Specialised screening

Advanced technologies for radiation detection

Advances in radiation detection technology and their deployment in effective system architectures are critical components of global proliferation protection initiatives and strategies. **Craig Wuest** describes and assesses the work of the Lawrence Livermore National Laboratory and elsewhere to counter radiological and nuclear threats

KEY POINTS

- Advanced radiation detection technologies have the potential to make detection of nuclear and radiological materials more effective through better identification and discrimination of threat and non-threat sources.
- Emerging security measures are underway in the United States and elsewhere to field and optimize radiation detection systems in maritime- and land-based ports and transportation corridors.
- Countering terrorist threats requires a combination of advanced technology with effective operating procedures and optimized implementation architectures.

Nuclear radiation detectors and concepts of operation (CONOPs) designed to implement effective nuclear/radiological detection capabilities constitute a critical part of any strategy to counter the threat of nuclear/radiological terrorism. In a United States Congressional Research Service (CRS) report published in August 2009 entitled *Detection of Nuclear Weapons and Materials: Science, Technologies, Observations*, Jonathan Medalia, a specialist in nuclear weapons policy, observed: "Nuclear detection technology has a dual role in thwarting a terrorist nuclear attack – deterrence and defense."

Simply stated, effective radiation detection technology is pivotal in deterrence by posing an unacceptable risk of detection and interdiction to potential terrorists. Operational radiation detector use by law enforcement officers and other personnel from relevant agencies enhances the ability to defend against threats. This is accomplished through incidental screening during the course of normal law enforcement, commerce and transportation activities, as well as by more targeted operations in response to intelligence-based alerts.

The nuclear detection challenge

Materials posing the greatest nuclear/radiological threats, and therefore are the greatest concern for detection, include fissile materials – enriched uranium-235 (U-235) and plutonium-239 (Pu-239) – used in nuclear weapons and nuclear reactors, along with materials used in medical and industrial applications, such as radioactive isotopes of cesium and cobalt, which emit x-rays and gamma-rays, as well as neutron emitters, such as americium, beryllium and californium. Owing to potential severity of a terrorist nuclear explosion, radiation detection system development tends to focus on identifying and interdicting nuclear weapons or their components by detecting the fissile materials in their nuclear cores. Identifying other radioactive materials that could be used in a radioactive dispersal device (RDD) – a so-called 'dirty bomb' – is also important to preventing significant quantities from being acquired and used as a weapon.

Fundamentals of nuclear radiation

To better understand the challenges of detecting nuclear threats using specific radiation detection technologies, it is first helpful to review the fundamentals of nuclear radiation. Radiation is most commonly comprised of high-energy photons (x-rays or gamma-rays) or neutrons. These radioactive emissions are produced by atomic elements that are unstable and decay over time, typically characterised by the half-life of the material. Radioactive elements or isotopes can occur naturally (for instance, potassium-40 in bananas, where 40 refers to the number of protons and neutrons in the nucleus) or they can be produced artificially in nuclear reactors and accelerators (for example, cesium-137 and cobalt-60, used as radiographic sources or for sterilising medical equipment and food products).

X-ray or gamma-ray emitting isotopes emit photons with energies typically ranging from about 100 kiloelectron volts (keV) to over 1 megaelectron volt (MeV). X-rays and gamma-rays are energetic enough that they can penetrate through significant amounts of intervening material and still be detected using x-ray film or scintillator-based detectors. A scintillator is a material that absorbs the energy from x-rays or gamma-rays passing through or stopping in the material and converts this energy into visible light pulses that can be detected by photo-detectors attached to the scintillator. All radioactive isotopes emit x-rays or gamma-rays with a unique spectrum of energies that can be measured using energy-sensing detectors, thereby providing a nuclear 'fingerprint' that identifies the source of the radiation.

