CZT/NaI Hybrid Hand-Held Performance Evaluation

W. Russ, D. Nakazawa, I. Hau, M. Morichi
Research and Development
Canberra Industries, an AREVA company
Meriden, Connecticut, USA
wruss@canberra.com

***Abstract*—New hybrid spectroscopic systems directly combine spectra from detectors with very different energy resolutions, accommodating standard analyses of the output hybrid spectrum. Hand-held hybrid systems consisting of a 0.5 cm^3 cadmium zinc telluride detector combined with either a 1 cm^3 NaI(Tl) scintillator mounted on a photomultiplier tube or a 1 cm^3 CsI(Tl) mounted on a silicon photomultiplier were evaluated for performance by source measurements for a variety of acquisition times. Repeated 300 second background measurements were analyzed and found a small increase in false alarm rate for the hybrid combinations compared to the individual component detectors. Repeated measurements with a 100 μR/h ^{137}Cs source and acquisition times of 5, 10, 30, 100, and 300 seconds were analyzed, with the results showing that hybridization significantly enhances peak detectability relative to the individual constituent detectors, especially at shorter times. At 5 and 10 seconds, the probability of detection was more than twice that of the individual components. The hybrid approach enables the consideration of a greater variety of measurement system solutions in terms of cost and performance.**

Keywords-hybrid; hand-held; CZT; NaI;CsI; SiPM; system

I. INTRODUCTION

Cadmium-zinc telluride (CZT) detectors, with energy resolution on the order of about 1% and good intrinsic efficiency, promise good performance as a hand-held identifier. However, the limitations of CZT crystal growth prevent a single crystal from being more than about 1-2 cm^3 in volume with significant commercial yields [1]. The resulting limitation in absolute efficiency hampers general performance. One approach for overcoming this limitation is to combine a large array of CZT crystals [2]. While this approach has merits, there are also significant drawbacks in complexity and cost.

NaI(Tl) and CsI(Tl) scintillators are also commonly used for hand-held identifiers [3] and can be made quite large and efficient. However, they suffer the limitations of typical energy resolutions of about 6-10%, limiting relative identification performance. CZT and lower resolution scintillators complement each other, reversing strengths and weaknesses. This study evaluates a way to combine these detectors in a single system that allows these weaknesses to be offset by complementary component strengths.

II. HYBRID SYSTEMS

It is recognized that the combination of multiple radiometric detectors into a system yields benefits in terms of system sensitivity, as with vehicle portals [4]. Sensitivity of any measurement system is a function of the amount of signal (efficiency) and noise (background) contributed by the added components. Efficiency adds to sensitivity linearly while background detracts from sensitivity less than linearly (approximately a square root function), so adding resources to a system improves net sensitivity. For example, doubling the detector volume might double the efficiency and double the background, providing a net improvement of about $\sqrt{2}$ (~ 41%) to the system sensitivity.

Historically, systems of multiple spectroscopic detectors have been limited to combinations of like types of detectors, all with nearly identical peak response functions. This classical

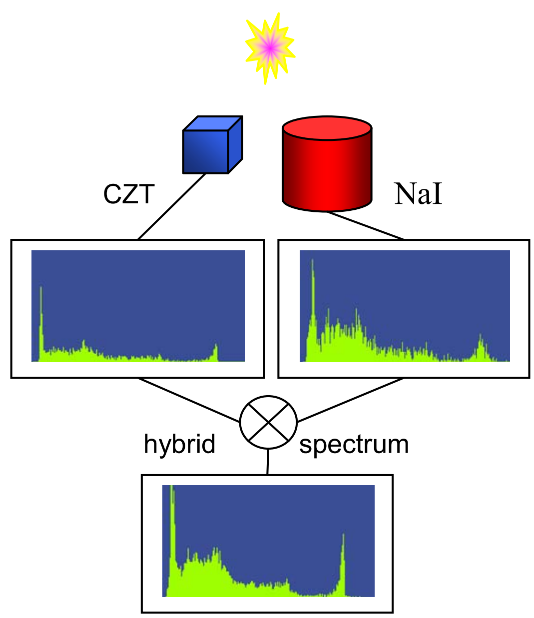

Figure 1. Process diagram for a hybrid system combining a CZT and NaI detectors

approach needs only to match system energy calibrations using hardware gain matching or software spectral rebinning prior to channel-by-channel summation (also known as shift-summing). A novel method of combining spectra from system constituent detectors with differing peak response functions has been conceived and implemented [5]. Figure 1 shows a process diagram illustrating the implementation of such a hybrid system. The hybrid process rebins peak counts to a common spectrum based on a function derived from the complementary response of the constituent detectors. The hybrid spectrum output of the system yields a combined spectrum with a single peak response function more closely approximating that of the higher resolution constituent (in this case, the CZT detector). Importantly, the output single mode peak response function can be accurately handled by current standard peak shape calibration functions, so standard algorithms can be used for identification analysis.

