Handheld Device for Simultaneous Monitoring Of Fast Neutrons and Gamma Rays

R. Aryaeinejad, E. L. Reber, and D. F. Spencer
Idaho National Engineering and Environmental Laboratory
P. O. Box 1625, Idaho Falls, ID 83415-2114

Abstract-- Currently at the INEEL, a handheld device is being developed to measure fast neutrons and gamma rays using a single detector instead of a previous two detector system. The handheld detection system presented here uses a single 1/2 inch (diameter) by 1/2 inch (long) liquid scintillator detector (BC501). This means the detection system can be made smaller, lighter, less expensive, and is expected to be more sensitive than the original system. A smaller and lighter device makes it possible to be used in several applications such as customs inspection, border security, environmental radiation monitoring, and so on. The use of only one detector requires that the neutrons and gamma rays be distinguished by the shape of their pulses in the detector. Two methods of pulse shape discrimination (PSD) are: presented here, charge integration and crossover timing. Figures of merit were calculated for both methods for a threshold energy range of 50 to 600 keV. Results show that the crossover method gives much better PSD for electron energy of 100 keV and lower, whereas the charge integration method leads to better separation above 100 keV. However, the neutrons and gamma rays are totally separated for energies of 100 keV and above in both techniques. We are currently designing a miniaturized electronic system to be incorporated in the handheld device.

I. INTRODUCTION

The earlier neutron/gamma detection system developed at the INEEL [1] uses a combination of two Li-6/Li-7 glass scintillators. Because Li-6 is only sensitive to thermal neutrons, these detectors need to be inside a polyethylene block. This makes the detection system bigger and heavier than what is required for some applications. By the use of a liquid scintillator detector (BC501) and pulse shape discrimination (PSD) techniques, we will be able to use only one detector. PSD methods have been extensively used to separate fast neutrons from gamma rays [2-6]. These techniques are based on the fact that neutrons and gamma rays give different pulse shapes when interacting with the fast-neutron sensitive organic scintillators. The neutron interaction results in a slower timing signal and a poorer timing resolution than the gamma-ray interaction. This means that a gamma-ray pulse decays faster to the baseline than a neutron pulse generated by the recoiled protons. Figure 1 shows pulses created by a gamma ray (a) and a neutron (b) in a liquid scintillator.

The difference between these two signals occurs in the tail. A neutron creates a large ionization density by producing a recoil proton. This causes the long tail as shown in Figure 1. A gamma ray, on the other hand, produces a scattered electron with a very small ionization density, and as a result, decays much faster.

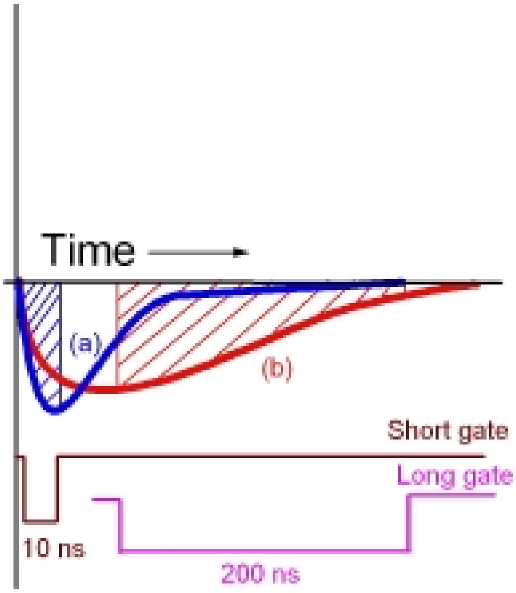


Fig. 1. Gamma ray and neutron pulse shape.

There are two different methods of pulse shape discrimination: “Charge Integration” and “Crossover Timing”. In the charge integration method, two charge-sensitive Analog-to-Digital Converters (ADCs) are used to differentiate between the two pulses. Here, one ADC looks at the fast rise-time part of the detector pulse, while the other ADC looks at the slow decay-time part. In the crossover method, the detector signal is sent to an RC-shaping amplifier. The gamma pulse crosses the baseline much earlier than the neutron pulse. The crossover point for gamma rays are fixed and independent of its energy, whereas the crossover point for the neutron changes as a function of its energy. Also, the low-energy neutron crossover is closer to the gamma crossover. In this method, a Time to Amplitude Converter (TAC) is used to measure the crossover timing and to separate the neutron pulse from the gamma-ray pulse.