Another type of radiation associated with nuclear/radiological threats is neutron radiation. Neutrons are found in the nuclei of all elements except hydrogen. The number of neutrons in a nuclear isotope can vary and certain isotopes with a larger number of neutrons are unstable, which results in the emission of neutrons from the isotope's nucleus. For example, the fissile isotope of plutonium, Pu-239, used in nuclear weapons components or in nuclear reactor fuel emits on average 15 neutrons per second per kilogramme. Neu-

A Maritime Safety and Security Team officer and a San Diego Lifeguard compare results on a handheld radiation identifier as part of a vessel sweep in Mission Bay, California, during the Domestic Nuclear Detection Office's (DNDO) Boat Mounted Detector Drill on 23 September 2010.

US Coast Guard/1390130

tron detection could indicate the presence of plutonium or some other neutron emitter, such as americium/beryllium or californium. Unfortunately, U-235 has a much lower neutron emission rate and so detection by its spontaneous neutron emission is typically not practical. Fissile materials can be induced to fission by applying energetic gamma-rays or neutrons. Some detection techniques propose to use beams of gamma-rays or neutrons to actively interrogate containers for the presence of nuclear weapons or fissile material components by producing fission in U-235 or Pu-239 and detecting fission decay products.

Neutrons are emitted with energies typically in the few MeV range and special detectors are required to detect them. These rely on materials that have the ability to slow down and capture neutrons, such as helium-3 or boron-10. Once captured, the neutron emits charged particles that can be detected using gas-filled ion chambers or solid-state detectors. Scintillators sensitive to neutrons are also available and operate by slowing down and capturing neutrons then detecting scintillation light associated with charged particles generated as a result of the neutrons' capture.

The neutrons' penetrating nature allows nuclear and radiological materials to be detected even when they are shielded from view in a cargo container or other enclosure.

Limitations of current technology

Surprisingly, the core technology used in most x-ray, gamma-ray or neutron radiation detectors has not changed significantly over the past 50 years. Detectors that were developed for basic and applied physics experiments at nuclear reactors and accelerators in the 1940' have been refined over time and commercialised for use in environmental, medical and industrial applications. These detectors rely on inorganic scintillators, such as sodium iodide doped with thallium (NaI(Tl)), and cesium iodide doped with thallium (CsI(Tl)) to detect x-rays and gamma-rays. Organic scintillators based on specially formulated polyvinyl toluene-based plastics doped with fluorescent dyes have also been used for decades.

Inorganic scintillators are typically grown as large crystals and mated to photo-detectors and electronics. They are heavy and exhibit undesirable sensitivity to temperature and moisture. They are relatively expensive compared to plastics, but do provide good sensitivity and energy resolution (the ability to distinguish between x-rays or gamma-rays of a given energy, which is important for identifying radioactive materials based on their distinctive radiation energy spectra).

Plastic scintillators are less expensive to fabricate in larger sizes, are lighter and more

The Coast Guard Cutter Osprey serves as a mother ship to several small boats from federal, state and local agencies participating in a full scale exercise to test non-intrusive small vessel radiological screenings at three Puget Sound security zones in Washington State on 23 September 2009. The exercise was part of a pilot demonstration funded by the Department of Homeland Security Domestic Nuclear Detection Office (DNDO) to evaluate radiation detection sensors and operational protocols for the small vessel maritime environment.

US Coast Guard/1390132

robust, but they typically do not have the ability to identify the isotope being detected. Therefore, plastic scintillators are mainly used in portal monitoring applications, such as screening large cargo containers at seaports or trucks at weigh stations.

Low-energy neutron detectors typically use helium-3, but these instruments are large, require high voltage to operate and are sensitive to vibration. In addition, the global supply of helium-3 is decreasing as the demand for tritium for nuclear weapons and other applications decreases (helium-3 is the decay product of tritium, which has a half-life of 12.5 years). This has led to a dramatic supply shortage and associated price increase for helium-3 and is driving the search for alternatives.

The best material for detecting high-energy 'fast' neutrons is an organic scintillator crystal called stilbene, but the crystal is difficult to grow, expensive and available from just one company in Ukraine. Lithium-6 iodide doped with europium (6LiI(Eu)) is also commonly used as a scintillator for detecting neutrons, but is expensive to produce in large sizes.

