Science and Technology and Counterterrorism

Jeffrey Wadsworth

The following article is based on the plenary presentation given by Jeffrey Wadsworth (Lawrence Livermore National Laboratory) at the 2002 Materials Research Society Spring Meeting on April 3 in San Francisco.

Introduction

As the deputy director for science and technology at the Lawrence Livermore National Laboratory, I will discuss the role of science and technology in national and international security and, specifically, how the national laboratories have played a critical role in the fight against terrorism. This issue has obviously become very visible and intense since the September 11 attacks,* but work in this field has actually been under way for many years.

Before I begin my talk, I would like to congratulate the Materials Research Society (MRS) for its success in creating this particular community of scientists. As you know, since its inception, MRS has attracted scientists at the forefront of innovation in the multidisciplinary field of materials research and development. This has resulted in a unique forum for exploring the boundaries and intersections of materials science, chemistry, physics, nanoscience, engineering, computing, earth sciences, and, more recently, biology. I am very pleased to have been an MRS member for many years.

I believe that as a result of the innovative spirit and multidisciplinary character of MRS, our community is ideally poised to have a significant impact on the way in which science and technology will help solve one of the most important and pressing issues of our time: the fight against terrorism and weapons of mass destruction [WMD]. The events of September 11 dramatically changed the way in which we view the world around us. The challenges are enormous, and the science community has an opportunity—indeed, it has a responsibility—to play a key role in helping minimize and, where possible, eliminate this threat. As I will discuss, the current emphasis is one of very-near-term deliverables; the present social and political turmoil dictates such priorities. However, we will see an evolution into the necessary emphasis on the science and technology underpinnings that will lead to the next generation of counterterrorism tools.

I will start with a brief overview of the Lawrence Livermore National Laboratory. Then I will discuss the world of terrorism, as well as the post–September 11 political scene, from the perspective of our national-security-based laboratory. I will then discuss some specific technical examples that both are being used and are under development in the fight against terrorism.

LLNL Overview

LLNL is a multidisciplinary national security laboratory managed by the University of California for the National Nuclear Security Administration of the U.S. Department of Energy (DOE). The laboratory is located about 45 miles southeast of San Francisco in the Livermore Valley and employs approximately 8000 people. About 1700 of the employees are scientists with doctorate degrees working in fields such as materials science, chemistry, physics, engineering, and biology.

Lawrence Livermore was founded 50 years ago, during the early days of the Cold War, by Nobel Laureate Ernest O. Lawrence. Indeed, we are immersed in a year of special activities and publications celebrating our 50th anniversary. Ernest Lawrence was a pioneer who believed in solving problems of national importance using multidisciplinary teams in large-scale scientific efforts. Over the last 50 years, our core capabilities have developed to include large-scale computers, nuclear-weapons science, lasers, and materials. By way of example, we currently have the world's biggest, fastest computer (ASCI White, at 12 teraflops), and we are building the world's largest laser, the National Ignition Facility. Both of these tools are needed for the science-based stockpile stewardship program. In this sense, a half century after its founding, we are still Lawrence's laboratory.

Throughout its history, along with the two other national security laboratories, Los Alamos and Sandia National Laboratories [LANL and SNL], Livermore has been an essential component of the United States' deterrent against attack. During the Cold War, the threat was clear—it came from Soviet nuclear warheads pointed at the United States and its allies. Today, the threat is much more complex, and the challenges appear to be very broad. Science was essential to meeting the Cold War challenge, and it will be essential to meeting the terrorist challenge. In fact, our mission at LLNL has been continuously evolving within the defense arena since 1952 from the singular focus on nuclear weapons to a much broader set of national-security-related areas. The national security mission not only includes the stockpile stewardship program (which seeks to assure the safety, security, and reliability of nuclear weapons in the absence of underground nuclear testing), but also nonproliferation, arms control treaty verification, and international security work, as well as support to the Department of Defense and other agency programs.

The investments in the national security area, however, allow us to bring unique capabilities, facilities, and people to bear on other important areas such as energy, environment, and biology. As examples, we have programs in such areas as the development of the nuclear cycle, climate modeling, and sequencing the human genome. We work closely with universities and with industry in executing nearly all of our programs.

