

Effective Detection of Buried Radioactive Waste - 9295

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ABSTRACT

A method based on matched filtering is developed to detect buried depleted uranium. It does not require background information and its performance is robust under very low-count conditions. Based on lab data experiments using a 10×10×40cm NaI detector and FIDLER detector, this approach can easily detect a 25mm penetrator with 100g mass buried 30cm deep with a detector dwell time as short as 0.1s. This method can be easily implemented in near real-time to provide immediate response in critical situations.

INTRODUCTION

Depleted uranium (DU) is considered both a toxic and radioactive hazard. Effectively detecting DU is of great importance. DU can be detected using gamma spectroscopy collected from sodium iodide (NaI) scintillation detectors, e.g, a 10×10×40cm NaI detector and a FIDLER (Field Instrument for the Detection of Low Energy Radiation) detector, due to unique spectral features presented [1]. A NaI detector can be used as a radiation portal monitor (RPM) for border screening [2]. Traditionally, detection can be achieved by calculating the ratio between the counts at the energy levels of interest [3-7]. More advanced approaches include gross-count material basis set (GC-MBS) model [8-10], energy windowing method [11-12], spectral comparison ratio with spectrum correction [13], and principal component analysis-based method [14].

When DU is buried, energy counts can be very low. The performance of the aforementioned methods may be limited. In our research, we employ a more advanced signal processing algorithm based on matched filtering to detect buried DU. First, important features are extracted from the gamma spectroscopy collected when the penetrator is located on the surface; then, a matched filter-based detector is applied to the spectrum when the penetrator is buried using the extracted features. This approach has three major advantages: 1) there is no background information that is required (as long as the Gamma spectrum when the penetrator is on the surface is known); 2) there is a correlation between the output of the matched filter and the mass of depleted uranium (in other words, the mass of depleted uranium may be retrieved from a multiple regression analysis); and 3) fast and near real-time implementation can be achieved to provide immediate response in critical situations.

In practical surveys, the dwell time of a detector in each specific location may be very short. In other words, the energy counts captured by the detector may be much smaller than in the case

when the dwell time is long enough. This requires the algorithm be robust under very low-count conditions. Lab data collected by a 10×10×40cm NaI detector and a FIDLER detector with short dwell time are used in the experiments. The preliminary results demonstrate the effectiveness of the proposed approach for buried DU detection.

APPROACH

In communication and signal processing, a matched filter is obtained by correlating (i.e., convolving) a known signal template with an unknown signal to detect the presence of the desired template. The matched filter is the optimal linear filter for maximizing the signal to noise ratio (SNR) in the presence of additive random noise [15].

Let an observed signal x be expressed as the desirable signal s and additive noise n , i.e.,

$$x = s + n. \quad (1)$$

Let a finite impulse response (FIR) filter be represented by h . The filter output is

$$y = h^T x = h^T s + h^T n. \quad (2)$$

The objective is to design a filter h such that the SNR of the filter output, defined as

$$SNR = \frac{|h^T s|^2}{E(|h^T n|^2)} = \frac{|h^T s|^2}{h^T R_n h} \quad (3)$$

is maximized such that the detection of s can be achieved, where $E(\cdot)$ denotes the operation of statistical expectation and R_n is the noise correlation matrix. The solution of this optimization problem is

$$h = R_n^{-1} s. \quad (4)$$

When the signal s has low energy, the data correlation matrix R can be used to replace R_n without noise estimation, i.e.,

$$h = R^{-1} s. \quad (5)$$

The key of the success of the matched filter is to choose an appropriate signal template as s . In this research, the s will be part of the energy spectrum that distinguishes the DU from other radioactive materials and background.

