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Symetrica Measurements at PNNL

Technical Support for DoD Radiological Protection Issues

Revision 0
PIET-48581-TM-037

RT Kouzes
EK Mace
RL Redding
DC Stromswold

January 2009

Pacific Northwest
NATIONAL LABORATORY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

Symetrica is a small company based in Southampton, England, that has developed an algorithm for processing gamma ray spectra obtained from a variety of scintillation detectors. Their analysis method applied to NaI(Tl), BGO, and LaBr spectra results in deconvoluted spectra with the "resolution" improved by about a factor of three to four. This method has also been applied by Symetrica to plastic scintillator with the result that the deconvolved spectra have full energy peaks. If this method is valid and operationally viable, it could lead to a significantly improved plastic scintillator based radiation portal monitor system.

Symetrica's method of spectral analysis was demonstrated at Pacific Northwest National Laboratory (PNNL) using NaI(Tl) and plastic scintillators. Unfortunately, the plastic scintillator was damaged in shipment from England, and no useful data were obtained. However, NaI(Tl) detectors were tested using various industrial sources, special nuclear material (SNM), and naturally occurring radioactive material (NORM).

Symetrica's analysis generally provided detection and correct identification of the sources (typically a few μCi for the industrial sources and 100 g for SNM, located at one to two meters) in measurement intervals lasting10 seconds.

The data were also analyzed at PNNL using GADRAS, a gamma ray template-based, spectral analysis software toolset. GADRAS correctly classified most of the sources and identified their main isotopes. It also categorized them by SNM probability and Threat Level. There were several instances where GADRAS identifies isotopes that were not present during data collection but acknowledged it as a weak identification (ID) with either fair or low confidence. The only Bad ID was on the NORM sample of lanthanum carbonate but it was still classified as a very low probability SNM.

ScintiVision, a gamma-ray spectral analysis program from ORTEC, was also used at PNNL to analyze the data. ScintiVision was not as easy to use for analysis as GADRAS and the results from it were generally unsatisfactory, with many incorrect nuclides being identified.

Although it was not possible to test the Symetrica algorithm with PVT scintillator because of its damage in shipment, it would be highly desirable to do this testing in the future. The good performance of Symetrica's algorithm, and GADRAS, with NaI(Tl) suggests that significant improvements in spectral processing might also be obtained for PVT detectors. In particular, reduction in nuisance alarms for portal monitors might be accomplished, in comparison to what is traditionally observed for PVT detectors.

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1.0 Introduction

Scintillation detectors for gamma rays play a central role for homeland security applications for the detection of illicit radioactive materials. Polyvinyl toluene (PVT) plastic scintillator is the most commonly used detector material for radiation portal monitor (RPM) systems, while NaI(Tl) is used in spectroscopic portal monitor (SPM) systems and handheld devices. Some handheld detectors using LaBr, and CZT detectors are in development. While PVT-based systems provide the required capability to alarm on the presence of gamma radiation, they cannot in general distinguish all threat materials from some naturally occurring radioactive material (NORM) that can produce an operational burden for homeland security applications. Identification of the radionuclides responsible for producing an alarm in a RPM system is thus desired, and has driven the need for SPM systems in some applications. Systems based upon NaI(Tl) detectors are much more costly than those based on PVT, so if the spectroscopic capability of PVT could be improved it may be possible to use the more cost effective PVT-based systems for radionuclide identification, or at least for NORM rejection.

Symetrica is a small company based in Southampton, England, that has developed an algorithm for processing gamma ray spectra obtained from a variety of scintillation detectors [Burt 2008; Foster 2008; Meng and Ramsden 2000; Ramsden and Dallimore 2008; Crossingham et al. 2003; Dallimore et al. 2003]. Their analysis method applied to NaI(Tl), BGO, and LaBr spectra results in deconvoluted spectra with the "resolution" improved by about a factor of three to four. This method has been applied to PVT with the result that full energy peaks are produced, as seen in Figure 1 [Ramsden and Dallimore 2008]. A NaI(Tl) analysis example is shown in Figure 2. If this method is valid and operationally viable, it could lead to an improved PVT-based RPM system.

In order to test Symetrica's algorithm, equipment was brought to PNNL for measurements with a variety of sources, including special nuclear material (SNM). This provided Symetrica with data on SNM that was previously unavailable. Dr. Matthew Dallimore and Thomas Meeks of Symetrica came to PNNL November 3-5, 2008, to make these measurements, working with the authors of this report.

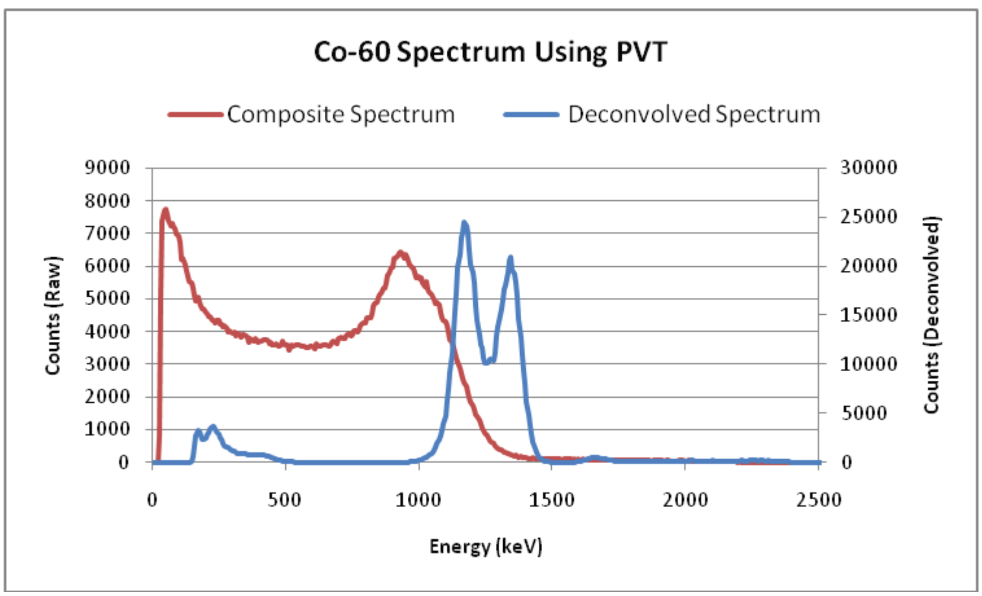
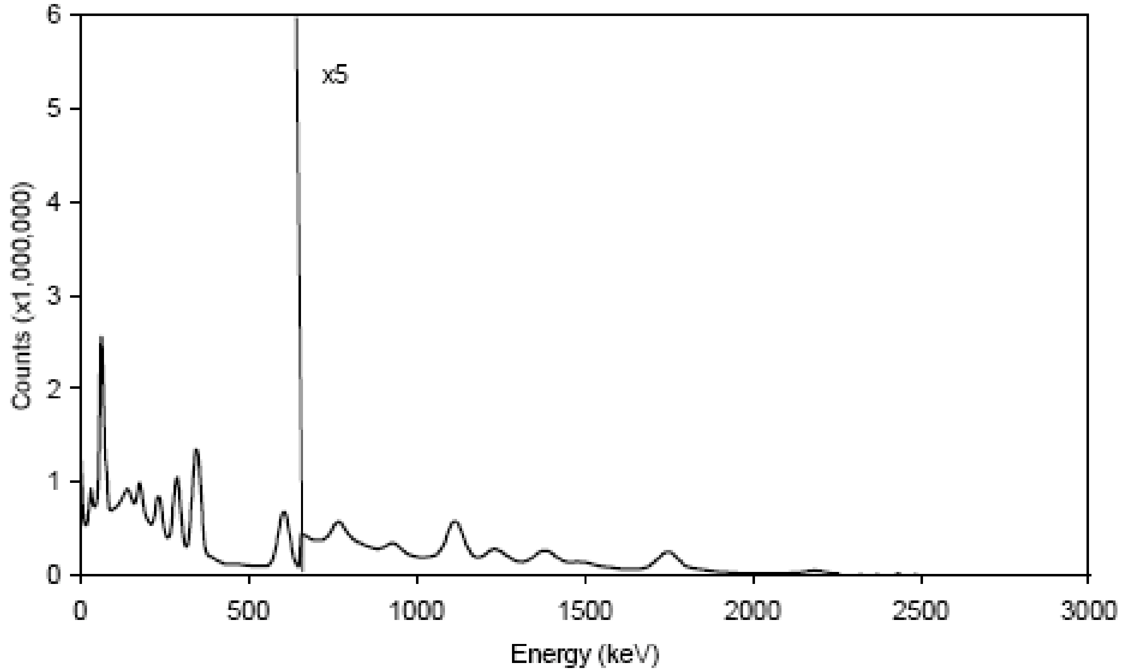


Figure 1. Example of PVT Spectrum of ^{60}Co and Deconvoluted Spectrum [Ramsden and Dallimore 2008]



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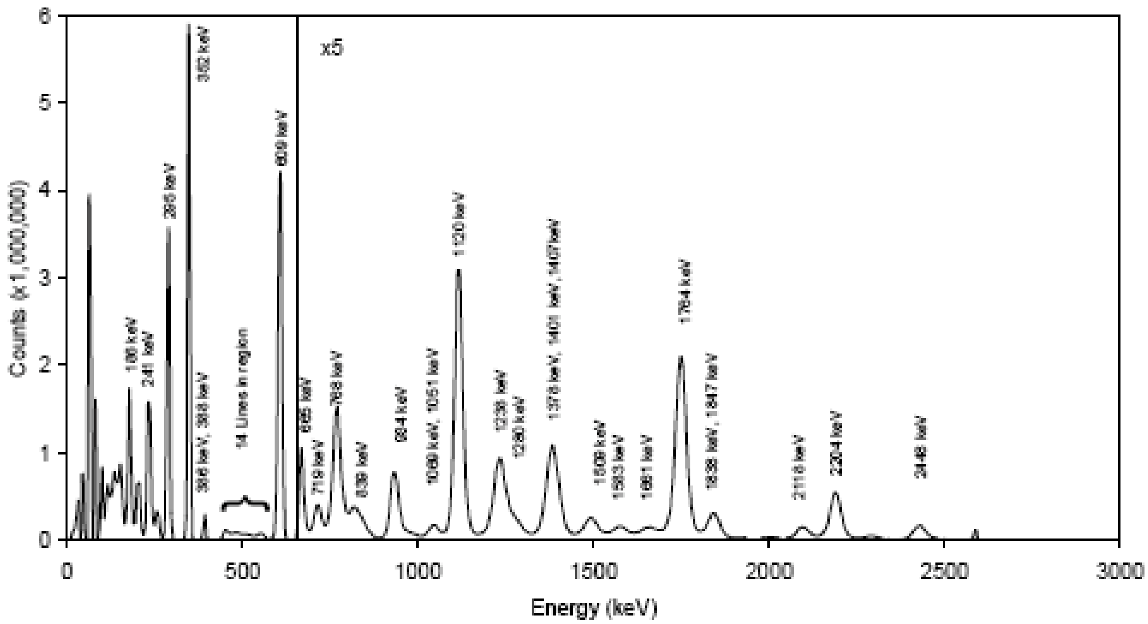

b)

Figure 2. a) A Raw ^{226}Ra Energy Spectrum Recorded with a 2”x2” NaI(Tl) Detector and b) the Deconvoluted Spectrum with the Peaks Labeled [Crossingham et al. 2003]

2.0 Symetrica Equipment Used

Symetrica brought two systems (Figure 3) to PNNL for testing: a dual 2”x4”x16” NaI(Tl) system, and a PVT based system (~1 m x 0.25 m).

Figure 3. Symetrica Systems Against Far Wall: NaI(Tl) system (left) and PVT System (right)

Both of the Symetrica systems arrived broken from mishandling in shipment. The two NaI(Tl) detectors were swapped out for PNNL-owned detectors. The NaI(Tl) system was then ready for use (although at poorer energy resolution than achieved by the original detectors)..

The phototubes were removed and remounted on the PVT system. But much poorer resolution was still obtained at PNNL. PVT data were taken for some sources. Figure 4 shows ^{22}Na source spectra taken with their PVT system in Chillworth, England, and at PNNL. The PVT system remained too degraded in performance, and did not have sufficient resolution to be used for the Symetrica algorithm. Symetrica’s more robust PVT assembly is being tested at AWE in England, and this assembly, or one like it, should be used for any future measurements.

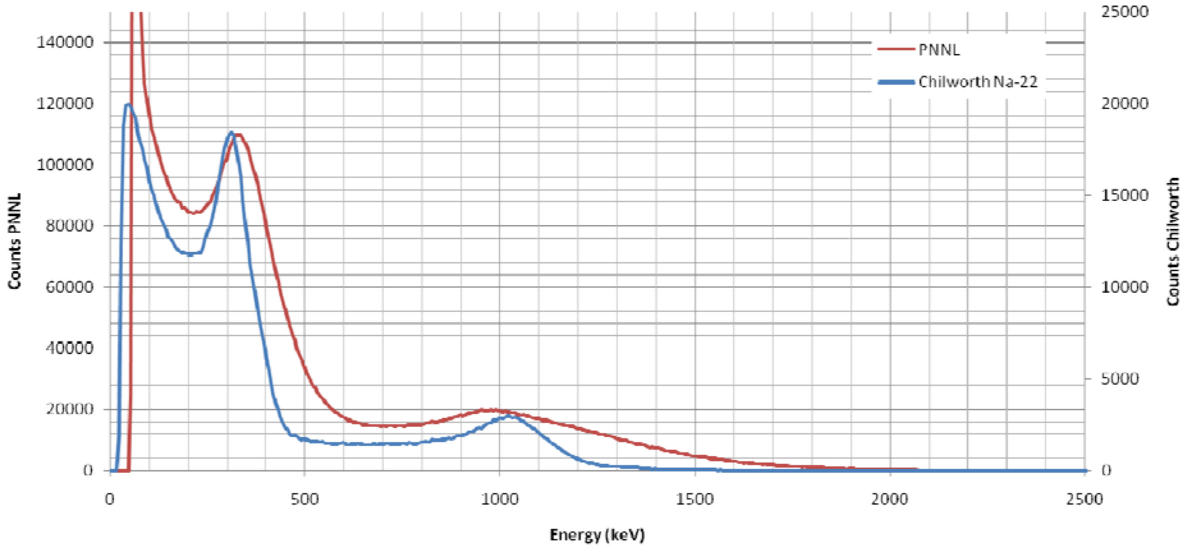

Figure 4. Response of Symetrica PVT System to a ^{22}Na source in England and PNNL

3.0 Sources Used

A variety of SNM, industrial and NORM sources were used during these measurements. Table 1 lists the sealed industrial sources used, Table 2 lists the SNM sources used, and Table 3 lists the NORM sources used.

Table 1. Sources (non-SNM)

Isotope ID	Source ID	Half-life	Assay Date	Current Activity
Ba-133	56595-125	10.52y	11.0uCi – Aug1, 2003	7.77uCi
Co-57	58705-49	271.8d	19.9uCi – Jun15, 2006	2.13uCi
Co-60	58705-79	5.27y	9.870uCi – Jan1, 2007	7.74uCi
Cs-137	58705-84	30.2y	9.609uCi – Feb1, 2007	9.23uCi
Eu-152	4491-125-0-1	13.33y	265.5uCi – Oct13, 1982	69uCi
Na-22	56595-151G	2.6y	10.4uCi – Oct15, 2004	3.523uCi

Table 2. SNM Sources

Source	Source ID	Amount		
WGPu	19B14B	98g	94.4% Pu239, 5.6% Pu240	4.5 cm diameter double-encapsulated stainless steel cylinder
RGPu	19B14C	98g	80.3% Pu239, 19.1% Pu240	4.5 cm diameter double-encapsulated stainless steel cylinder
HEU	56238-81B	125g	93.1% U235	Sealed inside Lexan
DU		3.3kg		4~6 cm diameter steel cylindrical container
Yellowcake		413g	Nat. U: 99.275% U238, 0.72% U235, 0.0055% U234	Sealed in glass inside a PVC cylinder
Heisenberg Cube		2” cube	Nat. U: 99.275% U238, 0.72% U235, 0.0055% U234	2” cube sealed inside Lexan cube

Table 3. NORM Sources

Source	Major Activity
Zircon Sand	Ra-226, Th-232
Ice Melt	K-40
Kitty Litter	K-40, Th-232
Tiles	K-40, Th-232
Fertilizer	K-40
Granite	K-40, Th-232
Lanthanum Carbonate	La-138

4.0 Analysis of NaI(Tl) Data

The data obtained with the NaI(Tl) detectors was analyzed by Symetrica, and at PNNL using traditional spectral analysis and by using GADRAS.

4.1 Analysis Results From Symetrica

This section summarizes the report in the Appendix provided by Matt Dallimore et al. of Symetrica on their analysis. Symetrica's aim of the testing was to acquire data from SNM sources to which the Large Area Detector System (LADS) module had not previously been exposed. PNNL's aim for the testing was to observe the performance of Symetrica's algorithm for SNM and also for industrial sources and NORM.

Tests on plastic scintillator (PVT) were also a priority for PNNL, although these tests were not accomplished, as mentioned previously because of detector damage. Symetrica has reported previously on their PVT work, and they will perform further measurements with their next prototype. This PVT analysis is of very high interest and needs to be actively pursued.

