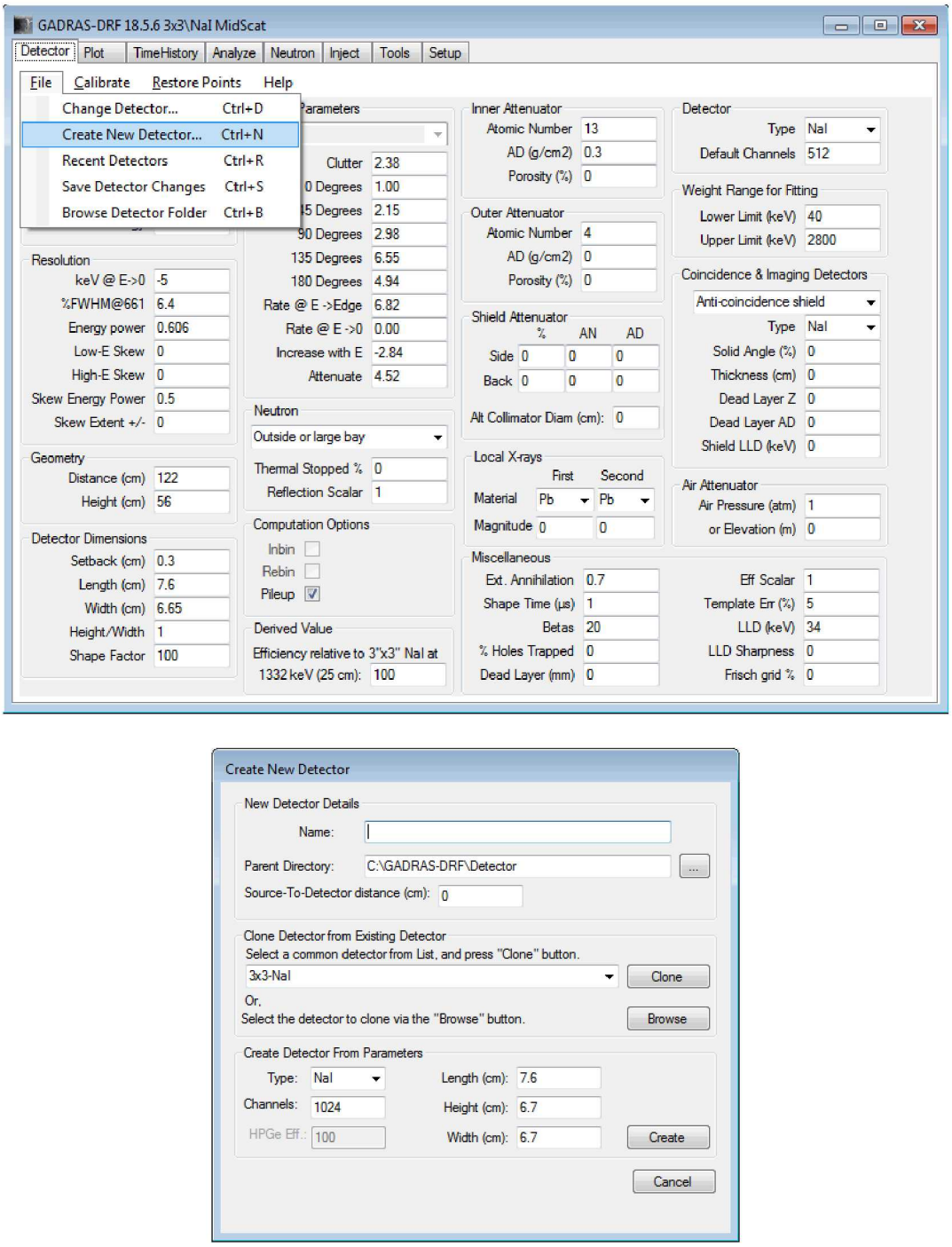

Figure 3: File Drop-down Menu (*top*) for Create New Detector Dialog (*bottom*)

New detectors may be created by clicking the **Clone** button located in the middle of the window or the **Create** button located at 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. (Note: 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.) The user can then click the **Create** button to create the new directory with the appropriate **Detector.dat** file.

   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-DRF 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.

2.1.2 Copying an Existing Detector Response Function (Detector.dat)

Detector.dat files for characterized detectors are contained in subdirectories under the primary detector directory “GADRAS-DRF\Detector”. Detectors may be copied using a Windows Explorer window. An existing **Detector.dat** file can be copied and pasted manually to a new directory to create a new detector parameter file that GADRAS-DRF will recognize as a valid detector.

*Note: It is advisable to always work with copies 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-DRF will overwrite any changes to the original files.*

GADRAS-DRF expects spectral data files and the response function file (i.e. **Detector.dat**) to reside together in the same subdirectories of “GADRAS-DRF\Detector”. The main criterion for GADRAS-DRF to recognize a detector directory is the existence of a **Detector.dat** file. The application will not recognize multiple **Detector.dat** files in the same directory.

2.2 Detector Parameters in Detector.dat Files

From the **Detector** tab, the detector response function parameters (as found in the **Detector.dat** file) can be accessed and edited. For example, these parameters are displayed in Figure 4 for a NaI detector. For other detector types, similar screens are displayed with some detector-specific variations. Response function parameters are grouped on the page and will be discussed using these headings.

Dimensions and distances can be entered in the following units: centimeters, meters, feet, or inches. GADRAS-DRF will convert the user input to centimeters. The convention for entering alternative

dimensions is to type an identifying letter after the numerical entry. 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].

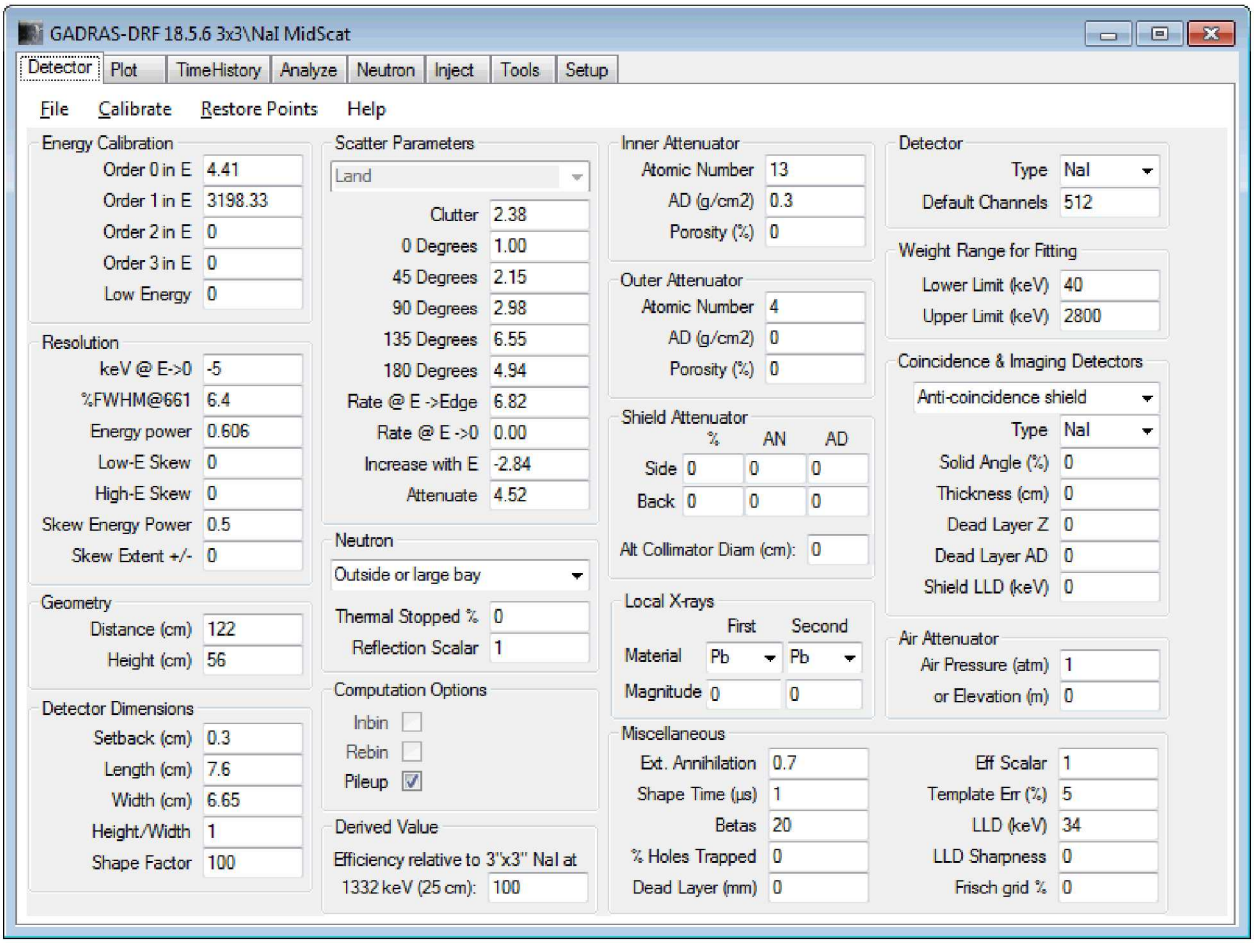

Figure 4: Example Detector Response Function Parameters for a NaI Detector

2.2.1 Energy Calibration

Routine energy calibration is usually performed elsewhere in GADRAS-DRF. Adjusting the energy calibration is discussed in Section 6.

The energy calibration parameters are described in reference [8]. There are a few general remarks about what values might be reasonable for the calibration of a detector.

- **E0 or Order 0 in Energy**: should a small number (<100) either positive or negative
- **E1 or Order 1 in Energy**: should be a number close to the maximum energy scale of the detector in keV
- **E2 or Order 2 in Energy**: should be zero unless the detector is non-linear
- **E3 or Order 3 in Energy**: should be zero unless the detector is highly non-linear
- **Low Energy**: non-linear high order parameter (usually zero)

In general, it is advised to initially have values only for E0 and E1.

2.2.2 Resolution

The following parameters can be used to modify the detector resolution:

- **keV @ E->0** is the limit of the FWHM as the photopeak energy approaches 0 (can be negative)
- **keV @ 1332 (%FWHM@661)** is the FWHM of the photopeak at 1332 keV (or %FWHM at 661 keV for non-HPGe detectors)
- **Energy power** describes the rate at which the FWHM increases as a function of energy. If the energy power is $\boldsymbol{n}$, then the equation for FWHM (keV) for a photopeak at energy $\boldsymbol{E}$ (keV) is
$$\boldsymbol{FWHM \propto E^n}$$
- **Low-E Skew** describes the magnitude of photopeaks' low energy tails
- **High-E Skew** describes the magnitude of photopeaks' high energy tails

2.2.3 Geometry

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 it is assumed that the detector and source are at the same height.

2.2.4 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.
- **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**.

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 and Shape factor (S)** are parameters that describe 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. radiations 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 values of S. 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. Alternatively, from the shape entry, the user can select one of three shapes (flat, circular, or custom) and the shape factor value will automatically be adjusted.

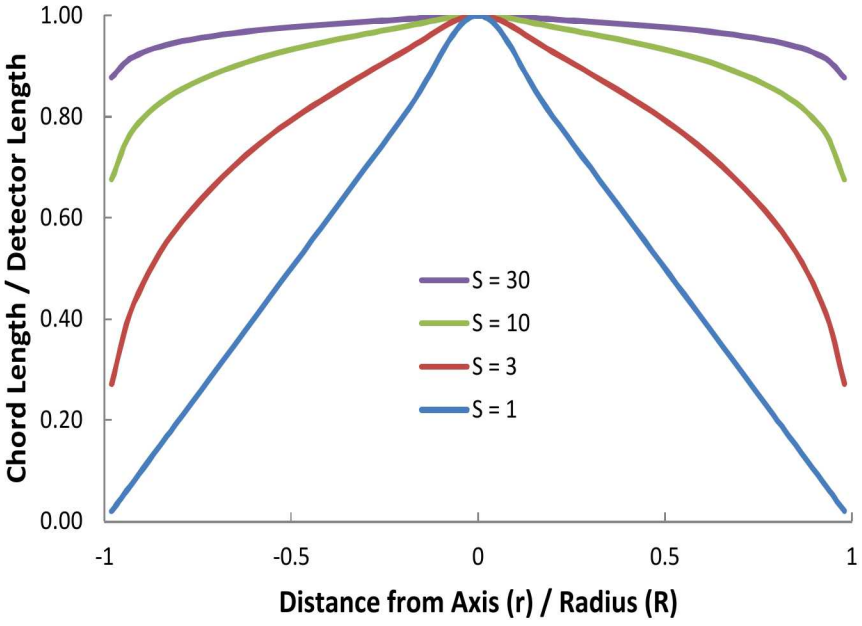

Figure 5: Detector Cross-section Profiles for Several Shape Factors

2.2.5 Scatter Parameters

GADRAS-DRF 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. 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 describes 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.

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-DRF\Detector\3x3\NaI AboveSource”.

2.2.6 Neutron

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
- **Reflection Scalar** directly scales the rate of neutrons reflected by the surrounding environment uniformly across all energies

2.2.7 Computation Options

- **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.

- **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.
- **Pileup** this checkbox toggles whether or not GADRAS-DRF should simulate pileup from intense or close sources. See Section 2.2.9.2 for additional information on pileup.

2.2.8 Attenuator

The third column of the **Detector** tab file is composed of different attenuator types and settings. These parameters are provided in GADRAS-DRF to describe the attenuation of incident radiation before it passes into the active detector volume. These are useful in describing attenuation from detector housing, shielding, and collimators.

To define an attenuator, the effective atomic number (**AN**) and areal density (**AD**) (in g/cm^2) (density multiplied by thickness) must be entered. For porous materials, the porosity of the attenuating material can be provided, this allows for a shield with holes or apertures. These attenuation corrections are applied to all incident radiation, including the computed flux of photons scattered into the detector from the external environment.

- **Inner Attenuator**: describes the attenuation associated with the detector enclosure and the surface dead layer.
- **Outer Attenuator**: describes additional shielding placed between the detector and source, such as graded shielding to reduce fluorescent x-rays.
- **Shield Attenuator**: describes the shielding on the sides and back of the detector.
- Shielding materials are specified by specifying a % **side shield** parameter and a % **back shield** parameter. The % **side shield** is defined as the percent of the side of the detector that is surrounded by the shield. This will be set to 100 if the shield completely covers the sides but does not extend in front of the 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 shield** 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.
- **Air Attenuator**: describes attenuation associated with 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 or the elevation.

2.2.9 Other Parameters

2.2.9.1 External Annihilation

High-energy gamma-rays can form electron-positron pairs by interacting with materials near the detector crystal, such as detector housing. When this occurs, the positron annihilates with a nearby electron, and two 511 keV photons are emitted. The **Ext. Annihilation** parameter adjusts the magnitude of this effect.

2.2.9.2 Random Pileup and the Shaping Time Constant

The effect of random pileup is estimated in GADRAS-DRF using a provided pileup check box and entering an appropriate amplifier shaping time constant (**Shape Time (μs)**) parameter. To consider the effects of pileup, the pileup check box must be checked *(the default setting)*. In addition, an approximate **Shape Time** (in microseconds) is required. Since the amplifier shape time constant is generally only approximate, it is often necessary to characterize this parameter from calibration spectra.

When pileup rejection techniques are used, the **Shape Time** constant 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.

2.2.9.3 Local X-ray Source and Magnitude

Gamma-ray detectors are often surrounded with lead or other high-Z materials as a shield. These shields emit fluorescence x-rays when excited by incident radiation. The resulting x-rays can be eliminated by lining the shield with lower atomic number materials like copper. However, these liners may not be included when the x-rays do not interfere with the gamma-rays of interest.

The adjustable parameters that characterize fluorescent x-rays include **Local X-rays** (source material) and **X-ray Magnitude** (x-ray intensity). An approximate energy dependence is applied for these x-rays. X-rays have two main sources: (1) photons that scatter out of the active detector element into the high-Z material, and (2) photons that interact directly in the high-Z material. *Note: the single parameter characterization may not be adequate if high precision is required in the x-ray region using high-Z shields.*

2.2.9.4 Betas

When beta particles undergo negative acceleration, radiation is emitted in the form of bremsstrahlung photons. Bremsstrahlung radiation is displayed as a continuum with the maximum intensity at low energy and extending up to the end point energy of the beta particles. The **Betas** parameter provides the ability to estimate the continuum produced by bremsstrahlung emission. A good first estimate for this parameter is 20*. Note: Except for limited cases, a correction of this bremsstrahlung parameter is*

neither necessary nor advised. If a more accurate representation is required, a radiation transport calculation should be performed.

2.2.9.5 % Holes Trapped

This is used as an empirical term related to hole trapping by detectors such as CdTe. This parameter does not have quantitative significance.

2.2.9.6 Dead Layer

The dead layer 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.

2.2.9.7 Efficiency Scalar

The efficiency scalar directly scales the simulated channel counts uniformly across the entire energy range. This can be useful when a single detector is characterized, but a system utilizes an array of multiple detectors and sums their signals for higher efficiency.

2.2.9.8 Template Err

This parameter defines the average percent error that is applied when the variance is estimated.

2.2.9.9 LLD

The lower-level discriminator setting in keV is represented by this setting. The simulated LLD is not a step-function; the slope of the simulated spectrum at the LLD is determined by the detector's resolution.

2.2.9.10 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.

2.2.9.11 Detector and Weight Range

The detector type has a drop-down menu which should match the user's detector type. The number of detector channels is either what the user specified when the detector response function was created or is the default value from the cloned detector.

The **Weight Range** area has two fields: **Lower Limit** and **Upper Limit**. During any analysis or fitting, GADRAS-DRF 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.

2.2.9.12 Anticoincidence (AC) Shields

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 subtended by the AC shield from the primary detector
- **Thickness**: 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**: Lower-level discriminator of the AC shield

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-DRF without saving the parameters, GADRAS-DRF 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 Calibrate Menu

2.3.2.1 Energy and Resolution Calibration

The **Calibrate** menu item automatically adjusts detector parameters. The **Automatic Calibration (ecal and resolution)** option shown in Figure 6 can be used to perform an energy calibration and resolution adjustment automatically using an existing spectrum. This option is described further in Section 6.1.

Manually energy calibration by choosing peaks in a spectrum is done through the **Peak Search and Manual Energy Calibration** option under the **Calibrate** menu. This is described further in Section 6.2.

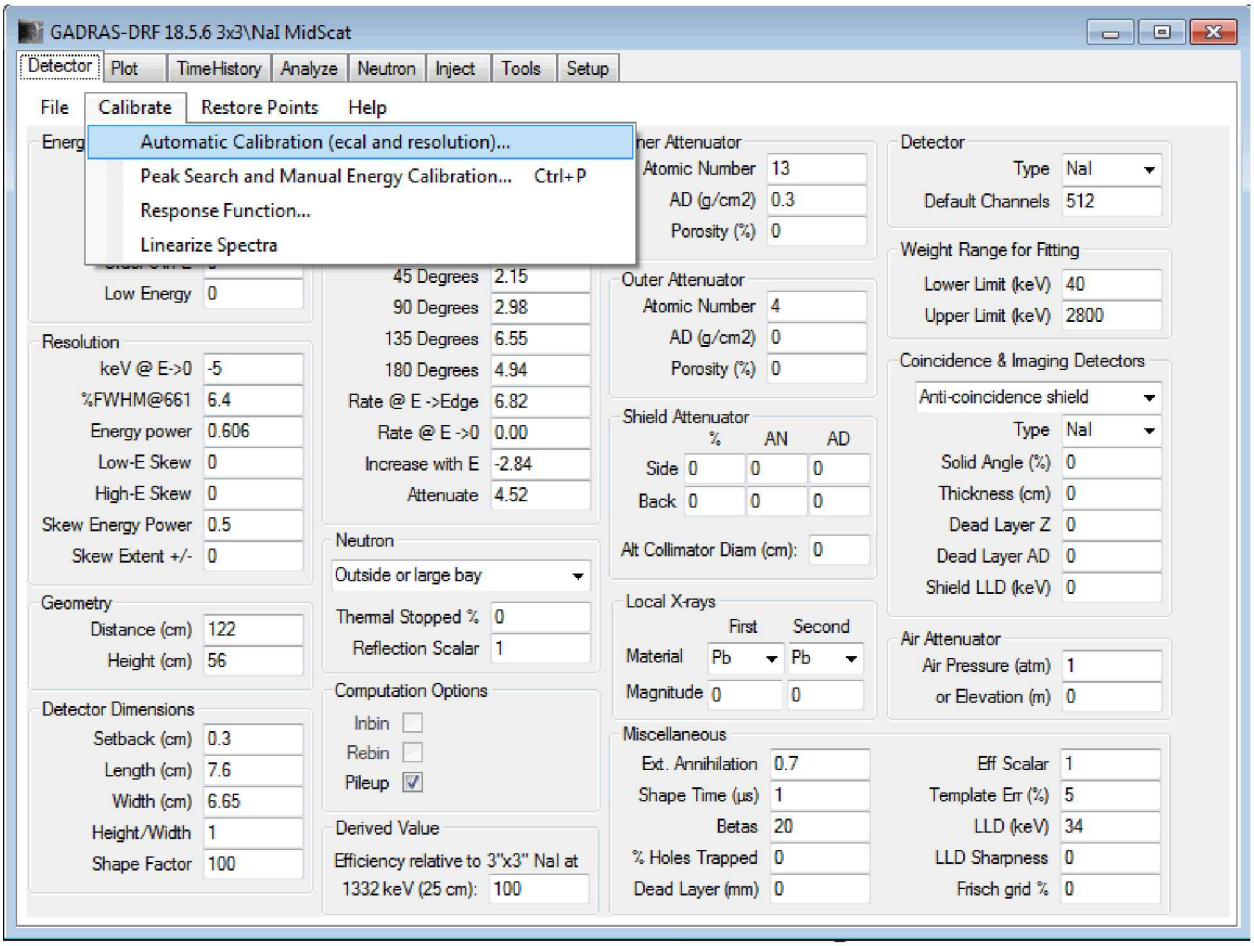

Figure 6: Calibrate Menu on Detector Tab

2.3.2.2 Response Function Parameters

To optimize other parameters, choose the **Response Function** option in the **Calibrate** menu. This option adjusts the parameters that the user has selected in order 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 cyan have been chosen for adjustment. After clicking on the **Response Function** option, users are presented with the **Detector Response Function Calibration** form. This form, which is shown in Figure 7, looks very similar to the **Plot** tab (Section 4).

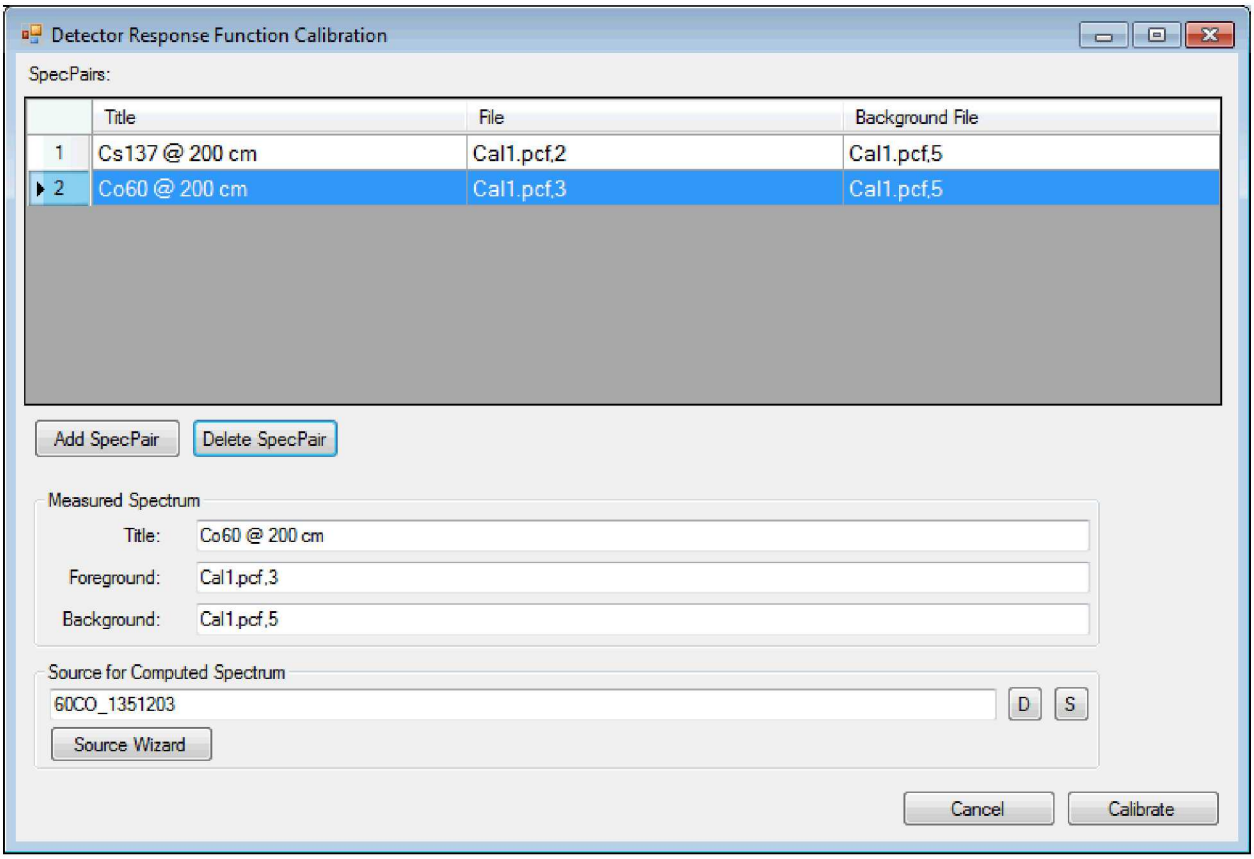

Figure 7: Detector Response Function Calibration Form

Using entries from the **PCF Viewer** window (Section 3), users can add up to six SpecPairs to use in the calibration. Users should specify a Foreground and Background as well as a Source for Computed Spectrum. GADRAS-DRF 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-DRF will then vary the adjustable parameters and find the best parameter fit through non-linear regression iterations.

To effectively calibrate a new detector to measured spectra, it is highly advised to determine the energy calibration and resolution before varying other parameters in the Detector tab. Users should also 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 instead 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 put in the parameters before attempting any detector response function calibrations.

2.3.2.3 Linearize Spectra

The **Linearize Spectra** option in the **Calibrate** menu item applies a linear energy calibration to all spectra in the current PCF file. This option will only work if a PCF file is currently open in the **PCF Viewer** window. By selecting this option, all spectra in the PCF file will be assigned a linear energy calibration and use the defined deviation pairs (if any).

2.3.3 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 8). If the detector parameters are adjusted incorrectly, they can be reverted to a set of previous parameters by clicking the appropriate Restore Point.

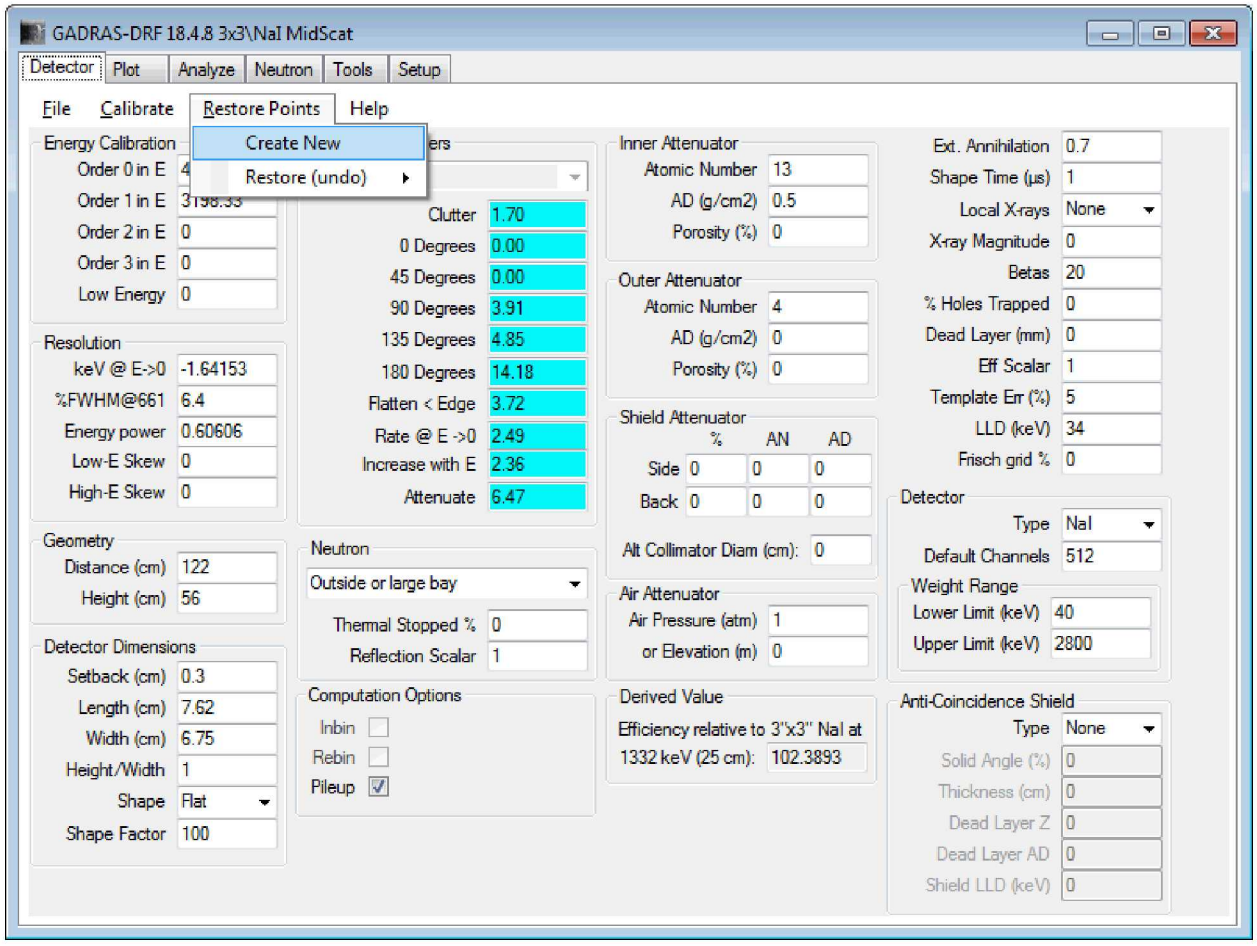

Figure 8: Restore Points Menu Item

3 PCF SPECTRAL FILE

3.1 PCF File Description

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

GADRAS-DRF generates and stores **PCF** files in the same file location as the **Detector.dat** file. This is typically a user-chosen subdirectory in "GADRAS-DRF\Detector". 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 data file can be generated or 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 9. This action opens a Windows Explorer window **Error! Reference source not found.**with "eventList.pcf" as the default file name for the PCF. This file name can be modified by the user if desired. The default location is the current detector directory. Once the file name is chosen, the **PCF Viewer** will display a blank PCF file as shown in Figure 10.

