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SpecFIDLER User Manual

Software Version 2.4.0

March 2022

Mitchell J Myjak
Scott J Morris
Jesse A Willett

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Richland, Washington 99354

Executive Summary

The Spectroscopic Field Instrument for Detection of Low Energy Radiation (SpecFIDLER) allows response teams to detect and quantify plutonium contamination on the ground. Notional scenarios include dispersion from a weapon accident, or the launch failure of a space probe containing a radioisotope thermoelectric generator. Unlike other instruments, the thin-window sodium iodide detector is sensitive to the low-energy gamma rays emitted by plutonium isotopes. The system supports both mobile survey as well as stationary sampling.

This manual provides information about installing, maintaining, and troubleshooting the SpecFIDLER. The scope of this document includes the physical hardware, software for data acquisition, and algorithms for data analysis. Recent changes to the software and algorithms aim to streamline the operation of the system.

Acronyms and Abbreviations

γpm	gammas per minute
cpm	counts per minute
DFM	Digital Field Monitoring
dpm	disintegrations per minute
MDA	minimum detectable activity
NaI:Tl	thallium-doped sodium iodide
ROI	region of interest
RSL	Remote Sensing Laboratory
SNL	Sandia National Laboratories
SpecFIDLER	Spectroscopic Field Instrument for Detection of Low Energy Radiation
USB	Universal Serial Bus

Contents

Figures

1.0 Introduction

The Spectroscopic Field Instrument for Detection of Low Energy Radiation (SpecFIDLER) allows response teams to detect and quantify plutonium contamination on the ground. The system contains the following components:

- Thallium-doped sodium iodide (NaI:Tl) detector with a thin beryllium window.
- Bridgeport Instruments usbBase for detector readout.
- Enclosure containing a rechargeable battery and Universal Serial Bus (USB) hub.
- Battery power switch and power indicator on the outside of the enclosure.
- USB cables to the detector and an external tablet computer.

Figure 1 depicts the components of the SpecFIDLER in their representative setup. The tablet computer may be mounted on the back side of the unit or carried separately.

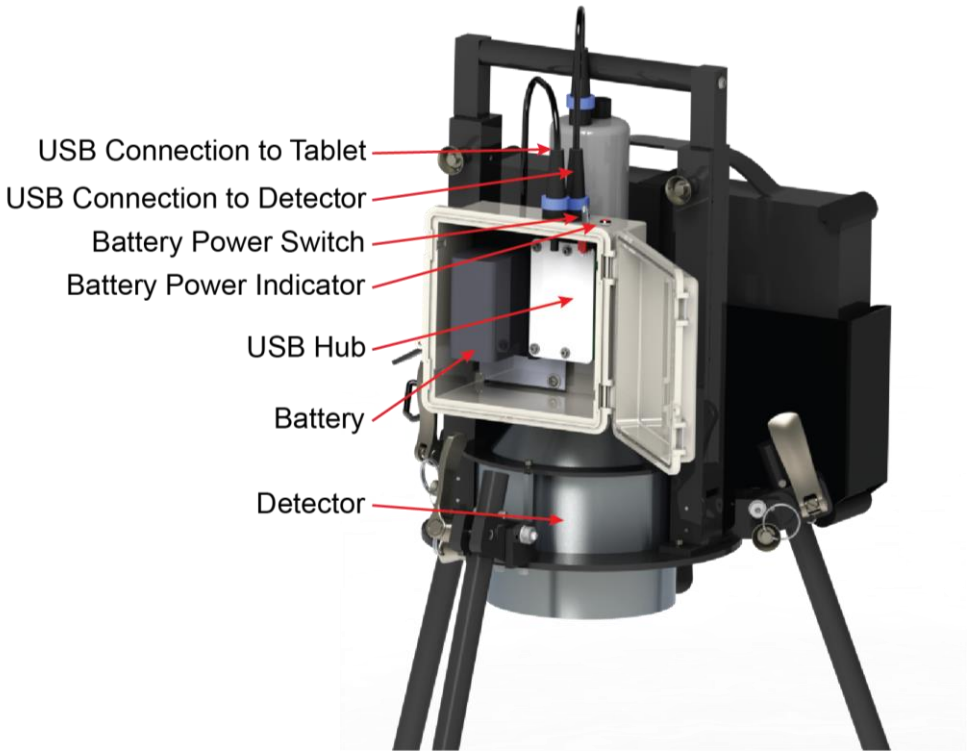

Figure 1. Components of the SpecFIDLER.

The remainder of this manual describes the setup, operation, calibration, and maintenance of the SpecFIDLER. The appendices provide additional information about the configuration file, settings file, and algorithms employed for data analysis.

2.0 Setup

This section describes how to assemble the SpecFIDLER for deployment, disassemble the unit for storage, transport the unit to another location, and install the software on the tablet.

2.1 Assembly

To assemble the SpecFIDLER, follow the procedure below.

1. Open the shipping container and remove the Velcro hold-down strap. Grasp both handles (Figure 2) and lift the unit straight out.

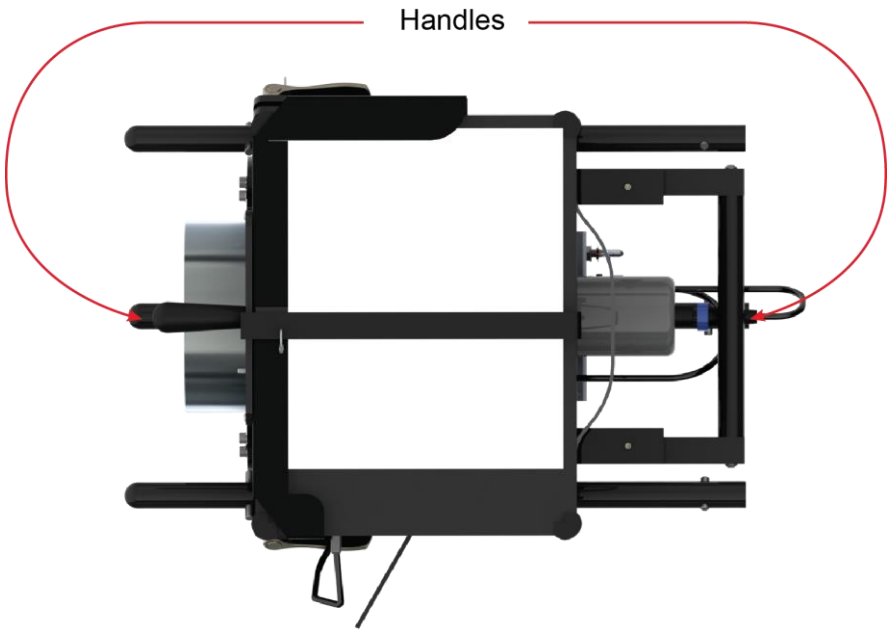

Figure 2. Handle locations.

2. Extend the top handle by pulling the pins (Figure 3) and lifting straight up until the desired height is reached. Use the pins to lock the handle into place.

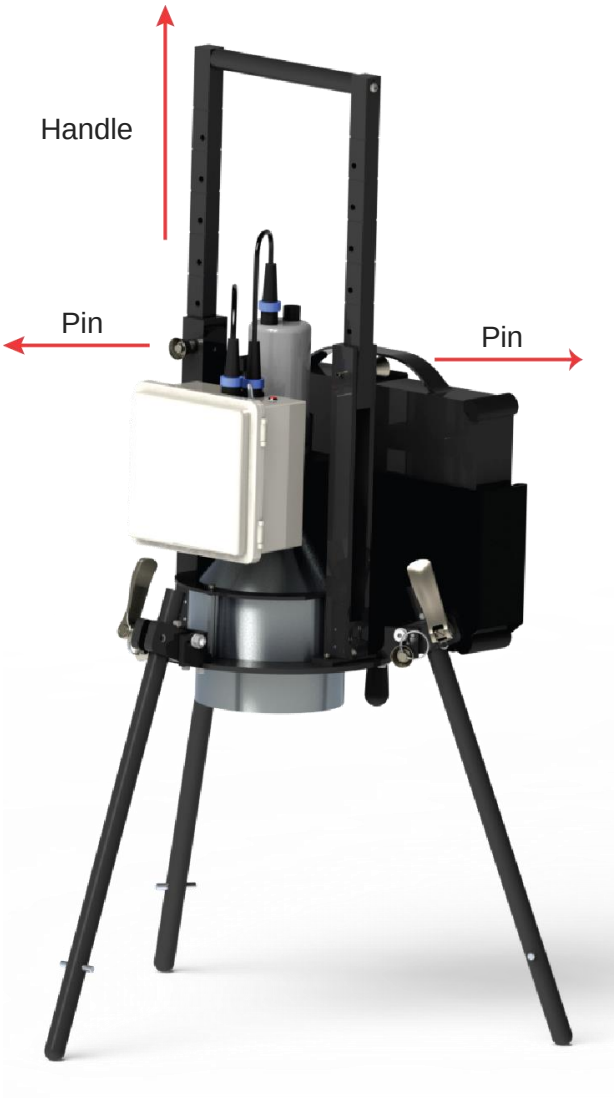

Figure 3. Extending the top handle.

3. Loosen the leg locks (Figure 4) and extend the legs down. Swing the legs out by pulling the pin, swinging the leg, and inserting into the second hole. Lock the legs in place. Consider tying rubber gloves onto each leg to prevent contamination.

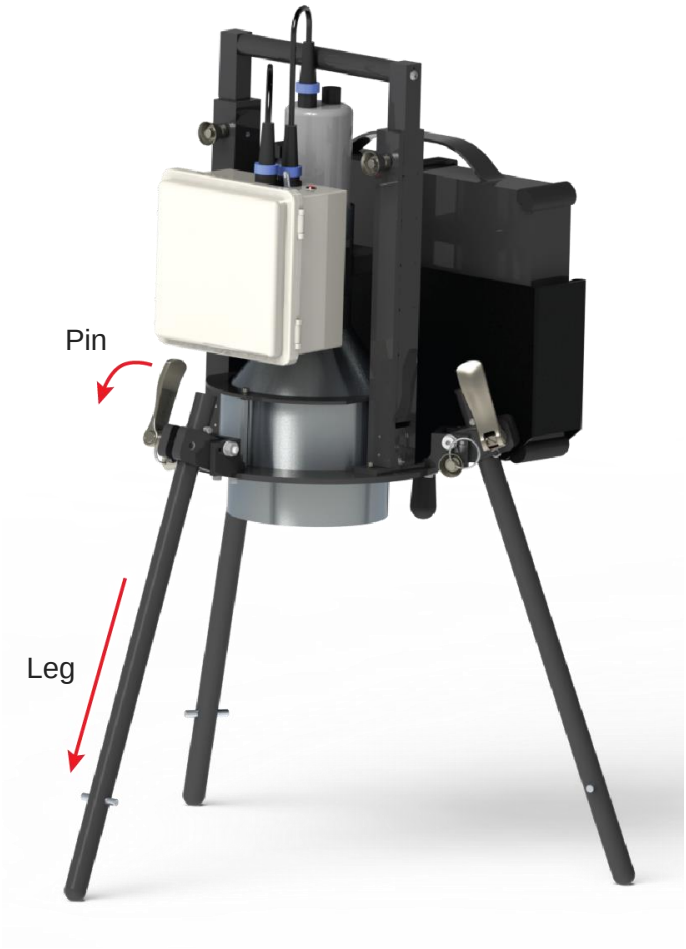

Figure 4. Extending the legs.

4. Carefully remove the cover from the fragile beryllium window (Figure 5), ensuring that it is not scratched or damaged in any way.

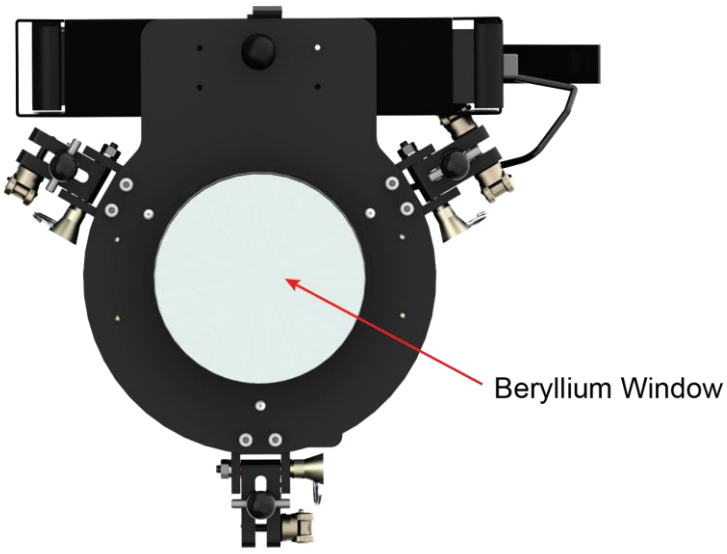

Figure 5. Beryllium window.

NOTE: Beryllium is a potentially hazardous material that is controlled by most industrial hygiene groups. However, solid beryllium metal, alloys, ceramic objects, and finished products, such as the detector window used in the SpecFIDLER instrument, pose no special health risks unless their use or handling generates airborne aerosols or surface contamination. Exposure can occur by inhaling particles from aerosols, by getting loose particles of beryllium or beryllium solutions on the skin, or by cutting the skin with sharp edges of beryllium or beryllium-contaminated materials. Damaged beryllium objects should be handled with care to avoid injury from sharp pieces and dispersal of beryllium dust.

5. Ensure that the USB cables are connected properly to the enclosure (Figure 6). However, do not connect the USB cable to the tablet yet.

