OAK RIDGE NATIONAL LABORATORY

REVIEW

• MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY •

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National Security Technologies

Preparing for the Threats

Designing the "Soldier of the Future"

MANAGING THE SOVIET LEGACY

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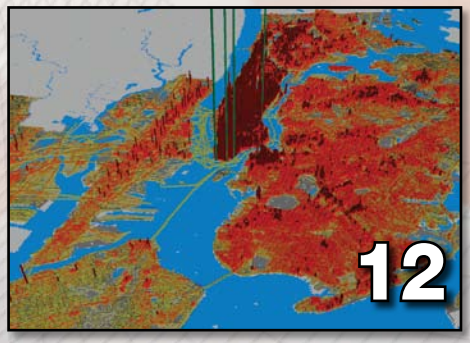


COVER: Artist's concept of natural and human threats challenging researchers. *Cover design by LeJean Hardin.*

Science for Security

Since the terrorist attacks of September 11, 2001, national security has become a priority mission of the Department of Energy. This mission, which in addition to public safety focuses on the protection of America's economic and energy security assets, is supported by an increasingly robust program of technological innovation. The vigilance required to deter future attacks, including the development of an ever-increasing number of breakthrough technologies, is a core motivation for the National Security Directorate at Oak Ridge National Laboratory.

Such vigilance takes a variety of forms. An internal business assessment, conducted before UT-Battelle was awarded the management contract for ORNL in April 2000, convinced the Laboratory's new leadership that, outside the Department of Energy, the greatest potential for research and development growth resided in the area of national security technologies. Over the following months the Laboratory gradually aligned its resources to capitalize on the opportunity, taking steps that included creating a new directorate, hiring an Associate Laboratory Director committed to national security, and conceiving a new $43 million facility dedicated to the directorate's mission. The reorganization was validated 18 months later when terrorists attacked the Pentagon and the World Trade Center. In the days and months that followed, ORNL was positioned to respond quickly to a range of new and complex national security challenges.

Today the largest program associated with ORNL's National Security Directorate is the Nuclear Nonproliferation Programs Office. The program assists the Department of Energy and the National Nuclear Security Administration in the daunting task of preventing nuclear-related materials and technologies from falling into the hands of America's adversaries, with much of the effort executed in Russia and the countries of the former Soviet Union. The challenge involves identifying, categorizing, accounting for, and verifying that nuclear materials and technologies, quite simply, are where they are supposed to be. ORNL also plays a significant role in addressing and verifying the commitments of the U.S. and other signatories to various nuclear treaty obligations. As part of this role, ORNL conducts research on extending the capability of existing nuclear material detection devices and is developing new, more sensitive materials to be used in the next generation of detectors.

Over the past five years, Nuclear Nonproliferation Programs have been joined by four National Security Directorate program activities that together provide a broad suite of capabilities. These programs are, respectively, Department of Defense, Department of Homeland Security, Advanced Technologies, and Technology Development and Deployment. They are dedicated in part to matching unique technologies available at ORNL with distinct customer needs.

Department of Defense activities provide technologies and expertise to the military services and other related organizations such as the Defense Advanced Research Projects Agency and the Defense Threat Reduction Agency. Similarly, ORNL's homeland security research activities focus on the needs of the federal government's newest agency to find affordable ways to reduce America's vulnerabilities, identify rapidly the right response in the event of an attack or, as in recent months, provide critical emergency assets in response to a natural disaster.

The directorate's Advanced Technologies Programs provide classified assistance to specialized organizations within the U.S. Government, while the newest activity, Technology Development and Deployment, is developing the expertise required to manage selected high-potential technologies that can be matched against an evolving range of national security needs.

With challenges that are at times sophisticated and unfamiliar, the war on terrorism demands that the United States draw upon all of its assets, not the least of which is a vast inventory of technologies in the national laboratories. This issue of the *ORNL Review* is dedicated to a portion of those technologies at Oak Ridge National Laboratory, and to the men and women dedicated to using those technologies in creative new ways to sustain our nation's security and our freedom.

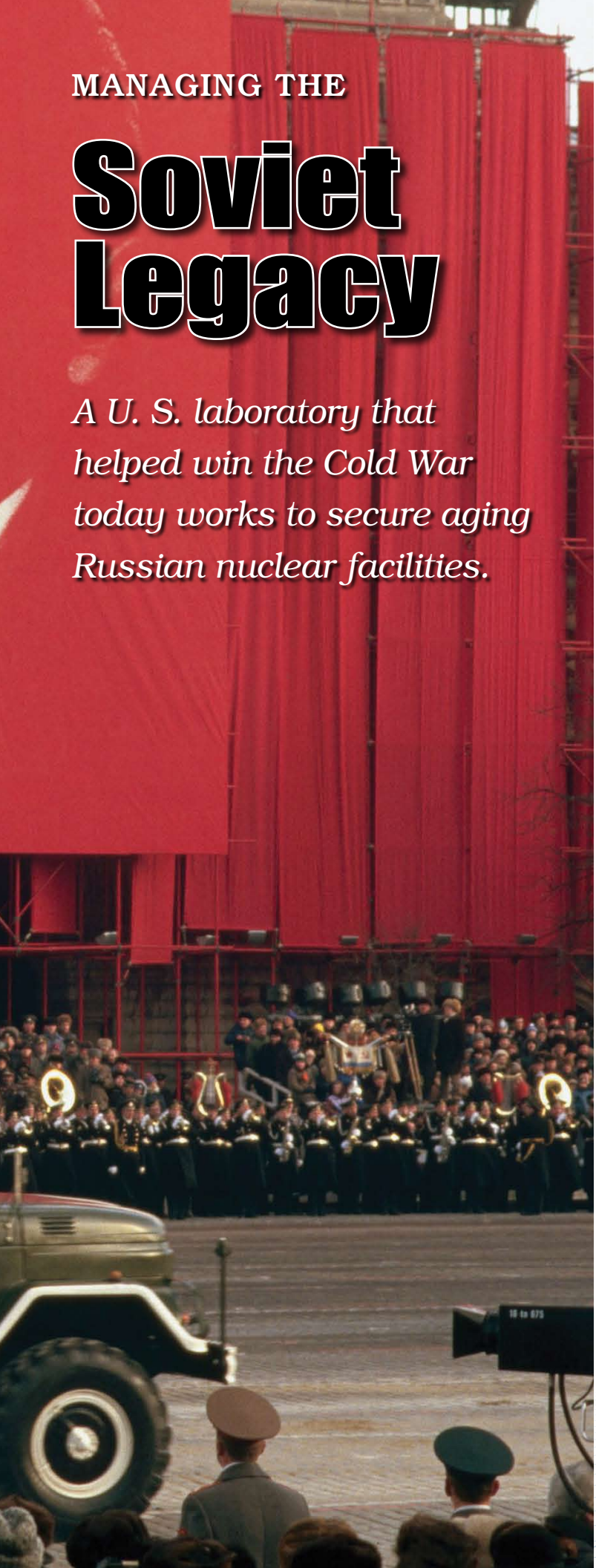
OAK RIDGE National Laboratory

Frank H. Akers, Jr.
Associate Laboratory Director
for National Security

MANAGING THE

Soviet Legacy

A U. S. laboratory that helped win the Cold War today works to secure aging Russian nuclear facilities.



An intact nuclear weapon is stolen and detonated. A terrorist group somehow steals, purchases, or produces fissile material and fabricates a crude bomb, called an improvised nuclear device, which the group threatens to detonate if its demands are not met. Medical radioisotopes are stolen from a cancer treatment center and combined with conventional explosives to build a radiological dispersal device, or "dirty bomb," which may be used to contaminate and render uninhabitable a large urban area. A disgruntled employee sabotages a nuclear power plant's safety system.

These four different nuclear terrorism threats are realistic scenarios that keep government officials awake at night. The threat of nuclear terrorism to American and global security and stability looms larger today than ever before. Terrorists have demonstrated their resolve to escalate the destructiveness of their attacks, while control over nuclear and radioactive materials becomes a growing challenge in a world increasingly shaped by nationalism, religious zeal, and the disintegration of historic boundaries and alliances.

Nuclear nonproliferation has been historically defined as "relating to, or calling for, an end to the acquisition of nuclear weapons by additional nations." More recent events have required that the definition be broadened to include non-state entities, such as terrorists, and other radiological weapons, such as dirty bombs. U.S. nuclear nonproliferation policy seeks to protect America's national security interests through a variety of programs that provide technical, regulatory, and infrastructure improvements. These programs are implemented through a number of U.S. government agencies around the world.

The U.S. Department of Energy, which houses the National Nuclear Security Administration, directly supports a range of nuclear nonproliferation activities in foreign countries. ORNL plays a large role in supporting DOE and NNSA in the task of reducing both internal and external threats to the United States from weapons of mass destruction. ORNL's Nuclear Nonproliferation Program (NNP) office provides extensive technical support to help the U.S. government address a range of critical nonproliferation issues and counter the threat of nuclear terrorism.

ORNL's suite of nonproliferation capabilities includes enhancing physical protection of nuclear material storage sites, developing new measurement techniques, improving personnel reliability for insider threat protection, and physically removing nuclear materials from regions of risk around the world. Although some of the work is conducted in research laboratories at ORNL, dedicated staff members carry out most of NNP's activities on foreign soil under occasionally difficult conditions. Because ORNL activities span the globe, many NNP staff members spend weeks at a time traveling and working in Russia and other former Soviet Union countries, where many of the nuclear weapons and related materials are located. The primary goal of the NNP office, which is managed by Larry Satkowiak, is to use ORNL experience and technical capabilities in a variety of ways to reduce the likelihood that nuclear materials will end up in the hands of America's adversaries.

Deterring Nuclear Terrorism

The most straightforward way to deter nuclear terrorism is to deny terrorists access to nuclear materials. More than 80 Russian facilities possess nuclear materials that U.S. officials fear could "leak" to rogue nations and terrorist groups. To lessen

Former Soviet storage facility for highly enriched uranium

the likelihood of such an occurrence, the U.S. and Russian governments work together on ways to secure these facilities' weapons-usable nuclear material, help upgrade their safeguards and security systems, and improve their nuclear material accounting systems. The U.S. effort is coordinated by NNSA's Material Protection, Control & Accounting (MPC&A) program, a large multidisciplinary effort managed jointly at ORNL by Satkowiak, David Lambert, and Teressa McKinney.

Security measures intended to deter theft of nuclear weapons and materials in Russia and other countries have been enhanced using ORNL expertise in physical protection, material control, and accounting. The Laboratory manages a cadre of experts with more than 500 years of combined nuclear safeguards and security experience in DOE, the Department of Defense, the Nuclear Regulatory Commission, and the private sector.

In this role, ORNL experts have the lead in several multimillion-dollar Russian projects that involve the design and installation of technical protection systems, as well as major construction. ORNL project management, physical protection, and engineering expertise have benefited the design and construction of consolidated nuclear material storage buildings for both civilian and military components in the Russian weapons complex. Over time, several ORNL engineers have become almost as familiar with Russian construction regulations as with those in the United States.

During the Cold War, the Soviet Union provided research reactors, and the highly enriched uranium (HEU) to fuel them, to most of the Central and Eastern European satellite countries in the Soviet Bloc, including Bulgaria, Romania, Hungary, East Germany, Poland, and Czechoslovakia. After the collapse of the Soviet Union in 1992, stockpiles of weapons-usable nuclear material, mainly HEU, remained in former Soviet republics with varying degrees of safeguards and security. ORNL has assisted NNSA's Office of Global Threat Reduction in recovering these materials and transporting them to more secure locations for disposition. Since 2002, ORNL personnel have been actively involved in the repatriation of HEU fuel of Russian origin from seven of these research reactors. The most recent return of fuel—from the Czech Republic to Russia—occurred in September 2005.

