LAWRENCE LIVERMORE NATIONAL LABORATORY

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Detection, Classification and Estimation of Radioactive Contraband from Uncertain Low-Count Measurements

J. V. Candy

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Auspices Statement

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FY09 LDRD Final Report

Detection, Classification and Estimation of Radioactive Contraband from Uncertain Low-Count Measurements

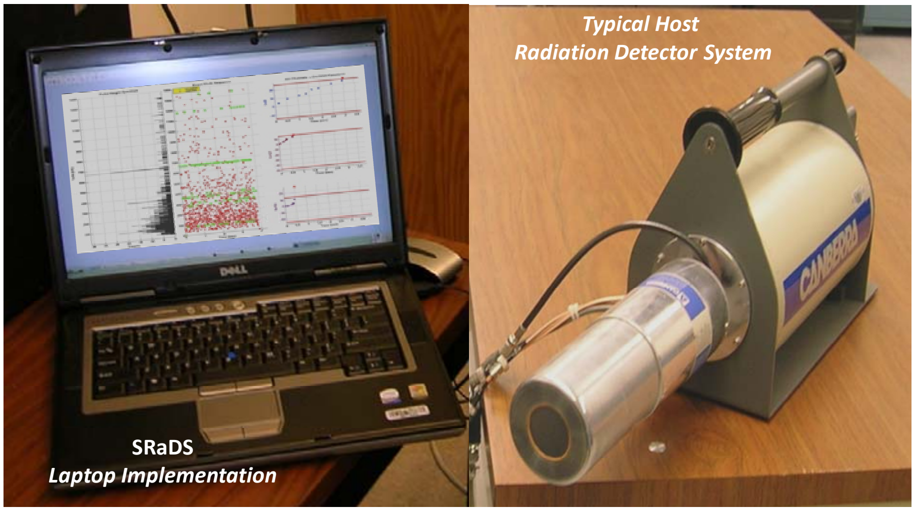
LDRD Project Tracking Code: 07-ERD-019

James Candy, Principal Investigator

Abstract

In this final report we discuss the development of the Statistical Radiation Detection System (**SRaDS**), the next-generation radiation detection software system capable of extracting all available physics information, photon-by-photon, employing Bayesian model-based sequential statistical processing techniques and capable of making a decision when statistically justified. It is a system of computational algorithms consisting of a simple photoelectron processor for the *basic* system with a combined photoelectron/downscatter processor for the *advanced* system. Both algorithms have been demonstrated on laboratory data and are available for integration into standard radiation detectors and acquisition systems as well as specialized embedded processing hardware for real-time operations.

This report incorporates the basic research performed leading to the development of SRaDS in the form of attached publications discussing the theory, development and validation of the processor and subsequent designs for this powerful solution to the detection problem plaguing the radiation area for a long time.



Introduction / Background

Radionuclide detection is a critical first line defense employed by Customs and Border Protection (CBP) to detect the transportation of radiological materials by potential terrorists. Detection of these materials is particularly difficult due to the inherent low-count emissions produced. These low-count emissions result when sources are shielded to hide or disguise their existence or, when being transported, are in relative motion with respect to the sensors. Radionuclide identification from low-count gamma ray emissions is a critical capability that is very difficult to achieve, moreover, this methodology must cope with background noise, finite detector resolution, and the heterogeneous media along transport paths between the sources and detectors. Detection/identification, therefore, becomes a question of increasing signal-to-noise ratio (SNR) since low-count emissions become "buried" in the background and Compton scattering noise, rendering a meaningful and timely detection highly improbable.

Detection of threat radiological materials is a difficult problem primarily because of low observable count rates and short detection intervals available. For instance, semi-trailer vehicles move through portal systems allowing less than 10 seconds for the initial screening. Shielding materials from packaging and adjacent cargo present major difficulties in these low-count, hostile environments. Low-count detection is a challenging problem made difficult because of background noise, measurement system inadequacies, and the heterogeneous transport paths between source and detector. Even the modern methods of gamma-ray spectrometry incorporating high resolution detectors are challenged by the low-count problem. These traditional spectrum analysis systems only take the distribution of *energies* into account and discard the important arrival time information. Thus, the basic problem we solve with **SRaDS** is the detection and identification of radioactive contraband from low-count measurements using all of the statistical information available.

The identification of radionuclide sources from their gamma ray emission signatures is a well-established discipline using spectroscopic techniques and algorithms. Numerous tools exist to aid the analyst interpreting these signatures. Historically, sufficient time existed to accumulate the data necessary to reasonably identify these sources. Furthermore, highly accurate detectors exist that yield an accurate spectrum. Unfortunately, these techniques fail on low-count measurement data. Contemporary tools reveal that the underlying algorithms rely upon heuristic approaches based upon the experience of analysts. Most of these tools may even require the intervention of a trained practitioner to analyze the results and guide the interpretation process. In a terrorist type scenario, this is not acceptable, since timely and accurate performance is imperative.

Currently gamma-ray spectrometry is used to identify radionuclides by estimating the energy distribution or spectrum. It decomposes the gamma-ray emissions into energy bins *discarding* the temporal information. The role of the gamma-ray spectrum is analogous to the role of the Fourier spectrum for identifying sinusoidal spectral lines in noise. A particular radionuclide can be characterized by its "energy spectral lines" in the energy spectrum. These sharp lines are used to identify the corresponding energy bin, thus "detecting" the presence of a particular component of the radionuclide. In the ideal case, the spectrum consists only of lines or spikes located at the correct bins of each constituent energy uniquely characterizing the radionuclide. A search of the spectrum for the strong presence of these lines is used for identification. A typical laboratory spectrum is shown in Fig. 1 below where the event mode sequence (EMS) or set of energy vs time measurments is shown in 1a, and the corresponding PHS is shown in Fig. 1b illustrating photo-peaks, downscattering, background and noise.