LLNL, LANL, and SNL have been at the forefront of the war against terrorism for at least a decade. As national security laboratories, our broad charter is to provide the U.S. government with the technology and expertise required to prevent the spread and use of WMD. The labs take a comprehensive approach to the prob-

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*On September 11, 2001, terrorist attacks destroyed the Twin Towers and other buildings in and around the World Trade Center complex in New York City and damaged the Pentagon in Washington, D.C.

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lem, developing technologies and tools to counter nuclear, chemical, and biological terrorist threats and working closely with federal, state, and local response agencies to ensure that our technological solutions meet real-world operational needs. Many of our counterterrorism technologies and technical capabilities have been deployed, before September 11 and in its aftermath, to assist state and local governments in defending against WMD terrorism. As will be discussed subsequently, our large multidisciplinary teams have also been developing sophisticated technologies for WMD proliferation prevention, arms control treaty verification, bioagent and chemical warfare agent detection, and nuclear and radiological materials and weapons proliferation prevention. But, while the national laboratories have been at the forefront of this fight, the stakes today are very high, and bold new science and technology initiatives will be required in order to minimize the threats and ensure a peaceful future.

The World of Terrorism

Because of an ability to invest in a vision for the future national security needs of the country, the laboratories were able to provide immediate assistance following the September 11 attacks. The ability to invest in long-range R&D was based in part on the Laboratory Directed Research and Development Program, in which a small percentage tax is levied on programs funded at the lab and reinvested in future research areas.

Our assistance started immediately following the September 11 attacks. On September 12, teams were immediately deployed to ground zero† to use advanced radar techniques and imaging methods to aid in search and recovery efforts. There are other areas that cannot be discussed, for reasons of national security, but nuclear and biological capabilities are regularly deployed by the national security laboratories at high-profile events such as the Olympics. Current operational work ranging from anthrax analysis to container inspection is also under way. Some examples will be given shortly.

The threats to national security are broad. Direct threats include those based on biological, chemical, nuclear and radiological, conventional explosive, and cyber methods. Indirect threats include the proliferation of weapons of mass destruction and special nuclear materials, the diversion of materials, and the misuse of U.S. facilities.

†Ground zero is the term used for the location of the World Trade Center collapse as a result of the terrorist attacks.

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Of course, terrorist attacks are not a new phenomenon, even within the United States. There were, for example, a casino bombing in Nevada in 1980, a car bomb at Sandia National Laboratory in California in 1987, the first attack at the World Trade Center in 1993, the truck bomb at the Oklahoma City federal building in 1995, and the Unabomber episodes. All are examples of U.S.-based terrorist attacks prior to September 11. In addition, there have been the recent attacks on U.S. assets overseas, at our embassies in Nairobi, Kenya, and Dar es Salaam, Tanzania, in 1998; on military installations at Riyadh (1995) and the Khobar Towers (1996) in Saudi Arabia; and on the USS Cole in Aden, Yemen, in 2000. In the early 1980s, there were several attacks on the U.S. embassy and Marine barracks in Beirut, Lebanon. Other pieces of the terrorist scene include the Pan Am Airways bombing over Lockerbie, Scotland, in 1988, and the Sarin attack in the Tokyo subway in 1995. There is also a long list of averted attacks; most recent examples are the explosives detected at the Canadian border and the shoe bomb found on an airplane. Our laboratories routinely investigate nuclear-based threats around the country; they are also subject to a myriad of cyber-based attacks.

The Post–September 11 Political Scene

Although this list of terrorist activities foreshadowed the September 11 attack, the reality of an attack of this scale on U.S. soil was a transforming event. It is probably true to say that fundamental aspects of everyday life have been irreversibly changed.

Not surprisingly, the short-term reaction in the national counterterrorism scene is to want immediate solutions, and operational issues dominate long-term investments in the underpinning science and technology needed for advanced concepts. One realization that has emerged is the highly distributed and complex nature of federal responsibilities in the area of counterterrorism. Many federal agencies have responsibility for a piece of the problem, but central control is unclear, and until now, counterterrorism has been no single agency's first mission. The creation of the Office of Homeland Security is one attempt to provide clarification and leadership, but it will take time to create long-term order out of the current activities. The issue of agency ownership is of course important to the R&D community because we need to know who has responsibility and resources to invest in new science and technology initiatives and ideas. There is also the fact that some legislators and political leaders are hopeful that science investments are not in fact necessary because of the long-term implications of such investments. Rather, they hope that the use of existing science will be sufficient to allow the required technology developments. It is also difficult to prioritize the areas on which to work—this is because the present challenges represent choices among rare events with high consequences. The problem deepens when issues of classified work are added.

