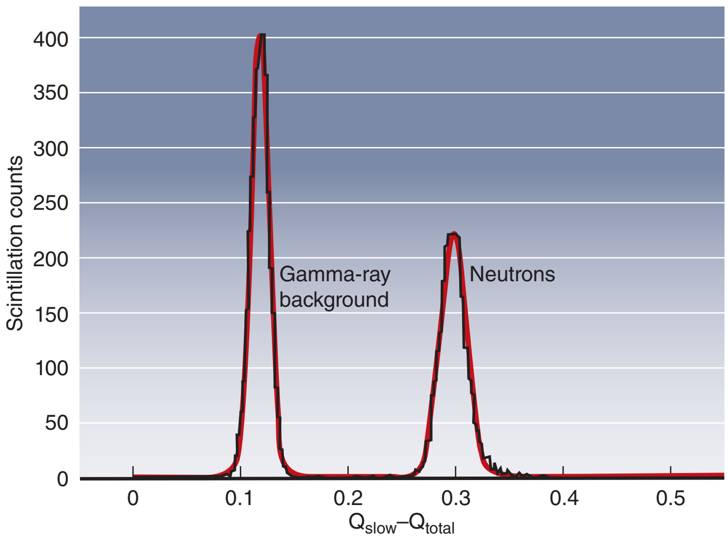
A Solid Solution for Neutron and Gamma-Ray Differentiation

ACCURATELY detecting illicit radioactive material moving through customs, border crossings, and pedestrian and transportation inspection portals is a critical national security objective for the U.S. Although highly sensitive and reliable detection systems are available today, existing systems consist of certain materials that are difficult to deploy in large volumes. What's needed is a new material that is easily fabricated and deployed. An effective detector in portal-inspection applications must also differentiate potentially dangerous radioactive sources from nonthreatening sources, such as cosmic rays, fertilizers, ceramics, decorative uranium glassware, welding rods, medical radioisotopes administered to cancer patients, and even bananas.

Lawrence Livermore scientists joined forces with collaborators from Eljen Technology in Texas to develop an enhanced plastic scintillator material that is a solid solution to efficient neutron and gamma-ray differentiation. The breakthrough material consists of a very high concentration of scintillating dye suspended in a polyvinyltoluene polymer matrix. This unique dye–polymer combination is extremely soluble. While plastic scintillators have been around since the 1950s, using such a high concentration of dye had not been considered to be a viable pathway. The team has received an R&D 100 Award for their work.



The new plastic scintillator is the first of its kind to discriminate between the desired neutrons and the gamma-ray background. In this experimental test with a Californium-252 fission source, the measured scintillation pulses from the neutrons are clearly distinguishable from the background signal. (Q_{slow}–Q_{total} is the ratio of delayed light to total light.)

Scintillating Materials Detect Radiation

Simply put, a scintillator is a substance that lights up when excited by ionizing radiation. This property makes scintillators useful in gamma-ray detection devices. For years, plastic scintillators have been used in gamma-ray detectors at transportation portals and at international crossing points. They have also been used in high-energy-physics experiments conducted at CERN in Switzerland and at Fermilab in the U.S. While conventional plastic scintillators can detect both gamma rays and neutrons, they have not been capable of distinguishing one from the other.

Organic crystals currently serve as one of the best types of neutron detectors, but the crystals can be difficult to grow and obtain in large volumes. Liquid scintillators present several hazards that hinder their use. Negative aspects of organic liquid neutron-detector materials include their toxicity, flammability, freezing points, and the difficulties in handling large amounts of these materials in field conditions.

Conversely, plastic scintillators pose none of the hazards or difficulties associated with those scintillator options. Given the low cost of plastic scintillator material, the material could be economically fabricated onto far larger surface areas than is possible with other neutron-detector materials, improving the nation's ability to identify radiation from illicit sources at transportation portals. Despite these benefits, plastic scintillators have always been considered to be far inferior to crystals or liquids. "It has been established opinion since the 1950s that organic crystals and liquid scintillators can work for detecting neutrons, but that plastics are not suitable for neutron detection," says materials scientist Natalia Zaitseva, who led the Livermore team.

Overcoming the Skeptics

After studying the available options and long-standing concerns, researchers at the Laboratory decided that the ease at which plastic scintillators can be shaped and fabricated makes them an extremely

Livermore physicist Natalia Zaitseva leads a research team that has developed the first plastic material capable of efficiently distinguishing neutrons from gamma rays.

useful material for gamma-discrimination applications. Further studies indicated that dye concentration in the plastic had to be at least 10 times greater than the amount previously used to achieve efficient discrimination of neutrons from gamma rays using plastic scintillators.

The thought that plastic scintillators could be created to efficiently discriminate neutrons from gamma rays came about, in part, from growing crystals with mixtures of the scintillating chemicals diphenylacetylene (DPAC) and stilbene. "We mixed DPAC with stilbene at 5 percent, 10 percent, and 15 percent, with no results," recalls Livermore materials scientist Steve Payne. "Suddenly at 18 percent, we could distinguish neutrons from gamma rays. Once we hit 40 percent, we had the full function." The result was the development of enhanced plastic scintillators that efficiently discriminate between neutrons and gamma rays.

Scintillators coupled to an electronic light sensor enable pulse-shape discrimination (PSD). PSD is a technique for detecting neutrons in the presence of background gamma radiation where particles are identified by the decay characteristics of the electronic pulse. These characteristics can then be analyzed and provide meaningful information about the particles that struck the scintillator. Tests have shown that the performance of the first plastic scintillators with PSD capability is comparable to that of the best commercially available liquid scintillators. (See the figure on p. 10.) Also, it may become possible to obtain scintillator plastics that are as good as the best scintillator crystals now in use.

"When we started this work, we had little understanding of how PSD was affected by the chemical composition of the scintillating materials. We have found some of the major principles of molecular interaction that determine the presence or absence of PSD properties in organic scintillators," Zaitseva says.

Reversing more than five decades of prevailing opinion by skeptics who said it could not be done, this diverse team of Laboratory researchers has demonstrated that their enhanced plastic scintillator material can efficiently differentiate neutrons from the gamma rays emanating from radioactive substances. Moreover, Eljen Technology, Livermore's industrial partner, has rapidly commercialized the new formulation and will have a product on the market within a few months.

—Geri Freitas

Key Words: diphenylacetylene (DPAC), gamma ray, neutron, organic crystal, plastic scintillator, polyvinyltoluene, pulse-shape discrimination (PSD), R&D 100 Award, radiation, stilbene.

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Livermore development team for plastic scintillators: (standing from left) Paul Martinez, Andrew Glenn, Sebastien Hamel, Steve Payne, and Keith Lewis; (sitting from left) Nerine Cherepy, Natalia Zaitseva, Iwona Pawelczak, Michelle Faust, and Leslie Carman. (Not shown: Ben Rupert; Charles Hurlbut, Loretta Hernandez, and Matt Jackson of Eljen Technology.)