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IMPROVED TECHNNOLOGY TO PREVENT ILLICIT TRAFFICKING IN NUCLEAR MATERIALS

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Introduction
The proliferation of nuclear, chemical, and biological weapons (collectively known as weapons of mass destruction, or WMD) and the potential acquisition and use of WMD against the world by terrorists are extremely serious threats to international security.

These threats are complex and interrelated. There are myriad routes to weapons of mass destruction—many different starting materials, material sources, and production processes. There are many possible proliferators—threshold countries, rogue states, state-sponsored or transnational terrorists groups, domestic terrorists, and even international crime organizations. Motives for acquiring and using WMD are similarly wide ranging—from a desire to change the regional power balance, deny access to a strategic area, or alter international policy to extortion, revenge, or hate.

Because of the complexity of this threat landscape, no single program, technology, or capability—no silver bullet—can solve the WMD proliferation and terrorism problem. An integrated program is needed that addresses the WMD proliferation and terrorism problem from end to end, from prevention to detection, reversal, and response, while avoiding surprise at all stages, with different activities directed specifically at different types of WMD and proliferators. Radiation detection technologies are an important tool in the prevention of proliferation. A variety of new developments have enabled enhanced performance in terms of energy resolution, spatial resolution, predictive modeling and simulation, active interrogation, and ease of operation and deployment in the field.

The radiation properties of nuclear materials, particularly highly enriched uranium (HEU), make the detection of smuggled nuclear materials technically difficult. A number of efforts are under way to devise improved detector materials and instruments and to identify novel signatures that could be detected. Key applications of this work include monitoring for radioactive materials at choke points, searching for nuclear materials, and developing instruments for response personnel.

Radiation Detection Center at Lawrence Livermore National Laboratory (LLNL)
Lawrence Livermore, which has been developing radiation-related technologies for decades, continues to adapt radiation detection devices for national security needs. In 1999, the Laboratory began forming its Radiation Detection Center (RDC), a multidisciplinary organization that centralizes Livermore's radiation detection efforts. The RDC's mission is to provide a focal point for radiation detection activities across

LLNL, bringing together the LLNL community of radiation detection specialists and thereby creating a center of excellence in radiation detection at LLNL. The RDC helps to initiate and support many projects throughout LLNL that are developing new technology for national security and basic science programs.

The RDC's primary focus is the detection, identification, and analysis of nuclear materials and weapons. Specifically, the RDC:

- Fosters the development and support of innovative radiation detection techniques and technologies required in many technical fields (e.g., nuclear physics, nuclear chemistry, particle physics, atomic physics, plasma physics, astrophysics, medical technology, nondestructive evaluation) to meet programmatic goals (e.g., in stockpile stewardship, nonproliferation, homeland security, emergency response).
- Serves as an institutional resource in radiation detection for LLNL and U.S. government agencies.
- Provides special facilities for instrument development, demonstrations, and joint experiments in radiation detection.
- Trains individuals in the use of radiation detection equipment and protocols (e.g., U.S. Customs, IAEA, Euratom, academic classes).

Imaging Detectors

One of the challenges facing nuclear researchers today is developing smarter detection systems that distinguish between radiation emissions from background and legitimate sources (e.g., medical isotopes) and those from threatening sources. Radioactive material is everywhere, from the concrete in our streets to the food we eat. Advances are being made in semiconductor-based gamma-ray imaging detectors. These imagers use increased sensitivity and spatial resolution to detect weak radioactive sources that would otherwise be masked by background gamma-ray emissions. Gamma-ray imagers are particularly useful when searching for lost, stolen, or hidden nuclear material in a large area. Two gamma-ray imaging approaches, with different objectives, are being pursued at LLNL.

The first imager is a hybrid semiconductor-based, collimatorless Compton imaging instrument. Recent efforts are working toward confirming that improvements can be achieved by using semiconductor-based, high-energy, position-resolution Compton imaging systems. The Compton camera operates without a mask or collimator, which can block many of the gamma rays emitted from a source. Instead, gamma rays coming from all directions at once are tracked as they scatter inside the detector. The camera's omni-directional sensitivity is significantly higher than that of other imaging systems. Mathematical algorithms are used to retrace the paths of the gamma rays within the detector, and the results reveal the direction of the source. The main goal for the camera is to detect clandestine nuclear materials. A field deployable prototype of the Compton camera is still a few years away. These systems will be modular and are therefore scalable from compact (near- and mid-range detection) and potentially portable systems to large-scale (long-range detection) and transportable systems. The initial hybrid system uses two double-sided strip detectors (DSSD) made from high-purity Si and Ge. This instrument has demonstrated imaging from energies of 120 keV to 12 MeV.