In this work, the neutron/gamma discrimination is investigated using both techniques. The results of the measurements are compared to decide which method leads to better performance and easier miniaturization of the electronics suitable for use in a handheld device.

II. EXPERIMENTAL SETUP

A. Charge Integration Method

Figure 2 shows the electronic setup of the charge integration method. We used a 2-inch in diameter and 2-inch long liquid scintillator detector (BC501) to perform our measurements. A Cf-252 source was used in all tests. The detector anode signal is sent to two charge integrating ADCs (QDC). As shown in Figure 1, one QDC gates the prompt part of the signal (short gate), while the other gates the tail portion of the signal (long gate). This gating method is different than ones conventionally used in the past [2-6]. The common way of gating the signals has been to gate the total signal and comparing it to the gate of the tail. We found that the separation was better by just gating the prompt part of the signal and compare it with the gating of the tail part of the signal. Since in this application we are only interested in the number of neutron and gamma ray counts, the total energy does not need to be measured. Also, our method is much more flexible than the traditional one because one can independently adjust the widths and positions of either gate to get a better PSD, whereas in the other method, one can only adjust the starting position of the tail gate.

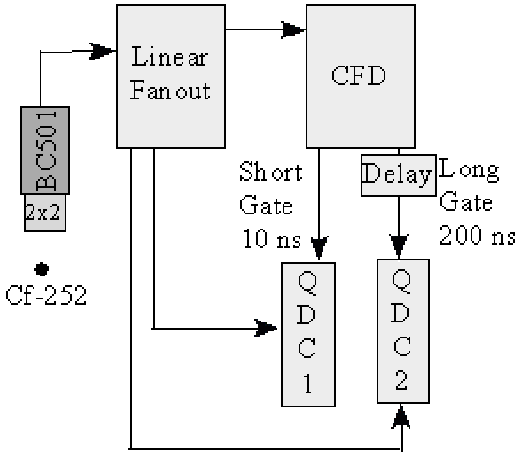


Figure 2. Electronic setup for the charge integration method.

Figure 3 shows the two-dimensional (2D) plot of the digitized integration of the short-gate pulse versus the long-gate pulse. Two bands can clearly be seen which intersect each other at low values of the charges in the two gates. The upper band corresponds to the neutrons and the lower band to the gamma rays. The region where they converge corresponds to the cases of very low-energy neutrons or low-energy gamma rays. This is the region that determines how well the neutrons are separated from the gamma rays, which consequently determines the minimum neutron energy threshold.

To evaluate the separation of the neutrons and gamma rays at various gamma ray energies, we took vertical slices on the 2D plot and projected them onto the y-axis.

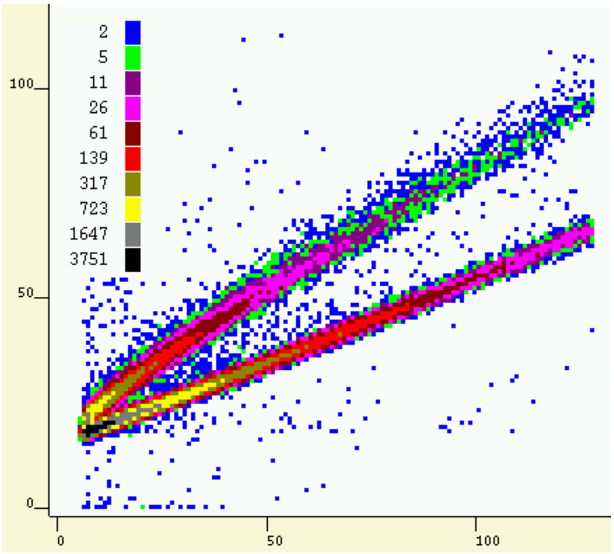


Fig. 3. 2-d plot of short gate (x-axis) vs. long gate (y-axis).

