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Signatures of Special Nuclear Material: High-Energy γ Rays Following Fission

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Since September 11, 2001, much effort has been devoted to the development of new and improved means for the detection and prevention of the clandestine transport of special nuclear material (SNM, i.e. ^{235}U or ^{239}Pu) and other materials for producing weapons of mass destruction. In a recent *Brief Communication*, Borozdin *et al.*[1] showed that cosmic-ray muons could be used to image dense objects inside containers. Here we describe a method for unequivocally identifying SNM in large seagoing containers. Our method is based on the fact that neutron-induced fission of ^{235}U or ^{239}Pu is followed by β decays of short-lived fission fragments during which large numbers of high-energy γ rays (above 3000 keV) are emitted.[2,3] These γ rays have energies above those of natural γ background, are emitted with significantly greater intensity per fission than β-delayed neutrons, have much higher probabilities of escaping hydrogenous cargo loadings than neutrons, and their energy spectra and time dependencies provide a unique signature of SNM.

To demonstrate the main properties of high-energy delayed γ rays, we produced neutrons by bombarding a 1-inch thick water-cooled Be target with 16-MeV deuterons from Lawrence Berkeley National Laboratory's 88-Inch Cyclotron. Neutrons were moderated using steel and polyethylene. We employed a pneumatic transfer system to shuttle targets from the irradiation location inside the polyethylene moderator to a remote shielded counting station. We irradiated ^{235}U (93% isotopic content), ^{239}Pu (95% isotopic content), wood, polyethylene, aluminum, sandstone, and steel targets for 30 seconds (in a thermal-neutron flux of 1.5×10^6/cm^2-sec) and acquired 10 sequential γ-ray spectra, each of 3 sec. duration starting 3 sec. after the end of bombardment. We used an 80% relative efficiency coaxial germanium detector and a 30-cm x 30-cm x10-cm plastic scintillator to detect γ rays and acquired data using ORTEC PC-based electronics and software.

The qualitative difference in the spectra from SNM versus that of any other material is illustrated in Figure 1, where we show the results obtained following the irradiations of 0.568 grams of ^{239}Pu and 115 grams of steel. From the steel target, we observed a small number of low-energy γ rays produced by the decays of long-lived isotopes such as ^{56}Mn ($t_{1/2}$ = 2.58 hours). Similar results were obtained for all other non-SNM targets. However, we observed a large number of high-energy γ rays produced by the decays of short-lived fission fragments from the ^{239}Pu target. Thermal-neutron fission of ^{235}U produces about 3 times as many delayed high-energy γ rays as from ^{239}Pu. We concluded that a sensitive method to identify SNM is simply to

integrate the total number of events in a wide energy interval. The results of this type of analysis for two energy intervals, (3000-4000 keV) and (4000-8000 keV), are shown in the inset of Figure 1. The integrated numbers of events from irradiated SNM decay with a short effective half-life of approximately 25 seconds, whereas those from all other materials tested showed much longer decay times. These two features – large numbers of high-energy γ rays decaying with a short effective half-life - provide a unique signature of SNM.

Because of the high-density of γ-ray lines produced by the decays of fission fragments, a practical system for interrogating large objects would not require high resolution detectors. In fact, we obtained the same results using the low-resolution plastic scintillator as we did with the germanium detector. Based on our measurements, we have estimated the response of a full-scale system employing a 14-MeV neutron generator producing 10^{11} neutrons per second and an array of scintillator detectors surrounding a standard cargo container in which a 5-cm diameter sphere of ^{239}Pu was hidden inside a load of wood . Neutron irradiation of this container for 30 seconds would result in about 350 *detected* γ-ray events above 3000 keV in 30 seconds (for ^{235}U the detected yield would be approximately 1000 events). Thus an entire cargo container could be scanned for SNM in about 1 minute. This system could be combined with a radiographic imaging system for rapid identification of SNM in a wide range of applications.

References

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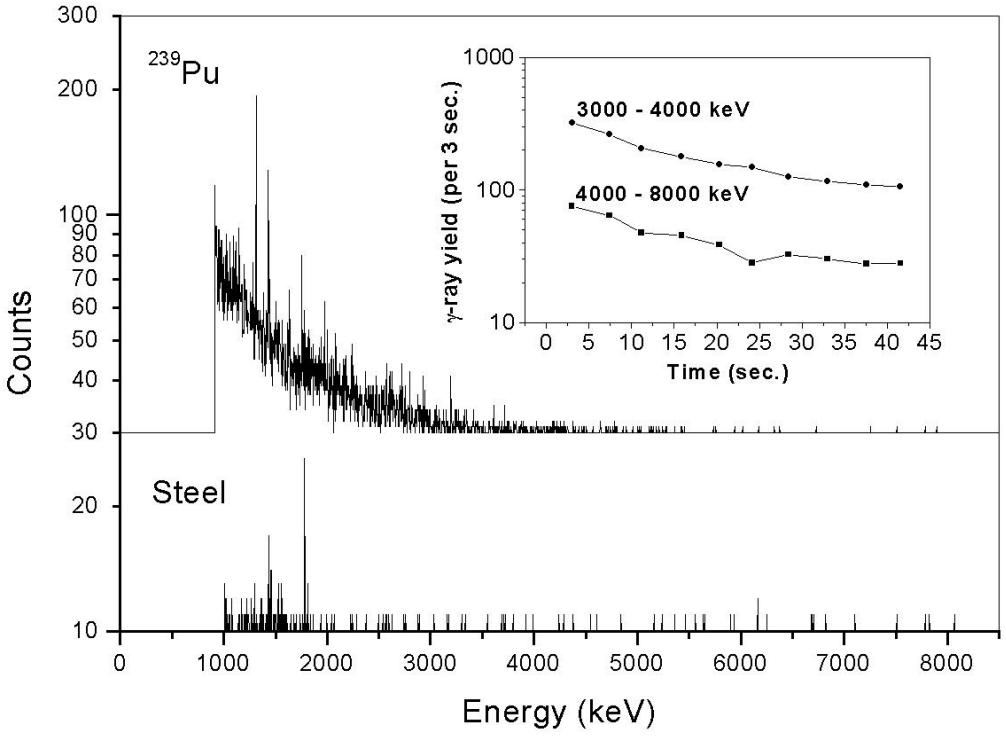

Figure 1. γ-ray spectra observed in a germanium detector in 30 seconds of live time following the neutron irradiation of 0.568 grams of ^{239}Pu and of 115 grams of steel. In order to display these two spectra on the same plot, offsets of 30 and 10 counts per channel were added to the data obtained from the ^{239}Pu and steel targets, respectively. Inset: background-corrected decay curves for gamma rays in the energy intervals 3000-4000 keV and 4000-8000 keV observed from the ^{239}Pu target. Similar results were obtained from a ^{235}U target.