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PNNL-20444

PVT Analysis With A Deconvolution Algorithm

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February 2011

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Executive Summary

Polyvinyl Toluene (PVT) plastic scintillator is the most common gamma ray detector material used for large systems when only gross counting is needed because of its low cost, robustness, and relative sensitivity. PVT does provide some energy information about the incident photons, as has been demonstrated through the development of Energy Windowing analysis. There is a more sophisticated energy analysis algorithm developed by Symetrica, Inc., and they have demonstrated the application of their deconvolution algorithm to PVT with very promising results. The thrust of such a deconvolution algorithm used with PVT is to allow for identification and rejection of naturally occurring radioactive material, reducing alarm rates, rather than the complete identification of all radionuclides, which is the goal of spectroscopic portal monitors. Under this condition, there could be a significant increase in sensitivity to threat materials. The advantage of this approach is an enhancement to the low cost, robust detection capability of PVT-based radiation portal monitor systems.

The success of this method could provide an inexpensive upgrade path for a large number of deployed PVT-based systems to provide significantly improved capability at a much lower cost than deployment of NaI(Tl)-based systems of comparable sensitivity.

Acronyms and Abbreviations

ANSI	American National Standards Institute
CZT	Cadmium-zinc-telluride
EW	Energy Windowing
HPRDS	Human Portable Radiation Detection Systems
PNNL	Pacific Northwest National Laboratory
PVT	polyvinyl toluene
RPM	Radiation Portal Monitor
RSP	Radiation Sensor Panel
SAIC	Science Applications International Corporation
SNM	special nuclear material

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1 Purpose

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. Currently, border security screening uses PVT-based RPM systems in primary screening, and performs identification in secondary using handheld devices.

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), which 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 development of SPM systems in some applications. Large systems based upon NaI(Tl) detectors are much more costly to procure and maintain than those based on PVT, so if the energy resolving 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, thus reducing the operational burden.

The interaction of gamma rays in PVT is through the Compton scattering process, and results in a broad energy distribution. A spectrum in this form does not provide enough information for a simple analysis of what source produced the spectrum. Energy windowing (EW) analysis, which is currently performed by deployed RPM systems, divides the PVT energy spectrum into wide energy regions and looks at relationships between these energy regions [Ely and Kouzes 2003]. These resulting EW statistics provide information about whether a source is dominantly high energy or low energy gamma rays, thus giving some categorization to the source type. This has raised the question about whether a more sophisticated analysis could be performed, and several approaches have been tried without significantly better results [e.g., Keller et al. 2007]. A mathematically based deconvolution algorithm has recently been applied to PVT with promising results.

2 Approach

Symetrica is a small company based in Southampton, England, that has developed a deconvolution 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), bismuth germanate (BGO), and LaBr spectra results in deconvoluted spectra with the resolution improved through the calculation by about a factor of three to four compared to the original raw spectra. The resulting enhanced spectra contain only full-energy peaks where all counts are "reassigned" to a spectral line, and library-based line identification methods can be used for radionuclide identification, just as it is for high purity germanium (HPGe) detectors. This algorithm is the basis for the operation of the handheld Human Portable Radiation Detection Systems (HPRDS) device sold by Smith Detection Systems, which uses the Symetrica algorithm.

This deconvolution method has also been applied to PVT, with the result that full energy peaks are generated , as seen in Figure 1 [Ramsden and Dallimore 2008]. Figure 1 shows the raw spectrum from PVT produced with a ^{60}Co source (red line), which is the normal, broad Compton distribution, and is difficult to interpret directly by a trained spectroscopist.

Deconvolution is an algorithmic approach to reverse the effects that a detector has on the original source spectrum. In simplistic terms, the observed energy spectrum is the convolution of the original source energy spectrum and a response function for a specific detector system. This can be thought of as the product of two matrices. The deconvolution method is a mathematical transform that inverts the detector response function and multiplies this times the observed spectrum, resulting in the original source spectrum. The result of this inversion for the observed Compton spectrum is shown by the blue line in Figure 1. This deconvoluted spectrum shows the two characteristic lines of ^{60}Co at 1173 keV and 1332 keV, which can readily be identified by standard spectral analysis. This deconvoluted spectrum from PVT has a resolution similar to that normally produced by a NaI(Tl) detector.