The Symetrica systems use their own unique spectral analysis [Meng and Ramsden 2000]. This analysis incorporates knowledge of the intrinsic detector response to deconvolve a measured spectrum into a good approximation of the gamma-ray spectrum incident upon the detector. In this way the gamma rays that only partially interact in the detector (i.e., the Compton-scattered portion of the spectra) can be "reassigned" to full-energy peaks. This deconvolved spectrum is then analyzed for peaks that match a library.

Computer simulations using the Monte Carlo code GEANT is used to produce the response functions for each specific detector and measurement geometry. The response functions are then used in calculations with the unknown (measured) spectrum in an iterative procedure to obtain a calculated spectrum having the same number of counts as in the original spectrum but with the counts redistributed primarily into full-energy peaks.

The spectrum obtained from this processing has narrower peaks than those in the original spectrum. For NaI(Tl) data, this results in an apparent energy resolution that is two to three times better than that in the original spectrum. The narrow peaks make it easier to identify isotopes based on their characteristic peak energies. In addition, the narrow peaks help in resolving closely spaced peaks and determining their individual peak intensities (areas). The library of potential sources included the 40 isotopes typically used for SNM, industrial, and natural sources in spectral applications for national security applications [ANSI 2006].

Table 4 shows a summary of the isotopes identified during the measurements using Symetrica's analysis technique. The table shows various shielding configurations that lead to attenuation of the lines at 186 keV for HEU or at 414 keV for Pu, with the corresponding success rate for identification of the nuclide. Even with a non-optimum detector system the LADS demonstrated excellent identification performance with WGPu, identifying it bare at a distance of 5.4 m, as well as identifying the source through an inch of steel and copper shielding at a distance of 1 m in most of the 10-second runs. The software was subsequently modified to the resolution specification of the PNNL detectors, and the results from that reanalysis are also presented in the table. For example, the WGPu source attenuated by 90%

resulted in eight out of ten (8/10) correct identifications for the original calculation and 10/10 for the reanalysis with the appropriate energy resolution. Table 5 gives a summary of all the source identifications from the Symetrica system. Full results from Symetrica are given in the Appendix.

Table 4. Summary of Shielded-Source Identification From Symetrica

Attenuation Level @ 414 keV	Attenuation Level @ 186 keV	Identified As Recorded	Identified In Reanalysis	Shielding materials Steel (mm)	Copper (mm)	Lead (mm)
37% WGPu		7/10	10/10	6.35		
75% WGPu		9/10	10/10	19.05		
90% WGPu		8/10	10/10	19.05	6.35	
96% WGPu		5/10	7/10	19.05	6.35	3.175
100% WGPu		0/10	1/10			50.8
37% RGPu		5/10	10/10	6.35		
75% RGPu		11/15	12/15	19.05		
90% RGPu		3/5	5/5	19.05	6.35	
	16% HEU	10/10	10/10	1.1		
	69% HEU	10/10	10/10	7.5		
	87% HEU	4/9	9/9	13.8		

Table 5. Summary of Source Identifications From Symetrica

Source	Batch Results: Source ID at >= 80%/Runs	Source Isotopes at >= 80% identification level	Other Isotopes at >= 80% identification level
Cs-137	4/4	Cs137	
Co-57	4/6	(Co57 19/30)	
Co-60	6/6	Co60	
Ba-133	1/1	Ba133	
Zircon Sand	2/2	Ra226	
Ice Melt	1/1	K40	
Kitty Litter	0/1	(K40 5/10, Th232 5/10)	
Tiles	1/1	K40	
Fertilizer	1/1	K40	
Granite	1/1	K40	
Lanthanum Carbonate	1/1	La138	
WGPu	7/8	Pu239	
WGPu (shielded)	6/9	(Pu239 32/45)	(I123 29/45)
RGPu	6/6	Am241 Pu241 Pu239	Sm153
RGPu (shielded)	5/6	Pu241 Am241 Pu239	Cs137
HEU	12/13	U235	
DU	3/4	U238	
Yellowcake	5/5	U238	
Heisenberg Cube	4/5	U238	

4.2 Analysis Results Using GADRAS

While the Symetrica systems incorporate their own unique spectral analysis package, the data were also analyzed at PNNL using the spectral analysis software package GADRAS. GADRAS uses a full-spectrum analysis method to analyze gamma-ray spectra, where an entire spectrum is convoluted with a detector response function and is then fitted with one or more computed spectral templates (template matching). These templates are computed using a detector response function that can be defined by the user to fit a specific detector.

The detector settings used to analyze the Symetrica data are shown in Figure 5. These settings characterize a 2”x4”x16” NaI crystal that is then scaled by two to represent both detectors in the Symetrica case. The calibration coefficients were determined using data collected by the system on several standard sources: ^{137}Cs, ^{60}Co, and ^{133}Ba.

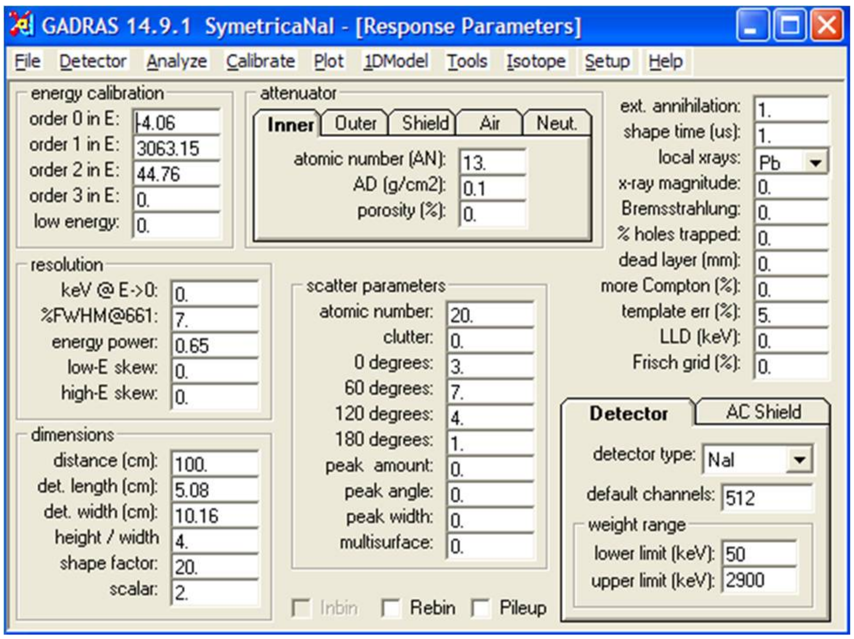

Figure 5. Screen Capture of Detector Response Parameters

The data were analyzed in GADRAS using the DHS Isotope ID Fit-to-DB function. The library/database (DB) of isotopes contains 5 main categories: Natural, Industrial, Medical, SNM, and Beta. There are 46 isotopes in total that are used by GADRAS in the Fit-to-DB routine. The results show the initial gamma-ray spectrum in black markers and the solid color fills represent the isotopes detected by GADRAS. An example of one such spectrum is shown in Figure 6 for a ^{60}Co source.

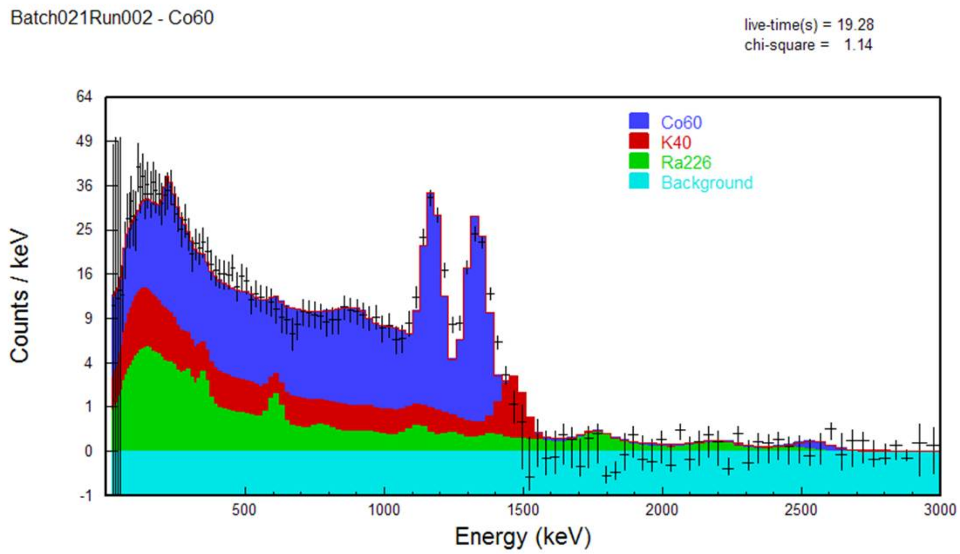

Figure 6. ^{60}Co Spectrum Analyzed in GADRAS

GADRAS correctly classified most of the sources and identified their main isotopes. It further categorized them by SNM probability and Threat Level. There are several instances where GADRAS identifies isotopes that were not present during data collection but acknowledges it as a weak ID with either fair or low confidence. The only Bad ID was on the NORM sample of lanthanum carbonate but it was still classified as a very low probability SNM. Table 6 summarizes the results from GADRAS. In the table, industrial sources are colored green, NORM sources are colored blue, and SNM sources are colored red. The data analyzed in GADRAS represents only a portion of all the data files collected by Symetrica. For each batch of data, there were at least 5 runs taken back to back on a given sample. The analysis in GADRAS included approximately 1 out of 5 runs for every sample. Table 6 has two columns with fractions listed. Those columns indicate the percentage of batch runs on a given source that GADRAS identified and classified consistently. For a detailed compilation of the GADRAS results for the individual runs, see Appendix Table C.1.

Table 7 is similar to Table 4 but includes a summary of the isotopes identified using GADRAS compared to those identified using the Symetrica technique. This table again shows various shielding configurations that lead to attenuation of the lines at 186 keV for HEU or at 414 keV for Pu, with the corresponding success rate for identification of the nuclide, this time using GADRAS. GADRAS successfully *classified* all of the WGPu, RGPu, and HEU data as High Probability SNM threats. It correctly *identified* the main isotope of the WGPu data for each shielding scenario except for 50.8mm of Lead. In that case, it misidentified the main isotope but was still classified as a High Probability SNM threat. The RGPu data was correctly classified and identified for all runs, as was the HEU data. The complete GADRAS analysis of the SNM data is shown in Appendix Table D.2.

Table 6. Summary of Source Identification in GADRAS

Source	SNM Probability		Threat Level		Main Isotope(s)	Additional Isotopes (confidence level)
Cs-137	4 / 4	0 (Very Low)	4 / 4	3 (Industrial)	Cs137	n/a
Co-57	6 / 6	0 (Very Low)	6 / 6	3 (Industrial)	Co57	Na22 (fair)
Co-60	6 / 6	0 (Very Low)	6 / 6	3 (Industrial)	Co60	Na22 (fair), Lu177m (fair)
Ba-133	1 / 1	0 (Very Low)	1 / 1	3 (Industrial)	Ba133	Cf252 (fair)
Zircon Sand	1 / 2	0 (Very Low)	1 / 2	3 (Suspect)	Ra226, Th232	U238
Ice Melt	1 / 1	0 (Very Low)	1 / 1	4 (High Gamma)	K40, Th232	n/a
Kitty Litter	1 / 1	2 (Fair)	1 / 1	6 (SNM = F)	K40, Th232	U232 (fair)
Tiles	1 / 1	0 (Very Low)	1 / 1	1 (Natural)	K40, Th232	n/a
Fertilizer	1 / 1	0 (Very Low)	1 / 1	4 (High Gamma)	K40, Th232	n/a
Granite	1 / 1	0 (Very Low)	1 / 1	1 (Natural)	K40, Th232	n/a
Lanthanum Carbonate	1 / 1	0 (Very Low)	1 / 1	4 (Bad ID)	K40	Ho166m (fair), Mn54 (fair)
WGPu	8 / 8	3 (High)	8 / 8	7 (SNM = H)	Pu239	U238 (fair),
WGPu (shielded)	9 / 9	3 (High)	9 / 9	7 (SNM = H)	Pu239	Am241 (fair), Tl201 (fair), Cs137 (fair), Ba133 (fair), U235 (fair), U238 (fair), In111 (High), Np237 (High), U237 (High), I123 (High)
RGPu	6 / 6	3 (High)	6 / 6	7 (SNM = H)	Pu239, Am241, U237	Th228 (fair), U238 (fair), Co57 (fair), U235 (low)
RGPu (shielded)	6 / 6	3 (High)	6 / 6	7 (SNM = H)	Am241, Pu239	Th232 (high), U238 (high), U237 (high), U235 (fair), Cs137 (high)
HEU	13/13	3 (High)	13/13	7 (SNM = H)	U235	U238 (fair)
DU	4 / 4	2 (Fair)	2 / 2	6 (SNM = F)	U238	n/a
Yellowcake	5 / 6	3 (High)	5 / 6	7 (SNM = H)	U238	Am241 (high), Pu239 (high), U235 (high)
Heisenberg Cube	5 / 5	2 (Fair)	5 / 5	6 (SNM = F)	U238	U235 (fair)

Table 7. Summary of Shielded-Source Identification using GADRAS

Attenuation Level @ 414 keV	Attenuation Level @ 186 keV	Identified By Symetrica	Identified In GADRAS	Shielding materials Steel (mm)	Copper (mm)	Lead (mm)
37% WGPu		10/10	10/10	6.35		
75% WGPu		10/10	10/10	19.05		
90% WGPu		10/10	10/10	19.05	6.35	
96% WGPu		7/10	10/10	19.05	6.35	3.175
100% WGPu		1/10	0/10			50.8
37% RGPu		10/10	10/10	6.35		
75% RGPu		12/15	15/15	19.05		
90% RGPu		5/5	5/5	19.05	6.35	
	16% HEU	10/10	10/10	1.1		
	69% HEU	10/10	10/10	7.5		
	87% HEU	9/9	9/9	13.8		

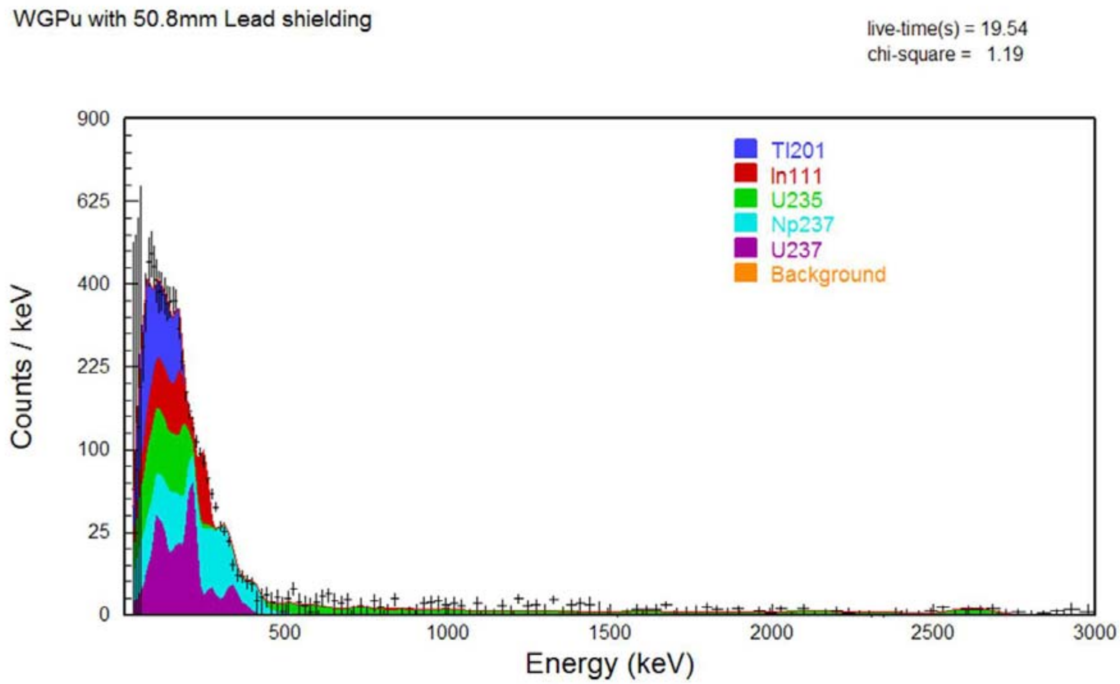

Figure 7. GADRAS Example of Misidentification but Correct Classification

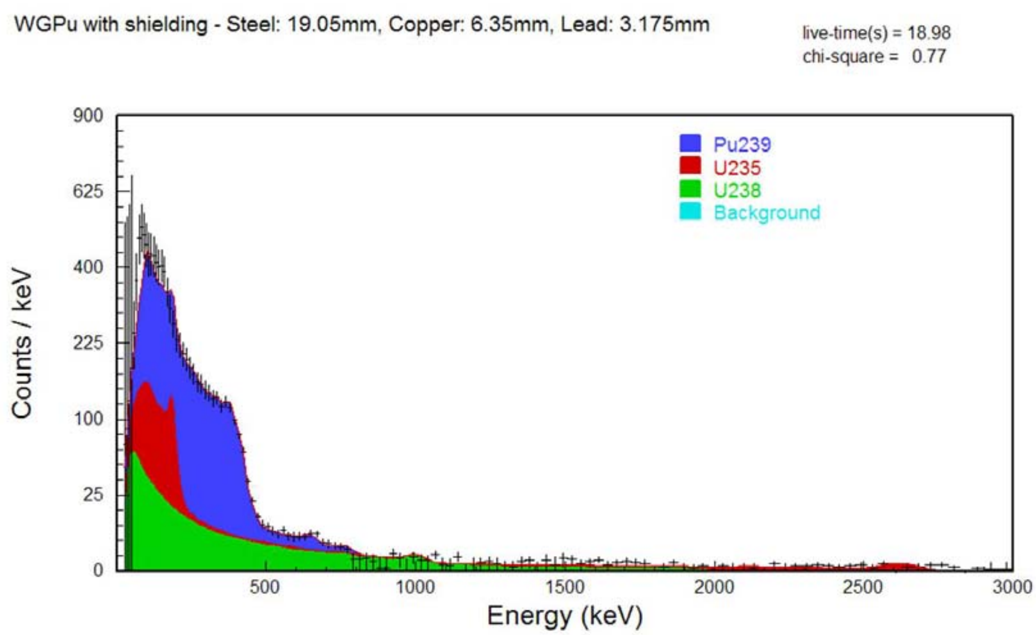

Figure 8. GADRAS Example of Correct Identification and Correct Classification

The results from GADRAS serve to confirm its excellent reputation for spectral analysis. The GADRAS analysis in the present tests was performed off-line, and for Guardian applications this would need to be done on-line. At least one commercial adaptation of GADRAS (leased to Thermo) exists for portal monitors.

