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An Operational Shielding Algorithm System (SAS) Software for the Analysis of Gamma Ray Spectra

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An Operational Shielding Algorithm System (SAS) Software for the Analysis of Gamma Ray Spectra

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Abstract

The objective of the Special Nuclear Material (SNM) detection work being conducted at Defence Research and Development Canada (DRDC) is to develop technologies that improve the ability of the Canadian Armed Forces (CAF) to detect, quantify, and determine the threat level of SNM. The Shielding Algorithm System (SAS) software, developed at the DRDC Ottawa Research Centre, is one such tool that uses an improved analysis of gamma ray spectra from radiological sources or SNM to determine the quantity and threat level of the material. The SAS C++ software calculates the shielding factor for several combinations of shielding materials, including self-shielding effects, using a chi-squared minimization routine based on the Minuit code. The software has been tested for several spectra involving multiple isotopes and as a result of this testing, several improvements to the SAS software were implemented in this work. Major changes to the user interface have greatly improved the speed at which the user can input the data from their spectrum, which allows a greater number of peaks to be included more easily in the analysis. An automated background subtraction algorithm was implemented to estimate the expected background from a spectrum without requiring the user to take a separate background measurement. These changes are expected to improve the reliability and accuracy of the software. Users from DRDC Suffield have tested the program for usability, found issues, and these have been addressed in the current version of the software.

An unknown spectrum from a Canadian Special Operations Force Command (CANSOFCOM) exercise was analyzed using the current version of the SAS software. A greater number of input peaks were used compared to previous analyses and an automated background subtraction was included. Therefore, the software is expected to give a more accurate estimate

of the source activity. The source was determined to be a combination of Pu-239, Pu-240, and Am-241, with the most likely scenario corresponding to 2.6 ± 0.4 kg of plutonium as a sphere or cube of roughly 1.5 cm in size, with minimal additional shielding ($\sim$ 8 cm of beryllium or $\sim$ 5 cm of concrete) and an enrichment of 87 ± 3 %. This would indicate an immediate SNM threat, as this amount of plutonium could be used in a nuclear weapon, and is exactly the type of scenario for which the SAS program was designed to analyze and identify.

The SAS software tool has demonstrated that an improved estimate of the activity and shielding materials of shielded isotopes can be achieved in realistic scenarios. An operational version of the SAS software was installed on a Linux virtual machine for use by DRDC Suffield in the near future. Further testing must be done to improve the calculations and efficiency of the code, and additional features should be included to make this a more powerful tool for analyzing gamma ray spectra. The final product will then be made available to the CAF to determine the threat level of SNM, or any radiological material, encountered in the field.

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1. Introduction

The objective of the Special Nuclear Material (SNM) detection work being conducted at Defence Research and Development Canada (DRDC) is to develop technologies that improve the ability of the Canadian Armed Forces (CAF) to detect, quantify, and determine the threat level of SNM. The Shielding Algorithm System (SAS) software is one such tool, which uses an improved analysis of gamma ray spectra from radiological sources or SNM to determine the quantity and threat level of the material. Determining the activity of a radioactive gamma ray source becomes very difficult when shielding materials are involved, as the gamma ray spectrum will change significantly in the presence of shielding, with a reduction in the detected activity of the source. This makes it difficult to determine the threat level and is especially true for SNM due to self-shielding effects. The SAS software uses measurements of the shielded spectra, particularly the peak areas, to determine the shielding materials and calculate the shielding factors, which are then used to determine the total activity and (for SNM) the enrichment of the source. The program then determines the most likely isotope(s), activities, and shielding materials that would conform to all of these parameters. The main focus of this work is for SNM, although the same calculations will work for all radioactive materials that have several different peak energies available to measure. Therefore, the program also includes other major isotopes which would be encountered in the field.

The photoelectric effect, coherent (Rayleigh) and incoherent (Compton) scattering, and pair production are the most relevant interactions for gamma ray spectra. As seen in Figure 1.1, the photoelectric effect dominates at low energies. The photoelectric effect occurs when an electron absorbs all the energy of an incident photon, thus ejecting it from the

valence shell. This is a preferable interaction for gamma ray spectroscopy because the measured energy of the electron by the detector will be equal to the energy of the photon. Rayleigh (coherent) scattering occurs when the photon is scattered without transferring energy through ionization or excitation. Compton (incoherent) scattering occurs when only some of the photon's energy is transferred to the valence electron and the photon is then scattered. Although the electron can be ejected, the total energy of the emitted photon is not accurately quantified. This creates additional features within the spectrum, such as Compton plateaus and edges. Pair production can only occur when a photon's energy is greater than 1.022 MeV, resulting in the annihilation of the photon and the creation of an electron-positron pair. These interactions all contribute to the attenuation length of gamma rays in a material as well.

The objective of gamma ray spectroscopy is to identify the radioisotopes within a radioactive source based on their gamma ray emissions and to quantify their activity. The most common gamma spectrometers are high-purity germanium detectors and sodium iodide detectors. Once a gamma ray interacts within the detector, a signal proportional to its energy is created and then binned using a multichannel analyzer. Each photon represents a random event within the spectrum and multiple events at approximately the same energy generate Gaussian peaks. These peaks can be used to identify isotopes by matching known isotope photopeak energies with the centroid of the measured peaks.

Once an isotope is identified, its activity, I, can be calculated as

$$I = \frac{\text{CPS}}{\epsilon \times \text{BR} \times \text{GF}} \ . \tag{1.1}$$

The detector efficiency (ϵ), represents the probability of detection for a given photon. Efficiency curves are produced when the efficiency of a detector is plotted as a function of energy, and these curves vary for different detector configurations. The branching ratio (BR) represents the probability that the isotope will decay in such a way that results in a gamma

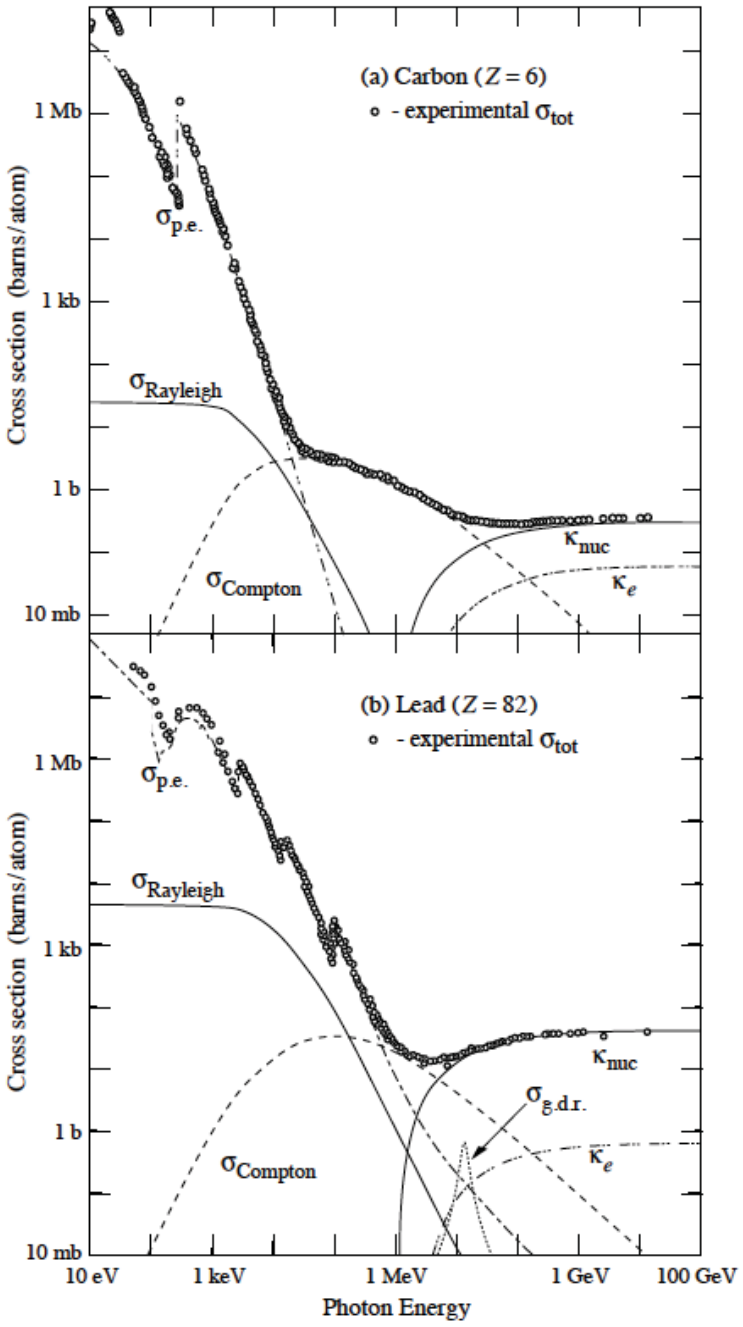

Figure 1.1: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of the different processes. The most relevant interactions for gamma ray spectra are the photoelectric effect ($\sigma_{\text{p.e.}}$), Rayleigh scattering (σ_{Rayleigh}), Compton scattering (σ_{Compton}) and pair production (κ_{nuc} and κ_{e}). [1–3]

emission at a specific energy. The area under each peak is measured, and the net counts per second (CPS) can simply be calculated by dividing the peak area by the live-time, and subtracting the corresponding background level CPS within the region of interest. Finally, the geometry factor (GF) represents the entire system of the measurement, including the source configuration, any shielding between the source and detector, the detector configuration, and the distance from the source to detector. The distance effect (as part of the geometry effect) is inversely proportional to the square of the source-detector distance.