IN TUNE WITH THE RUSSIANS

When in Russia, Bill Hopwood likes to sing "Rocky Top," the University of Tennessee's fight song. Oak Ridge's expert in accounting for nuclear materials and former church cantor says, "I bet I have sung all three verses of 'Rocky Top' in more places in Russia than anyone else. The Russians toast from the heart and I find that singing 'Rocky Top' and Tennessee Ernie Ford's 'Sixteen Tons' at banquets and dinners helps break down cultural barriers and promotes cooperation. As a bonus, our hosts reciprocate and allow me to enjoy some wonderful Russian folk songs." Hopwood says such cooperation between the Russians and Americans is critical when the task involves processing weapons-grade material.

In 2002 Hopwood and ORNL's Stan Moses visited Serbia to monitor the packaging of 5,000 highly enriched uranium (HEU) fuel slugs and loading of the material on a Russian aircraft. The nuclear fuel being packaged for shipment came from a research reactor at the Vinca Nuclear Science Institute outside Belgrade. The ORNL researchers observed and collected accountability data on the fuel preparation, including uranium content, uranium-235 enrichment, and other safeguards.

The successful transfer of HEU from Serbia to Russia was announced to the world's news media after arrival of the Vinca fuel at the Research Institute of Atomic Reactors in Dimitrovgrad, Russia, 600 miles southeast of Moscow. Hopwood now travels to Dimitrovgrad and other facilities to provide technical monitoring of HEU materials received from civilian sites around Russia, including nuclear research laboratories. He also monitors the conversion of highly enriched to low-enriched uranium.

What song did he first sing in Russia? Hopwood's response: "Let There Be Peace."

Highly enriched uranium fuel slugs

Nuclear facilities in Russia and the former Soviet republics

TELLTALE EVIDENCE

Wielding cotton swabs, inspectors with the International Atomic Energy Agency take swipes from grungy surfaces on counters and cabinets in a nuclear power plant. Some swabs may pick up only trace amounts of telltale plutonium, as little as several nanograms, or even femtograms, that apparently escaped cleanup. If the inspection reveals evidence of these tiny amounts, the agency is likely to begin an extensive investigation that could lead to accusing the country running the reactor with a violation of the Nuclear Nonproliferation Treaty. The charge: separating plutonium from the spent fuel for an illicit nuclear weapons program.

IAEA conducts inspections of nuclear sites to assure the international community that countries are complying with their own nonproliferation commitments. ORNL supports DOE's International Safeguards initiatives designed to support IAEA activities. For example, ORNL-developed mass spectrometry methods are helping IAEA measure uranium and plutonium concentrations in environmental samples to detect "undeclared activities."

Lee Riciputi and his team in ORNL's Chemical Sciences Division provide the IAEA with high-precision isotope measurements of actual uranium and plutonium samples from the surfaces of nuclear reactors and nuclear fuel processing facilities, such as gas centrifuge plants that could be used to separate fissionable and nonfissionable uranium isotopes.

"We are trying to improve the sensitivity of mass spectrometry so we can analyze smaller and smaller samples of uranium and plutonium while retaining the precision and accuracy required for the data," Riciputi says. "We work with samples as small as 1 to 1000 nanograms for uranium and down to a femtogram for plutonium. A femtogram is a millionth of a nanogram, which is a billionth of a gram. Natural uranium is found everywhere due to fallout from aboveground testing of atomic bombs decades ago. We are trying to detect uranium and plutonium traces that were not removed during cleanup at a nuclear facility inspected by IAEA. The minimal sample may be all we get." Scientists use a mass spectrometer to separate all the isotopes in the sample based on differences in mass. "We simultaneously detect many isotopes using our state-of-the-art equipment," Riciputi says.

With funding from DOE's National Nuclear Security Administration, the ORNL group has enhanced the mass spectrometer's thermal ionization efficiency. By successfully developing a cavity ion source and coupling it with the magnetic sector of the mass spectrometer, Riciputi was able to detect 1 in every 4 uranium atoms present, much better than 1 in every 10,000 atoms of uranium, when the instrument was operating at its lowest efficiency.

The cavity ion source consists of a metal rod that replaces the traditional filament. The sample is placed in a hole bored into one end of the rod.

"Using electron bombardment, we can heat our metal rod 1000°C hotter than the filament, vaporizing more atoms in the sample and improving the efficiency at which electrons are stripped from the atoms in the vapor," Riciputi says. "As a result, more ions are introduced into the mass spectrometer for analysis."

Repatriated HEU fuel is transported to special Russian facilities after safeguards have been upgraded under the MPC&A program. At these facilities the weapons-grade uranium is diluted, or blended down, into low-enriched uranium (LEU), which cannot be used as a nuclear weapon. NSTD's Bill Hopwood leads a team of inspectors that monitors the blend-down process, thus transforming the material from a potential threat to a valuable fuel for nuclear power plants.

In 2005 the United States and Russia reached a notable milestone in the plan to reduce the availability of HEU to hostile weapon makers, and ORNL helped another major DOE-NNSA program achieve this goal. On September 30, 2005, the United States and Russia issued a Joint Statement to mark the completion of the conversion of the equivalent of 10,000 Russian nuclear warheads into fuel for nuclear reactors that provide 10% of America's electricity. In 1993, the United States and Russia signed an agreement to down-blend 500 metric tons of HEU from Russian nuclear weapons (enough for 20,000 weapons) to LEU. This uranium is then supplied to manufacturers that prepare nuclear fuel for use in commercial nuclear power plants in the United States. About half of the nuclear fuel that the United States Enrichment Corporation (USEC) sells to American nuclear utilities comes from down-blended Russian HEU.

NSTD's Danny Powell leads a team of more than 20 Oak Ridge personnel who assist in nearly continuous "on-the-ground" monitoring of the blend-down operation in Russia. In addition, Powell led a technology integration team, including José March-Leuba, Tanner Uckan, and Ray Brittain, that developed and installed blend-down monitoring systems, based on time-varying neutron activation of uranium hexafluoride, that continually monitor the down-blending of HEU to LEU. ORNL Corporate Fellow John Mihalczo, March-Leuba, and James Mullens developed the heart of this blend-down monitoring system, which provides assurances to the world that the Russians are, indeed, moving away from five decades of Cold War nuclear policies.

For many people living in the former Soviet Union, the face of the U.S. government is a friendly group of Oak Ridge safeguards specialists. ORNL's nonproliferation programs have been successful primarily because dedicated Laboratory staff have provided a critical service under difficult conditions. Much of the work has been accomplished on a technical level through collaborations with foreign government agencies, laboratories, and scientists. Equally important, however, is the positive impact exerted by ORNL personnel on a more personal level. While the value of these personal interactions between technical

experts from Russia and Tennessee cannot be measured in the laboratory, it is hoped that the residual goodwill will outlast the weapons of destruction that brought them together.

Whom Can We Trust?

Nonproliferation officials are placing increasing emphasis on assessing the threat from insiders—personnel with authorized access to a facility and/or its systems—as part of the broader effort to stem the flow of nuclear materials. Thefts of nuclear and radiological material are accomplished most frequently by insiders or by persons receiving assistance from insiders.

ORNL has undertaken the task of developing stronger human reliability programs at Russian civilian and military facilities to supplement their conventional physical security measures. As a result of ORNL's strong partnership with the Department of Defense and U.S. industry, the Laboratory has formed a team of physiological, psychological, and technical specialists with expertise in human reliability. ORNL's approach is to help develop effective insider protection programs through drug and alcohol testing, aberrant behavior recognition, and stringent procedural requirements.

From Johannesburg to Beijing

When a nation decides to terminate its nuclear weapons program, chances are high that Oak Ridge expertise will be involved in the program's dismantlement. In 1991 the Republic of South Africa shocked the world with an announcement that six nuclear weapons devices had been secretly produced and dismantled. South Africa had agreed to sign the Nuclear Nonproliferation Treaty and provide the IAEA with a complete inventory of nuclear materials, including residual uranium powders contained in thousands of multi-sized drums. When the IAEA sought U.S. help in 2001 to assist South Africa in measuring and declaring the amount of fissionable uranium present in the drums, Oak Ridge offered a solution. An unused drum scanner and a South African national trained to operate the device were sent from Oak Ridge to South Africa.

With a growing peaceful nuclear energy program, China is becoming increasingly concerned about the threat from insiders working with terrorists. China has adopted new regulations on protecting and accounting for nuclear materials and has been eager to learn about U.S. methodologies. In October 2005 Michael Whitaker and several ORNL colleagues participated in a Joint U.S.-China Integrated Nuclear Materials Management Technology Demonstration conducted in Beijing. The Department of Energy called the event "a model for successful cooperative projects" that "marks an important step in continued collaboration between the United States and China in the area of nonproliferation, nuclear security, and safeguards."

Russia, Kazakhstan, Serbia, Iraq, Czech Republic, South Africa, and China are among the countries where ORNL staff have been involved in nuclear nonproliferation work. In each instance, they represent locations where only a decade ago few would have imagined scientists from East Tennessee would have a presence. As the world's political stage evolves, so, too, does the Laboratory's mission. ®

ONE THREAT AT A TIME

In early 2004, 20 ORNL employees led by Alex Riedy quietly entered a building located on the outskirts of Baghdad. Their mission: Determine the amount of natural uranium dumped onto a floor by Iraqi looters, repackage the non-fissionable material in appropriate containers, and close the containers with seals approved by the International Atomic Energy Agency.

The looters apparently needed uranium-containing canisters to store water. Indifferent to the contents, they broke the IAEA seals and emptied the canisters onto the floor. The Oak Ridge participants in the secret project hoped the episode might become public when President Bush addressed ORNL employees in July 2004. Seated near the podium, they were disappointed but not surprised when the president did not mention their efforts in Iraq. Instead, his remarks focused on Oak Ridge's role in the shutdown of Libya's nuclear program (see p. 20).

"We do exciting work," says Michael Whitaker, manager of the Safeguards Group in ORNL's Nuclear Science and Technology Division. "But a difficulty in our job is that we cannot tell the news media when and why we do something until our work with a country's nuclear material is complete."

A similar news blackout was maintained in 1994 when Riedy led the Project Sapphire team that removed from Kazakhstan enough highly enriched uranium to make more than 20 atomic weapons. Riedy's team packaged the material, loaded it onto U.S. Air Force C-5 cargo airplanes, and oversaw the safe transportation of the material to the Dover Air Force Base in Delaware, where the uranium was transferred onto secure tractor-trailer rigs and transported to the Oak Ridge Y-12 National Security Complex for interim storage.

U. S. Air Force C-5 cargo airplane

RUSSIAN ENRICHMENT

In a land where religious holidays and the spirit are often an afterthought, ORNL's Danny Powell has opened his heart to the orphans who live outside Russia's four closed cities. At Christmas he brings them books and boots, toys and tools, DVDs, clothing, and sewing machines—whatever the orphanage directors tell him are most needed. Last spring before school graduation day, he and several Oak Ridge colleagues purchased graduation dresses and suits for the young students living in an orphanage.

Powell collects donations of money and various items in Oak Ridge, makes purchases in Russia, and distributes the gifts to orphanages in rural areas outside Novouralsk, Zelenogonsk, Mayak, and Tomsk, where temperatures can drop to –40°F in the winter.

"Orphans received less support from the government after the Soviet Union's collapse in 1992. The dramatic devaluation of the rouble during the 1998 Asian monetary crisis only made matters worse," Powell says.