CZT/NaI and CZT/CsI hybrid spectroscopic systems have been created to take advantage of the benefits provided by systems of complementary detectors. These hybrid systems directly combine the individual spectra from the detectors, shown in Figure 2, with very different energy resolutions, yielding a single, melded spectrum that accommodates standard analysis algorithms.

One prototype hybrid system consists of a standard 0.5 cm^3 hemispherical CZT detector (Ritec CZT/500) with a Canberra Inspector 2000 digital signal processor and a 1 cm^3 NaI(Tl) crystal (Scionix) mounted on a 2 inch photomultiplier tube with Canberra Osprey digital tube-base electronics. The other prototype hybrid system uses the same CZT system combined with a 1 cm^3 CsI(Tl) crystal (Scionix) on a silicon photomultiplier (SPMArray4 from SensL) with a Canberra Lynx digital signal processor. Custom software merges the constituent spectra on a standard computer for automated transient or manual triggering and identification analysis.

The energy resolutions of the detectors at the ^{137}Cs 662 keV peak are 1.2% for the CZT, 7% for the NaI and 9% for the CsI. The detector characteristics are summarized in Table I. The CZT is a hemispherical configuration with significant low energy tailing in the peak response. The NaI 662 keV peak efficiency relative to the CZT is less than expected because of the significantly attenuating encapsulation around the crystal as seen in Figure 2.

TABLE I. COMPONENT DETECTOR CHARACTERISTICS

Detector	Size (cm^3)	Energy Resolution (% at 662 keV)	Peak Efficiency (662 keV relative to CZT)
CZT	0.5	1.2	1
NaI	1	7	1.34
CsI	1	9	2

Figure 2. Component detectors used for the evaluations. The 0.5 cm^3 CZT (Ritec CZT/500, left), the 1 cm^3 CsI (Scionix) mounted on the silicon photomultiplier prior to final light-tight wrapping (SensL SPMArray4, upper middle), the 1 cm^3 NaI (Scionix, bottom middle), and NaI mounted on a photomultiplier tube and Canberra Osprey MCA (right).

III. METHODOLOGY

Previous studies [6] have shown the benefits of hybridizing HPGe detectors with large slab NaI detectors. That initial evaluation used measurements for benchmarking but relied on simulations by necessity to generate identification performance curves (probability of detection versus false alarm rates) with significant statistics for a broad range of sources. In this study, the performance evaluation relies entirely on measurements, but with a smaller set of sources.

The false alarm rate is determined by repeating 100 background measurements for 300 seconds each. Analysis was performed using an ANSI N42.34-based library of 30 typical nuclides with standard Canberra Genie 2000 peak search nuclide identification algorithms. This background false alarm rate evaluation was performed with the CZT, CsI and NaI detectors separately and as hybrid units (CZT + CsI and CZT + NaI).

The probability of detection for the individual and combined detectors are also determined with a ^{137}Cs source dose rate of 100 µR/h at a variety of acquisition times (5, 10, 30, 100, and 300 seconds). 100 trial acquisitions were performed with each detector at each live time setting. The same standard Canberra Genie 2000 peak search nuclide identification algorithms used for the background analyses were used for these source evaluations. The merit of the hybrid detectors is assessed by comparing the combined performance against that of the individual components under equivalent conditions.

IV. RESULTS

Table II shows the results of the background false alarm rate testing.

TABLE II. RESULTS OF BACKGROUND FALSE ALARM RATE TESTING

	CZT	CsI	NaI	CZT+ CsI	CZT+ NaI
Background False Alarm Rate (# per 100 trials)	0	0	2	5	6

Figure 3 shows example spectra for 300 second acquisitions with the CZT detector, NaI detector and the hybrid combination of the two. These spectra have been rebinned to a common energy calibration to maintain fidelity of the relative amplitudes of the overlaid spectra.

Figure 4 shows the results of the detection sensitivity testing. Given the 100 µR/h intensity of the ^{137}Cs source, the acquisitions times of 5, 10, 30, 100, and 300 were selected to traverse the full range of spectral statistical significance.