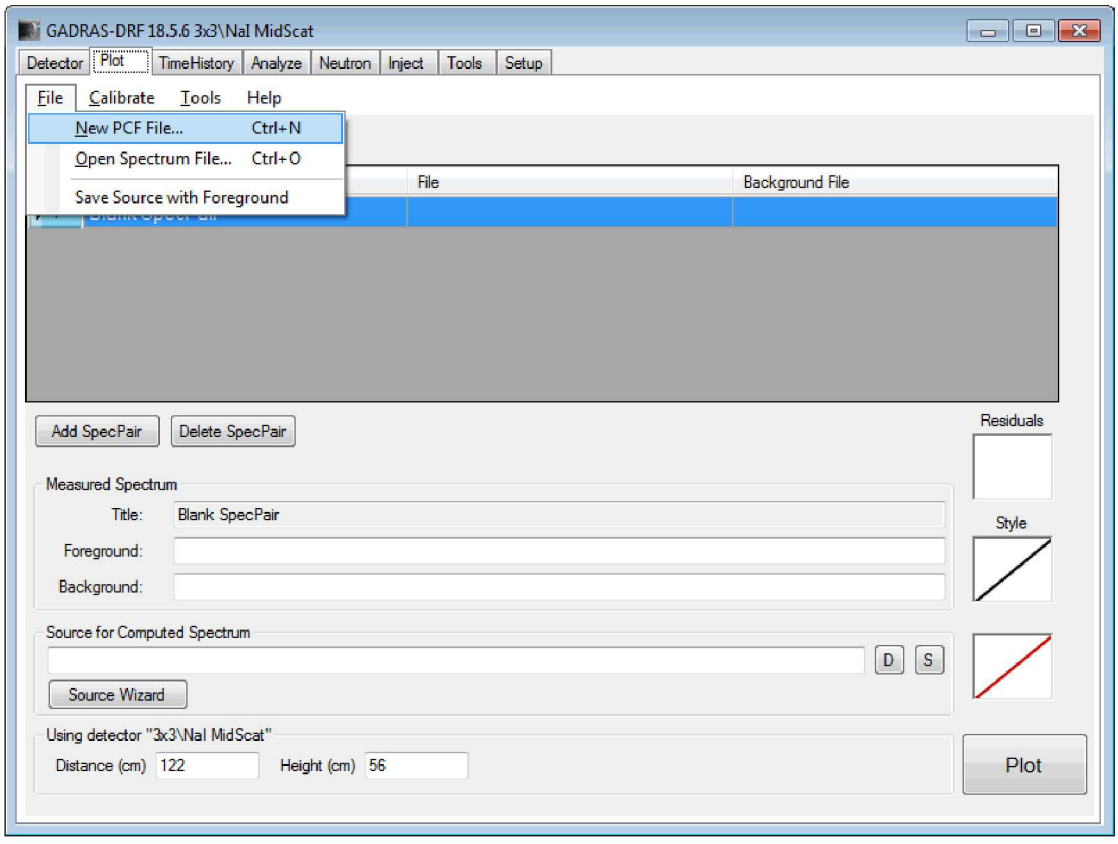

Figure 9: Creating a New PCF File From the Plot Tab Within the File Menu

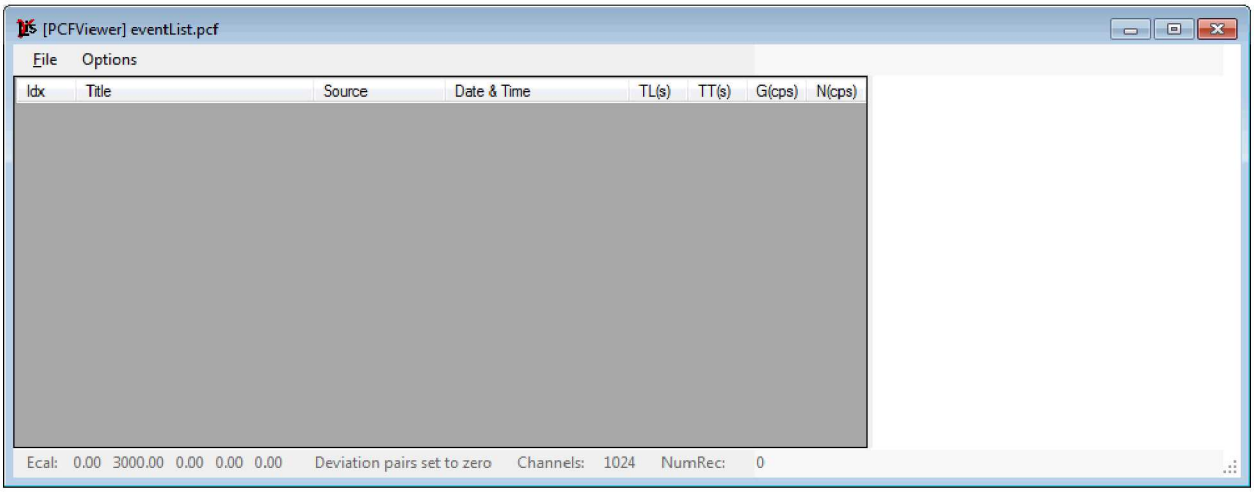

Figure 10: Newly Created PCF Shown in the PCF Viewer

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 11 shows the file list form after populating the PCF file with eight spectral entries (five calibration source spectra and three background spectra).

GADRAS-DRF can process spectral data taken at different source-to-detector distances and heights. Processing the spectral data is facilitated by entering the source-to-detector distance for each spectrum in the file title field so that these values are entered as defaults when computed spectra are compared with measurements. The source-to-detector distance must be contained between the character "@" and the string "cm" or "m," indicating distances in centimeters or meters, respectively. The interpretation of the string defining distance is not case sensitive. If the detector height is also entered, the height must be contained between the string "H=" and the string "cm" or "m." Similarly, the strings are not case sensitive. For example, a spectrum taken at a height of 20 cm and a source-to-detector distance of 50 cm can have the following string in the Title "@ 50 cm H=20 cm". Figure 11 shows the **PCF Viewer** with the "Th-228 @ 122 cm" entry highlighted in blue and a spectral preview on the right in red.

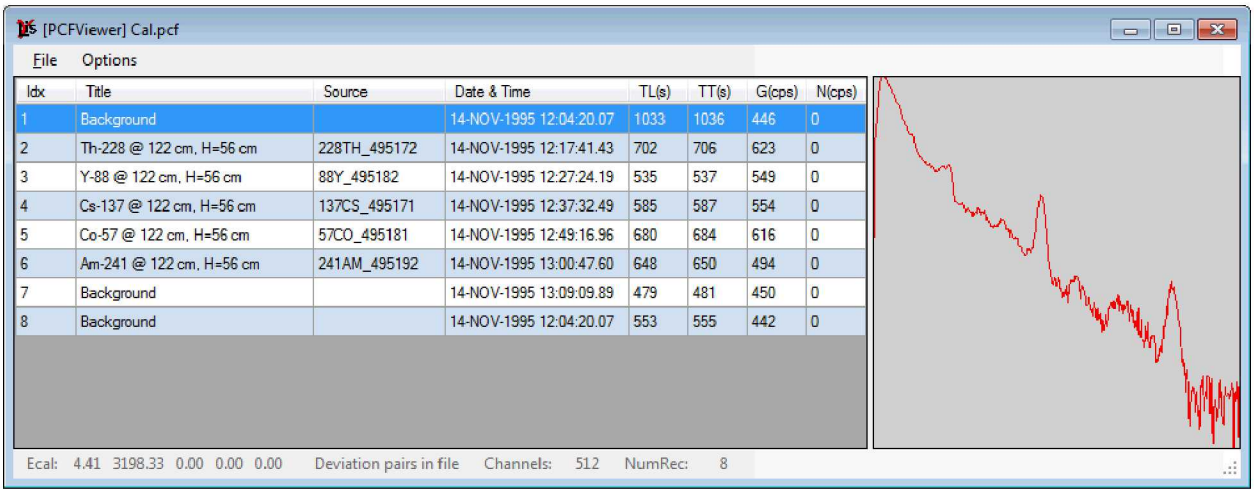

Figure 11: PCF Viewer with the Spectral Preview of the Highlighted Entry (Background) (*right)*

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 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**, **Date & Time**, **TL** (live time), **TT** (total time), and **N** (neutron count rate). If users inadvertently change a field in the PCF file, they can choose **Restore to Last Backup** in the **PCF Viewer**'s **File** menu.

3.3 PCF Viewer Menu Items

Under the **File** menu, the **Open** option loads an existing PCF file; the **New** option creates a new one; the **Print** command sends the contents of the **PCF Viewer** window to a printer.

The **Options** menu item allows users to select which columns should be displayed in the PCF file. There is also an option to toggle the spectrum preview window on the right side of the **PCF Viewer**.

4 PLOTTING/VIEWING SPECTRA

4.1 Measured Spectra

Users can plot one or more gamma-ray spectra in a PCF file using the **Plot** button located on the bottom-right corner of the Plot tab (Figure 12).

A record of interest from a PCF file can be plotted by dragging and dropping an entry from the **PCF Viewer** to the **Foreground** text box or to the plot table that lists current Spectral Pairs. The plot table consists of three columns. The first column is the Title of the SpecPair, which is the title of the Foreground spectrum if present. If the Foreground is absent, the **Title** will be the Computed Spectrum name. If this is absent, the **Title** will be "Unknown" and will not be included in the plot display. The second column is the **File** associated with the SpecPair. This will be the foreground spectrum file name and record, or the computed source file name if the foreground textbox is blank. The third column specifies the background associated with the SpecPair. A spectrum specified in the **Background** textbox is time-normalized to the current foreground spectrum and is subtracted from the foreground before being displayed on the **Plot** tab. Clicking the **Plot** button will display the desired background-subtracted spectra. Figure 13 shows a plot of a ^{228}Th spectrum.

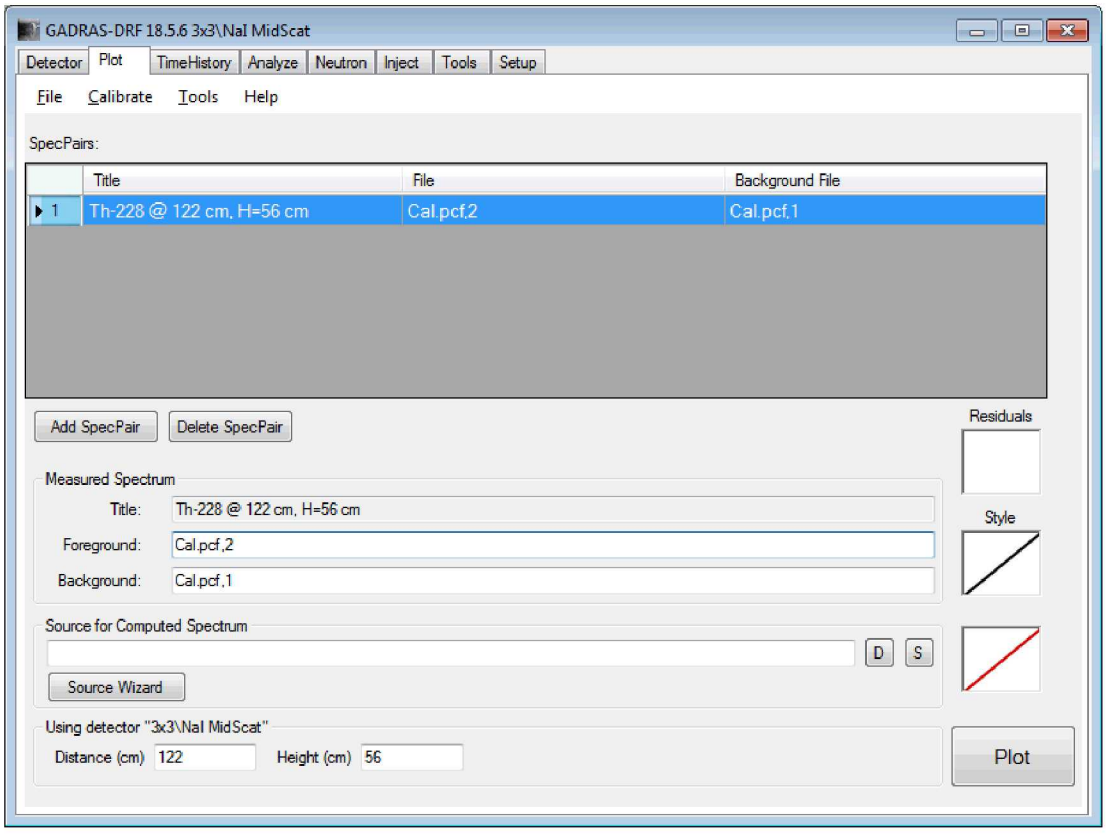

Figure 12: Plot Tab with Entries to be Plotted From the "Cal.pcf" File

The **Add SpecPair** and **Delete SpecPair** buttons in the middle of the screen are used to add or remove spectra from the drawn plot. When the **Add SpecPair** button is clicked, GADRAS-DRF 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.

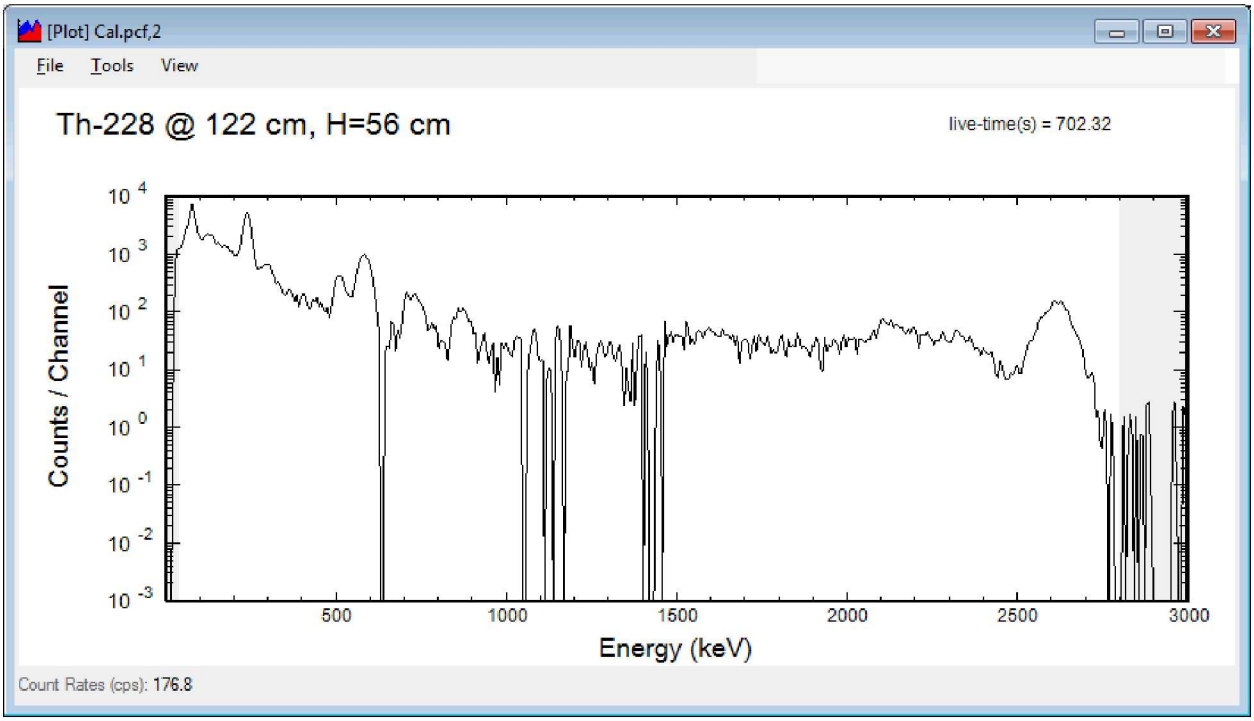

Figure 13: Plot of Background Subtracted ^{228}Th Spectrum

Figure 14 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.

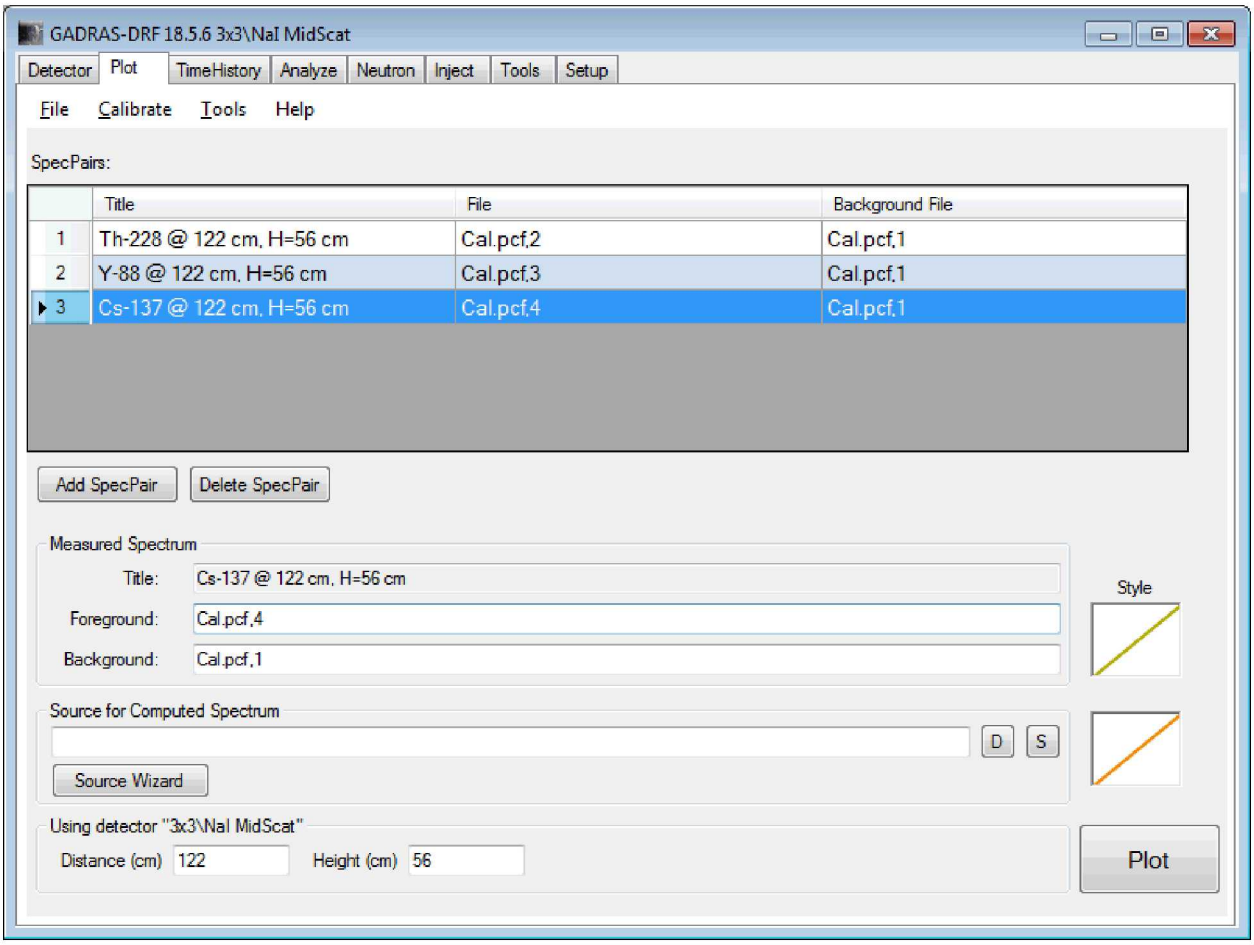

Figure 14: Plot Tab Example with Three Background-Subtracted Spectral Pairs

Figure 15 shows the graph of the three spectral pairs identified in Figure 14. The graphs are identified for each spectrum by the color selected in the style box in the **Plot** tab. The ^{137}Cs plot is displayed in purple as shown in the style box in Figure 14.

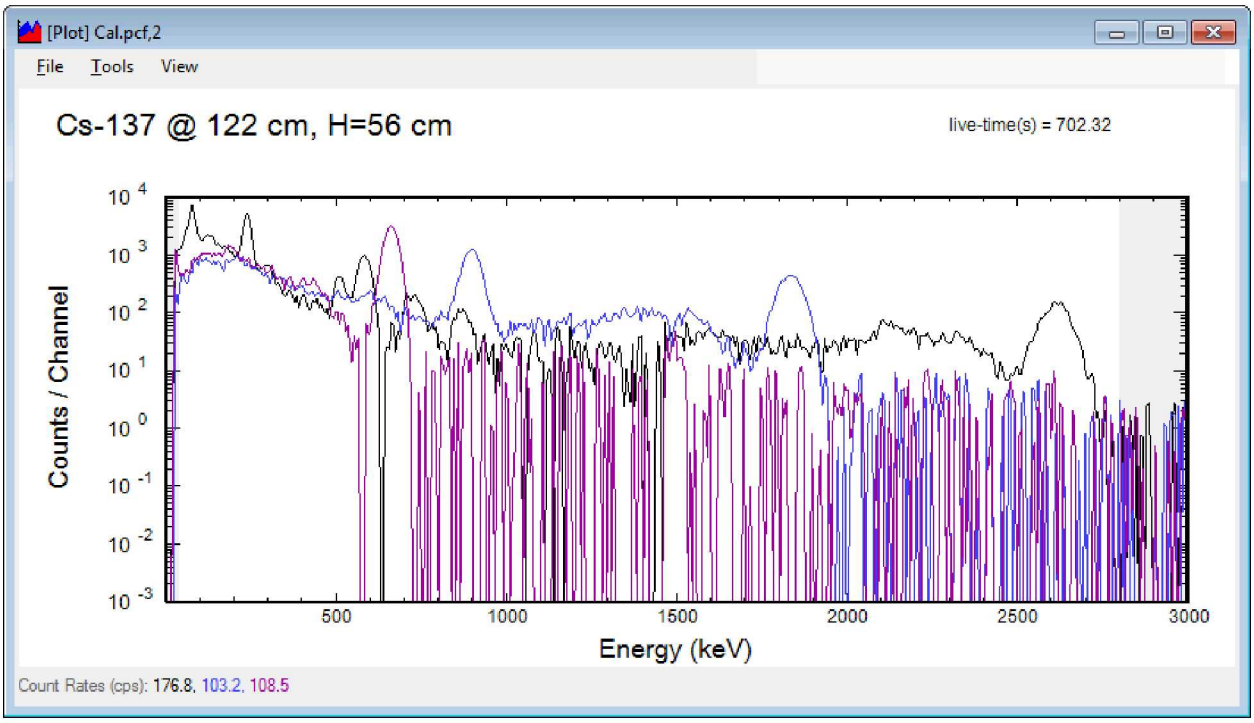

Figure 15: Plot of the Three Background-Subtracted Spectral Pairs: ^{228}Th (*black*), and ^{88}Y (*blue*), and ^{137}Cs (*purple*).

4.2 Zooming and Navigating a Plotted Spectrum

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 16. Drag from right to left a small amount to partially zoom out. Drag from the right to left a larger amount to completely zoom out. Use the mouse wheel if available to change the number of log cycles displayed, or to switch between linear and logarithmic scales. Other graph navigation options can be set from the **Setup** tab.