EXPERIMENTS

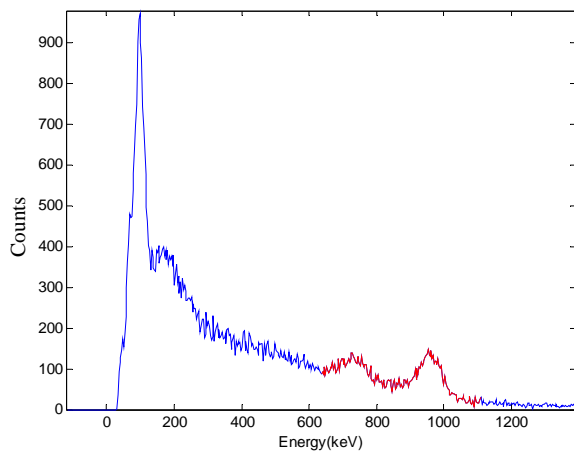
We present two experiments using lab data, one collected by a 10×10×40cm NaI detector and the other by a FIDLER detector. The major purpose is to demonstrate the effectiveness of the proposed matched filter approach in the detection of buried DU and the discrimination from the background (soil and sand) and natural ore. Another purpose is to investigate its robustness when dealing with the data collected with short detector dwell time (i.e., 1s, 0.5s, 0.1s). Two penetrators were used in the experiments: a 105 mm penetrator with 4.3kg mass and a 25mm penetrator with 100g mass.

10×10×40cm NaI Detector

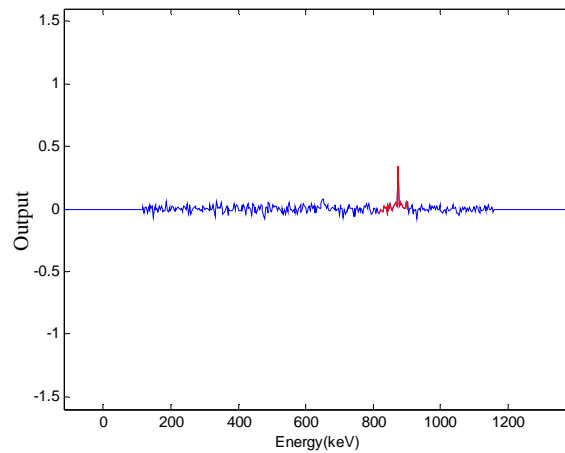
For each dwell time, six energy spectra were studied: DU on the surface, DU buried 15cm deep, 23cm deep, 30cm deep, natural ore, and background. The energy spectrum from 620 keV to 1100 keV when the DU is on the surface are considered as the feature used in the matched filter. This spectral region is referred to as region of interest (ROI).

Figures 1 and 2 show the detailed energy spectra and matched filter outputs for the six cases when the dwell time was 1s for the 105mm penetrator, where the ROIs were highlighted. It is obvious that when the DU was present, the output in ROI was strong and the outputs outside ROI were suppressed; when the DU was buried deep or absent, outputs inside and outside ROI became noisy.

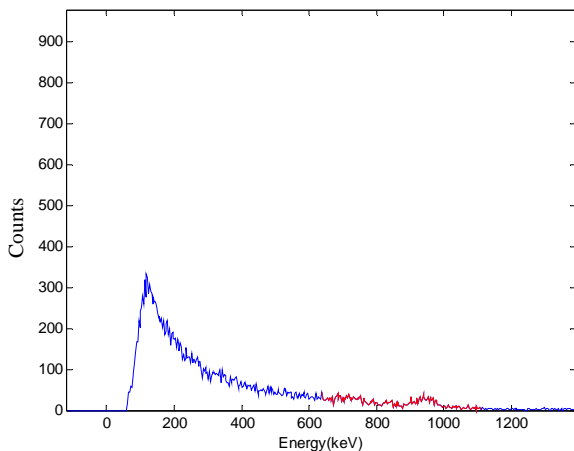
The SNR values of the outputs were calculated and listed in Table I, where we can see that even when the DU was buried 30cm deep, the output was still greater than the natural ore and background. The outputs were decreased when the dwell time was reduced to 0.5s and 0.1s. It is worth mentioning that the SNR was estimated as the ratio between the square of the maximum output in ROI and the output variance in the rest of the spectrum.



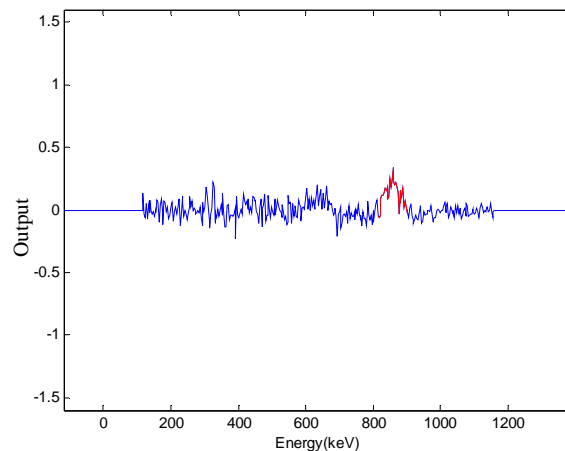
1(a) original spectrum when DU on the surface