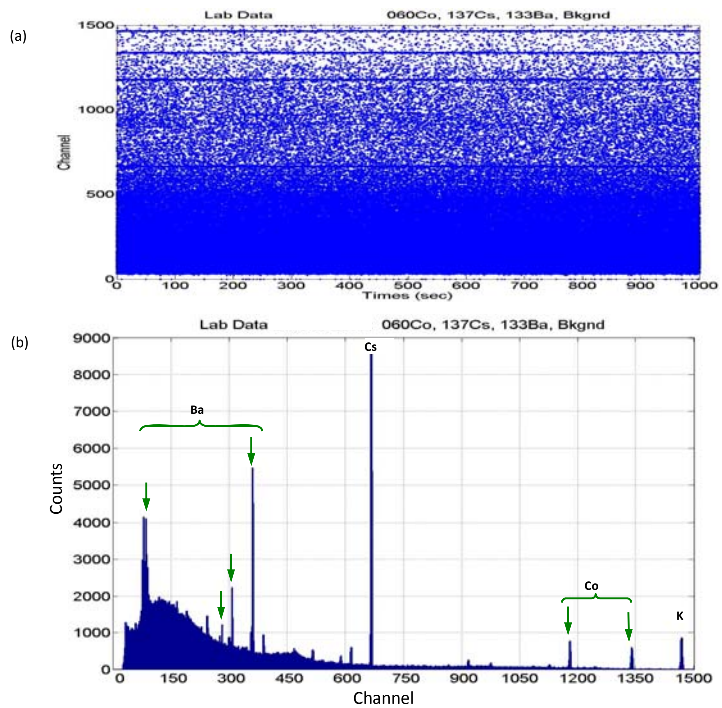


Figure 1. *Laboratory Data. (a) Measured event mode sequence (EMS) of arrivals. (b) Energy histogram or pulse height spectrum (PHS).*

Research Activities

SRaDS is a completely no vel software system capable of r apidly and confidently identif ying *any* set of pre-specified r adionuclides (RN) in a wide r ange of scenarios such as portal systems, first respon der activities, verification activities, harbor and c argo inspections a nd more. It represents the *next generation* of radiation detection software systems based on the no vel approach of B ayesian sequential photon processing. **SRaDS** satisfies the critical need to dev elop a fast and reliable automated technique to de tect and identi fy radioactive materials from uncertain radionuclid e measurements especially when measurement time is short and the demand for confidence is high.

SRaDS utilizes the statistical nature of radiation transport as well as modern processing techniques to implement a physics-based, *Bayesian sequential statistical processor*. Instead of accumulating a pulse-height spectrum (PHS) as is done in current systems, each photon is processed individually upon arrival and then discarded. Upon arrival at the detector, a decision is updated and refined using the energy deposited as well as the photon arrival time. Detection is declared when such a decision is *statistically justified* using estimated detection and false alarm probabilities specified by a receiver operating characteristic (ROC) curve obtained during calibration. This implementation results in a system that has significantly improved detection performance with higher reliability and shorter decision time.

SRaDS reliably detects and identifies radioactive materials in a variety of environments and scenarios from uncertain low-count radiation measurement data. It represents the future of radiation detection systems by incorporating transport physics and sequential detection methods that are empowered by newly evolved Bayesian signal processing algorithms. Because of its novel approach, **SRaDS** is capable of making a more rapid decision (timely) with higher confidence (reliability) than traditional radiation detection systems and possesses an inherent ability to quantify its performance (detectability). **SRaDS** provides a faster, more reliable way to detect radioactive contraband in a variety of critical screening applications.

SRaDS consists of algorithms capable of being integrated into existing radiation detector systems while also enabling high-speed embedded processing hardware implementations. It possesses an inherent parallel and distributed structure providing a fast and robust methodology capable of performing in even the harshest environments. **SRaDS** has been developed using modern Bayesian statistical signal processing techniques popularly known as "particle filters" which are enabled by the evolution of high-speed, high throughput microcomputers or embedded hardware (FPGAs). Building on these techniques, radiation transport physics are incorporated to provide outstanding reliability and detectability while minimizing false positives.

Results / Technical Outcome

The key issue that **SRadS** adresses is developing reliable statistical models of both emission and measurement processes that can effectively be used in the Bayesian framework. These stochastic models of the physical process must incorporate the loss of information resulting from the absorption of energy between an ideal source and the detector. The underlying probability distributions describe the physics of the radiation transport between the source and the detector. Our approach differs from spectroscopy in that it models the source radionuclides by decomposing them uniquely as a mixture of monoenergetic sources that are then smeared, scattered and distorted as they are transported to the detector for measurement and counting. The measured data consists of a set of energy vs time measurements in the form of an EMS and is obtained from pulse shaping circuitry available in all commercial radiation detectors. While traditional spectroscopy ignores both the temporal information as well as any energy not found in the main peaks of the spectrum, **SRaDS** uses all of the information available in each and every photon arrival.

SRaDS utilizes the statistical nature of radiation transport as well as modern Bayesian signal processing techniques to implement the processor. **SRaDS** is an automated technique that "decides" when a particular target radionuclide is present or not based on parameters that evolve from the physics information contained in the EMS. The inherent structure of the BASIC and ADVANCED processor is shown in Fig. 2. After the single photon is pre-processed by the acquisition system, the energy and arrival time measurements are passed to the energy/rate discriminators to determine if the photon will be accepted or rejected. If acceptable, the parameters used by the system are updated and provided as input to improve the decision function for detection and eventual identification. If rejected, the photon is discarded in contrast to PHS systems. The advanced system incorporates the Compton (downscatter) processor (shown in dashed lines).