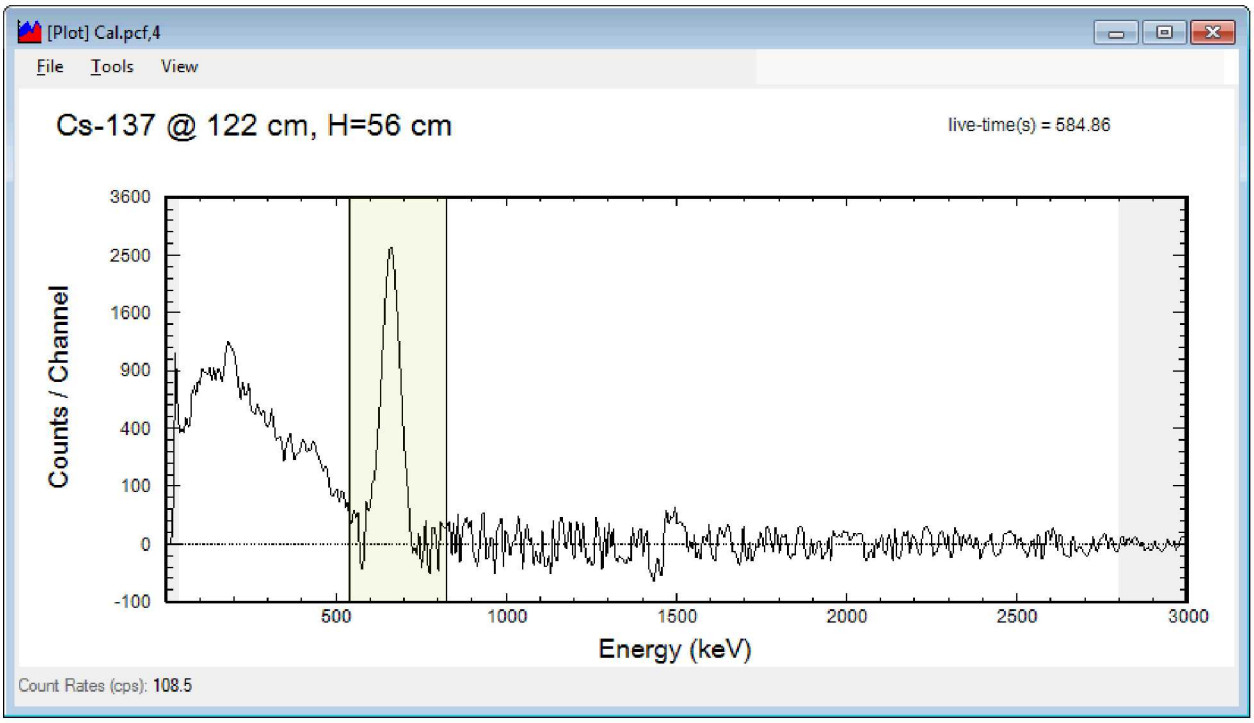

Figure 16: Zooming-in on a Plotted Spectrum

4.2.1 Plot Display Screen File Menu

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

- **Copy to Clipboard (Ctrl+C)**: copies the plot screen to the clipboard as an image and can be pasted into another application
- **Save to Metafile… (Ctrl+S)**: saves the plot screen to an image file (.emf)
- **Write Computed Spectrum to File**…: saves the computed spectrum to a pcf file for future plotting
- **Print…**: allows users to print the displayed graph

4.2.2 Plot Display Screen Tools Menu

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

- Options… (Ctrl+O) (graph options)
    - **X-Axis Minimum and Maximum**: sets the minimum and maximum energy (keV) limits for the graph
    - **X-Axis Units**: choose between Channel Number and Energy (keV) (if Channel Number is chosen, the energy scale is moved to the top of the graph)
    - **Y-Axis Units**: choose between Counts/keV or Counts/Channel

    - **Y-Axis Scale**: options include square root, linear, or different log cycles. Note: this can also be changed using a scrolling wheel on an external mouse when focused on a displayed spectrum.
    - **Positives Only?**: determines whether to allow negative values to be plotted
    - **Graph Type**: Bar Chart, Curve, or Histogram
    - **Grid**: choose what type of grid, if any, should appear on the spectrum
    - **Smoothing**: the spectrum can be smoothed in various ways including no smooth, display only 1024 channels, apply a smooth function (energy %) or by peak width (FWHM))
    - **Default True Time (s)**: data entry for live time to provide appropriate statistics for generated or computed spectra
- **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 8.1).
- **Show Isotope DB…**: displays the Isotope Database for use in analyzing displayed spectra (discussed in Section 11.1.2)

4.2.3 Plot Display Screen 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 17).

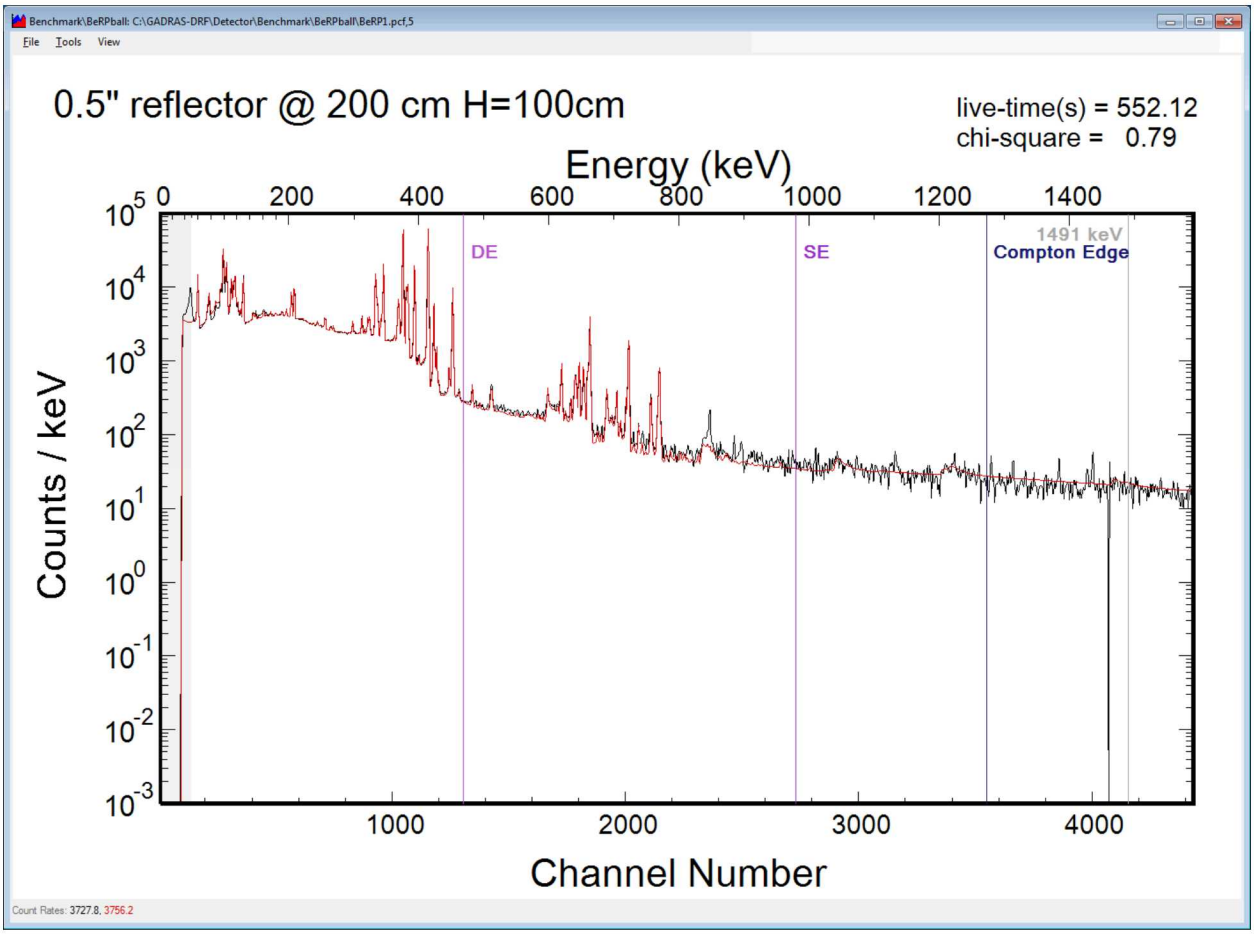

Figure 17: Spectral Features Can be Viewed Using the View Menu

4.3 Source Wizard and Computed Spectra

Besides displaying measured spectra, GADRAS-DRF can also display computed spectra or isotope source spectra. Sources for computed spectra are entered on the **Source for Computed Spectrum** entry at the bottom of the **Plot** tab or by using the **Source Wizard** button.

4.3.1 Source Wizard

The **Source Wizard** button shown in Figure 14 is located just below the **Source for Computed Spectrum** entry. The **Source Wizard** form is shown in Figure 18.

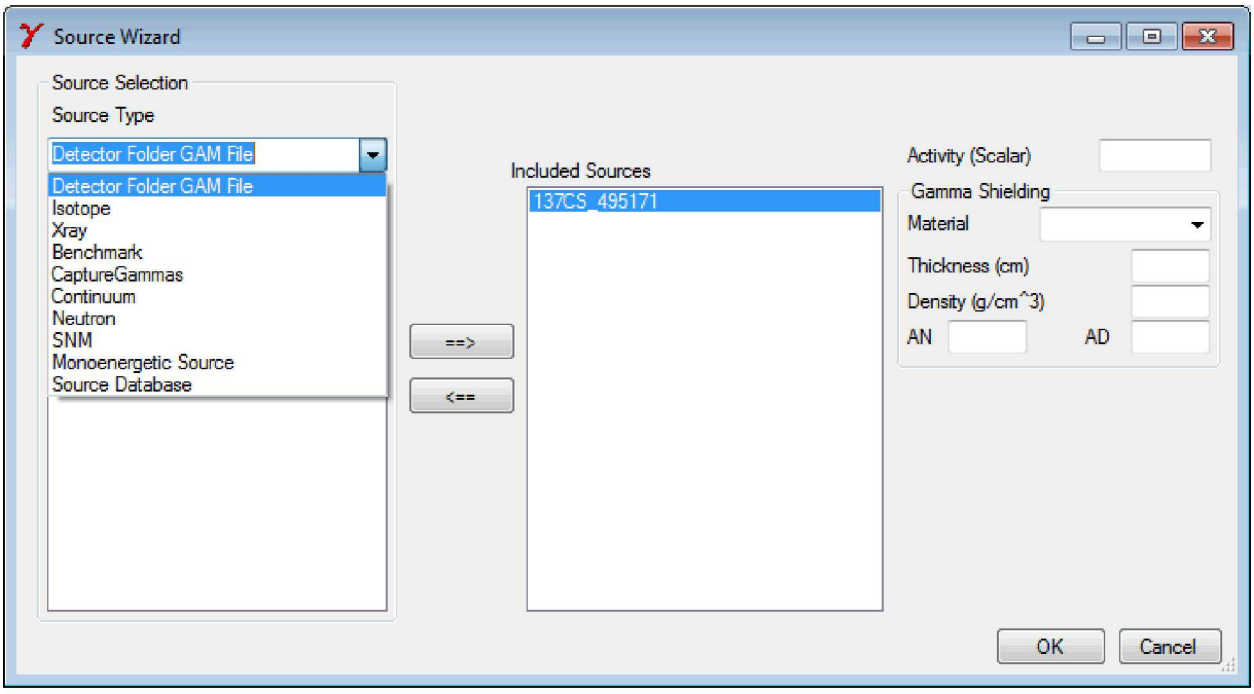

Figure 18: Source Wizard Screen

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 GADRAS-DRF shorthand notation for shielding. After clicking **OK**, the Source Wizard will automatically generate the GADRAS-DRF shorthand string in the Computed Spectrum text box.

4.3.2 Computed Source Line

In lieu of using the source wizard button, the user can enter source information on the computed source line.

Sources may include:

- the name/serial number of a calibration source in the source library/database,
- distributed GAM files, and
- an isotopic designation and source strength (e.g., **232U, 1.5uC**).

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 (*Note: these are 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, the activity level specified in Curies determines the scaling factor for the source. Thus, an activity of "1C" indicates that the source should not be scaled, and an activity of "2C" indicates that the source strength should be doubled.

The simulated/computed spectrum can be a mixture or sum of several spectra. The individual spectra 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 given sources. If one spectral pair is plotted, the reduced χ^2 fit residuals between the measured and computed spectra are calculated and displayed.

4.3.3 Viewing Spectra

Figure 19 shows the **Plot** tab with a ^{88}Y spectrum (cal.pcf, 3) on the foreground line and a background spectrum (cal.pcf, 1) on the background line. The **Source for Computed Spectrum** line 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.

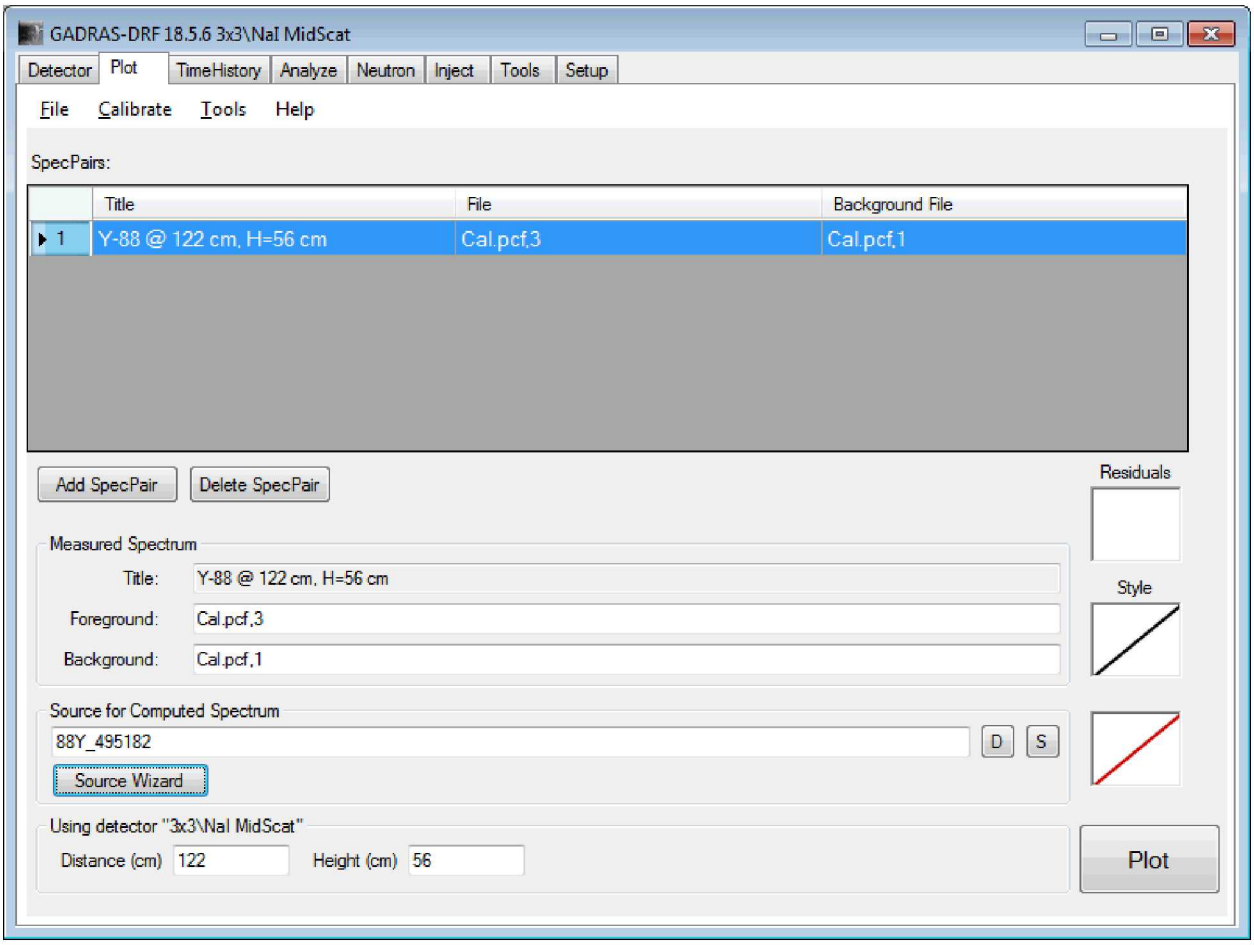

Figure 19: The Plot Tab Displaying Selections for a Foreground, Background, and Computed Spectrum

Figure 20 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.

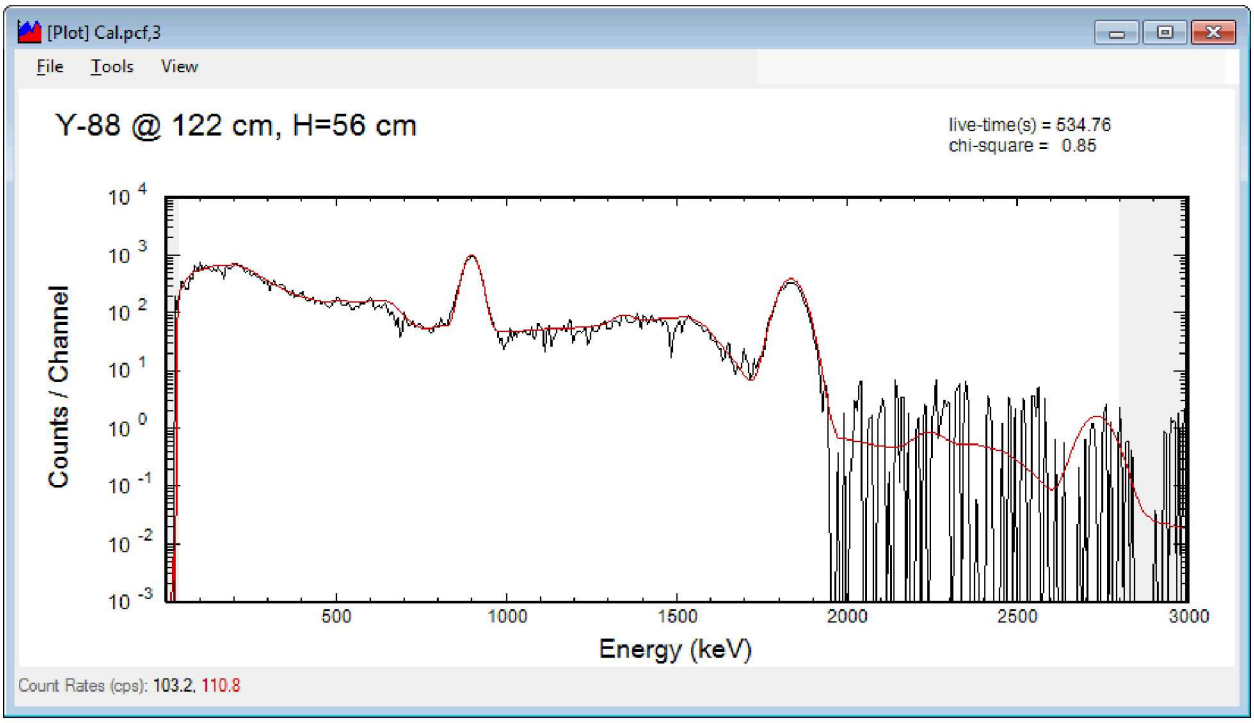

Figure 20: Plot of a Measured ^{88}Y Spectrum (background subtracted) and the Computed Spectrum from ^{88}Y Calibration Source

Computed sources may be plotted by themselves by using the **Source for Computed Spectrum** line without a measured spectra on the foreground or background lines. If desired, effects of shielding materials can be estimated by specifying the material on the **Source for Computed Spectrum** line. The atomic number and areal density of the absorbing material can also be entered on the input line using the following convention:

232U,10uCi {26,10} + 137Cs,3.2mCi {13,5}*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.

5 COUPLING GADRAS-DRF TO EXTERNAL RADIATION TRANSPORT CODES

To accurately model non-point sources or sources in complex scattering environments using GADRAS-DRF, an external code must 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. The output from these codes can be used with the detector response function in GADRAS-DRF to model 3-dimensional sources or complex scattering environments. This section describes how users should set up the radiation transport codes (specifically MCNP) to use with GADRAS-DRF. Users may also elect to use other codes such as GEANT, PARTISN, DENOVO, or custom user codes.

GADRAS-DRF 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-DRF has several scatter parameters which simulate a general scattering environment. If the scattering environment is complex, external transport codes can be used to calculate the incident radiation instead of GADRAS-DRF. To do this, MCNP should be used to model the radiation current separately on multiple facets of the detector. Using the MCNP results, GADRAS-DRF 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 default scatter parameters. If a source cannot be approximated with a point source, MCNP can be used to calculate the radiation transport from the source to the detector with a higher degree of fidelity than GADRAS-DRF alone.

The MCNP 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-DRF. These input files are called “multi-faceted GAM files.” GADRAS-DRF processes these multi-faceted GAM files by calculating the detector response from the radiation that scatters within the detector housing, and assuming that MCNP has accounted for the external radiation scattering.

To correctly process multi-faceted data generated by MCNP, users need to suppress GADRAS-DRF’s external scatter radiation calculations by setting all of the scatter parameters to zero (Figure 21). 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-DRF will account for radiation scatter within the detector.

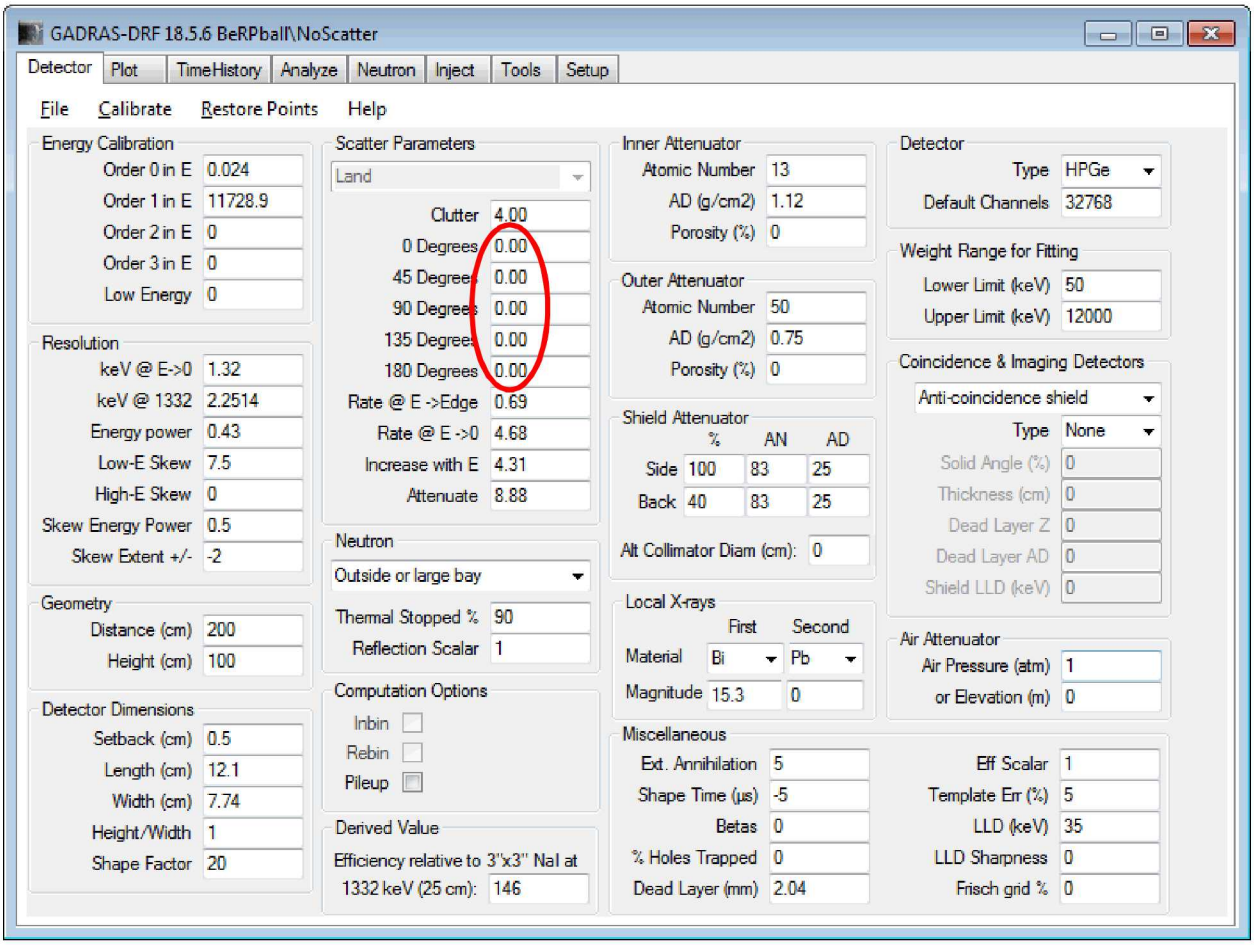

Figure 21: Set all Scatter Parameters to 0 When Using Multi-faceted GAM Files

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-DRF, as this tally represents the detector response function generated by MCNP and cannot be readily converted to a format that is usable by GADRAS-DRF. The current tally should be generated with the energy bin structure provided with the GADRAS-DRF distribution in the "MCNPbins.dat" file, (energies in this file must be converted from keV to MeV for usage in MCNP). Figure 22 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 22: A Simple MCNP Input Deck

The MCNP output file needs to be converted into a format usable by GADRAS-DRF. 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 23 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-DRF multi-faceted GAM file.

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

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

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

Figure 23: Pseudo-code for Scaling MCNP Surface Current Outputs to Units Suitable for use with GADRAS-DRF

Figure 24 below shows an example of a multi-faceted GAM file with current densities for the three facets of a detector. GADRAS-DRF 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.

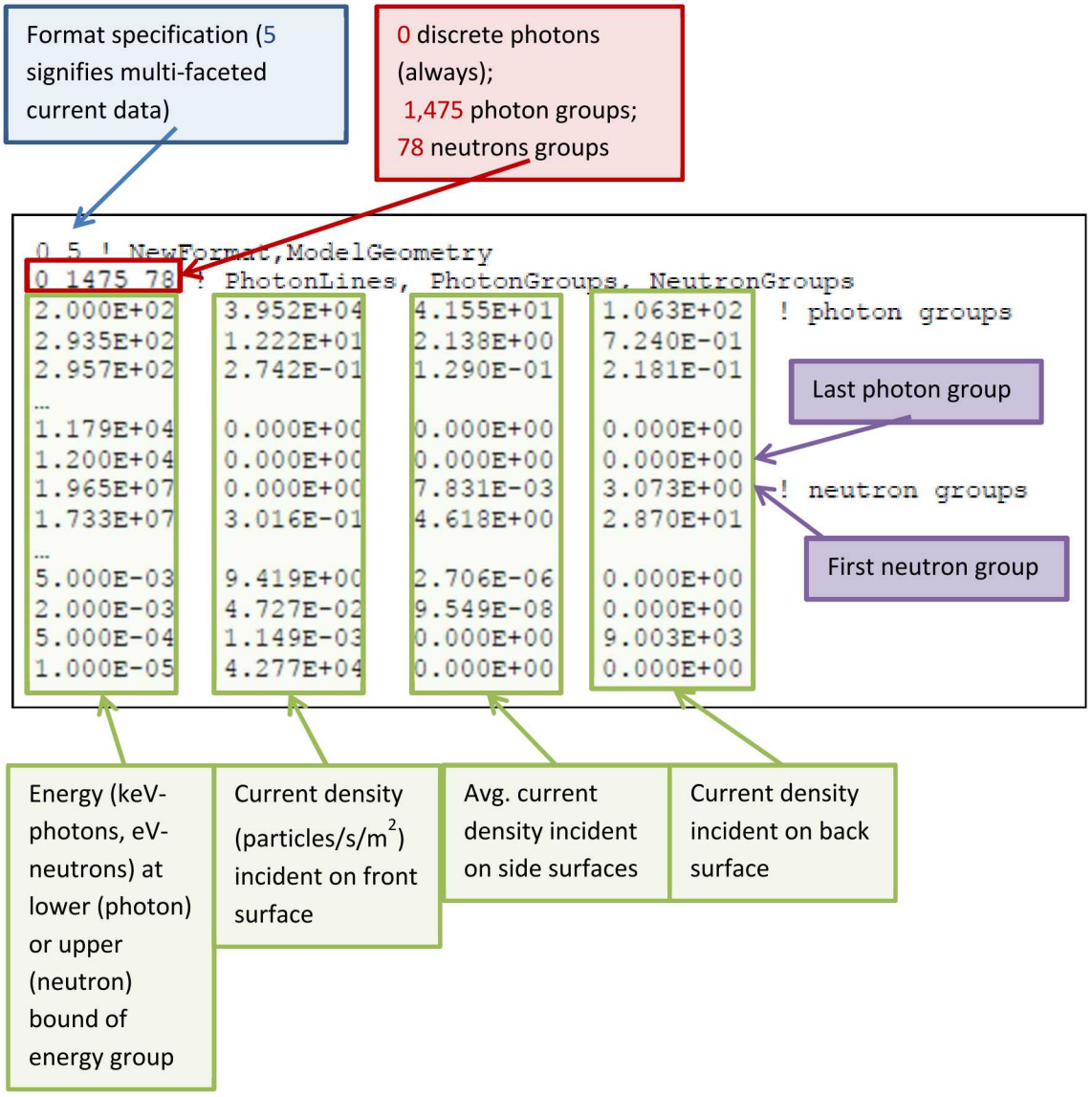

Figure 24: Multi-faceted GAM File Example

In Figure 24 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-DRF 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-DRF Input

GADRAS-DRF is distributed with python scripts that will convert MCNP output files into GADRAS-DRF input files. These scripts are located in the GADRAS-DRF data folder (usually **C:\GADRAS-DRF**), 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-DRF. 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

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 or 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.

The **PhotoPeak List** library is shown in Figure 25. The blue highlighted entry corresponds to the gamma-ray automatically selected by GADRAS-DRF 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.

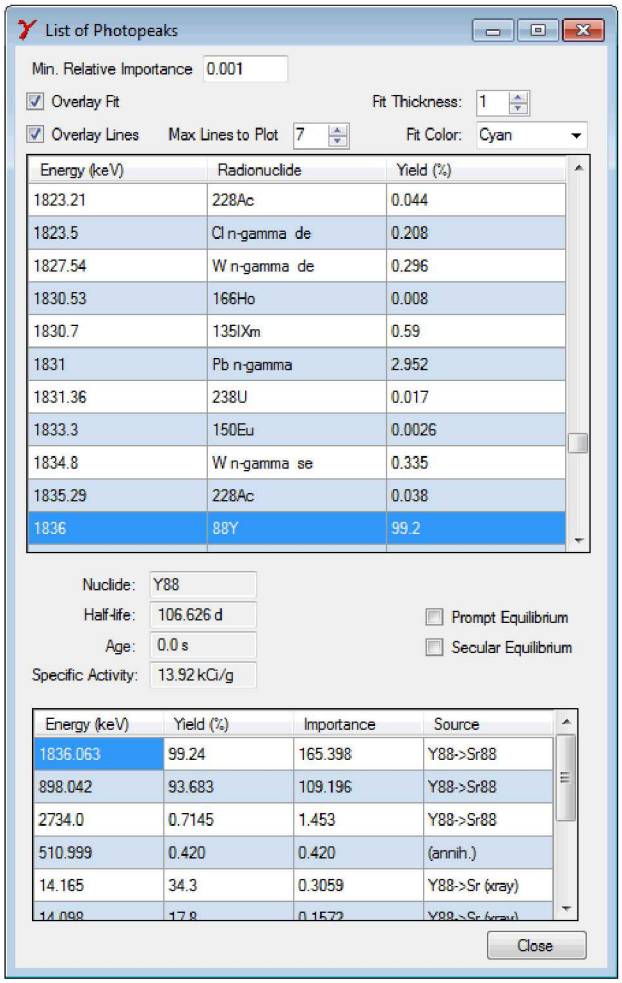

Figure 25: PhotoPeak List Library with ^{88}Y Highlighted and Both Overlay Options Boxes Checked

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 25 are shown in the displayed graph in Figure 26.