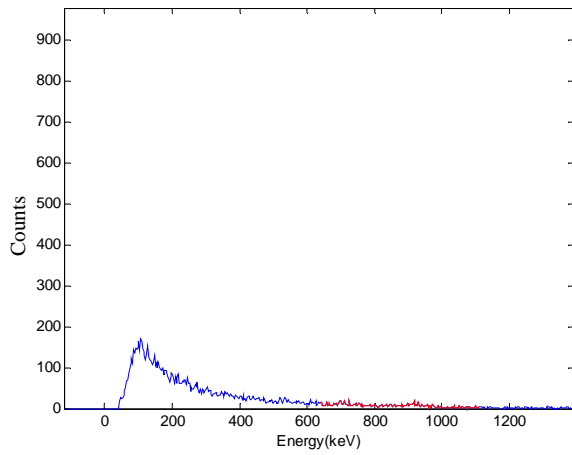
1(b) matched filter output for 1(a)



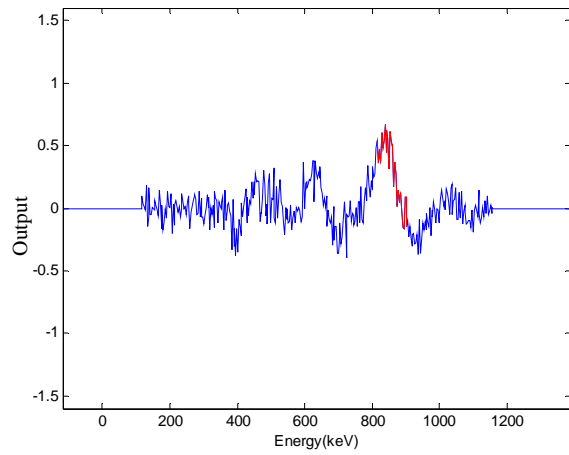
1(c) original spectrum when DU buried 15cm deep



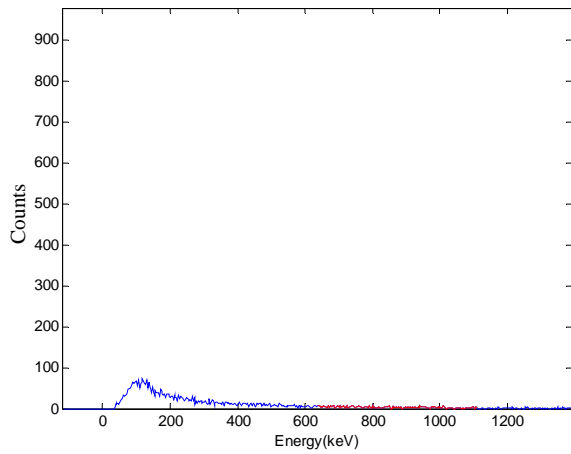
1(d) matched filter output for 1(c)



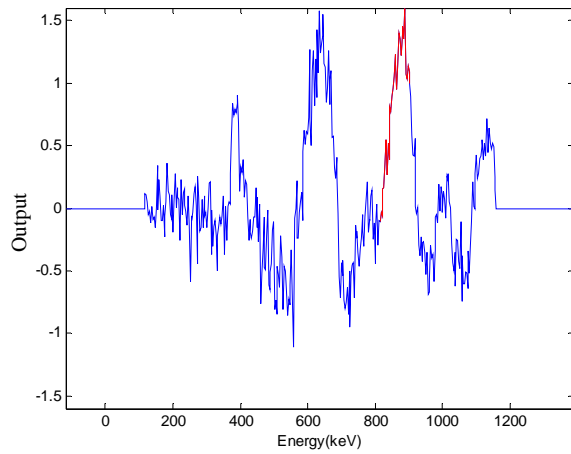
1(e) original spectrum when DU buried 23cm deep



1(f) matched filter output for 1(e)



1(g) original spectrum when DU buried 30cm deep



1(h) matched filter output for 1(g)

Fig. 1. DU detection using a 10×10×40cm NaI detector (ROI is highlighted).

