A Small Diameter, Flexible, All Attitude, Self-Contained Germanium Spectrometer

Operator's Manual

May 1997

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Developed by
R. L. Brodzinski, E. A. Lepel, J. H. Reeves¹
R. Kohli^{2*}

for
Battelle, Columbus Laboratory, Columbus, Ohio

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Operator's Manual

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I. Introduction

The end of the Cold War has brought about tremendous changes in the nuclear complex of the Department of Energy. One of the many changes has been the shutdown or decommissioning of many facilities that performed nuclear work. One of the steps in the process of decommissioning a facility involves the decontamination or removal of drain lines or pipes that may have carried radioactive materials at one time. The removal of all these pipes and drain lines to a nuclear disposal facility could be quite costly. It was suggested by Pacific Northwest National Laboratory (PNNL) that a germanium spectrometer could be built that could fit through straight pipes with a diameter as small as 5.08 cm (2 inches) and pass through curved pipes with a diameter as small as 7.6 cm (3 inches) such as that of a 3-inch p-trap in a drain line. The germanium spectrometer could then be used to simultaneously determine all gamma-ray emitting radionuclides in or surrounding the pipe. By showing the absence of any gamma-ray emitting radionuclides, the pipes could then be reused in place or disposed of as non-radioactive material, thus saving significantly in disposal costs.

A germanium spectrometer system has been designed by PNNL and fabricated by Princeton Gamma Tech (PGT) that consists of three segments, each 4.84 cm in diameter and about 10 cm in length (Figure 1). Flexible stainless steel bellows were used to connect the segments. Segment 1 is a small liquid nitrogen reservoir. The reservoir is filled with a sponge-like material which enables the detector to be used in any orientation. A Stirling cycle refrigerator is under development which can replace the liquid nitrogen reservoir to provide continuous cooling and operation.

Figure 1: Picture of flexible, small diameter, all attitude, self-contained germanium spectrometer

The liquid nitrogen is used to cool a flexible copper braid that connects to the germanium crystal in segment 2. The p-type germanium crystal has an atypical aspect ratio - 38 mm diameter by 56 mm long. The active volume is 58 cm³ with a relative efficiency of 11% and a resolution of 1.76 keV for the 1332.5-keV gamma ray of ⁶⁰Co. The inner and outer walls of segment 2 are coated with polished gold to provide a high emissivity for insulation against infra-red radiation.

Segment 3 houses the preamplifier electronics. The bellows connecting segments 2 and 3 is the conduit through which the wires from the detector for signal and bias are routed. An additional wire was added by Princeton Gamma Tech during fabrication to allow monitoring the crystal temperature during initial testing. The preamplifier wires, detector bias cable, detector signal cable, and detector temperature cable exit the preamplifier housing through two holes in the end. In addition, a small cable was also attached to the preamplifier end of the detector system as a guide wire/rope. A small ring welded to a vented nut which mates with the threaded fill opening of the Dewar was used to attach a guide wire/rope to the other end of the detector assembly. This second guide wire/rope is 30.5 m (100 ft) long. In this manner the detector can be pulled through a pipe in either direction.

Approximately 23 m (75 ft) of guide wire, signal, detector bias, preamplifier, and detector temperature cables were enclosed in a flexible plastic sheath for connecting to the multichannel analyzer which is a computer controlled Nomad Plus system from EG&G Ortec. The Nomad Plus is a self-contained small suitcase that contains the detector bias supply, amplifier, and ADC and sends its data to a portable computer through its parallel port.

The liquid nitrogen reservoir can be filled using a small funnel that mates to the screw threads of the fill opening. The detector specifications require a cooling time of 6 hours before the detector can be used. It was experimentally determined that 4 hours was sufficient time to cool the germanium crystal to less than 100 °K when a vigorous filling schedule was maintained. The detector could then be used with bias on for at least two hours after a complete fill. In the next hour the detector temperature would slowly rise to about 150 °K. This should provide sufficient time to remove the detector from the pipe and refill the reservoir for continued use. Refilling the cold detector/Dewar assembly only requires a few minutes.

Since the liquid nitrogen reservoir for the detector needs to be filled every 2 to 3 hours, a larger "chicken feeder" was built that could be attached to the detector when it was not actually deployed in piping. This reservoir holds enough liquid nitrogen to keep the detector cold for more than 72 hours.

Peripheral equipment includes a foam padded storage/transport case, a plexiglass support stand for aid in filling with liquid nitrogen, a set of hand tools for assembly/disassembly of any components of the system, a "Richardson" valve for removing the main vacuum valve and accessing the detector/Dewar vacuum chamber, a safety cable to prevent stressing the electronic connections when the Richardson valve is attached, a laminated Coleman lantern mantle for energy calibration and system control, and a short jumper cable for attaching the detector temperature cable to a volt-ohm meter.

II. Operation of Detector

A. Cool to Operating Temperature (Initial)

The first step in the operation of the detector is to cool the intrinsic germanium crystal to operating temperature. The easiest way to do this is by pouring liquid nitrogen from a Dewar of approximately 4 liters into the fill funnel. Remove the detector assembly from the shipping box and mount it upright in the plexiglass support stand. The Dewar segment (segment 1) should be resting on top of the support stand and be secured in place with the removable plastic wedge. Attach the small funnel with vent tube to the fill opening by screwing on the funnel assembly.

Start cooling the detector by pouring liquid nitrogen into the Dewar. Use **CAUTION** when handling liquid nitrogen. At first there will be significant venting of nitrogen gas as the liquid nitrogen begins cooling the funnel assembly, the flexible copper braid, and the intrinsic germanium crystal in segment 2. As soon as the stainless steel funnel has reached liquid nitrogen temperature (most obvious when drops of condensed liquid oxygen drip off the bottom of the funnel), a rubber stopper or rubber bulb can be held on top of the funnel to create a pressure head that will aggressively force the liquid nitrogen into the Dewar. Initially, nitrogen gas will escape the vent tube followed by some drops of liquid nitrogen that are carried out with the gas flow. When a solid flow of liquid nitrogen comes out of the vent tube, the Dewar has been cooled to a temperature near that of the liquid nitrogen. It may take one-half to one hour to reach this point. Frost will form on the funnel and the Dewar during this process (See Figure 2). You should not see frost on the detector segment, segment 2. If frost forms on the detector segment it indicates loss of system vacuum and high convection heat transfer between the detector and the environment. Should this situation occur, stop cooling and refer to the pump-out instructions and the trouble shooting section of Appendix F and G.

At this point the Dewar should be continuously topped off while the detector is cooling. Heat transfer via the copper braid will be high at first and decrease as the temperature differential becomes smaller. It will take about 2 to 3 hours before the detector reaches an equilibrium operating temperature. Note that the Detector Performance Sheet (Appendix B) recommends a 6 hour cooling period although 4 hours has been experimentally determined to be more than adequate. Princeton Gamma Tech also recommends 2 hours as the maximum time between refills and 2.5 hours as the Dewar holding time. These values have been substantiated experimentally.

During fabrication of the detector, PGT installed a thermistor next to the germanium crystal so that they could monitor the temperature during the cooling process. This sensor was not removed after completion of the detector and has been used by PNNL to monitor the detector cooling process. The thermistor essentially measures resistance which can be converted to temperature by using the Temperature vs. Resistance Table in Appendix C. Therefore, the detector temperature could be monitored by observing the resistance readings obtained with a volt-ohm meter by using the supplied jumper cable with the small round LEMO connector at one end and the red and black banana plugs on the other end. The small LEMO connector is attached

Figure 2: Cooling the Detector

to a wire that comes from the preamplifier (about 15 inches long) and the red and black banana plugs are connected to the inputs on a volt-ohm meter measuring resistance.

Under ideal conditions, following bake-out and pump-down, the detector has been brought from room temperature of 24°C (resistance of $109\ \Omega$) to operating temperature of -175°C (98°K , resistance of $29.2\ \Omega$) in about three hours. PGT has indicated the operating temperature should be less than 100°K when high voltage bias is applied. With continued cooling, the lowest detector temperature observed was 90.5°K .

Unfortunately, this thermistor has shorted out and is not currently useable.

B. Electronics

The electronic components necessary to operate the detector are the same as those typically used for gamma-ray spectroscopy. The detector is connected to a preamplifier, the preamplifier is connected to the input of an amplifier, the output of the amplifier goes to an analog-to-digital-converter (ADC), and the output of the ADC goes to a multichannel analyzer (MCA). High

voltage is supplied to the germanium crystal to provide bias, and low voltage power is supplied to the preamplifier. A typical block diagram is shown in Figure 3 below. The power supplies, amplifier, and ADC are contained in the EG&G Ortec system called Nomad Plus which is controlled by a PC computer.

Figure 3: Detector Schematic

C. Nomad Plus - A Portable, Self-Contained, Computer Controlled Gamma Spectroscopy System

A portable, self-contained, computer controlled gamma spectroscopy system called Nomad Plus was purchased from EG&G Ortec. This brief-case size system contains the high voltage bias supply, amplifier, ADC, and memory that previously required a full size NIM bin worth of electronic components (See Figure 4). In addition, there is a battery contained in the case which provides 8 hours of remote operation. A hardware manual is also supplied with the Nomad Plus.

The Nomad Plus has the equivalent functionality of an Ortec Model 672 amplifier, an Ortec Model 918A ADC Acquisition Module (ADCAM), and an Ortec Model 659 High Voltage Bias supply. It is controlled by a user supplied PC that will run either Ortec's Maestro for Windows or Ortec's GammaVision software. The software also controls the on/off high voltage bias supply switch (a knob can be used to set the proper voltage) as well as the amplifier and the ADC parameters.

EG&G Ortec supplies three software programs that can be used to control the detector, acquire and store spectra, and analyze a spectrum. The first two programs provide only a rudimentary analysis of the spectrum while the third program is a full blown gamma-ray analysis, data reduction program. A brief description is given of detector set up and control using the preferred programs.

D. Initial Operation

Plug the Nomad Plus into a standard 110 VAC outlet for normal operating power (a slide switch is provided on the Nomad to change to 220 V European power). Connect the Nomad Plus to the computer via the parallel port with the three foot long cable provided for that purpose. If printer capability is desired, the printer is then connected via its parallel port to the printer outlet on the Nomad Plus.

The 75 ft cable set is used to connect the detector to the Nomad Plus. This includes the detector high voltage cable, the signal cable, the preamplifier power cable, and the temperature monitor cable. Each cable has unique connectors and cannot be hooked up incorrectly. The high voltage is an SHV connector at both ends, the signal is a BNC at both ends, the preamplifier power is a large LEMO (round) connector at the preamplifier end and a standard 9-pin D-shell connector at the Nomad Plus end, and the temperature monitor cable has the small LEMO (round) connector at both ends.

Figure 4: Picture of Computer and Nomad Plus

1. Maestro II and MAESTRO for Windows Detector Setup

The first two programs are called Maestro II and MAESTRO for Windows. They are essentially the same program but the first operates only in DOS and the second operates in Windows 3.1 and Windows 95. Since the preferred mode of running the computer is using Windows 95, Maestro II will not be discussed. MAESTRO for Windows is a software program that controls the high voltage, shaping time constant, pole zero, amplifier gain, conversion gain, and zero offset of the ADC. After the detector has been energy calibrated and a spectrum acquired, a simplified library may be loaded for use. The software is able to perform a simple Mariscotti peak search of the spectrum and output the results as net peak areas or the result of the net peak area divided by a constant which is supplied in the nuclide library. This analysis does not correct for sample decay, correct for branching fractions associated with each gamma-ray, or take into account the appropriate efficiency curve for the sample geometry. These could all be combined together as the constant that is in the nuclide library, but it would be very cumbersome to use and implement for more than one geometry. Consequently, the full blown gamma-ray spectrum analysis package, GammaVision, was obtained for quantitative analysis. To simply acquire spectra using Maestro, the following setup is required.

On the acquisition computer, click on the WinMCA icon to open up the program. To set up the system, choose **Acquire**, then choose **ADC Setup**. Choose **4096** for the conversion gain and then **OK**. Choose **Acquire** again, choose **Adjust Controls** (See Figure 5), under **Shaping Time** choose **Long**, and under **Preamplifier type/Automatic Pole Zero** check **Resistive Feedback/Auto PZ**. Pole zero is set by clicking the **Trigger** button. Verify the high voltage bias setting knob is set to 0.0. Under **Detector Bias**, check the box to **Enable HV**. Verify that the detector bias has been turned on by observing the red light for High Voltage "On", on the Nomad Plus case. Also verify that the positive polarity light is on. The detector specifications are positive polarity and we have found that an operating voltage of 2000 V is currently optimum although a higher voltage was initially recommended. Slowly turn the high voltage up at a rate no greater than 100V/sec until the desired voltage is reached. The computer will also display the value of the high voltage. Adjust the amplifier gain to 1 keV/channel. This is done by checking the appropriate coarse gain and then either adjusting the slide meter or inputting a value in the window. This will be further discussed in the next section. Once the approximate energy calibration is attained, click on **Trigger** and then readjust the gain for the desired energy calibration. Choose **Close** to exit the window.

Figure 5: Maestro and GammaVision Adjust Controls screen

2. GammaVision Detector Setup

GammaVision is the data acquisition and data analysis program that is supported by EG&G Ortec. It uses nuclide libraries that include the branching fractions of the various gamma-rays, it will do decay corrections, and it will calculate an energy calibration curve as well as the efficiency calibration curve for the detector and chosen geometry.

