PULSE SHAPE DISCRIMINATION FOR THE NUCLEAR MATERIALS IDENTIFICATION SYSTEM (NMIS)

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ABSTRACT
Preliminary results from efforts to implement on-line, fast pulse shape discrimination (PSD) methods in the Nuclear Materials Identification System (NMIS) are discussed. Previous NMIS implementations used fast plastic scintillation detectors that did not allow discrimination of neutrons and gamma rays. Time coincidence signatures acquired by NMIS thus included contributions from both neutrons and gamma rays. It has been shown that attributes of the fissile material under investigation are related to features extracted from the signatures measured by NMIS. The ability to separate the total signature into its neutron and gamma components will lead to the possibility of extracting new features. On the basis of previous studies, these new features are more sensitive to the attributes of the fissile material than the features extracted from the total signature.

PSD implementation used the method of charge integration over two different time periods. Liquid organic scintillators (BC501-A) were used to detect neutrons and gamma rays from a Cf-252 source. Pulse type was differentiated using the time-of-flight technique, and pulses were digitized for subsequent analysis using a fast digital oscilloscope. Analysis of digitized pulses provided optimum signal integration periods for pulse discrimination. Electronic circuits were designed, built, and tested to implement our PSD technique. Results to date indicate promise as an effective PSD methodology for future use in the NMIS.

INTRODUCTION
Previous studies using the Nuclear Materials Identification System (NMIS) [1] have demonstrated the sensitivity of time-dependent coincidence signatures between two or more detectors to the attributes of fissile material [2-6]. It has been shown that attributes of the fissile material under investigation are related to features extracted from the signatures measured by NMIS. The ability to separate the total signature into its neutron and gamma components will lead to the possibility of extracting new features. On the basis of previous studies, these new features are more sensitive to the attributes of the fissile material than the features extracted from the total signature [7,8].

Recent work simulated detector-detector covariance functions for passive measurements on plutonium spheres and cylinders using the MCNP-PoliMi code [9]. The total signatures were subdivided into four components according to the particle that generated the detector pulse. The possible pairs of detections are neutron-neutron, photon-photon, neutron-photon, and photon-neutron. Figure 1 presents simulation results for a 2 kg, 6 wt% ^{240}Pu metal cylinder performed with $7*10^5$ spontaneous fissions of ^{240}Pu. The inspected cylinder was placed between two fast plastic scintillation detectors, 25 cm from cylinder center to the front face of the detectors.

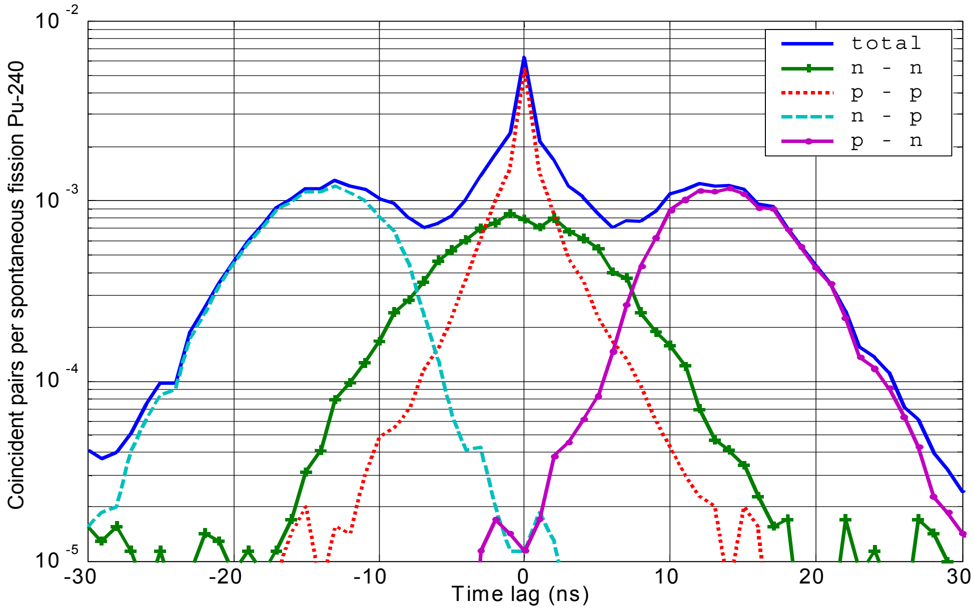

Figure 1. MCNP-PoliMi simulation of detector-detector covariance functions for 2 kg plutonium metal cylinder. The total signature is subdivided into its components given by neutron and photon contributions (neutron-neutron, photon-photon, neutron-photon, and photon-neutron).