Table I. Matched filter outputs for the NaI detector quantified with SNR in dB

Penetrator/Dwell time	105mm/1s	105mm/0.5s	25mm/0.1s
Surface	179.20	86.95	265.54
15cm depth	19.77	5.76	8.84
23cm depth	14.07	3.99	7.17
30cm depth	8.88	2.67	4.08
Natural ore	2.37	2.04	2.98
Background	1.29	2.19	1.17

FIDLER Detector

Since the energy spectrum is different from the FIDLER detector, the feature used for the matched filter has to be changed. Here, the energy spectrum from 10 keV to 50 keV when the DU is on the surface is considered as the feature, which is ROI in this case.

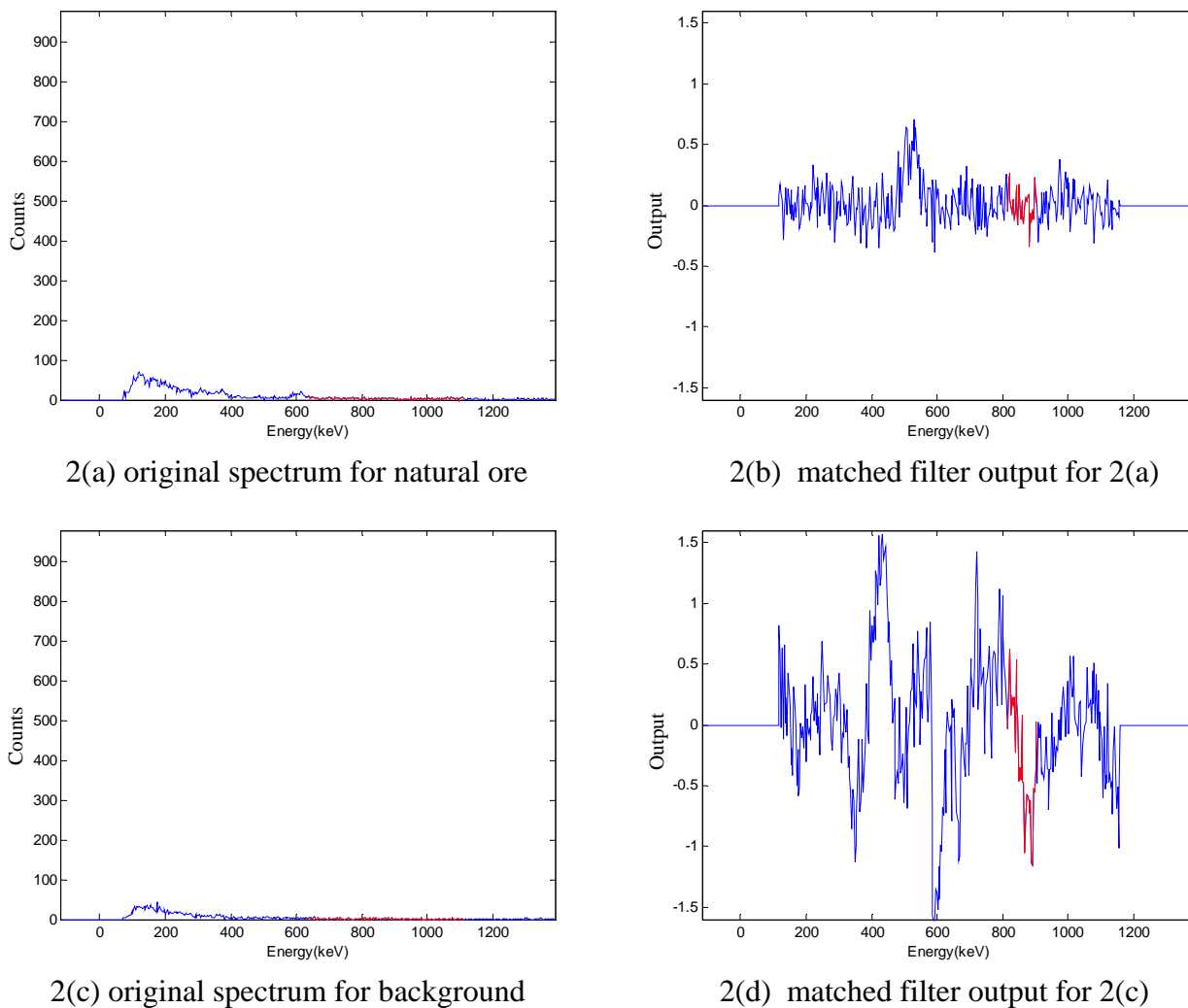
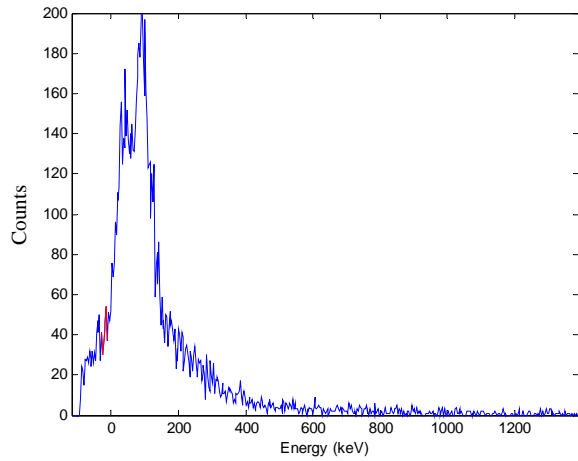


