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Prospects For Improved Detection Of Chemical, Biological, Radiological, and Nuclear Threats

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Improved chemical, biological, radiological, and nuclear (CBRN) detection systems are a critical means of countering the threat of CBRN use against an unsuspecting population. Craig Wuest, Brad Hart, and Thomas Slezak assess the future trajectory of CBRN detection technologies.

Key Points

Acquisition and use of Chemical, Biological, Radiological, and Nuclear (CBRN) weapons continue to be a major focus of concern for the security apparatus of nation states because of their potential for mass casualties when used by a determined adversary.

CBRN materials with the greatest potential for use as weapons of mass destruction (WMD) are no longer relegated to the domain of nation-states with strong controls on their production, dissemination, and use. The Internet provides a wealth of knowledge on CBRN materials, recipes for WMD production, and guidance on weaponization and use of these materials.

Against this backdrop improved sensor technologies and concepts of operations, when applied as part of an optimized and integrated intelligence- and law enforcement-driven detection system, will constitute a crucial part of national and global security programs.

The threat of the use of chemical, biological, radiological and nuclear (CBRN) weapons against unsuspecting populations continues to be a major area of concern to the security and intelligence agencies of nation states. When asked to project the likelihood of different types of CBRN scenarios, most experts suggest that a biological attack is the likely near term threat, followed by radiological, chemical, and nuclear attack, this assessment being based in significant part on analysis of the relative logistical burden on a terrorist group to plan and execute such attacks successfully.

In 2008, the U.S. Congress mandated a 180-day assessment of activities, initiatives, and programs to prevent CBRN proliferation and terrorism. The resulting report, *World at Risk: The Report of the Commission on the Prevention of WMD [Weapons of Mass Destruction] Proliferation and Terrorism* provides a stark assessment of the CBRN threat. The report concluded:

"The Commission believes that unless the world community acts decisively and with great urgency, it is more likely than not that a weapon of mass destruction will be used in a terrorist attack somewhere in the world by the end of 2013.

The Commission further believes that terrorists are more likely to be able to obtain and use a biological weapon than a nuclear weapon. The Commission believes that the U.S. government needs to move more aggressively to limit the proliferation of biological weapons and reduce the prospect of a bio-terror attack."

To date, there is no reason to believe that the risk of biological attack by a terrorist group is diminished. Indeed, recent debates in academic and government circles have taken place regarding the wisdom of publishing research on the alteration of flu viruses to make them more likely to be transmitted from animals to humans and to increase the pathogenicity or virulence of these organisms. Yet despite these concerns, a paper identifying the mutations to make bird flu virus transmissible to humans was published in the journal Science in June 2012. Adding to the concern is what some analysts regard as the lack of controls on biological research in general, and the relative ease of acquiring equipment and knowledge to produce potentially dangerous pathogens, including toxic substances, viruses, and bacteria.

In the nuclear and radiological domain, the threat of nuclear weapons is acknowledged to have the highest consequence of use, based on their ability to cause massive prompt and delayed casualties, long-term socio-economic impacts, and deep psychological harm to an affected population. On the other hand, the likelihood of nuclear terrorism remains low, according to most experts. This is in part because of the difficulty of obtaining sufficient quantities of nuclear materials to fashion a viable nuclear weapon. Strong safeguards in place as a result of international treaties, such as the Nuclear Nonproliferation Treaty, have helped to ensure that nuclear materials are in the vast majority of cases properly declared and continually accounted for. To date, a number of cases of seizures of small amounts of enriched uranium or weapons-grade plutonium have been reported. According to IAEA's 2011 report on Nuclear Security, there were 2,164 confirmed cases of illicit trafficking in nuclear and radiological materials worldwide from 1993 through 2011. In 2004 a smuggler trying to sell weapons-grade plutonium was arrested in a sting operation in Kyrgyzstan. A similar case involving highly enriched uranium occurred in Georgia in 2001. However, as noted in the IAEA report, in all cases the amounts were insufficient to constitute a threat. Internationally, the network of radiation portal monitors and hand-held detectors used by border security agencies, have proved effective in detecting illicit transport of contraband nuclear material, however, most, if not all of these cases have involved unskilled or unwitting actors with little indication of terrorist intent.

Radiological materials – materials used in medical or industrial imaging, cancer therapy, and food and medical device sterilization – can constitute a significant health threat if introduced into the environment, for example, in the form of a radiological dispersal device (RDD), commonly known as a "dirty bomb." Much work in the U.S, for instance, has involved understanding means by which radiological materials might end up in terrorist hands, along with research on environmental and population impacts, recovery, and remediation. In general, most experts believe that the use of a dirty bomb in a heavily populated area will have much less of an effect from the standpoint of short- and long-term casualties, when compared with a nuclear weapon. This is because the dispersal of radioactive material is likely to be smaller in size and the health effects can be mitigated by quickly removing affected populations from the contamination zone, applying decontamination procedures, and providing medical treatment designed to remove ingested or inhaled radioactive material. Richard Meserve, former Chairman of the U.S. Nuclear Regulatory Commission, in testimony to the U.S. Senate Committee on Foreign Relations in 2002, stated that an RDD might cause "deaths on the order of tens of people in most scenarios."