The process of calculating activity changes dramatically when shielding is involved, as can be seen in Figure 1.2, which shows the spectrum for 789 g of reactor grade plutonium with no additional shielding material as the black curve, whereas a spectrum for the same source with an additional 1/4-inch of lead shielding is shown as the blue curve. When a source is shielded, the intensity of the peaks in the gamma ray spectrum will decrease, with low-energy peaks being attenuated more than high-energy peaks. Some peaks may disappear from the spectrum, some peaks may change height drastically, and the count time may need to increase. In most field cases the shielding material(s) may not be known, and thus are not accounted for. This will have consequences in scenarios involving the detection of illicit radiological or nuclear materials.

The decrease in the activity of gamma radiation resulting from passage through a shielding material is described by

$$I = I_0 \times \mathrm{SF} \tag{1.2}$$

where I_0 is the initial activity of the source, I is the activity after passing through a material of thickness, t, with the shielding factor, SF, given by

$$\mathrm{SF} = e^{-\mu t} = e^{-\left(\frac{\mu}{\rho}\right)\rho t} \tag{1.3}$$

where μ is the linear attenuation coefficient of the material. Dividing the linear attenuation

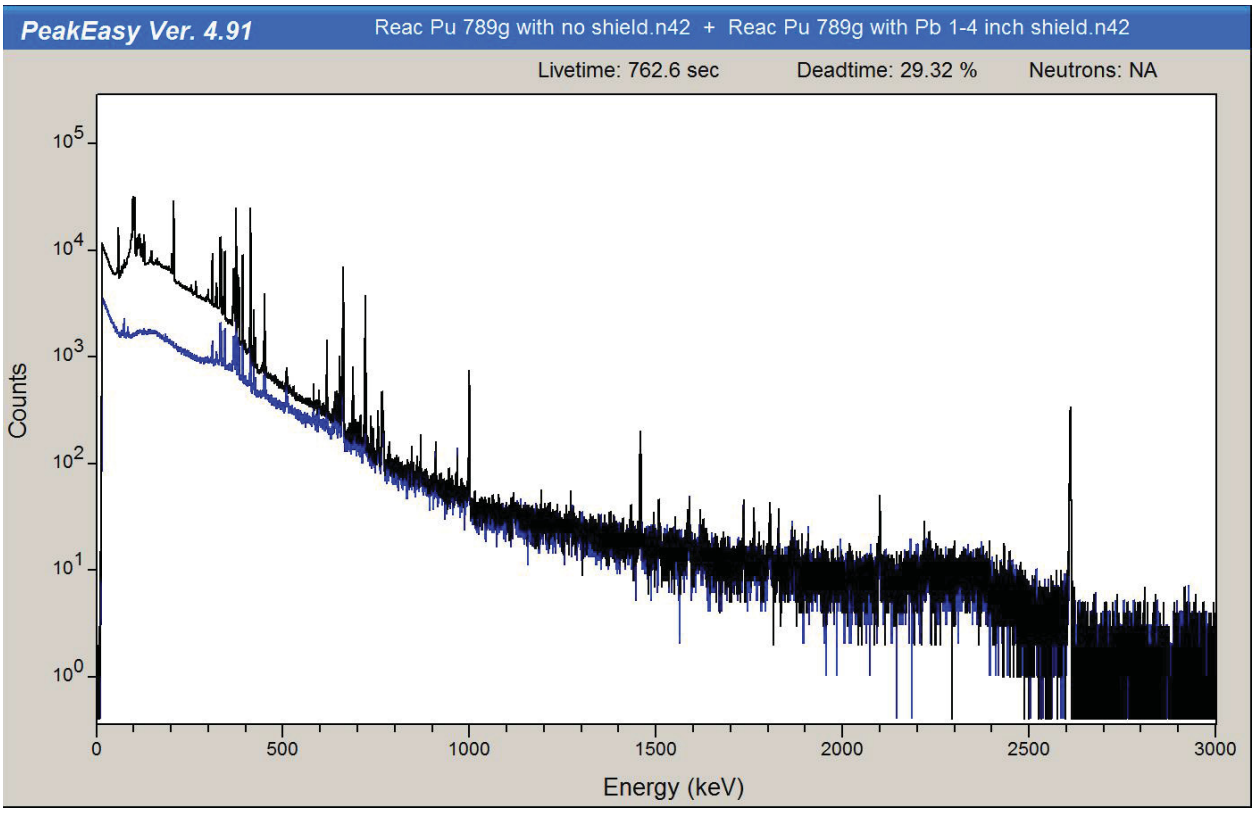

Figure 1.2: Gamma ray spectra of a 789 g reactor grade plutonium source with no additional shielding material (black curve) and with an additional 1/4-inch of lead shielding (blue curve). Note that the live-time of the latter spectrum (735.24 s) is normalized to the live-time of the bare spectrum (762.58 s).

coefficient by the material's density gives the mass attenuation coefficient (MAC):

$$\text{MAC} = \frac{\mu}{\rho} \ . \tag{1.4}$$

Given measurements of the net area of each peak, the live-time, detector efficiency, branching ratio and the source-detector distance, the measured activity is determined from Equation 1.1. The goal of the SAS software is then to calculate the shielding factor from Equation 1.3 and determine the initial activity of the source, I_0, from Equation 1.2.

These calculations were implemented in an early version of the SAS software [4], and a more robust algorithm was later developed and tested [5]. Improvements to the code in Ref. [5] were implemented and these changes are discussed in Ref. [6], along with results from testing the improved version of the SAS software. The focus of this report is to describe the updates to the SAS software since Ref. [6] was published, and these improvements are discussed in Chapter 2 of this report. Results from testing the latest version of the SAS software are presented in Chapter 3 along with recommendations for future development, followed by a summary in Chapter 4.

2. Improvements to the SAS Software

2.1 The SAS Software

In the SAS software, as described in Refs. [5, 6], the shielding factors are calculated using the mass attenuation coefficients for several shielding materials, varying their thicknesses as the minimization parameter. The best-fit parameters are then passed to a chi-squared (χ^2) minimization routine based on the Minuit code [7]. Although this algorithm may be a more brute-force computation than that in Ref. [4], it is expected that this will accurately calculate the shielding factor for a range of material thicknesses, allowing a more accurate determination of the source activities and uncertainties. Furthermore, this algorithm can be generalized for the case where multiple shielding materials are present, and can also account for self-shielding effects.

The SAS program uses the material thicknesses and average activities that minimize the χ^2 value for each set of materials as a starting point for a Minuit minimization, which is performed using TMinuit, the implementation of the Minuit code used in the ROOT [8] library. As the shielding factors always decrease with increasing material thickness, we expect the χ^2 function to be reasonably well-behaved, with the presence of false-minima to be rare. We therefore expect the values of these parameters to give a good initial estimate as input to Minuit. Minuit then calculates an improved estimate of the minimum χ^2 and determines the material thicknesses and source activities, along with uncertainties on these parameters.

In scenarios where self-shielding is present, three common source geometries, namely a sphere, a cube (viewed face-on to simplify the symmetry in the calculations) and a concentric

spherical shell, are used as the first shielding material. Expressions for the self-shielding factors for these configurations are given in Refs. [5, 6]. Although it is difficult to model every possible source geometry, the more that are included in the code, the more likely the program will be able to identify them. For this reason, including the self-shielding factor due to a concentric spherical shell is useful, as it is a common shape used in implosion-type nuclear weapons [9]. In the expressions for the self-shielding factors of the sphere and cube-shaped source, only one parameter (the diameter of the sphere or the edge length of the cube) is involved. However, for the spherical shell, two parameters, chosen to be the outer diameter of the shell and its thickness, are varied to minimize the chi-squared. Because this results in one less degree of freedom in the fit, the minimum number of peaks needed to analyze the spherical shell geometry must be one larger than the minimum number of peaks needed to analyze the sphere and cube source.

In Ref. [6], an automated peak rejection algorithm was added to the SAS program to automatically discard any incorrectly entered data, or energy peaks that are difficult to analyze. Once the peak data is entered into the SAS interface and the user clicks the "Analyze" button, the program removes peaks with energies that are outside the range of the detector efficiency curve, peaks that are below or near the K-edge energy for the selected isotope(s), and peaks that do not fit the shielded activity curve of the form AE^B for some parameters A and B and the energy E in keV. A chi-squared test is used for the latter case to determine which peaks to discard. The program then performs a second chi-squared test to discard peaks that do not fit the expected counts per second for each material thickness combination. These criteria essentially remove the peaks that contribute the most to the chi-squared, thus improving the fit to the remaining peaks.

Once the program is finished running, it generates a dialog box and output file that give the user essential information such as the geometry (size and shape of the source and shielding materials), the activity, mass and enrichment of the isotopes involved for the top

five best-fit material configurations, sorted by p-value. A "Debug" mode gives more verbose output in a separate file that is useful to examine the calculations in more detail and to diagnose errors. This verbose output includes details on the isotopes and peaks entered by the user, the steps in the outlier peak rejection, and a detailed summary of the input and output parameters from Minuit. A list of all the material configurations considered, not simply those with the top five p-values, is also included. Plots that show the parameter space from the initial scan over the material thickness, and plots that show details on the rejection of outlier peaks are also generated using the ROOT analysis package [8]. For more details of these calculations, please refer to Refs. [5, 6].

The following sections provide details on the changes to the SAS software that have been implemented since Ref. [6] was published.

