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Detection of Pulsed, Bremsstrahlung-induced, Prompt Neutron Capture Gamma-rays with a HPGe Detector

James L. Jones

Idaho National Engineering Laboratory
P.O. Box 1625, MS 2802
Idaho Falls, Idaho 83415

ABSTRACT

The Idaho National Engineering Laboratory (INEL) is developing a novel photoneutron-based nondestructive evaluation technique which uses a pulsed, high-energy (up to 8-MeV) electron accelerator and gamma-ray spectrometry. Highly penetrating pulses of bremsstrahlung photons are produced by each pulse of electrons. Interrogating neutrons are generated by the bremsstrahlung photons interacting within a photoneutron source material. The interactions of the neutrons within a target result in the emission of elemental characteristic gamma-rays. Spectrometry is performed by analyzing the photoneutron-induced, prompt gamma-rays acquired between accelerator pulses with a unique, high-purity germanium (HPGe) gamma-ray detection system using a modified transistor reset preamplifier. The detection system, the experimental configuration, and the accelerator operation used to characterize the detection system performance are described. Using a 6.5-MeV electron accelerator and a beryllium metal photoneutron source, gamma-ray spectra were successfully acquired for Al, Cu, polyethylene, NaCl, and depleted uranium targets as soon as 30 μs after each bremsstrahlung (or x-ray) flash.

1. INTRODUCTION

Many practical radioisotopic-based[1] and accelerator-based[2,3,4] nondestructive evaluation (NDE) methods using neutron-induced prompt gamma-rays have been successfully developed for various applications over the last decade. In addition, accelerator-based, x-ray radiography has been well established for over 100 years. Combining the advantages of these two NDE technologies has been limited by the fact that gamma-ray detectors are rendered ineffective by the intense bremsstrahlung photons (i.e., x-ray flash) associated with each electron accelerator pulse. In support of a Department of Energy (DOE) project, a prototype HPGe-based, NDE system is being developed which permits spectrometry from gamma-rays acquired between accelerator-produced, bremsstrahlung pulses.

2. EXPERIMENTAL METHOD

All experiments were performed at the Idaho State University Particle Beam Laboratory using a photoneutron source produced with a 500 g beryllium metal target and the selectable-energy, transportable, INEL-designed, VARITRON electron accelerator[5] and a modified HPGe detection system. The INEL VARITRON was operated with an average current of 1 μA, an approximately 6.5-MeV electron beam energy (see measured beam energy profile in Figure 1), and a repetition rate up to 90 Hz. Each electron accelerator pulse width was 2.5-μs wide. The operation resulted in a maximum x-ray dose rate of 30 rads/min (in air) at one meter along the beam axis.

The gamma-ray detection system included a portable, 20 percent, p-type, 102-cc Princeton Gamma Technology Inc. (PGT), coaxial HPGe detector (Model IGC 2020) with power supply, a PGT transistor reset preamplifier (TR14P), a Canberra 2025 spectroscopy amplifier, a standard Ortec gate delay signal generator, a Nuclear Data Model 579 ADC, and a multi-channel spectrum analyzer. The transistor reset preamplifier was modified to allow the additional input of an external 5-μs wide, TTL pulse which enabled functional resets of the detector/preamplifier assembly within 30 μs after each x-ray flash. The energy resolution of the detector was checked with a cobalt-60 source before and during each test to provide energy calibration and to assess possible resolution degradation due to neutron damage. No damage was observed.

A top view of the experimental configuration used is shown in Figure 2. The electron beam axis is normal to the axial HPGe detector axis, which is aligned with the primary photoneutron source (the beryllium metal target) positioned 12-cm directly in front of the electron-to-bremsstrahlung converter. The detector's front face was 42 cm from the primary neutron source. Two 2.54-cm thick sheets of polyethylene were located near the beryllium to provide some neutron thermalization to enhance capture gamma-ray emissions from the target material. To reduce the x-ray flash effect on the HPGe detector, high-Z photon