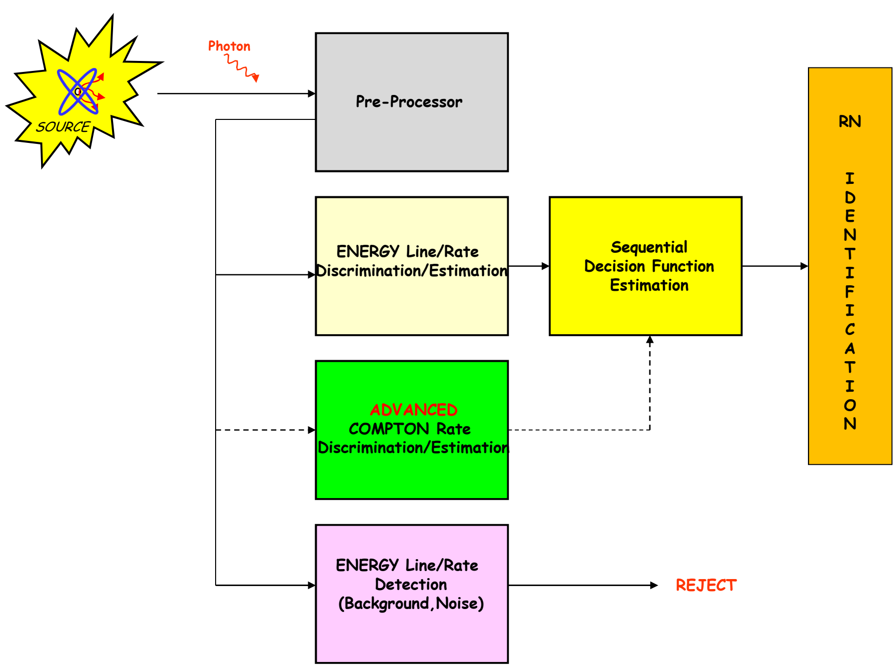


Figure 2. **SRaDS** BASIC and ADVANCED *Bayesian radiation detection structure: Acquisition, pre-processing (optional), energy/rate discrimination, estimation, Compton processing (ADVANCED), background and extraneous line rejection, decision function estimation and RN identification.*

SRaDS processes each unique component of a target radionuclide in a separate channel resulting in its inherent parallel/distributed processor structure shown in Fig. 3. After the photon is acquired, the distributed processor: (1) *discriminates* the photon energy, identifying one of the parallel channels; (2) *discriminates* the corresponding detection rate (interarrival) parameter for that particular channel; (3) *enhances* the channel energy and interarrival parameters; (4) *updates* the corresponding decision function; and (5) *detects/identifies* the target radionuclide by thresholding the decision function . From the figure we observe the basic processor illustrated in the upper diagram. Investigating further we see the **SRaDS** processor consists of a discriminator for both energy and interarrival time in the middle diagram. If the photon is accepted, it is processed further to improve the estimates of energy, rate and other parameters used to update the decision function. Finally at the more detailed structural level, the lower diagram illustrates the parallel/distributed internal structure utilized in performing each of these steps for each energy component of each targeted RN. Clearly, **SRaDS** is a distributed sequential processor performing its operations using multiple *identical* channels, each with a *unique set* of parameters suited to that particular component.

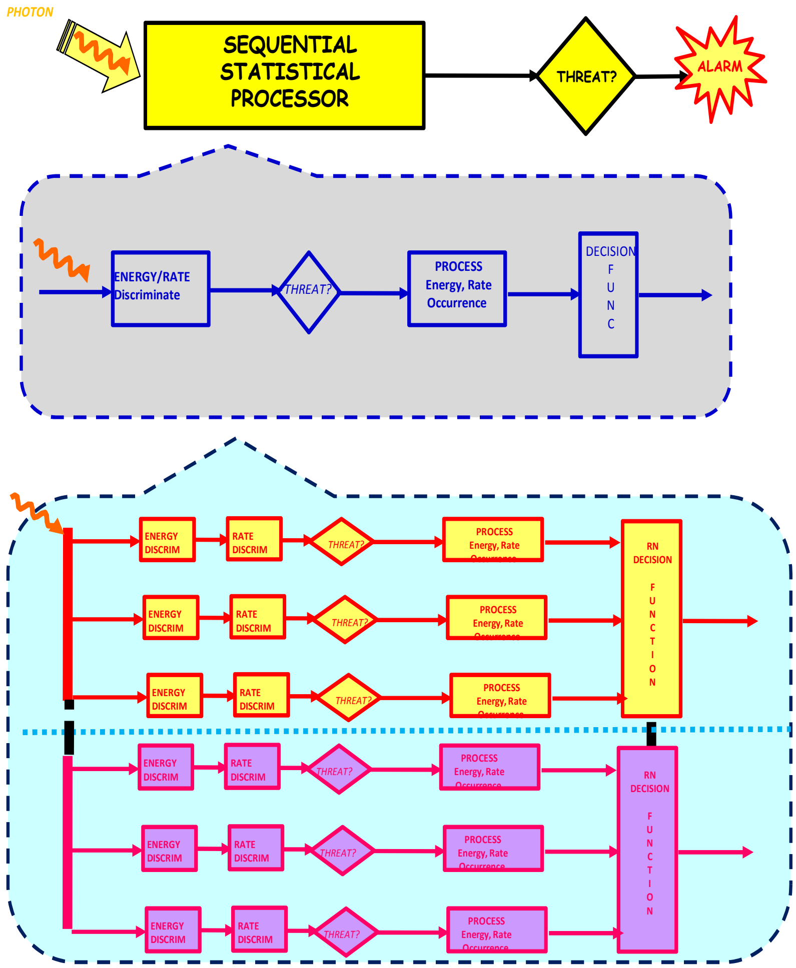


Figure 3. SRaDS *processor parallel/distributed structure: (a) Simple processing (upper). (b) Detailed discriminator, parameter estimation and decision function calculation (middle). (c) Multiple channels for multiple lines/multiple radionuclides (lower).*

Conceptually, we depict the generic sequential detection technique in Fig. 4 illustrating each photon arrival along with the corresponding decision function and thresholds. At each arrival the decision function is *sequentially updated* and compared to thresholds to perform the detection --- "photon-by-photon". The thresholds are selected from a ROC curve and are based on user-selected detection and false alarm probabilities. In this way, **SRaDS**' performance can be tailored to a wide variety of field scenarios depending on the needs of the user. If the need for minimizing false positives is a priority, then that configuration parameter can be set accordingly. Alternately, if the detection probability must be high and there is less regard for the cost of false alarms, the system can be configured for those needs.

