MINIMUM RESOLUTION REQUIREMENTS FOR GAMMA IDENTIFICATION ALGORITHMS

A Thesis

by

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ABSTRACT

Each year, millions are spent to improve detector resolution. This research indicates that higher resolution detectors are not always necessary. The Gamma Detector Response and Analysis Software (GADRAS), Gamma Acquisition and Analysis (Genie), and GammaVision identification routines were employed to analyze simulated NaI spectra of highly enriched uranium (HEU) under various conditions as detector resolution was increased. The purpose was to determine the detector resolution where HEU was no longer identified. The programs were evaluated using six source configurations: bare HEU, with shielding, and with shielding and an interference source. GammaVision was inappropriate for this research because its identification always assigned "peaks" from its library without confidence levels even at 100% resolution. GADRAS identified isotopes using template matching while Genie and GammaVision utilized mathematical routines. GADRAS was the most successful for suboptimal detector resolution isotope identification. Furthermore, suboptimal detector resolutions can effectively identify HEU even with interfering photopeaks.

DEDICATION

To my parents, Vicky and Scott Ash. Thank you for supporting me through all of my goals in life. You are always there every time I need help, a hug, someone to talk with about my day, or to celebrate an accomplishment.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

Dr. Craig Marianno, Dr. John Ford, and Dr. Jasen Castillo were members of the thesis committee supervising this work.

Dr. Craig Marianno provided the outputs from Genie and GammaVision using the resolutions provided by the student.

All other work was completed by the student.

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1. INTRODUCTION

Radiation detectors are used in many national security areas, such as portal monitors, handheld detectors, and in research laboratories. Every year, the government spends millions of dollars to improve the resolution of detectors that operate at room temperature for their use in border security. With improved resolution, the detector spectra are more defined and have less interference present between the peaks. Rather than striving to make marginal improvements in detector resolution, this research addressed the question of how suboptimal a detector could become before software could no longer identify a highly enriched uranium (HEU) source. A 90% enriched ^{235}U HEU source was selected because it can be easily masked with common radioisotopes used in medical procedures. In the field of spectroscopy, a minimum resolution is needed in order to have a high confidence in automated source identification analysis. [1] This research was completed in order to inform interested government agencies and manufacturers of minimum resolution requirements for detectors.

This research focused on three radionuclide identification software programs, the Gamma Detector Response and Analysis Software (GADRAS), GammaVision, and the Gamma Acquisition and Analysis (Genie) software. Their outputs were analyzed to determine the minimum resolution necessary to identify a HEU source by itself and in the presence of an interference radionuclide. Interference radionuclides are sources that have peaks in close proximity to the HEU source which could cause an automated identification algorithm to identify the interference source and not the HEU.

The resolution of a detector directly impacts the potential for interference between sources. Detector resolution is how well the detector can distinguish between two closely located peaks. [2] Resolution is the full width at the half maximum (FWHM) of a peak's height divided by the centroid energy of the peak (Equation 1). [3] For scintillation detectors, the reference photopeak to determine resolution is produced for 662 keV photon emitted from ^{137}Cs.

$$Resolution = \frac{FWHM}{H_0} * 100\% \qquad \text{Equation 1}$$

Where:

FWHM = the full width at the half maximum of the 662 keV photopeak

H_0 = the peak centroid of the 662 keV photopeak

The smaller the resolution percentage the more defined the spectra appears and the easier it is for the identification algorithms to distinguish between peaks. [1] This can be seen in Figure 1 where the top spectra, seen in red, is the poorer resolution and the bottom spectra, seen in yellow, is the better resolution. The peaks for the better resolution spectra, taken with a high purity germanium (HPGe) detector are much sharper in comparison to the peaks for the poorer resolution spectra, taken with a sodium iodide detector (NaI), and as such contain much more detail throughout the spectra.

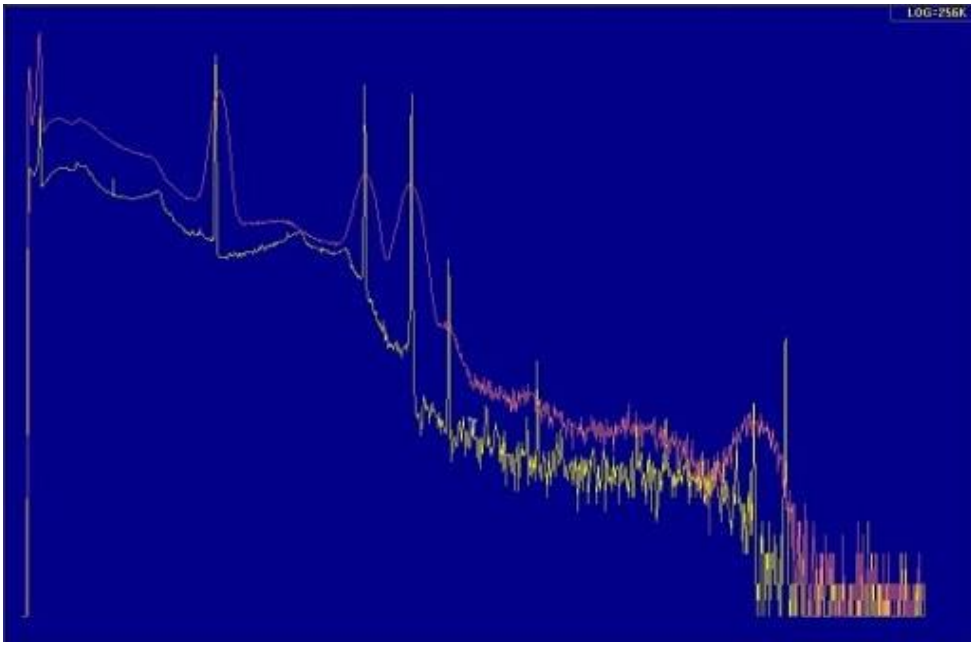

Figure 1. Example spectra taken with two different detectors, NaI and HPGe. The top red spectrum was taken with a NaI detector, and the bottom yellow spectrum was taken with a HPGe detector. The HPGe has the better resolution in comparison to the NaI.

If a detector were to experience a set number of pulse events, a poorer resolution detector would have a wider peak than the better resolution detector due to fluctuations that would occur in each recorded pulse. [2] Therefore, sources that have high branching ratios or greater activity can obscure close neighboring peaks that possess lower branching ratios or less activity. This has the potential to allow special nuclear material (SNM) to slip past monitors without raising an alarm, which is unacceptable. For example, ^{235}U has peaks at 144 keV, 163 keV, 186 keV, and 205 keV while ^{99m}Tc has a peak at 140 keV. In a detector with poor resolution, the 140 keV peak could obscure the ^{235}U peaks. This effect can be seen in Figure 2.

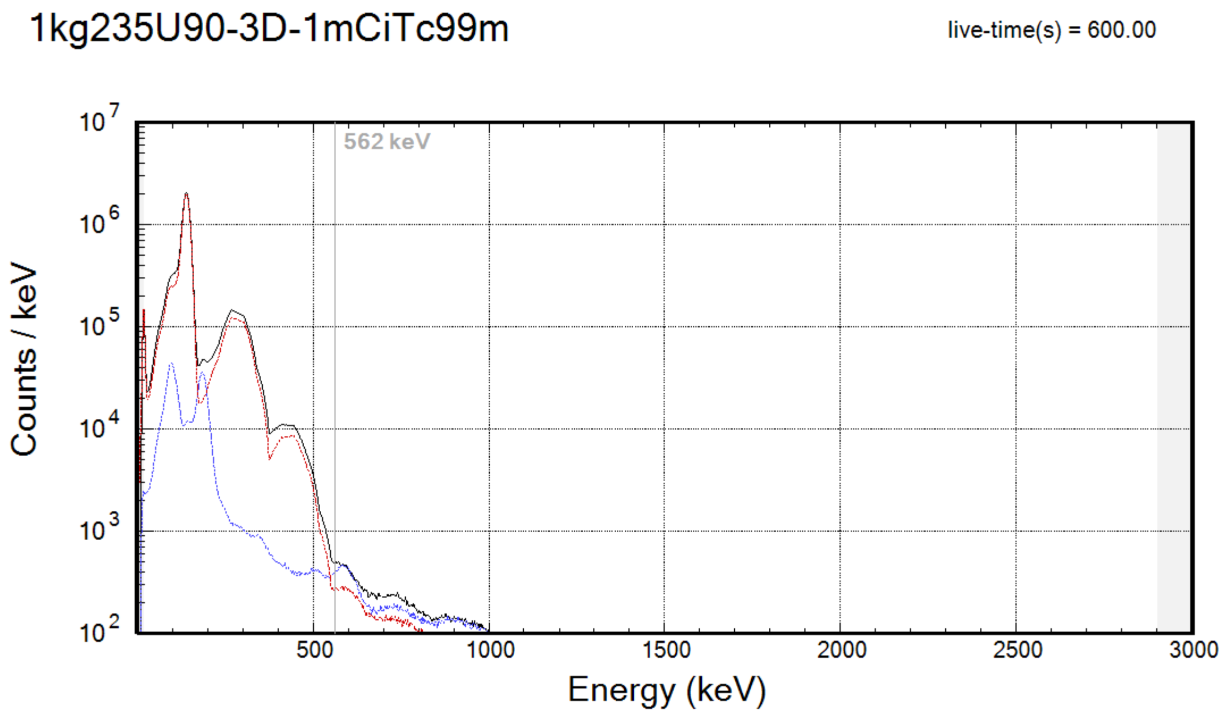

Figure 2. HEU and interference spectra generated with GADRAS using a NaI detector with an 8.92% resolution. The red line is the spectra for the 1 mCi ^{99m}Tc source placed 90 cm from the detector. The blue line is the spectra for the 1 kg ^{235}U enriched to 90% placed 100 cm from the detector. The black line is the combined spectra of the two sources together, with the HEU 100 cm from the detector and the ^{99m}Tc 90 cm from the detector.

In Figure 2, the red spectrum is from a 1 mCi ^{99m}Tc source placed 90 cm from the detector, the blue spectrum is from a 1 kg ^{235}U source enriched to 90% and placed 100 cm from the detector, and the black spectra is from the two configurations combined. As seen with the black spectra, the ^{99m}Tc is masking the ^{235}U peaks. When the combined configuration is analyzed in GADRAS, the ^{235}U is not identified. This led to the selection of ^{235}U as the HEU source and ^{99m}Tc as the interference source for the purposes of this research. A sodium iodide (NaI) detector was utilized for this research as it is a commonly used detector in national security activities, such as border security. However, the type of detector was unimportant to this research as the focus was on proving that suboptimal detector resolution could identify HEU in the presence of an interference source and shielding.

Every commercially developed detector has an initial resolution that can degrade over time, causing the peaks to widen. The resolution of the detector is determined by the interior crystal's geometry, clarity, and material. These physical properties cannot be adjusted in a laboratory. Since this research needed incrementally adjusted resolutions, GADRAS was used to model different detector configurations. GADRAS allows the user to run deterministic simulations with simulated detectors that are created by the user to produce spectra. Terrestrial background data can be simulated in GADRAS, in addition to the detector response simulations, for 121 different background locations throughout the world. [4] GADRAS also includes default detectors the user can choose to copy in addition to allowing the user to create their own detector with its own specifications, such as the default detector with an altered resolution.

2. THE SOFTWARE

2.1 Gamma Detector Response and Analysis Software (GADRAS)

2.1.1 Introduction To GADRAS

GADRAS Version 18, used in this research, was created by Sandia National Laboratories in Albuquerque, New Mexico. It was created to solve the inverse transport problem, meaning that it would identify an unknown radionuclide using one or more radiation signatures. [5] The radionuclide identification process of GADRAS was designed with the intent that the software would be able to identify sources not just with peaks but the entire continuum of the spectra. As a result, GADRAS uses template matching to analyze spectra for nuclide identification.

Template matching is based on the knowledge that a spectral image is essentially a photograph. A database of known spectral images is utilized for template matching. Ideally, this database of spectral images is scalable based on the detector parameters specified by the user, like it is with GADRAS. For template matching, an unknown spectrum would be taken and compared with a library of known spectra. Then the known spectra that most closely matches the unknown would be identified as the radioisotope or mixture of radioisotopes. A confidence level would be included with this identification that specified how accurate the match likely is. This method considers both the peaks and continuum of the spectra when conducting the identification process.

GADRAS has many different functions. It allows the user to simulate detectors, sources, and their associated spectra with and without terrestrial background data. The software also allows for analysis of unknown radionuclides by using simulated detectors, which can be modeled and calibrated after physical detectors in addition to theoretical standard detectors. GADRAS version 18 was used for this research.

2.1.2 GADRAS Detector Response Simulation

Generating a new detector in GADRAS creates a detector response function (DRF). Each DRF is saved in a detector directory as a .dat file. This file contains the response function parameters for the detector and does not typically need to be altered after the initial detector characterization during creation. [4] However, changes to shielding or substantial changes in the detector's surroundings for data acquisition would require the DRF parameters to be adjusted. [4]

When creating a new detector in GADRAS the user can decide to either create a new detector or clone an existing detector. To do this the user selects the 'Create New Detector' option on the Detector Tab. Examples of this will be shown in the 3rd section. Creating a new detector, whether from scratch or by cloning, requires the user to name the new detector, select a parent directory for the detector, and specify the distance between the source and the detector. [4] The source-to-detector distance can be altered at this time if needed once the detector has been created. Cloning a detector will create a new detector directory with a new name and the appropriate .dat files as modified by the specified source-to-detector distance. [4] Creating a new detector gives the user control over the specifics of the detector including the type, number of spectral channels, and dimensions of the detector. A rectangular prism is always assumed for the detector shape. However, if a circular detector is desired a slightly different creation process needs to be followed. [4] After the detector has been created, the detector response function parameters are able to be seen and changed on the Detector Tab. From this tab a known detector can also be spectrally calibrated using real spectral files obtained with the actual physical detector. [4] This allows the simulated detector to more closely match the physical detector.

2.1.3 GADRAS Source Simulation

Sources can be simulated in GADRAS using the Model Tab. The user can create 1D and 3D models of their source configurations. The 3D model is created using a collection of 1D models that have been rotated in 3D from their location. [4] The 1D models used to create the 3D models should be kept in the same source or detector directory. When saving a 1D model, a physics simulation is immediately conducted by GADRAS, using multiple deterministic transport codes and input libraries. [4]

From the Model Tab, the user may specify the simulated source geometry, the material, and other specifications such as age and density. The material manager used in the Model Tab allows the user to copy, alter, or create their own material configurations for use in the models as desired. [4] When generating a 3D simulation, the user can also specify the origin of the 1D model being added to the 3D model. This is helpful when generating a source configuration that uses multiple sources at different locations in relation to the detector face.

2.1.4 GADRAS Spectral Generation

For this research, simulated spectra were generated using the Inject Tab in GADRAS. This tab allows the user to specify the general settings such as date, time, source location, and file names for the generated spectra. The Inject Tab also allows users to specify the virtual gamma detector information. This is the detector that was used to "collect" the generated spectra. The type of detector selected and opened in the Detector Tab will be the same as the type available for spectral generation in the Inject Tab, so if a user wants simulated spectra obtained using a NaI detector then a NaI detector must be opened in the Detector Tab. [4] The gamma detector information is where the resolution of the detector was changed for the simulations used in this research. Finally, the Inject Tab allows the user to add spectral background data to any generated spectrum. GADRAS is capable of generating background data from several geographic locations around the world. [4] If terrestrial background information is not included, the spectra will appear as if it has been background subtracted. [4] There is also a neutron section available if the detector being simulated has neutron detection capability. [4]

2.1.5 GADRAS Isotope Identification

Using the Analyze Tab, the spectra can be analyzed using Single Regression, Multiple Regression, IsotopeID, Search, Compute Flux, SNM Analysis, and 1DModel Fit FSA. For this research the IsotopeID function was used to identify the spectra. From the Analyze Tab, the user could drag the spectral plot file into the Foreground section of the table. Then the user alters the distance and height information between the source and detector, if needed. The user could also choose whether to subtract the background information of not. If electing to subtract the background the user can either specify the background information by dragging a spectral file to the Background section of the table or leaving the background information unknown. If the strip background is selected but the background information is left unknown, GADRAS will estimate the background to subtract based on different spectral features in the measurement process. [4]

The IsotopeID function was used in this research. This function analyzed the spectra searching for nuclides in a template database. A default DB.dat database file was used, but it can be altered by the user if desired. If the file is altered and GADRAS is updated, the file will be overwritten, therefore alteration of the database file is not recommended. [4] From the IsotopeID section, the user can specify the gamma rate alarm threshold, radiation detection device activity threshold, false alarm parameter, and whether to show the activity estimate or allow background scaling. The user can also choose to either apply the energy calibration in file or process as raw spectra with nominal energy calibration. For each new detector, the IsotopeID analysis will create new templates for the current detector. [4] GADRAS attempts to fit these templates to the unknown spectra to determine a best fit that most closely follows the unknown spectra. [4] These templates will not need to be altered again unless the user changes the detector parameters. [4]

The program will generate spectra and compare them to the “unknown” spectrum. An example is displayed in Figure 3. The top black line of the spectra is the original spectral image. The dark blue is the portion of the spectra that GADRAS has fit ^{235}U and the teal is the portion fit to the ^{232}U template. There are also background spectra visible that GADRAS suspects to be present in the analyzed spectra.

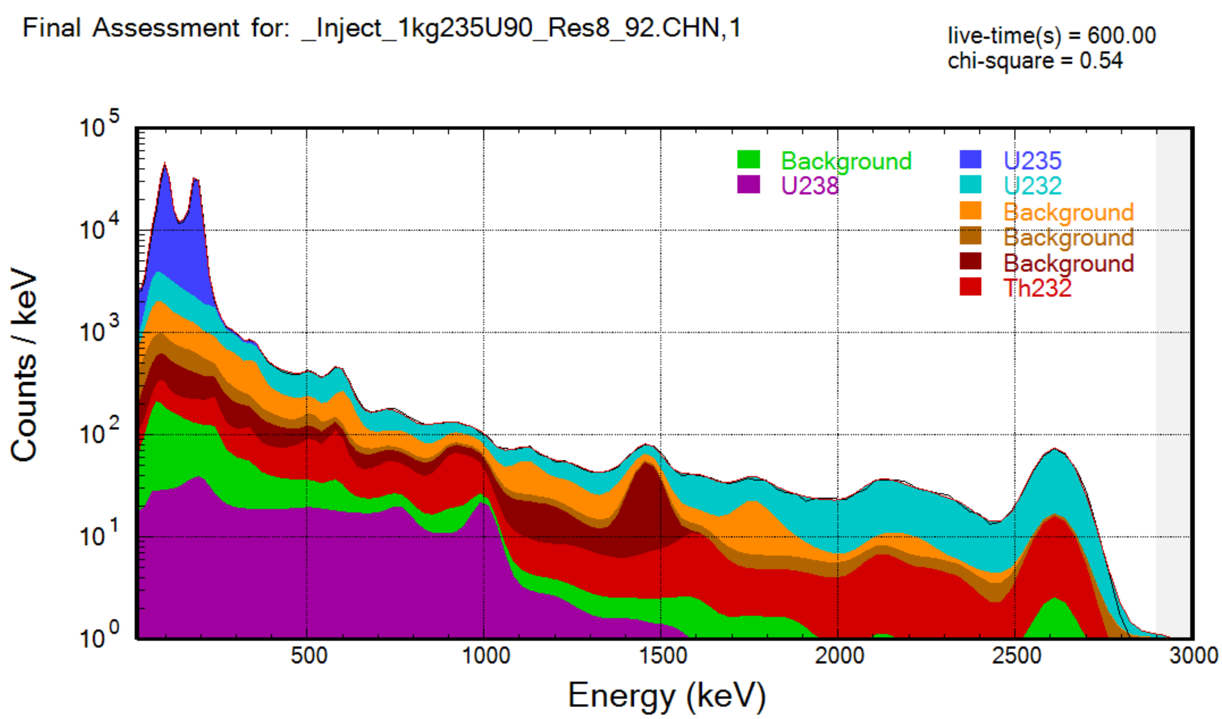

Figure 3. Final analysis spectral results for 1 kg ^{235}U enriched to 90% with a default detector resolution of 8.92%.

A text result also accompanies the spectral results, the corresponding example is shown in Figure 4. These results summarize the information in the spectral results and provide more information, such as the threat, the probability that SNM is present, alarm severity and description, and the gamma and neutron information. In Figure 4, GADRAS expects there to be almost 1 kg of ^{235}U present, as well as some background materials.

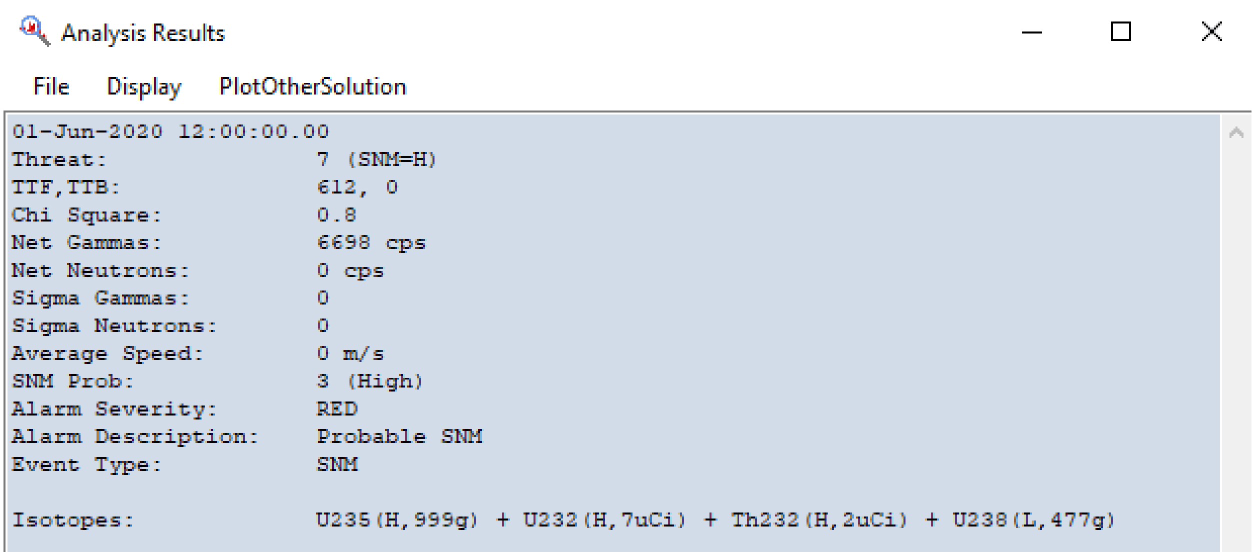

Figure 4. Final text results for 1 kg 235U enriched to 90% with a default detector resolution of 8.92%.

2.2 Gamma Acquisition and Analysis (GENIE)

2.2.1 Introduction to Genie

The Gamma Acquisition and Analysis (Genie) 2000 Spectroscopy Software was created by Canberra Industries. Genie was created for the acquisition and analysis of spectra obtained from multichannel analyzers (MCAs). Genie is considered a comprehensive program for MCA control, spectral display and manipulation, basic spectrum analysis and reporting, comprehensive spectrum analysis for use in alpha and gamma spectroscopy, quality assurance, and system automation for specified applications. [6] Genie possesses both an interactive environment for experienced users and a more restrictive batch environment for technicians who are not trained or qualified to operate all functions of Genie. [6] The batch environments are used in routine applications that possess lots of repetition such as sample counting, waste assay, or safeguards measurement confirmations and can be unique for those specific requirements. [6] The interactive environment was utilized for this research.

2.2.2 Genie Nuclide Library Editor

For this research, a user specified radionuclide library was used for the nuclide identification process. This was done using the Nuclide Library Editor in Genie. A unique library can be created for specific nuclides using either existing libraries and/or manual input. [6] The uncertainty associated with the energy lines for each radionuclide can be altered in this library. [6] For this research, the radionuclides listed in the library were the same for both Genie and GammaVision.

2.2.3 Genie Analysis Sequence

Genie utilizes what is called an “analysis sequence” to automatically analyze spectra. [6] The user may create a sequence by selecting steps from a menu and inserting them into a sequence in a desired order. [6] For this research, Peak Locate, Peak Area, Save Datasource, and Nuclide Identification plus w/Interference Correction were used. An Unidentified 2nd Differential algorithm setup was used for the Peak Locate function and a Sum/Non-Linear Least Squares Fit algorithm setup was used for the Peak Area function.

2.2.4 Genie Peak Locate

The Peak Locate function in Genie utilizes different algorithms to determine the peaks of interest in a spectrum. The possible different algorithms include 'User Specified', 'Library (Simple)', 'Library (Gamma-M)', 'Unidentified 2^{nd} Diff', and 'VMS Standard Peak Search'. [7] For this research Peak Locate was conducted using an Unidentified 2^{nd} Differential algorithm because this method is most appropriate for situations where the nuclides in the spectra are not known prior to analysis. [7] This algorithm locates the peaks of interest, that are significantly higher than the Compton continuum within a specified search region. [6] In the Unidentified 2^{nd} Differential, peak localization method, Genie uses a Generalized Second Difference method to identify peaks in a spectrum. Genie also estimates the FWHM of peaks in the spectrum using a Gaussian distribution. [7]

The Generalized Second Difference method begins by assuming that all of the spectral peaks can be described by Gaussian functions. [7] The background is assumed to be described by a linear function, when using short spectral intervals. Assuming a short interval is used, the number of counts at a particular channel number is given by Equation 2. [7] If the number of counts is assumed to be a continuous function, its second derivative becomes independent of the spectral background and anywhere where the number of counts does not equal zero a peak exists. [7]

$$N(x) = G(x) + B + Cx \qquad \text{Equation 2}$$

Where,

x = channel number

$G(x)$ = the Gaussian peak function

$B + Cx$ = the linear function describing the background

Every 100 channels, the linear function calculation is repeated to ensure accuracy. [7] The absolute value of the standard deviation of the generalized second difference equation must be greater than the user specified threshold value in order for the algorithm to consider a peak as found. [7] If no user specified threshold value is chosen, a default of four is used. [6]

Any peaks located can be added to the existing results through the setup screen if desired by the user, assuming the peaks are not within an existing peak's energy tolerance. [7] If the user does not choose to add the peaks to the existing results, the original peaks in the library will be overwritten by the peaks found during the peak locate phase. [7] While the peak locate algorithm is running, a peak shape test is conducted that classifies different spectral locations as Compton edges or continuum features rather than peaks due to the sign of the second difference remaining unchanged for an extended period. [7]

2.2.5 Genie Peak Area

The Peak Area function utilizes the Sum/Non-Linear Least Squares Fit Algorithm to determine the net peak area for every peak discovered in the peak locate phase of the analyze sequence. The Non-Linear Least Squares Fit Algorithm is used to determine the peak area for multiplets, which are overlapping peaks, whereas the Summation method is used to determine the area of singular peaks. [6] If preferred, the user can choose to use the peak fitting method for singular peaks rather than the summation method. The Sum/Non-Linear Least Squares Fit algorithm for the peak area phase determines the Region of Interest (ROI) for each peak automatically using the selected peak locate method. [7] Any closely located peaks are analyzed as multiplets and grouped into multiplet ROIs. [7]

The automatic calculation of ROI limits in this research also determined whether the closely located peaks would be analyzed as multiplets or two single peaks in the peak area phase.

[7] The algorithm automatically checked all the centroids from smallest to largest, comparing each peak to the next largest, to determine if a multiplet needed to be formed. [7] To be considered part of a multiplet, Equation 3 needs to be true for a lower centroid location, i, and the next larger peak location, $i+1$. [7] If a multiplet is located, the next larger peak, $i+2$, is checked against $i+1$, and so on until Equation 3 is false. [7] A maximum of 16 peaks are allowed in a single multiplet. [7]

$$C_{i+1} - C_i < n_W * W \qquad \text{Equation 3}$$

Where:

C_{i+1} = the centroid of peak $i+1$ [channels]

C_i = the centroid of peak i [channels]

W = the expected FWHM [channels]

n_W = the separation parameter, user selectable [channels]

Once the singlets and multiplets are determined, they need to be analyzed for their left and right boundaries. Starting at the peak centroid minus 0.8*FWHM, for each channel, point averages are calculated. [7] When the expected peak width is five or less, the point average is five. [7] When the expected peak width is greater than five, the point average is the smallest, odd number that is equal to the expected peak width or greater. [7] The left ROI boundary is the first channel where the point average reaches a minimum to the left of the peak and the right ROI boundary is the first channel where the point average reaches a minimum to the right of the peak. [7]

After the boundaries of the ROIs are determined, the number of channels in the ROI is determined. There are two possible methods for this, one where the number of channels are fixed and one where the number of channels are variable and calculated based on the FWHM at the middle of the ROI, with a minimum of one always being used. [6] A maximum of 512 channels is allowed in a single ROI. [7]

For singular peaks, not using the fitted method, the net area is calculated using Equation 4. [7] The continuum can be calculated as a linear continuum as defined by the Genie 2000 Customization manual. The uncertainty associated with the net peak area is then automatically calculated by the peak area algorithm. [7]

$$S = G - B \qquad \text{Equation 4}$$

Where:

S = the net peak area

G = the sum of the cross counts in the peak ROI

B = the continuum

For multiplets and the single peak fitting method, the Non-Linear Least Squares Fit algorithm techniques are used as described in the Genie 2000 Customization manual. First, the algorithm ensures that the matrix is solvable and not singular, because peak locate algorithms can place peaks where peaks are not present and create unsolvable matrices. [7] The Non-Linear Least Squares fit algorithm deletes peak information from the results when the peaks fall within the energy tolerance of another peak, even if it does as a result of iterative calculations. [7] If the peak that was removed was removed from a multiplet, the multiplet is refit using the remaining peak or peaks as either a multiplet or single peak, as needed. [7] Once the fit has been made, the area of that peak or multiplet is calculated, followed automatically by the associated error. [7]

2.2.6 Genie Nuclide Identification

Nuclide Identification plus w/ Interference Correction calculates the activity of the nuclides and identifies the nuclides. It also automatically performs an interference correction and weighted mean calculation because the analyzation steps chosen already determined the areas of the peaks and conducted efficiency corrections. [6] The Genie nuclide identification can be used over a specified energy range utilizing a user specified nuclide library. [6] For this research a library of expected nuclides and expected interference nuclides was created for use in the nuclide identification phase and will be discussed in greater detail in a following section. A tolerance value is the allowable difference between an identified peak and the library defined peak information which must be specified in either energy or FWHM. This value will be used when comparing spectral peaks to the list of peaks in the nuclide library. Confidence factors must also be chosen for the nuclide identification threshold and the minimum detectable activity (MDA) confidence factor. [6] The nuclide identification threshold sets a minimum confidence level for the nuclides identified by Genie, which must be surpassed in order to report a nuclide identification for a spectral peak. [6] The MDA confidence factor requires a value but will only be used when the Critical Level test is selected during the Peak Area phase, and as such was not utilized in this research. [6] At the end of the identification phase, if the Generate Report box was checked, a report would be generated in the Report Window containing the analysis performed by Genie.

2.3 GammaVision

2.3.1 Introduction to GammaVision

GammaVision Version 9, a Gamma-Ray Spectrum Analysis and MCA Emulator created by ORTEC, was also used to analyze the spectrum in this research. GammaVision was designed to provide the user with tools to simplify the work conducted in a counting laboratory. [8] Originally, GammaVision was designed for use with High Purity Germanium (HPGe) detectors to analyze high resolution spectra. [8] Beginning with version 8, GammaVision introduced an analysis routine for use with NaI detectors to analyze low resolution spectra. [8] GammaVision was selected for investigation in this research due to the low-resolution spectral analysis routine.

2.3.2 GammaVision Peak Identification

GammaVision's Peak Identification process was conducted by selecting a spectra for analysis, selecting a library for analysis, and then adjusting the analysis parameters in the Settings submenu. The user must select a working library for use in the identification process because GammaVision will specifically use that library for comparison to the spectral unknowns during the nuclide identification process. [8] The library used was the same for the GammaVision and Genie software and will be discussed in greater detail in the following sections. Once the working library was selected, the analysis parameters were adjusted using the settings submenu.

First, the analysis parameters were adjusted using the Sample tab of the Settings submenu. Here, the user could define a name for the analysis sequence so that it could be saved as a unique sequence. The user could also define the range for analysis between the ROIs and spectral continuum which would be used to calculate the spectral background when determining the area of the peaks. [8] Next, the user would set the file directory location for the user defined working library for GammaVision to utilize in the analysis process. Then, the user would specify the calibration file for the algorithm to use when defining the energies of the peaks during the analysis process. [8]

Next, the Systems tab of the settings submenu was utilized to further adjust the analysis parameters. This tab allows the user to define the Match Width, which was the minimum distance allowed for comparison between the library's nuclide peaks and the actual spectral peaks being identified. [8] A Peak Search Sensitivity value was also selected to prevent the algorithm from identifying peaks where no peaks were present. [8] This tab also allowed the user to specify a Suspected Nuclides library for the analysis process to compare against.

The analysis parameters were then further adjusted using the Analysis tab of the settings submenu. From this tab, the user was able to adjust the sensitivity of the peak identification process to limit the amount of false peaks by specifying the Peak Cutoff percentage. [8] The user was also able to specify the desired systematic and random errors allowable in the analysis process. Finally, the user was able to choose the analysis method for the identification process. The “NAI32 Analysis” routine was selected for the analysis process because it was specifically created for NaI analysis. [8] This analysis process displayed results for all potential nuclide matches along with the activity for all located peaks without including user defined confidence levels or identification confidence levels.

The NAI32 analysis process is a set analysis method in GammaVision whose program is not altered by the user. The NAI32 analysis process begins with a Mariscotti peak search and any energy peaks in the library that were not spectrally located with sufficient energy peaks were automatically removed, creating a reduced library. [8] The reduced library is then utilized for a more in-depth peak search and the raw data peak search is utilized a second time to ensure that all peaks were accounted for in the reduced library search. [8] For the NAI32 analysis process, the Library Based Peak Stripping cannot be disabled. [8] This is a peak interference correction where the program automatically detects overlapping peaks and separates the peak areas. [8]

3. METHODS

3.1 GADRAS

3.1.1 Simulating the Detector With GADRAS

The Detector tab on GADRAS, seen in Figure 5, was used to create a new detector using user defined parameters. First, the 'Create Detector from Parameters' function was selected to open the Create New Detector popup window, seen in Figure 6. A name for the detector was chosen and the parent directory was specified. Here, the desired source-to-detector distance used in the research was specified to be 100 cm. Throughout this research the HEU source was always 100 cm away from the face of the detector. Next, the detector type was set to a NaI detector with 1024 channels, a length of 2 in (5.08 cm), height of 16 in (40.64 cm), and a width of 4 in (10.16 cm). This created a default 2 x 4 x 6 NaI detector with a default resolution of 8.92%. After detector creation, nothing further was adjusted on the simulated detector. Copies of the original default 8.92% detector were created throughout the research and the resolution was adjusted on the copied versions of the original simulated detector.

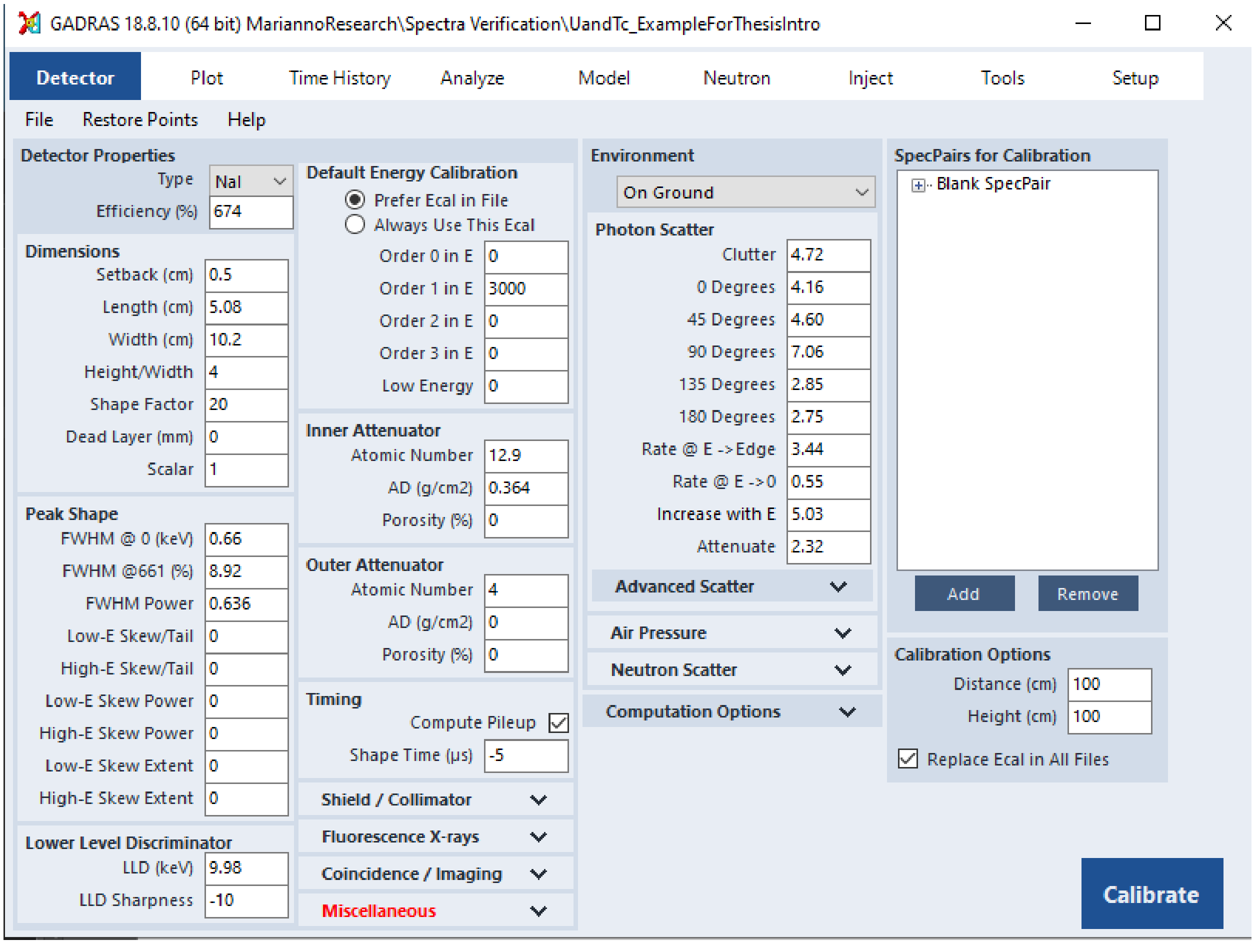

Figure 5. The Detector Tab in GADRAS.

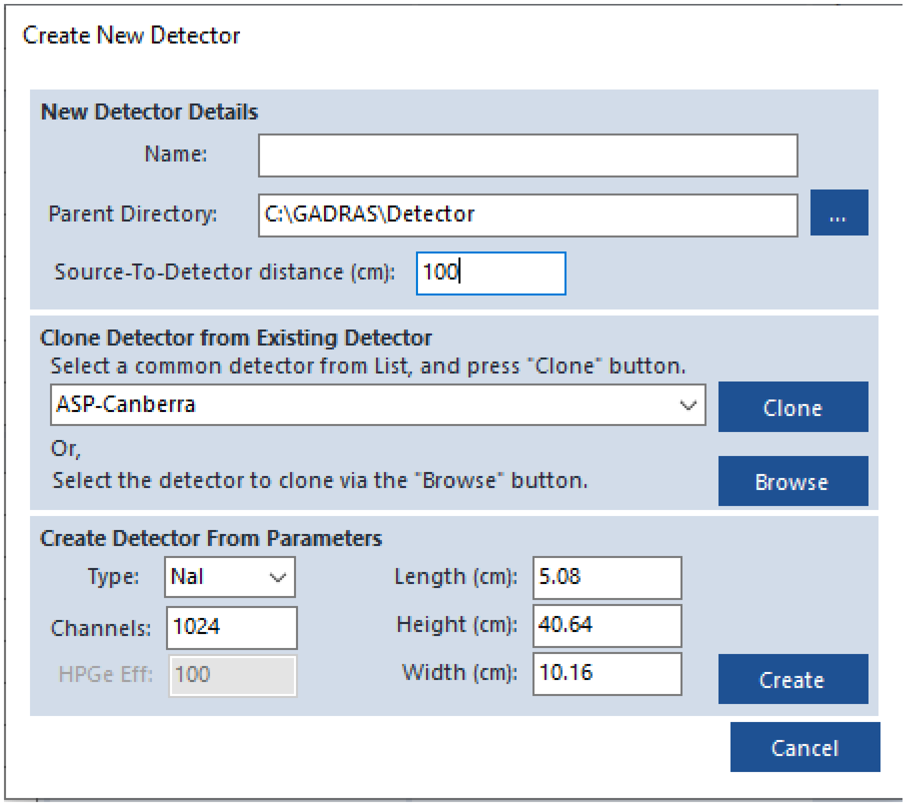

Figure 6. The Create New Detector window that was accessed from the Detector tab in GADRAS to simulate NaI detectors for this research.

3.1.2 Simulating the Sources With GADRAS

When choosing the sources for simulation in GADRAS, consideration was given to what source could interfere with HEU for use as an interference source. ^{99m}Tc is a common medical radioisotope that has a gamma peak at 140 keV and ^{235}U has gamma peaks at 144 keV, 163 keV, 186 keV, and 205 keV. The close proximity between the ^{99m}Tc 140 keV peak and the ^{235}U peaks can create interference for a suboptimal resolution detector. This interference has the potential to be strong enough to allow the HEU to go through a portal monitor undetected. For this reason, ^{99m}Tc was chosen as the interference source for the HEU source.

The source configurations used for analysis in this research were created in the Model tab of GADRAS, an example of which can be seen in Figure 7. The source configurations, which can be seen in Figure 8-13, include:

1) a 1 kg HEU cylinder with no shielding placed 100 cm from the detector
2) a 1 kg HEU cylinder placed 100 cm from the detector. It was shielded with a stainless-steel slab to reduce the dose rate of the source to 50% of its computed dose rate.
3) a 1 kg HEU cylinder placed 100 cm from the detector. It was shielded with a stainless-steel slab to reduce the dose rate of the source to 90% of its computed dose rate.
4) a 1 kg HEU cylinder placed 100 cm from the detector with a 100 μCi ^{99m}Tc sphere placed between the detector and HEU
5) a 1 kg HEU cylinder placed 100 cm from the detector with a 100 μCi ^{99m}Tc sphere placed between the detector and HEU. It was shielded with a stainless-steel slab to reduce the dose rate of the source to 50% of the computed dose rate of both sources.
6) a 1 kg HEU cylinder placed 100 cm from the detector with a 100 μCi ^{99m}Tc sphere placed between the detector and HEU. It was shielded with a stainless-steel slab to reduce the dose rate of the source to 90% of the computed dose rate of both sources.

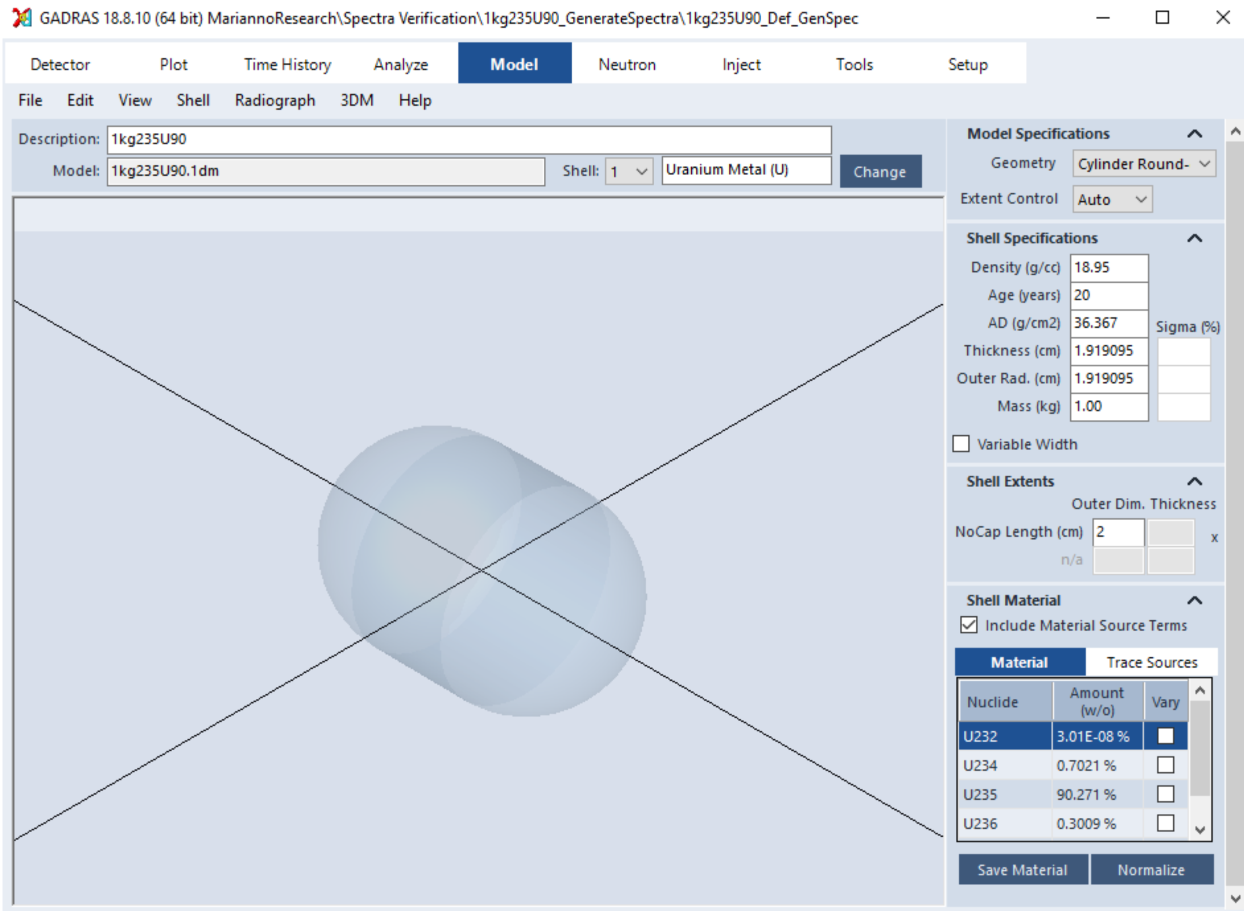

Figure 7. The Model Tab in GADRAS utilized to simulate the source configurations.

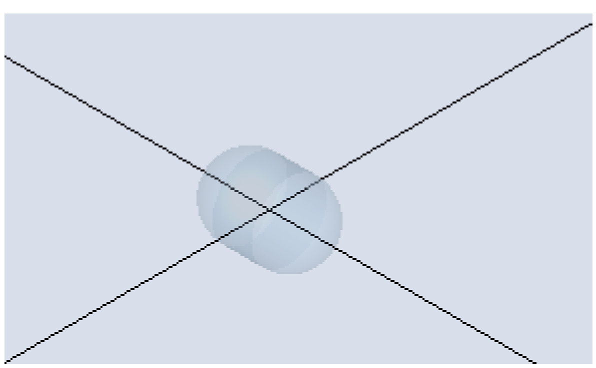

Figure 8. A GADRAS generated graphic of the first source configuration, bare HEU.

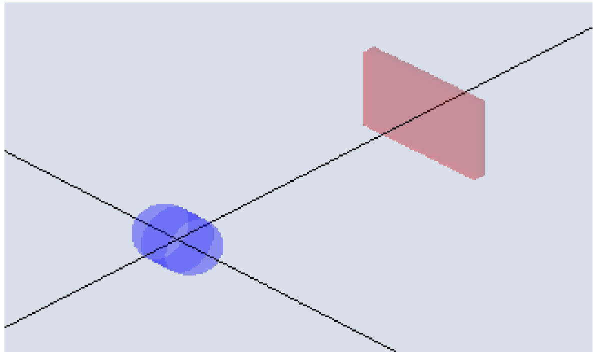

Figure 9. A GADRAS generated graphic of the second source configuration, bare HEU with 50% shielding.

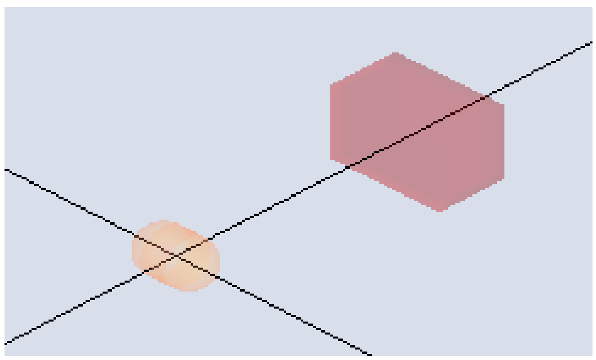

Figure 10. A GADRAS generated graphic of the third source configuration, bare HEU with 90% shielding.

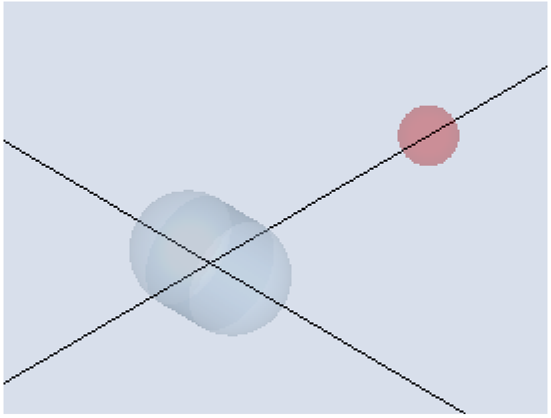

Figure 11. A GADRAS generated graphic of the fourth configuration, HEU and interference source.

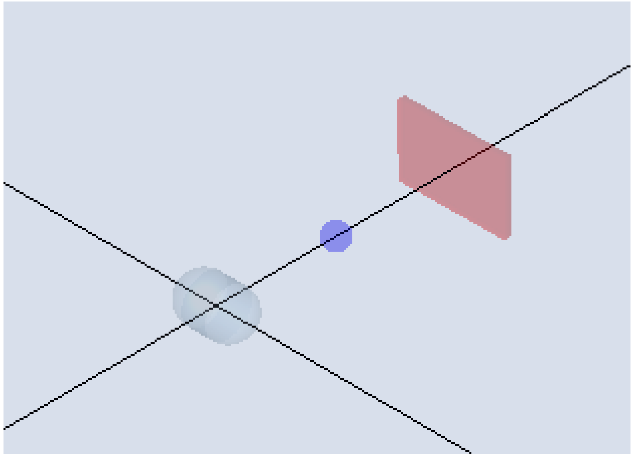

Figure 12. A GADRAS generated graphic of the fifth configuration, HEU and interference source with 50% shielding.

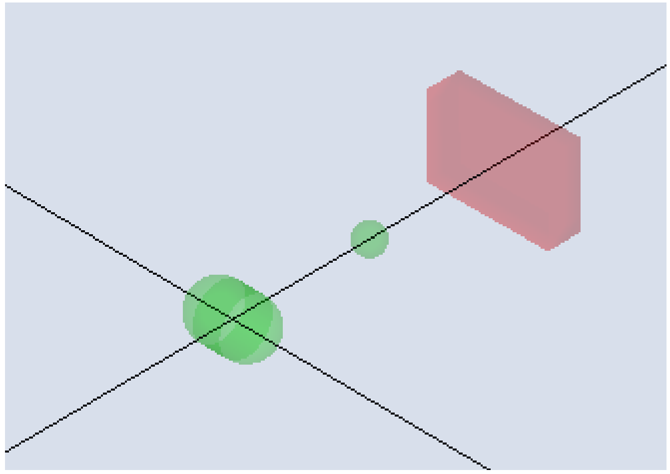

Figure 13. A GADRAS generated graphic of the sixth configuration, HEU and interference source with 90% shielding.

For the six configurations, calculations had to be conducted to ensure that the stainless-steel shielding was thick enough to reduce the dose rate of the source to 50% or 90% of its computed dose rate, as needed. The Tools Tab in GADRAS, Figure 14, contains many helpful items, including the Dose Calc Calculator. The built-in Dose Calc calculator was utilized to automatically compute the dose rate for the source model currently open on the Model tab. For the first configuration, the computed dose rate determined by GADRAS was 4.1 μRem hr^{-1}, Figure 15. The computed dose rate for the second and third configurations were reduced to 50% and 90% of the first configuration, respectively, coming out to 2.1 μRem hr^{-1} and 0.412 μRem hr^{-1}, respectively. For the fourth configuration, the computed dose rate determined by GADRAS was 12.7 μRem hr^{-1}. The computed dose rate for the fifth and sixth configurations were reduced to 50% and 90% of the first configuration, respectively, coming out to 6.3 μRem hr^{-1} and 1.2 μRem hr^{-1}, respectively.

Figure 14. The Tools Tab in GADRAS where the dose calculation function of GADRAS was accessed.

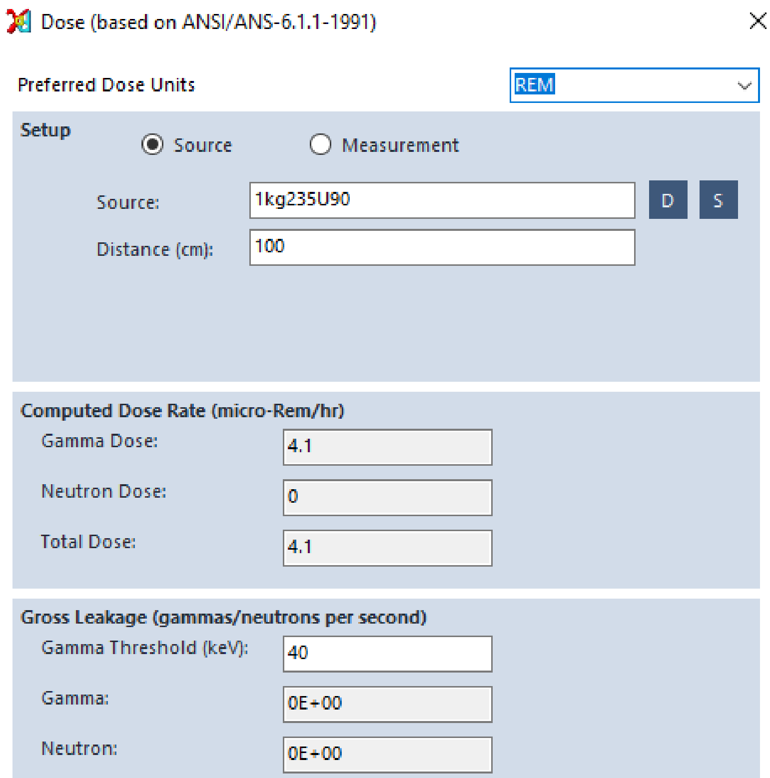

Figure 15. The Dose Calculation window that displays the dose calculations for the specified source.

Source configurations were created as new models in the Model Tab and saved to the detector folder or source folder. Beginning with the first configuration, a round-end cylinder was modeled from 1 kg ^{235}U enriched to 90%. An example of the GADRAS model specifications input window is displayed in Figure 16.

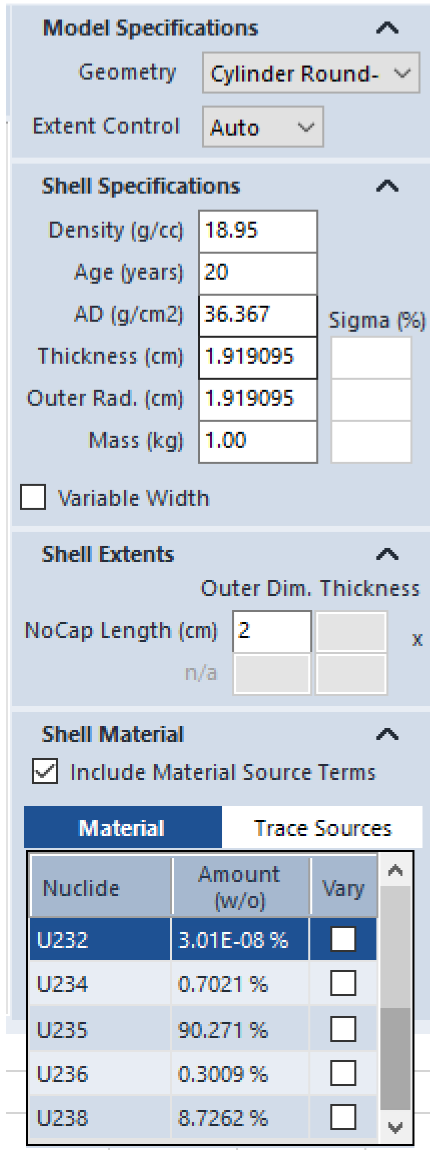

Figure 16. Information used to model the first configuration in GADRAS.

The copies of the first configuration were used as base models for the second and third configurations. A new model was created of a stainless steel 304 (SS-304) slab. Copies of the SS-304 slab were also created to serve as base models. Then, for the second configuration, the copied cylinder file was opened and a "NEW 3DM From Current Model" was selected to create a 3D model of this cylinder so the face of the detector was 100 cm away. From there, "Insert

Model" was selected to add the SS-304 slab to the 3D model. The slab was placed 80 cm from the detector face. The thickness of the slab was increased until the calculated dose rate was reduced to 50% of its unshielded value, using the "Dose Calc" function in GADRAS. The thickness of the slab was increased in the third configuration until the calculated dose rate was reduced to 90% of its unshielded value, using the "Dose Calc" function in GADRAS. For the fourth configuration, a new model was created for the spherical 100 μCi ^{99m}Tc source. The copied cylinder file was opened and a "NEW 3DM From Current Model" was selected to create a 3D model of the HEU cylinder so that the detector face was 100 cm. From there, "Insert Model" was selected to add the ^{99m}Tc sphere to the 3D model so that the detector face was 90 cm away. A copy of the fourth configuration was made and "Insert Model" was selected to add the SS-304 slab to the 3D model so that the detector face was 80 cm away. The thickness of the slab was then increased until the calculated dose rate was reduced by 50% of its unshielded value. For the sixth configuration the thickness of the slab was increased until the calculated dose rate was 90% of its unshielded value.

3.1.3 Simulating the Spectra With GADRAS

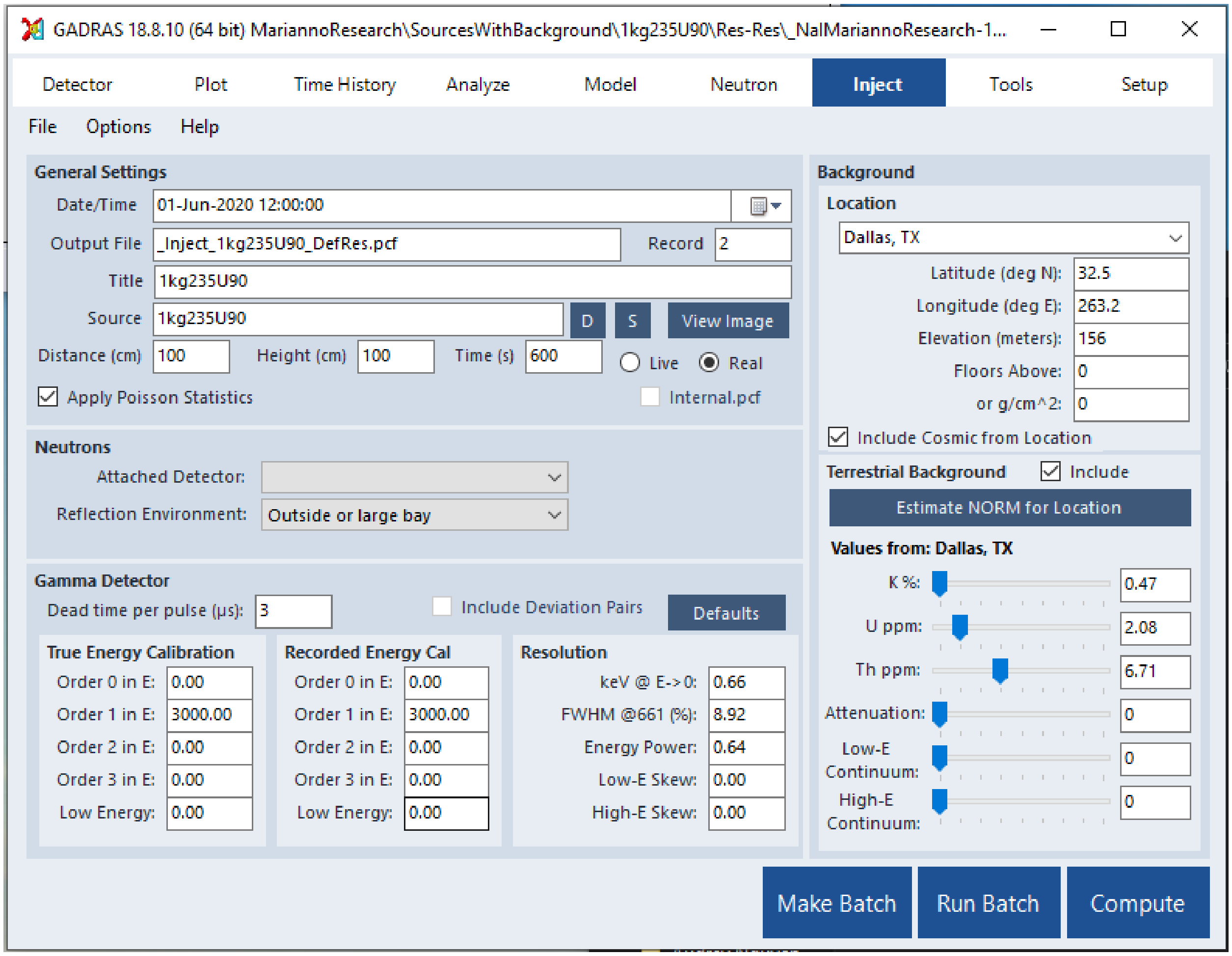

Figure 17. A visual of the Inject tab for the first configuration at the default NaI resolution of 8.92% using background data from Dallas, TX.

The spectra files used in this research were created using the Inject tab in GADRAS, Figure 17. This was done by creating the desired detector in the GADRAS Detector tab and modeling the desired source configuration in the Model tab. Then the created model configuration was selected in the Inject tab in GADRAS. For each spectrum generation, the date/time was set to 01-June-2020 12:00:00. This date and time are important because the cosmic background files in GADRAS are date and time dependent. The name of the output file and title were both specified and the desired source configuration was chosen. For each simulation, the distance between the source and detector was 100 cm, the height was 100 cm, and the simulated acquisition time was 600 s. The time was set to live time and “Apply Poisson Statistics” was selected. Live time was selected so that the acquisition time acquired for a full 600-s, accounting for dead time. The terrestrial background location was set to Dallas, TX and the boxes for “Include Cosmic from Location” and “Terrestrial Background Include” were both selected. The Estimate NORM for Location button was employed because GADRAS does not always automatically update the location when it is changed. Then, the “FWHM @661 (%)” was set to 8.92% and the simulated spectra was generated with an 8.92% resolution. Then the “FWHM @661 (%)” was incrementally increased until 100% resolution had been simulated. Once the spectra were generated, the spectral analysis began. If an identification routine failed to identify the HEU, finer changes in resolution were used to locate the terminal resolution to an accuracy of 1%. For instance, if HEU was not identified at 45% but was at 40%, more spectra were generated for that configuration for resolutions of 41%, 42%, 43%, and 44%.

3.1.4 Verifying the Simulated Resolution Increase in GADRAS Using PeakEasy

Before analysis could be conducted using GADRAS, the accuracy of the resolution adjustment in GADRAS needed to be tested. To do this, a gamma spectroscopy software known as PeakEasy was used. PeakEasy was created by Los Alamos National Laboratory to allow a user to quickly confirm the isotopes suspected when looking at a spectrum using Gaussian peak analysis and it provides the user with isotopic information. [9] PeakEasy is able to display and convert different file formats from commercial and government spectral software. [10]

Peak Easy was used to verify that GADRAS was increasing resolution as expected. To begin, a default 2” x 4” x 16” NaI detector was simulated in GADRAS with a default 8.92% resolution. Then, a spherical 1 mCi ^{137}Cs source model was simulated, Figure 18. Next, spectra were generated for resolutions at 8.92% and 11% before increasing by 2% increments until 51% resolution was achieved. After 51%, the resolution was increased by 10% increments until 100% resolution was achieved. Once generated, the spectrum was opened in PeakEasy and the 662 keV region of interest (ROI) was highlighted, the program would display the selected ROI’s resolution. The resolutions provided by PeakEasy matched the expected resolution based on the information input in GADRAS, up to roughly 25%, Table 2. Beginning at 25% resolution, GADRAS and PeakEasy started having variation between the two.

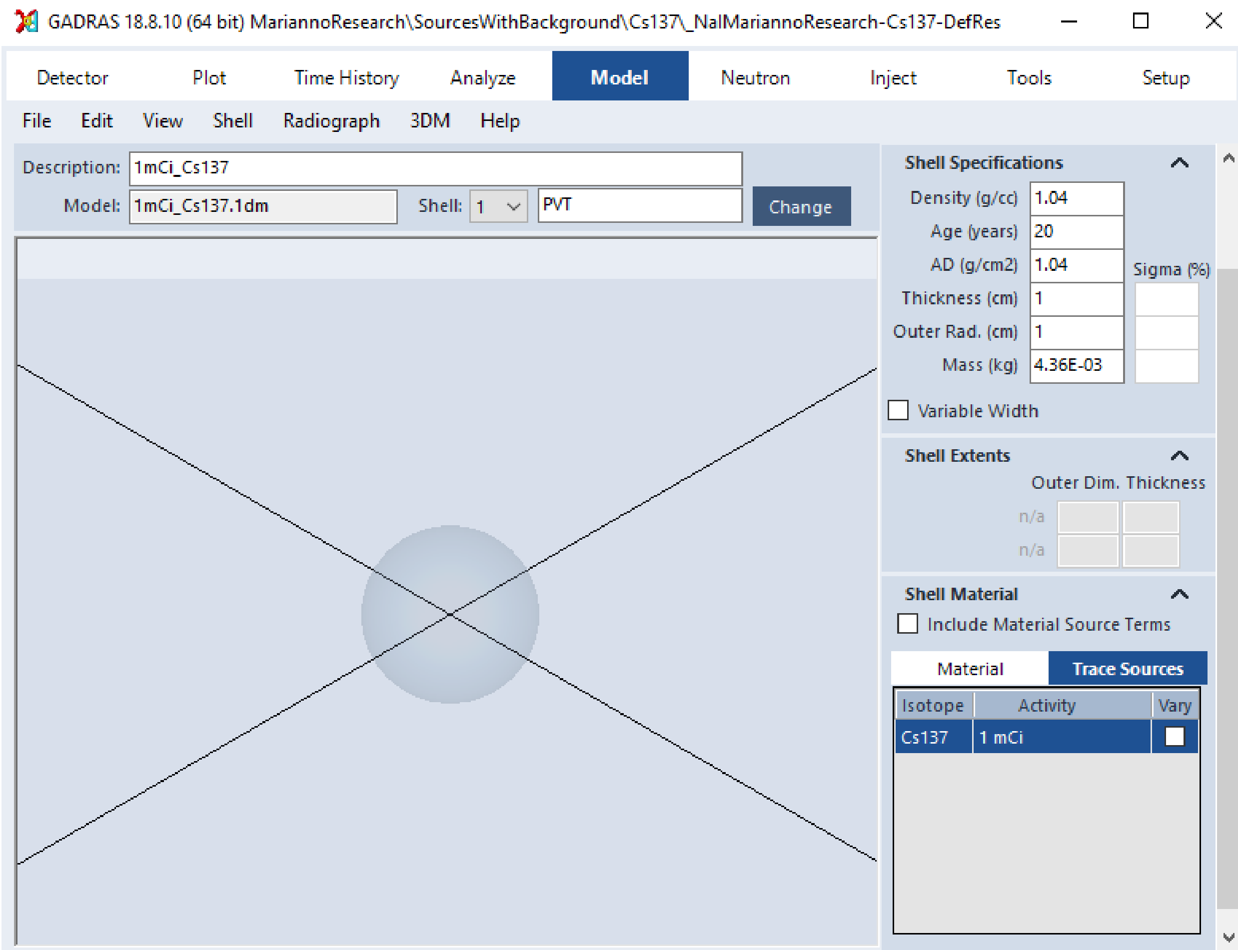

Figure 18. A GADRAS graphic of the spherical 1 mCi ^{137}Cs source utilized to verify the simulated detector resolution.

Table 1. The known GADRAS resolution compared to the associated resolution determined by PeakEasy.

GADRAS Resolution	PeakEasy Resolution
8.92	9
11	11
13	13
15	15
17	17
19	19
21	21
23	23
25	24
27	26
29	28
31	29
33	31
35	33
37	35
39	37
41	38
43	41
45	43
47	44
49	46
51	47
61	55
71	57
81	64
91	73
100	67

3.1.5 Two Different Approaches with GADRAS

A GADRAS user must indicate with the software the resolution of the detector that collected the unknown spectra. For this research, two different approaches were used to analyze the detector spectra. The first method used a default 2” x 4” x 16” NaI detector with an expected 8.92% resolution to analyze spectra taken with increasing resolution. This simulated the process where a user did not know the resolution of the detector that collected the data and therefore used the default resolution. The second method used a default 2” x 4” x 16” NaI detector but altered its resolution by changing the “FWHM @661(%)” to match the increasing resolution for the generation of the simulated detector spectra. Here, the user would know the resolution of the detector collecting the gamma spectrum. For the purposes of this research, both methods used terrestrial background data from Dallas, Texas in all the simulations. These two methods allowed for the comparison of results when a user knew the resolution of the detector system and when they did not.

3.1.6 Identifying the Unknowns with GADRAS

For the first method, where a detector with degraded resolution collected the spectra and GADRAS assumed a resolution of 8.92% was used to acquire the data, the Detector tab was set to the default NaI detector with an 8.92% resolution. The degraded resolution spectral data was loaded into the foreground of the Analyze tab in GADRAS starting with the 8.92% spectrum. The IsotopeID algorithm was selected for the identification process. Using the IsotopeID analysis window, Figure 19, the desired information was selected. After analysis the results were saved, the spectral file was changed to the next resolution value for that source configuration until the software could no longer identify the HEU. This process was repeated for each source configuration.

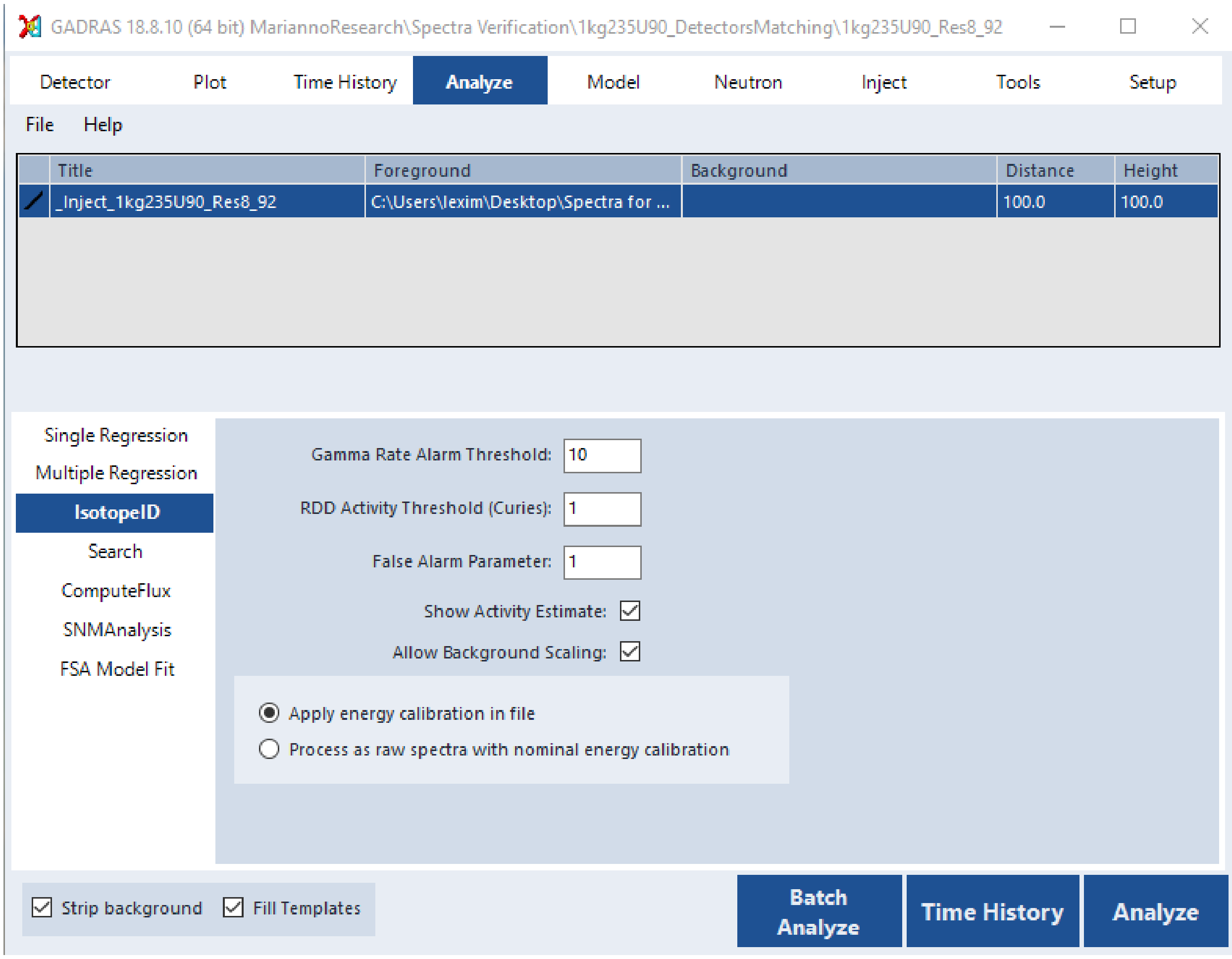

Figure 19. An example of the IsotopeID window of the Analysis tab used to analyze the unknown spectra.

For the second method, where the same detector was used for spectral collection and analysis, the Detector tab was set to the resolution used for the spectral generation of that particular spectral file. The default 8.92% detector was copied and then altered and saved for each resolution change. Beginning with the 8.92% default detector resolution, the spectral files were loaded into the foreground of the Analysis tab and the analysis was executed, always ensuring that the Detector tab detector resolution matched the resolution used to generate the spectral file. The results of the analysis were saved before changing to the next increased detector resolution and spectral file. This process was repeated until the software would no longer identify the HEU, for each configuration.

3.2 Libraries

3.2.1 Selecting the Libraries for Nuclide Identification

The libraries used in the nuclide identification processes and their effect on the analysis results had to be considered prior to conducting the nuclide identification for all three programs. GADRAS uses template matching for its peak identification. Limiting this library would reduce the effectiveness of the program as it would be missing templates needed for identification. For this reason, the default library was used in GADRAS which contained 309 different sources and source configurations. GammaVision and Genie use mathematical algorithms for their peak identification using the radionuclides in either a user specified or default library. Utilizing a user defined library limited to the sources of concern would reduce the false positive source identification results from the programs as there would be less gamma lines to test against.

Before beginning the identification process with Genie and GammaVision, a library of desired radionuclides and interference nuclides were created in Excel for eventual use in both GammaVision and Genie. The library was created by assembling a list of radioisotopes typically seen by border portal monitors. From there the list was reduced to only include radioisotopes of concern and their interference sources of concern. For this research, the library was comprised of HEU, background sources, and common medical and industrial radioisotopes. This kept the library limited in order to reduce the false positive identifications that results due to competing gamma lines. The final list of radioisotopes chosen for eventual use in the identification regimes are listed in Table 3.

Table 2. The isotopes used in the user defined libraries for Genie and GammaVision, with their associated gamma energies and yields.

Isotope	Gamma Energy (keV)	Yield (%)
^{228}Ac	338	11.3
	911	26.6
	969	16.2
^{241}Am	60	35.9
^{133}Ba	81	34.1
	276	7.2
	303	18.33
	356	62.1
	385	8.9
^{214}Bi	609	44.8
	1120	14.8
	1764	15.4
^{137}Cs	662	85.1
^{192}Ir	296	30.2
	308	31.8
	468	51.8
	604	8.9
^{40}K	1461	10.7
^{234m}Pa	766	0.3
	1001	0.9
^{212}Pb	239	43.3
	295	15.7
	352	35.8
^{99m}Tc	140	89.1
^{208}Tl	2614	100
^{235}U	144	10.96
	163	5.08
	185	57.2
	205	5

3.3 Genie

3.3.1 Identifying the Unknowns with Genie

Genie utilizes an analysis sequence for nuclide identification that consists of different phases. A sequence is defined by selecting different analysis steps from a menu and adding them into the sequence in the desired order. The first phase introduced was Peak Locate. Peak Locate was set up using an Unidentified 2nd Differential algorithm. The search region for this phase was limited between the spectrum channels of 5 and 1024. To limit the amount of false alarms generated by the sequence, a significance threshold of 3 was chosen, as suggested by the manual. The FWHM tolerance was then set to 1. This tolerance sets the phase to consider any peaks found within the FWHM to be part of the current peak. Any peaks located outside of the tolerance were defined as a new peak.

The next phase of the analysis sequence was Peak Area. This phase was set up with a Sum/Non-Linear Least Squares Fit algorithm to determine the area of the peaks located in the previous phase. For this phase, the region of analysis was set to be the same as the previous phase and the continuum was set to 1 FWHM with a step function to specify how the continuum surrounding the peaks, or background, should be used when calculating the net area of the peaks. The Perform Search box in the Residual Search section was selected with a threshold of 3 and a minimum separation of 1 FWHM in order to have the phase search the ROIs for other components in the peak region that were not found by Peak Locate. This would allow for new peaks to be identified for the highest residual that was at least 1 FWHM from the nearest established peak, until no more peaks could be added. The ROI Limits Determination was also set to 1 for the maximum number of FWHMs between the peaks to limit how close the phase could look for new peaks next to existing peaks. Any peaks located within the limits were classified as multiplets under the same ROI.

Next an Efficiency Correction phase was conducted, as required by Genie, but the specifics of which are not pertinent to this research. Finally, a fourth phase, the Nuclide Identification plus Interference Correction phase, was added to the analysis sequence. From this phase the identification range was set to the same channel numbers as the previous three phases. The user-created radioisotope library, which included the sources and interference sources of concern in Table 3, was selected as the NID library. A tolerance of 0.5 FWHM was specified to tell the program how close the photopeak centroids needed to be to the gamma energies in the user library in order to be identified. The NID confidence level was also specified as 0.1, so the program needed to have a 10% confidence or a 10% correlation with the library for the identified nuclide to be reported. This Analysis sequence was saved and could be used for future analysis in Genie. Once a spectrum was loaded into Genie, “Execute Sequence” was selected from the analysis dropdown menu and the saved sequence was selected. Once all of the phases were executed, the analysis routine generated a report.

3.4 GammaVision

3.4.1 Identifying the Unknowns with GammaVision

GammaVision analysis is completed in the “Sample Type” settings window selected from the “Analyze” submenu. The GammaVision analysis process began by selecting a spectrum file for analysis in the full spectrum view before opening the Sample Type settings window. The Settings’ submenu was used to adjust the settings for the analysis process. From the submenu the Sample tab was opened and a file name for the analysis sequence was chosen. From this tab the analysis process was limited to channels 5 to 1024. The background type was adjusted to two points to help define the net peak area by setting how far the background should be calculated from the ROI into the continuum. Then radioisotope library created for this research was selected under Nuclide Library for the analysis process. A Calibration file was also selected that defined the spectral file to be analyzed. Next, the System tab was opened on the settings submenu and the match width was adjusted to 0.5 to set the minimum distance allowed for comparison between the spectral peaks being identified and the library's peaks used for identification. This is the same as the value used in the Genie analysis sequence. Then the Peak Search Sensitivity was set to four because three was consistently registering peaks where there were none. Then the Analysis tab of the settings submenu was selected and the Peak Cutoff was set to 25% to adjust the sensitivity of the peak identification. This percentage was chosen because it allowed for the identification of major background peaks without identifying a significant number of peaks that were not present. Also on this tab, the Program for the Analysis Method was chosen to be the "NAI32 Analysis" because it was specifically created for NaI analysis and low-resolution spectrums. After selecting all settings for the analysis routine, the Sample tab was reopened and the analysis settings were saved to a "Sample Description (.SDF)" file. This allowed the same analysis process to be used in the future on other spectra files without having to reselect all of the analysis settings. Once the submenu was adjusted, 'OK' was selected and the analysis process was conducted.

4. RESULTS AND ANALYSIS

4.1 GADRAS

The identification algorithm performed by GADRAS used a spectral template matching method for nuclide identification, which provides output with various identification terminology. The nuclide identification process generated different source configurations and shielding configurations using the defined detector and compared the simulated spectra to the unknown spectra to determine which template was the closest match to the unknown spectra. The GADRAS output also included a confidence level, as well as listing the potential threat type as SNM, Medical, a Bad ID, and more. The possible confidence levels included "High" for the most confident, "Fair" for the middle confidence level, and "Low" for the least confident identification. The 2" x 4" x 16" NaI detector simulated in GADRAS for this research had a default resolution of 8.92%.

It is important to note, GADRAS is a deterministic software that uses Gaussian distributions for spectral simulations. [10] The user can choose whether to generate spectra using the theoretical standard or by applying Poisson statistics to the theoretical standard. [4] For this research, Poisson Statistics were applied to the Gaussian Distributions for the spectral simulations. As a result, if the user were to generate five of the same spectra with all of the same input, GADRAS would generate five slightly different spectrum files. Therefore, the analysis of the terminal resolutions can vary slightly if the spectral files are repeatedly simulated.

It was found that the identification results obtained by GADRAS could be affected by the user's inputs when simulating the source spectra and identifying the radionuclide. The user could increase the detector resolution on both the Detector tab and the Inject tab, keeping the two resolutions the same. This simulated a situation in which the detector used to measure the spectra was the same as the one used to identify the spectra. The other option was for the user to increase the resolution on the Inject tab used to generate the spectra and keep the Detector tab resolution at the default 8.92%. This simulated a situation in which the spectrum was obtained using a poor resolution detector and then analyzed using a typical detector. This information is helpful in knowing what results to potentially expect if the user knows nothing about the detector used to obtain the spectral data.

Table 4 and Table 5 display data obtained using the first user input method in which the detector identifying the spectra was the same as the detector obtaining the spectra to be analyzed. The terminal resolution was defined as the last resolution in which the ^{235}U isotope could be identified, with any confidence level. These results are listed in Table 4. The terminal resolution at which GADRAS had a high confidence level is listed in Table 5.

Table 3. The terminal resolutions identified by GADRAS, with any confidence level, using a NaI detector where the same detector resolution was used for identification and spectral simulation.