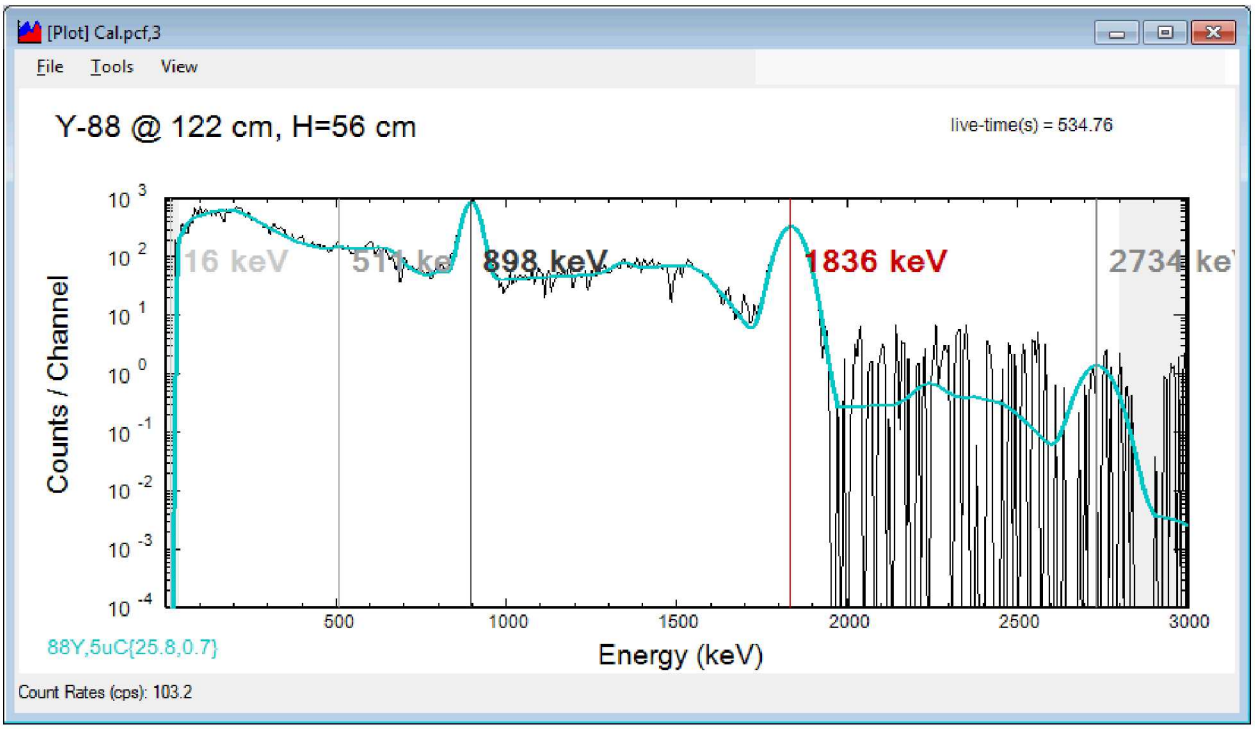

Figure 26: Graph Displays the Measured ^{88}Y Spectrum (black) with Both Overlay Options

The graph in Figure 26 displays the measured ^{88}Y spectrum (black) along with both overlay options. The overlay fit option generates a spectrum which is cyan in color and has a thickness value of three. The overlay lines option displays the lines and their energies.

6.1 Automatic Energy Calibration using GADRAS-DRF

Spectra can be calibrated automatically from the **Detector** tab or the **Plot** tab on the main window. The Calibrate drop-down contains the **Automatic Calibration (ecal and resolution)** option. This option takes a single SpecPair as its input and estimates the energy range, resolution, and some peak shape

parameters based on the spectrum. This quick method of calibrating a spectrum should not be used for detailed analysis.

6.2 Manual Energy Calibration using GADRAS-DRF

Spectra can be calibrated manually from the **Detector** tab or the **Plot** tab on the main window. The Calibrate drop-down list contains the **Peak Search and Manual Energy Calibration** option as shown in Figure 27.

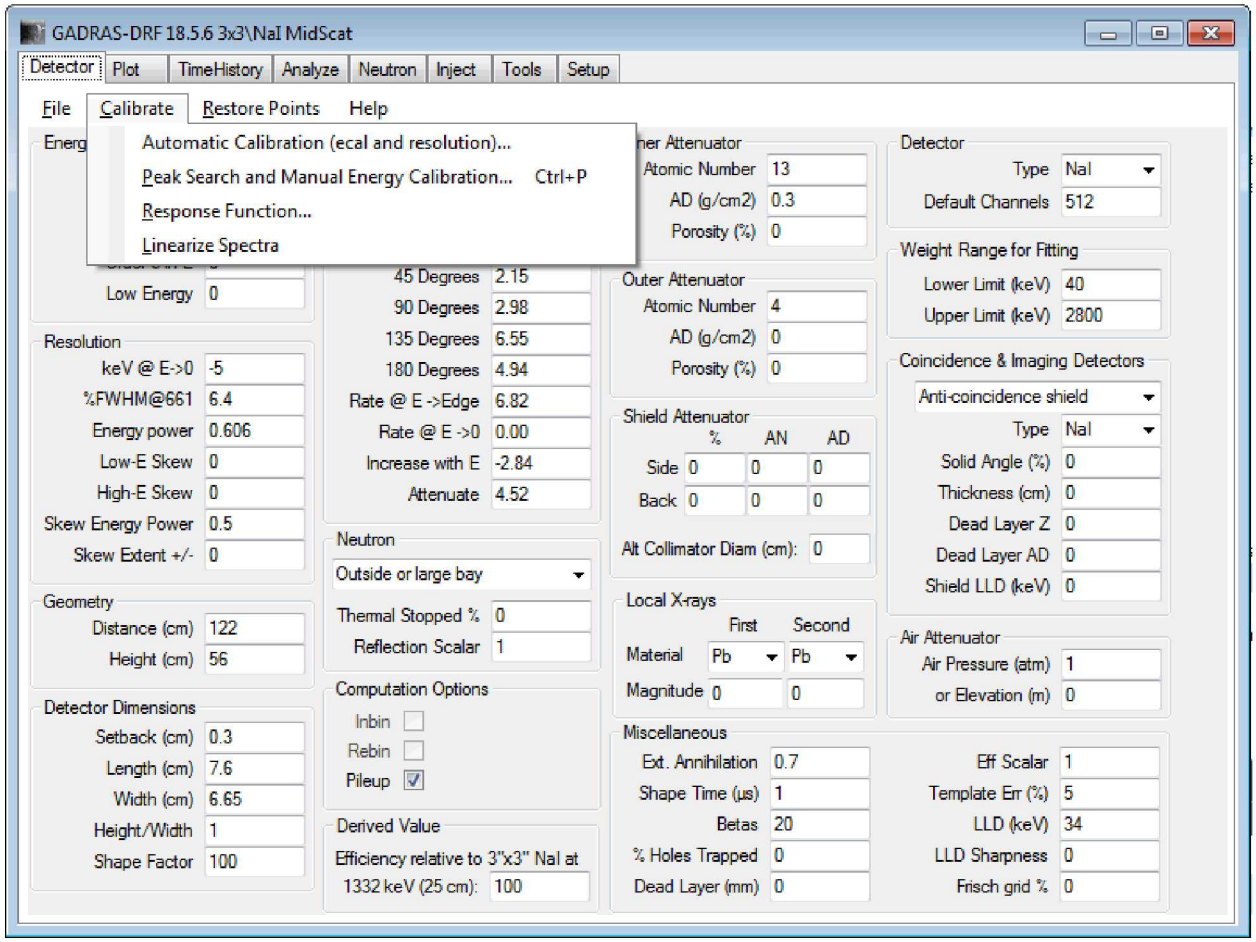

Figure 27: Peak Search and Manual Energy Calibration is Located in the Detector Tab

By selecting this option, the Peak Search and Manual Energy Calibration form appears (shown in Figure 28, *left*). To show a list of available spectra, a PCF file should by loaded by selecting Open Spectrum File in the File dropdown menu. A user can then drag and drop a record (row) from the PCF table into the blank portion of the **Peak Search** window. The zooming functionality on this plot is similar to the mechanism for normal plots. Users can click-and-drag right over regions of interest to zoom in. To zoom out, click-and-drag left. To include a peak in the fitting routine, the user should click a visible peak in the

displayed spectrum. Peaks recognizable by GADRAS-DRF for this procedure are shown in *green* above a *red* continuum with the default 5 sigma peak threshold, as shown in Figure 28 (*right)*.

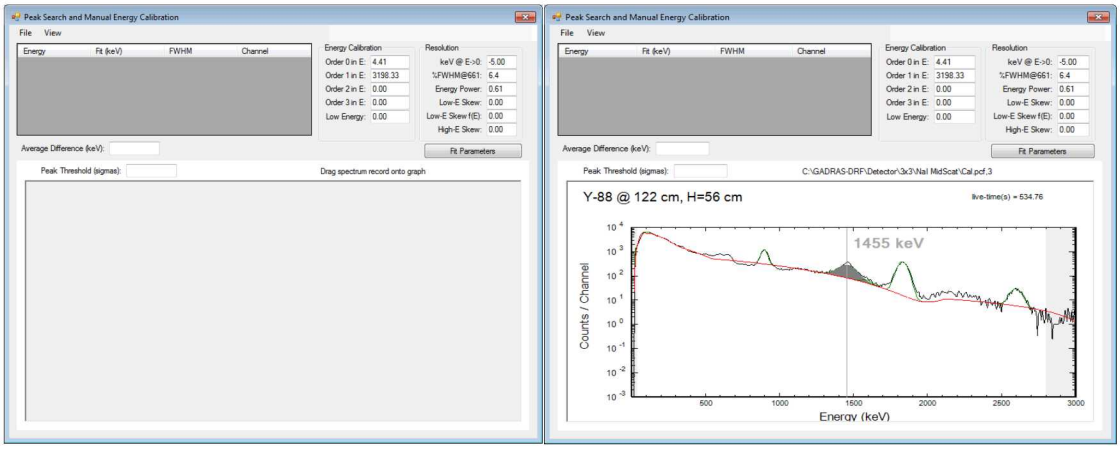

Figure 28: The Peak Search and Manual Calibration Screen is Blank When First Opened (*left*) and Populated When a Spectrum is Loaded (*right*)

The **Peak Threshold (sigmas)** option can either be lowered to recognize additional peaks or raised to recognize fewer peaks. For the new peak threshold value to take effect, it may be necessary to reload the spectrum by dragging the file to the window. Clicking a recognized peak will open a window to specify the energy of the peak as shown in Figure 29. If the centroid energy is close to a known peak for an isotope included in the GADRAS-DRF 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 current energy calibration parameters existing for the detector. 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.

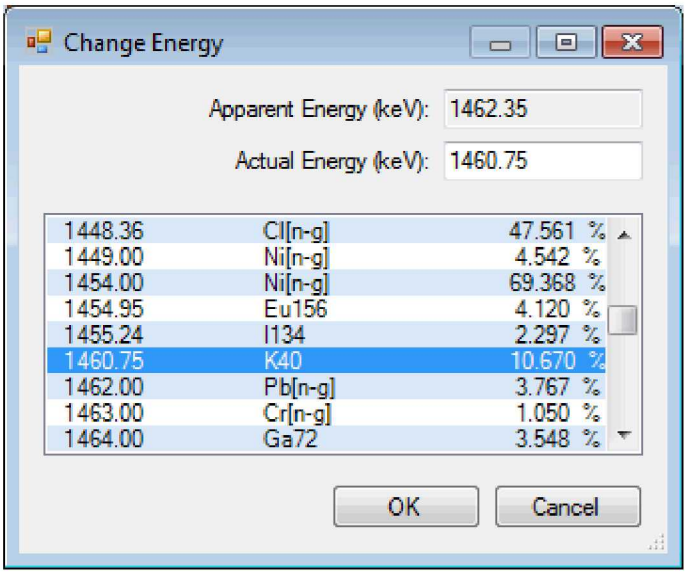

Figure 29: Users Select the Energy of the Peak From the Popup Window, or may Manually Enter the Known Energy

For high-precision spectra (e.g., HPGe spectra), a region of interest (ROI) of the graph can be selected by dragging to the right over the ROI. Dragging left will zoom out the display. Individual peaks may be easier to identify and select in the new ROI.

After entering an appropriate number of peaks in the channel/energy table, the energy parameter adjustment can be performed. The upper-left portion of Figure 30 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 (*cyan*) parameters will be adjusted. After the peak selection process is complete and the appropriate parameters are adjusted, the user should click the **Fit Parameters** button below the parameter group boxes to initiate the least-squares fit to the data.

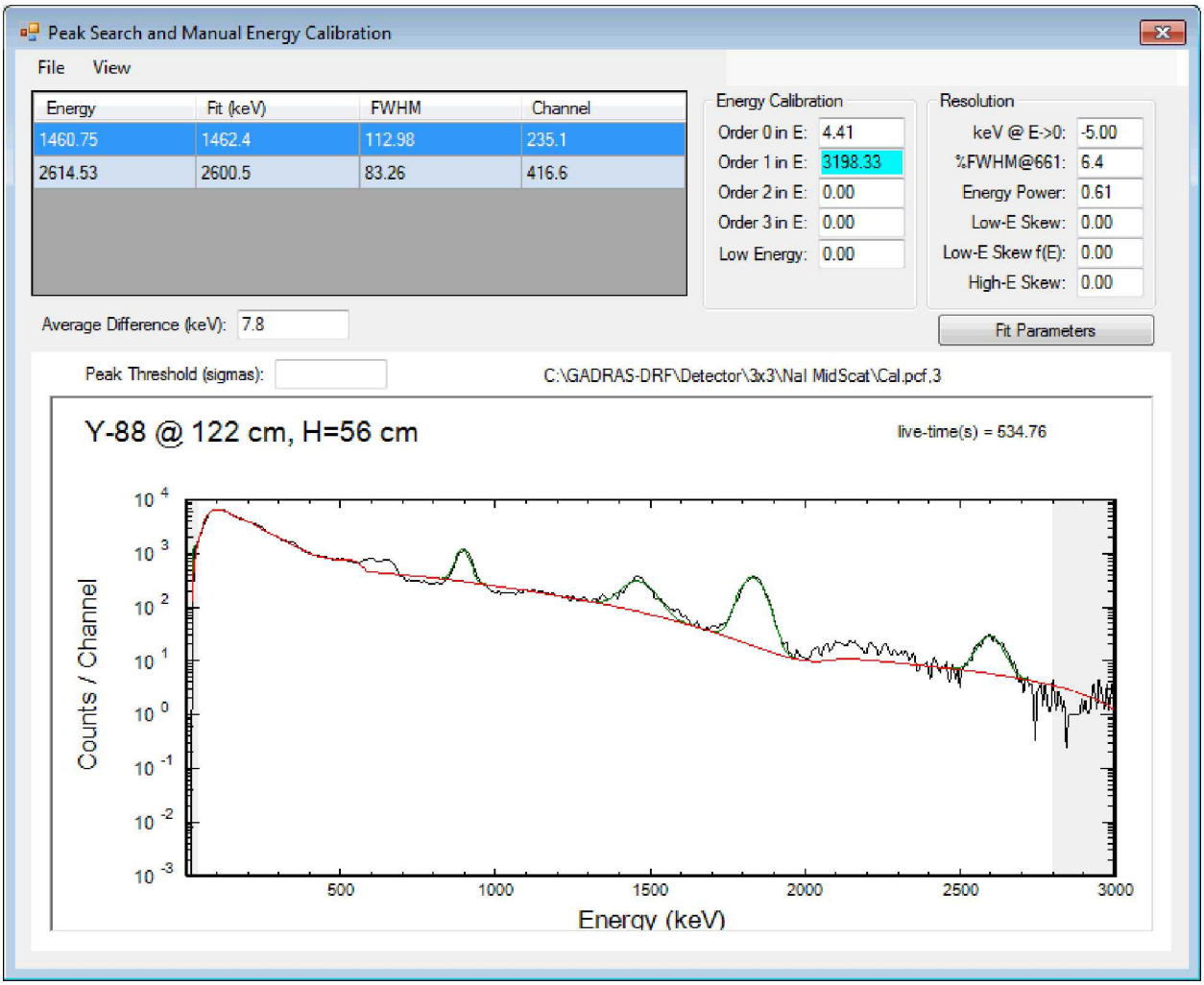

Figure 30: Energy Calibration Screen Showing the Selected Peaks and the Highlighted (*cyan*) Parameters that will be Adjusted (*center*)

To ensure a proper energy calibration, a small subset of well-known peaks should be selected. GADRAS-DRF 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 (low/high-E skew) should be adjusted.

Figure 31 illustrates a properly calibrated measured spectrum for ^{137}Cs. To examine the peak, the user can access the **PhotoPeak List** (*shift-left mouse click*) near the peak around 661 keV. Alternatively, if the isotope is known, the **Isotope DB** form can be accessed from the **Tools** menu. As shown in Figure 31, the

measured spectrum corresponds with the library spectrum overlay (the computed peaks match well with the measured data). The legend on the graph (*lower left*) states the isotope, the activity, and the shielding configuration that best fits the measured spectrum

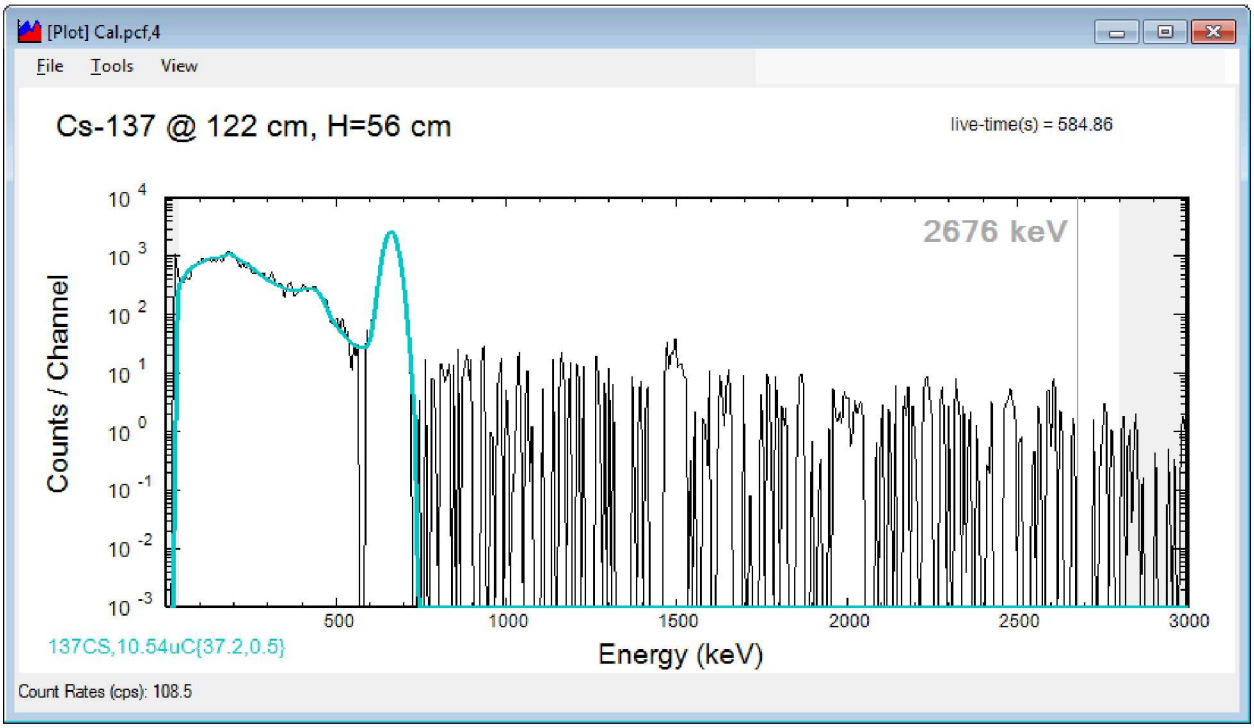

Figure 31: A Measured Spectrum (*black*) with a ^{137}Cs Library Spectrum Overlay (*cyan*)

6.3 Graphical Energy Calibration

A graphical calibration method is an alternative to using the Peak Search and Manual Energy Calibration process. This can be used for the adjustment of the gain and offset (**Order 0 and Order 1**) of the spectrum. The calibration will occur using a graph of the measured spectrum and the appropriate overlaid spectrum from the **PhotoPeak list** or **Isotope DB** library. Figure 32 shows a measured ^{137}Cs spectrum (*black*) and a library ^{137}Cs spectrum (*red*) where the ^{137}Cs peak at 661 keV in the measured spectrum does not coincide with the energy of the library peak. This implies that an energy calibration of the data (measured spectrum) is needed.

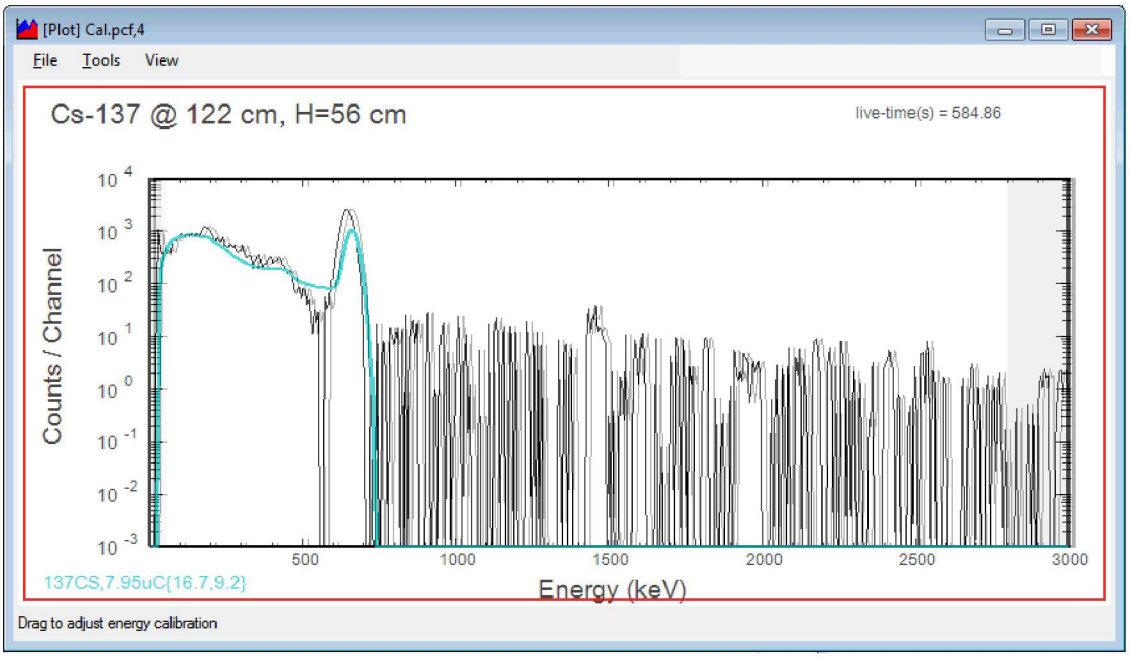

Figure 32: Energy Calibration is not Correct for Displayed Spectrum

In this example, to calibrate the measured spectrum correctly, the centroid of the measured peak (*black*) should be adjusted to match the centroid of the computed spectrum (*red*). To make this adjustment, the user should right-click on the peak in the measured spectrum and drag the peak to the correct energy (the centroid of the peak in the computed spectrum). Once this action has been performed, the energy calibration window shown in Figure 33 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.

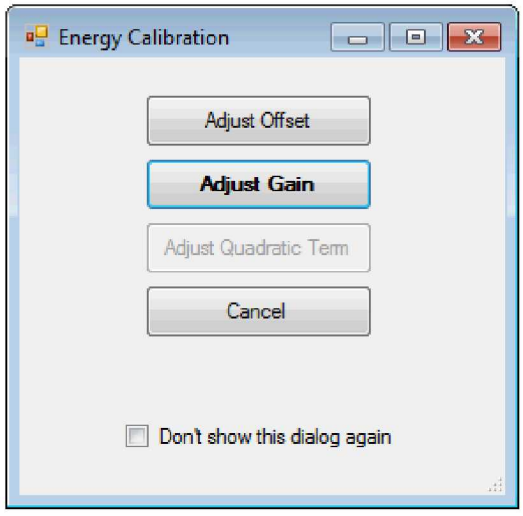

Figure 33: Energy Calibration Parameter Selection and Confirmation Window

Due to the potential for inadvertent changes to calibration parameters, GADRAS-DRF requests confirmation for the parameters to be adjusted when the dragging operation is used (unless another graphical calibration adjustment has been performed within one minute).

The graphical calibration compensates for high-order energy calibration parameters so that the graphic adjustment is accurate regardless of non-linear energy calibration parameter settings. Figure 34 displays the successful completion of the graphical energy calibration for the measured ^{137}Cs spectrum to the computed spectrum.

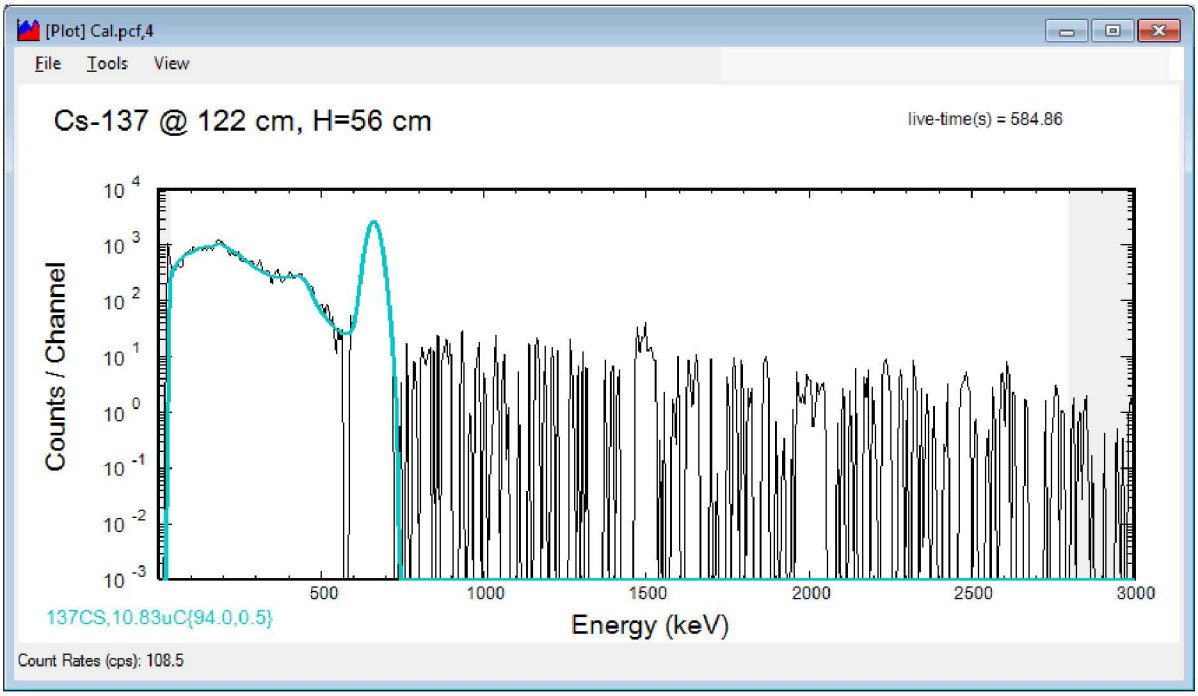

Figure 34: Sucessful Graphical Energy Calibration

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 TimeHistory tab allows users to plot and manipulate these types of spectral records. Upon opening the TimeHistory tab, users are presented with a screen involving several input fields as shown in Figure 35. Users may specify the following:

- **File**: The PCF file containing the time history spectra
- **Time Start** (optional): Time in seconds to start summing (default: 0 s)
- **Time End** (optional): Time in seconds to end summing (default: end of file)
- **Photons/Neutrons/Both**: The particle(s) of interest to display (default: Photons)
- **Detectors**: If there are multiple detectors specified in the file, this panel box specifies which detectors to display the data from (default: all detectors)
- **Include Background**: Whether a background should be specified to subtract from the specified foreground (default: not checked)
- **Include Computed Spectrum**: Whether a computed spectrum should be displayed on the Time History graph display

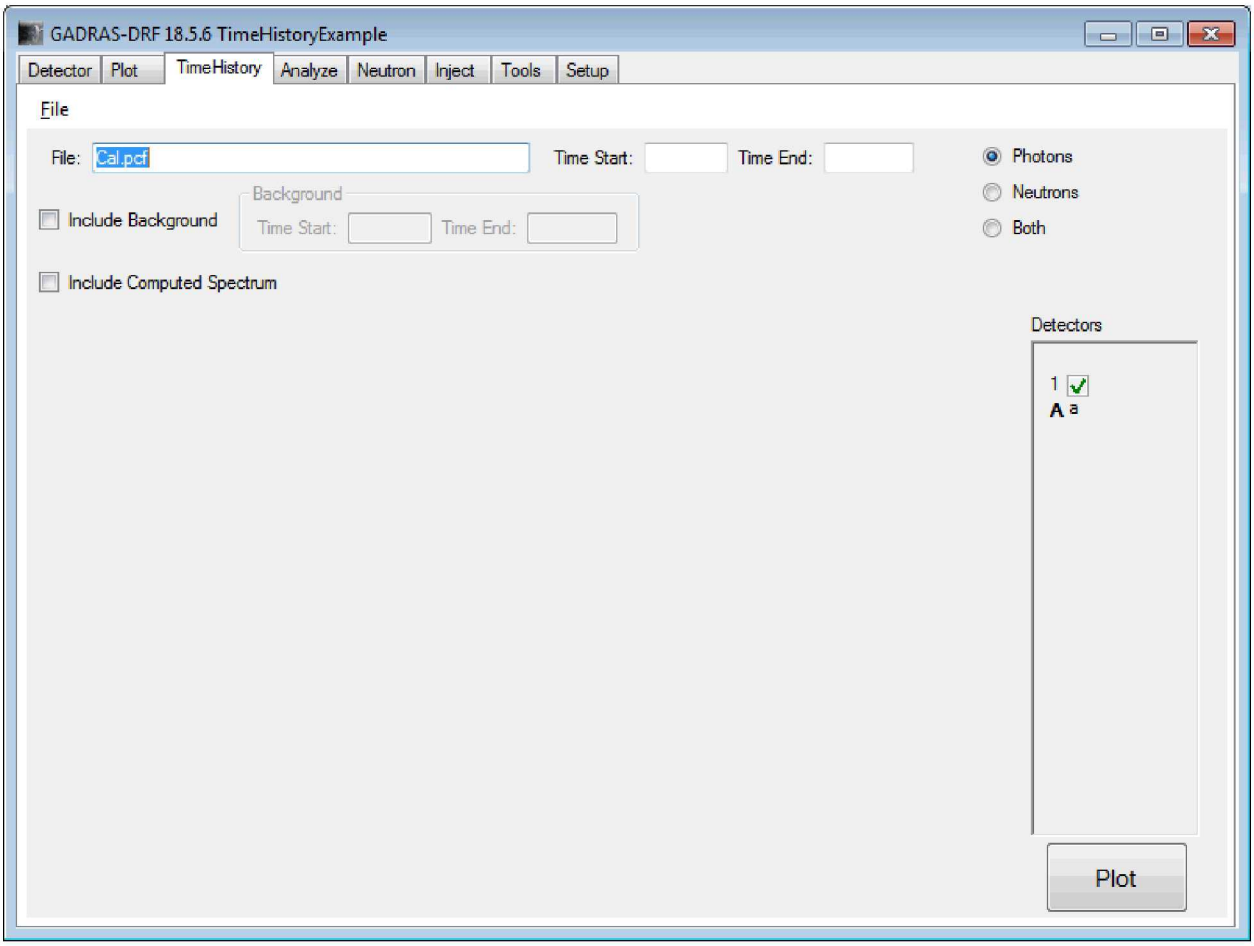

Figure 35: Time History Page

7.1 Plotting Time History Spectra

Although no time history spectra are distributed with GADRAS-DRF, a detector and spectrum have been displayed here for the sake of example. After specifying a file and any desired options, the user may click **Plot** to display the time history spectrum graph. GADRAS-DRF generates two graphical displays as shown in Figure 36. 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, 12536 seconds). The right side of the Time History display gives the user several options to manipulate 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.