A member of ORNL's Nuclear Security Technologies Group, Powell's "day job" is with a U.S.–Russian Federation program whose goal over the next 20 years is to remove 500 metric tons of highly enriched uranium from dismantled Russian nuclear weapons.

"We monitor the automated conversion of weapons' HEU to low-enriched uranium," Powell says. "The product is transported to the U.S. Enrichment Corporation, which sells it as nuclear fuel to American nuclear power plants."

For Powell, his work with Russian orphans has redefined the meaning of enrichment.

FINDING THE TRAIL

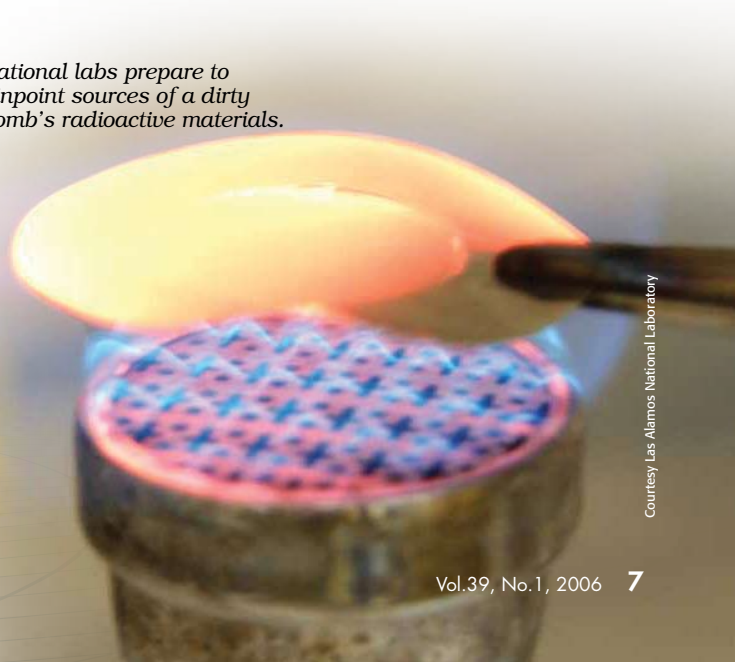
In the heyday of ORNL's isotope program, the Laboratory produced and sold 99 different radioisotopes and made 1200 to 1500 shipments per month. Since the mid-1940s, radioisotopes from ORNL have been distributed worldwide to promote the peaceful use of radioactive materials. Many of those radioisotopes are used in life-saving medical applications such as diagnosing and treating cancer. Other isotopes are used in agriculture, transportation, space exploration, public safety, and environmental protection. Terrorist groups conceivably could steal radioisotopes that originated at ORNL—such as cesium, californium, and strontium—and use them in a dirty bomb that combines a conventional explosive with illicit nuclear material.

ORNL staff are mining the Lab's radioisotope production records to obtain information on radiation sources that contain californium, cesium, and strontium, which have relatively long half-lives. Other isotopes from ORNL have such short half-lives that they are no longer of concern. Staff also are analyzing ORNL-produced material and foreign material in a search for isotope "fingerprints" such as the distribution of radioisotopes and traces of chemicals. Even the tap water used to process certain isotopes may be a clue to the origin of the material.

In yet another area, the team is involved in "forensics and attribution" work for the Department of Homeland Security—figuring out where the radiation source came from and who is responsible for incorporating it in a dirty bomb. The goal is a database that can track over the past decades customers who purchased and packaged ORNL radioisotopes for distribution.

Using mass spectrometry, ORNL researchers hope to identify isotope signatures—telltale ratios of various isotopes in reactor fuel and spent fuel—to help them quickly pinpoint the country of origin for a dirty bomb, should one ever be detonated. In this instance, they hope their research will never be needed.

National labs prepare to pinpoint sources of a dirty bomb's radioactive materials.



Courtesy Las Alamos National Laboratory

Researchers hope high-powered lasers can be used for underwater communication.

Technologies for the Troops

ORNL's National Security Directorate is solving an array of technology challenges for the Department of Defense.

Oak Ridge National Laboratory is the Department of Energy's largest multipurpose research facility. Part of the Laboratory's research agenda includes the National Security Directorate's Department of Defense organization, designed to make ORNL's research and technology capabilities available to solve specific technical challenges for the Department of Defense. In this way, ORNL supports the Secretary of Energy's goal to "protect our national security by applying advanced science and nuclear technology to the nation's defense."

The directorate is organized to match DOD needs with ORNL capabilities in two fundamental ways: Applying ORNL technologies to specific DOD needs, gaps, or shortfalls, and making DOD aware of evolving ORNL capabilities that might be of benefit to one or more military services. To accomplish these tasks, the Laboratory's DOD organization has a unique blend of joint military experience representing more than 400 years of military service. This combination of military experience and technological expertise represents a broad and unique collection of talent available to address scientific challenges for the Department of Defense.

Getting Out of a Jam

The opposition in Iraq is a "thinking enemy." As the American military has become increasingly adept at developing countermeasures for the use of improvised explosive devices (IEDs), the enemy in turn has responded with equally creative ways to deliver the devices, says Mike Kuliasha, the NSD's chief scientist.

"This past year I have spent a good portion of my time on IEDs," he says. "I've put together a consortium of five Department of Energy national labs, including ORNL, to demonstrate to the Department of Defense how to take a systematic approach to solving the IED problem."

A technology that may make U.S. radios much more difficult to jam is currently under development. The U.S. military is working with Boeing to upgrade its radio technology to a modern Joint Tactical Radio System. The base technology of JTRS is software-defined radio (SDR), in which software modifies characteristics of the system's radios at specified times. For example, software could periodically change the fundamental characteristics of the radio waveforms, making it difficult for the signal to be jammed. The SDR would allow all coalition radios to talk to each other, providing much needed interoperability.

"Our SDR focus is different from the mainstream JTRS approach," says Mark Buckner of ORNL's Engineering Science and Technology Division. "We have developed a dynamic, software-reconfigurable, computing, communications, and sensing platform. Although this platform could support military waveforms and provide an anti-jamming capability, our primary focus has been on tagging, tracking, and locating, as well as logistics applications."

The platform that Buckner and his colleagues in ESTD have developed has reconfigurable digital and analog/radiofrequency circuits. Also, they have designed software that reprograms the circuits, enabling the device to assume a new personality. Thus, the platform could be a global positioning system (GPS) device, cell phone, satellite phone, or secure first-responder radio. In the future, if insurgents in Iraq or Afghanistan attempt to jam the U.S. communication channel, a new set of parameters to switch the radios to different modes of communication could quickly be pushed out to radios using this technology.

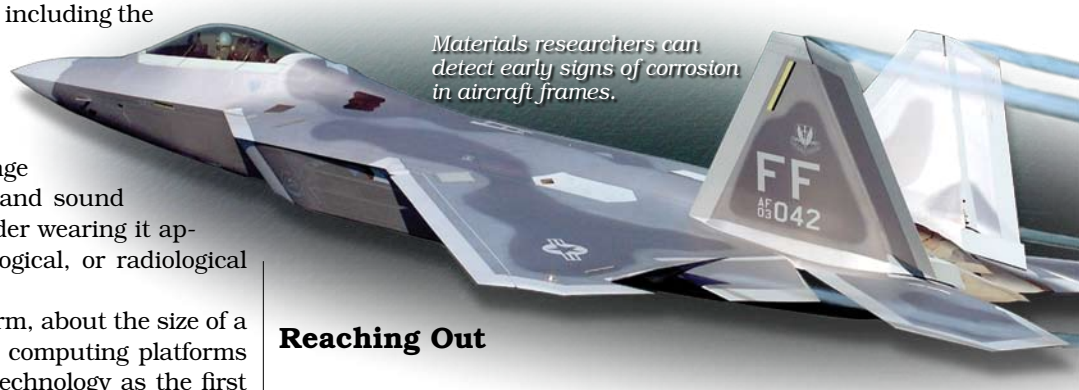
This research is part of ORNL's Cognitive Radio Program. The program's mission is to integrate SDR, sensors, and computational intelligence capabilities to address both government and commercial problems in a manner that enhances U.S. national security. A cognitive radio uses sensors to gain awareness of

its radio environment and surroundings, including the identity and health of the user.

"We're in the process of embedding sensors, cameras, and microphones into our cognitive radio to increase its awareness," Buckner says. "Our long-range plan is to program our radio to sense and sound an alarm when a soldier or first responder wearing it approaches an area where chemical, biological, or radiological hazards exist.

"Our current cognitive radio platform, about the size of a tissue box, is a nexus of reconfigurable computing platforms and sensors. Our vision is to use this technology as the first step toward developing a cognitive sentry for soldiers and first responders. The radio will get your attention, provide the needed information, and assist you in performing required actions."

In another laboratory, ORNL researchers are developing technologies to help soldiers navigate their way around the battlefield. Soldiers equipped with ORNL's Triply Redundant Integrated Navigation and Asset Visibility (TRI-NAV) system can determine their precise location regardless of foliage, terrain, buildings, and attempts by the enemy to jam GPS signals. The key to the proprietary system, which requires very little power for the user's unit, is the seamless combination of a highly advanced GPS, an inertial navigation unit, and the new ORNL-developed Theater Positioning System (TPS). The TRI-NAV system also features precision timing to ensure that the three systems work together to provide instant and highly accurate location information, which is critical to soldiers in combat situations. A novel spread-spectrum, radiofrequency scheme for the TPS signals makes it difficult to jam TRI-NAV. Researchers expect the final soldier unit to be about the size of a cellular telephone and accurate to less than one meter.



Materials researchers can detect early signs of corrosion in aircraft frames.

Reaching Out

In 2003 Frank Akers decided that ORNL's growing technology capabilities made it practical to reach out beyond the Army to all the DOD services. He appointed Richard Snead, a native of Clinton, Tennessee, and a former commander of a squadron of six attack submarines near Hawaii, as head of NSD's Navy programs. Snead, who previously managed the Program and Budget Division for the chairman of the Joint Chiefs of Staff, hired a collaborator, John O'Neil. The two are helping ORNL staff understand the unique culture and needs of the U.S. Navy. At the same time, they are seeking to convince former Navy colleagues that ORNL has capabilities beyond its nuclear expertise that could help the Navy meet a range of technology needs. In particular, Snead believes that ORNL's computational and communications expertise could benefit the Navy's development of ForceNet for tomorrow's naval warfare. Snead describes ForceNet as a way to transform information in a networked combat force into decisive action.

Researchers are seeking to develop coherently combined beams from large arrays of high-powered semiconductor lasers that could be used for directed energy sources and underwater communication in support of ForceNet. Snead is also enthusiastic about research on metal fuels that he believes could offer a much higher energy density than today's batteries for unmanned submersible vessels (see p. 26).

Expanding NSD's outreach to the Air Force and Marines is the assignment of Tim Vane, director of NSD's Thought Leadership Programs Division. ORNL has established research and training programs with the USAF where three uniformed officers spend 10 months at ORNL learning about Laboratory capabilities.

According to Vane, ORNL has a unique combination of facilities and talent to help the Air Force monitor the condition of a fleet that includes B-52 bombers that date to the 1950s, as well as the most sophisticated airplanes ever built. ORNL's materials researchers, he says, can detect early signs of corrosion in aircraft frames that could lead to failure, especially in fighter jets and helicopters that undergo sustained stress from numerous takeoffs and landings in Iraq and Afghanistan.