2.2 Changes to the User Interface

An example of the user interface from the previous version of the SAS program from Ref. [6] is shown in Figure 2.1. There have been a number of changes to the user interface in the latest version of the SAS program, as shown by the updated user interface in Figure 2.2. Implementing these changes required extensive coding using the Qt programming language, version 4.8.6 [10].

Several features were either removed or altered in the user interface to improve its layout for better ease of use:

- The "PRINT?" checkbox was removed. This checkbox was found to be unnecessary, as unselecting it caused no output to be written when the SAS program finished running. It was removed, and "Print" mode is now enabled by default. The "DEBUG?" checkbox was moved to the bottom of the user interface and re-labeled as "Enable Debug Mode (Verbose Output)".

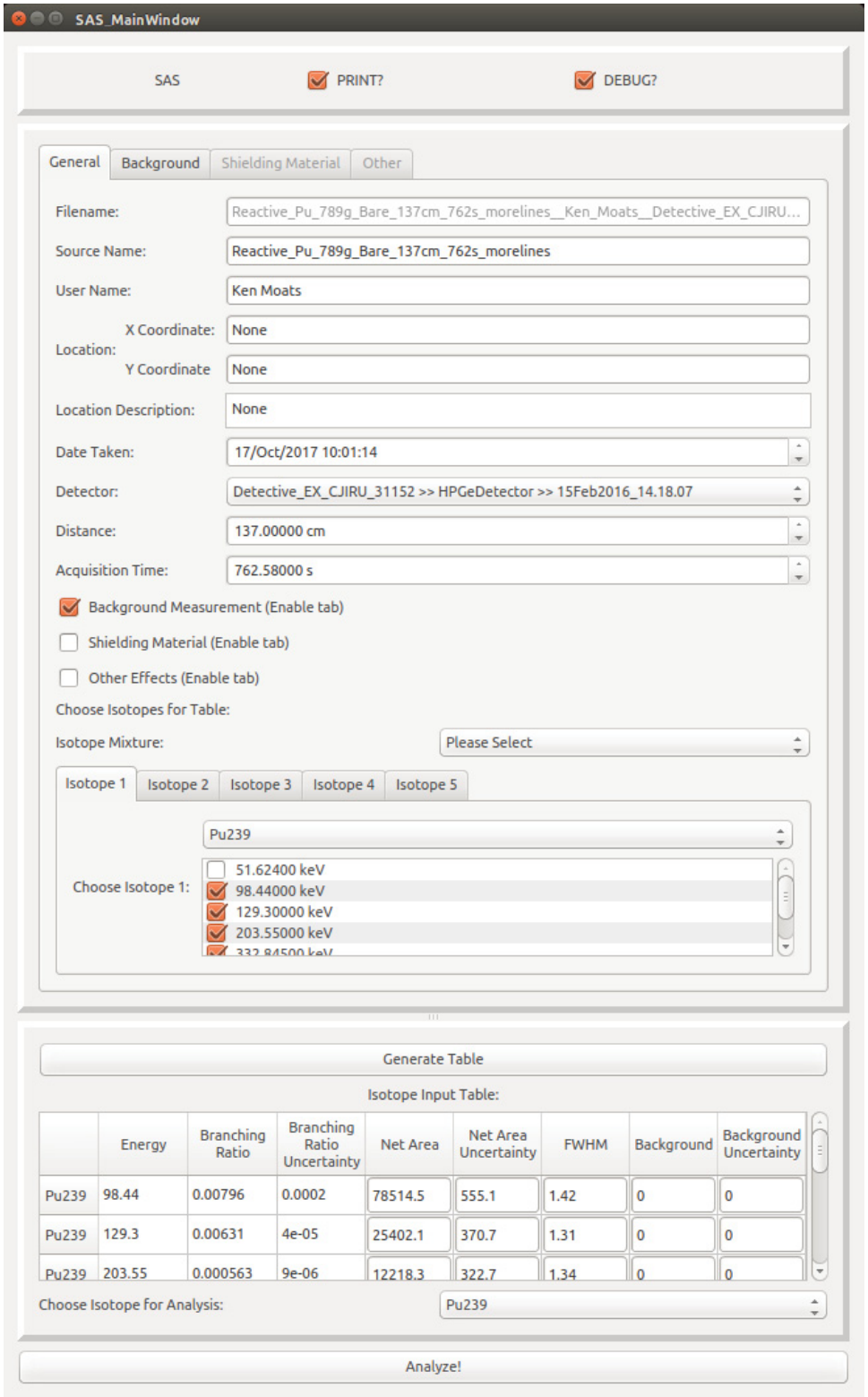

Figure 2.1: An example of the user interface for the previous version of the SAS software [6] showing the input values for the spectrum of 789 g of reactor grade plutonium with no additional shielding.

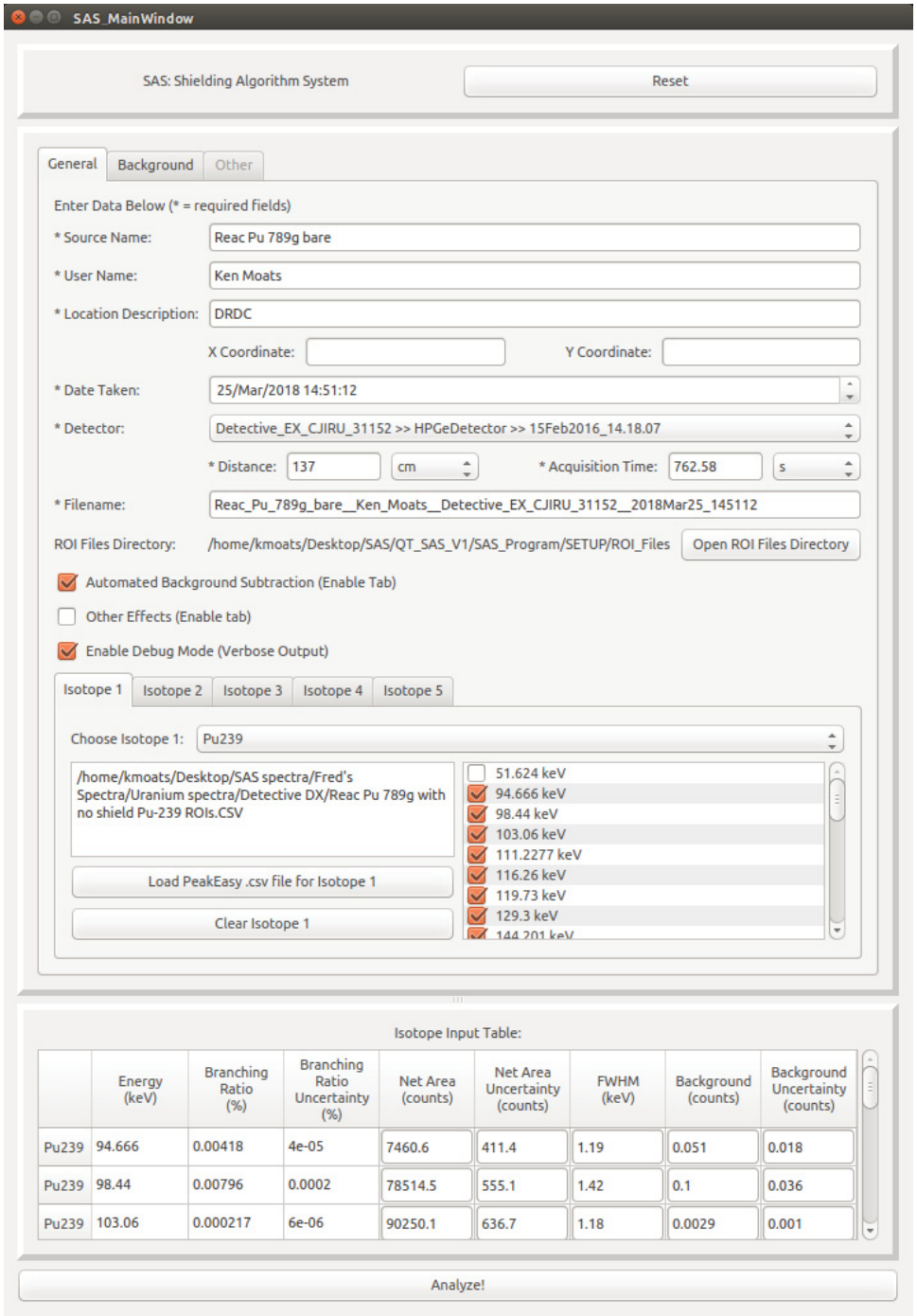

Figure 2.2: An example of the updated user interface for the current version of the SAS software, showing the input values for the spectrum of 789 g of reactor grade plutonium with no additional shielding.

- A "Reset" button was added to the top-right of the user interface. Clicking this button clears all data from the interface in case the user wants to start over or analyze a different spectrum.

- The filename field was moved to near the bottom of the user interface. As the filename field is automatically filled when the user enters the source name, user name, detector and date taken, it is more intuitive for the user to enter information in these fields first. The user can then alter the filename manually if desired.

- The layout of the location fields was rearranged to be more user-friendly.

- The distance and acquisition time fields were redesigned to be more user-friendly. The user also now has the option to enter the source-detector distance in centimetres (default) or metres, and the acquisition time in seconds (default) or minutes.

- The location of the Region of Interest (ROI) files directory within the SAS directory is displayed in the user interface, along with a button that, when clicked, opens the ROI files directory in a separate window in the Linux file browser. The user must select the appropriate ROI file from this directory for the isotope of interest and load it into their spectrum in PeakEasy [11]. The user then generates a .csv file containing the peak energies, the net areas and their uncertainties, and the FWHM for the peaks from the ROI file that were found in their spectrum for that isotope. The user must then load a .csv file into the SAS program for each isotope of interest. This must also be done using the "Background Identification and Quantification" ROI file if the user wishes to include an automated background subtraction.