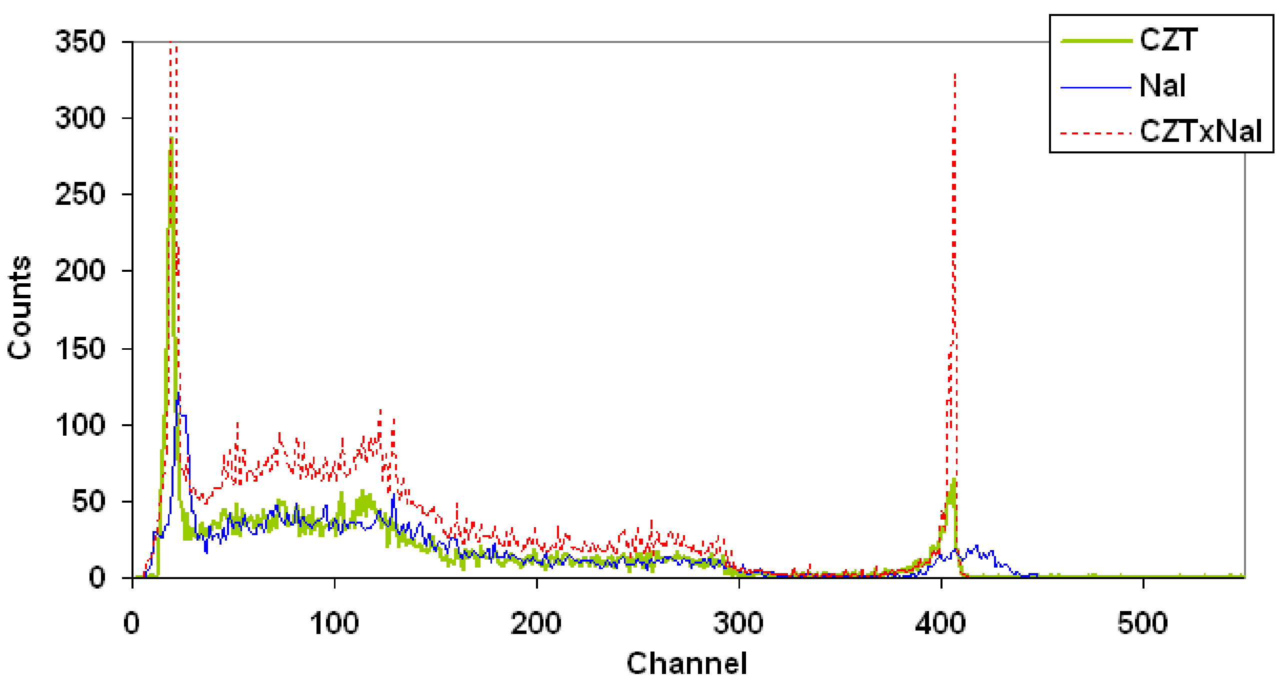

Figure 3. Example CZT, NaI, and CZT+NaI hybrid spectra for a 300 second acquisition of a 100 µR/h ^{137}Cs source