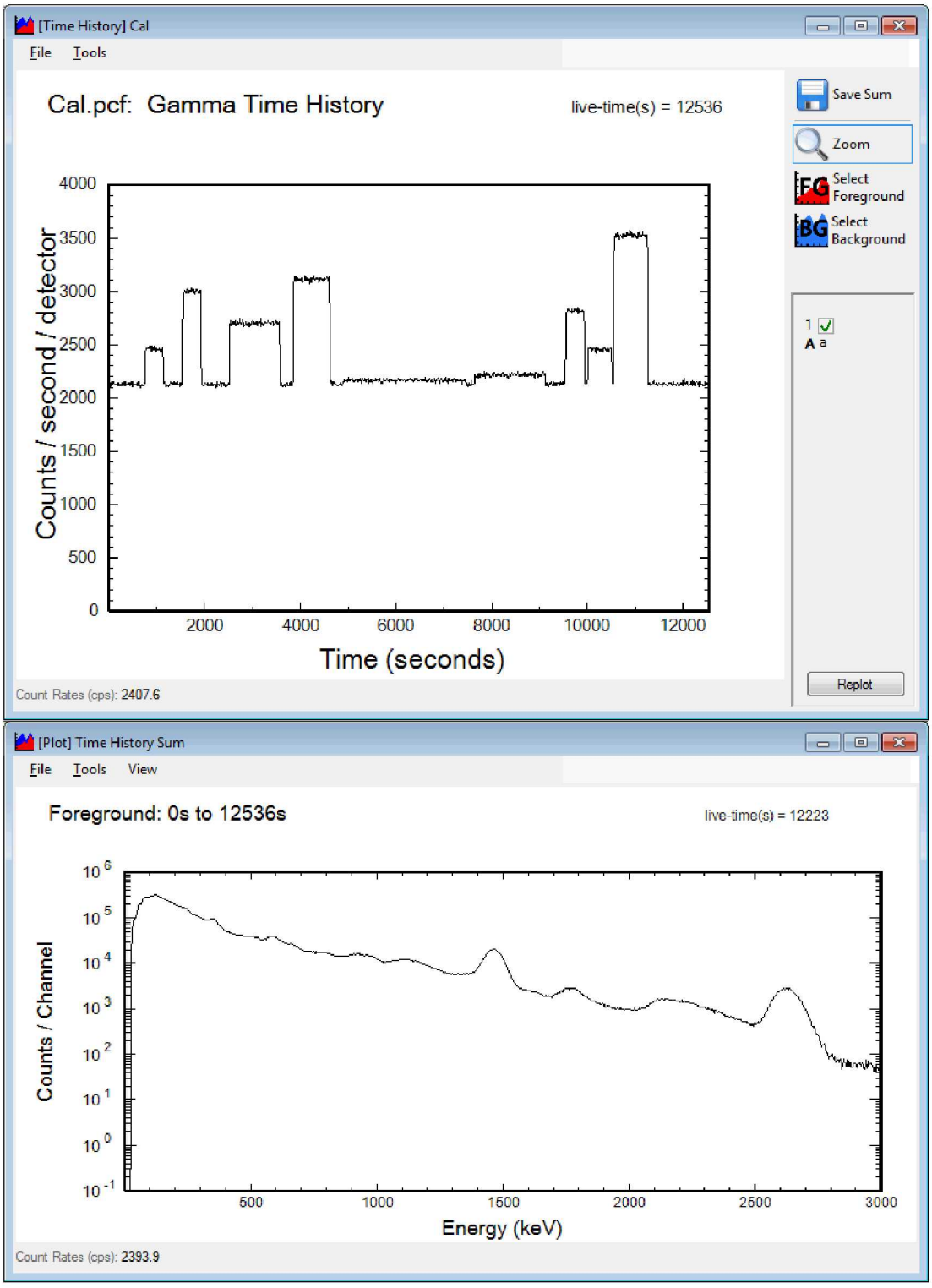

Figure 36: Time History Display (top) and Sum Spectrum (bottom)

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 37).

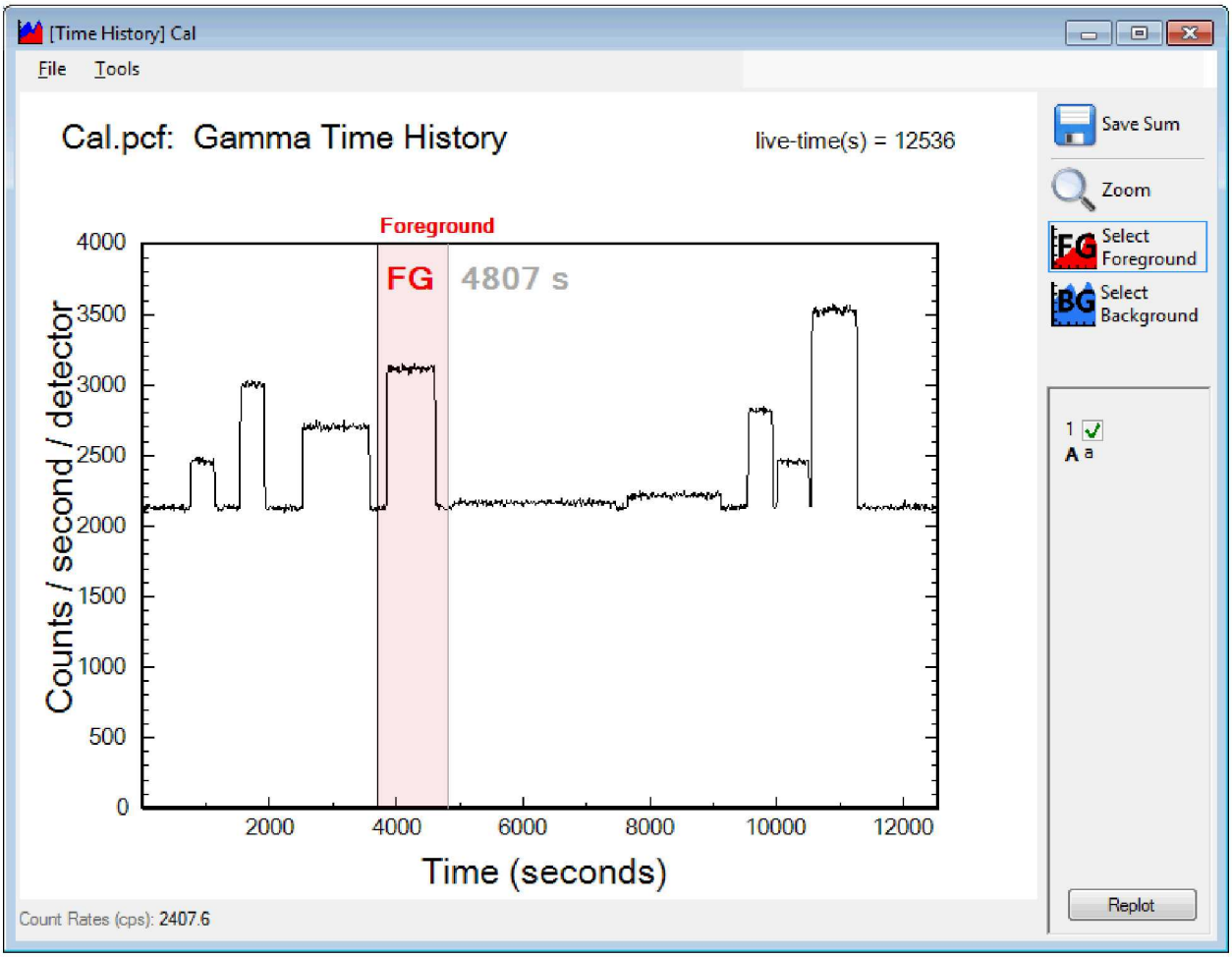

Figure 37: Selecting a Foreground to Sum Over

Upon selection of a foreground, the Time History Sum display updates automatically to display the sum over the selected time region (Figure 38). As shown, the title of the spectrum reflects the specified time interval ("Foreground: 3720s to 4807s").

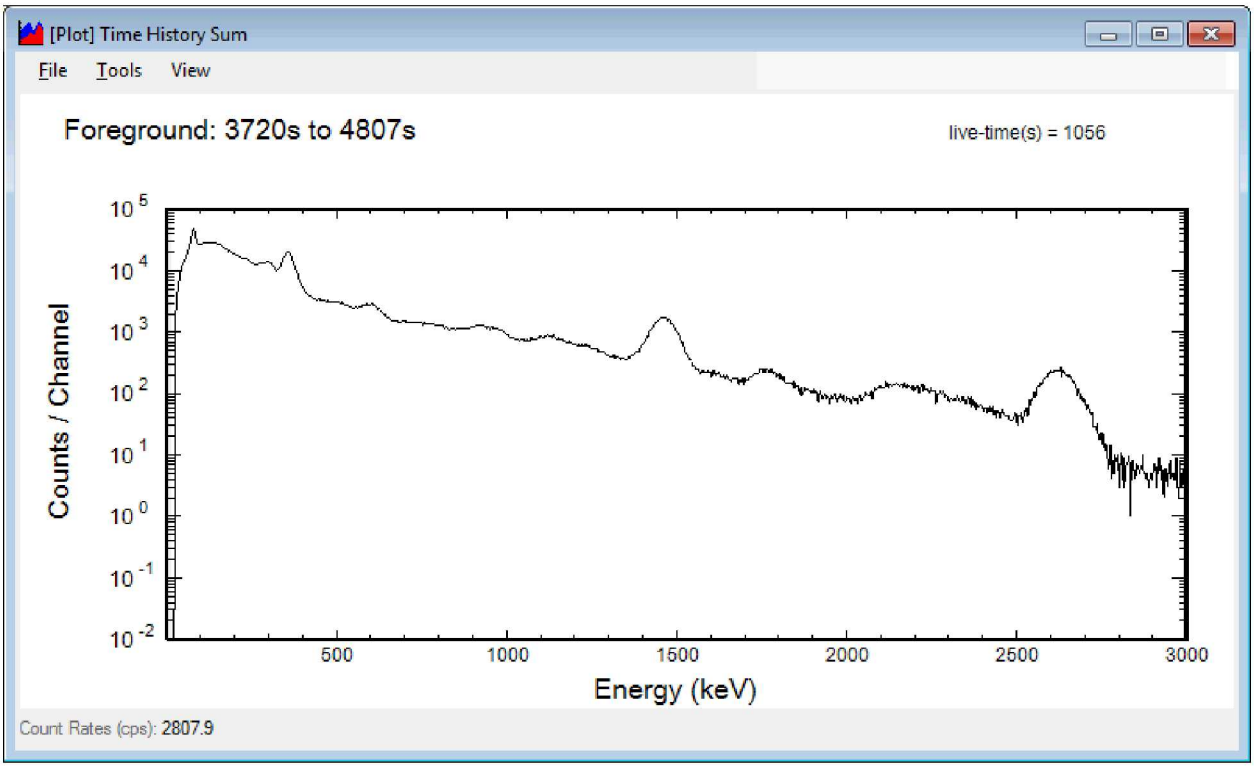

Figure 38: Time History Sum over Selected Time Interval

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 39. 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 40. This particular example highlights the portion of the time history spectrum when 133Ba was placed in front of the detector.

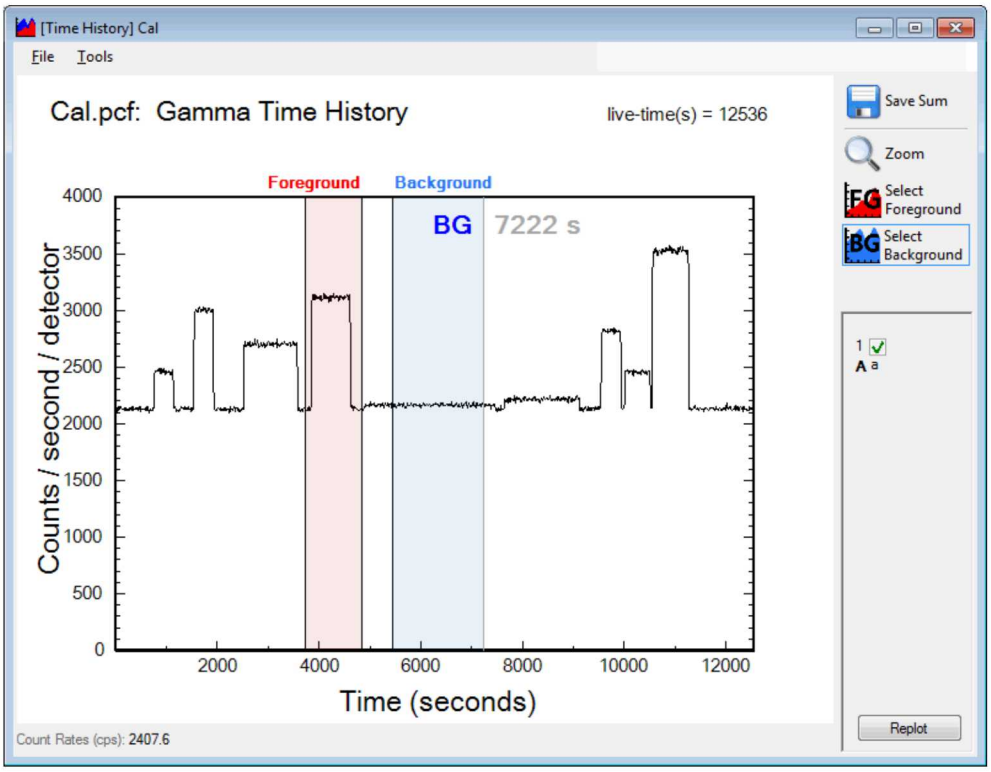

Figure 39: Selecting a Background to Subtract from the Specified Foreground

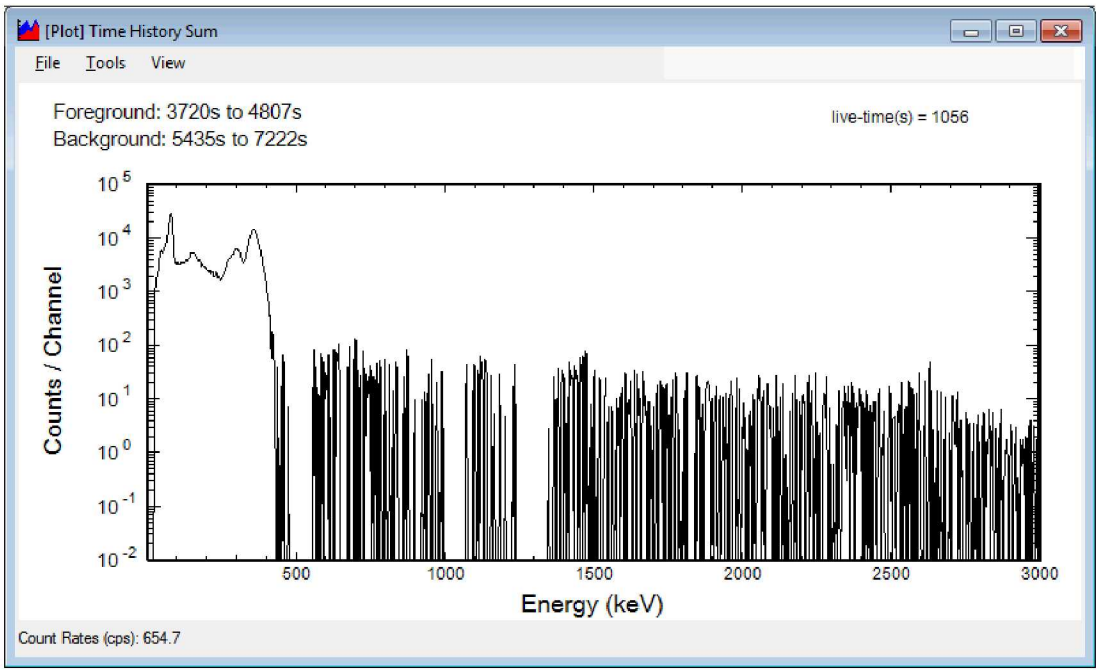

Figure 40: Background-Subtracted Spectrum

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 41. The user may specify the foreground or background on this page and click **Plot** to update the graph display forms appropriately.

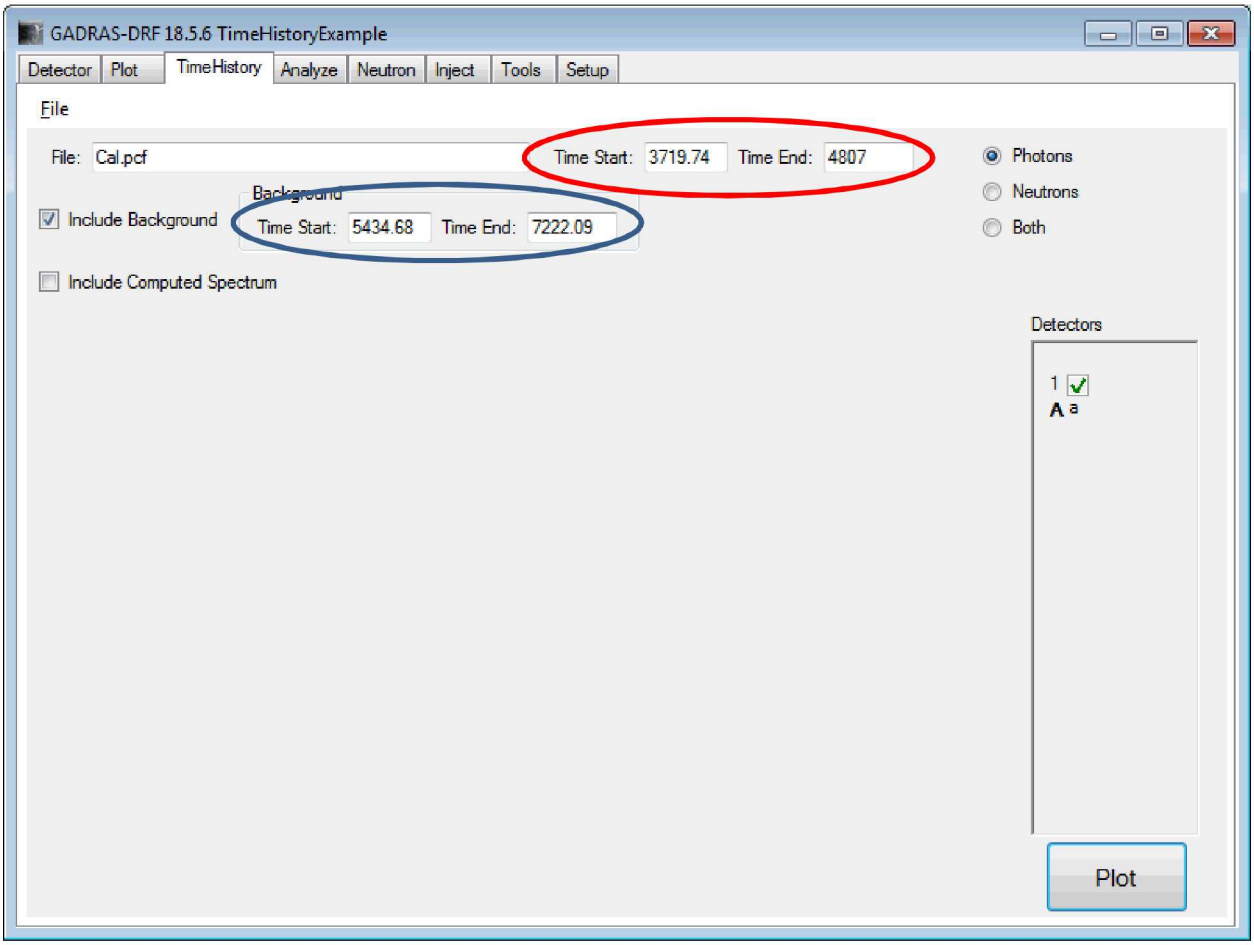

Figure 41: Foreground and Background Time Periods Are Updated on the Main Display

Besides 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 width of the rectangle, but changes its location.

If a time history spectrum file contains multiple detectors, these will be displayed both on the main TimeHistory page and the Time History display form. The user may change which detectors are included

in the displayed spectrum by checking or unchecking the appropriate boxes and clicking **Plot** on the main page or **Replot** on the Time History display form.

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 42. For most situations, the default values will suffice for the user, but there may be some special 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
- **Shift spectra to uniform energy-group structure**: Users may select this option to rebin the spectra into a desired energy calibration
- **Offset (keV)**: The 0^{th} order parameter of the new energy calibration
- **Full-scale energy (keV)**: The 1^{st} order parameter of the new energy calibration
- **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)

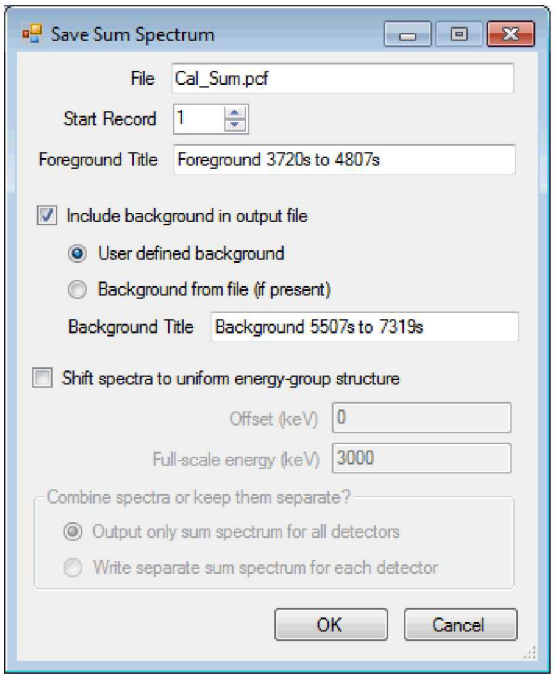

Figure 42: Save Sum Spectrum Form

7.3 Computed Time History

GADRAS-DRF also offers the ability to compute a time history spectrum and either display it individually or overlay it on a measured time history spectrum. When a user checks the **Include Computed Spectrum** checkbox, the computed spectrum parameters appear along with several options near the bottom of the page (Figure 43). 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 (or sources if there are multiple) 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 sou. 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 sou 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 sou 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

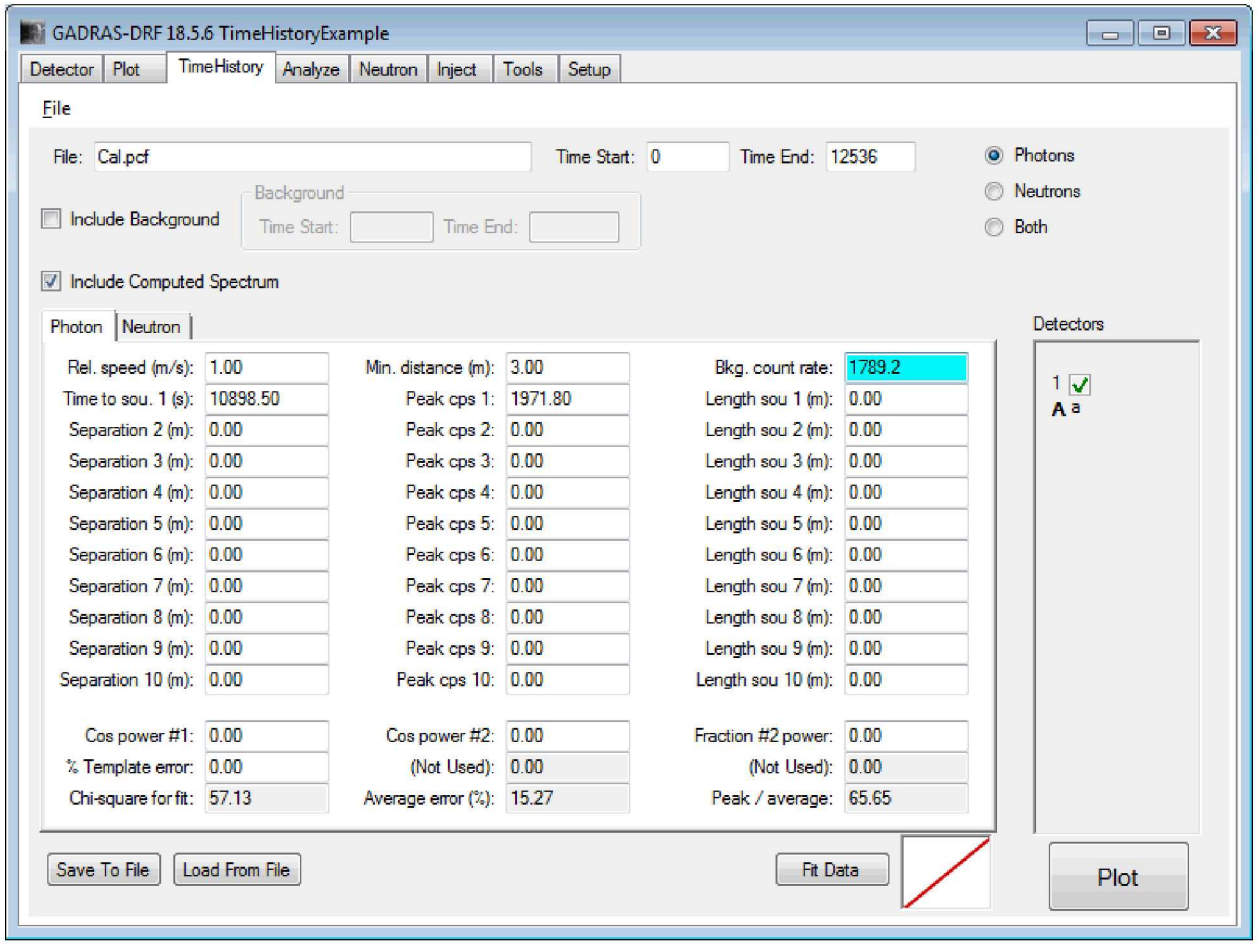

Figure 43: Time History Page with Computed Spectrum Options

By clicking **Save To File**, the specified parameters will be saved 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-DRF also has the capability of fitting 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 43. Any parameters that are highlighted will vary when the user clicks **Fit Data**. The computed spectrum before and after fitting the Bkg. count rate is shown in Figure 44.