Configuration	Terminal Resolution	Confidence Level
1 kg HEU	100%	Fair
1 kg HEU 50% Shielded	69%	Fair
1 kg HEU 90% Shielded	76%	Fair
1 kg HEU w/ 100 μCi ^{99m}Tc	25%	High
1 kg HEU w/ 100 μCi ^{99m}Tc 50% Shielded	26%	Low
1 kg HEU w/ 100 μCi ^{99m}Tc 90% Shielded	20%	High

Table 4. The terminal resolutions identified by GADRAS, with a high confidence level, using a NaI detector where the same detector resolution was used for identification and spectral simulation.

Configuration	Terminal Resoltuion	Confidence Level
1 kg HEU	99%	High
1 kg HEU 50% Shielded	65%	High
1 kg HEU 90% Shielded	74%	High
1 kg HEU w/ 100 μCi ^{99m}Tc	25%	High
1 kg HEU w/ 100 μCi ^{99m}Tc 50% Shielded	25%	High
1 kg HEU w/ 100 μCi ^{99m}Tc 90% Shielded	20%	High

It is important to note that when GADRAS was compared to PeakEasy to test the actual resolution distortion in GADRAS, they did not always match up. For resolutions from 8.92% to 23%, the resolution in GADRAS and the resolution identified by PeakEasy matched perfectly, Table 2. From resolutions of 25% through 51%, the GADRAS resolution was anywhere from 1% to 4% higher than what was identified by PeakEasy. By the time GADRAS reached a 100% resolution, PeakEasy was identifying it as a 67% resolution. This indicates that GADRAS may struggle to accurately model resolutions beyond the 50% resolution. This could have an impact on the results of the terminal resolutions for the HEU configurations that identify the terminal resolutions to 99% with a high confidence since the corresponding resolution in PeakEasy at that resolution is actually in the 60%s. This would indicate that any terminal resolutions identified in GADRAS beyond a 50% resolution may be simulated incorrectly, leading to skewed results at large resolutions.

Table 6 and Table 7 display data obtained using the second method in which the detector simulating the spectra had a different resolution than what GADRAS assumed. For this, spectra were generated with increasing resolution while the GADRAS ID algorithm used to analyze the spectrum assumed a resolution of 8.92%. The terminal resolutions with any associated confidence level are listed in Table 6. The terminal resolutions with only high confidence levels are listed in Table 7.

Table 5. The terminal resolutions identified in GADRAS, with any confidence level, using a NaI detector where a different resolution was used for identification and the spectral simulation.

Configuration	GADRAS	Genie
1 kg HEU	29%	High
1 kg HEU 50% Shielded	34%	Fair
1 kg HEU 90% Shielded	34%	Low
1 kg HEU w/ 100 μCi ^{99m}Tc	46%	Fair
1 kg HEU w/ 100 μCi ^{99m}Tc 50% Shielded	42%	Fair
1 kg HEU w/ 100 μCi ^{99m}Tc 90% Shielded	14%	Fair

Table 6. The terminal resolutions identified by GADRAS, with a high confidence level, using a NaI detector where a different resolution was used for identification and spectral simulation.

Configuration	Terminal Resoltion	Confidence Level
1 kg HEU	29%	High
1 kg HEU 50% Shielded	32%	High
1 kg HEU 90% Shielded	26%	High
1 kg HEU w/ 100 μCi ^{99m}Tc	41%	High
1 kg HEU w/ 100 μCi ^{99m}Tc 50% Shielded	40%	High
1 kg HEU w/ 100 μCi ^{99m}Tc 90% Shielded	10%	High

For the template matching identification process in GADRAS, the information in the Detector tab was used in the Analysis tab when generating spectral images for identification through template matching. The information in the Inject tab, used to generate the unknown spectra, is only used for simulating the unknown spectra, not for analysis purposes for simulating the spectral images for identification. Therefore, the identification process was not biased because GADRAS did not "know" the resolution of the spectra to be analyzed. To help simplify the analysis discussion, the results from GADRAS have been summarized in Table 8 for ease of viewing.

Table 7. The terminal resolutions and associated confidence levels identified in GADRAS, summarized for ease of viewing.

Configuration	Detectors Matching		Detectors NOT Matching	
	GADRAS High Confidence	GADRAS Any Confidence	GADRAS High Confidence	GADRAS Any Confidence
1 kg HEU	99% (High)	100% (Fair)	29% (High)	29% (High)
1 kg HEU 50% Shielded	65% (High)	69% (Fair)	32% (High)	34% (Fair)
1 kg HEU 90% Shielded	74% (High)	76% (Fair)	26% (High)	34% (Low)
1 kg HEU w/ 100 μCi ^{99m}Tc	25% (High)	25% (High)	41% (High)	46% (Fair)
1 kg HEU w/ 100 μCi ^{99m}Tc 50% Shielded	25% (High)	26% (Low)	40% (High)	42% (Fair)
1 kg HEU w/ 100 μCi ^{99m}Tc 90% Shielded	20% (High)	20% (High)	10% (High)	14% (Fair)

For 1 kg of HEU without an interference source, GADRAS was able to identify the HEU to a high confidence at higher resolutions when the detector used to obtain the spectra was the same as the detector used to identify the isotope in the spectra. When an interference source was present, GADRAS was able to identify the HEU to a high confidence at higher resolutions when the detectors did not match for no shielding and 50% shielding. This is believed to be due to the program utilizing all aspects of the spectral image for the identification process rather than only identifying the spectra by its peaks. The areas of ‘noise’ throughout the spectral image generated from a detector with a default resolution aided GADRAS in being able to identify the HEU spectra generated by a detector with a poorer resolution that muddled more of the areas of noise. It is believed that this allowed GADRAS to register the differences between the HEU and interference source better since the default simulated identification spectra would have more defined spectral features that would be muted in the unknown spectra of poor resolution. Whereas when the detectors matched GADRAS had a harder time distinguishing between the HEU and interference sources until the HEU was heavily shielded to 90% since the simulated spectra for identification and the unknown spectra were equally muted and distorted. The equal distortion between the matching detectors did greatly aid GADRAS in identifying HEU alone when it was not being obscured by an interference source since the images would be more similar, even with the Poisson Statistics adding in simulated realistic fluctuations.

The use of the entire spectra for identification, rather than mathematical peak identification, allowed GADRAS to not experience a steady decline in its identification capabilities as shielding and interference sources were added. Each configuration was treated as its own independent image and the identification capability became dependent on how well the spectral images could distort and be matched between the simulated template-matching spectra used for identification and the spectra being analyzed. For high confidence terminal resolutions in GADRAS for a bare HEU source using detectors of the same resolution, the source shielding by 50% was identified at broader resolution (65%) than the configuration with 90% shielding (74%). This is unexpected because increased shielding would typically cause a steady decrease in the identification abilities, causing a program to require a better resolution to identify the shielded source. It is believed that GADRAS did not experience this decrease in ability for the increase shielding to 90% because the distortion resulting from the decreased resolution and increased shielding eliminated enough noise for the full spectrum analysis to have more confidence in the identification of the HEU. This is because GADRAS analyzes the entire spectra for template matching rather than identifying the spectra based solely off of the peaks. It is believed that GADRAS still experienced the decrease in ability for the increased shielding to 50% because the decreased resolution and increased shielding did not eliminate enough noise for the full spectrum analysis to have a high confidence in identifying the HEU. In addition, it appears that GADRAS may struggle to properly simulate the results beyond a 50% resolution. If this is the case, GADRAS can confidently identify the bare HEU configurations to 50%, but anything simulated and analyzed beyond a 50% resolution in GADRAS should not be a trusted result.

These results demonstrate the importance of knowing the actual resolution used when obtaining the spectra because when it is significantly different from the resolution used to analyze the spectra there is a large difference in the terminal resolutions for HEU without an interference source. Being aware of the effect that occurs for HEU identification as a result of knowing and not knowing the detector resolution can aid in the user confidence for the overall identification process. There is also a large difference in the consistency of identifying HEU in the presence of interference sources and shielding ranging between 20%-25% for high confidence when the detectors match versus the larger range in terminal resolutions for non-matching detectors ranging from 41% to 10%. When determining minimum resolution requirements for detectors, the consistency of matching detectors using high confidence terminal resolutions will be beneficial in establishing confidence in the overall identification process for poorer resolution detectors.

4.2 GammaVision

GammaVision conducts its isotope identification process using peak analysis. For this process, GammaVision allows the user to either specify a radionuclide library or use the default. Unlike GADRAS and GENIE, GammaVision does not have a confidence level or allow the user to define one during analysis. Therefore, there was no way of determining how accurate the GammaVision radionuclide identification was for each spectrum. For instance, GammaVision identified ten different peaks, including the 186 keV peak for ^{235}U, at 100% resolution, Figure 20. This is not accurate and is an issue with GammaVision. Since there is no confidence level, GammaVision always tried to assign “peaks” with a radionuclide from the library that was close to the registered peak. These results lead to the conclusion that GammaVision was not an appropriate program for use in this research application.

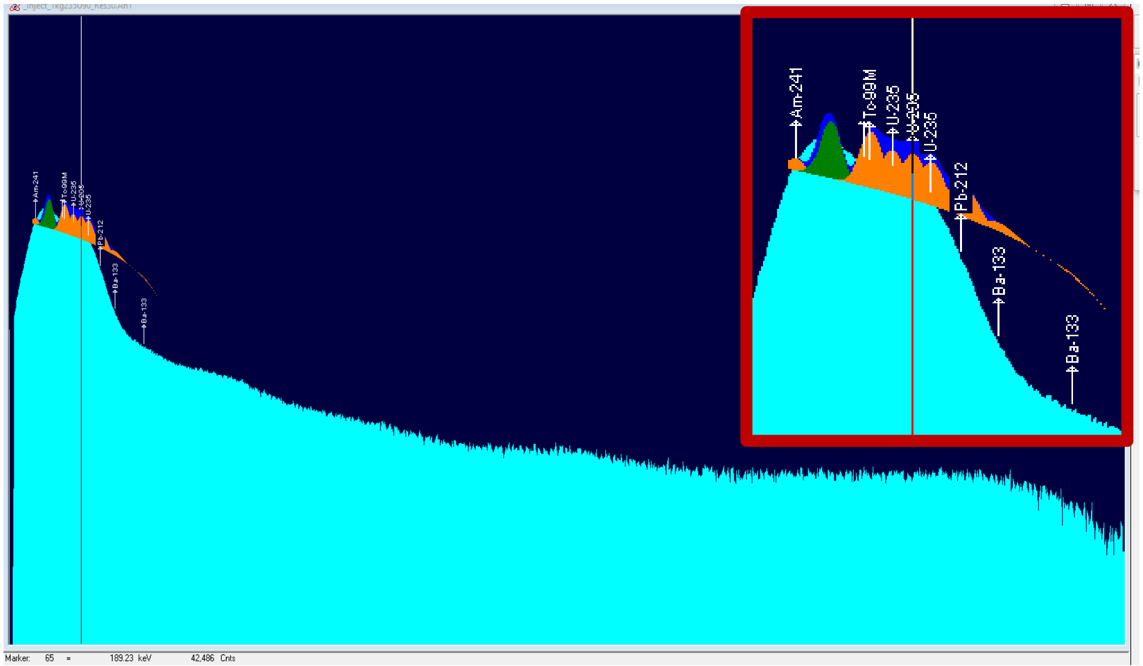

Figure 20. GammaVision nuclide identification results at 100% resolution. The zoomed in peak is enclosed in a red square on the upper right side of the Figure.

The problems with GammaVision can be further seen through comparison with GADRAS at 100% resolution. Again, at 100% resolution for 1 kg ^{235}U enriched to 90%, the 1st configuration, GammaVision identified 10 different peaks, Figure 20. For the same resolution and configuration, GADRAS template matched ^{235}U and background to the spectrum, Figure 21. GADRAS also included textual output that gave further information about the identification conducted by GADRAS, Figure 22. This difference in identification demonstrates the difference in identification abilities and illustrates why GammaVision was not an appropriate identification algorithm for this research.

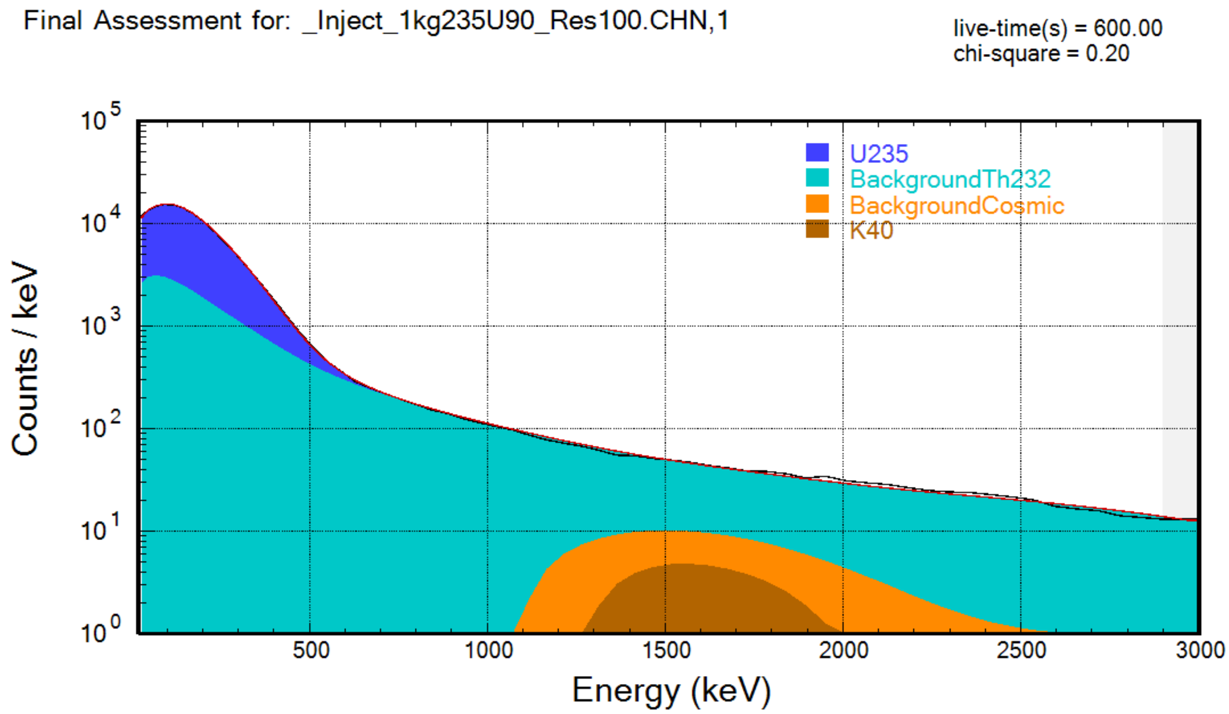

Figure 21. GADRAS spectral nuclide identification results at 100% resolution for the 1st configuration.

```
01-Jun-2020 12:00:00.00
Threat:                 6 (SNM=F)
TTF,TTB:                612, 0
Chi Square:             0.4
Net Gammas:             6446 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               2 (Fair)
Alarm Severity:         RED
Alarm Description:      Possible SNM
Event Type:             SNM

Isotopes:               K40(H,10uCi) + U235(F,483g)
```

Figure 22. GADRAS textual nuclide identification results at 100% resolution for the 1st configuration.

The issues created through the use of GammaVision are further illustrated through comparison of all three software programs for the 1st configuration of plain HEU at a 20% resolution. The nuclide identification conducted by GammaVision identified 7 different peaks, including the 186 keV peak for the ^{235}U, Figure 23. GADRAS template matched ^{235}U to a high confidence level, Figure 24, and Genie identified the HEU at a 0.544 confidence level, Figure 25. These results and figure comparisons demonstrate the differences between the nuclide identification conducted by each software. GADRAS and Genie produced accurate results that could be explored in this research while GammaVision again demonstrated why it was an inappropriate identification software for the purposes of this research. As a result, the minimum resolution requirements for GammaVision were no longer explored.

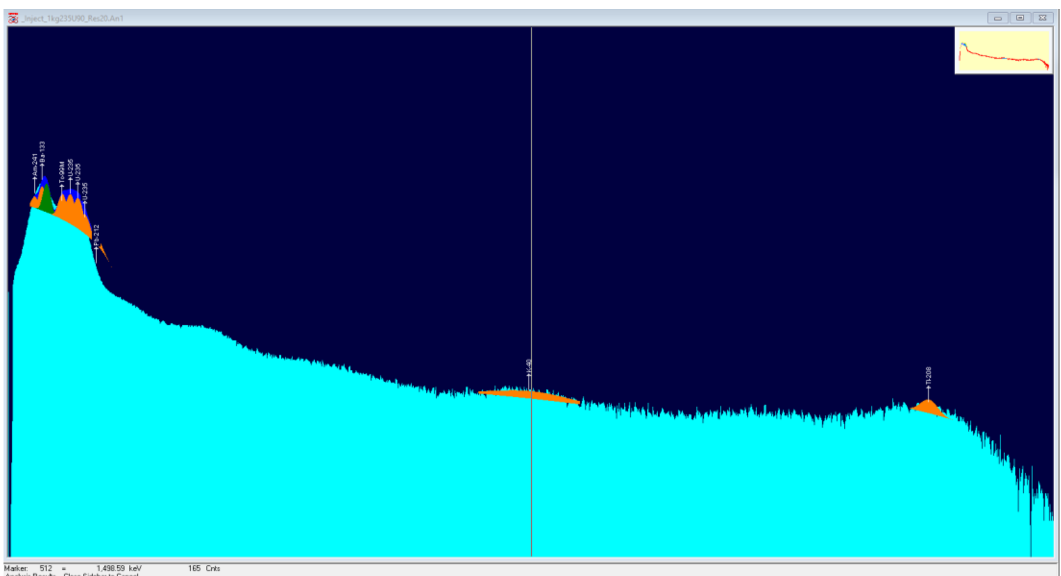

Figure 23. GammaVision identification results for HEU without shielding at a 20% resolution.

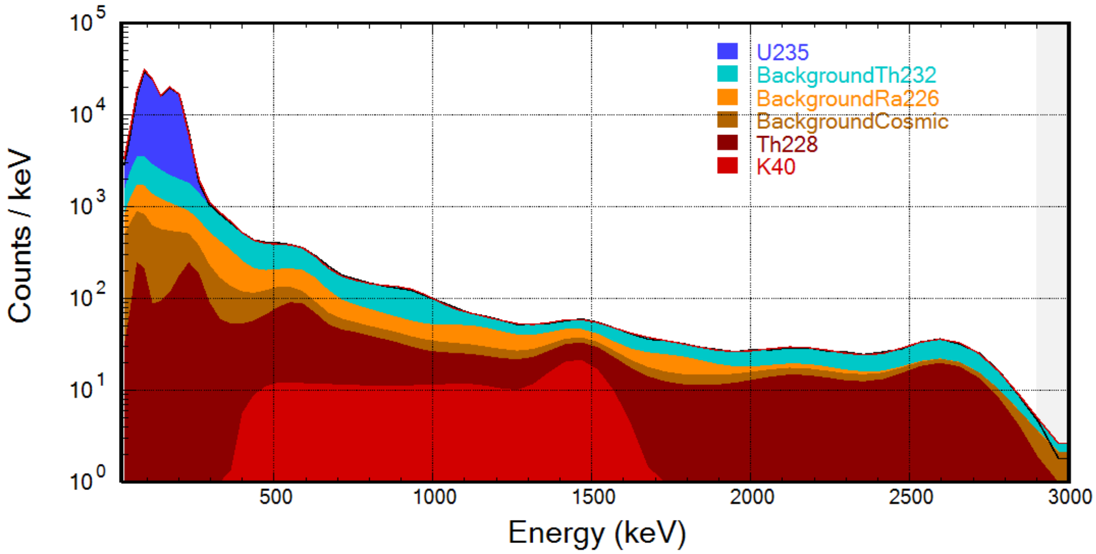

Figure 24. GADRAS spectral identification results for HEU without shielding at a 20% resolution.

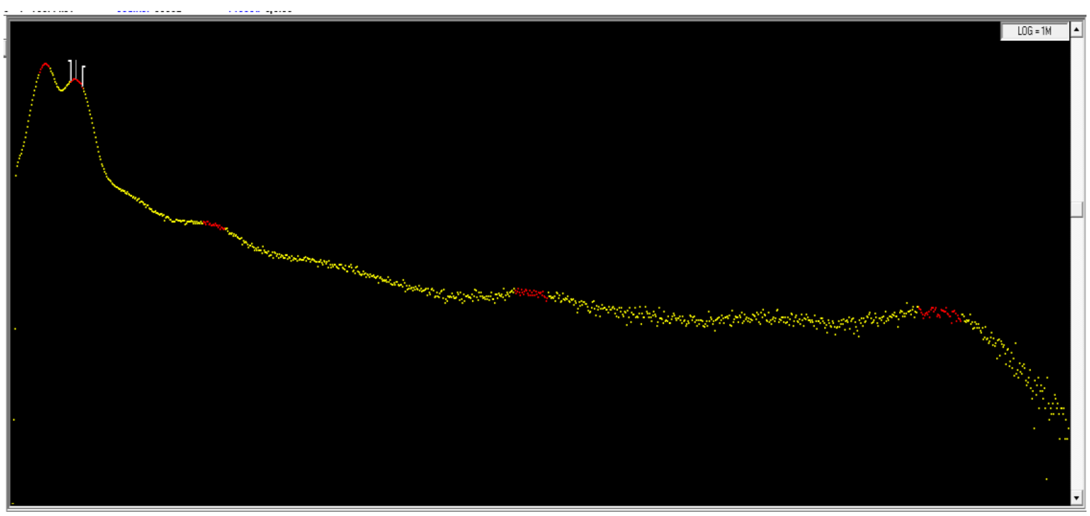

Figure 25. Genie identification results for HEU without shielding at a 20% resolution.

4.3 Genie

Genie conducts its isotope identification analysis through peak analysis. The analysis sequence first locates the peaks, determines their area, and then identifies the radioisotopes based on the user defined library. It is necessary for this library to be appropriate for the types of nuclides that are of interest for a given application. An abundance of unnecessary isotopes present in a library can lead to false identifications due to interfering peaks. GENIE allows the user to define a confidence threshold and displays the peak confidence next to the isotope in the identification results. The last resolution in which the ^{235}U isotope could be identified by GENIE, along with its associated confidence level, can be seen in Table 9.

Table 8. The last resolution in which ^{235}U could be identified by GENIE, with the associated confidence level.

Configuration	Terminal Resolution	Confidence Level
1 kg HEU	22%	0.543
1 kg HEU 50% Shielded	24%	0.543
1 kg HEU 90% Shielded	24%	0.544
1 kg HEU w/ 100 μCi ^{99m}Tc	No ID at default 8.92% ID'd at 5%	0.776
1 kg HEU w/ 100 μCi ^{99m}Tc 50% Shielded	9%	0.775
1 kg HEU w/ 100 μCi ^{99m}Tc 90% Shielded	10%	0.774

Genie's analysis sequence consistently identified the HEU configurations with and without an interference source. Without an interference source, Genie consistently identified the HEU configurations to terminal resolutions between 22%-24% at confidence levels higher than 0.5. The confidence level in Genie ranges from 0 to 1, where 0 represents no correlation between the unknown peak and library identified peak and 1 represents perfect correlation. Genie was able to identify the shielded HEU configurations to a broader peak, terminal resolution of 24%, than the unshielded configuration, terminal resolution of 22%, due to the shielding blocking the background noise which allowed for more accurate peak height to continuum calculations in the Peak Locate and Peak Area phases. This phenomenon can also be seen in increasing terminal resolutions from the 5% for the unshielded HEU and interference configuration to the 9% and 10% of the shielded HEU and interference configurations, resulting from increased shielding. The unshielded HEU with interference source was not able to be identified at the default resolution, 8.92%, and required the resolution to be improved to 5% in order to identify the HEU. This is a result of the ^{99m}Tc peak masking and creating interference with the HEU peak, causing Genie to not identify the HEU, even when the confidence level was decreased to only 10% confidence.

4.4 Comparison of GADRAS and Genie

GADRAS and Genie were both able to identify terminal resolutions in all six configurations, Table 10. GADRAS consistently performed higher than Genie for all configurations when the detectors used in the GADRAS analysis matched. When the detectors were not matching, GADRAS was able to identify HEU to higher terminal resolutions than Genie for all configurations except HEU with an interference source and 90% shielding at high confidence levels, where the two analysis processes identified the configuration to the same terminal resolution. The success of GADRAS is believed to be a result of the template matching identification process conducted by GADRAS versus the peak analysis conducted by Genie. Template matching analyzes all aspects of the spectra rather than identifying the spectra based solely on the peaks, thus making it more successful overall in nuclide identification.

Table 9. Terminal resolution data summarized for GADRAS and Genie for ease of viewing.

Configuration	Detectors Matching		Detectors NOT Matching		Genie
	GADRAS High Confidence	GADRAS Any Confidence	GADRAS High Confidence	GADRAS Any Confidence	
1 kg HEU	99% (High)	100% (Fair)	29% (High)	29% (High)	22% (0.543)
1 kg HEU 50% Shielded	65% (High)	69% (Fair)	32% (High)	34% (Fair)	24% (0.543)
1 kg HEU 90% Shielded	74% (High)	76% (Fair)	26% (High)	34% (Low)	24% (0.544)
1 kg HEU w/ 100 μCi ^{99m}Tc	25% (High)	25% (High)	41% (High)	46% (Fair)	No ID at default 8.92% ID'd at 5% (0.776)
1 kg HEU w/ 100 μCi ^{99m}Tc 50% Shielded	25% (High)	26% (Low)	40% (High)	42% (Fair)	9% (0.775)
1 kg HEU w/ 100 μCi ^{99m}Tc 90% Shielded	20% (High)	20% (High)	10% (High)	14% (Fair)	10% (0.774)

5. CONCLUSIONS

Every year, the government spends millions to improve the resolution of detectors that operate at room temperature. Rather than striving for marginal improvements in detector resolution, this research addressed the use of suboptimal detectors for identification algorithms to identify HEU. The terminal resolution of a NaI detector, or highest detector resolution at which identification algorithms fail to identify HEU was evaluated using GADRAS, Genie, and GammaVision. This was done to determine if detectors with suboptimal resolutions could be used to identify HEU by itself, in the presence of shielding, in the presence of an interference source, and in the presence of an interference source with shielding. The three programs were compared and analyzed to determine the terminal resolutions for each of the six source configurations to determine which performed best at identifying the HEU. GADRAS utilized template matching for its identification algorithm while Genie and GammaVision utilized mathematical approaches for peak search and identification sequences. Once unknown spectra were simulated using a GADRAS tool the resulting spectra were then analyzed for nuclide identification using GADRAS, Genie, and GammaVision.

In conclusion, GADRAS was the most successful in identifying isotopes with suboptimal detector resolution through its use of template matching. Although, to improve performance in GADRAS, the user should be aware of the detector resolution used to obtain spectra and the resolution being used to analyze the spectra as the difference in these does affect the results. While GENIE was able to identify 5 of the 6 source configurations at the default detector resolution up to 24%, it was not the most successful through its use of peak identification for nuclide identification. Again, GammaVision was not an appropriate program for this research and was eliminated. The suboptimal detector resolution was able to be increased to roughly 20%

while still identifying the HEU in GADRAS, when the same resolution was used to generate the spectra and analyze the spectra. GADRAS was able to identify the HEU at 20% resolution even when masking the 1 kg HEU with 100 μCi ^{99m}Tc and a stainless-steel shield. It was concluded that the template matching process, utilized by GADRAS, was the most successful nuclide identification process, in comparison to the peak matching process, for suboptimal detector resolution. In addition, it was also concluded that suboptimal detectors could be used to identify HEU, even in the presence of interfering photopeaks and shielding. In the future, further consideration should be given to analyzing automated algorithms that are used in radio isotopic identification devices (RIIDs).

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APPENDIX A – GADRAS Output for Configuration 1 Using the Same Resolution for Collection and Identification

8.92% Resolution for Collection and Identification

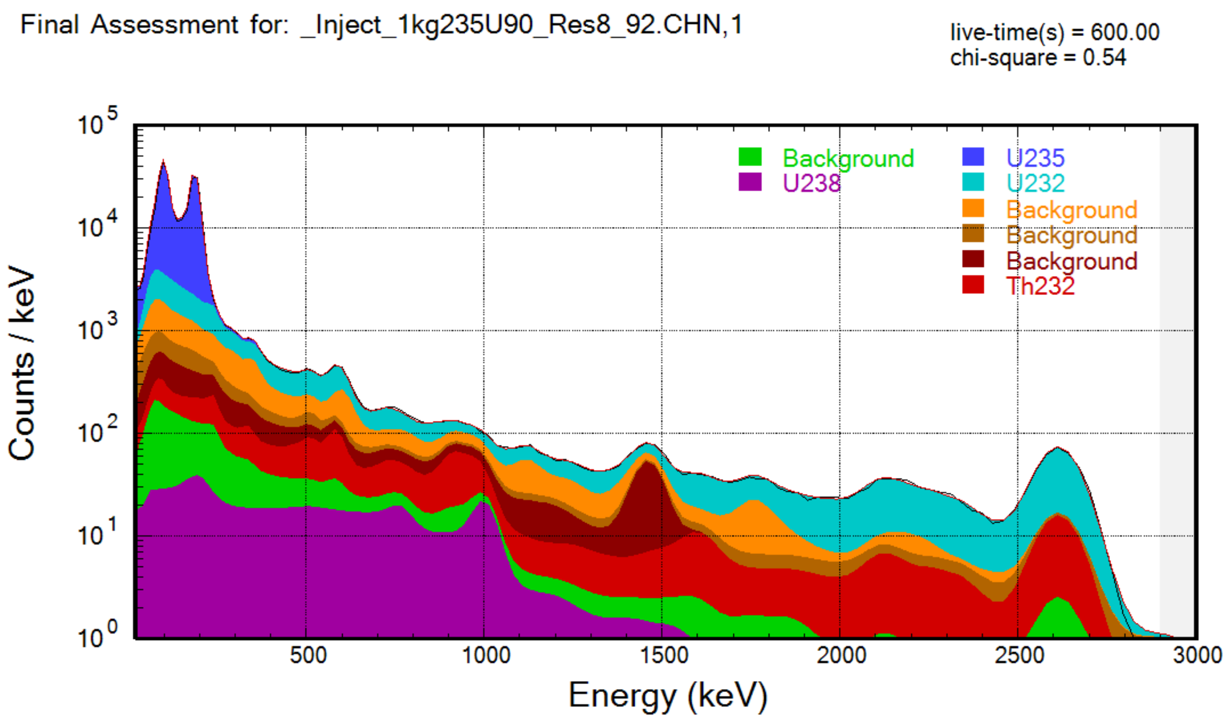


Figure A.1. GADRAS spectrum for HEU at an 8.92% resolution.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                612, 0
Chi Square:             0.8
Net Gammas:             6698 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,999g) + U232(H,7uCi) + Th232(H,2uCi) + U238(L,477g)
```

Figure A.2. GADRAS textual results for HEU at an 8.92% resolution.

10% Resolution for Collection and Identification

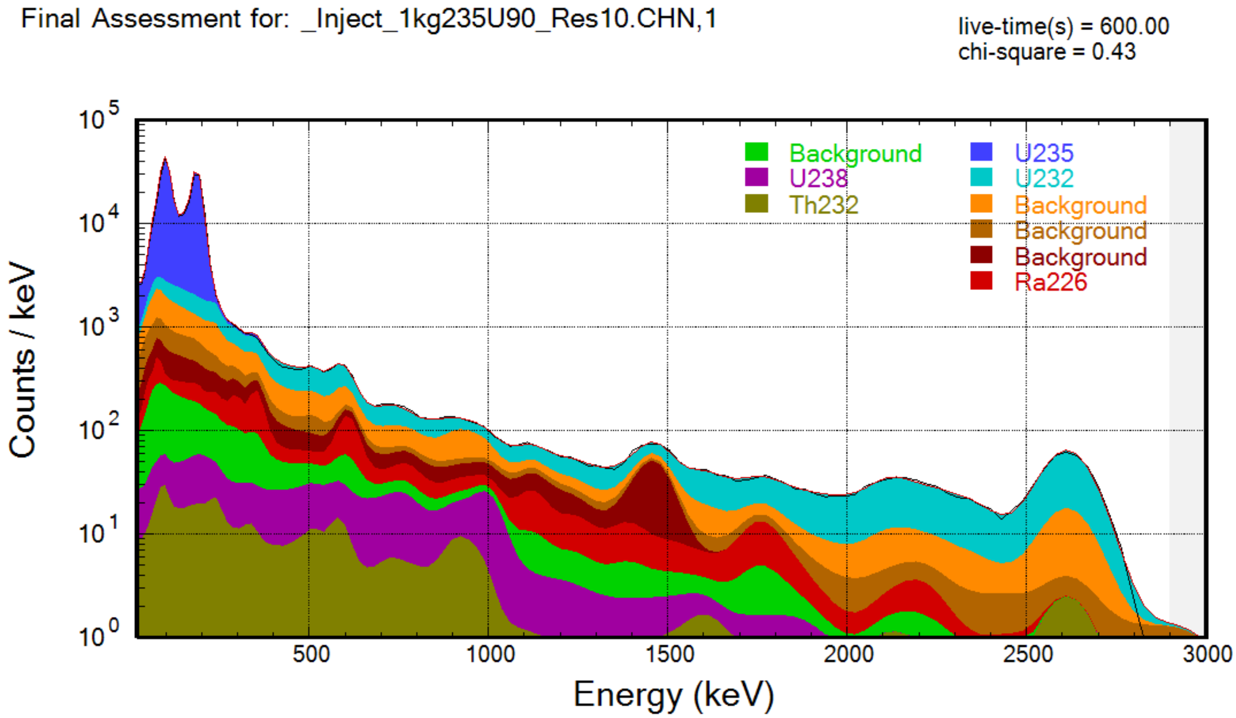


Figure A.3. GADRAS spectrum for HEU at an 10% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.7
Net Gammas:	6701 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,1kg) + U232(H,6uCi) + Th232(H,1uCi) + U238(L,483g)

Figure A.4. GADRAS textual results for HEU at an 10% resolution.

15% Resolution for Collection and Identification

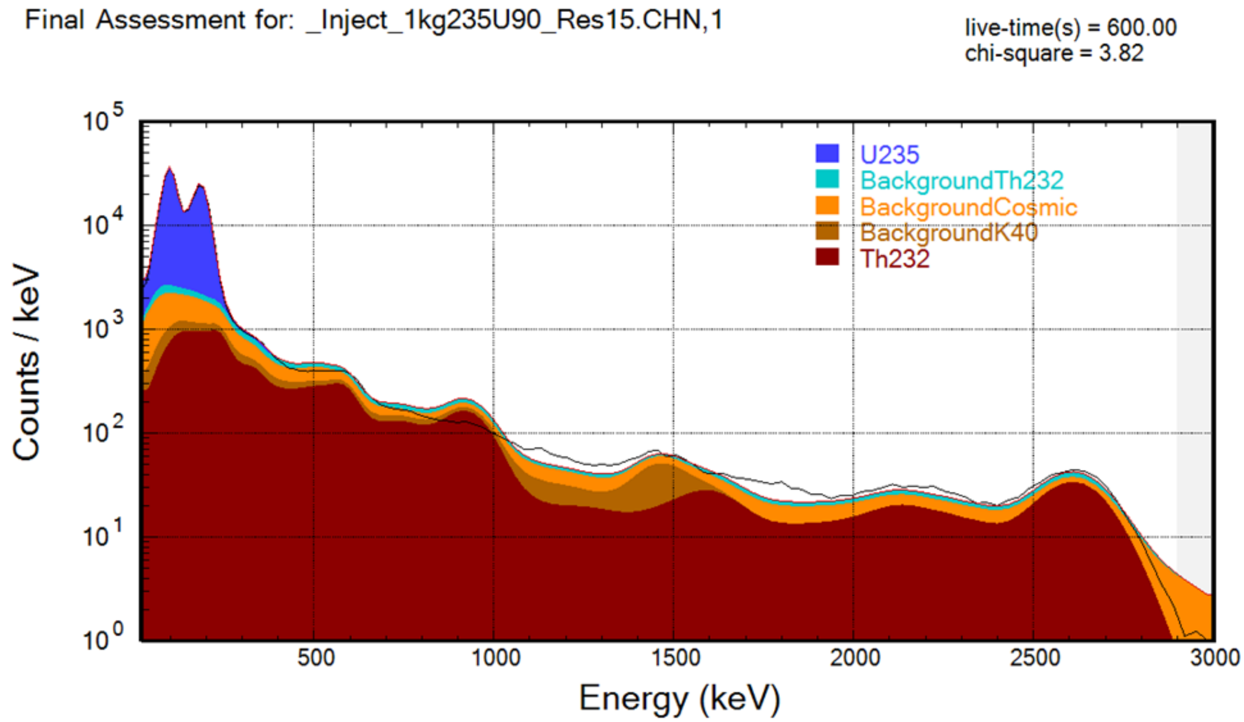


Figure A.5. GADRAS spectrum for HEU at a 15% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	4.3
Net Gammas:	6692 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,998g) + U232(H,1uCi)

Figure A.6. GADRAS textual results for HEU at a 15% resolution.

20% Resolution for Collection and Identification

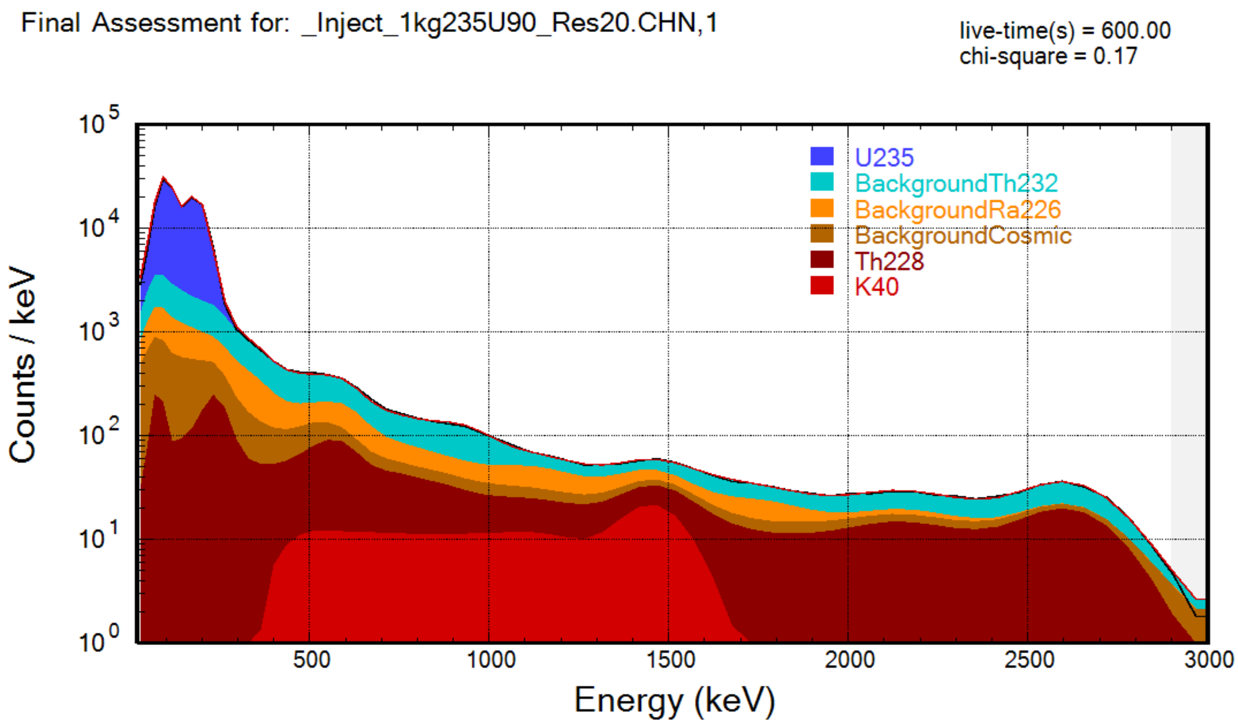


Figure A.7. GADRAS spectrum for HEU at a 20% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.4
Net Gammas:	6693 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,988g) + Th228(F,1uCi)

Figure A.8. GADRAS textual results for HEU at a 20% resolution.

25% Resolution for Collection and Identification

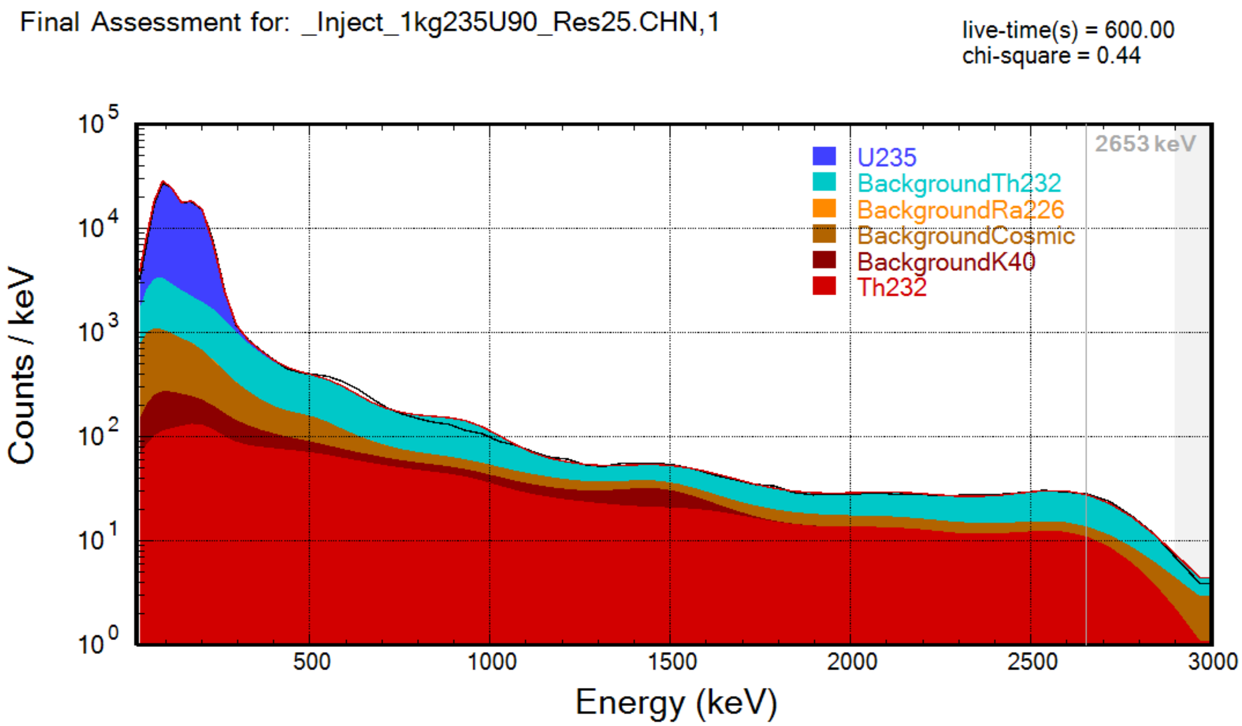


Figure A.9. GADRAS spectrum for HEU at a 25% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.7
Net Gammas:	6688 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,968g) + U232(F,1uCi)

Figure A.10. GADRAS textual results for HEU at a 25% resolution.

30% Resolution for Collection and Identification

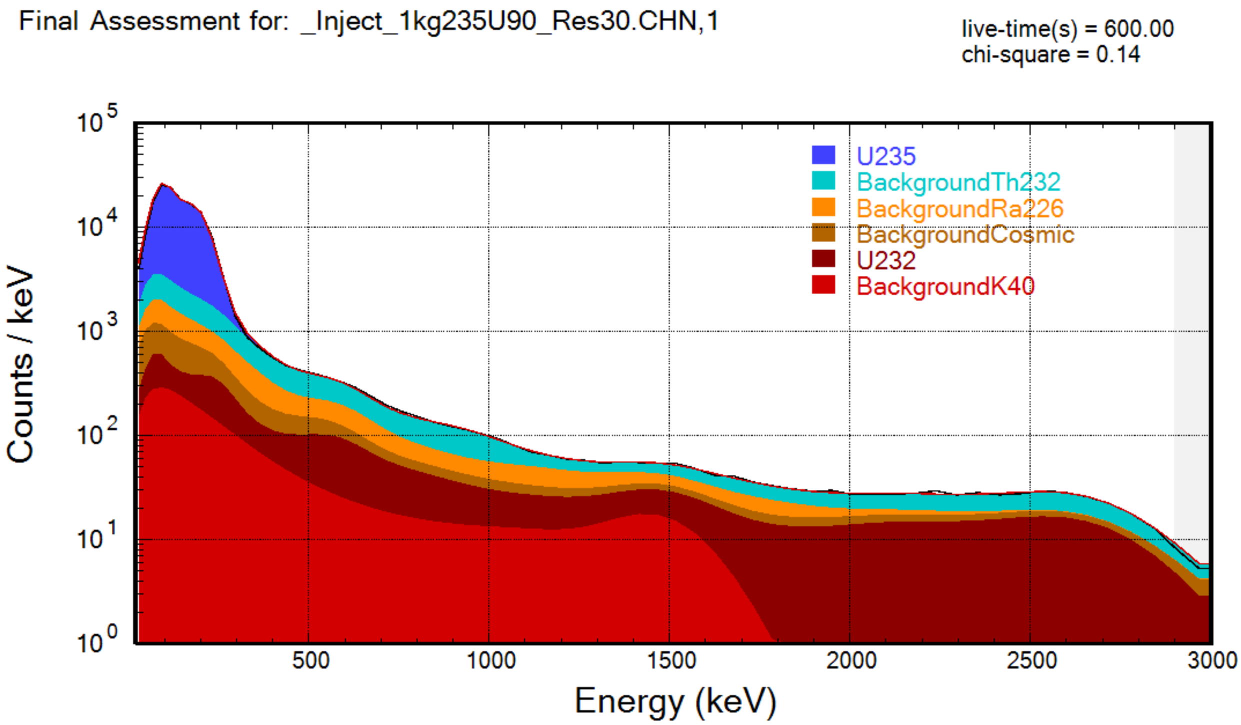


Figure A.11. GADRAS spectrum for HEU at a 30% resolution.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                612, 0
Chi Square:             0.4
Net Gammas:             6687 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,964g) + U232(F,1uCi)
```

Figure A.12. GADRAS textual results for HEU at a 30% resolution.

35% Resolution for Collection and Identification

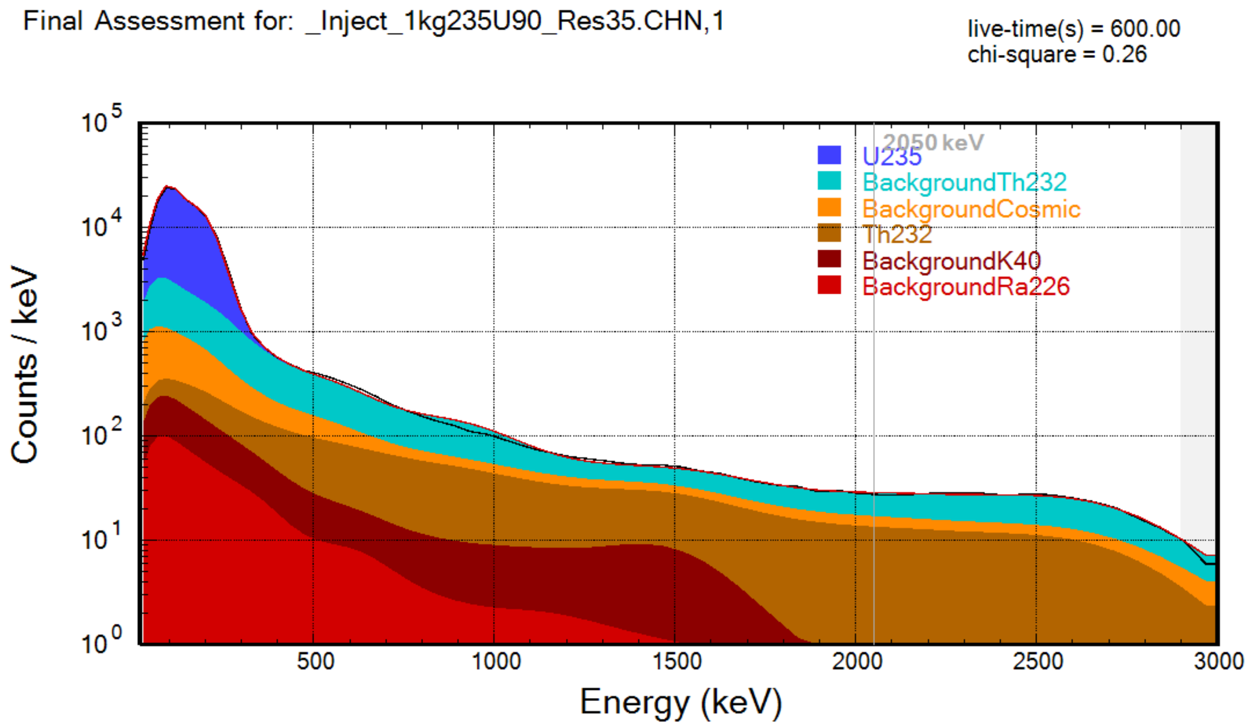


Figure A.13. GADRAS spectrum for HEU at a 35% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.5
Net Gammas:	6668 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,973g) + U232(F,1uCi)

Figure A.14. GADRAS textual results for HEU at a 35% resolution.

40% Resolution for Collection and Identification

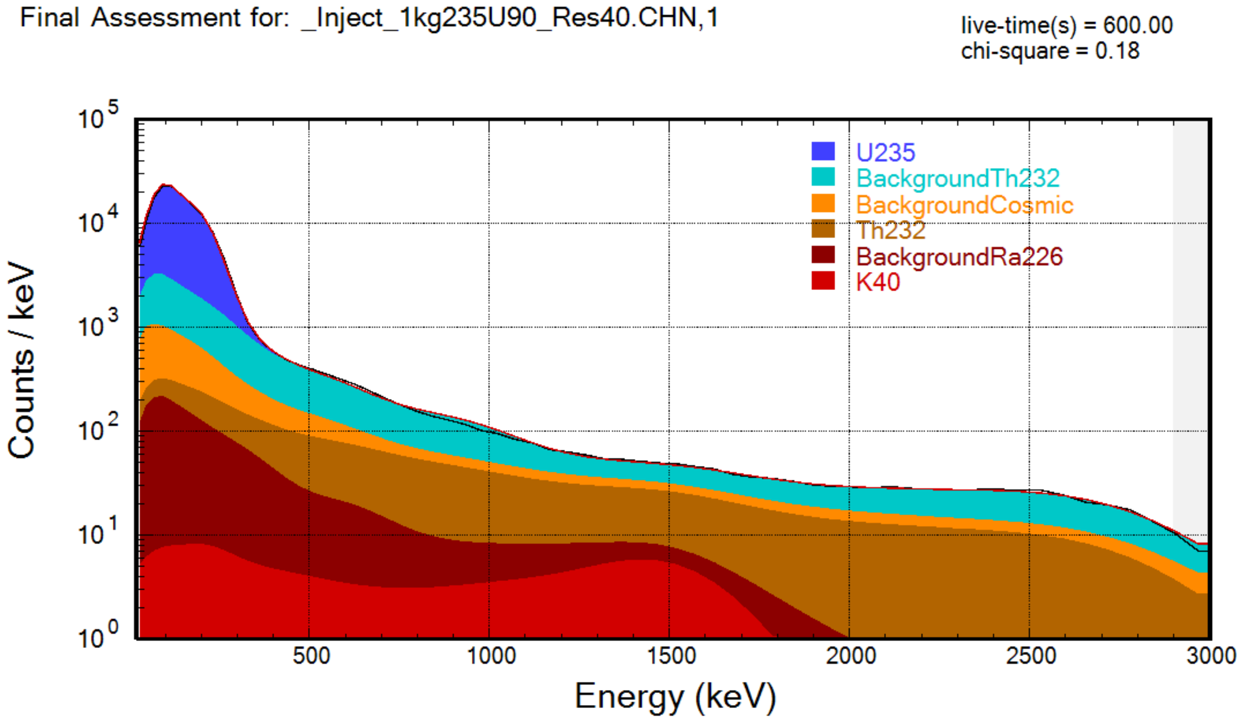


Figure A.15. GADRAS spectrum for HEU at a 40% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.4
Net Gammas:	6648 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,969g) + Th232(H,46uCi)

Figure A.16. GADRAS textual results for HEU at a 40% resolution.

45% Resolution for Collection and Identification

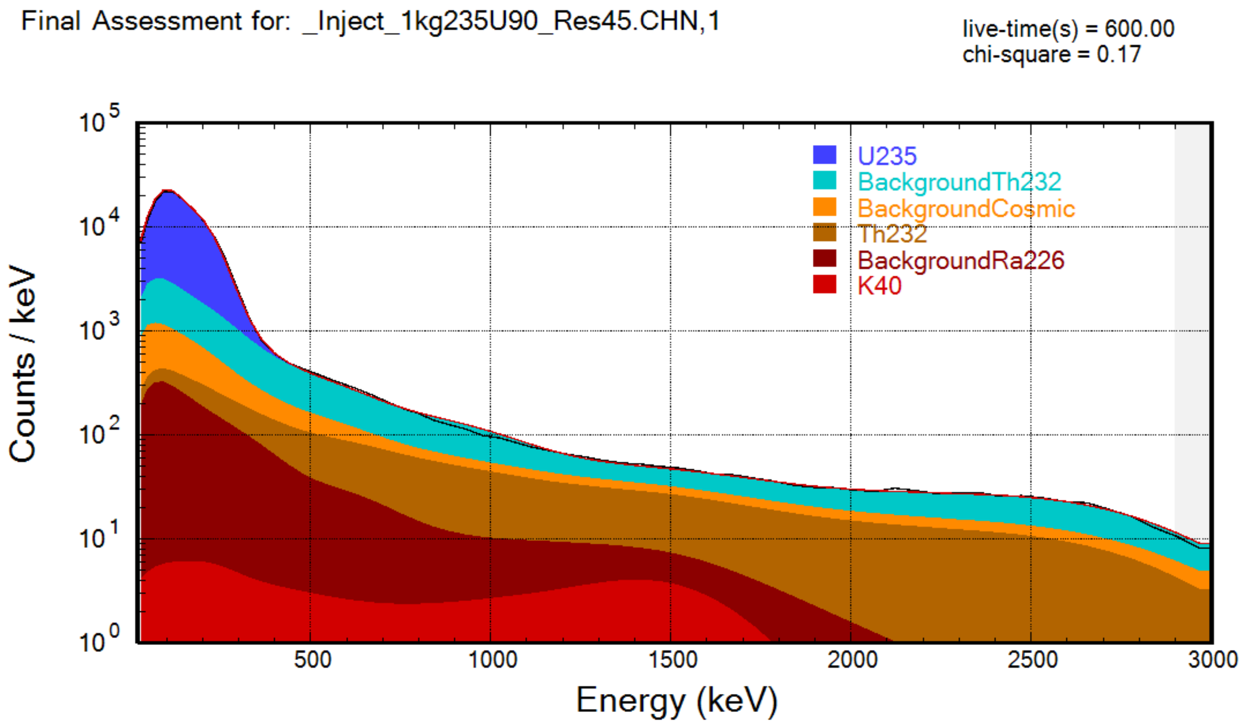


Figure A.17. GADRAS spectrum for HEU at a 45% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.4
Net Gammas:	6624 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,968g) + Th232(H,49uCi)

Figure A.18. GADRAS textual results for HEU at a 45% resolution.

50% Resolution for Collection and Identification

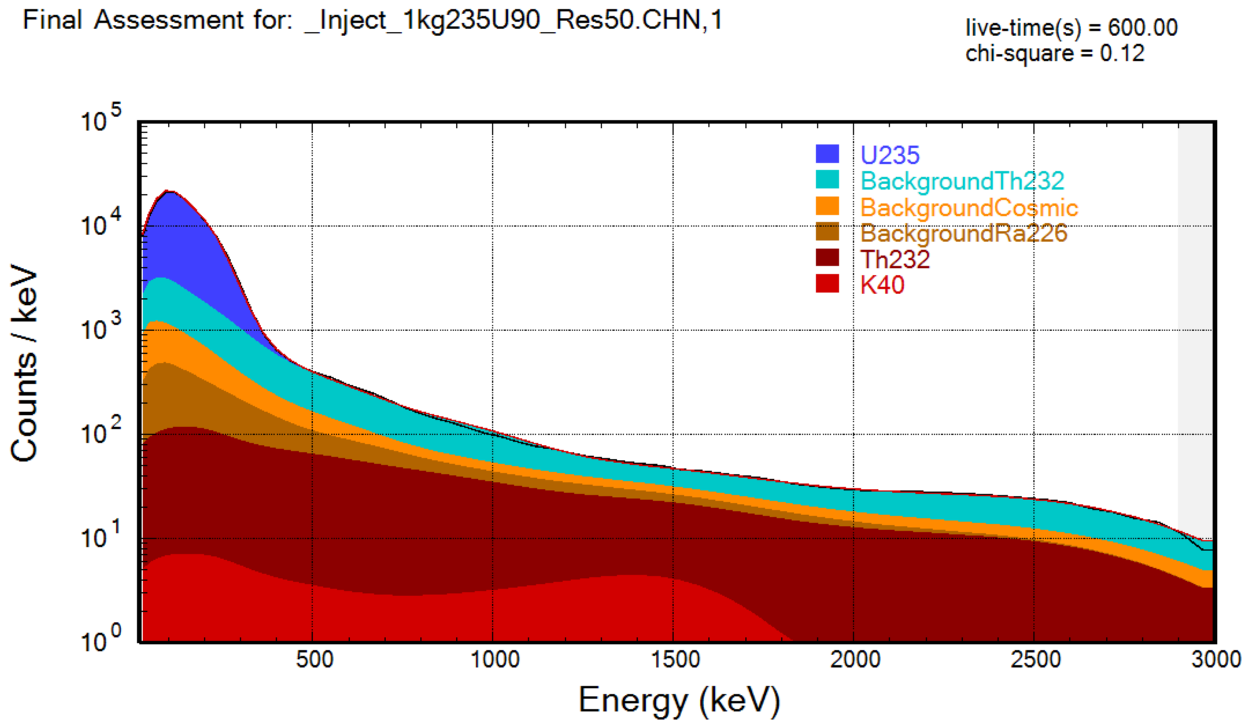


Figure A.19. GADRAS spectrum for HEU at a 50% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.3
Net Gammas:	6603 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,963g) + Th232(H,45uCi)

Figure A.20. GADRAS textual results for HEU at a 50% resolution.

55% Resolution for Collection and Identification

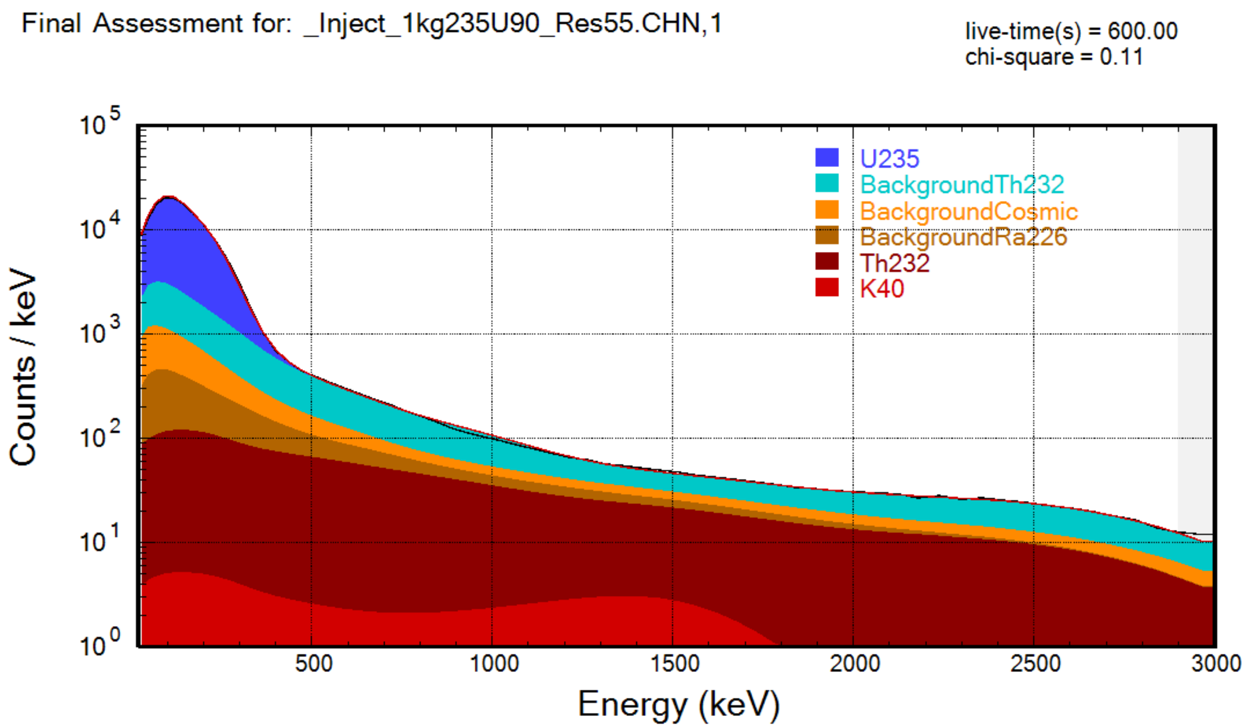


Figure A.21. GADRAS spectrum for HEU at a 55% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.3
Net Gammas:	6579 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,962g)

Figure A.22. GADRAS textual results for HEU at a 55% resolution.

60% Resolution for Collection and Identification

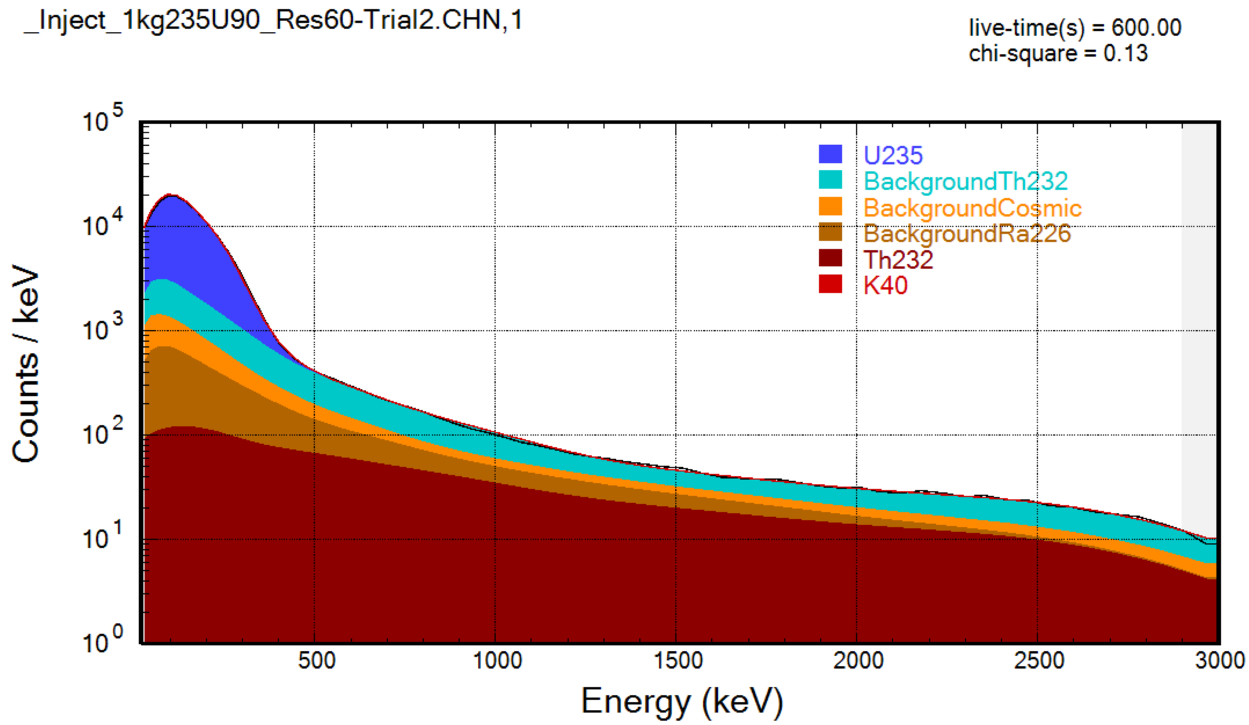
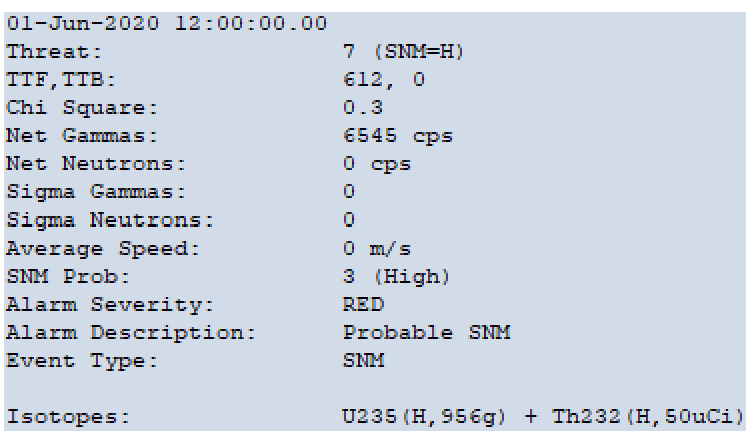


Figure A.23. GADRAS spectrum for HEU at a 60% resolution.



01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.3
Net Gammas:	6545 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,956g) + Th232(H,50uCi)

Figure A.24. GADRAS textual results for HEU at a 60% resolution.

65% Resolution for Collection and Identification

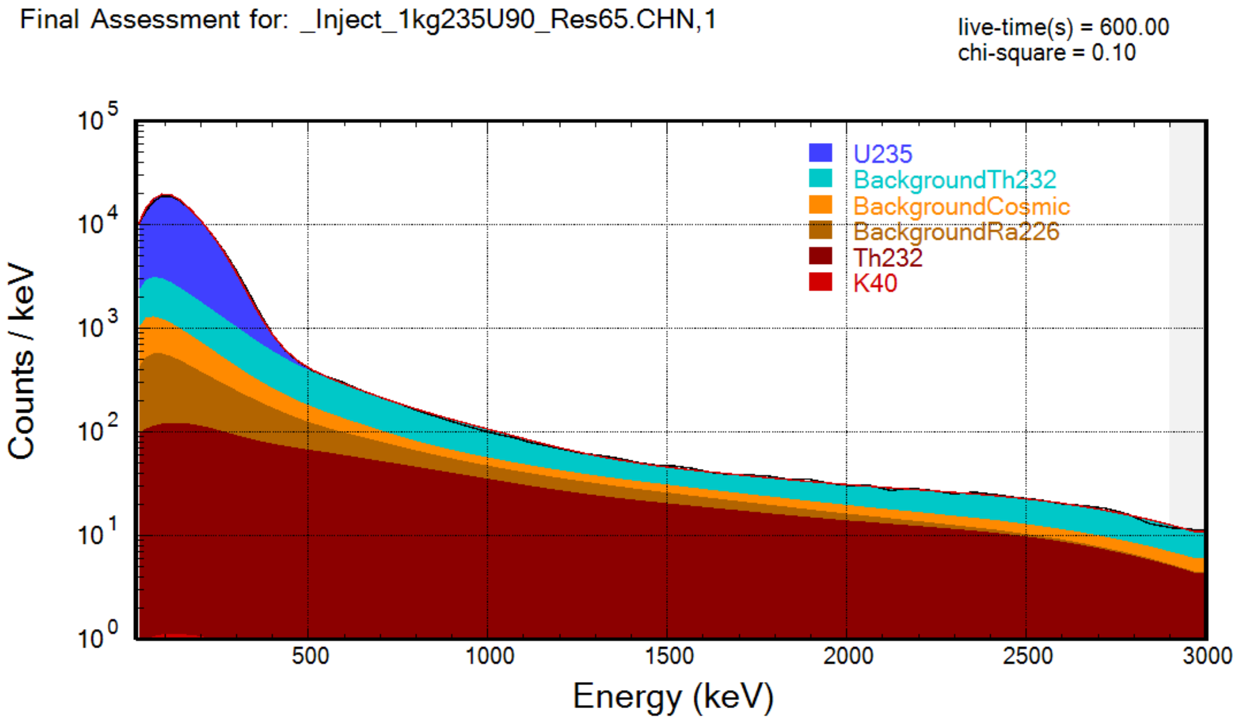
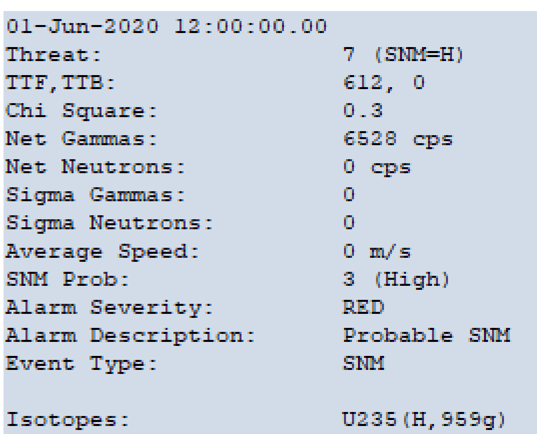


Figure A.25. GADRAS spectrum for HEU at a 65% resolution.



01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.3
Net Gammas:	6528 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,959g)

Figure A.26. GADRAS textual results for HEU at a 65% resolution.

70% Resolution for Collection and Identification

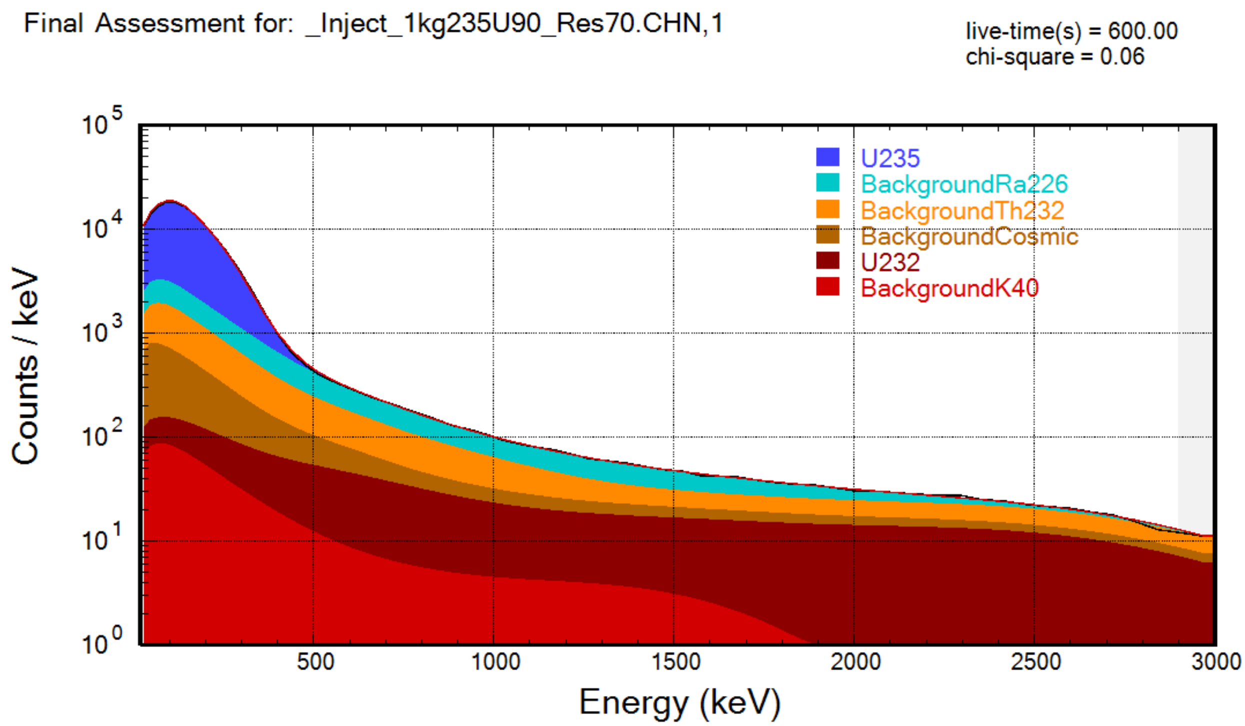


Figure A.27. GADRAS spectrum for HEU at a 70% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.3
Net Gammas:	6511 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,933g) + U232(F,1uCi)

Figure A.28. GADRAS textual results for HEU at a 70% resolution.

75% Resolution for Collection and Identification

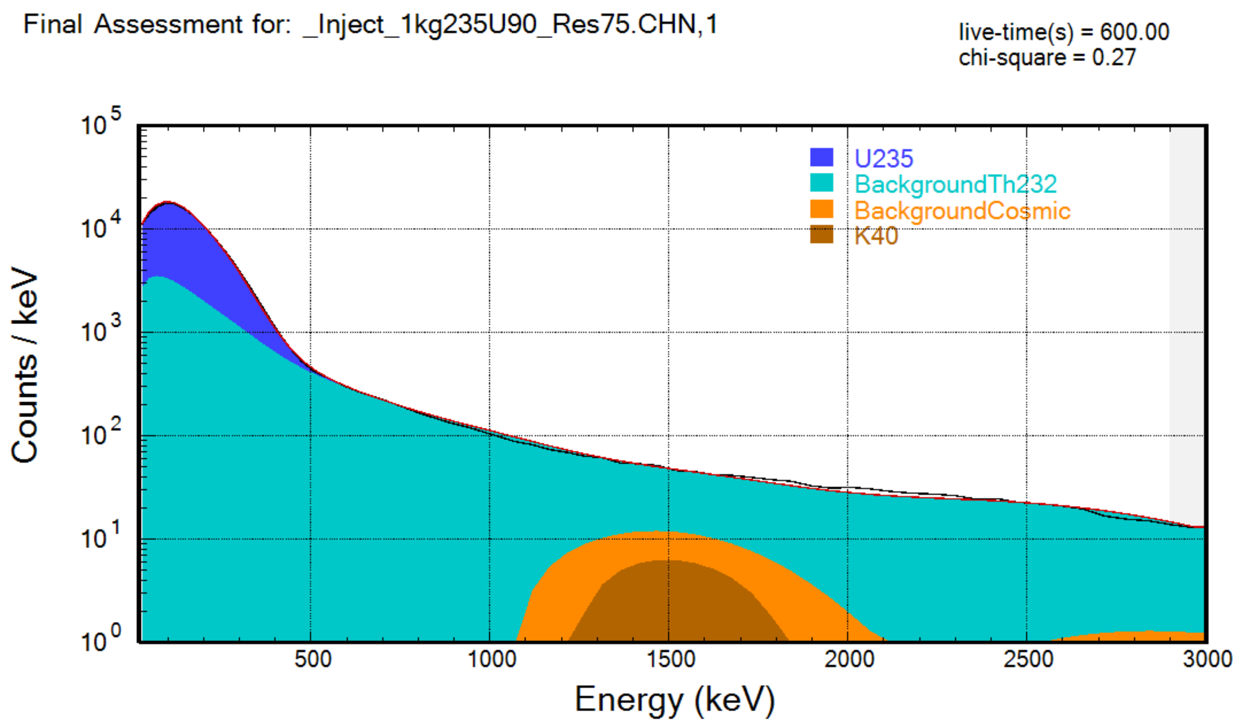


Figure A.29. GADRAS spectrum for HEU at a 75% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.5
Net Gammas:	6495 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,924g) + K40(H,9uCi)

Figure A.30. GADRAS textual results for HEU at a 75% resolution.

80% Resolution for Collection and Identification

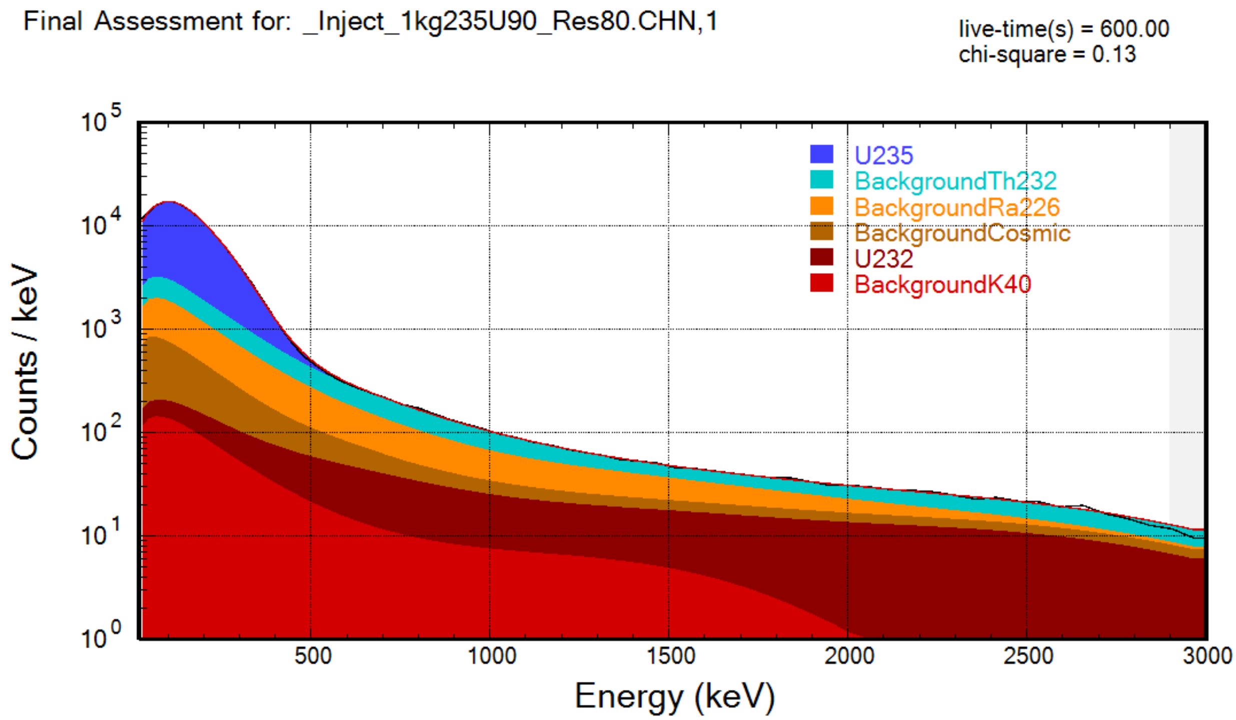
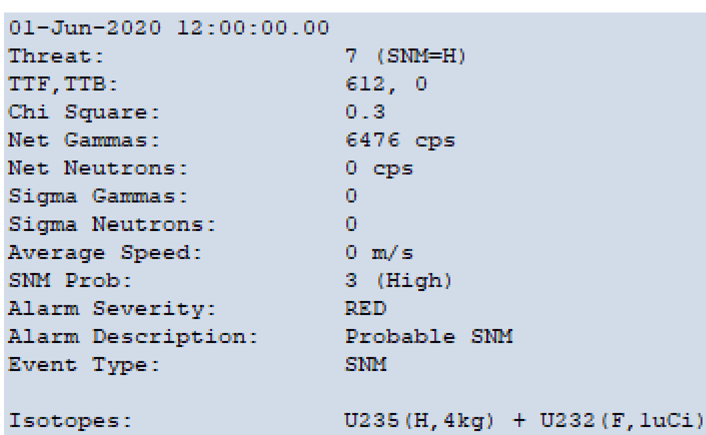


Figure A.31. GADRAS spectrum for HEU at an 80% resolution.



01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.3
Net Gammas:	6476 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,4kg) + U232(F,1uCi)

Figure A.32. GADRAS textual results for HEU at an 80% resolution.

85% Resolution for Collection and Identification

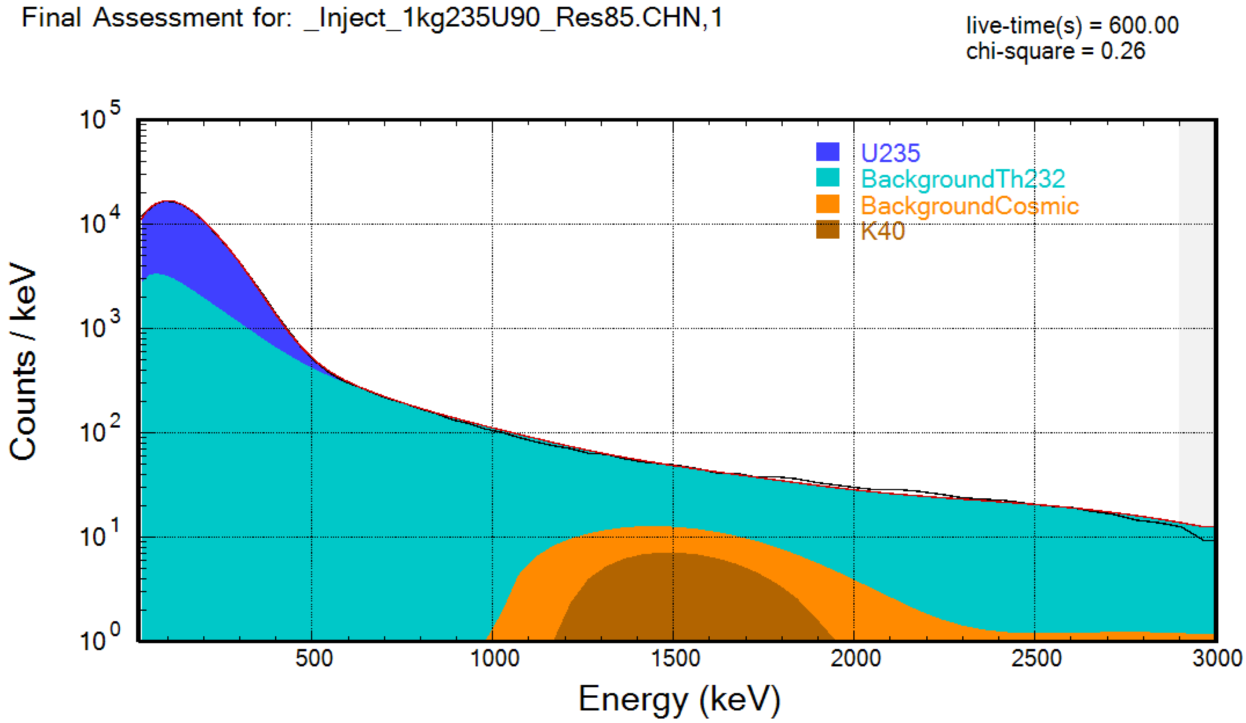


Figure A.33. GADRAS spectrum for HEU at an 85% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.4
Net Gammas:	6471 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,4kg) + K40(H,9uCi)

Figure A.34. GADRAS textual results for HEU at an 85% resolution.