I believe, however, that science not only has played, but will continue to play, a compelling role in the world of counterterrorism. The current desire for immediate technological solutions is understandable. But the need for investments in high-risk, high-payoff science projects will become apparent, and the need for fundamental, multidisciplinary work to underpin future counterterrorism activities will also become evident.

Fighting Terrorism: Specific Technical Areas

The areas of principal concern are biological, chemical, conventional explosive, and nuclear (including radiological) weapons and materials. The area of cyber-based threats is also of concern, but I will not discuss that here. Irrespective of the nature of the threat, the methodology for developing a defense against terrorism and weapons of mass destruction requires a systematic and broad approach—there is no single comprehensive solution. Over the years, a viable process has been developed that cycles through deterrence, detection, response, consequence mitigation, recovery, and forensics and attribution. Science and technology affects all of these areas, but I will give examples mainly from the needs in detection. I will also comment on the area of forensics and attribution. Since I am an LLNL employee, I

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will largely draw on examples from that laboratory because I am most familiar with them; but notably, all of our work is carried out in partnerships with other laboratories, universities, and industry, and similar contributions are being made by other national laboratories.

Biological Area

Pathogen detection systems developed at LLNL and LANL have been successfully used. The biodefense capabilities that have been deployed in the wake of September 11 have, at their core, advances in biological detection instrumentation and DNA signatures made at Livermore and Los Alamos. We are developing gold-standard DNA signatures of top-priority threat pathogens (e.g., anthrax, plague) and are working with the Centers for Disease Control and Prevention to validate these signatures and distribute them to public health agencies nationwide.

We have made technology breakthroughs in biodetection instrumentation, pioneering the miniaturization and "ruggedization" of both flow cytometry and DNA identification devices. One example of a deployed capability is the biological aerosol sentry and information system (BASIS), which is a mobile field laboratory that collects samples and utilizes polymerase chain reaction techniques to identify DNA. This system has been deployed for special events such as the recent Winter Olympics in Salt Lake City, Utah. In developing BASIS, Livermore and Los Alamos worked closely with the many law enforcement, emergency response, and public health agencies that would be involved in dealing with a bioterrorism event to develop appropriate sample handling (chain of custody), communications, and response protocols.

LLNL has developed a concept for correlated sensor networks for detecting and tracking ground-delivered nuclear devices or nuclear materials. A novel algorithm integrates data from the various sensors with information from other sources (e.g., an intelligent traffic system) to identify sources of concern, track their movement through the road network, and guide responders in intercepting suspect vehicles. Advanced versions, as well as miniaturized hand-held portable versions, are now being commercialized. In addition, advanced analysis methods are being applied to the "anthrax letters" problem, and a new spore detector has been deployed to the Florida Department of Health to assist in screening mail.

One biological terrorism scenario that has already been the subject of a primetime TV show, is that of deliberately infected (with smallpox, for example) terrorists entering the country. The scenario is an interesting one in that it exemplifies the dilemma between operational and scientific approaches. On the one hand, the scientific and technological advances required to address civilian protection include a fundamental understanding of host–pathogen interactions and pre-symptomatic diagnosis. In short, there is the need to develop the underpinnings to move the detection time frame to very early stages of infection—well before epidemic symptoms occur. If such a system were developed and deployed, significant bioethical issues and massive information and data challenges would be associated with such a venture. On the other hand, operational approaches focus on effective, affordable, and rapid vaccine development for large-scale distribution. Models for dealing with the sociological implications of such scenarios, such as the mass-panic effects on transportation systems, for example, represent another ramification of terrorism that is under study.

In the longer term, advanced detection systems will require advances in materials science such as smart membranes and surfaces for biosensing in liquids and gases, microfabrication and microelectromechanical systems technologies, and chip-based architectures for rapid multiplexed detection. Advanced diagnostics and treatments will ultimately rely on high-resolution protein–protein and protein–DNA imaging and high-throughput methods for rapid determination of protein structures.