The area of the neutron-neutron contribution to the covariance and the second central moment (spread) of the neutron-neutron contribution are two features from the NMIS signatures found to be sensitive to metal versus oxide composition. These simulations demonstrated the feasibility to distinguish plutonium metal from oxide for the spherical and cylindrical samples without taking into account the shape or mass of the samples. In order to realize these simulations in the lab or the field, one must separate the neutron-neutron portion of the covariance function from the other possible pairs of detections. To separate individual gamma and neutron pulses, one must employ pulse shape discrimination (PSD) techniques.

Numerous other measurements using the NMIS require PSD. The PSD module can be used in any measurement scheme that requires discrimination of radiation type and utilizes time constants on the order of our design variables. Our design goals included <300 ns processing time (detection, decision, and reset).

ELECTRONIC PULSE SHAPE DISCRIMINATION

Electronic PSD techniques generally fall into one of three categories [10,11]: (1) sensing differences in rise time of pulses, (2) integrating charge over different time periods, and (3) digital capture and shape analysis.

The rise time, or crossover, method passes individual pulses through a shaping network, produces a bipolar pulse where "zero" is a function of pulse shape and rise time, and examines the time difference between the beginning of a pulse and the zero as converted by a time-to-amplitude-converter (TAC) into a pulse amplitude.

The charge integration method utilizes differing fluorescence properties in organic scintillators in response to neutrons and gamma rays. While organic scintillators typically have both fast and slow components of scintillation, the majority of produced light is typically associated with the fast component. The fraction of produced light in the slow component often depends on the nature of the exciting particle, with this fraction depending primarily on the rate of energy loss, dE/dx.

The digital capture and shape analysis method acquires pulse waveforms using Flash ADC with sampling rates >1GigaSample per second. The captured waveforms can be analyzed off-line to determine particle type, energy, and timing information.

DESIGN METHODOLOGY

The PSD module has been designed to utilize the charge integration method. Commercial PSD modules generally measure differences between the integrated charge in the entire pulse and the integrated charge over the rising or falling portion of the pulse. The integrated charge over the entire pulse is a function of both the energy of the radiation and the type of radiation detected. The rising portion of the pulse is most representative of the energy of the radiation while the falling portion of the pulse is most representative of the type of radiation detected. The module examines the ratio of charge in the pulse tail to the rising portion peak amplitude of the pulse (hereafter referred to as the charge ratio) [12]. The module thus normalizes pulses on energy and increases sensitivity to radiation type. In our case, the BC-501A scintillator may be described by the mean decay times of three components: 3.16, 32.3 and 270 ns. It is assumed that these decay constants did not vary with particle type, but rather that the difference in neutron and gamma signals is due to varying proportions of the first two (3.16 and 32.3 ns) decay times.

While scintillation decay constants for numerous organic scintillators are well documented, the PSD module has enough variability in time collection periods to allow optimization of individual detectors as well as to accommodate a range of potential scintillators.

As part of the design investigation process, liquid organic scintillators (BC-501A) were used to detect neutrons and gamma rays from a Cf-252 source. Pulse type was differentiated using the time-of-flight technique, and pulses were digitized for subsequent analysis using a fast digital oscilloscope. Analysis of digitized pulses provided insight into optimum signal integration periods for pulse discrimination. A representative plot of discrimination charge ratios, with an integration period from 5-60 ns, is presented in Figure 2. While it is recognized that this plot (and its associated measurement) provided limited statistical information due to the small number of recorded pulses, these brief measurements were intended only to provide design insight.