Fig. 2. Detection when DU is absent using a 10×10×40cm NaI detector (ROI is highlighted).

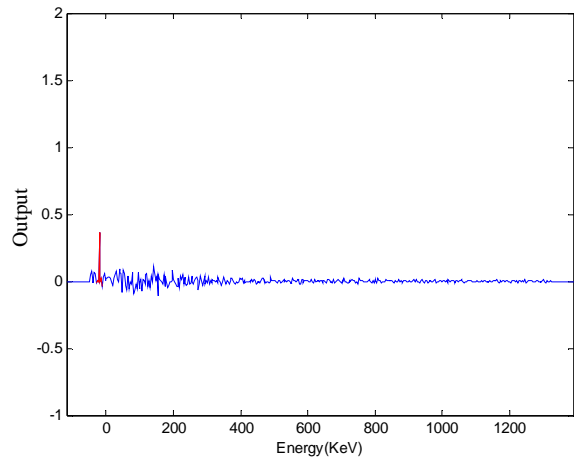
Figures 3 and 4 show the detailed energy spectra and matched filter outputs for the six cases when the dwell time was 1s for the 105mm penetrator, where the ROIs were highlighted. Once again, when the DU was present, the output in ROI was strong and the outputs outside ROI were suppressed; when the DU was buried deep or absent, outputs inside and outside ROI became very noisy.

The SNR values were calculated and listed in Table II, where we can see that even when the DU was buried 23cm deep, the output was still greater than those of the natural ore and background. The outputs were decreased when the dwell time was reduced to 0.5s and 0.1s, but they were still significantly larger for accurate detection.

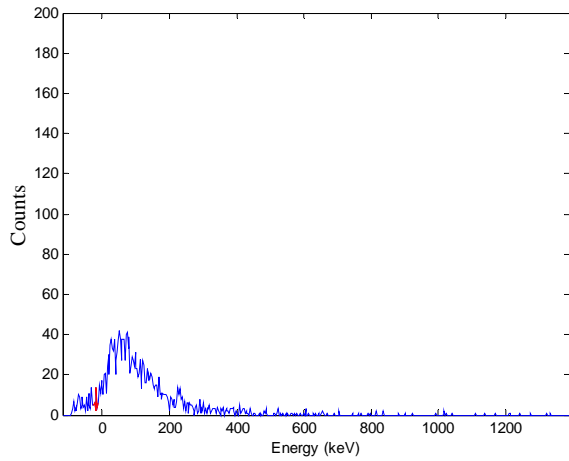
From Tables I and II, we can see that an appropriate threshold can be derived for a decision of detection based on the prior information of the responses from undesired materials and background.



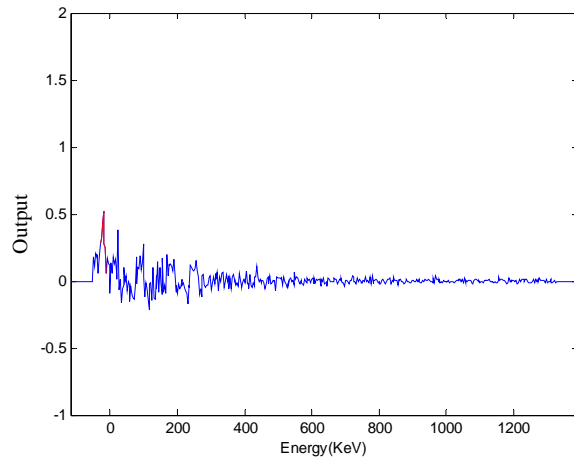
3(a) original spectrum when DU on the surface