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Chemical Area

Remote detection of the release of harmful chemicals is a very important capability. One development that was utilized at ground zero was HIRIS, the hyperspectral infrared imaging spectrometer. HIRIS uses traditional spectroscopy and imagery to identify gases and their points of origin. The deployment of HIRIS in a DOE airplane to ground zero was a partnership among LLNL, LANL, and the Remote Sensing Laboratory. The system helped identify Freon-22 (chlorodifluoromethane) and ammonia from remote fly-overs and thereby assisted the Environmental Protection Agency and New York City authorities in positioning their ground-based sensors to assure the safety of the rescue teams.

A second area requiring scientific and technological development is the detection of illicit chemical-weapons production. There is a need for widespread deployment of unobtrusive technologies to detect signatures as well as computer techniques to extract useful information from massive amounts of data. Science and technology needs here include materials-science-based ideas such as novel chemical sensors; miniature air vehicles; low-power, high-bandwidth communications; and ultra-lightweight optical systems.

Nuclear and Radiological Areas

Our Nuclear Threat Assessment Program has provided comprehensive assessments of nuclear threats for more than 20 years. This program is also the DOE lead for assessing illicit trafficking in alleged nuclear materials. We apply long-standing LLNL expertise in nuclear materials, nuclear weapons, and device diagnostics to develop improved capabilities for dealing with radiological emergencies, including terrorist events. We are also a key participant in the DOE's national nuclear-incident response groups, including the Nuclear Emergency Search Team (which deals with nuclear terrorism or extortion threats), the Accident Response Group (which responds in the event of an accident involving U.S. nuclear weapons), and the Radiological Assessment Program (which assists state and local agencies). LLNL maintains a deployable response capability, called HOTSPOT, which can be relocated anywhere by military aircraft to provide local radiological field support.

The major areas of concern in nuclear and radiological detection are obviously detecting a nuclear device or nuclear or radiological materials possibly combined with conventional explosives. Many of the problems and challenges in these scenarios are centered on inspection and detection. A key concern is that such weapons and materials could be smuggled into the country or transported around the United States in containers. Large transportation containers are abundant; it is estimated that approximately six million containers per year enter the

United States. There is therefore a logistical problem of remarkable proportions—even if one assumes that a technical solution exists regarding the methods for inspecting containers.

Assuming that the logistical problems of containers entering the country by sea, air, and land could be overcome, there is one set of technical challenges based on detection and examination of the contents of stationary containers, and another set based on detection and examination of the contents of moving containers, for example, as they enter and move around cities on trucks.

Many of the most dangerous nuclear materials (U, Pu) actually emit or yield very low signals of gamma rays or neutrons. Some of the radiological materials (isotopes of Cs, Co, Sr, Ir) used in medical devices emit higher levels of gamma rays. Nonetheless, among the technical challenges of detection using gamma-ray detectors and passive or active neutron (and photon) detectors is the possibility of deliberate shielding to prevent (or reduce to undetectable levels) the sources of radiation. Recent work by LLNL, LANL, and the Lawrence Berkeley National Laboratory (LBNL) has led to the development of the hand-held Cryo3 detector, based on Ge detectors, to "fingerprint" radioactive materials. The detector was miniaturized using a Si-based cooling engine for the Ge. Work at LLNL in collaboration with LBNL is under way, developing advanced gamma-ray images using novel, segmented, high-purity Ge detectors. So, work on advanced detectors is key and is highly materials-science-based. It is also probably inevitable that control of nuclear materials at their source, combined with intelligence gathering, will be a vital component of all of the counterterrorism efforts based on detection.

Forensics and Attribution

In the area of forensics and attribution, there are also many new emphases. In 1991, LLNL established its Forensics Science Center for Ultratrace Analysis in Support of National Security. The center contains state-of-the-art equipment and highly motivated personnel. Since the inception, its capabilities have found application in intelligence work, nonproliferation, law enforcement, and counterterrorism. Expertise and instrumentation are available for complete chemical and isotopic analyses of nuclear materials, inorganic materials, organic materials (e.g., chemical warfare agents, illegal drugs), and biological materials (e.g., toxins, DNA). The Forensic Science Center also develops advanced laboratory and field capabilities for ultratrace analysis, including a portable (55 lb) gas chromatograph/mass spectrometer, field kits for thin-layer chromatography, and novel sample collectors using solid-phase microextraction.