4.3 Analysis Results Using ScintiVision

The NaI(Tl) data were also analyzed at PNNL using the commercial, spectral analysis program ScintiVision-32 from ORTEC. ScintiVision (SV) was designed specifically for the unique characteristics of NaI(Tl) spectra. It uses a peak searching algorithm with a Gaussian cross correlation peak search that adapts to the resolution and peak shape of the particular NaI(Tl) detector being used. Multiplets located by the peak search process are deconvoluted by a method that allows the number of peaks, the peak positions, and their width and area to vary until the minimum value of Chi-squared is obtained. This is intended to ensure that positive identification is statistically reasonable.

The library that SV uses to find the peaks can be user defined. For this analysis, a library was created by using every peak previously identified by the GADRAS method, including misidentifications, and then by going through the Symetrica data files and adding any other isotopes that were not previously included. The library had 34 nuclides and 146 peaks, which are listed in the Appendix.

Table 8 contains a summary of the ScintiVision results, with more complete results being contained in the Appendix. SV was not as useful as GADRAS when identifying isotopes in many spectra. It correctly identified the main isotope in most cases but also identified multiple other sources as well. Most of the superfluous peak identification occurred in the lower energy region circled in Figure 9. Figure 9 shows a ^{60}Co spectrum with the analysis results listed above the plot. The ^{60}Co peaks at 1173 keV and 1332 keV are easily found by the peak search but in the lower energy region, it erroneously finds ^{166m}Ho, ^{238}U, ^{177m}Lu, and ^{232}U. It appears that the peak identification algorithm is extremely sensitive to the user-defined library.

The problem of identifying erroneous nuclides is particularly significant for radiation portal monitors. Numerous false alarms and incorrect nuclide identifications effectively negate the potential benefits provided by spectral analysis. Thus, SV appears to be unsuitable for direct use for NaI(Tl)-based portal monitor applications unless improvements in the nuclide identification part of the software can be achieved.

Table 8. Summary of Source Identification in ScintiVision

Source	Number of Runs	Main Isotopes	Additional Isotopes Identified	Improbable Isotopes Found (High Uncertainty)
Cs-137	4/4	Cs137	K40, Th232	Ba133, Co57, Eu152, Pu239, Se75, U232, U233
Co-57	1/6	Co57, Se75, Ga67	K40, Th232	Ba133, Co60, Eu152, I123, In111, Lu177m, Np237, Ra226, U232, U238
Co-60	5/6	Co60	K40, Th232	Ba133, Cr51, Eu152, I123, Ir192, Lu177m, Pu241, Ra226, U232, U235
Ba-133	0/1	Eu152, Pu239	K40, Th232	Ra226, Se75, U232
Zirc Sand	2/2	Ra226, Th232	K40	Ba133, Eu152, Lu177m, Mo99, U232
Ice Melt	1/1	K40		
Kitty Litter	1/1	K40	Ra226	Eu152, Se75, U232
Tiles	1/1	K40	Ra226	
Fertilizer	1/1	K40		
Granite	1/1	K40, Th232	Ra226	Eu152
Lanthanum Carbonate	1/1	K40, Th232		

Table 8. (contd)

Source	Number of Runs	Main Isotopes	Additional Isotopes Identified	Improbable Isotopes Found (High Uncertainty)
WGPu	3/8	Pu241	K40, Th232	Co57, I123, I131, In111, Lu177m, Mo99, Ra226, Se75, Sm153, Tl201, U235
WGPu (shielded)	5/9	Pu239, U238, U235, U233, U232	K40, Ra226, Th232	Co57, Co60, Ho166m, I123, Lu177m, Mo99, Se75
RGPu	1/6	Np237	Cs137, Ga67, K40, Th232	Ba133, Cr51, Eu152, I123, Ra226
RGPu (shielded)	3/6	Pu239, U232, U233	Cs137, K40, Th232	I123, Cr51, Mo99, Co57, I131, In111, Bi207, Lu177m
HEU	4/13	U235, U232, U233	Cs137, Pu241, K40, Th232	Sm153, I123, Ga67, In111
DU	2/4	U232, U238	K40, Th232	Ra226, Se75, In111, Eu152, Cr51, Mo99,
Yellowcake	4/6	U238	K40, Th232	Ba133, Np237, Cs137, Se75, Ra226, Sm153, Mo99, U233
Heisenberg Cube	4/5	U238, U235	K40, Th232	In111, Se75, Ho166m, Mo99, Ba133, U233, U232, Pu239

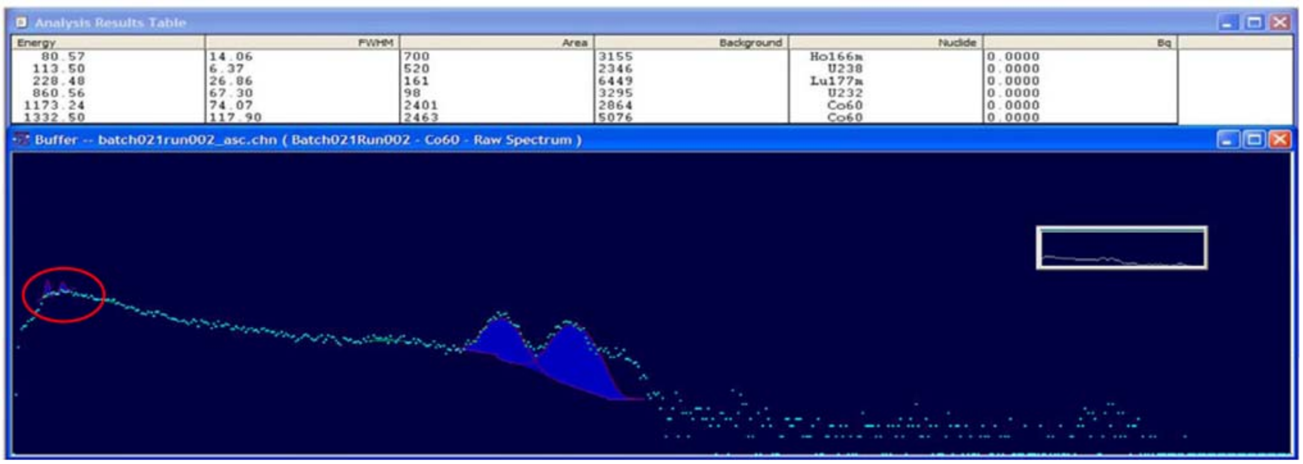

Figure 9. ^{60}Co spectrum Analyzed in ScintiVision

5.0 Conclusions

The results of measurements made at PNNL with Symetrica are encouraging. In general, Symetrica's analysis correctly identified the isotopes present during the experiments. Comparison of these results to those of GADRAS and ScintiVision showed that GADRAS also performed well in isotope identification, but that ScintiVision did not perform well for this application.

While GADRAS correctly identified the same isotopes as the Symetrica analysis for the LADS NaI(Tl) based system, it would be interesting to see how the Symetrica analysis technique handles multiple sources or mixtures of sources. A comparison should be made of GADRAS and Symetrica performance for such complex source mixtures.

During testing at PNNL, the PVT analysis portion of Symetrica's algorithm was not tested due to damage/degradation of the system. The potential use of PVT for isotopic identification requires an improved hardware configuration and specialized software analysis. It may turn out that the analysis by Symetrica using spectral deconvolution is more applicable than GADRAS when it comes to isotope identification in PVT detectors, but this should be investigated. The application of Symetrica's analysis to PVT is of very high interest and should be pursued further.

GADRAS is well established as an isotope-identification program for homeland security applications. The brief experiments reported here with Symetrica's analysis technique also showed good results, indicating that their technique warrants further evaluation for homeland security applications, such as with NaI(Tl) and PVT-based radiation detectors.

6.0 Recommendations

Since the results from the NaI(Tl) detector measurements at PNNL and previous results by Symetrica with PVT have been promising, it is recommended that further work be performed. Specifically, the following steps should be taken:

1. The Symetrica NaI(Tl) system should be considered for inclusion in the testing of spectroscopic systems that is planned for Guardian, if Symetrica can provide a near-deployable system such as they used in the Advanced Spectroscopic Portal testing.
2. Since the cost savings for an improved PVT system could be substantial, Guardian should consider providing funds for Symetrica to assemble an improved prototype PVT system for further testing. This system should be tested side-by-side with both standard PVT systems and spectroscopic portal systems.
3. Since the development of the PVT system for a deployable system may take a year or more for validation, the pursuit of this option may need to be, in the near term, in addition to the deployment of current Guardian systems.
4. Future testing should include, in addition to standard sources and NORM, the Guardian threat basis and combinations of sources. Comparative analysis with GADRAS should be included in this work.

7.0 References

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Appendix A
Measurements Performed

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Measurements Performed

Table A.1. Summary of Measurements Performed

Batch Number	Source	distance cm	time s	runs	shielding material	thickness mm	Date
2	**WGPu 98g**	300	10	5	can SS	0.635	3/11/08
3	**WGPu 98g**	300	10	5	can SS	0.635	3/11/08
4	**WGPu 98g**	300	10	5	can SS	0.635	3/11/08
5	**WGPu 98g**	300	10	5	can SS	0.635	3/11/08
6	**WGPu 98g**	420	10	5	can SS	0.635	3/11/08
7	**WGPu 98g**	420	10	5	can SS	0.635	3/11/08
8	**WGPu 98g**	530	10	5	can SS	0.635	3/11/08
9	**WGPu 98g**	530	10	5	can SS	0.635	3/11/08
11	**RGPu 98g**	300	10	5	can SS	0.635	3/11/08
12	**RGPu 98g**	300	10	5	can SS	0.635	3/11/08
13	**RGPu 98g**	420	10	5	can SS	0.635	3/11/08
14	**RGPu 98g**	420	10	5	can SS	0.635	3/11/08
15	**RGPu 98g**	530	10	5	can SS	0.635	3/11/08
16	**RGPu 98g**	530	10	5	can SS	0.635	3/11/08
17	**Cs137**	200	10	5			4/11/08
18	**Cs137**	200	10	5			4/11/08
19	**Cs137**	300	10	5			4/11/08
20	**Cs137**	300	10	5			4/11/08
21	**Co60**	100	10	5			4/11/08
22	**Co60**	100	10	5			4/11/08
23	**Co60**	200	10	5			4/11/08
24	**Co60**	200	10	5			4/11/08
25	**Co60**	300	10	5			4/11/08
26	**Co60**	300	10	5			4/11/08
27	**DU 3.3kg**	100	10	5			4/11/08
28	**DU 3.3kg**	100	10	5			4/11/08
29	**DU 3.3kg**	50	10	5			4/11/08
30	**DU 3.3kg**	50	10	5			4/11/08
31	**Co57**	50	10	5			4/11/08
32	**Co57**	50	10	5			4/11/08
33	**Co57**	200	10	5			4/11/08
34	**Co57**	200	10	5			4/11/08
35	**Co57**	100	10	5			4/11/08
36	**Co57**	100	10	5			4/11/08
37	**Ba133**	100	nts batch				4/11/08

Table A.1. (contd)

Batch Number	Source	distance cm	time s	runs	shielding material	thickness mm	Date
38	**Zircon Sand**	100	30	7			4/11/08
39	**Zircon Sand**	11.43	10	10			4/11/08
40	**Ice Melt**	contact	10	30			4/11/08
41	**Kitty Litter**	contact	10	30			4/11/08
42	**Tiles**	contact	10	30			4/11/08
43	**Fertilizer**	contact	10	30			4/11/08
44	**Granite**	contact	10	30			4/11/08
45	**Lanthanum Carbonate**	contact	10	30			4/11/08
46	**HEU 125g**	100	10	5			5/11/08
47	**HEU 125g**	100	10	5			5/11/08
48	**HEU 125g**	200	10	5			5/11/08
49	**HEU 125g**	200	10	5			5/11/08
48	**HEU 125g**	300	10	5			5/11/08
49	**HEU 125g**	300	10	5			5/11/08
50	**HEU 125g**	400	10	5			5/11/08
51	**HEU 125g**	400	10	5			5/11/08
52	**HEU 125g**	400	10	5			5/11/08
53	**HEU 125g**	100	10	5	steel plate	1.1	5/11/08
54	**HEU 125g**	100	10	5	steel plate	1.1	5/11/08
55	**HEU 125g**	100	10	5	steel plate	7.5	5/11/08
56	**HEU 125g**	100	10	5	steel plate	7.5	5/11/08
57	**HEU 125g**	100	10	5	steel plate	13.8	5/11/08
58	**HEU 125g**	100	10	5	steel plate	13.8	5/11/08
61	**WGPu 98g**	100	10	5	steel plate	6.35	3/11/08
62	**WGPu 98g**	100	10	5	steel plate	6.35	3/11/08
63	**WGPu 98g**	100	10	5	steel plate	19.05	3/11/08
64	**WGPu 98g**	100	10	5	steel plate	19.05	3/11/08
65	**WGPu 98g**	100	10	5	steel + Cu	19.05	3/11/08
66	**WGPu 98g**	100	10	5	steel + Cu	19.05	3/11/08
65	**WGPu 98g**	100	10	5	steel + Cu	19.05	3/11/08
66	**WGPu 98g**	100	10	5	steel + Cu	19.05	3/11/08
69	**WGPu 98g**	100	10	5	Pb	50.8	3/11/08
70	**WGPu 98g**	100	10	5	Pb	50.8	3/11/08
71	**RGPu 98g**	100	10	5	steel plate	6.35	3/11/08
72	**RGPu 98g**	100	10	5	steel plate	6.35	3/11/08
73	**RGPu 98g**	100	10	5	steel plate	19.05	3/11/08
74	**RGPu 98g**	100	10	5	steel plate	19.05	3/11/08
75	**RGPu 98g**	100	10	5	steel plate	19.05	3/11/08

Table A.1. (contd)

Batch Number	Source	distance cm	time s	runs	shielding material	thickness mm	Date
77	**RGPu 98g**	100	10	5	steel + Cu	19.05	3/11/08
78	**Yellowcake**	50	10	5			
79	**Yellowcake**	50	10	5			
80	**Yellowcake**	50	10	5			
81	**Yellowcake**	50	10	5			
82	**Heisenberg**	100	10	5			
83	**Heisenberg**	100	10	5			
84	**Heisenberg**	50	10	5			
85	**Heisenberg**	50	10	5			
87	**Heisenberg**	50	30	10			
88	**Yellowcake**	50	30	10			
89	**Yellowcake**	50	30	10	steel plate	6.35	

Appendix B
Summary of Measurements Made at PNNL

Appendix B
Summary of Measurements Made at PNNL

This section provides a log of the measurements made over the three-day visit by Symetrica, and is presented as a record of the activities.

Participants

Symetrica: Matthew Dallimore, Thomas Meeks
PNNL: Richard Kouzes, Emily Mace, Rebecca Redding, David Stromswold

Day 1: Monday, Nov. 3, 2008

Location: 326/25A
Room Setup: Figure B.1

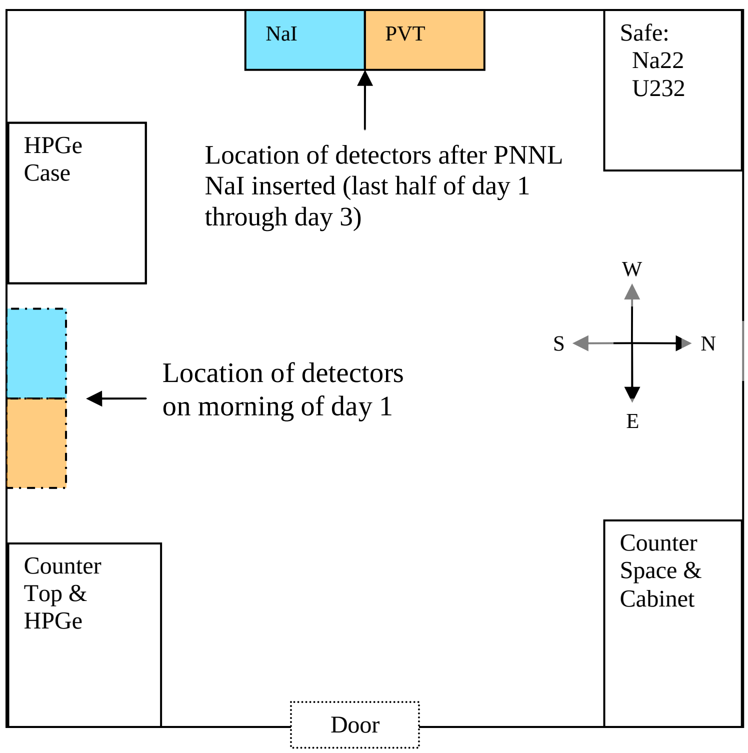


Figure B.1. Room Setup in 326/25A

At the beginning of Day 1, Symetrica took several batch runs of data using their NaI detectors and PVT.