90% Resolution for Collection and Identification

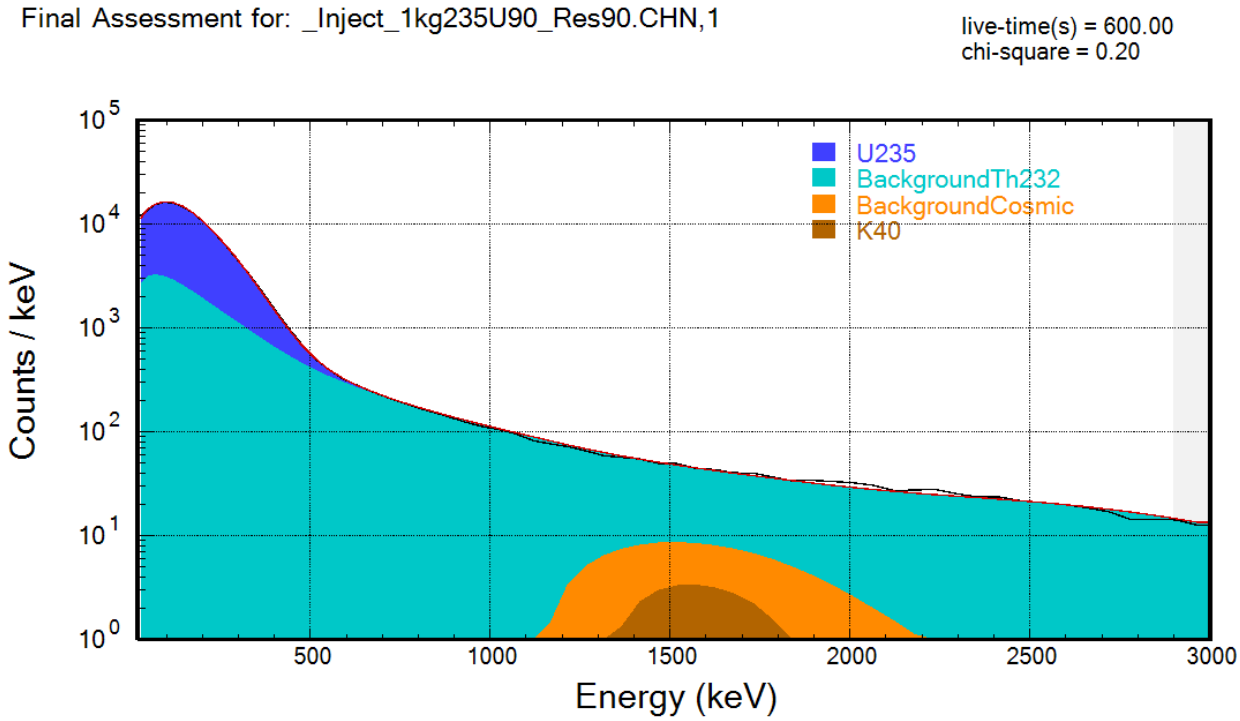
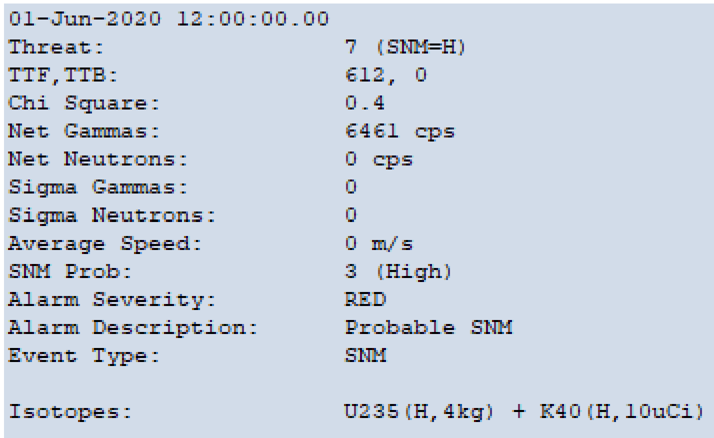


Figure A.35. GADRAS spectrum for HEU at a 90% resolution.



```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                612, 0
Chi Square:             0.4
Net Gammas:             6461 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,4kg) + K40(H,10uCi)
```

Figure A.36. GADRAS textual results for HEU at a 90% resolution.

95% Resolution for Collection and Identification

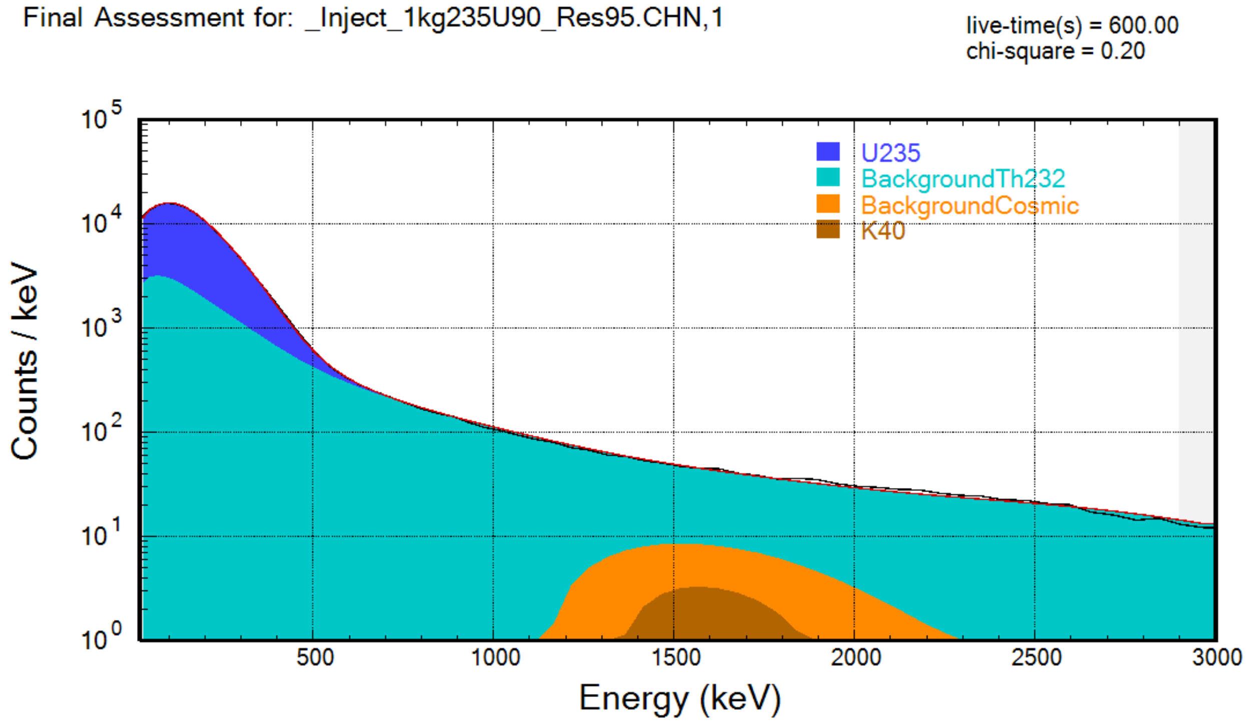


Figure A.37. GADRAS spectrum for HEU at a 95% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.4
Net Gammas:	6452 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,5kg)

Figure A.38. GADRAS textual results for HEU at a 95% resolution.

100% Resolution for Collection and Identification

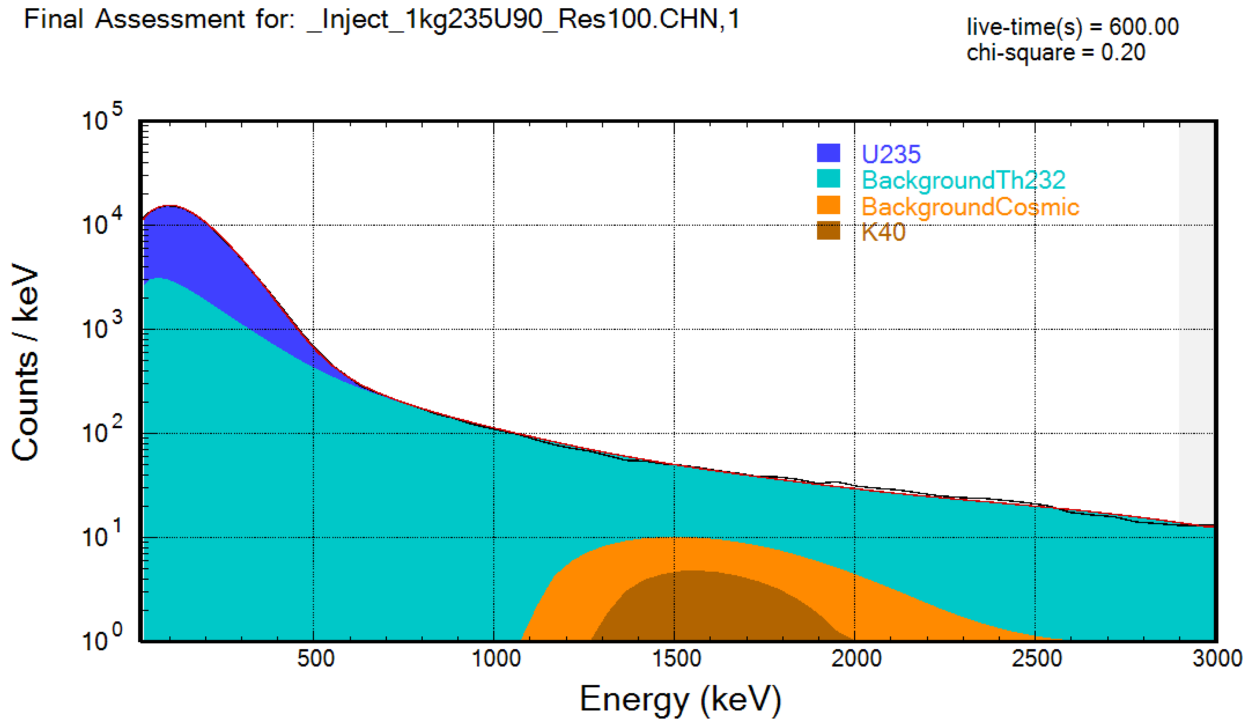


Figure A.39. GADRAS spectrum for HEU at a 100% resolution.

```
01-Jun-2020 12:00:00.00
Threat:                  6 (SNM=F)
TTF,TTB:                 612, 0
Chi Square:              0.4
Net Gammas:              6446 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                2 (Fair)
Alarm Severity:          RED
Alarm Description:       Possible SNM
Event Type:              SNM

Isotopes:                K40(H,10uCi) + U235(F,483g)
```

Figure A.40. GADRAS textual results for HEU at a 100% resolution.

99% Resolution for Collection and Identification

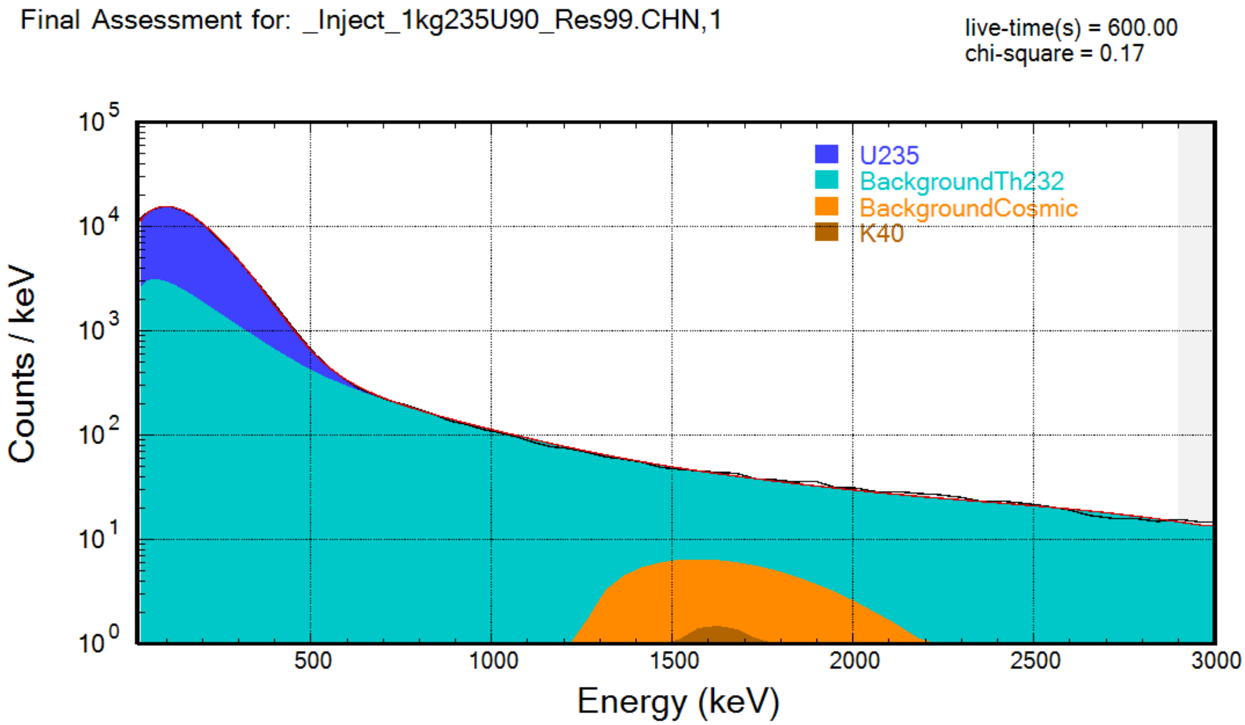


Figure A.41. GADRAS spectrum for HEU at a 99% resolution.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	0.4
Net Gammas:	6450 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,5kg) + K40(H,10uCi)

Figure A.42. GADRAS textual results for HEU at a 99% resolution.

APPENDIX B - GADRAS Output for Configuration 1 Using the Different Resolutions for Collection and Identification

8.92% Resolution for Collection and 8.92% Resolution for Identification

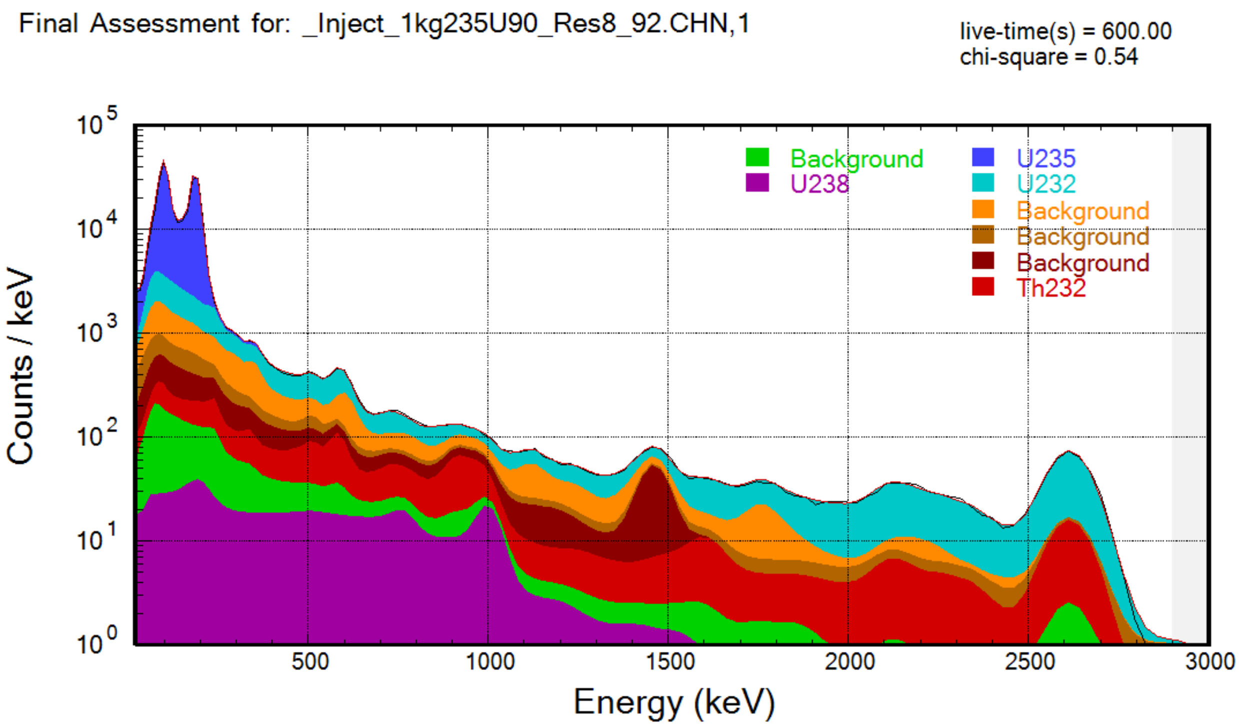


Figure B.1. GADRAS spectrum for HEU at an 8.92% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                612, 0
Chi Square:             0.8
Net Gammas:             6698 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,999g) + U232(H,7uCi) + Th232(H,2uCi) + U238(L,477g)
```

Figure B.2. GADRAS textual results for HEU at an 8.92% resolution for collection and an 8.92% resolution for identification.

10% Resolution for Collection and 8.92% Resolution for Identification

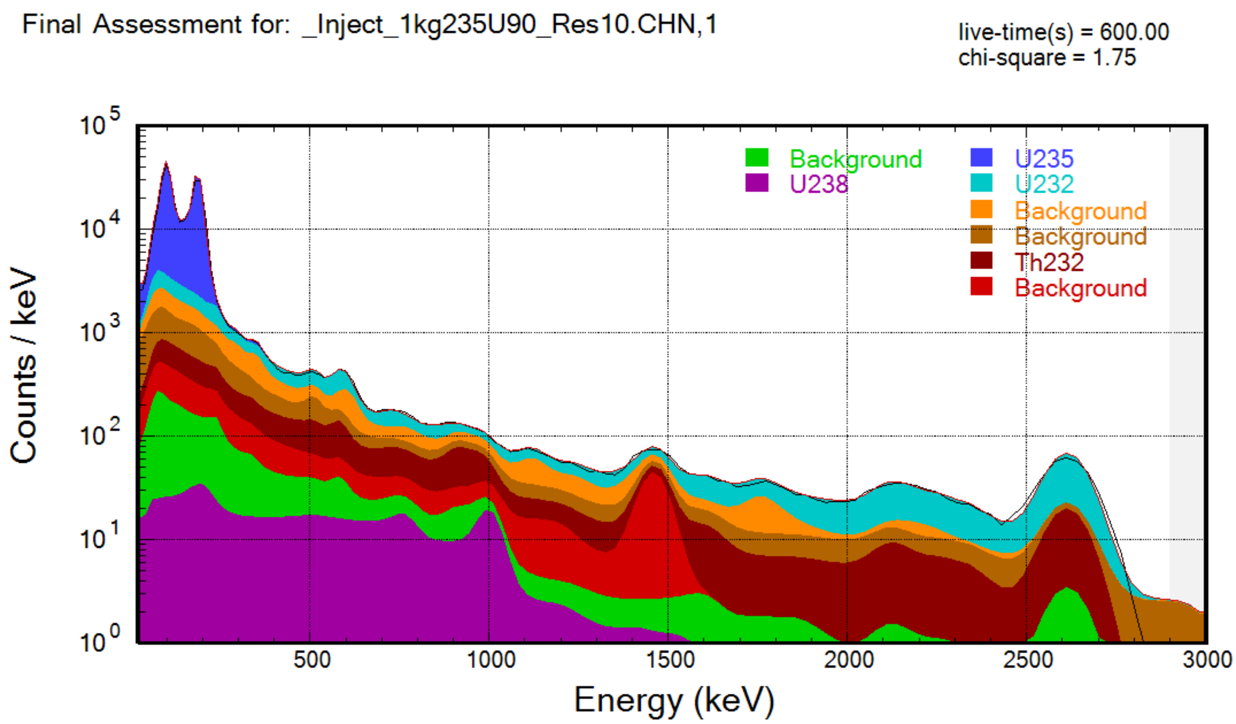


Figure B.3. GADRAS spectrum for HEU at a 10% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	2.1
Net Gammas:	6702 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,989g) + U232(H,5uCi) + U238(L,424g)

Figure B.4. GADRAS textual results for HEU at a 10% resolution for collection and an 8.92% resolution for identification.

15% Resolution for Collection and 8.92% Resolution for Identification

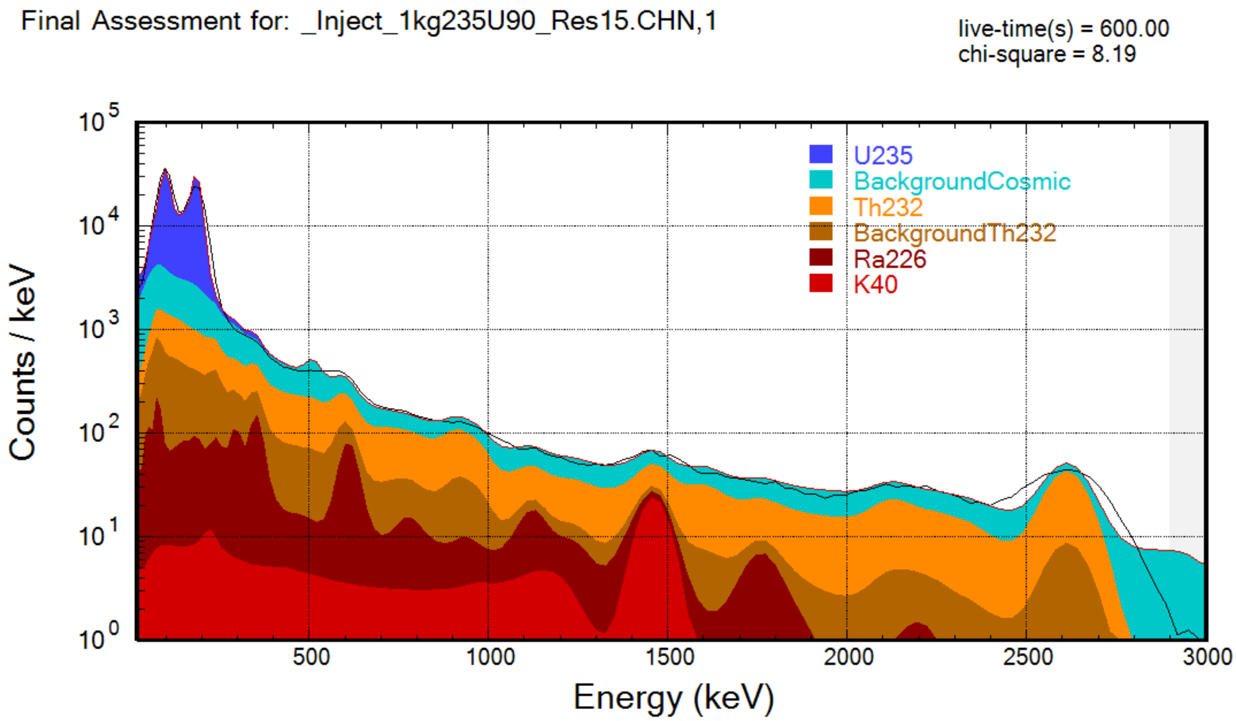


Figure B.5. GADRAS spectrum for HEU at a 15% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                612, 0
Chi Square:             9.7
Net Gammas:             6692 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               Th232(H,22uCi) + U235(H,19kg) + Te132(F,1uCi)
```

Figure B.6. GADRAS textual results for HEU at a 15% resolution for collection and an 8.92% resolution for identification.

20% Resolution for Collection and 8.92% Resolution for Identification

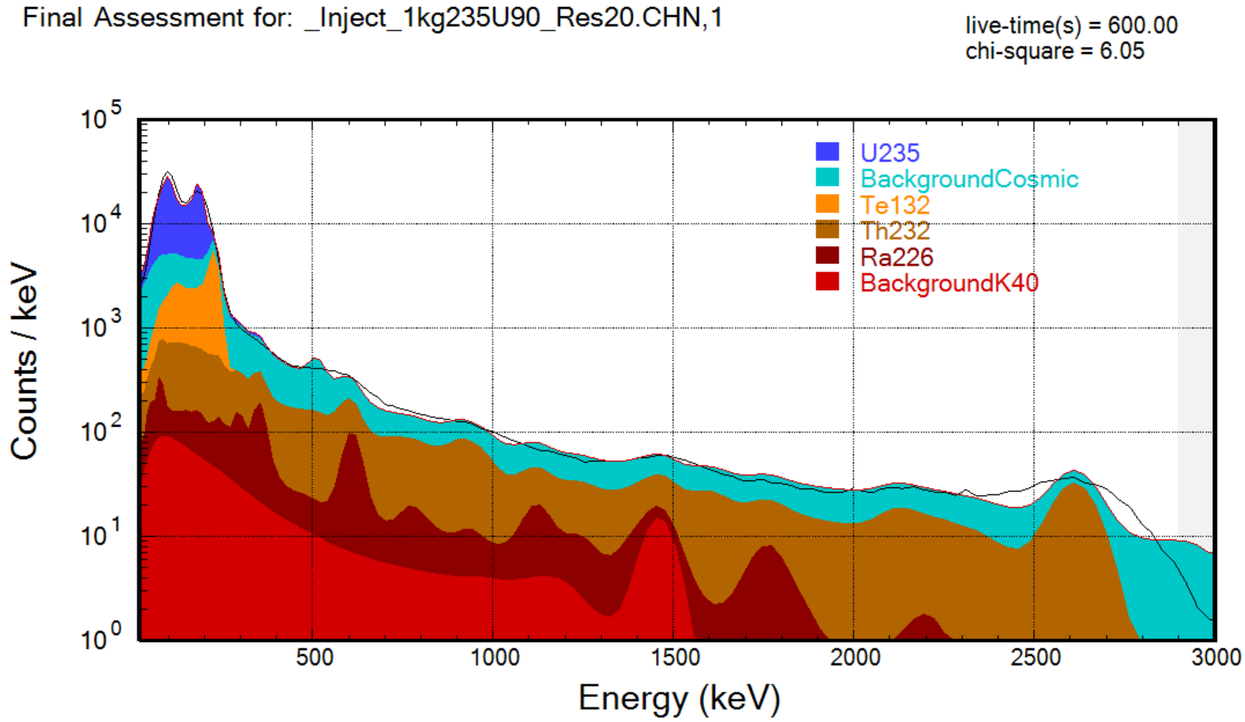


Figure B.7. GADRAS spectrum for HEU at a 20% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	8.3
Net Gammas:	6692 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,34uCi) + U235(H,3kg) + Te132(F,1uCi)

Figure B.8. GADRAS textual results for HEU at a 20% resolution for collection and an 8.92% resolution for identification.

25% Resolution for Collection and 8.92% Resolution for Identification

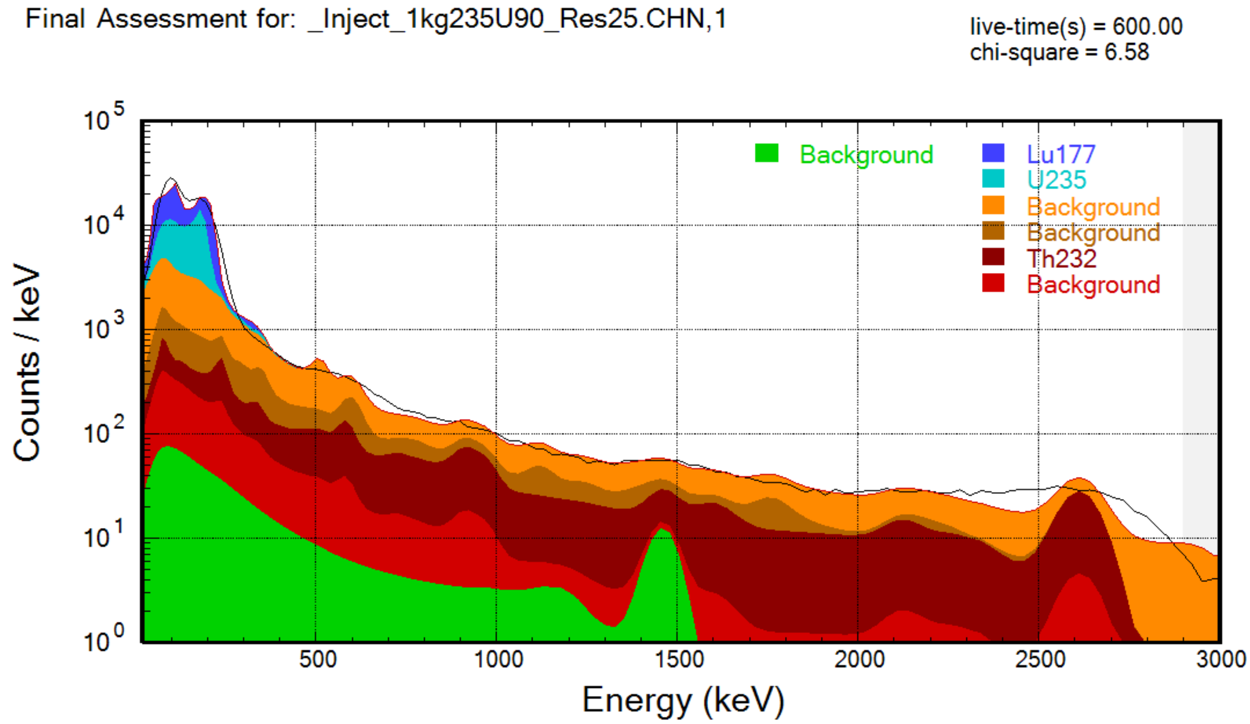
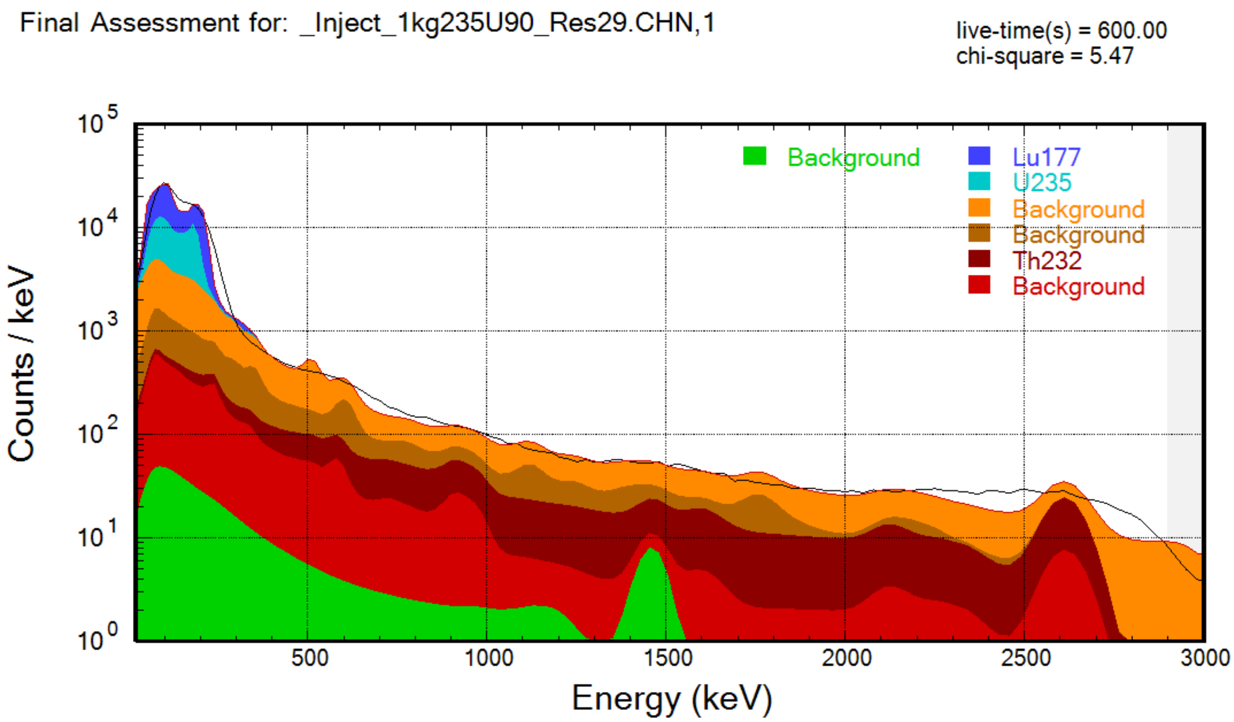


Figure B.9. GADRAS spectrum for HEU at a 25% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	8.8
Net Gammas:	6687 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,36uCi) + U235(H,20kg) + Lu177(H,97uCi) + Te132(L,1uCi) + In111(L,1uCi)

Figure B.10. GADRAS textual results for HEU at a 25% resolution for collection and an 8.92% resolution for identification.

29% Resolution for Collection and 8.92% Resolution for Identification



Figures B.11. GADRAS spectrum for HEU at a 29% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	612, 0
Chi Square:	7.7
Net Gammas:	6685 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,38uCi) + Lu177(H,123uCi) + U235(H,2kg) + In111(F,1uCi)

Figure B.12. GADRAS textual results for HEU at a 29% resolution for collection and an 8.92% resolution for identification.

30% Resolution for Collection and 8.92% Resolution for Identification

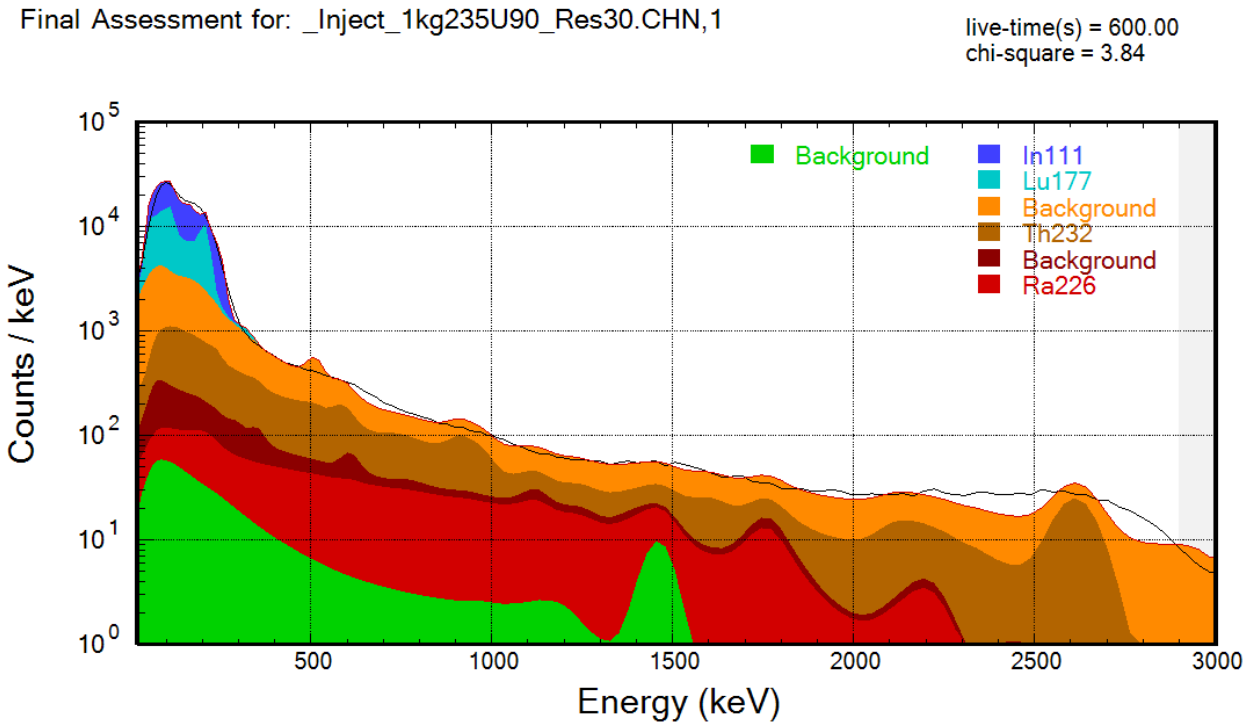


Figure B.13. GADRAS spectrum for HEU at a 30% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	4 (Bad ID)
TTF,TTB:	612, 0
Chi Square:	6
Net Gammas:	6686 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Unknown source
Event Type:	Industrial
Isotopes:	Th232(H,3uCi) + Lu177(H,96uCi) + In111(H,20uCi)

Figure B.14. GADRAS textual results for HEU at a 30% resolution for collection and an 8.92% resolution for identification.

APPENDIX C - GADRAS Output for Configuration 2 Using the Same Resolution for Collection and Identification

8.92% Resolution for Collection and Identification

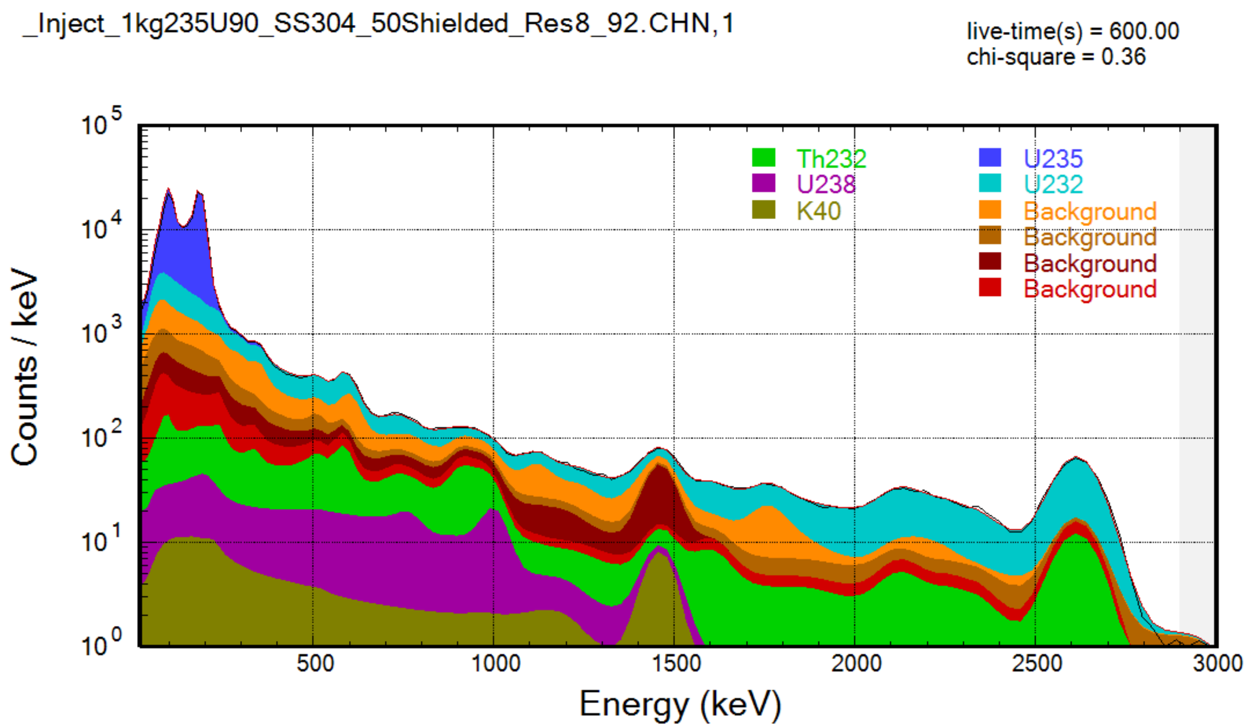


Figure C.1. GADRAS spectrum for HEU shielded to 50% intensity at an 8.92% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                609, 0
Chi Square:             0.6
Net Gammas:             4739 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,5kg) + U232(H,6uCi) + U238(L,419g)
```

Figure C.2. GADRAS textual results for HEU shielded to 50% intensity at an 8.92% resolution for collection and identification.

10% Resolution for Collection and Identification

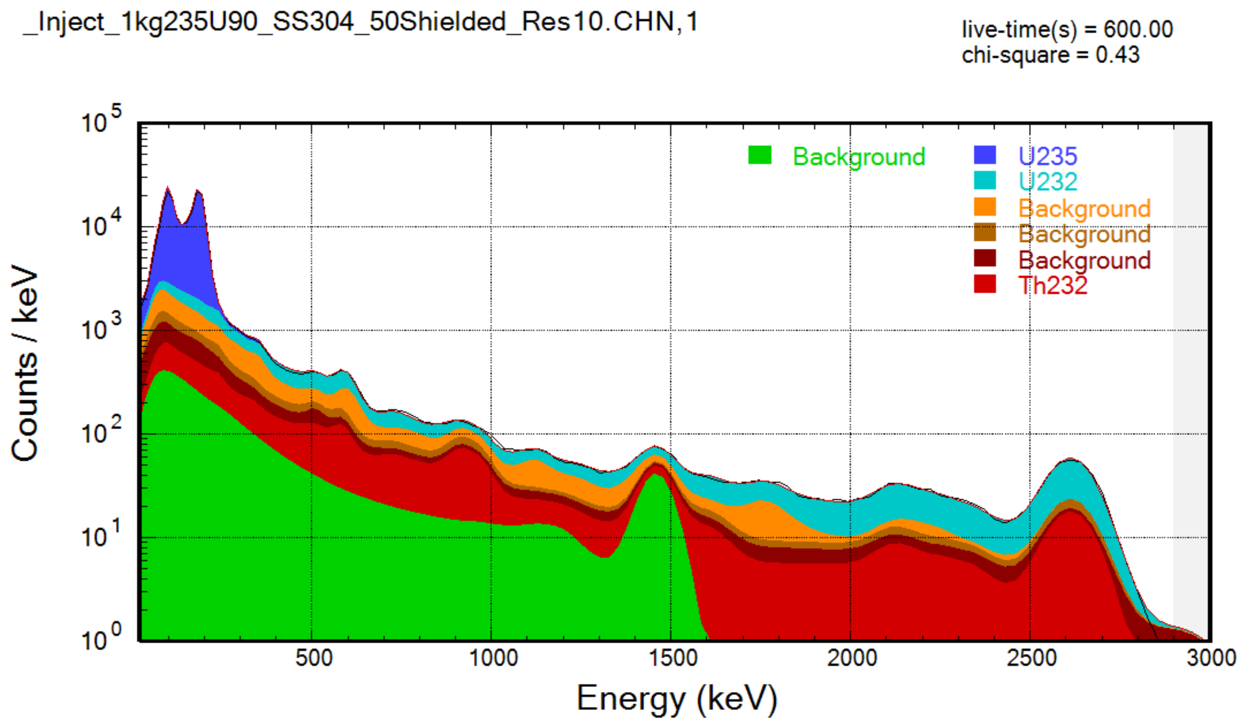


Figure C.3. GADRAS spectrum for HEU shielded to 50% intensity at a 10% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.7
Net Gammas:	4738 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,5kg) + U232(H,5uCi) + K40(H,6uCi)

Figure C.4. GADRAS textual results for HEU shielded to 50% intensity at a 10% resolution for collection and identification.

15% Resolution for Collection and Identification

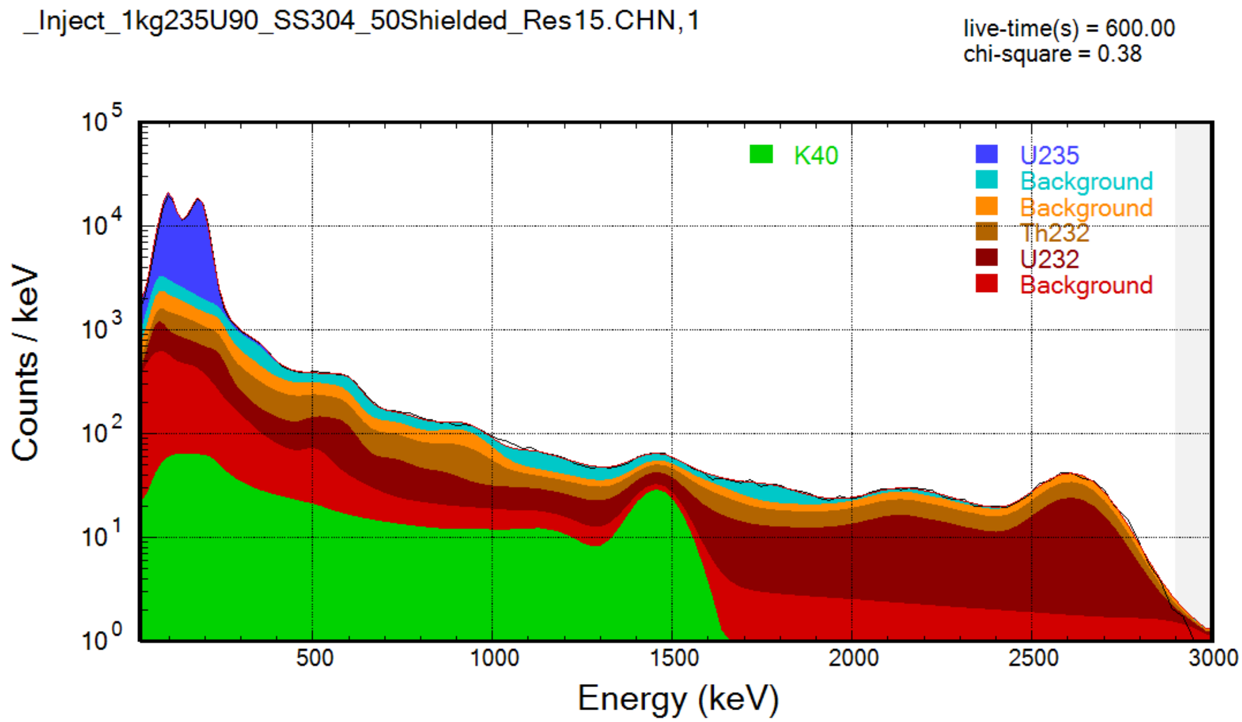


Figure C.5. GADRAS spectrum for HEU shielded to 50% intensity at a 15% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                609, 0
Chi Square:             0.6
Net Gammas:             4747 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,5kg) + U232(H,4uCi) + Ra226(H,1uCi)
```

Figure C.6. GADRAS textual results for HEU shielded to 50% intensity at a 15% resolution for collection and identification.

20% Resolution for Collection and Identification

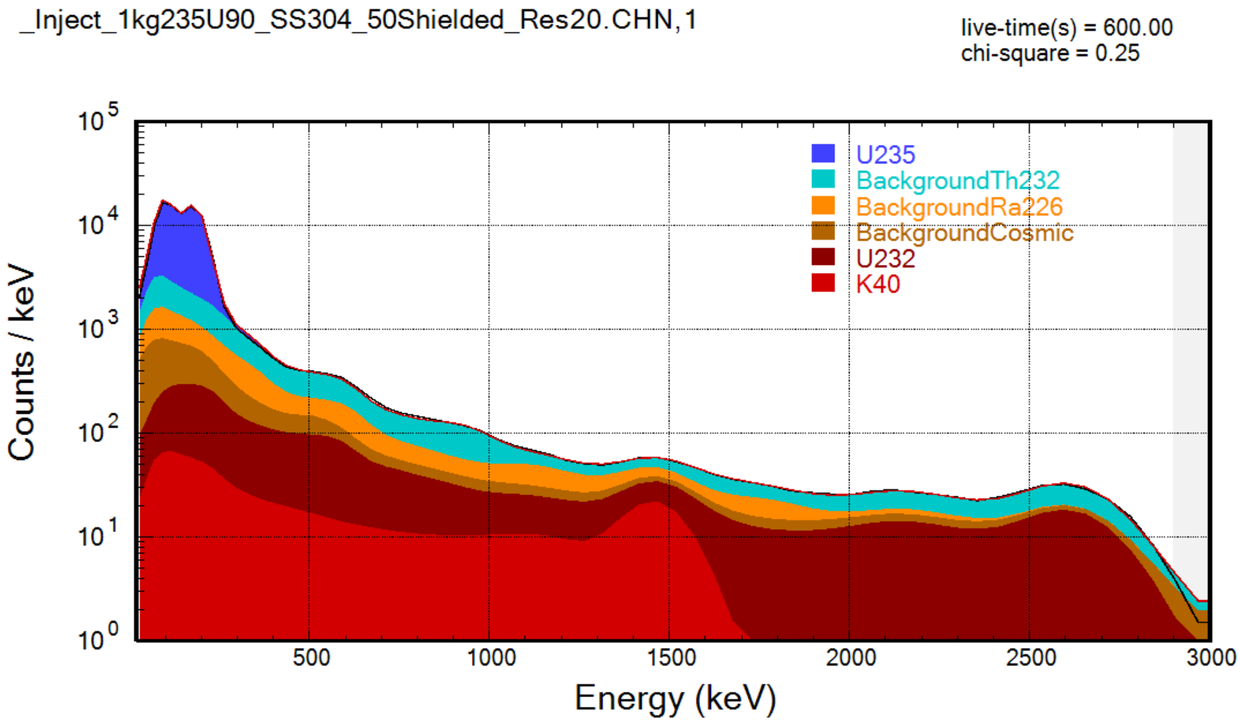


Figure C.7. GADRAS spectrum for HEU shielded to 50% intensity at a 20% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.5
Net Gammas:	4749 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,6kg) + U232(H,5uCi)

Figure C.8. GADRAS textual results for HEU shielded to 50% intensity at a 20% resolution for collection and identification.

25% Resolution for Collection and Identification

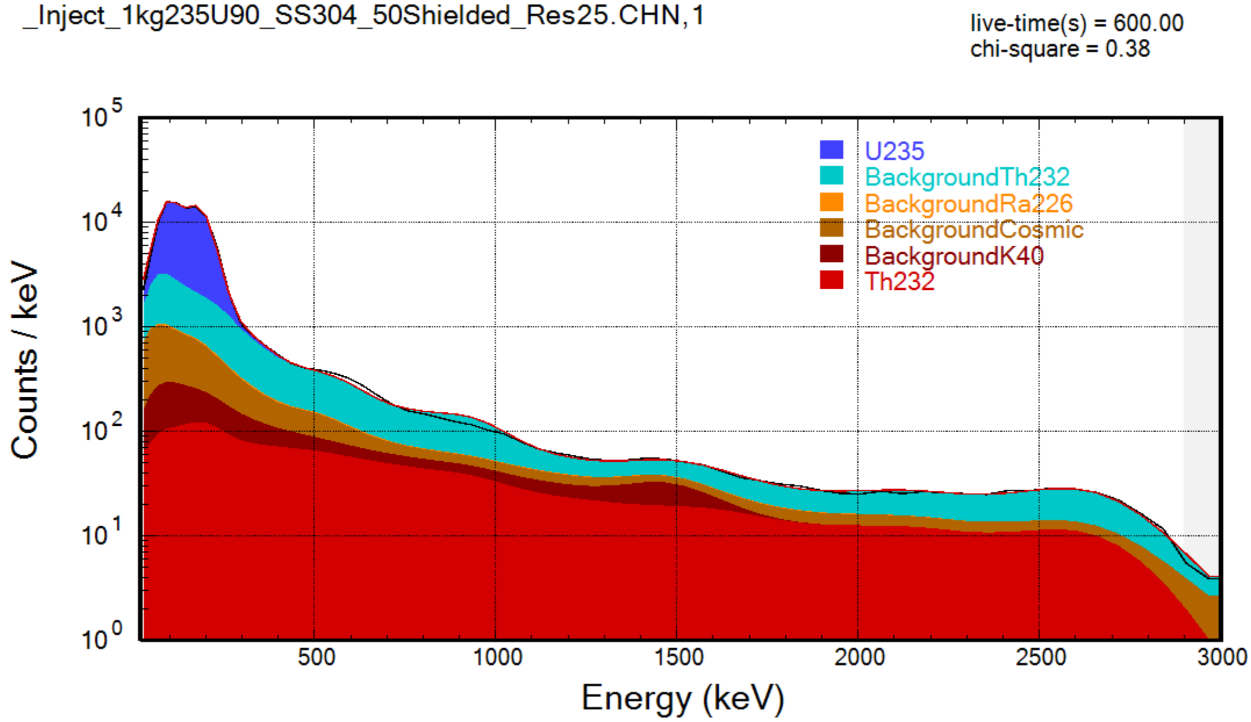


Figure C.9. GADRAS spectrum for HEU shielded to 50% intensity at a 25% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                609, 0
Chi Square:             0.6
Net Gammas:             4741 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,7kg) + U232(H,1uCi) + K40(H,1uCi)
```

Figure C.10. GADRAS textual results for HEU shielded to 50% intensity at a 25% resolution for collection and identification.

30% Resolution for Collection and Identification

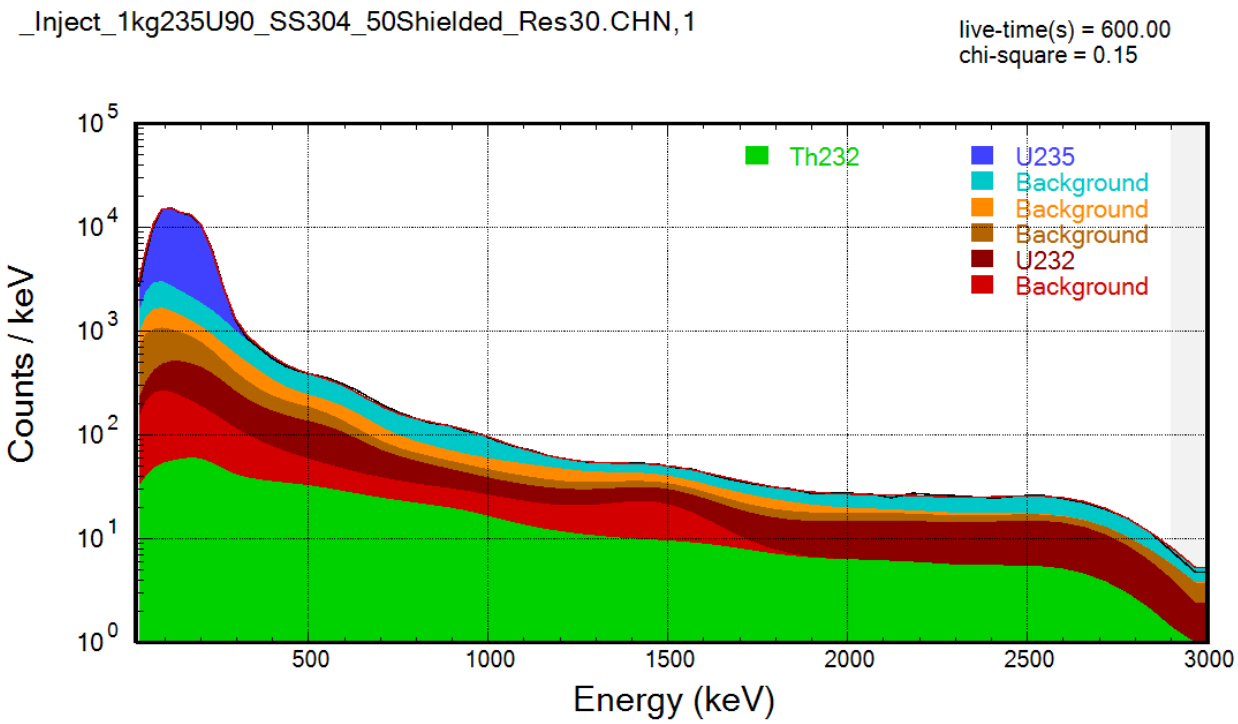


Figure C.11. GADRAS spectrum for HEU shielded to 50% intensity at a 30% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.4
Net Gammas:	4729 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,6kg) + U232(F,1uCi)

Figure C.12. GADRAS textual results for HEU shielded to 50% intensity at a 30% resolution for collection and identification.

35% Resolution for Collection and Identification

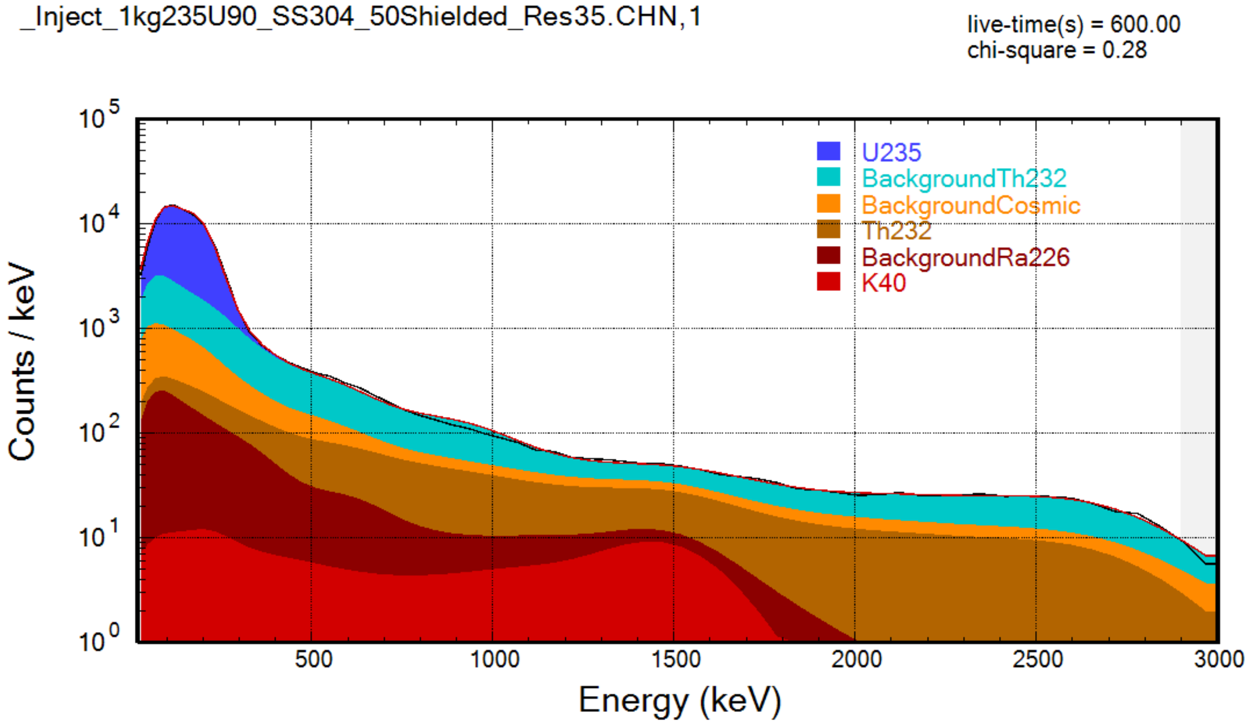


Figure C.13. GADRAS spectrum for HEU shielded to 50% intensity at a 35% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.5
Net Gammas:	4726 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,7kg) + U232(H,1uCi)

Figure C.14. GADRAS textual results for HEU shielded to 50% intensity at a 35% resolution for collection and identification.

40% Resolution for Collection and Identification

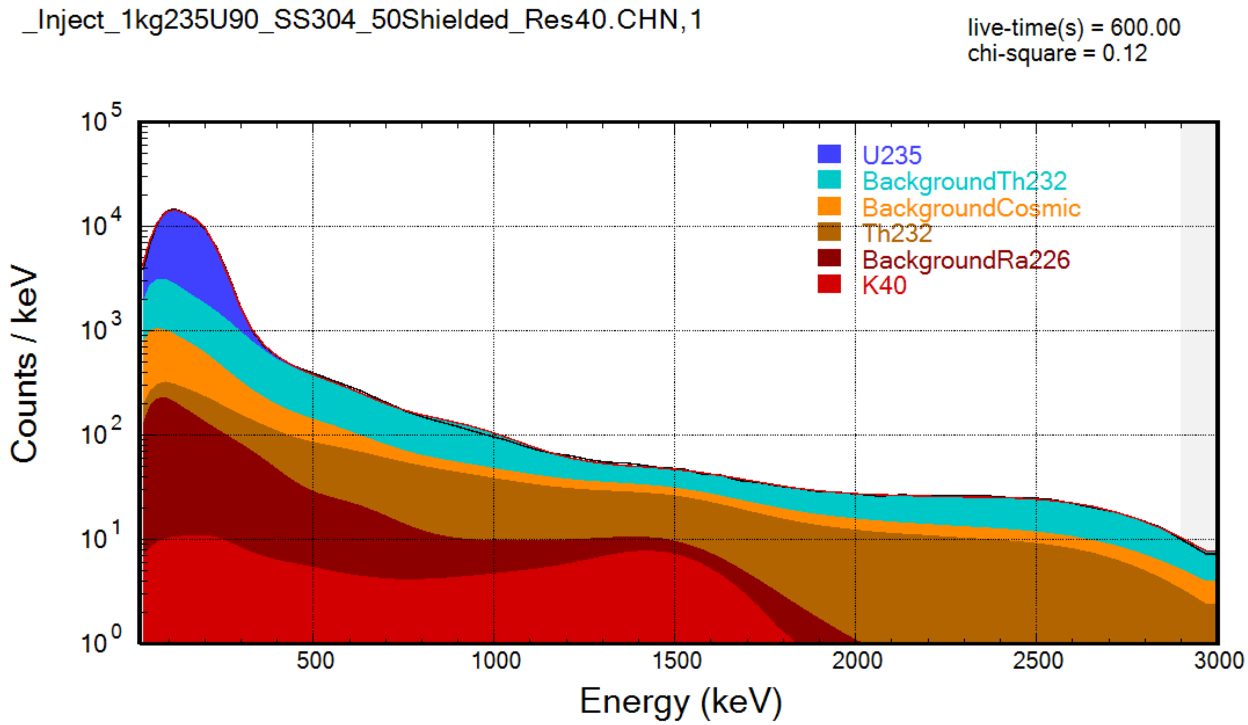


Figure C.15. GADRAS spectrum for HEU shielded to 50% intensity at a 40% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.4
Net Gammas:	4709 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,7kg) + Th232(H,41uCi)

Figure C.16. GADRAS textual results for HEU shielded to 50% intensity at a 40% resolution for collection and identification.

45% Resolution for Collection and Identification

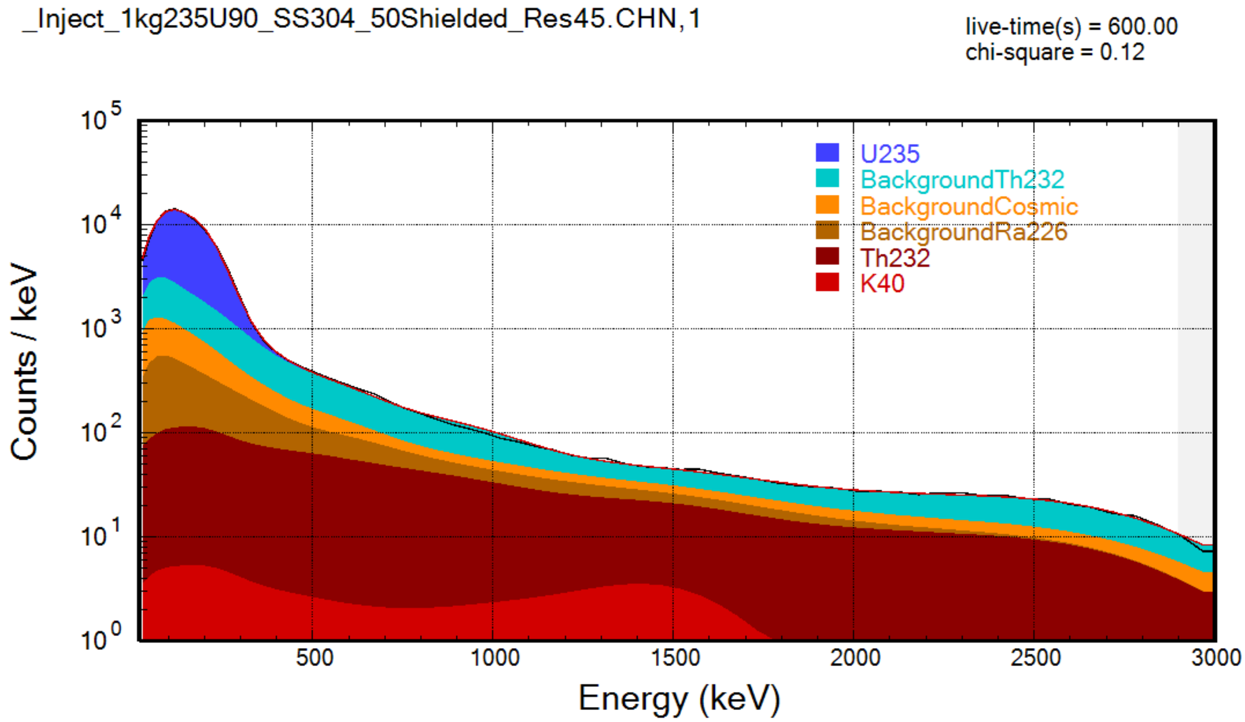


Figure C.17. GADRAS spectrum for HEU shielded to 50% intensity at a 45% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.3
Net Gammas:	4696 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,8kg) + Th232(H,44uCi)

Figure C.18. GADRAS textual results for HEU shielded to 50% intensity at a 45% resolution for collection and identification.

50% Resolution for Collection and Identification

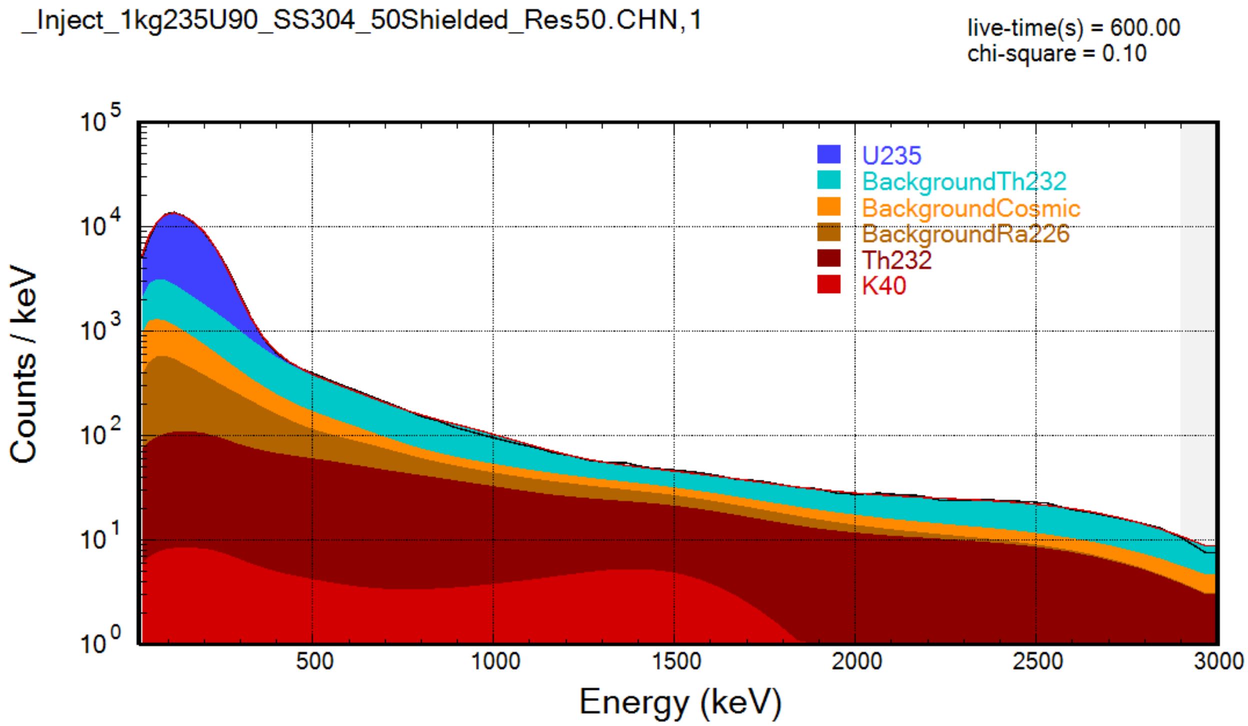


Figure C.19. GADRAS spectrum for HEU shielded to 50% intensity at a 50% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.3
Net Gammas:	4678 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,8kg)

Figure C.20. GADRAS textual results for HEU shielded to 50% intensity at a 50% resolution for collection and identification.

55% Resolution for Collection and Identification

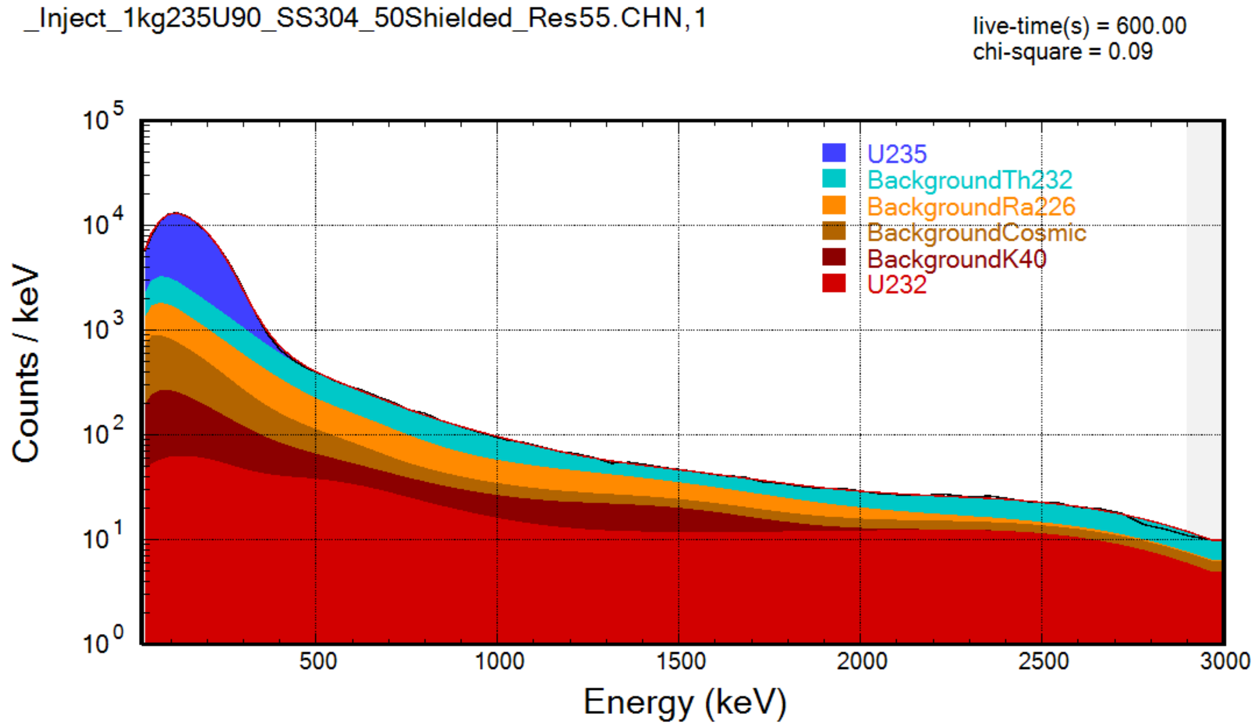


Figure C.21. GADRAS spectrum for HEU shielded to 50% intensity at a 55% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.3
Net Gammas:	4669 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,7kg) + U232(F,1uCi)

Figure C.22. GADRAS textual results for HEU shielded to 50% intensity at a 55% resolution for collection and identification.

60% Resolution for Collection and Identification

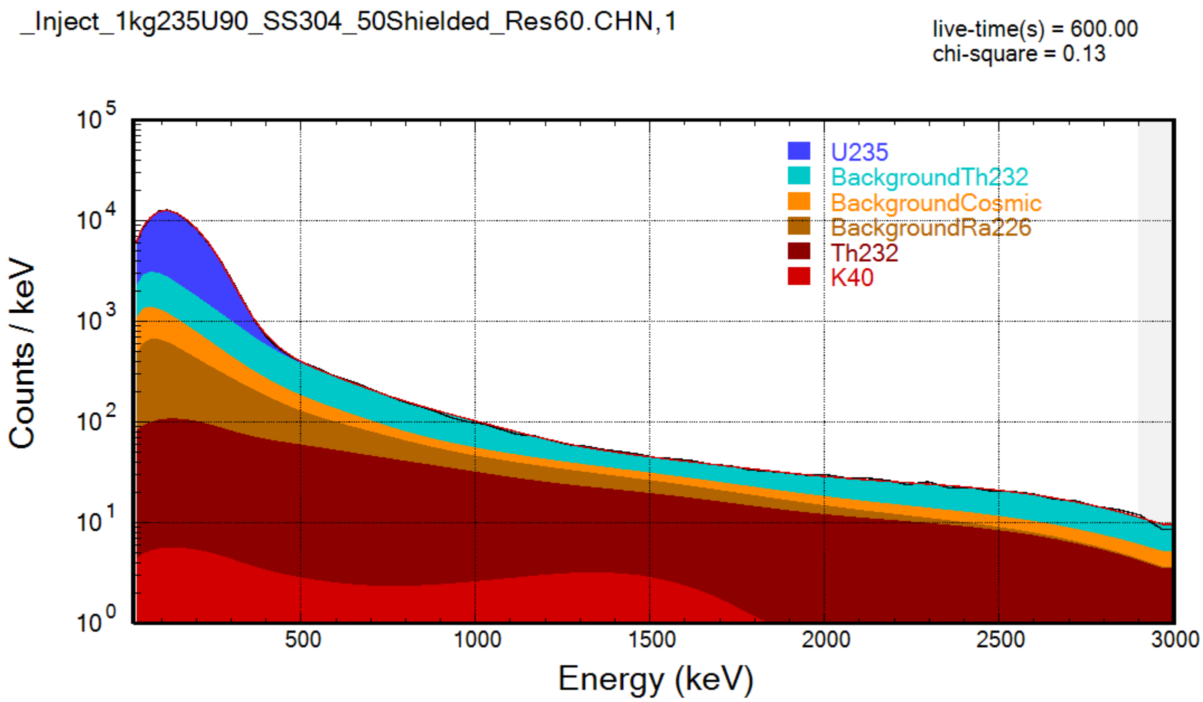


Figure C.23. GADRAS spectrum for HEU shielded to 50% intensity at a 60% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.3
Net Gammas:	4650 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,8kg)

Figure C.24. GADRAS textual results for HEU shielded to 50% intensity at a 60% resolution for collection and identification.

65% Resolution for Collection and Identification

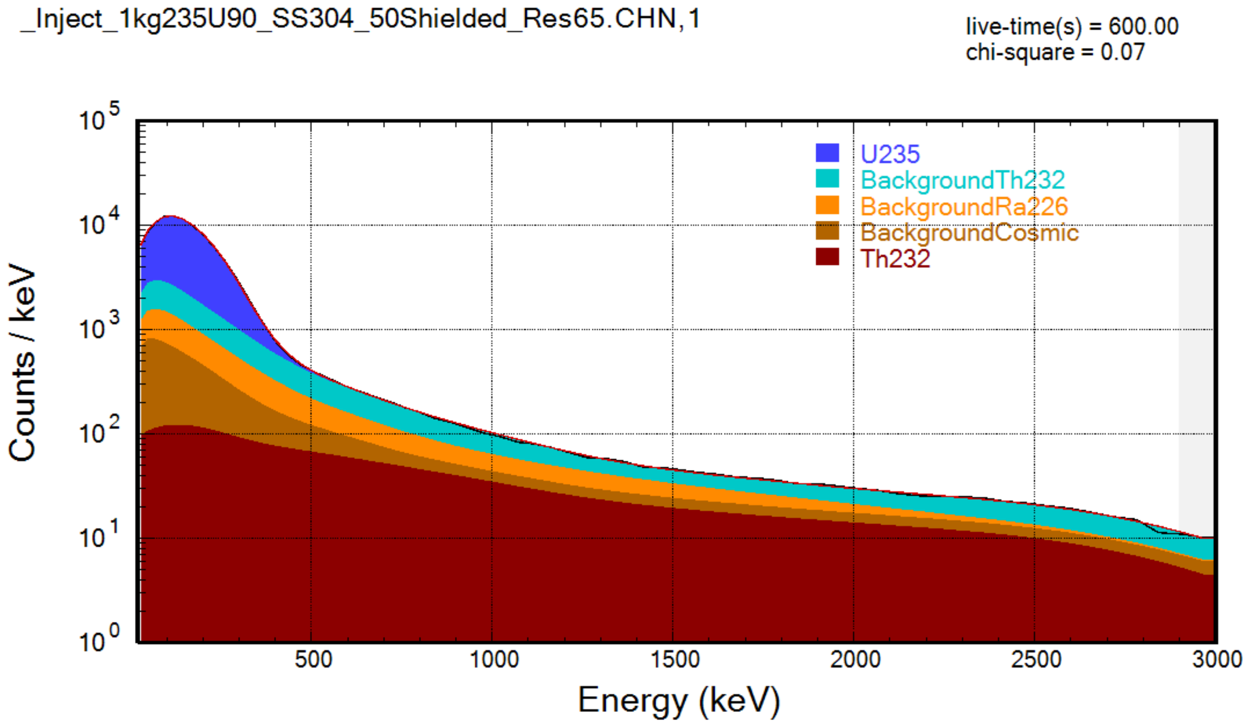


Figure C.25. GADRAS spectrum for HEU shielded to 50% intensity at a 65% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	0.3
Net Gammas:	4634 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,8kg)

Figure C.26. GADRAS textual results for HEU shielded to 50% intensity at a 65% resolution for collection and identification.

70% Resolution for Collection and Identification

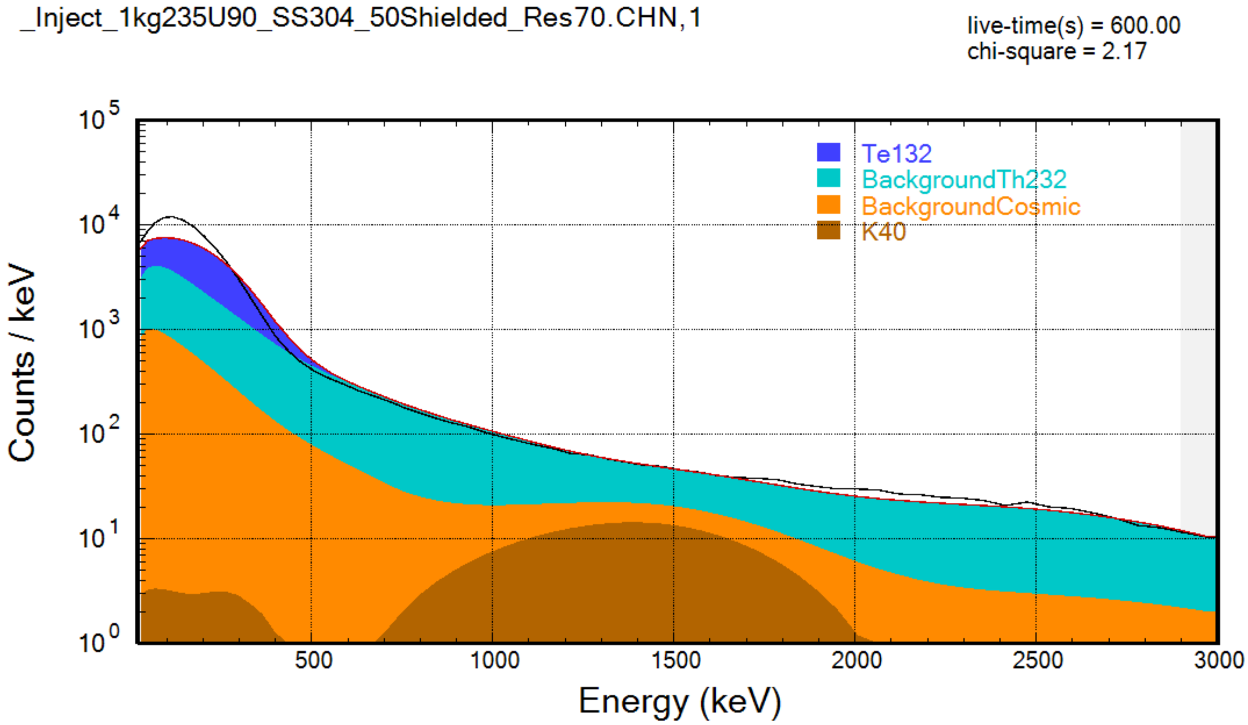


Figure C.27. GADRAS spectrum for HEU shielded to 50% intensity at a 70% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	3 (Fission)
TTF,TTB:	609, 0
Chi Square:	2.5
Net Gammas:	4620 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Industrial
Event Type:	Fission
Isotopes:	Te132(F,2uCi) + Co57(L,1uCi)

Figure C.28. GADRAS textual results for HEU shielded to 50% intensity at a 70% resolution for collection and identification.

69% Resolution for Collection and Identification

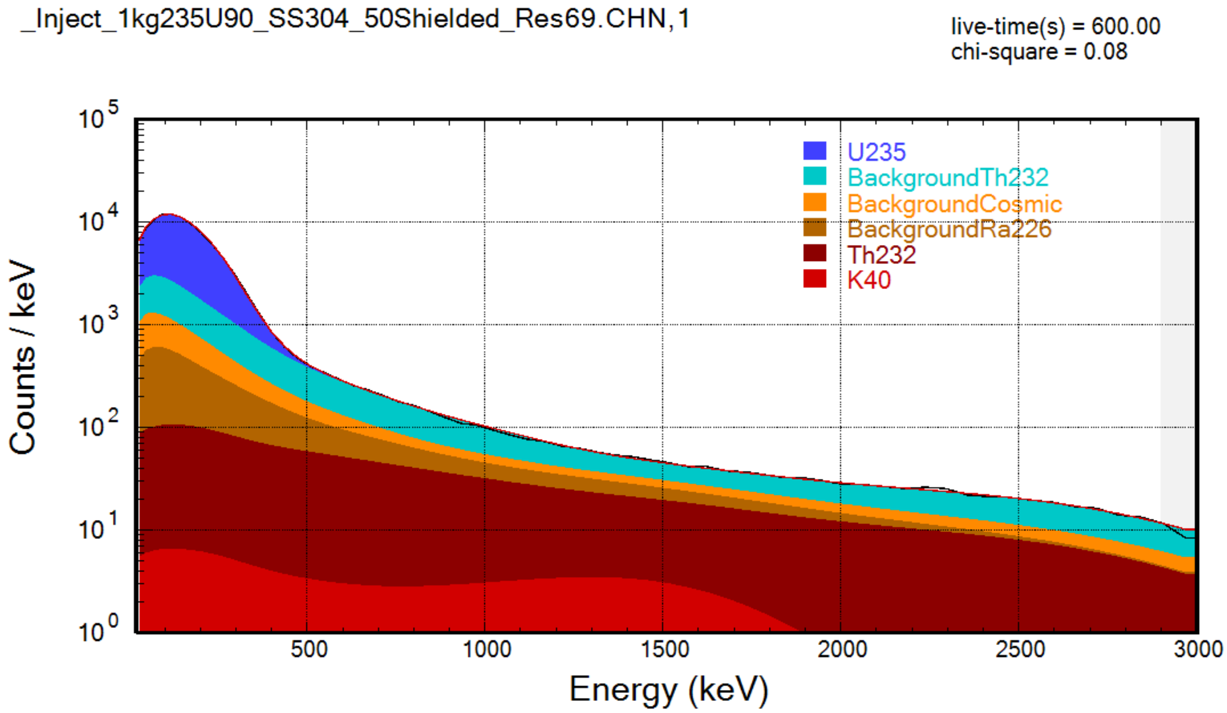


Figure C.29. GADRAS spectrum for HEU shielded to 50% intensity at a 69% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	609, 0
Chi Square:	0.3
Net Gammas:	4620 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	U235(F,803g)

Figure C.30. GADRAS textual results for HEU shielded to 50% intensity at a 69% resolution for collection and identification.

68% Resolution for Collection and Identification

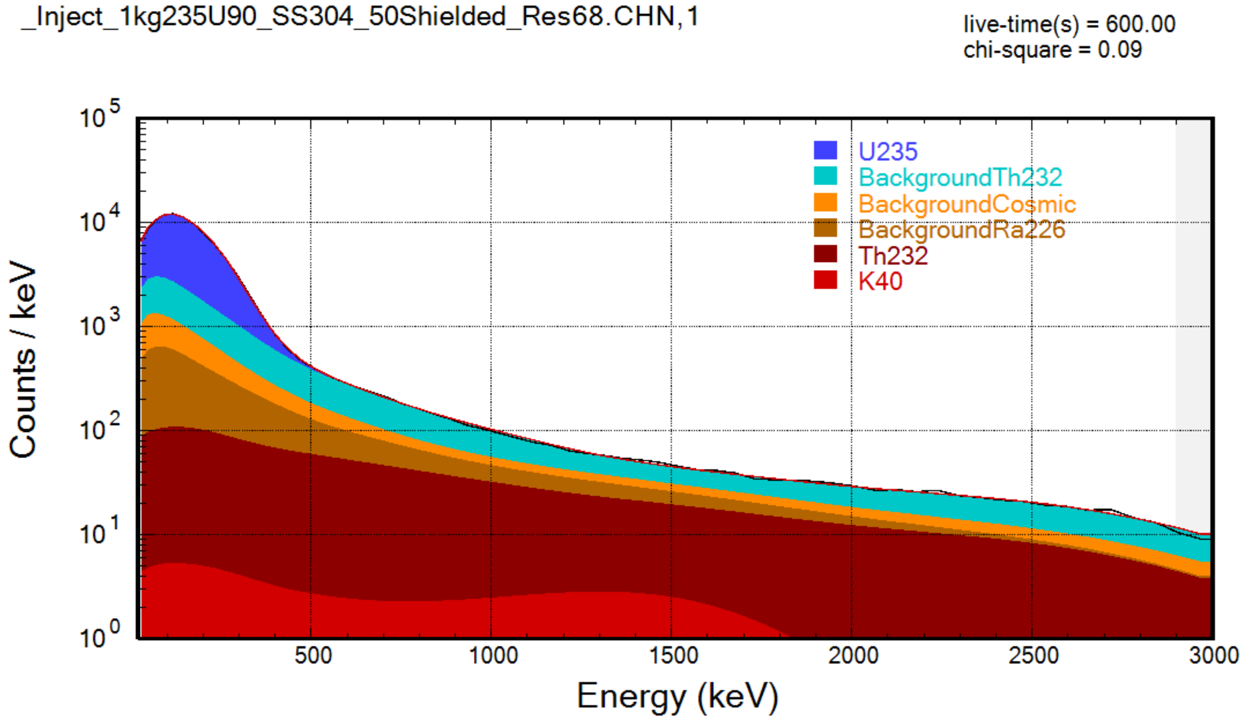


Figure C.31. GADRAS spectrum for HEU shielded to 50% intensity at a 68% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	609, 0
Chi Square:	0.3
Net Gammas:	4622 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	U235(F,788g)

Figure C.32. GADRAS textual results for HEU shielded to 50% intensity at a 68% resolution for collection and identification.

67% Resolution for Collection and Identification

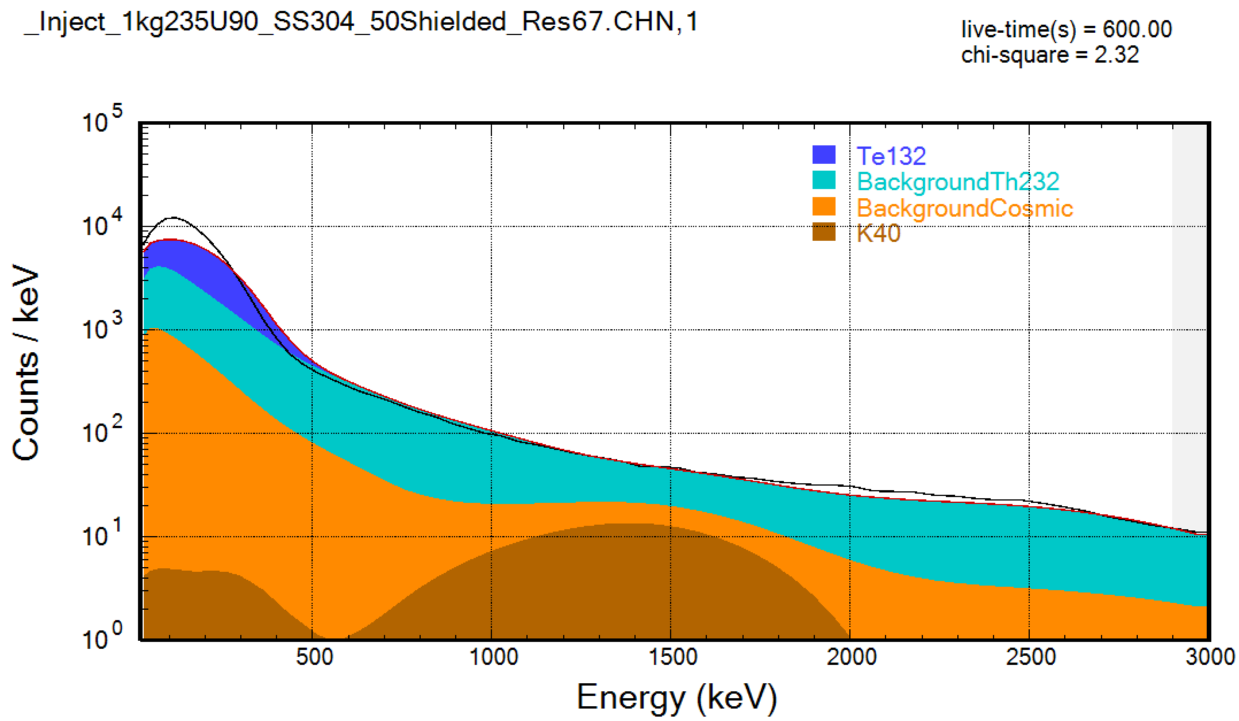


Figure C.33. GADRAS spectrum for HEU shielded to 50% intensity at a 67% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                  3 (Fission)
TTF,TTB:                 609, 0
Chi Square:              2.6
Net Gammas:              4628 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                0 (Very Low)
Alarm Severity:          RED
Alarm Description:       Industrial
Event Type:              Fission

Isotopes:                Te132(F,2uCi) + Co57(L,1uCi)
```

Figure C.34. GADRAS textual results for HEU shielded to 50% intensity at a 67% resolution for collection and identification.