Decades ago, researchers found that stilbene could quickly discriminate neutrons from gamma radiation using a process called pulse shape discrimination (PSD). Today, liquid organic scintillators are more commonly used for PSD due to stilbene's limited availability and high cost. However, flammability, toxicity and environmental concerns have encouraged research into alternatives.

Nuclear detection renaissance

Research and development (R&D) on new radiation detection technologies has undergone a worldwide renaissance over the past decade, largely as a result of the creation of the US Department of Homeland Security (DHS) and the Domestic Nuclear Detection Office (DNDO), which is responsible for addressing nuclear and radiological threats to the US posed by Al-Qaeda and other terrorist organisations. The DNDO, US Department of Energy (DOE), US Department of Defense's Defense Threat Reduction Agency (DTRA) and international agencies, such as the International Atomic Energy Agency (IAEA) are supporting the development of applications related to monitoring nuclear proliferation and arms control treaty verification that now promise to dramatically improve the ability of nation states to detect and interdict illicit nuclear materials.

The 2010 Symposium on Radiation Measurements and Applications provides an indication of the dynamic nuclear detection technology R&D environment. Held at the University of Michigan in May 2010 under the sponsorship of the DOE and DTRA, it featured over 130 plenary presentations and more than 300 poster presentations by researchers from 30 countries, including a special workshop for DNDO-sponsored work.

Lawrence Livermore National Laboratory (LLNL) has a number of programmes – some outlined below – in advanced radiation detector research and in many ways exemplifies the diversity of approaches being taken to arrive at better radiation detection technology.

Advanced scintillators

Advances in scintillator materials often involve trial-and-error study of candidate materials in a decades-long process that has yielded a handful of useful new materials, most with applications for medical or high-energy physics. However, access to greatly improved tools for measuring material properties, combined with faster, more accurate computer simulations, now enable researchers to rapidly evaluate materials for performance. High-throughput studies of potentially promising materials are under way at LLNL in collaboration with a number of other national laboratories, indus-

try, and academia in the US.

Currently the best gamma-ray detection technologies use liquid nitrogen or mechanically cooled high-purity germanium (HPGe) crystal detectors, which provide superior energy resolution for identifying specific isotopes in radioactive material. LLNL developed the first small, field-portable HPGe detector that did not require liquid nitrogen cooling and licensed the technology to Ortec, which manufactures a hand-held version of the detector as the MicroDetective. The complexity associated with having to cool a radiation detector has prompted researchers to look for room temperature scintillator materials with comparable performance to HPGe.

Scintillators made from lanthanum bromide doped with cerium (LaBr3(Ce)) now offer the best energy resolution among commercially available devices. However, LaBr3(Ce) is difficult to grow and is expensive. Ironically, lanthanum-138 is itself naturally radioactive, an undesirable trait that complicates its performance by increasing the background noise level. Researchers therefore continue to work to find a high energy-resolution material that is not radioactive, operates at room temperature, is inexpensive, and can be manufactured in large volumes. Two materials in particular are being studied at LLNL: transparent ceramic gadolinium-based garnets and strontium iodide crystals.

Transparent ceramics were originally developed in Japan for use as a laser material, replacing more expensive crystals and exhibiting desirable mechanical and thermal properties. As a scintillator, transparent ceramic garnet is relatively inexpensive, strong and can be fabricated into large, uniform ingots for use in radiation detectors. A novel fabrication technique for transparent ceramics starts with nanoparticles of garnet, which are carefully pressed at high temperature and pressure into useful sizes. The room-temperature energy resolution of the best ceramic garnets is approaching that of cryogenically cooled HPGe and researchers are looking at ways to improve the resolution even further.

Another scintillator material showing great promise is strontium iodide doped with europium (SrI2(Eu)). This material is easily grown in crystals with energy resolution even better than lanthanum bromide. Crystals around 1 inch (25mm) long of this material are routinely produced. Work is under way to grow larger, purer crystals and develop the optimum tailored detector electronics for them.