Choose the GammaVision icon on the desktop. Choose **Acquire**, then choose **ADC Setup**. Choose **4096** for the conversion gain, and then **OK**. Choose **Acquire** again, choose **Adjust Controls**, and the same Adjust Controls screen is presented as used with Maestro (see Figure 5). Under **Shaping Time** choose **Long**, and under **Preamplifier type/Automatic Pole Zero** check **Resistive Feedback/Auto PZ**. Pole zero is set by clicking the **Trigger** button. Verify the high voltage bias knob is set at 0.0. Under **Detector Bias**, check the box to **Enable HV**. Verify that the detector bias has been turned on by observing the red light for High Voltage "On" on the Nomad Plus case. Also verify that the positive polarity light is on. The detector specifications are positive polarity and we have found that an operating voltage of 2000 V is currently optimum although a higher voltage was initially recommended. Slowly turn the high voltage up at a rate no greater than 100V/sec until the desired voltage is reached. The computer will also display the value for the high voltage. Adjust the amplifier gain to 1 keV/channel. This is done by checking

the appropriate coarse gain and then either adjusting the slide meter or inputting a value in the window. An effective gain of 11.39 is desired. Once the approximate energy calibration is attained, click on **Trigger** and then readjust the gain for the desired energy calibration. Choose **Close** to exit the menu. Many times adjusting the gain and zero level is an iterative process. The above process is somewhat cumbersome because you have to go back and forth between the MCA display and the Acquire menu. The gain can also be adjusted by using the **ALT +** or the **Alt-** keys while in the MCA display.

E. Spectrum Acquisition and Storage

Acquisition of a gamma-ray spectrum involves choosing the detector to be displayed, clearing the spectrum, setting the count time, starting the count, stopping the count or letting it time out, and storing the spectrum. To initiate this process choose **Detector 1** to Display, then choose **Acquire** on the menu bar. Choose **Clear**, then choose **Start**. A window may open up asking for the length of count. Normal operation is to set a specified live time, but an indefinite time period may be selected by leaving the live time and real time entries blank.

The "Sample Description" should be updated to reflect the sample currently being counted. This is done by choosing **Services**, then **Sample Description**, and updating the contents of the window with the correct sample information.

Alternatively, choose **Analyze**, then **Settings**, then **Sample Type**. A window opens up with the heading Sample Type Settings (See Figure 6). In this window the **Sample Description** can be updated, the **Acquisition Presets** can be chosen (**Live**, **Real**, **Peak**, **Integral** or **Uncertainty**), the **Calibration** is found (choose **Internal**), the **Nuclide Library** is found, what to use for the **Background Type** (choose **Auto**), how to do the **Peak Background Correction**, whether to perform any **Decay Correction** (either from the time of collection or during acquisition), **Analysis Range** in channels (choose 30 to 4000), the **Type of Uncertainty** reporting (choose results in **Percent** and the error calculated for **Counting** statistics), the **Confidence level** of the reported results (choose **1 sigma**). The last options are the various reports that can be output - **Unknown peaks**, **Library peak list**, **Library peak matrix**, and **Nuclide Abundance**, and where they are sent - printer, file , or program.

Figure 6: Sample Type Window

When the count is finished, store the spectrum in the directory **c:\user** by choosing **File**, then **Save As** which opens a **Save Spectrum File** window. Choose to save the spectrum as a **Real SPC** spectrum (the extension is “.spc”), and the directory should point to **c:\user**. Under **File Name** enter the name of the spectrum to be saved minus the extension.

F. Energy Calibration

The detector system must be energy calibrated before extensive analysis of the spectrum can be accomplished. The energy calibration calculates two parameters necessary for the data analysis software: an equation representing the energy vs. channel number and an equation representing Full Width at Half Maximum (FWHM) vs. energy.

Typically, a simple spectrum is collected for energy calibration with very well resolved peaks spanning the entire energy region. A typical laboratory calibration source consists of ^{241}Am with a peak at 59.5 keV, ^{137}Cs with a peak at 661.7 keV, and ^{60}Co with peaks at 1173.2 and 1332.5 keV. Because this spectrum consists of only 4 gamma-rays, it is very easy to identify the peaks and to adjust the gain accordingly. Typically the gain is adjusted so that the 59.5 keV peak is in channel 59.5 and the 1332.5 peak is located in channel 1332.5. If the gain is close to start with, the **Alt +** and **Alt -** keys can be used to bring the gain into calibration. Sometimes the zero level needs to be adjusted also. There is a small screw located on the Nomad Plus labeled ADC zero which may be used to make the adjustments. Focus on the 59.5 peak and adjust the zero level until the peak centroid is located at channel 59.5. Once the zero level is set, final adjustments to

the gain can be made to bring the 1332.5 keV peak into channel 1332.5. Calibration is performed by choosing **Calibrate** and then **Energy**. The **Calibration** window opens on the right side of the screen along with a window labeled **Energy Table** and **Energy Calibration Fit** if a calibration has been previously used (See Figure 7). Since a new calibration is to be performed, click on **Calibration** and then choose **Destroy**. The old calibration will be deleted and a new calibration can now be entered. Choose the highest energy peak having good statistical accuracy and highlight it with the cursor. The Calibration window will display the peak at channel number and the true energy value for that peak is then entered in the box. **Enter** is then clicked, and then an Energy Calibration Fit window comes up and shows the calibration curve for that spectrum based on that peak and assuming it goes through 0,0. Next, put the cursor on the 1173.2 keV peak, and repeat the process until the 59.5 keV peak has also been entered. The Energy Calibration Fit window shows the energy vs. channel calibration curve as well as the FWHM vs. channel curve. If the calibration curves are acceptable, choose **Save** and save the calibration curve data to a known file name.

Figure 7: Calibration Screen

Because of DOT transportation and other regulatory concerns for radioactive material, this type of source may be onerous to use in the field. A calibration source has been provided consisting of Coleman lantern mantles which contain ^{232}Th decay products. Because this source is an exempt material, it can be transported and used freely.

Five easily discernible peaks present in the Coleman lantern mantle spectrum are used for the energy calibration: the 238.626 keV peak of ^{212}Pb , the 583.14 keV peak of ^{208}Tl , the 911.07 keV and 968.9 keV peaks of ^{228}Ac , and the 2614.47 keV peak of ^{208}Tl . The same procedure is used for the energy calibration as described above.

III. Detector Usage in Piping

The detector has been designed to pass through 5.08 cm (2 inch) diameter straight piping and curved pipes with a diameter as small as 7.6 cm (3 inches). A small ring welded to a vented nut mates to the screw threads of the Dewar fill opening. A 30.5 m (100 ft) guide wire/rope attaches to this ring. The preamplifier end of the detector also has a small loop that the guide wire/rope in the cable set is attached to. This cable set is 23 m (75 ft) long. In this manner the detector can be pulled in either direction.

The preamplifier segment is not completely water tight due to a machined indentation on the collar that attaches the bellows between segment 2 and segment 3. Therefore, to keep the preamplifier dry and the detector system generally clean, it is recommended that a sacrificial plastic sheath be kept over the detector when in use. Heat shrink tubing is recommended. Polyethylene tubing may also be used to help protect the detector and cabling.

It is recommended that spectra **NOT** be acquired while the detector is in motion. The best resolution will be attained if the detector is stationary (reduced microphonics). It is also suggested that a 300 second count will provide sufficient statistical accuracy for most needs.

IV. Library Creation

PNNL has provided two libraries for use with the primary intended application. They are Westjeff.lib and King.lib and were based on information supplied by the Battelle Columbus Laboratory. These libraries are listed in Appendix E.

A. Library Creation by GammaVision

A nuclide library can be created using GammaVision. However, because of the ease of use of the Nuclide Navigator program, it is recommended and will be discussed further below. For further information on the GammaVision version, please refer to their manual.

B. Library Creation by Nuclide Navigator

The EG&G Ortec software package Nuclide Navigator makes the creation of nuclide libraries virtually painless. Start Nuclide Navigator and choose the Library Manager view by choosing **Options** and then **Library Manager**. Choose the source library, typically it is **pc_nudat.mdb**, and then pick a name for the target library. Two windows will open up that are side by side (See Figure 8). Choose **Options** and then choose **Copy/Report**. A window will open to choose the number of gamma-rays to be copied - choose **Top 5**. Then close the window. To create a new library, find the isotope of interest on the left window, highlight it, and then drag it over to the section under **Nuclides** on the right side window. If the isotope is highlighted, the various gamma-rays associated with that isotope will be listed. The list of gamma-rays may also be edited by highlighting a given gamma-ray, choosing **Edit**, and then choosing **Delete gamma-rays**. Other editing choices are available if needed. Continue by choosing the isotope needed in the left window and then drag it over to the right window. In this manner, the entire library is created. Some fine tuning of this library may then be performed if necessary. The new library is automatically saved with the extension ".mdb" which implies it is saved in a format compatible with Microsoft Access. However, the new library must also be saved in a format that is compatible with GammaVision and that is done by choosing **File, Save as**, and then choosing **GammaVision**. A Window opens asking if the file should be saved with the previously entered name. Choose **OK**, and the file is then saved with the extension ".lib."

Figure 8: Nuclide Navigator...Library Manager View

Additional information on the use of Nuclide Navigator may be obtained by consulting the *Nuclide Navigator II, Interactive Gamma Ray Reference and Library Program for Microsoft Windows Software User's Manual*.

V. Data Analysis Using GammaVision

The process of analyzing a gamma-ray spectrum can be complex. For this exercise, the assumption is made that a spectrum has been acquired using the flexible detector inside a pipe. The assumed geometry is that the radioactive material is distributed homogeneously about the pipe so that the calibration file "snakehom.clb" is used. The library used is "Westjeff.lib." The report will be sent to a printer attached to the system.

To initiate the analysis process, load the efficiency curve "snakehom.clb". Choose **Calibrate** from the menu bar, then choose **Recall Calibration**, then choose "c:\user\snekehom.clb". This loads both an energy and efficiency calibration. If the energy calibration needs to be changed, do so at this time. Next load the library "Westjeff.lib" by choosing **Library**, then **Select File**, and then select "c:\ortec\lib\westjeff.lib."

Verify the analysis parameters and sample ID by choosing **Analyze**, then **Settings**, and then **Sample Type**. The Sample Type Settings window opens up (See Figure 9). Update the sample description, choose **Calibration** and check **Internal**, choose **Nuclide Library** and check **Internal**, choose **Background Type** and check **Auto**. Leave **Peak Background Correction** and **Decay Correction** unchecked. Under **Analysis Range** set the range as channel 40 to

Sample Type Settings

File:

Description:

Acquisition Presets

Real: Peak:
Live: Intg:
Unct.: %

Calibration

Internal ☒ File:

Nuclide Library

Internal ☒ File:

Background Type

☒ Auto. ☐ 1-pt. ☐ 3-pt. ☐ 5-pt.

Peak Background Correction

☐ On ☐ File:

Decay Correction

☐ Collection... date: time:
☐ During Acquisition

Analysis Range (channels)

from: to:

Uncertainty Reporting

☒ Percent ☒ Counting
☐ Activity ☐ Total

Confidence level

☒ 1- ☐ 2- ☐ 3-Sigma

Reporting Options

☒ Unknown peaks ☒ Library peak list ☒ Library peak matrix ☒ Nuclide abundance

Peak Cutoff: %

Output

☒ Printer
☐ File:
☐ Program:

Figure 9: Sample Type Settings Window

channel 4000. Choose **Percent** and **Counting Uncertainty Reporting**. Then choose **1 Sigma Confidence** level. Check the 4 **Reporting Options**, set the **Peak Cutoff** at 50%, and choose **Output Printer**.

Verify the **Analysis Settings** by choosing **Analyze**, then **Settings**, then **System**. The Analysis

The screenshot shows a dialog box titled "Analysis Settings" with a close button in the top right corner. The dialog is divided into several sections. The first section, "SYSTEM TYPE DEFAULTS", contains fields for "Laboratory name:" (Battelle) and "Operator name:" (Battelle). Below this is a "Units" section with radio buttons for "Bq" and "uCi" (selected), and input fields for "Multiplier:" (1000.00) and "Divisor:" (1.00). A "Label:" field contains "pCi/sam". The next section, "MDA Type:", has a dropdown menu set to "Currie limit". Below that, "Lib. match width:" is set to "0.50" and "File for suspected nuclides:" is set to "SUSPECT.LIB". The "PEAK SEARCH SENSITIVITY" section has a scale from "Most..." to "...least" with radio buttons for "1", "2" (selected), "3", "4", and "5". At the bottom are "OK" and "Cancel" buttons.

SYSTEM TYPE DEFAULTS	
Laboratory name:	Battelle
Operator name:	Battelle
Units	
☐ Bq	Multiplier: 1000.00
☒ uCi	Divisor: 1.00
Label:	pCi/sam
MDA Type:	
	Currie limit
Lib. match width:	0.50
File for suspected nuclides:	SUSPECT.LIB
PEAK SEARCH SENSITIVITY	
Most...	...least
☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5

OK Cancel

Figure 10: Analysis Settings...System Window

Settings window opens (Figure 10), and you can update the **Laboratory name** and **Operator name**. Also choose the **Units** for data reporting. Choose **uCi** and set the label as **uCi/g** with a **Multiplier** of 1000 and a **Divisor** of 1. Choose an **MDA Type** such as **Currie Limit**, **Library match width** of 0.5, **File for suspected nuclides** as Westjeff, and the **Peak Search Sensitivity** of 2. Then click **OK**.

To analyze the spectrum, choose **Analyze**, then choose **Entire spectrum in memory** (See Figure 11). The spectrum will be analyzed and a report printed on the attached printer. In addition, the data report file will be stored on the computer with the filename it was given and an extension of ".rpt." The report will be reported in the units chosen - uCi/g.

Figure 11: Analyze Window

For information on other ways to perform the data analysis or where to send the report, refer to the *GammaVision, Gamma-Ray Spectrum Analysis and MCA Emulation for Microsoft Windows3.x and Microsoft Windows for Workgroups Software User's Manual*.

VI. Detector Cooling (Long-Term)

It is vitally important that the detector be at liquid nitrogen temperature any time high voltage is applied to it. As mentioned previously, when the detector is in operation the nitrogen dewar needs to be filled about every 2 hours.

When the detector is not being used, but has been previously cooled to liquid nitrogen temperature, it is recommended that the chicken feeder be attached to the Dewar. The time between fills of the chicken feeder is a maximum of about 72 hours. Because of the small size of the detector and small quantity of getter material inside the Dewar, it is recommended that the detector be kept cold continuously if possible.

