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A Detector Radioactive Particles Can't Evade

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A DETECTOR RADIOACTIVE PARTICLES CAN'T EVADE

As part of its national security mission, Lawrence Livermore develops technologies to help government agencies prevent terrorists from smuggling nuclear materials into the country. One ongoing effort is to design radiation detectors that can distinguish threat sources from legitimate sources, such as medical isotopes, and naturally occurring radiation. (See *S&TR*, September 2004, pp. 4–11; May 2006, pp. 4–10.) Detectors intended for use by nonspecialists must be easy to operate and require minimal maintenance. To be most effective, they also must detect both gamma and neutron energies.

That may sound like a lot to ask of one instrument, but the Ultrahigh-Resolution Gamma and Neutron Spectrometer (UltraSpec) delivers all of these features. UltraSpec is so sensitive that even the minute thermal energy deposited by a single gamma ray or neutron can be detected with high precision. With this capability, the detector can identify differences in composition that help reveal a material's origin, processing history, and likely intended use. In addition to its application as a counterterrorism technology, UltraSpec can be used to protect nuclear material stored at nuclear power plants, to evaluate weapon stockpiles, and to verify material composition.

UltraSpec is an ultrahigh-resolution spectrometer that can be configured to detect either gamma rays or neutrons. The instrument operates at extremely low temperatures to reduce thermal noise, and its measurement precision is 10 times higher than conventional gamma and neutron spectrometers. Data-acquisition electronics provide spectra that are displayed on a laptop computer.

UltraSpec was developed by a team of scientists and engineers from Livermore's Physics and Advanced Technologies and Engineering directorates working with VeriCold Technologies of Ismaning, Germany. The detector's design builds on a technology base established in three Laboratory Directed Research and Development projects. The UltraSpec team, which is led by Laboratory physicist Stephan Friedrich, received a 2006 R&D 100 Award for the detector's innovative design.

Analyzes All Signatures

UltraSpec uses an ultrasensitive thermometer to measure radiation energy. The thermometer is a superconducting sensor whose resistance changes rapidly with changes in temperature. Thus, when the detector absorbs a gamma ray or a neutron, the sensor precisely records the resulting increase in temperature. UltraSpec can operate as a gamma-ray or neutron spectrometer, depending on which radiation absorber is attached to the sensor. "To convert the spectrometer from one form to the other, a user simply opens the instrument and changes the sensor inside," says Friedrich.

Gamma-ray and neutron spectrometry is widely used to determine the isotopic composition of radioactive materials. During the decay process, radioactive isotopes emit characteristic energies that provide a "fingerprint" of a material's composition. Researchers use spectroscopic line intensities to determine the abundance and ratio of particular isotopes. With this information, they can then infer a material's age, origin, and processing history. The more precise a spectrometer is, the smaller the differences it can measure in isotopic composition and, thus, the more reliable it will be in identifying the source of an unknown material.

Most spectrometers are limited in the energy resolution and precision they can provide—a particular concern when analyzing complicated mixtures of radioactive elements. Some detectors cannot differentiate between legitimate and illicit sources of gamma rays. This capability is crucial when the threat source involves uranium or plutonium.

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As a gamma-ray spectrometer, UltraSpec uses a tin-foil detector to achieve a measurement precision greater than 0.1 percent for gamma-ray energies of about 100 kiloelectronvolts—the energy most relevant for nuclear forensics. This precision is about 10 times better than that of conventional gamma-ray spectrometers using high-purity germanium crystals.

Configured as a neutron spectrometer, UltraSpec uses lithium fluoride crystals and achieves a precision of 1 percent for neutrons in the megaelectronvolt range. The neutron spectrometer can also measure the amount of light elements, such as oxygen, that may be bound to a nuclear element. Gamma-ray spectrometers cannot detect these elements because many light elements do not emit gamma rays.

In addition, as a neutron spectrometer, UltraSpec can detect a nuclear material even when it is covered with dense shielding. For example, if a threat source were placed behind a heavy metal such as lead, the metal could absorb some of the emitted gamma rays, thus making the signal too weak for a gamma-ray spectrometer to record. Neutrons, however, can travel through heavy metals, providing a signal strong enough for UltraSpec to record.

The UltraSpec development team (from left to right): Stephan Friedrich, Owen Drury, Jan Batteux, Simon Labov, and Thomas Niedermayr.

Cool and Calm under Heat

As with all high-precision gamma-ray spectrometers, UltraSpec relies on extremely low operating temperatures to reduce the thermal motion, or noise, during operation. In the past, spectrometers have been cooled with liquefied gases such as liquid nitrogen or liquid helium. However, liquefied gases are expensive and difficult to handle, and cooling systems that use them require frequent maintenance. Mechanical refrigerators have been used in some detectors, but these systems have been susceptible to vibration, which precludes their use in high-precision measurement applications.

VeriCold Technologies has developed refrigerator technology that eliminates the vibration problem. The company's novel system uses a mechanical pulse-tube refrigerator to cool UltraSpec to its required operating temperature of about 0.1 kelvin.

Preserves the Evidence

Another advantage offered by UltraSpec is that the collected samples remain intact. Conventional mass spectrometers vaporize a sample and electromagnetically separate its elements based on the differences in their masses. The sample is therefore essentially destroyed, which prevents further analysis. In addition, traditional mass spectrometry, which must be performed by a trained specialist, may require several weeks to analyze a dilute sample with high precision. In contrast, UltraSpec does not chemically separate the elements, reducing analysis time from weeks to hours. And the cost to operate this fieldable detector is half that of conventional mass spectrometers.

UltraSpec's speedy analysis and automated operation make it a valuable technology for people working on the front lines of the nation's nonproliferation and counterterrorism efforts. With it, law-enforcement officers, airline and customs inspectors, and other security officials have a powerful tool to help keep the nation safe.

—Gabriele Rennie

Key Words: lithium fluoride, mechanical pulse-tube refrigerator, radiation detection, R&D 100 Award, Ultrahigh-Resolution Gamma and Neutron Spectrometer (UltraSpec).

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