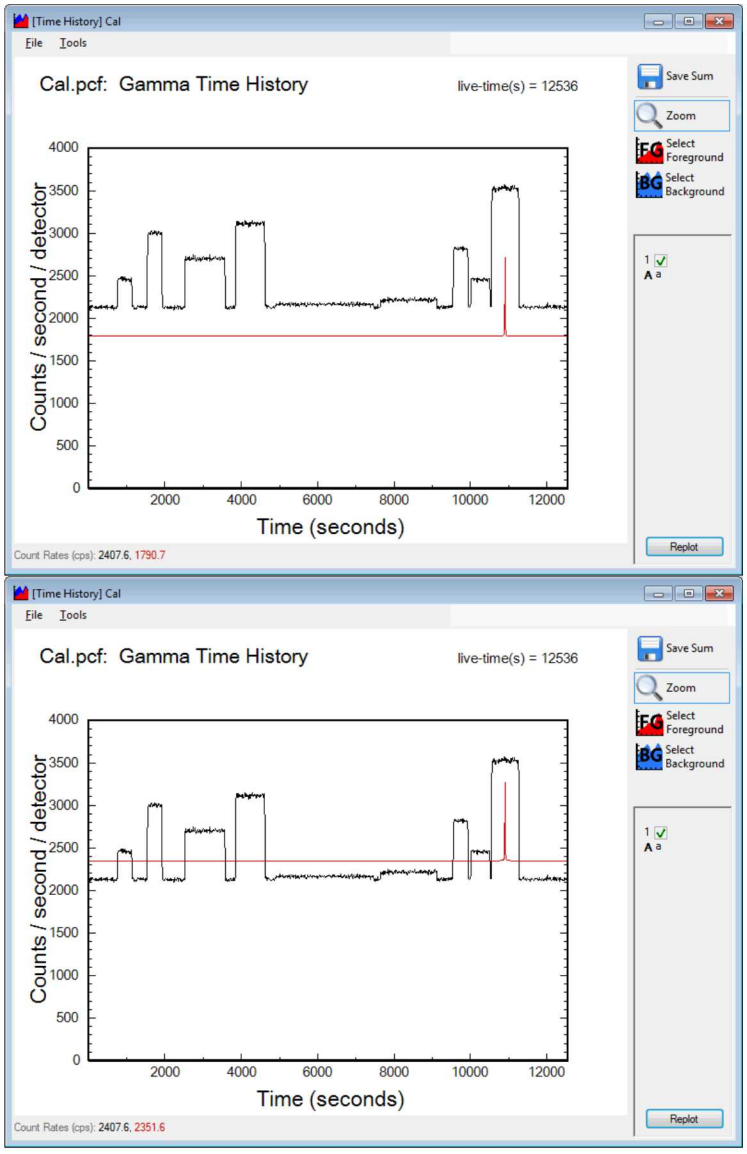

Figure 44: Computed Spectrum before Fit (top) and after Fit (bottom)

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

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

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-DRF plotting menu allows for some preliminary spectral analysis. This graphical capability facilitates the comparison of selected peaks and energies in a measured spectrum with library spectra from the **Isotope DB** or the **PhotoPeak List**.

The left side of Figure 45 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 898 keV peak. The activity of ^{88}Y in this sample is estimated to be 5.13 uCi with no shielding. The PhotoPeak list is shown on the right side of Figure 45. If the overlay does not match, another peak may be chosen for comparison with the measured spectrum.

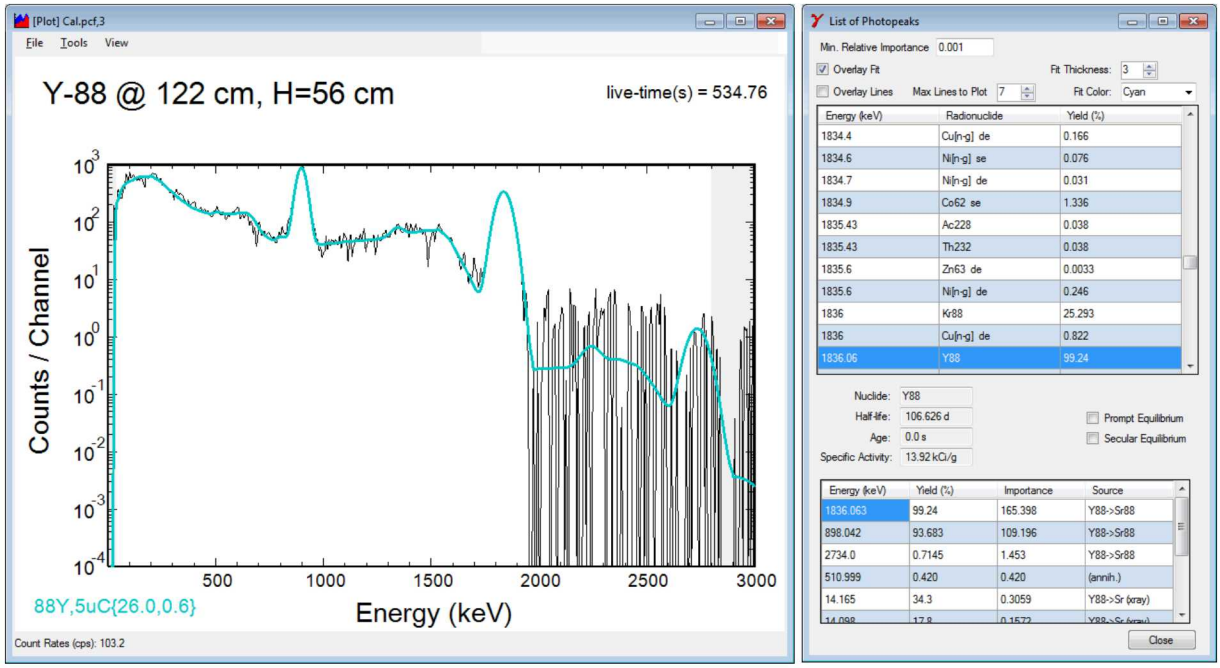

Figure 45: Graph of Measured Spectrum with Overlay (*left*); Photopeak List with Displayed Isotope Highlighted (*right)*

8.2 Numerical Spectral Analysis

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

- Single Regression

- Multiple Regression
- ComputeFlux

The Analyze tab shown in Figure 46 contains text boxes that accept input for foreground and background spectra similar to the **Plot** tab. Display options for the analysis output are located on the right side of the **Analysis** tab. The ensuing plot will only subtract the background if the **Strip background** option is selected. There is also an option to perform an analysis routine on a time history file. This option is selected by checking the **Time History** checkbox next to the Foreground text box. 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 long (such as with ComputeFlux). In this case, after the user selects the foreground and background segments, they may click **Do Analysis** on the Time History display form (Figure 47).

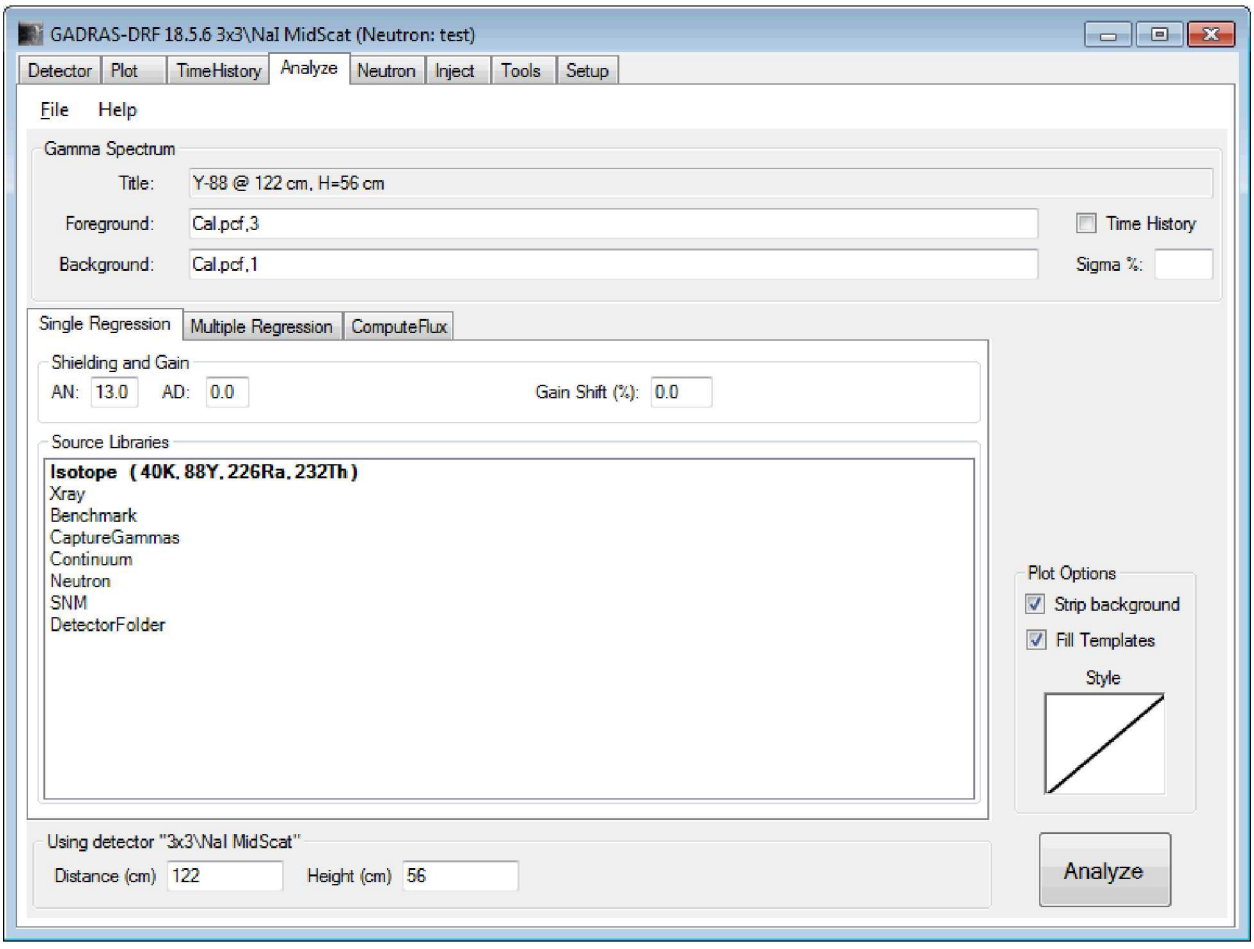

Figure 46: The Analyze Tab on the Main Form

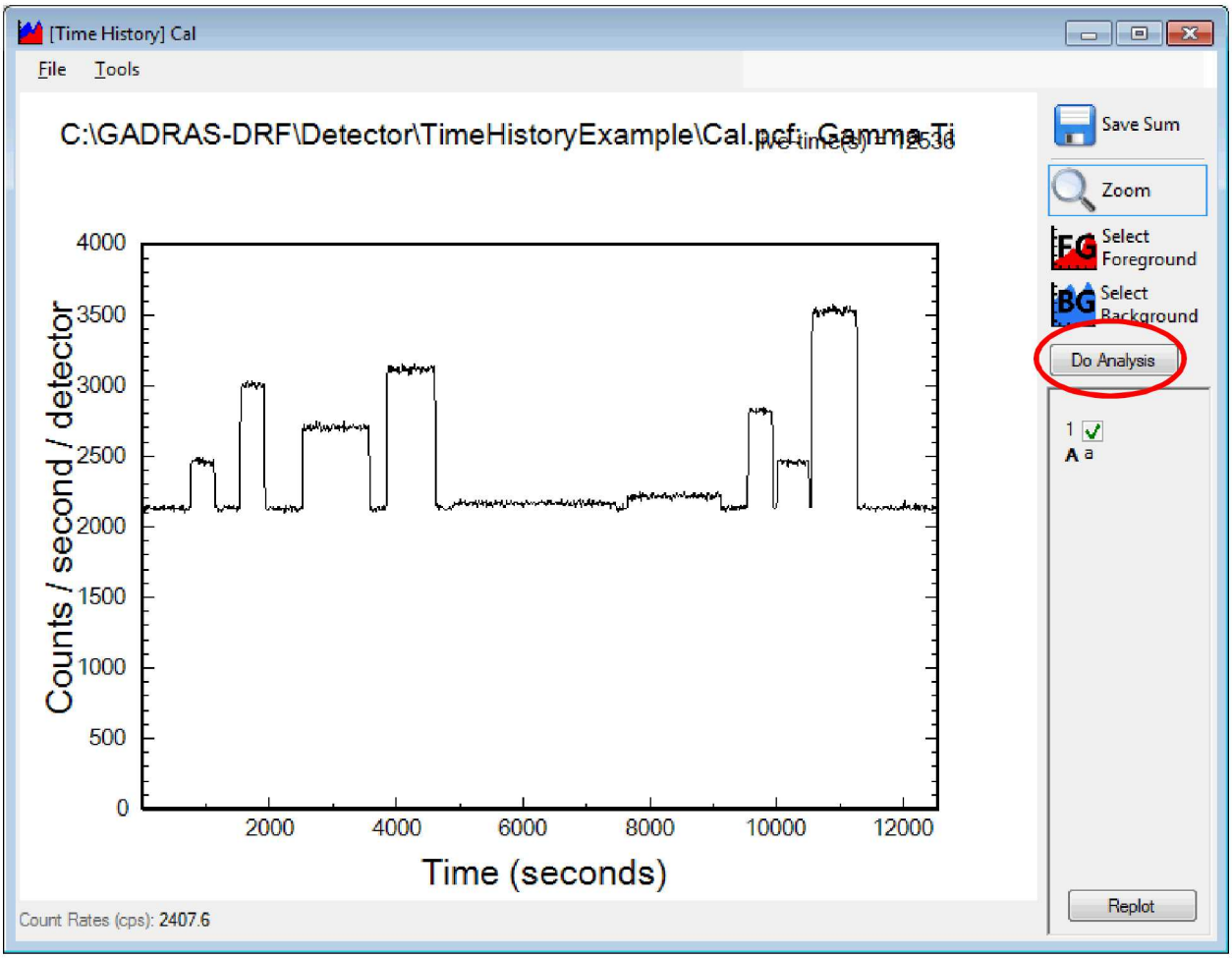

Figure 47: Compute Spectrum Analysis on Time History File

8.2.1 Source Libraries

Several source libraries are generally available for inclusion in any numerical analysis, as shown above in the large box labeled Source Libraries (Figure 46).

The available source libraries:

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

Other libraries can be created and included by individual users. This is done by creating new directories under **GADRAS-DRF\Source**. Each library/directory contains a series of files that defines emission rates of gamma-rays or neutrons. Files with the extension **ISO** in the **Isotope** directory define discrete gamma-rays emitted by unshielded isotopic sources.

Within each library are lists of sources that can be selected for use in the current analysis by clicking on the individual source designator. The selected sources are then available for analysis. Multiple Regression analysis allows for multiple libraries to be utilized.

The most commonly used library in a typical analysis is the Isotope library. Figure 48 shows the Isotope library window with several of the isotopic sources selected and highlighted (*blue*). Users may select various groups of isotopes in the Group Selection Options portion of the window. The group selection of isotopes carries no guarantee of accuracy or completeness; it is provided only to save time in selecting such isotopic groups. These groups include:

- **Fission** – fission daughter products
- **Natural** –naturally occurring isotopes
- **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

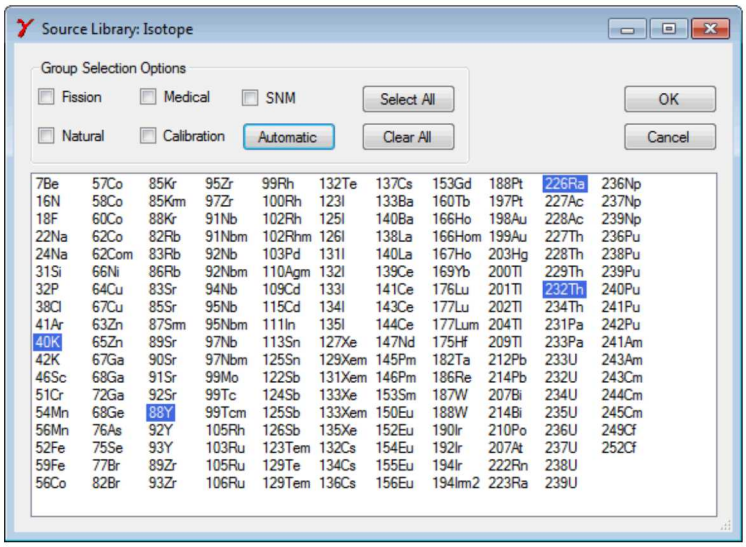

Figure 48: Isotope Library Window

Fitting the continuum caused by the presence of a neutron source cannot be done by selecting a neutron emitter (e.g., ^{252}Cf) out of 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-DRF contains two routines used to analyze gamma-ray spectra by linear regression. The two programs, located on the **Analysis** screen have the same user interface and analysis approach, but are used for different purposes.

- **Multiple Regression** performs a similarity (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.
- **Single Regression** performs a similarity (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.

Both analysis routines report a χ^2, which indicates the deviation between the measured and the calculated sets of data (relative to estimated uncertainties in the two sets). The value of χ^2 should be near unity if the two data sets were produced by the same radioactive source(s).

The spectrum to be analyzed is selected by dragging and dropping a foreground and background spectrum from the PCF record window (or by entering it manually). **Multiple** and **Single Regression** analyses attempt to fit the measured spectrum with selected source(s). 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 isotopes are ranked for consistency with the measurements when **Single Regression** is performed and more than one isotope is selected. **Multiple Regression** finds the combination of selected isotopes and associated activities that gives the best fit to the spectrum. Parameters associated with intervening materials can be adjusted by clicking on the **AN** and **AD** labels (clicking these labels highlights the adjacent boxes, turning them cyan). There is also a check box for the option of allowing independent shielding for each radioactive source in the measured spectrum.

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 0), Source Libraries, for description). Figure 49 shows the **Single Regression** tab with the selected sources from the available source libraries. To perform the analysis, click the **Analyze** button at the bottom right corner of the page.

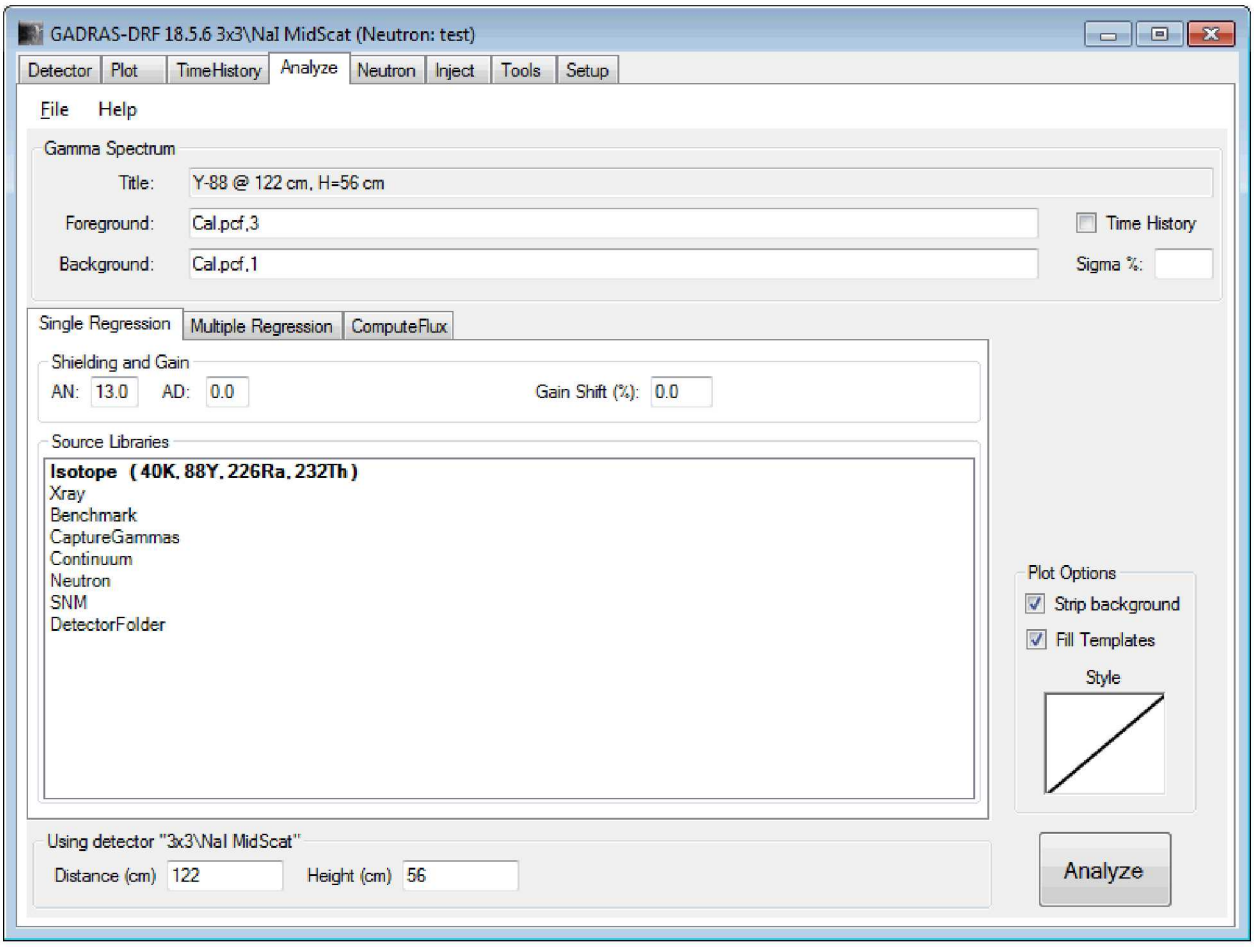

Figure 49: Single Regression Analysis Tab

Single Regression analysis generates a single graph of the best fit data and a summary page. The best fit is plotted as shown in Figure 50, and the summary page (Figure 51) ranks the selected isotopes based on similarity to the measurement using the reduced chi-square (χ^2).

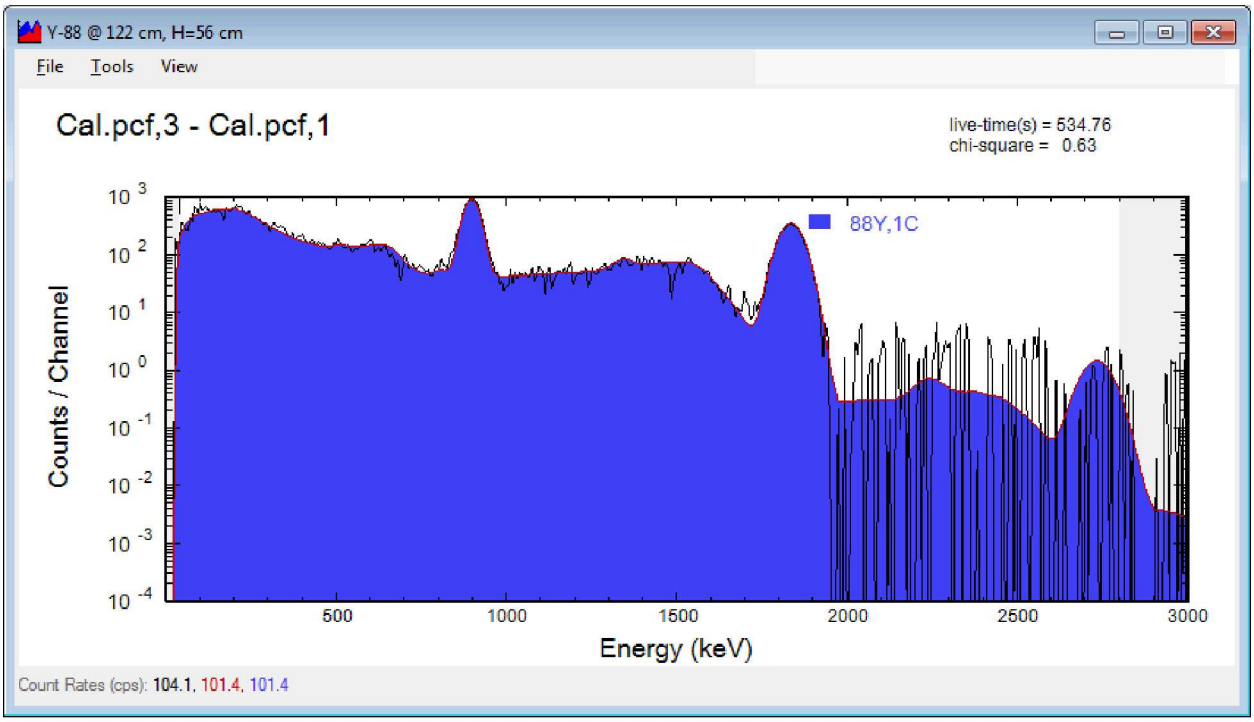

Figure 50: Single Regression Analysis Results of Unshielded ^{88}Y Spectrum

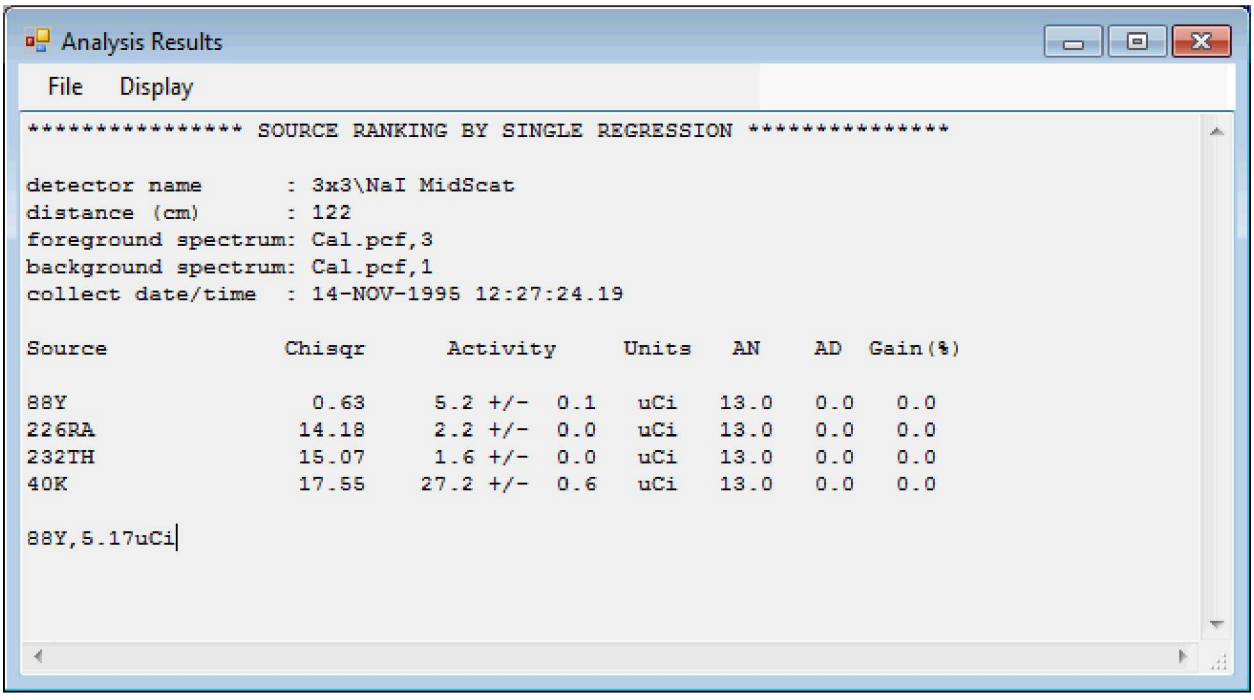

Figure 51: Single Regression Analysis Summary Page

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 a large number of sources are selected, especially if the shielding is allowed to vary. Figure 52 shows the Multiple Regression tab.

The **Multiple Regression** analysis generates a single graph of the best fit 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 53 displays each selected source's contribution. The summary of the multiple regression analysis results shown in Figure 54 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.