Research on the growth of inorganic crystals for laser applications at LLNL has resulted in developing methods that can produce remarkably large (approximately 0.5 m x 0.5 m) potassium dihydrogen phosphate (KDP) crystals weighing nearly 250 kg in a timeframe of one month (prior growth methods required up to two years to produce a crystal of this size). LLNL researchers are now taking advantage of the experience gained with rapid crystal growth techniques and applying it to scintillator materials that are sensitive to detecting neutrons.

An extensive review of more than 100 different organic compounds was undertaken to identify candidate neutron detector materials that have desirable properties, such as the ability to distinguish between neutrons and gamma-rays using PSD. Characteristics known to be important for fast-neutron detection include: the presence of benzene rings for efficient scintillation; high hydrogen content for interactions with neutrons; only low-atomic-number constituents, such as hydrogen or carbon, to avoid excessive interaction with gamma radiation; and a delayed scintillation light emission for improved PSD.

> **"Advanced screening technology in a layered, defence-in-depth approach is the favored method being deployed to defend countries against threats"**

Experiments at LLNL revealed that some molecules were close to or even better than stilbene at separating the neutron and gamma signals. Researchers consulted with experts in quantum molecular simulations who provided modeling of organic molecules and their properties to reveal how the PSD mechanism in crystals works in an effort to narrow the search for candidate materials.

One particularly promising material is 1,3,5-triphenylbenzene. This material has been grown using LLNL's fast growth methods to a size of 8 cm x 5 cm in just a week. LLNL researchers have also successfully grown stilbene crystals using the fast growth method, which could significantly reduce the cost of this material.

As noted, helium-3 gas derived from the decay of tritium has for many years served as a neutron-absorbing material in ionization chambers. However, finding a substitute for this material has become essential to developing improved neutron detectors.

A solid-state material substitute for helium-3 has some advantages. Moving from a gas to a solid medium increases the density of the neutron-absorbing material, reducing the size of the detector. Researchers at LLNL are focusing their efforts on a material made from a combination of silicon and boron, from which they have created a three-dimensional, pillar-shaped sensor. Incoming neutrons interact with boron to produce charged particles that, in turn, interact with the silicon semiconductor and create an electronic signal. The silicon-boron pillar detector is expected to offer efficiency of more than 50 per cent and require less power than helium-3 ionisation chambers. Detectors can be tailored to meet the needs of many end users. For example, the wafer can be cut in smaller pieces for covert applications or tiled to cover large areas for portal monitors.

While these advances are promising, research is continuing on ways of fabricating these materials in the sizes and quantities that will be required for practical applications to nuclear detection. In addition to efforts under way to improve the materials' performance, researchers are also exploring the possibility of engineering polymer scintillators that incorporate heavy elements, which combine the best features of inorganic and organic scintillators for high efficiency and suitable energy resolution, while being inexpensive and environmentally safe.

There is also still much to be learned regarding potential radiation detection materials. An unexpected result of the work on alternative neutron detection materials described above is the discovery of a compound that can discriminate among energetic neutrons, low energy neutrons and gamma-rays. This compound may even prove to be an effective material for detecting antineutrinos,

which are produced in nuclear reactor operations and can be detected at extremely large distances from the source.

A key difference between current scintillator R&D and previous trial-and-error approaches is the application of more directed search methodologies aided by computational simulations to identify promising candidate materials and guide experimentation.

Nuclear detection systems

While effective radiation detection materials are a key part of any advanced system, detecting radiation and the challenge of identifying and discriminating threats from naturally occurring radioactive materials (NORM) and legitimate transport of radioactive substances continue to be daunting.

Each year, millions of cargo containers are shipped between countries worldwide. Monitoring and screening the contents in such a vast volume of containers for the presence of chemical, biological, radiological, nuclear, and explosive (CBRNE) threats is extremely challenging. Advanced screening technology in a layered, defense-in-depth approach is the favored method being deployed to defend countries against potential threats. In the US, the DNDO has developed a Global Nuclear Detection Architecture (GNDA) consisting of a number of elements, including the placement of radiation portal monitors (RPMs) and other detection equipment for primary screening at maritime ports in countries around the world, at entry points at US border crossings, and in venues where there is a confluence of commercial, military and private activities – as in the maritime areas of San Diego, California and the Puget Sound in Washington State.