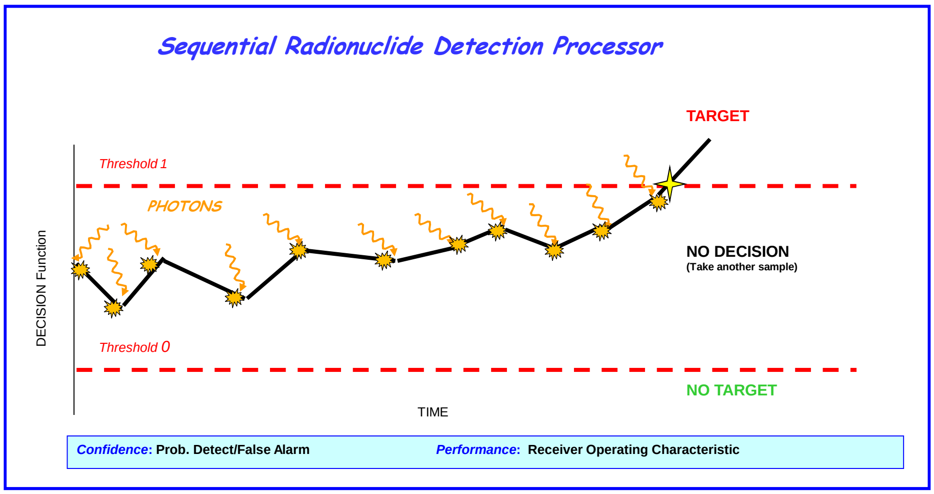


Figure 4. *Conceptual implementation of the sequential Bayesian radionuclide detection technique. As each individual photon is extracted, it is discriminated, estimated, the decision function updated and compared to the thresholds to "decide" if the targeted radionuclide is present or not. Quantitative performance and sequential thresholds are determined from the estimated receiver operating characteristic (ROC) curve and the selected operating point (detection/false alarm probability).*

The practical implementation is accomplished in various stages: (1) photon *discrimination*; (2) monoenergetic parameter *estimation*; (3) decision function calculation and (4) threshold comparison for *detection* as illustrated in Fig. 5. We observe the basic structure in (a) with more details in Fig. 5 b. Operations are performed in the three phases: discrimination, estimation and detection with confidence interval estimators performing the simple channel discrimination tasks, sophisticated parameter algorithms (nonlinear Kalman and particle filters) performing the estimation, updating the sequential decision function and performing the threshold detection---"photon-by-photon." These task details are illustrated in Fig. 6 for the single (identical) channel implementation.

Discrimination is performed with the "true" parameters obtained from the tables of radionuclides (energy, emission probability and rate (interarrival)) and from a radiation transport model in the advanced implementation. From this information we construct the confidence intervals to decide if the photon arrival is valid for one of the targeted radionuclide components. If so, we then perform the parameter estimation using a linear Kalman filter for energy (Gaussian model) and particle filter for rate/interarrival (exponential model). The emission probability is calculated by sequentially updating valid counts in the channel. With the parameter estimates available, the decision function is sequentially updated and compared to the thresholds (see Fig. 4). Finally, in order to calculate the required thresholds for detection we must generate a ROC curve from simulation or high fidelity calibration data and select an operating point specified by the desired detection and false alarm probabilities. The individual channel processor is shown in Fig. 6 illustrating the discrimination, estimation and decision function update steps, while the detailed algorithm implementation architecture is shown in Fig. 7.

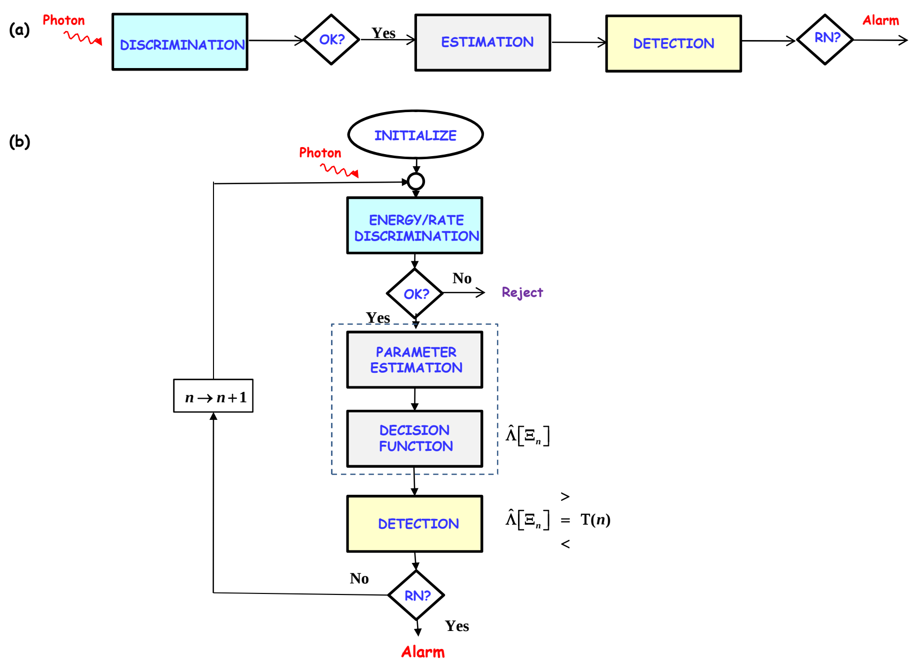


Figure 5. SRaDS *implementation of radionuclide detection showing discrimination, estimation, and detection phases: (a) Simplified flow of basic algorithm. (b) Detailed flow diagram illustrating major calculations.*

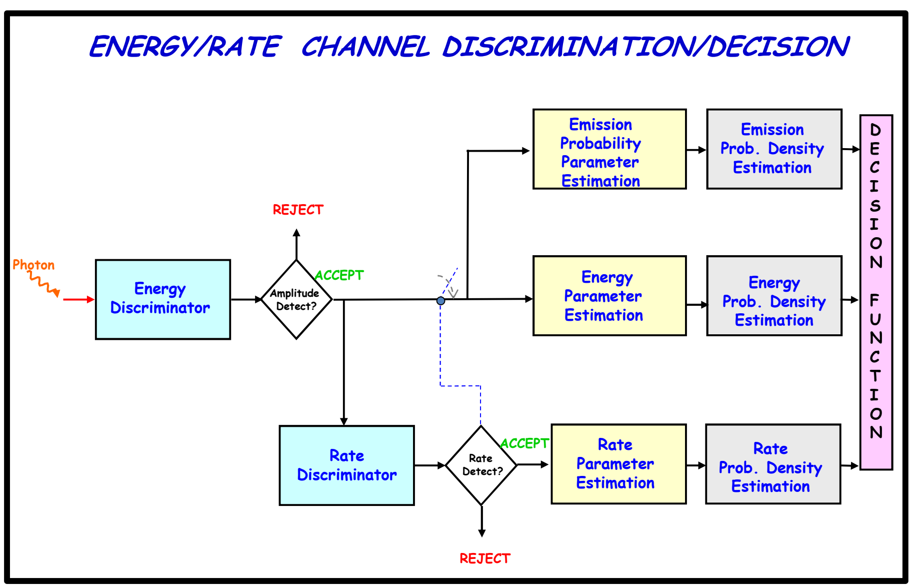


Figure 6. SRaDS *Bayesian photon channel processing for radionuclide detection/identification including: energy/interarrival (detection rate) discrimination, energy/rate parameter estimation, emission/occurrence probability estimation and decision function calculation.*