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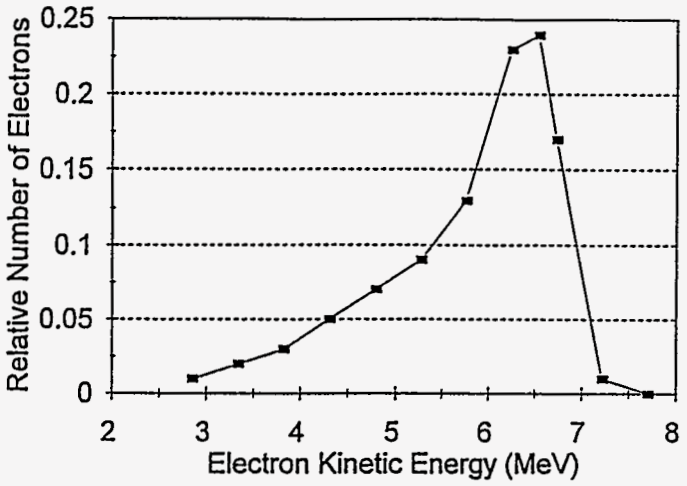

Figure 1. Measured electron beam energy profile.

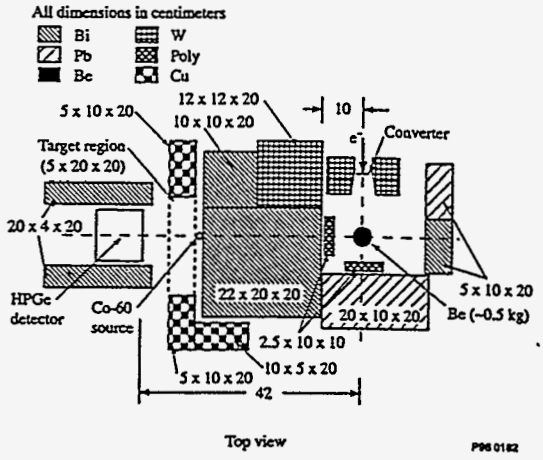

Figure 2. Experimental configuration.

shielding completely surrounded both the x-ray converter and the beryllium metal. In addition, the detector was axially surrounded by a 4-cm thick bismuth annulus. A 22-cm thick channel of bismuth was incorporated into the photon shielding along the HPGe detector axis to provide neutron transport to the target region. The specific amount of shielding material in this configuration has not been minimized.

The target region was positioned normal to the detector axis, located directly in front of the detector, and had a volume of 5 x 20 x 20-cm. Target materials were Al metal(2.8 kg), Cu metal(9.3 kg), polyethylene(0.9 kg), NaCl granules(2.7 kg), and depleted uranium metal(2.2 kg). All targets, except the last two, were in the form of two standard bricks, each having the dimensions - 5.08 x 10.2 x 20.3-cm. The NaCl target was in granular form having a density of 1.34 g/cc. The uranium target was configured as a stack of two rectangular plates, each 0.3-cm thick (along the detector axis) and having a mass of 1.1 kg.

3. RESULTS

The transistor reset preamplifier circuit was custom modified to permit enhanced electronic reset. The circuit modification allowed the remaining electronic circuit to recover during the discharge of the detector immediately after each x-ray flash. The 5-μs wide, TTL reset pulse was synchronized with the accelerator trigger pulse. For a 33 Hz accelerator repetition rate and an air-filled target (See Figure 2), Figure 3 shows the oscilloscope traces of the preamplifier output response before and after the preamplifier modification. Note the time scale differences between these two traces. Before the modification, the preamplifier quickly (within 100 μs) performed an initial reset. The remaining circuit design prohibited subsequent resets (seen as repeated responses of parallel, negative linear slopes) until about 25 ms after each accelerator pulse. With the modification, the preamplifier recovered within 100 μs and continued resetting normally. Recovery as soon as 30 μs after each x-ray flash event was obtained.

The acquired gamma-ray spectra, with major gamma-ray emission lines indicated, are presented in Figures 4 and 5. Spectra have been scaled by constant factors to provide visual separation. Each spectra was acquired within 600 s and used an acquisition window beginning 30 μs after the x-ray flash and extending to the beginning of the next accelerator pulse. The accelerator's repetition rate was 47 Hz. The large, single peak occurring between channels 1000 and 1250 in some spectra was an acquisition artifact, which was corrected in the data acquisition of the polyethylene and depleted uranium targets. Clearly, material identifiable gamma-ray emissions are observed along with the cobalt-60 emissions.