To quantify the separation of the peaks corresponding to the neutrons and gamma rays, a figure of merit (FOM) [2] was used:

$$FOM = \frac{peak\_separation}{FWHM_{\gamma} + FWHM_{n}} .$$

Figure 4 shows the projections at electron energy levels ranging from 50 to 600 keV with a width of 30 keV.

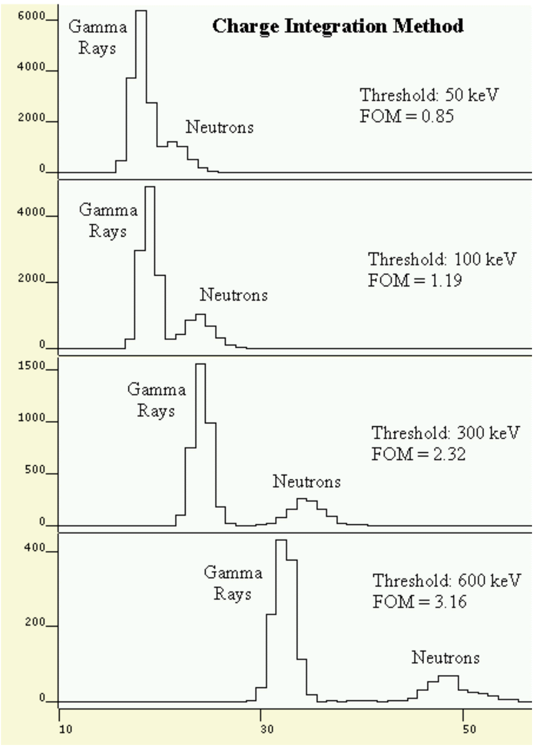


Fig. 4. 2-d projections at various electron energy thresholds.

The FOM is shown for each energy threshold. One can easily separate the neutrons from the gamma rays with energies above 100 keV. At 50 keV, the peaks are not separated enough to discriminate between the neutrons and gamma rays with great accuracy.

B. Crossover Timing Method

Figure 5 shows the electronic setup of the crossover timing method.

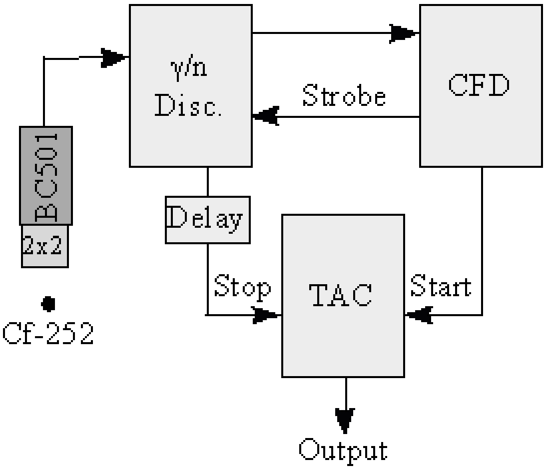


Fig. 5. Electronic setup for the crossover method.