66% Resolution for Collection and Identification

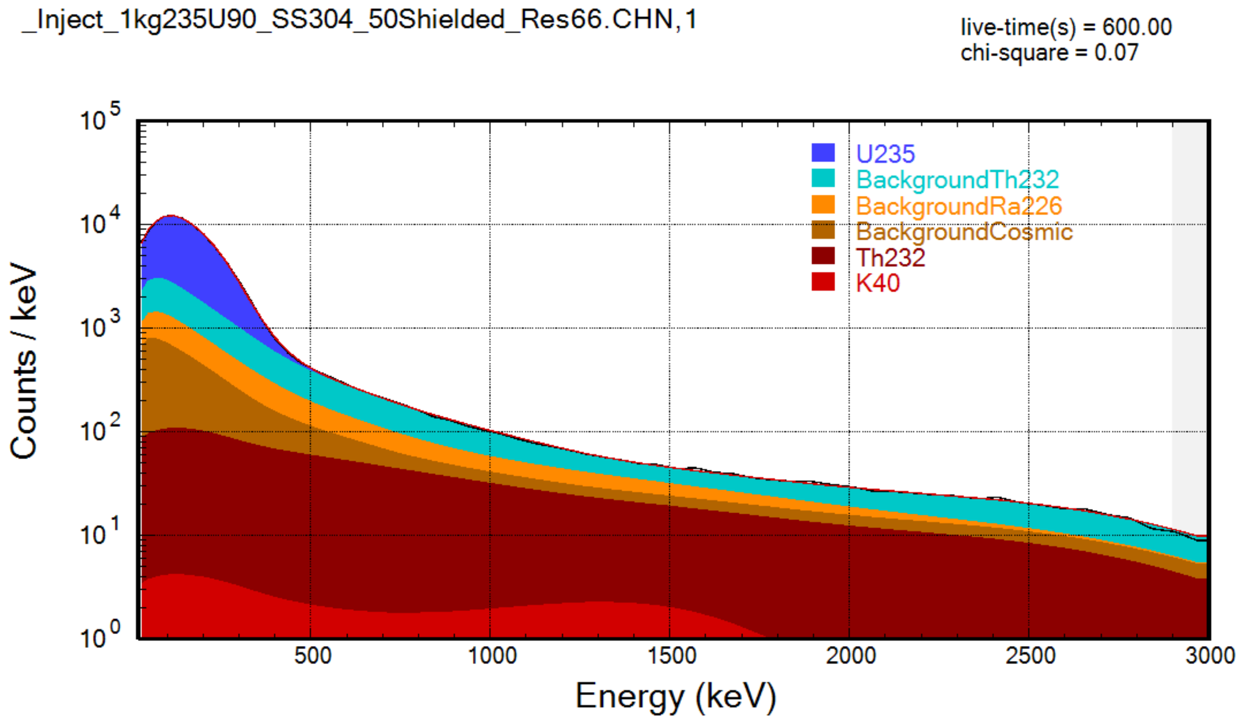


Figure C.35. GADRAS spectrum for HEU shielded to 50% intensity at a 66% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	609, 0
Chi Square:	0.3
Net Gammas:	4631 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	U235(F,762g)

Figure C.36. GADRAS textual results for HEU shielded to 50% intensity at a 66% resolution for collection and identification.

APPENDIX D - GADRAS Output for Configuration 2 Using Different Resolutions for Collection and Identification

8.92% Resolution for Collection and 8.92% Resolution for Identification

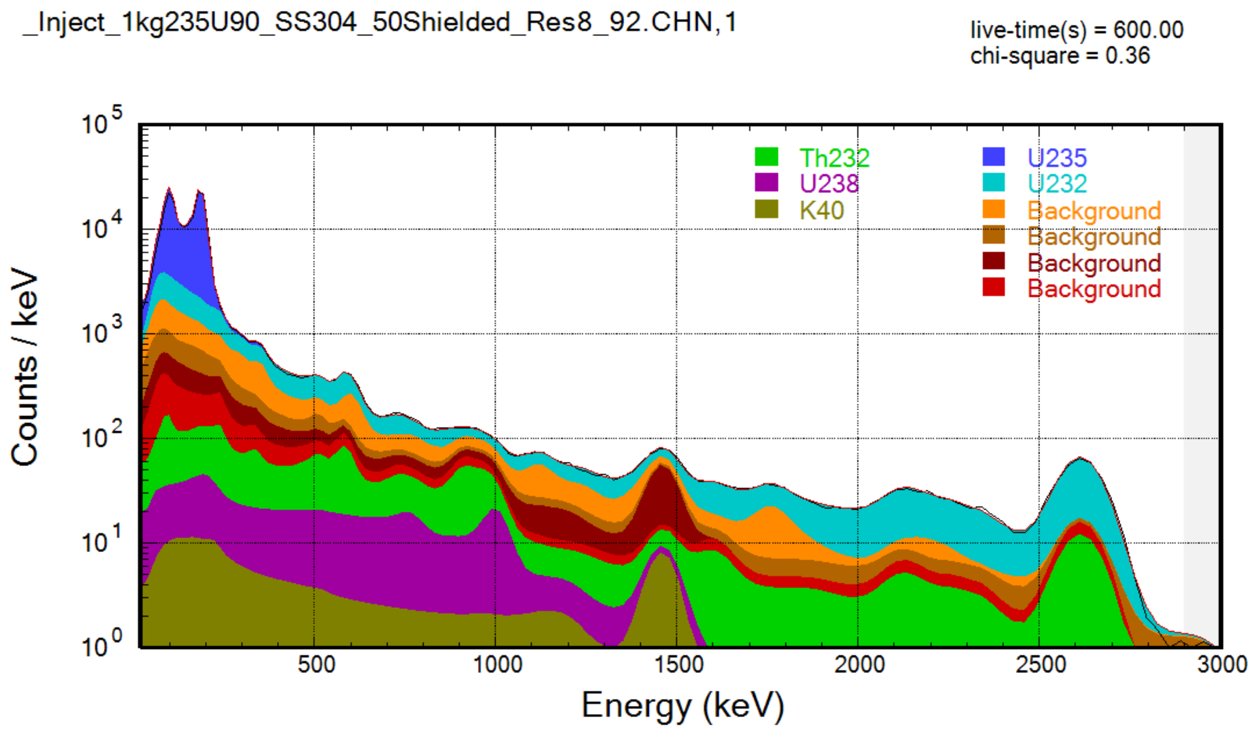


Figure D.1. GADRAS spectrum for HEU shielded to 50% intensity at an 8.92% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                  7 (SNM=H)
TTF,TTB:                 609, 0
Chi Square:              0.6
Net Gammas:              4739 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                3 (High)
Alarm Severity:          RED
Alarm Description:       Probable SNM
Event Type:              SNM

Isotopes:                U235(H,5kg) + U232(H,6uCi) + U238(L,419g)
```

Figure D.2. GADRAS textual results for HEU shielded to 50% intensity at an 8.92% resolution for collection and an 8.92% resolution for identification.

10% Resolution for Collection and 8.92% Resolution for Identification

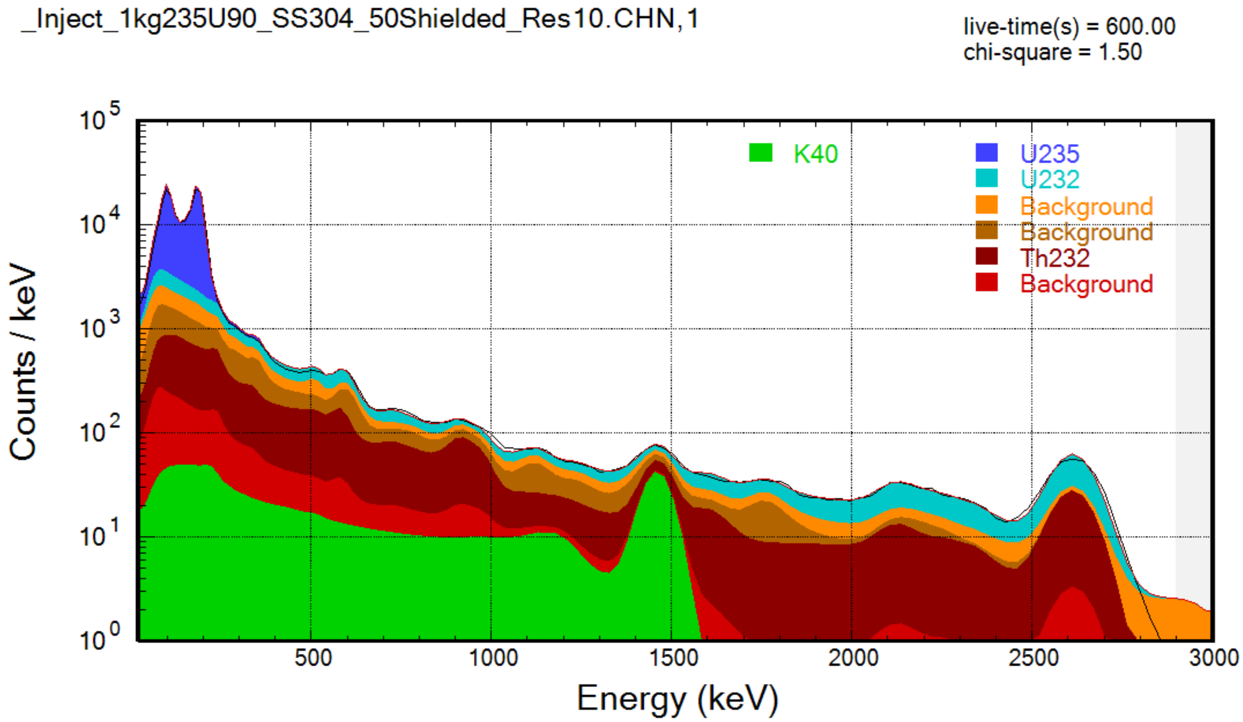


Figure D.3. GADRAS spectrum for HEU shielded to 50% intensity at a 10% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                609, 0
Chi Square:             1.8
Net Gammas:             4738 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,5kg) + K40(H,11uCi) + U232(H,5uCi)
```

Figure D.4. GADRAS textual results for HEU shielded to 50% intensity at a 10% resolution for collection and an 8.92% resolution for identification.

15% Resolution for Collection and 8.92% Resolution for Identification

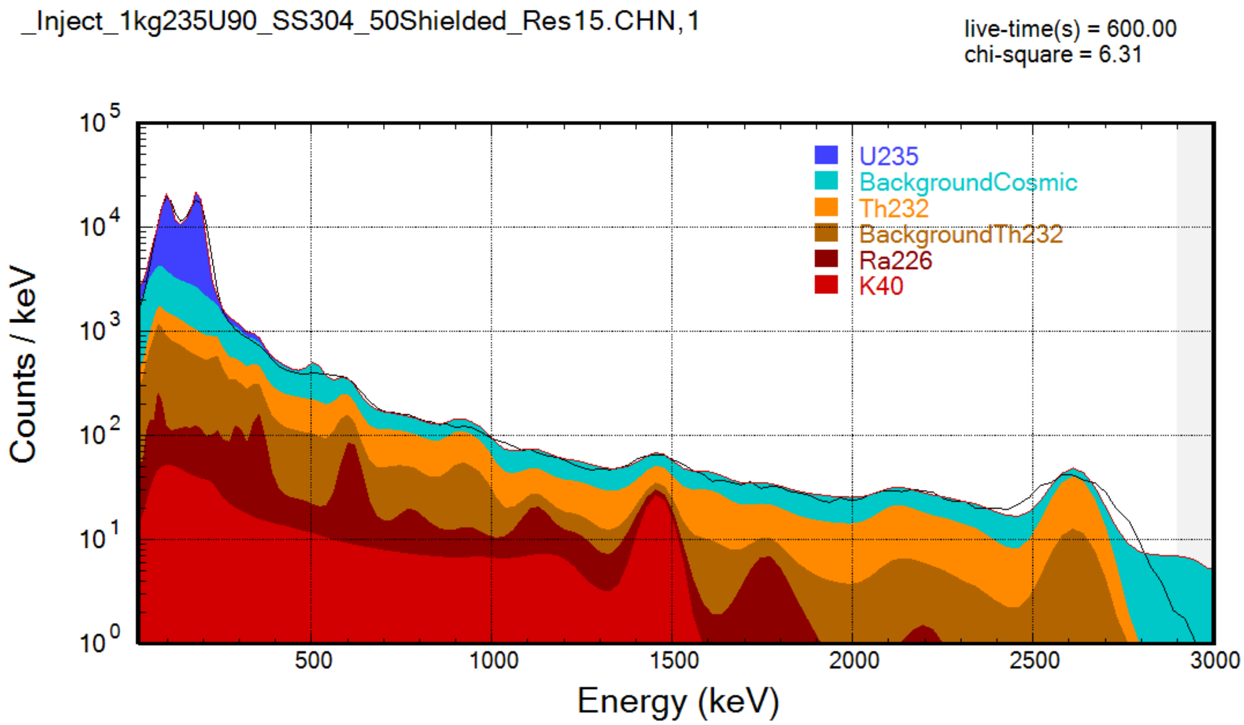


Figure D.5. GADRAS spectrum for HEU shielded to 50% intensity at a 15% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	7.6
Net Gammas:	4747 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,20uCi) + U235(H,26kg)

Figure D.6. GADRAS textual results for HEU shielded to 50% intensity at a 15% resolution for collection and an 8.92% resolution for identification.

20% Resolution for Collection and 8.92% Resolution for Identification

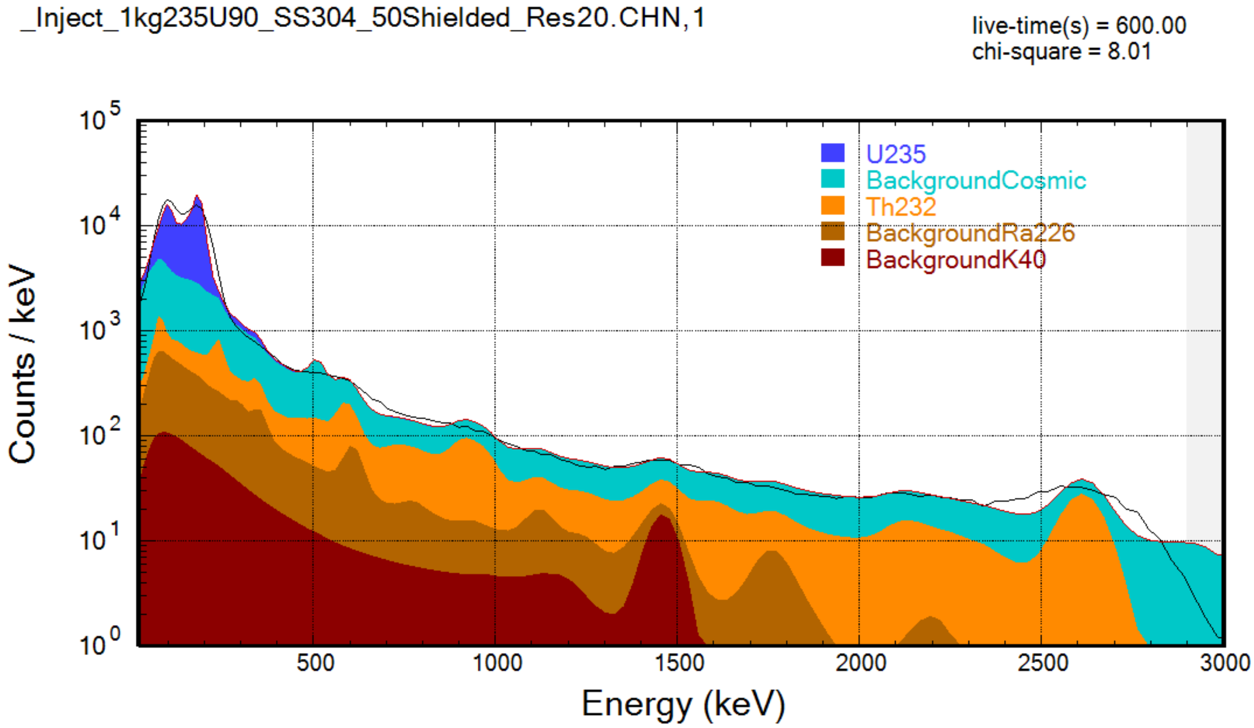


Figure D.7. GADRAS spectrum for HEU shielded to 50% intensity at a 20% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                609, 0
Chi Square:             10.5
Net Gammas:             4748 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               Th232(H,30uCi) + U235(H,31kg)
```

Figure D.8. GADRAS textual results for HEU shielded to 50% intensity at a 20% resolution for collection and an 8.92% resolution for identification.

25% Resolution for Collection and 8.92% Resolution for Identification

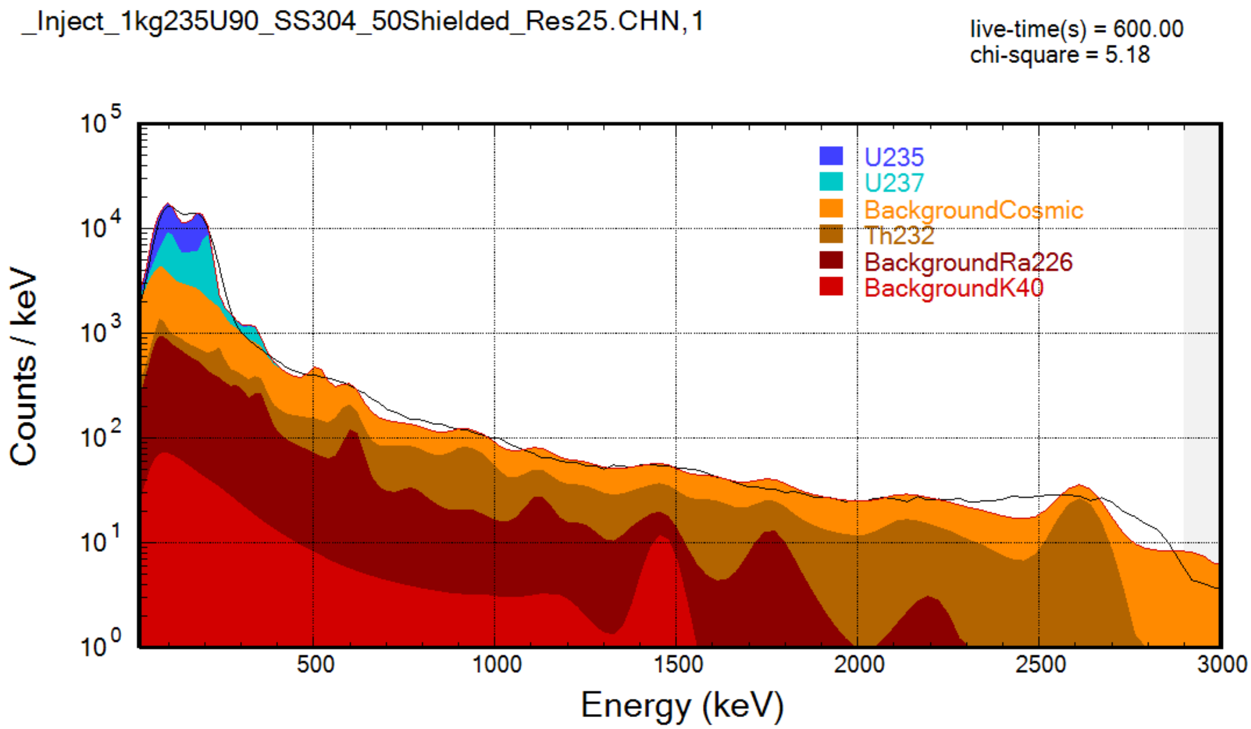


Figure D.9. GADRAS spectrum for HEU shielded to 50% intensity at a 25% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	7
Net Gammas:	4741 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,39uCi) + U235(H,2kg) + U237(H,49uCi)

Figure D.10. GADRAS textual results for HEU shielded to 50% intensity at a 25% resolution for collection and an 8.92% resolution for identification.

30% Resolution for Collection and 8.92% Resolution for Identification

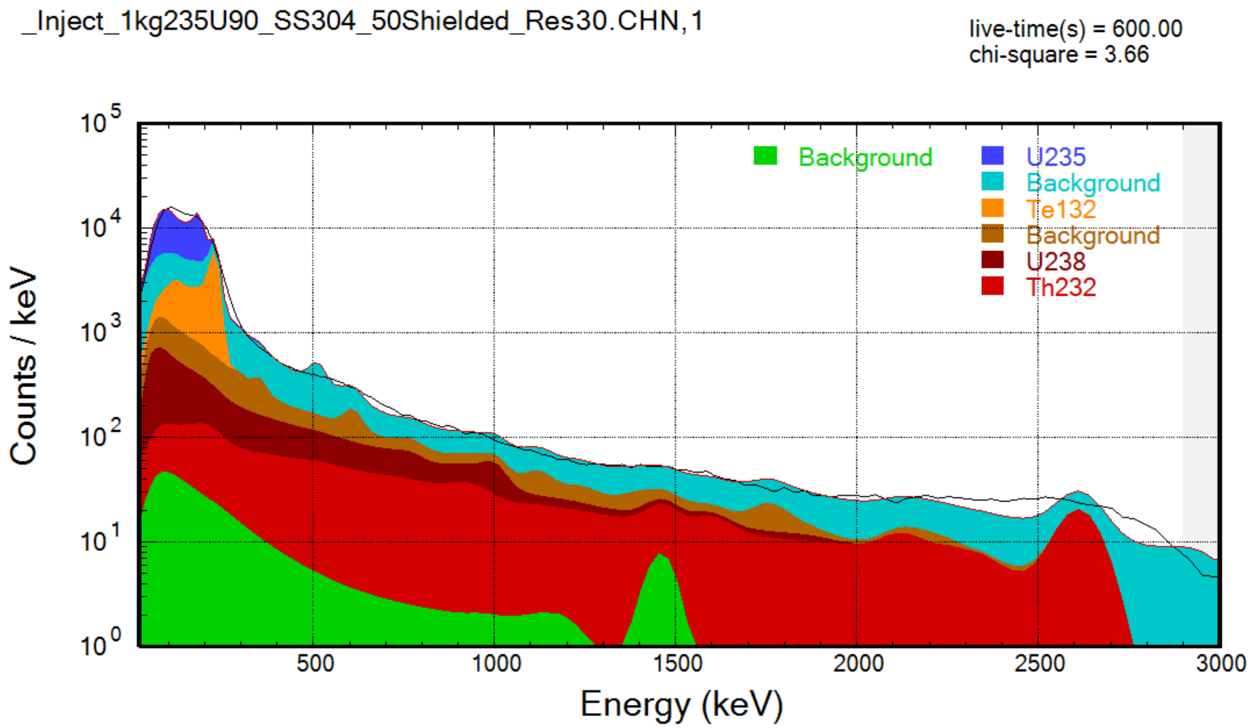


Figure D.11. GADRAS spectrum for HEU shielded to 50% intensity at a 30% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                609, 0
Chi Square:             5.8
Net Gammas:             4729 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               Th232(H,38uCi) + U235(H,3kg) + Te132(F,1uCi) + U238(L,2kg)
```

Figure D.12. GADRAS textual results for HEU shielded to 50% intensity at a 30% resolution for collection and an 8.92% resolution for identification.

35% Resolution for Collection and 8.92% Resolution for Identification

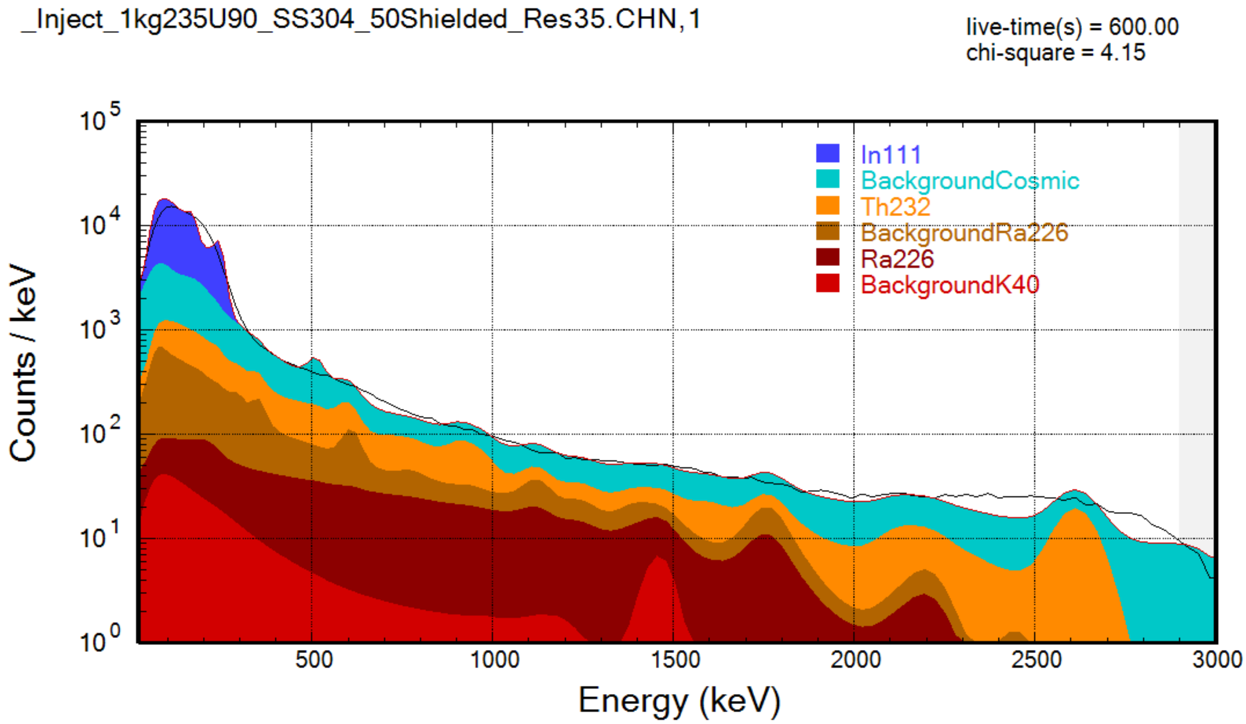


Figure D.13. GADRAS spectrum for HEU shielded to 50% intensity at a 35% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	4 (Bad ID)
TTF,TTB:	609, 0
Chi Square:	6.2
Net Gammas:	4725 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Unknown source
Event Type:	Medical
Isotopes:	Th232(H,3uCi) + In111(H,22uCi)

Figure D.14. GADRAS textual results for HEU shielded to 50% intensity at a 35% resolution for collection and an 8.92% resolution for identification.

34% Resolution for Collection and 8.92% Resolution for Identification

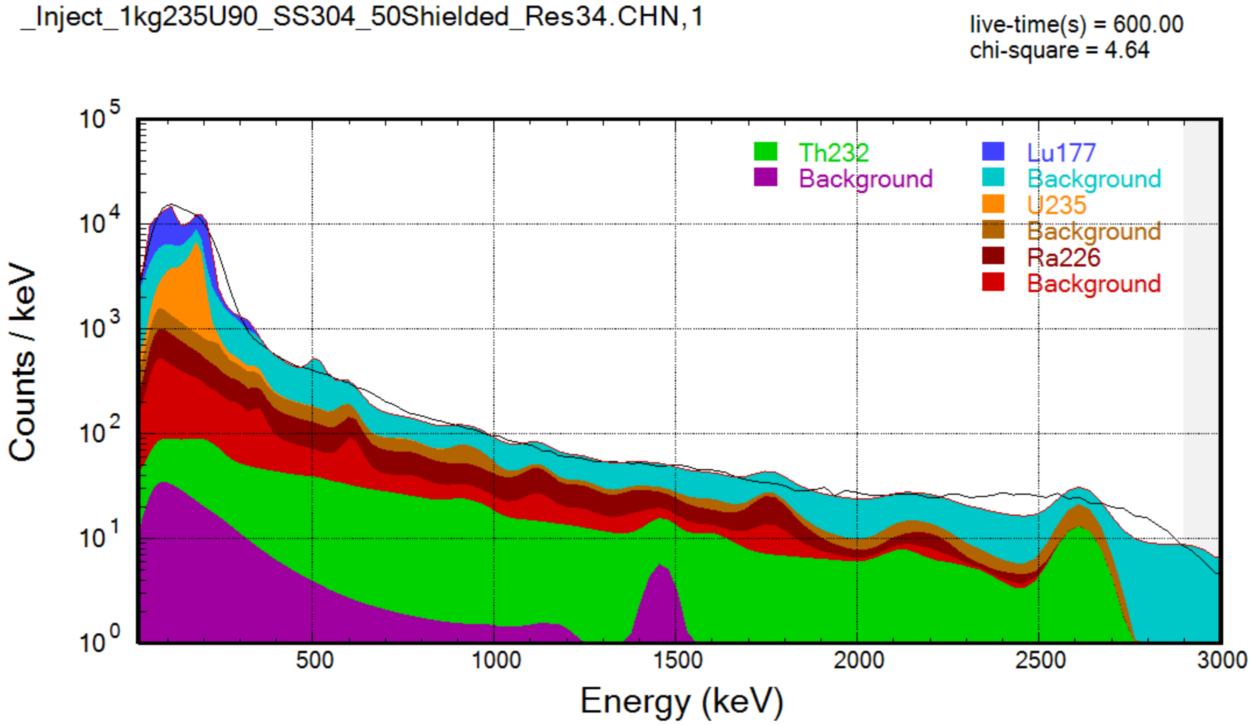
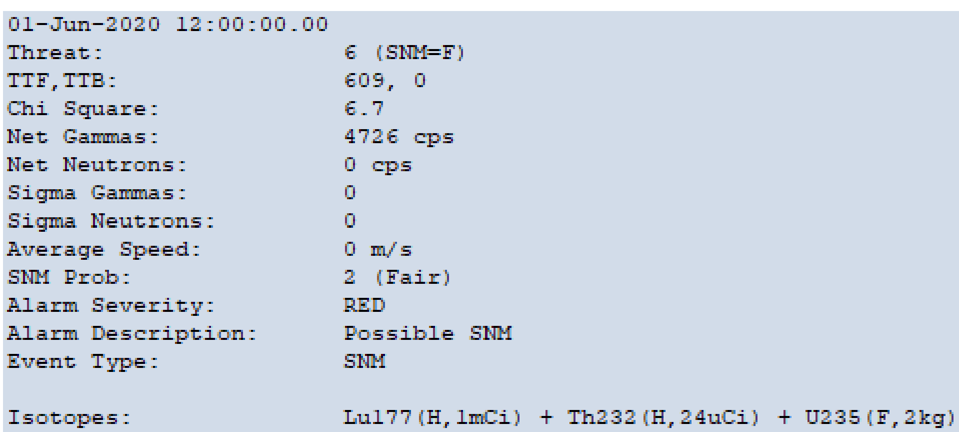


Figure D.15. GADRAS spectrum for HEU shielded to 50% intensity at a 34% resolution for collection and an 8.92% resolution for identification.



01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	609, 0
Chi Square:	6.7
Net Gammas:	4726 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	Lu177(H,1mCi) + Th232(H,24uCi) + U235(F,2kg)

Figure D.16. GADRAS textual results for HEU shielded to 50% intensity at a 34% resolution for collection and an 8.92% resolution for identification.

33% Resolution for Collection and 8.92% Resolution for Identification

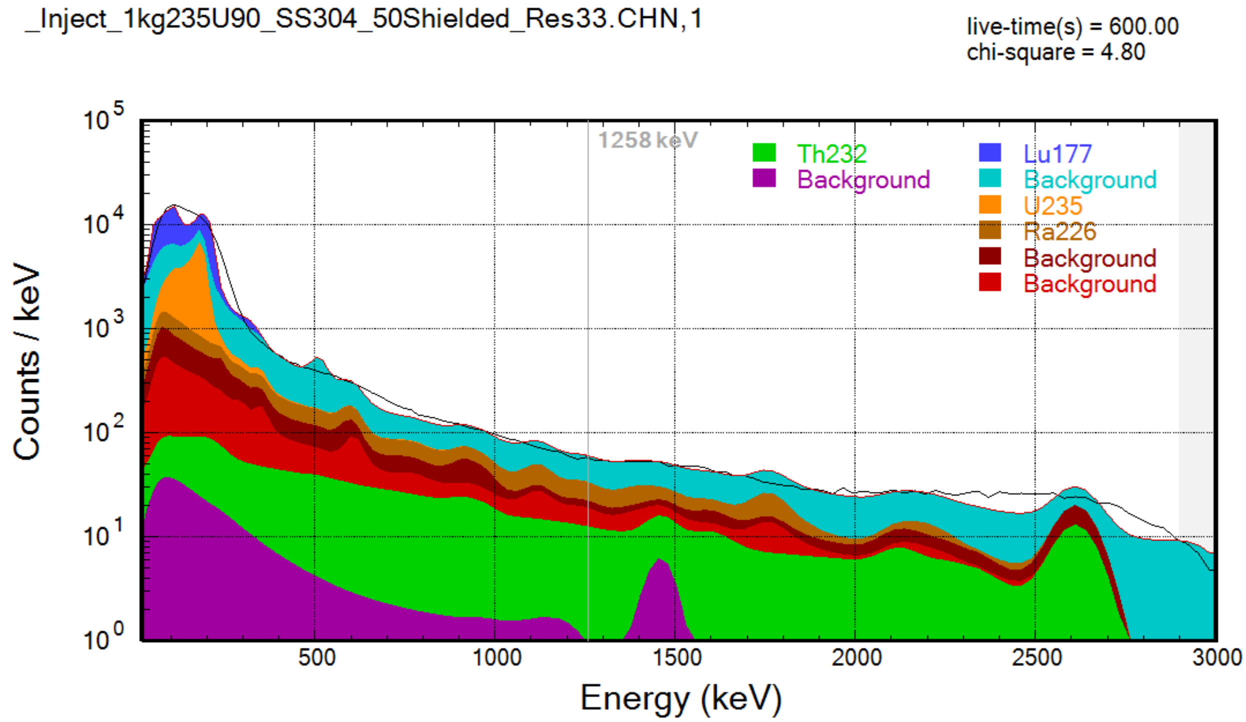


Figure D.17. GADRAS spectrum for HEU shielded to 50% intensity at a 33% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 6 (SNM=F)
TTF,TTB:                609, 0
Chi Square:             7.1
Net Gammas:             4729 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               2 (Fair)
Alarm Severity:         RED
Alarm Description:      Possible SNM
Event Type:             SNM

Isotopes:               Lu177(H,1mCi) + Th232(H,24uCi) + U235(F,2kg)
```

Figure D.18. GADRAS textual results for HEU shielded to 50% intensity at a 33% resolution for collection and an 8.92% resolution for identification.

32% Resolution for Collection and 8.92% Resolution for Identification

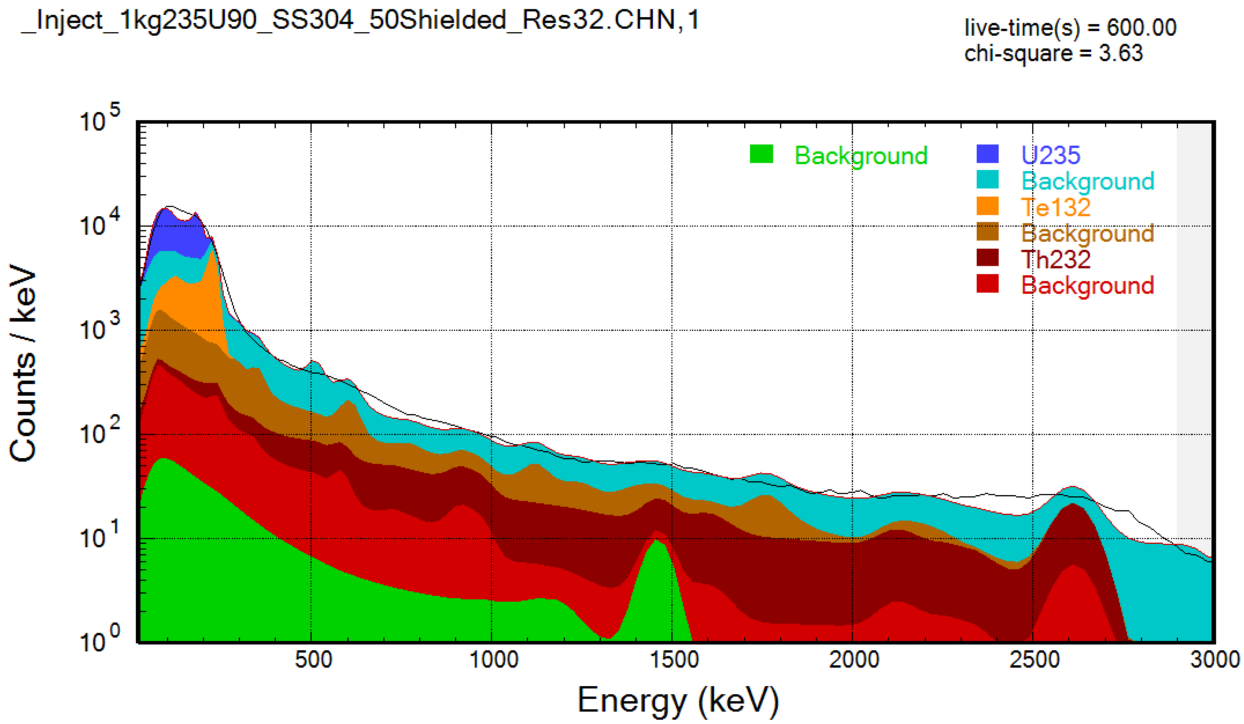


Figure D.19. GADRAS spectrum for HEU shielded to 50% intensity at a 32% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	5.6
Net Gammas:	4734 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,3kg) + Th232(H,39uCi) + Te132(F,1uCi)

Figure D.20. GADRAS textual results for HEU shielded to 50% intensity at a 32% resolution for collection and an 8.92% resolution for identification.

31% Resolution for Collection and 8.92% Resolution for Identification

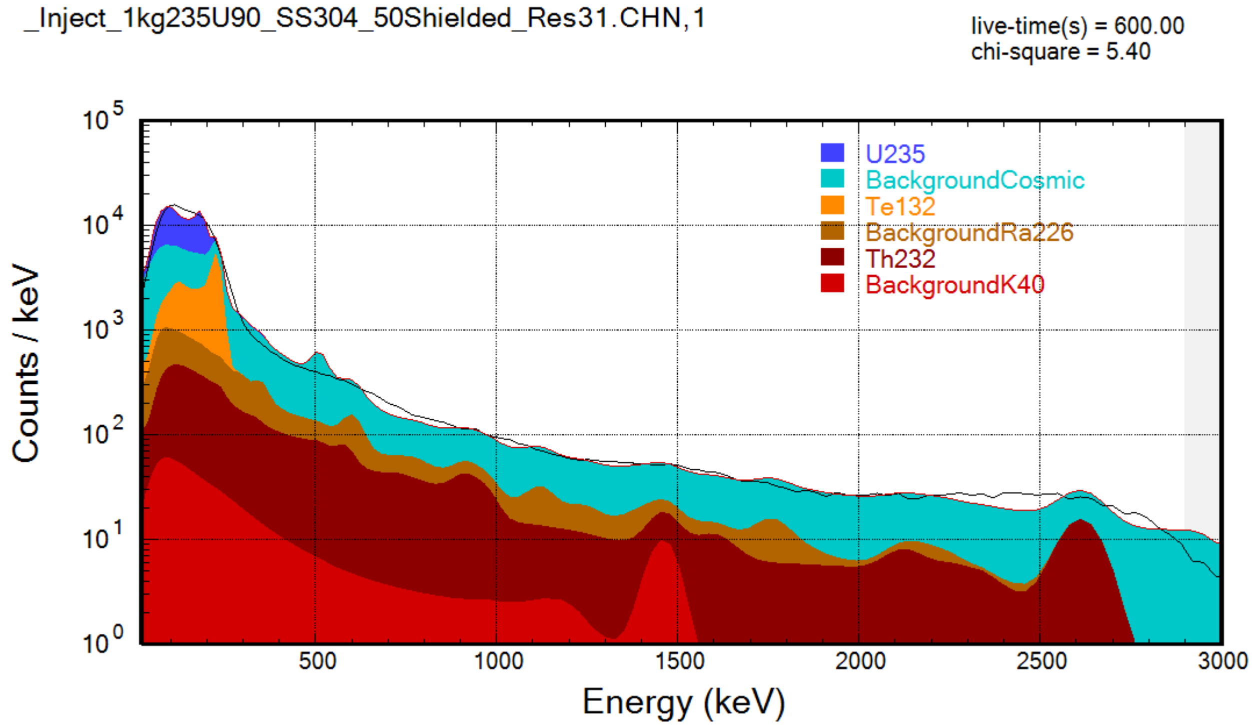


Figure D.21. GADRAS spectrum for HEU shielded to 50% intensity at a 31% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	609, 0
Chi Square:	9.6
Net Gammas:	4733 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,8uCi) + U235(H,2kg) + Te132(F,1uCi)

Figure D.22. GADRAS textual results for HEU shielded to 50% intensity at a 31% resolution for collection and an 8.92% resolution for identification.

APPPENDIX E - GADRAS Output for Configuration 3 Using the Same Resolution for Collection and Identification

8.92% Resolution for Collection and Identification

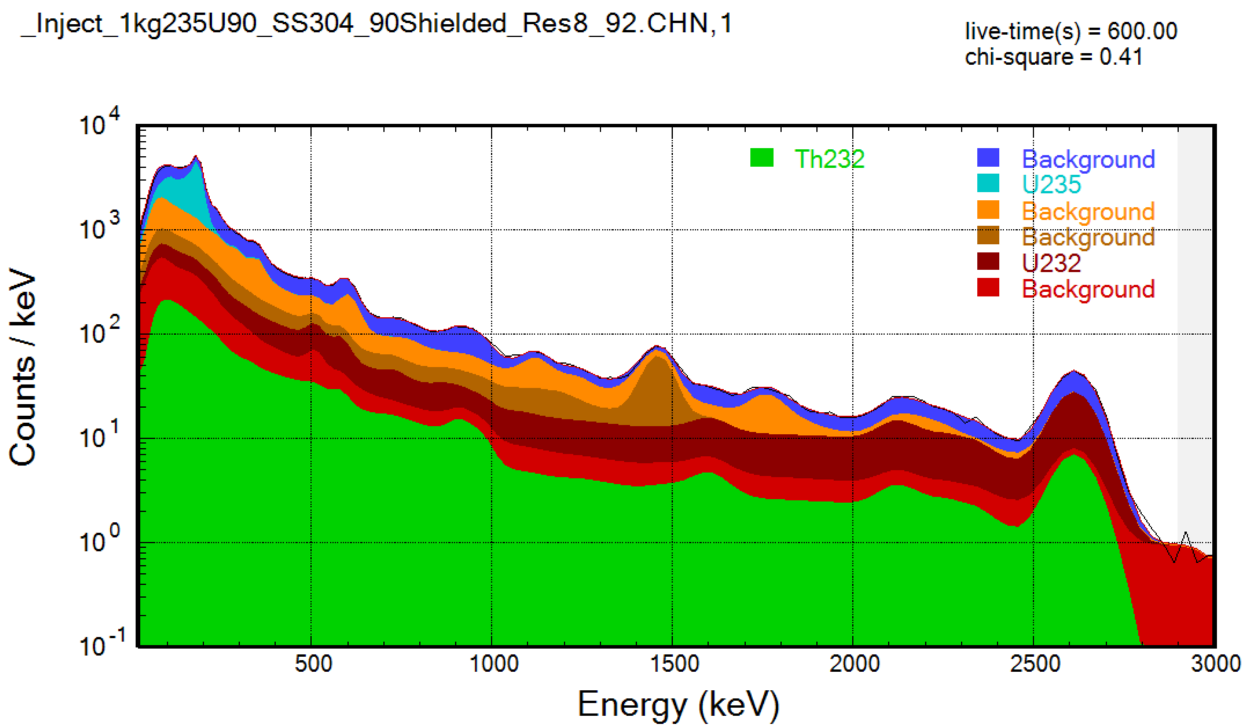


Figure E.1. GADRAS spectrum for HEU shielded to 90% intensity at an 8.92% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.6
Net Gammas:	1745 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,2kg) + U232(H,4uCi)

Figure E.2. GADRAS textual results for HEU shielded to 90% intensity at an 8.92% resolution for collection and identification.

10% Resolution for Collection and Identification

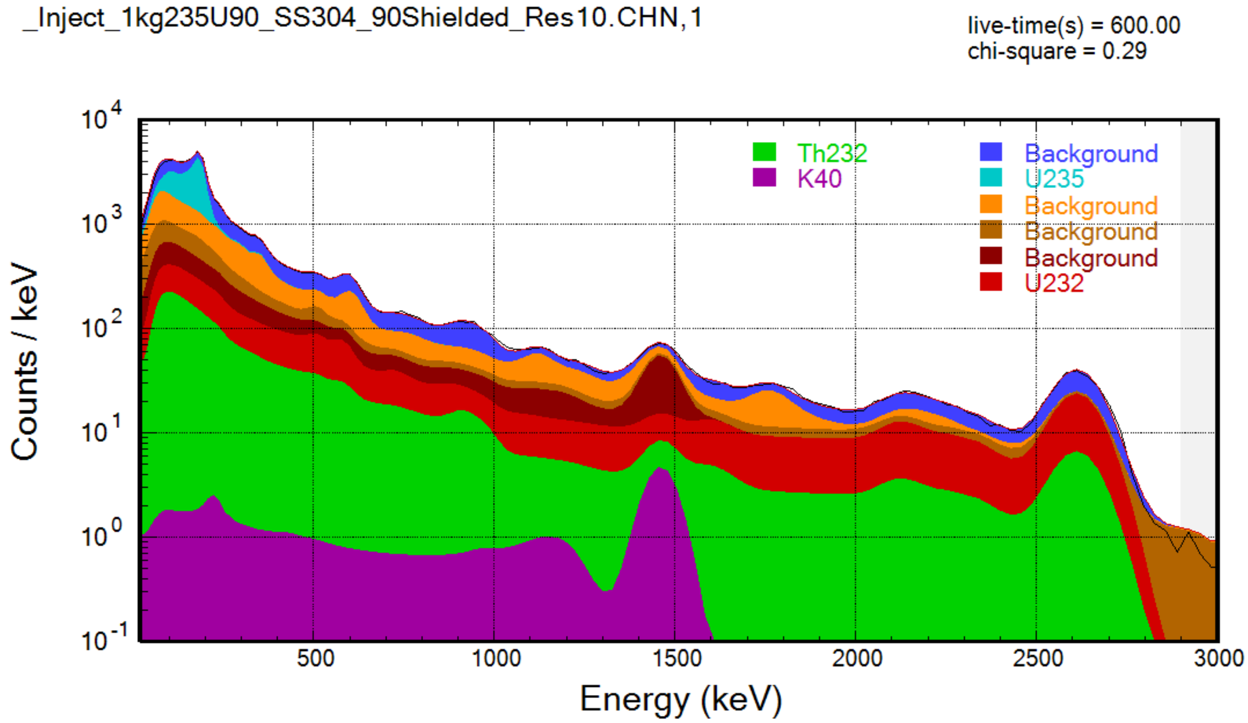


Figure E.3. GADRAS spectrum for HEU shielded to 90% intensity at an 10% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.5
Net Gammas:	1747 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,2kg) + U232(F,1uCi)

Figure E.4. GADRAS textual results for HEU shielded to 90% intensity at an 10% resolution for collection and identification.

15% Resolution for Collection and Identification

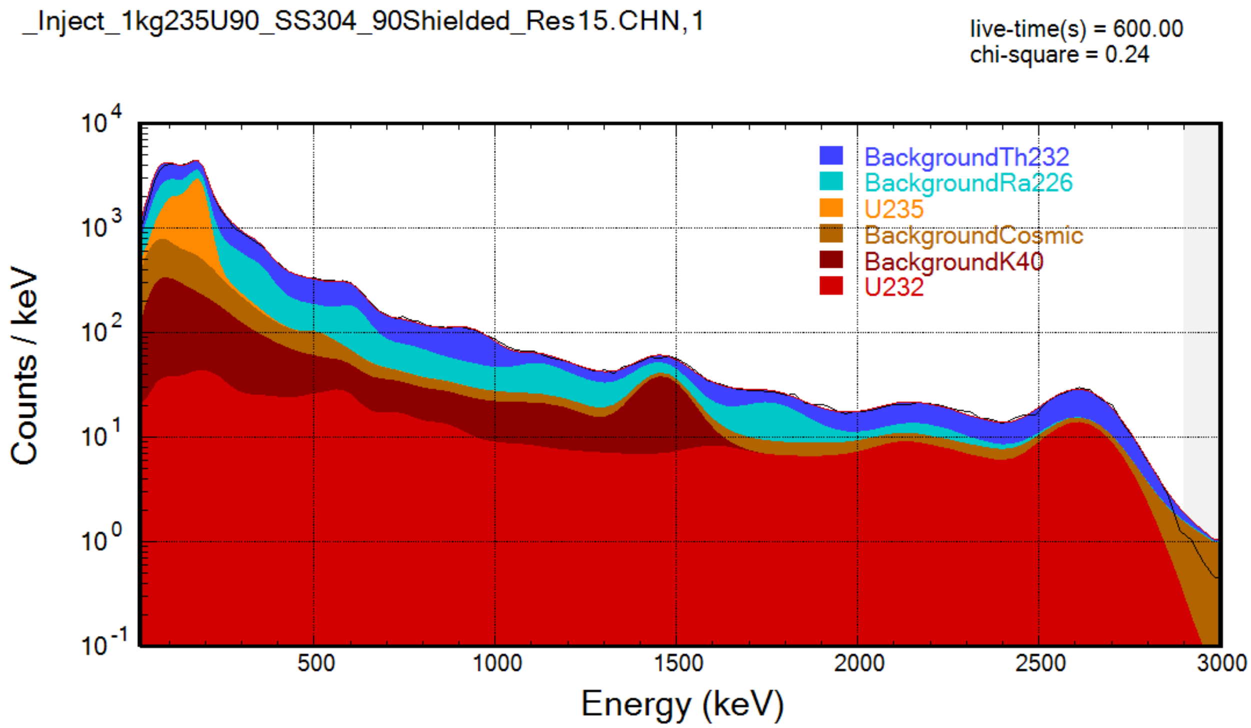


Figure E.5. GADRAS spectrum for HEU shielded to 90% intensity at a 15% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.4
Net Gammas:	1747 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,2kg) + U232(F,1uCi)

Figure E.6. GADRAS textual results for HEU shielded to 90% intensity at a 15% resolution for collection and identification.

20% Resolution for Collection and Identification

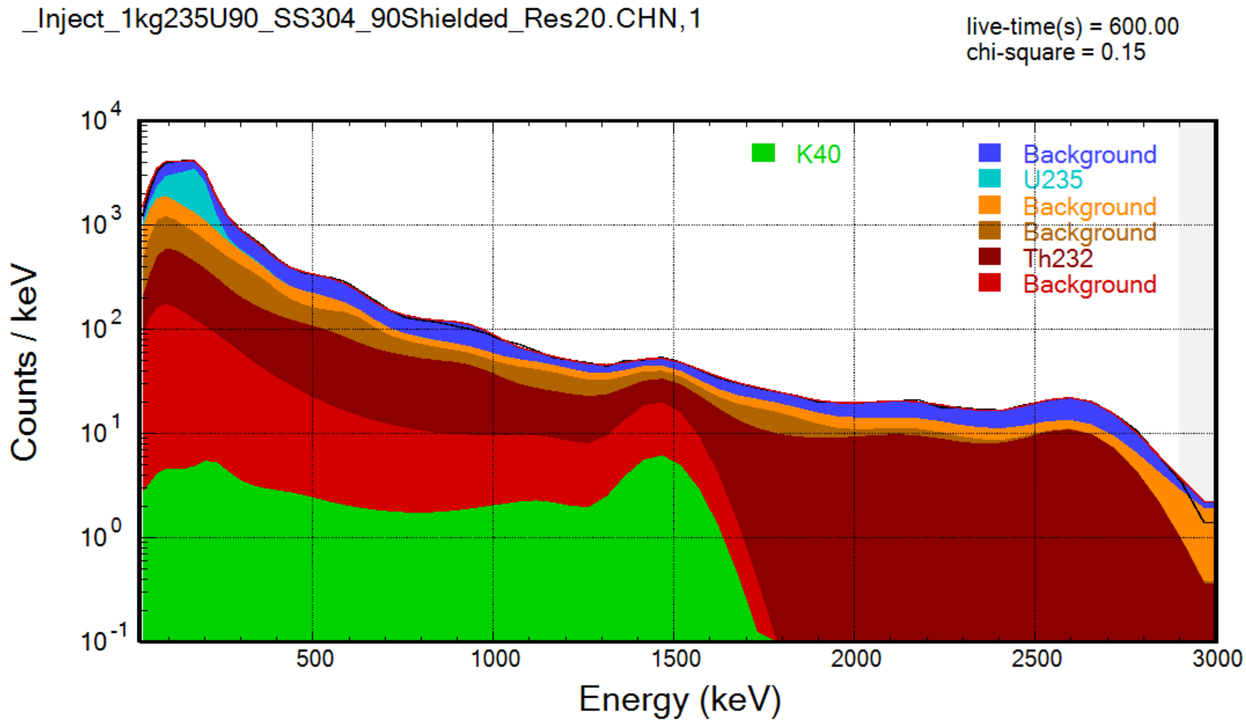
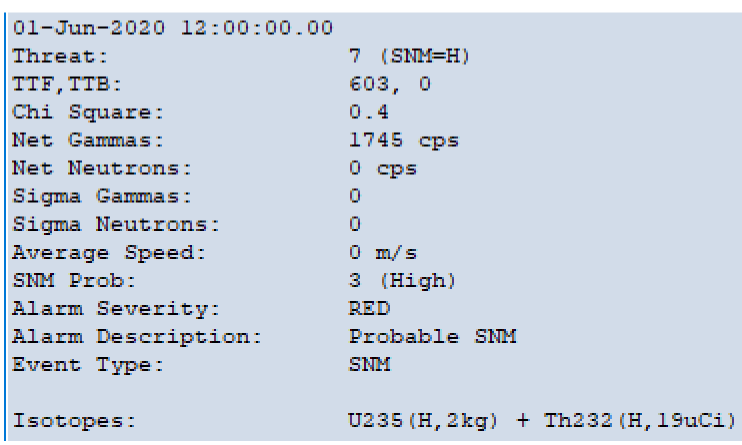


Figure E.7. GADRAS spectrum for HEU shielded to 90% intensity at a 20% resolution for collection and identification.



```
01-Jun-2020 12:00:00.00
Threat:                  7 (SNM=H)
TTF,TTB:                 603, 0
Chi Square:              0.4
Net Gammas:              1745 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                3 (High)
Alarm Severity:          RED
Alarm Description:       Probable SNM
Event Type:              SNM

Isotopes:                U235(H,2kg) + Th232(H,19uCi)
```

Figure E.8. GADRAS textual results for HEU shielded to 90% intensity at a 20% resolution for collection and identification.

25% Resolution for Collection and Identification

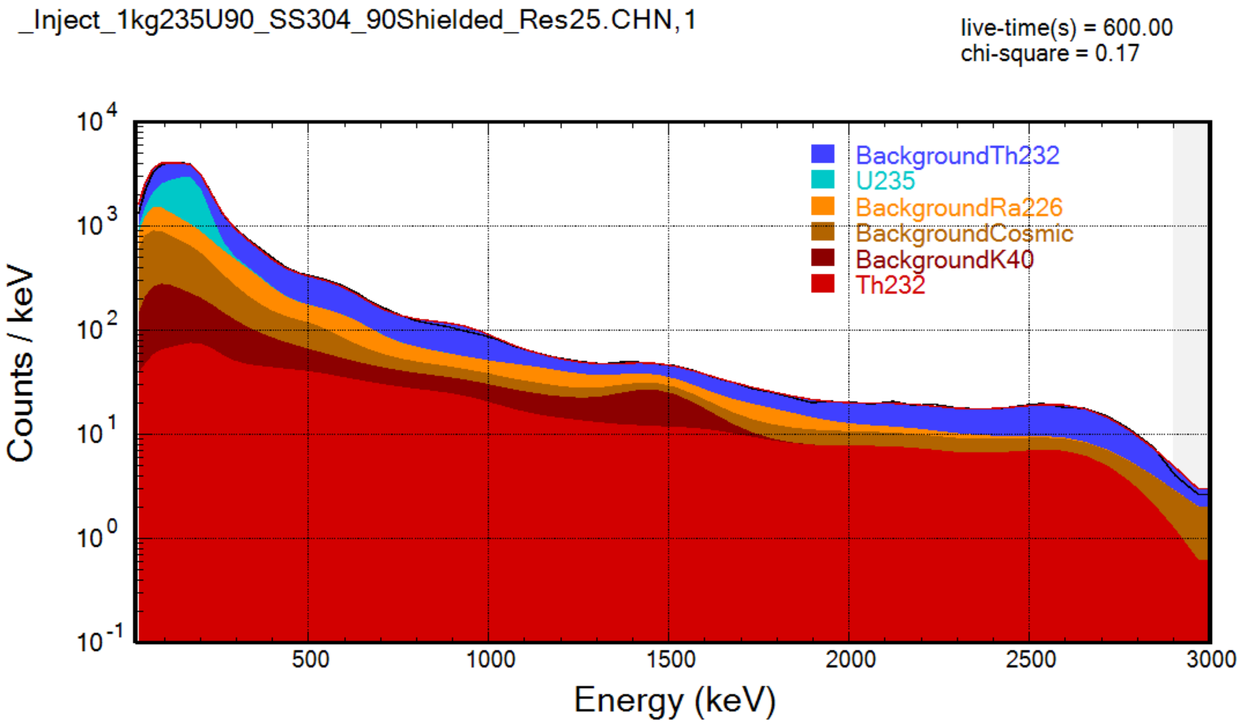


Figure E.9. GADRAS spectrum for HEU shielded to 90% intensity at a 25% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.4
Net Gammas:	1740 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,2kg) + Th232(H,29uCi)

Figure E.10. GADRAS textual results for HEU shielded to 90% intensity at a 25% resolution for collection and identification.

30% Resolution for Collection and Identification

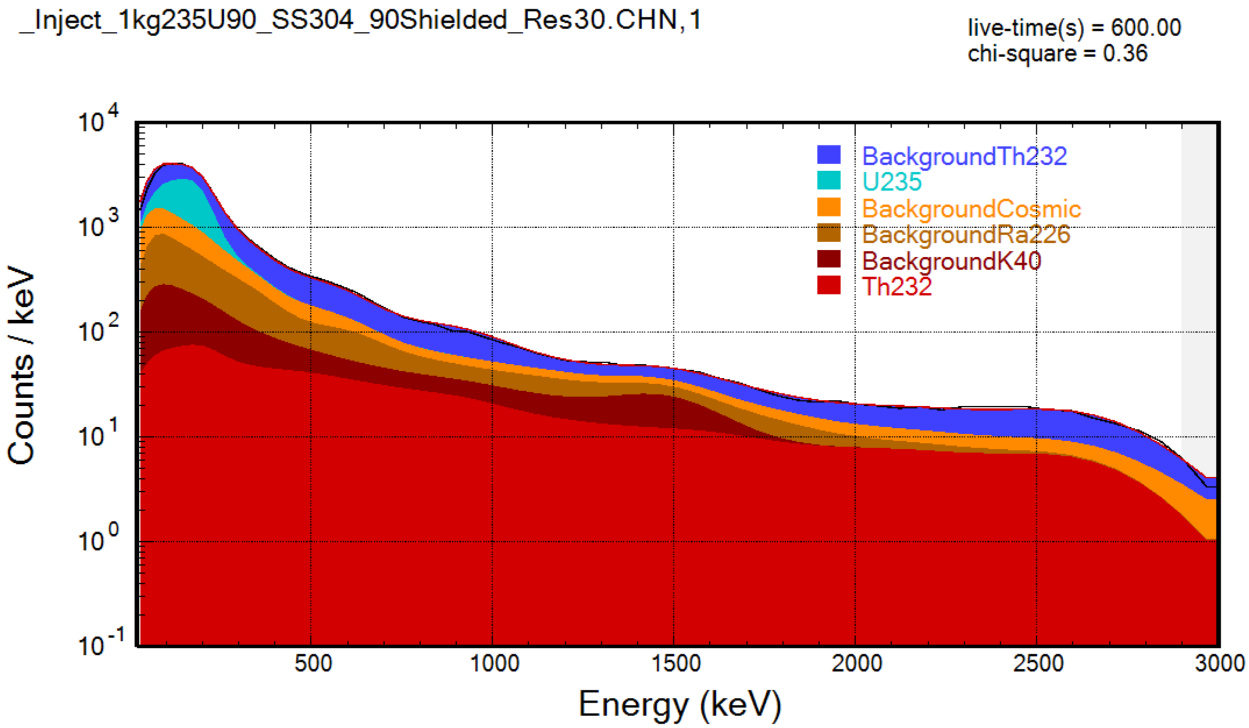


Figure E.11. GADRAS spectrum for HEU shielded to 90% intensity at a 30% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.6
Net Gammas:	1743 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,2kg) + U232(H,1uCi)

Figure E.12. GADRAS textual results for HEU shielded to 90% intensity at a 30% resolution for collection and identification.

35% Resolution for Collection and Identification

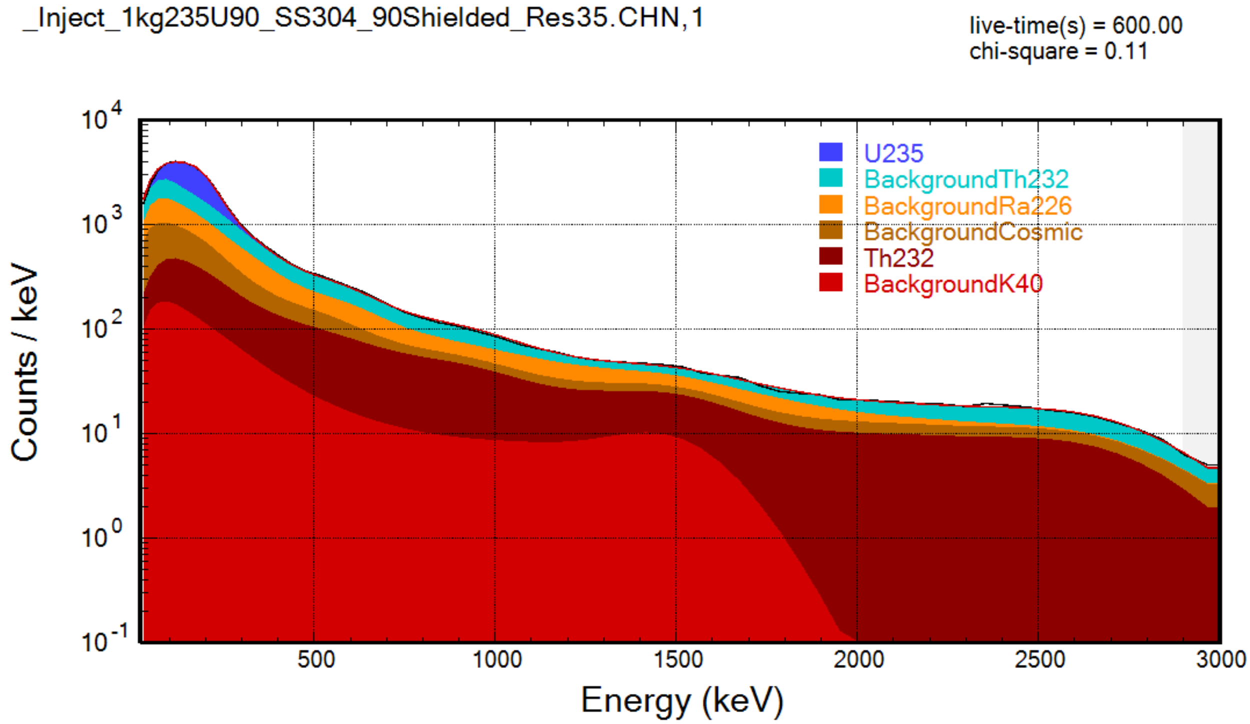


Figure E.13. GADRAS spectrum for HEU shielded to 90% intensity at a 35% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                603, 0
Chi Square:             0.4
Net Gammas:             1739 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               Th232(H,28uCi) + U235(H,9kg)
```

Figure E.14. GADRAS textual results for HEU shielded to 90% intensity at a 35% resolution for collection and identification.

40% Resolution for Collection and Identification

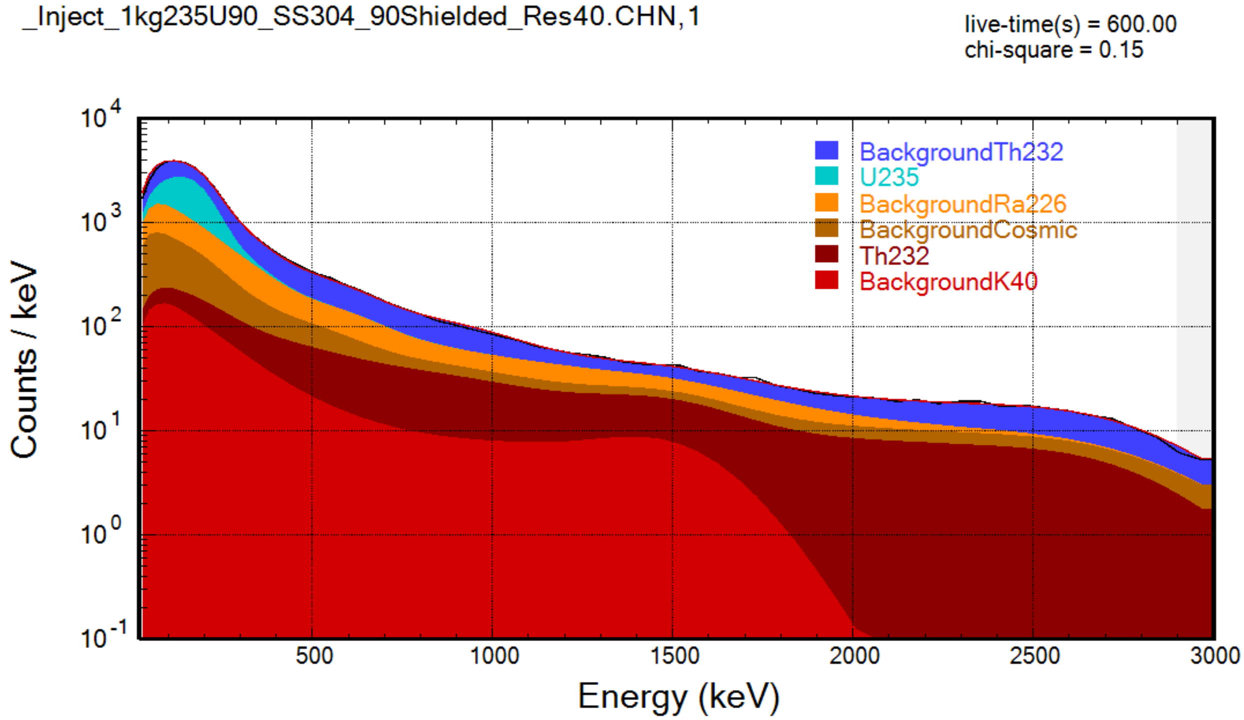


Figure E.15. GADRAS spectrum for HEU shielded to 90% intensity at a 40% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.4
Net Gammas:	1727 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,9kg) + Th232(H,31uCi)

Figure E.16. GADRAS textual results for HEU shielded to 90% intensity at a 40% resolution for collection and identification.

45% Resolution for Collection and Identification

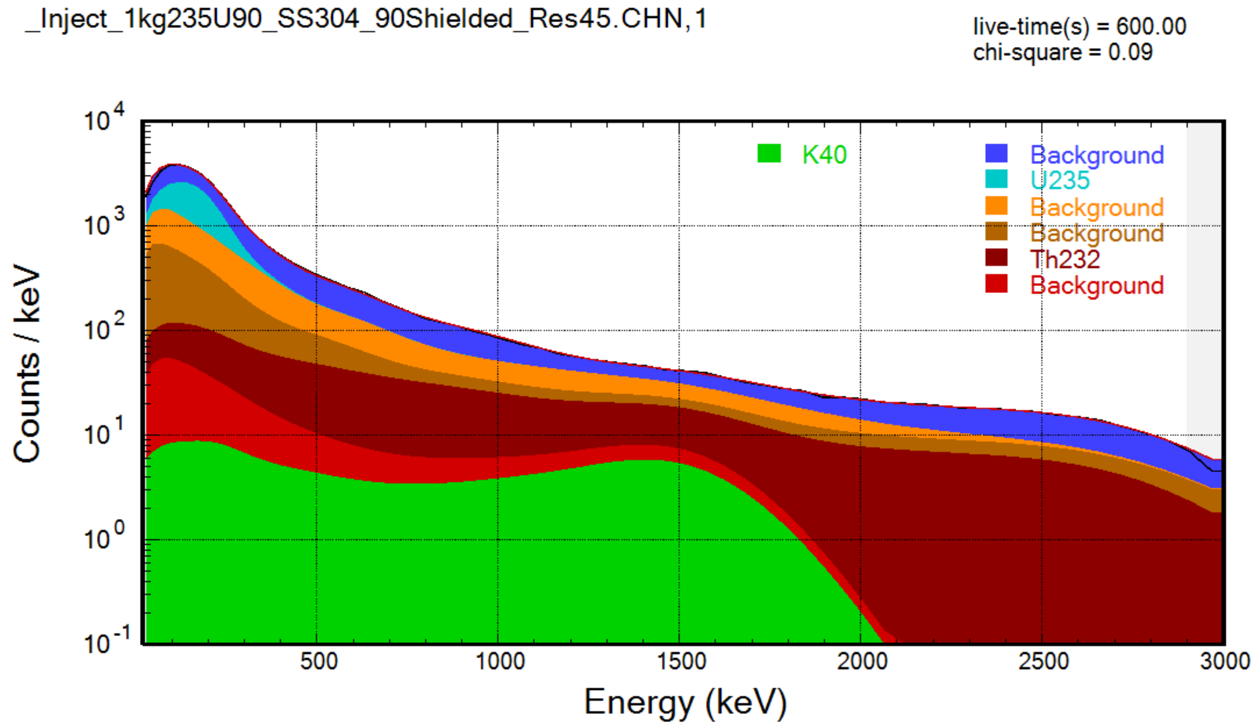


Figure E.17. GADRAS spectrum for HEU shielded to 90% intensity at a 45% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.3
Net Gammas:	1724 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,28uCi) + U235(H,9kg)

Figure E.18. GADRAS textual results for HEU shielded to 90% intensity at a 45% resolution for collection and identification.

50% Resolution for Collection and Identification

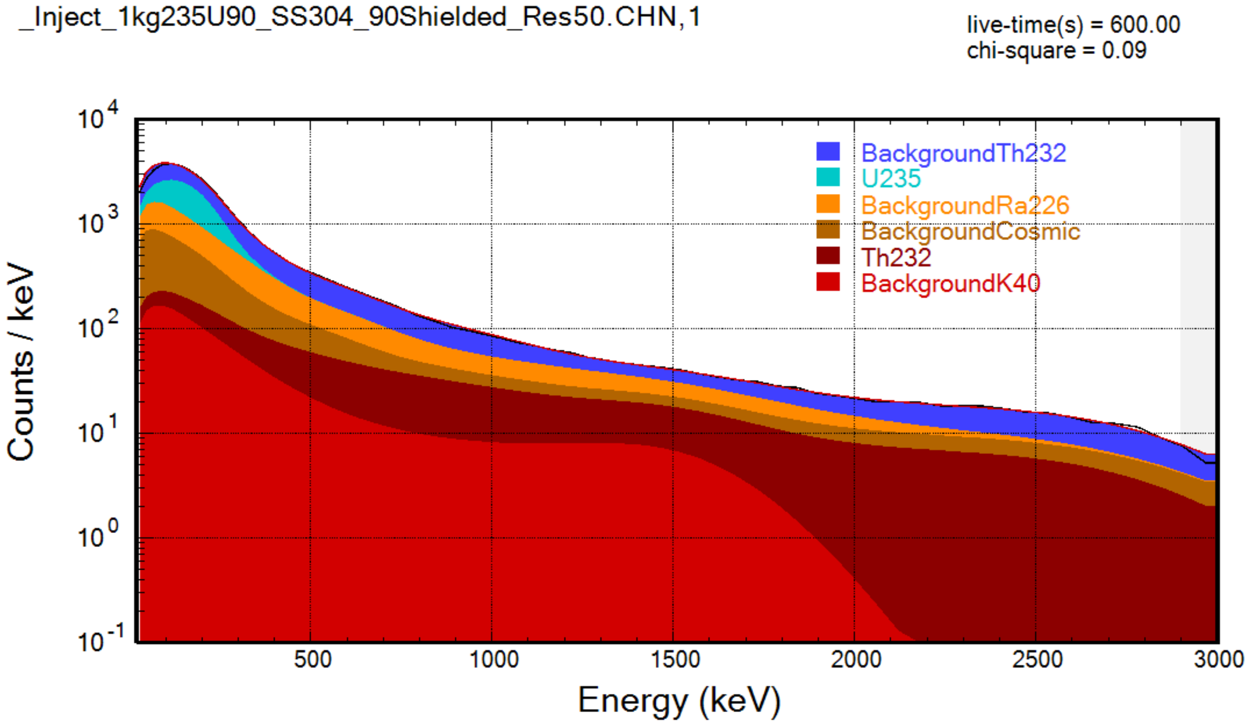


Figure E.19. GADRAS spectrum for HEU shielded to 90% intensity at a 50% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.3
Net Gammas:	1720 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,28uCi) + U235(H,2kg)

Figure E.20. GADRAS textual results for HEU shielded to 90% intensity at a 50% resolution for collection and identification.

55% Resolution for Collection and Identification

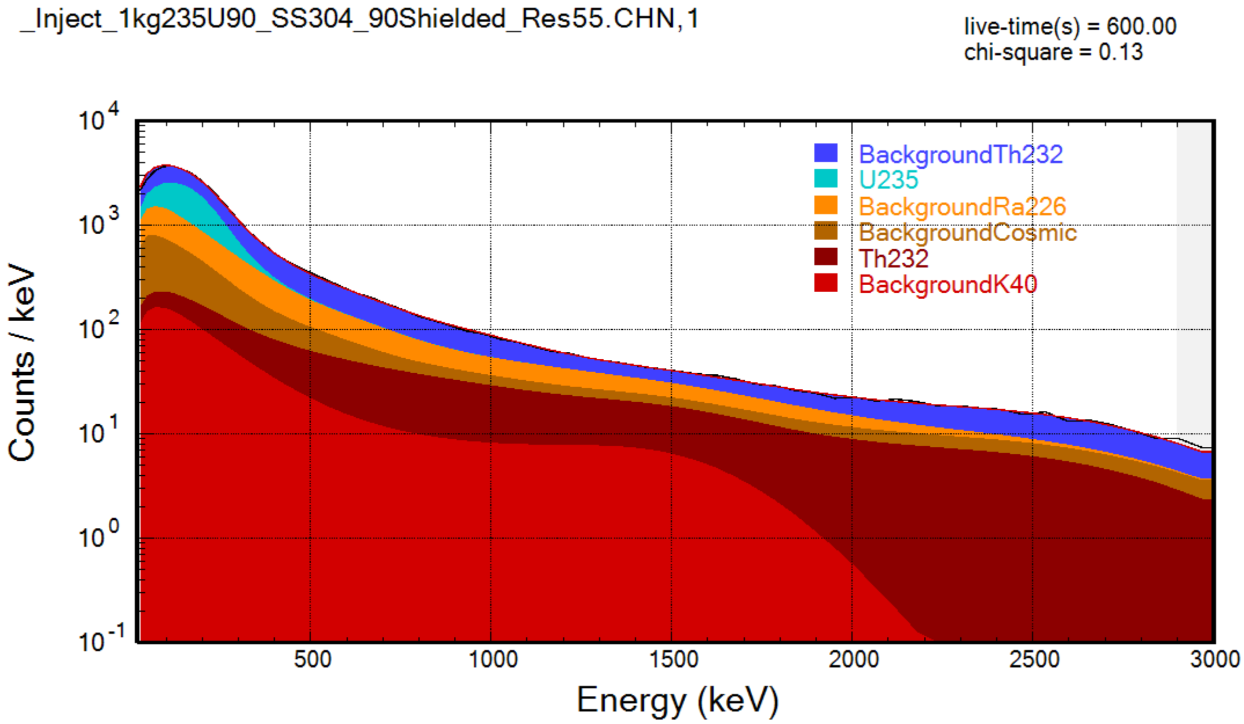


Figure E.21. GADRAS spectrum for HEU shielded to 90% intensity at a 55% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.4
Net Gammas:	1717 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,9kg) + Th232(H,30uCi)

Figure E.22. GADRAS textual results for HEU shielded to 90% intensity at a 55% resolution for collection and identification.