Soldier of the Future

In 2001 ORNL's Roger McCauley persuaded Department of Defense leaders in the Pentagon to come to Oak Ridge National Laboratory for a brainstorming session. The topic: fielding a technologically advanced army consisting of faster, tougher, smarter soldiers integrated into a networked, computerized war-fighting system. Citing ORNL's Manhattan Project legacy and the Laboratory's comprehensive research and development

program, McCauley convinced staff in the Office of the Undersecretary of Defense for Acquisition, Technology and Logistics that ORNL could lead a process to envision the soldier of the future, or Objective Force Warrior. McCauley told his audience that ORNL is the place to determine what will be required for the future American soldier to outthink, outmaneuver, and outshoot the enemy and communicate more effectively with other soldiers and military leaders.

Frank Akers, ORNL's Associate Laboratory Director for National Security, asked George Fisher, director of NSD's Department of Defense Programs Division, to lead this effort. Army leaders told Fisher they wanted to put the Objective Force Warrior concept out for bid to private industry but needed help building a technologically feasible vision and architecture.

"The Army had lots of questions about the soldier of the future," Fisher says. "How is he going to be outfitted and armed and how is he going to communicate? What sensors will be embedded in the uniform or helmet? We get all kinds of lists but we need someone to put the military requirements and technology developments together to make a feasible architecture by 2012 that challenges the bounds of science."

In 2001 Fisher's team agreed to take on DOD's mission and called in nationwide panels of experts, some of whom had no experience with the military. "We brought to Oak Ridge the head ride designer for Disney, the chief of surgery at Yale, the head scientist for NASA, and lots of military experts and scientists," Fisher says. "We closed the doors and challenged the panelists to come up with a vision of the soldier of the future. The product we gave the Army went out as part of the solicitation to industry."

Information Overload

ORNL's recent work with the Department of Defense is the latest in a series of collaborations that date to the Laboratory's inception in the 1940s. In 1999, intelligence analysts working for the U.S. military's Pacific Command asked ORNL for assistance in a unique category of research. As a result of time limitations, analysts charged with scanning newspapers and summarizing articles for their commanders about potential threats were able to read only 10% of the region's newspapers. Thomas Potok and his colleagues solved the Pacific Command's problem.

"We created software agents that could sort through all the region's online newspapers in one minute and pull down the desired information," Potok says. "Then we got our intelligent agents to work together to organize the documents based on their similar text features and to present the similarities visually as tree structures to the analysts. Now the analysts spend substantially more time on analysis and much less time on gathering information. Our challenge is to examine the roughly 10,000 documents being published per day and help the analysts identify the 5 or 10 threat scenarios with which they should be concerned."

Potok's information technology, called Virtual Information Processing Agent Research (VIPAR), has been licensed to TechConnect, an Oak Ridge business that matches government requirements with the capabilities of the private and public sectors.

Chemical Detection

One tactic for slowing down an advancing military unit is to spread on the ground chemical warfare agents, such as toxic Sarin or VX, to force the unit to circumvent the contaminated area. The U.S. Army has long sought an accurate detector for each of its reconnaissance vehicles to spot quickly any contamination zones.

Responding to the challenge, ORNL researchers have developed the Block II Chemical Biological Mass Spectrometer (CBMS II), which the Army plans to deploy on the Stryker and Joint Services Lightweight reconnaissance vehicles for detecting

America's "soldier of the future" will look dramatically different.

ORNL's portable weigh-in-motion system can weigh military vehicles more quickly and accurately than the manual method.

toxic chemical contaminants on the ground. Army tests show that CBMS II can distinguish between chemical warfare agents and diesel fuels or oil fire fumes, meeting the Army goal of an instrument that sounds fewer false alarms than the detectors used in the 1991 Persian Gulf war.

Hamilton Sundstrand, a subsidiary of the United Technologies Corporation, is building prototype CBMS II units for testing. In 2006 the Army will complete tests of CBMS II's ability to detect biological warfare agents (bacteria, toxins, and viruses) and liquid toxic industrial chemicals, such as nitric acid, that troops might encounter when approaching a bombed factory or stockpiles of chemicals encapsulated in drums. The Army will also test an ORNL-developed application probe that safely picks up a chemical sample from a drum for a controlled transfer to the sampling probe and mass spectrometer for analysis.

In DOD's vision, future soldiers will wear a sensor that can detect a very low level threat, such as a nerve agent or other toxic gas, and evacuate the area in time to survive. In a project funded by the Defense Advanced Research Projects Agency (DARPA), ORNL is teaming with Honeywell to develop a microgas analyzer the size of a cell phone that combines a very small gas chromatograph and mass spectrometer. Researchers are testing the analyzer's ability to detect trace amounts of dimethyl methylphosphonate, a nerve gas simulant.

Similarly, the U.S. military services, joined by elected and public health officials, are concerned about the possibility of municipal drinking water supplies being poisoned by terrorists. ORNL scientists have developed a technology that provides early warning of contamination in primary-source water supplies. Called AquaSentinel, the device collects real-time data in the field and transmits the data to a remote computer to provide almost instantaneous warning of potential contamination problems, some of which can be addressed effectively by early remediation. ORNL's AquaSentinel monitors light emitted by healthy freshwater algae during photosynthesis in their natural habitat. If the algae are exposed to a toxin, the nature of the emitted light changes, providing a signature for the toxin and a warning to security officials. The ORNL technology has been licensed to United Defense (BAE Systems), which markets a device called WaterSentry™.

Getting There Faster

The Department of Defense must be able to deploy troops and equipment rapidly anywhere in the world. Moving massive amounts of equipment and supplies involves loading carefully weighed trucks on cargo aircraft so that the plane is balanced and within safe weight limits. Currently, DOD personnel manually weigh trucks with an error rate approaching 15 percent. ORNL researchers have developed and tested a 100-pound prototype of a portable weigh-in-motion system that can weigh military vehicles and their cargos automatically in less than half the time with virtually no errors. According to NSD's Dick Davis, "The latest generation of the compact WIM system can be carried on aircraft and used at austere landing strips such as are often found in Afghanistan, Iraq, and other current theaters of operation. In 2006 soldiers and Marines will field test WIM systems at Army, Air Force, and Navy/Marine Corps sites."

As each DOD service endeavors to improve the ability to move not only troops and equipment but also large amounts of fuel, food, and ordinance to operational locations around the world, military planners hope to benefit from ORNL's Collaborative Force-Building Analysis, Sustainment, Transportation (CFAST), a web-based, collaborative tool for such complex logistics. CFAST, which has its roots in ORNL's JFAST, could assist commanders in making collaborative decisions, both in deliberative planning and during crisis actions.

A Growing Partnership

Taken together, an expanding collection of new technologies represents a steadily growing partnership between ORNL and the nation's military services. In ways that soldiers of past wars could never have imagined, these technologies will shape the nature of future conflicts by redefining the capabilities of the American combatant. By continuing to provide our troops with a critical technological edge, we are contributing to the ultimate goals of reducing casualties and securing our nation's freedom. ®

Preparing for the Threats

ORNL plays a growing role in preparations for natural disasters and terrorist attacks.

When Congress created the Department of Homeland Security in 2003, most Americans understandably associated the department's mission with the threat of a terrorist attack. From August through October of 2005, however, the greatest threats came from hurricanes that slammed the Gulf Coast. The hurricanes' aftermath dramatically illustrated that the Department of Homeland Security is also responsible for preparation for and response to natural disasters as well as terrorist attacks. The government and citizen response to Hurricane Katrina, which breeched the levees protecting New Orleans and caused unprecedented levels of destruction, was significant, according to Vivian Baylor, director of the Law Enforcement Programs Division of ORNL's National Security Directorate.

"There are striking similarities between a natural disaster and a terrorist incident in terms of the failure of the infrastructure, the needed response, and the economic consequences," Baylor says. "Portions of the response would not have been substantially different if a terrorist had blown up the levee."

"There are striking similarities between a natural disaster and a terrorist incident in terms of the failure of the infrastructure, the needed response, and the economic consequences."

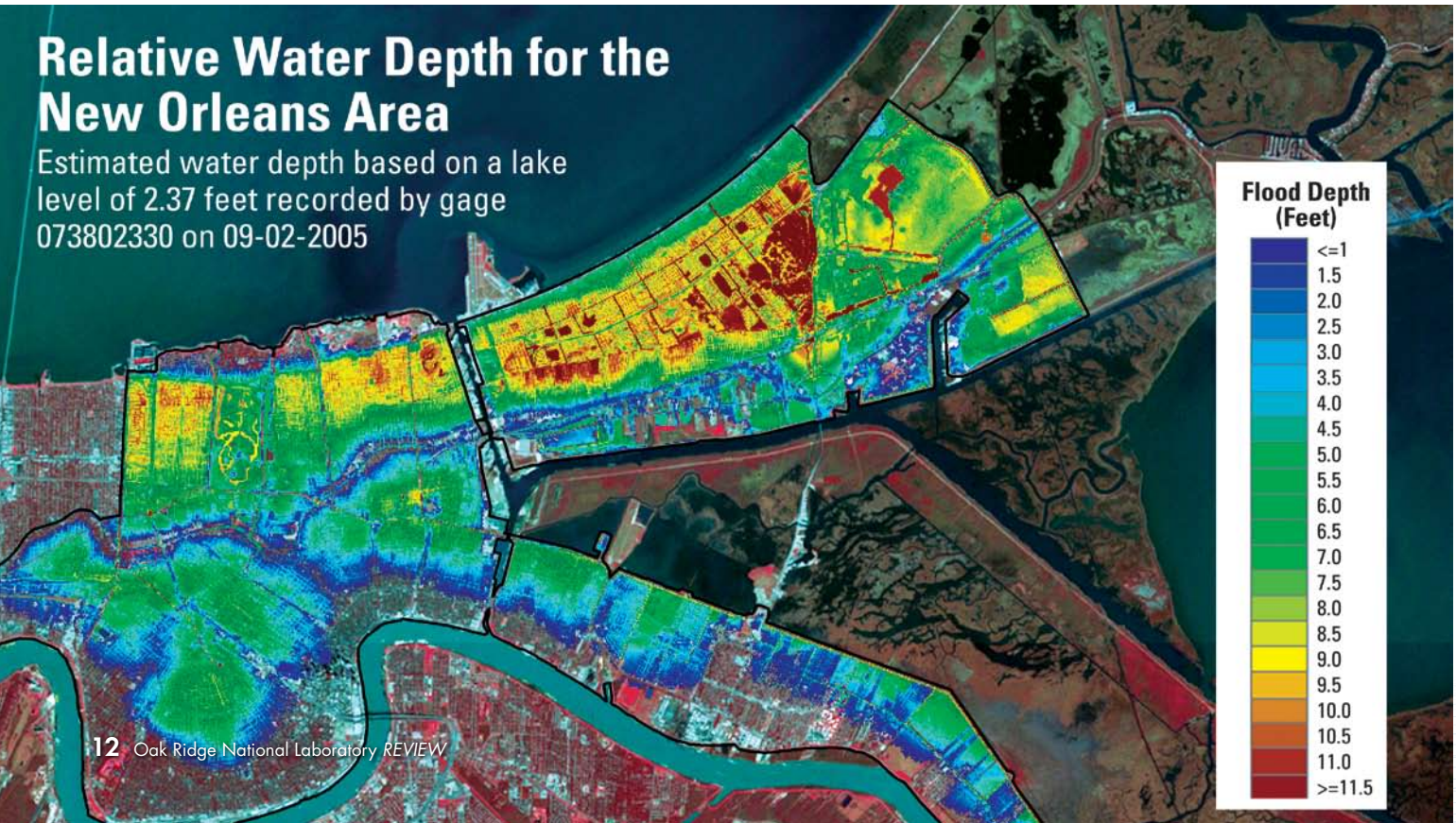
Research in the Aftermath

ORNL received $35 million in fiscal year 2005 from DHS for research that paid benefits before, during, and after hurricanes Katrina, Rita, and Wilma. Budhendra Bhaduri and members of his Geographic Information Science and Technology (GIST) group were bombarded with questions about affected populations. Using the ORNL-developed LandScan population database and modeling program (see sidebar), the GIST group produced visual results that became part of President George Bush's daily briefings the first week after Katrina struck.