- A checkbox was added to include an automated background subtraction. This enables a tab named "Background" at the top of the user interface, in which the user can enter a PeakEasy .csv file containing the background peaks for their spectrum, using

the "Background Identification and Quantification" ROI file as described above. The details of the automated background subtraction are explained below in Section 2.4.

- The "Shielding Material" checkbox and tab were removed as they were determined to be obsolete in the new version of the SAS program. The "Other Effects" checkbox and tab were kept as placeholders for additional features that may be added in the future.

- The "Isotope Mixture" drop-down menu was removed, along with the "Generate Table" button and the "Choose Isotope for Analysis" drop-down menu. These features were determined to be obsolete given the new method for selecting peaks from the PeakEasy .csv files.

The above changes are relatively minor. However, the most important update to the user interface is the addition of a drag and drop area and a file browser to give the user two methods for loading PeakEasy .csv files that contain the peak energies, areas, uncertainties and FWHM values for each isotope from a spectrum. There is also a button that clears the file and the selected isotope in case the user wishes to change their input for an isotope. This interface for loading the input files appears in the five isotope tabs, as shown in Figure 2.2, and also in the automated background subtraction tab, if enabled, as shown in Figure 2.3.

These changes remove the need for the user to manually input the spectrum data, which greatly speeds up and reduces the chance of errors in data-entry, especially when there is a large number of peaks that the user wishes to analyze. This makes it much easier and faster for the user to enter information on a greater number of peaks than was previously possible, which should also improve the accuracy of the SAS software. As a result, the SAS software is now a much more user-friendly and powerful tool for analyzing gamma ray spectra than previous versions of the software.

Once the user loads a PeakEasy .csv file into the SAS program and selects the corresponding isotope, the SAS program automatically parses the .csv file, reading in the energy,

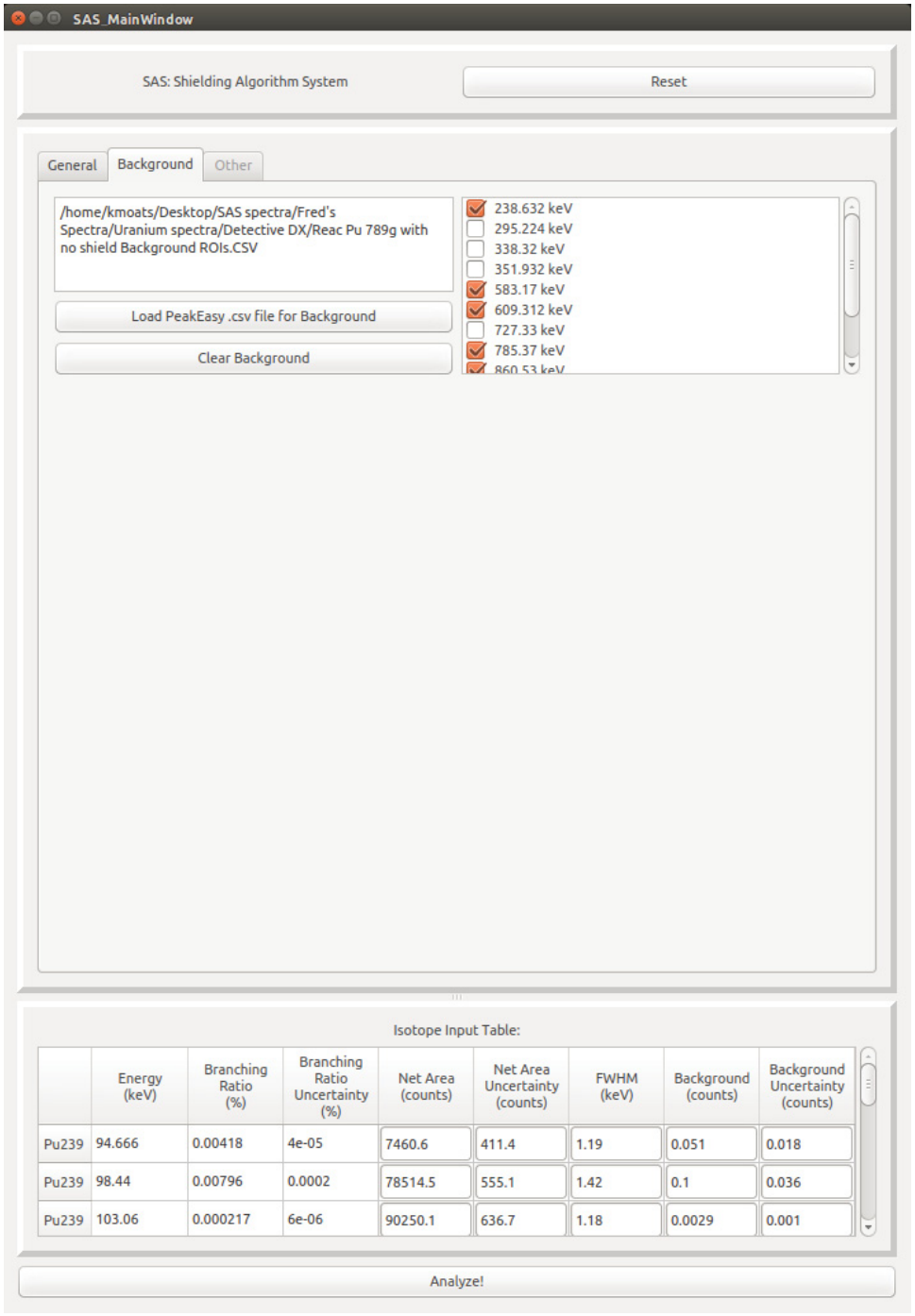

Figure 2.3: An example of the updated user interface for the current version of the SAS software, showing the automated background subtraction tab for the spectrum of 789 g of reactor grade plutonium with no additional shielding. Note that checkboxes for the background peaks that were found in the .csv file are automatically checked in the interface.

the area and its uncertainty, and the FWHM for each peak. If the value of the peak energy is found to be within its FWHM of any peaks in the SAS library files, then this peak is selected and its data is added to the isotope table to be included in the analysis.

When the user clicks the "Analyze" button, the SAS program initializes. If there are any warning messages or errors, the user is notified. If the user did not enter information in any of the required fields (now indicated with a * in the interface), they are prompted to do so and then restart the analysis. After testing the program, both internally and by users from DRDC Suffield, the layout of the error message dialog was changed and additional possible error messages were included. For example, if all the peaks of a given isotope are removed, then the user is notified that the program will use the remaining peaks of any other isotopes to continue the analysis. These changes have helped reduce the possibility of the program crashing when encountering these scenarios.

Another useful feature that was added is a progress indicator. This is displayed once the user clicks the "Analyze" button and accepts any warning messages that may appear. This progress indicator displays a percentage of the total number of shielding material combinations that have been analyzed and is incremented until it reaches 100%, at which point the program is finished running and the output is generated. The user also has the option to click a cancel button to stop the analysis at any time, which brings the user back to the user-interface to change any data that were entered and restart the analysis if desired.

2.3 Additional Peaks and Isotopes

A number of additional isotopes were included in the SAS program library. These are Lu-176, Na-22, W-188 (as a mixture with Re-188), Tl-202 (whose peaks were previously included with the Tl-201 isotope), Xe-133^m (whose peaks were previously included with the Xe-133 isotope), and additional SNM threats such as Pa-233 and Np-237. The full list of available isotopes is shown when the user selects the isotope name from the drop-down menu in each

isotope tab.

Several new energy peaks were added for many of the isotopes, and the values of their branching ratios were taken from Refs. [12, 13]. If two or more of the SAS library peaks of a given isotope are within the FWHM value of the user-entered peak from the .csv input file, then the SAS program adds the branching ratio of these peaks together. This is especially evident when there are two peaks at the same energy. For example, U-238 has two peaks at 62.7 keV whose branching ratios are included as separate entries in the SAS library file for that isotope. One peak is from a transition involving Pa-234 and the other is from a transition involving the metastable Pa-234^m, with branching ratios of $(2.40 \pm 0.75) \times 10^{-3}$ % and $(1.3 \pm 0.4) \times 10^{-3}$ %, respectively [12].

2.4 Automated Background Subtraction

To more accurately account for the background, an automated background subtraction algorithm was implemented in the SAS program. The advantage of this feature is that the user is no longer required to take a separate background measurement to obtain a background spectrum. The automated background subtraction uses known Th-232 and U-238 background peaks which may contribute to the spectrum loaded into the SAS program by the user. To enable this feature, the user must select the "Automated Background Subtraction" checkbox, which enables the "Background" tab at the top of the user interface. Once in that tab, the user can load their background .csv file that was generated in PeakEasy using the "Background Identification and Quantification" ROI file, which contains the known background peaks. These peaks and their branching ratios are shown in Table 2.1.