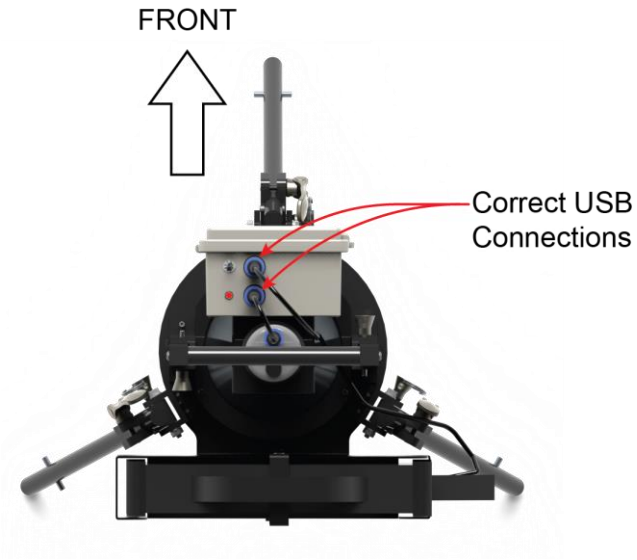

Figure 6. USB connections.

6. Charge the lithium ion battery if necessary.

7. Install the lithium ion battery inside the enclosure. Ensure that both battery contacts make a good connection; unfortunately, the battery holder is very tight.

8. Turn on the power switch and verify that the red light is illuminated. If not, double-check the battery connections.

9. Finally, connect the USB cable to the tablet. The tablet may be placed in the pocket on the frame behind the detector.

NOTE: If the tablet is connected to the SpecFIDLER before turning on the power switch, then the tablet will supply power rather than the internal battery. This configuration works fine but will shorten the tablet's battery life. The red light is illuminated in either case.

2.2 Disassembly

Disassembly is the reverse of assembly:

1. Unplug the tablet and turn off the power switch.
2. Remove the lithium ion battery.
3. Place the cover back onto the detector to protect the fragile beryllium window.
4. Retract the top handle and the legs.
5. Finally, place the unit back into the storage container.

If the legs become contaminated, they may be removed. Loosen the leg locks, twist the legs such that the long end of the pin faces the center of the instrument (Figure 7), and drop the legs down through the clamps.

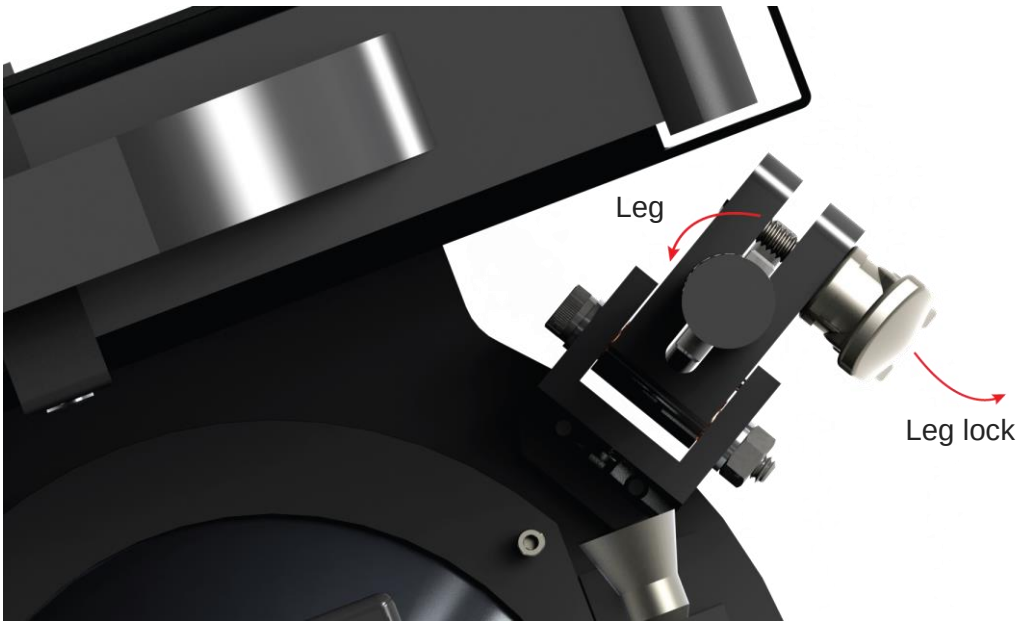

Figure 7. Detector leg removal, viewed from top of instrument looking downward.

NOTE: The long side of the pin must face away from the threads on the leg lock. Otherwise, the pin will not fit through the hole.

2.3 Transportation

Often it is necessary to load the SpecFIDLER into a vehicle and transport it to another measurement location. For shorter trips, the following steps are recommended:

1. Remove any protective gloves from the legs to avoid contaminating the vehicle.
2. Place the cover back onto the detector to avoid damaging the beryllium window.
3. Lay the unit on its side, orienting the unit so that other objects do not contact the detector. Secure the unit so that it does not slide around.

For longer trips, consider packing the unit back into the storage container.

NOTE: Protect the fragile beryllium window at all times.

2.4 Software Installation

The SpecFIDLER software is integrated with the Digital Field Monitoring (DFM) software on the Consequence Management tablet. Normally, the tablets come preloaded with all the requisite programs and utilities. However, follow the procedure below if it is necessary to install, upgrade, or repair the SpecFIDLER software:

1. The installation package consists of two files: **setup.exe** and **Installer.msi**. Copy these files to a temporary folder on the tablet.

2. Uninstall the existing SpecFIDLER software if necessary. The data and configuration files are retained.

NOTE: All versions of the SpecFIDLER software must be uninstalled first.

3. Next, install the SpecFIDLER software. Locate the temporary folder and run **setup.exe**. Click **Next** and select the installation folder (Figure 8). Click **Next** two more times. If a dialog appears asking to confirm security access to the installer, select **Yes**.

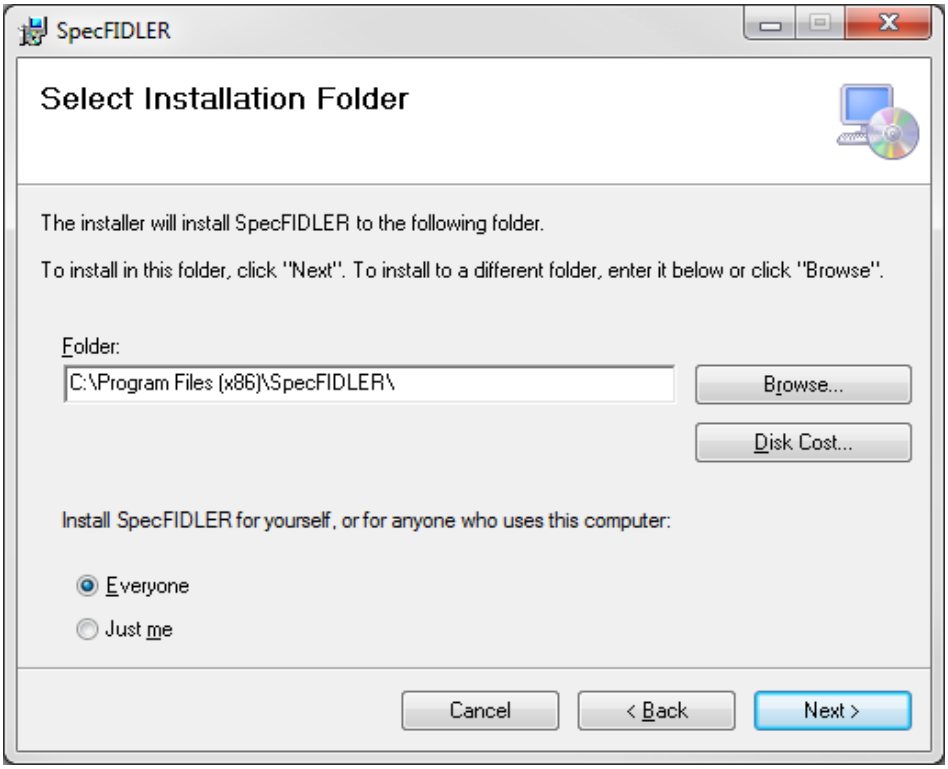

Figure 8. SpecFIDLER setup wizard.

NOTE: The **eM_DLL.dll** file in the installation folder is a custom version of the Bridgeport Instruments library. It has bug fixes and additional features applied. Do not replace this file with the stock version provided by Bridgeport Instruments; otherwise, runtime errors will occur.

4. Use the procedure in Section 2.1 to assemble the SpecFIDLER and connect the USB cable to the tablet.

5. Associate the Bridgeport Instruments usbBase with the correct driver. Run **Zadig** from the **SpecFIDLER** folder in the Start Menu. Select the **eMorpho** device from the drop-down. (If this option does not appear, select **Options->List All Devices** from the menu.) Change the driver to **WinUSB** and click **Install Driver** (Figure 9).

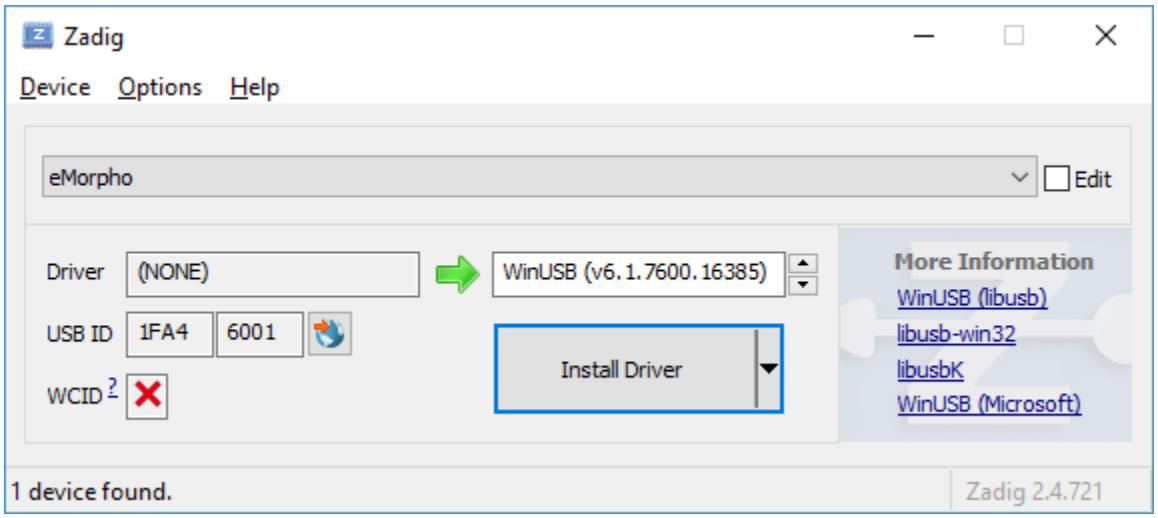

Figure 9. Zadig configuration.

NOTE: The new version of the software requires the **WinUSB** driver rather than **lib-usbwin32**. The **libusbK** driver is also acceptable. The software will fail if the correct driver is not associated with the usbBase.

6. Use the procedure in Section 5.1 if upgrading from an older version of the software to version 2.

3.0 Operation

The SpecFIDLER software is called by the DFM software on the tablet. Click the **Launch SpecFIDLER** button to begin.

The tabs along the right side of the main screen (Figure 10) switch between various modes. The **Rate** and **Spectra** tabs acquire data from the detector. The **Source term** tab defines the mixture of nuclides in the source term. The **Analysis** tab computes the quantities of these nuclides. The **Energy Cal** and **Efficiency Cal** tabs are used to calibrate the detector. The **Settings** tab allows operators to adjust and save settings. Finally, the **Shutdown** button returns to the DFM software.

The remainder of this section describes how to operate the SpecFIDLER for both mobile survey and stationary sampling. These procedures assume that the detector has already been calibrated. Section 4.0 describes the calibration process.

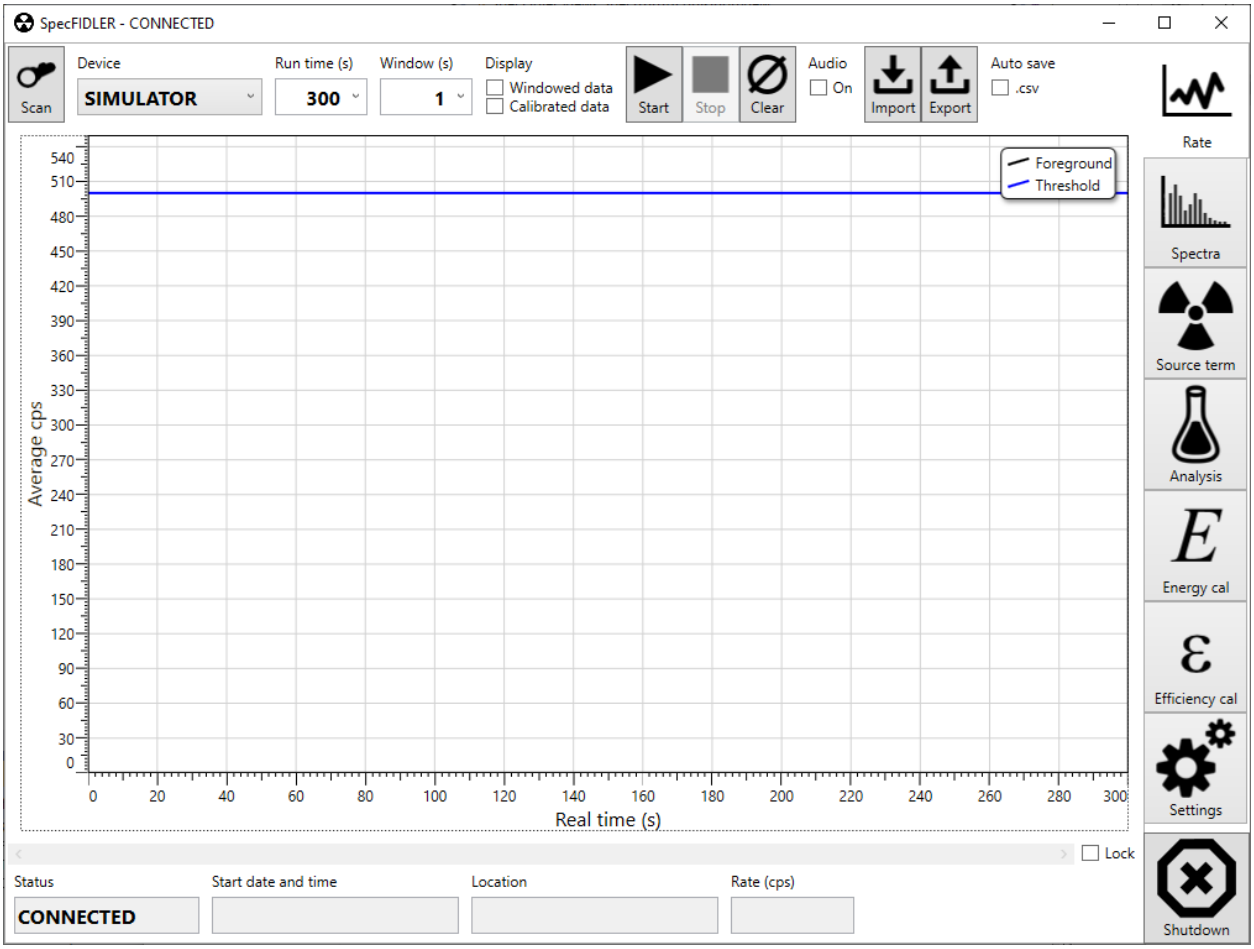

Figure 10. Main screen showing various tabs.