VII. Detector Controls

A check source has been fabricated to be used with this detector. It consists of two undisturbed Coleman lantern mantles mounted between two curved pieces of lucite. The check source holder can be attached to the side of the detector in a reproducible fashion. In this way, a series of counts can be taken to establish a history of the detector operation and to verify correct efficiency. It is recommended that the check source be counted before each use of the detector and the data analysis results for two peaks be monitored. Choose the low energy peak at 238.6 keV and monitor the peak channel number, peak energy, net peak area, and the FWHM of the peak. This should also be done for a high energy peak such as the 2614.5-keV peak. The livetime of the check source count should be chosen such that the net peak areas have counting statistical errors of less than 1%.

Chapter 7 of the GammaVision software package describes the Quality Assurance module. Please refer to that for set up of the detector quality assurance file. It also provides the ability to have control charts with warning and alarm settings.

References

- Browne, E., R. B. Firestone. *Table of Radioactive Isotopes*, John Wiley & Sons, 1986
- EG&G Ortec, *GammaVision, Gamma-Ray Spectrum Analysis and MCA Emulation for Microsoft Windows 3.x and Microsoft Windows for Workgroups, A66-BI, Software User's Manual. Software Version 2.4.*
- EG&G Ortec, *Nomad Plus Portable Spectroscopy System, Hardware Reference Manual.*
- EG&G Ortec, *Nuclide Navigator II, Interactive Gamma Ray Reference and Library Program for Microsoft Windows, C53-BI, Software User's Manual, Software Version 2.*
- D. C. Stromswold, "Calibration Facilities at Hanford for Gamma-Ray and Fission-Neutron Well Logging," PNL-9958/UC-606. July 1994.

Appendix B Detector Specifications

DETECTOR PERFORMANCE

	MODEL NUMBER	SERIAL NUMBER
DETECTOR	IGC 10	2769
PREAMPLIFIER	RG11C/C	101
CRYOSTAT	IPM	

CRYSTAL GEOMETRY	P TYPE COAXIAL	
CRYSTAL DIAMETER	38 mm	LENGTH 56 mm
CRYSTAL ACTIVE VOLUME	58 cm ³	
DEAD LAYER	<1 mm	

DEWAR HOLDING TIME	2.5 hours	
MAXIMUM RECOMMENDED TIME BETWEEN REFILLS	2 hours	
COOLING PERIOD BEFORE OPERATION	5 hours	

DETECTOR BIAS	+2500 V
BIAS POLARITY	POSITIVE
RAISE DETECTOR BIAS AT RATE NO FASTER THAN 100 VOLTS PER SECOND.	

PREAMPLIFIER OUTPUT POLARITY	NEGATIVE
FEEDBACK VOLTAGE AT OPERATING BIAS	-.24 V

PERFORMANCE:

AT 1332KeV

FWHM	1.75 KeV	FWHM	3.22 KeV
RELATIVE EFFICIENCY	*10.93 %	P/C	37.10 :1

*Measured with the source at 25cm from the side of the crystal section.

TEST EQUIPMENT:

AMPLIFIER	PGT 347
BIAS SUPPLY	PGT 314
PULSE HEIGHT ANALYZER	APTEC MCARD

TEST CONDITIONS:

COUNT RATE	900 cps
AMPLIFIER TIME CONSTANT	4 us
RESTORE	LOW /ASYM

DATA FILE #	78-244
REPORT #	71-244

TESTED BY : Gleny L. L. L. DATE : OCT-30-96

Appendix C Temperature vs Resistance Table

Temperature Vs. Resistance Table

For European Curve, Alpha = .00385

1° Celsius Increments

°C	Ohm	Diff.	°C	Ohm	Diff.	°C	Ohm	Diff.	°C	Ohm	Diff.	°C	Ohm	Diff.	°C	Ohm	Diff.
-200	16.49		-140	43.87	0.42	-80	69.33	0.41	-20	97.15	0.39	+0	100.00	0.39	+60	125.24	0.38
-199	18.93	0.44	-139	44.28	0.41	-79	68.73	0.40	-19	96.55	0.39	+1	100.39	0.39	+61	125.62	0.38
-198	19.36	0.43	-138	44.70	0.42	-78	68.13	0.40	-18	95.95	0.40	+2	100.78	0.39	+62	126.01	0.39
-197	19.79	0.43	-137	45.11	0.41	-77	67.53	0.40	-17	95.34	0.39	+3	101.17	0.39	+63	126.39	0.38
-196	20.22	0.43	-136	45.52	0.41	-76	66.93	0.40	-16	94.73	0.39	+4	101.56	0.39	+64	126.77	0.38
-195	20.65	0.43	-135	45.94	0.42	-75	66.33	0.40	-15	94.12	0.39	+5	101.95	0.39	+65	127.15	0.39
-194	21.08	0.43	-134	46.35	0.41	-74	65.73	0.40	-14	93.52	0.40	+6	102.34	0.39	+66	127.54	0.38
-193	21.51	0.43	-133	46.76	0.41	-73	65.13	0.40	-13	92.91	0.39	+7	102.73	0.39	+67	127.92	0.38
-192	21.94	0.43	-132	47.18	0.42	-72	64.53	0.40	-12	92.30	0.39	+8	103.12	0.39	+68	128.31	0.39
-191	22.37	0.43	-131	47.59	0.41	-71	63.93	0.40	-11	91.69	0.39	+9	103.51	0.39	+69	128.69	0.38
-190	22.80	0.43	-130	48.00	0.41	-70	63.33	0.40	-10	91.09	0.40	+10	103.90	0.39	+70	129.07	0.38
-189	23.23	0.43	-129	48.41	0.41	-69	62.73	0.40	-9	90.48	0.39	+11	104.29	0.39	+71	129.45	0.38
-188	23.66	0.43	-128	48.82	0.41	-68	62.13	0.40	-8	89.87	0.39	+12	104.68	0.39	+72	129.84	0.39
-187	24.09	0.43	-127	49.23	0.41	-67	61.53	0.40	-7	89.26	0.39	+13	105.07	0.39	+73	130.22	0.38
-186	24.52	0.43	-126	49.64	0.41	-66	60.93	0.40	-6	88.65	0.39	+14	105.46	0.39	+74	130.60	0.38
-185	24.94	0.42	-125	50.06	0.42	-65	60.33	0.40	-5	88.04	0.39	+15	105.85	0.39	+75	130.98	0.38
-184	25.37	0.43	-124	50.47	0.41	-64	59.73	0.40	-4	87.44	0.40	+16	106.24	0.39	+76	131.37	0.39
-183	25.80	0.43	-123	50.88	0.41	-63	59.13	0.40	-3	86.83	0.39	+17	106.63	0.39	+77	131.75	0.38
-182	26.23	0.43	-122	51.29	0.41	-62	58.53	0.40	-2	86.22	0.39	+18	107.02	0.39	+78	132.13	0.38
-181	26.65	0.42	-121	51.70	0.41	-61	57.93	0.40	-1	85.61	0.39	+19	107.40	0.39	+79	132.51	0.38
-180	27.08	0.43	-120	52.11	0.41	-60	57.33	0.40				+20	107.79	0.39	+80	132.89	0.38
-179	27.50	0.42	-119	52.52	0.41	-59	56.73	0.40				+21	108.18	0.39	+81	133.27	0.38
-178	27.93	0.43	-118	52.92	0.40	-58	56.13	0.40				+22	108.57	0.39	+82	133.66	0.39
-177	28.35	0.42	-117	53.33	0.41	-57	55.53	0.39				+23	108.96	0.39	+83	134.04	0.38
-176	28.78	0.43	-116	53.74	0.41	-56	54.93	0.40				+24	109.35	0.39	+84	134.42	0.38
-175	29.20	0.42	-115	54.15	0.41	-55	54.33	0.40				+25	109.73	0.39	+85	134.80	0.38
-174	29.63	0.43	-114	54.56	0.41	-54	53.72	0.40				+26	110.12	0.39	+86	135.18	0.38
-173	30.05	0.42	-113	54.97	0.41	-53	53.11	0.39				+27	110.51	0.39	+87	135.56	0.38
-172	30.47	0.42	-112	55.38	0.41	-52	52.51	0.39				+28	110.90	0.39	+88	135.94	0.38
-171	30.90	0.43	-111	55.78	0.40	-51	51.91	0.40				+29	111.28	0.39	+89	136.32	0.38
-170	31.32	0.42	-110	56.19	0.41	-50	51.31	0.40				+30	111.67	0.39	+90	136.70	0.39
-169	31.74	0.42	-109	56.60	0.41	-49	50.70	0.39				+31	112.06	0.39	+91	137.08	0.38
-168	32.16	0.42	-108	57.00	0.40	-48	50.10	0.40				+32	112.45	0.39	+92	137.46	0.38
-167	32.59	0.43	-107	57.41	0.41	-47	49.50	0.40				+33	112.83	0.38	+93	137.84	0.38
-166	33.01	0.42	-106	57.82	0.41	-46	48.90	0.39				+34	113.22	0.39	+94	138.22	0.38
-165	33.43	0.42	-105	58.22	0.40	-45	48.29	0.40				+35	113.61	0.39	+95	138.60	0.38
-164	33.85	0.42	-104	58.63	0.41	-44	47.69	0.40				+36	113.99	0.38	+96	138.98	0.38
-163	34.27	0.42	-103	59.04	0.41	-43	47.08	0.39				+37	114.38	0.38	+97	139.36	0.38
-162	34.69	0.42	-102	59.45	0.40	-42	46.48	0.40				+38	114.77	0.39	+98	139.74	0.38
-161	35.11	0.42	-101	59.85	0.41	-41	45.88	0.40				+39	115.15	0.39	+99	140.12	0.38
-160	35.53	0.42	-100	60.25	0.40	-40	45.27	0.39				+40	115.54	0.39	+100	140.50	0.38
-159	35.95	0.42	-99	60.66	0.41	-39	44.67	0.40				+41	115.93	0.39	+101	140.88	0.38
-158	36.37	0.42	-98	61.06	0.40	-38	44.06	0.39				+42	116.31	0.38	+102	141.26	0.38
-157	36.79	0.42	-97	61.47	0.41	-37	43.46	0.40				+43	116.70	0.39	+103	141.64	0.38
-156	37.21	0.42	-96	61.87	0.40	-36	42.85	0.39				+44	117.08	0.38	+104	142.02	0.38
-155	37.63	0.42	-95	62.28	0.41	-35	42.25	0.40				+45	117.47	0.39	+105	142.40	0.37
-154	38.04	0.41	-94	62.68	0.40	-34	41.64	0.39				+46	117.85	0.38	+106	142.77	0.38
-153	38.46	0.42	-93	63.09	0.41	-33	41.04	0.40				+47	118.24	0.39	+107	143.15	0.38
-152	38.88	0.42	-92	63.49	0.40	-32	40.43	0.39				+48	118.62	0.38	+108	143.53	0.38
-151	39.30	0.42	-91	63.90	0.41	-31	39.83	0.40				+49	119.01	0.39	+109	143.91	0.38
-150	39.71	0.41	-90	64.30	0.40	-30	39.22	0.39				+50	119.40	0.39	+110	144.29	0.38
-149	40.13	0.42	-89	64.70	0.40	-29	38.62	0.40				+51	119.78	0.38	+111	144.67	0.37
-148	40.55	0.42	-88	65.11	0.41	-28	38.01	0.39				+52	120.16	0.38	+112	145.04	0.38
-147	40.96	0.41	-87	65.51	0.40	-27	37.40	0.39				+53	120.55	0.39	+113	145.42	0.38
-146	41.38	0.42	-86	65.91	0.40	-26	36.80	0.40				+54	120.93	0.38	+114	145.80	0.38
-145	41.79	0.41	-85	66.31	0.40	-25	36.19	0.39				+55	121.32	0.39	+115	146.17	0.37
-144	42.21	0.42	-84	66.72	0.41	-24	35.59	0.40				+56	121.70	0.38	+116	146.55	0.38
-143	42.62	0.42	-83	67.12	0.40	-23	34.98	0.39				+57	122.09	0.39	+117	146.93	0.38
-142	43.04	0.41	-82	67.52	0.40	-22	34.37	0.39				+58	122.47	0.38	+118	147.31	0.38
-141	43.45	0.41	-81	67.93	0.40	-21	33.77	0.39				+59	122.85	0.38	+119	147.69	0.37

100 Ohm, 100 Ohm, 100 Ohm

100 Ohm, 100 Ohm, 100 Ohm

Appendix D Calibration of Detector

The detector was taken to a calibration facility used for gamma-ray and fission-neutron well logging tools on the Hanford site. This facility is described in the report *Calibration Facilities at Hanford for Gamma-Ray and Fission-Neutron Well Logging* by D. C. Stromswold (1994).

The Thorium and Potassium module (SBT/SBK) was chosen to calibrate the detector. The module is 4 ft in diameter with 4-ft thick enhanced radionuclide zones. The total height of the module is 21.5 ft. There is a barren zone 5-ft thick between the lower enriched zone of potassium and the upper enriched zone of Th. The size of the zones is sufficient for the source of radiation to appear "infinite" in extent to the detector inside the module. Spectra were obtained by lowering the detector down the center-hole to the mid-point of each zone and collecting data for 1039 sec in the top zone (Th std) and 1006 sec in the lower zone (K std). These spectra were labeled 0213003.spc and 0213004.spc and are shown in Figures D1 and D2, respectively.

Figure D1: Thorium Calibration Spectrum

The published values for the SBT/SBK module are listed in Table D1.