The SAS program automatically compares the peaks from the user's background .csv file with the peaks in Table 2.1. If any are found, the activity is calculated for each background peak using

$$I = \frac{\text{CPS}}{\epsilon \times \text{BR} \times \text{GF}} \tag{2.1}$$

Table 2.1: Energies and branching ratios for the Th-232 and U-238 background peaks, along with the isotopes involved in each transition. [12]

	Energy (keV)	BR (%)	Isotope
Th-232	238.632	43.6 ± 0.5	Pb-212
	338.32	11.4 ± 0.4	Ac-228
	583.17	30.54 ± 0.11	Tl-208
	727.33	6.65 ± 0.04	Bi-212
	785.37	1.11 ± 0.01	Bi-212
	860.53	4.46 ± 0.04	Tl-208
	911.196	26.2 ± 0.8	Ac-228
U-238	295.224	18.41 ± 0.04	Pb-214
	351.932	35.60 ± 0.07	Pb-214
	609.312	45.49 ± 0.19	Bi-214
	1120.287	14.91 ± 0.03	Bi-214

where the counts per second (CPS) is given in terms of the area of the peak and the acquisition time (in seconds) by

$$\mathrm{CPS} = \frac{\mathrm{Area}}{\text{time (s)}} \ . \tag{2.2}$$

The activity uncertainty is calculated using error propagation

$$\sigma_I = I\sqrt{\left(\frac{\sigma_{\mathrm{CPS}}}{\mathrm{CPS}}\right)^2 + \left(\frac{\sigma_\epsilon}{\epsilon}\right)^2 + \left(\frac{\sigma_{\mathrm{BR}}}{\mathrm{BR}}\right)^2} \tag{2.3}$$

where we have assumed a 5 % uncertainty on the detector efficiency curve, $\sigma_\epsilon/\epsilon = 0.05$, and the error on the counts per second is given by

$$\sigma_{\mathrm{CPS}} = \frac{\sigma_{\mathrm{Area}}}{\text{time (s)}} \ . \tag{2.4}$$

If there are two peaks found with the same isotope (the final column in Table 2.1), then

their activities are compared. If these peaks are due to background, then their activities should be equal, as they are unshielded. They are therefore compared using a Student's t-test, by computing the ratio

$$t = \frac{|I_1 - I_2|}{\sqrt{\sigma_{I_1}^2 + \sigma_{I_2}^2}} \ . \tag{2.5}$$

If $t \leq 2$, then these activities are found to be consistent at 95% confidence level, and their average value is computed and used in the subsequent calculations. If $t > 2$, then these peaks are both included, but one or both of these peaks will get discarded during the next step of the algorithm. All peak activities (using the average value of two peaks if applicable) are then combined into a global average value, $I_{avg} \pm \sigma_{I_{avg}}$, for all peaks. A chi-squared variable is computed using

$$\chi^2 = \sum_{i=1}^{N_{peaks}} t_i^2 \tag{2.6}$$

where

$$t_i = \frac{|I_i - I_{avg}|}{\sigma_{I_{avg}}} \ . \tag{2.7}$$

Using a chi-squared test, if the value of χ^2 exceeds some critical value χ_c^2 for $N_{dof} = N_{peaks} - 1$ degrees of freedom, then the largest value of t_i is discarded and the chi-squared value is recalculated until $\chi^2 < \chi_c^2$. The values of χ_c^2 are obtained from contingency tables such as Table I.7 of Ref. [14]. The resulting average activity value using the remaining peaks is used in the next step of the algorithm.

The average background activity, $I_{avg} \pm \sigma_{I_{avg}}$, is then converted to an expected background counts per second for each peak, i, in the signal spectrum by inverting Equation 2.1:

$$\mathrm{CPS}_{\mathrm{bkgd},i} = I_{avg} \times \epsilon_i \times \mathrm{BR}_i \times \mathrm{GF} \tag{2.8}$$

with an uncertainty given by

$$\sigma_{\mathrm{CPS}_{\mathrm{bkgd},i}} = \mathrm{CPS}_{\mathrm{bkgd},i}\sqrt{\left(\frac{\sigma_{I_{avg}}}{I_{avg}}\right)^2 + \left(\frac{\sigma_{\epsilon_i}}{\epsilon_i}\right)^2 + \left(\frac{\sigma_{\mathrm{BR}_i}}{\mathrm{BR}_i}\right)^2} \ . \tag{2.9}$$

This is then converted to a net area and uncertainty for the expected background from each signal peak, given by

$$\mathrm{Area}_{\mathrm{bkgd},i} = \mathrm{CPS}_{\mathrm{bkgd},i} \times \mathrm{time} \tag{2.10}$$

$$\sigma_{\mathrm{Area}_{\mathrm{bkgd},i}} = \mathrm{Area}_{\mathrm{bkgd},i} \times \mathrm{time} \ . \tag{2.11}$$

This value is listed in the final two columns of the isotope table in the SAS interface, as shown in Figure 2.2. When performing the remaining calculations in the SAS software, the corrected counts per second is used, which is calculated as the difference between the spectrum and expected background counts for each peak:

$$\mathrm{CPS}_{\mathrm{corr},i} = \mathrm{CPS}_i - \mathrm{CPS}_{\mathrm{bkgd},i} \ . \tag{2.12}$$

2.5 Optimizing the Code

The Valgrind code profiler, version 3.10.1 [15], was used to improve the efficiency of the code by optimizing the processor time needed to perform the calculations. It was also useful in diagnosing and fixing memory leaks found in the code. Further code optimization can be done with this tool to improve the speed of the program, particularly for complicated scenarios where the spectra contain a large number of peaks to analyze.

2.6 Documentation

Documentation for the SAS software was generated using Doxygen version 1.8.13 [16], and is located in the /SAS/documentation folder of the source code. This includes a full list of the C++ classes and methods in the code, in .html and .pdf formats. Upkeep of the documentation should be continued as further changes to the code are made. Version control of the code is being handled by a GIT repository, using GIT version 1.9.1 [17], stored in the SAS software source folder.

2.7 Virtual Machine

The SAS software was developed in the Linux operating system. To allow this code to be run as an operational code on any platform, it was installed onto a Linux virtual machine running Ubuntu Linux 14.04. This virtual machine includes all necessary dependencies and libraries to run the SAS software, particularly the ROOT analysis package version 5.34.34 [8]. A screenshot from the Linux virtual machine with the SAS interface running is shown in Figure 2.4. This virtual machine can be run in full screen mode as shown here, or it can be run in a single window within the host operating system, such as Microsoft Windows, to more easily transfer PeakEasy files between the two operating systems. On the desktop, the "SAS" folder contains the source files, the "SAS_Program" icon can be double clicked to launch the SAS Program, and the three folders named "documentation", "ROI_Files" and "OUTPUT" provide the user with shortcuts to these important directories. This virtual machine was tested by running it with the VMware software [18], on both Mac and Windows operating systems and will be given to DRDC Suffield for further development and testing.

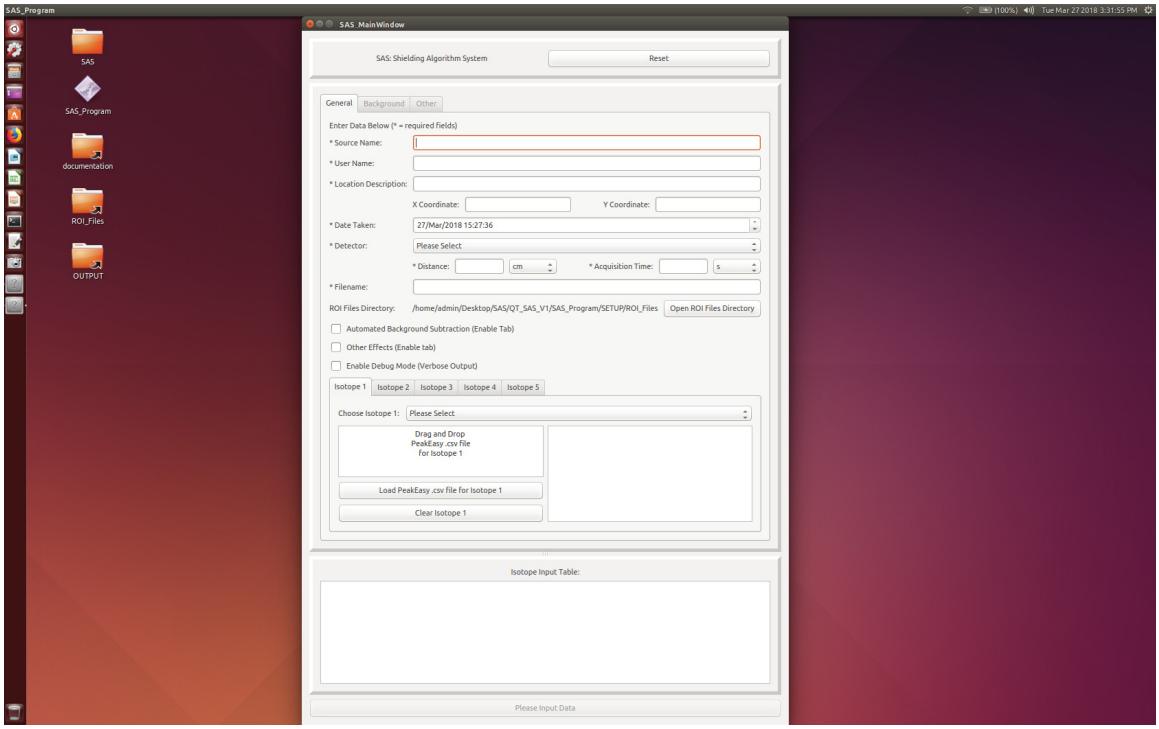

Figure 2.4: A screenshot of the Linux virtual machine running the SAS software.

3. SAS Test Results

Gamma ray spectra using various isotopes, shielding materials, and detectors were obtained at the DRDC Ottawa Research Centre for the purposes of testing the SAS software [5, 6]. The PeakEasy software (version 4.91) [11] was used to measure the peak areas and FWHM of these spectra. This was also done for a spectrum from a Canadian Special Operations Force Command (CANSOFCOM) exercise, and in this section we present results from the current version of the SAS software using these measurements as input.