3.1 General Settings

Before acquiring data with the SpecFIDLER, take a moment to update the user and site name. This information is found on the **Settings** tab (Figure 11), which lists all the settings used by the software. The values are stored in a file named **settings.xml** in the SpecFIDLER working directory (**c:\fidler** by default).

Fill in the **User** and **Site** text boxes with the appropriate values. These values are saved in the exported N42.42 data files.

Click **Save** to save the parameters to the settings file. Alternatively, click **Revert** to discard all changes and reload the settings file. The software will also prompt whether to save changes to the settings on exit.

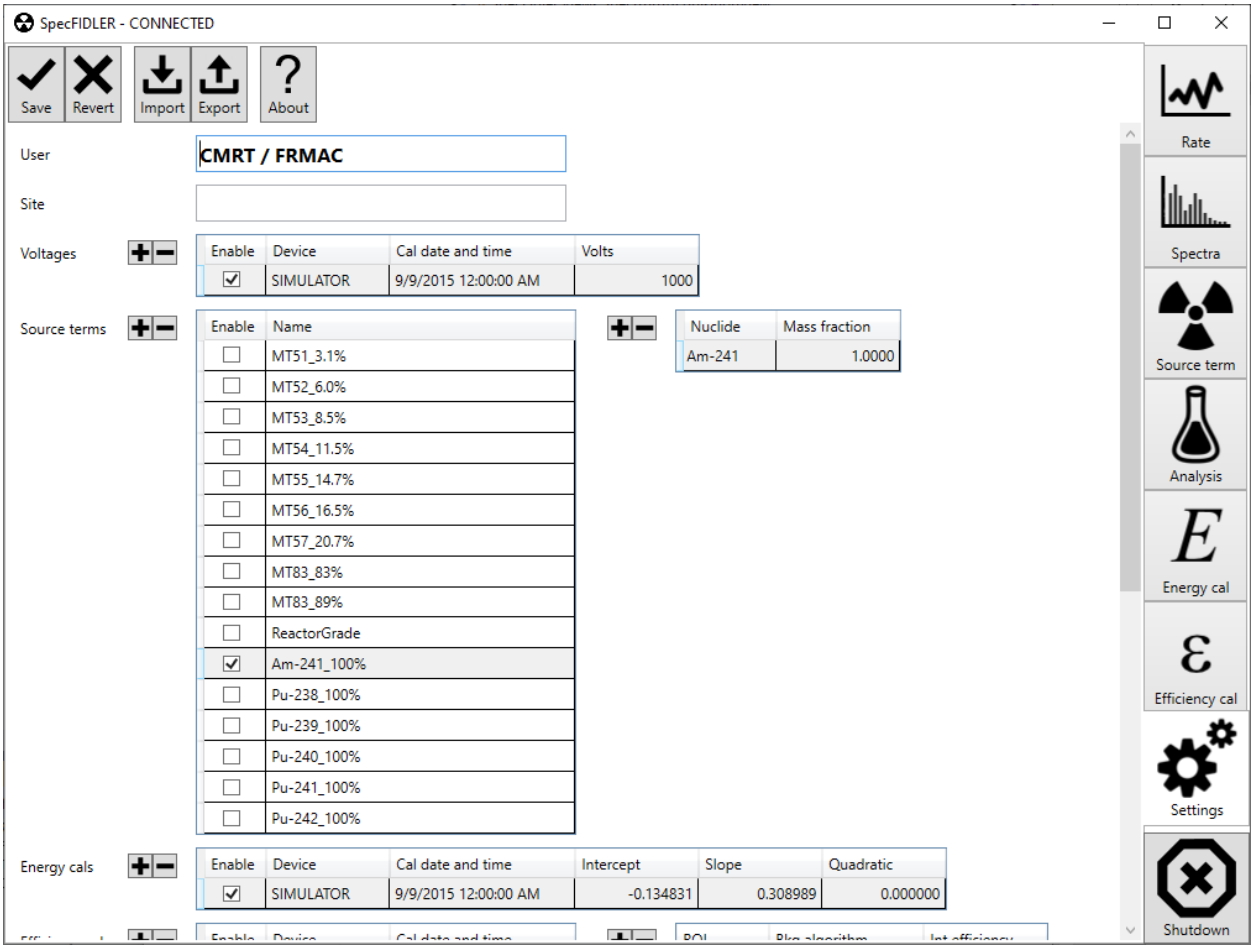

Figure 11. **Settings** tab.

3.2 Mobile Survey

To use the SpecFIDLER for mobile survey, carry the unit by the top handle, keeping the detector a uniform distance from the ground. Retract the legs if more convenient.

NOTE: Never set the detector face down on the ground. The beryllium window will be damaged.

Use the **Rate** tab (Figure 12) to acquire data. The main plot displays the count rate versus time in black, along with the alarm threshold in blue. The connection status, start time, location, and present count rate are displayed below the plot. Large spikes in the count rate indicate potential hotspots that may warrant further sampling.

Before acquiring data, ensure that the correct detector is selected from the **Device** drop-down. Typically, only one detector is connected to the tablet, so only one serial number appears in the drop-down list. The **SIMULATOR** option uses simulated detector data for training purposes. The **DISCONNECTED** option disconnects from all detectors. Changing the selection takes a few seconds, as the high voltage needs to be ramped up or down.

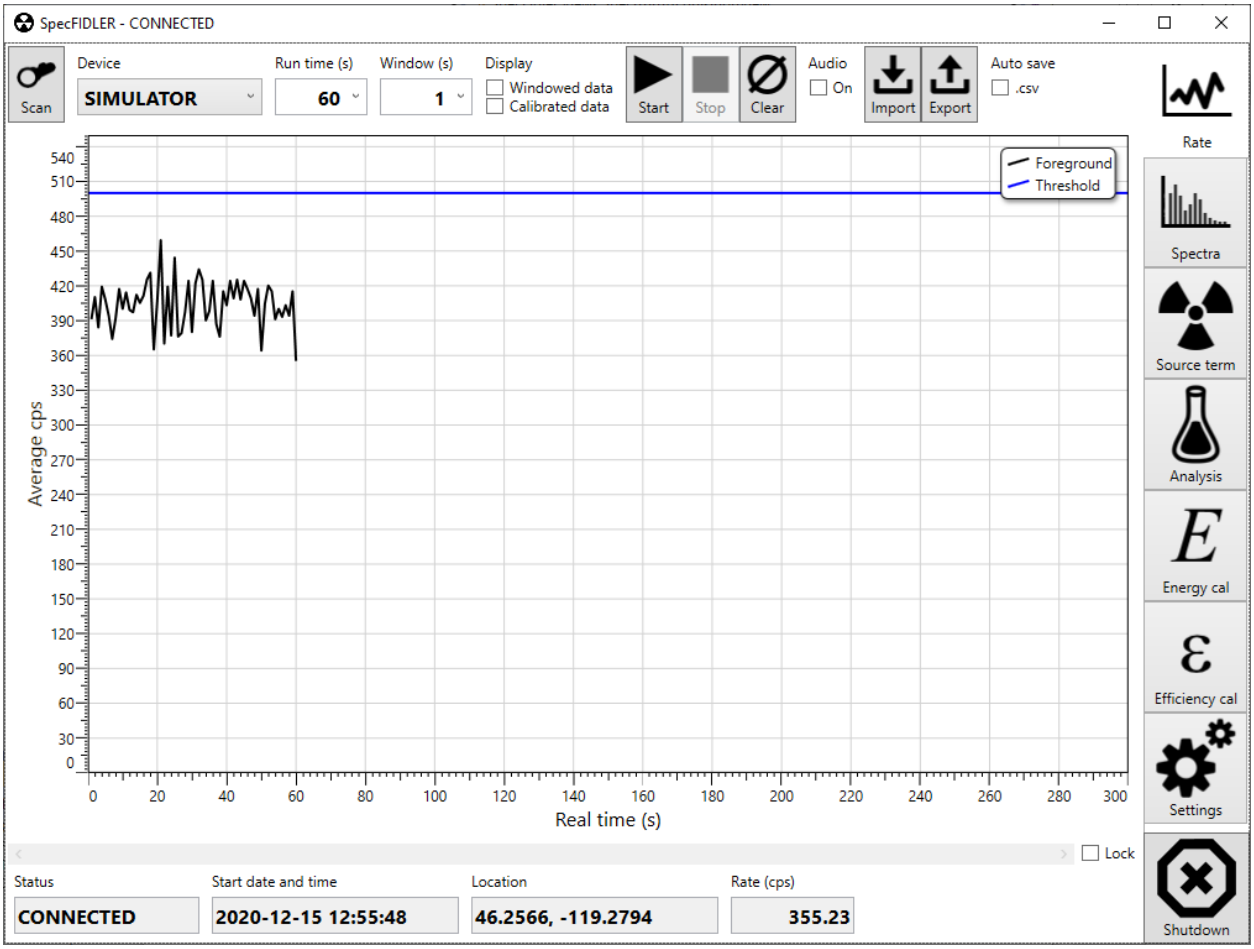

Figure 12. **Rate** tab.

To connect to a different detector, first set the **Device** to **DISCONNECTED**. Unplug the old detector from the tablet and plug in the new detector. Click **Scan** to refresh the list of detectors and select the new detector from the **Device** drop-down.

The **Run time** drop-down specifies the total run time in seconds. Type in a value or choose an option from the list.

The **Window** drop-down specifies the integration time. For example, a value of 3 means that the count rate is computed over the previous three seconds, while still updating every second. Note that the integration time is only used for the plot and not for exported files or streamed data.

The **Display** checkboxes control the count rate displayed in the plot. Select **Windowed data** to integrate across the **Rate Window** defined in the **Settings** tab; deselect to integrate across the entire spectrum. In the former case, select **Calibrated data** to use the calibrated window (in keV); deselect to use the uncalibrated window (in channels). If using the calibrated window, be sure to specify an energy calibration in the **Settings** tab.

Click **Start** to start the data acquisition and **Stop** to stop the data acquisition before the total run time has elapsed. Click **Start** again to accumulate additional data. Note that the total run time may need to be increased to continue. Click **Clear** to discard accumulated data.

The **Audio** checkbox enables audible alarms. A sound is played if the count rate exceeds the corresponding **Alarm Threshold** defined in the **Settings** tab.

Click **Import** to read a previous data file in CSV format. The present detector is disconnected.

Click **Export** to write a data file in CSV format. Each row in the file specifies the sample number, start time, real time in microseconds, GPS location, one-second count rates, and raw spectrum. The first channel is the live time in microseconds. By default, the file is saved to a subfolder of the working directory (**c:\fidler** by default). The file can be loaded into AVID for processing.

Use the **Auto save** check box to automatically export the data when acquisition is complete. If acquisition is restarted, the previous file is overwritten.

Use the scroll bar at the bottom of the plot to navigate through the data. The **Lock** checkbox prevents the graph from scrolling when new samples are added. Use the **Rate x-axis** field in the **Settings** tab to control the amount of data shown. A value of zero auto-scales the x axis.

The **Status** text box displays the present connection state:

- **BUSY**: Scanning for devices or ramping high voltage.
- **DISCONNECTED**: No detector is connected.
- **CONNECTED**: Detector connected but not acquiring data.
- **RUNNING**: Detector acquiring data.
- **CLOSING**: Shutting down software.
- **ERROR**: A communication error occurred. Try connecting to the detector again.

The status is repeated in the title bar for reference.

3.3 Streaming to AVID

As an alternative to viewing data within the SpecFIDLER software, operators may stream data to AVID for visualization and processing. This feature requires AVID 2022 Update 1 or later.

To enable streaming, scroll to the bottom of the **Settings** page (Figure 13) and check the box beside **Streaming to AVID**. Open AVID and configure the SpecFIDLER stream manager to connect to the SpecFIDLER software. Provide the IP address where the software is running (usually the local address 127.0.0.1) and the port number (4002 by default). The port number is defined in the settings file, as explained in Appendix B. The SpecFIDLER software then transmits the sample information, GPS location, count rates, raw spectrum, and present energy calibration each second while acquisition is running.