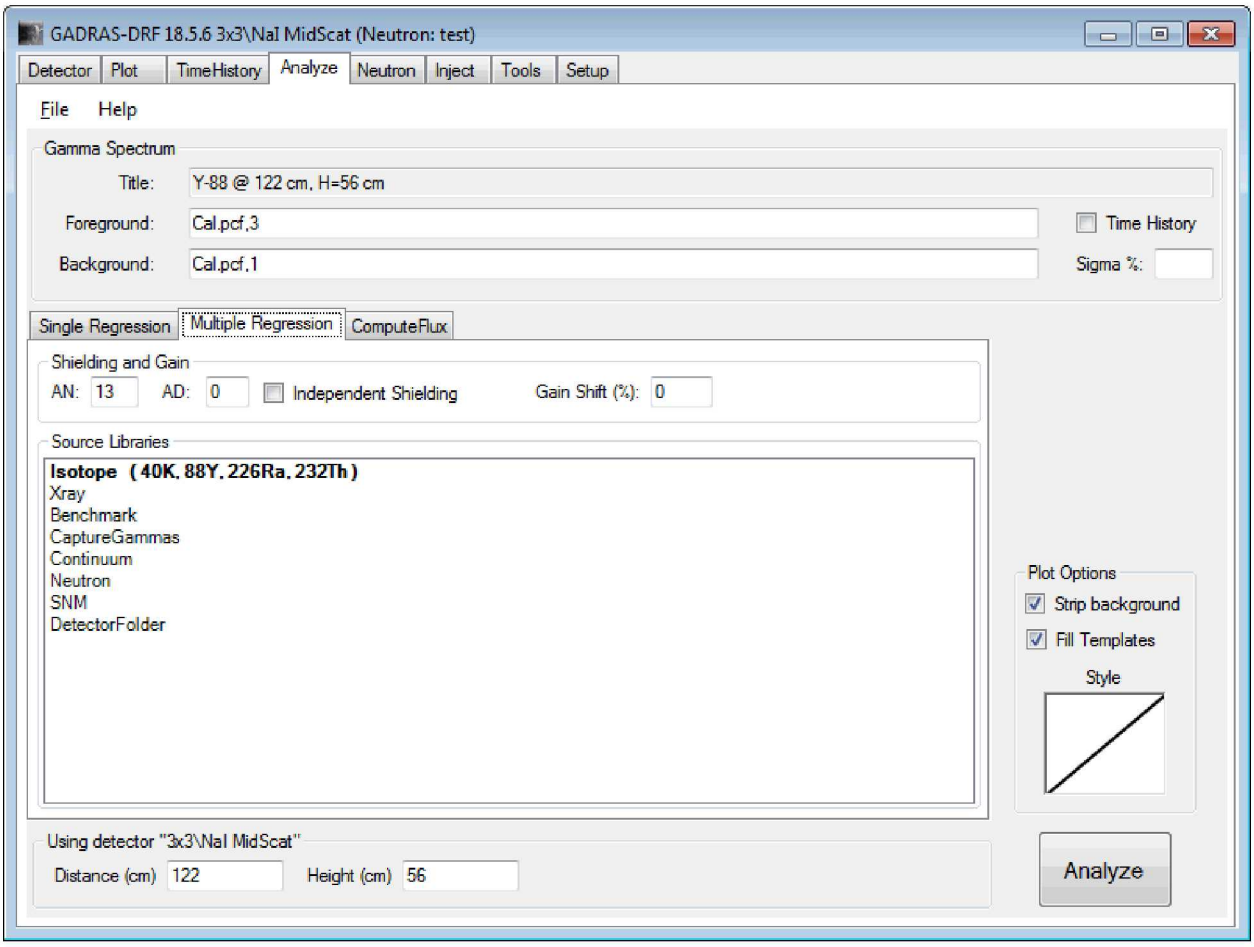

Figure 52: Multiple Regression Analysis Tab

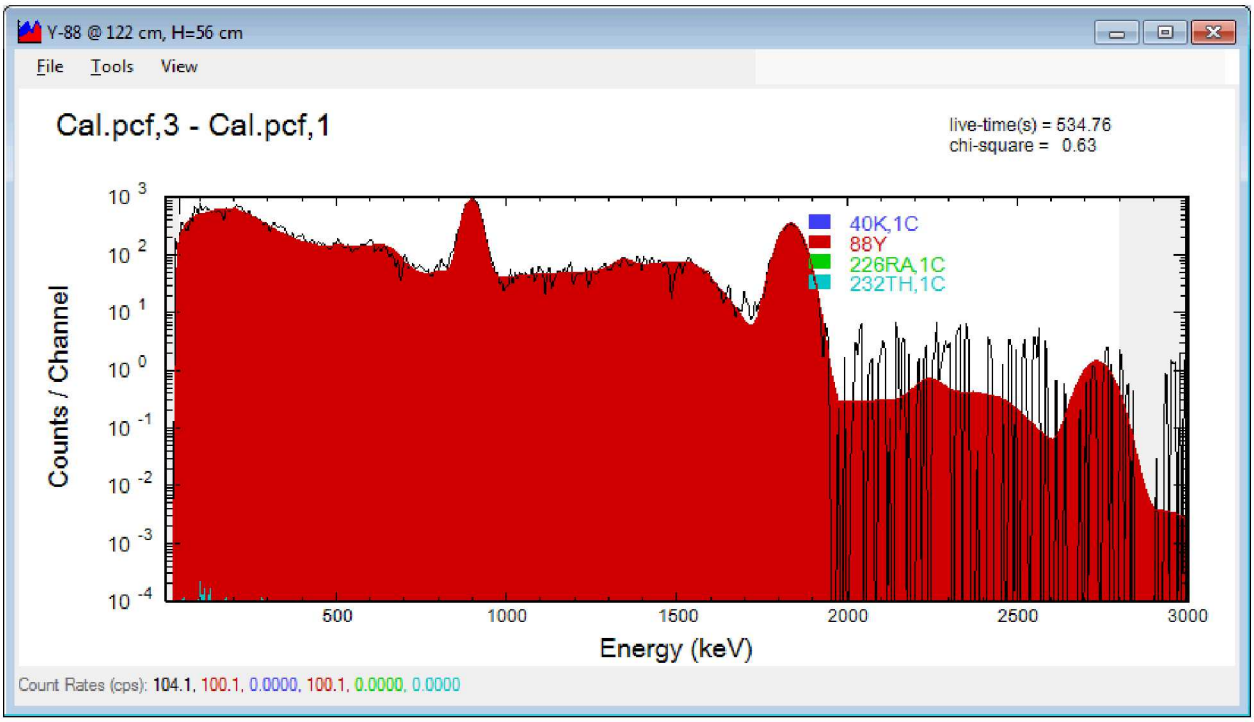

Figure 53: Multiple Regression Analysis Results of ^{88}Y Spectrum

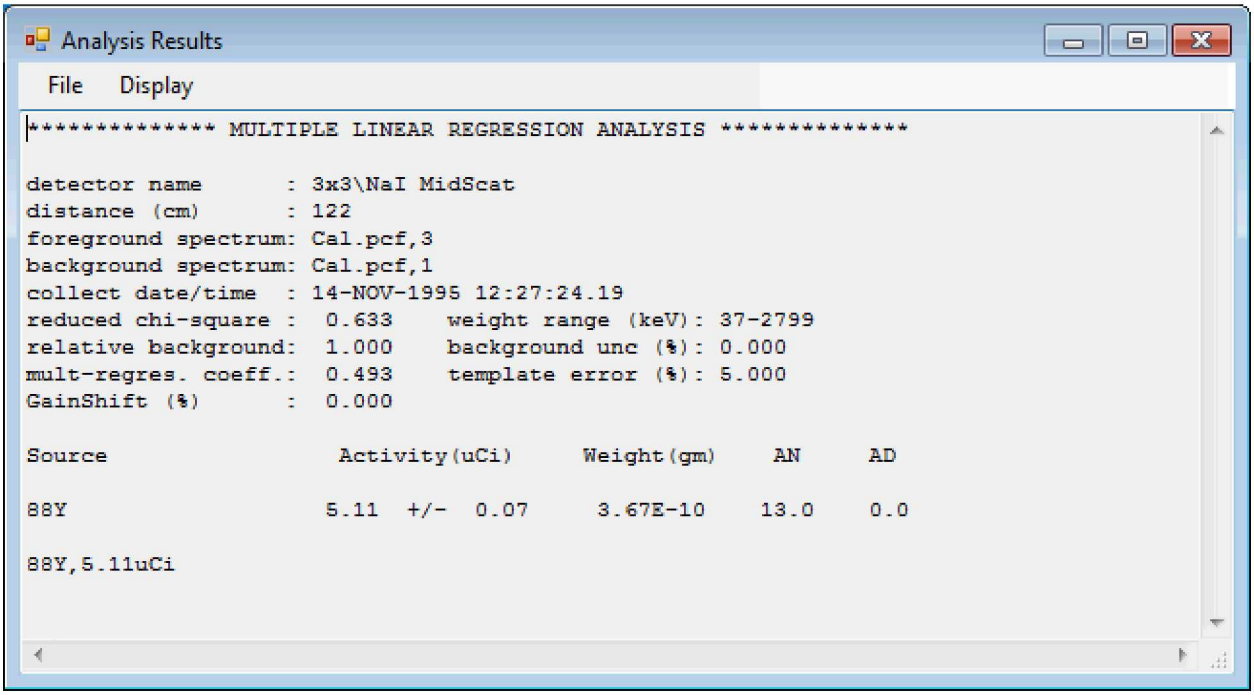

Figure 54: Multiple Regression Analysis Summary Page

8.2.3 *Compute Flux*

The **ComputeFlux** algorithm can be selected as shown in Figure 55. 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 56. The flux profile is also saved in a file with a **GAM** extension.

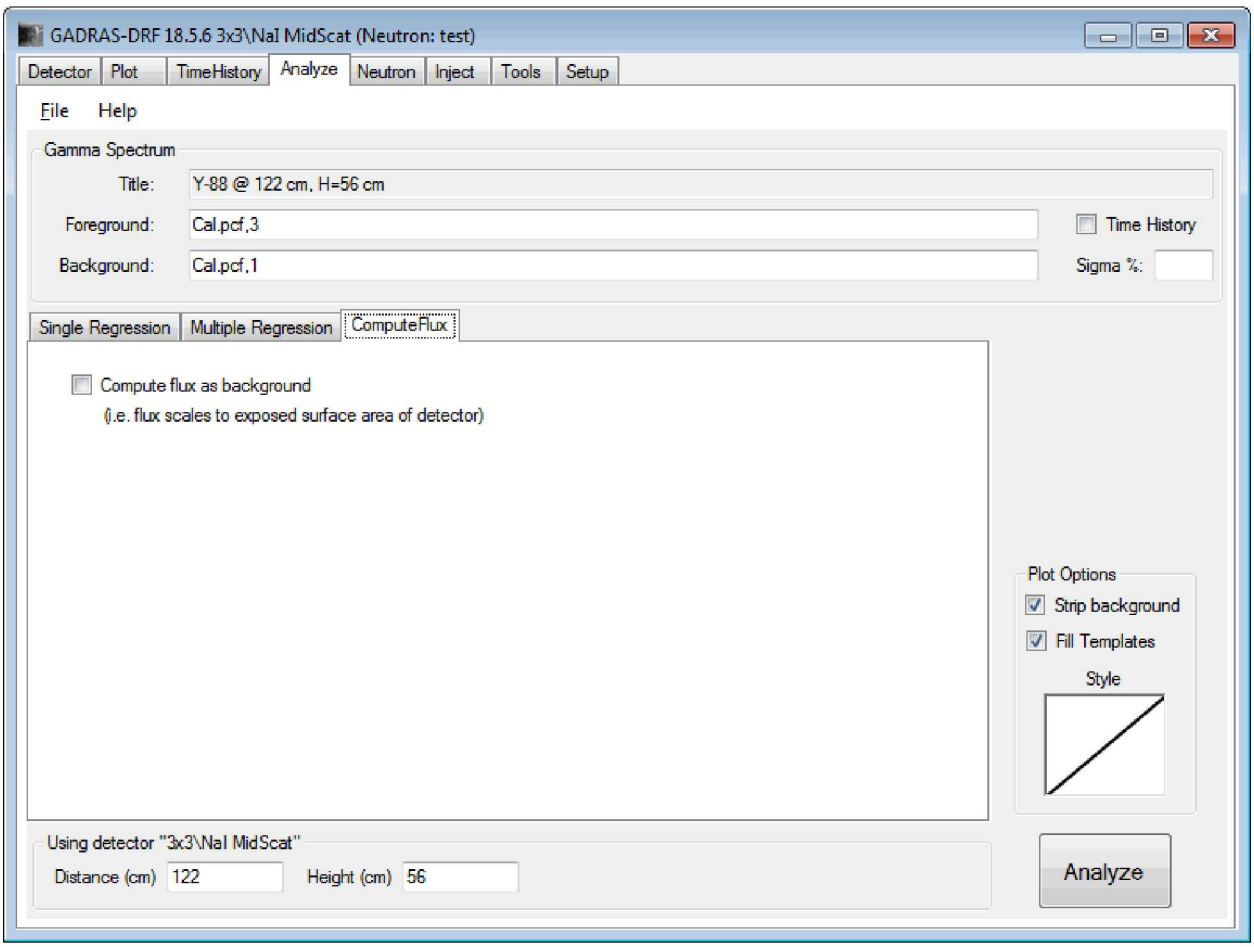

Figure 55: ComputeFlux Analysis Tab

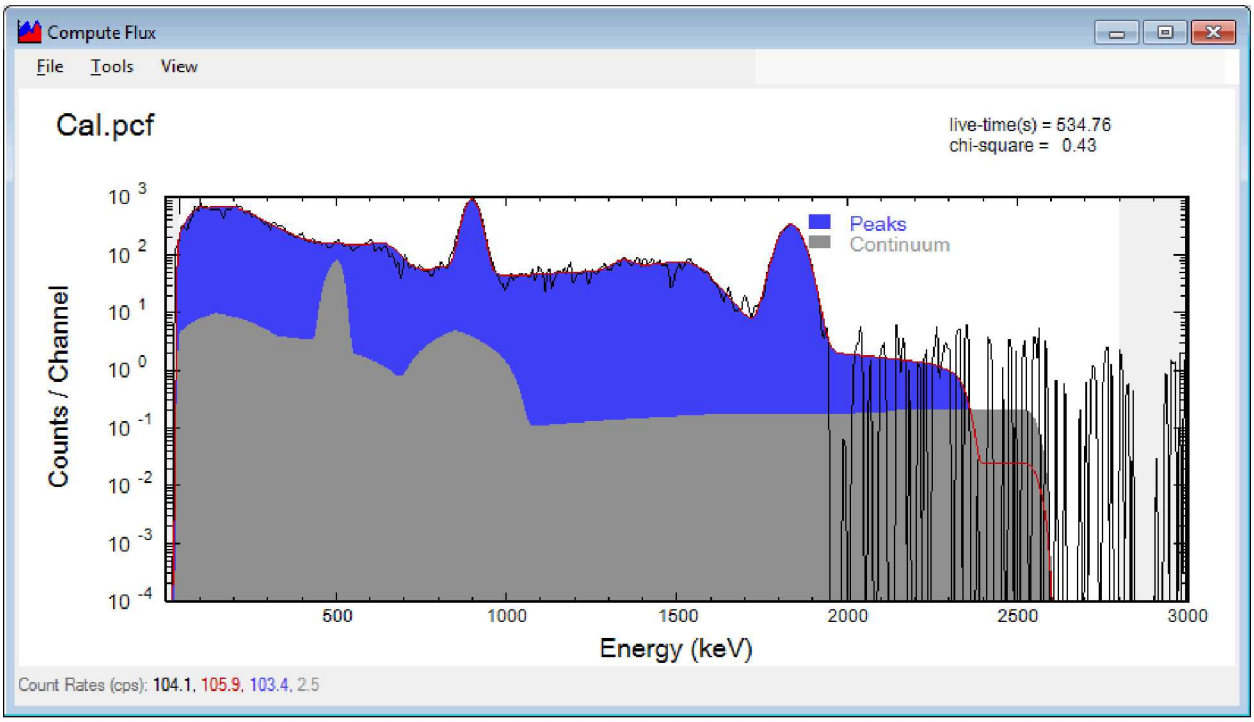

Figure 56: Graph of ComputeFlux Showing the Peaks and Continuum From the Flux Calculation

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 similar to Figure 57.

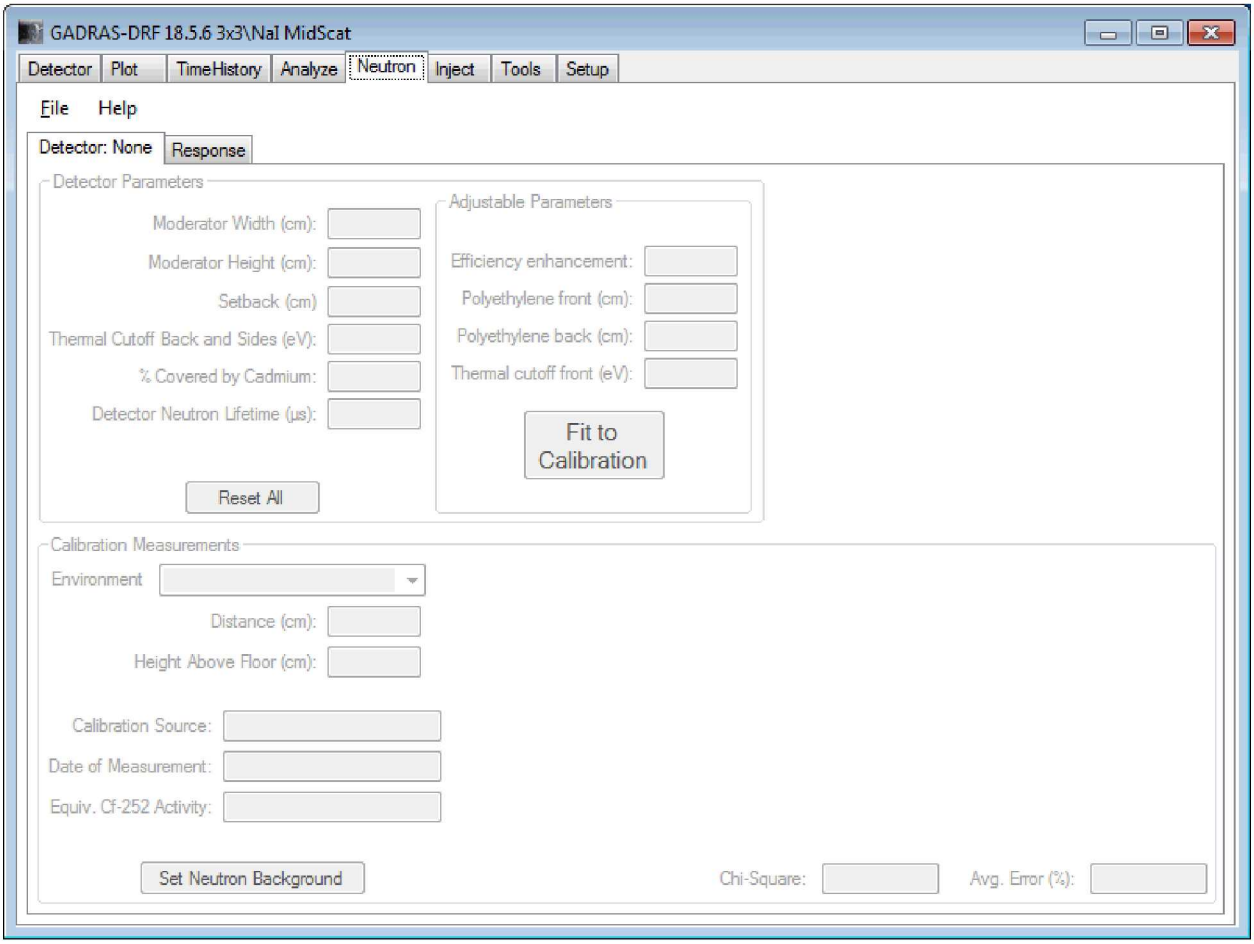

Figure 57: Neutron Tab without Selected Neutron Detector

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 58). 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.

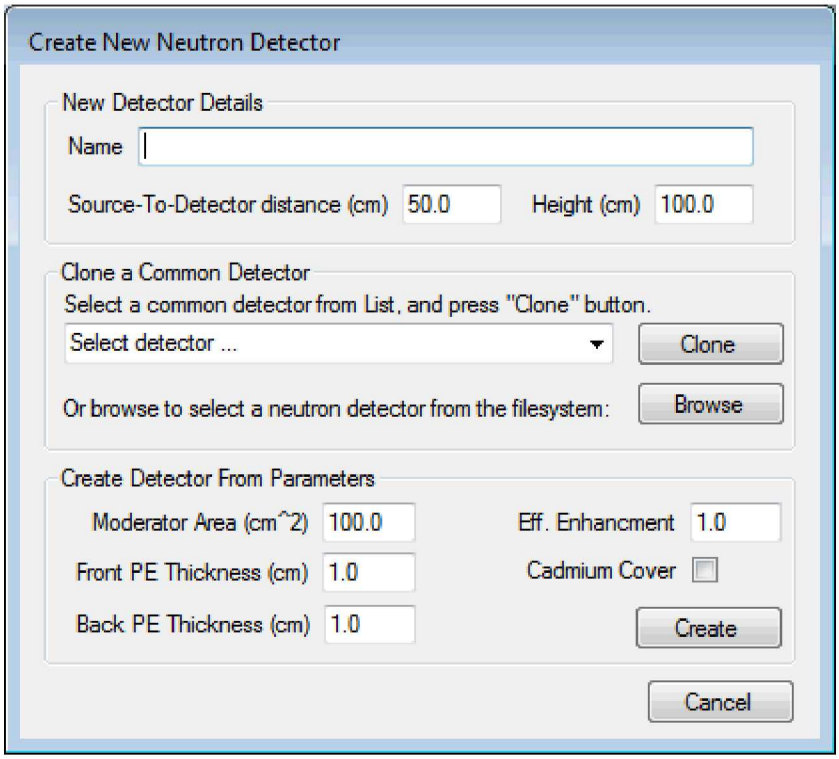

Figure 58: Create New Neutron Detector Form

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 58). 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 measurement environment and neutron detector. The first drop-down menu describes the overall scattering environment for the measurement. 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 fairly 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 source to the detector face; the setback of the neutron detector element should also be specified after the "+"
- **Height Above Floor (cm)**: the height of the detector above the floor
- **Moderator Height (cm)**: the vertical height of the moderator
- **Moderator Width (cm)**: the horizontal width of the moderator
- **Thermal Cutoff Back and Sides**: the energy at which neutron are killed if they enter from the back or sides of the detector housing
- **Detector Neutron Lifetime (μs)**: the lifetime of the neutron in the detector
- **% Covered by Cadmium**: percent of the detector covered by cadmium

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 11.1.4). 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.

A range of moderated ^{252}CF sources is required for GADRAS-DRF to determine the proper energy-dependent response function of the neutron detector. Measurement information for each moderated sources 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 59). 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.

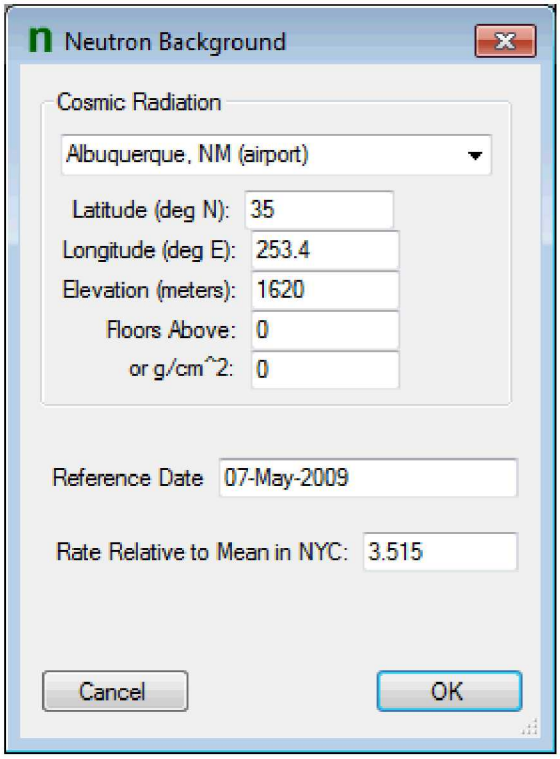

Figure 59: Neutron Background Form

The **Adjustable Parameters** groupbox 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-DRF will optimize the cyan colored 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 of the parameters on the form.

9.3 Neutron Response

The response function of the neutron detector can be seen in the **Response** tab. Users can see the efficiency of the detector for different neutron energies or the detector response for a source. Users can specify the measurement environment, the distance, and the height for the measurement. Users have two options for the y-axis – log10(Energy * Differental flux) or log10(Neutrons / eV / s). If the user specifies a source, the blue spectrum corresponding to the detector response for the source will be populated in the graph. The source neutron leakage and multiplication fields will be populated, as well as the detector count rate and efficiency fields.

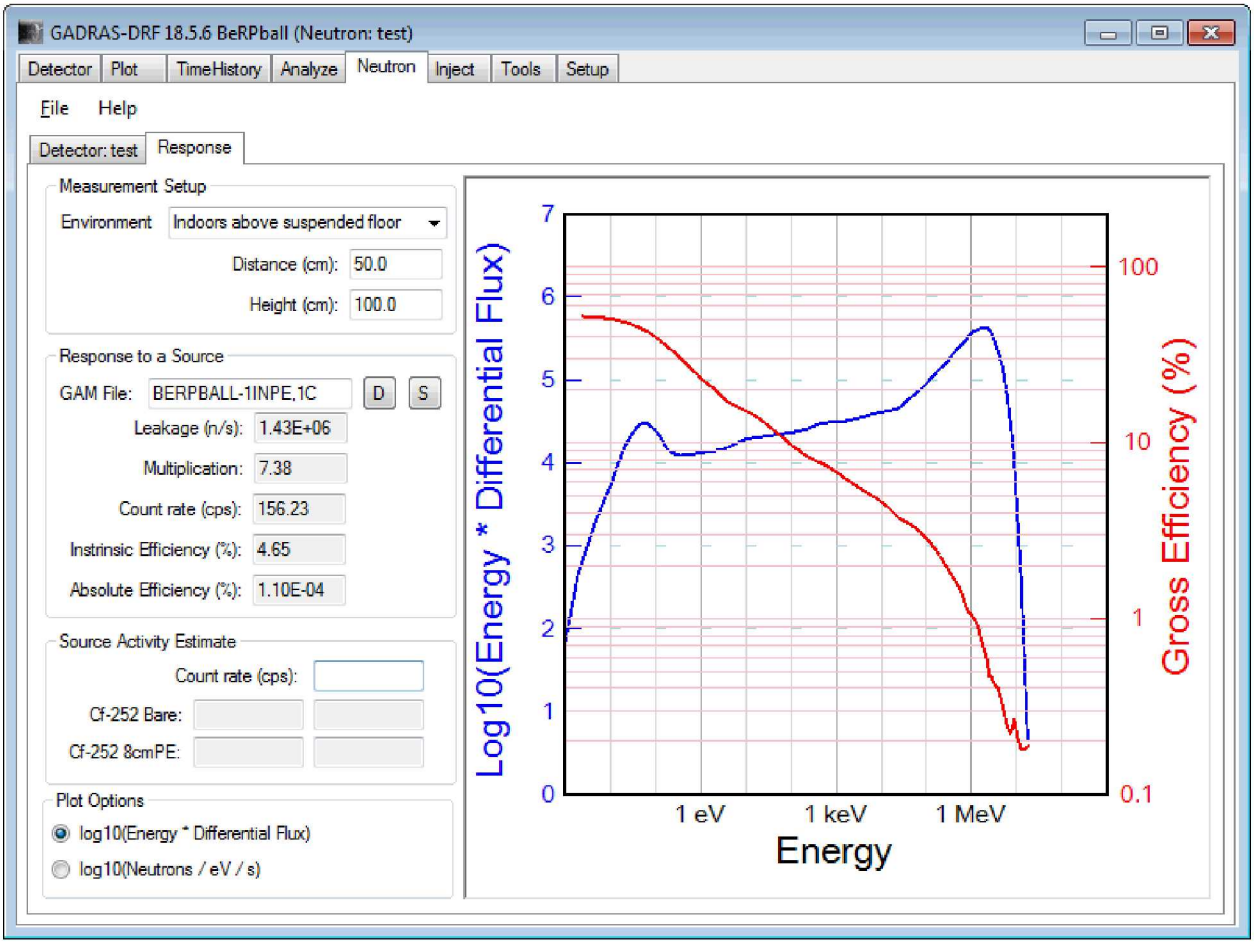

Figure 60: Neutron Response Tab

10 INJECT CALCULATIONS

10.1 Creating Inject Data

GADRAS-DRF has the capability of synthesizing spectra for training or demonstration purposes. The results of these computations are called inject spectra. There are three main sections that should be discussed when creating inject data. They are the general settings, detector settings, and background settings. The inject page may be seen in Figure 61.