The socio-economic impacts associated with RDD use are arguably more significant than the health impact. One 2009 study conducted by the University of Southern California's National Center for Risk and Economic Analysis of Terrorism Events focused on the release of radiological material in the financial district of Los Angeles. This study projected significant long-term economic costs in the order billions of dollars, mainly due to the loss of productivity due to inaccessibility of buildings and resources in the contamination zone, and the cost of removal of contaminated materials and remediation of buildings and infrastructure.

To date, no terrorist group is known to have executed a successful RDD attack. Chemical terrorist attacks, however, have a precedent, if not an extensive one. In 1994, members of the Japanese doomsday cult Aum Shinrikyo released a quantity of the nerve agent Sarin in Matsumoto, and again in the Tokyo subway system in 1995. According to the Monterey WMD Terrorism Database, maintained at the Monterey Institute for International Studies, these releases resulted in the combined deaths of 20 people and both injury and long-term health effects estimated to number in the thousands. The techniques for the manufacture of chemical weapons agents, particularly nerve agents and blister agents is relatively well known and easily found on the Internet and in a number of publications. However, terrorist chemical weapons use is deemed to be relatively unlikely, in part because of the difficulty of manufacturing the chemical agents and the challenges of controlling the release of the agents to achieve terrorist objectives. More likely is the targeting of toxic industrial materials and chemicals, for example, using explosives to rupture storage tanks containing chlorine, ammonia, and other commonly used industrial chemicals. For example, Al Qaeda in Iraq developed and detonated vehicle-borne improvised explosive devices, equipped with chlorine cylinders in Iraq in 2007, which resulted in two fatalities and hundreds injured due to exposure to chlorine gas.

Advances in CBRN Detection Technologies

The most effective detectors of CBRN agents are based on technologies that offer sensitivity, timeliness, accuracy, and precision. In general, the most desirable trait for a detector is sensitivity to the particular threat agent or material, which allows it to detect smaller amounts more quickly, and possibly at a greater standoff distance. Ideally, the detector should be able to discriminate between the actual material needing to be detected and background "noise" associated with naturally occurring materials present in the environment. These can include radioactive materials normally found in nature and, in the case of biological threats, closely related but benign organisms. Much of the research and development taking place in the U.S. and elsewhere is focusing on improving detection sensitivity through the discovery and application of new detector materials and techniques.

For example, the ability to tailor detectors to positively identify specific pathogens, or to more quickly and accurately detect and identify radiological or nuclear material is key to providing an enhanced capability that can have the greatest impact on future global security.

This paper will explore some of the most promising areas of detector research that are already finding their way into real-world CBRN threat detection applications. The paper will take as a case study the work being undertaken at Lawrence Livermore National Laboratory (LLNL), administered by the U.S. Department of Energy's National Nuclear Security Administration (NNSA), where the authors are members of the scientific and technical staff.

Chemical Sensing Technologies

Chemical detection now spans a wide range of technologies, from Active Mass Spectroscopy measurements that can identify and characterize individual molecules and compounds, to Passive Colorimetric Filters and Swipes, which indicate the presence of a chemical, e.g., trace amounts of high explosive, by changing color when exposed to the chemical. However, recent research has focused in particular on functionalized detection techniques that utilize specific chemical reactions to signal the detection of a particular chemical. Advantages of this method include good detection sensitivity for specific chemicals of interest, while minimizing false positives and the ability to detect a variety of chemicals using a suitably prepared array of detector elements. Detection techniques include optical fluorescence, direct electrical, or chemical reactions resulting in optically observable signatures using color change or other markers to indicate the presence of a chemical of interest.

Micro-cantilever Chemical Detector

A novel detection technique, developed at LLNL utilizes micro-electromechanical systems (MEMS) fabrication technology to produce a chemical sensor based on what is known as a microcantilever transducer (shown in Figure 1). The surface of the cantilever is coated with a polymer compound that exhibits some degree of affinity for the chemical of interest. The sensor operates by measuring the change in electrical resistance when a differential strain is induced between the silicon and silicon dioxide layers of the cantilever as chemicals to be detected are absorbed in the polymer coating. On average, it takes one to two minutes to identify the vaporous chemical. Once the ambient vapor dissipates, the absorbed molecules will naturally diffuse, and the polymer coatings will dry out, much like wetted sponges. This process can be hastened with added airflow or gentle heating to allow the detector array to be reused.