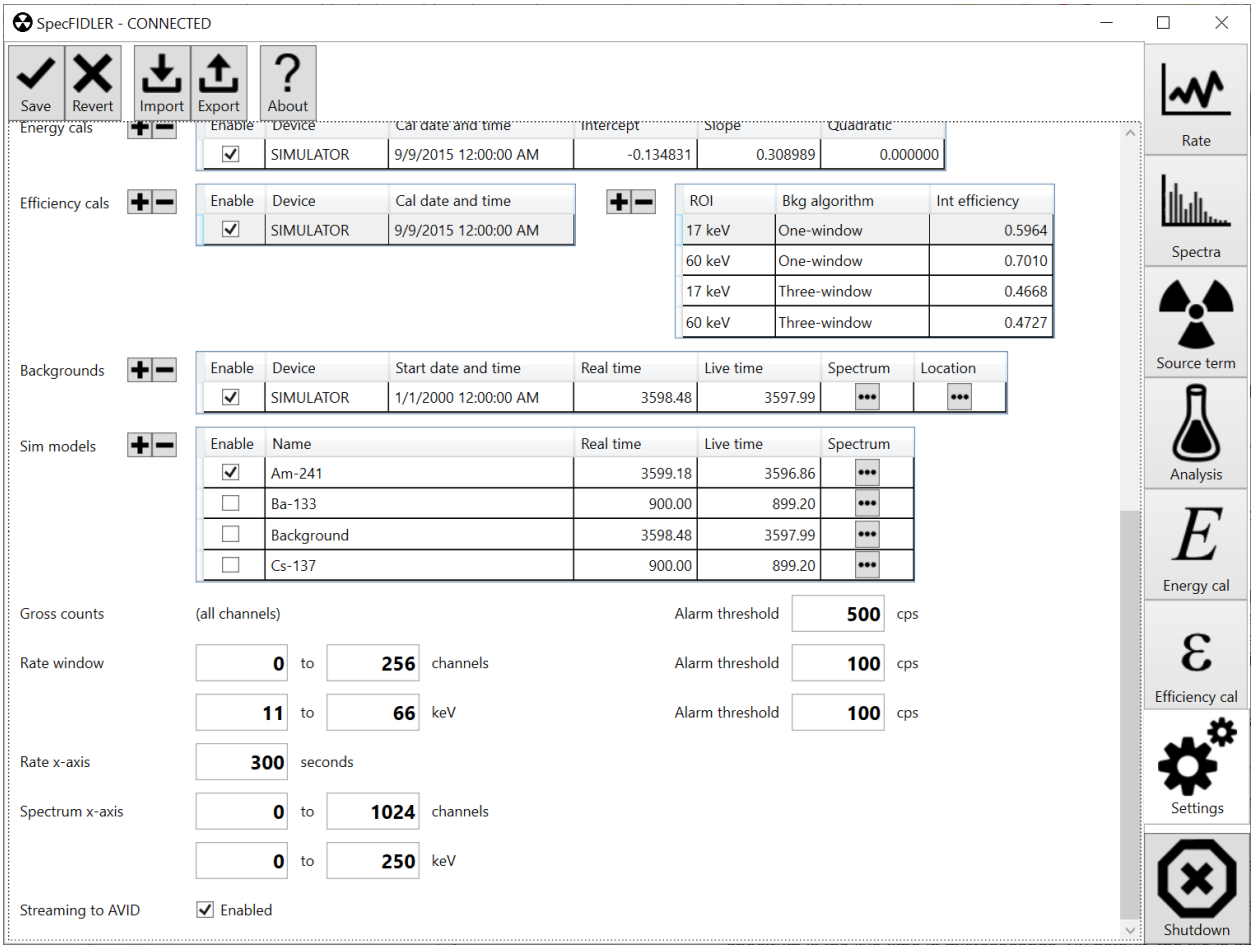

Figure 13. Bottom of **Settings** page showing the streaming checkbox.

3.4 Stationary Sampling

To use the SpecFIDLER for stationary sampling, extend the legs and place the unit over the desired location. The detector is 30 cm from ground level with the legs extended. The first measurement should be a representative background that matches the terrain type as closely as possible. Subsequent measurements can then use that background to determine the amount of contamination. However, analysis can be performed without a background if necessary.

Use the **Spectra** tab (Figure 14) to acquire data and display the accumulated spectrum. The connection status, start time, real time, live time, and total counts are displayed below the plot.

The **Rate** and **Spectra** tabs display the same data and share many of the same controls. As a reminder, select the **Device** and check the **Status**. Enter the desired **Run time**, then use **Start** and **Stop** to control the data acquisition. **Clear** the accumulated data to start over.

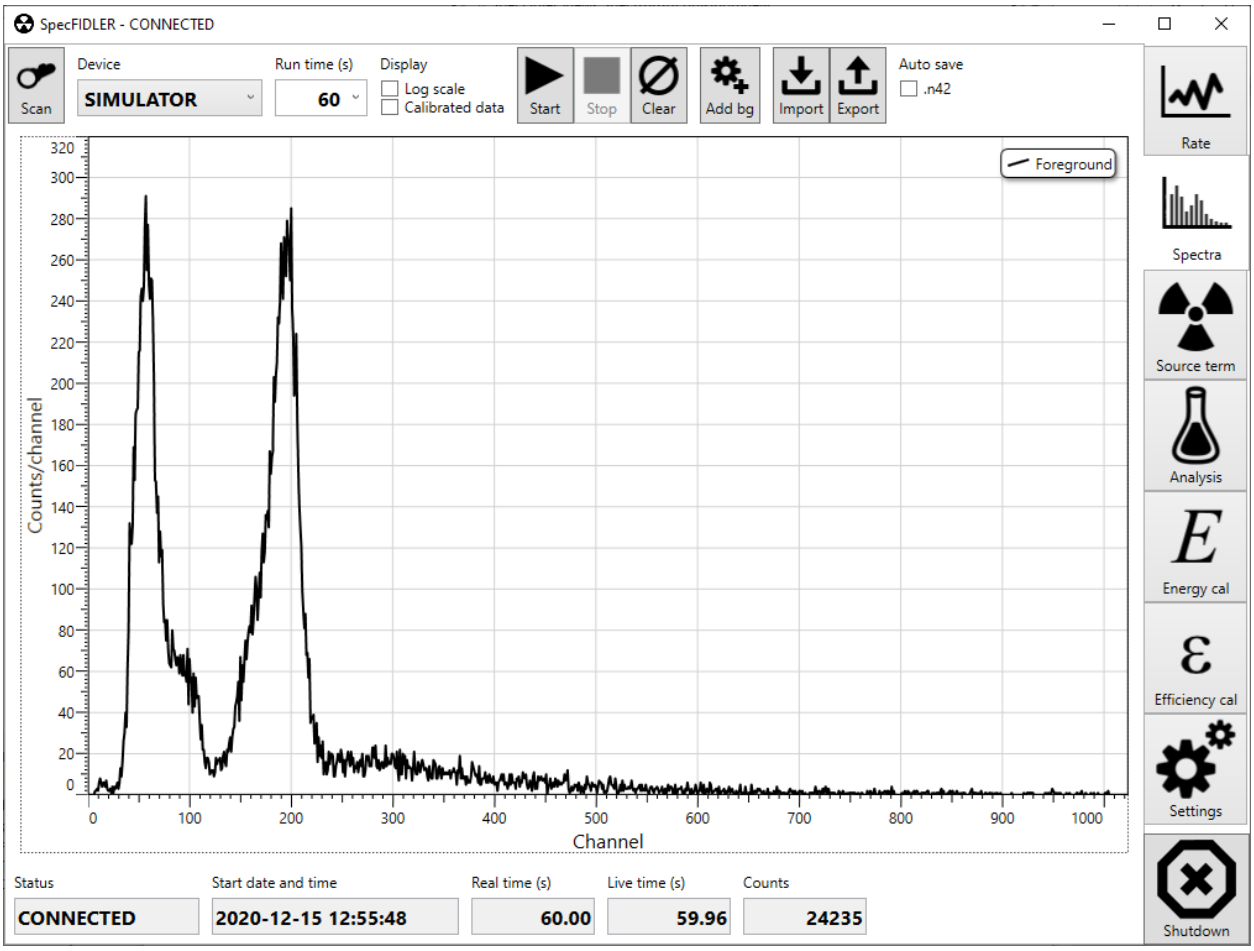

Figure 14. **Spectra** tab.

The **Display** checkboxes set plot options. Use **Log scale** to specify the y-axis. Use **Calibrated data** to control whether the plot displays the raw or calibrated spectrum. If using the calibrated spectrum, be sure to specify an energy calibration in the **Settings** tab.

If collecting a background, click **Add bg** to add the present measurement to the settings. Go back to the **Settings** tab and confirm that a new row appears under **Backgrounds**. The settings can store multiple backgrounds, but only one background is enabled for each detector. Older backgrounds may be removed using the **–** button, if desired.

Click **Import** to read a previous data file in N42.42 format. The present detector is disconnected.

Likewise, click **Export** to write a data file in N42.42 format. Unlike the **Rate** tab, only the total spectrum is saved; thus, the time series is not displayed on import. The file also does not contain the present background or energy calibration. To save this information, use the **Export** button in the **Analysis** tab instead.

Use the **Auto save** check box to automatically export the data when acquisition is complete. If acquisition is restarted, the previous file is overwritten.

3.5 Source Term

Use the **Source term** tab (Figure 16) to define the mixture of nuclides in the source term. Several common source terms are predefined in the software. The software can take a previous source term and apply aging calculations to create a new source term.

First select the **Original source term** and click **Load**. The **INITIAL** table is populated with each nuclide, mass fraction, and activity fraction in the mixture. Alternatively, define a new source term from scratch by starting with an empty table. Click **Add** to append a new row and **Remove** to delete the highlighted row. All fields are editable.

Either the mass fraction or the activity fractions may be supplied. The buttons below the **Original source term** select which set of fractions will be used for the calculations. For example, if **Activity fractions** is selected, mass fractions are calculated from activity fractions.

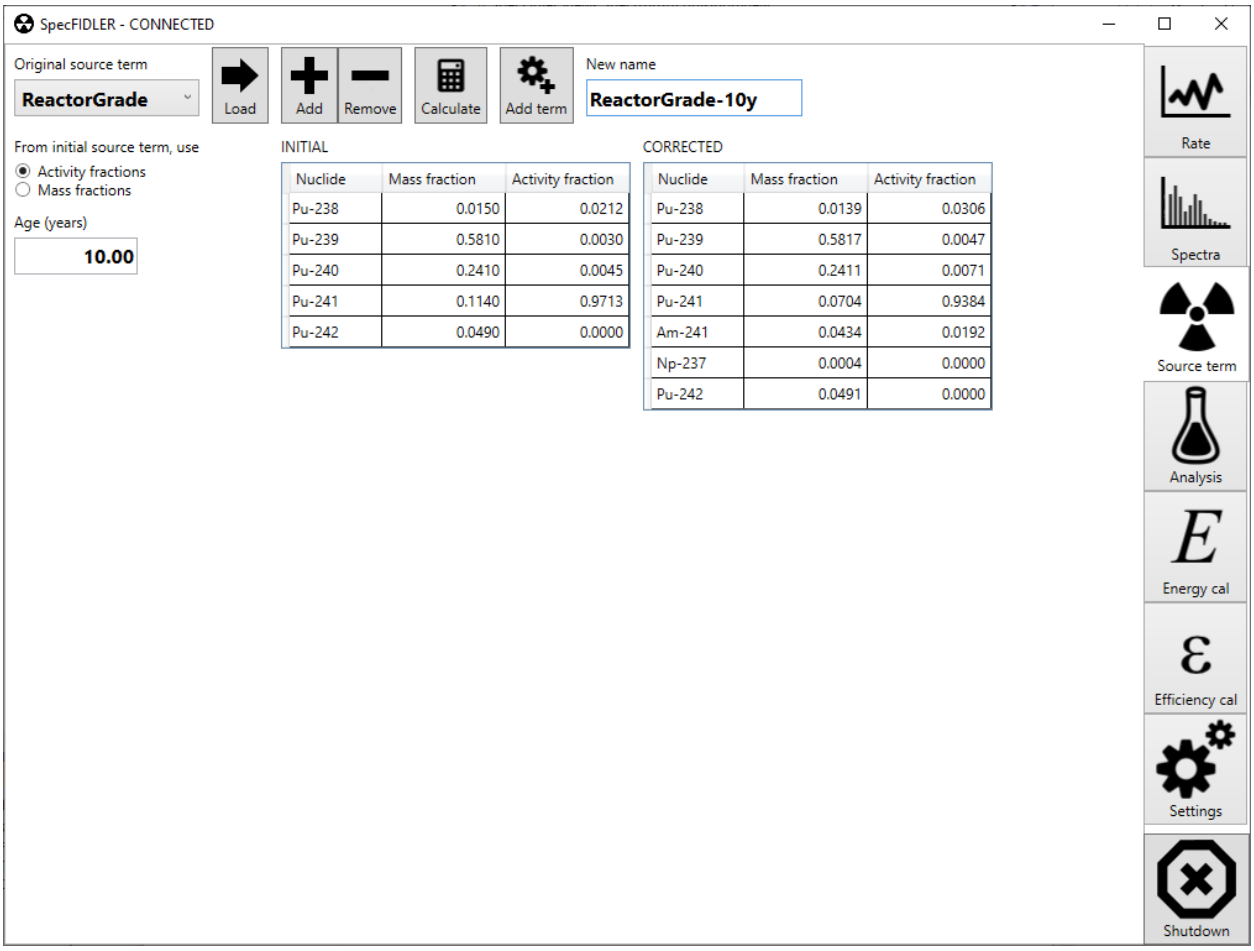

Figure 15. **Source term** tab.

Now enter the **Age** in years and click **Calculate**. The **CORRECTED** table is populated with the nuclide, mass fraction, and activity fraction of the decay-corrected source term. Set the **Age** to zero if no decay corrections are needed.

Type the **New name** of the source term and click **Add term** to add the corrected source term to the settings. Go back to the **Settings** tab and confirm that a new row appears under **Source terms**. Highlight the row to see the breakdown of nuclides and mass fractions.

NOTE: The new source term overwrites any existing source term of the same name.