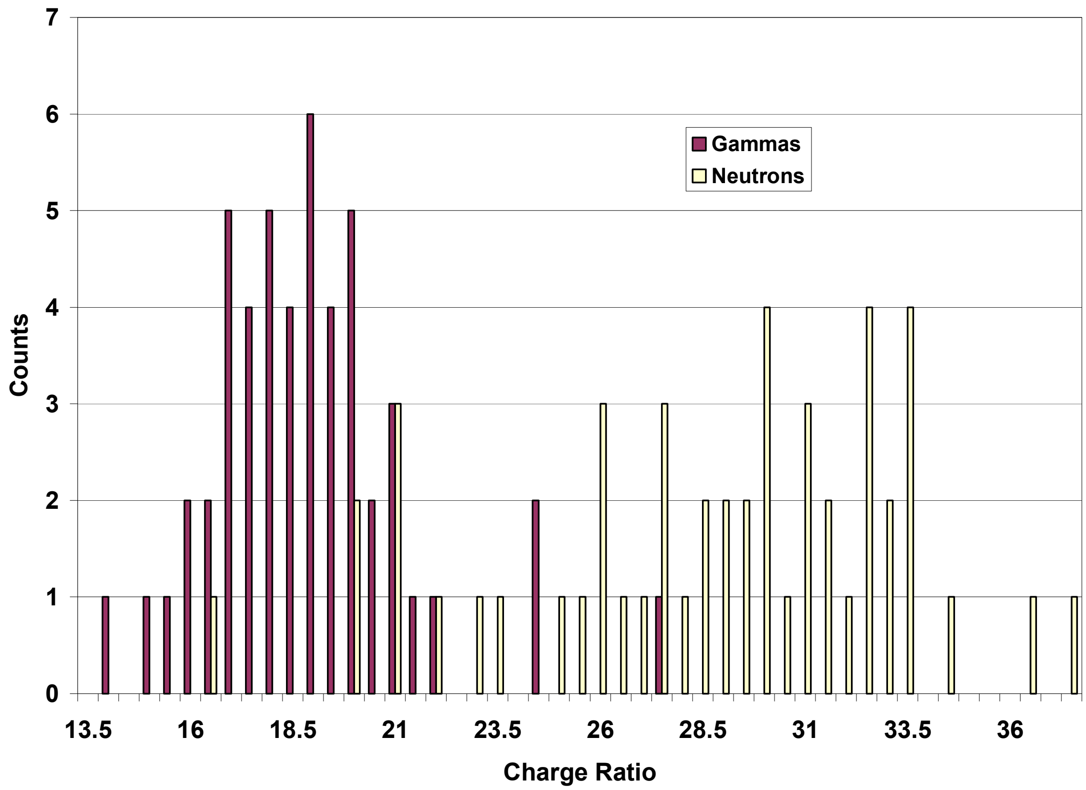

Figure 2. Charge ratio for gamma and neutron pulses from Cf-252 collected using the time-of-flight technique.

These scoping measurements revealed a range of charge ratios (20-25) in which gamma and neutron signals mixed in nearly equal proportions. In order to reduce neutron-gamma classification errors, the PSD module was designed to be able to reject signals in a similar range of ratios through the use of window discriminators. Numerous measurements were performed with multiple scintillator/photomultiplier tube/base combinations at various bias voltages to develop a sense of the variability in measurements and then designed this variability into our PSD module.

PSD MODULE TESTING

The fundamental function of the on-line, fast PSD module is to perform a fast calculation of the charge ratios from organic scintillator detector signals and our initial testing has concentrated on this calculation function. To date, testing of the PSD module included tuning peak stretcher, gated integrator and fast analog divider electronics. We have not completed testing on the backend windowing discriminator circuits. Tuning involved the adjustment of the timing and duration of gate signals for the gated peak stretchers and the gated integrator, adjusting the gated integrator integration time constant and gain and offset adjustments throughout to optimize analog dynamic range constraints. The output of the fast analog divider circuit was input to a multi-channel analyzer to gauge the resulting charge ratio calculations. Cs-137 and Co-60 gamma sources and a mixed neutron and gamma source (Cf-252) were used to help in making these initial adjustments. The experimental setup consisted of a BC-501A scintillator (cylinder with 4.625-inch diameter and 4-inch height) coupled to an XP4512B phototube and the PSD module. The radiation sources were placed approximately 6 inches from the detector face with allowance for a 4x4x4-inch tungsten cube used as a gamma shield.

Adjustments were performed to first insure that gammas of any energy above a certain threshold were identified in the same charge ratio range. Preliminary charge ratios for shielded and unshielded Co-60 and Cs-137 gamma sources are plotted in Figures 3 and 4. Preliminary measurements were performed using both a gamma-shielded and unshielded Cf-252 source with results plotted in Figure 5 with further optimization in progress.