60% Resolution for Collection and Identification

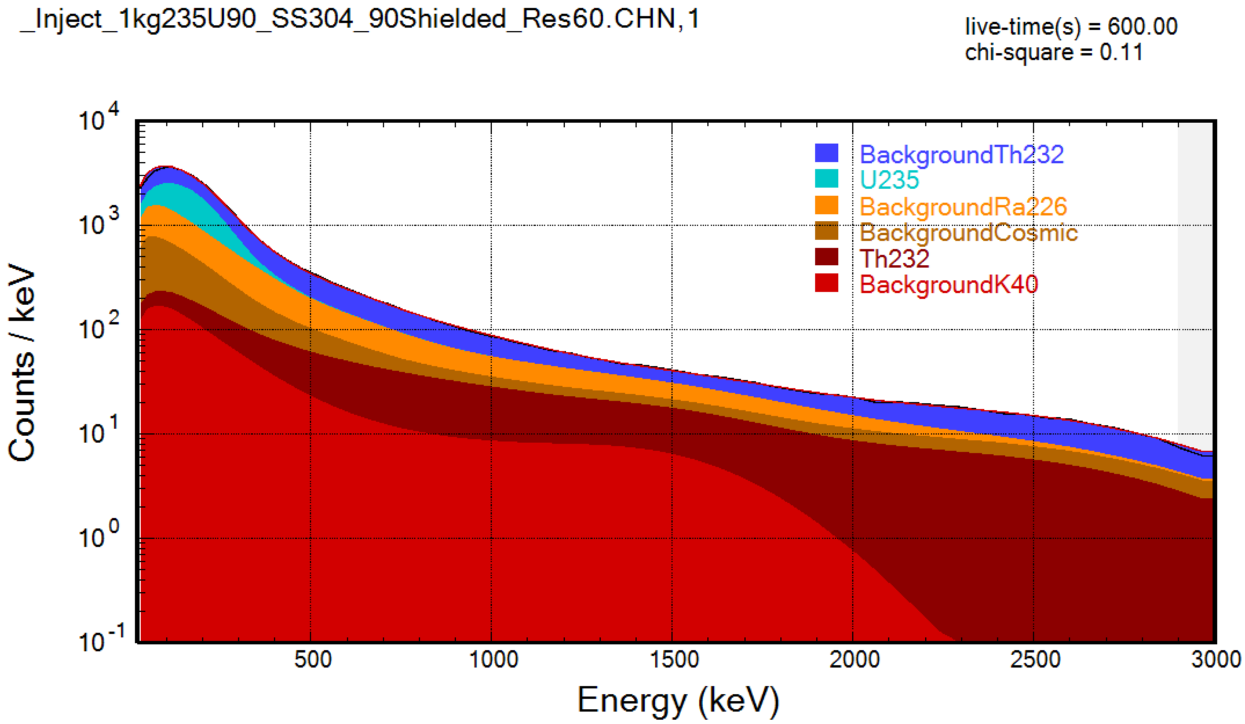


Figure E.23. GADRAS spectrum for HEU shielded to 90% intensity at a 60% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.3
Net Gammas:	1708 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,8kg) + Th232(H,29uCi)

Figure E.24. GADRAS textual results for HEU shielded to 90% intensity at a 60% resolution for collection and identification.

65% Resolution for Collection and Identification

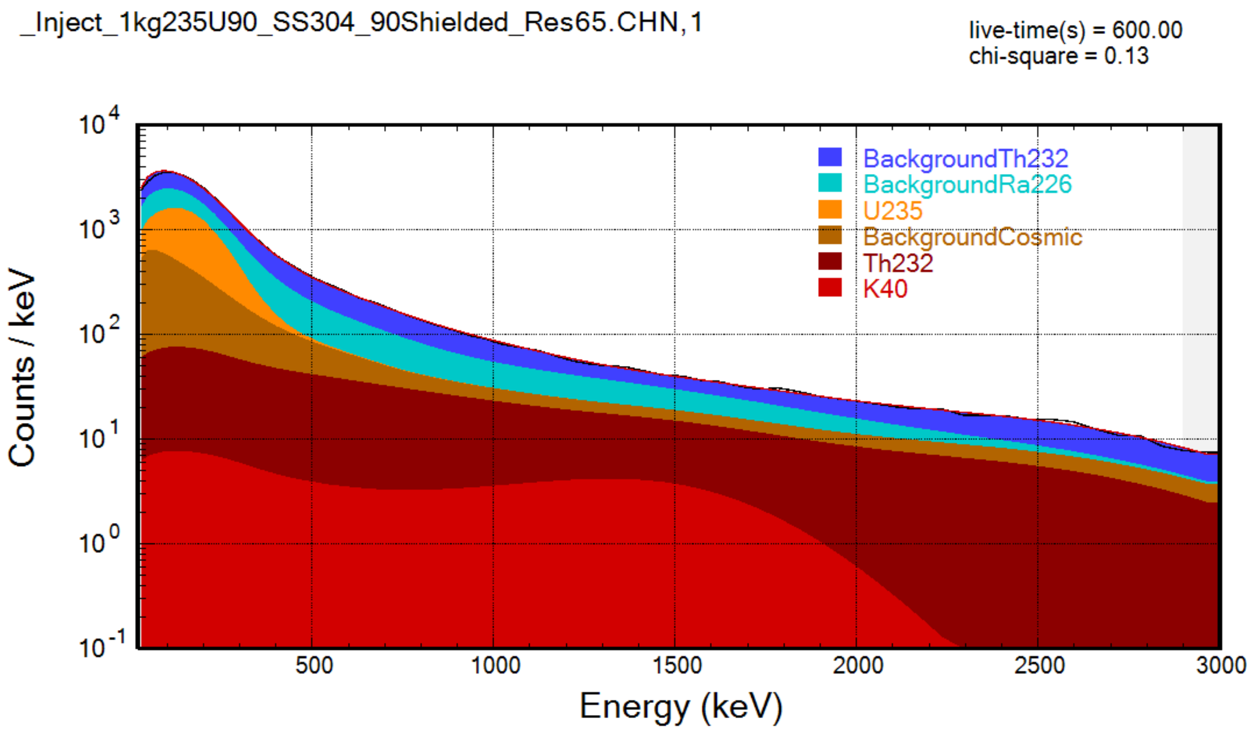


Figure E.25. GADRAS spectrum for HEU shielded to 90% intensity at a 65% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	603, 0
Chi Square:	0.4
Net Gammas:	1706 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	U235(F,812g)

Figure E.26. GADRAS textual results for HEU shielded to 90% intensity at a 65% resolution for collection and identification.

70% Resolution for Collection and Identification

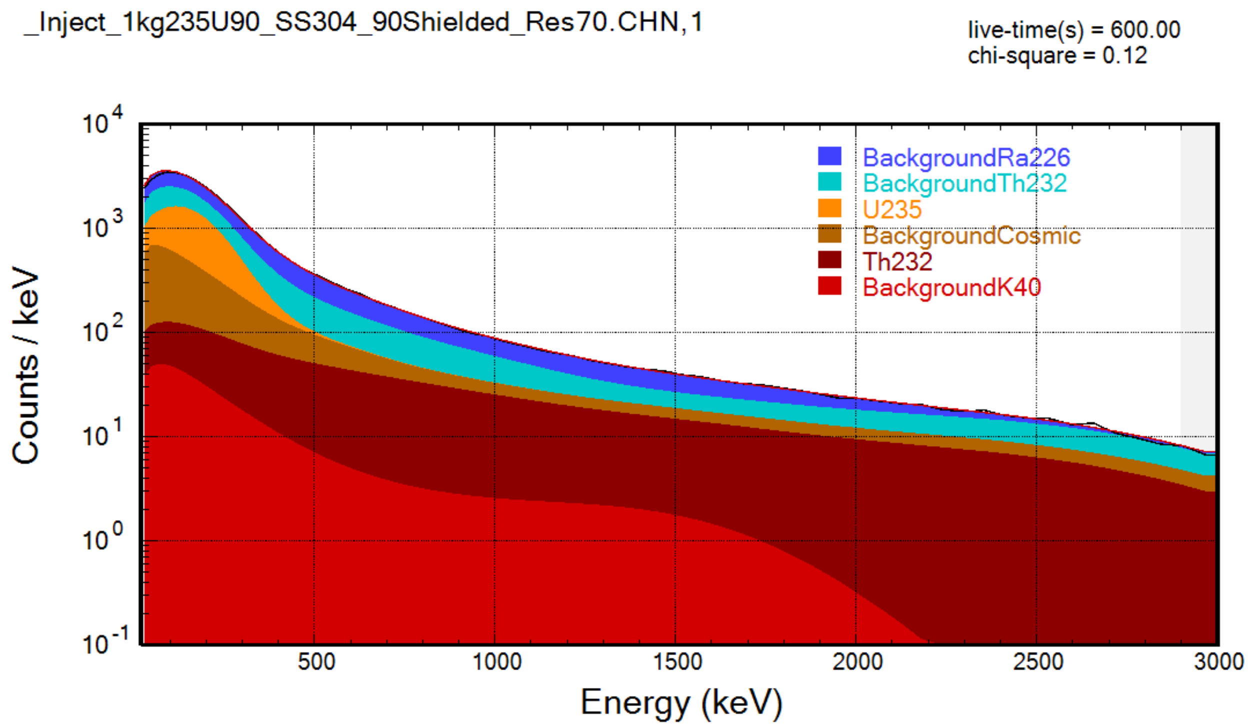


Figure E.27. GADRAS spectrum for HEU shielded to 90% intensity at a 70% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.4
Net Gammas:	1699 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,33uCi) + U235(H,8kg)

Figure E.28. GADRAS textual results for HEU shielded to 90% intensity at a 70% resolution for collection and identification.

74% Resolution for Collection and Identification

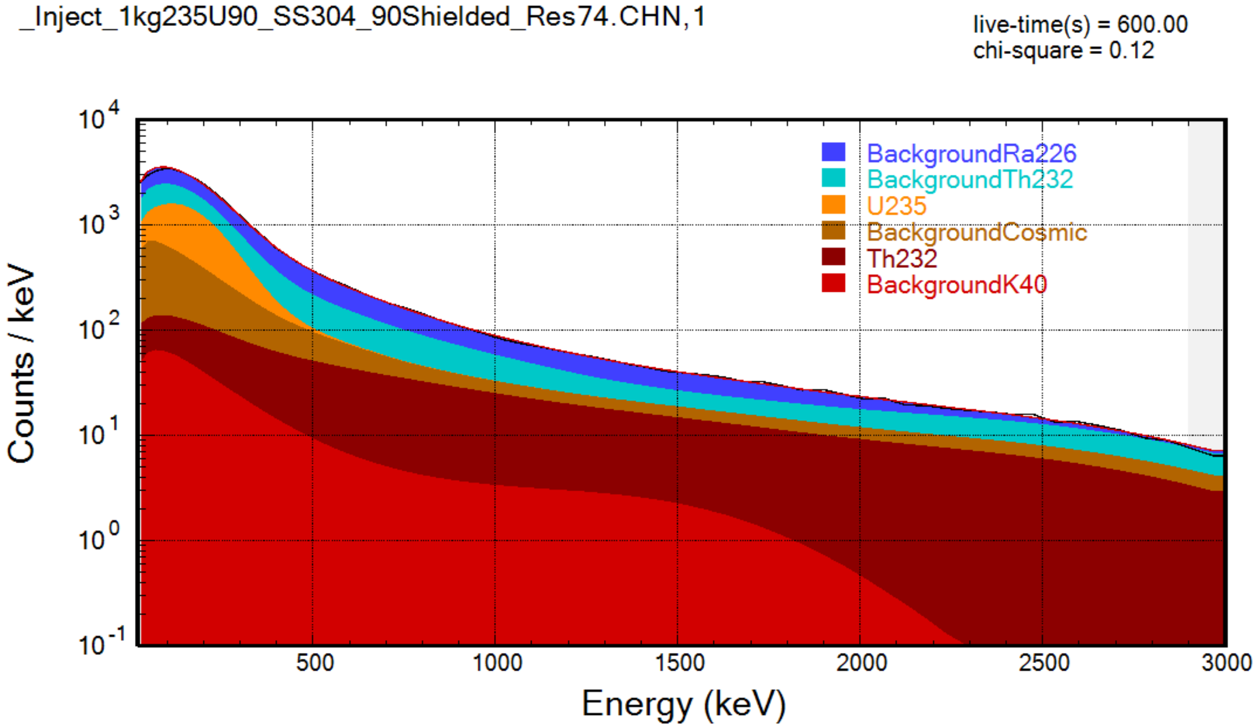


Figure E.29. GADRAS spectrum for HEU shielded to 90% intensity at a 74% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	0.4
Net Gammas:	1702 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,32uCi) + U235(H,8kg)

Figure E.30. GADRAS textual results for HEU shielded to 90% intensity at a 74% resolution for collection and identification.

75% Resolution for Collection and Identification

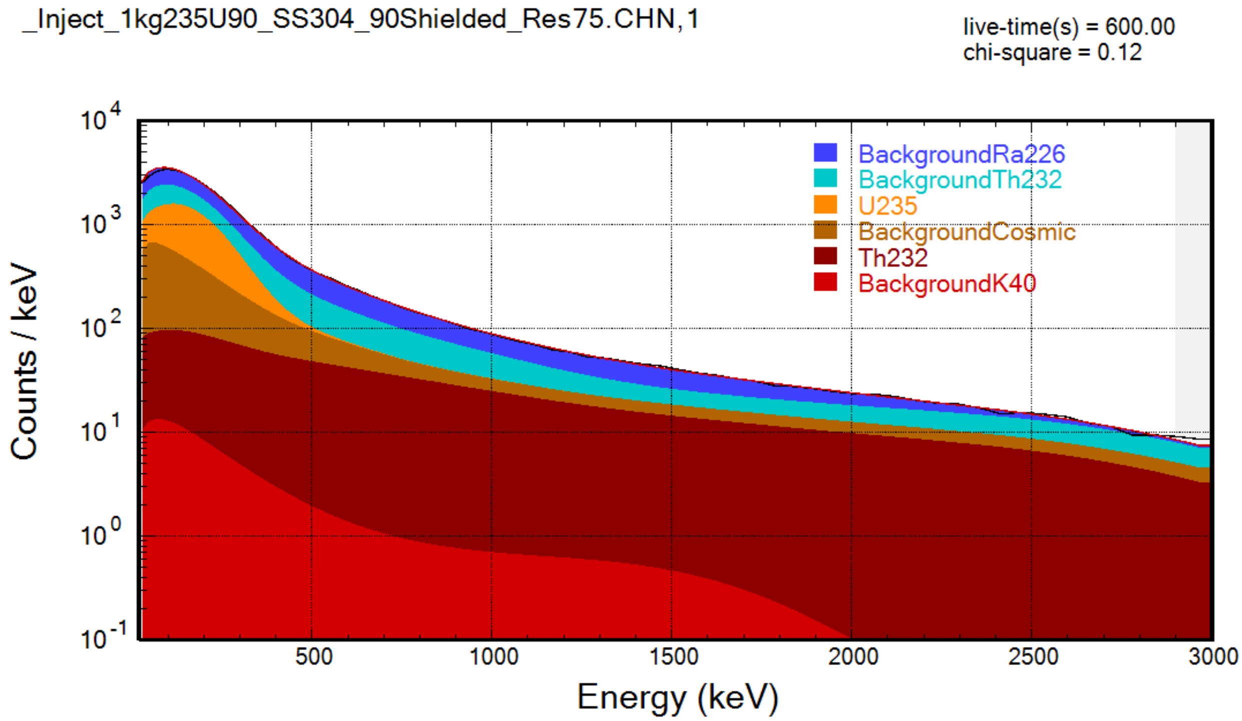


Figure E.31. GADRAS spectrum for HEU shielded to 90% intensity at a 75% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                  6 (SNM=F)
TTF,TTB:                 603, 0
Chi Square:              0.4
Net Gammas:              1703 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                2 (Fair)
Alarm Severity:          RED
Alarm Description:       Possible SNM
Event Type:              SNM

Isotopes:                Th232(H,35uCi) + U235(F,827g)
```

Figure E.32. GADRAS textual results for HEU shielded to 90% intensity at a 75% resolution for collection and identification.

76% Resolution for Collection and Identification

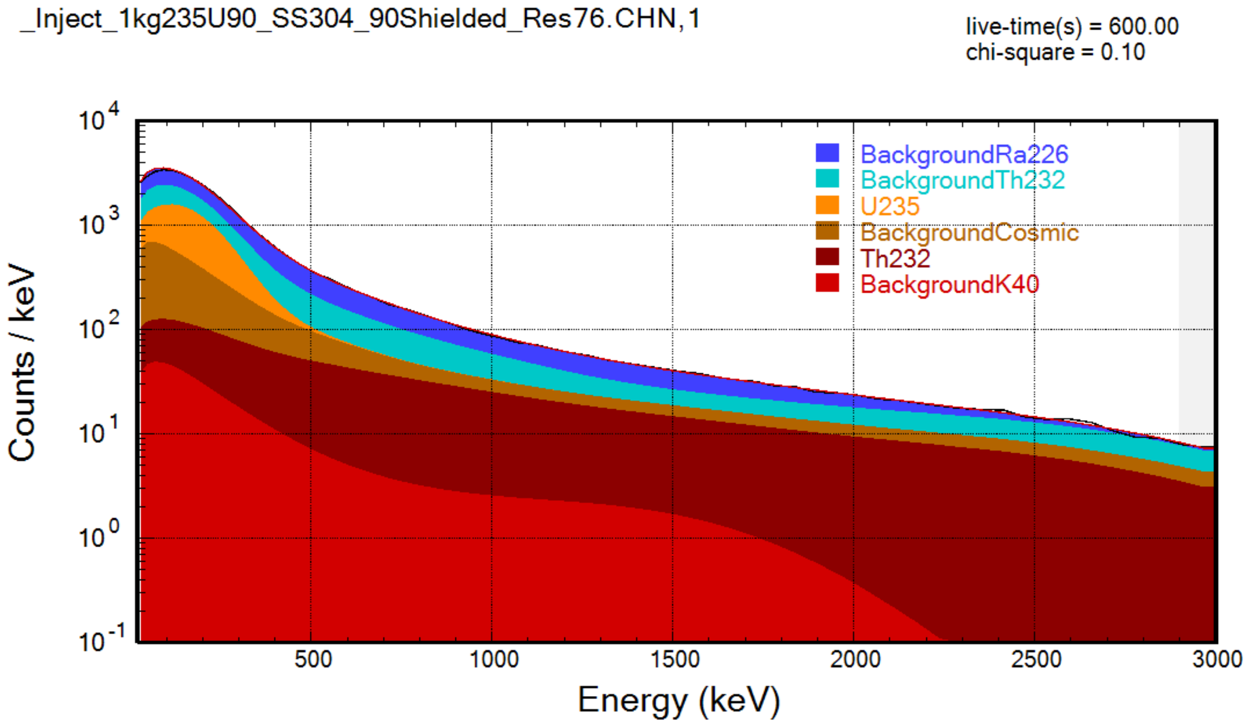


Figure E.33. GADRAS spectrum for HEU shielded to 90% intensity at a 76% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 6 (SNM=F)
TTF,TTB:                603, 0
Chi Square:             0.3
Net Gammas:             1702 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               2 (Fair)
Alarm Severity:         RED
Alarm Description:      Possible SNM
Event Type:             SNM

Isotopes:               Th232(H,33uCi) + U235(F,809g)
```

Figure E.34. GADRAS textual results for HEU shielded to 90% intensity at a 76% resolution for collection and identification.

77% Resolution for Collection and Identification

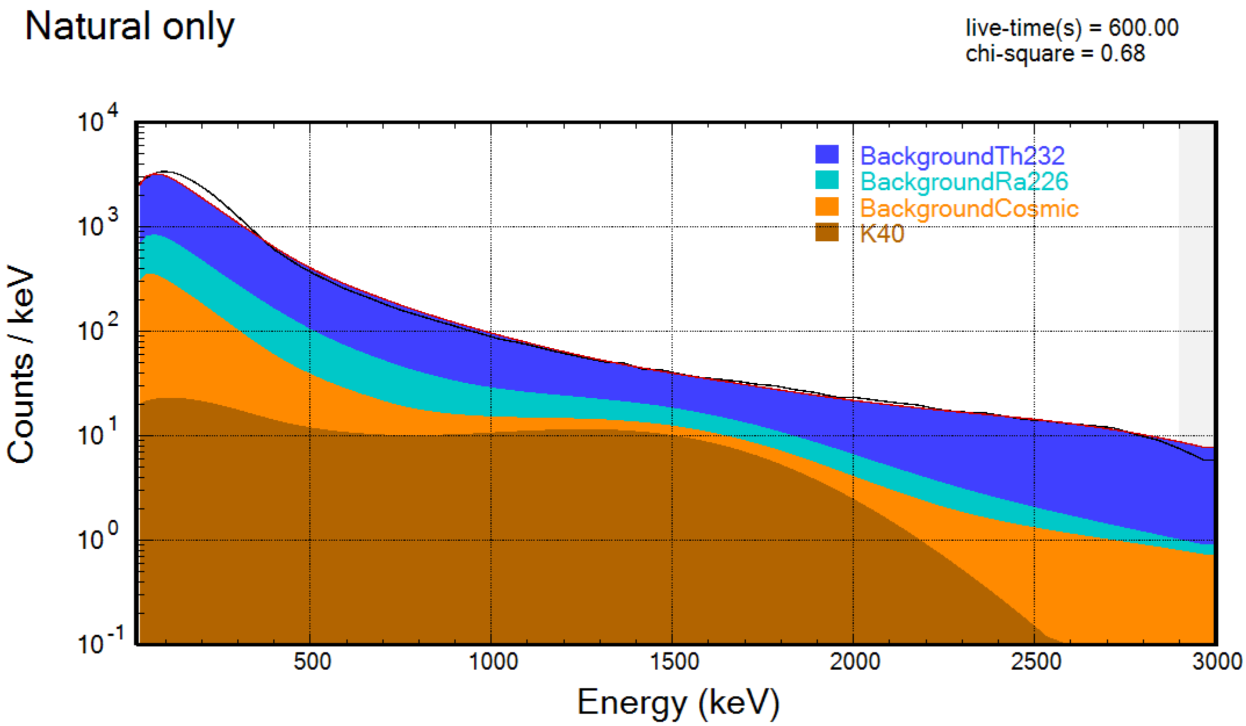


Figure E.35. GADRAS spectrum for HEU shielded to 90% intensity at a 77% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	0 (None)
TTF,TTB:	603, 0
Chi Square:	0.2
Net Gammas:	1700 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	WHITE
Alarm Description:	No Alarm
Event Type:	None
Isotopes:	None

Figure E.36. GADRAS textual results for HEU shielded to 90% intensity at a 77% resolution for collection and identification.

APPENDIX F - GADRAS Output for Configuration 3 Using Different Resolutions for Collection and Identification

8.92% Resolution for Collection and 8.92% Resolution for Identification

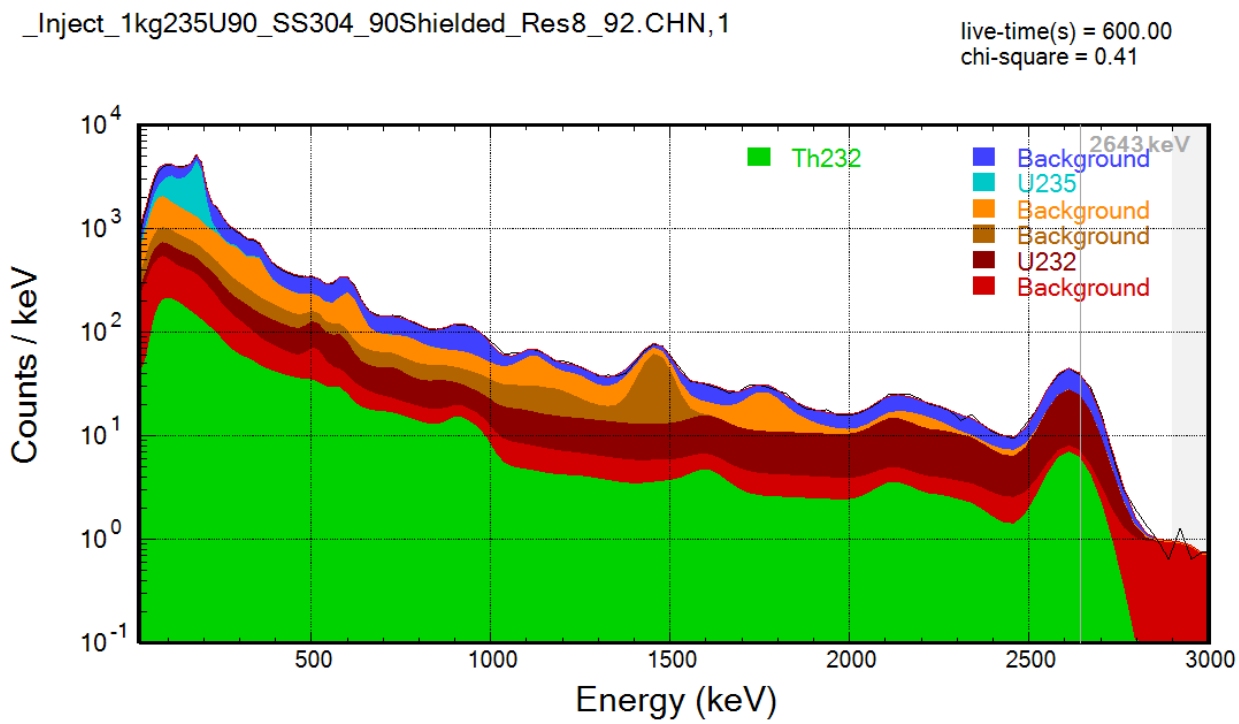


Figure F.1. GADRAS spectrum for HEU shielded to 90% intensity at an 8.92% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                603, 0
Chi Square:             0.6
Net Gammas:             1745 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,2kg) + U232(H,4uCi)
```

Figure F.2. GADRAS textual results for HEU shielded to 90% intensity at an 8.92% resolution for collection and an 8.92% resolution for identification.

10% Resolution for Collection and 8.92% Resolution for Identification

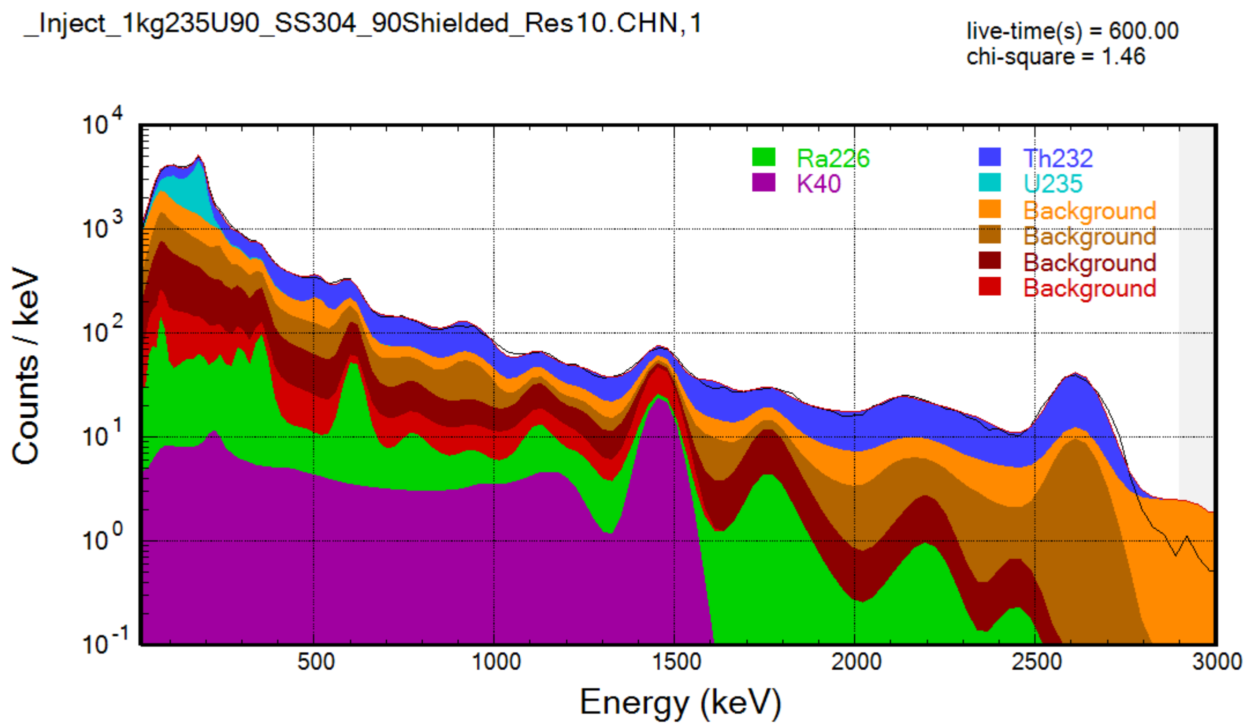


Figure F.3. GADRAS spectrum for HEU shielded to 90% intensity at a 10% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	1.8
Net Gammas:	1747 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,2kg) + Th232(H,8uCi)

Figure F.4. GADRAS textual results for HEU shielded to 90% intensity at a 10% resolution for collection and an 8.92% resolution for identification.

15% Resolution for Collection and 8.92% Resolution for Identification

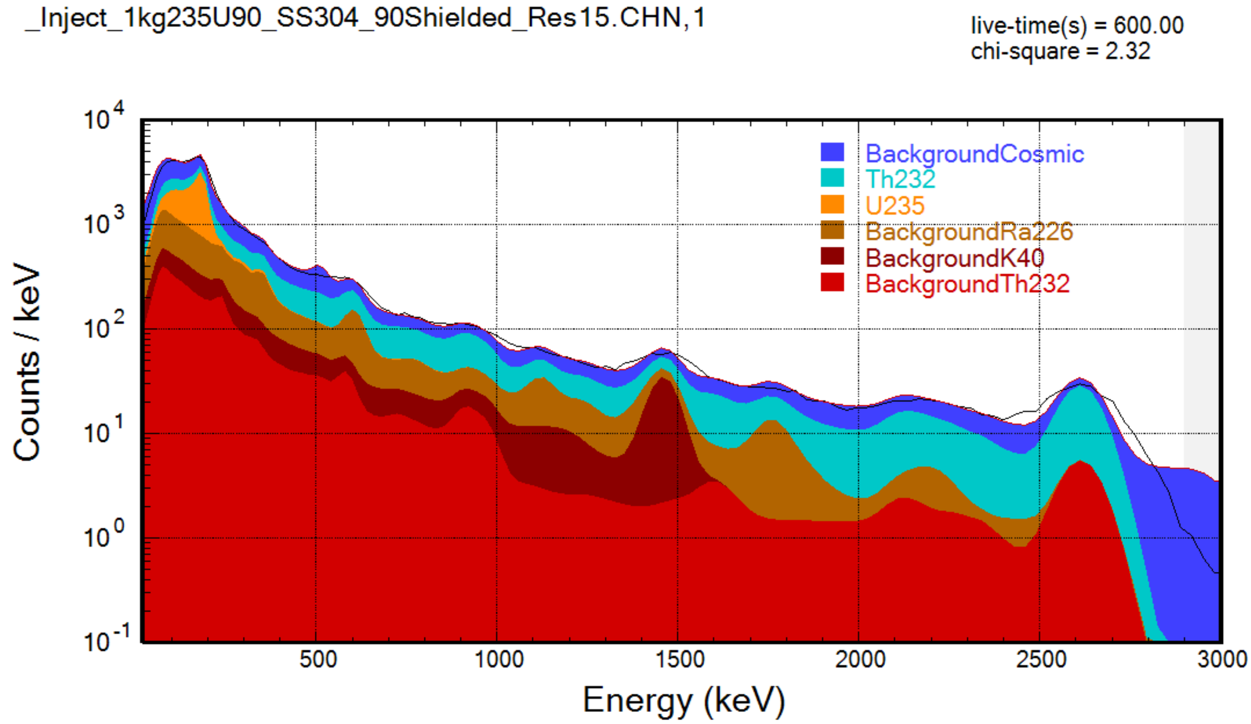


Figure F.5. GADRAS spectrum for HEU shielded to 90% intensity at a 15% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	2.8
Net Gammas:	1747 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,13uCi) + U235(H,7kg)

Figure F.6. GADRAS textual results for HEU shielded to 90% intensity at a 15% resolution for collection and an 8.92% resolution for identification.

20% Resolution for Collection and 8.92% Resolution for Identification

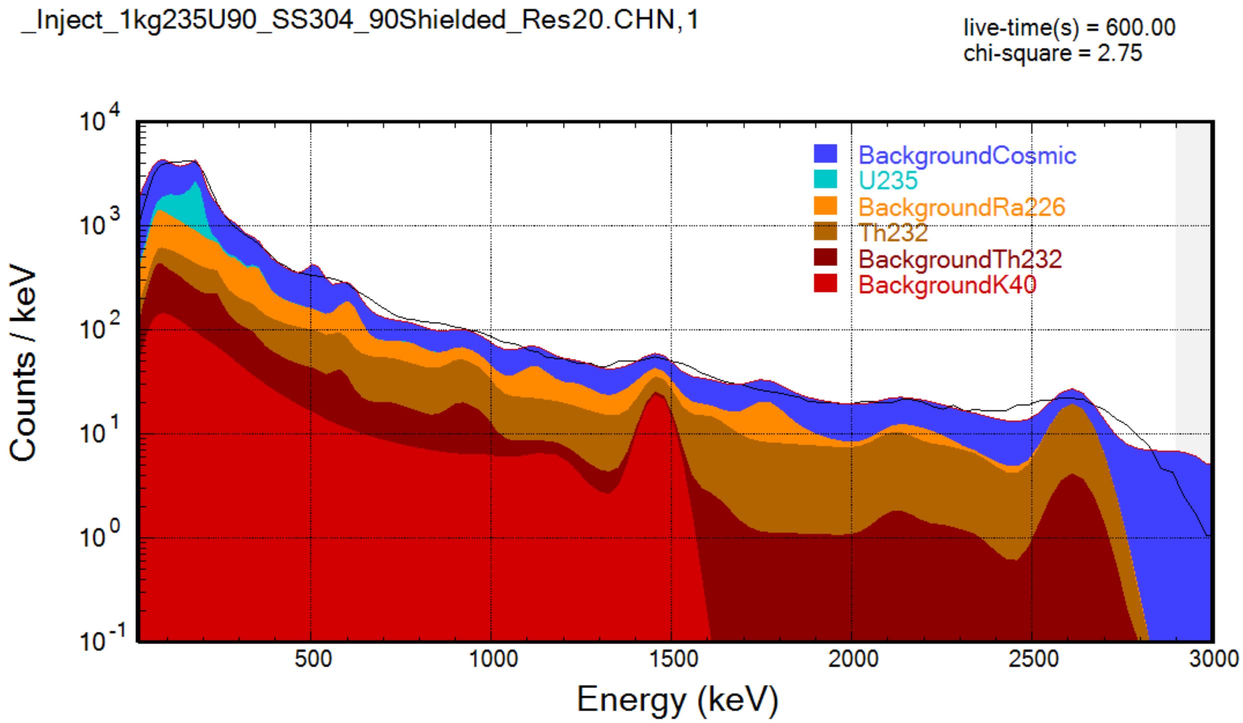


Figure F.7. GADRAS spectrum for HEU shielded to 90% intensity at a 20% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	3.9
Net Gammas:	1745 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,5kg) + Th232(H,21uCi)

Figure F.8. GADRAS textual results for HEU shielded to 90% intensity at a 20% resolution for collection and an 8.92% resolution for identification.

25% Resolution for Collection and 8.92% Resolution for Identification

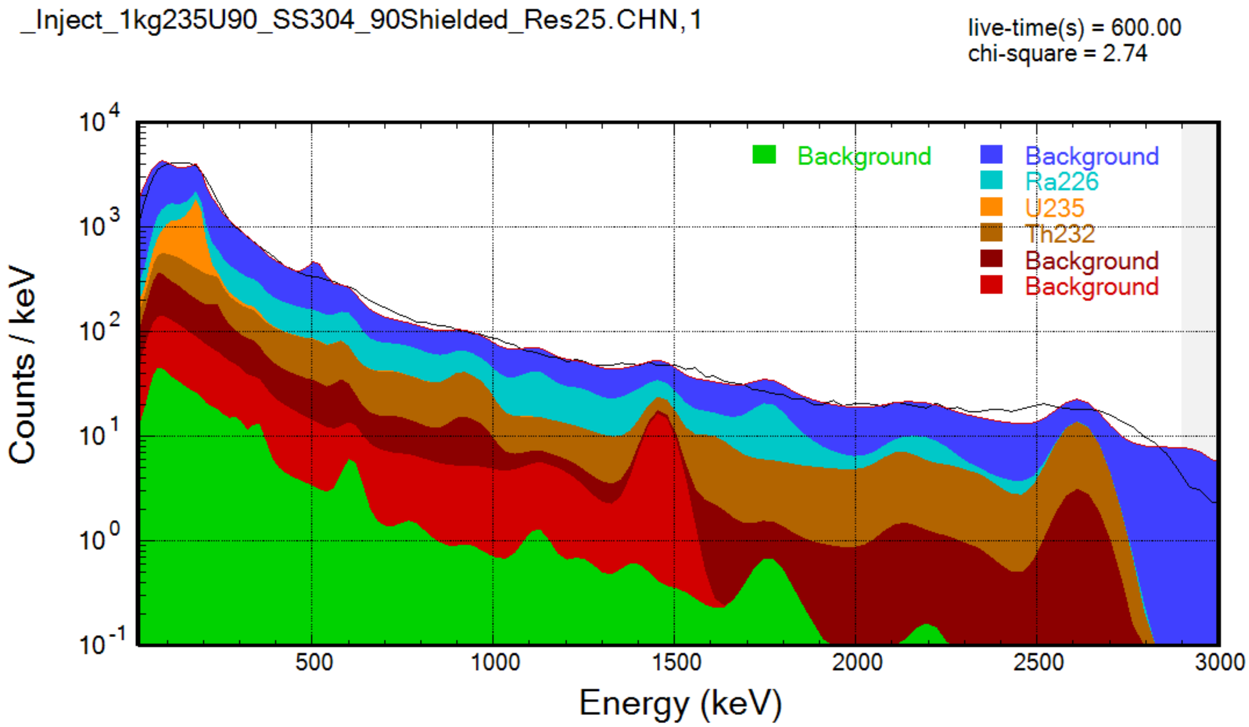


Figure F.9. GADRAS spectrum for HEU shielded to 90% intensity at a 25% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	4.3
Net Gammas:	1740 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,8uCi) + U235(H,4kg)

Figure F.10. GADRAS textual results for HEU shielded to 90% intensity at a 25% resolution for collection and an 8.92% resolution for identification.

26% Resolution for Collection and 8.92% Resolution for Identification

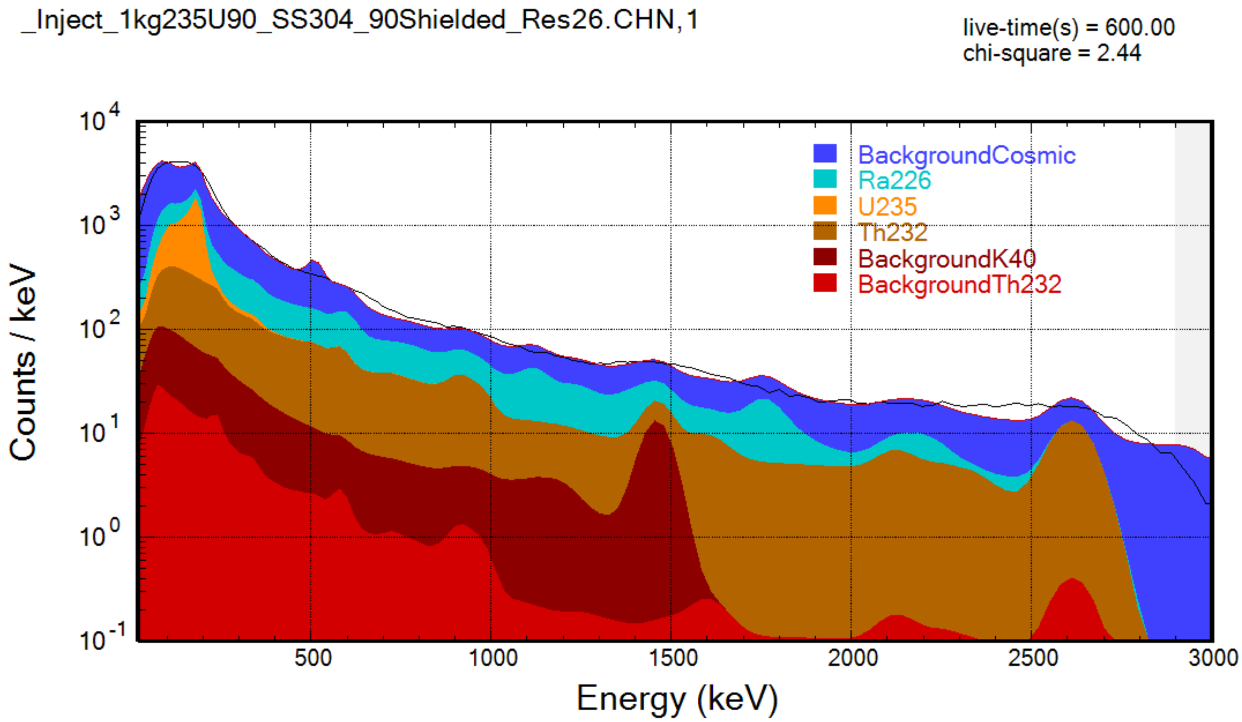


Figure F.11. GADRAS spectrum for HEU shielded to 90% intensity at a 26% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	603, 0
Chi Square:	4
Net Gammas:	1740 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Ra226(H,6uCi) + Th232(H,9uCi) + U235(H,4kg)

Figure F.12. GADRAS textual results for HEU shielded to 90% intensity at a 26% resolution for collection and an 8.92% resolution for identification.

27% Resolution for Collection and 8.92% Resolution for Identification

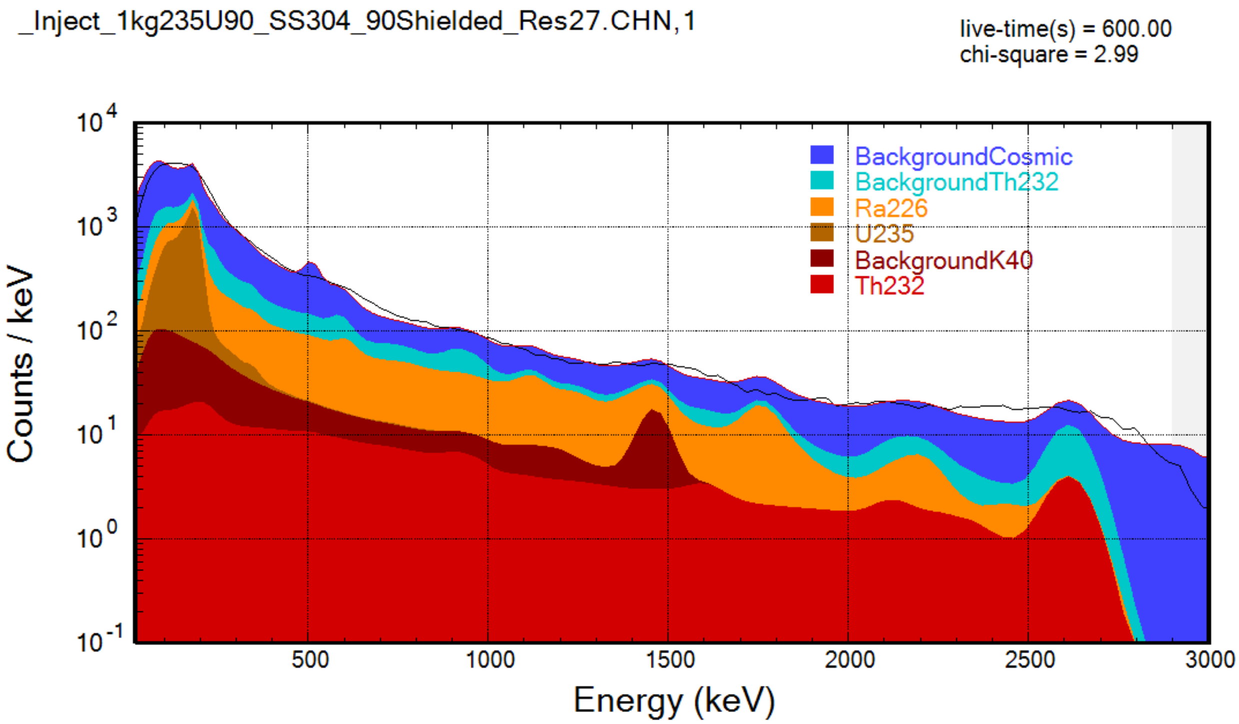


Figure F.13. GADRAS spectrum for HEU shielded to 90% intensity at a 27% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	5 (SNM=L)
TTF,TTB:	603, 0
Chi Square:	4.6
Net Gammas:	1742 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	1 (Low)
Alarm Severity:	RED
Alarm Description:	Maybe RDD
Event Type:	Natural
Isotopes:	Ra226(H,25uCi) + U235(L,4kg)

Figure F.14. GADRAS textual results for HEU shielded to 90% intensity at a 27% resolution for collection and an 8.92% resolution for identification.

28% Resolution for Collection and 8.92% Resolution for Identification

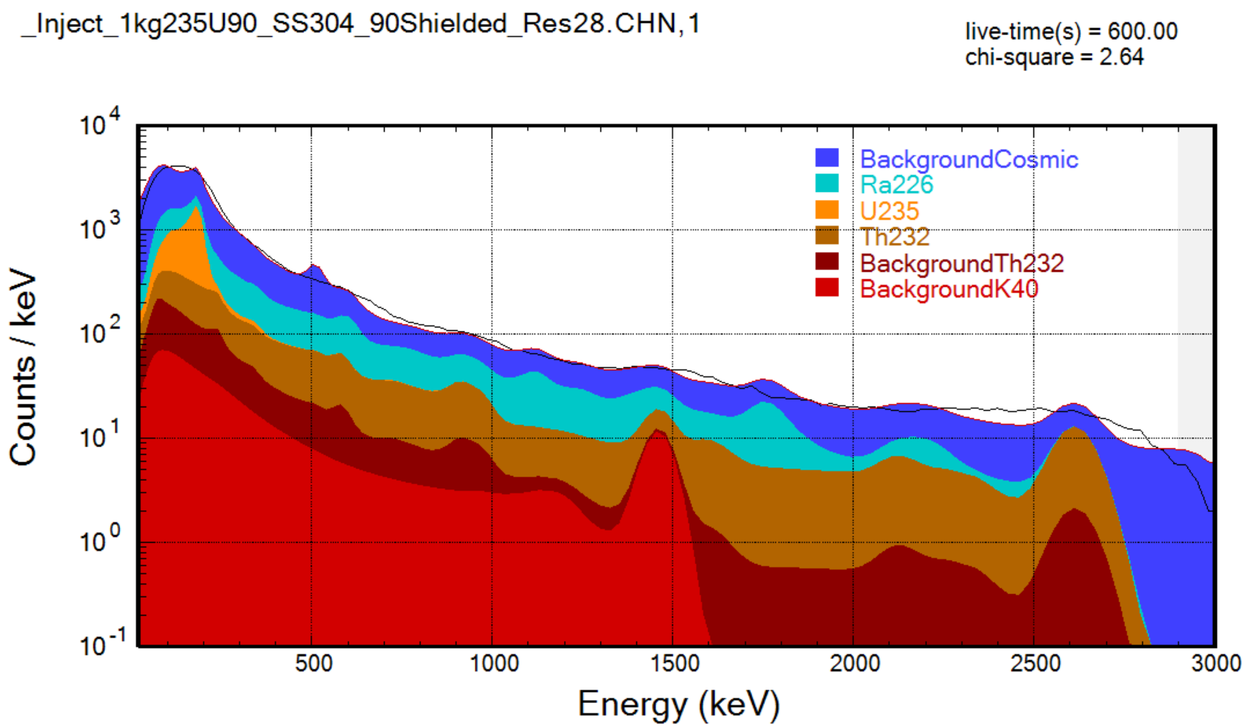


Figure F.15. GADRAS spectrum for HEU shielded to 90% intensity at a 28% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	5 (SNM=L)
TTF,TTB:	603, 0
Chi Square:	4.2
Net Gammas:	1743 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	1 (Low)
Alarm Severity:	RED
Alarm Description:	Maybe RDD
Event Type:	Natural
Isotopes:	Th232(H,10uCi) + Ra226(H,7uCi) + U235(L,4kg)

Figure F.16. GADRAS textual results for HEU shielded to 90% intensity at a 28% resolution for collection and an 8.92% resolution for identification.

29% Resolution for Collection and 8.92% Resolution for Identification

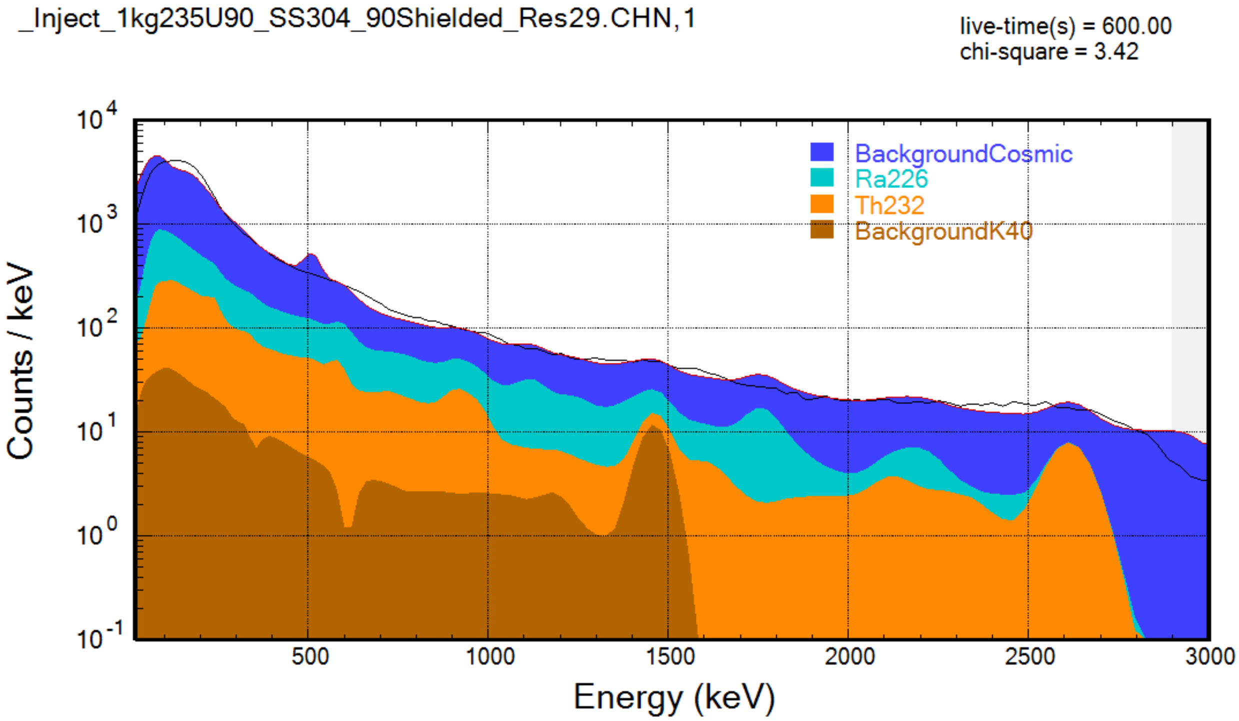


Figure F.17. GADRAS spectrum for HEU shielded to 90% intensity at a 29% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	4 (Bad ID)
TTF,TTB:	603, 0
Chi Square:	6.2
Net Gammas:	1738 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Unknown source
Event Type:	Natural
Isotopes:	Th232(H,1uCi)

Figure F.18. GADRAS textual results for HEU shielded to 90% intensity at a 29% resolution for collection and an 8.92% resolution for identification.

30% Resolution for Collection and 8.92% Resolution for Identification

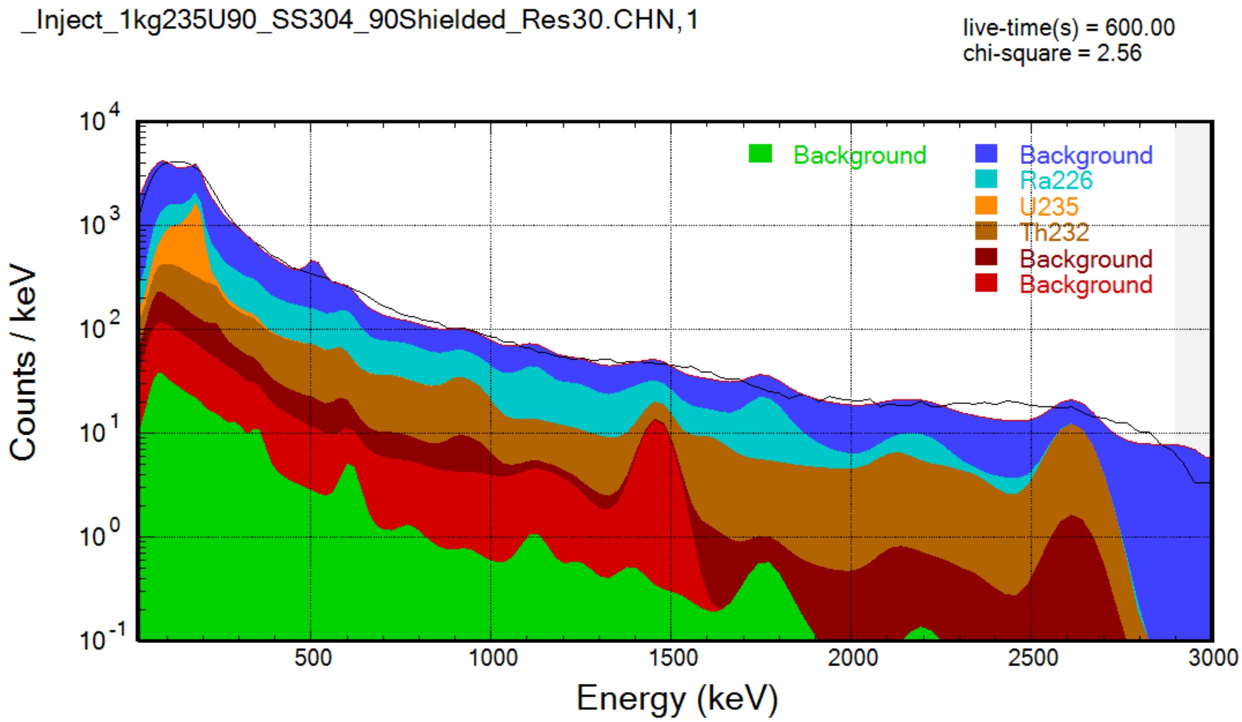


Figure F.19. GADRAS spectrum for HEU shielded to 90% intensity at a 30% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	603, 0
Chi Square:	4.1
Net Gammas:	1743 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	Th232(H,9uCi) + U235(F,379g)

Figure F.20. GADRAS textual results for HEU shielded to 90% intensity at a 30% resolution for collection and an 8.92% resolution for identification.

35% Resolution for Collection and 8.92% Resolution for Identification

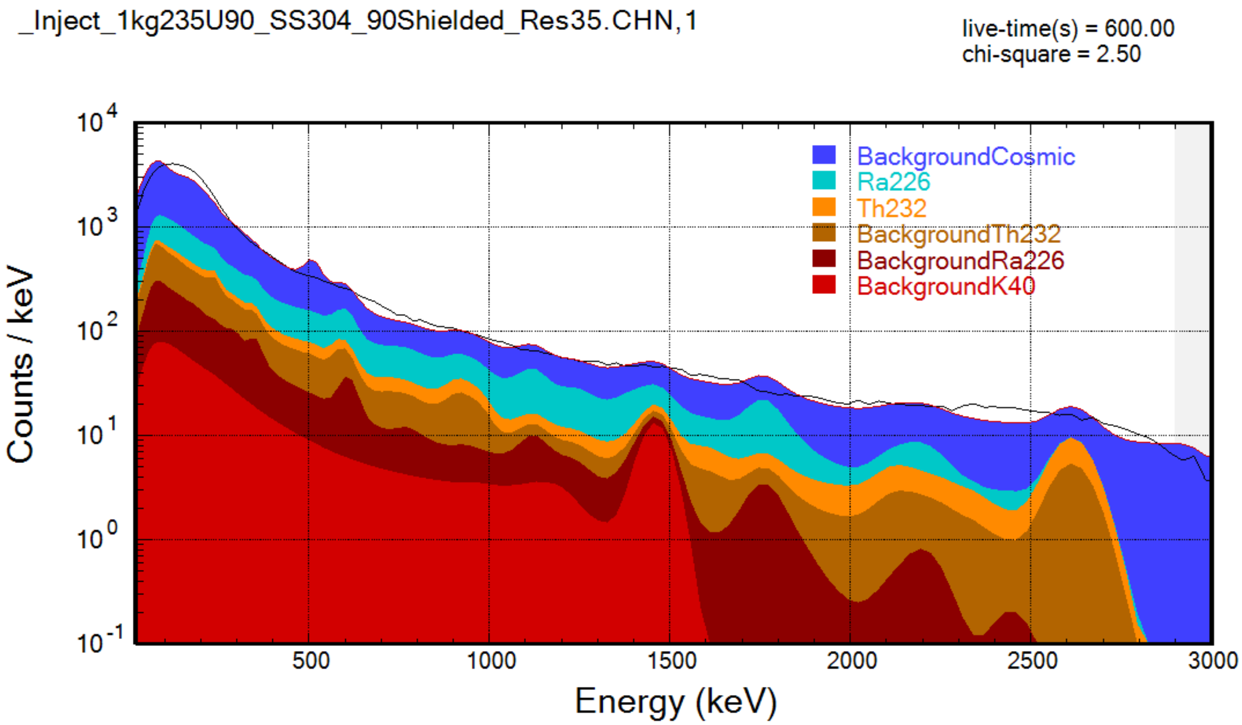


Figure F.21. GADRAS spectrum for HEU shielded to 90% intensity at a 35% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	1 (Natural)
TTF,TTB:	603, 0
Chi Square:	4.3
Net Gammas:	1738 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	GREEN
Alarm Description:	Innocent source
Event Type:	Natural
Isotopes:	Th232(H,8uCi)

Figure F.22. GADRAS textual results for HEU shielded to 90% intensity at a 35% resolution for collection and an 8.92% resolution for identification.

34% Resolution for Collection and 8.92% Resolution for Identification

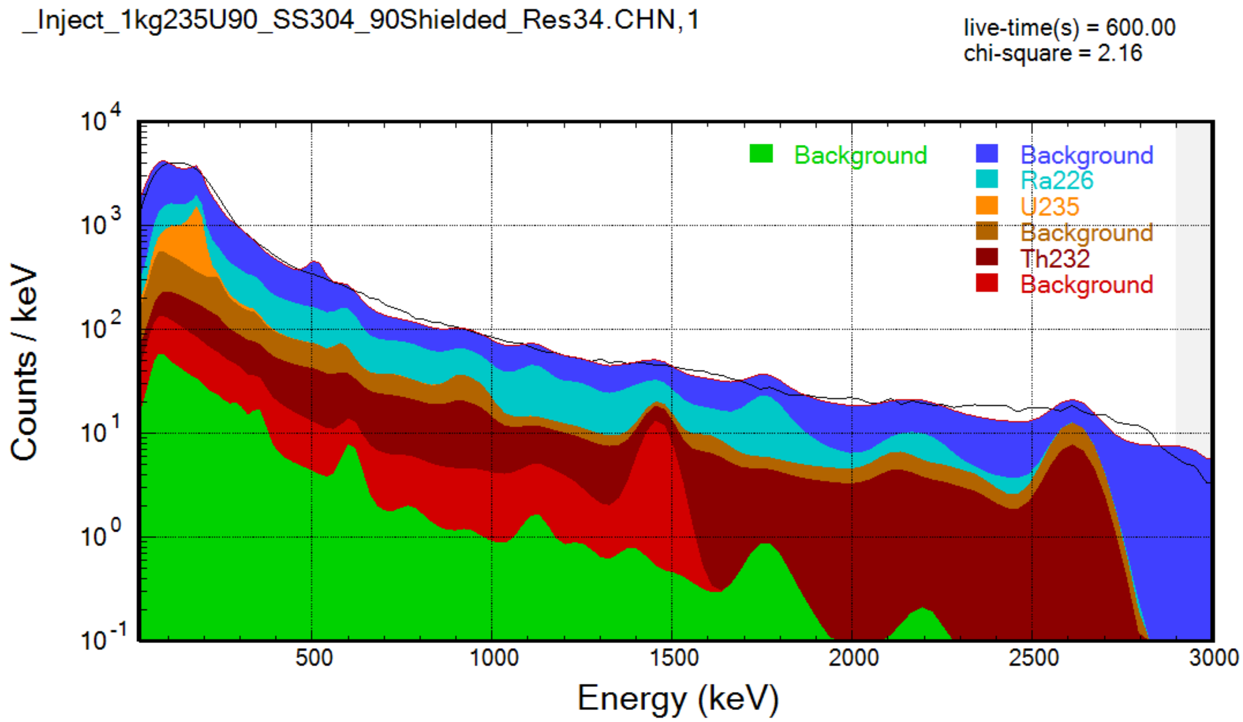


Figure F.23. GADRAS spectrum for HEU shielded to 90% intensity at a 34% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	5 (SNM=L)
TTF,TTB:	603, 0
Chi Square:	3.6
Net Gammas:	1736 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	1 (Low)
Alarm Severity:	RED
Alarm Description:	Maybe RDD
Event Type:	Natural
Isotopes:	Th232(H,10uCi) + Ra226(H,7uCi) + U235(L,3kg)

Figure F.24. GADRAS textual results for HEU shielded to 90% intensity at a 34% resolution for collection and an 8.92% resolution for identification.

33% Resolution for Collection and 8.92% Resolution for Identification

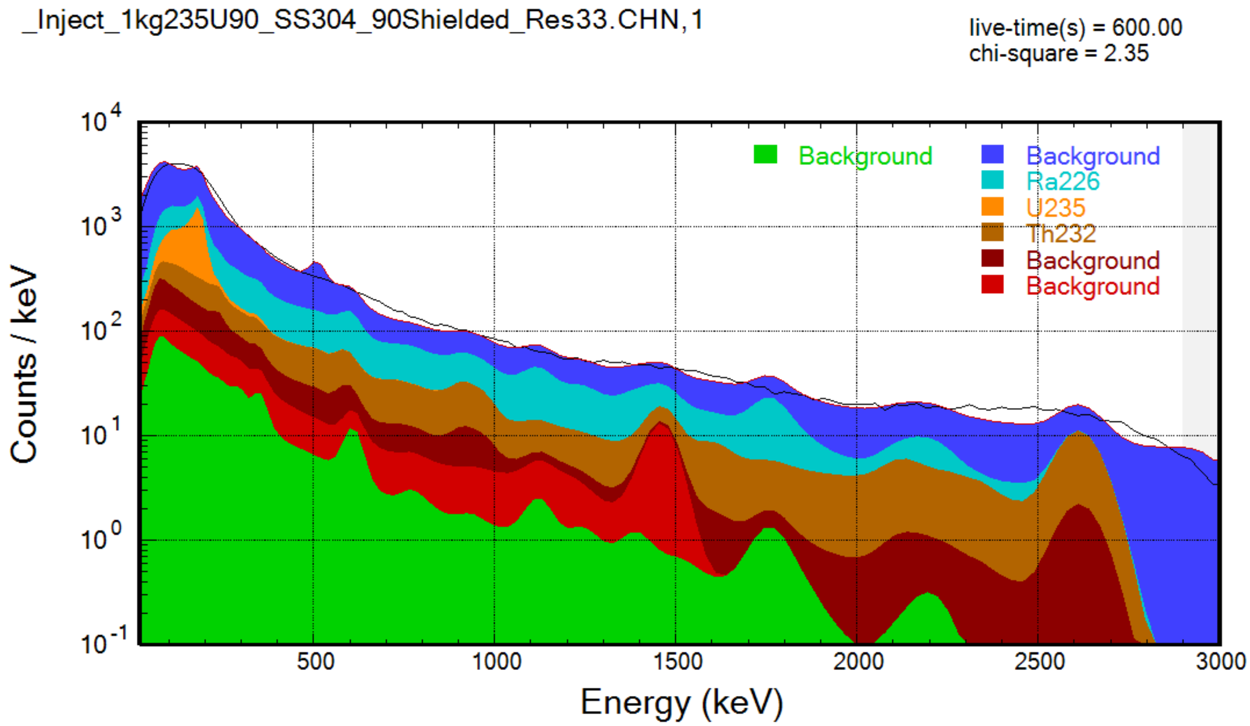


Figure F.25. GADRAS spectrum for HEU shielded to 90% intensity at a 33% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	603, 0
Chi Square:	3.9
Net Gammas:	1735 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	Th232(H,8uCi) + Ra226(H,7uCi) + U235(F,337g)

Figure F.26. GADRAS textual results for HEU shielded to 90% intensity at a 33% resolution for collection and an 8.92% resolution for identification.

32% Resolution for Collection and 8.92% Resolution for Identification

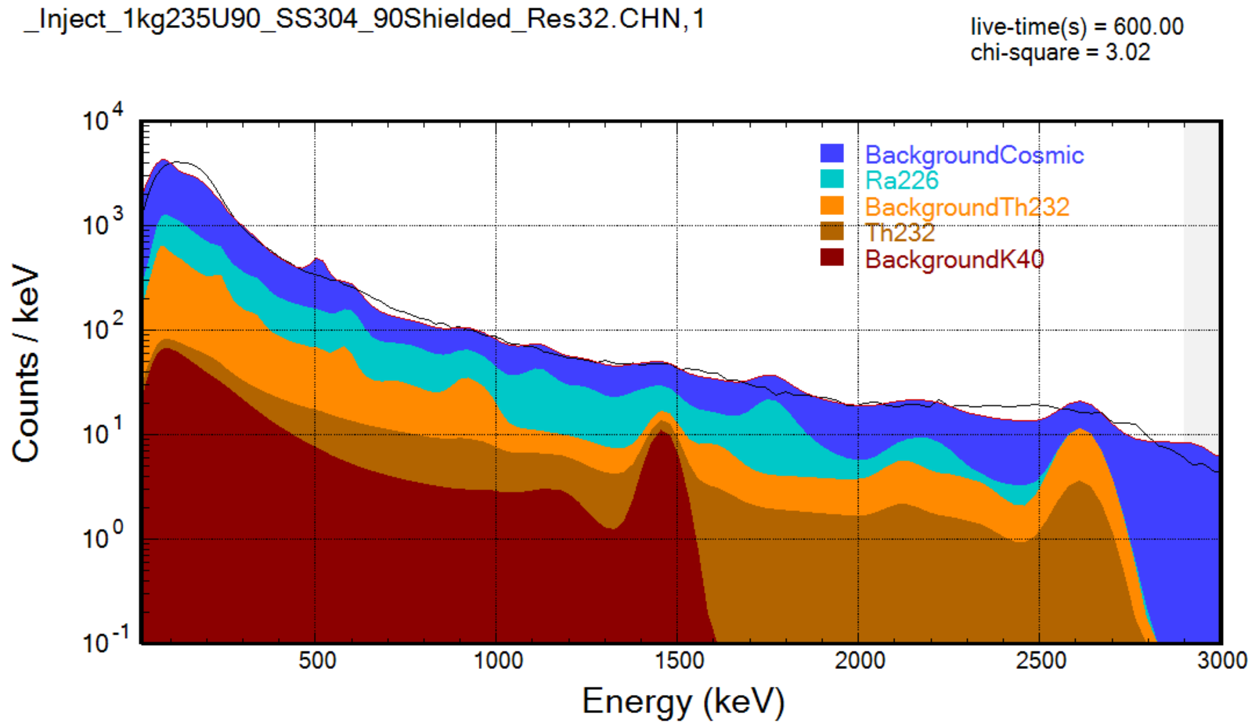


Figure F.27. GADRAS spectrum for HEU shielded to 90% intensity at a 32% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 1 (Natural)
TTF,TTB:                603, 0
Chi Square:             4.8
Net Gammas:             1737 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               0 (Very Low)
Alarm Severity:         GREEN
Alarm Description:      Innocent source
Event Type:             Natural

Isotopes:               Ra226(H,7uCi) + Th232(H,14uCi)
```

Figure F.28. GADRAS textual results for HEU shielded to 90% intensity at a 32% resolution for collection and an 8.92% resolution for identification.

31% Resolution for Collection and 8.92% Resolution for Identification

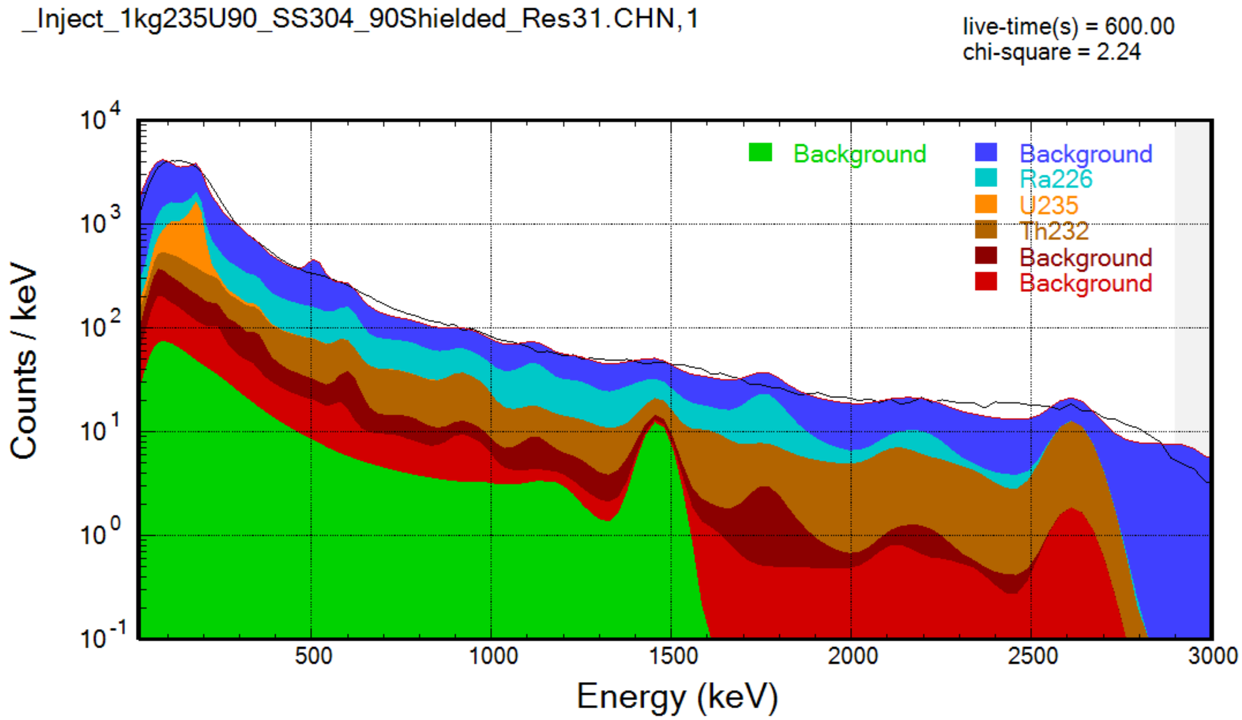


Figure F.29. GADRAS spectrum for HEU shielded to 90% intensity at a 31% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	5 (SNM=L)
TTF,TTB:	603, 0
Chi Square:	3.7
Net Gammas:	1738 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	1 (Low)
Alarm Severity:	RED
Alarm Description:	Maybe RDD
Event Type:	Natural
Isotopes:	Th232(H,11uCi) + U235(L,4kg)

Figure F.30. GADRAS textual results for HEU shielded to 90% intensity at a 31% resolution for collection and an 8.92% resolution for identification.

APPENDIX G – GADRAS Output for Configuration 4 Using the Same

Resolutions for Collection and Identification

8.92% Resolution for Collection and Identification

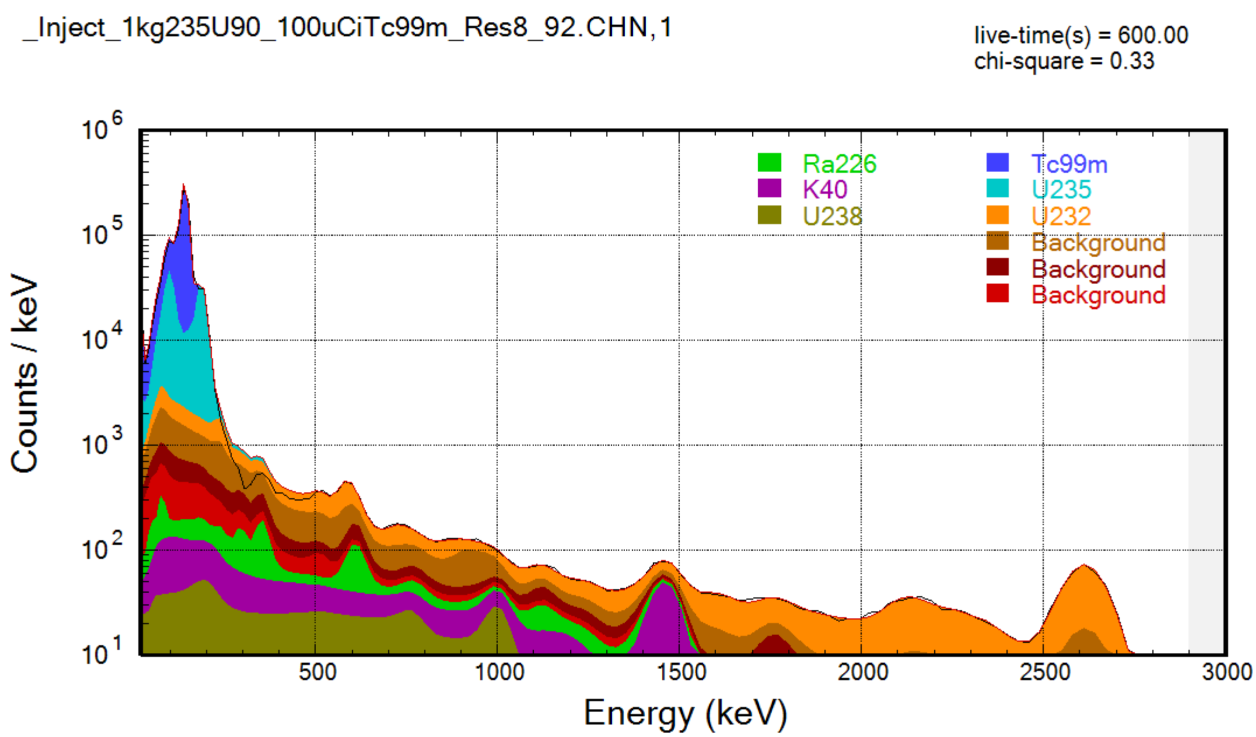


Figure G.1. GADRAS spectrum for HEU and the interference source at an 8.92% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                646, 0
Chi Square:             0.6
Net Gammas:             23928 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,1kg) + U232(H,6uCi) + K40(H,9uCi) + Tc99m(H,130uCi) + U238(F,64g)
```

Figure G.2. GADRAS textual results for HEU and the interference source at an 8.92% resolution for collection and identification.

10% Resolution for Collection and Identification

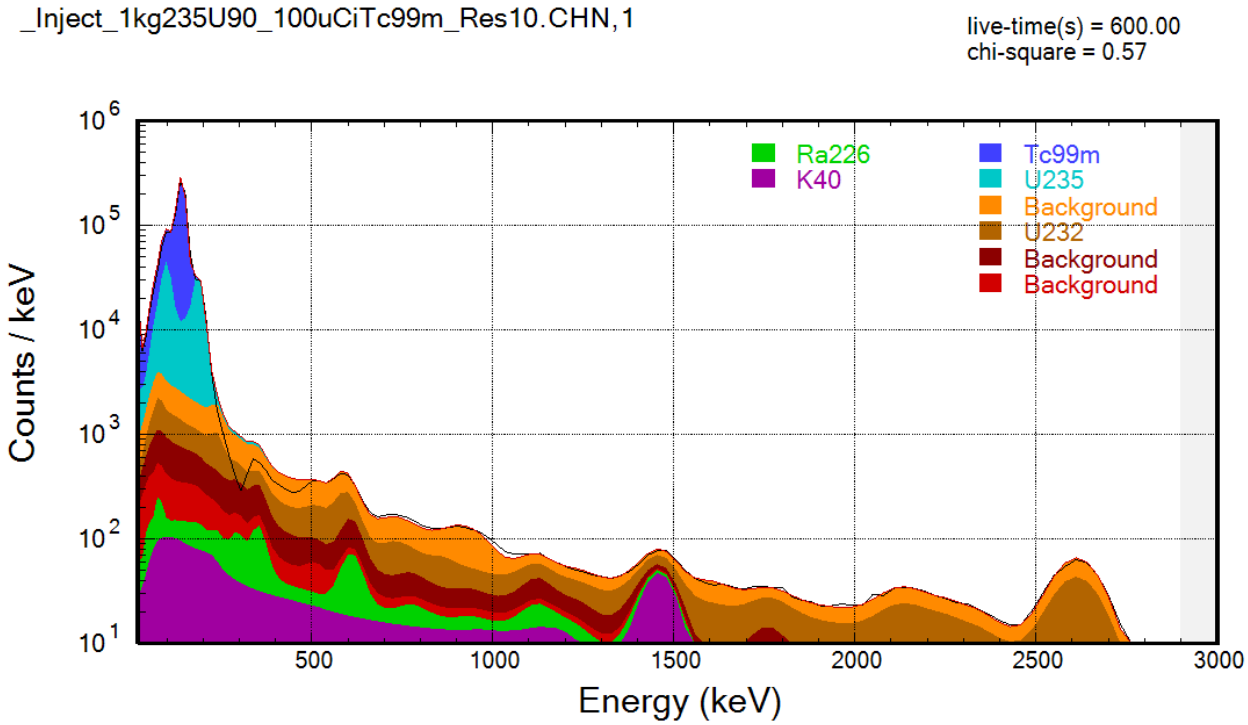


Figure G.3. GADRAS spectrum for HEU and the interference source at a 10% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	646, 0
Chi Square:	0.8
Net Gammas:	23920 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,1kg) + U232(H,6uCi) + Tc99m(H,130uCi) + K40(H,10uCi)

Figure G.4. GADRAS textual results for HEU and the interference source at a 10% resolution for collection and identification.

15% Resolution for Collection and Identification

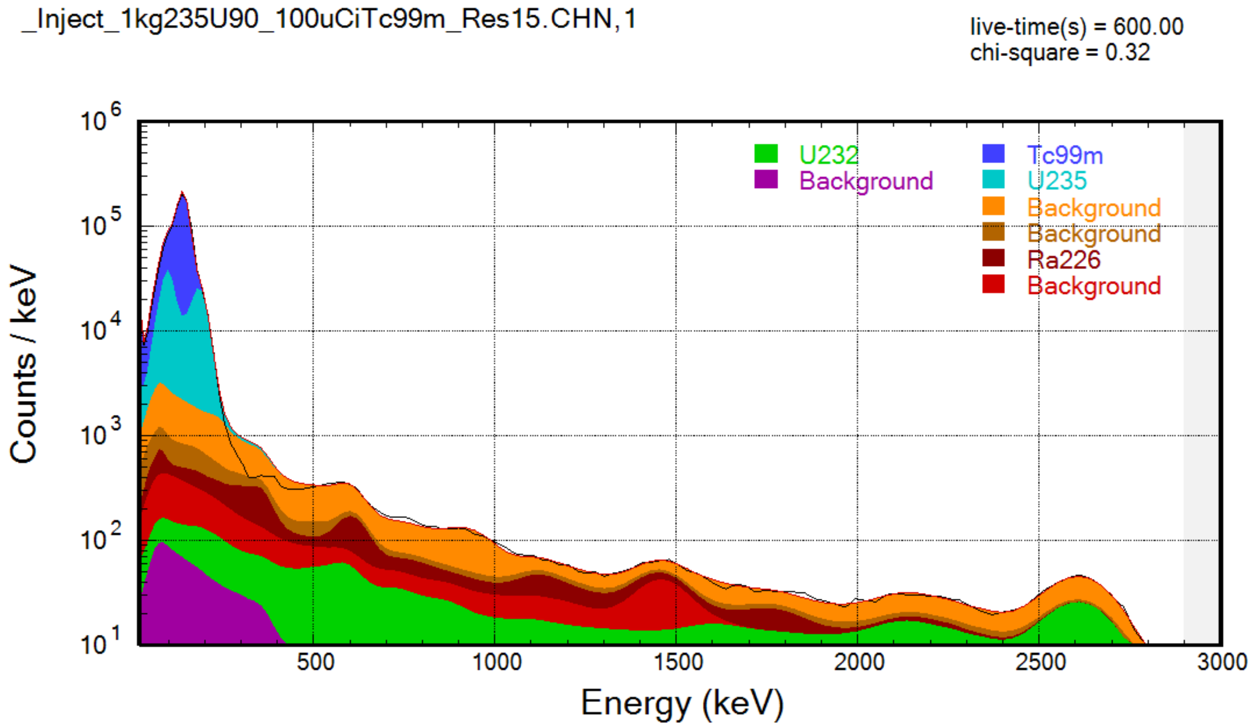


Figure G.5. GADRAS spectrum for HEU and the interference source at a 15% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                646, 0
Chi Square:             0.5
Net Gammas:             23930 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,1kg) + U232(H,6uCi) + Ra226(H,1uCi) + Tc99m(L,128uCi)
```

Figure G.6. GADRAS textual results for HEU and the interference source at a 15% resolution for collection and identification.