It was determined that the two NaI detectors from Symetrica were damaged in transit from the UK and were then swapped out for two NaI from PNNL (borrowed from M. Myjak). The PVT was also not performing as expected so the two 5" PMTs were removed, cleaned, and reapplied. This did not solve the issue, and so there are very few PVT data runs.

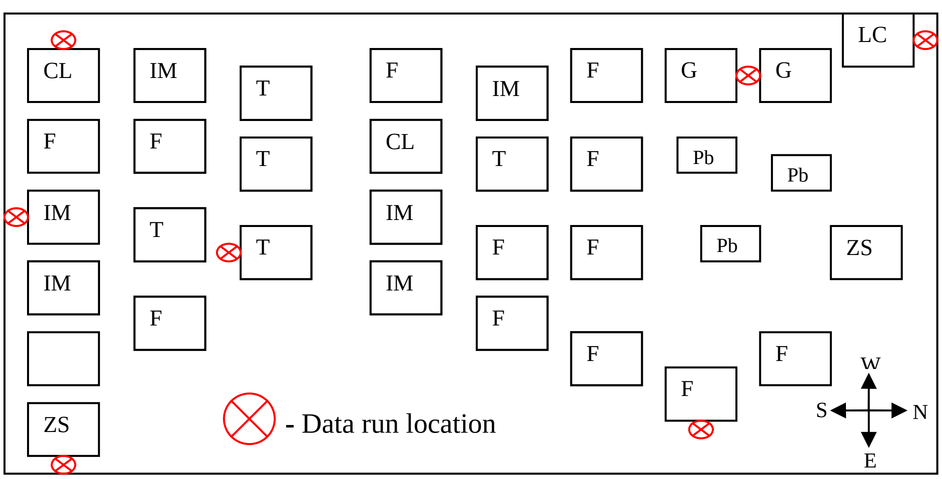
Data were collected on industrial, SNM, and NORM sources. These runs were collected on both bare sources at varying distances and then shielded sources at a fixed distance. Specific information on the source, location, and shielding for each data run can be found in Appendix A.

The industrial sources were placed on a tripod at a height above the floor of 50 cm. The SNM sources were placed on the seat of a chair due to the awkwardness of the sealed containers and the weight of the sources. The height from the seat of the chair to the floor was 48 cm, which is comparable to the height of the tripod at 50 cm. Table B.1 shows the radiation dose rate (background subtracted) measured by a Bicron MicroRem meter at various distances from the sources, with an uncertainty of about 1 μR/hr. Dose was measured since some standards have requirements stated in dose.

Table B.1. Rates during Data Runs

Isotope	Distance (cm)	Net Rate (μR/hr)
Background (day1)	….	10
WGPu	100	75
	50	200
RGPu	100	140
	50	420

<u>Day 2: Tuesday, Nov. 4, 2008</u>
Location: First half day at 326/25A, last half day at 331G
Setup: 326/25A shown previously in Figure B.1; 331G shown in Figure B.2



*Not to scale

Isotope ID
Zirconium Sand (ZS)
Ice Melt (IM)
Cat Litter (CL)
Tile (T)
Fertilizer (F)
Granite (G)
Lanthanum Carbonate (LC)

Figure B.2. NORM sources at 331G

The first half of Day 2 was spent collecting data on the industrial sources at various distances. Table B.2 shows the dose rates from these sources. In preparation for the second half of the day outside at 331G, one of the NaI(Tl) detectors was removed from the case and the remaining NaI(Tl) was layered with additional foam for thermal insulation and vibration isolation.

The last half of Day 2 was spent collecting data from the NORM sources at 331G. The NaI(Tl) was then brought back into 326/25A to readjust to the temperature.

Table B.2. Rates during Data Runs

Isotope	Distance (cm)	Net Rate (μR/hr)
Background (day2)	….	9
Cs-137	100	6
	50	12
	20	70
Co-60	50	40
	20	170
DU	50	23
	20	110
Co-57	20	3
Ba-133	50	11
	20	60

<u>Day3: Wednesday, Nov. 5, 2008</u>
Location: 326/25A
Setup: as shown previously in Figure B.1

Day 3 began by replacing the second NaI detector back in the case with the first and allowing the system to stabilize. After the system was calibrated and had collected a background, data were collected on the remaining SNM material and then various types of shielding were introduced. There were varying thicknesses of steel, lead, copper, and aluminum. The total amount of shielding used in each data run is listed in the log file from Symetrica as mentioned previously. Table B.3 shows the dose rates at various distances from the unshielded sources.

Table B.3. Rates during Data Runs

Isotope	Distance (cm)	Net Rate (μR/hr)
Background (day3)	….	8
HEU	50	9
U (Yellowcake)	50	5
	20	50
U (Heisenberg Cube)	50	11
	20	11

It is noted that the measured background rate varied from 8 to 10 μR/hr over the three days of measurements, which was within the measurement error of the instrument used, though there may have been some change in radon levels due to weather changes.

Appendix C
Symetrica Results (by M. Dallimore et al.)

Appendix C
Symetrica Results (by M. Dallimore et al.)

C.1 Executive Summary

This report presents the results of testing performed at PNNL on November 3-5, 2008. The aim of the testing was to acquire data from SNM sources that the LADS module has not previously been exposed. Upon arrival at PNNL it was discovered that the NaI(Tl) detectors had been damaged in transit. Replacement detectors were loaned from PNNL to replace those damaged. Even with a non-optimum detector system the LADS demonstrated excellent identification performance with WGPu, identifying the 125 g at a distance of 5.4 m, as well as identifying the source through an inch of steel and copper. The software was subsequently modified to the specification of the detectors from PNNL and the results from that analysis are also presented.

C.2 System Description – Large Area Detector System (LADS)

The LADS is a scalable NaI(Tl) based radiation detection and identification system. The system is modular with each module based upon the use of two 2”x4”x16” NaI detectors in a single robust module. These modules can be networked together, increasing sensitivity to meet the particular requirement of the deployment. A two-module deployment, suitable for private vehicles can be seen in Figure C.1.

Figure C.1. LADS - Two Module Configuration

A single module LADS was shipped for testing at PNNL. The two detectors were damaged in transit and replaced with two units loaned from PNNL, having an energy resolution of 8.5%, compared with the original units that had a resolution of 7%. The Symetrica algorithms are reasonably tolerant to nominally identical detectors, and this change did not affect the main purpose of data collection. However, some performance would have been compromised. The analysis software has been modified, in line with the resolution of the loaned detectors, and the results of the re-analyzed data is presented in the following sections.

C.3 System description – Software

Isotope Identification

The Symetrica approach to isotope identification is two-fold, firstly deconvolution of the spectra, followed by the application of the isotope identification algorithms to correlate the lines identified in the spectra with an isotope library. The deconvolution step clarifies the spectra through the re-positioning of that component of Compton-scattering that occurs within the detector itself. This provides accurate locations and intensities of spectral features and is achieved by combining knowledge of the physical properties of the detector with its energy-response function. That is, the measure of its energy-resolution as a function of the incident photon energy. This technique has been successfully applied to improving the performance of a wide range of detector designs and scintillator materials. This range includes small NaI(Tl) probes for intra-operative applications in nuclear medicine, to large 5”x6” detectors for neutron activation gamma-ray spectroscopy.

In the case of a multiple detector system, such as the LADS, the spectra from individual detectors are combined into a single “composite” spectrum prior to data analysis. In the case of the LADS an appropriately scaled background is subtracted from the composite spectrum as part of the data analysis.

Deep Discovery

The LADS is controlled by the Deep Discovery Software, which manages all detector functions including stabilization, calibration, and isotope identification. As well as manual and Batch mode control, the system can be configured to automatically identify sources that register above the background count rate. This configuration is called Automatic Acquisition Mode and a representative screen can be seen in Figure C.2.

During the acquisition displayed in Figure C.2, a ^{22}Na source was introduced to the environment, generating an increase in the observed signal strength. The result of the isotope identification, for the highlighted area, is given in the isotope-identified table above the signal strength graph. For the purpose of data collection the software is operated in “Batch” mode, which allows multiple data sets to be collected without the need for user input. For the PNNL testing, the unit was used in batch mode.

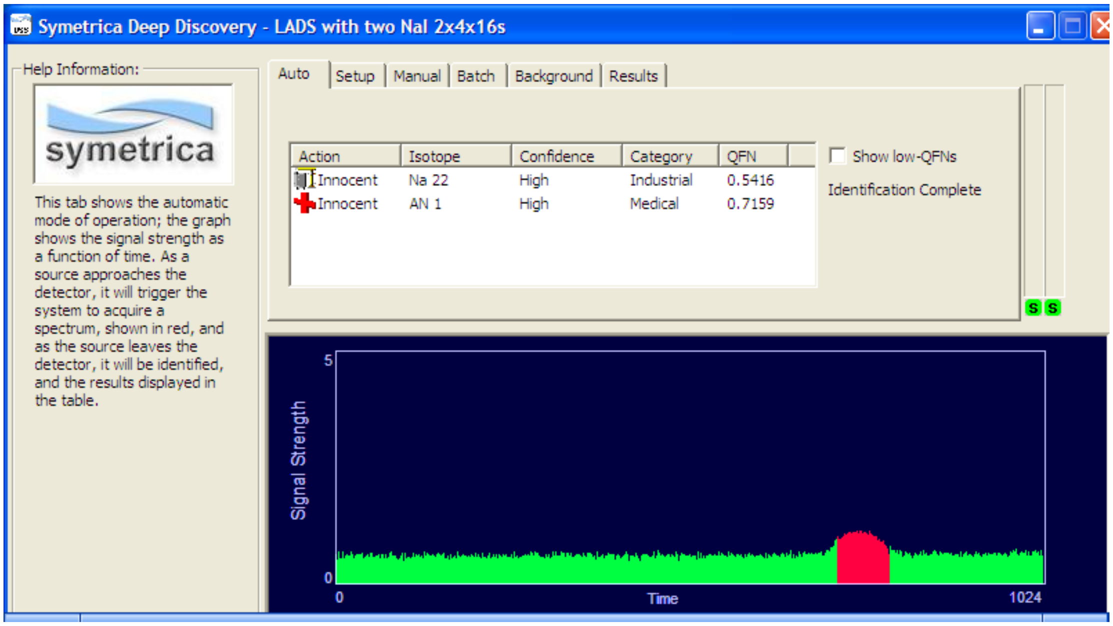


Figure C.2. Screen Shot of Symetrica Deep Discovery Software in Automatic Acquisition Mode

C.4 Analysis of data collected

Of the 490 data files collected at PNNL, there are some general comments:

- A small number failed to generate an identification due to a software issue.
- The resolution of the replacement detectors used was considerably worse than the configuration in the identification algorithm, resulting in some misidentifications.

Both of these issues were addressed through the re-analysis of the data collected. The reanalyzed results are presented in the following tables. It should be noted that the only modification to the data analysis was to include the correct detector resolution. Our experience with the analysis is that the algorithms are extremely robust to different detector resolutions, as demonstrated during the manufacture, and operational deployment of the SMITHS detection HPRID, which uses the same isotope identification principals, where an energy resolution window of +/- 0.5% is acceptable. However the energy resolution of the loaned detectors were so far from that of the original units that the software had to be adjusted. The adjustment for detector resolution was the only modification made, for the re-analysis. The SNM sources used in the data collection can be seen in Table C.1. Descriptions of the SNM, industrial and NORM sources can be found in Section 3.

The dose rates measured are presented in Table C.1 was collected using a μR meter provided by PNNL; the background dose in the laboratory was observed to be 9 μR/hr. In the following analysis, simple attenuation is used to determine the full energy peak attenuation. Even though the full energy peaks are attenuated, the down-scattered photons remain and are included in the analysis performed of the complete spectrum.

Table C.1. Source Details

Source	Mass (g)	Net Dose in uR/hr @50cm
WGPu	98g	200
RGPu	98g	420
DU	145g	23
HEU	125g	9

C.5 WGPu

Shielding

The WGPu sample was placed at a distance of 1 m from the detector case and was shielded by a number of different materials with varying thicknesses. The results of the identifications are summarized in Table C.2. The attenuation level was calculated from a simple attenuation calculation using the coefficients from NIST XCOM. From Table C.2, it is seen that the limit of full-energy peak attenuation of the source signal for identifying ^{239}Pu is between 90 and 96%.

Table C.2. Summary of Identifications with WGPu with Varying Shielding

	As recorded	Reanalyzed	Shielding materials		
Attenuation Level @ 414keV	Pu239 Identified	Pu239 Identified	Steel (mm)	Copper (mm)	Lead (mm)
37%	7/10	10/10	6.35		
75%	9/10	10/10	19.05		
90%	8/10	10/10	19.05	6.35	
96%	5/10	7/10	19.05	6.35	3.175
100%	0/10	1/10			50.8

Distance

The WGPu sample was placed at a range of distances to determine the sensitivity range of the single module LADS. It should be pointed out that the WGPu was housed in a steel container ¼” thick. The results can be seen in Table C.3. From Table C.3 can be seen that the limiting distance of sensitivity for the sample tested was in excess of 5.3 m.

Table C.3. Summary of Identifications with WGPu at Varying Distance

	Extrapolated dose at detector (µR/hr)	Pu239 Identified (original)	Pu239 Identified (Re-analyzed)
100	75	9/10	10/10
300	8.3	10/10	10/10
420	4.3	8/10	8/10
530	5.6	8/10	9/10

C.6 RGPu

Measurements of the RGPu sample were performed using a range of shielding materials. A summary of the results can be seen in Table C.4. From Table C.4 it can be seen that a lower limit of acceptable full-energy peak attenuation for RGPu can be set at 90%.

Table C.4. RGPu Results

Attenuation Level @ 414keV	As recorded Pu239 Identified	Reanalyzed Pu239 Identified	Shielding materials Steel (mm)	Copper (mm)	Lead (mm)
37%	5/10	10/00	6.35		
75%	11/15	12/15	19.05		
90%	3/5	5/5	19.05	6.35	

C.7 DU

The WGPu sample was placed at two distances from the LADS. A summary of the results can be seen in Table C.5. In the original results the depleted uranium sample was identified at 50 cm from the unit on 8 out of 10 occasions but on reanalysis there was a slight degradation in the result. The U238 identification from these tests was not ideal so spectra were inspected to determine the cause. The 1 MeV line is clear in the spectra but the region around the 766 keV line was not always resolved to a good enough standard to provide correct peak identification. Therefore an isotope library change was implemented to improve detection of U238 as can be seen in Table C.5. Note that the library change did not introduce any additional false positive alarms in the overall results.

Table C.5. Summary of Identifications with DU at Varying Distance

Distance (cm)	Extrapolated dose at detector (μR/hr)	U238 Identified	U238 Identified (reanalyzed)	U238 Identified (library change and reanalyzed
50	23	8/10	6/10	10/10
100	5.75	0/10	0/10	8/10

C.8 HEU

Shielding

The HEU sample was placed at a distance of 1 m and was shielded by a number of different materials with varying thickness. The attenuation level for the key line of ^{235}U has been calculated using the XCOM attenuation coefficients for stainless steel. The results of the identifications are summarized in Table C.6. From Table C.6, the full-energy peak attenuation limit for identification of HEU was not reached during the testing. However a lower limit of 87% attenuation is clearly achieved.

Table C.6. Summary of Identifications with HEU with Varying Shielding

Attenuation Level @ 186keV	U235 Identified	U235 Identified (reanalyzed)	Steel (mm)
16%	10/10	10/10	1.1
69%	10/10	10/10	7.5
87%	4/9	9/9	13.8

Distance

The HEU sample was placed at a range of distances to determine sensitivity range of the single module LADS. The results can be seen in Table C.7. From Table C.7 it can be seen that the limit of sensitivity for the sample tested was greater than 3 m, corresponding to a dose 1/30th that of the background level.

Table C.7. Summary of Identifications with HEU at Varying Distance

Distance (cm)	Extrapolated dose at detector (μR/hr)	U235 Identified	U235 Identified (reanalyzed)
100	2.3	10/10	10/10
200	0.6	10/10	10/10
300	0.3	2/10	9/10

C.9 Cs137

Distance

The Cs137 sample was placed at distances of 200 and 300 cm from the LADS module. The results can be seen in Table C.8. From Table C.8 it can be seen that, upon reanalysis, the limit of sensitivity for the sample tested was not reached.

TableC.8. Summary of Identifications with Cs137 at Varying Distance

Distance (cm)	Extrapolated dose at detector (μR/hr)	Cs137 Identified	Cs137 Identified (reanalyzed)
200	1.5	9/10	10/10
300	0.7	6/10	10/10

C.10 Co60

Distance

The Cs137 sample was placed at distances ranging from 100 to 300 cm from the LADS module. The results can be seen in Table C.9. From Table C.9 it can be seen that the limit of sensitivity for the sample tested was not reached.