3.6 Nuclide Analysis

After collecting a stationary sample, use the **Analysis** tab (Figure 16) to compute the nuclide concentrations. This step may be performed while acquiring additional data. The main plot displays the foreground spectrum in black, the background spectrum in red, each region of interest (ROI) in blue, and each background region in red. The table of computed nuclide concentrations appears below the plot.

First click **Load** to transfer the current acquired data into the foreground. This operation may be performed at any time, even before data acquisition is complete. However, the foreground only updates when **Load** is clicked.

Alternatively, click **Import** to read a previously exported file in N42.42 format. The **Device**, **Comment**, and spectral data are taken from the file. In addition, the background, energy calibration, and efficiency calibration are added to the settings, if defined in the file. However, the detector voltage and source term are not affected. Check the **Settings** tab to confirm which values are being used.

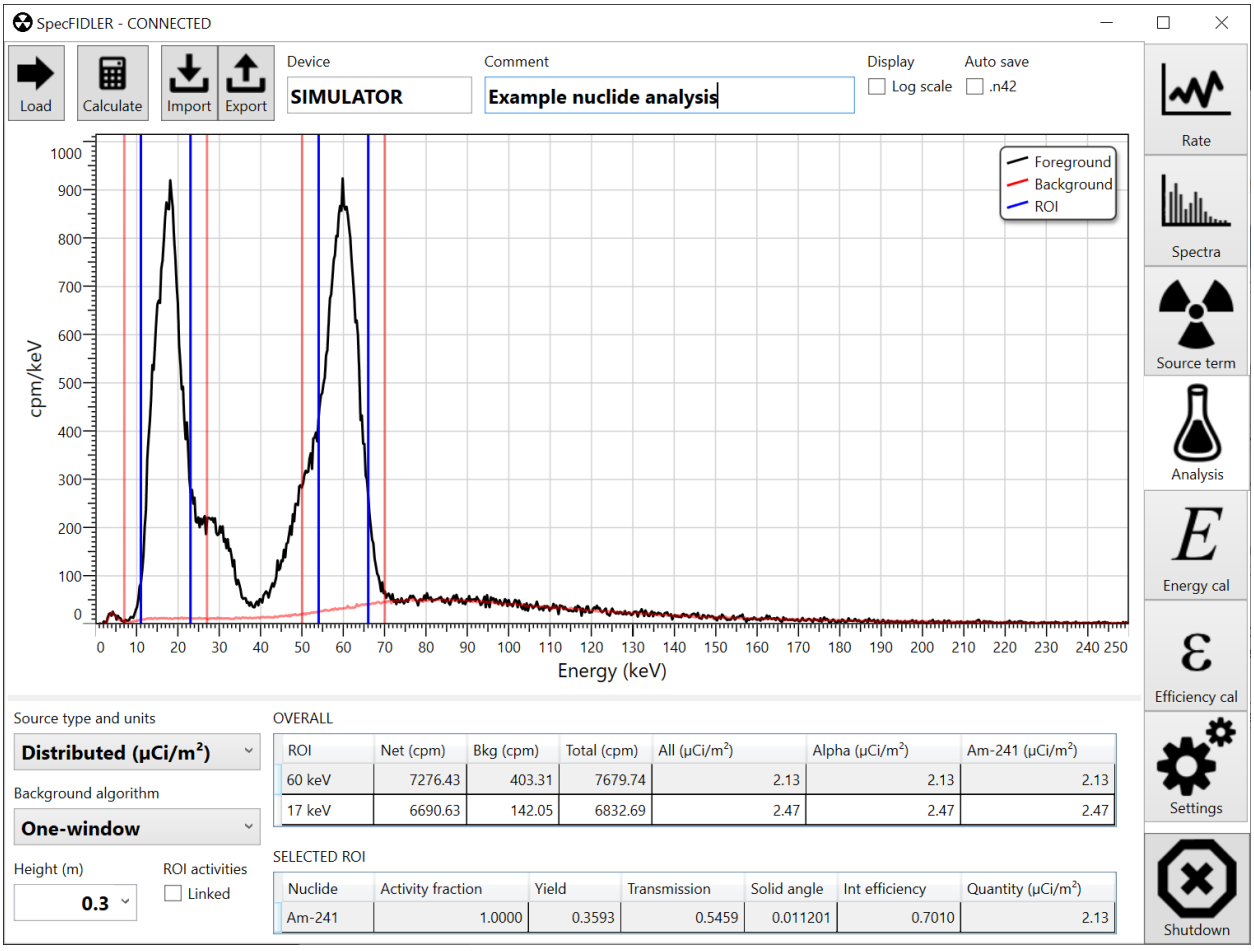

Figure 16. **Analysis** tab.

Next, specify the **Source type and units** in the drop-down on the lower right. The analysis can be performed for a distributed source or a point source, in units of microcuries or becquerels. The point source option may be useful when analyzing a small sample underneath the detector.

Also specify the desired **Background algorithm**. The **One-window** method uses a background spectrum collected previously. In contrast, the **Three-window** method extrapolates the background counts from the background regions to the left and right of the ROI. The **One-window** method is generally more accurate, but the **Three-window** method is useful if representative background is not available.

Ensure that the **Height** matches the detector height. Type in a value, in meters, or choose one of the predetermined values. The default detector height with the legs extended is 0.3 meters.

The buttons under **ROI activities** change the behavior of the nuclide analysis. Selecting **Independent** causes the software to compute the results in each ROI independently. The activity fractions from the specified source term are used to scale the total quantity. Selecting **Linked** causes the software to propagate results from one ROI to another. Specifically, the quantity of Am-241 is calculated first using the net counts in the 60 keV ROI. The activity fractions are then adjusted for the 17 keV ROI to provide a consistent quantity of Am-241. This option is useful when the fraction of Am-241 is not known precisely.

Click **Calculate** to run the nuclide analysis. The results are displayed in the two tables. The top table provides the count rates and computed quantities for each ROI. The bottom table lists the activity fraction, sensitivity parameters, and quantity for each nuclide in the selected ROI.

Click on a row in the top table to select a different ROI. Depending on the **Source type and units**, the quantities may be reported as activities (such as microcuries) or areal concentrations (such as microcuries per square meter). If a quantity is less than the minimum detectable activity (MDA), the text **< MDA** will appear instead.

Make note of the quantities displayed in the top table. At present, these values may need to be entered manually into the DFM software. Separate columns provide the overall quantity of all nuclides in the source term, the quantity of all alpha emitters, and the quantity of just Am-241. If using the **Independent** method, the 60 keV ROI calculations are usually the most accurate, since the gamma rays are less affected by surface roughness and other uncertainties. If using the **Linked** method, the 17 keV ROI calculations incorporate the corrected activity factors.

The bottom table provides more information about the factors that went into the calculation. The yield specifies the gamma emissions in the ROI per decay. The transmission factor accounts for the air attenuation between the ground and the detector. For distributed sources, this factor integrates activity over an infinite disc, accounting for changes to the solid angle and path length. The solid angle fraction is computed for gamma emissions directly underneath the detector. Finally, the intrinsic efficiency gives the results of the efficiency calibration.

Click **Export** to write the data and analysis results to a file in N42.42 format. Use the **Comment** field to enter any information about the measurement prior to exporting the data. The analysis results are written to the file in the same units as the calculations. Use the **Auto save** check box to automatically perform the analysis and export the results.

3.7 Shutdown

When data acquisition and analysis is complete, click **Shutdown** to shut down the SpecFIDLER and return to the DFM software. Alternatively, close the window using the **X** in the upper right corner. The shutdown process takes a few seconds to ramp down the bias voltage and disconnect from the usbBase.

NOTE: Do not unplug the tablet from the detector until the usbBase is disconnected. This may be done by shutting down the software or by changing the **Device** to **DISCONNECTED**.

4.0 Calibration

The SpecFIDLER requires several calibration steps before use: a voltage calibration performed when commissioning a detector, an energy calibration performed daily, and an efficiency calibration performed daily. The remainder of this section details the calibration procedures.

4.1 Voltage Calibration

The voltage calibration establishes the bias voltage for the detector. The detector must have a voltage listed in the settings; otherwise, data acquisition will be disabled. The voltage calibration should only need to be performed when commissioning a new detector, unless the detector performance changes significantly over time.

First, go to the **Settings** tab and click the **+** button next to **Voltages**. A new row appears for the present detector. Set **Volts** to 1000 and ensure that **Enabled** is checked.

Next, place an Am-241 source on the ground underneath the detector, centered on the detector axis. Go to the **Spectra** tab and start data acquisition. Confirm that the spectrum meets two requirements (Figure 17). First, the 13 keV x-ray should be visible as a shoulder to the 17 keV peak. Second, and more importantly, the 60 keV peak should return to background prior to channel 250.

Adjust the voltage up or down so that the requirements are met. After each change, change the **Device** to **DISCONNECTED** and then to the original serial number. This step will apply the new bias voltage to the detector.

NOTE: Setting the bias voltage above 1200 V is not recommended. Do not exceed 1500 V.

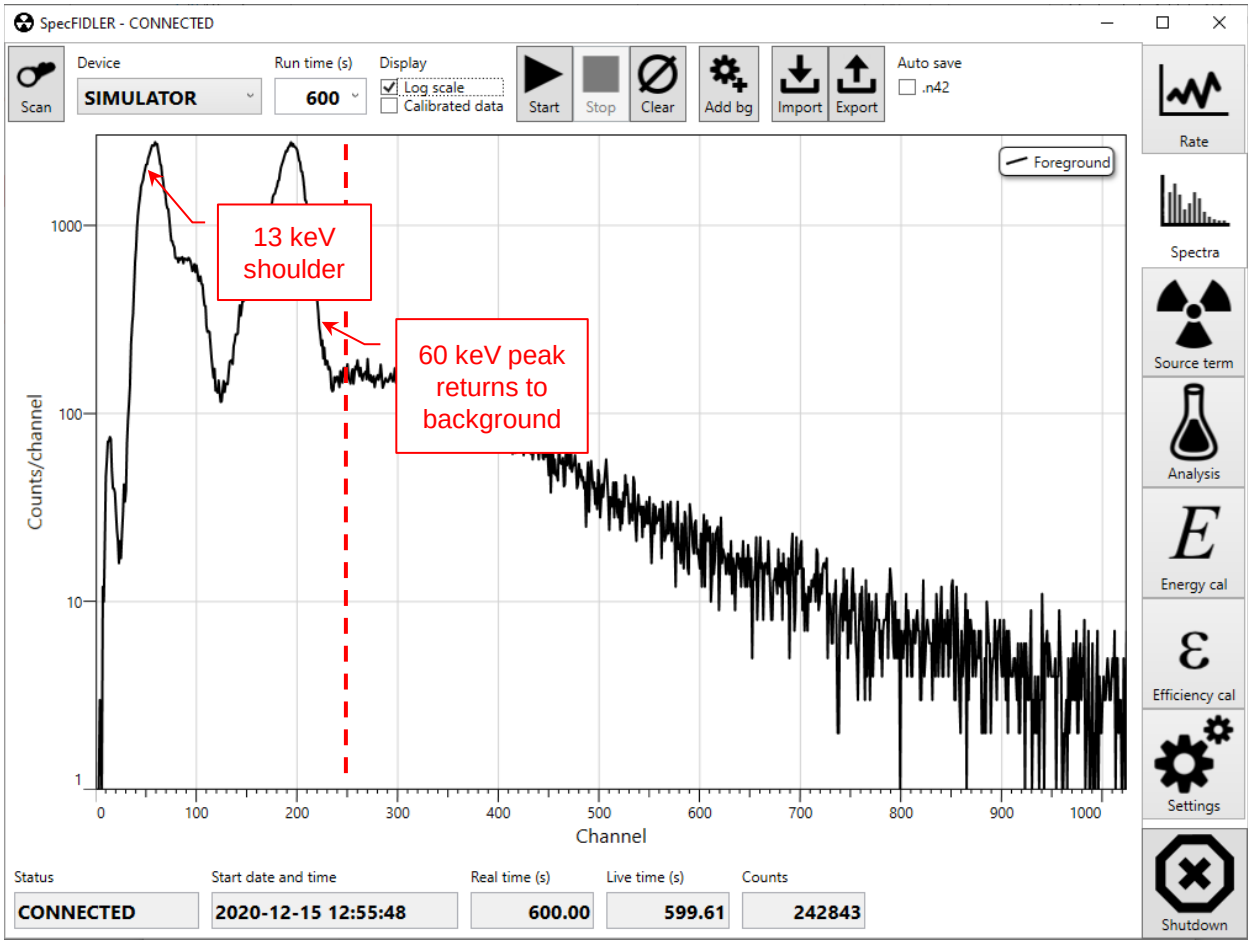

Figure 17. Am-241 spectrum with good high voltage setting.

4.2 Energy Calibration

The energy calibration should be performed daily prior to deployment. These channel-to-energy conversion factors are created by presenting a source to the instrument, acquiring a spectrum, and selecting the proper peak. Although the software supports different sources, the energy calibration can be completed using Am-241 alone. Thus, the following discussion uses Am-241 for illustration.

First, use the **Spectra** tab to acquire data with an Am-241 source. Alternatively, use the measurement previously collected for the voltage calibration.

Open the **Energy Cal** tab (Figure 18). The main plot displays the foreground spectrum in black, the fitted peaks in red, and each region of interest (ROI) in blue. The table of peaks and the computed calibration coefficients appear below the plot.

