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Monitoring Neutron Generator Output in a Mixed Neutron-Gamma Field Using a Plastic Scintillator

S. Mitra and L. Wielopolski

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Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

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***Abstract*–Quantitative neutron-induced gamma-ray spectroscopy employing neutron generators (NGs) entails monitoring them for possible fluctuations in their neutron output. We accomplished this using a plastic scintillator and recording a spectrum from which we selected a neutron region-of-interest (nROI) to discriminate between neutrons and the accompanying high-energy gamma-rays. We show that the selected nROI is insensitive to changes in the gamma-ray background, thus allowing satisfactory normalization of the gamma-ray spectra of an in-situ system for analyzing soil carbon.**

I. INTRODUCTION

NEUTRON Generators (NGs) are widely applied in fast neutron-induced gamma-ray spectroscopy for the elemental characterization of explosives, and contraband, and similarly in the oil-well logging, coal- and cement-industries [1-4]. In the present case, a pulsed 14 MeV NG is being used in a field-deployable instrument to measure carbon in soil, in-situ. Such analysis of bulk soil is required both for emerging precision agriculture and for monitoring and verifying the soil's carbon stocks resulting from carbon-sequestration programs [5, 6]. With these goals, it is essential that we ensure the accuracy and stability of our instrumentation. However, since the neutrons are produced electrically, the outputs of the NGs may fluctuate. Thus, it is important to monitor neutron outputs during any experimental run to normalize the gamma-ray spectra.

The commonest method of detecting fast neutrons is based on their elastic scattering of incident neutrons on hydrogen -containing scintillators. This results in a recoil proton ranging in energy up to the neutron's full energy. The energy of the recoil protons then is deposited in the scintillator and converted to fluorescence. Among the large variety of hydrogen-containing scintillators available, liquid scintillators and plastic scintillators are inexpensive, and therefore most often used. Although they efficiently detect fast neutrons, they also are sensitive to gamma-rays that usually accompany the neutrons. Hence, to accurately determine the fast neutron output of the NG, it is critical to distinguish the contribution of gamma-rays from the neutron counts in the neutron detector's total response. For liquid scintillators, the most popular method for discriminating between the scintillations due to neutrons and gamma-rays relies on the difference in the rise times of the scintillation pulses excited by neutrons (recoil protons) and gamma-rays (Compton electrons) [7]. However, for plastic scintillators, such discrimination between the shapes of the pulses from neutron and gamma-events cannot be resolved by current transit time spreads of photomultiplier tubes (PMTs) and fluorescence lifetimes of scintillators [8]. This report describes a method to monitor the neutron output of a pulsed 14-MeV neutron generator via a plastic scintillator. The method relies on recording a neutron-gamma spectrum in which a fast neutron region-of-interest (nROI) has been identified. The report discusses the effectiveness of the nROI for discriminating against the accompanying gamma-rays.

II. METHODS

A. Data Acquisition System and setting of nROI

A plastic scintillator (BC-400), 1.27 cm thick and 1.9 cm in diameter, was used for recording the neutron spectra. The pulse output of the PMT was directly input to a Canberra DSA 1000 digital multichannel analyzer (MCA). All spectra were recorded with a pulsed 14-MeV NG set at a pulsing frequency of 10 kHz with 25% duty cycle.

To distinguish the fast-neutron response from the composite neutron- and gamma-response, spectra were acquired separately, during the neutron burst and then between the bursts when the fast-neutron flux is expected to be absent and only slow neutrons and high-energy gamma-rays present. We accomplished this by gating the neutron spectroscopy system with the same logic pulse that also triggered the NGs ion-source for generating neutrons. The logic level HIGH (beam ON state) acquired the fast-neutron and gamma-ray spectra, while the logic level LOW (beam OFF state) acquired the slow-neutron and gamma-ray spectra. However, since the actual neutron burst always lags the leading edge of the ion-source pulse by a few microseconds, to better optimize the gates, we routed the pulse from the NG via a gate and delay generator. Fig.1 is a schematic of the data acquisition system.

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S. Mitra and L.Wielopolski are with the Department of Environmental Sciences, Environmental Research and Technology Division, Brookhaven National Laboratory, Upton, NY11973 (USA) (telephone: 631-344-6377, e-mail: smitra@bnl.gov).