Table D1: Calibration Facility Concentrations in Units of pCi/g

Module	Zone	Depth (ft)	Concentration			Dry Bulk Density (g/cm ³)
			⁴⁰ K	²²⁶ Ra	²³² Th	
SBT/SBK	Th	6.5 - 10.5	10.6 ± 1.3	10.0 ± 0.5	58.6 ± 1.5	1.92
SBT/SBK	K	15.5 - 19.5	53.5 ± 1.7	1.16 ± 0.11	0.11 ± 0.02	1.82

Based on this information, branching fractions for the individual gamma-rays from the Table of Isotopes (Browne, Firestone, and Shirley, 1986), and past experimental data, the efficiency of the detector was calculated. Table D2 shows the calculations for selected gamma-ray energy peaks used in the efficiency calibration. Note that this represents the situation for an infinitely thick, homogeneously distributed source about the detector.

Table D2: Efficiency Calibration of Detector

Isotope	Energy (keV)	Known gamma/sec/g	Detector cts/sec	Efficiency cts/gamma/g	Best Fit Effic cts/gamma/g
²¹² Pb	238.626	0.92668	28.331	30.573	30.570
²⁰⁸ Tl	583.14	0.66831	10.748	16.191	16.118
²²⁸ Ac	911.07	0.62352	7.527	12.072	12.398
²²⁸ Ac	968.90	0.37540	4.524	12.051	11.993
⁴⁰ K	1460.75	0.2330*	2.351	10.090	9.7893
²⁰⁸ Tl	2614.47	0.77188	5.898	7.6411	7.7578

* Actual ⁴⁰K concentration has been determined to be about 10% higher than the published value shown in Table D1 above.

Figure D3 shows the efficiency curve for the distributed source geometry.

Figure D3: Efficiency Curve for Homogeneously Distributed Source

The next step was to incorporate this information into an efficiency calibration curve useable by GammaVision. This was done by manually entering the “Best Fit” efficiency values as each peak was located in the calibration spectra.

However, this was not straight-forward, because the program would not accept the above efficiency values, apparently because they were greater than the acceptable range. After dividing the calculated efficiency values by 1000, the GammaVision efficiency calibration program would accept the values. This factor of 1000 must be reapplied to calculated results to obtain the correct units. For example, when analyzing a soil sample, results are typically requested in pCi/g of soil. GammaVision calculates its data in μCi , and if the results are desired in pCi, a factor of 10^6 would normally be included in the **Analyze...Settings...System** window as a normalization factor. However, since the efficiency curve has already been divided by 10^3 , an additional normalization factor of only 10^3 is needed to obtain the correct data units.

The energy and efficiency calibrations were saved in a file called “snakehom.clb.” It contains the following data. Note that the efficiency values shown in the final table are divided by the factor of 1000.

Calibration data from 0213003.spc and 0213004.spc contained in SNAKEHOM.CLB.

Calibration Data from file: 0213003.SPC

Date: 19-May-97 Time: 14:23:57

Count in Th section of SBT/SBK Calibration Facility with SNAKE d

Energy Calibration Fit

Energy = $-1.0531 + 1.001206 \cdot \text{Channel} + 9.82633\text{e-}009 \cdot \text{Channel}^2$

FWHM = $1.8391 + 0.000790 \cdot \text{Channel} - 1.15089\text{e-}007 \cdot \text{Channel}^2$

Energy/FWHM Table

Channel	Energy(keV)	Fit(keV)	Delta	FWHM	Fit	Delta
239.44	238.63	238.68	-0.02%	2.19	2.02	7.72%
339.12	338.40	338.47	-0.02%	1.96	2.10	-7.10%
583.58	583.14	583.23	-0.02%	2.28	2.26	0.92%
727.55	727.17	727.38	-0.03%	2.41	2.36	2.24%
911.12	911.07	911.18	-0.01%	2.29	2.47	-7.92%
967.83	968.90	967.95	0.10%	2.32	2.50	-7.85%
1459.80	1460.75	1460.53	0.02%	3.44	2.75	20.06%
1620.40	1620.56	1621.32	-0.05%	2.40	2.82	-17.64%
2612.18	2614.47	2614.34	0.01%	3.11	3.12	-0.33%

Efficiency Calibration Fit

Knee Energy = 150.00 keV

Above the Knee: Quadratic Uncertainty = 0.0159 %

LOG(Eff) = $3.8282 - 1.865547 \cdot \text{LOG}(\text{Eng}) + 0.0967816 \cdot (\text{LOG}(\text{Eng}))^2$

Below the Knee: None Uncertainty = 0.0000 %

Efficiency Table

Energy	Effic.	Fit	Delta
150.00		Knee	
239.63	0.030570	0.030566	0.01%
583.14	0.016119	0.016127	-0.05%
911.07	0.012398	0.012396	0.01%
968.90	0.011993	0.011991	0.02%
1460.75	0.009789	0.009786	0.03%
2614.15	0.007758	0.007759	-0.02%

Appendix D.1 GammaVision Analysis Results of Th Calibration Module - 0213003.spc

Sample description

SBT/SBK 8.5' CALIBRATION WELL COUNT TH STD

Spectrum Filename: 0213003.SPC

Acquisition information

Start time 13-Feb-97 14:10:31
Live time 1039
Real time 1201
Dead time 13.47%
Detector/Geometry IDs 0 & 0

Detector system

SNAKE #1

Calibration

Filename: 0213003.SPC
Created: 21-Feb-97 10:16:34 & 24-Feb-97 18:06:19
Count in Th section of SBT/SBK Calibration Facility with SNAKE d

Zero offset -1.053 keV; Gain 1.001 keV/channel

Library Files

Main analysis library: C:\USER\WESTJEFF.LIB

Analysis parameters

Start channel 10 for an energy of 8.96keV
Stop channel 4048 for an energy of 4051.99keV
Peak rejection level 50.000%
Activity scaling factor $1.0000\text{E}+00 / 1.0000\text{E}+00 = 1.0000\text{E}+00$
Detection limit method:
 Currie limit
Additional random error: 1.0000000E+00
Additional systematic error: 1.0000000E+00
Background width: best method (based on spectrum).

Corrections	Status	Comments
Decay correct to date	NO	
Decay during acquisition	NO	
Peaked background correction	NO	
Absorption (Internal)	NO	
Geometry correction	NO	
Random summing	NO	

Energy calibration normalized difference: .1052

***** UNIDENTIFIED PEAK SUMMARY *****

PEAK CHANNEL	CENTROID ENERGY	BACKGROUND COUNTS	NET AREA COUNTS	INTENSITY CTS/SEC	UNCERT 1 SIGMA	FWHM %	SUSPECTED keV	NUCLIDE
23.45	22.43	48429.	23307.	22.431	2.91	2.872	-	s
77.46	76.50	240884.	2912.	2.802	23.91	1.902	-	D
93.86	92.92	88364.	2573.	2.476	16.46	1.915	-	D
370.00	369.40	56717.	1474.	1.419	22.99	2.118	-	D
409.85	409.29	19019.	1248.	1.201	15.89	2.146	-	D
446.03	445.51	16920.	380.	.365	48.72	2.171	-	D
755.78	755.64	22927.	639.	.615	33.72	2.373	-	D
772.27	772.15	16109.	661.	.636	27.42	2.384	-	D
806.36	806.28	2312.	178.	.171	39.03	2.404	-	D
835.61	835.57	3990.	496.	.477	18.56	2.422	-	D
840.79	840.76	2295.	315.	.303	22.23	2.425	-	D
903.72	903.77	11327.	304.	.292	49.90	2.462	-	D
1033.05	1033.26	2241.	148.	.142	46.06	2.536	-	D
1077.92	1078.18	3878.	211.	.203	42.36	2.560	-	D
1094.45	1094.72	1465.	112.	.108	49.25	2.569	-	D
1154.23	1154.58	3634.	231.	.222	37.54	2.601	-	D
1246.62	1247.08	1324.	124.	.119	42.55	2.649	-	D
1281.02	1281.52	2776.	156.	.150	48.47	2.666	-	D
1287.82	1288.34	1943.	175.	.169	36.40	2.669	-	D
1495.17	1495.95	1272.	255.	.245	20.77	2.767	-	D
1501.77	1502.55	770.	155.	.150	26.49	2.770	-	D
1591.99	1592.88	1714.	1771.	1.705	4.07	2.809	-	D
1629.79	1630.73	1257.	346.	.333	15.46	2.825	-	D
1636.58	1637.52	712.	85.	.082	45.81	2.828	-	D
1660.27	1661.24	888.	95.	.091	45.60	2.837	-	D
1664.83	1665.81	736.	106.	.102	37.49	2.839	-	D
1847.25	1848.46	512.	166.	.160	39.33	3.364	-	s
1902.00	1903.28	510.	198.	.191	36.76	2.475	-	s
2102.30	2103.82	1038.	921.	.886	8.49	3.849	-	s
2444.39	2446.34	701.	114.	.110	34.02	3.087	-	D

s Peak fails shape tests.

D Peak area deconvoluted.

***** IDENTIFIED PEAK SUMMARY *****

NUCLIDE	PEAK CHANNEL	CENTROID ENERGY	BACKGROUND COUNTS	NET AREA COUNTS	INTENSITY CTS/SEC	UNCERT 1 SIGMA	FWHM %	keV
AM-241	60.52	59.54	372777	122	0.118	707.24	1.889D	
TI-44	68.77	67.8	312830	948	0.912	83.54	1.895D	
TI-44	79.36	78.4	224598	2075	1.997	32.38	1.903D	
EU-155	87.4	86.45	150590	1990	1.915	27.67	1.910D	
CD-109	88.99	88.04	130614	2444	2.352	21.01	1.911D	
EU-155	106.23	105.31	137543	1331	1.281	39.49	1.924D	
U-235	110.06	109.14	88099	1106	1.065	38.07	1.927D	
EU-152	122.68	121.78	417275	339	0.327	269.23	1.937D	
CO-57	122.97	122.07	417614	0	0	0	1.937D	
EU-154	124	123.1	416846	768	0.739	118.94	1.938D	
PU-239	130.18	129.28	337513	3043	2.929	27.06	1.942D	
CE-144	134.42	133.53	286736	1483	1.427	51.12	1.946D	

CO-57	137.32	136.43	247606	1434	1.38	49.15	1.948D
MO-99	141.39	140.51	197604	1354	1.303	46.51	1.951D
TC-99M	141.39	140.51	71631	0	0	78.78	.612D
NP-237	144.13	143.25	161586	848	0.816	67.11	1.953D
U-235	144.64	143.76	162071	363	0.35	156.86	1.953D
TI-44	147.08	146.2	125645	410	0.394	122.4	1.955D
PU-241	149.43	148.56	101879	392	0.377	115.24	1.957D
U-235	165.66	164.81	68856	674	0.648	103.15	4.959s
SB-125	177.13	176.29	53142	0	0	0	4.747D
MO-99	181.92	181.09	118386	3329	3.203	14.72	1.981D
U-235	186.55	185.72	74668	2076	1.998	18.75	1.985D
RA-226	186.93	186.1	75255	0	0	0	1.985D
U-235	202.93	202.12	88797	2979	2.867	14.26	1.997D
PU-239	204.33	203.52	90919	857	0.825	49.88	1.998D
U-235	206.11	205.31	82433	2099	2.02	19.47	1.999D
PU-241	208.81	208.01	69147	1010	0.972	36.96	2.001D
AC-228	210.2	209.4	52948	3451	3.321	9.58	2.002D
U-235	223.78	223	29113	235	0.226	162.83	1.183
▶ PB-212	239.39	238.63	80121	29438	28.331	1.48	2.024D
PB-214	242.68	241.92	84745	4620	4.446	9.03	2.027D
EU-154	248.79	248.04	34802	387	0.372	68.43	2.031D
AC-228	271.03	270.3	50053	3583	3.449	8.99	2.047D
BA-133	277.01	276.29	22141	0	0	0	2.442D
TL-208	278.08	277.36	25524	1895	1.824	12.14	2.052D
U-235	280.21	279.5	23504	371	0.357	58.61	2.054D
PB-214	295.92	295.22	67547	1656	1.594	22.33	2.065D
PB-212	300.78	300.09	59352	0	0	0	2.069D
NP-237	300.86	300.17	58145	2287	2.201	15.06	2.069D
BA-133	303.4	302.71	21928	0	0	0	1.699D
NP-237	312.69	312.01	25087	64	0.062	349.41	2.077D
AC-228	328.66	328	143453	5511	5.303	9.81	2.089D
PU-239	333.45	332.8	132595	3398	3.27	15.25	2.092D
AM-241	336.08	335.43	128339	2854	2.747	17.85	2.094D
AC-228	339.04	338.4	118882	8170	7.863	6.07	2.096D
NP-237	341.23	340.59	115179	2404	2.314	20.07	2.098D
EU-152	344.94	344.3	106072	1633	1.572	28.31	2.100D
PU-239	345.6	344.96	103973	1297	1.248	35.28	2.101D
PB-214	352.62	351.99	89573	361	0.348	117.33	2.106D
NP-237	352.63	352	89573	5168	4.974	8.31	2.106D
BA-133	356.48	355.86	81573	2120	2.04	19.18	2.109D
MO-99	367.05	366.44	62298	1334	1.284	26.6	2.116D
PU-239	375.62	375.02	45837	1162	1.118	26.23	2.122D
SB-125	381.1	380.51	10735	0	0	0	4.724D
BA-133	384.29	383.7	30217	792	0.762	31.26	2.128D
PU-239	393.64	393.06	15437	278	0.267	63.54	2.135D
PU-239	414.24	413.69	12155	270	0.26	58.13	2.149D
SB-126	415.35	414.8	9202	0	0	0	2.395D
SB-125	428.48	427.95	9628	164	0.158	85.11	2.159D
AG-108M	434.23	433.7	9671	9	0.009	1519.95	2.163D
PU-239	451.96	451.45	11130	210	0.202	71.46	2.175D
AC-228	463.49	463	17788	1940	1.867	9.99	2.183D
SB-125	464	463.51	19527	201	0.193	98.58	2.184D
CS-134	475.83	475.35	8320	123	0.119	104.88	2.192D
TL-208	511.15	510.72	12212	2823	2.716	5.85	2.216D