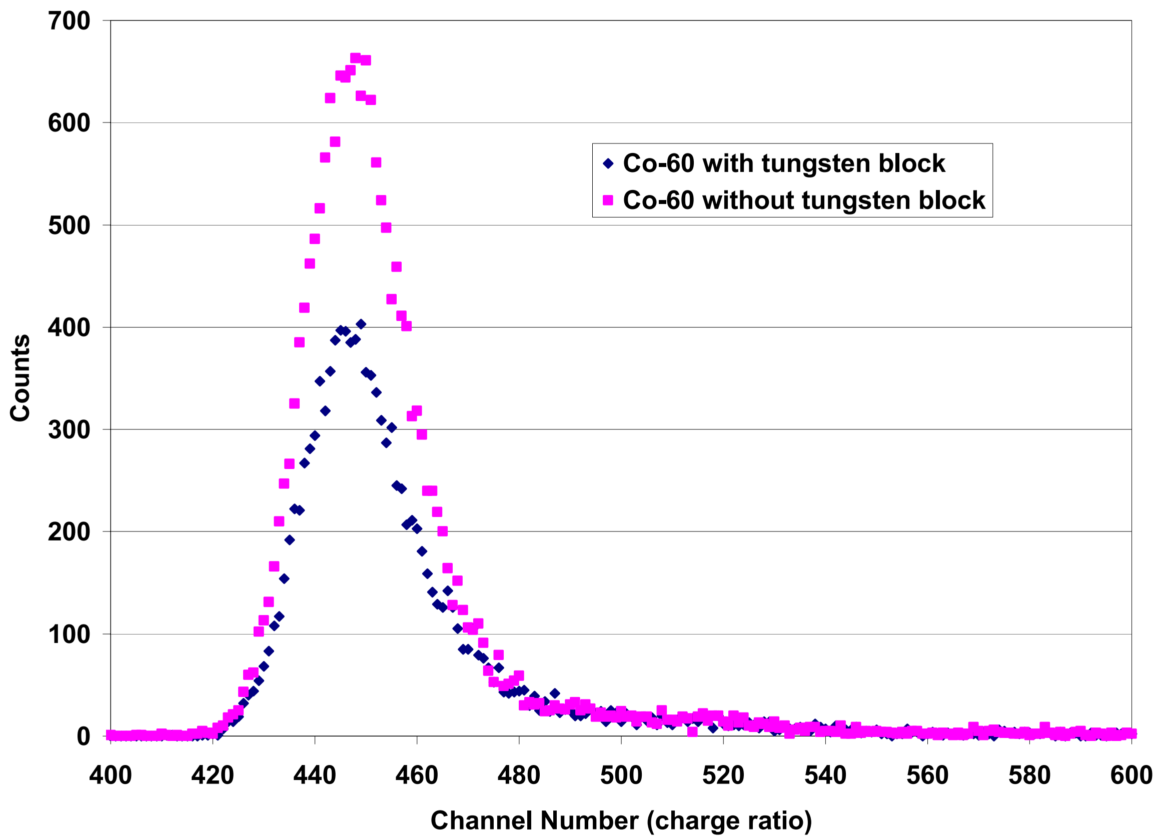

Fig. 3. Distribution of PSD module calculated charge ratios for a Co-60 source, with and without a tungsten gamma shield block.