Microcantilever detectors have been developed at LLNL that have reliably detected 11 vapors, including hexane, 1,4-dioxane, benzene, toluene, ethyl acetate, acetone, acetonitrile, methylene, chloride, methanol, and isopropanol. These chemical species were selected as simple representatives of several classes: alkane, ether, aromatic, ester, ketone, nitrile, haloalkane, and alcohol. The sensor also detected the chemical warfare agents

(CWA) VX and sulfur mustard, both of which were synthesized in trace quantities at LLNL's Forensic Science Center. Exposure to VX, a potent nerve gas, can lead to paralysis and respiratory failure. Sulfur mustard is a blister agent that was dispersed in aerosol form during World War I to incapacitate troops and contaminate areas to discourage entry. The sensor was exposed to VX and sulfur mustard at concentrations of 520 parts per billion (ppb) and 90 ppm, respectively. These values can be compared to the median lethal concentrations of 450 ppb for VX and 25 ppm for sulfur mustard, which correspond to percutaneous (passing through the skin) vapor exposure for 30 minutes. At these sensitivity levels, the sensor can function as an effective standoff detection system to identify lethal chemical agent levels and to warn personnel that personal protective measures need to be taken.

Applications and advantages of microcantilever sensors

The microcantilever sensor could potentially be used in a variety of applications because it is small, robust, and sensitive; it needs only minimal support electronics; and can be mass-produced. The device is ideal for autonomous operation for long periods. Example applications include environmental and industrial monitoring, such as for chemical leaks in manufacturing plants or storage facilities. Of particular interest to homeland security and defense experts is the speedy detection of gases that could indicate the onset of a chemical warfare attack. Soldiers could carry handheld sensors, or even miniaturized lapel pins, that warn of a chemical agent in the environment. Sensors could also be placed around an installation's perimeter and run autonomously, sensing for incoming plumes of chemicals. In addition, the sensors could prove useful as explosives "sniffers" in airports and as spoilage indicators for the food industry.

The challenge therefore is to develop sensing materials that, together, provide specificity to the entire range of chemical agents of interest, from CWA to toxic industrial chemicals and materials. Similar techniques are also being studied for biological applications that lend themselves to gaseous or vapor phase analysis, for example, detecting disease-causing agents or other forms of contamination in the breath of patients.

Exploiting Nanotechnology for Chemical Detection Applications

Another area of active research is the development of "batteryless" nanosensors that can identify different chemical species in less than a second, giving it potential for homeland security and medical applications. The operating principal of the nanosensor is similar to that of the microcantilever sensor discussed previously, except that the cantilever is replaced by zinc oxide (ZnO) nanowires embedded in a polymer matrix. Absorption of chemicals in the polymer induces electrical voltage changes in the nanowires, a process known as piezoelectricity, which can be detected with standard electronics. Figure 2 shows schematic representations of two different sensor types along with photographs of actual devices.

As an example of a practical use, the nanowire device was able to successfully detect and distinguish between different types of explosives, for example, TNT (trinitrotoluene) and

RDX (1,3,5-trinitro-1,3,5-triazacyclohexane). Nanowire sensors are potentially very sensitive and fast. The sensors can be incorporated in small, handheld systems that don't require batteries or power supplies.

Research is continuing into these technologies with an emphasis on refining the structure's detection of chemicals in liquids, as well as improving the device's sensitivity, which is currently in the parts-per-million scale. One way this might be achieved is by increasing the surface area exposed to the chemical. Work is also ongoing to explore the selective detection of certain biomolecules, a process that may be possible with specialized surface modifications to the ZnO nanowires.

Microbial Detection Arrays for Biological Detection

Microbial Detection Arrays – 'microarrays' for short – contain large numbers (typically, hundreds to millions) of detection elements called "probes", made from tiny strings of DNA, that utilize specific reagents to bring about a reaction that indicates the presence of the microbe to be detected. Microarrays can be used to detect both living and dead pathogens.

The presence of a microbe is typically signaled by fluorescence under ultraviolet light, resulting from the activation of the probe when bound to the target microbe, a process called hybridization. The probes are typically arranged on a solid substrate, such as a glass slide or a micro-well plate. Probes can also be attached to tiny polystyrene or glass beads/rods and kept in a liquid solution. The array of specific probes dictates utility, not the physical construction of the array itself. Figure 3 shows schematically the procedure used to identify an unknown biological material.

There are a large number of distinct applications for microarrays.