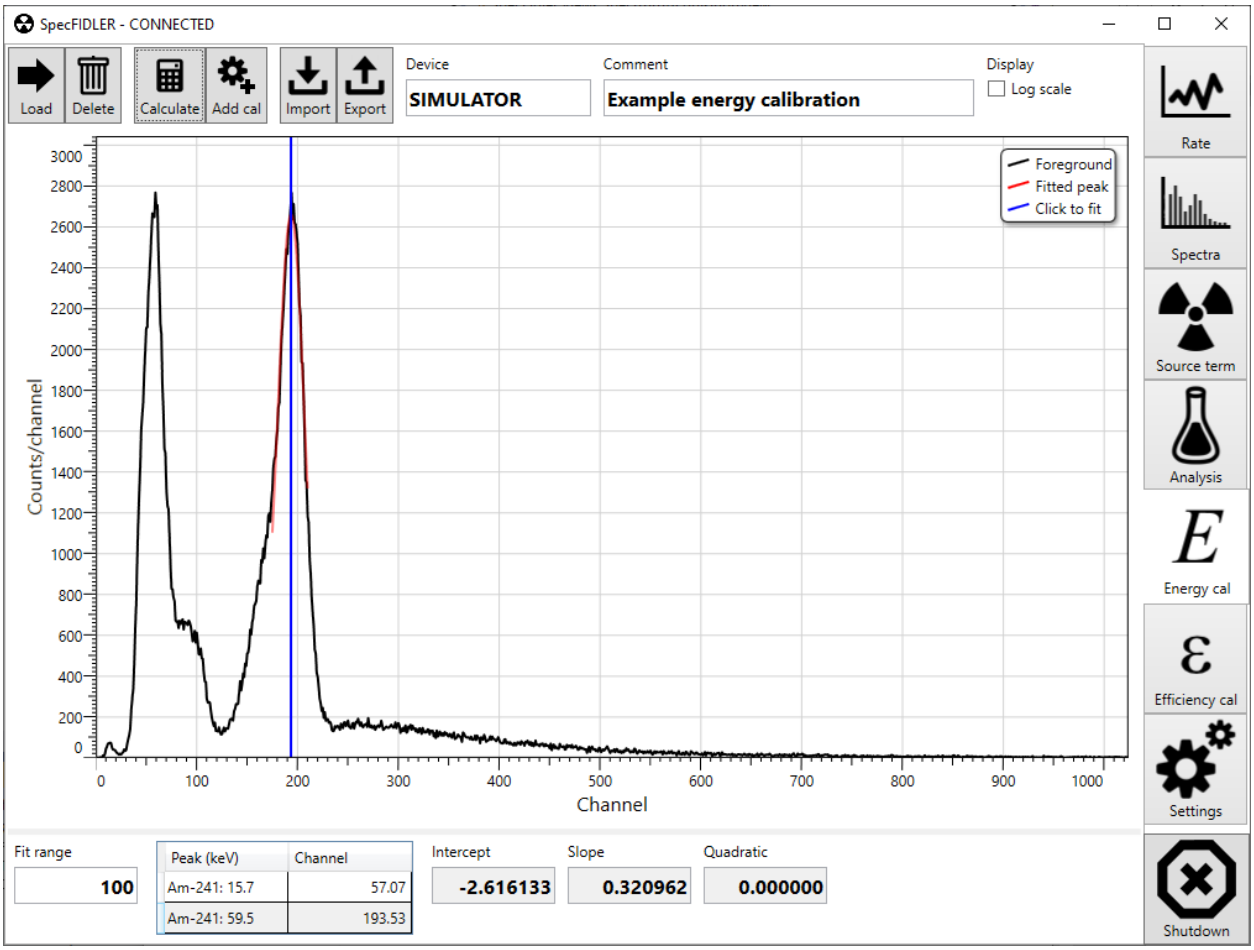

Figure 18. **Energy Cal** tab.

Click **Load** to transfer the acquired data. A new row appears in the table on the bottom left. Change the **Peak** to **Am-241: 15.7**. (This value is the weighted average of the x-rays between 13 and 17 keV.) Now click on the first peak in the plot to fit the peak to a Gaussian. Adjust the **Fit range** if necessary to achieve a good fit.

Click **Load** again to create a second row in the table with the same data. This time, change the **Peak** to **Am-241: 59.5**. Fit the peak as before.

Clicking on each row in the table selects the data with the corresponding peak. Use the **Delete** button to remove unneeded rows from the table.

Now click **Calculate** to compute the calibration coefficients. For this two-point calibration, the **Quadratic** term will be zero. The software performs various checks to ensure the calibration makes sense, and displays a warning message if something appears wrong.

As an alternative to clicking on the plot, the **Channel** numbers may be entered manually. The blue line on the plot updates after clicking **Calculate**. The red fitted curve is not displayed in this case.

Click **Add cal** to add the energy calibration to the settings. Go back to the **Settings** tab and confirm that a new row appears under **Energy cal**. The settings can store multiple energy calibrations for each detector, but only one is enabled at a time. Older energy calibrations may be removed using the **–** button, if desired.

Returning to the **Energy cal** tab, click **Export** to write the spectra to a file in N42.42 format. Storing the calibration data may be useful for future reference. Use the **Comment** field to enter any information about the measurement prior to exporting the data.

4.3 Efficiency Calibration

The efficiency calibration should be performed daily prior to deployment. This process determines the intrinsic efficiency of the detector for each ROI. Although the software supports different sources, typically just Am-241 is used to perform the calibration. Thus, the following discussion uses Am-241 for illustration.

First, use the **Spectra** tab to acquire background data. Click **Add bkg** when done.

Now acquire data with an Am-241 source. Place the source on the ground underneath the detector, centered on the detector axis. The source should have an activity of 10 µCi or greater. It is recommended to accumulate about 40,000 total counts so that the peaks have adequate statistics.

Next, open the **Efficiency Cal** tab (Figure 19). The main plot displays the foreground spectrum in black, the background spectrum in red, each ROI in blue, and each background region in red. The table of computed efficiencies appears below the plot.

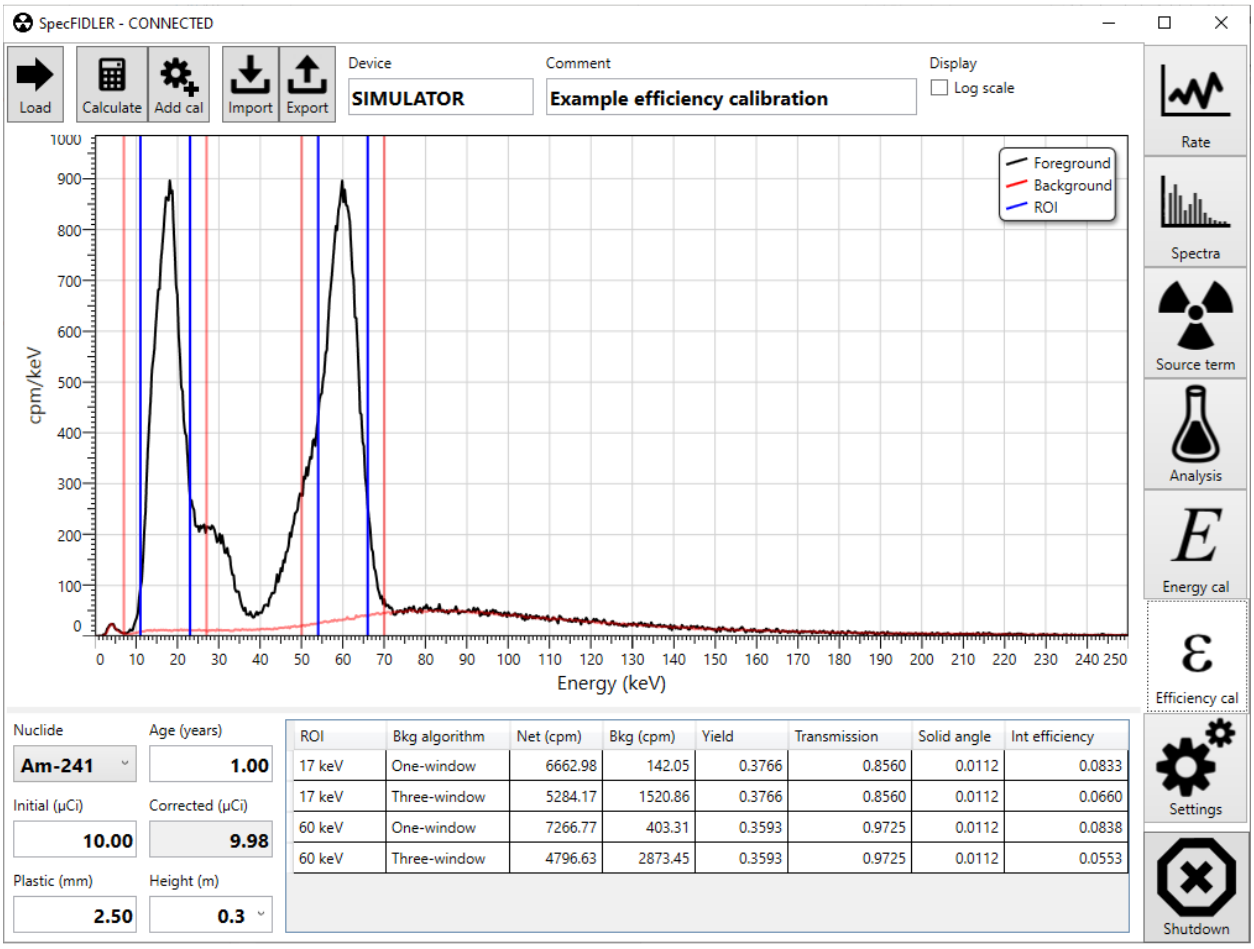

Figure 19. **Efficiency Cal** tab.

Change the **Nuclide** to **Am-241**. Fill in the **Age** of the source in years and **Initial** activity in microcuries. The software automatically performs the decay correction. Specify the **Plastic** thickness in millimeters on top of the source.

Ensure that the **Height** matches the detector height. Type in a value, in meters, or choose one of the predetermined values. The default detector height with the legs extended is 0.3 meters.

Now click **Calculate** to compute the calibration coefficients for each ROI and background algorithm. As a reminder, the One-window method uses a prior background measurement, whereas the Three-window method extrapolates the background counts from adjacent regions in the spectrum. The count rates, sensitivity factors, and computed intrinsic efficiency are displayed in the table.

As with the nuclide analysis, the yield specifies the gamma emissions per decay in the ROI. The transmission factor accounts for the air attenuation between the ground and the detector. The solid angle fraction is computed for gamma emissions directly underneath the detector.

Click **Add cal** to add the efficiency calibration to the settings. Go back to the **Settings** tab and confirm that a new row appears under **Efficiency cal**. The settings can store multiple efficiency calibrations for each detector, but only one is enabled at a time for each background algorithm. Older efficiency calibrations may be removed using the **–** button, if desired.

Returning to the **Efficiency cal** tab, click **Export** to write the spectra to a file in N42.42 format. Storing the calibration data may be useful for future reference. Use the **Comment** field to enter any information about the measurement prior to exporting the data.

5.0 Maintenance

This section discusses common maintenance tasks for the SpecFIDLER and gives suggestions for troubleshooting.

5.1 Upgrading Software

Version 2 of the SpecFIDLER software is not completely compatible with the settings used for older versions. The software will read the voltage and energy calibrations from the old settings file. However, some calibration steps need to be repeated. Use the following procedure when upgrading to version 2:

1. When opening the software, a warning message appears that about the settings format having the incorrect format. Dismiss this message as it is expected.

2. Go to the **Settings** tab and confirm that the voltage and energy calibrations appear correct.

3. Delete all efficiency calibrations from the page. Older versions of the software used a different method to perform the efficiency calibration. Thus, these calibrations are invalid and will show as blank.

4. Click **Save** to save the settings file in the updated format.

5. Repeat the efficiency calibration for the detector.

6. If it is necessary to use a prior background, go to the **Spectrum** tab, click **Import** to load the old .n42 file, and click **Add bg** to add the background measurement to the settings. Alternatively, manually add a measurement on the **Settings** tab, using copy-and-paste to define the 4096-channel spectrum.

5.2 Replacing usbBase

Occasionally a usbBase will stop communicating with the SpecFIDLER software. The cause of this issue is unknown, but it seems to occur most frequently when first commissioning a detector. Use the following procedure to exchange a base:

1. Unplug the old base from the USB hub.

2. Carefully cut the plastic heat shrink between the old base and the detector.

3. Unplug the old base from the detector.

4. Plug the new base onto the detector, taking care to line up the key on the detector end with the notch on the base socket.

5. Replace the heat shrink. The outer diameter of the usbBase is about 2.25”.

6. Perform a voltage calibration, energy calibration, and efficiency calibration on the new base.

5.3 Transferring Settings

Sometimes it may be necessary to connect the detector to a different tablet. The **Settings** tab makes it simple to transfer the background and calibration parameters from one tablet to another. Use the following procedure to transfer the settings:

1. Go to the **Settings** tab of the old tablet. Click **Export** to export the settings to a file. Attach a USB thumb drive or save the file to a known network location.

2. Go to the **Settings** tab of the new tablet. Click **Import** to import the settings from the file.

3. Examine the settings to ensure that the desired rows are present and enabled. The import process tries to remove duplicates and enable the imported settings.

4. Click **Save** when finished to save the settings file.

5.4 Log Files

The SpecFIDLER software saves daily log files to the SpecFIDLER working directory (**c:\fidler** by default). These log files contain more detailed information about warnings and errors encountered by the software.

Appendix A – Configuration File

The SpecFIDLER software uses a configuration file named **SpecFidler.exe.config** to define general application parameters. This file is in the same directory as the application **SpecFidler.exe**.

The values of most interest are as follows:

- **configuration/log4net/file**: Base path for log files.
- **appSettings**: Defines the working directory and enables simulated mode.