The second imager is based on a coded-aperture approach using NaI detector elements. Called GRIS (gamma ray imaging system), this instrument is useful for a variety of applications, including treaty inspections, mapping radioactive contamination, and determining what is inside a suspect object. The images are encoded on the detector by placing a sheet of material opaque to the radiation in front of the detector. The sheet is pierced with a carefully selected hole pattern that allows researchers to mathematically recover the image with a simple computer program. GRIS was first developed for use in treaty inspections to monitor the location of nuclear missile warheads in a non-intrusive manner. Another version of GRIS being developed, the large-area imager, is suited for longer-range searches. The large area imager, approximately the size of a sofa, is mounted in a small truck and is capable of picking out weak radioactive sources from as far away as 100 meters. This project is leveraging mature technology, and a field prototype is being tested.

Active Interrogation to Detect Shielded Nuclear Material

LLNL is developing a concept for the detection of highly enriched uranium (HEU) and other materials of concern that is suitable for use in inspecting maritime cargo containers. A new radiation signature unique to special nuclear material (SNM) has been identified that uses high-energy (3- to 7-MeV), fission-product gamma-ray emission. This high-energy gamma signature is robust, in that it is very distinct compared to normal background radiation where there is no comparable high-energy gamma radiation. It has a tenfold higher yield than delayed neutrons, which are the basis of classical active interrogation normally used on small, unshielded specimens of nuclear material. Experiments have verified this signature and its predicted characteristics. The first experiment was done at the Lawrence Berkeley National Laboratory's 88-inch cyclotron, where directing a deuteron beam onto a beryllium target produced low-energy neutrons, and the fission-product high-energy gamma rays from very small HEU and plutonium samples were characterized. Subsequently, experiments were configured at LLNL where a 14-MeV commercial D-T neutron generator (2×10^{10} neutrons/second) was used to interrogate a 22-kg natural uranium target located inside a standard cargo container at a distance of 3 meters. We are now in the process of building a prototype that will include a new neutron source and detectors for improved performance.

Ultrahigh-Resolution Spectroscopy

LLNL is also developing spectrometers with ultrahigh energy resolution using superconducting micro calorimeter thermistor technology. These spectrometers are based on measuring the temperature rise that results from gamma ray or neutron absorption. They offer an order-of-magnitude improvement in energy resolution over conventional semiconductor and gas-based spectrometers, making possible high-precision isotopic analysis of nuclear materials in cases where high-purity germanium (HPGe) detectors (the current state of the art) lack the spectral resolution to separate nearby emission lines. Such a capability is needed for various nuclear nonproliferation, monitoring, and forensics applications. To date, we have developed spectrometers that have already achieved a resolution below 0.1% for soft gamma rays (energies of 60 to 120 keV), which is more than five times the theoretical best resolution for HPGe spectrometers and a resolution below 1% for neutrons (2.3 MeV). The ultrahigh-resolution neutron spectrometer uses lithium fluoride to absorb incoming neutrons. It then measures the released energy from the neutrons interacting with the lithium fluoride combined with the energy of the neutrons as they enter the detector. Work is under way to increase spectrometer sensitivity by several orders of magnitude by building detector arrays, first using arrays of single pixels and then using arrays of multiplexed pixels.

New Detector Material

LLNL is developing aluminum antimonide (AlSb) as a promising new material for achieving germanium-like energy resolution in a room-temperature radiation detector. Although germanium detectors, which operate at liquid nitrogen temperatures, are unsurpassed for high-resolution gamma-ray spectroscopy, there is a continuing need for an ambient-temperature gamma-ray detector with the portability and convenience of a scintillator but with significantly improved energy resolution. Based on theoretical band-structure calculations, computer-simulated energy spectrum analyses, and LLNL's achievement in producing significantly high-resistivity single crystals, the III-V semiconductor AlSb holds promise for ambient-temperature, high-energy gamma detection. To produce electronic-device-quality AlSb single crystals, we have had to overcome technical challenges related to crystal purity and stoichiometry that have discouraged other researchers from pursuing AlSb for this application. Our first processing breakthrough led to Czochralski growth of large, undoped AlSb crystals with a resistivity of $>10^6$ ohm-cm. Our second processing breakthrough was the use of a controlled atmospheric heat treatment to adjust crystal stoichiometry, which led to the production of high-resistivity, undoped single crystals of AlSb. By combining these two processing methods, we can produce single crystals of AlSb with resistivity of $>10^7$ ohm-cm which have been used in radiation detection. Further processing optimization is expected to produce AlSb crystals suitable for gamma-ray detection at room temperature.

Nuclear Detection Systems

Combining various types of radiation detection devices into a network that maximized the benefits of each is a challenge to improving the use of radiation detection for the prevention of proliferation. Sensor fusion is the discipline that permits data to be combined and produce a sum greater than the parts. For example, information from a portable radiation detection system can be combined with that from handheld detectors and video cameras, and all of the data can be integrated to give a more complete report than one type of detector could provide. LLNL has several projects under way to develop integrated systems for detecting nuclear or radioactive material.