Strength of Microarrays for Biological Detection

Microarrays are excellent for interrogating *known* DNA regions, i.e., the organism needing to be detected must have its genome reasonably well characterized (sequenced). Clearly, microarray probes for totally unknown/unsequenced organisms cannot be designed. However, bioinformatics programs worldwide are continually adding to the body of knowledge for the genomes of potentially harmful organisms. Significantly, microarrays work well with DNA that is too highly degraded to be readily sequenced using more standard techniques such as polymerase chain reaction (PCR), which can be an advantage when detection in abnormal or harsh environments is required. Although the cost of DNA sequencing is dropping rapidly, many of these "next generation" sequencers are optimized for sequencing the entire human genome and application of these sequencers to detect known pathogens is inefficient. In contrast, microarrays are increasingly cost-effective for detecting biological hazards, particularly as the number of available specific probes increases. Additionally, the data processing from microarrays is straightforward and rapid, with results available for strongly concentrated samples in as little as one hour, compared to many hours for analyzing raw DNA sequencer reads.

Limitations of Microarrays

A key limitation of a microarray is that it can only find genomic sequences corresponding to *known* biologically harmful organisms (allowing for perhaps a maximum of 10% nucleotide variation from the probe sequence while still retaining high detection probability). Notably, most detection can be done relatively quickly, but low-concentration samples can require a long hybridization time (8-12 hours is typical) in order to produce detectable fluorescence, signaling a positive result.

Of a more regulatory and administrative concern, currently, the U.S. Food and Drug Administration (FDA) does not have guidelines for how to validate microarrays, which may have millions of probes each needing to be analyzed for efficacy. Additionally, the health insurance industry does not have guidelines for how to reimburse clinical laboratories for a single test using a microarray that could potentially identify all known human-infectious agents that a patient might be exposed to. For these and other reasons, this promising technology is not yet approved for human diagnostic use, at least in the United States. In Europe, the Danish government is currently in the process of licensing LLNL's microarray technology for primary clinical diagnostic use in that country.

Despite the restrictions mentioned above, microarrays are already being used to identify variants of interest in human DNA; Direct-To-Consumer DNA services such as 23andMe, for example, already utilize microarrays.) Microarrays can also be used to identify gene expression differences in human or other hosts, or in microbial organisms, for example, to determine which genes are expressed differently between a virulent and a non-virulent strain of a pathogen. Not knowing that a person has been exposed to a non-virulent strain of a pathogen can lead to unnecessary treatments that could place the patient at greater risk. The ability to detect virulence is therefore highly desirable when determining the best treatment to apply. Arrays can be also used to identify contaminants in food or other products. In a recent case published in the Journal of Virology in 2010, thanks to the use of microarray technology an FDA-approved human rotavirus vaccine in clinical use was found to have unexpected traces of porcine circovirus, which is thought to be due to the use of an enzyme derived from pigs for this particular method of vaccine preparation. This finding led to changes in the manufacture of the virus to eliminate the inadvertent contamination.

Microarrays can, of course, also be used in biodefense applications to search for dangerous human, animal, or plant pathogens. Probes have already been developed to detect thousands of other pathogens, including biowarfare agents. LLNL researchers have successfully applied microarrays to detect bacillus anthracis (anthrax), francisella tularensis (tularemia), salmonella, and yersinia pestis (plague) and are working to develop probes for a wide variety of other pathogens. LLNL is now participating in a two-year evaluation of this technology by U.S. Army Medical Research Institute for Infectious Disease (USAMRIID) and the U.S. Centers for Disease Control and Prevention (CDC) Laboratory Response Network.

Arrays versus sequencing

Historically, microarrays have offered a low-cost alternative to what used to be extremely expensive DNA sequencing. Additionally, microarrays can be processed from sample to result in less than 24 hours, as opposed to days-to-weeks for sequencing. As recent performance improvements in DNA sequencing technology have been made, the cost and time differences between the two techniques have become less pronounced for many applications and this trend is likely to continue. However, as noted earlier microarrays will likely continue to offer specific advantages when compared with sequencing, particularly because of their ability to target known pathogens and biohazards.

Full DNA sequencing will always be required to characterize novel, mutated, or engineered organisms (whether natural or deliberate.) However, once such additions and changes are identified the bioinformatics DNA database can be updated, and producing microarrays with new probes to screen for these organisms is relatively straightforward.

Research into microarray technology for the detection of biological agents is ongoing and will lead to improvements in future microarray technologies. Direct optical detection and electronic sensing of positive results could replace the current indirect detection of fluorescence, and reduce hybridization times for low concentration samples to less than one hour.

Smaller-scale and higher-throughput arrays are also active areas of research. For example, at LLNL, researchers are considering a 384-well plate with 10,000 array probes at the bottom of each well. This would be sufficient to develop symptomatic panels (e.g., respiratory, diarrheal, fever, etc.) that could be processed at laboratory facilities at costs that could drop to under $20 per exposure case.