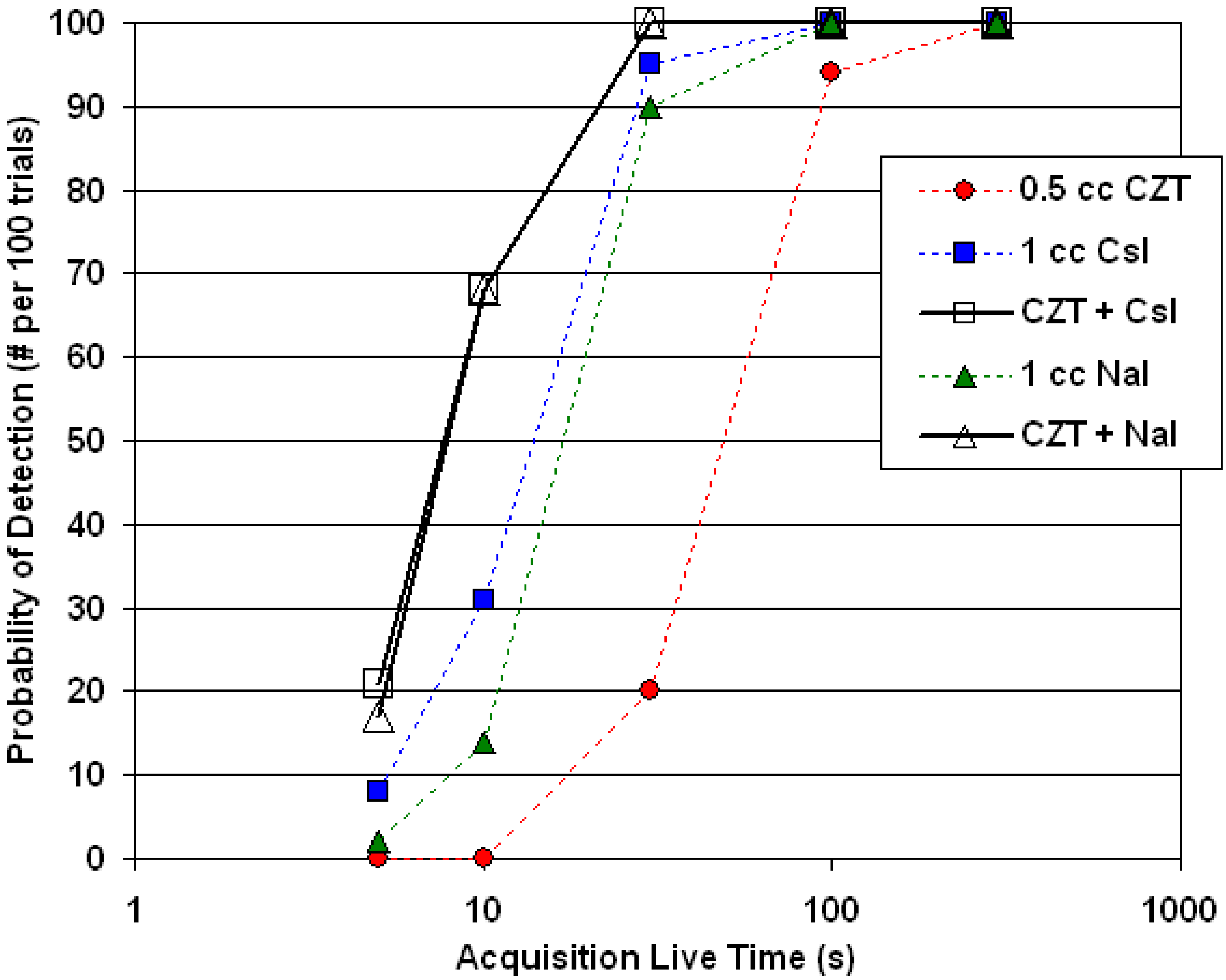

Figure 4. Results of identification testing with a 100 µR/h ^{137}Cs source, with each data point generated by 100 trial acquisitions. Trial acquisition times were for 5, 10, 30, 100, and 300 seconds. Lines added to guide the eye

V. Discussion

The false alarm rate for the background measurements shows an increase of occurrences with the hybrid combinations compared to the individual components. The hybridization process does amplify common spectral features as interpreted through respective peak response calibrations. Chance noise excursions are suppressed if they occur in only one constituent but are emphasized if they occur mutually. The hybridization process does include adjustable parameters to set the degree of amplification but the amount of sensitivity must be balanced by the corresponding need to minimize the weighting of chance coincident excursions. This remains an area of further exploration and refinement.

As expected, with the addition of more information with the hybrid combinations, the probability of detection was enhanced until saturation at long count times. At 5 and 10 second trial acquisitions, the probability of detection was at least twice that of the individual component detectors. For many time-critical applications, the first 30 seconds or less of acquisition determine the success of the measurement system. Such applications include portals assaying flow of commerce and personnel monitoring at border crossings. At long times, all cases converged to 100% detection when provided sufficient statistics. For the application of a hand-held measurement system, the rapid response to sources is an important, desired characteristic. It is this initial period of more challenging statistics that a hybrid system seems to exhibit the most benefits. With longer count times or more intense sources yielding sufficient statistics, it may be sensible to transition to considering just the higher resolution constituent to avoid adding the additional noise of the lower resolution constituent.

VI. CONCLUSIONS AND FURTHER WORK

A novel hand-held spectrometric system has been conceived and bench tested. A combination of constituent detectors with very different peak response functions into an integrated system has been demonstrated to perform well. Specifically, the ability to more rapidly identify sources has been shown. An increase in the false identification rate indicates the need to better optimize parameters and thresholds to balance sensitivity with suppression of noise, dependent on the needs of the application.

While the limited measurements done in this study have been with non–interfering sources, further studies should include more complex interfering source combinations. Such work would show the degree to which the inclusion of higher resolution constituent detectors would enable the more robust handling of such situations. The measurements need to be expanded to include a wider variety of sources to have a broader empirical evaluation. Furthermore, these measurements should be used to benchmark simulations with these hand-held configurations to enable a more comprehensive estimate of extrapolated performance.

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