AL-26	511.43	511	12352	1712	1.648	9.49	2.216D
ZN-65	511.43	511	9450	0	0	6.82	2.326D
NA-22	511.43	511	9450	0	0	6.82	2.326D
KR-85	514.41	513.98	10012	187	0.18	75.88	2.218D
CS-134	563.63	563.26	10773	322	0.31	45.97	2.251D
CS-134	569.65	569.29	6024	95	0.092	115.6	2.255D
▶ TL-208	583.49	583.14	29635	11168	10.748	2.38	2.264D
EU-154	592.04	591.7	24138	247	0.238	89.06	2.269D
SB-125	601.09	600.77	18115	171	0.165	111.58	2.275D
CS-134	604.98	604.66	15489	149	0.144	118.04	2.278D
SB-125	607.14	606.82	14348	0	0	0	2.279D
BI-214	609.63	609.32	9409	3071	2.956	4.82	2.281D
AG-108M	614.68	614.37	6595	161	0.155	71.61	2.284D
SB-125	637.08	636.8	2863	58	0.055	208.48	2.879s
AG-110M	658.01	657.75	13606	355	0.342	46.72	2.312D
CS-137	661.87	661.62	11983	246	0.236	63.32	2.314D
AM-241	662.67	662.42	11632	21	0.02	734.67	2.315D
SB-126	666.45	666.2	3132	0	0	0	1.802D
SB-125	671.9	671.66	6384	125	0.12	90.99	2.321D
AG-110M	677.84	677.61	4323	91	0.088	102.15	2.325D
CO-57	692.31	692.1	2943	0	0	0	.553D
SB-126	695.31	695.1	9566	0	0	0	2.336D
SB-126	697.21	697	8467	22	0.021	584.67	2.337D
NB-94	702.7	702.5	5144	265	0.255	38.79	2.340D
AG-110M	706.87	706.67	4139	61	0.059	149.5	2.343D
SB-126	720.58	720.4	3273	0	0	0	1.489D
AM-241	722.14	721.96	14536	78	0.075	220.25	2.352D
AG-108M	723.13	722.95	14115	0	0	0	2.353D
EU-154	723.48	723.3	14115	0	0	0	2.353D
BI-212	727.34	727.17	9757	2384	2.295	6.21	2.356D
MO-99	739.63	739.47	3960	67	0.065	132.42	2.363D
TL-208	763.43	763.3	20208	477	0.459	42.4	2.378D
AG-110M	764.06	763.93	20255	0	0	0	2.379D
PA-234M	766.72	766.6	18812	213	0.205	91.37	2.380D
BI-214	768.48	768.36	18129	420	0.405	45.56	2.381D
MO-99	777.99	777.88	13767	75	0.072	222.12	2.387D
EU-152	779.01	778.9	13302	156	0.151	104.54	2.388D
BI-212	785.52	785.42	10760	459	0.442	32.29	2.392D
PB-214	786.05	785.95	10830	22	0.021	664.27	2.392D
AL-26	786.82	786.72	10379	79	0.076	182.86	2.392D
AC-228	794.89	794.8	6171	1178	1.134	9.87	2.397D
CS-134	795.85	795.76	6659	344	0.331	34.02	2.398D
CS-134	801.92	801.84	3562	150	0.144	56.89	2.402D
SB-126	856.71	856.7	2080	0	0	0	2.348D
TL-208	860.48	860.47	22402	1574	1.515	13.68	2.437D
NB-94	871.1	871.1	19697	142	0.137	139.56	2.443D
EU-154	873.19	873.2	19127	181	0.174	108.2	2.444D
AG-110M	884.65	884.67	16392	173	0.166	105.19	2.451D
▶ AC-228	911.02	911.07	2020	7821	7.527	1.39	2.466D
BI-214	933.97	934.05	1701	233	0.224	25.86	2.480D
AG-110M	937.39	937.48	1871	20	0.02	302.23	2.482D
EU-152	963.88	964	8557	0	0	0	2.497D
AC-228	964.48	964.6	6953	1604	1.543	7.77	2.497D
▶ AC-228	968.78	968.9	2284	4701	4.524	2.05	2.500D

EU-154	996.14	996.3	1889	100	0.096	62.52	2.515D
PA-234M	1000.87	1001.03	1398	139	0.134	39.02	2.518D
EU-154	1004.63	1004.8	1491	38	0.037	143.81	2.520D
CS-134	1038.29	1038.5	1531	41	0.04	135.33	2.538D
EU-152	1085.53	1085.8	2888	16	0.016	468.73	2.564D
EU-152	1111.77	1112.07	4240	40	0.039	229.27	2.578D
ZN-65	1115.22	1115.52	3755	85	0.082	102.03	2.580D
BI-214	1119.97	1120.28	2304	813	0.782	9.06	2.583D
AL-26	1129.38	1129.7	1203	85	0.082	58.67	2.588D
CS-134	1167.49	1167.86	1830	113	0.109	54.46	2.608D
CO-60	1172.86	1173.23	1147	97	0.094	50.17	2.611D
BI-214	1237.66	1238.11	2369	271	0.261	26.09	2.644D
NA-22	1274.04	1274.54	3402	0	0	0	2.662D
EU-154	1274.3	1274.8	3356	46	0.044	177.82	2.662D
AL-26	1297.19	1297.72	983	76	0.074	59.09	2.674D
CO-60	1332.29	1332.86	1352	225	0.217	59.3	3.613s
CS-134	1364.52	1365.13	3438	84	0.081	99.29	2.706D
BI-214	1377.02	1377.65	1924	233	0.224	27.41	2.712D
AG-110M	1383.64	1384.27	1181	55	0.053	89.44	2.715D
BI-214	1407.32	1407.98	939	118	0.113	37.94	2.727D
EU-152	1407.42	1408.08	988	69	0.067	65.17	2.727D
K-40	1459.56	1460.29	1198	669	0.644	11.45	3.390s
AG-110M	1504.22	1505	921	1	0.001	5231.99	2.771D
AC-228	1587.01	1587.9	3329	698	0.671	12.29	2.807D
BI-212	1619.63	1620.56	2487	376	0.362	19.44	2.820D
BI-214	1729.12	1730.19	378	137	0.132	35.8	2.756
BI-214	1763.32	1764.42	927	710	0.683	9.69	2.802
AL-26	1810.35	1811.51	572	71	0.068	102.42	2.098s
BI-214	2201.99	2203.64	774	218	0.21	26.41	2.771s
TL-208	2612.17	2614.33	188.	6129.	5.898	1.37	3.109

s Peak fails shape tests.

D Peak area deconvoluted.

***** SUMMARY OF LIBRARY PEAK USAGE *****

NUCLIDE	AVERAGE ACTIVITY Becquerels	PEAK ENERGY keV	ACTIVITY Becquerels	CODE	MDA VALUE Becquerels	COMMENTS
NA-22	0.00E+00	511 1274.54	0.00E+00 0.00E+00	*(!(	1.32E-04 2.39E-04	Energy duplication
AL-26	1.54E-03	511 1808.72 1297.72 786.72 1129.7	1.55E-03 0.00E+00 0.00E+00 0.00E+00 0.00E+00	(& % % %	1.65E-04 1.22E-04 1.35E-04 3.26E-04 5.72E-03	Energy duplication
K-40	1.66E-02	1460.75	1.66E-02	*(	1.41E-03	
TI-44	0.00E+00	78.4 67.8 146.2	0.00E+00 0.00E+00 0.00E+00	(% %	0.00E+00 0.00E+00 0.00E+00	

CO-57	0.00E+00	122.07	0.00E+00	!(	0.00E+00	
		136.43	0.00E+00	(	0.00E+00	
		692.1	0.00E+00	!(	1.07E-01	
CO-60	0.00E+00	1332.51	0.00E+00	%	1.66E-04	
		1173.23	0.00E+00	%	1.39E-04	
ZN-65	0.00E+00	1115.52	0.00E+00	%	4.69E-04	Energy duplication
		511	0.00E+00	*	8.37E-03	
KR-85	0.00E+00	513.98	0.00E+00	%	5.74E-02	
NB-94	0.00E+00	871.1	0.00E+00	%	4.74E-04	
		702.5	4.79E-04		2.19E-04	
MO-99	0.00E+00	140.51	0.00E+00	(	0.00E+00	Energy duplication
		181.09	3.74E-02	+	6.45E-03	
		366.44	1.30E-01	+	4.04E-02	
		739.47	0.00E+00	%	1.50E-03	
		777.88	0.00E+00	%	8.50E-03	
TC-99M	0.00E+00	140.51	0.00E+00	%	0.00E+00	Energy duplication
AG-108M	0.00E+00	722.95	0.00E+00	!(	3.99E-04	
		614.37	0.00E+00	%	2.50E-04	
		433.7	0.00E+00	%	2.38E-04	
AG-110M	6.51E-04	657.75	6.52E-04	(	3.52E-04	
		884.67	0.00E+00	%	6.00E-04	
		937.48	0.00E+00	%	4.44E-04	
		1384.27	0.00E+00	%	6.16E-04	
		763.93	0.00E+00	-	1.99E-03	
		706.67	0.00E+00	%	1.16E-03	
		1505	0.00E+00	%	1.03E-03	
		677.61	0.00E+00	%	1.80E-03	
CD-109	0.00E+00	88.04	0.00E+00	(	0.00E+00	
SB-125	0.00E+00	427.95	0.00E+00	%	7.22E-04	
		600.77	0.00E+00	%	1.99E-03	
		636.15	0.00E+00	%	1.35E-03	
		463.51	0.00E+00	%	3.21E-03	
		176.29	0.00E+00	&	3.96E-03	
		606.82	0.00E+00	!	6.27E-03	
		671.66	0.00E+00	%	1.30E-02	
		380.51	0.00E+00	&	1.47E-02	
SB-126	0.00E+00	695.1	0.00E+00	!(	2.90E-04	
		666.2	0.00E+00	!(	1.62E-04	
		414.8	0.00E+00	!(	2.36E-04	
		720.4	0.00E+00	&(	3.03E-04	
		697	0.00E+00	%	8.53E-04	
		856.7	0.00E+00	&(	8.69E-04	

CS-134	0.00E+00	604.66	0.00E+00	%	3.48E-04
		795.76	7.83E-04		3.14E-04
		569.29	0.00E+00	%	1.32E-03
		801.84	0.00E+00	%	2.24E-03
		563.26	6.06E-03		3.26E-03
		1365.13	0.00E+00	%	8.27E-03
		1167.86	0.00E+00	%	9.62E-03
		475.35	0.00E+00	%	1.46E-02
		1038.5	0.00E+00	%	1.47E-02
CS-137	0.00E+00	661.62	0.00E+00	%	3.75E-04
BA-133	3.92E-03	355.86	3.92E-03	(	8.69E-04
		302.71	0.00E+00	&	1.34E-03
		383.7	1.09E-02	+	3.99E-03
		276.29	0.00E+00	&	3.19E-03
CE-144	0.00E+00	133.53	0.00E+00	%	0.00E+00
EU-152	0.00E+00	121.78	0.00E+00	%	0.00E+00
		344.3	6.81E-03		2.25E-03
		1408.08	0.00E+00	%	6.59E-04
		964	0.00E+00	!	2.26E-03
		1112.07	0.00E+00	%	1.85E-03
		778.9	0.00E+00	%	2.82E-03
		1085.8	0.00E+00	%	1.98E-03
EU-154	0.00E+00	123.1	0.00E+00	%	0.00E+00
		1274.8	0.00E+00	%	6.74E-04
		723.3	0.00E+00	!	1.83E-03
		1004.8	0.00E+00	%	8.08E-04
		873.2	0.00E+00	%	4.15E-03
		996.3	0.00E+00	%	1.51E-03
		248.04	0.00E+00	%	4.09E-03
		591.7	0.00E+00	%	9.09E-03
EU-155	0.00E+00	86.45	0.00E+00	(	0.00E+00
		105.31	0.00E+00	(	0.00E+00
TL-208	5.76E-02	2614.47	5.77E-02	(	2.12E-04
		583.14	5.93E-02	+	1.77E-03
		510.72	5.14E-02	-	3.68E-03
		860.47	7.17E-02	+	1.16E-02
		277.36	7.99E-02	+	1.15E-02
		763.3	1.39E-01	+	6.89E-02
PB-212	5.76E-02	238.63	5.76E-02	(	9.11E-04
		300.09	0.00E+00	-	1.24E-02
PB-214	0.00E+00	351.99	0.00E+00	%	1.52E-03
		295.22	8.65E-03		2.26E-03
		241.92	5.30E-02		5.65E-03
		785.95	0.00E+00	%	3.89E-02

BI-212	6.76E-02	727.17	6.69E-02	(	4.56E-03
		1620.56	7.05E-02	(	1.54E-02
		785.42	8.05E-02	+	3.05E-02
BI-214	1.11E-02	609.32	1.11E-02	(	5.74E-04
		1764.51	1.29E-02	+	1.21E-03
		1120.28	1.26E-02	+	1.43E-03
		1238.11	1.13E-02	(	3.33E-03
		2204.12	1.38E-02	+	3.27E-03
		768.36	1.64E-02	+	8.74E-03
		1377.65	1.50E-02	+	4.92E-03
		934.05	1.57E-02	+	4.86E-03
		1729.6	1.29E-02	+	3.51E-03
		1407.98	1.24E-02	+	5.64E-03
RA-226	0.00E+00	186.1	0.00E+00	!(	8.90E-03
AC-228	6.21E-02	911.07	6.17E-02	(	5.83E-04
		968.9	6.31E-02	(	1.05E-03
		338.4	8.07E-02	+	5.79E-03
		964.6	6.80E-02	+	6.45E-03
		794.8	5.28E-02	-	6.32E-03
		463	6.06E-02	(	6.85E-03
		209.4	6.77E-02	+	7.67E-03
		270.3	9.78E-02	+	1.04E-02
		1587.9	5.88E-02	-	8.80E-03
		328	1.93E-01	+	2.22E-02
PA-234M	3.65E-02	1001.03	3.65E-02	(	1.62E-02
		766.6	0.00E+00	%	1.37E-01
U-235	2.50E-03	185.72	2.50E-03	(	5.41E-04
		143.76	0.00E+00	%	0.00E+00
		205.31	3.14E-02	+	7.16E-03
		163.35	0.00E+00	&	5.26E-03
		109.14	0.00E+00	-	0.00E+00
		202.12	2.04E-01	+	3.41E-02
		221.38	0.00E+00	&	1.87E-01
		279.5	0.00E+00	%	9.05E-02
NP-237	0.00E+00	143.25	0.00E+00	%	0.00E+00
		352	1.97E+02		1.93E+01
		300.17	3.74E-02		6.62E-03
		312.01	0.00E+00	%	7.58E-04
		340.59	6.39E-02		1.50E-02
PU-239	0.00E+00	129.28	0.00E+00	(	0.00E+00
		375.02	8.80E+01	+	2.70E+01
		413.69	0.00E+00	%	1.56E+01
		332.8	7.31E+02	+	1.30E+02
		393.06	0.00E+00	%	5.80E+01
		451.45	0.00E+00	%	1.26E+02
		344.96	2.61E+02	+	1.07E+02