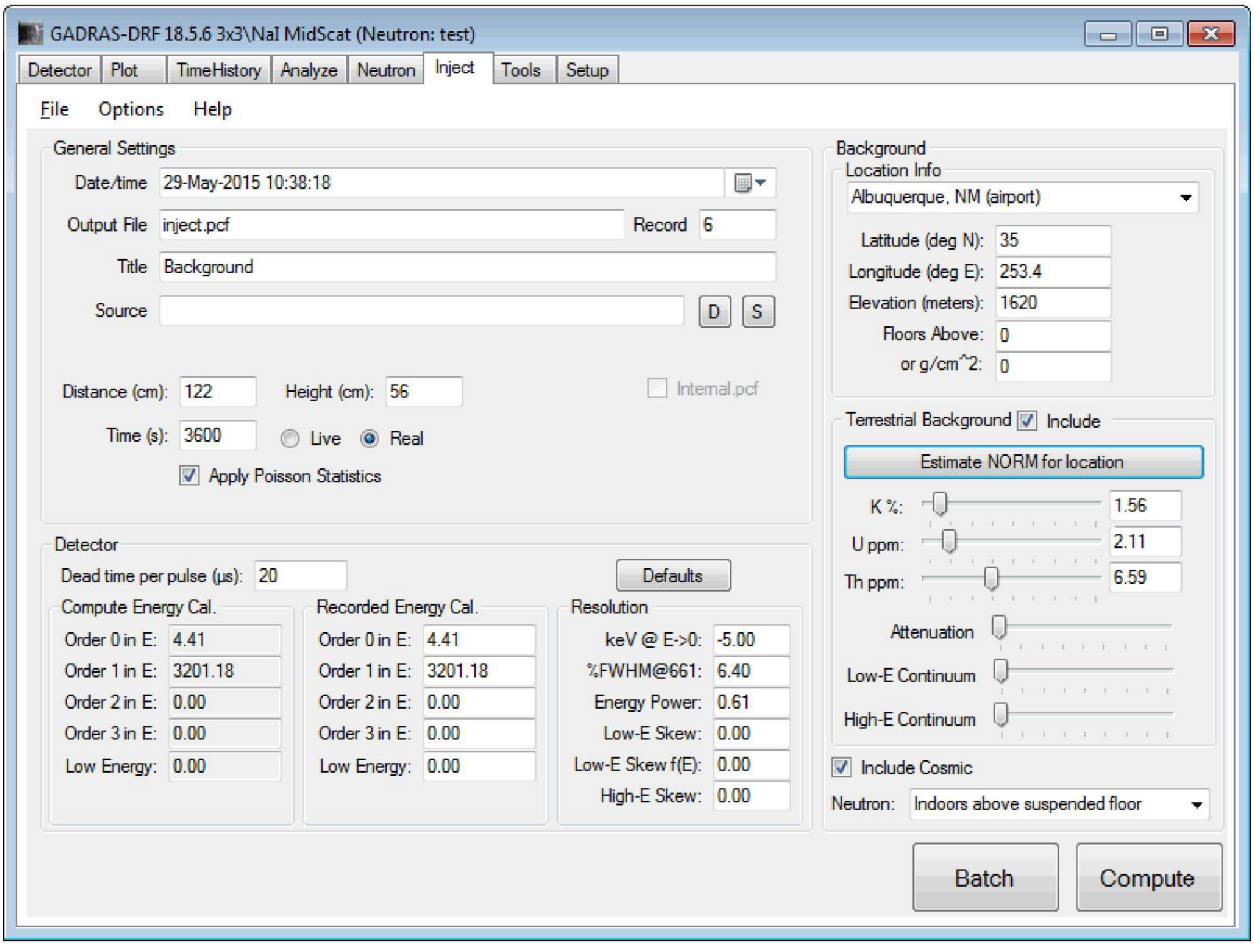

Figure 61: Inject Page

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 name of the output file for the inject data

- **Record**: The record number for this inject run
- **Title**: The title of the run
- **Source** (optional): The source information to include in the inject data; this field is similar to that on the **Plot** page (Section 4.3)
- **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 Detector Settings

Users may desire to change the detector settings from the default. Users may change the detector calibration, detector resolution, or detector dead time. The *Compute Energy Cal.* parameters are read-only and describe the default energy calibration parameters assigned to the detector. The *Recorded Energy Cal.* parameters may be used to offset the energy calibration in order to simulate data from a detector that is improperly calibrated. The *Resolution* parameters may be adjusted to simulate data that has different peak resolution than the default detector parameters. Users may adjust the *Dead time per pulse (μs)* parameter which will affect the live time of the simulation. Clicking the **Defaults** button will adjust the energy calibration and resolution parameters back to the default parameters assigned to the detector.

10.1.3 Background Settings

Background radiation primarily comes from two sources: cosmic and terrestrial. Cosmic radiation contribution to the spectrum is mainly a factor of elevation and material above the detector. This material may include shielding or building material. 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-DRF; 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
- **Neutron**: If the source consists of neutrons, the contribution to the spectrum is dependent on the scattering environment; the environment can be estimated based on the choices in the *Neutron* dropdown menu, which is described in more detail in Section 9.2

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: this only works for cities in the U.S.

Once all the settings have been specified, clicking the **Compute** button will generate the output. The *PCFViewer* 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-DRF allows users to perform batch inject calculations using a series of .inj

files. Users may create these text-based files themselves, as long as 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 62.

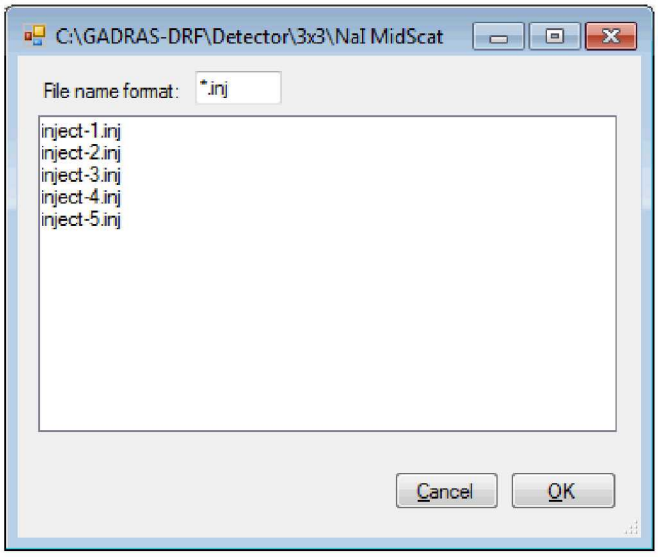

Figure 62: Batch Inject Form

To perform a batch inject calculation, select the desired files to perform the inject calculations with. If none of the files are highlighted, all of 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. Note: files do not need the .inj extension to be used in batch calculations.

11 GADRAS-DRF TOOLS

11.1 GADRAS-DRF 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 63. Editor options include:

- Deviation Pairs
- **Isotope DB** (Isotope database)
- **PhotoPeak List** (discussed in Section 6 – Energy Calibration)
- **Source DB** (Source database)

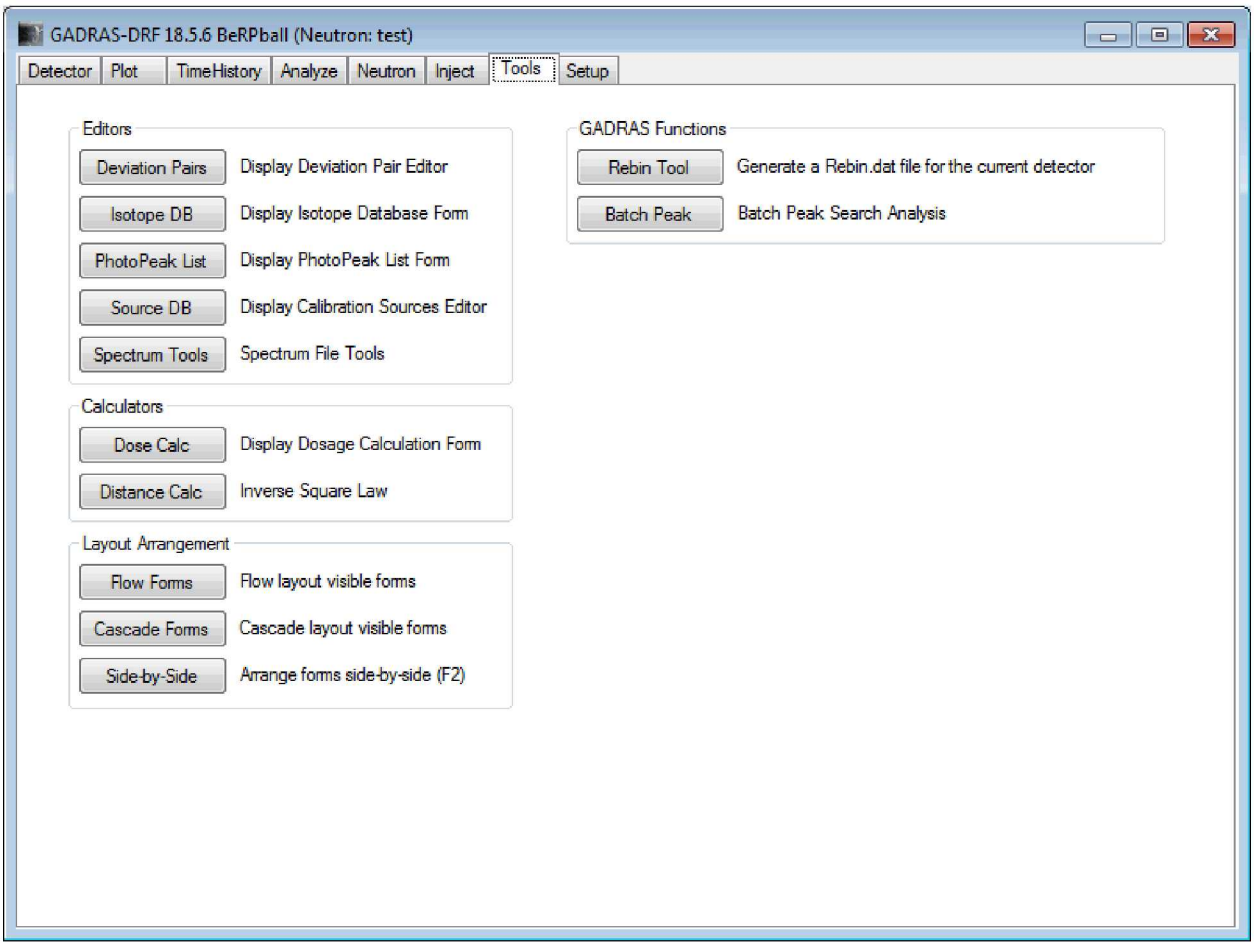

Figure 63: Tools Tab

11.1.1 Deviation Pairs

The **Deviation Pairs Editor** form is accessed from the **Tools** tab on the main window. This option allows users to edit and view deviation pairs for the current detector.

Deviation pairs are used when performing energy calibrations on non-linear detectors. An example of the **Deviation Pairs Editor** is shown in Figure 64. The source-detector distance is shown for reference in the upper right corner of the form. The Detector ID is used when an array of detectors is using the same detector response function parameters (separate deviation pairs can be specified for each detector in the array). Deviation pairs are specified with a known energy (left column) and the observed deviation (right column), both in units of keV. Deviation pairs are specified by first setting anchor points with deviations of 0 (239 and 2614 keV in Figure 64), then specifying other known deviation pairs. GADRAS-DRF can use a total of 20 deviation pairs. A further explanation of deviation pairs can be found in Reference [8], and should only be used by advanced users.

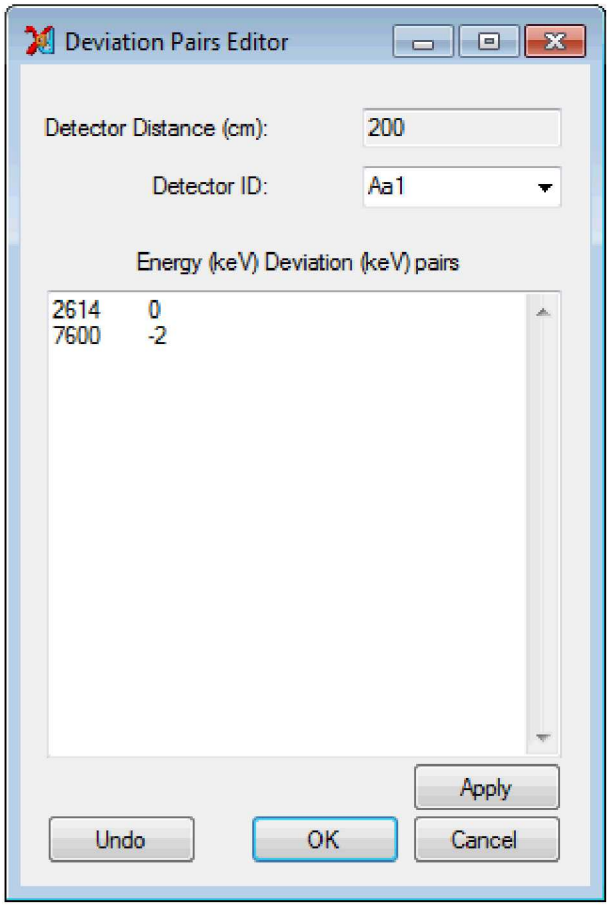

Figure 64: Deviation Pairs Editor

11.1.2 Isotope Database (DB)

The **Isotope DB** form is accessed from the **Tools** tab on the main window. This option allows users to select and view gamma-ray peak energies and yields for selected isotopes in the library.

Figure 65 shows the **Isotope DB** form populated with information for ^{7}Be. The drop-down list at the top-left corner of the window allows users to select an isotope. 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.

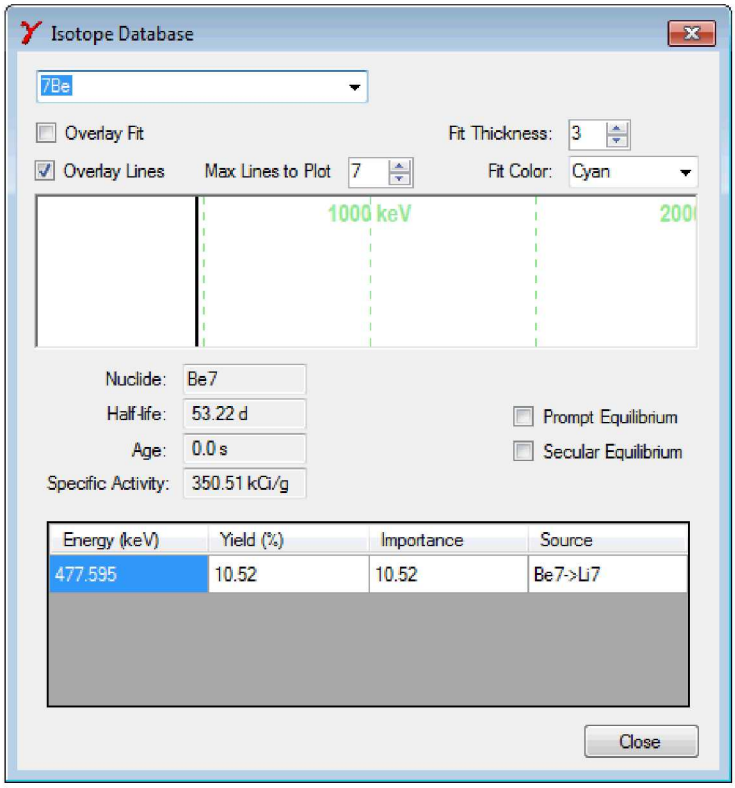

Figure 65: Isotope DB Tool Displaying ^{7}Be Isotopic Information

If a spectrum has been plotted, users can display overlays of the nuclide on a current plot using the two **Overlay** checkboxes located at the top of the **Isotope DB** 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-DRF developers commonly list gamma-ray emissions from daughter radionuclides in the gamma-ray emission list for the parent radionuclide. This generally occurs if the daughter radionuclide is traditionally 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.

11.1.3 PhotoPeak List

The PhotoPeak List form is described in Section 6.

11.1.4 (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-DRF directory. When GADRAS-DRF 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 66 illustrates a listing of calibration sources for ^{109}Cd and the activity calculator.

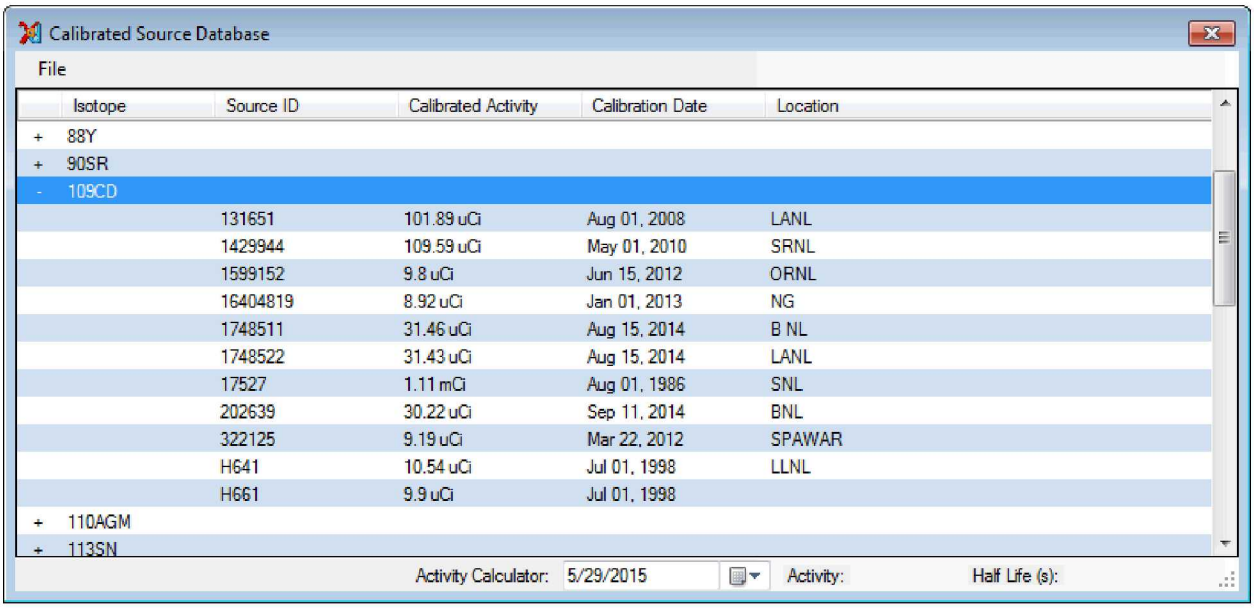

Figure 66: Source DB Tool with a ^{109}Cd Source Highlighted

11.1.5 Spectrum Tools

GADRAS-DRF 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 67.

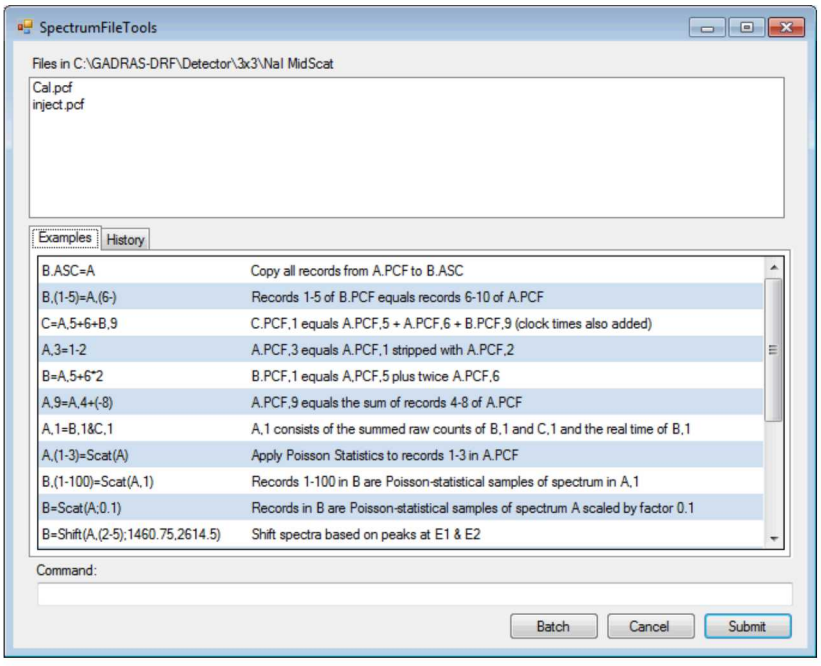

Figure 67: Spectrum Tools Form

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-DRF. If it is a valid command, it will appear in the History tab, otherwise, GADRAS-DRF 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-DRF will perform the commands sequentially. If one of the commands is invalid, GADRAS-DRF will inform the user which of the commands was invalid and which commands were executed successfully. GADRAS-DRF 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-DRF. **Note:** this calculation is independent of detector characteristics and any internal or external shielding. However, GADRAS-DRF 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 (Note: this only affects the gross leakage, not the computed dose).

The following calculated rates are shown in Figure 68:

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

- Gross Leakage (neutron)

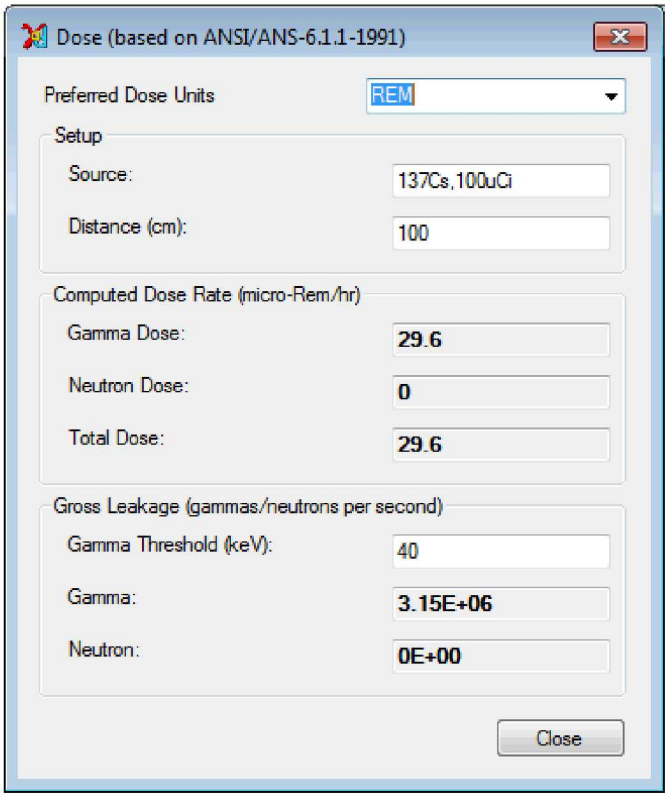

Figure 68: Dose Calculation Tool

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 69.

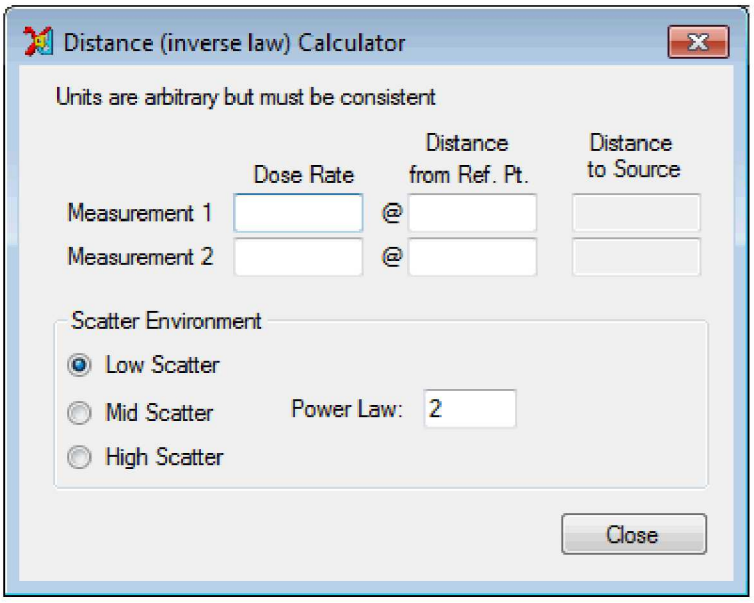

Figure 69: Distance Calculator Tool

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 70.

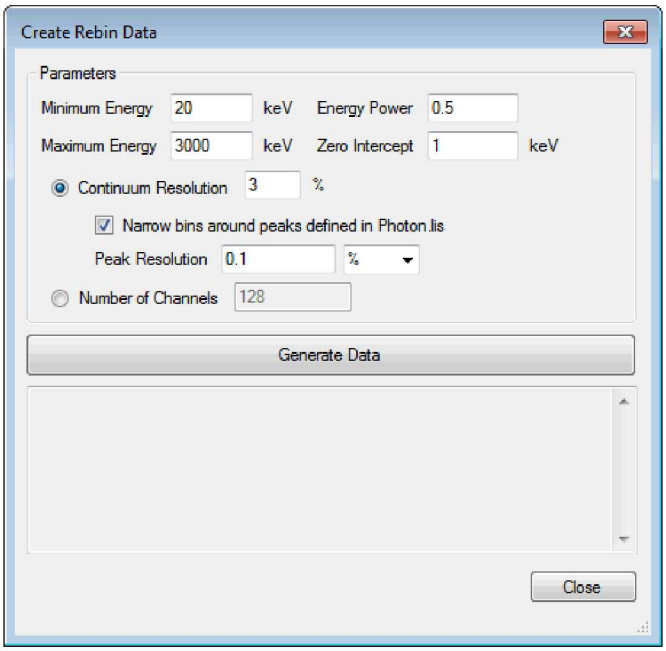

Figure 70: Rebin Tool

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 70, 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 70, 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-DRF** data directory (default is C:\GADRAS-DRF) 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 71.

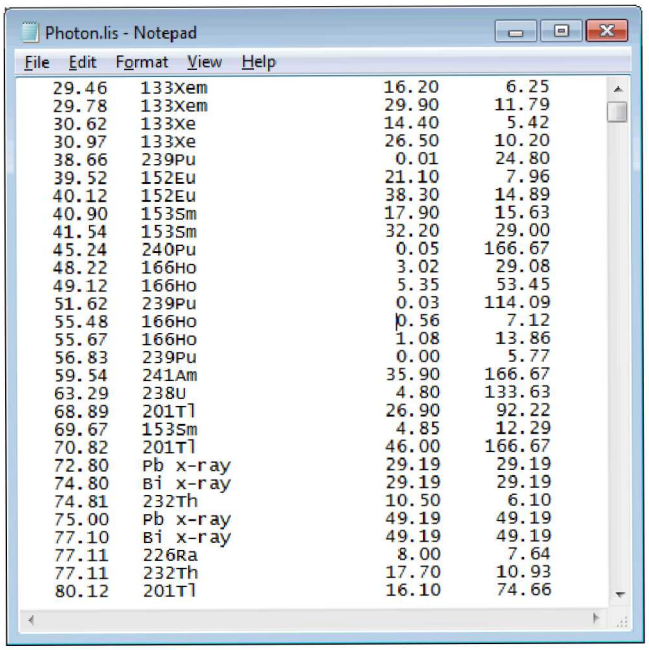

Figure 71: Photon.lis File

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 72). 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.

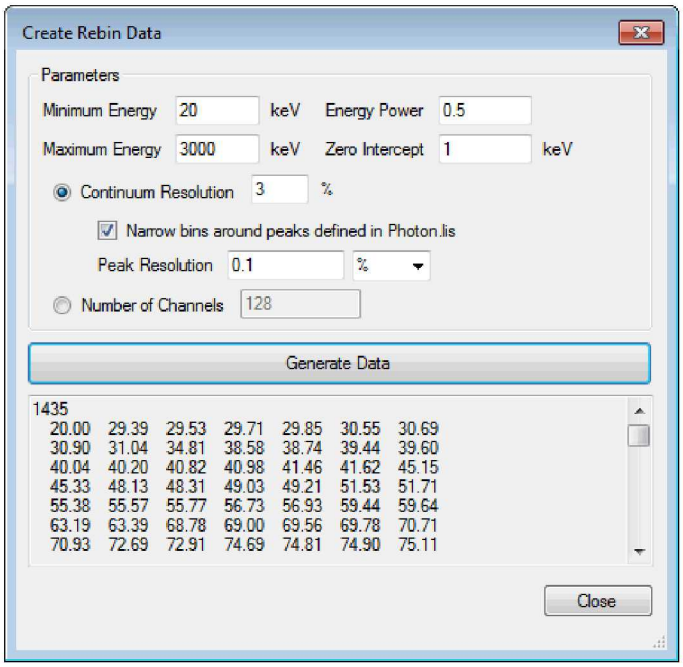

Figure 72: Rebin Data Tool with Data Generated

11.3.2 Batch Peak Search

Users can perform a peak search on multiple files by using the **Batch Peak Search** tool (Figure 73). Users can select which files they want to analyze using the **Filter** textbox. In Figure 73, 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.

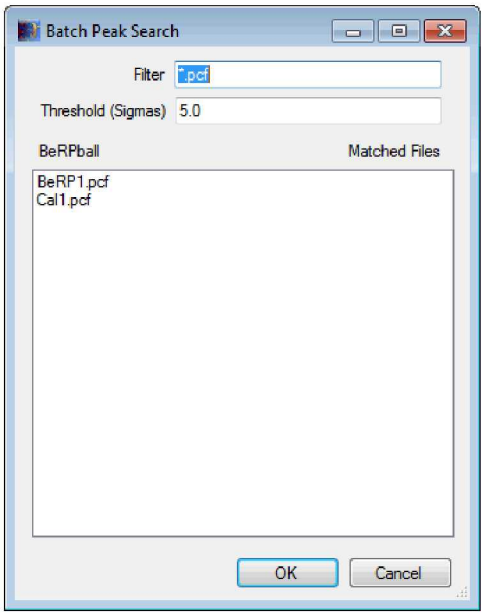

Figure 73: Batch Peak Search Tool

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-DRF\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-DRF SETTINGS

GADRAS-DRF 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-DRF 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 6.3), this option determines whether GADRAS-DRF 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-DRF 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-DRF splash screen as soon as GADRAS-DRF 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**

13 REFERENCES

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