3.1 CANSOFCOM Exercise Data

As a test of the updated SAS program, the spectrum shown in Figure 3.1 of an unknown source from a CANSOFCOM exercise, previously analyzed in Ref. [6], was re-analyzed. Previous results from Ref. [6] showed that the best-fit shielding material combinations were consistent with a sphere or cube of plutonium of roughly 20-30 cm in size, with minimal additional shielding ($\sim$ 1 cm of steel), with the most likely configuration corresponding to 45 ± 11 kg of plutonium and an enrichment of 84 ± 7 %.

As can be seen in Table 3.3 of Ref. [6], only eight Pu-239 peaks, two Pu-240 peaks, and six Am-241 peaks were used to obtain these results. However a minimum of seven of these peaks were discarded during the outlier rejection. Furthermore, the automated background subtraction had not yet been implemented. As a result, the uncertainties on these results were found to be rather large, roughly 24 % for the total plutonium mass.

In our updated analysis of this scenario, we take advantage of the updated user interface, which makes it much easier and faster for the user to enter a larger number of peaks from their spectrum. The peak energies, branching ratios (taken from the Laboratoire National Henri

Becquerel database [12], except for some that were taken from the Brookhaven National Laboratory National Nuclear Data Center [13]), their measured areas and uncertainties, as well as the FWHM values from PeakEasy are given in Table 3.1. The live-time was 1148.1 s and the Detective EX detector was at a distance of 50 cm. Only peaks that pass the outlier rejection algorithm are shown here, and the final column gives the expected background counts using the automated background subtraction. We see that we now have 35 Pu-239 peaks, two Pu-240 peaks and four Am-241 peaks that pass the initial outlier rejection. A few of these peaks may be discarded when performing a χ^2 test using the counts per second for some shielding material combinations, but using this many peaks to calculate the source activities is expected to increase the accuracy of the results for this scenario. We see that the background counts are relatively small compared to the net areas of the peaks, as expected in this case, but if there were uranium isotopes provided as input to the SAS program, then their background is expected to be larger.

Figures 3.2-3.3 summarize the output of the SAS software for this case. We see that the top five best-fit scenarios are consistent with a sphere or cube of plutonium of roughly 1.5 cm in size, with minimal shielding ($\sim$ 8 cm of beryllium or $\sim$ 5 cm of concrete), with the most likely configuration corresponding to 2.6 ± 0.4 kg of plutonium with an enrichment of 87 ± 3 %. This scenario would be an immediate SNM threat, as this amount of plutonium could be used in a nuclear weapon. We see that the relative uncertainties have been reduced compared to the previous results from Ref. [6], and we expect that this is primarily due to the increased number of input peaks resulting in a more reliable result.

3.2 Future Improvements

The SAS program is now an operational software that has been tested using spectra for several commonly encountered radiological isotopes and SNM, and has proven to be a useful tool for estimating the source activity and shielding in these scenarios. Although several

Table 3.1: Peak energies and areas for the CANSOFCOM exercise spectrum from Figure 3.1, obtained from PeakEasy and used as input for the SAS program. The live-time was 1148.1 s and the Detective EX detector was at a distance of 50 cm. Only peaks that pass the initial outlier rejection algorithm are shown here, and the final column gives the expected background counts using the automated background subtraction.

Isotope	Energy (keV)	BR ($\times 10^{-3}$ %)	Area (counts)	FWHM (keV)	Background Area (counts)
Pu-239	144.20	0.285 ± 0.007	10,345.0 ± 826.6	1.12	6.80 ± 0.51
	161.39	0.128 ± 0.006	20,998.0 ± 1,284.6	1.42	3.00 ± 0.26
	171.39	0.110 ± 0.003	13,105.0 ± 918.5	1.65	2.50 ± 0.19
	179.22	0.0656 ± 0.0019	9,974.9 ± 853.1	1.59	1.40 ± 0.11
	189.23	0.0930 ± 0.0018	14,528.0 ± 865.5	1.77	2.00 ± 0.15
	195.68	0.106 ± 0.002	18,986.0 ± 820.5	1.64	2.20 ± 0.16
	203.55	0.563 ± 0.009	112,650.0 ± 841.5	1.59	11.00 ± 0.83
	255.38	0.0795 ± 0.0020	27,656.0 ± 649.5	1.67	1.40 ± 0.10
	263.95	0.0259 ± 0.0010	9,812.8 ± 610.9	1.69	0.430 ± 0.035
	297.46	0.0492 ± 0.0013	20,496.0 ± 543.6	1.53	0.740 ± 0.056
	311.78	0.0257 ± 0.0008	25,123.0 ± 549.3	1.64	0.370 ± 0.029
	320.86	0.0540 ± 0.0012	35,145.0 ± 601.0	2.03	0.770 ± 0.057
	323.84	0.0530 ± 0.0013	37,120.0 ± 598.9	2.03	0.750 ± 0.056
	332.85	0.488 ± 0.008	324,830.0 ± 764.5	1.69	6.70 ± 0.49
	336.11	0.1110 ± 0.0026	103,160.0 ± 598.5	1.69	1.50 ± 0.11
	341.51	0.0650 ± 0.0013	32,352.0 ± 506.8	1.53	0.880 ± 0.065
	345.01	0.598 ± 0.009	295,510.0 ± 720.3	1.56	8.00 ± 0.58
	367.82	0.1748 ± 0.0024	127,100.0 ± 727.2	1.58	2.20 ± 0.16
	375.05	1.540 ± 0.021	960,360.0 ± 1,074.1	1.60	19.0 ± 1.4
	380.19	0.302 ± 0.004	187,540.0 ± 584.3	1.59	3.70 ± 0.27
	382.75	0.256 ± 0.004	161,710.0 ± 550.3	1.59	3.20 ± 0.23
	393.00	0.540 ± 0.023	371,370.0 ± 703.4	1.75	6.50 ± 0.54
	413.71	1.464 ± 0.021	1,053,600.0 ± 1,066.4	1.63	17.0 ± 1.2
	422.60	0.119 ± 0.002	87,172.0 ± 379.4	1.59	1.400 ± 0.099
	426.68	0.0239 ± 0.0006	18,505.0 ± 267.9	1.55	0.270 ± 0.020
	451.48	0.187 ± 0.003	150,680.0 ± 440.8	1.62	2.00 ± 0.15
	481.66	0.00461 ± 0.00010	4,080.1 ± 194.6	1.79	0.0470 ± 0.0035
	597.99	0.00174 ± 0.00006	3,215.8 ± 152.2	1.92	0.0150 ± 0.0012
	618.62	0.00327 ± 0.00012	17,655.0 ± 184.9	1.79	0.0270 ± 0.0021
	633.15	0.00255 ± 0.00006	3,196.4 ± 130.4	1.71	0.0200 ± 0.0015
	639.99	0.00846 ± 0.00020	5,440.8 ± 167.9	1.43	0.066 ± 0.005
	645.94	0.0149 ± 0.0003	16,953.0 ± 179.3	1.72	0.1200 ± 0.0086
	658.86	0.00959 ± 0.00026	7,772.3 ± 158.5	1.44	0.0730 ± 0.0055
	703.68	0.00410 ± 0.00013	4,691.0 ± 118.9	1.78	0.0290 ± 0.0022
	769.29	0.0119 ± 0.0016	20,075.0 ± 180.0	2.04	0.076 ± 0.011
Pu-240	160.31	0.4045 ± 0.0022	24,144.0 ± 1,148.2	2.26	9.50 ± 0.68
	874.00	0.00058 ± 0.00006	370.3 ± 69.3	2.74	0.00350 ± 0.00044
Am-241	322.52	0.151 ± 0.004	21,777.0 ± 555.9	1.66	2.10 ± 0.16
	662.40	0.367 ± 0.006	78,977.0 ± 303.0	1.77	2.80 ± 0.20
	688.72	0.0323 ± 0.0006	8,323.4 ± 141.1	1.94	0.230 ± 0.017
	722.01	0.196 ± 0.005	45,474.0 ± 234.7	1.81	1.30 ± 0.10