- (- This peak used in the nuclide activity average.
- * - Peak is too wide, but only one peak in library.
- ! - Peak is part of a multiplet and this area went negative during deconvolution.
- ? - Peak is too narrow.
- @ - Peak is too wide at FW25M, but ok at FWHM.
- % - Peak fails sensitivity test.
- \$ - Peak identified, but first peak of this nuclide failed one or more qualification tests.
- + - Peak activity higher than counting uncertainty range.
- - Peak activity lower than counting uncertainty range.
- = - Peak outside analysis energy range.
- & - Calculated peak centroid is not close enough to the library energy centroid for positive identification.
- P - Peakbackground subtraction

NUCLIDE	ACTIVITY	COUNTING
	sample	(1 SIGMA)

46

EU-154	<	0.00E+00	
EU-155	<	0.00E+00	
TL-208		5.76E-02	1.37%
PB-212		5.76E-02	1.48%
PB-214	<	1.52E-03	
BI-212		6.76E-02	6.21%
BI-214		1.11E-02	4.82%
RA-226	<	8.90E-03	
AC-228		6.21E-02	1.39%
PA-234m		3.65E-02	39.02%
U-235		2.50E-03	18.75%
NP-237	<	0.00E+00	
PU-239	<	0.00E+00	
PU-241	<	0.00E+00	
AM-241	<	0.00E+00	

All peaks for activity calculation had bad shape.

----- SUMMARY -----

TOTAL ACTIVITY (9.0 to 4052.0 keV) 3.1771110E-01 sample

The library has energies which are not separable.

Analyzed by: _____
Battelle

Reviewed by: _____
Supervisor

Appendix D.2 GammaVision Analysis Results of K Calibration Module - 0213004.spc

Sample description

SBT/SBK 17.5' CALIBRATION WELL COUNT K STD

Spectrum Filename: 0213004.SPC

Acquisition information

Start time 13-Feb-97 14:33:43
Live time 1006
Real time 1015
Dead time .94%
Detector/Geometry IDs 0 & 0

Detector system

SNAKE #1

Calibration

Filename: 0213004.SPC
Created: 21-Feb-97 10:16:34 & 24-Feb-97 18:03:14
Count in Th section of SBT/SBK Calibration Facility with SNAKE d

Zero offset -1.053 keV; Gain 1.001 keV/channel

Library Files

Main analysis library: C:\USER\WESTJEFF.LIB

Analysis parameters

Start channel 40 for an energy of 39.00keV
Stop channel 4000 for an energy of 4003.93keV
Peak rejection level 50.000%
Activity scaling factor $1.0000\text{E}+03 / 1.0000\text{E}+00 = 1.0000\text{E}+03$
Detection limit method:
Currie limit
Additional random error: $1.0000000\text{E}+00$
Additional systematic error: $1.0000000\text{E}+00$
Background width: best method (based on spectrum).

Corrections	Status	Comments
Decay correct to date	NO	
Decay during acquisition	NO	
Peaked background correction	NO	
Absorption (Internal)	NO	
Geometry correction	NO	
Random summing	NO	

Energy calibration normalized difference: .0512

***** UNIDENTIFIED PEAK SUMMARY *****

PEAK CHANNEL	CENTROID ENERGY	BACKGROUND COUNTS	NET AREA COUNTS	INTENSITY CTS/SEC	UNCERT 1 SIGMA %	FWHM keV	SUSPECTED NUCLIDE
438.84	438.32	617.	93.	.092	39.18	2.166	- D
829.81	829.77	230.	102.	.101	45.86	4.232	- s
2445.17	2447.12	0.	12.	.012	28.87	2.670	-

s Peak fails shape tests.

D Peak area deconvoluted.

***** IDENTIFIED PEAK SUMMARY *****

NUCLIDE	PEAK CHANNEL	CENTROID ENERGY	BACKGROUND COUNTS	NET AREA COUNTS	INTENSITY CTS/SEC	UNCERT 1 SIGMA %	FWHM keV
AM-241	60.52	59.54	15753	106	0.106	167.37	1.889D
TI-44	68.77	67.8	13199	128	0.128	126.92	1.895D
TI-44	79.36	78.4	8202	203	0.202	63.49	1.903D
EU-155	87.4	86.45	4116	21	0.021	423.4	1.910D
CD-109	88.99	88.04	3634	0	0	0	1.911D
EU-155	106.23	105.31	6410	133	0.132	85.57	1.924D
U-235	110.06	109.14	4224	50	0.05	183.09	1.927D
EU-152	122.68	121.78	24940	12	0.012	1913.83	1.937D
CO-57	122.97	122.07	24221	0	0	0	1.937D
EU-154	124	123.1	23459	8	0.008	2637.55	1.938D
PU-239	130.18	129.28	18963	142	0.141	137.88	1.942D
CE-144	134.42	133.53	16023	147	0.146	122.25	1.946D
CO-57	137.32	136.43	13903	50	0.049	335.7	1.948D
MO-99	141.39	140.51	11059	88	0.087	169.88	1.951D
TC-99M	141.39	140.51	4592	0	0	110.95	4.634D
NP-237	144.13	143.25	9056	0	0	0	1.953D
U-235	144.64	143.76	8954	102	0.101	132.19	1.953D
TI-44	147.08	146.2	7025	29	0.029	411.23	1.955D
PU-241	149.43	148.56	5642	64	0.064	166.15	1.957D
U-235	163	162.14	1569	103	0.102	67.33	.501s
SB-125	177.13	176.29	1389	0	0	0	.501D
MO-99	181.92	181.09	6801	246	0.245	47.77	1.981D
U-235	186.55	185.72	4396	198	0.196	47.99	1.985D
RA-226	186.93	186.1	4594	0	0	0	1.985D
U-235	202.93	202.12	5265	8	0.008	1212	1.997D
PU-239	204.33	203.52	5170	103	0.102	99.22	1.998D
U-235	206.11	205.31	4825	87	0.086	113.69	1.999D
PU-241	208.81	208.01	4038	93	0.092	97.49	2.001D
AC-228	210.2	209.4	2082	0	0	0	1.390D
U-235	224.79	224.01	1860	76	0.076	139.47	3.425s
PB-212	239.39	238.63	4898	241	0.239	41.64	2.024D
PB-214	242.68	241.92	4012	230	0.229	39.5	2.027D
EU-154	248.79	248.04	2298	150	0.15	45.81	2.031D
AC-228	271.03	270.3	1814	0	0	0	3.110D
BA-133	277.01	276.29	2233	19	0.019	355.71	2.052D
TL-208	278.08	277.36	1770	62	0.062	96.7	2.052D
U-235	280.21	279.5	1392	27	0.027	193.17	2.054D
PB-214	295.92	295.22	3438	319	0.317	26.61	2.065D

PB-212	300.78	300.09	2781	144	0.144	52.31	2.069D
NP-237	300.86	300.17	990	0	0	0	2.281D
BA-133	303.4	302.71	2216	152	0.151	44.57	2.071D
NP-237	312.69	312.01	980	0	0	0	1.303D
AC-228	328.66	328	653	0	0	0	1.789D
PU-239	333.45	332.8	8019	179	0.178	71.25	2.092D
AM-241	336.08	335.43	7773	148	0.148	84.37	2.094D
AC-228	339.04	338.4	844	0	0	0	2.940D
NP-237	341.23	340.59	924	0	0	0	2.974D
EU-152	344.94	344.3	6622	104	0.103	111.37	2.100D
PU-239	345.6	344.96	6546	38	0.037	305.13	2.101D
PB-214	352.62	351.99	5160	530	0.527	19.64	2.106D
NP-237	352.63	352	1031	0	0	0	2.200D
BA-133	356.48	355.86	4835	145	0.145	68.1	2.109D
MO-99	367.05	366.44	3510	130	0.129	65.07	2.116D
PU-239	375.62	375.02	2481	128	0.128	55.55	2.122D
SB-125	381.1	380.51	296	0	0	0	2.002D
BA-133	384.29	383.7	1528	107	0.106	52.55	2.128D
PU-239	393.64	393.06	620	63	0.063	57.14	2.135D
PU-239	414.24	413.69	527	16	0.016	207.93	2.149D
SB-126	415.35	414.8	617	21	0.021	168.47	2.150D
SB-125	428.48	427.95	1492	59	0.058	94.08	2.159D
AG-108M	434.23	433.7	274	0	0	0	1.678D
PU-239	450.6	450.09	670	104	0.103	79.31	2.401s
AC-228	463.49	463	556	0	0	0	1.099D
SB-125	462.16	461.67	556	99	0.098	68.11	1.099s
CS-134	474.72	474.24	293	38	0.037	103.28	1.132
TL-208	511.15	510.72	850	0	0	0	2.216D
AL-26	511.43	511	792	58	0.058	69.85	2.216D
ZN-65	511.43	511	484	0	0	82.68	2.257D
NA-22	511.43	511	484	0	0	82.68	2.257D
KR-85	514.41	513.98	623	29	0.029	121.7	2.218D
CS-134	563.63	563.26	305	0	0	0	2.690D
CS-134	569.65	569.29	243	0	0	0	2.091D
TL-208	583.49	583.14	2355	60	0.06	115.25	2.264D
EU-154	592.04	591.7	1947	15	0.014	430.93	2.269D
SB-125	601.09	600.77	1511	22	0.021	255.7	2.275D
CS-134	604.98	604.66	1322	9	0.009	602.56	2.278D
SB-125	607.14	606.82	1207	30	0.03	163.52	2.279D
BI-214	609.63	609.32	732	360	0.358	11.86	2.281D
AG-108M	614.68	614.37	360	0	0	0	1.240D
SB-125	635.5	635.22	207	30	0.03	118.88	1.808
AG-110M	658.01	657.75	2358	40	0.04	172.39	2.312D
CS-137	661.87	661.62	2181	19	0.019	347.37	2.314D
AM-241	662.67	662.42	2143	18	0.018	365.3	2.315D
SB-126	666.45	666.2	1959	65	0.064	97.47	2.317D
SB-125	671.9	671.66	1691	30	0.03	191.67	2.321D
AG-110M	677.84	677.61	1416	50	0.049	107.92	2.325D
CO-57	692.31	692.1	148	0	0	0	1.480D
SB-126	695.31	695.1	711	5	0.005	697.07	2.336D
SB-126	697.21	697	623	20	0.02	179.63	2.337D
NB-94	702.7	702.5	387	28	0.028	102.08	2.340D
AG-110M	706.87	706.67	314	8	0.008	333.89	2.343D
SB-126	720.58	720.4	1125	24	0.024	197.34	2.352D

AM-241	722.14	721.96	1108	0	0	0	2.352D
AG-108M	723.13	722.95	1068	0	0	0	2.353D
EU-154	723.48	723.3	1045	23	0.023	198.1	2.353D
BI-212	727.34	727.17	884	23	0.023	183.14	2.356D
MO-99	739.63	739.47	361	31	0.03	89.52	2.363D
TL-208	763.43	763.3	1594	35	0.035	163.4	2.378D
AG-110M	764.06	763.93	1629	0	0	0	2.379D
PA-234M	766.72	766.6	1585	12	0.012	464.41	2.380D
BI-214	768.48	768.36	1481	72	0.071	77.03	2.381D
MO-99	777.99	777.88	1119	29	0.029	162.41	2.387D
EU-152	779.01	778.9	1075	30	0.03	153.21	2.388D
BI-212	785.52	785.42	833	40	0.039	104.27	2.392D
PB-214	786.05	785.95	829	0	0	0	2.392D
AL-26	786.82	786.72	781	3	0.003	1353.04	2.392D
AC-228	794.89	794.8	130	0	0	0	.518D
CS-134	795.85	795.76	375	65	0.064	44.18	2.398D
CS-134	801.92	801.84	248	35	0.034	66.76	2.402D
SB-126	856.71	856.7	1240	35	0.034	144.97	2.435D
TL-208	860.48	860.47	1228	24	0.024	203.38	2.437D
NB-94	871.1	871.1	874	16	0.016	256.09	2.443D
EU-154	873.19	873.2	800	21	0.021	187.92	2.444D
AG-110M	884.65	884.67	407	35	0.035	82.79	2.451D
AC-228	908.8	908.85	193	52	0.051	72.63	3.139s
BI-214	933.97	934.05	386	32	0.032	88.89	2.480D
AG-110M	937.39	937.48	292	39	0.038	64.83	2.482D
EU-152	962.83	962.95	175	36	0.036	98.64	2.475s
AC-228	964.48	964.6	175	0	0	0	2.475D
AC-228	968.78	968.9	125	0	0	0	1.252D
EU-154	996.14	996.3	412	21	0.021	135.67	2.515D
PA-234M	1000.87	1001.03	291	14	0.014	170.05	2.518D
EU-154	1004.63	1004.8	264	20	0.02	115.38	2.520D
CS-134	1041.17	1041.38	212	63	0.062	70.94	1.115s
EU-152	1086.44	1086.71	96	12	0.012	165.83	1.877
EU-152	1111.77	1112.07	958	76	0.076	58.68	2.578D
ZN-65	1115.22	1115.52	877	52	0.051	82.3	2.580D
BI-214	1119.97	1120.28	622	109	0.108	33.8	2.583D
AL-26	1129.38	1129.7	317	37	0.037	70.24	2.588D
CS-134	1165.55	1165.91	102	25	0.025	83.23	1.899
CO-60	1172.86	1173.23	141	0	0	0	1.669D
BI-214	1237.91	1238.37	186	58	0.058	59.08	1.599
NA-22	1272.64	1273.13	93	33	0.033	73.67	1.132s
EU-154	1274.30	1274.8	195	0	0	0	2.662
AL-26	1294.91	1295.43	96	11	0.011	220.26	2.045
CO-60	1328.55	1329.11	108	25	0.025	79.63	1.5
CS-134	1364.52	1365.13	253	3	0.003	706.13	2.706D
BI-214	1377.02	1377.65	154	20	0.02	88.44	2.712D
AG-110M	1383.64	1384.27	92	4	0.004	350.05	2.715D
BI-214	1406.45	1407.11	96	19	0.019	105.66	.848s
EU-152	1407.42	1408.08	85	0	0	0	2.727
▶ K-40	1460.07	1460.79	84	2364	2.351	2.2	2.567
AG-110M	1504.00	1504.78	3	0	0	0	.000s
AC-228	1587.13	1588.02	3	2	0.002	161.25	.601s
BI-212	1622.00	1622.93	2	0	0	176.38	.834s
BI-214	1728.14	1729.19	4	11	0.011	42.32	1.101s

BI-214	1763.41	1764.52	5	62	0.062	14.31	2.555
AL-26	1808.33	1809.49	2	4	0.004	72.57	.872s
BI-214	2202.38	2204.03	0	13	0.013	27.74	3.755s
TL-208	2612.38	2614.54	0	8	0.008	35.36	2.253

s Peak fails shape tests.
D Peak area deconvoluted.