An example configuration file appears below.

```
<?xml version="1.0" encoding="utf-8"?>
<configuration>
  <configSections>
    <section name="log4net"
             type="log4net.Config.Log4NetConfigurationSectionHandler,
             log4net"/>
  </configSections>
  <log4net>
    <root>
      <level value="INFO"/>
      <appender-ref ref="RollingFileAppender"/>
    </root>
    <appender name="RollingFileAppender"
             type="log4net.Appender.RollingFileAppender">
      <appendToFile value="true"/>
      <file value="C:\fidler\SpecFIDLER.log"/>
      <layout type="log4net.Layout.PatternLayout">
        <conversionPattern value="%date{HH:mm:ss} %-5level %logger{1} -
            %message%newline%exception"/>
      </layout>
      <lockingModel type="log4net.Appender.FileAppender+MinimalLock"/>
      <maxSizeRollBackups value="10"/>
      <maximumFileSize value="100KB"/>
      <rollingStyle value="Size"/>
      <staticLogFileName value="true"/>
    </appender>
  </log4net>
  <appSettings>
    <add key="WorkingDir" value="C:\fidler\"/>
    <add key="Simulated" value="true"/>
  </appSettings>
```

(truncated)

```
</configuration>
```

Appendix B – Settings File

The SpecFIDLER software uses a settings file named **settings.xml** to store all user parameters. Many but not all values may be modified through the user interface. This file is stored in the SpecFIDLER working directory (**c:\fidler** by default).

The software also has default settings built in. These defaults are loaded first, and then the settings file overrides the defaults. This mechanism allows the software to function if the settings file is missing or has the wrong version. The software issues a warning message in this case.

An example settings file appears below, with annotations describing each section.

First are general preferences, such as the y-axis scale, user name, and so forth.

```
<?xml version="1.0" encoding="utf-8" ?>
<SpecFIDLER>
  <audio>false</audio>
  <backgroundAlgorithm>OneWindow</backgroundAlgorithm>
  <calibratedData>false</calibratedData>
  <detectorRadius>0.0635</detectorRadius>
  <fitRange>100</fitRange>
  <linkedCalculations>false</linkedCalculations>
  <logarithmicScale>false</logarithmicScale>
  <site></site>
  <sourceTypeAndUnit>MicrocuriesPerMeterSquared</sourceTypeAndUnit>
  <user>CMRT / FRMAC</user>
  <windowedSpectrum>false</windowedSpectrum>
```

The **alarmThresholds** section defines the count rate thresholds for the audible alarm.

```
  <alarmThresholds>
    <channelWindow>100</channelWindow>
    <energyWindow>100</energyWindow>
    <grossCounts>500</grossCounts>
  </alarmThresholds>
```

The **backgrounds** section provides the background measurements for each device. Location information is saved with the background.

```
  <backgrounds>
    <background>
      <enabled>true</enabled>
      <deviceId>SIMULATOR</deviceId>
      <acquisitionDate>2000-01-01T00:00:00</acquisitionDate>
      <realTime>3598.480</realTime>
      <liveTime>3597.989</liveTime>
      <spectrum>1 1 2 3 4 7 12 27 50 92 171 300 374 (truncated) </spectrum>
      <latitude>46.349149028339191</latitude>
      <longitude>-119.27910736043991</longitude>
      <accuracy>1</accuracy>
    </background>
  </backgrounds>
```

The **calibrationSource** section stores the information about the calibration source. The **age** is in years, the **initialActivity** is in microcuries, and the **plasticThickness** is in millimeters.

```
<calibrationSource>
  <nuclide>Am-241</nuclide>
  <age>0.0</age>
  <initialActivity>10.0</initialActivity>
  <plasticThickness>0.0</plasticThickness>
</calibrationSource>
```

The **efficiencyCalibrations** section gives the efficiency calibrations for each device. One component exists for each ROI and background algorithm. The **intrinsicEfficiency** specifies counts per incident gamma in the ROI.

```
<efficiencyCalibrations>
  <efficiencyCalibration>
    <enabled>true</enabled>
    <deviceId>SIMULATOR</deviceId>
    <calibrationDate>2015-09-09T00:00:00</calibrationDate>
    <efficiencyComponents>
      <efficiencyComponent>
        <region>17</region>
        <backgroundAlgorithm>OneWindow</backgroundAlgorithm>
        <intrinsicEfficiency>0.596370309</intrinsicEfficiency>
      </efficiencyComponent>
      <efficiencyComponent>
        <region>59.5</region>
        <backgroundAlgorithm>OneWindow</backgroundAlgorithm>
        <intrinsicEfficiency>0.70102444</intrinsicEfficiency>
      </efficiencyComponent>
      <efficiencyComponent>
        <region>17</region>
        <backgroundAlgorithm>ThreeWindow</backgroundAlgorithm>
        <intrinsicEfficiency>0.466786589</intrinsicEfficiency>
      </efficiencyComponent>
      <efficiencyComponent>
        <region>59.5</region>
        <backgroundAlgorithm>ThreeWindow</backgroundAlgorithm>
        <intrinsicEfficiency>0.472717231</intrinsicEfficiency>
      </efficiencyComponent>
    </efficiencyComponents>
  </efficiencyCalibration>
</efficiencyCalibrations>
```

The **energyCalibrations** section gives the energy calibrations for each device.

```
<energyCalibrations>
  <energyCalibration>
    <enabled>true</enabled>
    <deviceId>SIMULATOR</deviceId>
    <calibrationDate>2015-09-09T00:00:00</calibrationDate>
    <yIntercept>-0.13483146067415</yIntercept>
    <slope>0.308988764044944</slope>
    <quadratic>0</quadratic>
  </energyCalibration>
</energyCalibrations>
```

The **heights** section provides the options for selecting the detector height.

```
<heights selected="0.30">
  <meters>0.30</meters>
  <meters>0.50</meters>
  <meters>1.00</meters>
</heights>
```

The **models** section provides the measurements used by the simulator.

```
<models>
  <model>
    <enabled>false</enabled>
    <name>Background</name>
    <realTime>3598.480</realTime>
    <liveTime>3597.989</liveTime>
    <spectrum>1 1 2 3 4 7 12 27 50 92 171 300 374 (truncated) </spectrum>
  </model>
  <model>
    <enabled>true</enabled>
    <name>Am-241</name>
    <realTime>3599.183</realTime>
    <liveTime>3596.861</liveTime>
    <spectrum>1 4 1 1 8 10 22 53 81 172 283 402 460 (truncated) </spectrum>
  </model>
  <model>
    <enabled>false</enabled>
    <name>Ba-133</name>
    <realTime>900.000</realTime>
    <liveTime>899.200</liveTime>
    <spectrum>3 19 21 21 37 49 49 43 26 26 26 8 6 6 (truncated) </spectrum>
  </model>
  <model>
    <enabled>false</enabled>
    <name>Cs-137</name>
    <realTime>900.000</realTime>
    <liveTime>899.200</liveTime>
    <spectrum>6 32 36 36 41 44 44 37 17 17 17 (truncated) </spectrum>
  </model>
</models>
```

The **output** section enables auto saving and provides additional parameters for the output files, such as the instrument information given in the .n42 file. Note that the **instumentClassCode** and **detectorCategoryCode** must have one of the enumerated values specified in the N42.42 schema.

```
<output>
  <autoSaveRate>false</autoSaveRate>
  <autoSaveSpectrum>false</autoSaveSpectrum>
  <autoSaveAnalysis>false</autoSaveAnalysis>
  <instrumentManufacturerName>
    Pacific Northwest National Laboratory
  </instrumentManufacturerName>
  <instrumentModelName>Scintillation Crystal</instrumentModelName>
  <instrumentClassCode>Radionuclide Identifier</instrumentClassCode>
  <instrumentComponentName>SpecFIDLER Software</instrumentComponentName>
  <detectorCategoryCode>Gamma</detectorCategoryCode>
  <detectorKindCode>NaI</detectorKindCode>
</output>
```

The **nuclides** section provides various parameters for nuclides of interest. The **key** is a unique identifier. The **halfLife** is in years whereas the **specificActivity** is in becquerels per gram.

```
<nuclides>
  <nuclide>
    <key>Am-241</key>
    <name>Am-241</name>
    <category>Am241</category>
    <single>true</single>
    <halfLife>4.3220e+02</halfLife>
    <specificActivity>1.2696e+11</specificActivity>
    <decayProduct>Np-237</decayProduct>
    <branchingRatio>1.0000e+00</branchingRatio>
    <emissions>
      <emission>
        <region>17</region>
        <yield>3.7660e-01</yield>
      </emission>
      <emission>
        <region>59.5</region>
        <yield>3.5925e-01</yield>
      </emission>
    </emissions>
  </nuclide>
  <nuclide>
    <key>Th-228</key>
    <name>Th-228</name>
    <category>Alpha</category>
    <single>false</single>
    <halfLife>1.9116e+00</halfLife>
    <specificActivity>3.0346e+13</specificActivity>
    <decayProduct></decayProduct>
    <branchingRatio>1.0000e+00</branchingRatio>
    <emissions>
      <emission>
        <region>17</region>
```

```
      <yield>8.6000e-02</yield>
    </emission>
  </emissions>
</nuclide>
<nuclide>
  <key>U-232</key>
  <name>U-232</name>
  <category>Alpha</category>
  <single>false</single>
  <halfLife>6.8900e+01</halfLife>
  <specificActivity>8.2738e+11</specificActivity>
  <decayProduct>Th-228</decayProduct>
  <branchingRatio>1.0000e+00</branchingRatio>
  <emissions>
    <emission>
      <region>17</region>
      <yield>1.1000e-01</yield>
    </emission>
  </emissions>
</nuclide>
<nuclide>
  <key>Pu-236</key>
  <name>Pu-236</name>
  <category>Alpha</category>
  <single>false</single>
  <halfLife>2.8580e+00</halfLife>
  <specificActivity>1.9608e+13</specificActivity>
  <decayProduct>U-232</decayProduct>
  <branchingRatio>1.0000e+00</branchingRatio>
  <emissions>
    <emission>
      <region>17</region>
      <yield>1.3000e-01</yield>
    </emission>
  </emissions>
</nuclide>
<nuclide>
  <key>Np-237</key>
  <name>Np-237</name>
  <category>Alpha</category>
  <single>false</single>
  <halfLife>2.1440e+06</halfLife>
  <specificActivity>2.6027e+07</specificActivity>
  <decayProduct></decayProduct>
  <branchingRatio>1.0000e+00</branchingRatio>
  <emissions>
    <emission>
      <region>17</region>
      <yield>1.0030e+00</yield>
    </emission>
  </emissions>
</nuclide>
<nuclide>
  <key>Pu-237</key>
  <name>Pu-237</name>
```

```
    <category>Alpha</category>
    <single>false</single>
    <halfLife>1.2375e-01</halfLife>
    <specificActivity>4.5091e+14</specificActivity>
    <decayProduct></decayProduct>
    <branchingRatio>1.0000e+00</branchingRatio>
    <emissions>
      <emission>
        <region>17</region>
        <yield>5.2000e-01</yield>
      </emission>
    </emissions>
  </nuclide>
  <nuclide>
    <key>Pu-238</key>
    <name>Pu-238</name>
    <category>Alpha</category>
    <single>true</single>
    <halfLife>8.7700e+01</halfLife>
    <specificActivity>6.3360e+11</specificActivity>
    <decayProduct></decayProduct>
    <branchingRatio>1.0000e+00</branchingRatio>
    <emissions>
      <emission>
        <region>17</region>
        <yield>1.0630e-01</yield>
      </emission>
    </emissions>
  </nuclide>
  <nuclide>
    <key>Pu-239</key>
    <name>Pu-239</name>
    <category>Alpha</category>
    <single>false</single>
    <halfLife>2.4110e+04</halfLife>
    <specificActivity>2.2950e+09</specificActivity>
    <decayProduct></decayProduct>
    <branchingRatio>1.0000e+00</branchingRatio>
    <emissions>
      <emission>
        <region>17</region>
        <yield>4.6600e-02</yield>
      </emission>
    </emissions>
  </nuclide>
  <nuclide>
    <key>Pu-240</key>
    <name>Pu-240</name>
    <category>Alpha</category>
    <single>false</single>
    <halfLife>6.5640e+03</halfLife>
    <specificActivity>8.3947e+09</specificActivity>
    <decayProduct></decayProduct>
    <branchingRatio>1.0000e+00</branchingRatio>
    <emissions>
```

```
    <emission>
      <region>17</region>
      <yield>1.0340e-01</yield>
    </emission>
  </emissions>
</nuclide>
<nuclide>
  <key>Pu-241</key>
  <name>Pu-241</name>
  <category>None</category>
  <single>false</single>
  <halfLife>1.4350e+01</halfLife>
  <specificActivity>3.8239e+12</specificActivity>
  <decayProduct>Am-241</decayProduct>
  <branchingRatio>1.0000e+00</branchingRatio>
  <emissions>
    <emission>
      <region>17</region>
      <yield>2.6115e-05</yield>
    </emission>
  </emissions>
</nuclide>
<nuclide>
  <key>Pu-242</key>
  <name>Pu-242</name>
  <category>Alpha</category>
  <single>false</single>
  <halfLife>3.7500e+05</halfLife>
  <specificActivity>1.4572e+08</specificActivity>
  <decayProduct></decayProduct>
  <branchingRatio>1.0000e+00</branchingRatio>
  <emissions>
    <emission>
      <region>17</region>
      <yield>8.7100e-02</yield>
    </emission>
  </emissions>
</nuclide>
<nuclide>
  <key>Pu-244</key>
  <name>Pu-244</name>
  <category>Alpha</category>
  <single>false</single>
  <halfLife>8.0000e+07</halfLife>
  <specificActivity>6.7747e+05</specificActivity>
  <decayProduct>Pu-240</decayProduct>
  <branchingRatio>9.9770e-01</branchingRatio>
  <emissions>
    <emission>
      <region>17</region>
      <yield>5.6900e-02</yield>
    </emission>
  </emissions>
</nuclide>
```