Radiological and Nuclear Detection

Advanced radiation detection technologies have the potential to make detection of radiological/nuclear (hereafter referred to as rad/nuc) materials more effective through better identification and discrimination of threat and non-threat sources. Materials that pose the greatest rad/nuc threats and thereby the greatest concern for detection include fissile materials - enriched uranium-235 and plutonium-239, which are used in nuclear weapons and nuclear reactors. There is also a need for detection technologies that can quickly and reliably identify materials used in medical and industrial applications, e.g., radioactive isotopes of cesium or cobalt, which emit X-rays and gamma rays, and neutron emitters such as americium/beryllium, and californium, to name a few. Many nations are concerned such materials represent a more easily accessible source of radiological material for terrorist uses.

Surprisingly, the core technology used in most X-ray, gamma ray, or neutron radiation detectors has not changed significantly over the past half century. Detectors that were developed for basic and applied physics experiments at nuclear reactors and accelerators in the 1940's have been refined over time and commercialized 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.

Scintillating materials detect radiation as it interacts with the atoms in the material. The radiation excites atomic electrons that emit near-UV or visible light as the atoms return to their ground state. This light can be detected using photomultiplier tubes or photodiodes to produce an electronic signal that is proportional to the fluence and energy of the radiation. Some of these scintillator detectors, while offering reasonable sensitivity and ability to differentiate between radiological sources, have limitations – some are extremely heavy, others are particularly sensitive to temperature and moisture or are otherwise compromised in ways that do not lend them to being useful as the basis for field instruments. Others use relatively expensive chemical elements as part of the scintillating material. However, a new generation of detection technologies is beginning to emerge that overcomes some of these issues and will have applications in defence and homeland security.

Advanced Nuclear Detection Materials

World-wide, research and development (R&D) on new radiation detection technologies has undergone a renaissance over the past decade in large part as a result of support from the U.S. Department of Homeland Security (DHS) and the Domestic Nuclear Detection Office (DNDO), which is responsible for addressing nuclear and radiological threats to the U.S. believed to be posed by Al-Qaeda and other terrorist organizations.

New technologies initially being developed with the support of U.S. and other international agencies such as the International Atomic Energy Agency (IAEA) for applications to nuclear weapons and arms control treaty verification now promise to dramatically improve countries' ability to detect and interdict trafficking of illicit nuclear materials.

As an illustration of the dynamic nuclear detection technology R&D environment, the 2010 Symposium on Radiation Measurements and Applications, held at the University of Michigan under the sponsorship of the Department of Energy and the Defense Threat Reduction Agency (DTRA), 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 has a number of programs in advanced radiation detector research and in many ways exemplifies the diversity of approaches being taken to arrive at better radiation detection technology. Research at LLNL has focused on identifying and developing better gamma-ray detectors based on new classes of inorganic materials that can be produced in single-crystal, ceramic, and plastic forms. Desirable scintillator properties for radiation detection and material identification include high sensitivity, good energy resolution, and good thermomechanical properties, i.e., robustness to temperature variations and rough handling.

Figure 4 shows a comparison of performance for three different LLNL-developed scintillators with the traditional scintillator thallium-doped sodium iodide NaI(Tl), and the solid-state detector using cryogenically-cooled high-purity germanium. As can be seen from the figure, the LLNL scintillators exhibit performance substantially better than NaI(Tl), but not as good as germanium. The improved performance, coupled with other desirable properties (discussed below) suggests these new types of scintillator show promise as the basis of future radiation detection and identification devices.

One promising new crystalline scintillator is strontium iodide doped with europium – SrI_2(Eu), which exhibits good energy resolution and low intrinsic radioactivity (important for reducing background noise). Coupling this scintillator material to advanced digital electronics that performs signal processing, allows for a compact, high performance radio-isotope and identification (RIID) capability. Because the material has higher atomic number and higher density than more traditional scintillators, a similar amount of material will exhibit greater detection efficiency, which allows for smaller, lighter systems for field use in human portable detectors, such as belt-worn pagers or backpack detectors. An industrial partner is currently working with researchers at LLNL to develop a commercially available SrI_2(Eu)-based RIID that is more compact and uses less power than currently available RIIDs using NaI(Tl).

Ceramics are used in a host of applications because of their ruggedness and resistance to environmental factors. Ceramic scintillators offer similar mechanical properties coupled with desirable radiation detection capability and are being actively studied at LLNL and elsewhere. Scientists have taken advantage of many decades of laser materials research at LLNL to develop a novel ceramic scintillator: gadolinium yttrium gallium aluminum garnet doped with cerium – GYGAG(Ce) – that exhibits very good energy resolution and light output. GYGAG(Ce) is formed from nanoparticles of the material that is sintered and hot-isostatically-pressed into transparent boules. The material is now finding its way into gamma-ray imaging systems that use small blocks or "voxels" of the scintillator to form large arrays suitable for single photon-emission computed tomography (SPECT) imaging for medical and industrial applications.