A pulsed helium-3 neutron detector[5], designed to operate in a pulsed bremsstrahlung environment, was centered along the HPGe detector axis but opposite the accelerator beam axis at one meter from the axis. The resulting total neutron production was 2.9×10^7 n/s (avg.) and 2.4×10^{11} n/s (peak) or a total assembly production of 6.1×10^5 neutrons per pulse. Monte Carlo calculations have predicted detector energy depositions rates of up to 1000 GeV/s (avg.) or about 21 GeV per accelerator pulse. The

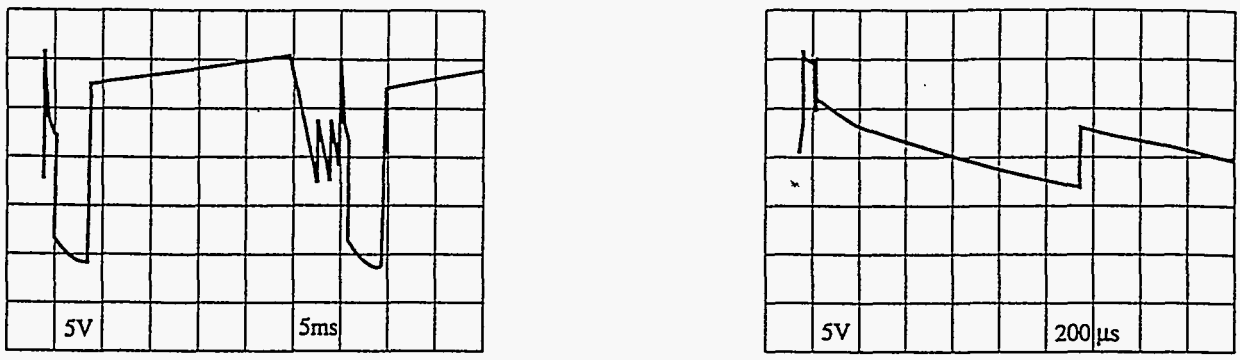

Figure 3. Preamplifier output response before and after x-ray flash reset modification.

detector's energy deposition from gamma-ray pulses is approximately four orders of magnitude less, and when compared to the bremsstrahlung contribution, the neutron energy deposition is negligible.

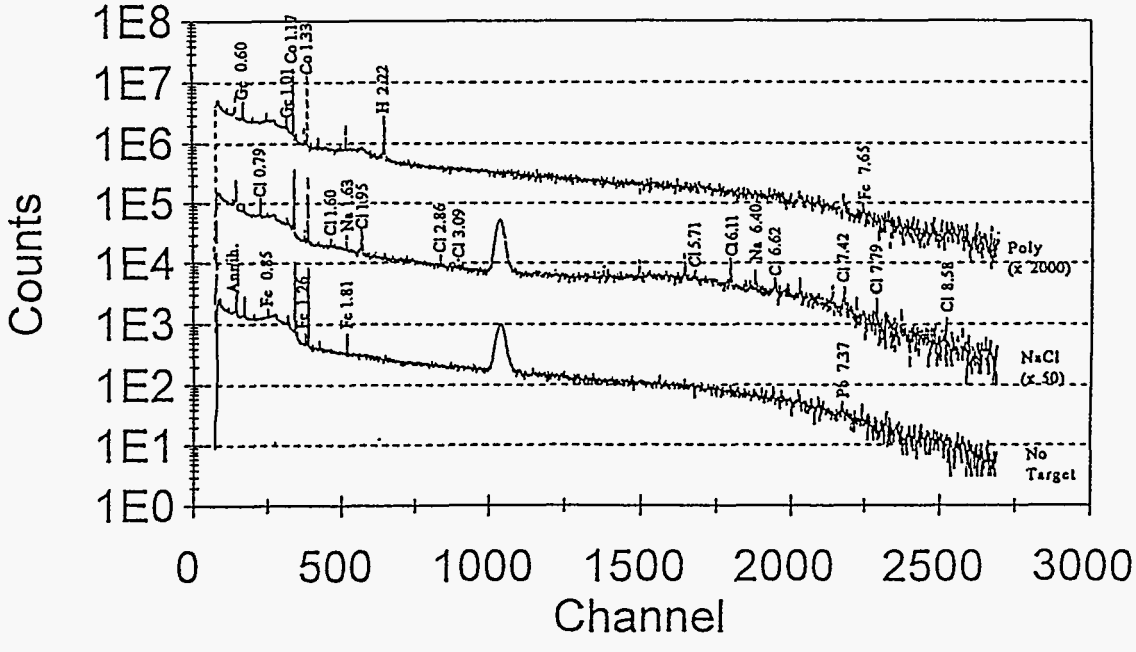

Figure 4. Measured gamma-ray spectra from polyethylene (Poly), NaCl, and no target (air) acquired between bremsstrahlung pulses (with a 30 µs to 21 ms acquisition window) using a modified HPGe-based detection system.