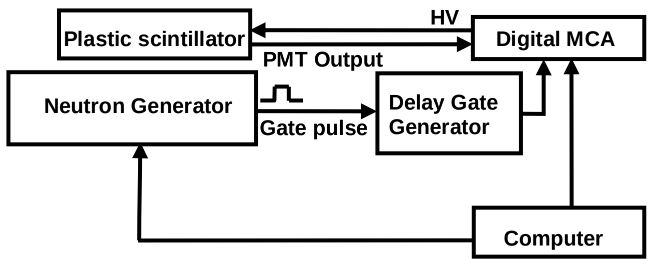

Fig.1. Schematic of the data-acquisition system for obtaining gated spectra during and between neutron bursts.

We established the time profile for the production of fast neutrons by recording spectra with a 1 µs- wide gate and different delay times from the leading edge of the ion-source pulse. Fig. 2 shows the composite yield (fast neutron and gamma) as a function of the delay time.

As depicted, although the ion-source pulse was 25 µs wide, neutron production began after a delay of about 10 µs after the leading edge of the ion-source pulse. Fig. 3 shows the gated spectra obtained for 1, 10, 20 and 25 µs time delays; it illustrates the time profile of fast neutrons. The optimized gate for recording the fast-neutron burst was accordingly selected to have a 10 µs delay and width of 15 µs.

Thus, outside this gate, during the OFF state data-acquisition we expect that the spectrum recorded will mainly reflect slow neutrons and high-energy prompt gamma-rays. Fig. 4 illustrates the response of the plastic scintillator during the optimized ON and OFF states. A prolonged 12 hour background due to high-energy cosmic-rays also was recorded: Furthermore, as the figure shows, the response to gamma rays and cosmic rays end at about the same channel number. We chose an nROI above this high-energy gamma-ray response.

B. Performance of the nROI in a mixed neutron- gamma field

The sensitivity of the selected nROI was tested by varying the high-energy gamma-ray component near the plastic scintillator during the ON state of the NG. This was done by (1) decreasing the production mainly of the "inelastic" prompt gamma-rays by removing the water shielding tanks that surround the NG, and, (2) varying the height of the spectroscopy system (the NG with the plastic scintillator mounted on it and the water tanks) from the ground to lower the intensity of gamma-rays induced in the soil.

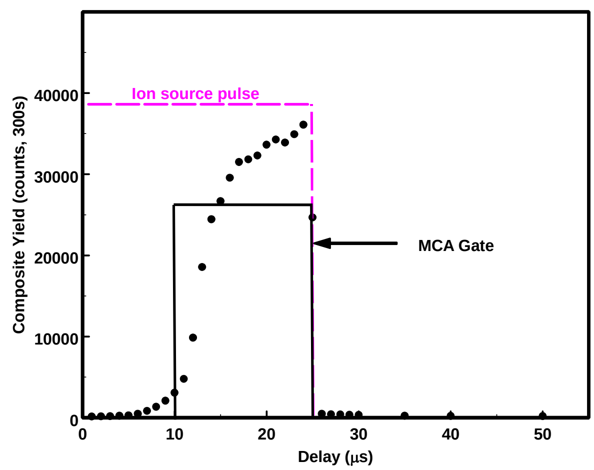

Fig. 2. Time profile of the neutron production relative to the leading edge of the ion-source pulse. The composite yield was recorded with a 1µs wide gate. The optimized" MCA Gate" (HIGH state) selected had a delay of 10 µs from the leading edge of the ion source pulse and width of 15 µs.

The neutron output also was monitored in parallel by activating Cu foils at a predetermined site on the NG. The foil activation technique utilizes the ^{63}Cu (n, 2n) ^{62}Cu reaction that has a threshold at a neutron energy of 11.5 MeV. Each foil was activated for 1200 s followed by a 30 s wait before counting the 0.511 MeV annihilation gamma-rays in a well-type gamma detector for 600 s.