"LandScan shows the number of people in various locations, such as hospitals, nursing homes, and schools," Bhaduri says. "The information is incredibly valuable for homeland security, which really means taking effective actions to save the lives of people known to be at risk."

ORNL's John Sorensen, an expert on evacuations and emergency responses to natural disasters and explosions at chemical facilities, discussed Hurricane Katrina's aftermath in interviews by National Public Radio and *Time* Magazine. Sorensen and his wife Barbara have developed a half-dozen popular training videos, including "React Fast," which have been used to train emergency responders and security people for the Olympic Games and other sites of potential terrorism.

Several of Sorensen's ORNL colleagues served as emergency resources in the wake of the hurricanes. After Katrina struck, staff responded to questions about the effects of the hurricane on the shipment of commodities by railroad. Others provided crucial information that included a response to a barge owner who wanted to know which ports along the Mississippi-Louisiana coast were open and undamaged.



ORNL's Andre Desjarlais surveyed the roofs of damaged commercial buildings along the Mississippi coast in the week following Hurricane Katrina. He examined the buildings to determine if energy-efficiency technologies recommended by the Department of Energy make roofs more or less vulnerable to wind damage. Except for buildings that house public safety functions or could serve as public shelters, he found that many buildings in Louisiana and Mississippi fared worse than similar structures he saw in Florida in 2004, perhaps because of differences in building codes. The biggest surprise came from roofs that were greatly damaged by wind-blown attachments such as air-conditioning units, lightning protection equipment, and cell towers.

A largely unanticipated problem in the aftermath of Hurricane Katrina was the failure of emergency communications systems, including cell phones and landline phones. Only satellite phones worked. Sheriffs and Coast Guard officials could not communicate through their radio systems. ORNL's Cognitive Radio Program led by Mark Buckner and Michael Moore is developing software-defined radio (SDR) technology that will help improve emergency communication after disasters. "SDR allows use of the same hardware to communicate either over the local network or by satellite," Moore says. "Our approach could greatly enhance the interoperability of radio systems in a situation where the communication infrastructure has been destroyed."

Courtesy of FEMA. Photo by Liz Roll

New Orleans roofs damaged by Hurricane Katrina

Bioterrorism

As director of NSD's Homeland Security Programs Division, John Doesburg is convinced that ORNL and its collaborators can assist the U.S. government in developing a variety of technologies to detect and defend against bioterrorism. He cites ORNL's expertise in mouse genetics, mass spectrometry, and high-performance computing as strengths that could contribute to the nation's anti-terrorism effort.

"By modifying the genes in our unique mouse population in ORNL's new vivarium, we could learn which genes might make humans more immune or more susceptible to select disease agents, such as anthrax, and diseases endemic to certain regions," Doesburg says.

To speed up identification of biological warfare agents, which can take 15 minutes, researchers must replace traditional wet chemistry involving buffer solutions. No one can tell whether anthrax organisms are alive or dead in a human for 24 to 48 hours.

"ORNL is harnessing the power of hybrid mass spectrometry, computational science, and bioinformatics to pursue the government's grand challenge of rapid identification of select agents and endemic diseases," Doesburg says. "Our goal is 4 minutes or less to identify a select disease organism and determine its viability."

Radiation Detectors

New ORNL technologies are contributing to the goal of developing more accurate, reliable detectors of chemical, biological, radiological, nuclear, and explosive threats. Researchers have developed a mass spectrometer that detects minute traces of explosive chemicals on airline tickets. The "boarding pass analyzer" is undergoing tests at the Transportation Security Administration's Laboratory in Atlantic City, New Jersey to determine the technology's viability for major airports.

With funding from DOE's Office of Biological and Environmental Research and the Federal Bureau of Investigation, ORNL has led the development of the Raman integrated tunable sensor (RAMITS), a lightweight, portable, laser-based instrument that can identify and analyze a chemical or biological threat in 11 seconds or less. A surface-enhanced Raman spectroscopy probe coated with nanoparticles of silver enhances RAMITS' signal more than a million times. The battery-powered, compact, cost-effective device, which has a touch screen and is simple to operate, has been licensed to ID Systems LLC, of Knoxville, Tennessee.

Mike Kuliasha, NSD chief scientist, says that RAMITS will make a critical difference for first responders involved in hazardous materials detection and firefighting who have to deal with chemical leaks from railroad cars and tanker trucks. "Sometimes HAZMAT responders must wait for hours before a chemical in a leak or spill is identified," Kuliasha says. "With RAMITS, responders can rapidly identify any chemical compound that enters the environment, including chemicals released by terrorists."

Since the department's creation, a top DHS priority has been to address the possibility that a terrorist group might attack an American city with an improvised nuclear device (IND) or a radiological dispersal device (RDD), also known as a "dirty bomb." Such a conventional explosive laced with radioactive material could contaminate and render inhabitable hundreds of square

Truck weigh-and-inspection station. Inset: Raman integrated tunable sensor (RAMITS)

miles in an urban area. DHS has established a new Domestic Nuclear Detection Office that funds the development of passive and active radiation detectors by DOE labs.

A passive radiation detector integrated with other passive sensors has been installed in the portal monitor through which trucks move at the weigh-and-inspection station on Interstate 40 in Knoxville. ORNL researchers, who work with the Tennessee Highway Patrol, South Carolina State Transport Police, and Kentucky Transportation Cabinet, say the challenge is to differentiate between radiation sources in truck trailers that are normal in commerce—such as ceramics, granite, kitty litter, smoke detectors, and medical radioisotopes—and radioactive materials that might be intended for use in a terrorist weapon. Similar multi-sensor, integrated portal monitors are deployed at truck weigh-and-inspection stations in Kentucky and South Carolina and at the Charleston, S.C., seaport.

"We must not impede commerce, but we want to screen for illicit nuclear material in truck trailers and shipping containers," says Bob Wham, who leads ORNL's Fuels, Isotopes, and Nuclear Materials Group. "We are conducting tests to determine how to screen packages and containers while minimizing false alerts."

According to Wham, passive detection involves identifying radioactive materials by the gamma

CREATING A SINGLE TEAM

The U.S. Department of Homeland Security's largest program at ORNL is one not widely known: the Protective Security Analysis Capability (PSAC). Vivian Baylor, the program's director, says that DHS envisions PSAC as a round-the-clock resource that integrates information, analyses, and vulnerability assessments to identify risk-based priorities for preventive and response measures. This collection of tools and tactical information will be used to support the Risk Management Division in DHS's newly formed Preparedness Directorate.

"At PSAC we concentrate on integrating capabilities from other supporting assets, such as the National Infrastructure Simulation and Analysis Center at Sandia National Laboratories and Los Alamos National Laboratory. Our goal is a single team that provides a robust, all-hazards, preparedness capability," Baylor says. Much of the work in fiscal-year 2006 will be focused on system hardware, software support and development, and data integration. A second major element in PSAC is modeling and visualization, including the use of ORNL's LandScan to develop improved population demographics for the United States.

The heart of PSAC is the National Asset Database, a compendium of important information about the nation's critical assets that would be useful to officials planning protective actions in response to emergencies, terrorist attacks, and natural disasters. The database's information for the Hoover Dam, for example, would include the dam's satellite-based, geospatial position, construction documents, vulnerability assessment results, protective actions taken, and routes of access to the dam. An ORNL Computational Sciences and Engineering Division team has been developing the hardware and software necessary to support the database's implementation. Another PSAC task involves maintaining ORNL's LandScan Dataset files. A few days before hurricanes Katrina, Rita, and Wilma pounded the southern U.S. coast, LandScan was used to help the Department of Energy estimate the numbers and locations of populations that would be without electrical power after the storms. ORNL staff also utilized LandScan to assist DOE in predicting where gasoline shortages would arise in Texas after one million people evacuated the Houston area to escape Hurricane Rita. In December 2004, LandScan was called upon by the United Nations to predict where the survivors fleeing the tsunami would relocate. The information was used to help the World Bank determine where to send emergency food supplies.

LandScan is currently being updated to provide information on the day and night population distribution for hundreds of America's most populous cities and counties. Building the database's foundation one block at a time, ORNL's next step is to incorporate information on transient populations, including people on business travel and vacation.

and neutron radiation they spontaneously emit. In active detection, neutrons or high-energy gammas are used to induce fission or other nuclear reactions and then neutrons or gammas caused by those reactions are detected.

Passive detection is needed to identify radioactive californium, cesium, cobalt, strontium, or other isotopes that could be used in dirty bombs. Active detection is required to find fissionable uranium in shipping containers that may be intended for a highly dangerous nuclear device. Detecting illicit nuclear materials in containers without causing false alerts is one of DHS's most complex and important challenges.

ORNL is a partner in DHS's Countermeasures Test Bed project for highways, railroads, and seaports, working with law enforcement personnel to figure out the most reasonable and effective protocol for deploying radiation detectors to screen containers for radioactive materials that could be intended for a terrorist bomb.

ORNL researchers also are developing more efficient radiation detection materials for portal monitors and hand-held detectors. Two radiation detector inventions have been licensed to NucSafe, an Oak Ridge company. (See p. 27.)

ORNL's Environmental Effects Laboratory is conducting tests to determine which commercial radiation detectors perform the best in rigorous applications. The most useful radiation detectors must be rugged and able to detect four types of radiation accurately under a variety of conditions, including extreme temperatures and high levels of humidity, vibration, shock, dust, and electromagnetic fields.

Finally, hundreds of thousands of isotope sources, many of which were produced at ORNL, are in circulation or have been abandoned. With a minimum of expertise, these sources could be diverted for use in a dirty bomb. ORNL is helping DHS with forensics and attribution research to assist law enforcement investigations. The ORNL team focuses on isotope source design, fabrication details, and isotope signatures to narrow down the possible origins of source materials that could be used in a dirty bomb. It is hoped the data collected at ORNL will not be needed. ®

AT THE LOCAL LEVEL

Al Fuentes is a celebrity in both New York and Tennessee. The fire chief is remembered as the last person to be pulled out alive from the rubble created September 11, 2001, after the second tower collapsed at the World Trade Center. Fuentes had arrived from a fireboat after the two airplanes hijacked by terrorists crashed into the towers. As a building structure fell on him, Fuentes suffered broken bones and stayed in a coma for three weeks.

Fuentes became known in Tennessee as a result of his contributions to an ORNL-led team that examined the ability of Memphis to respond to a terrorist attack. The Regional Technology Integration team, which was launched in 2004 by the U.S. Department of Homeland Security to determine how technology can better protect cities against terrorist attacks, also recommended that Memphis adopt technologies and make organizational changes to improve the city's security readiness.

Fuentes was quick to notice that Memphis, which is the fourth largest inland port in the United States, lacked a maritime firefighting capability. If a boat caught fire on the Mississippi River, it would burn to the water. Fuentes knew of a surplus rescue firefighting boat in New York City, so he arranged to have the vessel transferred free to Memphis.

The ORNL-led Regional Technology Integration team was the first of four DHS teams to complete the assignment. Memphis is already adopting the team's recommendations in a 2005 report, according to Dave Lannom, the RTI team leader, senior program manager in ORNL's National Security Directorate, and chief of plans and technology for the Tennessee Governor's Office of Homeland Security in Nashville.

Lannom says the team tried to answer questions such as, "If you were a terrorist, what parts of Memphis would you attack and how? Would you use a truck bomb or more sophisticated explosives? What technologies should be inserted to prevent such disasters?"

