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Development of an "isotopics" pulser*

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Abstract

We have developed a pulser that is able to generate a simulated signal from a high-purity germanium (HPGe) detector for various plutonium isotopes. In this paper we describe the development of an "isotopics" pulser for the simulation of signals that are produced by an HPGe detector. The present pulser generates the waveforms that are produced by an HPGe detector both before and after the preamplifier. These signals have been input into a normal MCA and the result closely simulates a genuine pulse-height distribution.

Goal of the Development

The goal of this project was to show that it is possible to generate electronic signals that can accurately mimic the signals that are produced by a high-purity germanium (HPGe) gamma-ray detector. The underlying reason for the pulser was to develop a method that would allow the production of signals that are produced by a source of plutonium or uranium without the logistical difficulty of measuring actual material.. We believe that this electronic source has at least three immediate applications:

1. development of analysis software
2. Authentication of. measurement systems
3. As a training aid..

We see other applications of the "isotopics" pulser; however, all of the applications of the pulser have a common theme. The interrogation of plutonium or uranium is logistically complicated, particularly for low-burnup plutonium and highly enriched uranium, and therefore rather expensive..

Production of the electronically synthesized HPGe gamma-ray spectra

Production of electronically synthesized HPGe gamma-ray spectra proceeded in two phases. In the first phase, a library of computed waveforms was computed that represented the pulse train from gamma-ray interactions in an HPGe detector from a plutonium source. The second phase accesses the library to generate a simulated detector output.

Phase 1: computing and recording a pulse train library. This phase consists of four steps.

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1. We generated the detailed gamma-ray source term for a specific plutonium isotopic mixture. For this demonstration we assumed a low-burnup plutonium source with a ^{240}Pu to ^{239}Pu ratio of approximately 0.06. In addition, the other isotopes associated with low-burnup plutonium (^{236}Pu, ^{238}Pu, ^{241}Pu, and ^{242}Pu) were included in this calculation. This was accomplished by using the heavy-element gamma-ray source term code GamGen[1].
2. This source term description was used as part of the input to a radiation transport calculation using the MCNP code[2]. In the MCNP model we assumed a 1-kg sphere of plutonium placed at meter from the face of an HPGe detector. The MCNP model followed each of the gamma rays to the surface of the germanium detector. The four-vectors of the gamma rays at the surface of the detector were recorded.
3. These gamma-ray four-vectors were then used as input to the GEANT[3] code from CERN to computationally transport the gamma rays and their induced charge carrier pairs in an applied electric field until all of their energy was deposited. At every interaction point the position of the interaction was recorded, as was the amount of energy deposited at that point.
4. The position of the interaction point and the energy deposition was used to generate a waveform[4]. This waveform is detector-dependent and, for the first stage of development the calculations were performed for an HPGe detector of 50% relative efficiency. The waveforms were digitized into 128 contiguous time bins of 15 ns width, producing a pulse duration of 1.9 µs. These waveforms are stored on disk for later use.

Phase 2: Accessing the library to simulate a detector output

1. The digitized waveforms on disk are then used to generate an electronic waveform using a commercial arbitrary waveform generator. For this purpose we used a model AWG1000 arbitrary waveform generator from the Chase Scientific Company[5]. The software that was used to read the waveforms recorded on the disk is a simple C code.

   In retrospect this card had more capability than we needed for this project. The AWG1000 has the ability to have a sampling rate of 1 Gs/sec; we only ran the AWG1000 at 66 Ms/sec. The reasons why we did not take full advantage of the AWG1000 was twofold: 1) the features of the waveform could be reproduced on the 15 ns/bin time frame, 2) we wanted to limit the size of the files that we were using.
2. The signals from the waveform generator can be fed directly into a commercial multichannel analyzer, which generated the simulated plutonium pulse-height distributions.

   In addition, we have made a version of the waveforms that can be input directly into a preamplifier of a HPGe detector. This option has not been fully debugged at this time.

Experimental Results

The results using the gamma-ray synthesizer were quite satisfactory. Pulse-height distributions produced by the synthesizer were analyzed using the Pu-600 software[6] to determine the ^{240}Pu to ^{239}Pu ratios and produced results that were consistent within measurement uncertainties with the isotopic ratio that was used to generate the pulse height distribution. The errors in the analysis were due mainly to the limited number of waveforms that were generated.

Conclusions

We have shown that an electronic gamma-ray synthesizer can be made based on first principles calculations. The results, in fact, exceeded our expectations. We have concluded that a larger number of waveforms are necessary to recreate the features of the continuum at higher energies. We also determined that more work is necessary to insure the fidelity of the spectrum at low-energies. We are pursuing the generation of a data base of waveforms that could be used for a variety of isotopic mixtures of plutonium and uranium.

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