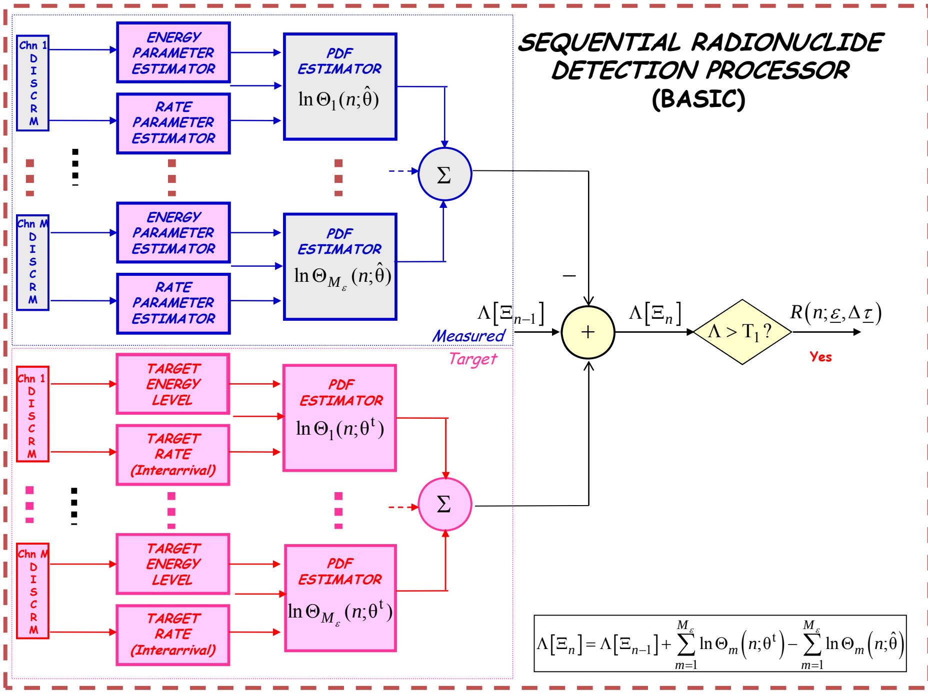


Figure 7. SRaDS BASIC *detailed implementation structure of the overall sequential Bayesian radionuclide detection processor showing the discriminated channel inputs (energy/arrival time), energy/rate parameter estimates, probability distribution and decision function (log-likelihood) estimates with threshold detection.*

The **SRaDS** sequential detection paradigm wa s applied to the laboratory data set illustrated in Fig. 1. Based on the experimental SNR, the selected operating po int (detection and false-alarm probabilities) was (98%, 2%) specif ying the threshol ds which were calculated accordingly for each ra dionuclide. The system undergoes a calibration phase which consists of "tuning" the processor s on simulated and controlled data, setting initial parameters, etc. The overall results of the processing are shown in Fig. 8. We note three columns of data, the first column is the composite pulse-height spectrum which we show for compar ison only. The second column is the composite EMS wi th the gr een circles representing the *discriminator* output photons. Notice that the photons are chose n by the discriminator based on *both* energy and interarrival and aligns with the PHS energy lines. The final column is the decision function for each of the targeted radionuclides with corresponding thresholds determined from the ROC curves.[1]

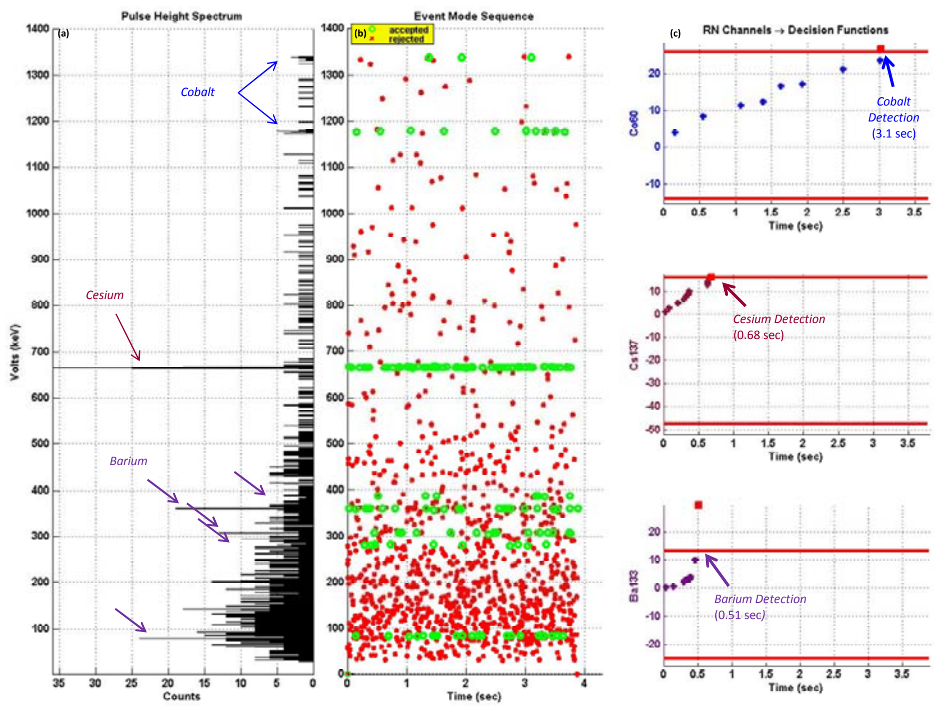


Figure 8. SRaDS BASIC *sequential Bayesian detection and identification. (a) Pulse-height spectrum (after calibration). (b) EMS with discrimination (circles). (c) Decision functions for* ^{60}*Co (detection time: 3.05 sec),* ^{137}*Cs (detection time: 0.678 sec) and* ^{133}*Ba (detection time: 0.513 sec) radionuclide detection/identification (see SRaDS_BASIC video).*

