FUTURE TECHNOLOGY CHALLENGES IN NONPROLIFERATION

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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. Because of the complexity of this threat, no single technology can solve the WMD proliferation and terrorism problem. 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.

The Radiation Detection Center (RDC) at Lawrence Livermore National Laboratory (LLNL) continues to adapt radiation detection devices for national security needs. 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’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.
- Serves as an institutional resource in radiation detection for LLNL.
- Provides special facilities for instrument development and experiments.
- Trains individuals in the use of radiation detection equipment and protocols.

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 and those from threatening sources. Advances in detection are being made in semiconductor-based, gamma-ray imaging systems. 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 are being pursued at LLNL.

The first imager is a hybrid semiconductor-based, collimatorless Compton imaging instrument. Gamma rays coming from all directions are tracked as they scatter inside the detector. The camera’s 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 initial hybrid system uses two double-sided strip detectors (DSSD) made from high-purity silicon and germanium. This instrument has demonstrated imaging from energies of 120 keV to 1 MeV.

The second imager is based on a coded-aperture approach using NaI. This instrument uses an imaging technique originally developed for high-energy astrophysics. 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. Another version, the large-area imager, will be suited for longer-range searches. This imager will be mounted in a truck and is capable of picking out weak radioactive sources from as far away as 100 meters.

**Active Interrogation to Detect Shielded Nuclear Material:** LLNL is developing a concept for the detection of highly enriched uranium that is suitable for use in inspecting maritime cargo containers. A new radiation signature unique to HEU has been identified that uses high-energy (3- to 7-MeV), fission-product gamma-ray emission. This high-energy gamma signature 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. The first experiment was done at the Lawrence Berkeley National Laboratory’s 88-inch cyclotron. Subsequently, an experiment was configured at LLNL where a 14-MeV commercial D-T neutron generator (2 x 10¹⁰ neutrons/second) was used to interrogate a 22-kg natural uranium target located inside a standard cargo container at a distance of 3 meters.

**Ultrahigh-Resolution Spectroscopy:** LLNL is also developing spectrometers with ultrahigh energy resolution using superconducting microcalorimeter 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 making possible high-precision isotopic analysis of nuclear materials. 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 five times the theoretical best resolution for HPGe spectrometers and a resolution below 1% for neutrons (2.3 MeV). Work is under way to increase spectrometer sensitivity by several orders of magnitude by building detector arrays.

**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 there are several detectors that can operate at room temperature (e.g., CZT), they have been limited by combinations of poor resolution, low efficiency, and degraded performance. Based on theoretical band-structure calculations, the III-V semiconductor AlSb holds promise for ambient-temperature, high-energy gamma detection. Our first processing breakthrough led to Czochralski growth of large, undoped AlSb crystals with a resistivity of >10⁶ 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 >10⁷ ohm-cm.

**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. 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. In addition to being lightweight and able to operate at low power, each RadNet unit has sufficient energy resolution to eliminate alarms from background radiation. 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 was demonstrated in April 2003. The system featured a new tracking algorithm that uses spectral signatures for correlating events detected throughout the network.

• **Waterway System:** LLNL has developed systems for detecting and characterizing radioactive 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.

**Technology Deployment and Commercialization:** Several LLNL-developed radiation detection technologies are being transitioned to the commercial sector. The Adaptable Radiation Area Monitor (ARAM) uses NaI and increases detector sensitivity and specificity to both high-speed moving sources and stationary sources through unique data analysis. The ARAM technology has been licensed and will be used by the California Highway Patrol. A second technology has been licensed and commercialized as the ORTEC Detective, a portable radionuclide identifier using a HPGe detector.

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. This year, Phase 2 of a DTRA-funded project to provide radiation portal monitoring system in Uzbekistan for the detection of smuggled nuclear materials was completed.

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).

**Radiation Detection Cooperation with the IAEA:** LLNL is developing a new safeguards tool—scintillator-based antineutrino detectors—that will provide a nonintrusive, 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. Use of such a detector for reactor safeguards provides a direct, continuous, and accurate measurement of changes in the amount of fissionable material in the reactor core.

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.