The advice of the RTI team continues to be sought by city staff in Memphis, especially after emergencies such as a recent industrial chemical fire. The success story in Memphis is an encouraging sign that municipalities are beginning to recognize a new generation of security threats and understand that American technology is providing an increasing number of options to counter these threats to public safety.

ORNL led a team that suggested ways to improve the security readiness of port facilities in Memphis, Tennessee.

Photo courtesy of James Richardson

Matching Technologies

ORNL technologies are proving a good match for America's defense and homeland security requirements.

"ORNL is a treasure trove of technology," says Rich Stouder, director of the new Technology Development and Deployment Programs Division in ORNL's National Security Directorate. "The first priority for our technologies is supporting the missions of the Office of Science and other offices in the Department of Energy. But increasingly our directorate is demonstrating that applications of ORNL technologies developed for DOE also make a good match for needs of the Department of Defense and Department of Homeland Security."

When Stouder first came to ORNL, he focused on developing personal relationships with principal investigators in the Laboratory's Chemical Sciences Division and the Metals and Ceramics Division. Through these relationships and his military experience, he was able to identify several ORNL technologies that seemed potentially valuable for agencies other than DOE.

Frank Akers, ORNL's associate laboratory director for National Security, decided to inject more rigor into the directorate's business and program development. He charged Stouder with the task of providing a more structured plan for cataloging ORNL's suite of technologies and aligning those technologies with mission needs in the Departments of Defense and Homeland Security. As Stouder surveyed ORNL technologies, he also cultivated contacts in the Department of Defense and the commercial sector.

During this process, Stouder helped researchers write proposals for seed money through ORNL's Laboratory Directed Research and Development Program and decide whether to collaborate with a commercial partner. Stouder is credited with invigorating several ORNL programs and with obtaining DOD funding for other innovative ORNL technologies.

A Success Story

In 2001, the manager and principal developers of ORNL's Block II Chemical Biological Mass Spectrometer (CBMS II) met with Stouder and expressed concern about funding trends for their Army-sponsored research.

Stouder says the request came at a time when all chem-bio programs in the U.S. military were being united under the Department of Defense. "After a series of meetings and presentations we were able to get CBMS accepted by the joint military programs. Through more work we succeeded in getting CBMS II adopted by the Joint Program Executive for CB Defense," Stouder adds. CBMS II, now being run by the Joint Program Manager, Nuclear Biological Chemical (NBC) Contamination Avoidance, is included in DOD's five-year budget.

Recent Army tests of CBMS II have validated its ability to identify chemical warfare agents. In 2006 the Army will complete tests of CBMS's capability to detect biological warfare agents. If the tests prove successful, CBMS II units will be fielded on all the U.S. military's NBC ground reconnaissance vehicles. Perhaps the most significant accomplishment is the fact that ORNL's CBMS II program has enjoyed a steady funding stream for the past three years.

Stouder also helped an ORNL team secure internal funding for a project that investigated whether the electrospray technique developed at ORNL for mass spectrometry could be used for next-generation biological detection. The project led to the development of a new hybrid mass analyzer and the filing of a patent application. ORNL's faster, more specific, more selective mass spectrometer system shows promise as a detector of both known and unknown microorganisms.

Stouder says that DOD, including its Defense Threat Reduction Agency, is impressed by ORNL's ability to assemble

and lead talented teams of national lab, industry, and university researchers that deliver results such as the CBMS project. DOD's chem-bio experts also like ORNL's "system-of-systems" approach, exemplified by the hybrid mass analyzer's integration with other technologies in the difficult effort to detect biological agents.

"This research might someday lead to a box that enables you to sneeze and learn immediately if you have allergies, the common cold, or the flu," Stouder says.

In a June 2005 forum that included ORNL's director, Jeff Wadsworth, Senate Majority Leader Bill Frist of Tennessee suggested that a 21st-century effort similar to the Manhattan Project might be required to solve the complex problem of identifying and combating disease agents, such as the smallpox virus, that a terrorist group or enemy nation might inflict on the United States. Just as with the original Manhattan Project in the 1940s, ORNL would likely play an important research role in such a massive undertaking.

Eli Greenbaum led the development of a device that tells whether drinking water has been poisoned.

Cool and Quiet

In 2003 a major general in charge of Army ground vehicles visited ORNL for a briefing on combat-vehicle technologies. The general explained that the next-generation Army ground vehicle being designed for 2018 has a potential problem. Each of the hybrid-electric vehicles would have a fan running as loud as a jet engine to cool the lithium ion battery that powers the vehicle's electric motor. Current infrared detectors would sense vehicle heat and emerging acoustic targeting technology would enable the enemy to "hear" the vehicles from a distance.

James Klett briefed the general about the carbon foam that conducts heat unusually well, a discovery made by the ORNL researcher in 1996. Using an ice cube, Klett demonstrated to the general the phenomenal heat flow properties of the lightweight graphite foam. As an added benefit, the foam has been shown to muffle sounds. Klett's demonstration convinced the general that carbon foam has the potential to make the operation of Army ground vehicles cooler and quieter.

The general asked ORNL to test carbon foam on an Army vehicle by teaming with United Defense, the manufacturer of the Bradley fighting vehicle and the Water Sentry™ based on ORNL's AquaSentinel technology (see p. 11). United Defense (later bought by BAE Systems) paid for a test of a carbon foam muffler bolted on the fan of an operating prototype vehicle.

"Testing of the foam was extremely successful," Stouder says. "We proved that the foam significantly reduced the fan's noise levels by 16 decibels and the engine exhaust temperature by more than 220°F. The results amazed the military folks."

Klett and Stouder recorded the test results in a white paper and briefed the general who had requested the experiments. The general arranged in August 2005 for Klett to brief the Army's chief scientist,Tom Killion, in an attempt to integrate the carbon foam muffler technology into the Army's Future Combat Systems program. ORNL and BAE Systems teamed with Georgia Tech Research Institute, one of the nation's leading research centers for acoustic science, on the development of a graphite foam muffler for Army vehicles. As a result of these efforts, the Army is now seeking funding options for further development of military applications of graphite foam.

SensorNet

In 2003 ORNL's Jim Kulesz testified before the Homeland Security Committee of the U.S. House of Representatives on the topic of SensorNet, a new early-warning system concept that can provide critical real-time information to federal, state, and local emergency response decision makers. Developed at ORNL through a partnership that includes the Open Geographical Information Systems Consortium and the National Oceanic and Atmospheric Administration, SensorNet provides a common "data highway" for the dissemination of critical information required to assess a chemical, biological, radiological, nuclear, or explosive hazard. With a tested and reliable architecture, SensorNet is moving toward the goal of a "system of systems" to provide nationwide detection and assessment of terrorist threats. The capabilities that together make up the portable SensorNet system include sensors in a box, software, architecture technologies for data management and integration, knowledge generation, situational awareness, and wireless communication technology.

The SensorNet node standards and technology developed at ORNL were contracted to Applied Innovations, Sentel, and 3ETI for prototypes. Other SensorNet applications include ORNL's Hazard Prediction and Assessment Capability and Landscan population models. As a result, SensorNet can provide—in real time—a plume model that identifies the chemical nature of the event, the number and location of people affected, and a proposed response for the communities at risk.

"The goal of SensorNet is detection, not detectors," says Frank DeNap, who heads the SensorNet program. "SensorNet is an Office of Naval Research program but we leverage funding from the Transportation Security Administration at the Port of Memphis, where SensorNet is deployed for continuous chemical detection at a chemical transportation and storage port on the Mississippi River. Fort Bragg, an Army installation in North Carolina, paid for a test of an interface among SensorNet and 911 functions, video cameras, and perimeter security, to screen for chemical, biological, and nuclear hazards. SensorNet has also been tested during special political events in Washington, D.C., National Football League games, NASCAR races, and the San Diego Mardi Gras celebration."

SensorNet is based on the principle that information can be collected, processed, and disseminated in real time in response to emergency conditions. The SensorNet node incorporates advances in the size, cost, and adaptability of sensor integration technologies. The node has a modular, open architecture that enables upgrades as new sensor technologies are developed. This mobile technology can be located at strategic sites—from national parks and sports arenas to truck weigh stations and airports—considered at risk of experiencing an attack or allowing the passage of the ingredients for a terrorist weapon.

"My role in SensorNet has been to figure out our strategic goals," Rich Stouder says. "I spend almost half my time determining with whom we should partner, which test beds we should use to evaluate SensorNet, and how we can expand the program and fund initiatives."

Safe to Drink

Soldiers on the battlefield go to a lot of trouble to make the water they find safe to drink. The military laboriously moves cumbersome trailers housing a combination of water-purifying chemicals and filters. ORNL has a solution to the Army's Herculean water purification chore: inorganic membranes developed by the Inorganic Membrane Technology Laboratory (IMTL) at ORNL. IMTL was originally established at the K-25 Site, now known as the East Tennessee Technology Park, which had extensive experience working with separative technology. IMTL has since moved to ORNL and has a cooperative research and development agreement with the Pall Corporation.

A team at ORNL has developed metal tubes with nanopores so small and specific in shape that only water molecule constituents are allowed through the tube walls. NSD and ORNL researchers have given several briefings that promote the idea of replacing the Army's logistically intensive trailer system with water production units that fit on the back of a five-ton truck operated by two men.

The ORNL team has made a similar pitch to the Navy. "We have been working with Aqua-Chem, a company in Knoxville, Tennessee, that produces water purification systems on 90% of the Navy's ships," Stouder says. "Currently Aqua-Chem uses fiber-bound filters that must be replaced periodically based on particulate level in the water. The water system must be shut down to replace the plugged-up filters. Replacement filters kept in storage take up valuable space on ships."

Because of these drawbacks, Aqua-Chem conducted tests on a bench-scale water purification system in which ORNL's inorganic membranes were used. "Inorganic membranes might someday be used for shipboard water filtration," Stouder says. "Discussions are ongoing among ORNL, Aqua Chem, and Pall Corporation. This approach to water filtration would respond to an enormous military need."

Cleaning Up

Imagine that biological warfare agents have been dispersed at a port of debarkation where troops are about to be offloaded. The scenario must take into account the time and effort required to bring in military decontamination units and large amounts of water and chemicals to decontaminate a wide area or one vehicle at a time. The scenario must also accommodate the psychological impact as the troops' operations are stopped.

Ted Huxford of ORNL's Metals and Ceramics Division has an idea how to speed up decontamination of wide areas and vehicles. According to Stouder, Huxford has observed that the Vortek plasma arc lamp at ORNL has an ultraviolet spectrum that is "in the sweet spot of what it takes to neutralize biological and chemical warfare agents." Stouder speculates that the lamp, mounted on the back of a Humvee, could be used for "wide-area decontamination of slimed ports and airfields and of contaminated combat vehicles." With a robotic arm and reflector around the lamp, the focal point of the lamp can be projected out to 17 meters.

"The goal is to get the slimed ground vehicle back into combat as soon as possible," Stouder says. "This technology may also work for decontamination of aircraft, although the environment can take care of bacteria in the nooks and crannies of a plane."

In 2004 Huxford and his colleagues received $23,000 in seed money to do proof-of-principle tests. One test showed that the plasma arc lamp could remove better than 99.99% of the anthrax simulant spores present on a wide test area. "We got four generations of kill with DMMP, a nerve agent simulant," Stouder says. "We used only nine percent of the lamp's power and left the slimed area better than 99.99% clean."