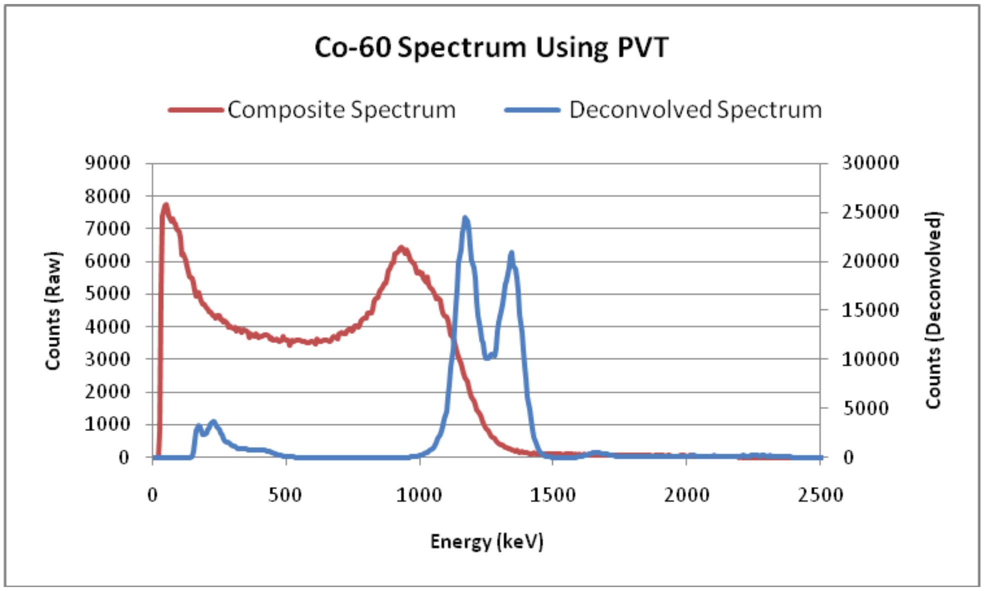
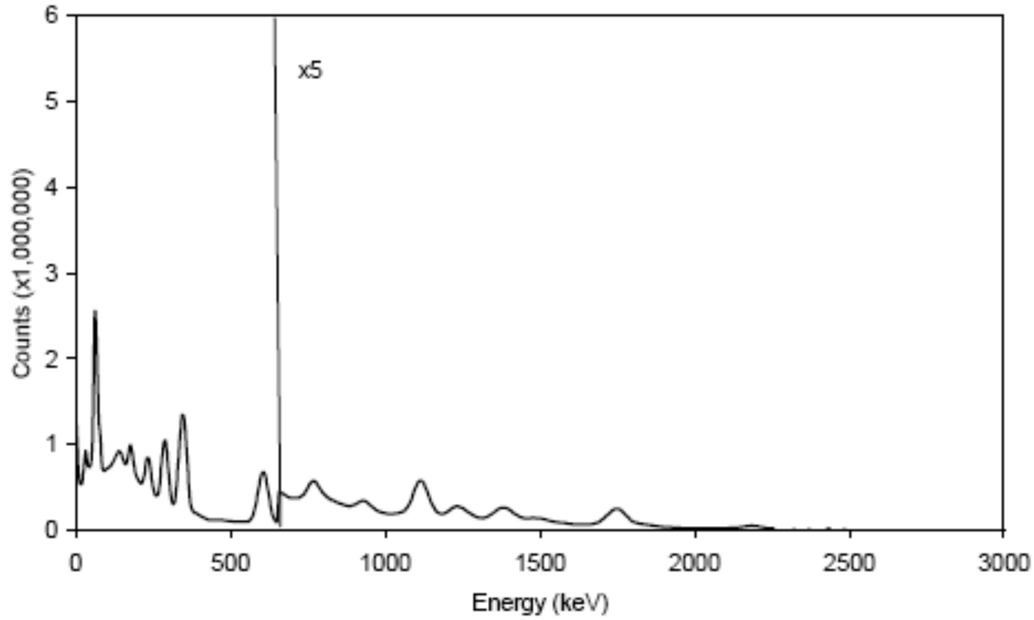


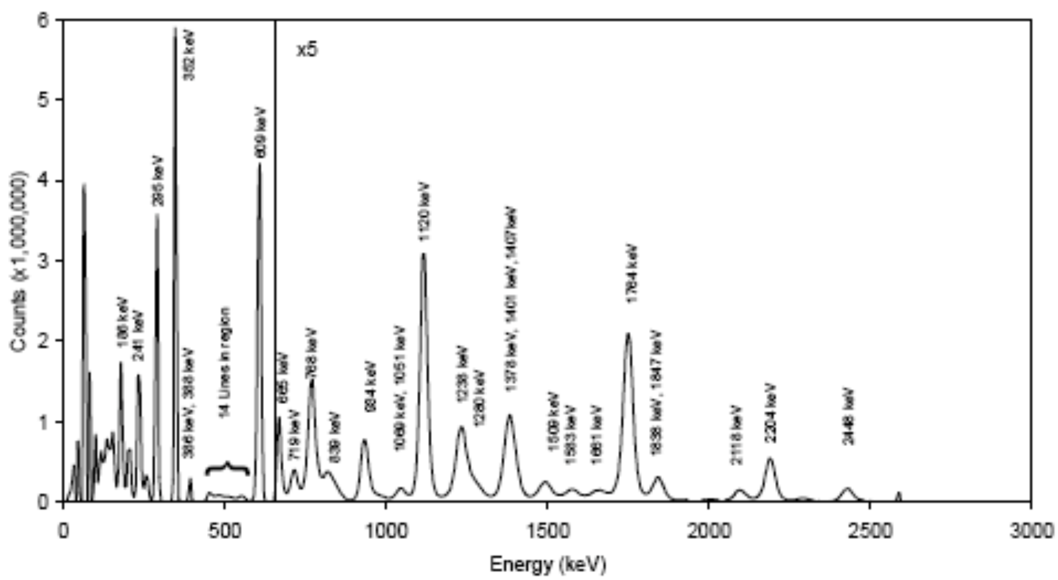
Figure 1. Example of PVT Spectrum of ^{60}Co and Deconvoluted Spectrum [Ramsden and Dallimore 2008]