Plastic scintillators can be fabricated in very large sheets, rods, and other shapes and they are used primarily for portal monitoring applications where very large items need to be screened for the presence of radioactive materials, e.g., for scanning cargo containers and vehicles at shipping ports and border crossings. Plastic scintillators typically don't have energy resolution sufficient to identify radioisotopes of interest and so are used to detect radiation and cue secondary screening using smaller, higher resolution systems.

A new class of plastic scintillators has been developed at LLNL – bismuth-loaded plastics – that may provide RIID functionality for large detection systems. Currently, this material has been formulated in small ~3 cm diameter cylinders, but work is progressing to develop the capability to form this material into larger rods or sheets. The ability to identify radioisotopes of interest using large, inexpensive plastic scintillator-based portal monitors incorporating LLNL's technology would constitute a major improvement in radiation detection systems for large object screening, potentially reducing the cost associated with secondary screening of cargo containing naturally occurring radioactive materials, and reducing the rate of false alarms.

Another type of plastic scintillator, doped with scintillating dye, has recently been developed at LLNL that exhibits the desirable capability to distinguish between gamma rays and neutrons by using a special electronic signal processing technique called pulse shape discrimination or PSD. Prior PSD techniques relied on liquid scintillators, which presented a number of disadvantages, including toxicity, flammability, and complexity of integrating into fieldable detector systems. The ability to fabricate large sheets of this new neutron sensing plastic for portal monitoring applications can enhance the probability of detection of neutron emitting materials, which are more likely to be associated with threat objects containing highly enriched uranium or plutonium, while reducing reliance on increasingly expensive He-3 detectors.

Finally, active interrogation of cargo using neutron beams or x-rays continue to be considered for non-intrusive cargo inspection applications. These radiographic techniques require a large format detection system with sufficient resolution and efficiency to create an image while minimizing radiation exposure to the cargo being interrogated. Gadolinium lutetium oxide doped with europium, or GLO(Eu) is a leading scintillator candidate for this application. Plates of GLO(Eu) up to 7 cm in diameter and 3 cm voxels have been fabricated at LLNL. A related material, lutetium oxide doped with europium provided a factor of two better contrast than current imaging materials when imaging 12 keV x-rays. This can lead to smaller and lighter imaging systems while maintaining performance. Radiographing large cargo containers and vehicles provides security screeners with additional information on the contents and could also indicate the presence of unusual amounts of heavy materials such as lead that might indicate the presence of a shielded threat object or other illicit cargo.

Systems studies for strengthening CBRN detection

System architecture studies are another growth area of CBRN research. These allow governments, defence and homeland security agencies to take a holistic view of CBRN threats and defensive countermeasures by integrating perspectives and data from other development efforts such as advanced detection technologies, field trials, and pilot programs.

These studies aid decision-making on the over all development and fielding of CBRN detection measures. As the number of systems and the complexity and cost of fielding detection systems increases, model-based systems analysis is helping provide a quantitative basis for decision-making regarding R&D investments, system development and acquisition, and test and pilot execution. For example, homeland security agencies can explore tradeoffs using performance metrics such as cost, risk, degree of implementation or integration into concepts of operations (CONOPs), probability of detection, probability of false alarm, area 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.

System analysts at LLNL, for instance, have developed a modeling framework that combines adversary behavior and choices for delivering a weapon to a particular location 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 and transported, potential transport routes (land, air, sea), and targets, as well as architecture-related variables such as the number, placement, and response of detectors. These models can be enhanced through the use of physics-based dispersion models for chemical or biological releases, nuclear radiation transport modeling and detector response simulations that more accurately capture different engagement scenarios and CONOPs.

The analysis can address scenarios for threats and attacks originating from a variety of sources. 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.

Detection architecture optimization can also assess the trade-offs for upgrading existing CBRN detection measures, for example by increasing the number of detectors in use. By forcing adversaries to change to less optimal attack options it may be possible to decrease their chances of success and increase the probability that they will be caught before they can cause harm.

Conclusions

Advanced CBRN detection technologies and deployment in effective system architectures are a key part of global security protection initiatives and strategies. It is clear that the international community has become increasingly concerned with the threat of illicit transport and use of weapons of mass destruction. International cooperation is evident in programs such as the NNSA Second Line of Defense and Megaports Initiatives, the multi-national Proliferation Security Initiative, and through the DHS's BioWatch program and ongoing development of the Global Nuclear Detection Architecture.

While this paper has focused heavily on advanced technologies taking place at institutions such as LLNL, significant work is being carried out at other U.S. national laboratories, in private industry and academia, and internationally to address the full spectrum of CBRN threats. Technologies for chemical and biological agent detection and identification are in development or are being fielded that can provide near-real-time identification of agents. Explosives detection is another area where progress is being made, where current efforts are focused on supporting 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 optimized implementation architectures. The experience being gained from the deployment and use of CBRN detection systems worldwide can help identify potential threats in order to better defend populations and deter terrorist attacks.