20% Resolution for Collection and Identification

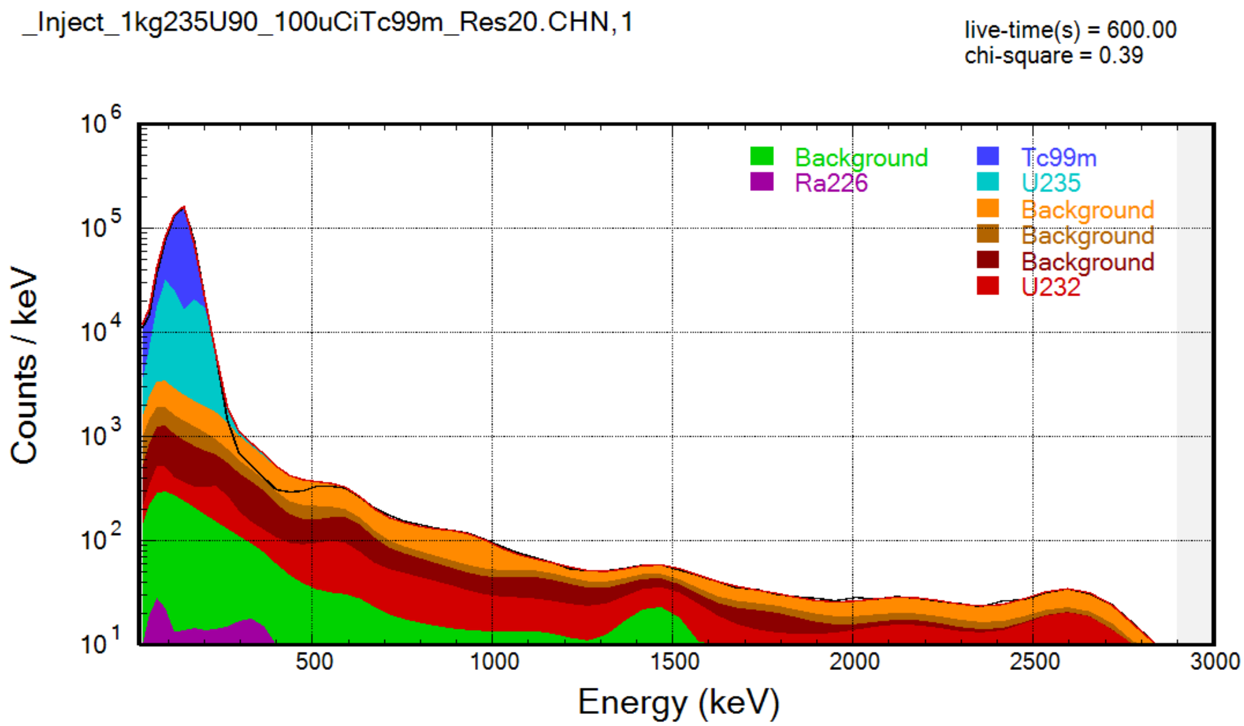


Figure G.7. GADRAS spectrum for HEU and the interference source at a 20% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                646, 0
Chi Square:             0.6
Net Gammas:             23955 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,1kg) + U232(H,6uCi) + Tc99m(L,127uCi)
```

Figure G.8. GADRAS textual results for HEU and the interference source at a 20% resolution for collection and identification.

25% Resolution for Collection and Identification

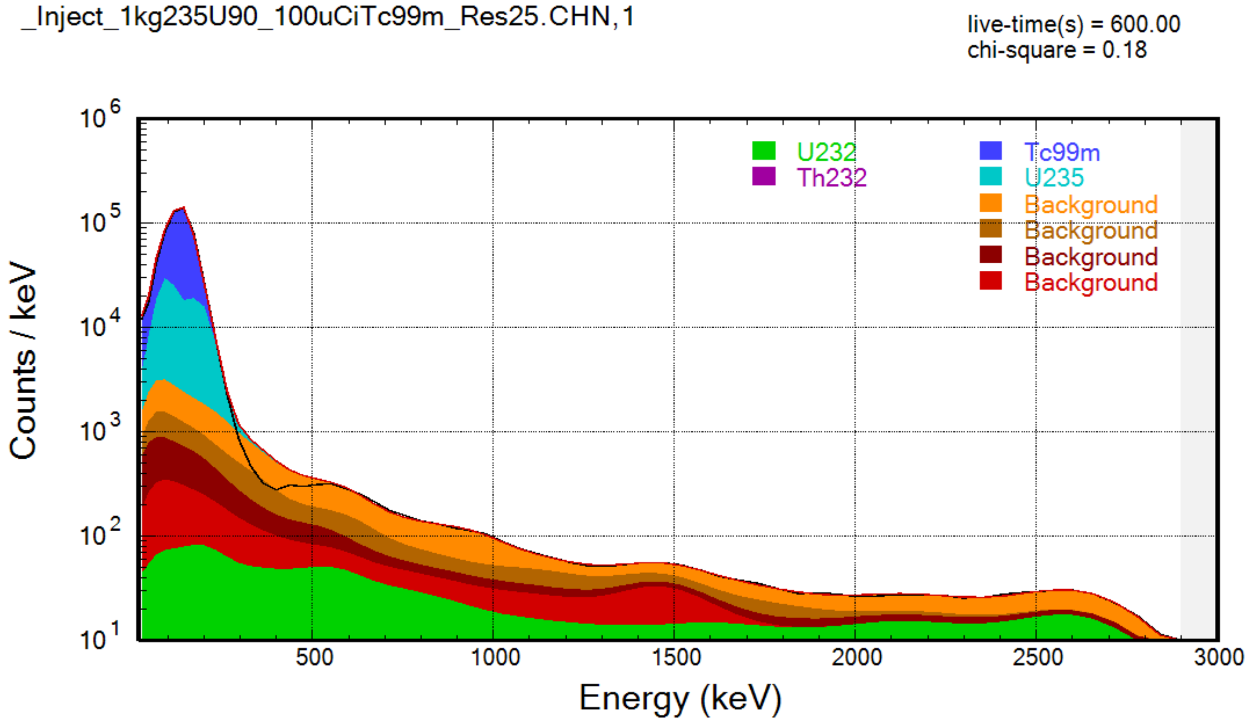


Figure G.9. GADRAS spectrum for HEU and the interference source at a 25% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                646, 0
Chi Square:             0.4
Net Gammas:             23940 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,1kg) + U232(F,1uCi) + Tc99m(L,127uCi)
```

Figure G.10. GADRAS textual results for HEU and the interference source at a 25% resolution for collection and identification.

26% Resolution for Collection and Identification

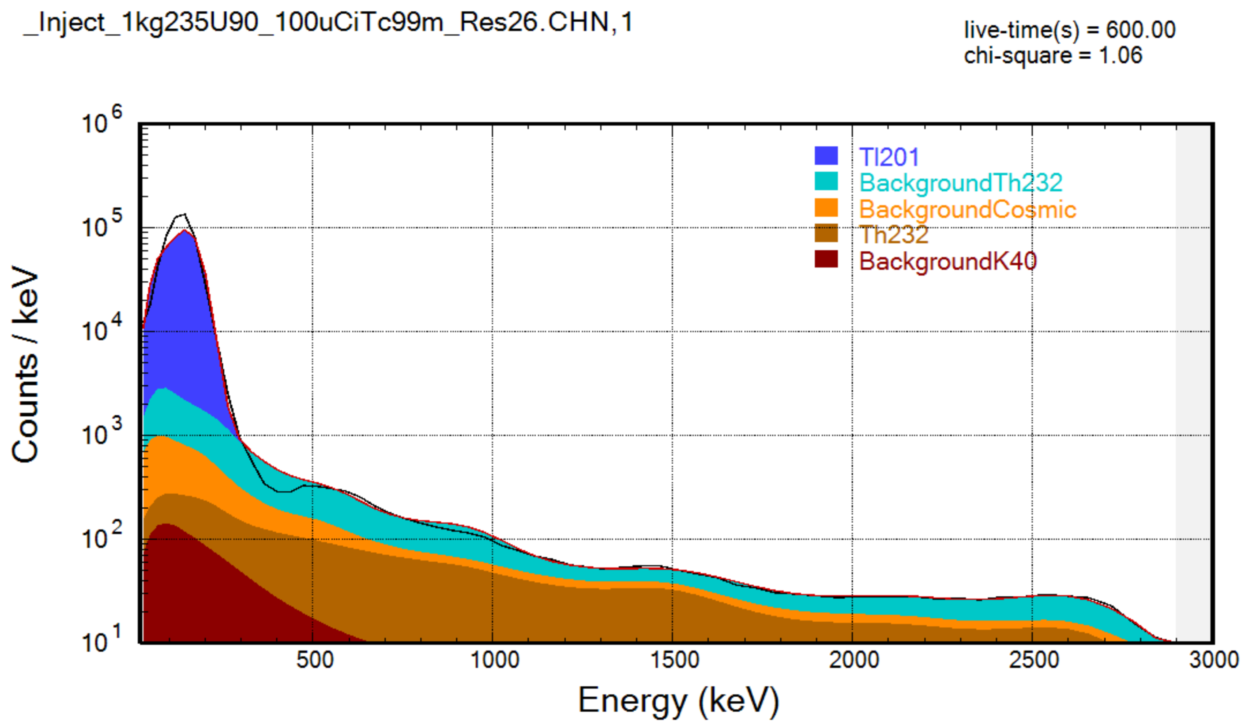


Figure G.11. GADRAS spectrum for HEU and the interference source at a 26% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                  6 (SNM=F)
TTF,TTB:                 646, 0
Chi Square:              1.4
Net Gammas:              23944 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                2 (Fair)
Alarm Severity:          RED
Alarm Description:       Possible SNM
Event Type:              Suspect

Isotopes:                T1201(H,3mCi) + U232(H,1uCi)
```

Figure G.12. GADRAS textual results for HEU and the interference source at a 26% resolution for collection and identification.

27% Resolution for Collection and Identification

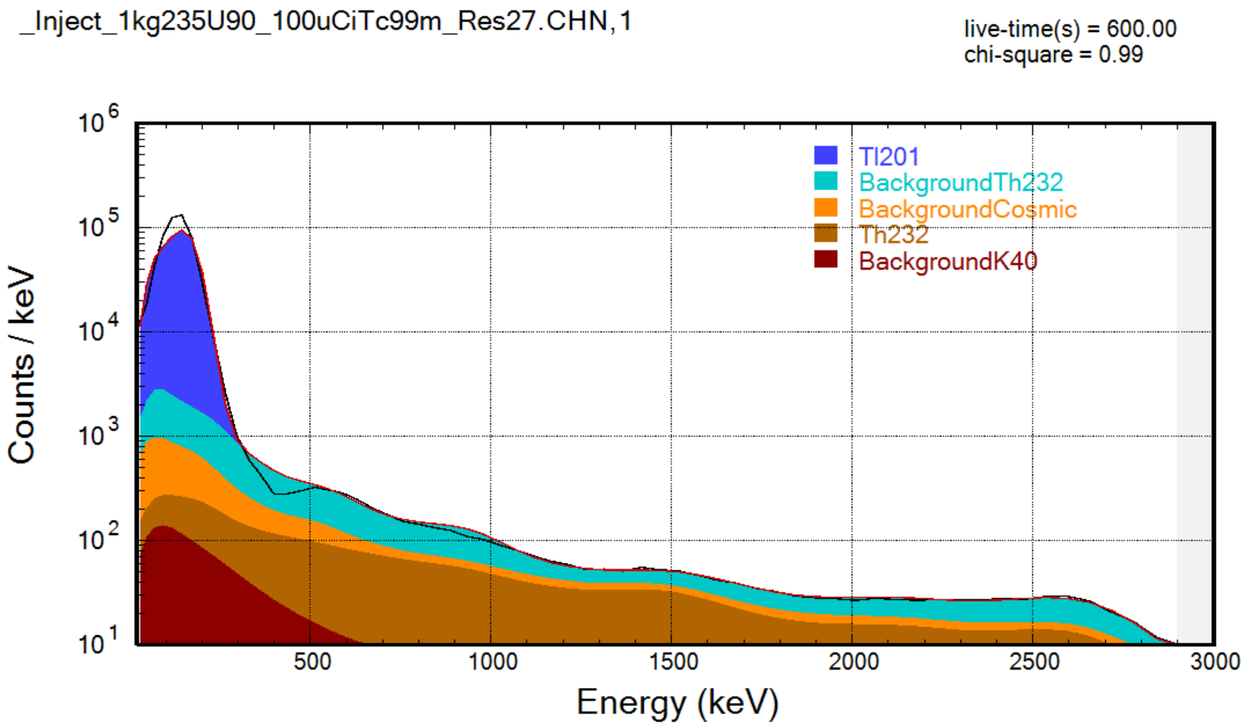


Figure G.13. GADRAS spectrum for HEU and the interference source at a 27% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	2 (Medical)
TTF,TTB:	646, 0
Chi Square:	1.3
Net Gammas:	23936 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Medical
Event Type:	Medical
Isotopes:	Th232(H,59uCi) + Tl201(H,3mCi) + Tc99m(L,1uCi)

Figure G.14. GADRAS textual results for HEU and the interference source at a 27% resolution for collection and identification.

28% Resolution for Collection and Identification

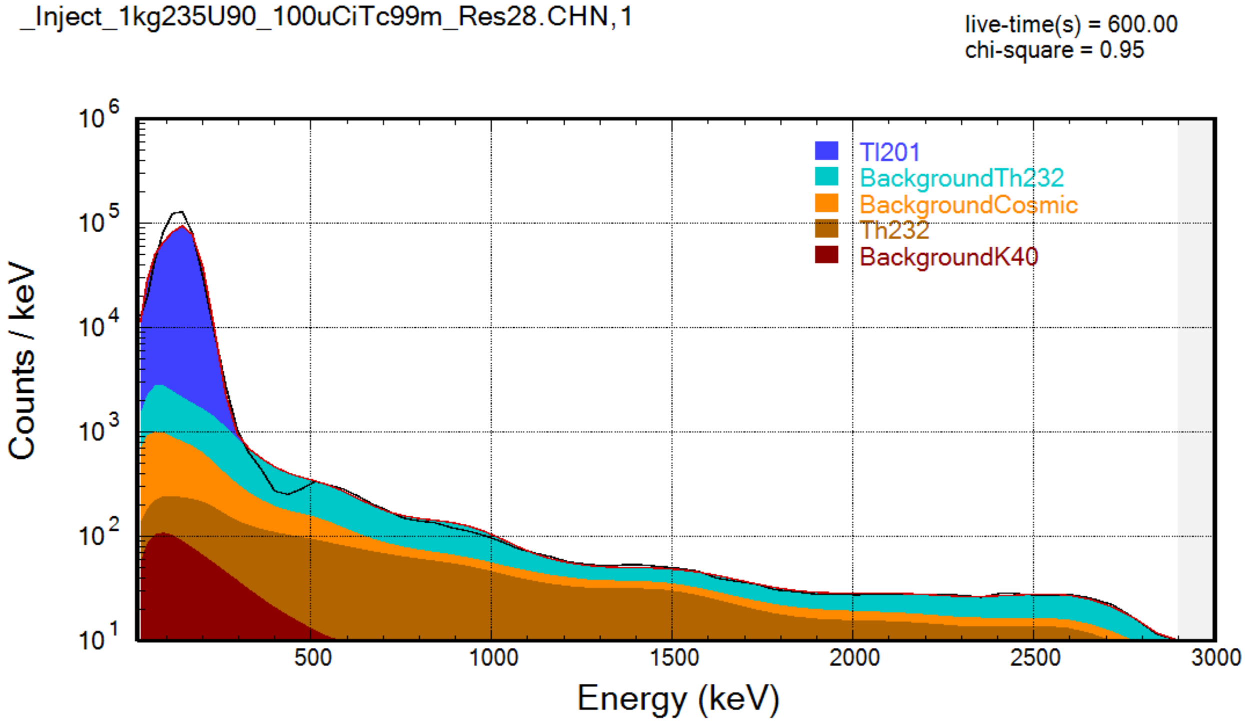


Figure G.15. GADRAS spectrum for HEU and the interference source at a 28% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 2 (Medical)
TTF,TTB:                646, 0
Chi Square:             1.3
Net Gammas:             23934 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               0 (Very Low)
Alarm Severity:         RED
Alarm Description:      Medical
Event Type:             Medical

Isotopes:               Tl201(H,3mCi) + U232(F,1uCi)
```

Figure G.16. GADRAS textual results for HEU and the interference source at a 28% resolution for collection and identification.

29% Resolution for Collection and Identification

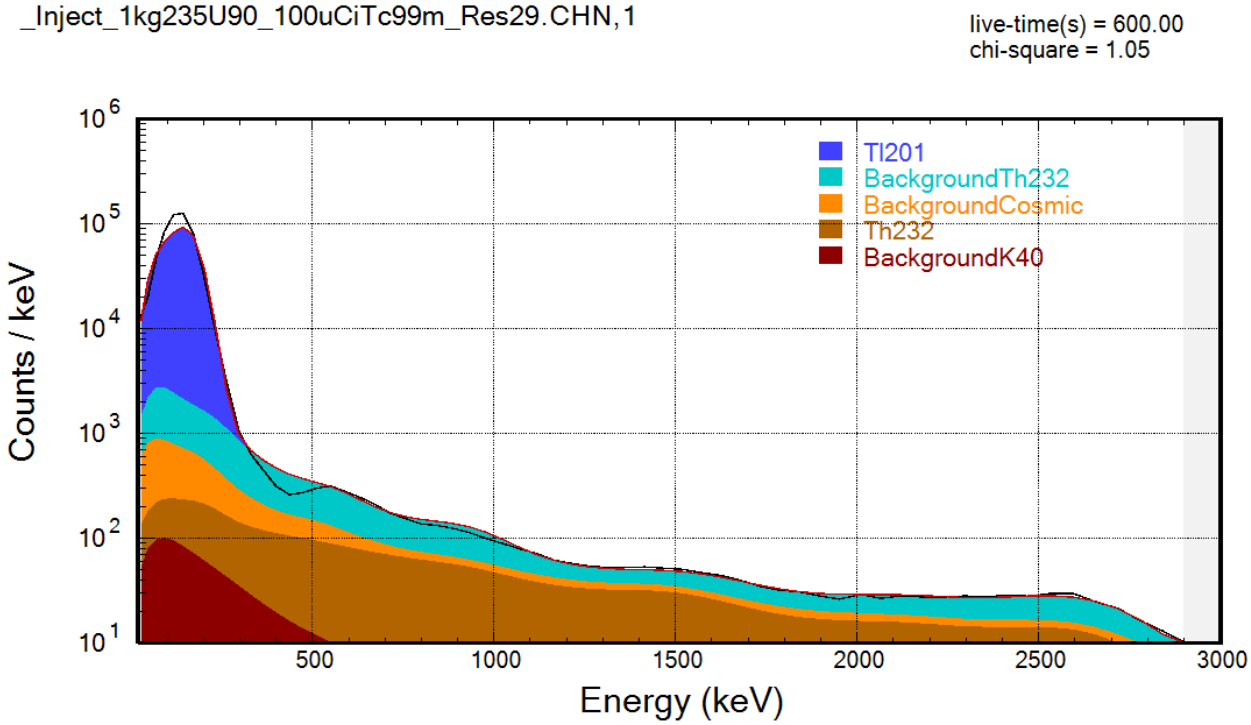


Figure G.17. GADRAS spectrum for HEU and the interference source at a 29% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	2 (Medical)
TTF,TTB:	646, 0
Chi Square:	1.4
Net Gammas:	23939 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Medical
Event Type:	Medical
Isotopes:	Tl201(H,3mCi) + U232(F,1uCi)

Figure G.18. GADRAS textual results for HEU and the interference source at a 29% resolution for collection and identification.

30% Resolution for Collection and Identification

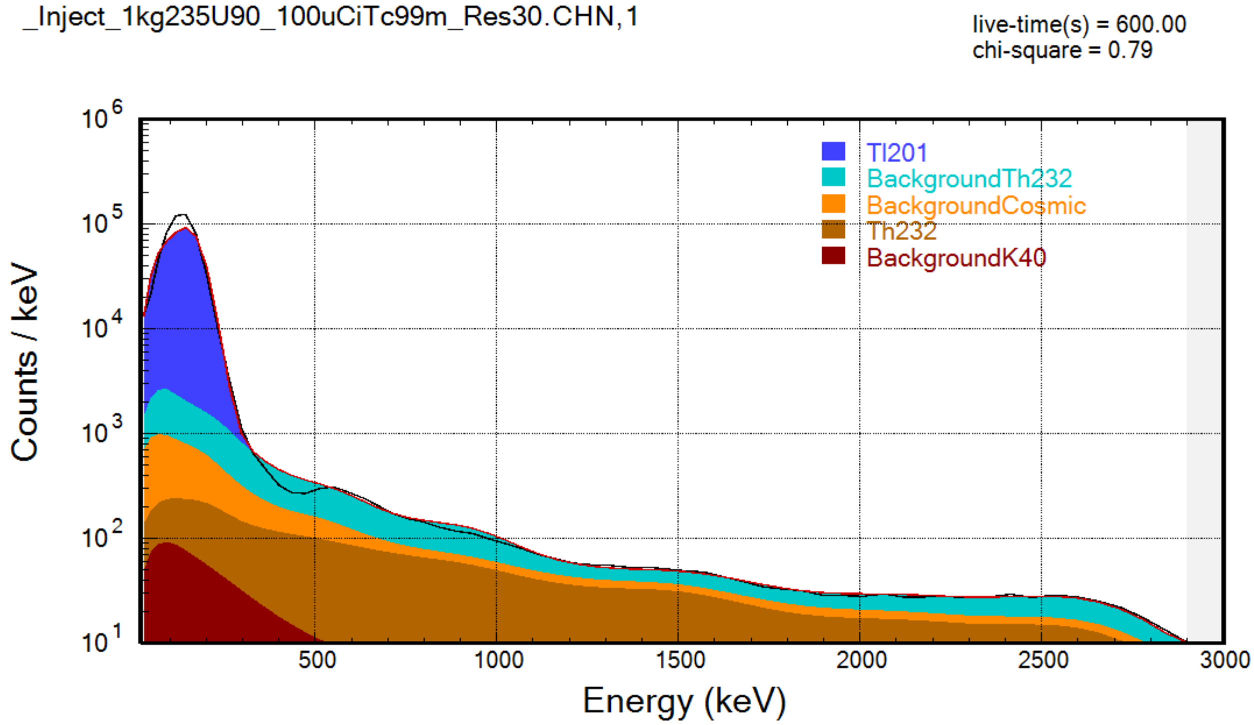


Figure G.19. GADRAS spectrum for HEU and the interference source at a 30% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	646, 0
Chi Square:	1.1
Net Gammas:	23939 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	Suspect
Isotopes:	Tl201(H,3mCi) + U232(H,1uCi)

Figure G.20. GADRAS textual results for HEU and the interference source at a 30% resolution for collection and identification.

APPENDIX H – GADRAS Output for Configuration 4 Using Different Resolutions for Collection and Identification

8.92% Resolution for Collection and 8.92% Resolution for Identification

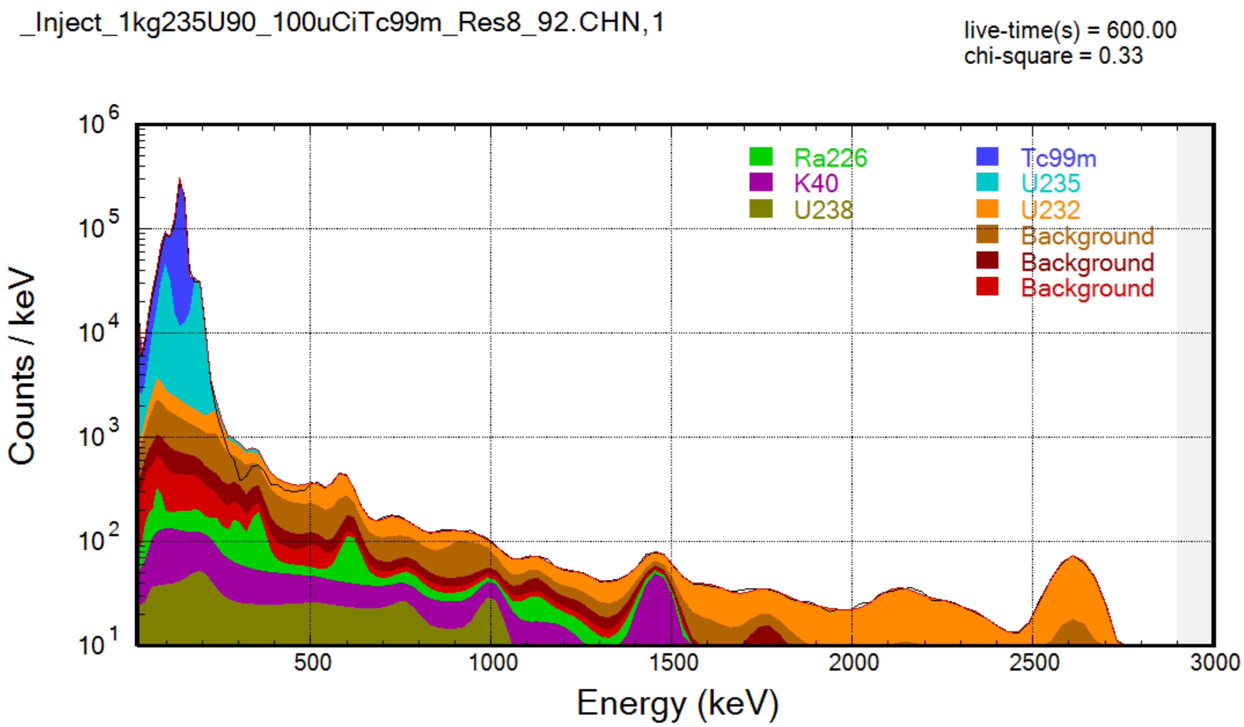


Figure H.1. GADRAS spectrum for HEU and the interference source at an 8.92% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                646, 0
Chi Square:             0.6
Net Gammas:             23928 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,1kg) + U232(H,6uCi) + K40(H,9uCi) + Tc99m(H,130uCi) + U238(F,64g)
```

Figure H.2. GADRAS textual results for HEU and the interference source at an 8.92% resolution for collection and an 8.92% resolution for identification.

10% Resolution for Collection and 8.92% Resolution for Identification

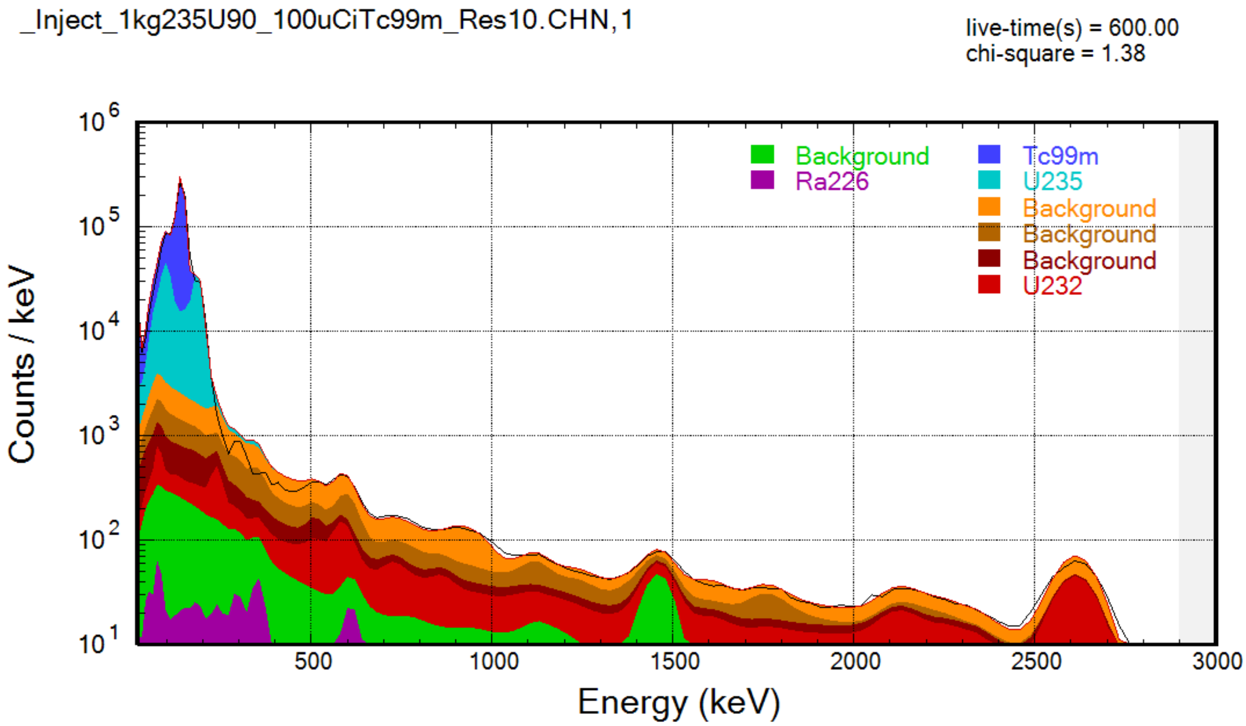


Figure H.3. GADRAS spectrum for HEU and the interference source at a 10% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                  7 (SNM=H)
TTF,TTB:                 646, 0
Chi Square:              1.6
Net Gammas:              23938 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                3 (High)
Alarm Severity:          RED
Alarm Description:       Probable SNM
Event Type:              SNM

Isotopes:                U235(H,3kg) + U232(H,6uCi) + Tc99m(H,125uCi)
```

Figure H.4. GADRAS textual results for HEU and the interference source at a 10% resolution for collection and an 8.92% resolution for identification.

15% Resolution for Collection and 8.92% Resolution for Identification

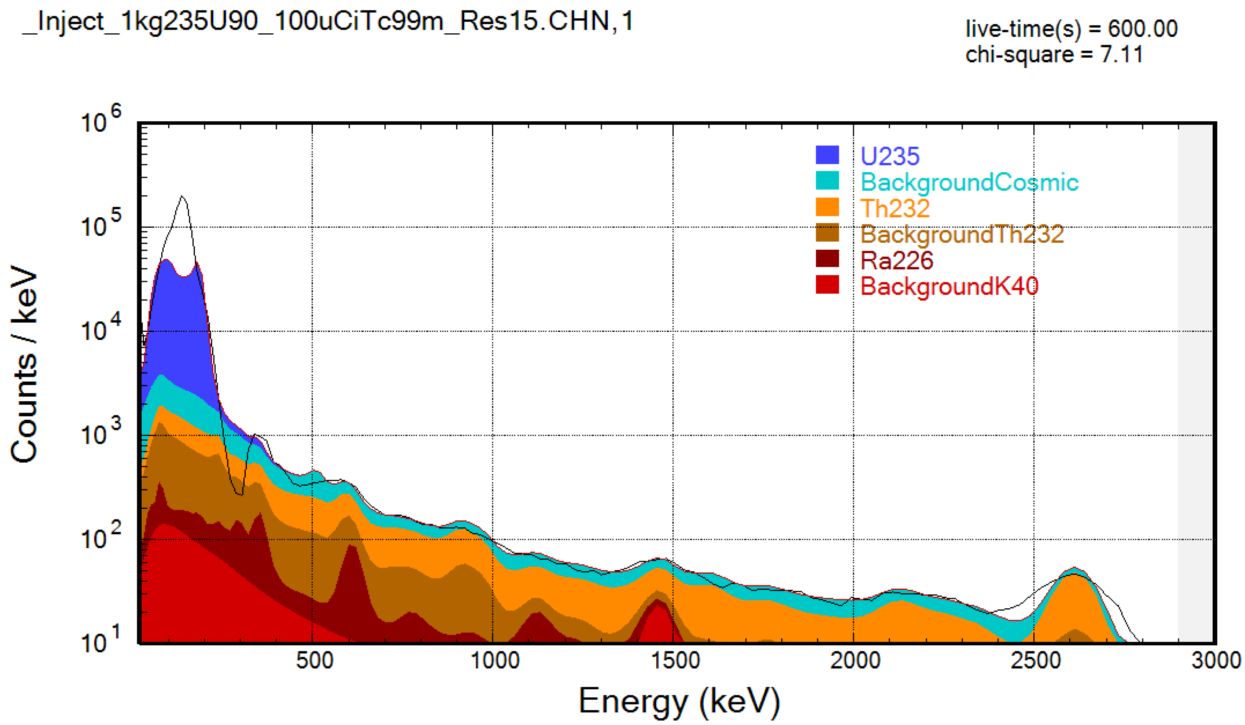


Figure H.5. GADRAS spectrum for HEU and the interference source at a 15% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                   7 (SNM=H)
TTF,TTB:                  646, 0
Chi Square:               7.9
Net Gammas:               23929 cps
Net Neutrons:             0 cps
Sigma Gammas:             0
Sigma Neutrons:           0
Average Speed:            0 m/s
SNM Prob:                 3 (High)
Alarm Severity:           RED
Alarm Description:        Probable SNM
Event Type:               SNM

Isotopes:                 U235(H,12kg) + Th232(H,32uCi) + Ra226(H,1uCi) + Xe131m(F,1uCi) + Tc99m(L,1uCi)
```

Figure H.6 GADRAS textual results for HEU and the interference source at a 15% resolution for collection and an 8.92% resolution for identification.

20% Resolution for Collection and 8.92% Resolution for Identification

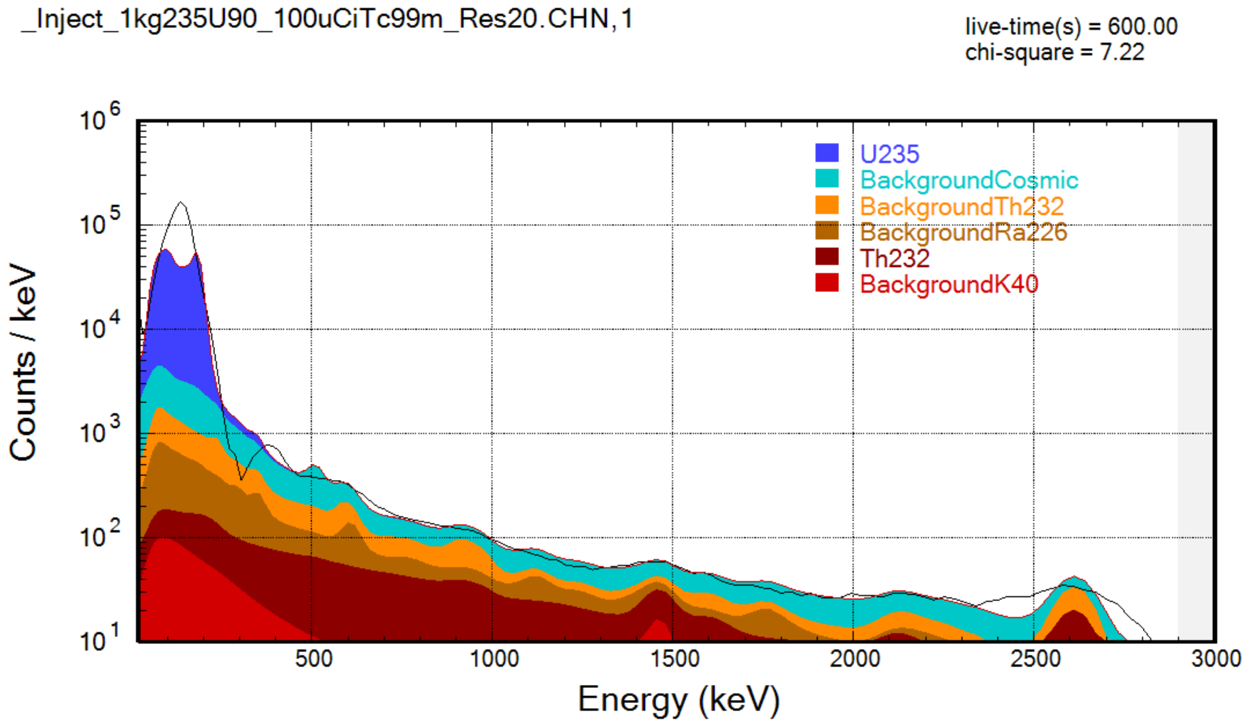


Figure H.7. GADRAS spectrum for HEU and the interference source at a 20% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	646, 0
Chi Square:	8.7
Net Gammas:	23932 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,40uCi) + U235(H,14kg) + Xe131m(F,1uCi) + Tc99m(L,1uCi) + Lu177m(L,1uCi)

Figure H.8. GADRAS textual results for HEU and the interference source at a 20% resolution for collection and an 8.92% resolution for identification.

25% Resolution for Collection and 8.92% Resolution for Identification

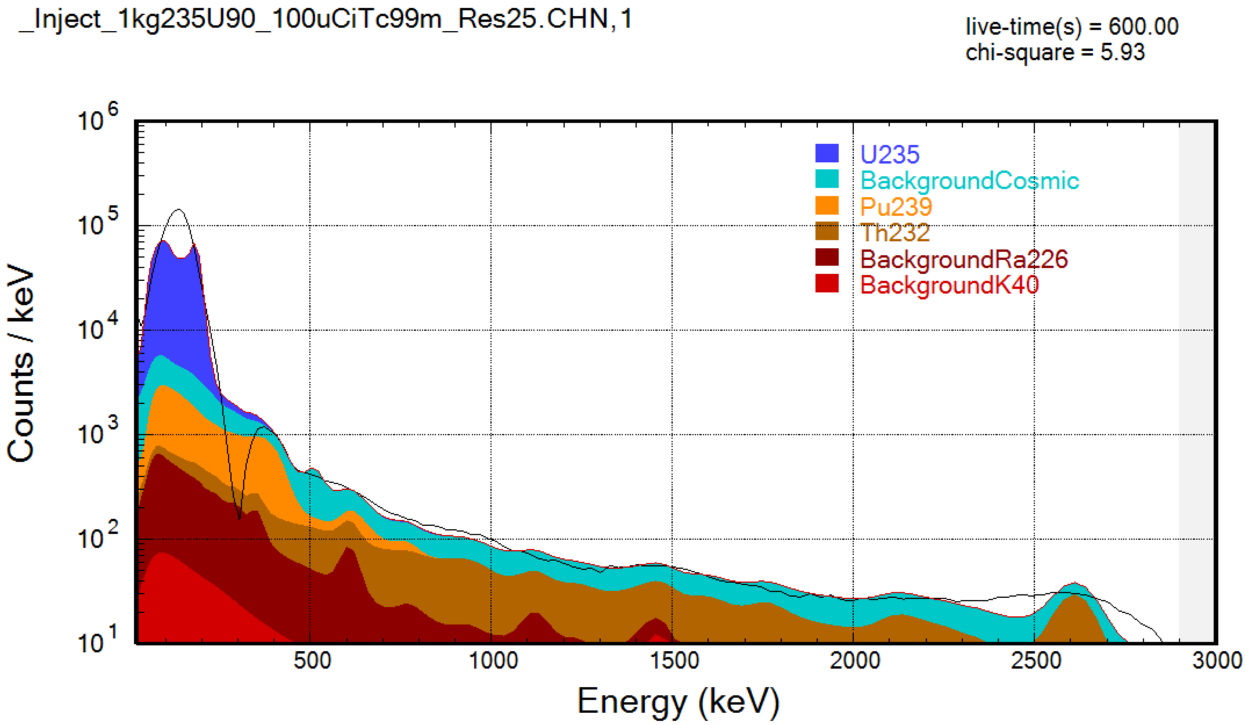


Figure H.9. GADRAS spectrum for HEU and the interference source at a 25% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                646, 0
Chi Square:             7.6
Net Gammas:             23931 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,18kg) + Th232(H,55uCi) + Pu239(H,530g) + Xe131m(F,1uCi) + Tc99m(L,1uCi)
```

Figure H.10. GADRAS textual results for HEU and the interference source at a 25% resolution for collection and an 8.92% resolution for identification.

30% Resolution for Collection and 8.92% Resolution for Identification

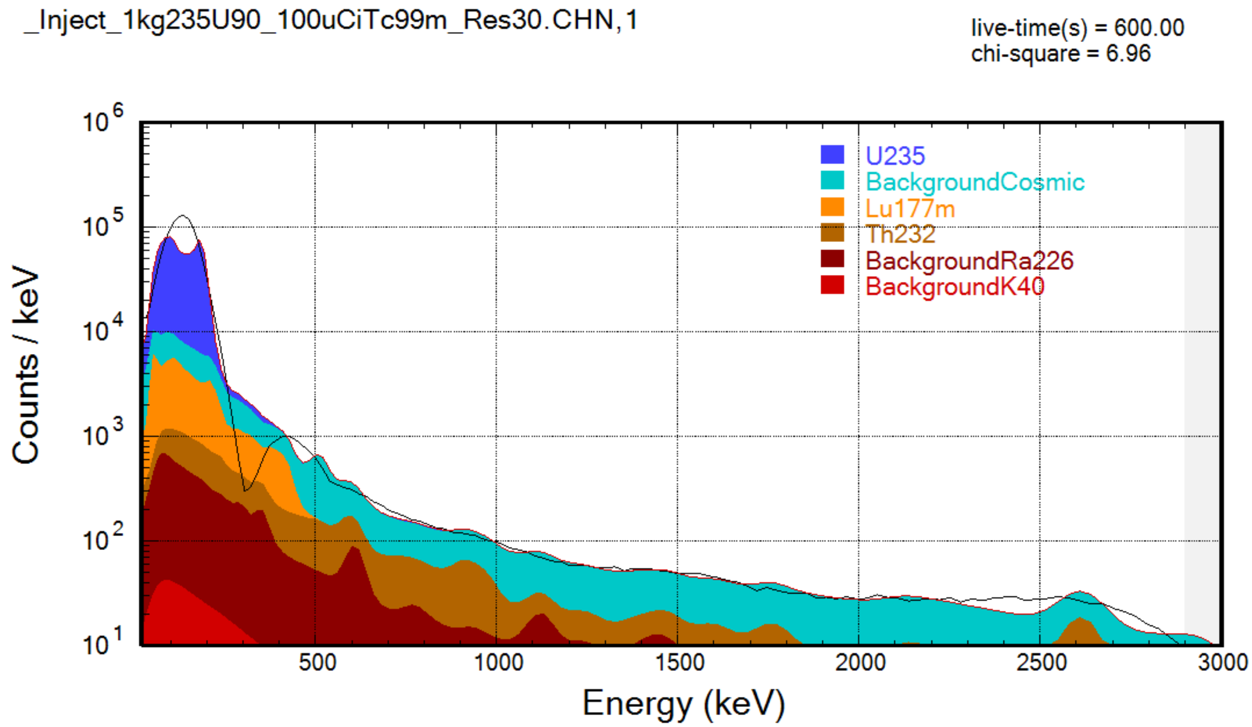


Figure H.11. GADRAS spectrum for HEU and the interference source at a 30% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	646, 0
Chi Square:	11.6
Net Gammas:	23914 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,4uCi) + U235(H,19kg) + Lu177m(H,2uCi)

Figure H.12. GADRAS textual results for HEU and the interference source at a 30% resolution for collection and an 8.92% resolution for identification.

35% Resolution for Collection and 8.92% Resolution for Identification

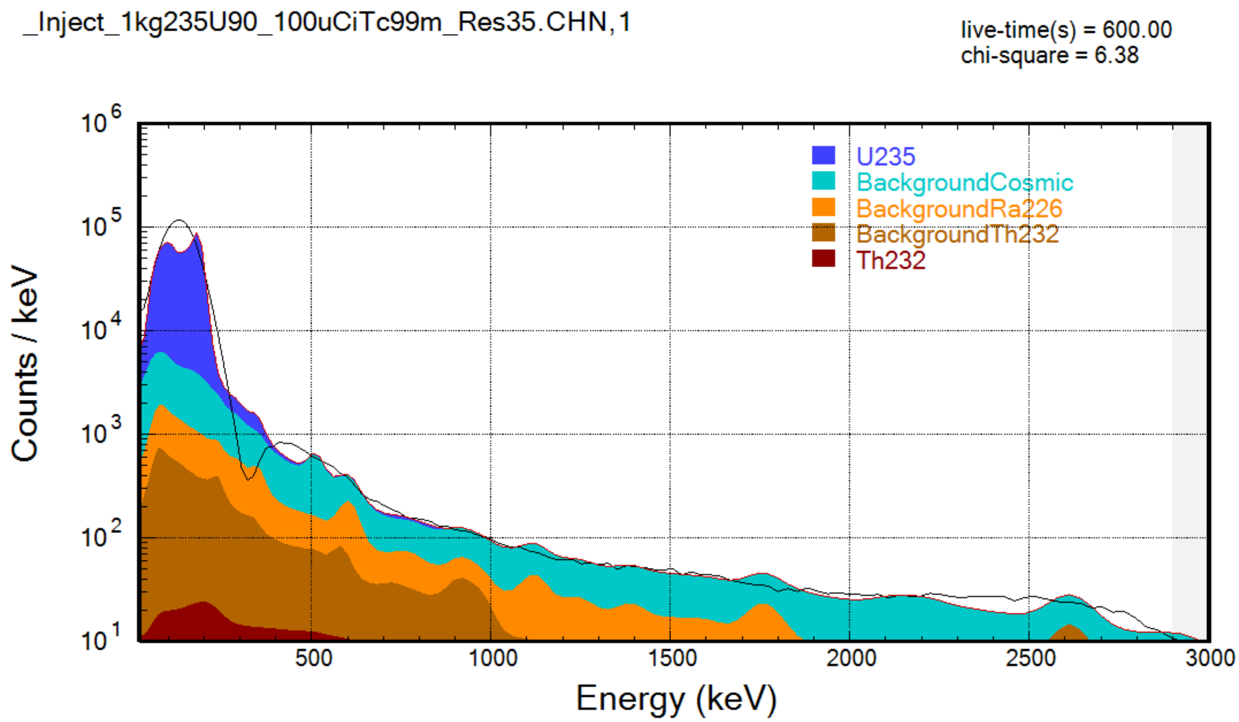


Figure H.13. GADRAS spectrum for HEU and the interference source at a 35% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                646, 0
Chi Square:             10.3
Net Gammas:             23866 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,104kg) + Th232(H,19uCi)
```

Figure H.14. GADRAS textual results for HEU and the interference source at a 35% resolution for collection and an 8.92% resolution for identification.

40% Resolution for Collection and 8.92% Resolution for Identification

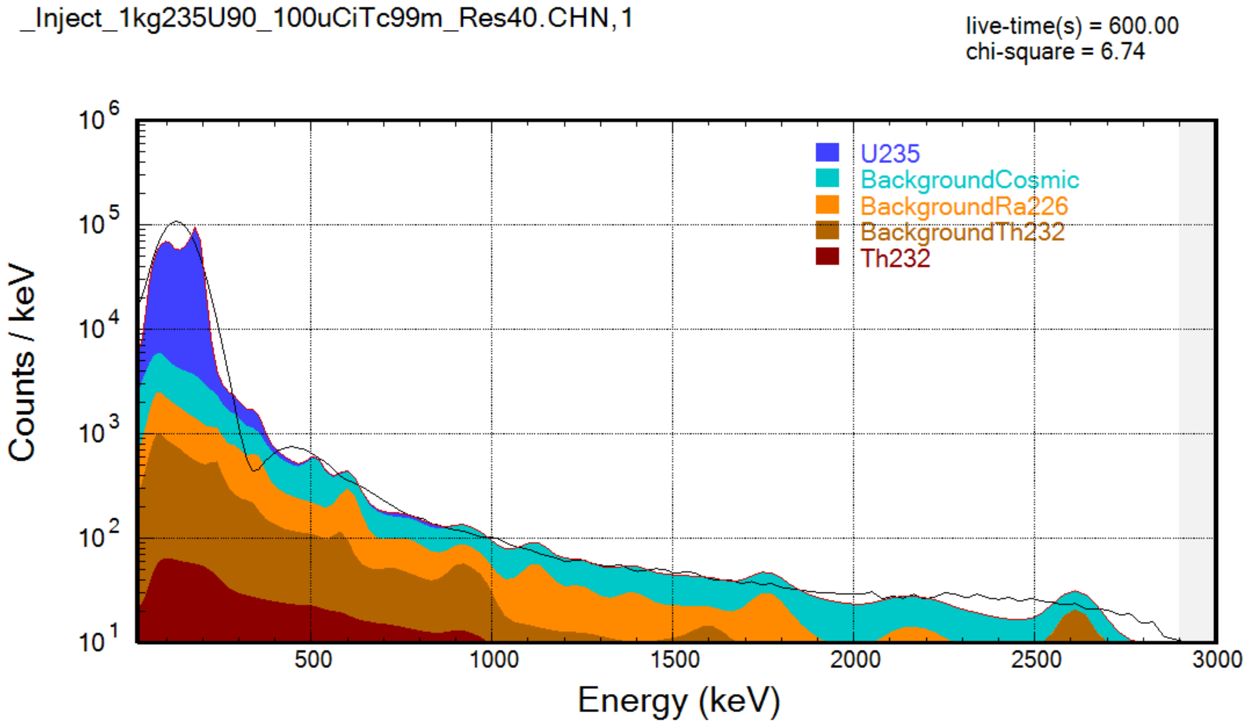


Figure H.15. GADRAS spectrum for HEU and the interference source at a 40% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	646, 0
Chi Square:	8.9
Net Gammas:	23808 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,131kg) + Th232(H,24uCi)

Figure H.16. GADRAS textual results for HEU and the interference source at a 40% resolution for collection and an 8.92% resolution for identification.

45% Resolution for Collection and 8.92% Resolution for Identification

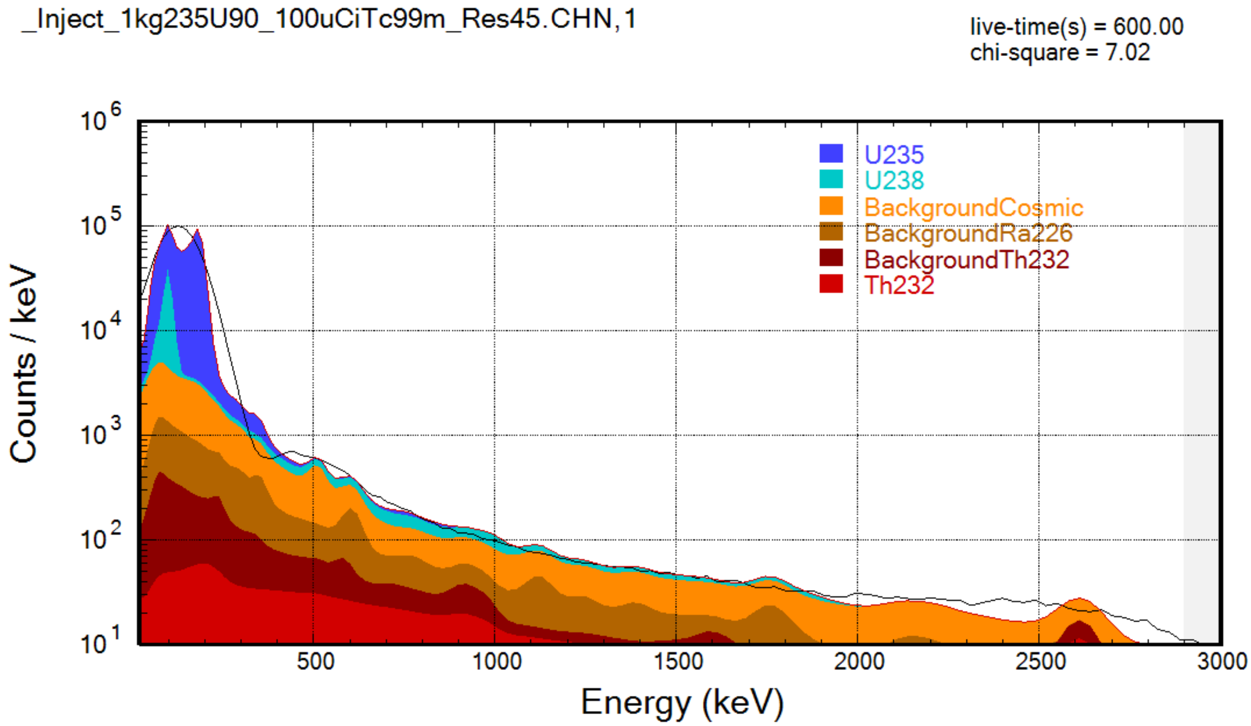


Figure H.17. GADRAS spectrum for HEU and the interference source at a 45% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	645, 0
Chi Square:	9.4
Net Gammas:	23731 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	Th232(H,21uCi) + U235(F,13kg) + U238(L,55kg)

Figure H.18. GADRAS textual results for HEU and the interference source at a 45% resolution for collection and an 8.92% resolution for identification.

41% Resolution for Collection and 8.92% Resolution for Identification

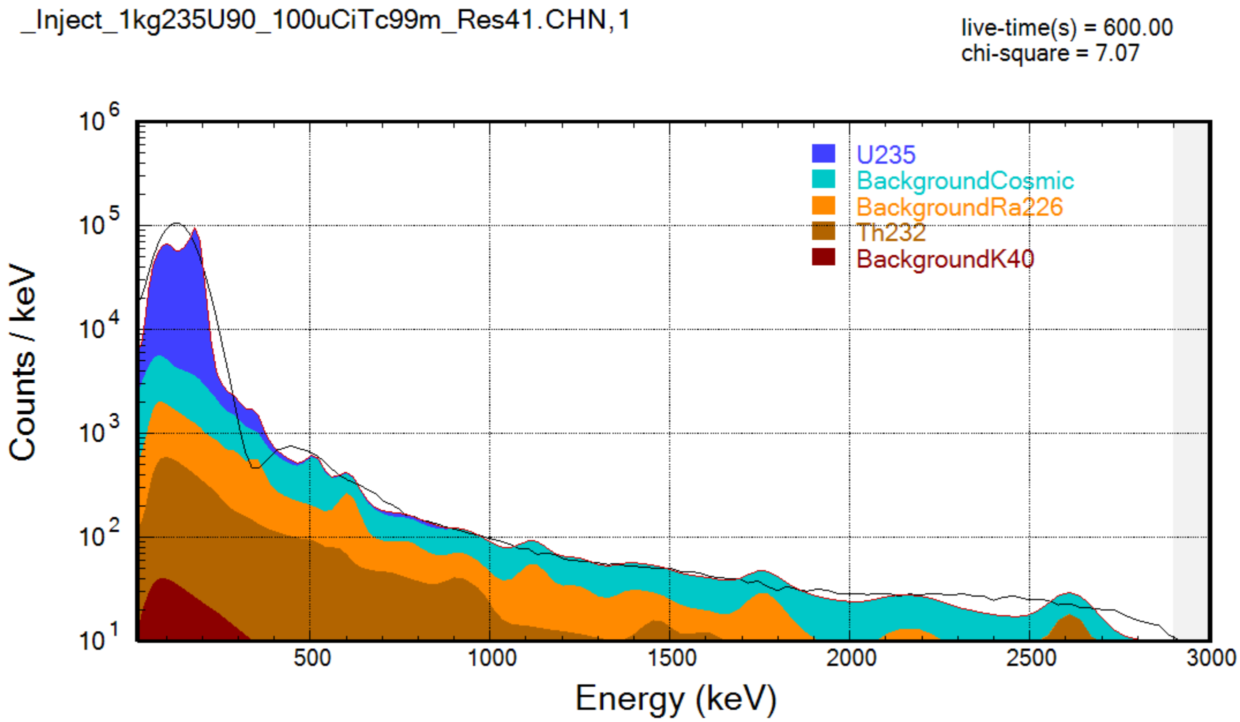


Figure H.19. GADRAS spectrum for HEU and the interference source at a 41% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	646, 0
Chi Square:	9.7
Net Gammas:	23807 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,5uCi) + U235(H,145kg)

Figure H.20. GADRAS textual results for HEU and the interference source at a 41% resolution for collection and an 8.92% resolution for identification.

42% Resolution for Collection and 8.92% Resolution for Identification

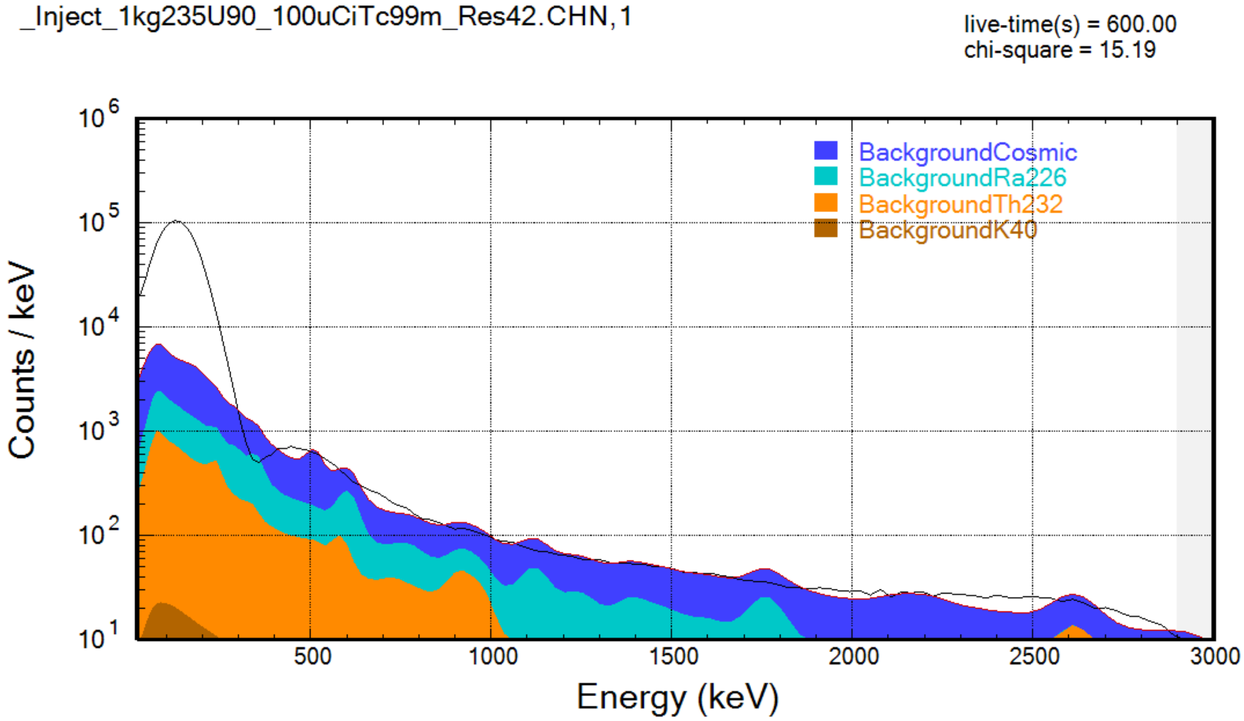


Figure H.21. GADRAS spectrum for HEU and the interference source at a 42% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 6 (SNM=F)
TTF,TTB:                646, 0
Chi Square:             19.1
Net Gammas:             23796 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               2 (Fair)
Alarm Severity:         RED
Alarm Description:      Possible SNM
Event Type:             SNM

Isotopes:               Th232(H,1uCi) + U235(F,1g) + U237(L,1uCi)
```

Figure H.22. GADRAS textual results for HEU and the interference source at a 42% resolution for collection and an 8.92% resolution for identification.

43% Resolution for Collection and 8.92% Resolution for Identification

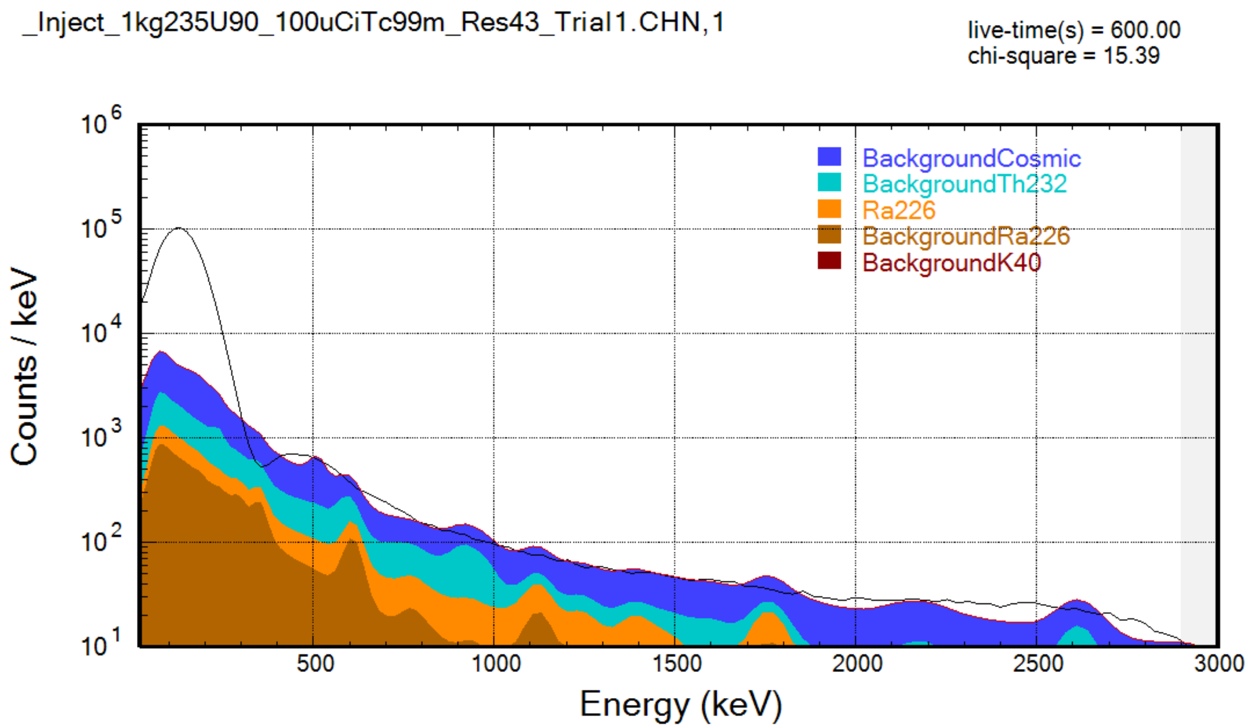


Figure H.23. GADRAS spectrum for HEU and the interference source at a 43% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 6 (SNM=F)
TTF,TTB:                645, 0
Chi Square:             18.9
Net Gammas:             23760 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               2 (Fair)
Alarm Severity:         RED
Alarm Description:      Possible SNM
Event Type:             SNM

Isotopes:               Th232(H,7uCi) + U235(F,1g) + U237(L,1uCi)
```

Figure H.24. GADRAS textual results for HEU and the interference source at a 43% resolution for collection and an 8.92% resolution for identification.

44% Resolution for Collection and 8.92% Resolution for Identification

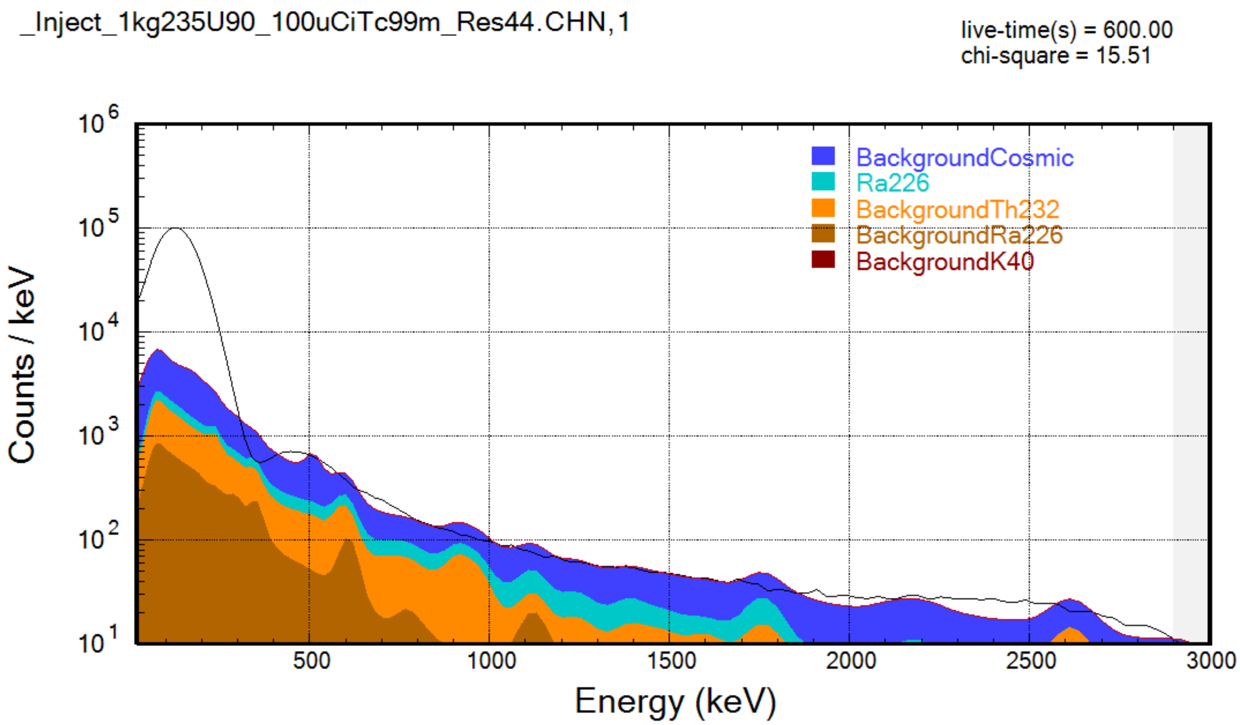


Figure H.25. GADRAS spectrum for HEU and the interference source at a 44% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	645, 0
Chi Square:	19.1
Net Gammas:	23747 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	Th232(H,6uCi) + U235(F,1g) + U237(L,1uCi)

Figure H.26. GADRAS textual results for HEU and the interference source at a 44% resolution for collection and an 8.92% resolution for identification.

46% Resolution for Collection and 8.92% Resolution for Identification

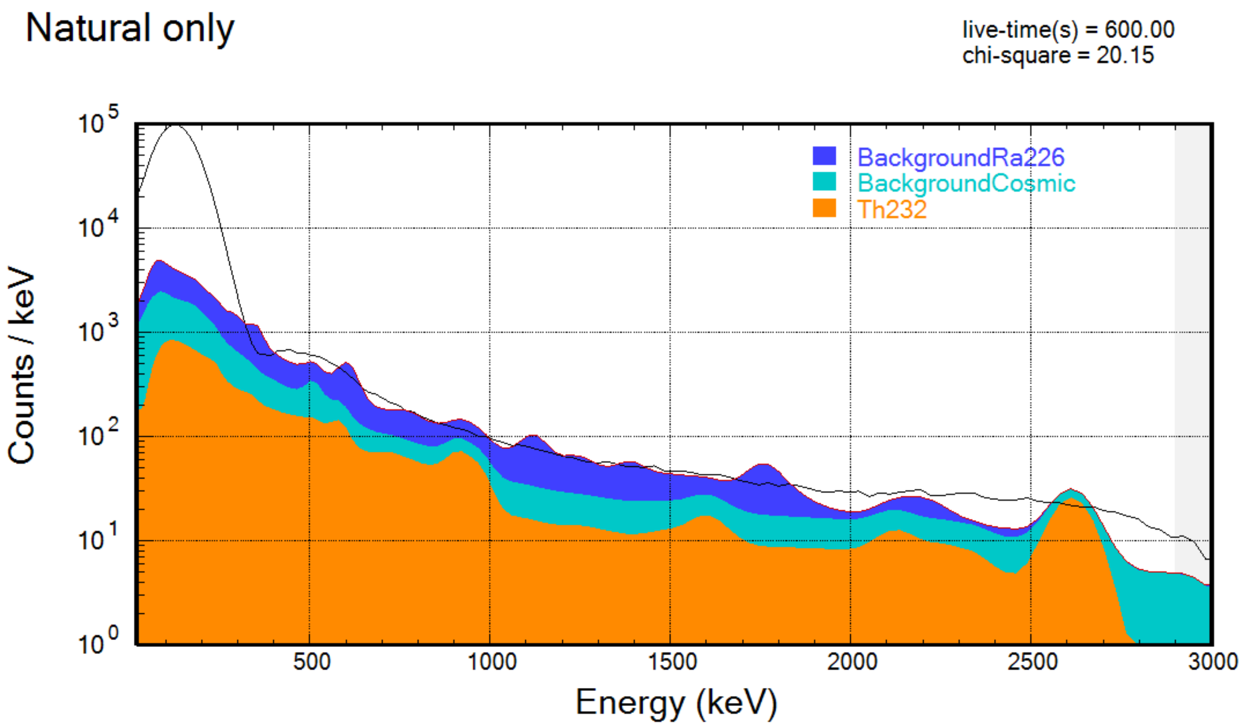


Figure H.27. GADRAS spectrum for HEU and the interference source at a 46% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	4 (Bad ID)
TTF,TTB:	645, 0
Chi Square:	12.5
Net Gammas:	23710 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Unknown source
Event Type:	Natural
Isotopes:	Th232(H,1uCi)

Figure H.28. GADRAS textual results for HEU and the interference source at a 46% resolution for collection and an 8.92% resolution for identification.

APPENDIX I – GADRAS Output for Configuration 5 Using the Same Resolution for Collection and Identification

8.92% Resolution for Collection and Identification

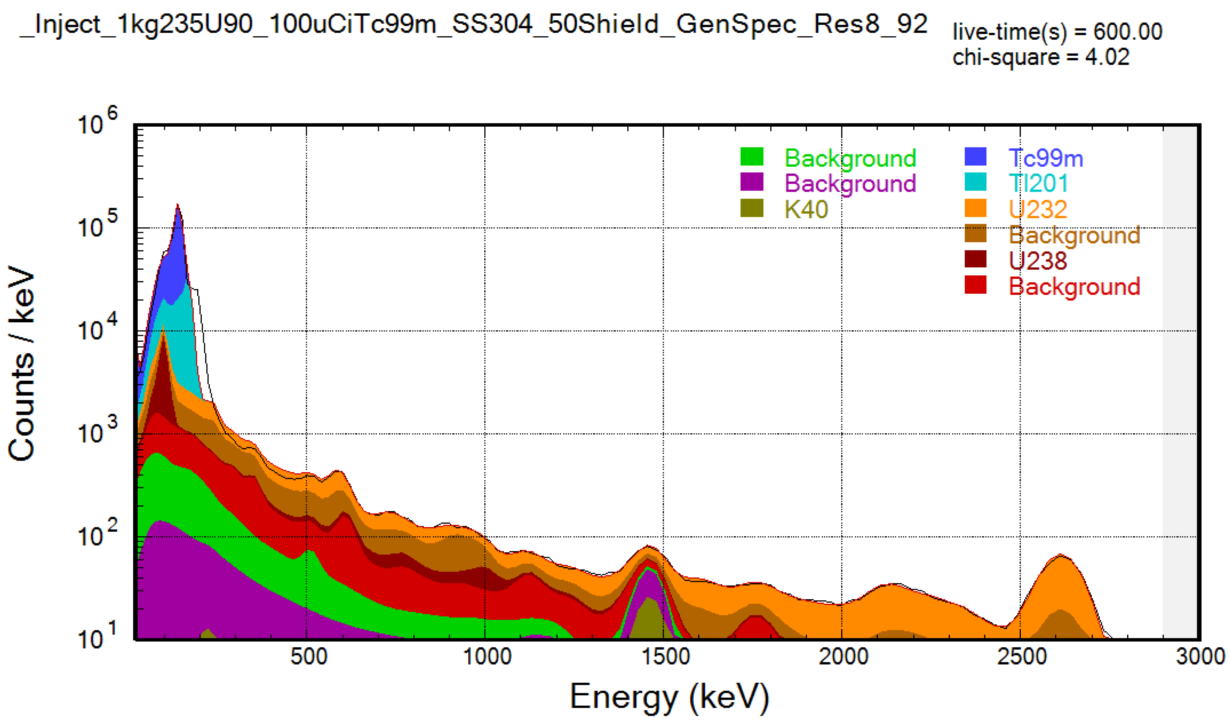


Figure I.1. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at an 8.92% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                    6 (SNM=F)
TTF,TTB:                   630, 0
Chi Square:                4.5
Net Gammas:                15929 cps
Net Neutrons:              0 cps
Sigma Gammas:              0
Sigma Neutrons:            0
Average Speed:             0 m/s
SNM Prob:                  2 (Fair)
Alarm Severity:            RED
Alarm Description:         Possible SNM
Event Type:                Medical

Isotopes:                  U232(H,6uCi) + Tc99m(H,6mCi) + Tl201(H,533uCi) + U238(L,474g)
```

Figure I.2. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at an 8.92% resolution for collection and identification.

10% Resolution for Collection and Identification

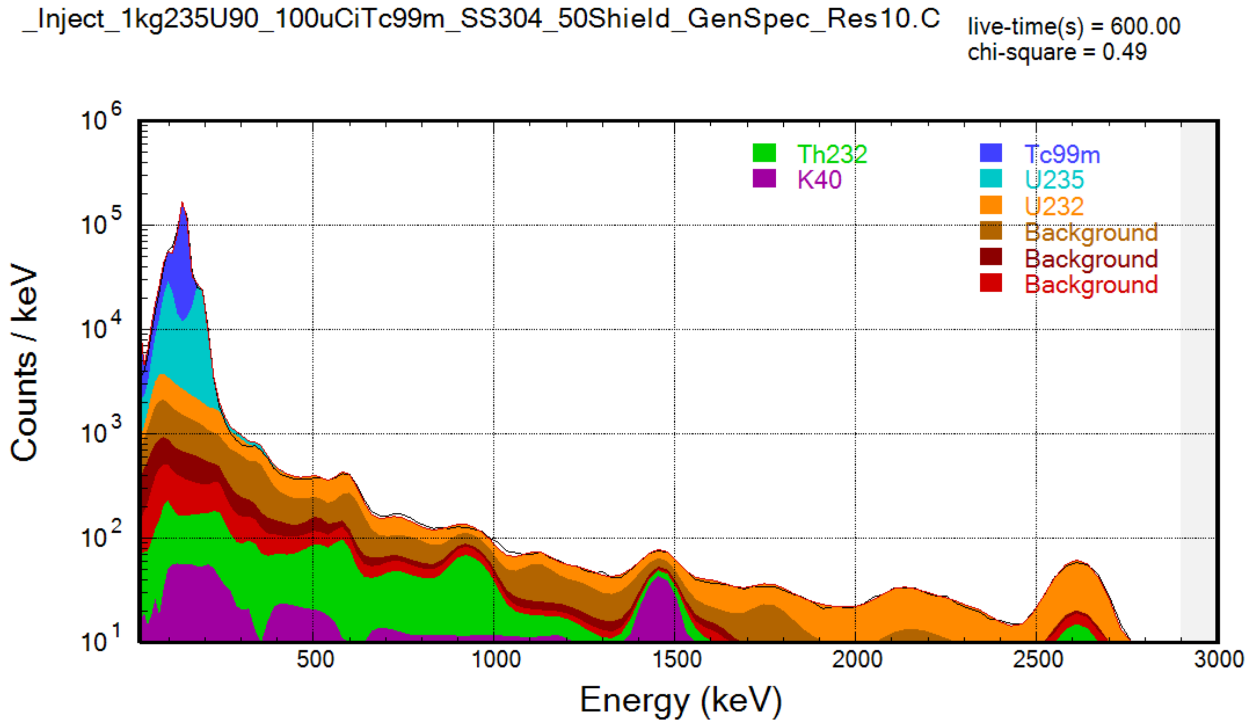


Figure I.3. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at an 10% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	0.8
Net Gammas:	15910 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,6kg) + U232(H,6uCi) + Tc99m(H,74uCi)

Figure I.4. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at an 10% resolution for collection and identification.

15% Resolution for Collection and Identification

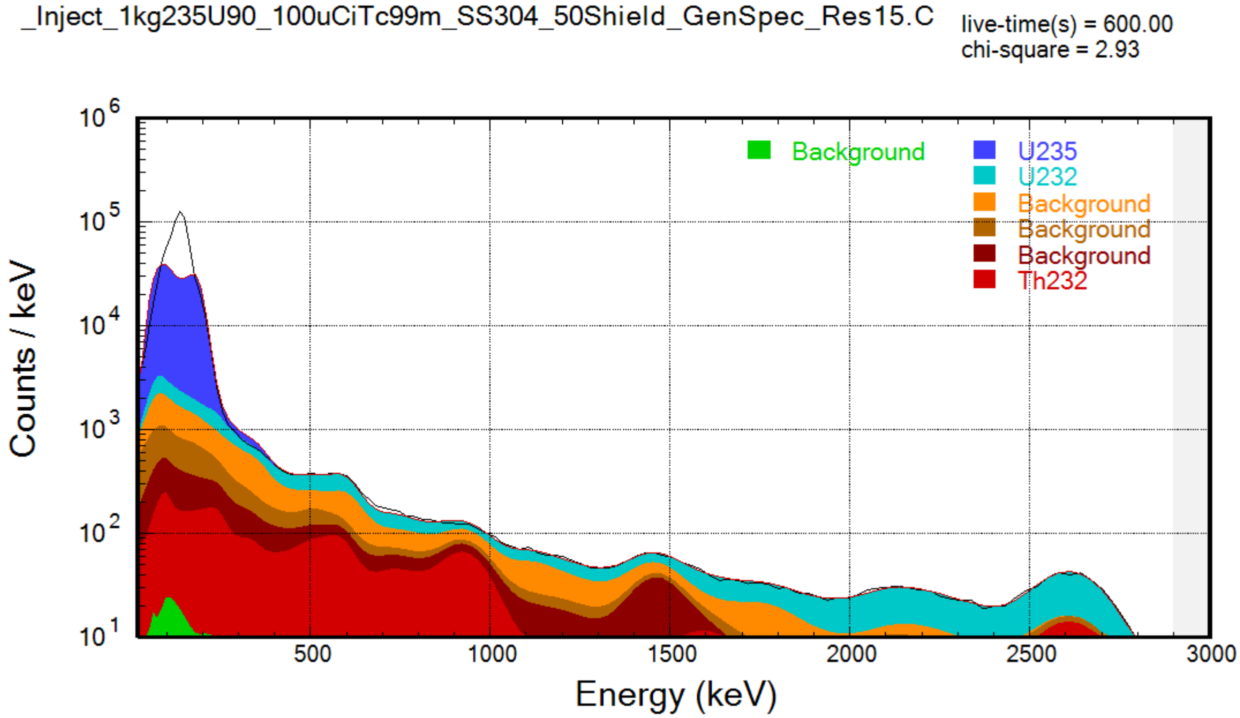


Figure I.5. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 15% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	3.3
Net Gammas:	15908 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,10kg) + U232(H,6uCi) + Tc99m(L,1uCi)

Figure I.6. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 15% resolution for collection and identification.

20% Resolution for Collection and Identification

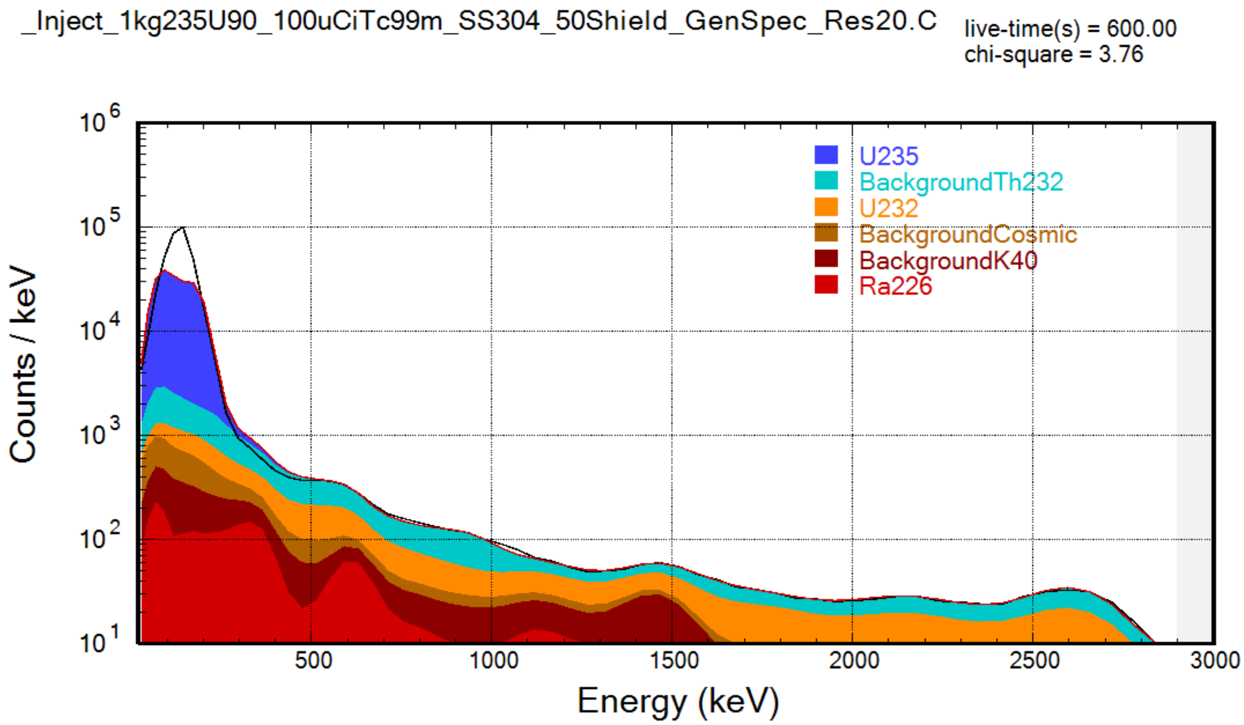


Figure I.7. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 20% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	4.3
Net Gammas:	15921 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,10kg) + U232(H,8uCi) + Tc99m(L,1uCi)

Figure I.8. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 20% resolution for collection and identification.

25% Resolution for Collection and Identification

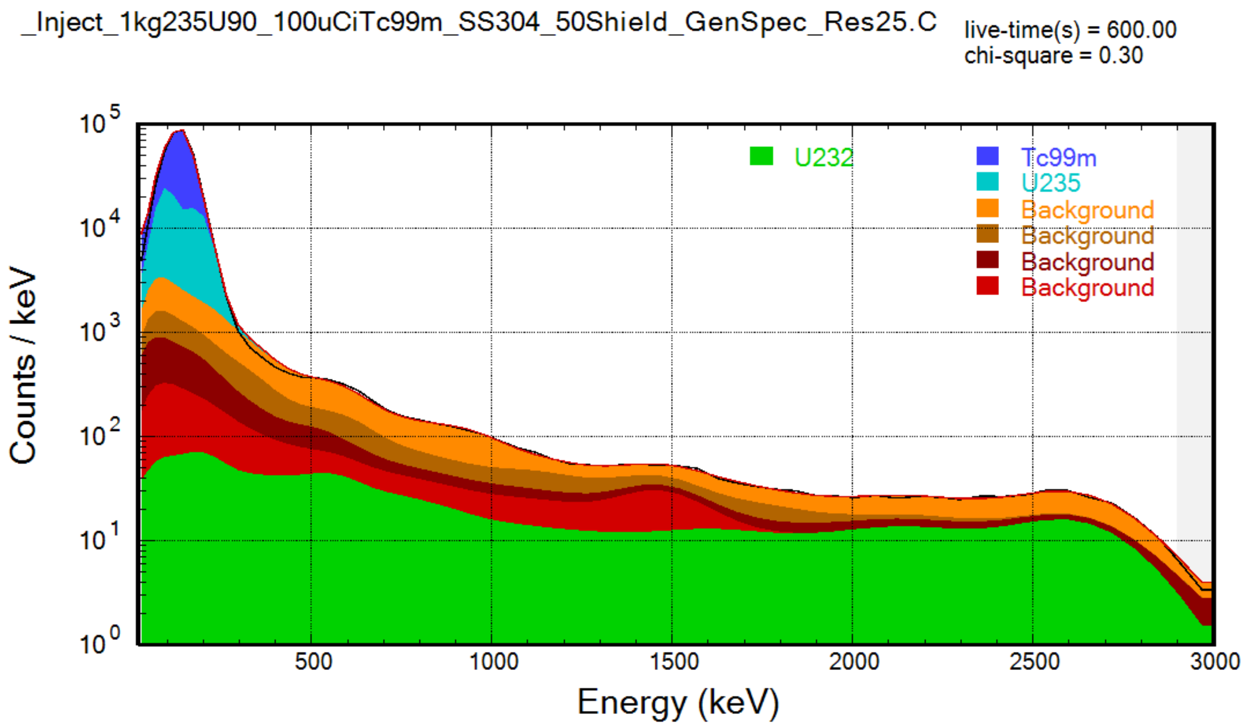


Figure I.9. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 25% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	0.5
Net Gammas:	15913 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U232(H,5uCi) + U235(H,815g) + Tc99m(L,76uCi)

Figure I.10. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 25% resolution for collection and identification.