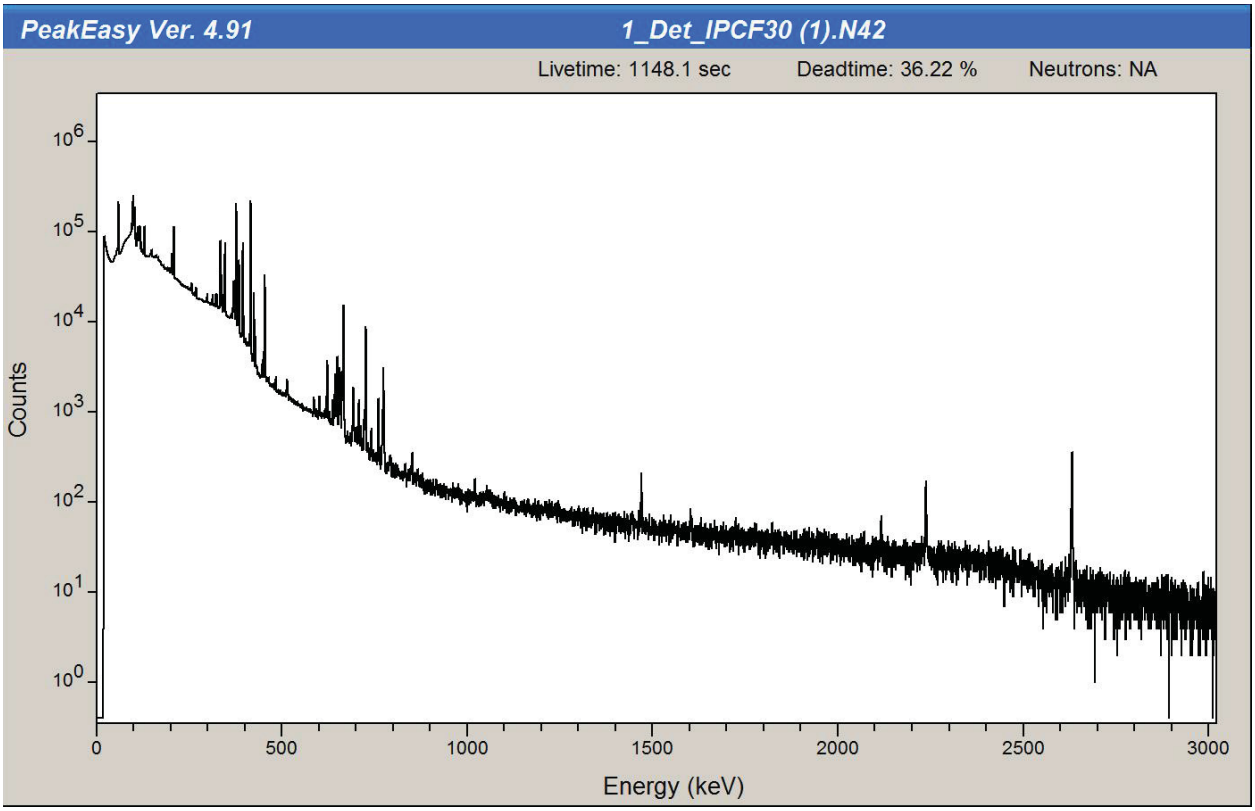

Figure 3.1: Gamma ray spectrum of an unknown source from a CANSOFCOM exercise. The live-time was 1148.1 s and the Detective EX detector was at a distance of 50 cm.

bugs have been fixed in the code, there may be others that have not yet been encountered. Therefore, further testing by multiple users should be done to diagnose and eliminate any additional bugs that may arise. Further work in optimizing the program, using Valgrind or other code profilers, should be done to improve the efficiency of the software and reduce processor time.

Features that would be useful to add to the software include the option to change the thresholds for rejecting outlier peaks, or the ability to add or remove peaks manually. These would give an advanced user more control over the input to the SAS program.

In some shielding material combinations, the Minuit minimization in the SAS software

```
###############
SAS FINAL REPORT
###############

Date: 24/Mar/2018
Time: 22:16:46

User: Ken Moats
Isotope Name: ExVA17


---------------------
Location Information:
---------------------

X-Coordinate:
Y-Coordinate:

Location Description:
DRDC

--------------------
Detector Information
--------------------

User: Ian_Watson
Detector Type: HPGeDetector

Date Calibrated: 15/Feb/2016
Time Calibrated:: 14:18:07


-----------------------------
Data Acquisition Information:
-----------------------------

Distance: 50cm
Time: 1148s


========
RESULTS:
========


============================================================
Shielding Configuration 1, chi2 = 7.043, Ndof = 18, p-value = 0.990
============================================================

     Material         Thickness         Thickness
                                       Uncertainty
                         (cm)              (cm)
     --------        ---------         ---------
    Plutonium_Cube             0.93              0.25     (Edge Length)
         Beryllium             7.79              0.81


     Isotope          Activity          Activity           Mass             Mass          MassPercent       MassPercent
                                       Uncertainty                      Uncertainty                       Uncertainty
                         (Bq)              (Bq)              (g)              (g)              (%)               (%)
     -------          --------          --------          ----             ----          -----------       -----------
             Pu239        5.173e+12         9.707e+11         2.252e+03        4.226e+02        8.738e+01         2.975e+00
             Pu240        2.735e+12         5.299e+11         3.254e+02        6.303e+01        1.262e+01         2.975e+00
          Pu Total        7.908e+12         1.106e+12         2.578e+03        4.273e+02
             Am241        1.002e+12         1.534e+11         7.886e+00        1.208e+00


============================================================
Shielding Configuration 2, chi2 = 7.085, Ndof = 18, p-value = 0.989
============================================================

     Material         Thickness         Thickness
                                       Uncertainty
                         (cm)              (cm)
     --------        ---------         ---------
  Plutonium_Sphere             1.53              0.59       (Diameter)
          Concrete             5.22              0.65


     Isotope          Activity          Activity           Mass             Mass          MassPercent       MassPercent
                                       Uncertainty                      Uncertainty                       Uncertainty
                         (Bq)              (Bq)              (g)              (g)              (%)               (%)
     -------          --------          --------          ----             ----          -----------       -----------
             Pu239        5.605e+12         1.434e+12         2.440e+03        6.245e+02        8.722e+01         3.980e+00
             Pu240        3.005e+12         7.485e+11         3.575e+02        8.905e+01        1.278e+01         3.980e+00
          Pu Total        8.611e+12         1.618e+12         2.798e+03        6.308e+02
             Am241        1.090e+12         2.404e+11         8.582e+00        1.893e+00
```

Figure 3.2: Report information and the first two best-fit shielding configurations and activities for the CANSOFCOM exercise spectrum, obtained from the Minuit minimization of the SAS program, and sorted by p-value.

```
============================================================
Shielding Configuration 3, chi2 = 7.289, Ndof = 18, p-value = 0.987
============================================================

    Material         Thickness        Thickness
                                     Uncertainty
                        (cm)             (cm)
    --------        ---------        ---------
  Plutonium_Sphere          1.51             0.57       (Diameter)
         Beryllium          8.17             1.01

    Isotope          Activity         Activity           Mass            Mass         MassPercent       MassPercent
                                     Uncertainty                      Uncertainty                      Uncertainty
                        (Bq)             (Bq)             (g)             (g)             (%)              (%)
    -------          --------         --------         ----            ----         -----------       -----------
            Pu239       6.099e+12        1.481e+12        2.655e+03       6.448e+02       8.735e+01        3.765e+00
            Pu240       3.231e+12        7.727e+11        3.844e+02       9.192e+01       1.265e+01        3.765e+00
         Pu Total       9.330e+12        1.671e+12        3.039e+03       6.513e+02
            Am241       1.178e+12        2.452e+11        9.277e+00       1.930e+00


============================================================
Shielding Configuration 4, chi2 = 7.292, Ndof = 18, p-value = 0.987
============================================================

    Material         Thickness        Thickness
                                     Uncertainty
                        (cm)             (cm)
    --------        ---------        ---------
  Plutonium_Sphere          1.38             0.50       (Diameter)
               C-4          7.48             0.97

    Isotope          Activity         Activity           Mass            Mass         MassPercent       MassPercent
                                     Uncertainty                      Uncertainty                      Uncertainty
                        (Bq)             (Bq)             (g)             (g)             (%)              (%)
    -------          --------         --------         ----            ----         -----------       -----------
            Pu239       5.644e+12        1.202e+12        2.457e+03       5.233e+02       8.736e+01        3.315e+00
            Pu240       2.988e+12        6.324e+11        3.555e+02       7.523e+01       1.264e+01        3.315e+00
         Pu Total       8.632e+12        1.358e+12        2.812e+03       5.287e+02
            Am241       1.097e+12        1.949e+11        8.640e+00       1.535e+00


============================================================
Shielding Configuration 5, chi2 = 7.393, Ndof = 18, p-value = 0.986
============================================================

    Material         Thickness        Thickness
                                     Uncertainty
                        (cm)             (cm)
    --------        ---------        ---------
  Plutonium_Sphere          1.36             0.49       (Diameter)
             Water         12.17             1.58

    Isotope          Activity         Activity           Mass            Mass         MassPercent       MassPercent
                                     Uncertainty                      Uncertainty                      Uncertainty
                        (Bq)             (Bq)             (g)             (g)             (%)              (%)
    -------          --------         --------         ----            ----         -----------       -----------
            Pu239       5.634e+12        1.166e+12        2.452e+03       5.074e+02       8.730e+01        3.238e+00
            Pu240       2.999e+12        6.183e+11        3.568e+02       7.355e+01       1.270e+01        3.238e+00
         Pu Total       8.633e+12        1.319e+12        2.809e+03       5.127e+02
            Am241       1.096e+12        1.881e+11        8.627e+00       1.481e+00
```

Figure 3.3: The third to fifth best-fit shielding configurations and activities for the CANSOFCOM exercise spectrum, obtained from the Minuit minimization of the SAS program, and sorted by p-value.

may return errors or warnings when trying to minimize the chi-squared, either due to difficulty in converging on the best-fit values of the parameters or in determining the uncertainties when computing the error matrix for these parameters. Although these should be rare in the relatively simple cases considered thus far, it would be very helpful if these warnings and errors could be added to the program output, allowing the user to judge how reliable their results are for more complicated scenarios. In addition to these error flags, other information can be added to the output, including a statement regarding the threat level of the source.

The SAS software currently requires at least three peaks to pass the outlier rejection criteria in order to analyze a spectrum. This is because for a single shielding material, the two minimization parameters are the material thickness and source activity, so there must be at least three peaks to give a non-zero number of degrees of freedom when calculating the chi-squared value. For scenarios in which only two peaks are used as input, the algorithm must be altered to give reasonable results. The material cannot be determined, and therefore only single material scenarios will be considered. If the material is assumed, the best-fit thickness for that material can be determined by setting the activities of each peak equal to each other and solving the shielding factors for value of the thickness. This results in an approximate activity derived from the two peaks. This should work well for Co-60 and other high energy gammas, but will be much less reliable at lower energies as the mass attenuation factors are more variable for different materials at lower energies.