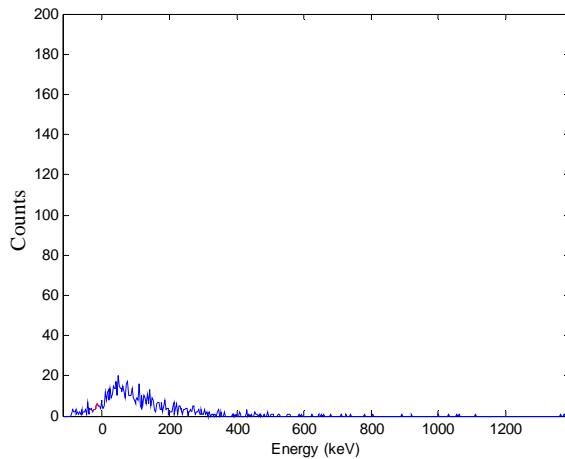
3(b) matched filter output for 3(a)



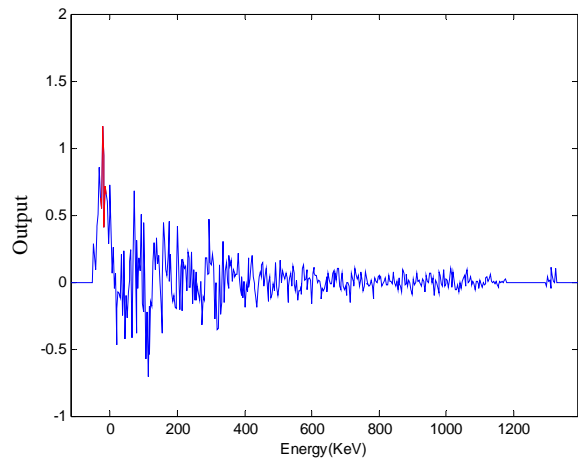
3(c) original spectrum when DU buried 15cm deep



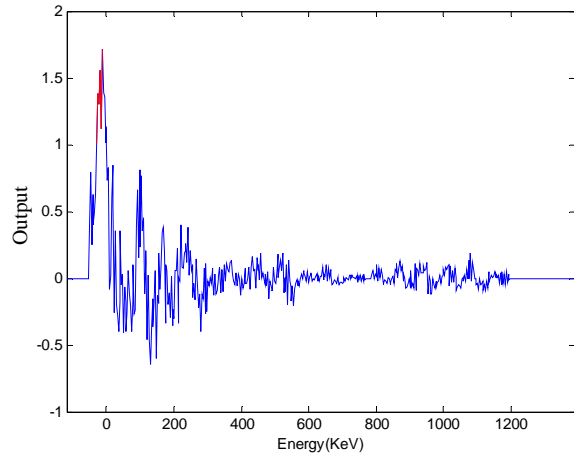
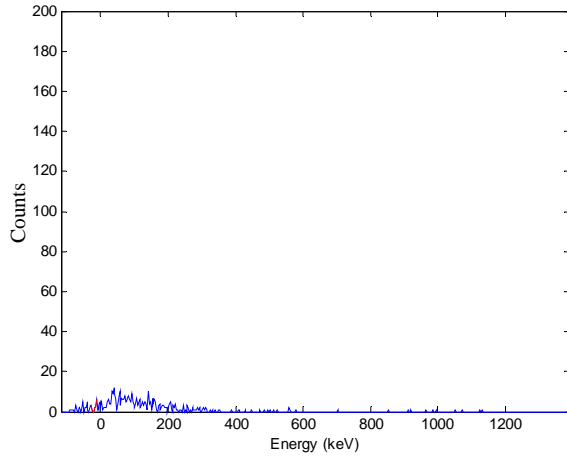
3(d) matched filter output for 3(c)