Two main detection systems are currently in use: the RPM is a passive detection system using plastic scintillators and helium-3 neutron detectors; and active non-intrusive inspection (NII) systems, which use x-rays to radiograph cargo containers and vehicles.

Passive detection of radioactive materials – using the intrinsic radioactivity of the material as the source to be detected – is limited in its effectiveness, particularly when the material is enclosed in a steel or lead shield. Shielding illicit nuclear materials is a well-known method of effectively masking the presence of potential threats. As a result, alternatives to passive detection have been developed. These so-called active detection techniques use lower energy x-ray sources to minimise environmental and health effects, typically tailored into a beam for screening objects, similar to the screening that occurs for baggage and cargo in commercial aviation. Active screening using neutrons has also been demonstrated, however, this technique, while quite effective at detecting and identifying fissile nuclear weapons materials, has the undesirable side effect of creating a hazardous radioactive environment. Materials being screened by this method can themselves be made radioactive for a period of time.

Active cargo screening methods use radiographic equipment to scan containers using gamma or x-rays. This process produces a two-dimensional image of the container's contents. Inspectors then compare these radiographs to information in the shipping manifests to determine whether additional searches are necessary. Upon observing a suspicious object, inspectors will conduct a more thorough secondary screening, which requires reviewing the manifest, opening the container and performing a visual inspection with hand-held radioisotope identification devices to pinpoint and identify potential sources of radiation. The screening process can be time-consuming and is not practical for checking millions of containers.

Research on active cargo screening systems is therefore focused on reducing the time required to scan cargo for potential threat objects. Researchers at LLNL, in collaboration with the University of California, Berkeley and a number of other institutions, are using sophisticated computer simulations to assess the effectiveness of a radiographic imaging technique for use as a primary screening tool to rapidly scan cargo shipments for the presence of small quantities, 100 g, of uranium and plutonium in under a minute. This detection technique uses a source of high-energy photons generated by a small electron accelerator that is transmitted through the cargo container and the objects within the container. Depending of the composition (density and atomic number) of the material, photons are absorbed or scattered in particular ways. A special pixilated scintillation detector measures the number of photons that escape through the container and distinguished between scattered photons that have lower energies and unscattered photons of higher energy. Algorithms based on the physics of photon interactions with matter are used to identify the location and composition of objects inside the container with enough confidence to warrant secondary screening if there is potential threat.

Two employees from the National Nuclear Security Administration (NNSA) use gamma-ray detectors to test the outside of a container of highly-enriched uranium (HEU) for surface contamination at the Charleston Weapons Station near Goose Creek, South Carolina, on 19 March 2010.

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The method is particularly attractive since it could potentially detect other heavy materials used as shielding for particular objects containing nuclear materials. Screening authorities applying the technique could greatly minimise the number of suspect containers, identify possible materials of interest, and then permit definitive searches as warranted. Ultimately, researchers plan to place two pixelated detectors at different angles to the container, one at the side and the other at

US Coast Guard/1390131

Radioactive materials have a variety of legitimate uses, such as this Iridium-192 gamma radiographic source in a shielded enclosure, used in the Domestic Nuclear Detection Officers. These types of sources are also used in the construction industry for inspecting materials and welds.

the top, to create a more detailed radiograph that will allow them to see an object of interest and determine its dimensions.

Another detection technique being studied is nuclear resonance fluorescence (NRF), which exploits the physics of the atomic nucleus when it is illuminated by gamma-rays of specific energies that excite the nucleus and cause an emission of a characteristic gamma-ray, thereby providing a signal indicating the presence of a material of interest, such as uranium or plutonium. NRF has the potential of providing unambiguous identification of nuclear materials, but is also tunable to other materials of interest, including illicit non-nuclear materials such as explosives, drugs or other contraband.