Coming Home

When an American soldier returns home from Iraq or Afghanistan, the U.S. military mandates a complete physical to determine whether the soldier exhibits evidence of exposure to diseases such as tuberculosis or smallpox. Four vials of blood are drawn as part of the physical examination and sent out for analysis. The process is both expensive and time consuming. Pending Food and Drug Administration approval, a multifunctional biochip developed by an ORNL team might supply all the information needed for a soldier's physical by analyzing a single drop of blood or urine taken at a battalion aid station. The results of a military physical using ORNL's diagnostic technology could be obtained in substantially less time and at a significantly lower cost.

Stouder says he loves working with ORNL's principal investigators. "I've never had a researcher say no to a request for information or a chance to host a visitor. Our researchers are great patriots. Even those who have not obtained their citizenship want to be a part of helping solve America's security challenges. They invest their time and their talents to develop programs that will make a real difference for this country. They believe in our mission, and they believe we can accomplish that mission. They make every day exciting for me." ®

Libyan leader Muammar Gaddafi

"Out of Sight" Missions

East Tennesseans take a place on the international stage.

On July 12, 2004, President George W. Bush came to Oak Ridge for a first-hand look at gas centrifuge components and uranium processing equipment that were at the heart of Libya's secret nuclear weapons program. The president received a briefing on these mechanical parts from Jon Kreykes, deputy director of the National Security Advanced Technology (NSAT) Division of ORNL's National Security Directorate. In a speech later that day to an ORNL audience, the president announced that Libya was "dismantling its weapons of mass destruction and long-range missile programs" as a result of "quiet diplomacy among America, Britain, and the Libyan government."

The evacuation of nuclear materials from Libya is one of the recent high-priority activities of NSAT, says division director Jim Sumner, who regards the event as an important milestone in the Laboratory's history. "We had one of our people on the ground in Libya and a cadre of people here doing the coordination and logistics support," he explains. In early 2004 the nuclear materials and equipment were flown under top security 5,000 miles from Tripoli to McGhee-Tyson Airport near Knoxville and transported by truck to Oak Ridge.

The bulk of the delivery consisted of gas centrifuges that Libya had planned to use to enrich uranium for nuclear weapons. "The assets from Libya included equipment for running the centrifuge facility and a modular uranium conversion facility," Sumner says. "Also transported to Oak Ridge were four cylinders of uranium hexafluoride in natural, un-enriched form." Sumner said that ORNL staff relied on support from partners across the ridge at Oak Ridge's Y-12 National Security Complex to handle and analyze the Libyan materials.

The timing of the event was critical. Only months before, the international community was stunned to learn that A. Q. Khan, one of Pakistan's leading nuclear scientists, had admitted to being leader of a network that supplied Libya, Iran, and North Korea with centrifuge equipment. The Oak Ridge group played an invaluable role in assisting the U.S. government and the International Atomic Energy Agency in verifying the accuracy of Libya's commitment to dismantle its nuclear weapons program and divest the assets needed to build a nuclear weapon. In the wake of the transfer of these assets to Oak Ridge, each of the parties certified that the Libyans indeed had turned over to the United States all of the uranium enrichment materials and technologies they were known to have.

NSAT is the Department of Energy's central point of contact when technical analysis and support are needed for nuclear matters of highest interest to the U.S. government. To support this role, NSAT houses some of the country's premier experts in nuclear technologies. NSAT personnel provide advanced experimentation and analytical services to various national-level government agencies, sharing their knowledge to advance the security posture of the United States. Their customers include the Department of Homeland Security, the Defense Threat Reduction Agency, the Department of Defense, and other intelligence agencies of the U.S. Government. NSAT staff members provide analytical problem-solving expertise and render opinions on serious national-level threats. For a range of mostly classified missions that deal with potential dangers around the world, NSAT calls upon the collective resources of the facilities in the DOE Oak Ridge Operations—ORNL, the Y-12 Nuclear Security Complex, the East Tennessee Technology Park, Oak Ridge Associated Universities, and the uranium enrichment sites at Paducah, Kentucky and Portsmouth, Ohio.

In addition to the analysis of nuclear assets, ORNL trains nuclear policy makers and other government personnel on nuclear technologies and nuclear nonproliferation activities. "Our mission has broadened to helping monitor law enforcement and other information traffic to determine if there are any terrorist threats to any DOE-ORO facility," Sumner says.

The mission is one that likely will remain out of sight, but not out of mind, for the foreseeable future. ®

ORNL's Jon Kreykes briefs President Bush on Libya's nuclear weapons production equipment sent to Oak Ridge.

A Secure Facility for New Technologies

A new building will increase ORNL's ability to execute sensitive national security research.

Responding to new international realities, the Department of Energy's national laboratories are supporting the effort to deliver the science and technology needed to protect U.S. homeland and national security interests worldwide. The challenge is to support DOE's mission and maximize the potential of DOE's S&T base by leveraging critical, classified national security, nonproliferation, and homeland security programs.

In the new Multiprogram Research Facility (MRF), DOE's research complex at Oak Ridge will have a state-of-the-art, secure S&T facility that provides the appropriate infrastructure and environment to integrate multidisciplinary scientific capabilities for sensitive defense, nonproliferation, and homeland security activities. Begun in February 2005, the new 214,000-sq.-ft facility will house a significant upgrade in classified capabilities critical to many of DOE's research and training activities.

The MRF's mission will include support for classified projects in the Department of Energy "Work for Others" program. The new building will provide classified space for research and development activities in support of weapons of mass destruction analysis; nonproliferation research, training, and operations; cyber security research and development; geospatial analysis; advanced thermal hydraulic research; inorganic membrane research and prototyping; and myriad special activities for which appropriate infrastructure is either lacking or inadequate. The MRF complex also contains chemical, biological, material, and electronics laboratories; fabrication and training spaces; supporting offices; and necessary support infrastructure. The facility's training capabilities include a 400-seat auditorium equipped to permit interactive, real-time control of outstations.

With an initial capability in the fall of 2006 and full capability in spring of 2007, the MRF will be a valuable addition to Oak Ridge National Laboratory's research portfolio and a critical resource in the Department of Energy's effort to provide technologies that will strengthen America's energy security and public safety. ®

PROFILE

Frank Akers: Building the Bridge

Frank H. Akers, Jr., a retired brigadier general from the U.S. Army, is the associate laboratory director for National Security at ORNL. He manages a focused research and development portfolio that includes nonproliferation and threat reduction, arms and export control, homeland security, and counterterrorism technologies for several federal agencies. A native of South Carolina, he holds a B.S. degree from the United States Naval Academy, two master's degrees, and a Ph.D. degree from Duke University. During his military career, General Akers held a variety of command positions at Fort Bragg, North Carolina; Fort Leavenworth, Kansas; and bases in South Korea and Vietnam. He also served in the Persian Gulf War. He has received numerous military decorations and awards, including the Distinguished Service Medal.

...there is literally no place else in the country, or in the world for that matter, where the military services can get access to the one-of-a kind tools we have.

Q. How did a general officer in the U.S. Army end up at ORNL?

It was due mostly to the efforts of Carl Stiner, a retired general who lives on his family farm in LaFollette, Tennessee. Carl is very familiar with business and government leaders in the state. He had heard about a need for someone with a military and leadership background for an opening at the Y-12 National Security Complex and contacted me when I told him I was going to retire from active duty. My wife and I visited Oak Ridge and really liked what we saw. Since our youngest child was about to enter middle school at the time, we checked out the Oak Ridge school system and found that it was extraordinary, so we decided to move here. Eventually I moved from Y-12 to ORNL.

Q. Are there any similarities between the military units you've been in and ORNL?

More than you'd think. The best military units I've been associated with take a lot of pride in what they do, are motivated, and want to succeed at every task they're given, no matter how big or how small. They may not always succeed at first, but they never stop trying. I see much the same thing at ORNL. The scientists, engineers, support staff, and crafts workers have that same sense of pride in what they do.

Q. With its own labs and research organizations, why would the Department of Defense come to ORNL?

Indeed, the military has some exceptional people and facilities. But no one organization has all the assets required to address all of the needs of the military services. We should look at the challenges that face us in a holistic manner and find the resources that best meet those needs. With regard to ORNL specifically, based on the tremendous investments in facilities and staff over the last six years, there is literally no place else in the country, or in the world for that matter, where the military services can get access to the one-of-a kind tools we have. Whether it's the Spallation Neutron Source, the Center for Nanoscale Materials Sciences, the Advanced Microscopy Laboratory, or our computational capabilities, ORNL has unique capabilities to help the military solve its technology challenges.

Q. How do you interest other departments of the federal government and industry in ORNL?

There is no single way to meet and interact with potential customers. The NSD staff have become very good at identifying those organizations that might benefit from what our researchers can do—even if these potential sponsors have never heard of ORNL or do not know that national laboratories are resources that are available to them. NSD staff go to both military and industrial conferences, review Broad Agency Announcements that appear on the Federal Business Opportunities website, conduct research using the Internet, read newspapers and periodicals, and ask for referrals from people in organizations they already know. Success mostly depends on ingenuity and tenacity. We try to establish relationships with key personnel in federal agencies and industry, learn about their challenges, and then determine if ORNL has the technology, expertise, or capability that will meet their needs. If we can persuade them to visit ORNL, they generally like what they see. As the saying goes, "Seeing is believing."

Q. What is ORNL's role in the war on terrorism?

Winning this war will require patience and a long-term approach. The U.S. will have to exert pressure on our adversaries in a variety of ways by using all of our assets—military, political, economic, and yes, technical. ORNL's role is to provide the technology and expertise that our side needs, and that doesn't mean exclusively for the military organizations in the Depart-

ment of Defense. The Department of Homeland Security, the Department of Energy's Nuclear Nonproliferation Program, and other customers we work with will also need access to our scientific assets. It's a war with a lot of dimensions. None of them is simple and we may be at this a long time, but I'm convinced that technology will enable America to defeat terrorists faster.

Q. You have several active duty military officers on your staff. Why are they here?

One of our goals is to develop relationships with the military services. What better way to show the capabilities of ORNL than by having people live with us, talk to our research staff, and see on a daily basis how our equipment and facilities are used? When they complete their 10-month tours, they will be able to explain convincingly that ORNL has the equipment and people to help them with many of their technical challenges. This year three officers from the United States Air Force are with us. Two of them are here under a Technical Fellowship Program with the Department of the Air Force's Strategic Security Directorate. The third officer is being sponsored by the Air Force Institute of Technology under the Education with Industry Program. We've also had a program over the past three years with the U.S. Army called Training with Industry. These relationships are proving valuable to both sides.

Q. What is your new program for "Thought Leadership?"

Since the days of the Manhattan Project in World War II, ORNL has enjoyed a reputation as a leader in the field of science and technology. However, in this interconnected world, the challenges we face as a nation don't lend themselves to easy solutions and thus require an interdisciplinary approach. That's why it's important to find leaders in other fields with whom we can collaborate in trying to understand the complex challenges of the 21st century, America's role in the world, and the impact of technology on society. Thought Leadership involves bringing together the talents of people from the world we know well at ORNL—scientists and engineers—with individuals from different backgrounds, such as the military and industry, who have extensive experience in areas where we do not. To help us in this effort, ORNL will engage the talents and capabilities of the Oak Ridge Center for Advanced Studies and the University of Tennessee's Howard Baker Center for Public Policy. We anticipate that the programs and workshops that ORCAS and the Howard Baker Center will develop will enable the Lab to make a unique contribution to issues of major importance to the country.