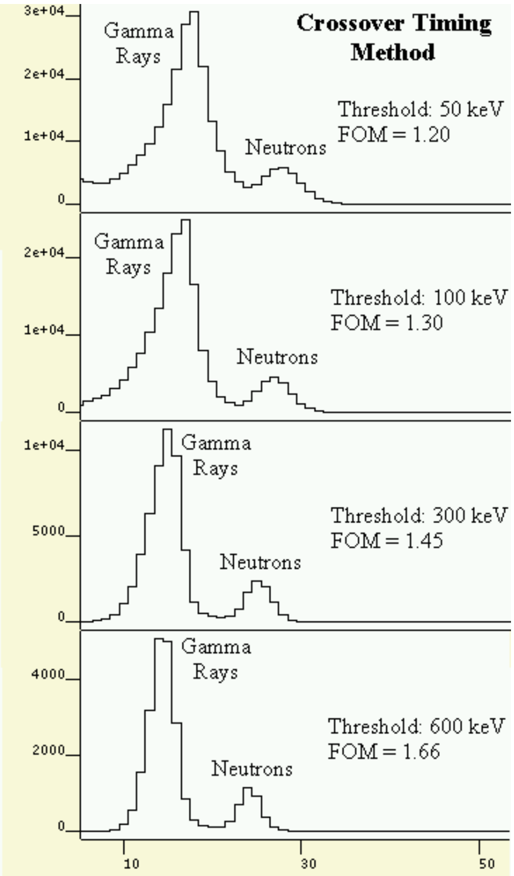
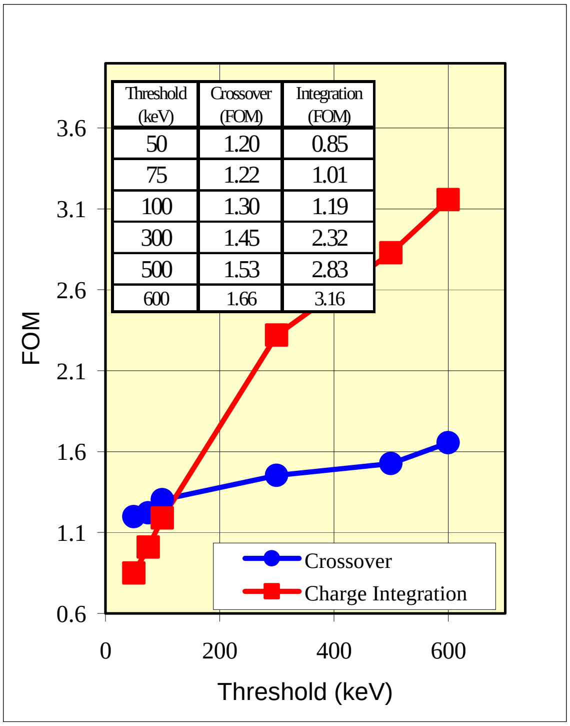


Fig. 6. TAC spectra at various electron energy thresholds.

The same detector was used as in the previous method. The signal is sent to a γ/n discrimination module, which contains an RC-shaping amplifier. The signal is also sent through to a constant fraction discriminator (CFD), which produces the start trigger for the TAC. The γ/n discrimination module sends a pulse corresponding to the crossover timing of the signal. This signal is delayed before it is sent to stop the TAC. A plot of the TAC output is shown in Figure 6. The gamma-ray pulses cross the baseline earlier than the neutron pulses and therefore appears to the left on the graph. To quantify the pulse shape discrimination of the crossover timing method, several measurements were made at different threshold settings. Figure 6 shows the TAC spectra for threshold levels between 50 to 600 keV. The same FOM as shown above was calculated for the different threshold levels. One can see that the γ/n discrimination is good even down to 50 keV.

III. METHOD COMPARISON

Figure 7 shows a summary of the results of the two methods of PSD. Figure of merit was used to compare the results of the two methods. At first glance, one can see from the graph that the crossover timing method is better for threshold values of 100 keV and lower. On the other hand, the charge integration method seems to be better for higher thresholds (>100 keV). Similar results have been reported by Wolski et al. in reference [7] except they used the traditional method of charge integration and were unable to resolve the γ/n below 300 keV without raising the gain of the photomultiplier.



Threshold (keV)	Crossover (FOM)	Integration (FOM)
50	1.20	0.85
75	1.22	1.01
100	1.30	1.19
300	1.45	2.32
500	1.53	2.83
600	1.66	3.16

Fig. 7. Comparison between charge integration and crossover methods.

Figures 4 and 6 show that when the FOM is about 1.5 or higher, the neutron and gamma ray peaks are well separated and there is no need for more separation. Therefore the crossover timing method is the best method to discriminate between neutrons and gamma rays over the entire range of thresholds.

IV. ELECTRONICS UNDER DEVELOPMENT

Figure 8 shows the ½" x ½ liquid scintillator detector which will be used in the prototype system.

Fig. 8. Photo of the ½" x ½" liquid scintillator (BC501).