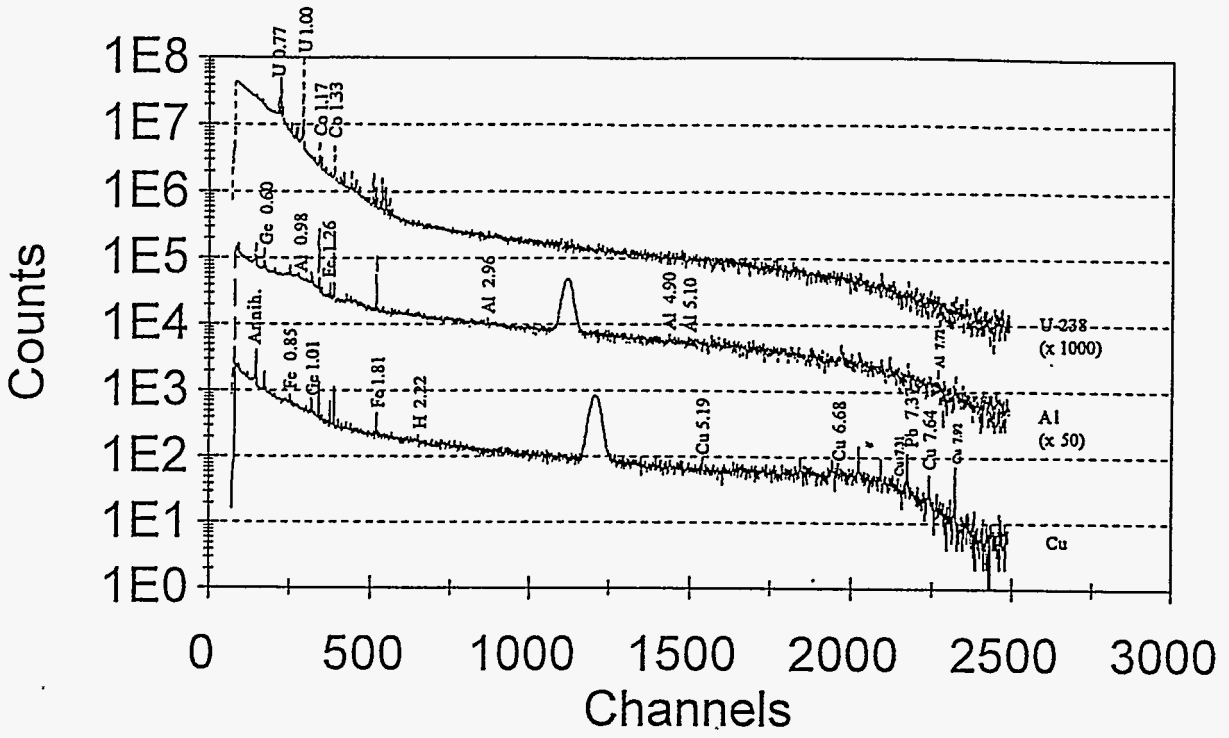

Figure 5. Measured gamma-ray spectra from U-238, Al, and Cu acquired between bremsstrahlung pulses (with a 30 μs to 21 ms acquisition window) using a modified HPGe-based detection system.

4. CONCLUSIONS

A photoneutron-based NDE technique has been investigated which uses prompt gamma-ray emissions acquired between bremsstrahlung pulses. Initial results, using a transportable, 6.5-MeV electron accelerator and a modified HPGe-based, gamma-ray detection system, have shown material identifiable gamma-ray spectra. The modified detection system allowed gamma-ray acquisition as soon as 30 μs after each accelerator pulse, with an accelerator repetition rate of up to 90 Hz.

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