30% Resolution for Collection and Identification

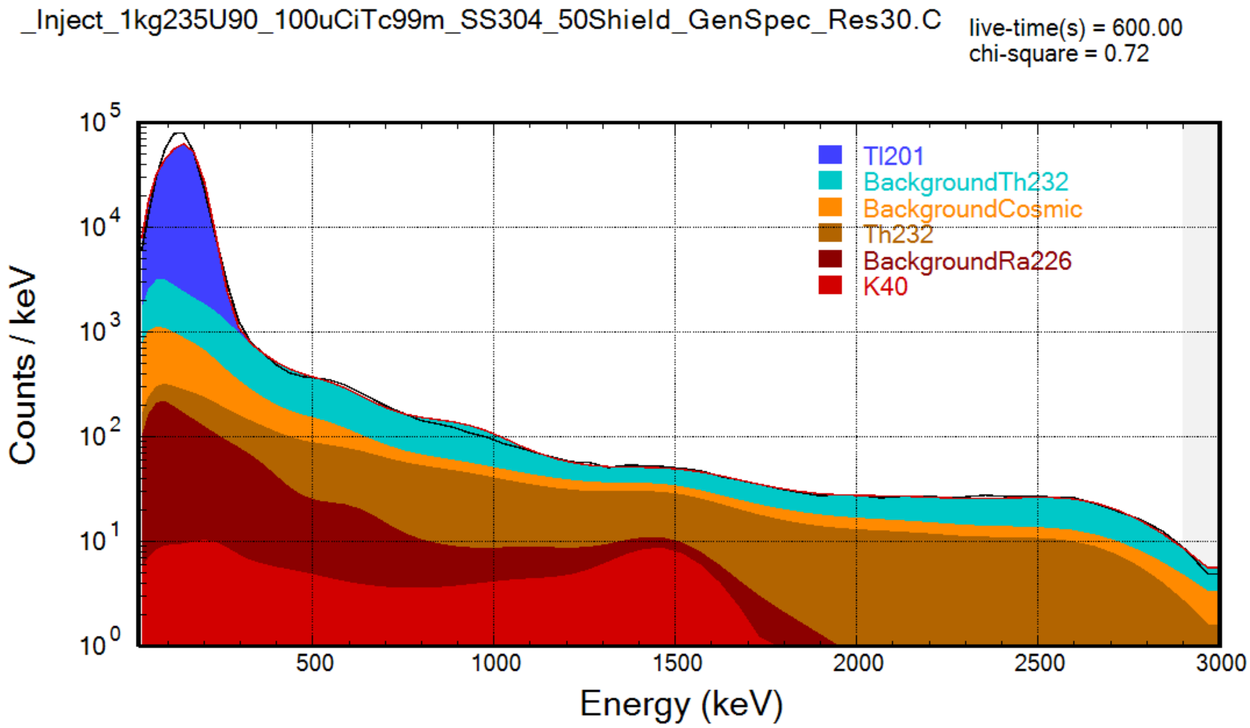


Figure I.11. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 30% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                  2 (Medical)
TTF,TTB:                 630, 0
Chi Square:              1
Net Gammas:              15896 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                0 (Very Low)
Alarm Severity:          RED
Alarm Description:       Medical
Event Type:              Medical

Isotopes:                Tl201(H,2mCi) + Th232(H,45uCi)
```

Figure I.12. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 30% resolution for collection and identification.

26% Resolution for Collection and Identification

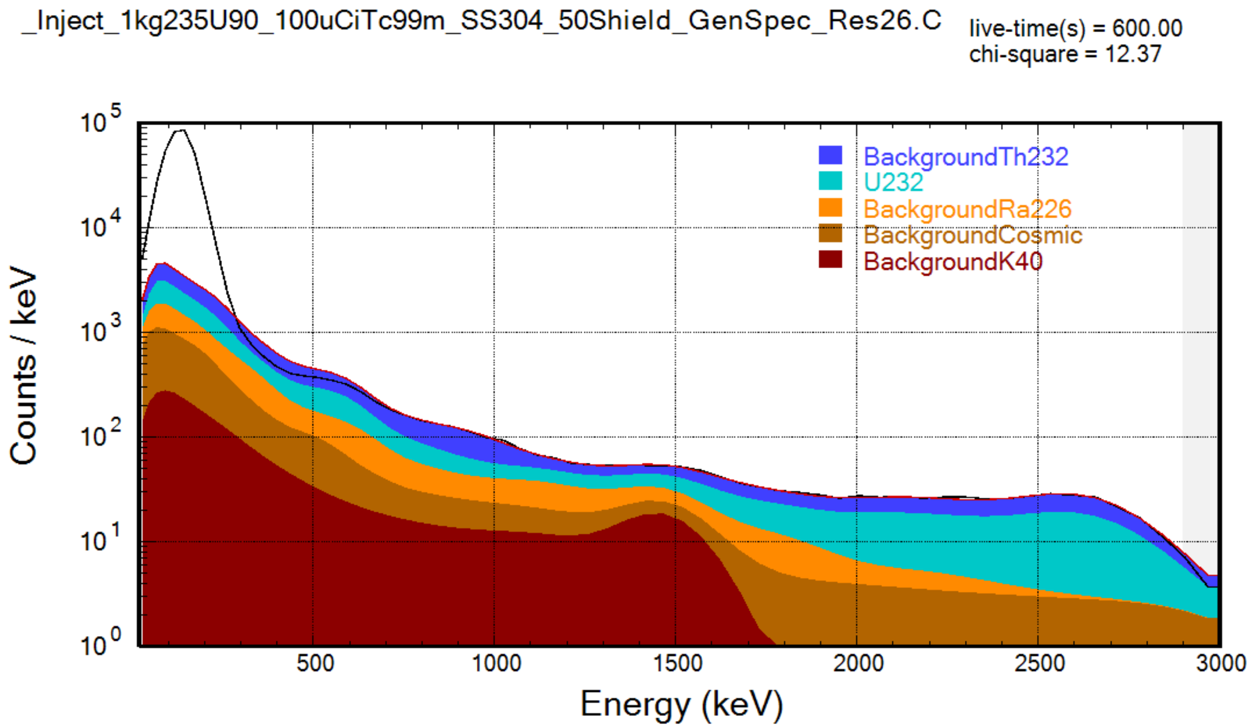


Figure I.13. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 26% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                  6 (SNM=F)
TTF,TTB:                 630, 0
Chi Square:              13.2
Net Gammas:              15910 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                2 (Fair)
Alarm Severity:          RED
Alarm Description:       Possible SNM
Event Type:              SNM

Isotopes:                U232(H,4uCi) + U235(L,1g) + Tc99m(L,1uCi)
```

Figure I.14. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 26% resolution for collection and identification.

27% Resolution for Collection and Identification

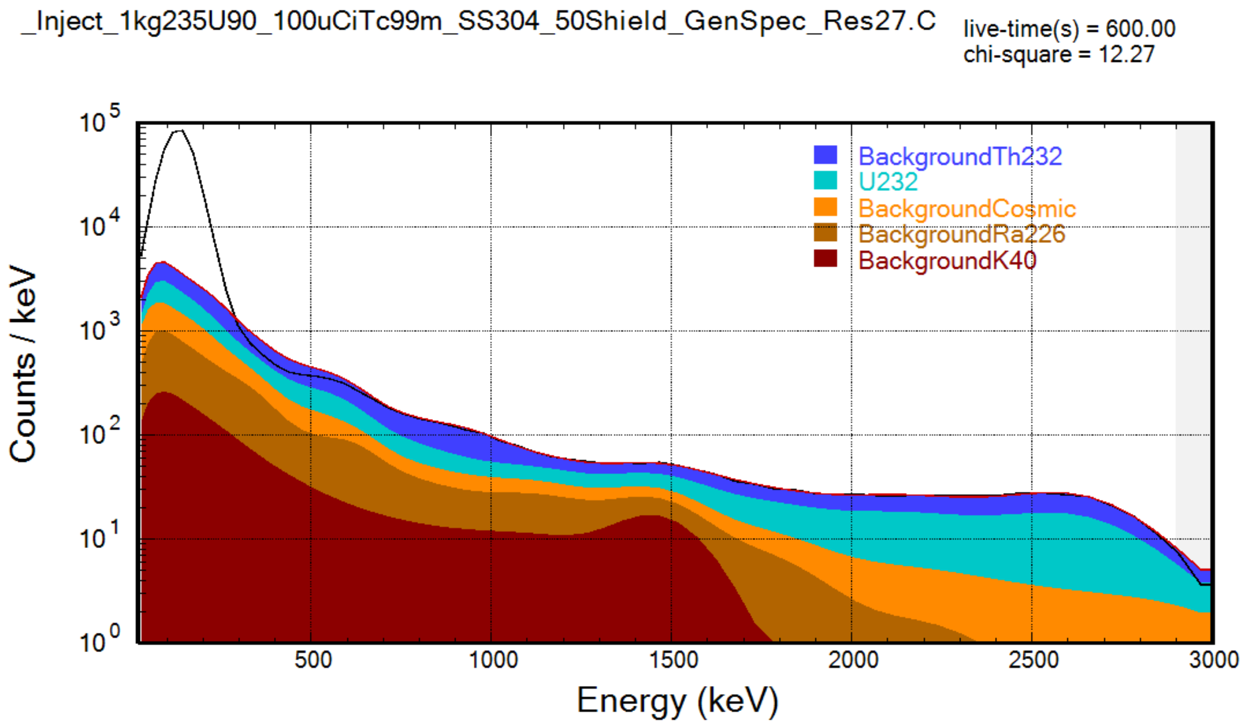
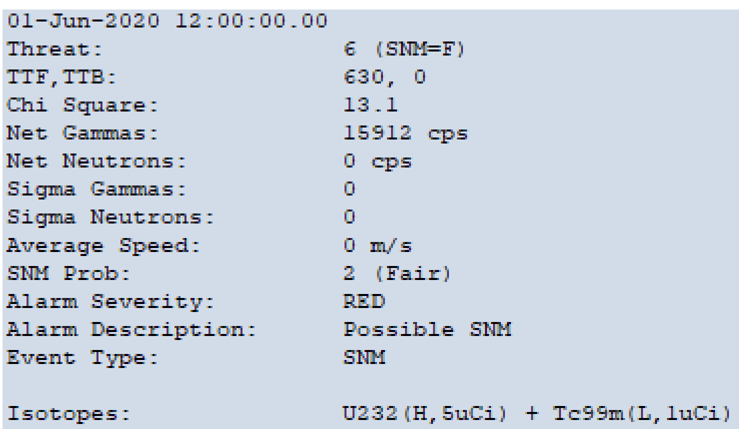


Figure I.15. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 27% resolution for collection and identification.



01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	630, 0
Chi Square:	13.1
Net Gammas:	15912 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	U232(H,5uCi) + Tc99m(L,1uCi)

Figure I.16. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 27% resolution for collection and identification.

28% Resolution for Collection and Identification

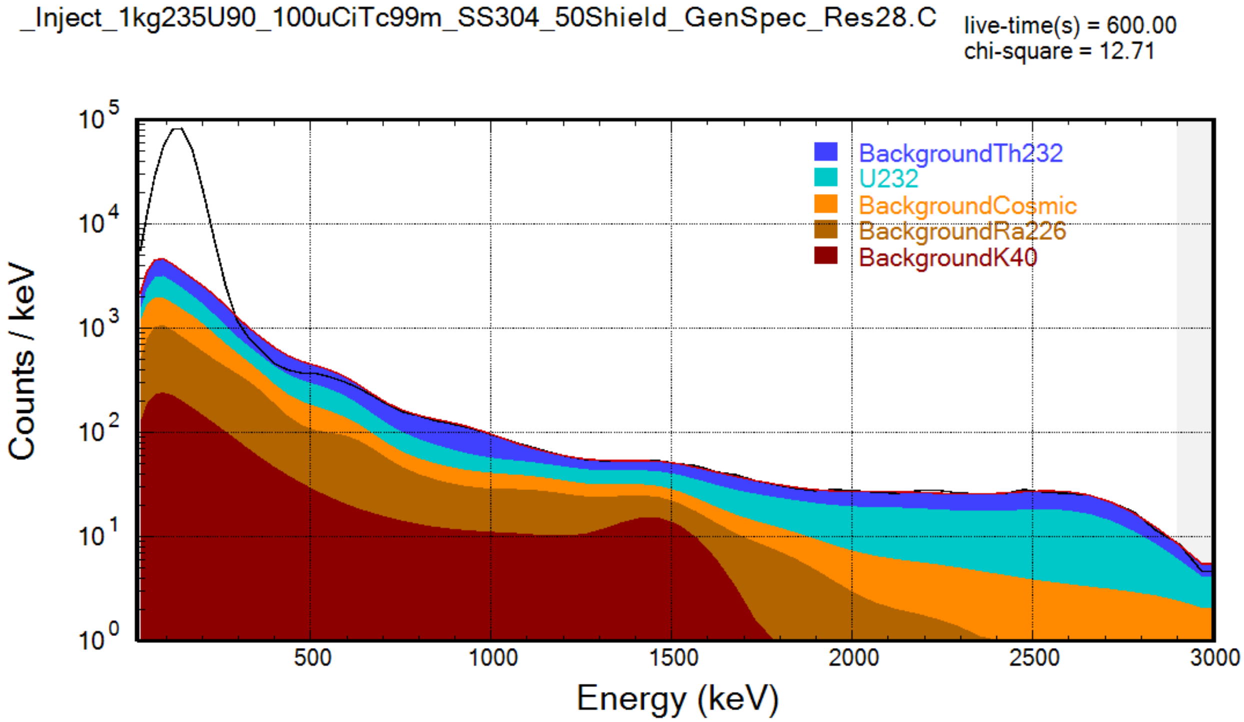


Figure I.17. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 28% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	5 (SNM=L)
TTF,TTB:	630, 0
Chi Square:	13.6
Net Gammas:	15899 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	1 (Low)
Alarm Severity:	RED
Alarm Description:	Maybe RDD
Event Type:	Suspect
Isotopes:	U232(F,1uCi) + Tc99m(L,1uCi)

Figure I.18. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 28% resolution for collection and identification.

29% Resolution for Collection and Identification

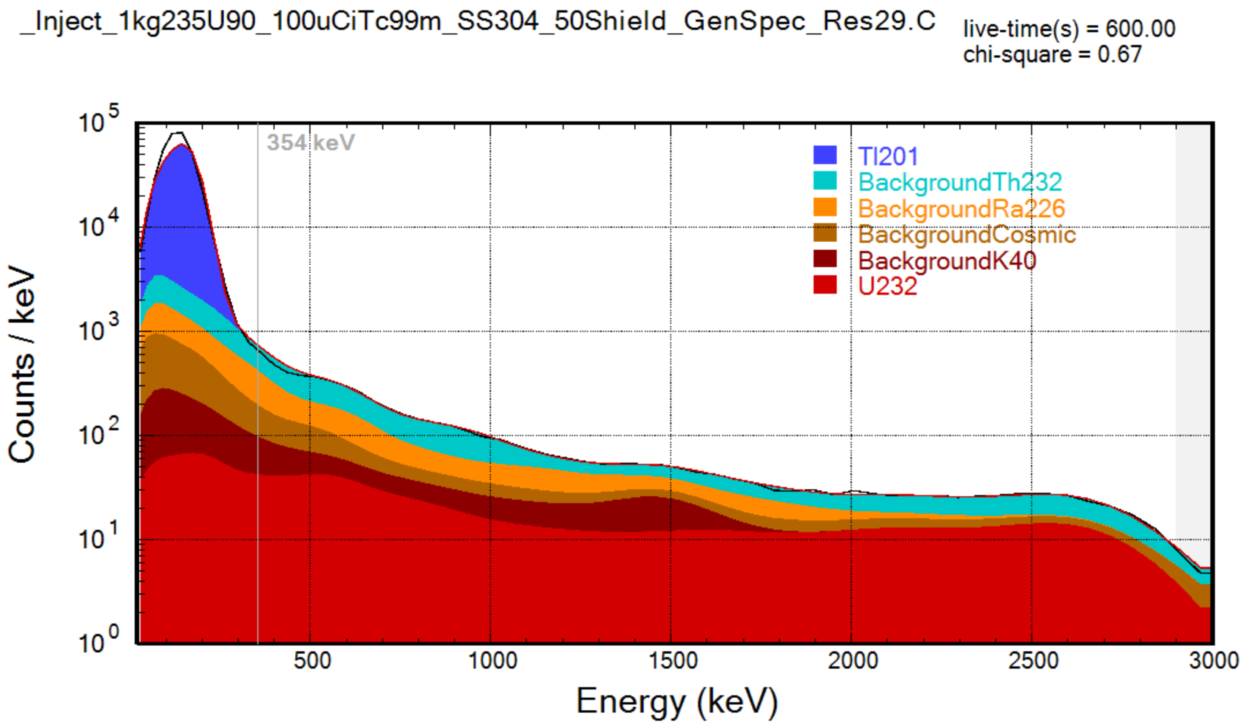


Figure I.19. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 29% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 6 (SNM=F)
TTF,TTB:                630, 0
Chi Square:             0.9
Net Gammas:             15911 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               2 (Fair)
Alarm Severity:         RED
Alarm Description:      Possible SNM
Event Type:             Suspect

Isotopes:               Tl201(H,2mCi) + U232(H,5uCi)
```

Figure I.20. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 29% resolution for collection and identification.

APPENDIX J – GADRAS Output for Configuration 5 Using Different Resolutions for Collection and Identification

8.92% Resolution for Collection and 8.92% Resolution for Identification

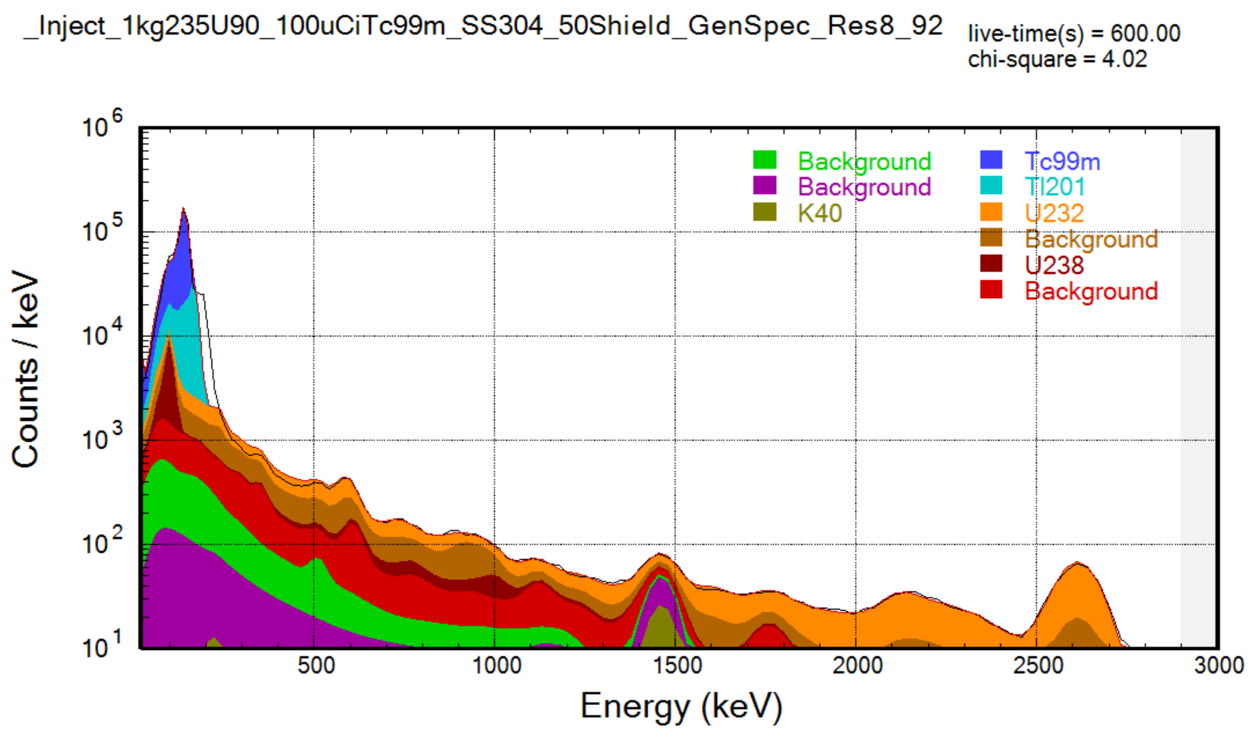


Figure J.1. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at an 8.92% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                  6 (SNM=F)
TTF,TTB:                 630, 0
Chi Square:              4.5
Net Gammas:              15929 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                2 (Fair)
Alarm Severity:          RED
Alarm Description:       Possible SNM
Event Type:              Medical

Isotopes:                U232(H,6uCi) + Tc99m(H,6mCi) + Tl201(H,533uCi) + U238(L,474g)
```

Figure J.2. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at an 8.92% resolution for collection and an 8.92% resolution for identification.

10% Resolution for Collection and 8.92% Resolution for Identification

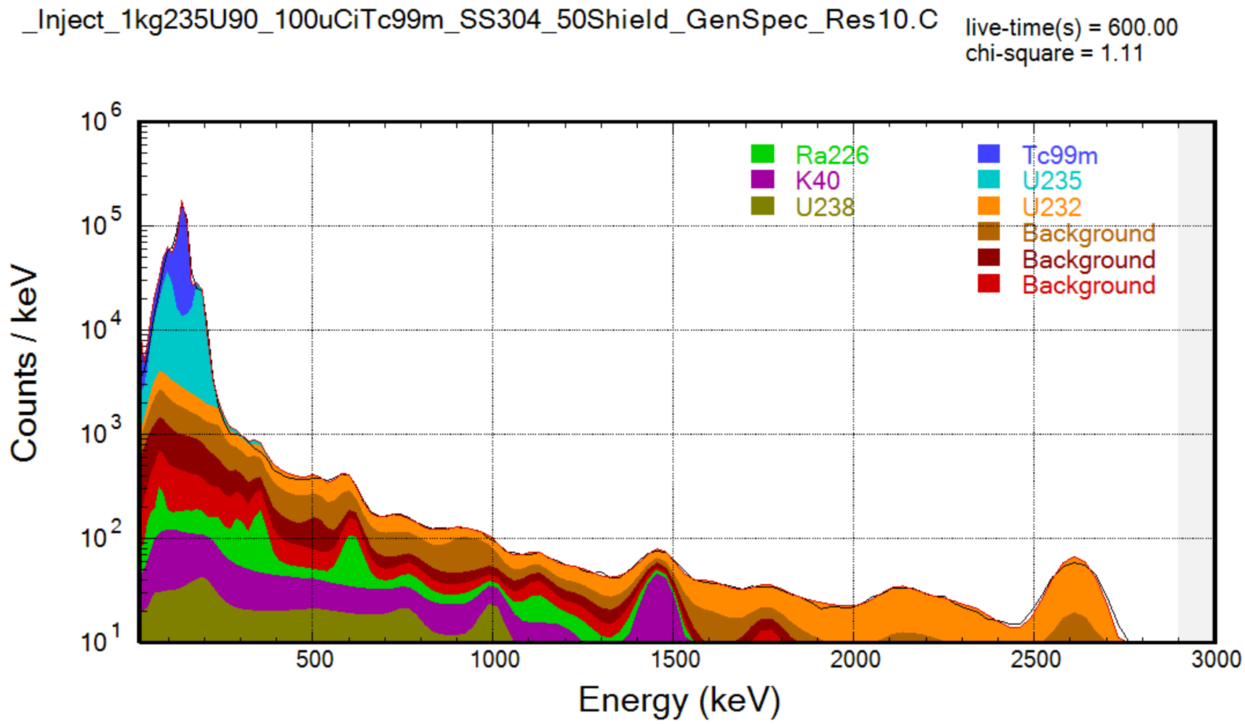


Figure J.3. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 10% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                630, 0
Chi Square:             1.4
Net Gammas:             15916 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,3kg) + U232(H,6uCi) + K40(H,9uCi) + Tc99m(H,70uCi) + U238(L,518g)
```

Figure J.4. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 10% resolution for collection and an 8.92% resolution for identification.

15% Resolution for Collection and 8.92% Resolution for Identification

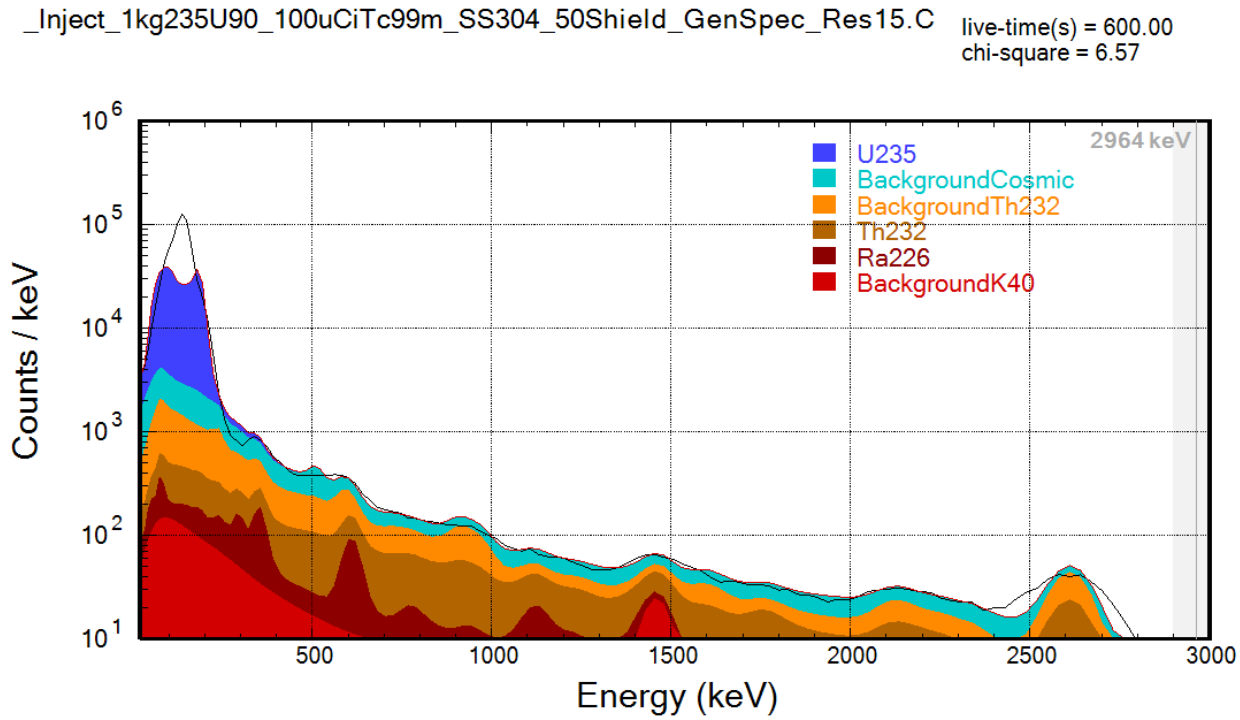


Figure J.5. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 15% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	7.5
Net Gammas:	15908 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,9kg) + Th232(H,34uCi) + Xe131m(F,1uCi) + Tc99m(L,1uCi)

Figure J.6. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 15% resolution for collection and an 8.92% resolution for identification.

20% Resolution for Collection and 8.92% Resolution for Identification

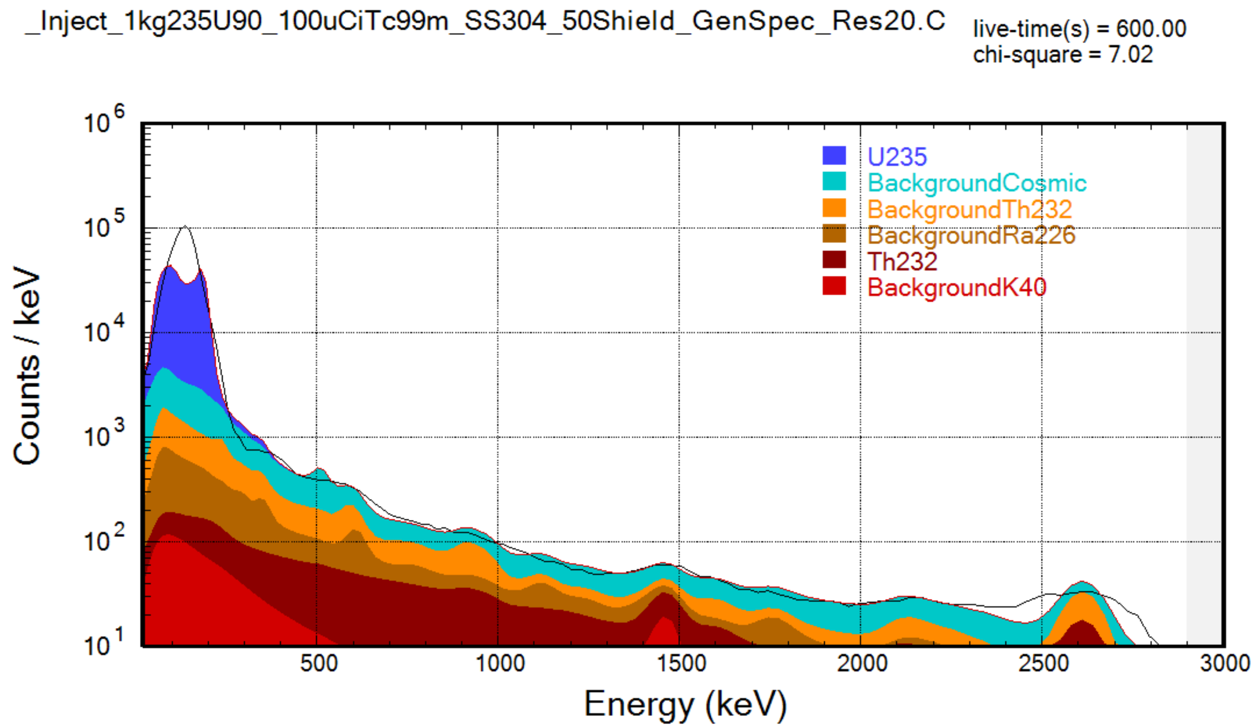


Figure J.7. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 20% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	8.5
Net Gammas:	15919 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,10kg) + Th232(H,37uCi) + Xe131m(F,1uCi) + Tc99m(L,1uCi)

Figure J.8. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 20% resolution for collection and an 8.92% resolution for identification.

25% Resolution for Collection and 8.92% Resolution for Identification

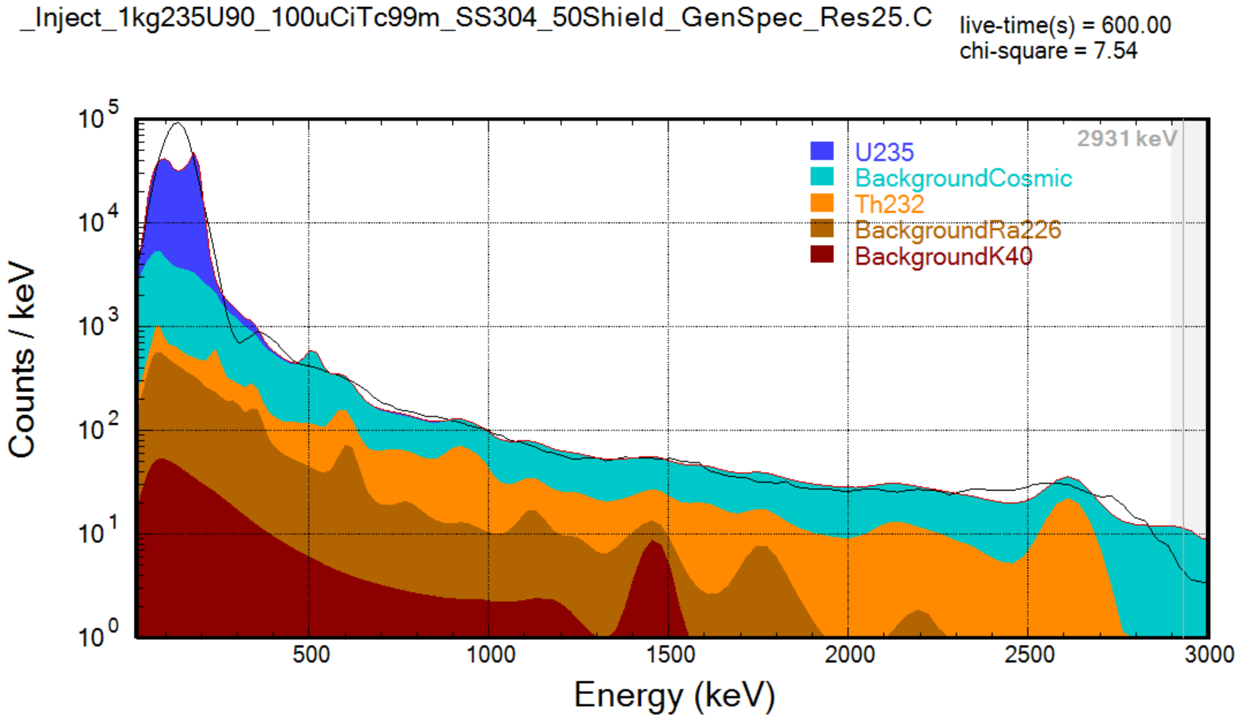


Figure J.9. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 25% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	11.4
Net Gammas:	15913 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,29uCi) + U235(H,45kg)

Figure J.10. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 25% resolution for collection and an 8.92% resolution for identification.

30% Resolution for Collection and 8.92% Resolution for Identification

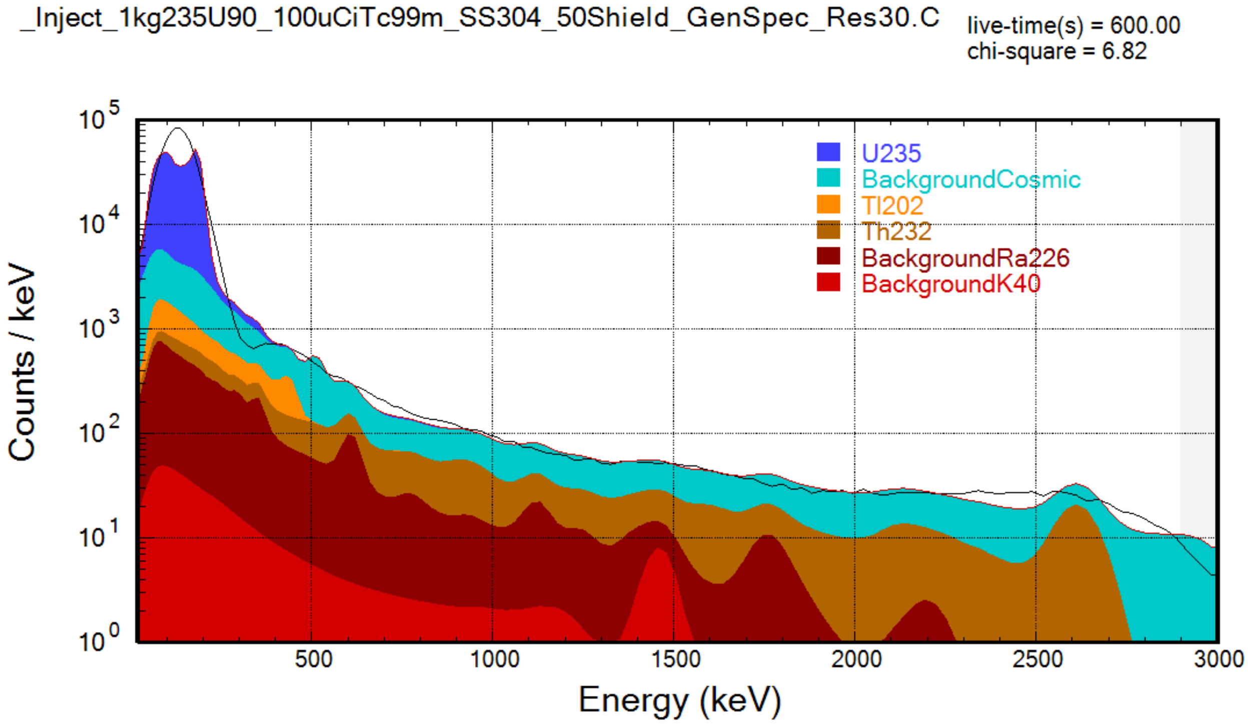


Figure J.11. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 30% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	10
Net Gammas:	15888 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,32uCi) + U235(H,39kg) + Tl202(H,7uCi)

Figure J.12. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 30% resolution for collection and an 8.92% resolution for identification.

35% Resolution for Collection and 8.92% Resolution for Identification

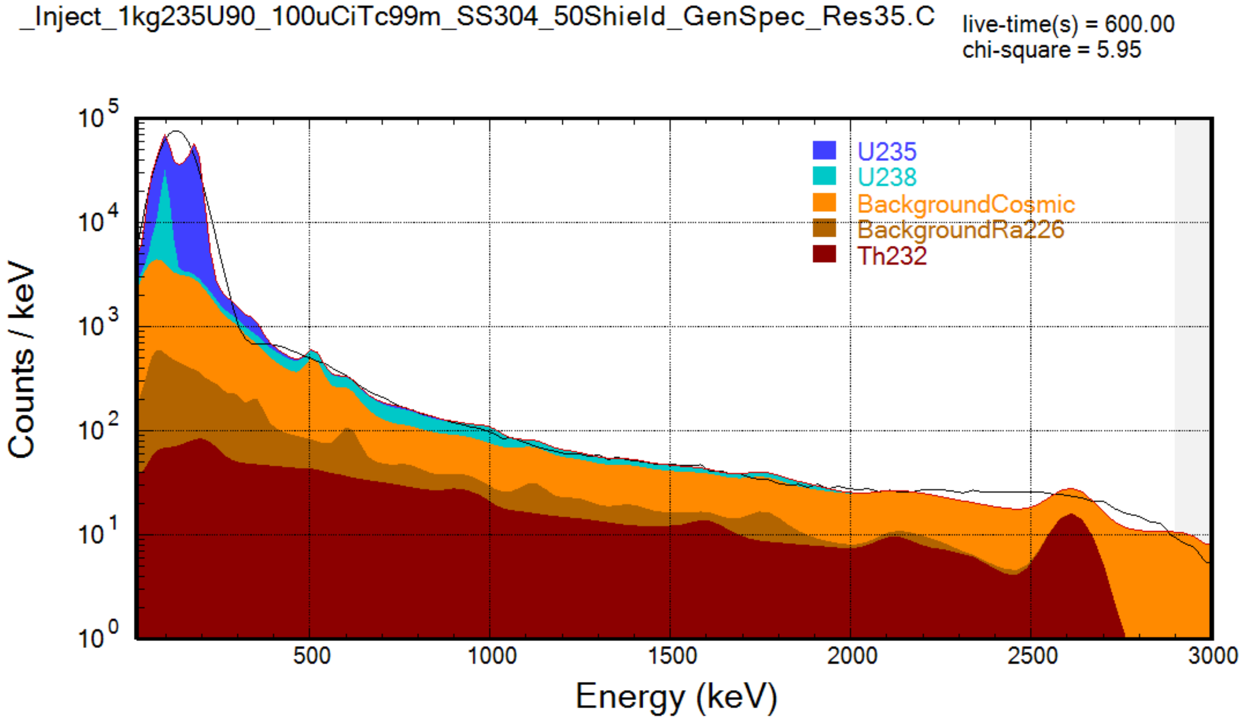


Figure J.13. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 35% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	8.9
Net Gammas:	15871 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	Th232(H,30uCi) + U235(H,80kg) + U238(L,63kg)

Figure J.14. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 35% resolution for collection and an 8.92% resolution for identification.

40% Resolution for Collection and 8.92% Resolution for Identification

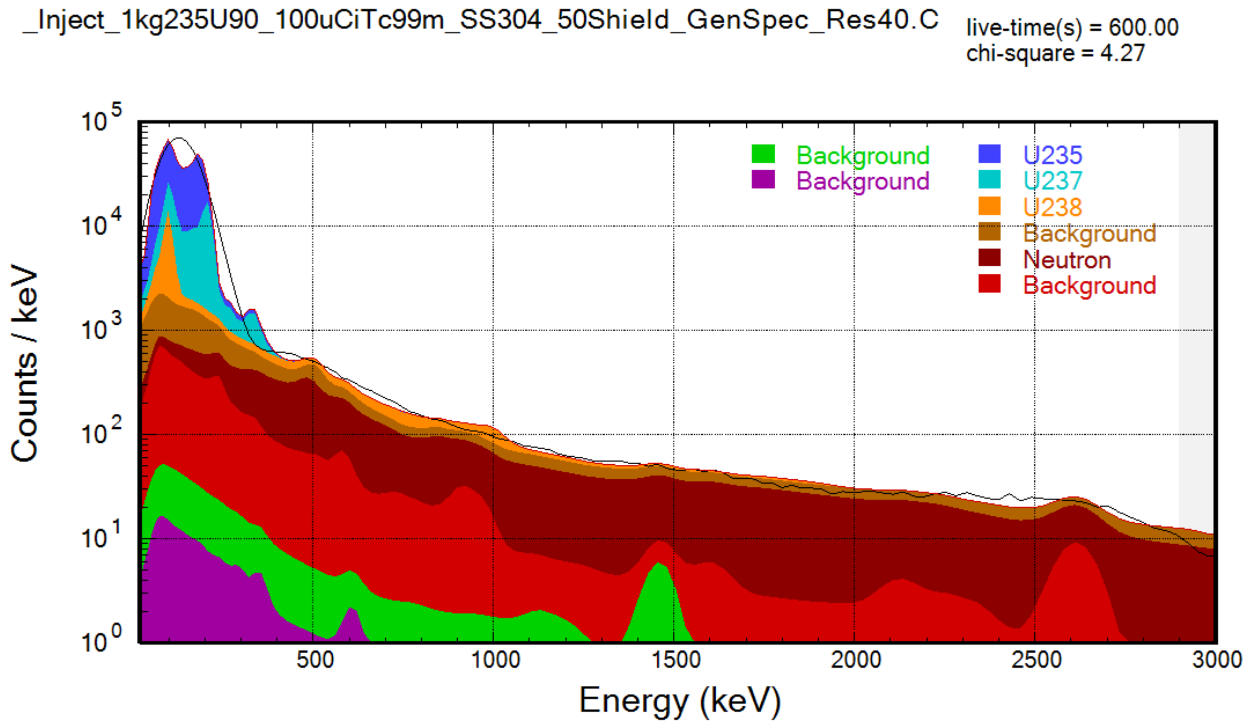


Figure J.15. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 40% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	630, 0
Chi Square:	4.9
Net Gammas:	15838 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,11kg) + U237(F,11uCi) + U238(F,209g) + Neutron(F) + Np237(L,1g)

Figure F.16. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 40% resolution for collection and an 8.92% resolution for identification.

45% Resolution for Collection and 8.92% Resolution for Identification

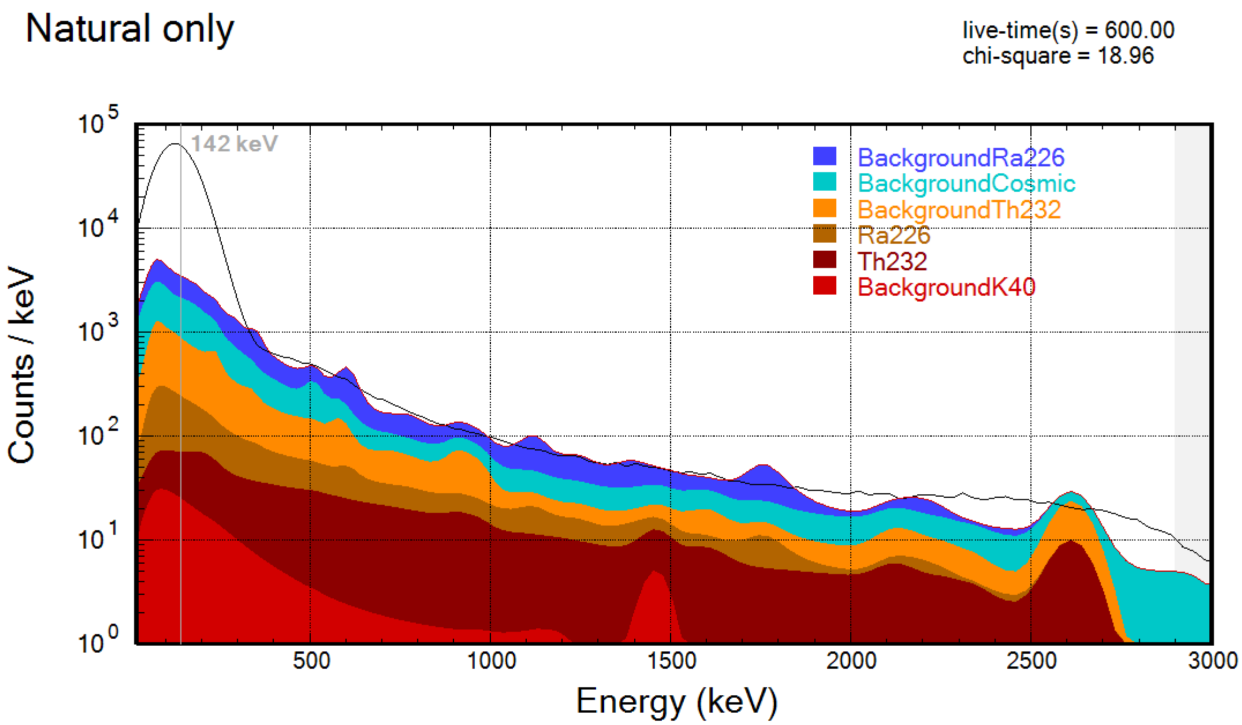


Figure J.17. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 45% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	4 (Bad ID)
TTF,TTB:	630, 0
Chi Square:	13.1
Net Gammas:	15775 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Unknown source
Event Type:	Natural
Isotopes:	Th232(H,1uCi)

Figure J.18. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 45% resolution for collection and an 8.92% resolution for identification.

41% Resolution for Collection and 8.92% Resolution for Identification

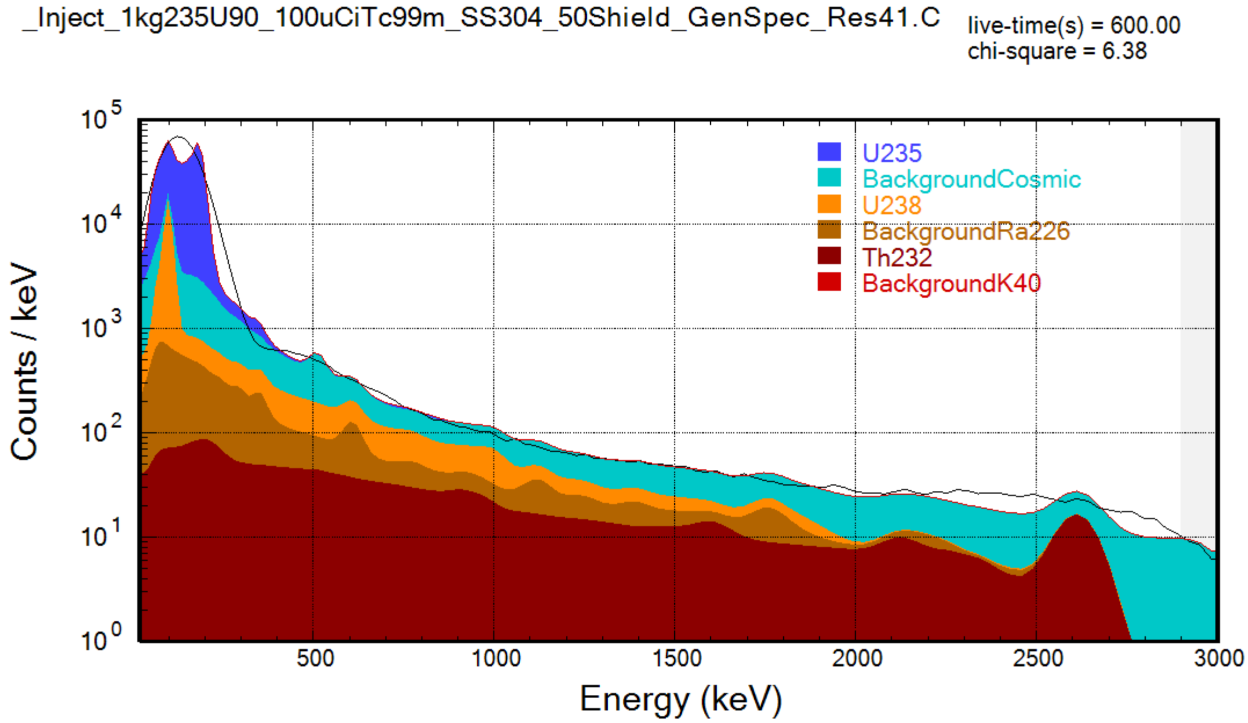


Figure J.19. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 41% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                  6 (SNM=F)
TTF,TTB:                 630, 0
Chi Square:              8.9
Net Gammas:              15814 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                2 (Fair)
Alarm Severity:          RED
Alarm Description:       Possible SNM
Event Type:              SNM

Isotopes:                Th232(H,31uCi) + U235(F,7kg) + U238(F,7kg)
```

Figure J.20. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 41% resolution for collection and an 8.92% resolution for identification.

42% Resolution for Collection and 8.92% Resolution for Identification

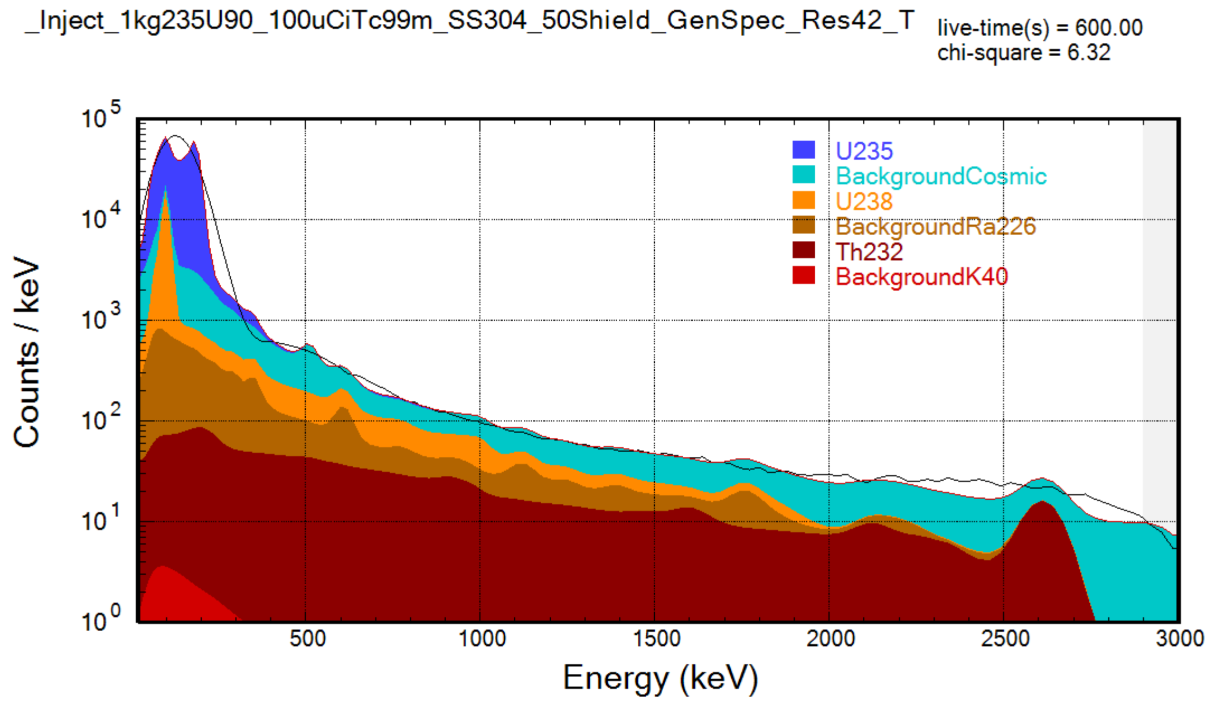


Figure J.21. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 42% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	630, 0
Chi Square:	8.8
Net Gammas:	15813 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	Th232(H,30uCi) + U235(F,7kg) + U238(F,7kg)

Figure J.22. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 42% resolution for collection and an 8.92% resolution for identification.

43% Resolution for Collection and 8.92% Resolution for Identification

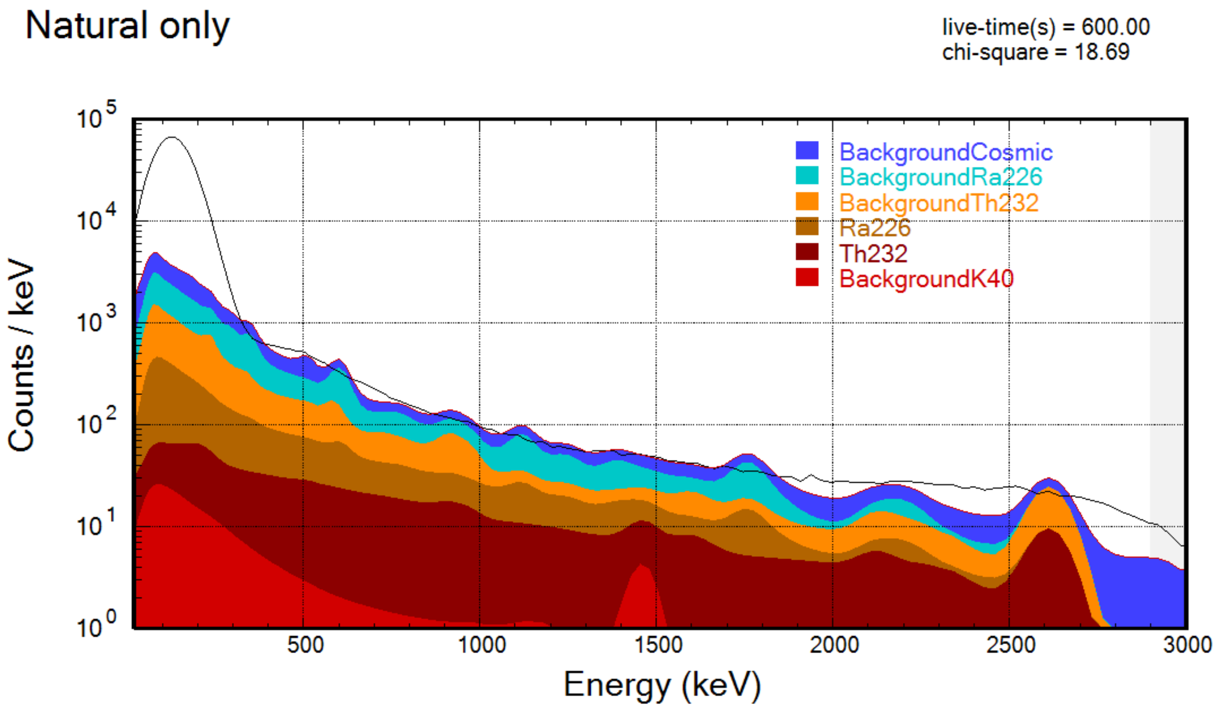


Figure J.23. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 43% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	4 (Bad ID)
TTF,TTB:	630, 0
Chi Square:	12.3
Net Gammas:	15797 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Unknown source
Event Type:	Natural
Isotopes:	Th232(H,1uCi)

Figure J.24. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 43% resolution for collection and an 8.92% resolution for identification.

44% Resolution for Collection and 8.92% Resolution for Identification

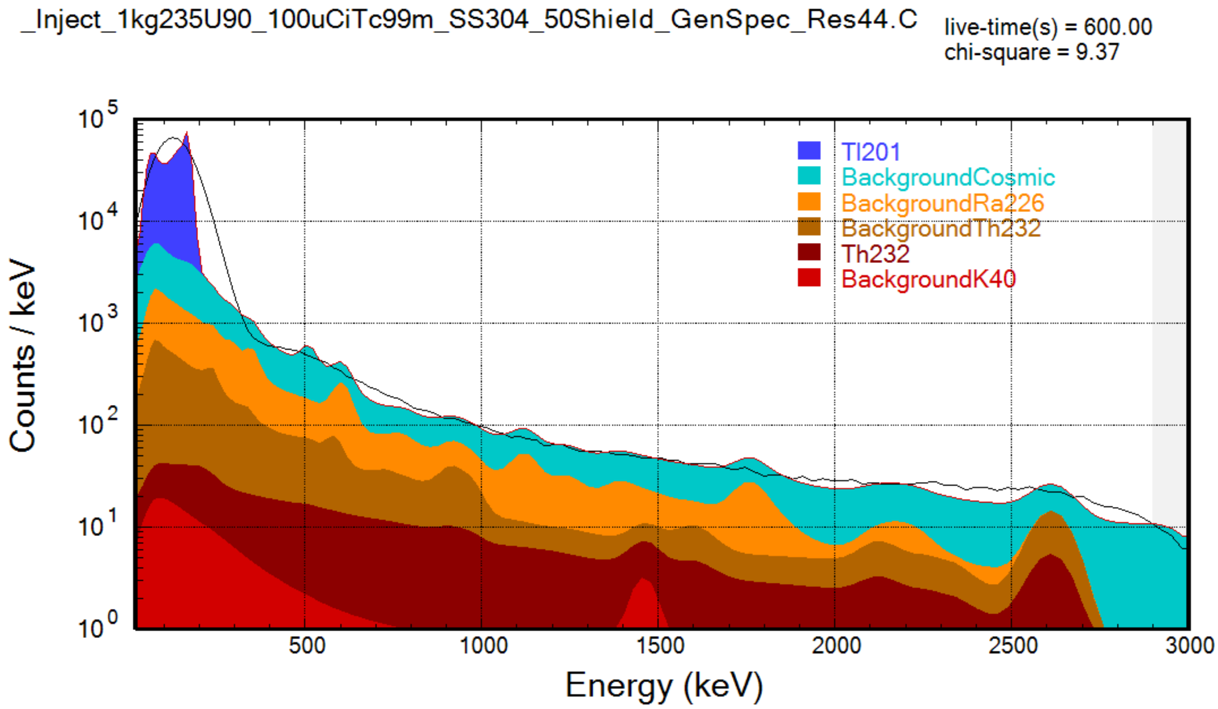
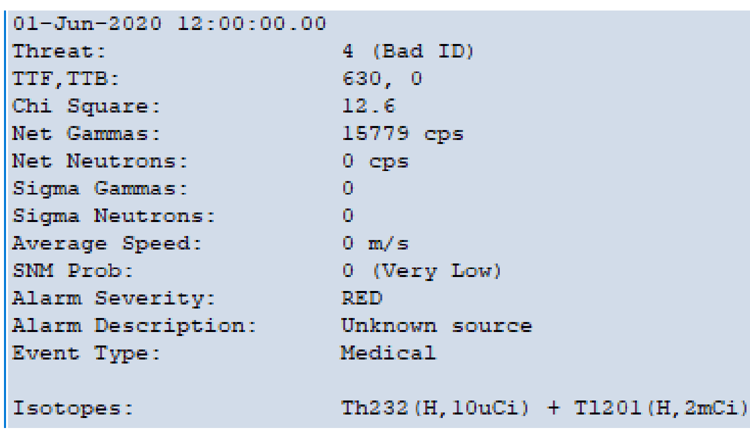


Figure J.25. GADRAS spectrum for HEU and the interference source shielded to 50% of their original intensity at a 44% resolution for collection and an 8.92% resolution for identification.



01-Jun-2020 12:00:00.00	
Threat:	4 (Bad ID)
TTF,TTB:	630, 0
Chi Square:	12.6
Net Gammas:	15779 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Unknown source
Event Type:	Medical
Isotopes:	Th232(H,10uCi) + Tl201(H,2mCi)

Figure J.26. GADRAS textual results for HEU and the interference source shielded to 50% of their original intensity at a 44% resolution for collection and an 8.92% resolution for identification.

APPENDIX K – GADRAS Output for Configuration 6 Using the Same Resolutions for Collection and Identification

8.92% Resolution for Collection and Identification

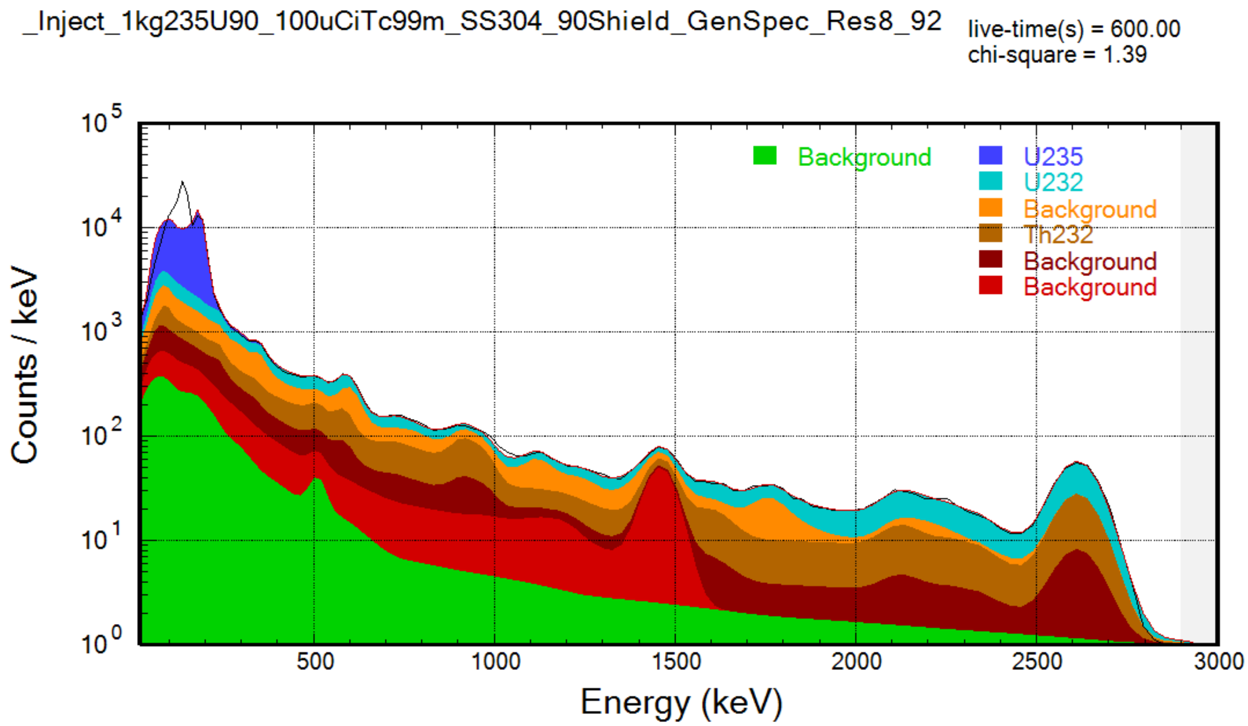


Figure K.1. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at an 8.92% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                608, 0
Chi Square:             1.7
Net Gammas:             4312 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,6kg) + U232(H,4uCi) + Tc99m(L,1uCi)
```

Figure K.2. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at an 8.92% resolution for collection and identification.

10% Resolution for Collection and Identification

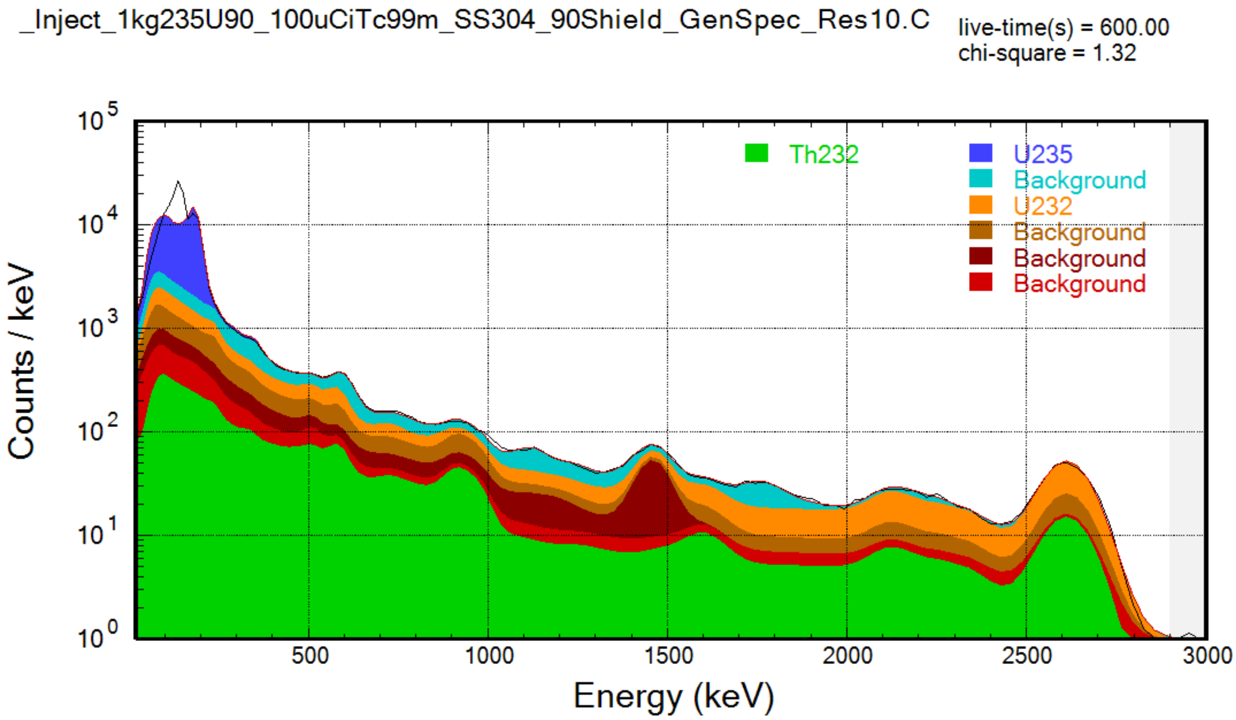


Figure K.3. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 10% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                608, 0
Chi Square:             1.6
Net Gammas:             4312 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U232(H,5uCi) + U235(H,6kg) + K40(H,1uCi) + Tc99m(L,1uCi)
```

Figure K.4. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 10% resolution for collection and identification.

15% Resolution for Collection and Identification

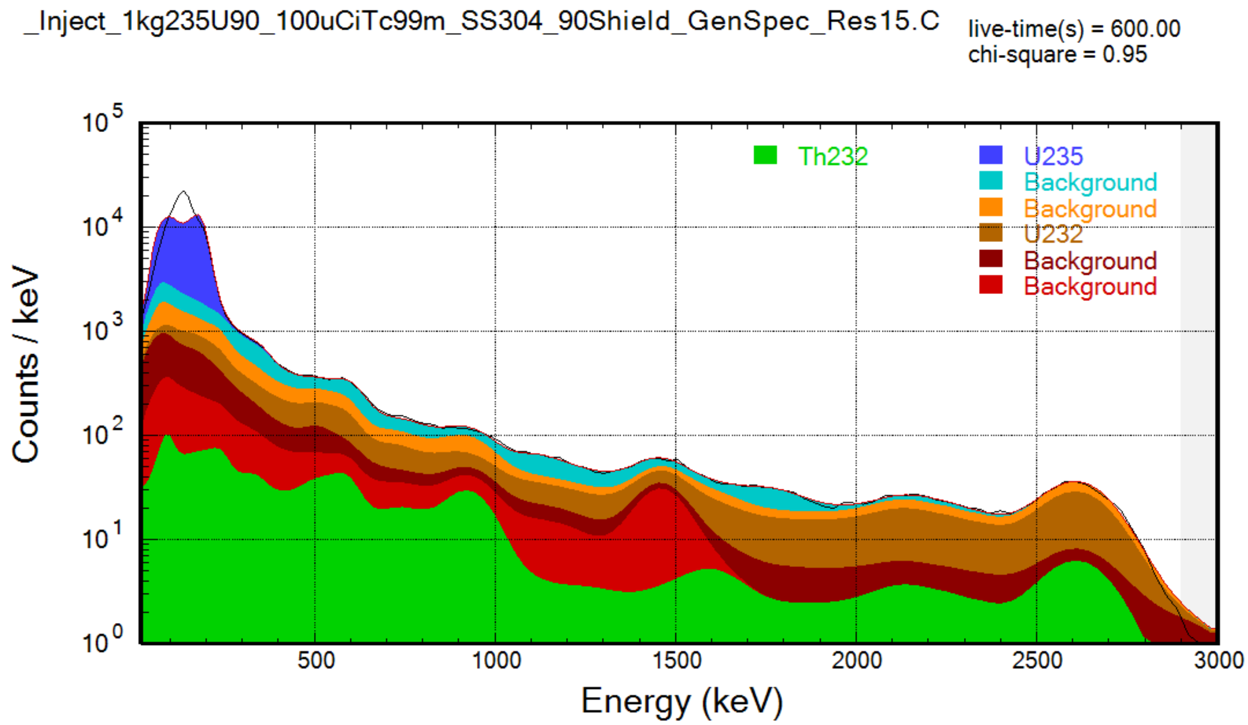


Figure K.5. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 15% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                608, 0
Chi Square:             1.2
Net Gammas:             4311 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,6kg) + U232(H,5uCi) + K40(H,1uCi) + Tc99m(L,1uCi)
```

Figure K.6. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 15% resolution for collection and identification.

20% Resolution for Collection and Identification

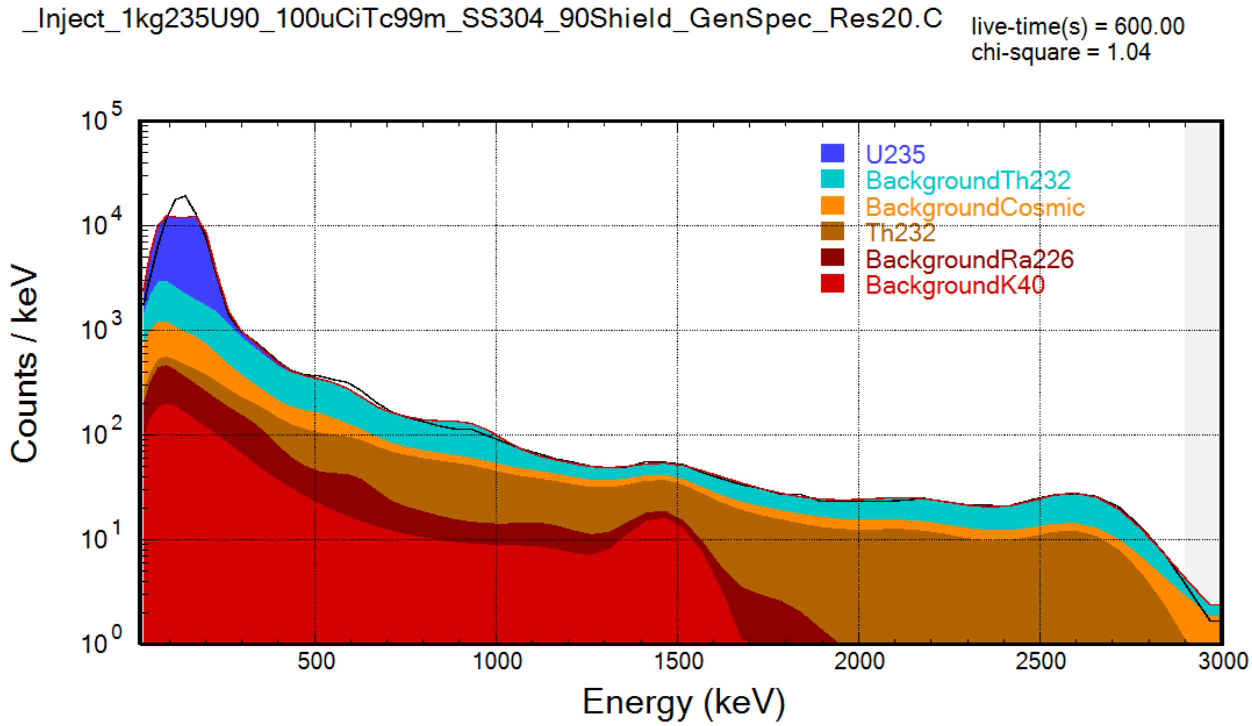


Figure K.7. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 20% resolution for collection and identification.