3(e) original spectrum when DU buried 23cm deep

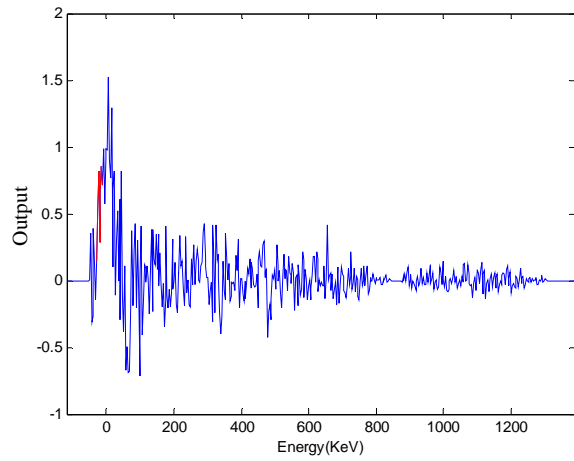
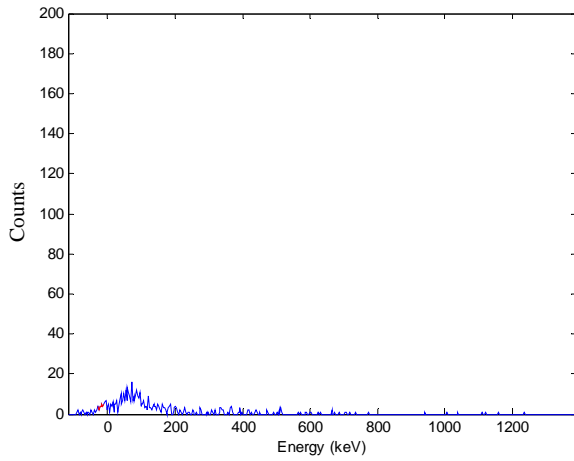


3(f) matched filter output for 3(e)



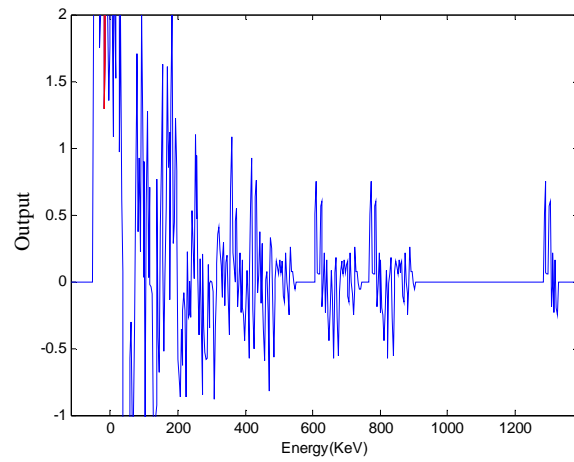
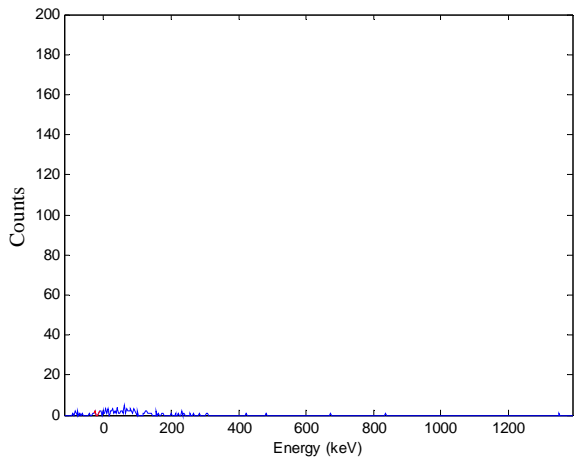
3(f) original spectrum when DU buried 30cm deep 3(g) matched filter output for 3(f)

Fig. 3. DU detection using a FIDLER detector (ROI is highlighted).



4(a) original spectrum for natural ore

4(b) matched filter output for 4(a)



4(c) original spectrum for background

4(d) matched filter output for 4(c)

Fig. 4. Detection when DU is absent using a FIDLER detector (ROI is highlighted).

Table II. Matched filter outputs for the FIDLER detector quantified with SNR in dB

Penetrator/Dwell time	105mm/1s	105mm/0.5s	25mm/0.1s
Surface	269.83	484.45	441.03
15cm depth	63.44	63.51	51.02
23cm depth	48.02	55.84	40.71
30cm depth	46.72	37.55	29.39
Natural ore	14.25	5.77	7.33
Background	19.60	11.09	4.87

CONCLUSION

A matched filter-based method is investigated for the detection of buried DU. This approach requires only the spectrum feature in ROI when DU is placed on the surface, and it does not require the background information. The estimated SNR value can be employed as the threshold for decision-making.

The preliminary result using lab data shows the effectiveness of this approach. Its performance on real field data needs to be studied in the future.

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