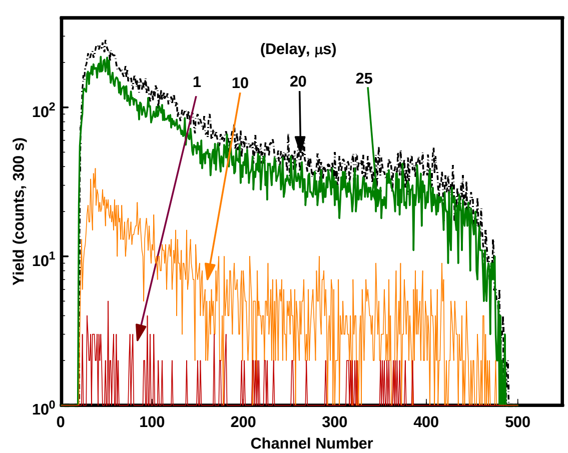

Fig. 3. Gated spectra from some selected time delays acquired with a 1 µs wide pulse.

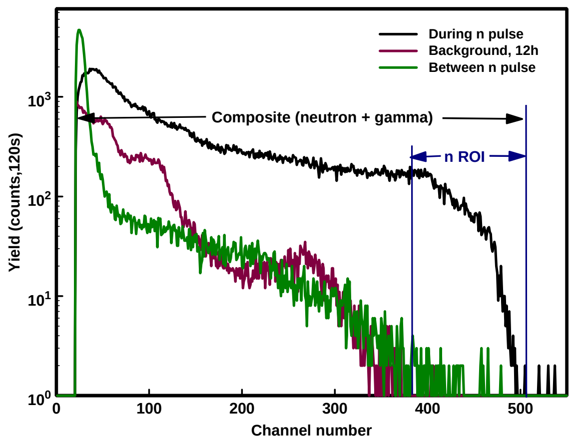

Fig.4. Neutron spectra recorded with the optimized gate. The LOW state (between the neutron pulses) was 85 µs wide to the end of the cycle. The NG was pulsed at a frequency of 10 kHz and 25% DC. The 12 h background was an ungated spectrum.

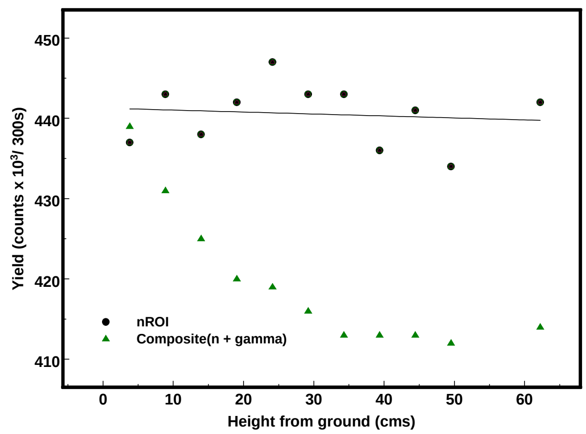

Fig.5. Variations in the yields of the composite (n + gamma) spectra and the nROI with distance from the ground. The nROI counts are normalized to the composite counts of the lowest position of the spectroscopy system. The line represents a linear fit to the nROI data points.

III. Results

Table I summarizes the effect of varying the fast neutron induced "inelastic" gamma-rays in the vicinity of the plastic scintillator. Data for the water-shielding experiments are the mean of 14 determinations from runs conducted on different days, while those without the water shielding are in triplicate.

TABLE I
PLASTIC SCINTILLATOR YIELDS WERE OBTAINED FROM TIME GATED SPECTRA DURING THE ON STATE OF THE NG. THE ^{62}CU YIELDS WERE FROM THE CONCURRENT CU FOIL ACTIVATIONS.

Water shielding	^{62}Cu Yield	Plastic scintillator yield	
		Composite (n+γ)	nROI
with	2175 ± 115	1673657± 5208	121046± 2313
without	2316 ± 161	1564199± 1251	121652± 349

The data show that the composite yield fell by nearly 7 % when the water tanks were removed, while the mean counts in the nROI remained nearly constant. The NG neutron output during these experiments as measured by Cu foil activation remained constant.

In a second series of experiments, the spectroscopy system was raised from the soil's surface and the neutron spectrum was recorded for 300s at each height. Fig. 5 shows that the composite yield decreased as the gamma-ray intensity induced in the soil decreased with increasing height from the soil. The nROI yield remained unaffected demonstrating that this region of the spectrum is relatively free from gamma-rays.

IV. CONCLUSIONS

Selecting the nROI effectively separates the fast neutrons from the neutron-induced gamma-rays. This change improves (a) the ability to monitor fluctuations in the NG output and, (b) quantitatively analyze a gamma-ray spectroscopy system.

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