```
01-Jun-2020 12:00:00.00
Threat:                  7 (SNM=H)
TTF,TTB:                 608, 0
Chi Square:              1.3
Net Gammas:              4311 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                3 (High)
Alarm Severity:          RED
Alarm Description:       Probable SNM
Event Type:              SNM

Isotopes:                U235(H,22kg) + U232(H,1uCi) + K40(H,1uCi) + Tc99m(L,1uCi)
```

Figure K.8. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 20% resolution for collection and identification.

25% Resolution for Collection and Identification

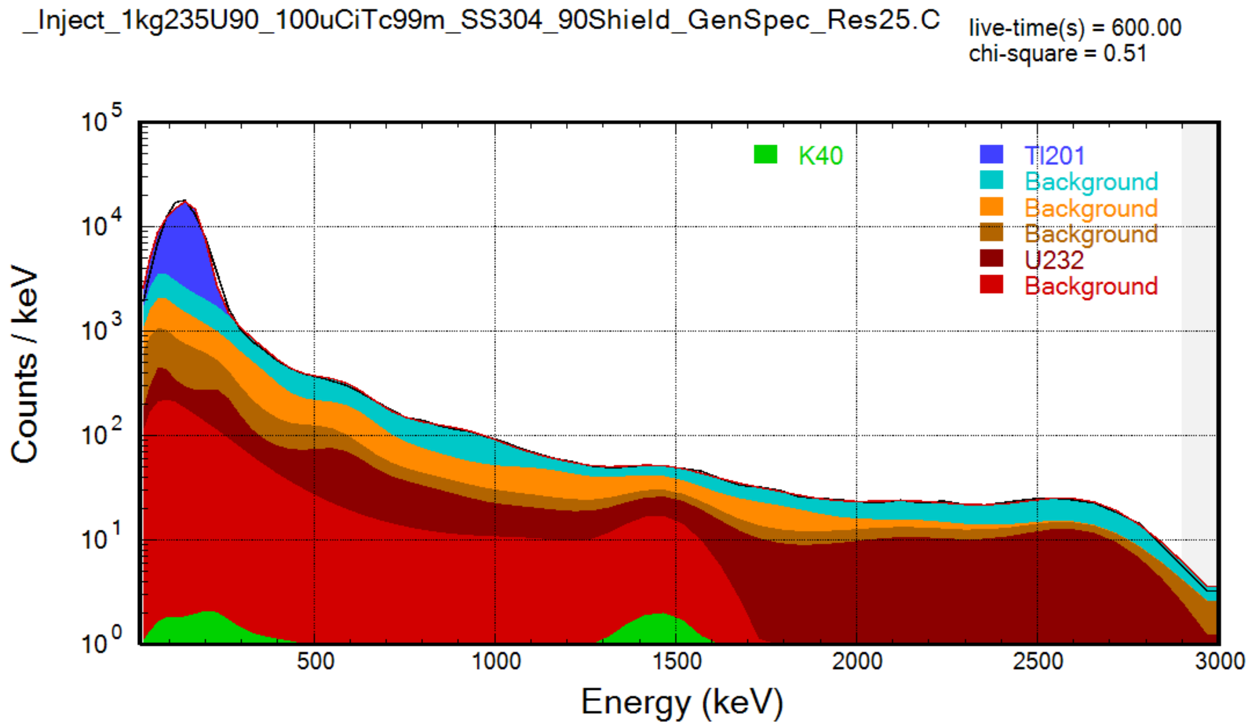
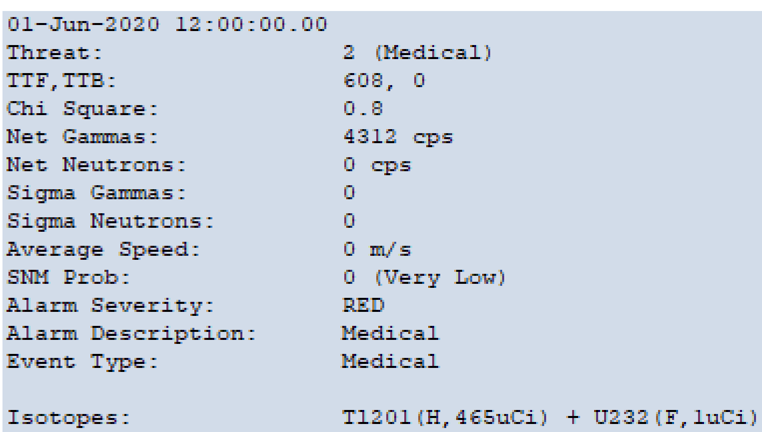


Figure K.9. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 25% resolution for collection and identification.



01-Jun-2020 12:00:00.00	
Threat:	2 (Medical)
TTF,TTB:	608, 0
Chi Square:	0.8
Net Gammas:	4312 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Medical
Event Type:	Medical
Isotopes:	Tl201(H,465uCi) + U232(F,1uCi)

Figure K.10. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 25% resolution for collection and identification.

21% Resolution for Collection and Identification

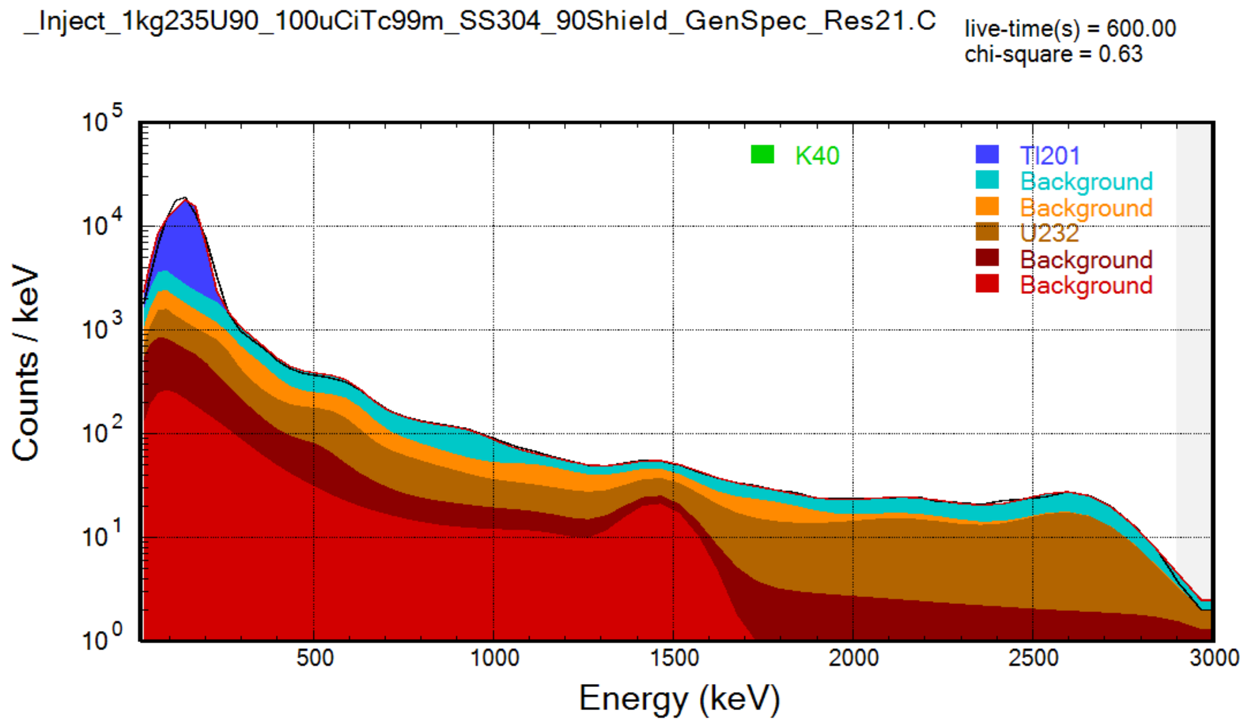


Figure K.11. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 21% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	608, 0
Chi Square:	0.9
Net Gammas:	4309 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	Suspect
Isotopes:	Tl201(H,448uCi) + U232(H,6uCi)

Figure K.12. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 21% resolution for collection and identification.

22% Resolution for Collection and Identification

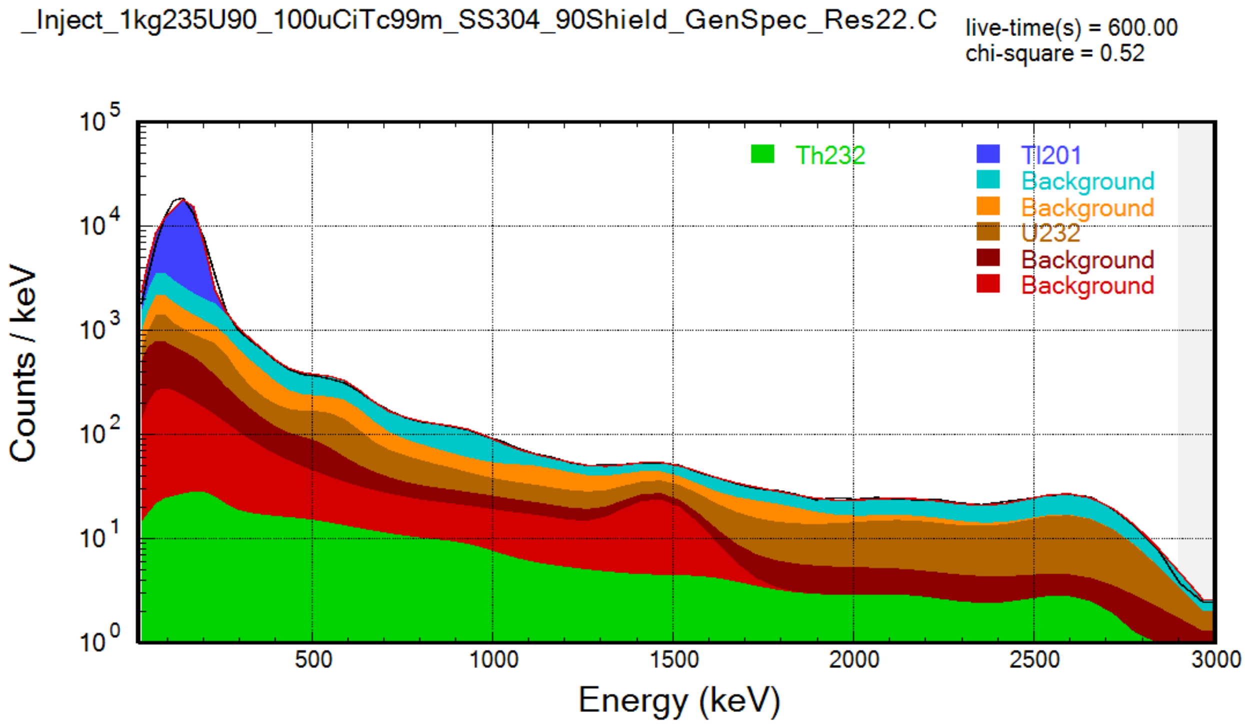


Figure K.13. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 22% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	5 (SNM=L)
TTF,TTB:	608, 0
Chi Square:	0.8
Net Gammas:	4314 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	1 (Low)
Alarm Severity:	RED
Alarm Description:	Maybe RDD
Event Type:	Medical
Isotopes:	Tl201(H,458uCi) + U232(F,1uCi)

Figure K.14. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 22% resolution for collection and identification.

23% Resolution for Collection and Identification

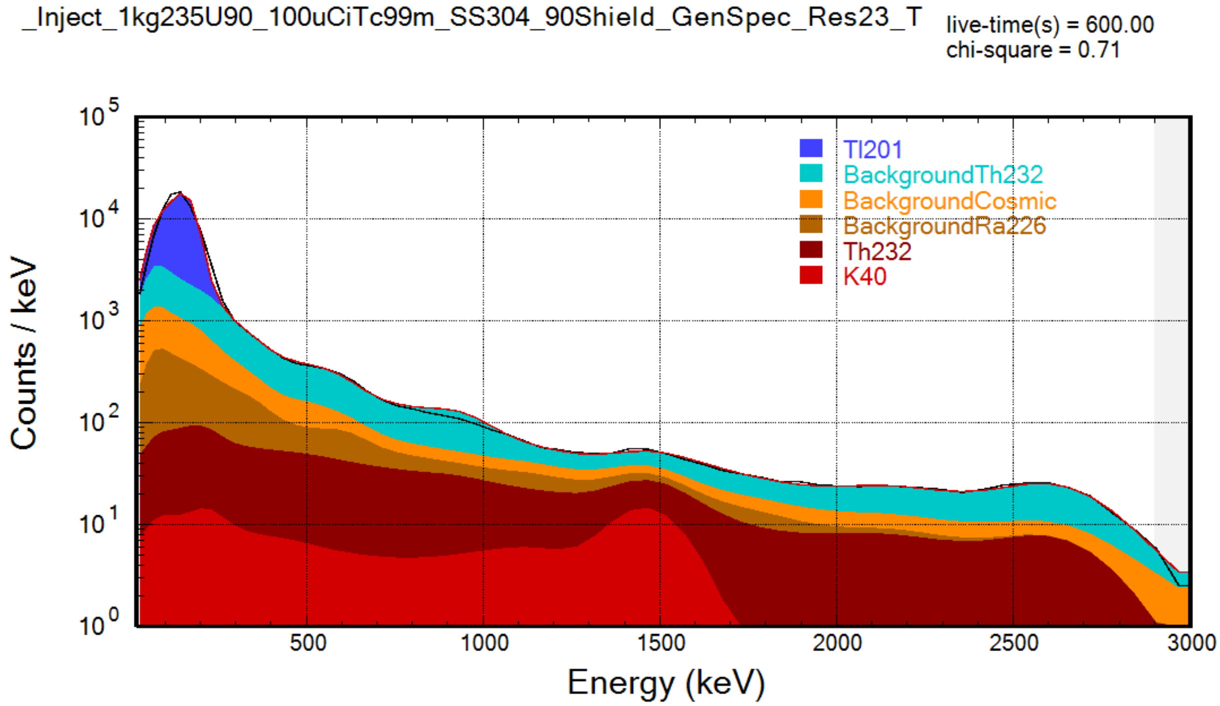


Figure K.15. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 23% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	2 (Medical)
TTF,TTB:	608, 0
Chi Square:	1
Net Gammas:	4312 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Medical
Event Type:	Medical
Isotopes:	Tl201(H,462uCi) + Th232(H,31uCi)

Figure K.16. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 23% resolution for collection and identification.

24% Resolution for Collection and Identification

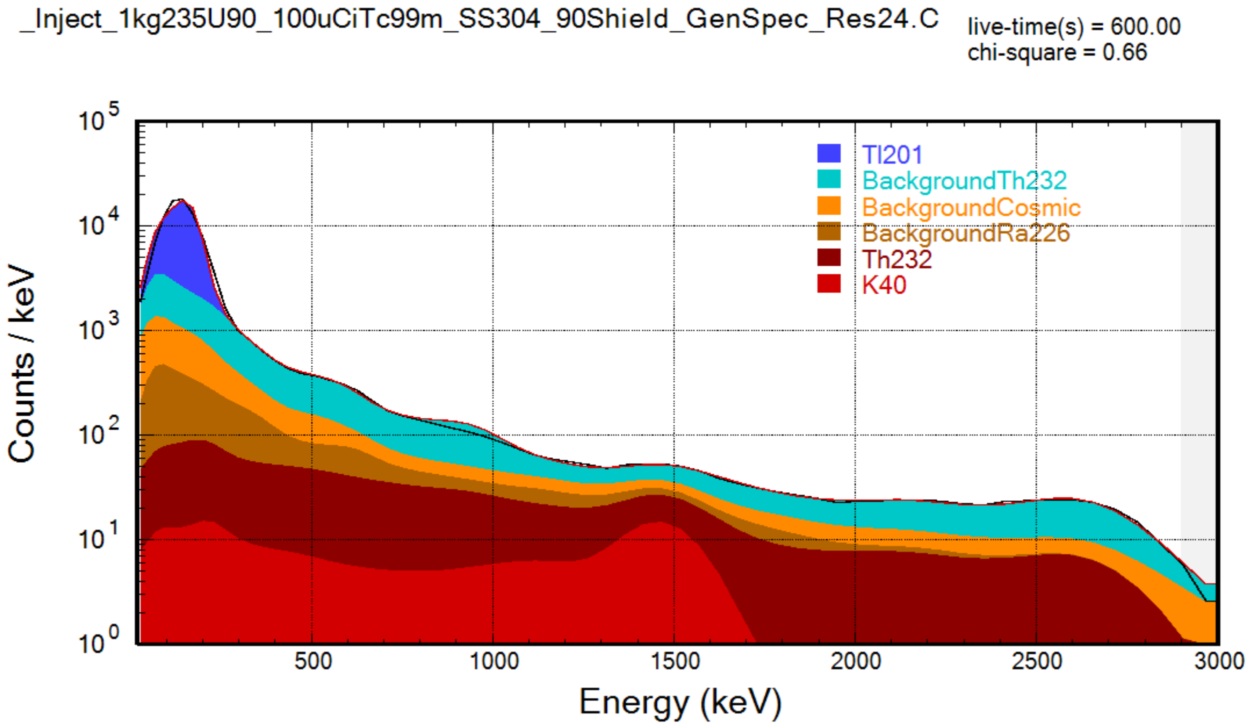


Figure K.17. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 24% resolution for collection and identification.

01-Jun-2020 12:00:00.00	
Threat:	2 (Medical)
TTF,TTB:	608, 0
Chi Square:	0.9
Net Gammas:	4313 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	0 (Very Low)
Alarm Severity:	RED
Alarm Description:	Medical
Event Type:	Medical
Isotopes:	Tl201(H,463uCi) + Th232(H,29uCi)

Figure K.18. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 24% resolution for collection and identification.

APPENDIX L – GADRAS Output for Configuration 6 Using Different Resolutions for Collection and Identification

8.92% Resolution for Collection and 8.92% Resolution for Identification

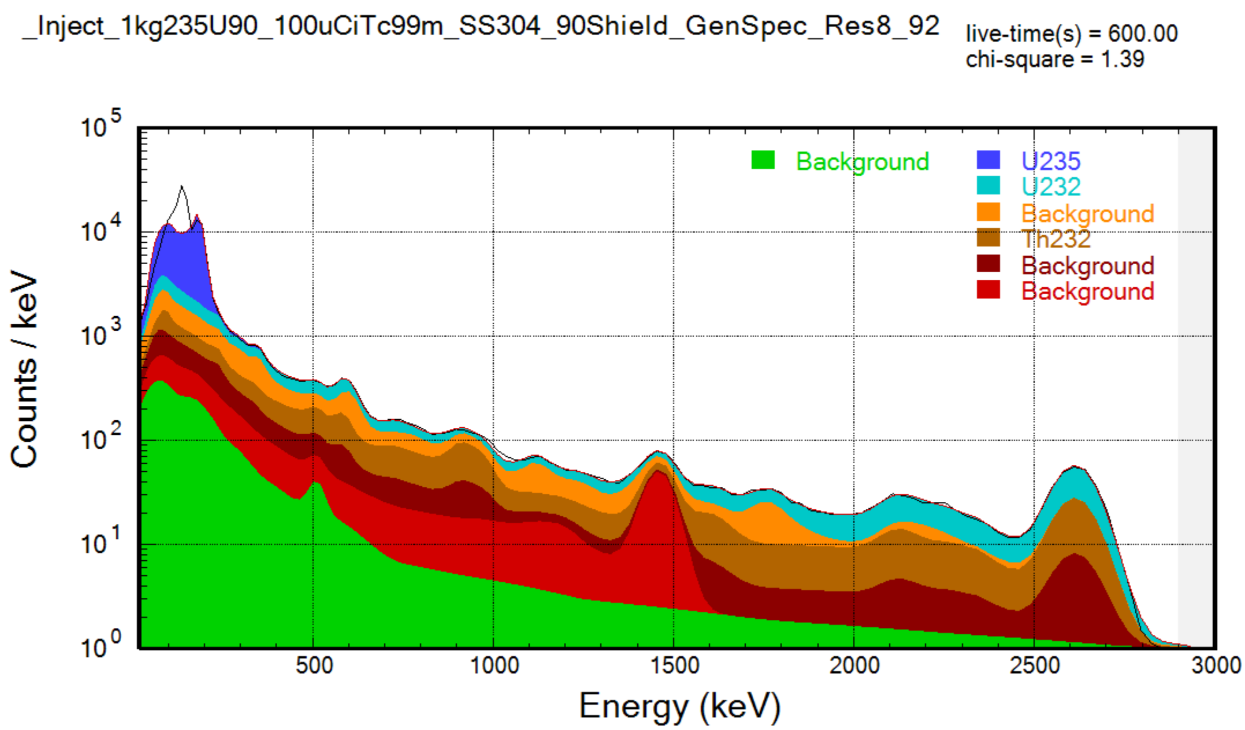


Figure L.1. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at an 8.92% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 7 (SNM=H)
TTF,TTB:                608, 0
Chi Square:             1.7
Net Gammas:             4312 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               3 (High)
Alarm Severity:         RED
Alarm Description:      Probable SNM
Event Type:             SNM

Isotopes:               U235(H,6kg) + U232(H,4uCi) + Tc99m(L,1uCi)
```

Figure L.2. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at an 8.92% resolution for collection and an 8.92% resolution for identification.

10% Resolution for Collection and 8.92% Resolution for Identification

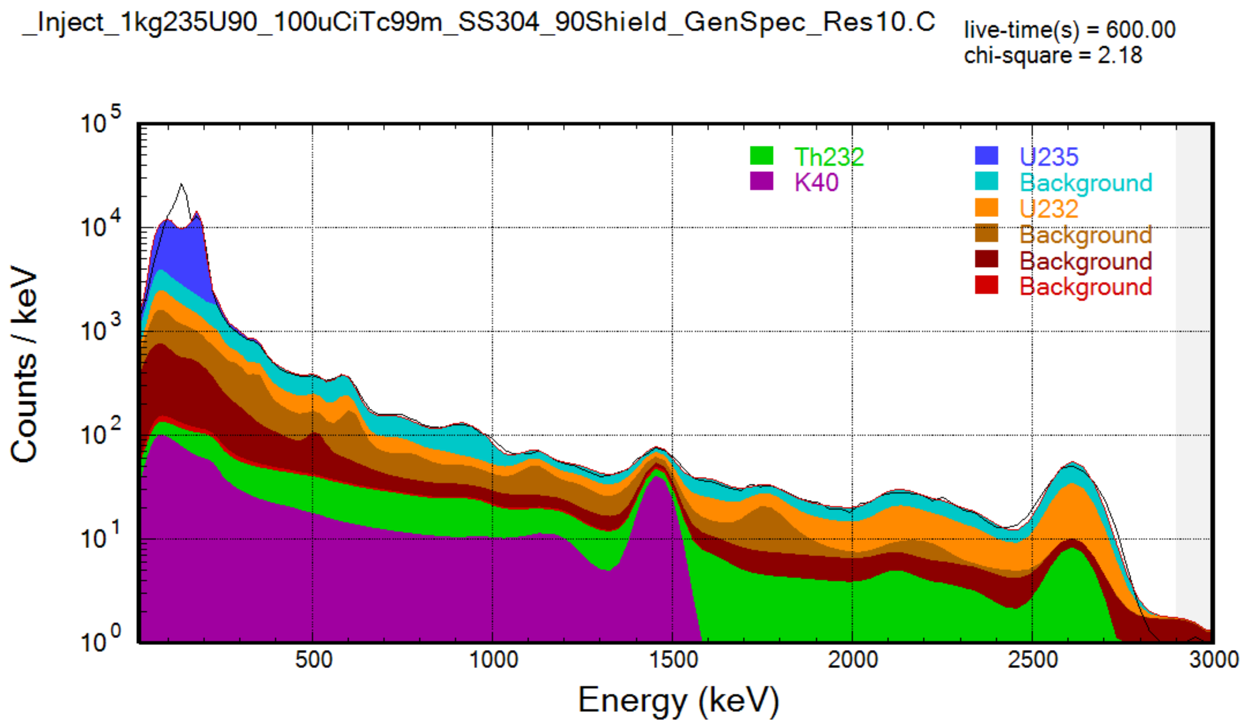


Figure L.3. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 10% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	608, 0
Chi Square:	2.5
Net Gammas:	4312 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U235(H,5kg) + U232(H,4uCi) + Tc99m(L,1uCi)

Figure L.4. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 10% resolution for collection and an 8.92% resolution for identification.

15% Resolution for Collection and 8.92% Resolution for Identification

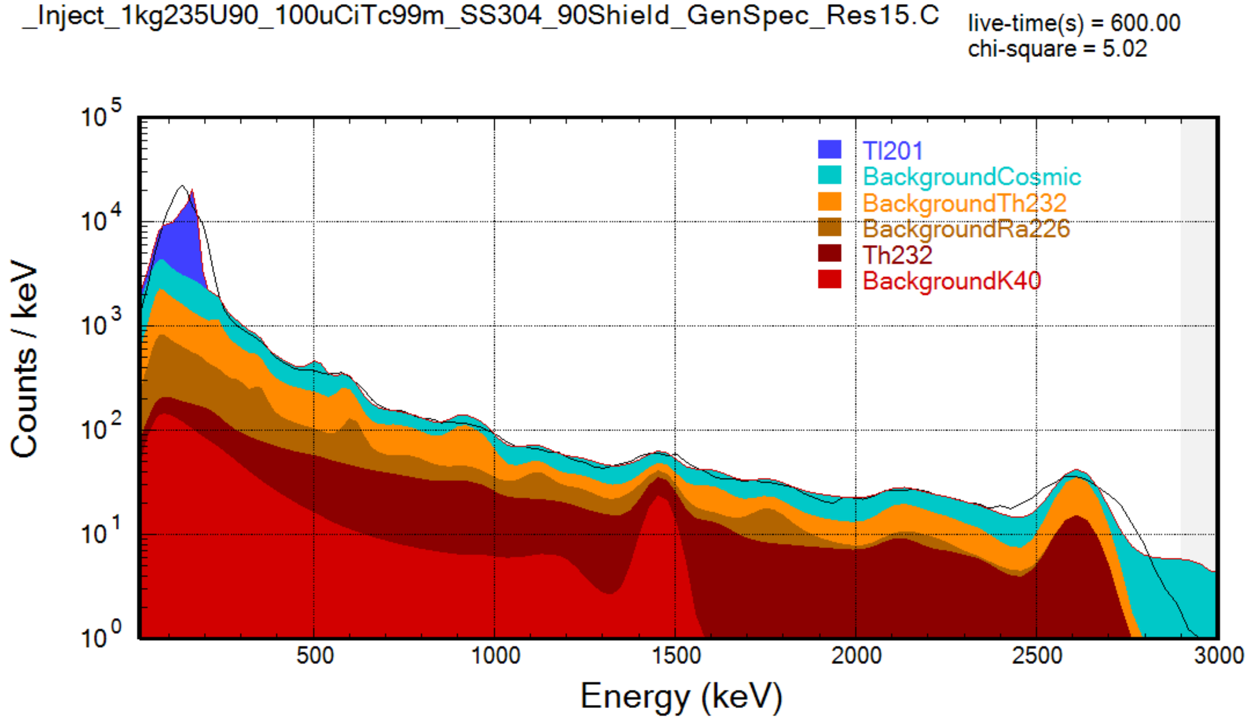


Figure L.5. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 15% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                 4 (Bad ID)
TTF,TTB:                608, 0
Chi Square:             5.8
Net Gammas:             4311 cps
Net Neutrons:           0 cps
Sigma Gammas:           0
Sigma Neutrons:         0
Average Speed:          0 m/s
SNM Prob:               0 (Very Low)
Alarm Severity:         RED
Alarm Description:      Unknown source
Event Type:             Medical

Isotopes:               Th232(H,29uCi) + Tl201(H,310uCi)
```

Figure L.6. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 15% resolution for collection and an 8.92% resolution for identification.

11% Resolution for Collection and 8.92% Resolution for Identification

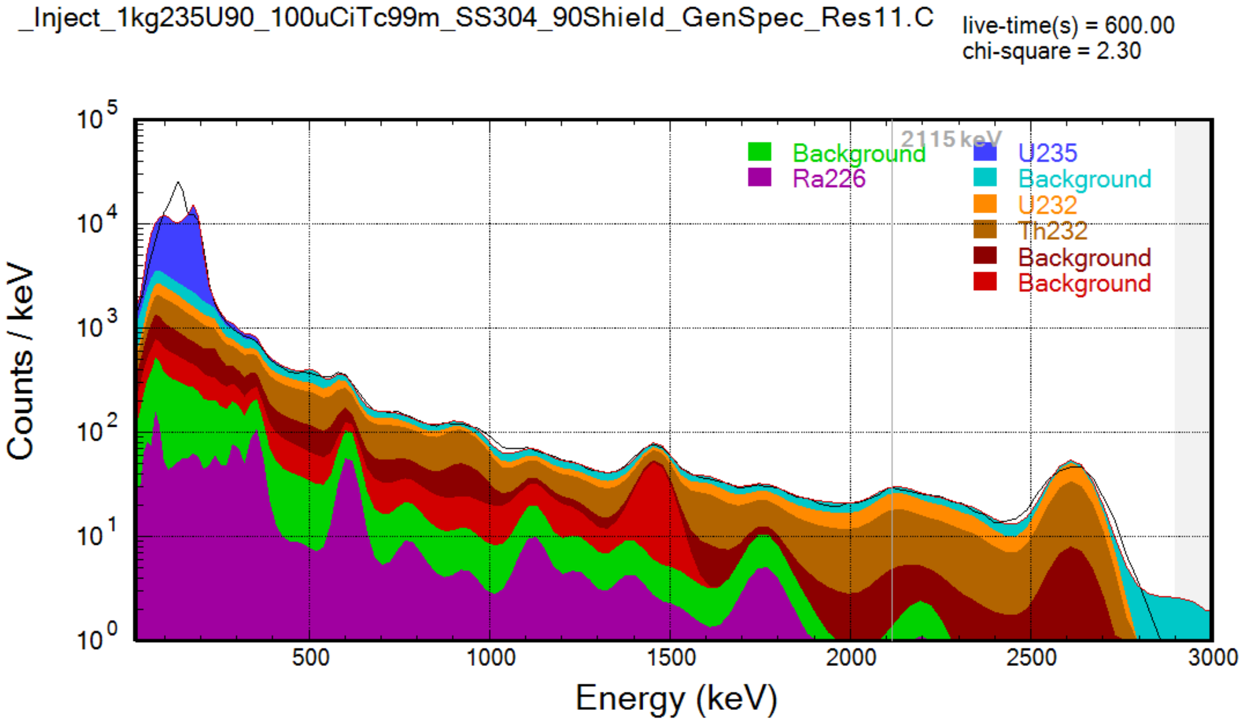


Figure L.7. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 11% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	7 (SNM=H)
TTF,TTB:	608, 0
Chi Square:	2.7
Net Gammas:	4315 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	3 (High)
Alarm Severity:	RED
Alarm Description:	Probable SNM
Event Type:	SNM
Isotopes:	U232(H,3uCi) + U235(F,2kg)

Figure L.8. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 11% resolution for collection and an 8.92% resolution for identification.

12% Resolution for Collection and 8.92% Resolution for Identification

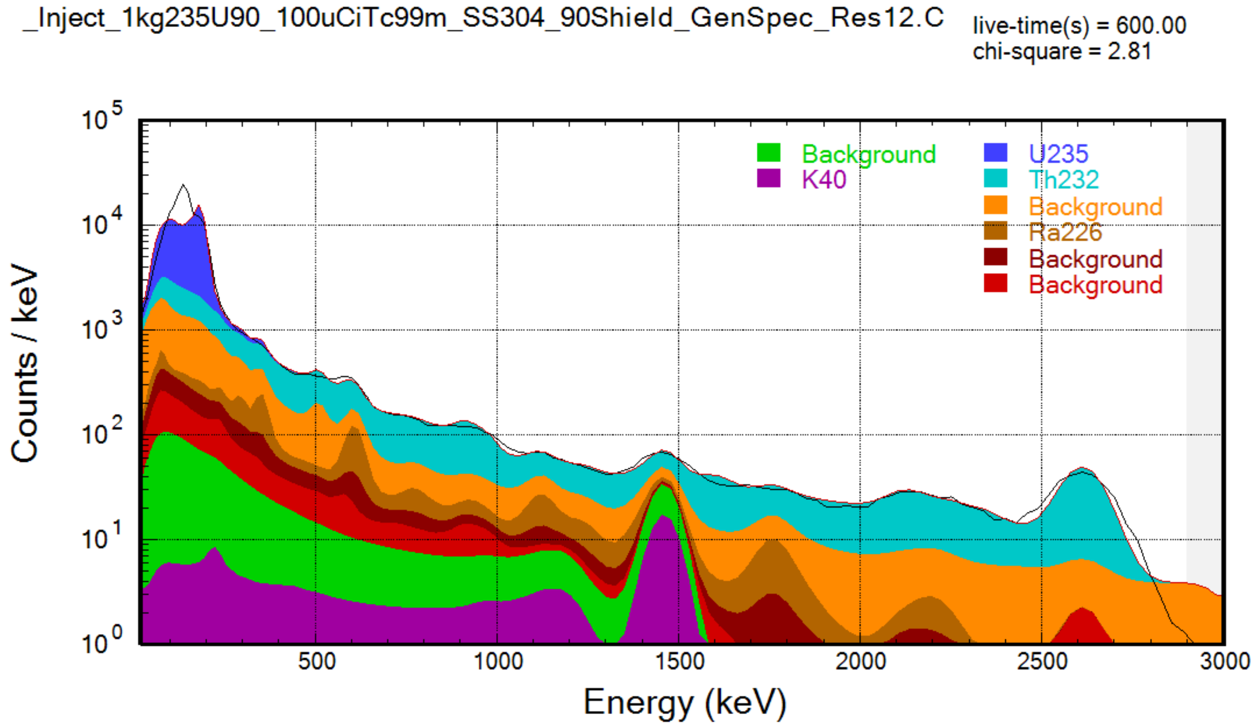


Figure L.9. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 12% resolution for collection and an 8.92% resolution for identification.

```
01-Jun-2020 12:00:00.00
Threat:                  6 (SNM=F)
TTF,TTB:                 608, 0
Chi Square:              3.3
Net Gammas:              4311 cps
Net Neutrons:            0 cps
Sigma Gammas:            0
Sigma Neutrons:          0
Average Speed:           0 m/s
SNM Prob:                2 (Fair)
Alarm Severity:          RED
Alarm Description:       Possible SNM
Event Type:              SNM

Isotopes:                Th232(H,12uCi) + U235(F,2kg)
```

Figure L.10. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 12% resolution for collection and an 8.92% resolution for identification.

13% Resolution for Collection and 8.92% Resolution for Identification

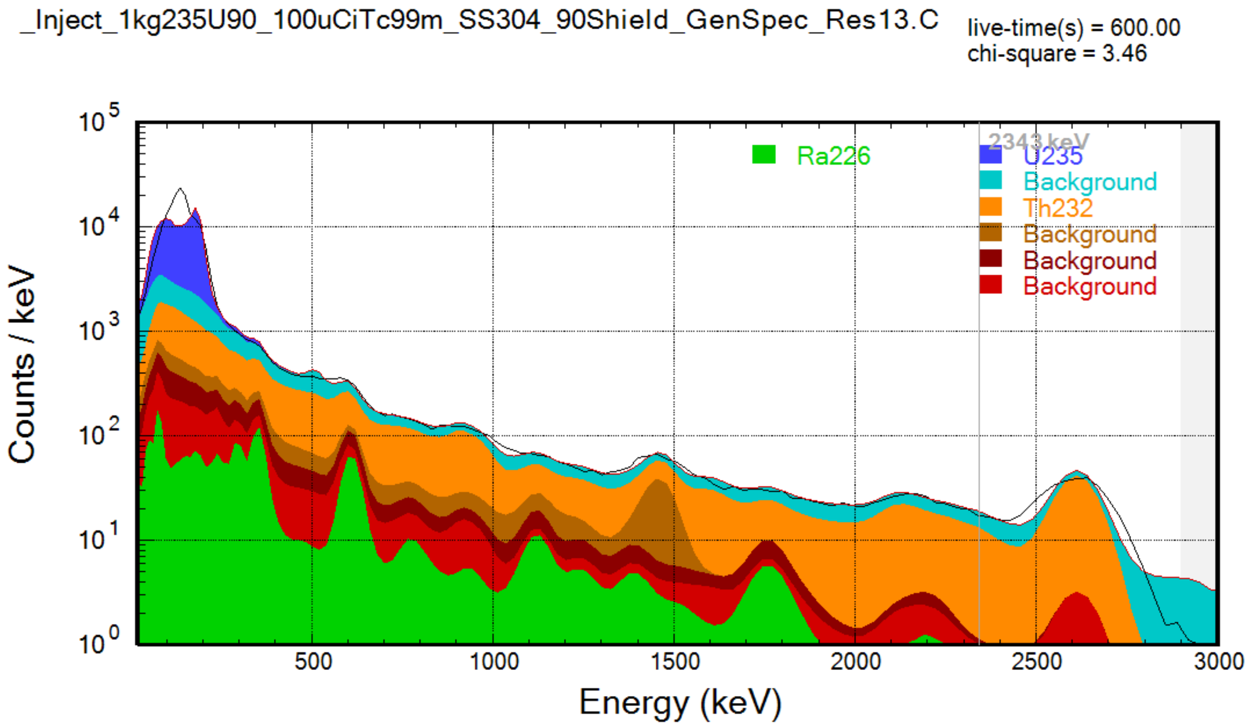


Figure L.11. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 13% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	608, 0
Chi Square:	4
Net Gammas:	4306 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	Th232(H,11uCi) + U235(F,2kg)

Figure L.12. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 13% resolution for collection and an 8.92% resolution for identification.

14% Resolution for Collection and 8.92% Resolution for Identification

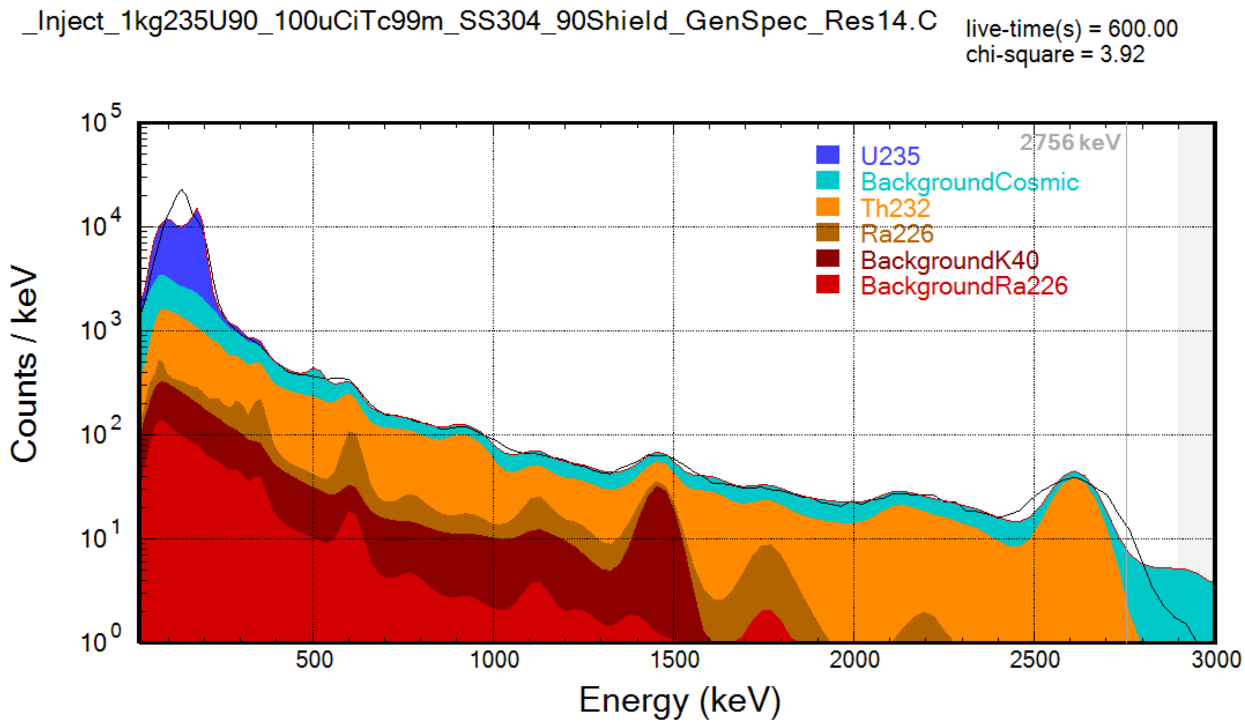


Figure L.13. GADRAS spectrum for HEU and the interference source shielded to 90% of their original intensity at a 14% resolution for collection and an 8.92% resolution for identification.

01-Jun-2020 12:00:00.00	
Threat:	6 (SNM=F)
TTF,TTB:	608, 0
Chi Square:	4.7
Net Gammas:	4313 cps
Net Neutrons:	0 cps
Sigma Gammas:	0
Sigma Neutrons:	0
Average Speed:	0 m/s
SNM Prob:	2 (Fair)
Alarm Severity:	RED
Alarm Description:	Possible SNM
Event Type:	SNM
Isotopes:	Th232(H,11uCi) + U235(F,2kg)

Figure L.14. GADRAS textual results for HEU and the interference source shielded to 90% of their original intensity at a 14% resolution for collection and an 8.92% resolution for identification.

APPENDIX M – Genie Output for Configuration 1

8.92% Resolution

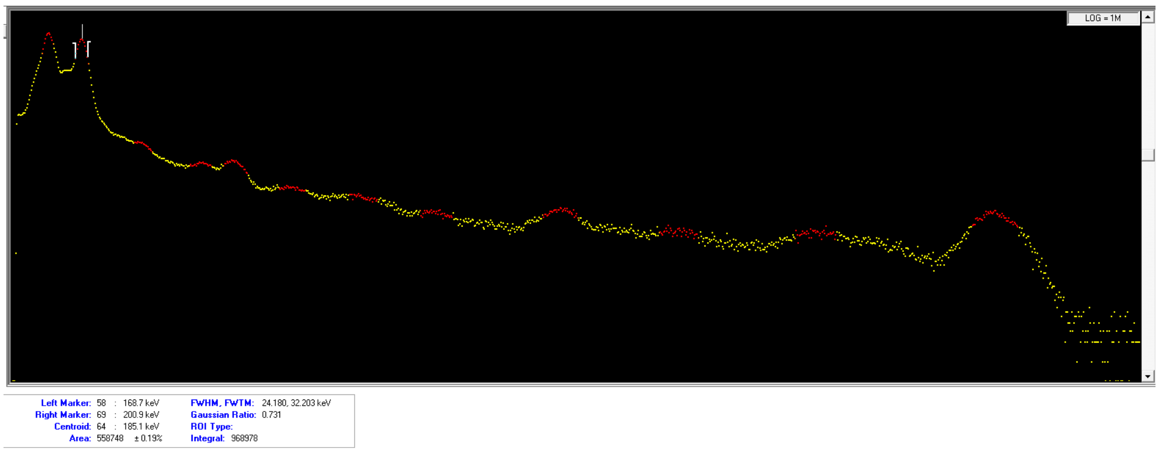


Figure M.1. Genie spectrum for HEU at an 8.92% resolution. The source configuration was identified with a 0.544 confidence level.

15% Resolution

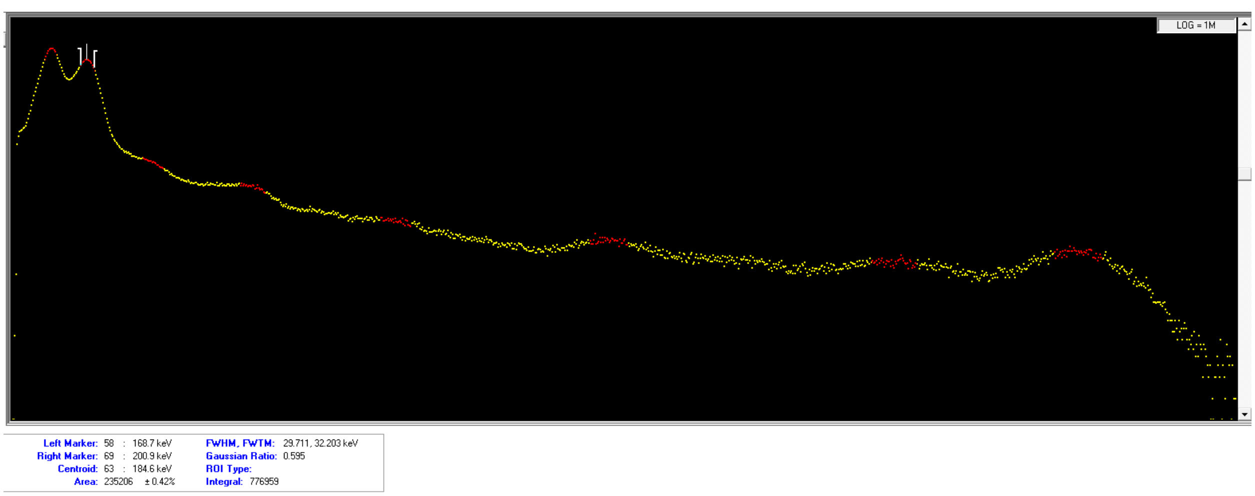


Figure M.2. Genie spectrum for HEU at a 15% resolution. The source configuration was identified with a 0.544 confidence level.

20% Resolution

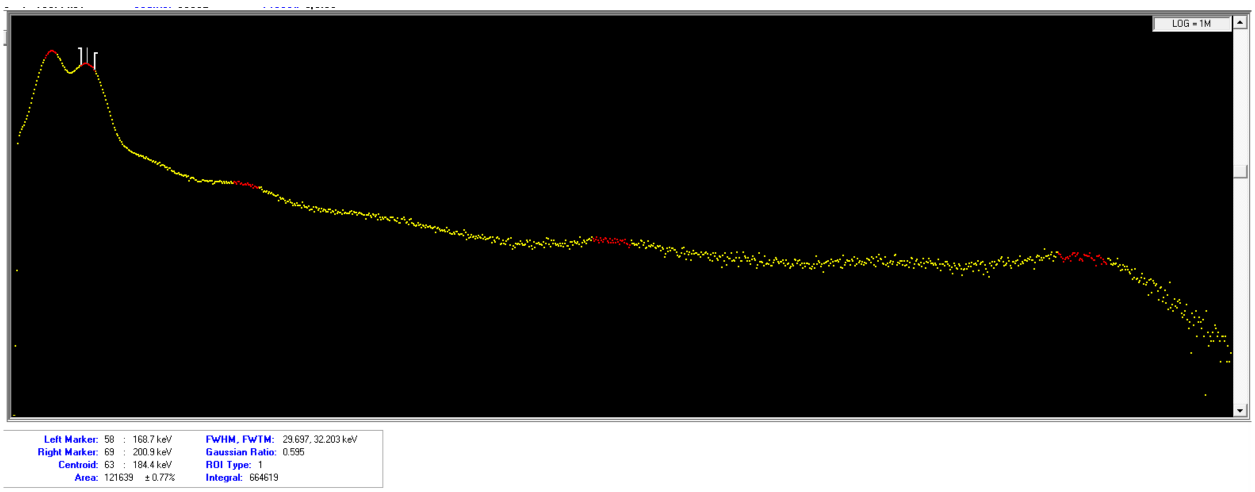


Figure M.3. Genie spectrum for HEU at a 20% resolution. The source configuration was identified with a 0.544 confidence level.

21% Resolution

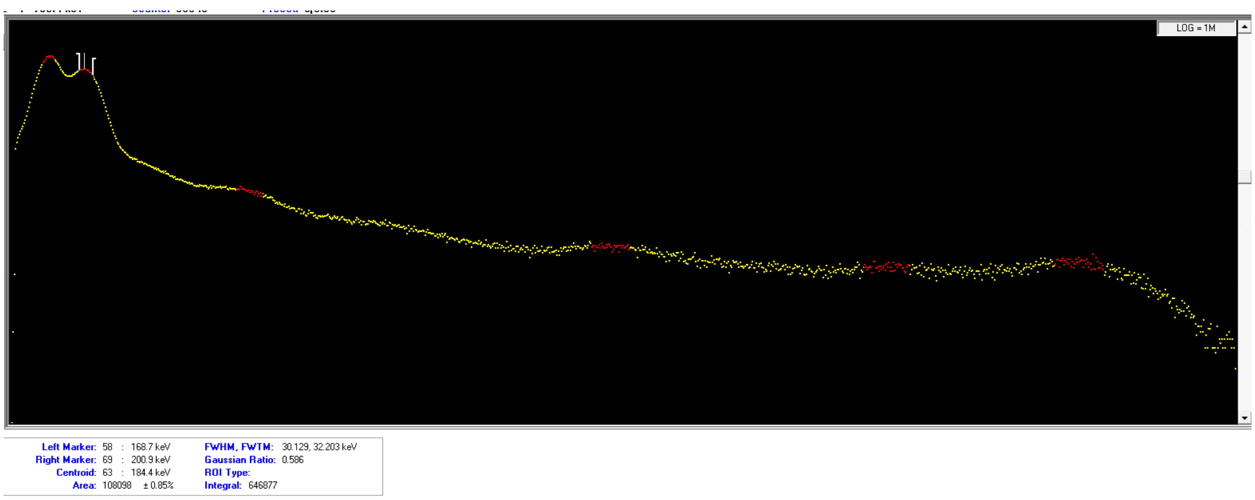


Figure M.4. Genie spectrum for HEU at a 21% resolution. The source configuration was identified with a 0.544 confidence level.

22% Resolution

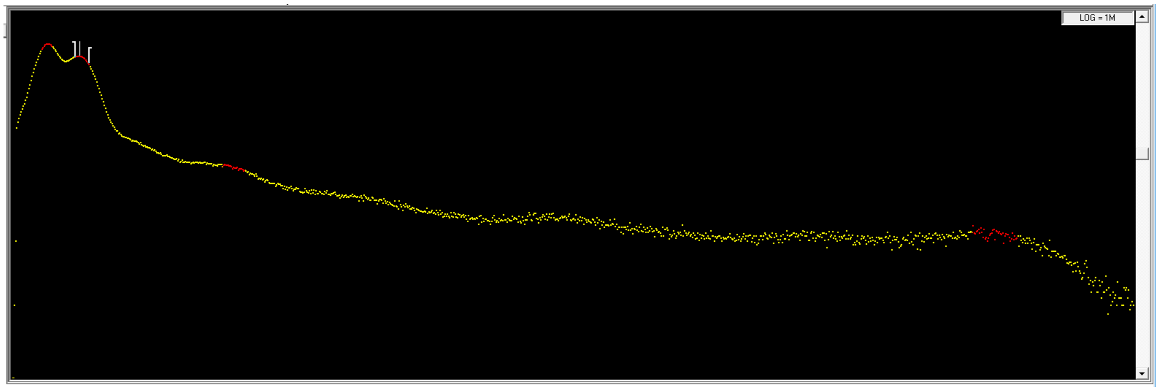


Figure M.5. Genie spectrum for HEU at a 22% resolution. The source configuration was identified with a 0.541 confidence level.

23% Resolution

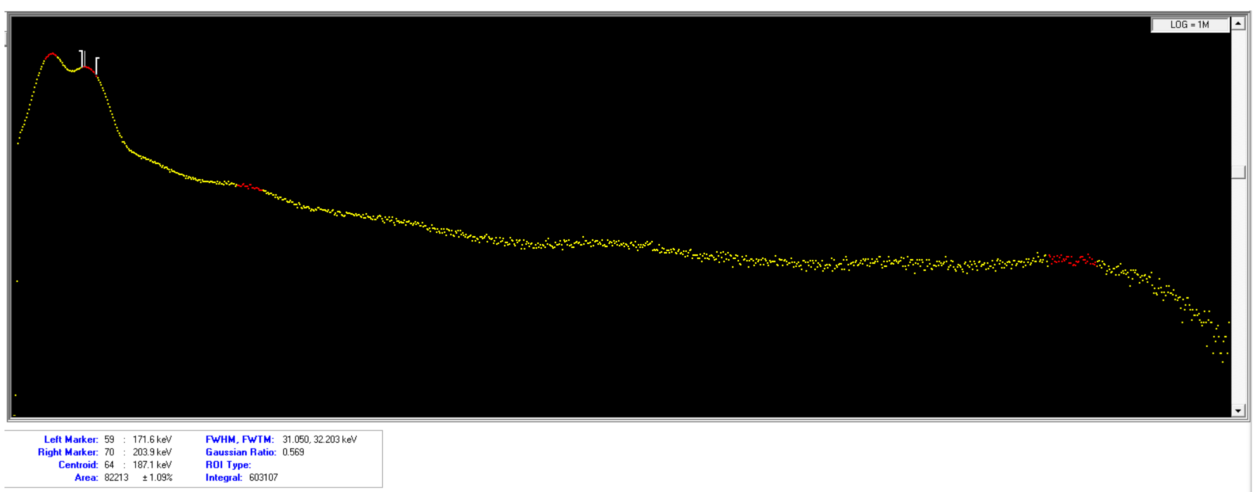


Figure M.6. Genie spectrum for HEU at a 23% resolution. The source configuration was not identified with a 0.540 confidence level.

25% Resolution

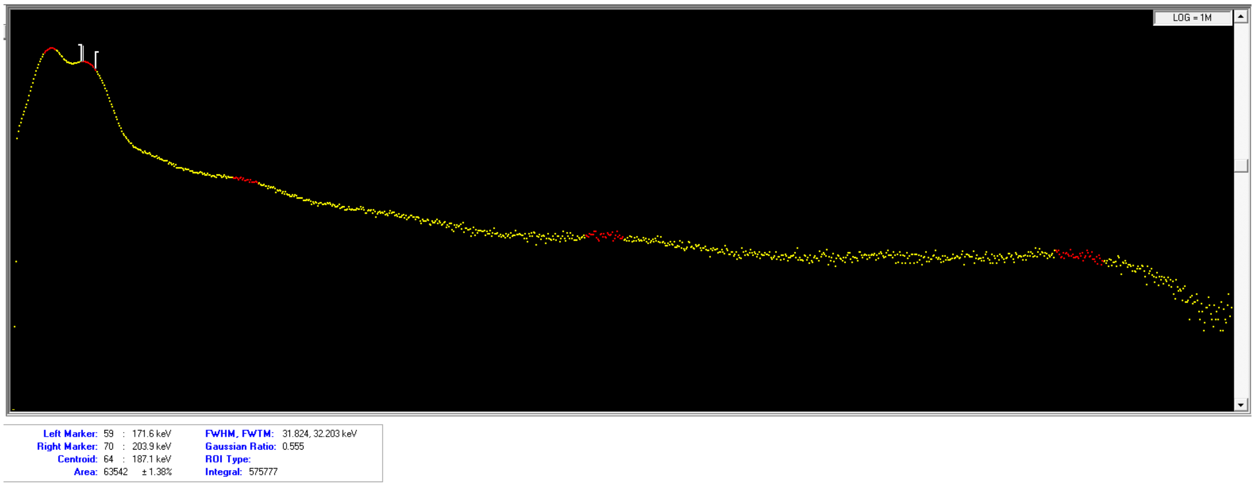


Figure M.7. Genie spectrum for HEU at a 25% resolution. The source configuration was not identified, even at a 0.1 confidence level.

APPENDIX N – Genie Output for Configuration 2

8.92% Resolution

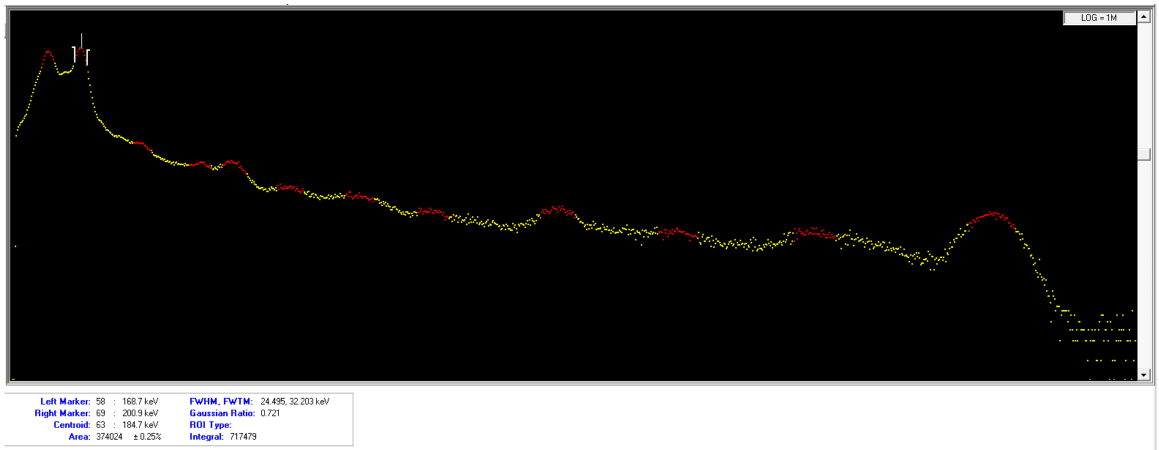


Figure N.1. Genie spectrum for HEU shielded to 50% intensity at an 8.92% resolution. The source configuration was identified with a 0.544 confidence level.

15% Resolution

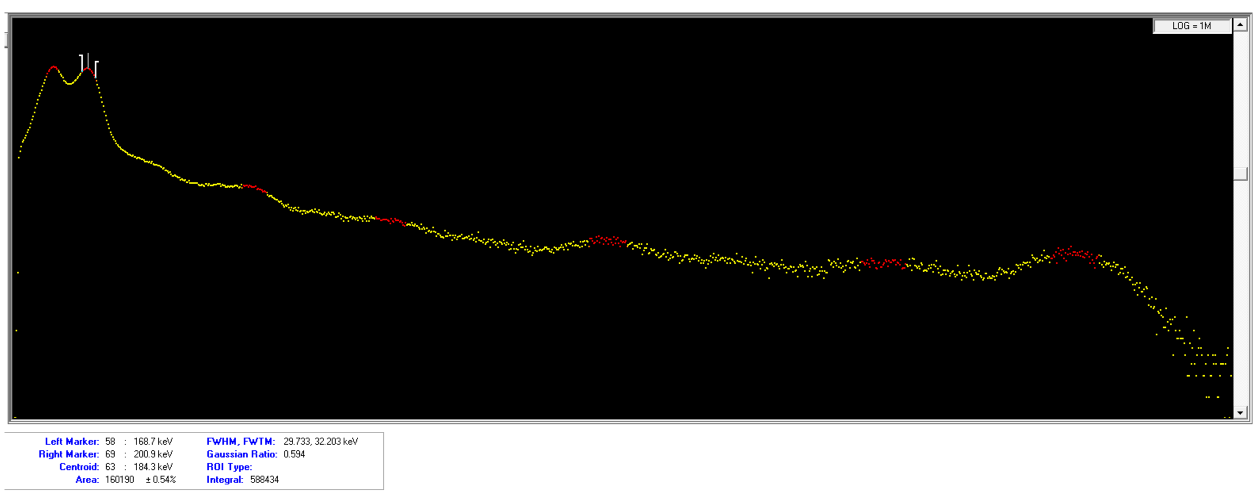


Figure N.2. Genie spectrum for HEU shielded to 50% intensity at a 15% resolution. The source configuration was identified with a 0.544 confidence level.

20% Resolution

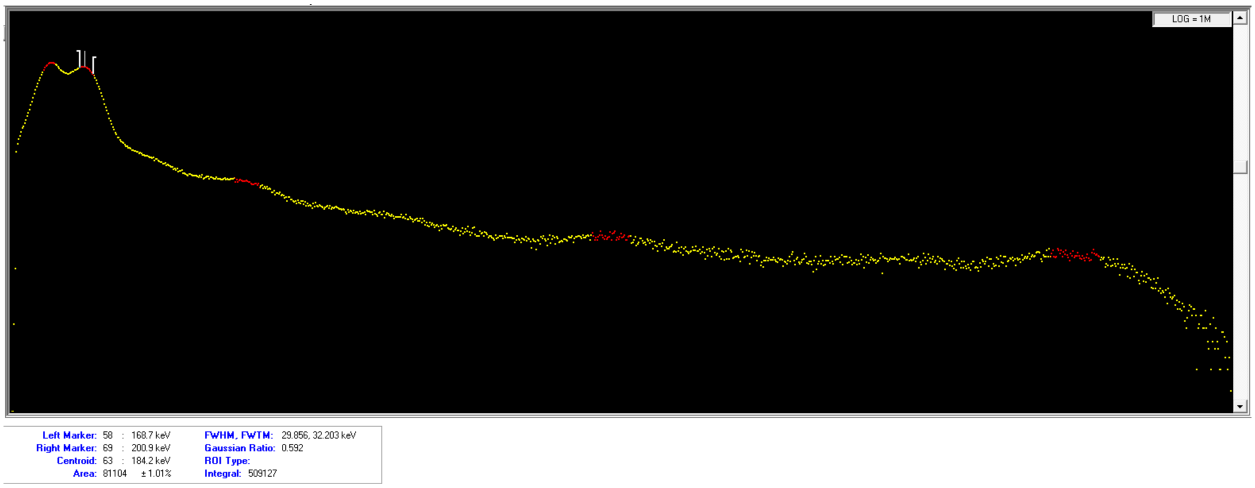


Figure N.3. Genie spectrum for HEU shielded to 50% intensity at a 20% resolution. The source configuration was identified with a 0.544 confidence level.

25% Resolution

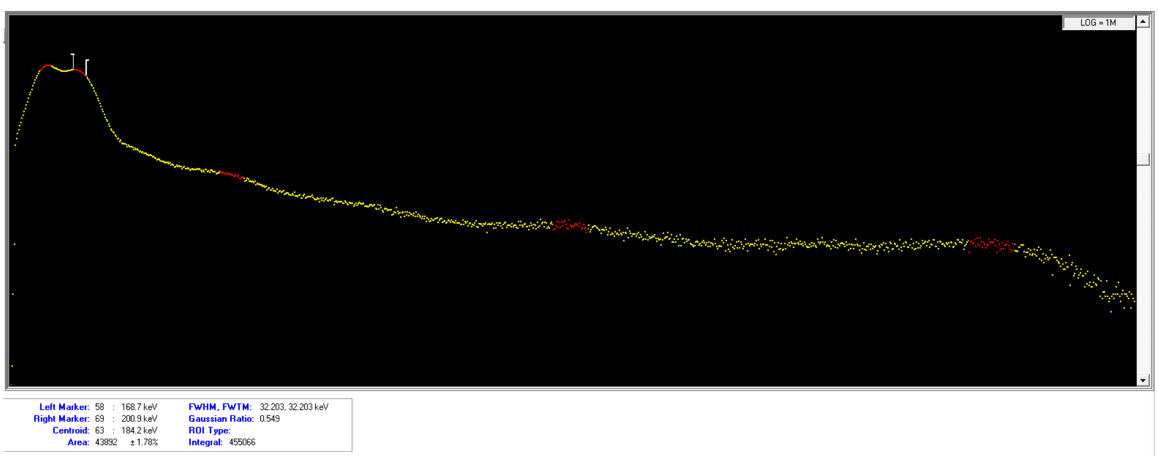


Figure N.4. Genie spectrum for HEU shielded to 50% intensity at a 25% resolution. The source configuration was identified with a 0.541 confidence level.

30% Resolution

Figure N.5. Genie spectrum for HEU shielded to 50% intensity at a 30% resolution. The source configuration was not identified, even with a 0.1 confidence level.

APPENDIX O – Genie Output for Configuration 3

8.92% Resolution

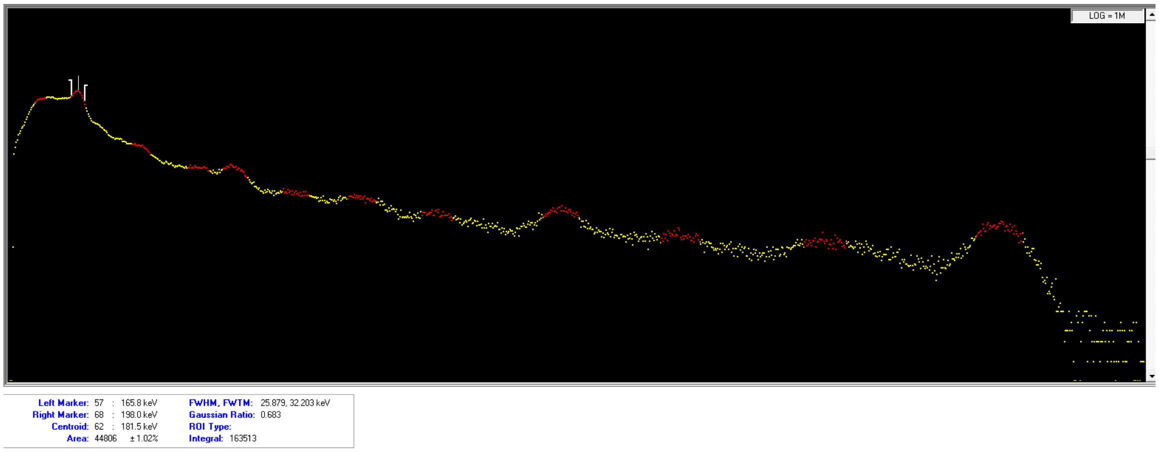


Figure O.1. Genie spectrum for HEU shielded to 90% intensity at an 8.92% resolution. The source configuration was identified with a 0.544 confidence level.

15% Resolution

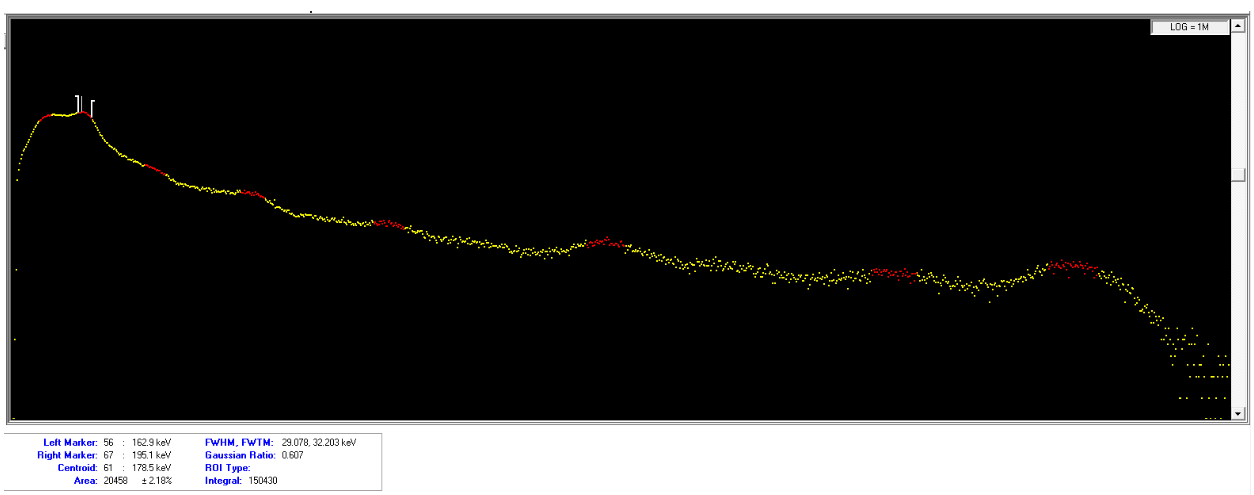


Figure O.2. Genie spectrum for HEU shielded to 90% intensity at a 15% resolution. The source configuration was identified with a 0.544 confidence level.

20% Resolution

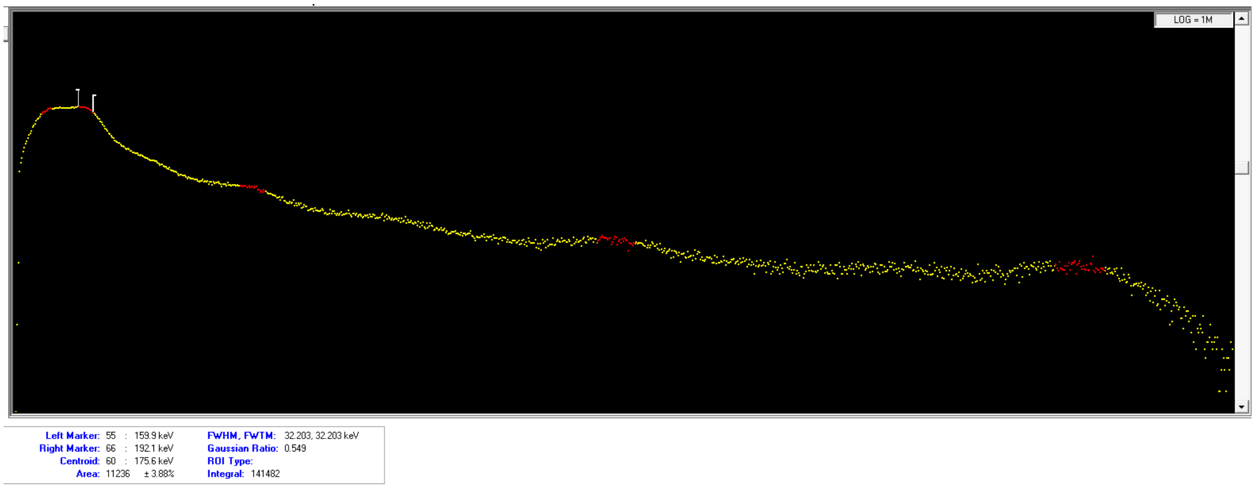


Figure O.3. Genie spectrum for HEU shielded to 90% intensity at a 20% resolution. The source configuration was identified with a 0.544 confidence level.

25% Resolution

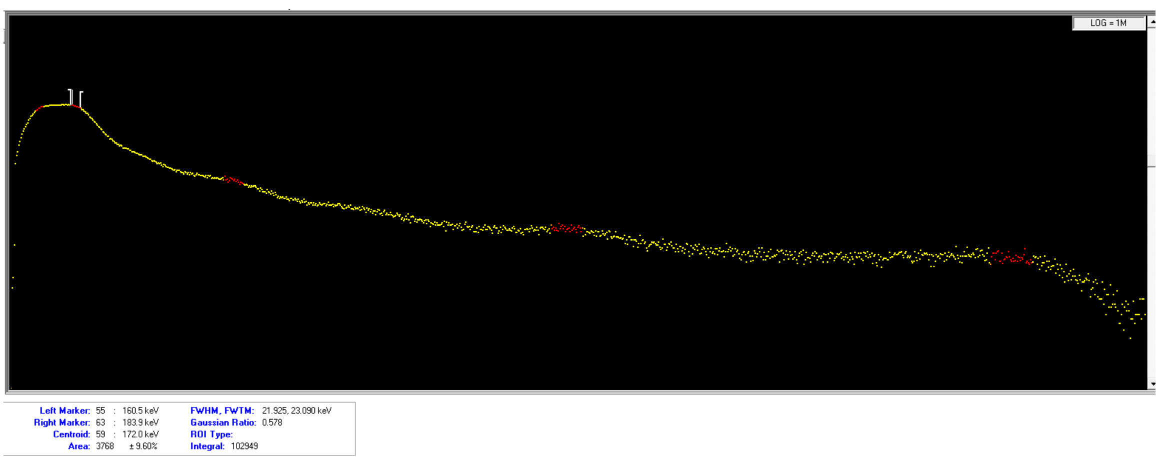


Figure O.4. Genie spectrum for HEU shielded to 90% intensity at a 25% resolution. The source configuration was identified with a 0.544 confidence level.

26% Resolution

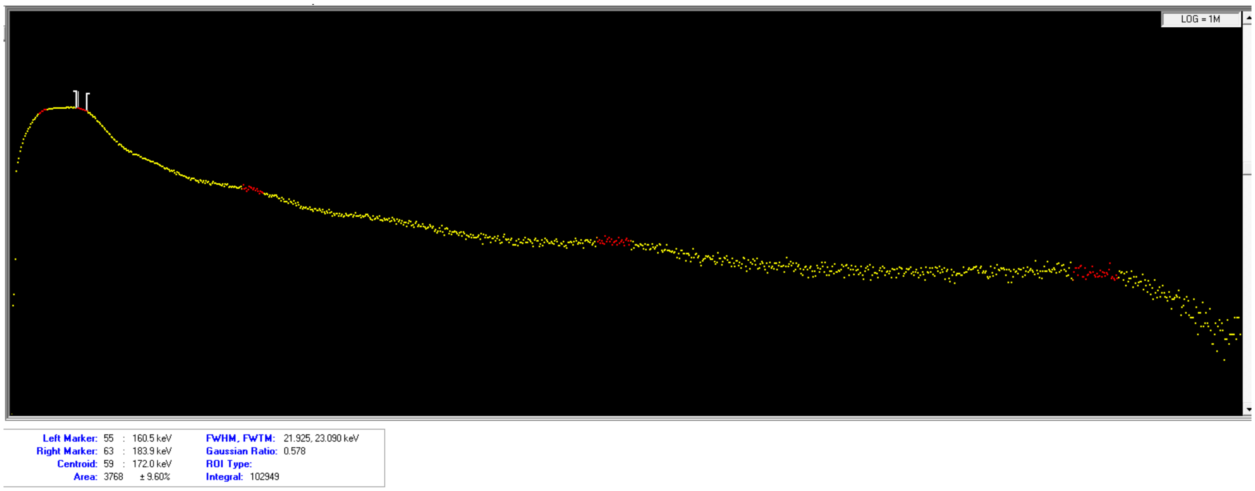


Figure O.5. Genie spectrum for HEU shielded to 90% intensity at a 26% resolution. The source configuration was not identified, even with a 0.1 confidence level.

APPENDIX P – Genie Output for Configuration 4

5% Resolution

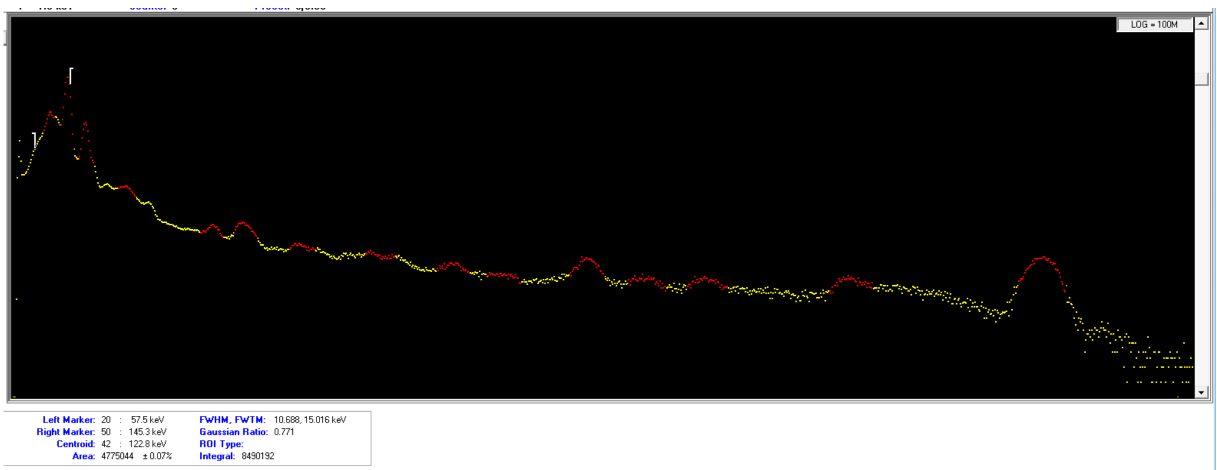


Figure P.1. Genie spectrum for HEU and ^{99m}Tc at a 5% resolution. The source configuration had no normal identification.

8.92% Resolution

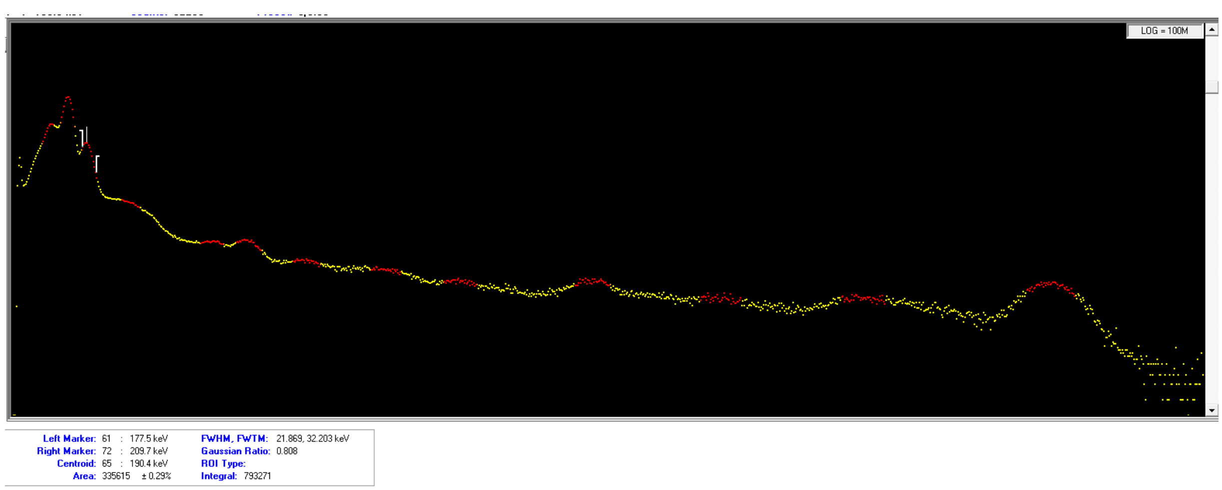


Figure P.2. Genie spectrum for HEU and ^{99m}Tc at an 8.92% resolution. The source configuration was not identified, even with a 0.1 confidence level.

APPENDIX Q – Genie Output for Configuration 5

8.92% Resolution

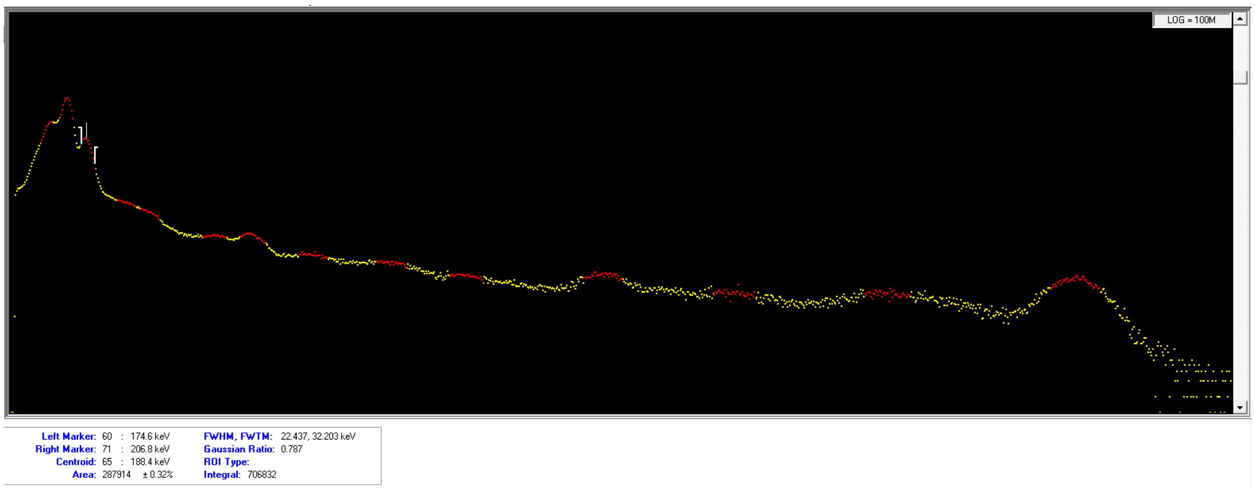


Figure Q.1. Genie spectrum for HEU and ^{99m}Tc shielded to 50% intensity at an 8.92% resolution. The source configuration was identified with a 0.775 confidence level.

9% Resolution

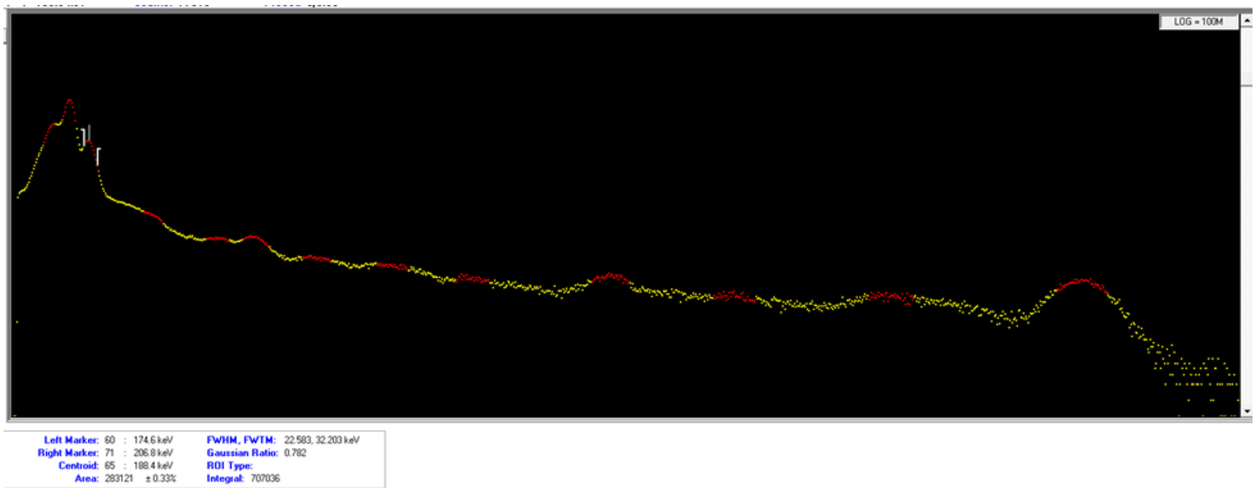


Figure Q.2. Genie spectrum for HEU and ^{99m}Tc shielded to 50% intensity at a 9% resolution. The source configuration was identified with a 0.775 confidence level.

10% Resolution

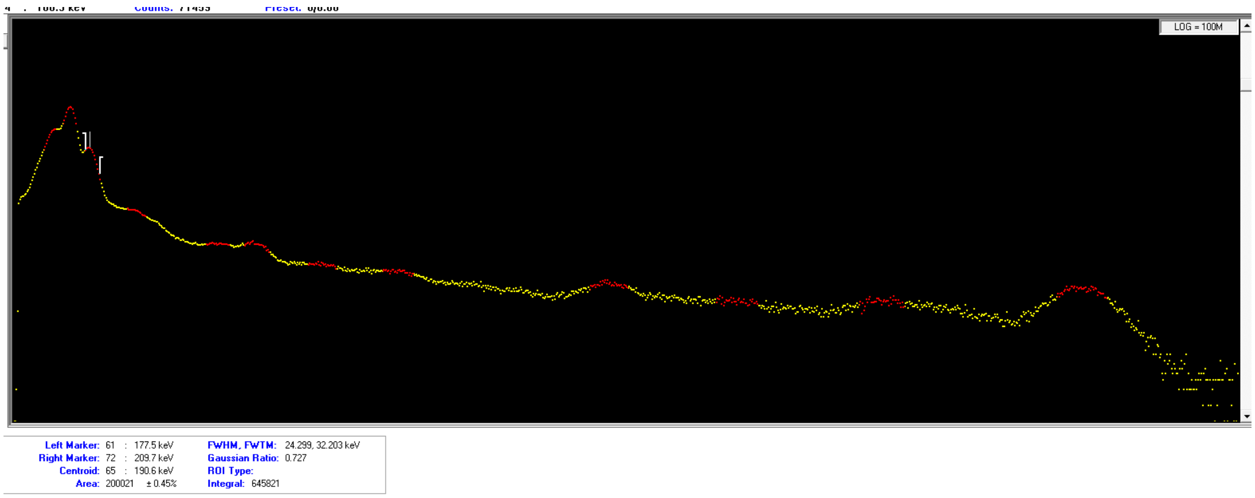


Figure Q.3. Genie spectrum for HEU and ^{99m}Tc shielded to 50% intensity at a 10% resolution. The source configuration was not identified, even with a 0.1 confidence level.

APPENDIX R – Genie Output for Configuration 6

8.92% Resolution

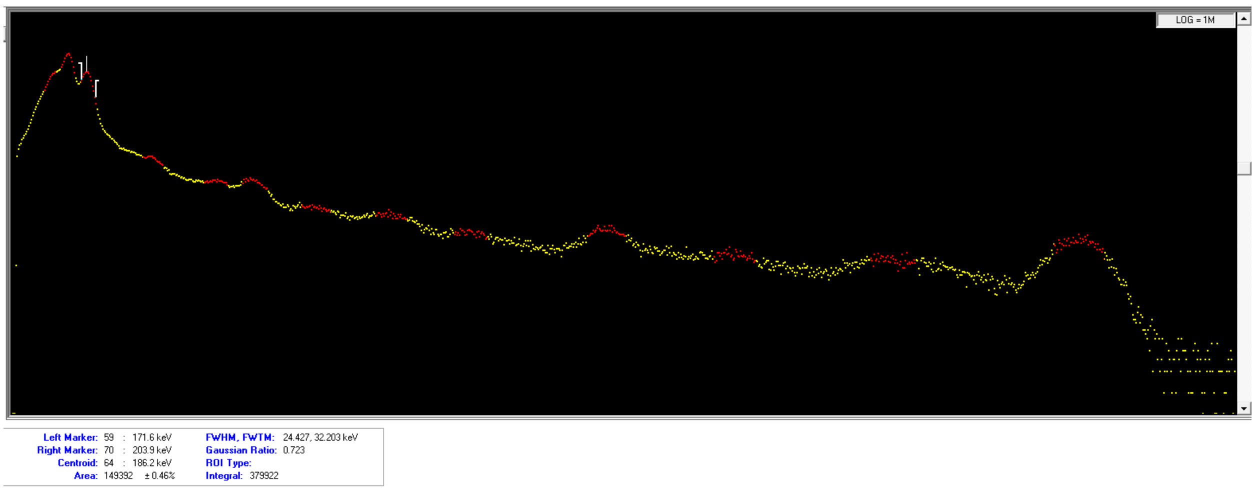


Figure R.1. Genie spectrum for HEU and ^{99m}Tc shielded to 90% an 8.92% resolution. The source configuration was identified with a 0.776 confidence level.

10% Resolution

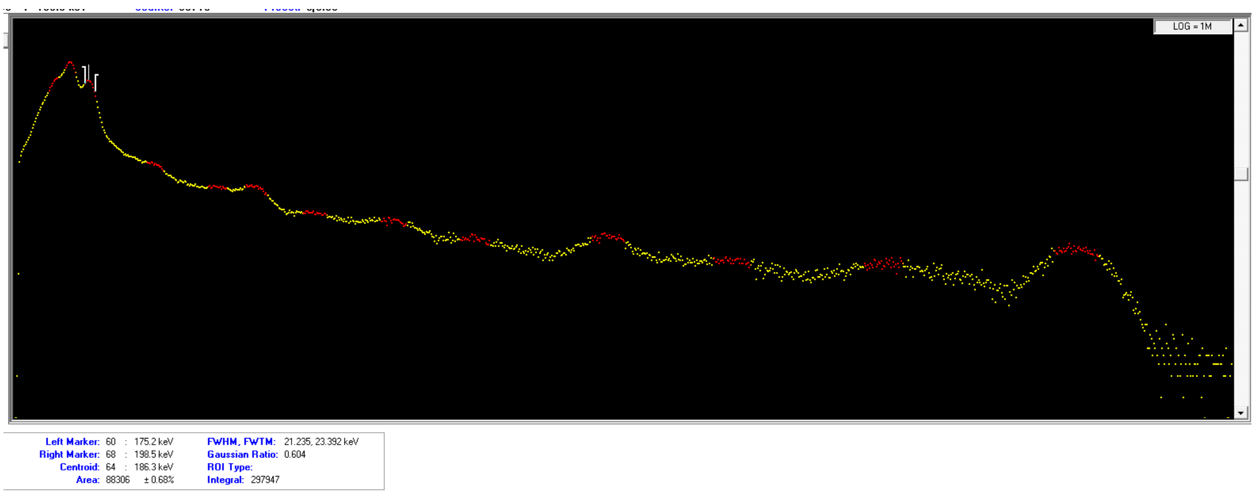


Figure R.2. Genie spectrum for HEU and ^{99m}Tc shielded to 90% an 10% resolution. The source configuration was identified with a 0.774 confidence level.

11% Resolution

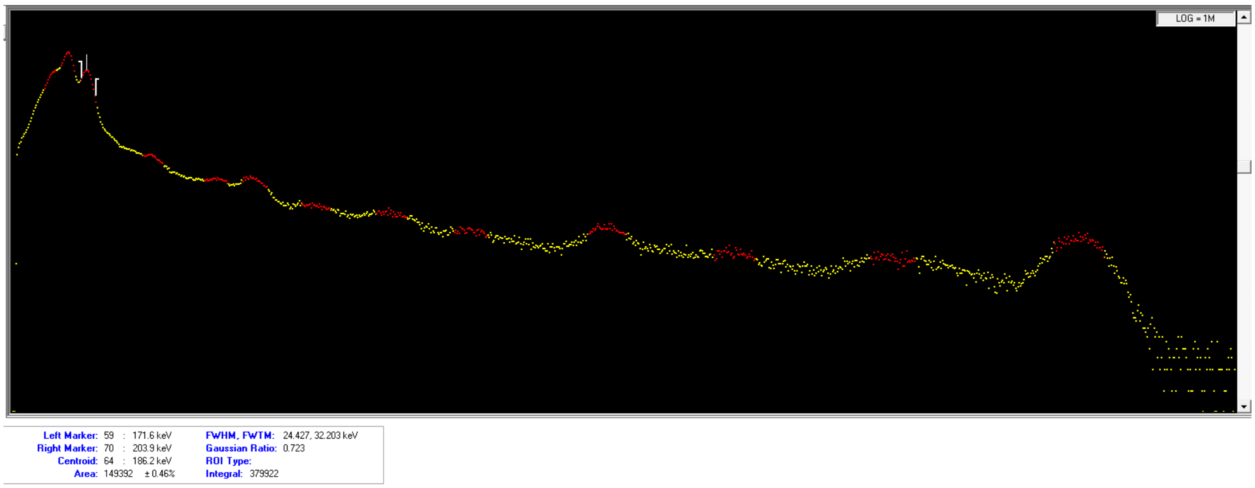


Figure R.3. Genie spectrum for HEU and ^{99m}Tc shielded to 90% intensity at a 11% resolution. The source configuration was identified with a 0.773 confidence level.

12% Resolution

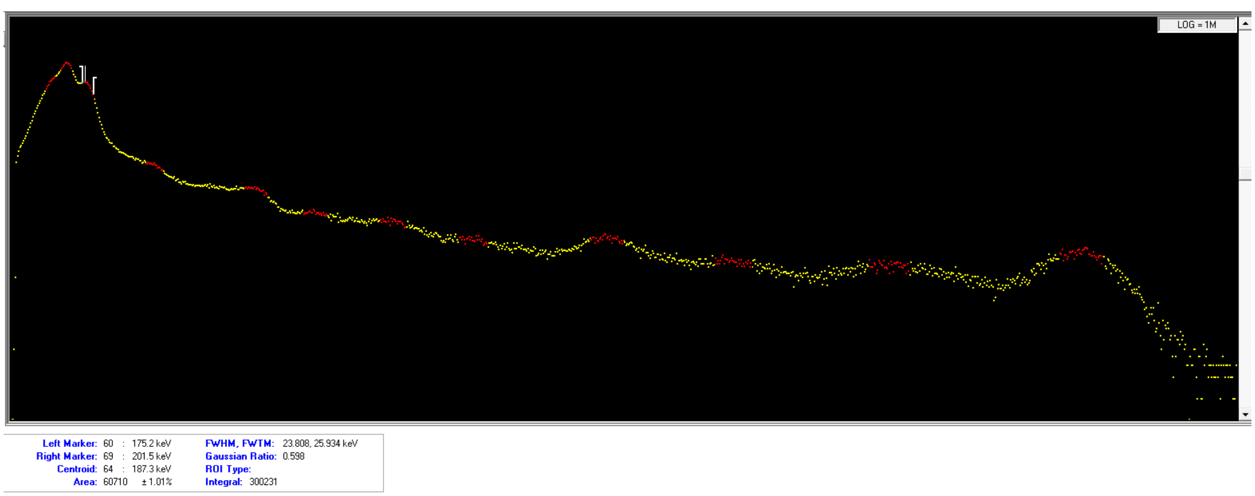


Figure R.4. Genie spectrum for HEU and ^{99m}Tc shielded to 90% intensity at a 12% resolution. The source configuration was not identified.