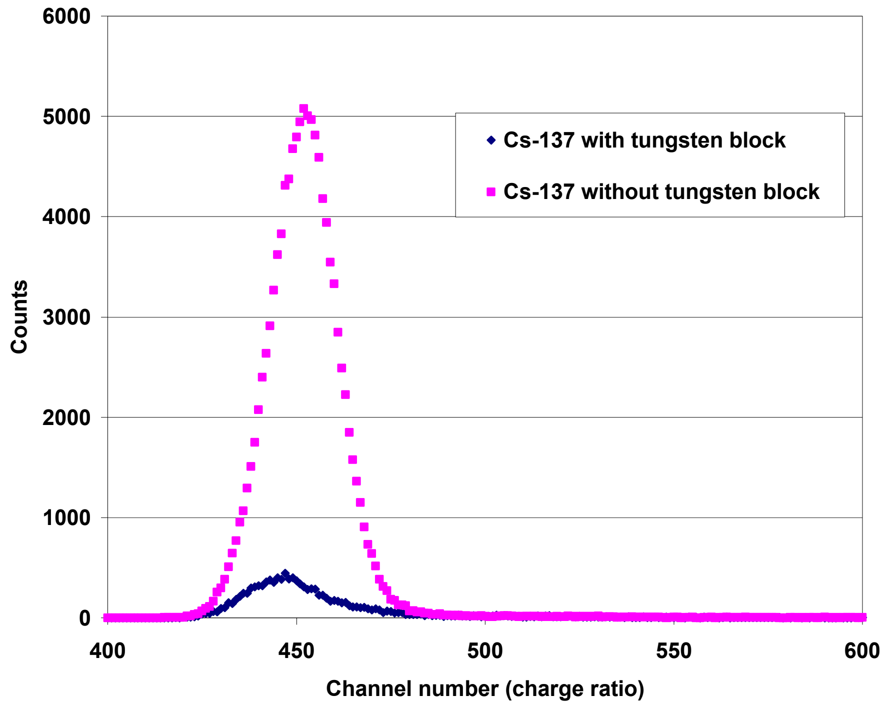

Fig. 4. Distribution of PSD module calculated charge ratios for a Cs-137 source, with and without a tungsten gamma shield block.

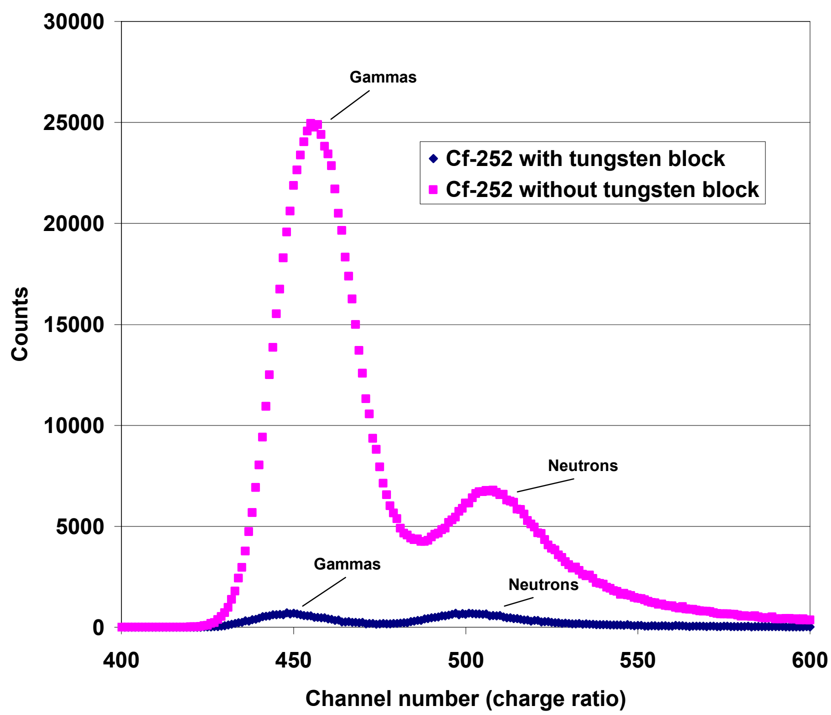

Fig. 5. Distribution of PSD module calculated charge ratios for a Cf-252 source, with and without a tungsten gamma shield block.

SUMMARY

A fast, on-line PSD method for use in the NMIS has been developed. It has been shown that attributes of the fissile material under investigation are related to features extracted from the signatures measured by NMIS. The ability to separate the total signature into its neutron and gamma components will lead to the possibility of extracting new features. On the basis of previous studies, these new features are more sensitive to the attributes of the fissile material than the features extracted from the total signature. Initial testing of the PSD module has indicated that a fast analog calculation of charge ratios for organic scintillator detector signals can discriminate radiation types in fewer than 300 nanoseconds. Future development and testing efforts on the fast, on-line PSD system for NMIS will attempt to optimize and improve the separation in charge ratio discrimination, decrease the decision time, and to test the windowing discrimination backend processing to eliminate regions of overlapping charge ratio for neutron and gammas and to become inputs to a radiation-type discriminating NMIS.

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