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***** SUMMARY OF LIBRARY PEAK USAGE *****
NUCLIDE   AVERAGE   ----- PEAK -----
          ACTIVITY   ENERGY ACTIVITY CODE   MDA VALUE
          Becquerels keV   Becquerels Becquerels   COMMENTS
+-----+-----+-----+-----+-----+-----+-----+
NA-22      0.00E+00      511      0.00E+00   %      3.08E-05   Energy duplication
                                1274.54   0.00E+00   &      4.76E-05
AL-26      0.00E+00      511      0.00E+00   %      4.47E-05   Energy duplication
                                1808.72   0.00E+00   %      1.22E-05
                                1297.72   0.00E+00   &      4.43E-05
                                786.72    0.00E+00   %      9.22E-05
                                1129.7    0.00E+00   %      3.10E-03
K-40       6.07E-02     1460.75   6.07E-02   (      3.87E-04
TI-44      0.00E+00      78.4      0.00E+00   %      0.00E+00
                                67.8      0.00E+00   %      0.00E+00
                                146.2     0.00E+00   %      0.00E+00
CO-57      0.00E+00     122.07    0.00E+00   ! (     0.00E+00
                                136.43    0.00E+00   %      0.00E+00
                                692.1     0.00E+00   ! (     2.47E-02
CO-60      0.00E+00     1332.51   0.00E+00   &      4.99E-05
                                1173.23   0.00E+00   !      4.84E-05
ZN-65      0.00E+00     1115.52   0.00E+00   %      2.38E-04
                                511       0.00E+00   %      1.96E-03   Energy duplication
KR-85      0.00E+00     513.98    0.00E+00   %      1.50E-02
NB-94      0.00E+00     871.1     0.00E+00   %      1.04E-04
                                702.5     0.00E+00   %      6.26E-05
MO-99      0.00E+00     140.51    0.00E+00   %      0.00E+00   Energy duplication
                                181.09    2.86E-03   %      1.60E-03
                                366.44    0.00E+00   %      9.98E-03
                                739.47    0.00E+00   %      4.83E-04
                                777.88    0.00E+00   %      2.53E-03
TC-99M     0.00E+00     140.51    0.00E+00   &      0.00E+00   Energy duplication
AG-108M    0.00E+00     722.95    0.00E+00   ! (     1.14E-04

```

		614.37	0.00E+00	&(	5.97E-05
		433.7	0.00E+00	!(	4.14E-05
AG-110M	0.00E+00	657.75	0.00E+00	%	1.53E-04
		884.67	0.00E+00	%	1.01E-04
		937.48	0.00E+00	%	1.92E-04
		1384.27	0.00E+00	%	1.77E-04
		763.93	0.00E+00	!	5.83E-04
		706.67	0.00E+00	%	3.31E-04
		1505	0.00E+00	%	6.69E-05
		677.61	0.00E+00	%	1.07E-03
CD-109	0.00E+00	88.04	0.00E+00	!(	0.00E+00
SB-125	0.00E+00	427.95	0.00E+00	%	2.97E-04
		600.77	0.00E+00	%	5.94E-04
		636.15	0.00E+00	%	3.98E-04
		463.51	0.00E+00	&	6.04E-04
		176.29	0.00E+00	&	6.62E-04
		606.82	0.00E+00	%	1.90E-03
		671.66	0.00E+00	%	6.90E-03
		380.51	0.00E+00	!	2.52E-03
SB-126	0.00E+00	695.1	0.00E+00	%	8.20E-05
		666.2	0.00E+00	%	1.34E-04
		414.8	0.00E+00	%	6.42E-05
		720.4	0.00E+00	%	1.86E-04
		697	0.00E+00	%	2.42E-04
		856.7	0.00E+00	%	7.03E-04
CS-134	0.00E+00	604.66	0.00E+00	%	1.05E-04
		795.76	1.52E-04		8.12E-05
		569.29	0.00E+00	&	2.72E-04
		801.84	0.00E+00	%	6.40E-04
		563.26	0.00E+00	&	5.58E-04
		1365.13	0.00E+00	%	2.30E-03
		1167.86	0.00E+00	&	2.54E-03
		475.35	0.00E+00	&	2.98E-03
		1038.5	0.00E+00	&	6.33E-03
CS-137	0.00E+00	661.62	0.00E+00	%	1.64E-04
BA-133	0.00E+00	355.86	0.00E+00	%	2.22E-04
		302.71	8.61E-04		4.54E-04
		383.7	0.00E+00	%	9.46E-04
		276.29	0.00E+00	%	1.05E-03
CE-144	0.00E+00	133.53	0.00E+00	%	0.00E+00
EU-152	0.00E+00	121.78	0.00E+00	%	0.00E+00
		344.3	0.00E+00	%	5.81E-04
		1408.08	0.00E+00		1.93E-04
		964	0.00E+00	%	3.66E-04
		1112.07	0.00E+00	%	9.38E-04

		778.9	0.00E+00	%	8.36E-04
		1085.8	0.00E+00	%	3.95E-04
EU-154	0.00E+00	123.1	0.00E+00	%	0.00E+00
		1274.8	0.00E+00		1.67E-04
		723.3	0.00E+00	%	5.19E-04
		1004.8	0.00E+00	%	3.60E-04
		873.2	0.00E+00	%	8.83E-04
		996.3	0.00E+00	%	7.28E-04
		248.04	2.06E-03		1.11E-03
		591.7	0.00E+00	%	2.66E-03
EU-155	0.00E+00	86.45	0.00E+00	%	0.00E+00
		105.31	0.00E+00	%	0.00E+00
TL-208	7.77E-05	2614.47	7.78E-05	(	1.60E-05
		583.14	0.00E+00	%	4.44E-04
		510.72	0.00E+00	-	9.03E-04
		860.47	0.00E+00	%	2.74E-03
		277.36	0.00E+00	%	3.07E-03
		763.3	0.00E+00	%	2.00E-02
PB-212	4.87E-04	238.63	4.87E-04	(	2.33E-04
		300.09	0.00E+00	%	2.85E-03
PB-214	1.82E-03	351.99	1.69E-03	(	3.76E-04
		295.22	1.72E-03	(	5.20E-04
		241.92	2.73E-03	(	1.24E-03
		785.95	0.00E+00	-	1.11E-02
BI-212	0.00E+00	727.17	0.00E+00	%	1.44E-03
		1620.56	0.00E+00	&	4.50E-04
		785.42	0.00E+00	%	8.80E-03
BI-214	1.28E-03	609.32	1.34E-03	(	1.65E-04
		1764.51	1.16E-03	(	6.89E-05
		1120.28	1.75E-03	+	7.15E-04
		1238.11	0.00E+00	%	1.10E-03
		2204.12	8.48E-04	-	3.87E-04
		768.36	0.00E+00	%	2.61E-03
		1377.65	0.00E+00	%	1.44E-03
		934.05	0.00E+00	%	2.34E-03
		1729.6	1.07E-03	?(	3.19E-04
		1407.98	0.00E+00	%	1.92E-03
RA-226	0.00E+00	186.1	0.00E+00	!(	2.27E-03
AC-228	0.00E+00	911.07	0.00E+00	&	2.09E-04
		968.9	0.00E+00	!	2.55E-04
		338.4	0.00E+00	&	4.87E-04
		964.6	0.00E+00	&	9.53E-04
		794.8	0.00E+00	?	8.69E-04
		463	0.00E+00	&	1.25E-03
		209.4	0.00E+00	&	1.52E-03

		270.3	0.00E+00	&	1.98E-03
		1587.9	0.00E+00	%	3.20E-04
		328	0.00E+00	!	1.52E-03
PA-234 M	0.00000E+00	1001.03	0.00E+00	%	7.81E-03
		766.6	0.00E+00	%	4.09E-02
U-235	2.46E-04	185.72	2.46E-04	(	1.36E-04
		143.76	0.00E+00	%	0.00E+00
		205.31	0.00E+00	%	1.78E-03
		163.35	0.00E+00	&	8.43E-04
		109.14	0.00E+00	%	0.00E+00
		202.12	0.00E+00	%	8.46E-03
		221.38	0.00E+00	&	4.97E-02
		279.5	0.00E+00	%	2.28E-02
NP-237	0.00E+00	143.25	0.00E+00	!(	0.00E+00
		352	0.00E+00	!(	2.08E+00
		300.17	0.00E+00	!(	8.76E-04
		312.01	0.00E+00	&(	1.55E-04
		340.59	0.00E+00	&(	1.37E-03
PU-239	0.00E+00	129.28	0.00E+00	%	0.00E+00
		375.02	0.00E+00	%	6.58E+00
		413.69	0.00E+00	%	3.37E+00
		332.8	0.00E+00	%	3.31E+01
		393.06	0.00E+00	%	1.25E+01
		451.45	0.00E+00	&	3.39E+01
		344.96	0.00E+00	%	2.77E+01
		203.52	0.00E+00	%	1.61E+01
PU-241	0.00E+00	148.56	0.00E+00	%	0.00E+00
		208.01	0.00E+00	%	1.56E+01
AM-241	0.00E+00	59.54	0.00E+00	%	0.00E+00
		335.43	0.00E+00	%	3.37E+01
		662.42	0.00E+00	%	3.83E+01
		721.96	0.00E+00	!	8.00E+01

(- This peak used in the nuclide activity average.

* - Peak is too wide, but only one peak in library.

! - Peak is part of a multiplet and this area went negative during deconvolution.

? - Peak is too narrow.

@ - Peak is too wide at FW25M, but ok at FWHM.

% - Peak fails sensitivity test.

\$ - Peak identified, but first peak of this nuclide failed one or more qualification tests.

+ - Peak activity higher than counting uncertainty range.

- - Peak activity lower than counting uncertainty range.

= - Peak outside analysis energy range.

& - Calculated peak centroid is not close enough to the library energy centroid for positive identification.

P - Peakbackground subtraction

***** SUMMARY OF NUCLIDES IN SAMPLE *****

NUCLIDE	TIME OF COUNT	ACTIVITY	UNCERTAINTY
		pCi/g	COUNTING
			(1 SIGMA)
NA-22	<	3.08E-02	
AL-26	<	4.47E-02	
K-40		6.07E+01	2.20%
TI-44	<	0.00E+00	
CO-57	<	0.00E+00	
CO-60	<	4.99E-02	
ZN-65	<	2.38E-01	
KR-85	<	1.50E+01	
NB-94	<	1.04E-01	
MO-99	<	0.00E+00	
TC-99M	<	0.00E+00	
AG-108M	<	1.14E-01	
AG-110M	<	1.53E-01	
CD-109	<	0.00E+00	
SB-125	<	2.97E-01	
SB-126	<	8.20E-02	
CS-134	<	1.05E-01	
CS-137	<	1.64E-01	
BA-133	<	2.22E-01	
CE-144	<	0.00E+00	
EU-152	<	0.00E+00	
EU-154	<	0.00E+00	
EU-155	<	0.00E+00	
TL-208		7.77E-02	35.36%
PB-212		4.87E-01	41.64%
PB-214		1.82E+00	17.17%
BI-212	<	1.44E+00	
BI-214		1.28E+00	11.86%
RA-226	<	2.27E+00	
AC-228	<	2.09E-01	
PA-234M	<	7.81E+00	
U-235		2.46E-01	47.99%
NP-237	<	0.00E+00	
PU-239	<	0.00E+00	
PU-241	<	0.00E+00	
AM-241	<	0.00E+00	

----- SUMMARY -----
TOTAL ACTIVITY (39.0 to 4003.9 keV) 6.4582470E+01 pCi/g

The library has energies which are not separable.

Analyzed by: _____
Battelle

Reviewed by: _____
Supervisor

Appendix E: Nuclide Libraries

Appendix E.1 Westjeff.lib

GammaVision Nuclide Library WESTJEFF.LIB

Created: 20-SEP-96 12:17:46

Edited: 02-OCT-96 10:05:15

Na-22 2.60032 Yrs.
511.00keV 179.8%
1274.54keV 99.94%

Al-26 7.162e+006 Yrs.
511.00keV 164.2%
1808.72keV 99.73%
1297.72keV 99.73%
786.72keV 99.73%
1129.70keV 2.425%

K-40 1.28e+009 Yrs.
1460.75keV 10.7%

Ti-44 47.31 Yrs.
78.40keV 94.7%
67.80keV 87.7%
146.20keV 0.1%

Co-57 270.023 Days
122.07keV 85.6%
136.43keV 10.6%
692.10keV 0.15%

Co-60 5.273 Yrs.
1332.51keV 99.98%
1173.23keV 99.86%

Zn-65 243.75 Days
1115.52keV 50.75%
511.00keV 2.83%

Kr-85 10.73 Yrs.
513.98keV 0.43%

Nb-94 20300 Yrs.
871.10keV 100%
702.50keV 100%

Mo-99	66.194 Hrs.
140.51keV	90.9%
181.09keV	6%
366.44keV	1.21%
739.47keV	13%
777.88keV	4.37%
Tc-99M	6.019 Hrs.
140.51keV	89.3%
Ag-108M	127.006 Yrs.
722.95keV	90%
614.37keV	90%
433.70keV	90%
Ag-110M	249.884 Days
657.75keV	94.74%
884.67keV	72.86%
937.48keV	34.31%
1384.27keV	24.35%
763.93keV	22.36%
706.67keV	16.74%
1505.00keV	13.11%
677.61keV	10.72%
Cd-109	453.356 Days
88.04keV	3.79%
Sb-125	2.77 Yrs.
427.95keV	29.6%
600.77keV	18.4%
636.15keV	11.2%
463.51keV	10%
176.29keV	6.3%
606.82keV	5.2%
671.66keV	1.8%
380.51keV	1.4%
Sb-126	12.5 Days
695.10keV	99.7%
666.20keV	99.66%
414.80keV	86%
720.40keV	57%
697.00keV	32%
856.70keV	17.5%

Cs-134 2.062 Yrs.
604.66keV 97.6%
795.76keV 85.4%
569.29keV 15.43%
801.84keV 8.73%
563.26keV 8.38%
1365.13keV 3.04%
1167.86keV 1.8%
475.35keV 1.46%
1038.50keV 1%

Cs-137 30.104 Yrs.
661.62keV 84.62%

Ba-133 10.701 Yrs.
355.86keV 62.27%
302.71keV 18.62%
383.70keV 8.84%
276.29keV 7.3%

Ce-144 284.144 Days
133.53keV 10.8%

Eu-152 12.701 Yrs.
121.78keV 29.24%
344.30keV 27%
1408.08keV 21.21%
964.00keV 14.58%
1112.07keV 13.58%
778.90keV 12.99%
1085.80keV 10.29%

Eu-154 8.502 Yrs.
123.10keV 40.46%
1274.80keV 35.5%
723.30keV 19.7%
1004.80keV 17.6%
873.20keV 11.3%
996.30keV 10.7%
248.04keV 6.6%
591.70keV 4.6%

Eu-155 4.959 Yrs.
86.45keV 32.74%
105.31keV 21.8%

Tl-208 1.9131 Yrs.
2614.47keV 35.64%
583.14keV 30.36%
510.72keV 8.125%
860.47keV 4.465%
277.36keV 2.267%
763.30keV 0.6522%

Pb-212 1.9131 Yrs.
 238.63keV 43.33%