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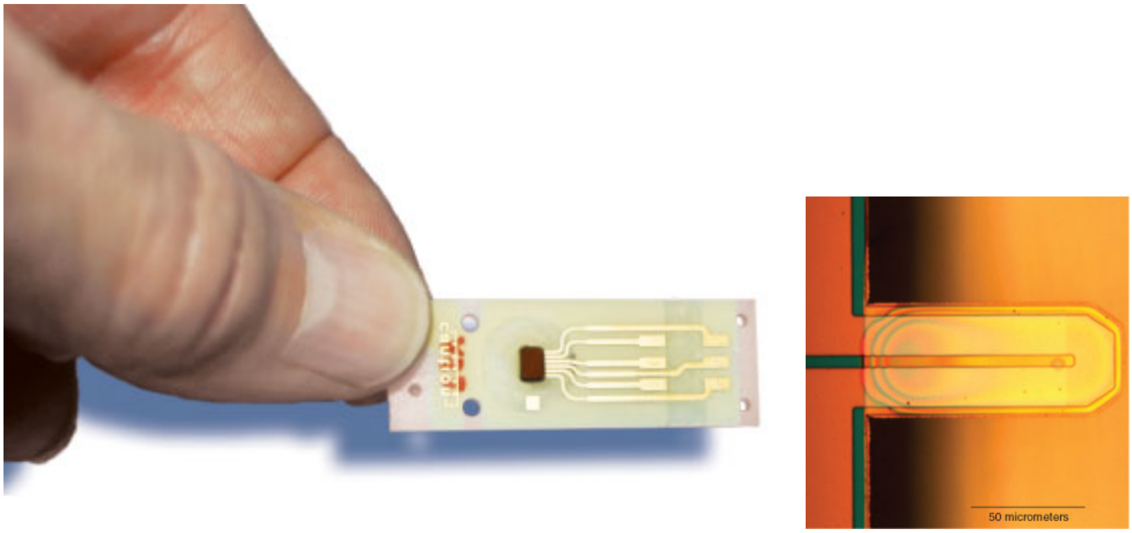

Figure 1. A pair of commercially produced four-cantilever arrays (black rectangle in center of circuit board) with electrical connections is combined with LLNL-developed components to form a sensor that works by flowing air through the device. A single cantilever is imaged on the right.

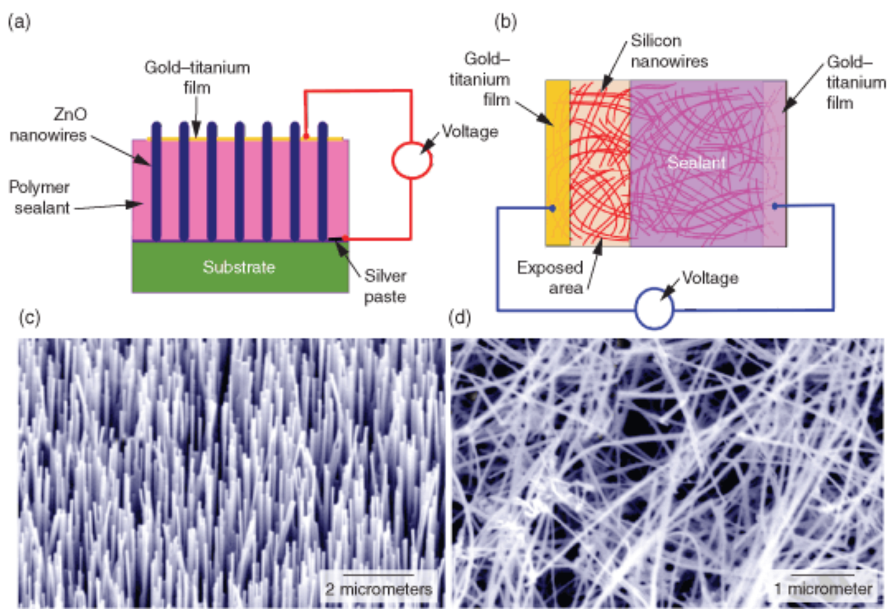

Figure 2. Chemical sensor designs use (a) zinc-oxide (ZnO) nanowires aligned vertically in a polymer sealant and (b) silicon nanowires in a tangled, randomly aligned formation, partially in sealant. Scanning electron micrographs show (c) ZnO nanowires and (d) a silicon nanowire tangle. In each system, chemical molecules cause changes in the charge distribution of the nanowire surface, producing a detectable electrical signal.