NRF research is focusing on developing gamma-ray sources for illuminating objects, as well as detectors that can distinguish the signature of the material based on measured spectrum of gamma-rays transmitted or scattered out of a container. Sources of gamma-rays are traditionally based on electron accelerators, similar to accelerators used in medical diagnostics and treatment. These accelerators are expensive to procure and operate and cannot typically provide tunable gamma-ray energies. Rather, they produce a continuous range of gamma-ray energies that make detection of the NRF signal more challenging.

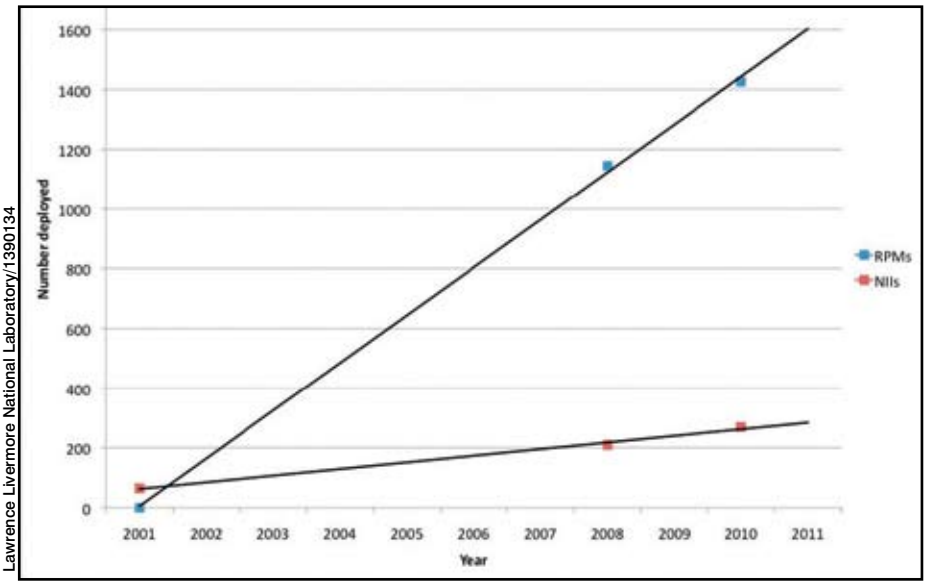
A novel source of tunable mono-energetic gamma-rays under development at LLNL is based on coupling a high-energy electron accelerator with a high-power laser. Under the proper conditions, the electron beam can interact with the laser beam to 'up-shift' the laser photons from visible light energy to gamma-ray energy, thereby providing a high intensity mono-energetic beam of photons tuned to identify a material of choice. Mono-energetic beams reduce the background significantly and also have the advantage of reducing potential radiation doses to materials and personnel by reducing the time required to inspect a container, but there is still the complexity of operating an accelerator and laser as an inspection system.

While there are a number of other R&D activities under way, advanced radiation detection technology is only part of the solution for defending against potential terrorist threats. Implementing effective CONOPs and procedures for optimal use of radiation detection systems is also an important factor. As Jonathan Medalia points out in the August 2009 CRS report: "Detectors can work at 'points', ie, places where people or cargo may enter the United States legally. There, detectors attempt to find SNM [special nuclear material] or weapons that may be hidden in cargo. In contrast, at 'lines', the vast distances between 'points' along coasts or borders, any entry is illegal, so interdiction is a matter of law enforcement."

Two pilot programmes in the US outlined below – the West Coast Maritime Pilot Program (WCMP) and the Southeast Transportation Corridor Pilot (SETCP) – are intended to address the challenges of interdicting nuclear and radiological threats.