Table C.9. Summary of Identifications with Co60 at Varying Distance

Distance (cm)	Extrapolated dose at detector (μR/hr)	Co60 Identified	Co60 Identified (reanalyzed)
100	10	10/10	10/10
200	2.5	10/10	10/10
300	1.1	9/10	10/10

C.11 Co57

Distance

The Co57 sample was placed at distances of ranging from 50 to 200 cm from the LADS module. The results can be seen in Table C.10. From Table C.10 it can be seen that there is a significant improvement with reanalysis. The limit of sensitivity for the sample tested is between 100 and 200 cm. At 200 cm the main Co57 peak in the spectra is still clear, but currently a threshold on the intensity of the Co57 source prevents detection at 200 cm.

Table C.10. Summary of Identifications with Co57 at Varying Distance

Distance (cm)	Extrapolated dose at detector (μR/hr)	Co57 Identified	Co57 Identified (reanalyzed)
50	0.5	5/10	10/10
100	0.1	0/10	9/10
200	0.03	0/10	0/10

C.12 Ba133

The Ba133 sample was placed at a distance of 100cm from the LADS module. At this distance an extrapolated dose of 2.8 μR/hr was calculated. Spectra were obtained using acquisition times ranging from 5 to 300 s. In total Ba133 was identified in 12/17 acquisitions but with reanalysis Ba133 is identified in 100% of the acquisitions. The Ba133 in the sample used could be identified from acquisitions with a maximum lower integration time limit of 5s.

C.13 NORM Sources

The NORM samples were in general placed in contact with the LADS module with the exception of the Zircon Sand source that was placed at two different distances. The results can be seen in Table C.11. In general the isotopes identified were as expected with only a few unexpected identifications of other isotopes. Ra226 was identified successfully from the Zircon sand sample and K40 was identified successfully from the Ice Melt and Fertilizer, however, Th232 identifications were not as frequent as might be expected for the Kitty Litter, Tiles and Granite. The K40 isotope is still the dominant isotope present in these spectra.

Note that in the Lanthanum carbonate test the stabilization of the system was lost for the duration of this test and the spectra needed recalibrating. The results shown are those obtained with the newly calibrated spectra.

TableC.11. Summary of Identifications with NORM Sources

Source	Distance (cm)	Isotopes Identified (reanalyzed)
Zircon Sand	100	Ra226 5/6
		Th232 2/6
		K40 1/6
		U232 1/6
		Co57 1/6
		Cr51 1/6
		Pu239 1/6
Zircon Sand	11.43	Ra226 9/10
		Th232 4/10
		U232 4/10
		Cr51 2/10
Ice Melt	Contact	K40 10/10
Kitty Litter	Contact	K40 5/10
		Th232 5/10
Tiles	Contact	K40 8/10
		Th232 5/10
		U233 1/10
Fertilizer	Contact	K40 10/10
Granite	Contact	K40 8/10
		Th232 1/10
Lanthanum Carbonate	Contact	La138 10/10
		K40 3/10

C.14 Natural Uranium Sources

A few tests were done with the Yellowcake and Heisenberg cube samples. The samples were placed at either 50 or 100 cm from with the LADS module. A test with the Yellowcake sample shielded by steel was also taken. The results of these tests are summarized in Table C.12. A similar issue to that seen with DU occurs with the identification of U238 in these tests and therefore the same library change was implemented. With this library change U238 is identified 100% of the time. The exception to this is the test with the Heisenberg cube placed at 100 cm from the LADS module. In this instance an intensity threshold prevents U238 identification 100% of the time.

TableC.12. Summary of Identifications with Natural Uranium Sources

Source	Distance (cm)	Shielding	U238 Identified	U238 Identified (reanalyzed)	U238 Identified (library change and reanalyzed)
Yellowcake	50	None	4/25	19/25	25/25
Yellowcake	50	6.35 mm Steel Plate	0/10	2/10	10/10
Heisenberg Cube	50	None	11/20	20/20	20/20
Heisenberg Cube	100	None	0/10	0/10	7/10

C.15 Summary of Results

The results from the Symetrica identification routine used to reanalyze the LADS data are summarized in Table C.13. Note that the results are those obtained from reanalysis with the U238 library change incorporated and recalibration of the Lanthanum Carbonate test spectra.

Table C.13. Summary of Source Identifications From Symetrica

Source	Batch Results: Source ID at >= 80%/Runs	Source Isotopes at >= 80% identification level	Other Isotopes at >= 80% identification level
Cs-137	4/4	Cs137	
Co-57	4/6	(Co57 19/30)	
Co-60	6/6	Co60	
Ba-133	1/1	Ba133	
Zirc Sand	2/2	Ra226	
Ice Melt	1/1	K40	
Kitty Litter	0/1	(K40 5/10, Th232 5/10)	
Tiles	1/1	K40	
Fertilizer	1/1	K40	
Granite	1/1	K40	
Lanthanum Carbonate	1/1	La138	
WGPu	7/8	Pu239	
WGPu (shielded)	6/9	(Pu239 32/45)	(I123 29/45)
RGPu	6/6	Am241 Pu241 Pu239	Sm153
RGPu (shielded)	5/6	Pu241 Am241 Pu239	Cs137
HEU	12/13	U235	
DU	3/4	U238	
Yellowcake	5/5	U238	
Heisenberg Cube	4/5	U238	

Appendix D
GADRAS Results

Appendix D
GADRAS Results

Table D.1. Complete GADRAS Results

Date	Batch Number	Source	Live time (sec)	Net Gamma (cps)	SNM Prob.	Threat:	Chi-square:	Isotopes:
3-Nov-2008	Batch002	**WGPu 100g**	18.84	4427	3 (High)	7 (SNM=H)	0.94	Pu239(H,201g); U328(F,274g)
3-Nov-2008	Batch003	**WGPu 100g**	19.12	4259	3 (High)	7 (SNM=H)	0.91	Pu239(H,183g); U238(F,605g)
3-Nov-2008	Batch004	**WGPu 100g**	19.2	4073	3 (High)	7 (SNM=H)	0.90	Pu239(H,167g); U238(F,349g)
3-Nov-2008	Batch005	**WGPu 100g**	19.04	4148	3 (High)	7 (SNM=H)	0.89	Pu239(H,163g); U238(F,118g)
3-Nov-2008	Batch006	**WGPu 100g**	19.26	2246	3 (High)	7 (SNM=H)	0.97	Pu239(H,100g)
3-Nov-2008	Batch007	**WGPu 100g**	19.22	2266	3 (High)	7 (SNM=H)	1.04	Pu239(H,156g)
3-Nov-2008	Batch008	**WGPu 100g**	19.48	1475	3 (High)	7 (SNM=H)	1.00	Pu239(H,114g)
3-Nov-2008	Batch009	**WGPu 100g**	19.44	1504	3 (High)	7 (SNM=H)	0.78	Pu239(H,64g); U238(H,329g)
3-Nov-2008	Batch011	**RGPu 98g**	18.06	13846	3 (High)	7 (SNM=H)	3.19	Am241(H,2Ci); Pu239(H,18g); U237(H32uCi); Th228(F,1uCi); U238(F,212g)
3-Nov-2008	Batch012	**RGPu 98g**	18.4	13604	3 (High)	7 (SNM=H)	2.44	Am241(H,2Ci); Pu239(H,735g); U237(H,43uCi); U238(F,213g); Th228(F,1uCi)
3-Nov-2008	Batch013	**RGPu 98g**	18.68	7518	3 (High)	7 (SNM=H)	2.11	Am241(H,992mCi); Pu239(H,378g); U237(H,17uCi); U238(F,206g)
3-Nov-2008	Batch014	**RGPu 98g**	18.74	7437	3 (High)	7 (SNM=H)	2.09	Pu239(H,409g); Am241(H,975mCi); U237(H,24uCi); U238(F,230g); Co57(F,6uCi)
3-Nov-2008	Batch015	**RGPu 98g**	19.02	4867	3 (High)	7 (SNM=H)	1.36	Am241(H,586mCi); Pu239(H,293g); U237(H,10uCi); U238(F,174g); U235(F,336g)
3-Nov-2008	Batch016	**RGPu 98g**	18.76	4942	3 (High)	7 (SNM=H)	1.31	Am241(H,597mCi); Pu239(H,317g); U237(H,10uCi); U238(H,173g); U235(L,317g)
4-Nov-2008	Batch017	**cs137**	19.32	309	0 (Very Low)	3 (Industrial)	0.50	Cs137(H,205mCi)
4-Nov-2008	Batch018	**cs137**	19.72	292	0 (Very Low)	3 (Industrial)	0.72	Cs137(H,162mCi)
4-Nov-2008	Batch019	**cs137**	19.56	173	0 (Very Low)	3 (Industrial)	0.46	Cs137(H,115mCi)
4-Nov-2008	Batch020	**cs137**	19.7	196	0 (Very Low)	3 (Industrial)	0.54	Cs137(H,45mCi)
4-Nov-2008	Batch021	**Co60**	19.28	1183	0 (Very Low)	3 (Industrial)	1.14	Co60(H,19uCi)
4-Nov-2008	Batch022	**Co60**	19.44	1160	0 (Very Low)	3 (Industrial)	0.98	Co60(H,6uCi); Lu177m(F,1uCi); Na22(F,1uCi)
4-Nov-2008	Batch023	**Co60**	19.28	444	0 (Very Low)	3 (Industrial)	0.69	Co60(H,5uCi)
4-Nov-2008	Batch024	**Co60**	19.44	454	0 (Very Low)	3 (Industrial)	0.65	Co60(H,2uCi); Na22(F,1uCi)
4-Nov-2008	Batch025	**Co60**	19.04	271	0 (Very Low)	3 (Industrial)	0.61	Co60(H,1uCi)
4-Nov-2008	Batch026	**Co60**	19.26	283	0 (Very Low)	3 (Industrial)	0.62	Co60(H,1uCi)
4-Nov-2008	Batch027	**DU**	19.3	1188	2 (Fair)	6 (SNM=F)	0.46	U238(H,3kg)
4-Nov-2008	Batch028	**DU**	19.36	1201	2 (Fair)	6 (SNM=F)	0.64	U238(H,3kg)
4-Nov-2008	Batch029	**DU**	19.2	2781	2 (Fair)	6 (SNM=F)	0.66	U238(H,52kg)

Table D.1. (contd)

Date	Batch Number	Source	Live time (sec)	Net Gamma (cps)	SNM Prob.	Threat:	Chi-square:	Isotopes:
4-Nov-2008	Batch030	**DU**	19	2773	2 (Fair)	6 (SNM=F)	0.74	U238(H,8kg)
4-Nov-2008	Batch031	**co57**	18.84	339	0 (Very Low)	3 (Industrial)	0.60	Co57(H,1uCi)
4-Nov-2008	Batch032	**co57**	19.7	323	0 (Very Low)	3 (Industrial)	0.63	Co57(H,1uCi)
4-Nov-2008	Batch033	**co57**	18.84	160	0 (Very Low)	3 (Industrial)	0.42	Co57(H,1uCi); Na22(F,1uCi)
4-Nov-2008	Batch034	**co57**	19.62	134	0 (Very Low)	3 (Industrial)	0.44	Co57(H,1uCi)
4-Nov-2008	Batch035	**co57**	19.54	257	0 (Very Low)	3 (Industrial)	0.49	Co57(H,1uCi)
4-Nov-2008	Batch036	**co57**	20.06	224	0 (Very Low)	3 (Industrial)	0.51	Co57(H,1uCi)
4-Nov-2008	Batch037	**Ba133**	19.36	1055	0 (Very Low)	3 (Industrial)	0.72	Ba133(H,19uCi); Cf252(F,1uCi)
4-Nov-2008	Batch038	**Zirc Sand**	29.42	1860	0 (Very Low)	3 (Suspect)	0.64	Ra226(H,9uCi); Th232(H,2uCi); U238(F,28kg)
4-Nov-2008	Batch039	**Zirc Sand**	28.26	8111	2 (Fair)	6 (SNM=F)	1.60	Ra226(H,38uCi); Th232(H,21uCi); U238(F,179kg)
4-Nov-2008	Batch040	**Ice Melt**	29.22	4614	0 (Very Low)	4 (High Gamma)	2.12	K40(H,91uCi); Th232(H,8uCi)
4-Nov-2008	Batch041	**Kitty Litter**	29.5	734	2 (Fair)	6 (SNM=F)	0.52	K40(H,2uCi); Th232(H,2uCi); U232(F,520g)
4-Nov-2008	Batch042	**Tiles**	29.42	868	0 (Very Low)	1 (Natural)	1.98	K40(H,4uCi); Th232(H,1uCi)
4-Nov-2008	Batch043	**Fertilizer**	29.06	3529	0 (Very Low)	4 (High Gamma)	4.38	K40(H,46uCi); Th232(H,6uCi)
4-Nov-2008	Batch044	**Granite**	29.98	585	0 (Very Low)	1 (Natural)	1.65	K40(H,4uCi); Th232(H,4uCi)
4-Nov-2008	Batch045	**Lanthanum Carbonate**	29.76	440	0 (Very Low)	4 (Bad ID)	3.27	K40(H,27uCi); Ho166m(F,2uCi); Mn54(F,1uCi)
5-Nov-2008	Batch046	**HEU**	19.56	2154	3 (High)	7 (SNM=H)	0.59	U235(H,624g)
5-Nov-2008	Batch047	**HEU**	19.56	2182	3 (High)	7 (SNM=H)	0.62	U235(H,594g)
5-Nov-2008	Batch048	**HEU**	19.14	773	3 (High)	7 (SNM=H)	0.60	U235(H,257g)
5-Nov-2008	Batch049	**HEU**	19.74	749	3 (High)	7 (SNM=H)	0.51	U235(H,242g)
5-Nov-2008	Batch050	**HEU**	19.52	349	3 (High)	7 (SNM=H)	0.43	U235(H,108g)
5-Nov-2008	Batch051	**HEU**	19.24	371	3 (High)	7 (SNM=H)	0.62	U235(H,126g)
5-Nov-2008	Batch052	**HEU**	19.34	222	3 (High)	7 (SNM=H)	0.46	U235(H,69g)
5-Nov-2008	Batch053	**HEU**	19.64	1787	3 (High)	7 (SNM=H)	0.65	U235(H,657g)
5-Nov-2008	Batch054	**HEU**	19.26	1777	3 (High)	7 (SNM=H)	0.56	U235(H,899g); U238(F,73g)
5-Nov-2008	Batch055	**HEU**	19.4	963	3 (High)	7 (SNM=H)	0.49	U235(H,493g)
5-Nov-2008	Batch056	**HEU**	19.42	927	3 (High)	7 (SNM=H)	0.48	U235(H,510g)
5-Nov-2008	Batch057	**HEU**	19.58	613	3 (High)	7 (SNM=H)	0.54	U235(H,317g)
5-Nov-2008	Batch058	**HEU**	19.38	625	3 (High)	7 (SNM=H)	0.46	U235(H,320g)
5-Nov-2008	Batch059	**HEU**	empty data file					
5-Nov-2008	Batch060	**Unlabeled**	17.5	18356	3 (High)	7 (SNM=H)	1.45	Pu239(H,2kg); U238(F,50kg)
5-Nov-2008	Batch061	**WGPu**	empty data file					
5-Nov-2008	Batch062	**WGPu**	17.74	18368	3 (High)	7 (SNM=H)	0.81	Pu239(H,768g); Am241(H753mCi); Tl201(F,44uCi)
5-Nov-2008	Batch063	**WGPu**	18.62	9952	3 (High)	7 (SNM=H)	0.82	Pu239(H,665g); Cs137(F,37mCi); Ba133(F,6uCi)

Table D.1. (contd)