- **Personal System.** RadNet is a low cost handheld radiation detector that includes a cellular telephone, a personal digital assistant with Internet access, and a Global Positioning System locator. The recently developed RadNet detector is both inexpensive (< $1000) and easily dispersed. When it is not measuring specific radioactive samples, a RadNet unit monitors the ambient radiation field and communicates with a central processing system in real time.
- **Road-Based System.** The Detection and Tracking System (DTS) is a rapidly deployable, reconfigurable network of sensors that can detect, characterize, and track ground-delivered nuclear and radioactive threats. A 20-node system,

developed in partnership with the Remote Sensing Laboratory, has been demonstrated near the entrance of a U.S. Army base. The system featured a new tracking algorithm that uses spectral signatures for correlating events detected throughout the network, source material identification, and pictures of suspect vehicles to facilitate law enforcement operations.

- **Waterway System.** For the Unconventional Nuclear Warfare Defense (UNWD) program, sponsored by DTRA, LLNL has developed systems for detecting and characterizing radioactive and nuclear threats delivered by water routes. Two buoys containing a suite of gamma and neutron detectors, telemetry systems, and solar- and wind-powered generators have been deployed at the waterway entrance to a U.S. Navy base.
- **Neutron detectors.** Alternate materials and methodologies for detecting neutrons offer the promise of more sensitive detection of nuclear materials.

Technology Deployment and Commercialization
Several LLNL-developed radiation detection technologies are being transitioned to the commercial sector. An electromechanically germanium detector has been commercialized as the ORTEC Detective, a portable radionuclide identifier using a high-purity germanium detector and based on the RadScout technology licensed from LLNL. A second technology, the Adaptable Radiation Area Monitor (ARAM) recently won an R&D 100 award. This NaI-based radiation detection system increases detector sensitivity and specificity to both high-speed moving sources and stationary sources through unique data analysis. The ARAM technology has been licensed to Innovative Survivability Technologies (IST) and is being used by the California Highway Patrol.

International Cooperative Efforts
As part of our integrated approach to nonproliferation and counterterrorism, LLNL is engaged in a number of projects addressing foreign border security and improving the ability of foreign customs services to detect and interdict illicit trafficking of weapons and weapons materials. Two phases of a DTRA-funded project to provide radiation portal monitoring system in Uzbekistan for the detection of smuggled nuclear materials has been completed. This work led to the development of a comprehensive plan for equipping approximately 40 points of entry in Uzbekistan with various types of radiation detection portal monitors (pedestrian, vehicle, rail).

We are collaborating with the Institute of Nuclear Physics in Tashkent, Uzbekistan, via Science and Technology Center of Ukraine (STCU) projects to develop enhanced fixed and mobile radiological analytical capability to augment the indigenous scientific infrastructure in Uzbekistan to detect illicit trafficking in nuclear, radiological, chemical, and high explosive materials. To expand cooperation in nuclear forensics, LLNL is helping to expand the scope of the Nuclear Smuggling International Technical Working Group (ITWG), presenting a concept for the ITWG Nuclear Forensic Laboratories (INFL). The INFL is an association of active practitioners of nuclear forensics, with the object of advancing the science of nuclear forensics and serving the needs of states and law enforcement agencies.

Radiation Detection Cooperation with the IAEA

LLNL is developing a new safeguards tool—scintillator-based antineutrino detectors—that will provide a non-intrusive, near-real-time, inexpensive way to measure changes in fissile content and total fission rates (i.e., power levels) at nuclear reactors. Detector Monte Carlo calculations, reactor simulations, and previous antineutrino detection experiments all demonstrate that a small detector placed a few tens of meters from a reactor core can measure gross power and fissile content of the reactor fuel in real time at the few-percent level or below. Experimental data are being acquired at the San Onofre California nuclear generating station to validate these simulations and experiments. This event rate will permit measurement of fuel burn-up and fissile content at the few-percent level with a few weeks of running. The ability to directly monitor fission processes from well outside the reactor core is unique to antineutrino detection. Use of such a detector for reactor safeguards offers several significant advantages. It provides a direct, continuous, and accurate measurement of changes in the amount of fissionable material in the reactor core, as opposed to the indirect and intermittent material surveillance and control methods (e.g., tags and seals) that are currently used. It can report the total end-of-cycle plutonium inventory to within a few tens of kilograms or below.

Advanced radiation detection technology will enable the international community to more reliably protect itself from the dangers inherent in illicit trafficking in nuclear materials. Such technology will also enable a greater degree of safeguards to be negotiated with respect to nuclear technology and the nuclear fuel cycle, thereby making an improved energy supply and hence improved living standard more accessible on a global scale.

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