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The Forensic Science Center has begun the rigorous testing required to become the second U.S. laboratory certified by the Organization for the Prohibition of Chemical Weapons (OPCW), which is responsible for implementing the Chemical Weapons Convention (CWC). Under the terms of the CWC, all samples collected from inspected facilities must be analyzed at two OPCW-designated laboratories. The U.S. Congress mandates that all U.S. samples be tested in the United States. Currently, the United States has only one designated laboratory, the Edgewood Chemical and Biological Forensic Analytical Center. LLNL will provide the second required facility.

Areas of contribution have included the miniaturization of equipment, development of field instrumentation kits, and novel trace-analysis techniques. Specialized approaches have been developed for biological, chemical, and radiological signatures. In order for these forensics approaches to be useful, they are often customized for particular field conditions. They have to be relatively straightforward to use and in many cases must meet law enforcement evidence requirements (e.g., chain of custody formalisms).

Applications include determination of the origins of weapons or weapon materials, possible suppliers, and intermediaries in support of legal, diplomatic, or military responses. One measure of the sophistication of the center's capabilities is the fact it is called upon to assist in the most difficult problems. The center has been brought in to analyze the "cold fusion" explosion at SRI International, "supernote" counterfeit bills, methamphetamine samples, biotoxins, suspect chemical-warfare specimens, and nuclear contraband. It has characterized explosive traces from the 1993 World Trade Center bombing, the Unabomber case, and the Fremont serial bomber; performed forensic sleuthing related to the Riverside "mystery fumes" case; and analyzed samples for the Glendale "Angel of Death" case. Locally, the center assisted Livermore police by rapidly identifying a vapor that sickened response personnel at the scene of a suicide; once the chemical was identified (malathion), law enforcement agencies were able to take appropriate personnel protection measures and complete their investigation.

At the height of the anthrax incidents, the Forensic Science Center was called upon to analyze a suspect powder found at a local business. LLNL scientists worked through the night to complete the analysis, confirming that the powder was harmless. The center was also requested to collect and analyze samples from the office of one of California's senators to provide independent confirmation of the Hart Office Building's decontamination, necessitated by the release of anthrax in the letter to U.S. Sen. Tom Daschle.

Atmospheric Modeling for Consequence Management

The Atmospheric Release Advisory Capability (ARAC), located and operated at LLNL, is a national emergency response service for real-time assessment of incidents involving nuclear, chemical, biological, or natural hazardous material. ARAC can map the probable spread of contamination in time for an emergency manager to decide whether protective actions are necessary. ARAC is on call to respond to real incidents and can also be used to evaluate specific scenarios for emergency-response planning, such as optimizing the siting of bioaerosol samplers or determining evacuation routes.

Since it was established in 1979, ARAC has responded to more than 70 alerts, accidents, and disasters and has supported more than 800 exercises. In addition to accidental radiological releases (e.g., Chernobyl, 1986; Three Mile Island, 1979), ARAC has assessed natural and human-made disasters (Mount Pinatubo volcanic ash cloud, 1991; Kuwaiti oil fires, 1991). ARAC has also provided assessments to state and local responders to toxic chemical accidents (e.g., Richmond sulfuric acid cloud, 1993; Sacramento River spill, 1991). State and local agencies can request ARAC support for actual releases or planning.

Concluding Remarks

The war against terrorism is not new, but it has intensified significantly since September 11. The mission-driven agencies will be the major centers focusing on this war. The science community will be vital in developing new technologies and also in providing honest evaluations about what is, and what is not, possible from scientific and technological viewpoints. Unlike science-based ventures, however, our community will have to ask different questions such as: What is really needed, versus what I want to do? Am I willing to work as a support function in a large team? Can my ideas be converted to a deployed technology that is cost-effective and rugged? Will responders in the field want to use it?

It is my opinion that the challenges evident now and in the future will in fact call upon the multidisciplinary innovations at the intersection of materials science, chemistry, physics, engineering, and biology. MRS is uniquely placed, because of its agile nature and intrinsically multidisciplinary foundation, to make major contributions. Sessions such as those held at this meeting illustrate the leadership that will make the war against terrorism a successful one.

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