A feature that would make the SAS software a more powerful tool is the addition of Compton effects to the shielding factors, which may require a Geant4 Monte Carlo simulation [19] to parametrize them. This is non-trivial, but it should allow the entire spectrum to be used for a better solution, as the plateau in the spectrum due to Compton scattering (at $\sim$ 1 MeV in Figure 1.1) can be modelled. Effects due to bremsstrahlung may be important for isotopes such as Sr-90/Y-90, and could also be modelled to more accurately use the entire spectrum.

Currently, the SAS software assumes up to three shielding materials when calculating the shielding factor, only one of which can be due to self-shielding. These are relatively simple geometries where the shielding materials are either a slab of material of some thickness, or in the case of self-shielding, a sphere, cube or spherical shell. More complex shielding scenarios, for example a sphere of plutonium shielded by a shell of depleted uranium, cannot be modelled accurately with the current SAS software. Furthermore, some of the peaks from the two isotopes may interfere if they have the same energy. An additional check that the SAS program currently makes is that the FWHM of a peak should be less than 3.5 keV, as this value exceeds the expected resolution of the detector. A peak with a FWHM greater than 3.5 keV would indicate that the peak being analyzed has interference from other radiation sources, and is discarded from the analysis. These interference effects should be accounted for in these scenarios to better model the source activity and shielding materials.

4. Summary

The objective of the SNM detection work being conducted at DRDC is to develop technologies that improve the ability of the CAF to detect, quantify, and determine the threat level of SNM. The SAS software, developed at the DRDC Ottawa Research Centre, is one such tool that uses an improved analysis of gamma ray spectra from radiological sources or SNM to determine the quantity and threat level of the material. The SAS C++ software calculates the shielding factor for several combinations of shielding materials, including self-shielding effects, using a chi-squared minimization routine based on the Minuit code. The software has been tested for several spectra involving multiple isotopes and as a result of this testing, several improvements to the SAS software were implemented in this work. Major changes to the user interface have greatly improved the speed at which the user can input the data from their spectrum, which allows a greater number of peaks to be included more easily in the analysis. An automated background subtraction algorithm was implemented to estimate the expected background from a spectrum without requiring the user to take a separate background measurement. These changes are expected to improve the reliability and accuracy of the software. Users from DRDC Suffield have tested the program for usability, found issues, and these have been addressed in the current version of the software.

An unknown spectrum from a CANSOFCOM exercise was analyzed using the current version of the SAS software. A greater number of input peaks were used compared to previous analyses [6] and an automated background subtraction was included. Therefore, the software is expected to give a more accurate estimate of the source activity. The source was determined to be a combination of Pu-239, Pu-240, and Am-241, with the most likely scenario corresponding to 2.6 ± 0.4 kg of plutonium as a sphere or cube of roughly 1.5 cm in

size, with minimal additional shielding (~ 8 cm of beryllium or ~ 5 cm of concrete) and an enrichment of 87 ± 3 %. This would indicate an immediate SNM threat, as this amount of plutonium could be used in a nuclear weapon, and is exactly the type of scenario for which the SAS program was designed to analyze and identify.

The SAS software tool has demonstrated that an improved estimate of the activity and shielding materials of shielded isotopes can be achieved in realistic scenarios. An operational version of the SAS software was installed on a Linux virtual machine for use by DRDC Suffield in the near future. Further testing must be done to improve the calculations and efficiency of the code, and additional features should be included to make this a more powerful tool for analyzing gamma ray spectra. The final product will then be made available to the CAF to determine the threat level of SNM, or any radiological material, encountered in the field.

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13. ABSTRACT/RÉSUMÉ (When available in the document, the French version of the abstract must be included here.)

ABSTRACT

The objective of the Special Nuclear Material (SNM) detection work being conducted at Defence Research and Development Canada (DRDC) is to develop technologies that improve the ability of the Canadian Armed Forces (CAF) to detect, quantify, and determine the threat level of SNM. The Shielding Algorithm System (SAS) software, developed at the DRDC Ottawa Research Centre, is one such tool that uses an improved analysis of gamma ray spectra from radiological sources or SNM to determine the quantity and threat level of the material. The SAS C++ software calculates the shielding factor for several combinations of shielding materials, including self-shielding effects, using a chi-squared minimization routine based on the Minuit code. The software has been tested for several spectra involving multiple isotopes and as a result of this testing, several improvements to the SAS software were implemented in this work. Major changes to the user interface have greatly improved the speed at which the user can input the data from their spectrum, which allows a greater number of peaks to be included more easily in the analysis. An automated background sub-traction algorithm was implemented to estimate the expected background from a spectrum without requiring the user to take a separate background measurement. These changes are expected to improve the reliability and accuracy of the software. Users from DRDC Suffield have tested the program for usability, found issues, and these have been addressed in the current version of the software.

An unknown spectrum from a Canadian Special Operations Force Command (CANSOF-COM) exercise was analyzed using the current version of the SAS software. A greater number of input peaks were used compared to previous analyses and an automated background sub-traction was included. Therefore, the software is expected to give a more accurate estimate of the source activity. The source was determined to be a combination of Pu-239, Pu-240, and Am-241, with the most likely scenario corresponding to 2.6 ± 0.4 kg of plutonium as a sphere or cube of roughly 1.5 cm in size, with minimal additional shielding (~ 8 cm of beryllium or ~ 5 cm of concrete) and an enrichment of 87 ± 3 %. This would indicate an immediate SNM threat, as this amount of plutonium could be used in a nuclear weapon, and is exactly the type of scenario for which the SAS program was designed to analyze and identify.

The SAS software tool has demonstrated that an improved estimate of the activity and shielding materials of shielded isotopes can be achieved in realistic scenarios. An operational version of the SAS software was installed on a Linux virtual machine for use by DRDC Suffield in the near future. Further testing must be done to improve the calculations and efficiency of the code, and additional features should be included to make this a more powerful tool for analyzing gamma ray spectra. The final product will then be made available to the CAF to determine the threat level of SNM, or any radiological material, encountered in the field.

RÉSUMÉ

Les travaux de détection de matières nucléaires spéciales (MNS) réalisés par Recherche et développement pour la défense Canada (RDDC) visent à concevoir des technologies qui accroissent la capacité des Forces armées canadiennes (FAC) à détecter et à quantifier des MNS, ainsi qu'à évaluer la menace qu'elles posent. Le logiciel d'algorithme de blindage (LAB) du Centre de recherches de RDDC à Ottawa permet de quantifier des MNS et d'en évaluer le degré de menace grâce à une analyse améliorée des spectres de rayonnement gamma issus de ces sources radiologiques. Le LAB C++ calcule le facteur de blindage de plusieurs combinaisons de matières, y compris leurs effets d'« autoblindage », à l'aide d'une routine de minimisation par test du chi carré fondée sur le code Minuit. Le logiciel a été éprouvé au moyen

de plusieurs spectres rattachés à de multiples isotopes, et plusieurs améliorations lui ont été apportées au cours des travaux traités ici. D'importants changements visant l'interface de l'utilisateur ont permis d'accélérer considérablement la vitesse à laquelle l'utilisateur peut entrer des données liées au spectre visé, ainsi que de faciliter l'intégration d'un nombre supérieur de pointes à l'analyse. Un algorithme de soustraction de bruit de fond automatisée a été mis en œuvre pour estimer le bruit prévu d'un spectre donné, sans que l'utilisateur ne doive effectuer une mesure distincte du bruit. Les changements effectués devraient accroître la fiabilité et l'exactitude du logiciel. Des utilisateurs de RDDC Suffield ont éprouvé le programme sur le plan de l'utilisabilité et des problèmes relevés, éléments dont la présente version du LAB tient compte.

Un spectre inconnu issu d'un exercice du Commandement des Forces d'opérations spéciales du Canada (COMFOSCAN) a été analysé avec la version actuelle du LAB. Comparativement aux analyses précédentes, de nombreuses pointes d'entrées ont été employées et une soustraction de bruit de fond automatisée a été effectuée. On s'attend donc à ce que le logiciel produise des estimations plus exactes de l'activité des sources. On a établi que la source analysée lors de l'exercice consiste en une combinaison de Pu-239, de Pu-240 et d'Am-241; le scénario le plus probable repose sur la présence de 2,6 ± 0,4 kg de plutonium, sous la forme d'une sphère ou d'un cube d'environ 1,5 cm présentant un blindage supplémentaire minimal (environ 8 cm de béryllium ou 5 cm de béton) et un enrichissement de 87 ± 3 %, ce qui témoignerait d'une menace immédiate posée par des MNS, car une telle quantité de plutonium pourrait servir à produire une arme nucléaire, scénario typique pour lequel le LAB a été conçu aux fins d'analyse et d'identification.

Le LAB a montré qu'une estimation améliorée de l'activité et du blindage d'isotopes peut être accomplie dans le cadre de scénarios réalistes. Une version opérationnelle du LAB a été installée sur un appareil virtuel, sous Linux, en vue d'une utilisation prochaine par du personnel de RDDC Suffield. D'autres essais doivent être exécutés pour améliorer les calculs et l'efficacité du code, et d'autres fonctions devraient être ajoutées, afin de rendre le logiciel plus puissant aux fins d'analyse de spectres de rayonnement gamma. Le produit final sera ensuite mis à la disposition des FAC aux fins d'évaluation de la menace posée par des MNS ou toute matière radiologique trouvées en campagne.