The **peaks** section lists possible peaks for the energy calibration. The **energy** has units of keV.

```
<peaks>
  <peak>
    <source>Am-241</source>
    <energy>15.7</energy>
  </peak>
  <peak>
    <source>Am-241</source>
    <energy>59.5</energy>
  </peak>
  <peak>
    <source>Ba-133</source>
    <energy>31.6</energy>
  </peak>
  <peak>
    <source>Ba-133</source>
    <energy>80.9</energy>
  </peak>
  <peak>
    <source>Cd-109</source>
    <energy>22.1</energy>
  </peak>
  <peak>
    <source>Cd-109</source>
    <energy>88.0</energy>
  </peak>
  <peak>
    <source>Co-57</source>
    <energy>122.1</energy>
  </peak>
  <peak>
    <source>Cs-137</source>
    <energy>32.1</energy>
  </peak>
</peaks>
```

The **rateWindows** section provides the options for the rate chart time binning.

```
<rateWindows selected="1">
  <seconds>1</seconds>
  <seconds>2</seconds>
  <seconds>3</seconds>
  <seconds>5</seconds>
  <seconds>10</seconds>
  <seconds>15</seconds>
  <seconds>30</seconds>
  <seconds>60</seconds>
</rateWindows>
```

The **regions** section lists the ROI for analysis. The **key** is a unique identifier. The **order** specifies the analysis order. The **energyLow** and **energyHigh** are the ROI bounds in keV. The **backgroundLow** and **backgroundHigh** define the background region in keV for the three-window method. The **airAttenuationCoefficient** gives the linear attenuation coefficient for air, in units of inverse meters. Finally, the **plasticAttenuationCoefficient** provides a similar value for the plastic on top of the calibration source.

```
<regions>
  <region>
    <key>17</key>
    <name>17 keV</name>
    <order>2</order>
    <energyLow>11.0</energyLow>
    <energyHigh>23.0</energyHigh>
    <backgroundLow>7.0</backgroundLow>
    <backgroundHigh>27.0</backgroundHigh>
    <airAttenuationCoefficient>1.2640e-01</airAttenuationCoefficient>
    <plasticAttenuationCoefficient>
      4.7021e+01
    </plasticAttenuationCoefficient>
  </region>
  <region>
    <key>59.5</key>
    <name>60 keV</name>
    <order>1</order>
    <energyLow>54.0</energyLow>
    <energyHigh>66.0</energyHigh>
    <backgroundLow>50.0</backgroundLow>
    <backgroundHigh>70.0</backgroundHigh>
    <airAttenuationCoefficient>2.1003e-02</airAttenuationCoefficient>
    <plasticAttenuationCoefficient>
      8.6226e+00
    </plasticAttenuationCoefficient>
  </region>
</regions>
```

The **runTimes** section provides the options for the run time.

```
<runTimes selected="600">
  <seconds>30</seconds>
  <seconds>60</seconds>
  <seconds>90</seconds>
  <seconds>180</seconds>
  <seconds>300</seconds>
  <seconds>600</seconds>
  <seconds>1200</seconds>
  <seconds>1800</seconds>
  <seconds>3600</seconds>
</runTimes>
```

The **sourceTerms** section lists the mixtures of nuclides defined for analysis.

```
<sourceTerms>
  <sourceTerm>
    <enabled>false</enabled>
    <name>ReactorGrade</name>
    <constituents>
      <constituent>
        <nuclide>Pu-238</nuclide>
        <massFraction>1.5000e-02</massFraction>
      </constituent>
      <constituent>
        <nuclide>Pu-239</nuclide>
        <massFraction>5.8100e-01</massFraction>
      </constituent>
      <constituent>
        <nuclide>Pu-240</nuclide>
        <massFraction>2.4100e-01</massFraction>
      </constituent>
      <constituent>
        <nuclide>Pu-241</nuclide>
        <massFraction>1.1400e-01</massFraction>
      </constituent>
      <constituent>
        <nuclide>Pu-242</nuclide>
        <massFraction>4.9000e-02</massFraction>
      </constituent>
    </constituents>
  </sourceTerm>
  <sourceTerm>
    <enabled>true</enabled>
    <name>Am-241_100%</name>
    <constituents>
      <constituent>
        <nuclide>Am-241</nuclide>
        <massFraction>1.0000e+00</massFraction>
      </constituent>
    </constituents>
  </sourceTerm>
  <sourceTerm>
    <enabled>false</enabled>
    <name>Pu-238_100%</name>
    <constituents>
      <constituent>
        <nuclide>Pu-238</nuclide>
        <massFraction>1.0000e+00</massFraction>
      </constituent>
    </constituents>
  </sourceTerm>
```

(truncated)

```
</sourceTerms>
```

The **streaming** section specifies the local IP address and port number of the streaming server. Normally set the IP address to 0.0.0.0 to accept any incoming connections.

```
  <streaming>
    <enabled>false</enabled>
    <ipAddress>0.0.0.0</ipAddress>
    <portNumber>4002</portNumber>
  </streaming>
```

The **voltages** section gives the high voltage setpoints for each device.

```
  <voltages>
    <voltage>
      <enabled>true</enabled>
      <deviceId>SIMULATOR</deviceId>
      <calibrationDate>2015-09-09T00:00:00</calibrationDate>
      <volts>1000</volts>
    </voltage>
  </voltages>
```

The **window** section specifies the bounds for the rate window. The **channelLow** and **channelHigh** are used for uncalibrated spectra. The **energyLow** and **energyHigh** are used for the calibrated spectra.

```
  <window>
    <channelLow>0</channelLow>
    <channelHigh>256</channelHigh>
    <energyLow>11</energyLow>
    <energyHigh>66</energyHigh>
  </window>
```

Finally, the **xAxis** section specifies the bounds for the x-axis on the plots. The **channelLow** and **channelHigh** are used for uncalibrated spectra. The **energyLow** and **energyHigh** are used for the calibrated spectra.

```
  <xAxis>
    <channelLow>0</channelLow>
    <channelHigh>1024</channelHigh>
    <energyLow>0</energyLow>
    <energyHigh>250</energyHigh>
  </xAxis>
</SpecFIDLER>
```

Appendix C – Algorithms

This appendix describes the algorithms used for background subtraction, energy calibration, efficiency calibration, and nuclide analysis. These algorithms incorporate the simplified calibration procedure developed by the Remote Sensing Laboratory (RSL) [Okada 2018]. In addition, the calculation framework draws heavily from the spreadsheet developed at Sandia National Laboratories (SNL) [Enghauser 2019].

C.1 Background Subtraction

The one-window method uses a prior background measurement to compute the net count rate in counts per minute (cpm):

1. Integrate the counts in the foreground spectrum between the ROI energy limits, interpolating between channels.

2. Divide the result by the live time to compute the total count rate C.

3. Repeat the above for the background spectrum to compute the background count rate B.

4. Subtract $C - B$ to compute the net count rate N.

In contrast, the three-window method extrapolates the background counts from adjacent regions in the spectrum:

1. Integrate the counts in the foreground spectrum between the ROI energy limits, interpolating between channels.

2. Divide the result by the live time to compute the total count rate C.

3. Repeat the above for the left and right windows adjacent to the ROI to compute the count rates L and R.

4. Use the following formula to compute the net count rate:

$$N = C - \frac{1}{2}\left(\frac{L}{\Delta E_L} + \frac{R}{\Delta E_R}\right)\Delta E_C$$

where ΔE_L, ΔE_R, and ΔE_C denote the energy span of each window (keV).

C.2 Energy Calibration

Clicking on a peak in the **Energy Cal** tab causes the software to fit the peak to a Gaussian function and report the center channel. This process involves the following steps:

1. Find the local maximum near the click. The search distance is specified by **FitRange**.
2. Find the local minima on either side. Again, the search distance is specified by **FitRange**.
3. Find the points halfway in amplitude between the minima and maximum.
4. Use a truncated-Newton optimization algorithm to minimize the mean squared error between the spectrum and the Gaussian function

$$a \exp\left(-\frac{(i-\mu)^2}{2\sigma^2}\right) + b$$

   between the two half maximum points. The value b specifies a constant baseline underneath the peak, which should be accurate enough for the present purpose.
5. Record the center channel μ.

To calculate the coefficients of the energy calibration, the software uses the truncated-Newton optimization package again to compute the quadratic regression between the channel numbers and associated peak energies. If only two peaks are specified, the software computes the linear regression instead.

The software then checks the results to ensure that the slope of the energy calibration remains positive and varies by less than 10% across the ROI range. In addition, the software verifies that the regression matches the actual peak energies to within 5%. Any unusual findings cause the software to display a warning message.

C.3 Efficiency Calibration

To compute the intrinsic efficiency ε of each ROI, the software uses the following formula:

$$\varepsilon = \frac{N}{k\ Q\ Y\ T\ S}$$

Here N is the net count rate in the ROI (cpm), k is a unit conversion factor (dpm/µCi), Q is the decay-corrected source activity (µCi), Y is the yield of the nuclide in the ROI, T is the transmission factor through the intervening plastic and air, and S is the solid angle fraction for a point source directly underneath the detector.

It is assumed that the detector has the same intrinsic efficiency to all gamma emissions in the ROI. As the width of the ROI is relatively small, and the low-energy gamma emissions from transuranic nuclides are consistent, this assumption should not introduce significant error.

The transmission factor T is the product of two terms:

$$T = \exp\left(-\mu_p\ d\right) \exp\left(-\mu_a\ h\right)$$

where μ_p is the linear attenuation coefficient of the plastic (1/m), d is the plastic thickness (m), μ_a is the linear attenuation coefficient of the air (1/m), and h is the detector height (m). Both attenuation coefficients are taken at the mean energy of the ROI with representative densities. For greater accuracy, the mean path lengths should be used in place of the plastic thickness and height; these values are about 10% larger than the straight-line distances given a detector height of 0.30 m. In practice, other sources of error will dominate.

The solid angle fraction S is the ratio of the detector area to the surface area of a sphere with radius h:

$$S = \frac{R^2}{4h^2}$$

where R is the detector radius (m).

C.4 Nuclide Analysis

Given a source term with a mixture of nuclides, the software first calculates the overall quantity Q in each ROI:

$$Q = \frac{N}{\sum_i (F_i\, Y_i)\, T\, S\, \varepsilon\, k}$$

Here N is the net count rate in the ROI (cpm), F_i is the activity fraction for one nuclide, Y_i is the yield of that nuclide in the ROI, T is the transmission factor through the air, S is the solid angle fraction for a point source directly underneath the detector, ε is the intrinsic efficiency in the ROI, and k is a unit conversion factor. This formulation supports both point sources and distributed sources.

The activity fractions are computed from the mass fractions specified by the source term, and then scaled to sum to one:

$$\sum_i F_i = 1$$

For a point source, the transmission factor T is simply

$$T = \exp\left(-\mu_a\, h\right)$$

where μ_a is the linear attenuation coefficient of the air (1/m) and h is the detector height (m). For a distributed source, the transmission factor integrates activity from differential area dA over infinite disc D, accounting for changes to the solid angle and path length:

$$T = \iint_D \frac{h^2}{h^2 + r^2} \cos\varphi \exp\left(-\mu_a \sqrt{h^2 + r^2}\right) dA$$

Here r is the radial offset to dA, whereas φ represents the angle between the vertical line through the detector center and the line from the detector center to dA. The first term accounts for the decrease in solid angle as dA moves further away from the detector. The second term accounts for the decrease in geometric efficiency as emissions from dA intercept the detector at an angle. The final term specifies the air attenuation over the path.

The corresponding integral

$$T = \int_0^{2\pi} \int_0^{\infty} \frac{h^3}{(h^2 + r^2)^{3/2}} \exp\left(-\mu_a \sqrt{h^2 + r^2}\right) r\, dr\, d\theta$$

has the solution

$$T = 2\pi h^2 \left(\exp(-\mu_a h) + \mu_a h\, \mathrm{Ei}(-\mu_a h)\right)$$

where Ei represents the exponential integral.

As before, the solid angle fraction S is the ratio of the detector area to the surface area of a sphere with radius h:

$$S = \frac{R^2}{4h^2}$$

where R is the detector radius (m).

The unit conversion factor k depends on the selected **Source type and units**. For a point source, the result Q will be in µCi, Bq, or kBq. For a distributed source, Q will be in µCi/m^2 or Bq/m^2.

The software also calculates the overall MDA in each ROI:

$$MDA = \frac{2.71 + 4.66\sqrt{B}}{\sum_i (F_i\, Y_i)\; T\; S\; \varepsilon\; k\sqrt{t}}$$

Here B is the background count rate in the ROI (cpm), t is the live time, and all other terms are the same as before.

The quantity and MDA of an individual nuclide are equal to the overall values multiplied by the activity fraction F_i. The software highlights the computed quantity of Am-241 as well as the sum of all alpha emitters.

If the ROI computations are performed independently, the results may well be different for each ROI. One source of uncertainty is the relative abundance of Am-241 versus other isotopes. The "independent" method assumes that the specified activity fractions are fixed. However, the quantity of Am-241 can be deduced from the 60 keV ROI and then propagated to the 17 keV ROI. The "linked" method implements this approach. The calculations proceed as above, but the 17 keV results are then adjusted as follows:

1. Copy the quantity Q_i of Am-241 from the 60 keV ROI to the 17 keV ROI.

2. Scale the activity fraction F_i for Am-241 to obtain the desired value of Q_i.

3. Scale F_i for all other isotopes so that $\sum_i (F_i\, Y_i)$ is the same as before. This returns the overall quantity Q in the 17 keV ROI to its original calculated value. This step assumes that the source term defines other isotopes besides Am-241.

4. After the above steps, $\sum_i F_i \neq 1$. Thus, scale Q and all F_i so that $\sum_i F_i = 1$ once more.

Note that the 17 keV ROI will specify the new activity fractions, but the 60 keV ROI will still contain the original ones.

C.5 References

Grove Software, Inc., “RadDecay 3.0”, July 2006.

C Okada, “The SpecFIDLER”, December 2018.

M Enghauser, “SNL_SpecFIDLER_V000” Excel spreadsheet, November 2019.

Appendix D – Licensing

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