The small vessel threat

In 2006, then US Coast Guard Chief of Staff Vice Admiral Thad Allen (now retired) stated in testimony to the US Senate Subcommittee on Homeland Security: "Much of the current public discourse focuses on container security... In fact, the greatest observed maritime



Lawrence Livermore National Laboratory/1390134

This graph shows the significant growth in the two main detection systems in use today: the Radiation Portal Monitor (RPM) system, which is a passive detection system using plastic scintillators and helium-3 neutron detectors; and active Non-Intrusive Inspection (NII) systems, which use x-rays to radiograph cargo containers and vehicles.

threat remains smuggling. There are a wide variety of maritime threat scenarios beyond the confines of a single container. For example, a formal Coast Guard risk assessment revealed that small boats actually pose a higher risk. These small boats, traditionally used to smuggle drugs and migrants, can also be used to carry out [USS] *Cole*-type attacks on US interests, bring in weapons of mass destruction (and other types of weapons) and/or to sneak terrorists into our communities."

In testimony before the US Senate Committee on Homeland Security and Governmental Affairs on 15 September 2010, Jane Holl Lute, deputy secretary of the US Department of Homeland Security, highlighted the US Coast Guard's role in defending against terrorist attacks: "The Coast Guard's layered defense against nuclear terrorism threats includes inspection of foreign ports and vessels, employment of cutters, aircraft and boats offshore and in the nation's ports, and deployable specialised forces with global reach... The Coast Guard conducts daily inspections and boardings to ensure vessels comply with maritime law and safety standards, applicable US law and regulations, and control procedures for access to the nation's ports. All Coast Guard vessel boardings and inspection teams are equipped with nuclear/radiological detectors. The Coast Guard also has access to over 5,000 facilities for enforcement of safety and security requirements, with each boarding and inspection team playing a role in the nuclear detection architecture."

In 2008, the DHS published its *Small Vessel Security Strategy*, which identified the need to defend against potential radiological or nuclear attacks by fostering partnerships with federal, state, local, private and international organisations as part of a layered approach to security that leverages technology and partnerships to enhance detection. DNDO also initiated the West Coast Maritime Pilot (WCMP) in 2008, which is now nearing completion in Washington State's Puget Sound (managed and executed by the Pacific Northwest National Laboratory: PNNL) and in San Diego, California (managed and executed by LLNL).

The WCMP programme has focused on developing CONOPs and standard operating procedures (SOPs) appropriate for the multiple agencies with jurisdiction in these maritime areas, equipping and training responder personnel with human-portable and boat-mounted radiation detector systems, and facilitating sustainable operations through close partnerships with key law enforcement, local, and state government agencies.

Since 2008, DNDO has procured large numbers of personal radiation detectors (PRDs) – pager-style radiation detectors worn by officers and responders and backpack-style detectors that can serve as either boat-mounted or human-portable systems for primary screening during their normal patrols and operations. A number of radioisotope identification devices (RIIDs) used in conjunction with PRDs for secondary screening (for instance during boarding operations) have also been procured and deployed. This equipment has been distributed to law enforcement personnel who have received extensive training and participated in drills and exercises designed to simulate the threat and non-threat scenarios that responder personnel are likely to encounter during normal operations. Law enforcement agencies will be allowed to keep the equipment after the conclusion of the pilot programme if they agree to apply for federal and state grants to support its continuing operation and maintenance.

Throughout the pilot process, both leadership and rank-and-file officers have been closely engaged to ensure acceptance and comfort with the equipment as an additional part of their law enforcement and responder capabilities and responsibilities. Factors affecting acceptance include: ease of use and maintenance; ability to effectively employ the equipment without interfering with other law enforcement functions; minimisation of nuisance alarms; and a consistent CONOPs with other agencies having maritime jurisdiction.

A significant effort has been made in both Puget Sound and San Diego to develop SOPs that incorporate existing maritime security organisations such as the Joint Harbor Operations Centers (JHOC), staffed by the US Coast Guard in San Diego and Seattle. JHOC watch standers and duty officers are trained to receive radiation alarm information from officers in the field and to initiate co-ordination with local, state and federal law enforcement and response agencies. They also assist in the communication of RIID data to local, state, and federal technical agencies who maintain nuclear/radiological subject matter experts on call (also known as 'technical reach back') for alarm adjudication.

Recent exercises conducted in Puget Sound and San Diego have also included the use of

computerised systems that aid the collection and transmission of incident information and radiation alarm data, thereby speeding up the adjudication process so that officers can make more timely decisions regarding the incident.