Figure 2 shows an example of the deconvolution algorithm applied to a NaI(Tl) spectrum. The upper plot shows the original energy spectrum, and the lower plot shows the deconvoluted spectrum. It is much easier to identify the source of the lines shown in the deconvoluted spectrum.

If this deconvolution method is validated for use with PVT, and shown to be operationally viable, it could lead to an improved PVT-based RPM system.



a)



b)

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

3 Tests of Deconvolution Using a NaI(Tl) Detector

In order to test Symetrica's deconvolution algorithm, a large NaI(Tl) detector was used at Pacific Northwest National Laboratory (PNNL) for measurements on November 3-5, 2008. The detector was a 4"x4"x16" NaI(Tl) detector belonging to PNNL, and the software was not optimized for that specific detector during the testing. Various industrial sources, special nuclear material (SNM), and NORM were measured. Symetrica's analysis generally provided both 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. Symetrica's aim of the testing was to acquire data from SNM sources. PNNL's aim for the testing was to observe the performance of Symetrica's algorithm for SNM, industrial sources and NORM.

Computer simulations using the Monte Carlo code GEANT are used to produce the response functions for each specific detector. 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 and the counts in the Compton peaks are shifted into the lines. 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 1 shows a summary of the SNM identified during the measurements using Symetrica's analysis technique. The table shows various shielding configurations of steel, lead and copper shielding for attenuation of the lines at 186 keV for HEU and at 414 keV for Pu, with the corresponding success rate for identification of the nuclide. The "Identified as Recorded" column shows the number of successful identifications made during the measurements, while the "Identified in Reanalysis" column shows the results after the software was later optimized for the detector used.

Table 1. Summary of Shielded-Source Identification From Symetrica

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

The detector demonstrated good identification performance with weapons grade plutonium (WGPu) and reactor grade plutonium (RGPu), 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 2 gives a summary of the industrial, NORM and SNM source identifications from the Symetrica system. The table shows the isotopes identified at greater than an 80% confidence as well as additional isotopes identified, if any. The analysis shows good performance.

Table 2. Summary of Source Identifications From Symetrica

Source	Source Isotopes at >= 80% identification level	Other Isotopes at >= 80% identification level
Cs-137	Cs137	
Co-57	(Co57 19/30)	
Co-60	Co60	
Ba-133	Ba133	
Zircon Sand	Ra226	
Ice Melt	K40	
Kitty Litter	(K40 5/10, Th232 5/10)	
Tiles	K40	
Fertilizer	K40	
Granite	K40	
Lanthanum Carbonate	La138	
WGPu	Pu239	
WGPu (shielded)	(Pu239 32/45)	(I123 29/45)
RGPu	Am241 Pu241 Pu239	Sm153
RGPu (shielded)	Pu241 Am241 Pu239	Cs137
HEU	U235	
DU	U238	
Yellowcake	U238	
Heisenberg Cube	U238	

4 Recommendation

We recommend that tests be performed with a PVT-based detector system for measurements of SNM and other sources, applying Symetrica's deconvolution algorithm to determine the capabilities and limitations of this approach. If this method is successful, it could provide an inexpensive upgrade path for a large number of deployed PVT-based systems to provide improved capability at a much lower cost than deployment of NaI(Tl)-based systems of comparable sensitivity.

The success of this effort could result in an option to use PVT for radionuclide identification with very large, inexpensive and robust detectors. There are currently over 1400 deployed RPM systems used for non-proliferation detection using PVT, and the possibility to upgrade these systems inexpensively to have improved performance would be of very high value.

The technical research issues that remain to be explored with PVT include:

1. Verification of the deconvolution algorithm's capability for identification of SNM,
2. Verification of the deconvolution algorithm's capability for identification of multiple sources, including masking scenarios,
3. Direct comparison to other PVT algorithms to quantify any increase in performance,
4. Verification with MCNP model predictions for spectra of shielded sources,
5. Feasibility for implementation of a system that can be fielded.

We recommend further research on this approach.

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