The miniaturized electronic system (shown in Figure 9) is currently under development at the INEEL. The output from a photomultiplier tube is amplified, inverted, and RC shaped. A comparator provides for a level adjustment, eliminating low-level and noisy input signals. The comparator output's leading edge starts a one-shot. The one-shot pulse time is set to be greater than the comparator pulse time of a gamma signal, but shorter than the pulse time of a neutron signal. The comparator output (gamma or neutron pulse) is also sent to the input of a latch. The latch clocks the input on the one-shot trailing edge. The output level of the latch will determine if the event is gamma (high) or neutron (low).

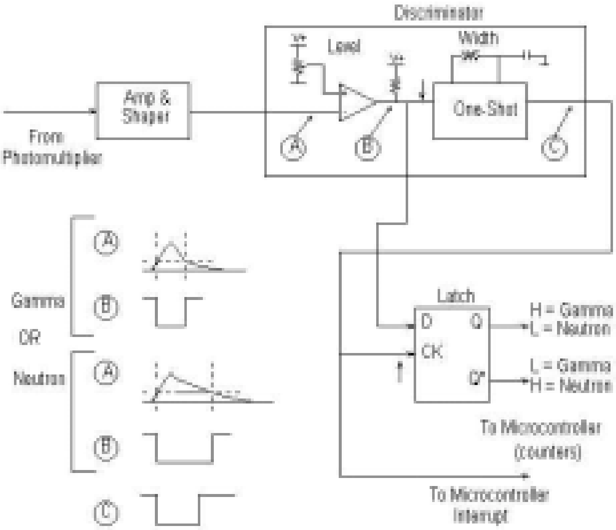


Fig. 9. Electronics Diagram.

V. CONCLUSIONS

To summarize, we are developing a handheld device to measure fast neutrons and gamma rays simultaneously. Two methods of pulse shape discrimination were investigated. The results show that the crossover technique gives a better γ/n separation at 100 keV electron energy and lower, whereas the charge integration method is better at higher thresholds. Since the gamma rays and neutrons are very well separated at higher thresholds in both techniques, the crossover method was chosen for building the handheld detection system. This device will operate on batteries and has the following advantages over the previously developed detection system.

- A single detector will be used instead of two.
- Since this detector is sensitive to fast neutrons, there will be no need for a moderator around the detector.
- A smaller and lighter detection system can be fabricated.
- Once a neutron hits the detector, the probability of detection is very high.
- Liquid scintillators are very easy to fabricate and less expensive than Li-6/Li-7 glass scintillators.

VI. ACKNOWLEDGEMENT

This work is supported by the U.S. Department of Energy under BBWI's DOE contract no. DE-AC07-99ID13727.

VII. REFERENCES

[1] R. Aryaeinejad, Y.X. Dardenne, J.D. Cole, and A.J. Caffrey, "Palm-size Low-level Neutron Sensor for Radiation Monitoring," IEEE Trans. On Nucl. Sci. vol. 43, n0. 3, pp1539-1543, (June 1996).
[2] G.F. Knoll, Radiation Detection and Measurement, pg. 680 (Wiley, New York, 1999).
[3] J.H. Heltsley, L. Brandon, A. Galonsky, L. Heilbronn, B.A. Remington, S. Langer, A. Vander Molen and J. Yurkon, "Particle Identification via Pulse-Shape Discrimination with a Charge-Integrating ADC," NIM A263, pp. 441-445 (1998).
[4] J. Bialkowski, M. Moszynski, and D. Wolski, "A Pulse Shape Discriminator with High Precision of Neutron and Gamma Ray Selection at High Counting Rate," NIM A275, pp. 322-328 (1988).
[5] M.S. Zucker and N. Tsoupas, "An n-γ Discrimination System for Wide Energy Ranges," NIM A299, pp. 281-285 (1990).
[6] M. Moszynski and DEMON Collaboration, "Study of n-γ Discrimination by Digital Charge Comparison Method for a Large Volume Liquid Scintillator," NIM A317, pp. 262-272 (1992).
[7] D. Wolski, M. Moszynski, T. Ludziejewski, A. Johnson, W. Klamra, O. Skeppstedt, "Comparison of n-γ Discrimination by Zero-Crossing and Digital Charge Comparison Methods," NIM A360, pp. 584-592 (1995).