As each photon is process ed, the decision function is updated until either the upper or lower thre shold is exceeded i ndicating the presence or absence of the target radionuclide. Note that barium is detected (threshold exceeded) first (0.513 sec) followed by the cesium (0.678 sec) and then cobalt (3. 05 sec). The corresp onding pulse-height spectra *at the time of detection*, that is, when the decisi on

[1] A video illustrating the sequential processing operations (Fig. 8) is available on the enclosed CD as an audio-visual (SRaDS_BASIC.avi) or windows media video (SRaDS_BASIC.wmv) file.

threshold is crossed, is shown in Fig. 9. This figure illustrates not only the total counts in each energy spectral line, but also the number of photons that were passed by both discriminators and used to update the decision function. Clearly, cobalt has the lowest count rate and the sequential processor must wait for enough photons to arrive in order to make the statistically justified decision (less than 10 counts/lines), while the barium detection is faster because of its higher count rates.

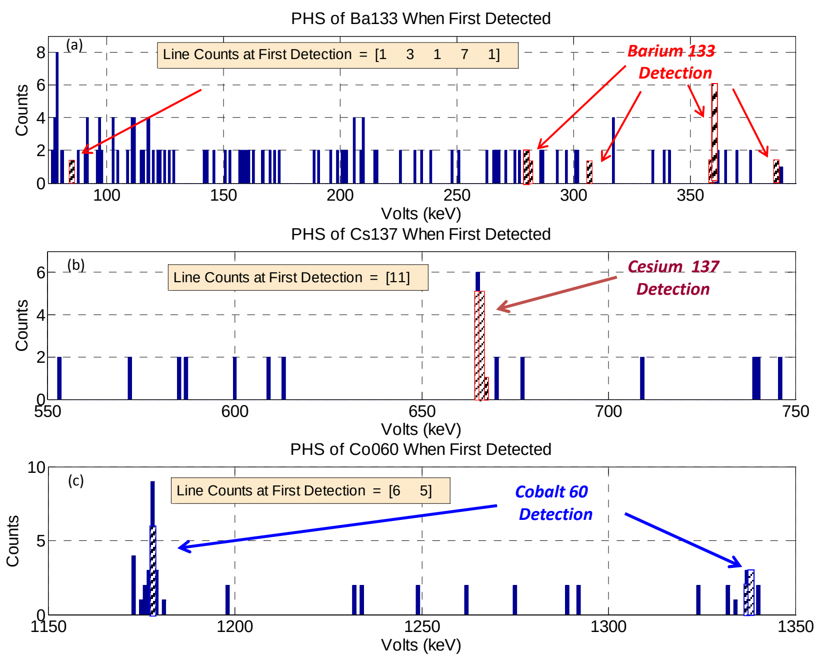


Figure 9. *Pulse-height spectra of targeted radionuclides at sequential Bayesian detection. (a) ^{60}Co pulse-height spectrum (at detection time: 3.05 sec). (b) ^{137}Cs pulse-height spectrum (at detection time: 0.678 sec). (c) ^{133}Ba pulse-height spectrum (at detection time: 0.513 sec). Line counts refer to enhanced (after estimation) photon lines used in decision function and arrows annotate their location.*

The performance of **SRadS** is evaluated using the ROC curves developed from our laboratory data. Rather than attempt to incorporate dependencies on geometry, source emissions etc., we choose to normalize the curves based on the total number of source photons passed by the discriminators and used to update the decision function. In this way the source size (mass), photon emission rate, distance to detector, geometry, etc. can be captured simply by the number of discriminated source photons for a given RN eliminating specifics. We show ROC curves for our ^{133}Ba source in Fig. 10. Here we see **SRadS** performance ranging from 5 total barium photons (including background etc.) to 50 barium photons. As expected as the number of photons increase, the processor performance improves significantly yielding higher detection probabilities and lower false alarm rates. We use these ROC curves to calculate the required upper and lower thresholds for **SRadS**, thereby, quantifying its expected performance.

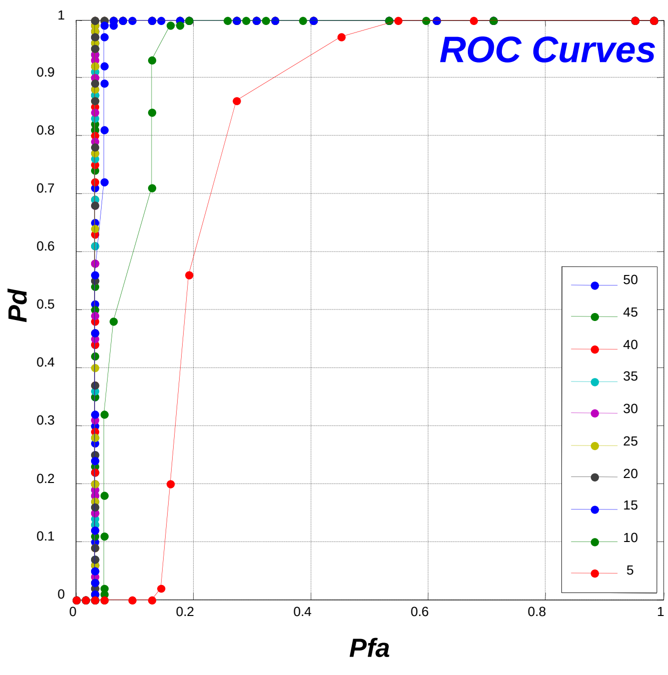


Figure 10. SRaDS *ROC curves parameterized by the total number of* ^{133}*Ba photon counts (5-50 counts) based on an ensemble of 100 measured EMS data.*

The ADVANCED **SRaDS** software system processes not only the photoelectrons of the BASIC version, but also the downscatter (Compton) photons providing a major breakthrough in detection technology! Thus, the **SRaDS** ADVANCED software system incorporates the Compton downscatter in its decision function (see attached 2010 paper). Its details are more complex than the BASIC version, but it is simply captured in Fig. 2 (dashed lines). The results of incorporating the Compton rate discriminator/estimator processing into **SRaDS** is shown in Fig. 10 (similar to Fig. 8). The three column format remains the same: PHS, EMS data with photoelectrons (circles) and now downscatter photons (squares) and the thresholded decision functions for the RNs (cobalt, cesium, barium). Because of this new information, the decision functions are able to incorporate "more physics" enabling the RN detection/identification to cross the thresholds even faster, that is, cobalt (2.2 sec), cesium (0.47 sec) and barium (0.14 sec) as shown in Fig. 11 indicating a 33% improvement (or better) in time-to-detection. Thus, we see that SRaDS truly is a novel innovation that will set the standard (and framework) for the next generation of radiation detection software systems.