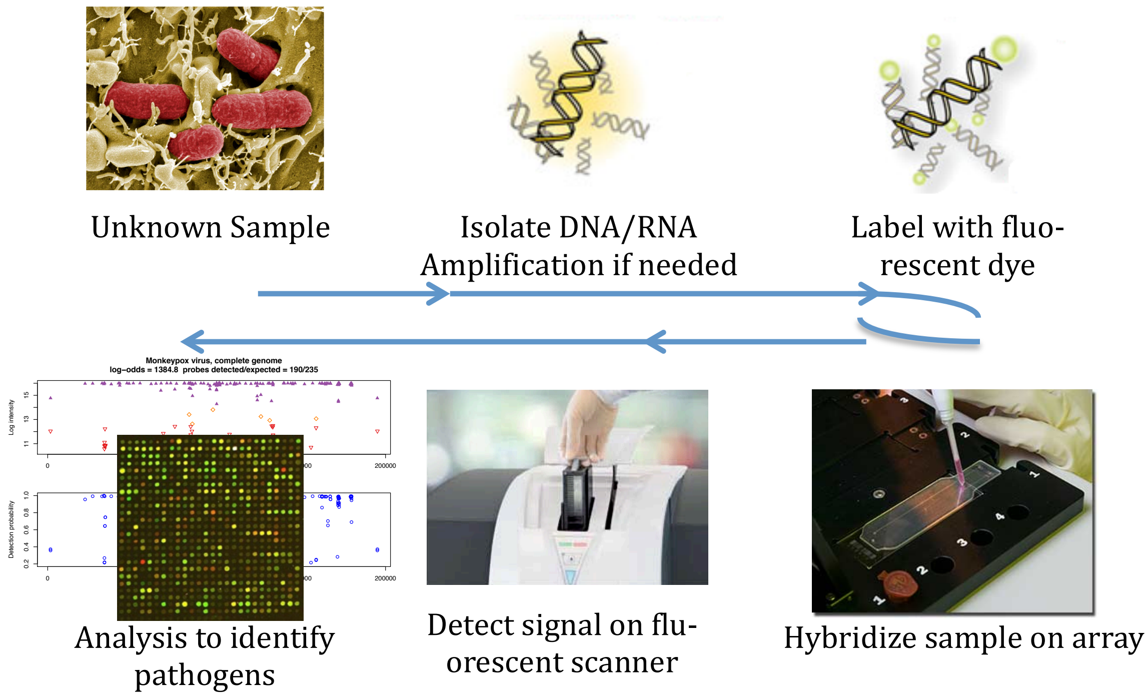

Figure 3. Schematic representation of microbial detection array concept of operations

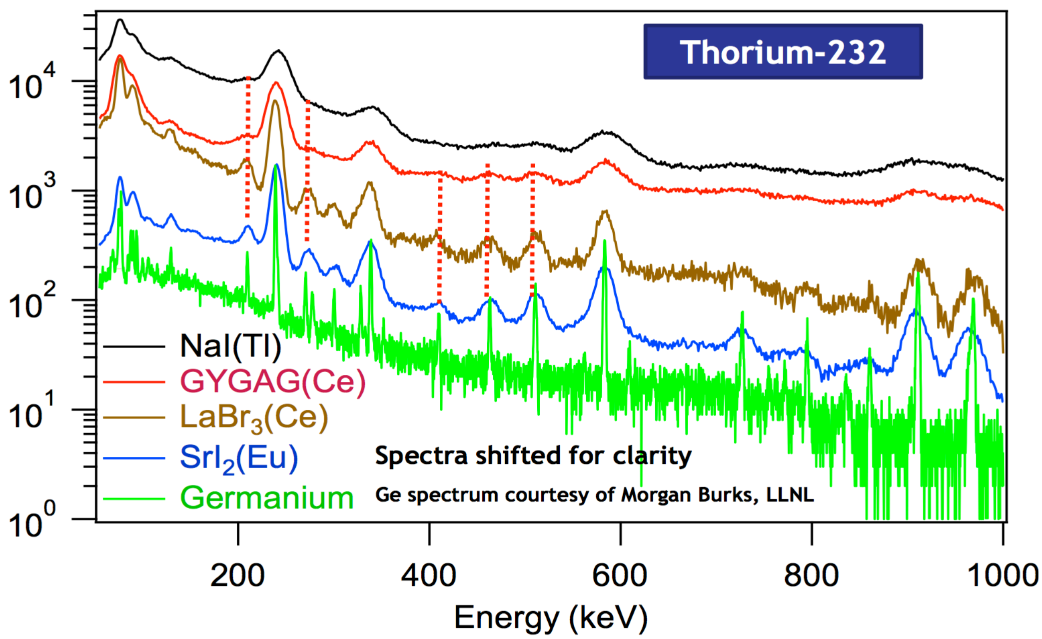

Figure 4. Energy resolution of different scintillators and germanium. The characteristic gamma-ray peaks in the energy spectra are for thorium-232. Higher performing scintillators have the ability to better distinguish these peaks, which can help discriminate between nuclear and radiological threat materials and naturally occurring or legitimate materials. Individual spectra have been displaced vertically for clarity.