Date	Batch Number	Source	Live time (sec)	Net Gamma (cps)	SNM Prob.	Threat:	Chi-square:	Isotopes:
5-Nov-2008	Batch064	**WGPu**	18.76	10013	3 (High)	7 (SNM=H)	1.50	Pu239(H,561g)
5-Nov-2008	Batch065	**WGPu**	18.78	7412	3 (High)	7 (SNM=H)	0.77	Pu239(H,2kg); U235(F,447g)
5-Nov-2008	Batch066	**WGPu**	18.6	7065	3 (High)	7 (SNM=H)	0.83	Pu239(H,966g); U235(F,447g)
5-Nov-2008	Batch067	**WGPu**	19.06	5133	3 (High)	7 (SNM=H)	0.72	Pu239(H,989g); U235(H,462g); U238(F,1kg)
5-Nov-2008	Batch068	**WGPu**	18.98	5008	3 (High)	7 (SNM=H)	0.77	Pu239(H,996g); U235(F,426g)
5-Nov-2008	Batch069	**WGPu**	19.54	3239	3 (High)	7 (SNM=H)	1.19	Np237(H,21g); In111(H,4uCi); Tl201(H,601uCi); U237(H,6uCi); U235(F,297g)
5-Nov-2008	Batch070	**WGPu**	19	3142	3 (High)	7 (SNM=H)	1.37	In111(H,3uCi); Np237(H,21g); U235(H,375g); I123(H,25uCi); U237(F,5uCi)
5-Nov-2008	Batch071	**RGPu**	15.34	43178	3 (High)	7 (SNM=H)	2.05	Am241(H,11Ci); Pu239(H,6kg); Th232(H,2uCi); U238(H,11kg); U237(H,2Ci)
5-Nov-2008	Batch072	**RGPu**	15.94	42349	3 (High)	7 (SNM=H)	1.87	Am241(H,10Ci); Pu239(H,7kg); Th232(H,5uCi); U237(H,99uCi); U238(H,2kg)
5-Nov-2008	Batch073	**RGPu**	15.58	43062	3 (High)	7 (SNM=H)	2.29	Am241(H,10Ci); Pu239(H,7kg); Th232(H,5uCi); U237(H,109uCi); U238(F,5kg)
5-Nov-2008	Batch074	**RGPu**	17.76	20167	3 (High)	7 (SNM=H)	2.10	Am241(H,4Ci); Pu239(H,1kg); U235(F,1kg)
5-Nov-2008	Batch075	**RGPu**	17.62	20430	3 (High)	7 (SNM=H)	3.52	Am241(H,4Ci); Pu239(H,3kg)
5-Nov-2008	Batch076	**?**	empty data file					
5-Nov-2008	Batch077	**RGPu**	18.02	16415	3 (High)	7 (SNM=H)	1.50	Pu239(H,2kg); Am241(H,951mCi); Cs137(H,289mCi); U235(F,744g)
5-Nov-2008	Batch078	**Yellowcake**	17.86	16311	3 (High)	7 (SNM=H)	1.32	Am241(H,3Ci); Pu239(H,2kg); U235(H,2kg)
5-Nov-2008	Batch079	**Yellowcake**	19.6	1416	3 (High)	7 (SNM=H)	0.51	U238(H,14kg); U235(H,38kg); Pu239(F,65g)
5-Nov-2008	Batch080	**Yellowcake**	19.52	1406	3 (High)	7 (SNM=H)	0.71	U238(H,977g); U235(H,40g)
5-Nov-2008	Batch081	**Yellowcake**	19.4	1403	3 (High)	7 (SNM=H)	0.58	U238(H,908g); Pu239(F,76g); U235(F,40g)
5-Nov-2008	Batch082	**Heisenberg**	19.48	858	2 (Fair)	6 (SNM=F)	0.51	U238(H,768g)
5-Nov-2008	Batch083	**Heisenberg**	20	822	2 (Fair)	6 (SNM=F)	0.48	U238(H,1kg)
5-Nov-2008	Batch084	**Heisenberg**	19.52	1952	2 (Fair)	6 (SNM=F)	0.54	U238(H,3kg)
5-Nov-2008	Batch085	**Heisenberg**	19.58	1948	2 (Fair)	6 (SNM=F)	0.50	U238(H,47kg); U235(L,32g)
5-Nov-2008	Batch086	**Heisenberg**	empty data file					
5-Nov-2008	Batch087	**Heisenberg**	58.28	1924	2 (Fair)	6 (SNM=F)	0.51	U238(H,58kg); U235(F,37g)
5-Nov-2008	Batch088	**Yellowcake**	57.68	1316	3 (High)	7 (SNM=H)	0.77	U238(H,776g); U235(F,29g); Pu239(F,18g)
5-Nov-2008	Batch089	**Yellowcake**	58.22	983	2 (Fair)	6 (SNM=F)	0.47	U238(H,2kg); U235(F,21g)
5-Nov-2008	Batch090	**Unlabeled**	58.12	986	2 (Fair)	6 (SNM=F)	0.45	U238(H,2kg); U235(L,22g)

Table D.2. Complete SNM data runs using GADRAS

Batch #	Run #	Source	Distance (cm)	Live time (sec)	Net Gamma (cps)	SNM Prob.	Threat	Chi Square	Isotopes
Batch053	Run001	HEU - Steel: 1.1mm	400	19.64	1787	3 (High)	7 (SNM=H)	0.70	U235 (H, 10kg)
Batch053	Run002	HEU - Steel: 1.1mm	400	19.64	1787	3 (High)	7 (SNM=H)	0.70	U235 (H, 10kg)
Batch053	Run003	HEU - Steel: 1.1mm	400	19.48	1716	3 (High)	7 (SNM=H)	0.40	U235 (H, 9kg), U237 (F, 27uCi)
Batch053	Run004	HEU - Steel: 1.1mm	400	19.48	1716	3 (High)	7 (SNM=H)	0.41	U235 (H, 9kg), U237 (F, 27uCi)
Batch053	Run005	HEU - Steel: 1.1mm	400	19.30	1759	3 (High)	7 (SNM=H)	0.63	U235 (H, 9kg)
Batch054	Run001	HEU - Steel: 1.1mm	400	19.26	1777	3 (High)	7 (SNM=H)	0.58	U235 (H, 10kg)
Batch054	Run002	HEU - Steel: 1.1mm	400	19.26	1777	3 (High)	7 (SNM=H)	0.58	U235 (H, 10kg)
Batch054	Run003	HEU - Steel: 1.1mm	400	19.18	1767	3 (High)	7 (SNM=H)	0.59	U235 (H, 12kg), U238 (F, 834g)
Batch054	Run004	HEU - Steel: 1.1mm	400	19.58	1729	3 (High)	7 (SNM=H)	0.54	U235 (H, 9kg)
Batch054	Run005	HEU - Steel: 1.1mm	400	19.32	1738	3 (High)	7 (SNM=H)	0.53	U235 (H, 9kg), U237 (F, 112uCi)
Batch055	Run001	HEU - Steel: 7.5mm	100	19.40	963	3 (High)	7 (SNM=H)	0.49	U235 (H, 493g)
Batch055	Run002	HEU - Steel: 7.5mm	100	19.40	963	3 (High)	7 (SNM=H)	0.49	U235 (H, 493g)
Batch055	Run003	HEU - Steel: 7.5mm	100	19.62	967	3 (High)	7 (SNM=H)	0.40	U235 (H, 502g)
Batch055	Run004	HEU - Steel: 7.5mm	100	19.62	967	3 (High)	7 (SNM=H)	0.40	U235 (H, 502g)
Batch055	Run005	HEU - Steel: 7.5mm	100	19.42	989	3 (High)	7 (SNM=H)	0.36	U235 (H, 507g)
Batch056	Run001	HEU - Steel: 7.5mm	100	19.72	933	3 (High)	7 (SNM=H)	0.36	U235 (H, 511g)
Batch056	Run002	HEU - Steel: 7.5mm	100	19.42	927	3 (High)	7 (SNM=H)	0.48	U235 (H, 510g)
Batch056	Run003	HEU - Steel: 7.5mm	100	19.42	927	3 (High)	7 (SNM=H)	0.48	U235 (H, 510g)
Batch056	Run004	HEU - Steel: 7.5mm	100	19.50	965	3 (High)	7 (SNM=H)	0.45	U235 (H, 510g)
Batch056	Run005	HEU - Steel: 7.5mm	100	19.22	925	3 (High)	7 (SNM=H)	0.38	U235 (H, 497g)
Batch057	Run001	HEU - Steel: 13.8mm	100	19.60	580	3 (High)	7 (SNM=H)	0.49	U235 (H, 316g)
Batch057	Run002	HEU - Steel: 13.8mm	100	19.58	613	3 (High)	7 (SNM=H)	0.54	U235 (H, 317g)
Batch057	Run003	HEU - Steel: 13.8mm	100	19.58	613	3 (High)	7 (SNM=H)	0.54	U235 (H, 317g)
Batch057	Run004	HEU - Steel: 13.8mm	100	*No data saved in file!					
Batch057	Run005	HEU - Steel: 13.8mm	100	19.58	597	3 (High)	7 (SNM=H)	0.47	U235 (H, 286g)
Batch058	Run001	HEU - Steel: 13.8mm	100	19.26	654	3 (High)	7 (SNM=H)	0.49	U235 (H, 330g)
Batch058	Run002	HEU - Steel: 13.8mm	100	19.38	625	3 (High)	7 (SNM=H)	0.46	U235 (H, 320g)
Batch058	Run003	HEU - Steel: 13.8mm	100	19.38	625	3 (High)	7 (SNM=H)	0.46	U235 (H, 320g)
Batch058	Run004	HEU - Steel: 13.8mm	100	19.64	621	3 (High)	7 (SNM=H)	0.40	U235 (H, 326g)
Batch058	Run005	HEU - Steel: 13.8mm	100	19.58	603	3 (High)	7 (SNM=H)	0.43	U235 (H, 321g)
Batch060	Run001	WGPu - Steel: 6.35mm	100	17.50	18356	3 (High)	7 (SNM=H)	1.45	Pu239(H, 2kg), U238(F, 50kg)
Batch060	Run002	WGPu - Steel: 6.35mm	100	17.50	18356	3 (High)	7 (SNM=H)	1.45	Pu239(H, 2kg), U238(F, 50kg)
Batch060	Run003	WGPu - Steel: 6.35mm	100	17.58	18385	3 (High)	7 (SNM=H)	1.41	Pu239(H, 2kg), U238(F, 55kg)
Batch060	Run004	WGPu - Steel: 6.35mm	100	17.66	18253	3 (High)	7 (SNM=H)	2.00	Pu239(H, 2kg), U238(F, 45kg)
Batch060	Run005	WGPu - Steel: 6.35mm	100	17.84	18176	3 (High)	7 (SNM=H)	1.68	Pu239(H, 2kg), U238(F, 40kg)
Batch062	Run001	WGPu - Steel: 6.35mm	100	17.74	18368	3 (High)	7 (SNM=H)	0.81	Pu239(H, 768g), Am241(H, 753mCi), Tl201(F, 44uCi), U238(F, 45kg)

Table D.2. (contd)

Batch #	Run #	Source	Distance (cm)	Live time (sec)	Net Gamma (cps)	SNM Prob.	Threat	Chi Square	Isotopes
Batch062	Run002	WGPu - Steel: 6.35mm	100	17.74	18368	3 (High)	7 (SNM=H)	0.81	Pu239(H, 768g), Am241(H, 753mCi), Tl201(F, 44uCi), U238(F, 45kg)
Batch062	Run003	WGPu - Steel: 6.35mm	100	17.70	18310	3 (High)	7 (SNM=H)	1.76	Pu239(H, 1kg), U238(F, 43kg)
Batch062	Run004	WGPu - Steel: 6.35mm	100	17.76	18148	3 (High)	7 (SNM=H)	1.77	Pu239(H, 2kg), U238(F, 47kg)
Batch062	Run005	WGPu - Steel: 6.35mm	100	17.64	18519	3 (High)	7 (SNM=H)	1.63	Pu239(H, 2kg), U238(H, 59kg)
Batch063	Run001	WGPu - Steel: 19.05mm	100	18.30	10043	3 (High)	7 (SNM=H)	1.27	Pu239(H, 704g)
Batch063	Run002	WGPu - Steel: 19.05mm	100	18.62	9952	3 (High)	7 (SNM=H)	0.82	P239(H, 665g), Cs137(F, 37mCi), Ba133(F, 6uCi)
Batch063	Run003	WGPu - Steel: 19.05mm	100	18.62	9952	3 (High)	7 (SNM=H)	0.82	P239(H, 665g), Cs137(F, 37mCi), Ba133(F, 6uCi)
Batch063	Run004	WGPu - Steel: 19.05mm	100	18.50	9919	3 (High)	7 (SNM=H)	0.98	Pu239(H, 1kg)
Batch063	Run005	WGPu - Steel: 19.05mm	100	18.50	9919	3 (High)	7 (SNM=H)	0.98	Pu239(H, 1kg)
Batch064	Run001	WGPu - Steel: 19.05mm	100	18.76	10013	3 (High)	7 (SNM=H)	1.50	Pu239(H, 561g)
Batch064	Run002	WGPu - Steel: 19.05mm	100	18.76	10013	3 (High)	7 (SNM=H)	1.50	Pu239(H, 561g)
Batch064	Run003	WGPu - Steel: 19.05mm	100	18.52	9824	3 (High)	7 (SNM=H)	0.77	Pu239(H, 674g), Cs137(F, 33mCi), Ba133(F, 5uCi)
Batch064	Run004	WGPu - Steel: 19.05mm	100	18.46	9803	3 (High)	7 (SNM=H)	1.06	Pu239(H, 856g)
Batch064	Run005	WGPu - Steel: 19.05mm	100	18.46	9803	3 (High)	7 (SNM=H)	1.06	Pu239(H, 856g)
Batch065	Run001	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.78	7412	3 (High)	7 (SNM=H)	0.77	Pu239(H, 2kg), U235(F, 447g)
Batch065	Run002	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.78	7412	3 (High)	7 (SNM=H)	0.77	Pu239(H, 2kg), U235(F, 447g)
Batch065	Run003	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.52	7236	3 (High)	7 (SNM=H)	1.09	Pu239(H, 615g), U235(F, 425g)
Batch065	Run004	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.52	7236	3 (High)	7 (SNM=H)	1.09	Pu239(H, 615g), U235(F, 425g)
Batch065	Run005	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.90	6827	3 (High)	7 (SNM=H)	0.64	Pu239(H, 960g), U235(F, 401g)
Batch066	Run001	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.60	7065	3 (High)	7 (SNM=H)	0.83	Pu239(H, 966g), U235(F, 447g)
Batch066	Run002	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.60	7065	3 (High)	7 (SNM=H)	0.83	Pu239(H, 966g), U235(F, 447g)
Batch066	Run003	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.98	6930	3 (High)	7 (SNM=H)	0.90	Pu239(H, 1kg), U235(F, 380g)
Batch066	Run004	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.98	6930	3 (High)	7 (SNM=H)	0.90	Pu239(H, 1kg), U235(F, 380g)
Batch066	Run005	WGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.90	6972	3 (High)	7 (SNM=H)	1.36	Pu239(H, 795g)
Batch067	Run001	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	19.16	5169	3 (High)	7 (SNM=H)	1.69	Pu239(H, 824g), Cs137(F, 126mCi), Tl201(F, 1uCi)
Batch067	Run002	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	19.06	5133	3 (High)	7 (SNM=H)	0.72	Pu239(H, 989g), U235(H, 462g), U238(F, 1kg)
Batch067	Run003	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	18.86	5049	3 (High)	7 (SNM=H)	0.72	Pu239(H, 1kg), I123(H, 36uCi)

Table D.2. (contd)

Batch #	Run #	Source	Distance (cm)	Live time (sec)	Net Gamma (cps)	SNM Prob.	Threat	Chi Square	Isotopes
Batch067	Run004	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	18.86	5049	3 (High)	7 (SNM=H)	0.72	Pu239(H, 1kg), I123(H, 36uCi)
Batch067	Run005	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	19.02	5418	3 (High)	7 (SNM=H)	2.16	Pu239(H, 1kg), Tl201(H, 1uCi)
Batch068	Run001	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	18.98	5008	3 (High)	7 (SNM=H)	0.77	Pu239(H, 996g), U235(F, 426g)
Batch068	Run002	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	18.98	5008	3 (High)	7 (SNM=H)	0.77	Pu239(H, 996g), U235(F, 426g)
Batch068	Run003	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	19.18	4868	3 (High)	7 (SNM=H)	1.66	Pu239(H, 1kg), Tl201(F, 1uCi)
Batch068	Run004	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	19.18	4868	3 (High)	7 (SNM=H)	1.66	Pu239(H, 1kg), Tl201(F, 1uCi)
Batch068	Run005	WGPu - Steel: 19.05mm, Copper: 6.35mm, Lead: 3.175mm	100	19.04	4898	3 (High)	7 (SNM=H)	0.78	Pu239(H, 976g), U235(F, 399g), U238(F, 1kg)
Batch069	Run001	WGPu - Lead: 50.8mm	100	19.54	3239	3 (High)	7 (SNM=H)	1.19	Np237(H, 21g), In111(H, 4uCi), Tl201(H, 601uCi), U237(H, 6uCi), U235(F, 297g)
Batch069	Run002	WGPu - Lead: 50.8mm	100	19.54	3239	3 (High)	7 (SNM=H)	1.19	Np237(H, 21g), In111(H, 4uCi), Tl201(H, 601uCi), U237(H, 6uCi), U235(F, 297g)
Batch069	Run003	WGPu - Lead: 50.8mm	100	19.44	3457	3 (High)	7 (SNM=H)	0.87	Np237(H, 23g), In111(H, 3uCi), Tl201(H, 691uCi), U235(H, 329g), U237(F, 5uCi)
Batch069	Run004	WGPu - Lead: 50.8mm	100	19.44	3457	3 (High)	7 (SNM=H)	0.87	Np237(H, 23g), In111(H, 3uCi), Tl201(H, 691uCi), U235(H, 329g), U237(F, 5uCi)
Batch069	Run005	WGPu - Lead: 50.8mm	100	19.20	3048	3 (High)	7 (SNM=H)	1.28	Np237(H, 20g), In111(H, 3uCi), Tl201(H, 547uCi), U235(H, 314g), U237(F, 5uCi)
Batch070	Run001	WGPu - Lead: 50.8mm	100	19.00	3142	3 (High)	7 (SNM=H)	1.37	In111(H, 3uCi), Np237(H, 21g), U235(H, 375g), I123(H, 25uCi), U237(F, 5uCi)
Batch070	Run002	WGPu - Lead: 50.8mm	100	19.00	3142	3 (High)	7 (SNM=H)	1.37	In111(H, 3uCi), Np237(H, 21g), U235(H, 375g), I123(H, 25uCi), U237(F, 5uCi)
Batch070	Run003	WGPu - Lead: 50.8mm	100	19.48	3075	3 (High)	7 (SNM=H)	1.17	Np237(H, 20g), In111(H, 3uCi), Tl201(H, 545uCi), U237(H, 6uCi), U235(H, 297g)
Batch070	Run004	WGPu - Lead: 50.8mm	100	19.04	3105	3 (High)	7 (SNM=H)	1.09	Np237(H, 21g), In111(H, 3uCi), Tl201(H, 601uCi), U237(H, 6uCi), U235(F, 273g)
Batch070	Run005	WGPu - Lead: 50.8mm	100	19.76	3102	3 (High)	7 (SNM=H)	1.03	Np237(H, 22g), In111(H, 3uCi), Tl201(H, 546uCi), U235(H, 309g), U237(F, 6uCi)
Batch071	Run001	RGPu - Steel: 6.35mm	100	15.34	43178	3 (High)	7 (SNM=H)	2.05	Am241(H, 11Ci), Pu239(H, 6kg), Th232 (H, 2uCi), U238(H, 11kg), U237(H, 2Ci)
Batch071	Run002	RGPu - Steel: 6.35mm	100	15.34	43178	3 (High)	7 (SNM=H)	2.05	Am241(H, 11Ci), Pu239(H, 6kg), Th232 (H, 2uCi), U238(H, 11kg),