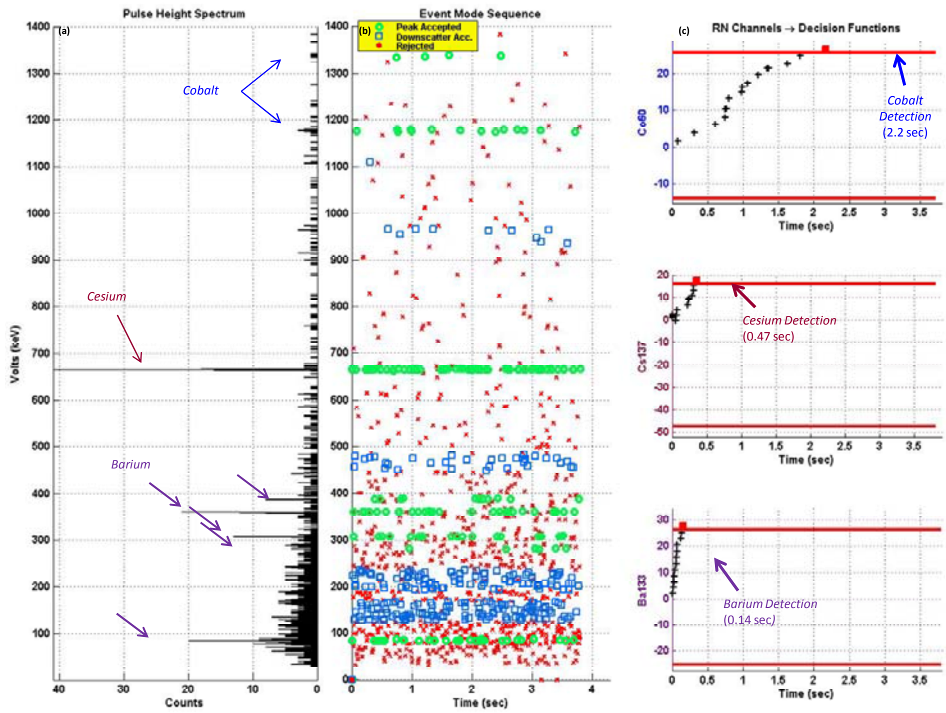


Figure 11. SRaDS ADVANCED *sequential Bayesian detection and identification. (a) Pulse-height spectrum (after calibration). (b) EMS with discrimination (circles). (c) Decision functions for* ^{60}*Co (detection time: 2.2 sec),* ^{137}*Cs (detection time: 0.47 sec) and* ^{133}*Ba (detection time: 0.14 sec) radionuclide detection/identification (see SRaDS_ADVANCED video).*

As our fi nal tests, we performed some figur e-of-merit (FOM) runs to benchmark the performance of both the BASIC and ADVANCED processors and also comp ared their performance to the GAMANL radiation detection (standard) software. We s ummarize this comparison simply that based on an ensemble of 100 la boratory data files (Barium radio nuclide) that the SRaDS B ayesian processor was able to a chieve a detection probability of 98%, while the G AMANAL processor could only achieve a 45 % probability of detection. We showed the ROC curves for SRaDS in Figure 10 where we chose our thresholds to achieve a 98% detect ion probability at a 2% false alarm rate.

Exit Plan

The plan for this exciting technolo gy is to develop the algorithms further in conjunction with a variet y of instrumentation manufacturers either through Work-For-Others co ntracts or CRADA agr eements. We have submitted an R&D 100 applicati on and expect to get exposure of our research through that mech anism as through the sci entific publications referenced subsequently. We have also applied to the DOE NA-22 organization for developmental funding. Currently we are team with the company ICx in response to a DNDO BAA and expe ct to expand the efforts to sodium-iodid e and other lower resolution but huge application volume detectors. Of course, our main tar get is licensing and royalties in a n effort to get the technology to the commercial sector

Summary

This project has progressed nicely fr om a high-risk, high payoff novel conceptual approach to an actual su ite of software algorithms ca pable of meeting all of t he initial expect ations of t he Bayesian approach. Besides being extremely exciting for the researche rs, it clearly demonstrates the teaming abil ity of mul ti-disciplinary projects resulting in a success and major cont ribution to radiat ion detection. Having access to the “old sa lts” (LLNL consultants—see acknowledgements) to ke ep us on track and contribute viable discussion and counterpoints to our arguments, led us to the final prototype design whic h will even tually be constructed thr ough potential CRADS or WFO projects to follow (see EXIT Plan).

We have published the following papers during the course of this research of this project as well as given a multitude of presentations on this project. We have also had two (2) provisional patents (ROIs: IL-11906, IL-12229) and one (1) filing to the US Patent Office (Oct, 2008). We highlight the most important below. [2] We have also submitted this as a brochure to the R&D100 review committee (Statistical Radiation Detection System **(SRaDS)**, LLNL-BR-425377, 2010).