When combined with radiation detection capabilities already in place with the US Coast Guard, the US Customs and Border Protection (CBP), and the National Guard Civil Support Teams, a significant enhancement in nuclear material detection probability has been achieved in the maritime areas for these two important US ports. DNDO is now in the process of evaluating the results of the WCMP program and intends to apply the experience gained to other ports in the US.

Land-based threats

A similar pilot programme was completed by DNDO in late 2009 to address potential land-based threats. The Southeast Transportation Corridor Pilot (SETCP) evaluated the incorporation of radiation detection systems into the regional commercial vehicle inspection (CVI) system already in place in the southeast US. This pilot included a programme of CONOPs and SOP development specific to the nine states in that region and the District of Columbia and included installing RPMs, control systems, data collection, and visualisation systems collocated with commercial vehicle weigh station scales. In the event of an alarm, RIIDs are used for secondary screening and a technical reach back process was developed in conjunction with state and federal agencies for alarm adjudication. In addition to fixed radiation detection portals, SETCP also examined using relocatable and mobile detection systems in an overall architecture.

These pilot programmes have taken the necessary approach to defence against radiological and nuclear threats by increasing the amount of fielded equipment and trained responder and law enforcement personnel to detect and interdict potential threats. However, these programmes were not focused on optimising detection architectures through, for example, developing modeling and simulation to explore the effects of traffic patterns, placement and detection system sensitivity, and other aspects that could decrease the probability of a successful terrorist attack.

Strengthening detection

System architecture studies take a holistic view of nuclear/radiological threats and defensive countermeasures by integrating perspectives and data from other development efforts, such as radiation detection technologies, field trials and pilot programmes. As the number of systems and the complexity and cost of fielding detection systems increases, model-based system analysis is helping provide a quantitative basis for decision-making regarding R&D investments, system development and acquisition, and test and pilot execution. Tradeoffs can be explored using performance metrics such as cost, risk, degree of implementation or integration into CONOPs, probability of detection, probability of false alarm, areal coverage and impact on deterrence. Importantly, system studies can assess potential adversary behavior in response to particular system architectures, as well as the robustness of the architecture, for example, as a function of detector reliability or loss of capability.

> **"New technologies being developed with the support of US and international agencies promise to dramatically improve the ability of nation states to detect illicit nuclear materials"**

System analysts at LLNL have developed a modeling framework that combines adversary behavior and choices for delivering a weapon to the US with models of various detection capabilities that could be deployed. The framework includes adversary-related variables, such as sources and types of materials that could be acquired, potential transport routes and targets, as well as architecture-related variables, such as the number, placement and response of detectors. These models can be enhanced through physics-based radiation transport and detector response simulations that more accurately capture different engagement scenarios and CONOPs.

The analysis can address end-to-end scenarios for threats originating overseas and transported to the US. For various adversary and detection architecture assumptions, the models determine the adversary probability of success and identify optimal adversary strategies. In this way, countermeasures to potential adversary actions can be developed and examined for effectiveness under constraints of cost and performance limitations.

Conclusion

Advances in radiation detection technology and its deployment in effective system architectures are a key part of global proliferation protection initiatives and strategies. The international community has clearly become increasingly concerned with the threat of weapons of mass destruction. International co-operation is evident in programmes such as the US NNSA's Second Line of Defense (SLD) and Megaports initiatives, the multi-national Proliferation Security Initiative (PSI), and through the development of the Global Nuclear Detection Architecture (GNDA).

Significant work is also taking place to address the full spectrum of CBRNE threats. Technologies detecting and identifying chemical and biological agents are in development or being fielded that can provide near-real-time identification of agents. Explosives detection is another area where progress is being made, currently in support of aviation and other transportation sectors, to detect and mitigate the effects of explosives.

In all of these areas, countering terrorist threats requires the marriage of advanced technology with effective operating procedures and optimised implementation architectures. The experience being gained from the deployment and use of radiation detection systems worldwide should be applied to other potential threats to defend our populations, preserve commerce, and deter terrorism. ■

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