Table D.2. (contd)

Batch #	Run #	Source	Distance (cm)	Live time (sec)	Net Gamma (cps)	SNM Prob.	Threat	Chi Square	Isotopes
									U237(H, 2Ci)
Batch071	Run003	RGPu - Steel: 6.35mm	100	15.72	42875	3 (High)	7 (SNM=H)	1.93	Am241(H, 11Ci), Pu239(H, 5kg), Th232 (H, 5uCi), U238(F, 456g), U237(F, 546uCi), Mn54(F, 15uCi)
Batch071	Run004	RGPu - Steel: 6.35mm	100	15.68	42892	3 (High)	7 (SNM=H)	1.40	Am241(H, 11Ci), Pu239(H, 4kg), Th232(H, 6uCi), U237(H, 2Ci), Bi207(F,1uCi), Mn54(F, 9uCi)
Batch071	Run005	RGPu - Steel: 6.35mm	100	15.68	42798	3 (High)	7 (SNM=H)	2.40	Am241(H, 10Ci), Pu239(H, 4kg), U238(H, 11kg), U237(F, 492uCi), Ba133(F, 47uCi), U235(L, 356g)
Batch072	Run001	RGPu - Steel: 6.35mm	100	15.94	42349	3 (High)	7 (SNM=H)	1.90	Am241(H, 10Ci), Pu239(H, 7kg), Th232(H, 5uCi), U237(H, 99uCi), U238(H, 2kg)
Batch072	Run002	RGPu - Steel: 6.35mm	100	15.94	42349	3 (High)	7 (SNM=H)	1.90	Am241(H, 10Ci), Pu239(H, 7kg), Th232(H, 5uCi), U237(H, 99uCi), U238(H, 2kg)
Batch072	Run003	RGPu - Steel: 6.35mm	100	16.02	42603	3 (High)	7 (SNM=H)	2.20	Am241(H, 11Ci), Pu239(H, 6kg), Th232(H, 5uCi), U237(H, 2Ci), U238(F, 52kg)
Batch072	Run004	RGPu - Steel: 6.35mm	100	15.64	42996	3 (High)	7 (SNM=H)	2.40	Am241(H, 10Ci), Pu239(H, 7kg), Th232(H, 5uCi), U238(H, 559g), U237(F, 542uCi)
Batch072	Run005	RGPu - Steel: 6.35mm	100	15.64	42996	3 (High)	7 (SNM=H)	2.40	Am241(H, 10Ci), Pu239(H, 7kg), Th232(H, 5uCi), U238(H, 559g), U237(F, 542uCi)
Batch073	Run001	RGPu - Steel: 19.05mm	100	15.64	43114	3 (High)	7 (SNM=H)	2.80	Am241(H, 10Ci), Pu239(H, 6kg), U237(H, 2Ci)
Batch073	Run002	RGPu - Steel: 19.05mm	100	15.58	43062	3 (High)	7 (SNM=H)	2.30	Am241(H, 10Ci), Pu239(H, 7kg), Th232(H, 5uCi), U237(H, 109uCi), U238(F, 5kg)
Batch073	Run003	RGPu - Steel: 19.05mm	100	15.58	43062	3 (High)	7 (SNM=H)	2.30	Am241(H, 10Ci), Pu239(H, 7kg), Th232(H, 5uCi), U237(H, 109uCi), U238(F, 5kg)
Batch073	Run004	RGPu - Steel: 19.05mm	100	15.48	42820	3 (High)	7 (SNM=H)	2.10	Am241(H, 10Ci), Pu239(H, 4kg), Th232(H, 5uCi), U238(F, 9kg), U237(F, 493uCi), Ba133(F, 48uCi), Mn54(F, 11uCi)
Batch073	Run005	RGPu - Steel: 19.05mm	100	15.48	42820	3 (High)	7 (SNM=H)	2.10	Am241(H, 10Ci), Pu239(H, 4kg), Th232(H, 5uCi), U238(F, 9kg), U237(F, 493uCi), Ba133(F, 48uCi), Mn54(F, 11uCi)
Batch074	Run001	RGPu - Steel: 19.05mm	100	17.76	20167	3 (High)	7 (SNM=H)	1.70	Am241(H, 4Ci), Pu239(H, 1kg), U235(F, 1kg)
Batch074	Run002	RGPu - Steel: 19.05mm	100	17.76	20167	3 (High)	7 (SNM=H)	1.70	Am241(H, 4Ci), Pu239(H, 1kg), U235(F, 1kg)
Batch074	Run003	RGPu - Steel: 19.05mm	100	17.64	21126	3 (High)	7 (SNM=H)	1.60	Am241(H, 5Ci), Pu239(H, 1kg), U235(F, 2kg)
Batch074	Run004	RGPu - Steel: 19.05mm	100	17.64	21126	3 (High)	7 (SNM=H)	1.60	Am241(H, 5Ci), Pu239(H, 1kg), U235(F, 2kg)
Batch074	Run005	RGPu - Steel: 19.05mm	100	17.54	20317	3 (High)	7 (SNM=H)	1.50	Am241(H, 4Ci), Pu239(H, 2kg)
Batch075	Run001	RGPu - Steel: 19.05mm	100	17.56	20133	3 (High)	7 (SNM=H)	1.30	Am241(H, 4Ci), Pu239(H, 2kg), U235(F, 1kg)
Batch075	Run002	RGPu - Steel: 19.05mm	100	17.62	20430	3 (High)	7 (SNM=H)	1.60	Am241(H, 4Ci), Pu239(H, 3kg)

Table D.2. (contd)

Batch #	Run #	Source	Distance (cm)	Live time (sec)	Net Gamma (cps)	SNM Prob.	Threat	Chi Square	Isotopes
Batch075	Run003	RGPu - Steel: 19.05mm	100	17.62	20430	3 (High)	7 (SNM=H)	1.60	Am241(H, 4Ci), Pu239(H, 3kg)
Batch075	Run004	RGPu - Steel: 19.05mm	100	17.44	20275	3 (High)	7 (SNM=H)	1.30	Am241(H, 4Ci), Pu239(H, 2kg), I131(F, 219uCi)
Batch075	Run005	RGPu - Steel: 19.05mm	100	17.44	20275	3 (High)	7 (SNM=H)	1.30	Am241(H, 4Ci), Pu239(H, 2kg), I131(F, 219uCi)
Batch077	Run001	RGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.02	16415	3 (High)	7 (SNM=H)	1.30	Pu239(H, 2kg), Am241(H, 951mCi), Cs137(H, 289mCi), U235(F, 744g)
Batch077	Run002	RGPu - Steel: 19.05mm, Copper: 6.35mm	100	18.02	16415	3 (High)	7 (SNM=H)	1.30	Pu239(H, 2kg), Am241(H, 951mCi), Cs137(H, 289mCi), U235(F, 744g)
Batch077	Run003	RGPu - Steel: 19.05mm, Copper: 6.35mm	100	17.72	16677	3 (High)	7 (SNM=H)	1.30	Am241(H, 2Ci), Cs137(H, 325mCi), Pu239(H, 2kg)
Batch077	Run004	RGPu - Steel: 19.05mm, Copper: 6.35mm	100	17.72	16677	3 (High)	7 (SNM=H)	1.30	Am241(H, 2Ci), Cs137(H, 325mCi), Pu239(H, 2kg)
Batch077	Run005	RGPu - Steel: 19.05mm, Copper: 6.35mm	100	17.76	16699	3 (High)	7 (SNM=H)	1.30	Am241(H, 3Ci), Pu239(H, 2kg), U235(F, 2kg)

Appendix E
Library of Isotopes Used for ScintiVision Analysis

Appendix E
Library of Isotopes Used for ScintiVision Analysis

Table E.1. Library of Isotopes for ScintiVision Analysis

ISOTOPES IDENTIFIED	HALF LIFE	UNCERTAINTY	ENERGY LINES (KEV)
Am241	432.6 y	0.6 y	26.35, 59.54
Ba133	10.52 y	0.13 y	80.89, 276.40, 302.85, 356.02, 383.85
Bi207	32.9 y	0.14 y	569.70, 1063.66, 1770.23
Co57	271.74 d	0.06 d	122.06, 136.47, 692.03
Co60	5.273 y	0.005 y	1173.24, 1332.50
Cr51	27.7025 d	0.00024 d	320.082397
Cs137	30.08 y	0.09 y	661.66
Eu152	13.506 y	0.006 y	121.78, 244.65, 344.30, 778.90, 964.00, 1100.00, 1408.00
Ga67	3.2617 d	0.0005 d	93.16, 184.58, 208.95, 300.22, 393.53
Ho166m	1.200e3 y	180 y	80.57, 184.41, 280.46, 410.94, 711.68, 752.29, 810.28
I123	13.2235 h	0.0019 h	158.97, 528.96
I131	8.0252 d	0.0006 d	284.30, 364.49, 636.99, 722.91
In111	2.8047 d	0.0004 d	171.28, 245.40
Ir192	73.827 d	0.0013 d	310.64, 469.10, 602.82
K40	1.248e9 y	3000000 y	1460.83
Lu177m	160.44 d	0.06 d	208.37, 228.48, 378.50, 418.54
Mn54	312.12 d	0.06 d	835
Mo99	65.94 h	0.01 h	40.58, 140.51, 181.06, 366.42, 739.50, 777.92
Na22	2.6027 y	0.001 y	1274.53
Np237	2.144e6 y	7.00E+03 y	29.37, 86.48, 96.30, 310.44, 340.81, 375.45, 398.62, 415.76
Pu239	24110 y	30 y	38.66, 51.62, 129.30, 203.55, 376.03, 413.71
Pu241	14.290 y	0.006 y	151.70, 208.00
Ra226	1.600e3 y	7 y	186.21, 295.22, 609.32, 768.36, 1120.28, 1238.11, 1758.90, 2204.12
Se75	119.79 d	0.04 d	96.73, 121.10, 136.00, 198.61, 264.65, 279.54, 303.92, 400.66
Sm153	46.284 h	0.004 h	69.67, 103.20
Sr89	50.53 d	0.07 d	908.96
Th228	1.9116 y	0.0016 y	84.37, 215.98
Th232	1.4e10 y	0.01e10 y	63.83, 140.86, 209.25, 238.84, 300.09, 338.32, 510.77, 583.19, 727.33, 794.95, 860.56, 911.20, 967.96, 1588.19, 2614.53
Tl201	3.0421 d	0.0017 d	31.40, 135.34, 167.43
U232	68.9 y	0.4 y	209.25, 238.83, 300.87, 510.77, 583.19, 727. 33, 794.95, 860.56, 1588.19, 2614.53
U233	1.592e5 y	200 y	29.19, 42.44, 54.70, 146.35, 164.52, 291.35, 317.16
U235	7.04e8 y	0.01e8 y	25.65, 143.76, 163.36, 185.71, 205.31
U237	6.75 d	0.01 d	59.54, 208.00
U238	4.468e9 y	0.003e9 y	49.55, 63.29, 92.58, 112.81, 113.50, 766.38, 1001.03

Appendix F
Complete ScintiVision Results

Appendix F
Complete ScintiVision Results

Table F.1. Complete ScintiVision Results

Batch	Source	Nuclide (peak energy in keV) **D = peak area deconvoluted*	Uncertainty Sigma %	Net Area Counts	Intensity (cnts/sec)
Batch002	**WGPu 100g**	K40 (1460.83)	8.09	607	32.240
		Th232 (2614.53)	17.35	822	43.609
		Ra226 (186.21) D	23.12	713	37.854
		Pu241 (208.00) D	25.65	362	19.219
		Tl201 (167.43) D	32.07	517	27.455
		Th232 (338.32) D	52.47	85	4.534
Batch003	**WGPu 100g**	K40 (1460.83)	10.13	456	23.829
		U235 (205.31) D	30.48	595	31.117
		I131 (636.99) D	31.79	479	25.069
		Se75 (264.65) D	34.67	208	10.885
		In111 (171.28) D	41.60	140	7.309
		Co57 (692.03) D	45.78	41	2.145
		Th232 (911.20)	119.69	431	22.547
Batch004	**WGPu 100g**	Se75 (400.66) D	3.41	2275	118.487
		Mo99 (366.42) D	4.73	2080	108.341
		K40 (1460.83)	6.87	4242	220.953
		Th232 (338.32) D	8.70	5480	285.435
		Sm153 (103.20)	9.11	604	31.471
Batch005	**WGPu 100g**	K40 (1460.83) D	6.60	1065	55.914
		I123 (158.97) D	12.67	1418	74.462
		Co57 (122.06) D	21.23	653	34.288
		Ra226 (1758.90) D	24.20	131	6.877
Batch006	**WGPu 100g**	K40 (1460.83)	6.99	571	29.633
Batch007	**WGPu 100g**	K40 (1460.83)	6.99	331	17.205
		Th232 (2614.53)	28.83	133	6.921
		Pu241 (208.00) D	42.07	78	4.055
		Ra226 (609.32) D	76.96	48	2.486
		In111 (245.40) D	98.89	560	29.144
		Co57 (692.03) D	121.39	58	3.003
Batch008	**WGPu 100g**	Lu177m (378.50) D	5.16	849	43.572
		K40 (1460.83)	8.60	2313	118.738
		Th232 (338.32) D	14.16	107	5.467
		Ra226 (609.32)	51.93	495	25.418
Batch009	**WGPu 100g**	K40 (1460.83)	6.70	59	3.040
		Ra226 (1120.28)	75.21	597	30.720
Batch011	**RGPu 98g**	Cs137 (661.66)	6.39	2864	158.581
		Th232 (338.32)	8.39	1783	98.707
		K40 (1460.83)	8.40	534	29.577
		Th232 (2614.53)	25.04	89	4.913
Batch012	**RGPu 98g**	Ba133 (383.85) D	3.81	5726	311.185
		Th232 (338.32) D	4.40	6500	353.264
		Cs137 (661.66)	5.63	2027	110.179
		K40 (1460.83)	8.69	505	27.449
		Th232 (2614.53)	15.92	135	7.347
Batch013	**RGPu 98g**	K40 (1460.83)	8.18	1731	92.668
		Cs137 (661.66)	9.31	967	51.783
		Th232 (2338.32)	10.62	529	28.305
		Th232 (2614.53)	18.33	102	5.458
Batch014	**RGPu 98g**	Ga67 (393.53) D	7.02	460	24.541
		K40 (1460.83)	9.25	1845	98.460
		Eu152 (344.30) D	10.64	2655	141.655
		Th232 (2614.53)	20.33	480	25.616
		I123 (158.97)	49.11	98	5.221

Table F.1. (contd)

Batch	Source	Nuclide (peak energy in keV) *D = peak area deconvoluted	Uncertainty Sigma %	Net Area Counts	Intensity (cnts/sec)
Batch015	**RGPu 98g**	K40 (1460.83) D	7.02	1175	61.768
		Cr51 (320.08) D	13.06	1061	55.795
		Ba133 (356.02) D	14.24	654	34.384
		Ra226 (1758.90) D	34.73	108	5.667
		Th232 (2614.53)	35.64	54	2.862
Batch016	**RGPu 98g**	K40 (1460.83)	6.59	1230	65.551
		Ga67 (393.53) D	8.61	1801	96.027
		Np237 (340.81) D	13.18	609	32.463
Batch017	**cs137**	K40 (1460.83)	6.41	54	2.810
		Cs137 (661.66) D	8.44	849	43.948
		Co57 (692.03) D	16.97	435	22.526
		U232 (238.83)	153.56	640	33.151
Batch018	**cs137**	Cs137 (661.66)	6.06	96	4.866
		K40 (1460.83)	6.64	105	5.335
		Ba133 (356.02) D	47.83	152	7.702
		Th232 (2614.53)	50.29	1096	55.560
		U233 (291.35) D	73.22	638	32.328
		Pu239 (203.55) D	90.32	37	1.865
Batch019	**cs137**	K40 (1460.83)	8.15	86	4.416
		Cs137 (661.66) D	12.95	37	1.886
		Th232 (2614.53)	29.26	174	8.887
		Eu152 (344.30) D	39.13	55	2.821
		Th232 (238.84) D	91.56	472	24.142
		U232 (510.77) D	108.79	534	27.317
		Ba133 (276.40) D	206.33	53	2.730
Batch020	**cs137**	K40 (1460.83)	10.23	85	4.299
		Cs137 (661.66)	16.40	381	19.315
		Se75 (198.61)	99.54	439	22.302
Batch021	**Co60**	Co60 (1173.24) D	3.71	126	6.561
		Co60 (1332.50) D	4.60	2594	134.566
		K40 (1460.83) D	13.64	2276	118.068
		Th232 (2614.53)	42.42	659	34.184
		Lu177m (228.48)	79.21	42	2.166
Batch022	**Co60**	Co60 (1173.24) D	3.64	211	10.867
		Co60 (1332.50) D	4.24	116	5.952
		K40 (1460.83) D	13.54	2613	134.400
		Pu241 (208.00) D	49.98	2430	124.990
		Ba133 (356.02) D	78.14	667	34.315
Batch023	**Co60**	Co60 (1173.24) D	9.93	86	4.477
		K40 (1460.83) D	10.67	89	4.628
		Co60 (1332.50) D	12.29	692	35.903
		Th232 (2614.53)	14.79	630	32.700
		Ra226 (1758.90) D	42.38	651	33.788
		Ra226 (609.32) D	74.30	103	5.336
		I123 (528.96) D	78.09	91	4.735
Batch024	**Co60**	Co60 (1173.24) D	12.27	111	5.727
		Co60 (1332.50) D	15.95	180	9.240
		Th232 (2614.53)	24.49	97	4.998
		U232 (238.83) D	48.31	549	28.243
		Cr51 (253.99) D	77.60	433	22.253
		U235 (205.31) D	78.69	67	3.459
Batch025	**Co60**	K40 (1460.83) D	8.27	461	24.203
		Co60 (1173.24) D	11.68	326	17.121
		Co60 (1332.50) D	19.02	626	32.889
Batch026	**Co60**	Th232 (2614.53)	20.82	75	3.886
		K40 (1460.83)	31.23	92	4.760
		U232 (510.77) D	43.15	80	4.177
		Ir192 (469.10) D	49.37	129	6.697
		Ba133 (276.40) D	87.39	145	7.545
		Eu152 (344.30) D	88.67	183	9.501