References

- ***Threat Detection of Radioactive Contraband Incorporating Compton Scattering Physics: A Model-Based Processing Approach***

J. V. Candy, Fellow, IEEE, D. H. Chambers, Senior Member, IEEE, E. F. Breitfeller, Member, IEEE, B. L. Guidry, Member, IEEE, J. M. Verbeke, M. A. Axelrod, K. Sale and A. M. Meyer Senior Member, IEEE

Abstract—The detection of radioactive contraband is a critical problem is maintaining national security for any country. Photon emissions from threat materials challenge both detection and measurement technologies especially when concealed by various types of shielding complicating the transport physics significantly. The development of a model-based Bayesian sequential processor that captures both the underlying transport physics of gamma-ray emissions including Compton scattering and the measurement of photon energies offers a physics-based approach to attack this challenging problem. The inclusion of a basic radionuclide representation of absorbed/scattered photons at a given energy along with interarrival times is used to extract the physics information available from the noisy measurements. It is shown that this representation leads to an "extended" physics based structure that can be used to develop an effective sequential detection technique. The resulting model-based processor is shown to outperform a photoelectric (absorption) only detector based on data obtained from a controlled experiment.

Under review IEEE TRANSACTIONS ON NUCLEAR SCIENCE (LLNL-JRN-422429), 2010

- ***Model-Based Detection of Radioactive Contraband for Harbor Defense Incorporating Compton Scattering Physics***

[2] For those still in doubt, we attach the reference along with 2 videos (computer outputs) to observe the processor performance both in the BASIC and ADVANCED modes (see R&D100 reference for details).

J. V. Candy, Fellow, IEEE, D. H. Chambers, Senior Member, IEEE, E. F. Breitfeller, Member, IEEE, B. L. Guidry, Member, IEEE, J. M. Verbeke, M. A. Axelrod, K. E. Sale and A. M. Meyer Senior Member, IEEE

Abstract—The detection of radioactive contraband is a critical problem is maintaining national security for any coun try. Photon emissions from threat materials challenge both detection and measurement technologies especially when concealed by various types of shielding complicating the transport physics significantly. This problem becomes especially important when ships are intercepted by U.S. Coast Guard harbor patrols searching for contraband. The development of a se quential model-based processor that captures bo th the underlying transport physics of gamma-ray emissions including Co mpton scattering an d the measurement of photon energies offers a physics-based approach to attack this challenging problem. The inclusion of a basic radionuclide representation of absorbed/scattered photons at a given energy along with interarrival times is used to extract the physics information available from the noisy measurements portable radiation detection systems us ed to interdict contraband. It is shown that this physics representation can incorporated scattering physics leading to an "extended" model-based structure that can be used to develop an effective sequential detection technique. The resu lting model-based processor is shown to perform quite well based on data obtained from a controlled experiment.

IEEE Oceans '10 Conference, Sydney, Austria May, 2010 (LLNL-CONF-425060).

- ***Physics-Based Detection of Radioactive Contraband: A Sequential Bayesian Approach***

J. V. Candy, Fellow, IEEE, E. Breitfeller, Member, IEEE, B. L. Guidry, Member, IEEE, D. Manatt, K. Sale, D. H. Chambers, Senior Member, IEEE, M. A. Axelrod and A. M. Meyer, Senior Member, IEEE

Abstract—The timely and accurate detection of nucl ear contraband is an extremel y important problem of national sec urity. The development of a prototype sequentia l Bayesian processor that inco rporates the underlying physics of -ray emissions and the measurement of photon energies and their intera rrival times that offers a physics-based approach to attac k this ch allenging problem is desc ribed. A basic radionuclide representation in t erms of its -ray energies a long with photon interarrival times is used to ex tract the p hysics information available from the uncertain measurements. It i s shown that not only does thi s approach l ead to a physics-based structure that can be used to develop an effective threat detection technique, but also motivates the implementation of thi s approach using advanced sequential Monte Carlo processors or pa rticle filters to extract the requi red information. The resulting processor is appl ied to experimental data to demonstrate its feasibility.

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 56, NO. 6, DECEMBER 2009 pp. 3694-3711 (LLNL-JRNL-411357).

- ***Radioactive Contraband Detection: A Bayesian Approach***

J.V. Candy, *Fellow, IEEE*, E. Breitfeller, *Senior Member, IEEE*, B. Guidry, *Senior Member, IEEE*, D. Manatt, K. Sale, D. Chambers, *Senior Member, IEEE*, M. Axelrod and A. Meyer, *Senior Member, IEEE*

Abstract—Radionuclide emissions from nuclear contraband challenge both detection and measurement technologies to capture and record each event. The development of a sequential Bayesian processor incorporating both the physics of gamma ray emissions and the measurement of photon energies offers a physics-based approach to attack this challenging problem. It is shown that a "physics-based" structure can be used to develop an effective detection technique, but also motivates the implementation of this approach using particle filters to enhance and extract the required information. The resulting processor is applied to feasibility data obtained from a controlled proof-of-concept experiment.

IEEE Oceans '09 Conference, Biloxi, MS Oct., 2009 (LLNL-CONF-411355).

- ***Bayesian Processing for the Detection of Radioactive Contraband from Uncertain Measurements***

James V. Candy, Kenneth Sale, Brian L. Guidry, Eric Breitfeller, Douglas Manatt and David Chambers

Abstract—With the increase in terrorist activities throughout the world, the need to develop techniques capable of detecting radioactive contraband in a timely manner is a critical requirement. The development of Bayesian processors for the detection of contraband stems from the fact that the posterior distribution is clearly multimodal eliminating the usual Gaussian-based processors. The development of a sequential bootstrap processor for this problem is discussed and shown how it is capable of providing an enhanced signal for eventual detection.

CAMSAP Confr., St. Thomas, VI, Dec. 2007 (UCRL-JRNL-232317)

- ***A Bayesian Sequential Processor Approach to Spectroscopic Portal System Decisions***

K. Sale,_ J. Candy, E. Breitfeller, B. Guidry, D. Manatt, T. Gosnell and D. Chambers

ABSTRACT-The development of faster more reliable techniques to detect radioactive contraband in a portal type scenario is an extremely important problem especially in this era of constant terrorist threats. Towards this goal the development of a model-based, Bayesian sequential data processor for the detection problem is discussed. In the sequential processor each datum (detector energy deposit and pulse arrival time) is used to update the posterior probability distribution over the space of model parameters. The nature of the sequential processor approach is that detection is produced as soon as it is statistically justified by the data rather than waiting for a fixed counting interval before any analysis is performed. In this paper the Bayesian model-based approach, physics and signal processing models and decision functions are discussed along with the first results of our research.

SPIE Confr. Paper, San Diego, CA, Dec. 2007 (UCRL-CONF-4233728).

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