 300.09keV 3.278%

Pb-214 1600 Yrs.
 351.99keV 37.1%
 295.22keV 19.2%
 241.92keV 7.47%
 785.95keV 0.85%

Bi-212 1.9131 Yrs.
 727.17keV 6.579%
 1620.56keV 1.486%
 785.42keV 1.102%

Bi-214 1600 Yrs.
 609.32keV 46.09%
 1764.51keV 15.92%
 1120.28keV 15.04%
 1238.11keV 5.916%
 2204.12keV 4.993%
 768.36keV 4.885%
 1377.65keV 4.02%
 934.05keV 3.165%
 1729.60keV 3.047%
 1407.98keV 2.477%

Ra-226 1600 Yrs.
 186.10keV 3.5%

Ac-228 5.75 Yrs.
 911.07keV 26.6%
 968.90keV 16.17%
 338.40keV 11.25%
 964.60keV 5.107%
 794.80keV 4.336%
 463.00keV 4.442%
 209.40keV 3.884%
 270.30keV 3.431%
 1587.90keV 3.272%
 328.00keV 3.099%

Pa-234M 4.7e+009 Yrs.
 1001.03keV 0.839%
 766.60keV 0.316%

U-235 7.038e+008 Yrs.

185.72keV	57.2%
143.76keV	10.96%
205.31keV	5.01%
163.35keV	5.08%
109.14keV	1.54%
202.12keV	1.08%
221.38keV	0.12%
279.50keV	0.27%

Np-237 2.14e+006 Yrs.

143.25keV	0.473%
352.00keV	0.003%
300.17keV	6.2%
312.01keV	36%
340.59keV	4.2%

Pu-239 24130 Yrs.

129.28keV	0.0062%
375.02keV	0.00158%
413.69keV	0.00151%
332.80keV	0.00051%
393.06keV	0.00044%
451.45keV	0.00019%
344.96keV	0.00056%
203.52keV	0.000569%

Pu-241 15.16 Yrs.

148.56keV	0.000183%
208.01keV	0.0005302%

Am-241 433.176 Yrs.

59.54keV	35.9%
335.43keV	0.000495%
662.42keV	0.00036%
721.96keV	0.00013%

Appendix E.2 King.lib

GammaVision Nuclide Library KING.LIB

Created: 30-SEP-96 09:35:58

Edited: 06-NOV-96 18:58:26

Na-22 2.6 Yrs.

511.00keV	179.8%
1274.54keV	99.94%

K-40 1.28e+009 Yrs.

1460.75keV	10.7%
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Co-60 5.273 Yrs.
 1332.51keV 99.98%
 1173.23keV 99.86%

Mo-99 66.194 Hrs.
 140.51keV 90.9%
 739.47keV 13%
 181.09keV 6%
 777.88keV 4.37%
 366.44keV 1.21%

Tc-99M 6.019 Hrs.
 140.51keV 89.3%

Cs-134 2.062 Yrs.
 604.66keV 97.6%
 795.76keV 85.4%
 569.29keV 15.43%
 801.84keV 8.73%
 563.26keV 8.38%
 1365.13keV 3.04%
 1167.86keV 1.8%
 475.35keV 1.46%
 1038.50keV 1%

Cs-137 30.104 Yrs.
 661.62keV 84.62%

Tl-208 1.9131 Yrs.
 2614.47keV 35.64%
 583.14keV 30.36%
 510.72keV 8.125%
 860.47keV 4.465%
 277.36keV 2.267%
 763.30keV 0.6522%

Pb-212 1.9131 Yrs.
 238.63keV 43.3%
 300.09keV 3.278%

Pb-214 1600 Yrs.
 351.99keV 37.1%
 295.22keV 19.2%
 241.92keV 7.47%
 785.95keV 0.85%

Bi-212 1.9131 Yrs.
 727.17keV 6.579%
 1620.56keV 1.486%
 785.42keV 1.102%

Bi-214 1600 Yrs.

609.32keV	46.09%
1764.51keV	15.92%
1120.28keV	15.04%
1238.11keV	5.916%
2204.12keV	4.993%
768.36keV	4.885%
1377.65keV	4.02%
934.05keV	3.165%
1729.60keV	3.047%
1407.98keV	2.477%

Ra-226 1600 Yrs.

186.10keV	3.5%
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Ac-228 5.75 Yrs.

911.07keV	26.6%
968.90keV	16.17%
338.40keV	11.25%
964.60keV	5.107%
794.80keV	4.336%
463.00keV	4.442%
209.40keV	3.884%
270.30keV	3.431%
1587.90keV	3.272%
328.00keV	3.099%

Pa-234M 4.7e+009 Yrs.

1001.03keV	0.839%
766.60keV	0.316%

U-235 7.038e+008 Yrs.

185.72keV	57.2%
143.76keV	10.96%
205.31keV	5.01%
163.35keV	5.08%
109.14keV	1.54%
202.12keV	1.08%
221.38keV	0.12%
279.50keV	0.27%

Am-241 433.176 Yrs.

59.54keV	35.9%
335.43keV	0.000495%
662.42keV	0.00036%
721.96keV	0.00013%

Appendix F Detector Trouble Shooting

Symptom: Dewar frosts up.

Solution: This is OK if it occurs only during filling with the funnel (See Figure 2 under Operation of the Detector). However, at other times it would indicate that the Dewar has lost vacuum. Refer to the section on vacuum pump-out and bake-out.

Symptom: Segment 2 (detector segment) frosts up.

Solution: This is only OK if a slight temporary frost buildup occurs on the detector segment during initial cooling. This could be due to downflow of cold nitrogen gas chilling the exterior of segment 2 during the filling process. However, if segment 2 frosts up at any other time, this also indicates loss of vacuum. Refer to the section on vacuum pump-out and bake-out.

Symptom: Poor peak resolution.

Solution: This may be a symptom of breakdown of bias on the surface of the germanium crystal. Lower the bias voltage in 100 volt increments until satisfactory peak resolution is attained. This operation does NOT alter the efficiency of the detector. If satisfactory resolution cannot be obtained by lowering the bias voltage, the detector may require factory repairs.

Symptom: Temperature sensor reading at detector different than at Nomad Plus.

Solution: A typical reading of the temperature sensor was 28.4 Ω at the detector. At the Nomad Plus the sensor would read 36.1 Ω . This differential can be explained by the resistance of the 75 ft long cable between the detector and the Nomad Plus. A ground loop also disturbs the reading if the connectors to the volt-ohm meter are switched. When using the temperature sensor connected at the end of the 75 ft long cable, subtract 7.7 Ω to obtain the true value.

Symptom: Atypical temperature sensor readings.

Solution: A temperature sensor reading near 0 indicates a short in the system. Most likely, the thermistor has shorted out in the detector segment. This is a factory repair best reserved for incidental correction during some other mandatory factory repair.

Symptom: GammaVision output results not consistent with unit labels.

Solution: When μCi are chosen as the reporting unit and a normalization factor (10^3 not 10^6 because of the built-in factor of 1000 in the efficiency factors) is included to output the results in pCi , the correct data is contained in the final table, "Summary of Nuclides in Sample." However, in the Table "Summary of Library Peak Usage," the columns under PEAK ACTIVITY CODE and Peak MDA VALUE indicate the units are Becquerels, but the units, in fact, are μCi . Contact EG&G Ortec to see if they have corrected this code problem in their next release of the software.

Appendix G - Detector Vacuum: Pump-Out and Bake-Out

Germanium crystal spectrometers must be manufactured and maintained at high purity and operated at low temperatures to minimize free electron currents when the bias voltage is applied across the p-n junction. In order to achieve and maintain satisfactory temperatures, it is necessary to minimize heat gain by the crystal through any process of conduction, convection, or radiation. When the crystal has been mounted properly and the supporting electronics installed, the cryostat is evacuated to a pressure of about 10^{-5} to 10^{-6} atm in order to inhibit heat gain by convection. To help maintain this low vacuum, a small amount of “getter” material has also been installed in the cryostat to absorb air and other impurities which may enter the vacuum.

A common failure mechanism for germanium detectors is the loss of vacuum in the cryostat and the consequent inability to maintain the germanium crystal at liquid nitrogen temperature. A valve port is installed on the preamplifier side of the detector segment for attaching to a vacuum system. A special valve, called a Richardson valve, has been fabricated for opening and closing the main valve port while the system is under vacuum. If the detector has lost vacuum, simply pumping it down to operating vacuum may be adequate to restore operation. However, if the detector surface has become contaminated with non-volatile materials, it may also be necessary to heat the detector assembly to assist in driving off these impurities from both the germanium crystal and the getter. Accumulation of these impurities on the surface of the germanium crystal can result in electron transport, and hence, dark currents, on the detector which will adversely affect the resolution. For this reason it is important that air not be allowed into the vacuum chamber while the detector is cold, because these impurities may become irreversibly attached to the crystal surface.

Pumping the detector requires removing the three screws that hold the bellows to the preamplifier end of segment 2. Carefully pull the bellows away from the detector segment (Figure G1), and install the short safety harness between segments 2 and 3 to prevent breaking any of the wires going through the bellows. Mount the Richardson valve, which has been connected to a suitable vacuum system, using two #40 machine screws through the ears of the valve by carefully screwing into the holes on the flat plate on either side of the main valve port. Figure G2 shows the Richardson valve. Screw the threaded pushrod of the Richardson valve into the main valve port plug. It may be advantageous to thread the pushrod into the plug before completely tightening the Richardson valve to the body of the detector cryostat.

Figure G1: Picture of Disconnected Bellows to Access the Vacuum Port

Figure G2: Richardson Valve

An oil-free type of vacuum pump should be used such as a helium leak detector system which has a pumping system along with a system to measure He gas. First obtain a good vacuum between the pump and the Richardson valve, and then pull the main valve port plug open with the attached rod. Generally speaking, a satisfactory vacuum can be re-established by pumping overnight. If it is suspected that the detector surface may have become contaminated, then the detector system needs to be baked at $\sim 100^\circ\text{C}$ for 24-72 hours while pumping. This is most easily accomplished by wrapping a heat tape connected to a Variac for temperature control around the detector and Dewar assembly. A digital thermometer can be used to monitor the temperature.

When a satisfactory vacuum has been obtained, seal the port by pushing the plug back into the main valve opening. Carefully unscrew the pushrod so it can be backed out of the plug, then vent the hose and carefully remove the Richardson valve. Remove the safety tether and reinstall the bellows.

Ultimately, if satisfactory detector specifications cannot be achieved, it may be necessary for the manufacturer to remove the germanium crystal and acid etch it (sometimes even a slight trim is required) to remove the surface contaminants from the crystal and re-establish optimum detector performance.