Table F.1. (contd)

Batch	Source	Nuclide (peak energy in keV) *D = peak area deconvoluted	Uncertainty Sigma %	Net Area Counts	Intensity (cnts/sec)
		U232 (238.83) D	110.71	82	4.253
Batch027	**DU**	K40 (1460.83)	8.57	125	6.455
		U232 (583.19) D	28.80	249	12.923
		U232 (510.77) D	42.82	141	7.283
		Ra226 (186.21) D	47.36	156	8.094
		Se75 (279.54) D	71.06	95	4.923
		In111 (245.40) D	81.61	212	10.965
		In111 (171.28) D	95.19	310	16.066
		Eu152 (344.30) D	107.10	552	28.603
Batch028	**DU**	K40 (1460.83)	8.19	87	4.477
		Th232 (2614.53)	16.47	138	7.118
		Cr51 (320.08) D	77.70	93	4.823
		Mo99 (366.42) D	110.20	579	29.885
		Se75 (198.61) D	136.16	86	4.443
Batch029	**DU**	U238 (1001.03)	8.13	1101	57.345
Batch030	**DU**	K40 (1460.83)	8.55	586	30.859
Batch031	**co57**	Se75 (121.10) D	3.51	1172	62.188
		Ga67 (93.16) D	6.86	3004	159.459
		K40 (1460.83) D	7.22	78	4.120
		Th232 (2614.53)	19.39	590	31.313
		Co60 (1173.24) D	55.89	73	3.860
Batch032	**co57**	K40 (1460.83)	6.15	985	50.012
		U238 (112.81)	10.10	34	1.730
		Th232 (2614.53)	19.30	85	4.334
		U232 (583.19) D	28.12	193	9.781
		Eu152 (344.30) D	36.61	85	4.315
		I123 (528.96) D	45.71	147	7.455
		U232 (300.87) D	79.71	222	11.291
		Unknown (443.33) D	80.31	651	33.047
		In111 (245.40)	220.47	80	4.051
Batch033	**co57**	K40 (1460.83)	6.91	596	31.615
Batch034	**co57**	K40 (1460.83)	7.42	66	3.355
		Th232 (2614.53)	29.51	76	3.892
		Ba133 (356.02) D	92.25	69	3.540
		Lu177m (228.48) D	103.40	582	29.672
		Se75 (198.61) D	124.45	54	2.731
Batch035	**co57**	Co57 (122.06) D	3.07	1314	67.254
Batch035		U238 (92.58) D	5.87	3061	156.670
		K40 (1460.83)	6.90	673	34.417
		I123 (158.97) D	15.95	295	15.115
		Th232 (2614.53)	15.99	114	5.818
		Se75 (198.61) D	27.74	619	31.654
		U232 (238.83) D	67.61	85	4.344
Batch036	**co57**	K40 (1460.83)	7.52	211	10.521
		Np237 (86.48)	39.64	135	6.716
		U232 (238.83) D	57.30	74	3.699
		Th232 (338.32) D	67.91	99	4.951
		Ra226 (609.32)	68.08	44	2.180
		Ra226 (295.22) D	97.52	82	4.069
		Unknown (436.79) D	133.68	570	28.407
Batch037	**Ba133**	Eu152 (344.30) D	4.77	96	4.959
		Pu239 (376.03) D	6.02	1038	53.633
		K40 (1460.83)	7.24	2639	136.316
		Ra226 (295.22) D	10.07	2018	104.240
		Th232 (2614.53)	26.24	90	4.633
		U232 (583.19)	60.45	573	29.587
		Se75 (121.10)	106.02	57	2.960
Batch038	**Zirc Sand**	K40 (1460.83) D	6.11	201	6.820
		Ra226 (609.32) D	8.74	337	11.443
		Th232 (2614.53) D	12.89	146	4.968
		Ra226 (1120.28) D	22.85	1247	42.387

Table F.1. (contd)

Batch	Source	Nuclide (peak energy in keV) *D = peak area deconvoluted*	Uncertainty Sigma %	Net Area Counts	Intensity (cnts/sec)
		Ra226 (2204.12) D	33.26	324	11.005
		Ba133 (356.02) D	42.36	1091	37.095
		U232 (510.77) D	75.28	97	3.310
		Lu177m (228.48) D	80.27	206	7.002
Batch039	**Zirc Sand**	Ra226 (609.32) D	4.25	1005	35.553
		Ra226 (1120.28) D	7.88	2899	102.595
		Ba133 (356.02) D	9.26	5278	186.782
		Ra226 (2204.12)	10.11	858	30.377
		Eu152 (964.00) D	13.93	1469	51.968
		Mo99 (777.92) D	25.08	2241	79.312
		Th232 (238.83) D	29.79	628	22.232
Batch040	**Ice Melt**	K40 (1460.83)	1.18	11872	406.287
Batch041	**Kitty Litter**	K40 (1460.83)	5.52	161	5.468
		Ra226 (609.32) D	26.81	83	2.798
		Eu152 (344.30) D	46.31	193	6.549
		U232 (238.83) D	66.56	295	9.985
		U232 (727.33) D	73.14	103	3.496
		Se75 (264.65) D	125.88	1031	34.946
Batch042	**Tiles**	K40 (1460.83)	3.81	230	7.810
		Ra226 (609.32)	35.22	1620	55.067
Batch043	**Fertilizer**	K40 (1460.83)	1.43	8728	300.359
Batch044	**Granite**	K40 (1460.83) D	4.00	163	5.453
		Th232 (2614.53)	12.37	52	1.729
		Ra226 (1120.28) D	30.94	198	6.604
		Eu152 (244.65) D	60.95	1539	51.332
		Th232 (300.09) D	177.57	146	4.854
Batch045	**Lanthanum Carbonate**	K40 (1460.83)	2.90	883	29.658
		Th232 (794.95)	9.20	2249	75.556
Batch046	**HEU**	K40 (1460.83)	5.69	77	3.953
		U232 (583.19)	71.71	678	34.674
Batch047	**HEU**	K40 (1460.83)	6.77	638	32.618
		Th232 (2614.53)	16.69	86	4.396
Batch048	**HEU**	K40 (1460.83)	8.16	1388	72.503
		Sm153 (103.20) D	9.73	732	38.236
		U235 (143.76) D	16.78	521	27.222
		Th232 (2614.53)	17.82	79	4.145
Batch049	**HEU**	K40 (1460.83)	5.96	680	34.432
Batch050	**HEU**	K40 (1460.83)	6.90	44	2.256
		Th232 (2614.53)	29.77	580	29.720
		U235 (143.76)	234.75	51	2.615
Batch051	**HEU**	K40 (1460.83)	7.27	136	7.050
		U233 (146.35)	76.71	580	30.150
Batch052	**HEU**	K40 (1460.83)	7.18	41	2.123
		U232 (583.19) D	35.71	152	7.880
		I123 (528.96) D	139.58	590	30.525
Batch053	**HEU**	Sm153 (103.20) D	7.15	2574	131.064
		K40 (1460.83)	7.65	1171	59.646
		U233 (146.35) D	14.05	533	27.117
		Th232 (2614.53)	21.57	74	3.758
Batch054	**HEU**	Ga67 (184.58)	3.21	5175	268.673
		K40 (1460.83)	8.14	512	26.606
Batch055	**HEU**	K40 (1460.83)	7.05	74	3.798
		Th232 (2614.53)	24.46	581	29.940
		U232 (583.19)	76.64	62	3.178
Batch056	**HEU**	K40 (1460.83)	6.40	92	7.738
		U233 (146.35)	153.96	645	33.188
Batch057	**HEU**	K40 (1460.83)	5.65	696	35.552
Batch058	**HEU**	K40 (1460.83)	8.32	1304	67.291
		In111 (171.28)	9.21	491	25.319

Table F.1. (contd)

Batch	Source	Nuclide (peak energy in keV) *D = peak area deconvoluted*	Uncertainty Sigma %	Net Area Counts	Intensity (cnts/sec)
		Th232 (2614.53)	17.92	69	3.580
Batch059	**HEU**				
Batch060	**HEU**	K40 (1460.83)	8.49	2089	119.381
		Cs137 (661.66)	15.83	1029	58.801
		Pu241 (208.00) D	16.96	669	38.224
		In111 (245.40) D	33.30	500	28.554
Batch061	**WGPu**				
Batch062	**WGPu**	U238 (113.50) D	1.45	12149	684.815
		U238 (92.58) D	2.18	21484	1211.024
		U233 (146.35) D	2.61	14925	841.336
		Ra226 (186.21) D	3.67	9867	556.210
		K40 (1460.83)	7.65	579	32.638
Batch063	**WGPu**	K40 (1460.83)	7.45	329	17.656
		U235 (163.36)	90.14	584	31.358
Batch064	**WGPu**	K40 (1460.83)	7.38	1626	86.687
		I123 (158.97)	17.97	558	29.730
Batch065	**WGPu**	U233 (164.52) D	6.80	1878	99.975
		K40 (1460.83)	7.70	4137	220.284
		Pu239 (129.30) D	14.65	292	15.572
		Se75 (303.92) D	27.63	808	43.044
		Ra226 (609.32)	51.30	138	7.333
		Lu177m (228.48) D	83.37	536	28.552
Batch066	**WGPu**	K40 (1460.83) D	7.83	1530	82.261
		U235 (163.36) D	8.68	3070	165.040
		Co57 (136.47) D	17.49	604	32.469
		Th232 (2614.53)	19.70	437	23.478
		Ra226 (186.21) D	43.38	39	2.088
		Se75 (264.65) D	52.23	588	31.615
		Co60 (1173.24) D	120.47	81	4.340
Batch067	**WGPu**	U235 (163.36) D	17.73	1330	69.767
		Lu177m (228.48) D	37.88	518	27.162
Batch068	**WGPu**	K40 (1460.83)	8.18	982	51.731
		Ho166m (410.94) D	12.99	1243	65.485
		Mo99 (366.42) D	17.94	537	28.268
Batch069	**WGPu**	K40 (1460.83)	7.94	120	6.117
		Ra226 (609.32) D	23.78	246	12.593
		U232 (510.77) D	48.89	548	28.034
Batch070	**WGPu**	K40 (1460.83)	6.54	213	11.203
		Th232 (2614.53)	25.95	619	32.590
		U235 (163.36)	100.55	58	3.057
Batch071	**RGPu**	Cs137 (661.66) D	2.81	1152	75.065
		U232 (727.33) D	3.89	9037	589.122
		K40 (1460.83)	15.41	6299	410.621
		I123 (158.97)	42.99	373	24.336
Batch072	**RGPu**	Cs137 (661.66)	2.97	1317	82.597
		Cr51 (320.08)	3.75	12690	796.096
		Th232 (2614.53)	10.16	8154	511.533
		I123 (158.97)	38.04	431	27.058
Batch073	**RGPu**	Mo99 (366.42) D	2.38	16891	1084.162
		Cr51 (320.08) D	2.97	21164	1358.418
		Cs137 (661.66) D	4.27	6100	391.525
		Co57 (692.03) D	4.80	5491	352.416
		U232 (727.33) D	5.82	4321	277.311
		Th232 (2614.53)	11.10	380	24.372
Batch074	**RGPu**	Mo99 (366.42) D	5.02	667	37.559
		Cs137 (661.66)	5.27	6261	352.515
		Cr51 (320.08) D	5.48	6698	377.151
		K40 (1460.83)	10.35	3269	184.056
		Th232 (2614.53)	13.15	523	29.472
		I123 (158.97)	58.48	287	16.181
Batch075	**RGPu**	Cs137 (661.66) D	4.55	3177	180.293

Table F.1. (contd)

Batch	Source	Nuclide (peak energy in keV) **D = peak area deconvoluted*	Uncertainty Sigma %	Net Area Counts	Intensity (cnts/sec)
		Pu239 (203.55) D	4.83	5233	296.974
		I131 (722.91) D	6.39	8031	455.809
		In111 (171.28) D	7.58	1120	63.559
		Th232 (2614.53)	10.08	2912	165.283
		Th232 (338.32) D	11.80	3987	226.292
		K40 (1460.83)	12.38	2720	154.352
		U233 (146.35) D	12.46	449	25.482
		Lu177m (228.48) D	33.73	352	19.953
Batch076	**?**				
Batch077	**RGPu**	K40 (1460.83) D	9.49	1051	58.342
		Th232 (2614.53)	14.35	602	33.410
		I123 (158.97)	34.59	135	7.507
		Bi207 (1770.23) D	35.74	232	12.867
Batch078	**Yellowcake**	Ba133 (383.85) D	5.76	2086	116.782
		Np237 (340.81) D	6.54	4622	258.806
		Cs137 (661.66)	6.89	4932	276.146
		Th232 (2614.53)	10.59	2157	120.774
		Np237 (310.44) D	14.54	289	16.157
Batch079	**Yellowcake**	K40 (1460.83) D	7.37	1440	73.451
		Se75 (96.73) D	9.65	891	45.477
		U238 (1001.03)	11.08	597	30.435
		Ra226 (186.21) D	13.60	653	33.335
		Ra226 (1758.90) D	26.36	143	7.306
Batch080	**Yellowcake**	K40 (1460.83)	8.41	374	19.173
		U238 (1001.03)	9.47	692	35.445
		Th232 (2614.53)	27.00	531	27.223
		Sm153 (103.20)	39.52	61	3.146
Batch081	**Yellowcake**	K40 (1460.83)	8.23	590	30.412
		U238 (1001.03)	11.23	549	28.323
Batch082	**Heisenberg**	Th232 (2614.53)	35.26	159	8.139
		U232 (510.77) D	60.82	77	3.970
		In111 (171.28) D	69.80	130	6.660
		Se75 (264.65) D	138.48	43	2.210
Batch083	**Heisenberg**	K40 (1460.83)	7.54	61	3.066
		Th232 (2614.53)	19.19	298	14.902
		U238 (1001.03)	21.09	594	29.698
		Ho166m (184.41)	174.00	83	4.151
Batch084	**Heisenberg**	U238 (1001.03)	7.15	1079	55.271
		K40 (1460.83)	7.17	663	33.979
Batch085	**Heisenberg**	K40 (1460.83)	8.21	1185	60.528
		Se75 (96.73) D	12.13	494	25.233
		U235 (205.31) D	22.96	577	29.483
		Mo99 (181.06) D	27.24	575	29.351
Batch086	**Heisenberg**				
Batch087	**Heisenberg**	K40 (1460.83)	4.11	841	14.422
		U238 (1001.03) D	5.09	1035	17.758
		U238 (766.38) D	11.49	219	3.750
		Th232 (2614.53)	12.58	311	5.341
		Pu239 (203.55) D	22.62	260	4.464
		Mo99 (181.06) D	27.77	1369	23.485
		Ba133 (356.02) D	64.51	2744	47.079
		Ho166m (410.94) D	72.64	1927	33.058
		U233 (317.16) D	96.26	197	3.385
Batch088	**Yellowcake**	K40 (1460.83)	4.14	989	17.154
		U238 (1001.03)	7.10	1169	20.265
		Se75 (198.61) D	18.38	108	1.865
		Mo99 (181.06) D	21.80	258	4.472
		Ba133 (356.02) D	67.78	1585	27.483
		U233 (317.16) D	171.84	1801	31.229
Batch089	**Yellowcake**	K40 (1460.83)	4.27	1760	30.235
Batch090	Unlabeled	K40 (1460.83) D	3.63	732	12.600

Table F.1. (contd)

Batch	Source	Nuclide (peak energy in keV) **D = peak area deconvoluted*	Uncertainty Sigma %	Net Area Counts	Intensity (cnts/sec)
		Th232 (2614.53)	11.23	1061	18.250
		Ra226 (1758.90) D	14.14	2155	37.074
		Se75 (198.61) D	18.89	411	7.077
		Tl201 (167.43) D	27.56	219	3.771

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