Q. The military is famous for acronyms. What's a YAGWAM?

The acronym means "Yet Another General Without Any Money." As part of our strategy, we have brought a number of high-ranking officers through ORNL so they could see what the Laboratory has to offer. We do this because we want them to know that other organizations can provide technology alternatives to either their own labs or industry—often for less money. We also believe that knowledge can be transferred throughout the military services from the top down. The results of these visits sometimes are not apparent for two or three years. We know the process can be frustrating to the scientific staff so we took the acronym and decided to have some fun by turning it into a certificate and an event. Once a year we have a YAGWAM Awards ceremony and present to selected scientists and engineers a YAGWAM certificate in recognition of all they do to help us. You've got to keep a sense of humor. ®

Hot-wired

Two Oak Ridge technologies may make superconducting wire cost-competitive.

Thanks to two ORNL technologies, the second-generation, high-temperature superconducting (HTS) wire that American Superconductor Corporation plans to produce at its pilot plant in 2006 may prove to be competitive in cost with conventional copper wire. Twenty years after high-temperature superconductivity was discovered, HTS wires may be used for underground transmission cables, oil-free transformers, superconducting magnetic-energy storage units, fault-current limiters, high-efficiency motors, and compact generators.

The first generation of high-temperature oxide superconductors relied on bismuth strontium calcium copper oxide in a silver tube. ORNL has worked with Southwire of Georgia, to demonstrate the use of 1G wires in the company's test power cables. The second generation, or 2G HTS wire, uses yttrium barium copper oxide (YBCO). This superconducting material allows electrical current to flow with little of the resistance, or heat losses, of copper wire. American Superconductor's goal has been to manufacture 2G HTS wire that outperforms copper wire at a comparable cost.

For the substrate of the 2G wire, American Superconductor has chosen a textured nickel-tungsten alloy fabricated by ORNL's rolling-assisted biaxially textured substrates (RABiTS) process. In this process developed by a team in ORNL's Metals and Ceramics Division, low-cost nickel replaces the high-purity silver of 1G wire, enabling the fabrication of 2G wires at a lower cost. The cost of 1G wire is 30 times that of copper wire.

RABiTS templates provide a texture that is transferred through buffer layers to the YBCO superconductor. American Superconductor currently uses a reactive sputtering system to deposit three buffer layers on RABiTS—yttrium oxide, yttrium-stabilized zirconium, and cerium oxide—followed by the superconductor.

Nickel can poison the YBCO layer, destroying the superconductive properties. To transfer the texture from the template to the superconductor while preventing the diffusion of nickel metal to the YBCO film, buffer layers are needed. These insulating layers also reduce both alternating current losses and the thermal expansion mismatch between the crystal lattices of the substrate and the superconductor.

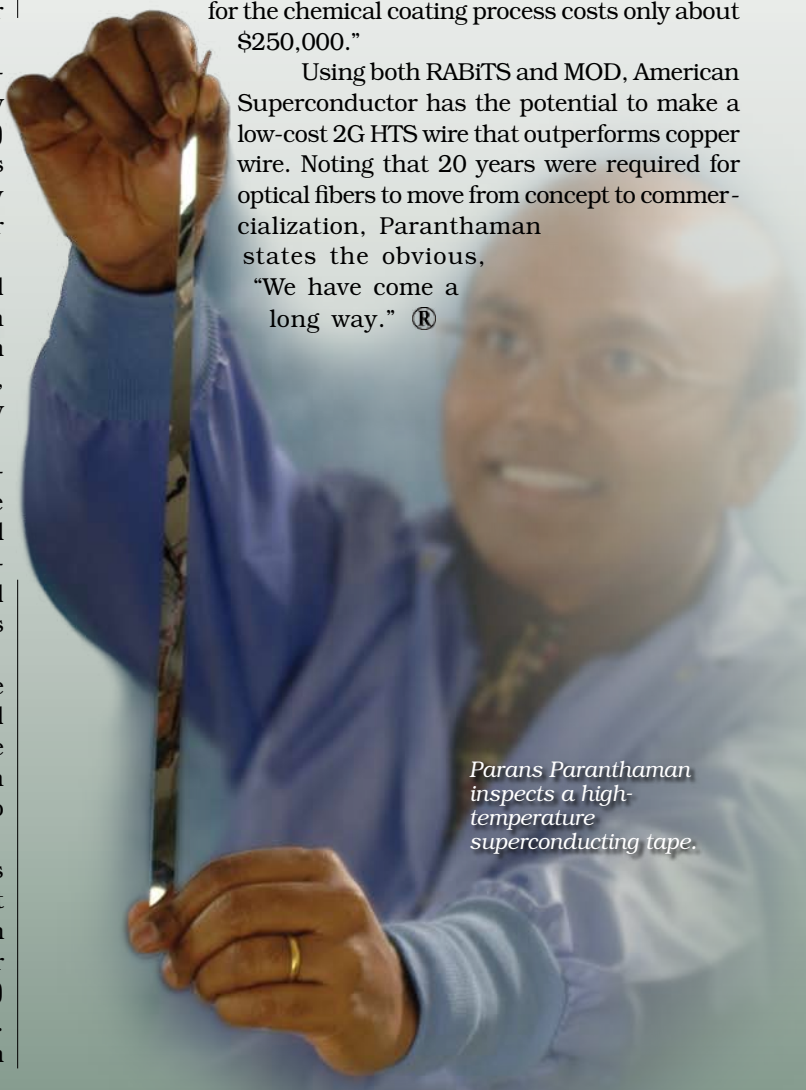
American Superconductor uses this architecture in the 4-centimeter (cm)-wide tapes that the company produces and slits into 4.4-millimeter (mm)-wide, 2G HTS wires. The wires are then topped with a thin layer of silver and sandwiched between protective copper layers, the only parts of the wire exposed to the liquid nitrogen coolant.

Parans Paranthaman, a materials chemist in ORNL's Chemical Sciences Division, has led the development of a wet chemical process to replace reactive sputtering in the deposition of the buffer layers on 2G HTS wire. American Superconductor has adopted ORNL's patented metal-organic deposition (MOD) technique to scale up their YBCO superconductor activities. They will switch to MOD buffers when Paranthaman's team makes a wire that achieves 250 amperes/cm. In 2005, the ORNL chemists used MOD to develop a superconducting wire with a current density of 200 amps/cm.

In the ORNL process, a nickel-tungsten tape on a spool is pulled through a chemical bath, much like a plastic substrate used to make movie film. The metal tape is dipped in or slot-die coated with alcohol-based solutions of lanthanum zirconium oxide, then cerium oxide, and finally a blue YBCO solution. When the tape is heated in a furnace between each coating, the alcohol evaporates, the organic compounds decompose, and a superconducting tape with only two buffer layers emerges.

"We use only 10 to 15 milliliters of solution to coat a 4-cm tape and recover all the leftover chemicals," Paranthaman says. "In reactive sputtering, only 10 to 20 percent of the material is used and the rest is deposited throughout the vacuum chamber. A reactive sputtering system for making hundreds of meters of wire costs $5 million, whereas an annealing furnace for the chemical coating process costs only about $250,000."

Using both RABiTS and MOD, American Superconductor has the potential to make a low-cost 2G HTS wire that outperforms copper wire. Noting that 20 years were required for optical fibers to move from concept to commercialization, Paranthaman states the obvious, "We have come a long way." ®



Parans Paranthaman inspects a high-temperature superconducting tape.

RESEARCH

An Archaeologist in the Laboratory

Mass spectrometry may resolve a lingering archaeological debate.

Most of the researchers who operate a secondary ion mass spectrometer at ORNL are trained in the physical sciences. Sharon Hull is an exception. A graduate student in archaeology at Eastern New Mexico University, Hull has quickly learned how to operate the SIMS instrument in a new way of value to archaeology. That's the assessment of her proud supervisor, Professor Mostafa Fayek, a University of Tennessee–ORNL joint faculty appointee.

"Sharon is one of the few archaeologists who has experience getting isotope signatures on turquoise using a SIMS instrument," he says. "She will be a go-to person in archaeology."

One question of interest to veteran archaeologists like Joan Mathien of the National Park Services is whether the peoples living in the American Southwest 1,000 years ago were isolated from Mesoamerica, a region extending south and east from central Mexico to include parts of Guatemala, Belize, Honduras, and Nicaragua. Mathien, who collaborates with Fayek, believes the peoples of both regions valued turquoise as a mark of high status and prized the blue-green mineral for its ritual significance.

"Lots of turquoise artifacts have been found in Mexico where very few turquoise mines exist," Hull says. "We would like to link with confidence the turquoise in high-quality artifacts with specific turquoise deposits. Then we can address a current archaeological debate: 'Were the American Southwest peoples in towns like Chaco Canyon, New Mexico, mining turquoise and trading it to the peoples of Mexico?' We believe the isotope signatures in turquoise that we obtain with mass spectrometry will enable us to connect the artifacts to the mines of origin."

Fayek says that Hull helped develop the SIMS technique for measuring how much more copper-65 than copper-63 is present in turquoise samples only 100 microns in diameter. Copper ratios have never been measured on a SIMS instrument. SIMS is ideal for archaeological studies because the technique is nondestructive and uses very small samples.

Turquoise is a chemical combination of copper, aluminum, phosphorus, and oxygen that forms only in the presence of nonacidic copper. Fayek thinks that rainwater plays an important role in the formation of turquoise. He reasons that rainwater dissolves the elements in rock fissures, allowing them to form turquoise when conditions are right. Rainwater falling at particular latitudes and longitudes has specific signatures revealed in turquoise as distinct ratios of hydrogen and deuterium isotopes, which also can be measured using SIMS.

Because SIMS can measure many different isotopes, it can provide archaeologists with a more definitive fingerprint of turquoise in artifacts that can be compared with signatures of raw turquoise samples from mines in Arizona, Colorado, Nevada, and New Mexico. In SIMS, a primary ion beam knocks out "secondary" ions from the sample surface, and a magnet separates selected ions according to their masses.

"Using SIMS Sharon completed 600 turquoise analyses in a month," Fayek says. "Using conventional techniques, other groups have required 20 years to conduct 3000 analyses. We're catching up."

Southwest archaeology was greatly influenced by a neutron activation study of turquoise conducted between 1979 and 1992 at Brookhaven National Laboratory. The findings established that most of the turquoise sources in North America are located in the Southwest, not Mesoamerica. The study suggested that several trade networks operated at various times using turquoise from mines in Arizona, Nevada, and New Mexico, and outlined three networks tied to the Cerrillos Hills near Santa Fe.

Armed with new data, Mathien disputes the 1992 study's claim that people in the Southwest did not value the mineral until they became aware of the demand for turquoise by royalty in central Mexico, where the ever more elaborate turquoise mosaics and masks conferred prestige on their owners. She also challenges the theories that Chaco Canyon turquoise is exclusively from Cerrillos Hills and that Chaco controlled Cerillos mines. Mathien is counting on innovative mass spectrometry at ORNL to resolve a lingering debate and help us better understand the peoples and culture of the ancient American Southwest. ®

Chaco Canyon, New Mexico. Inset: Turquoise from this ancient site

Running on Iron

Metal nanoparticles show promise as future fuels.

In the laboratory and on Capitol Hill, hydrogen has been touted by many as the potential fuel of the future in an age of rising gasoline prices and restricted oil supplies. But David Beach, leader of the Materials Chemistry Group in ORNL's Chemical Sciences Division, believes metallic nanoparticles may be even more promising candidates as a long-term solution to the rising cost of transportation fuels. He predicts that a car with a modified engine powered by boron powders could drive three times as far as today's gasoline-powered internal combustion engine. Metal fuels, he adds, also offer great potential for unmanned vehicles and battlefield power sources for military uses.

Like hydrogen, a metal fuel is an energy carrier and burns cleanly. But unlike hydrogen, metal fuels—such as iron, aluminum, and boron—possess a higher energy content per unit volume, can be stored and transported at ambient temperatures and pressures, reach combustion at high efficiency in a heat engine, and avoid the high costs of fuel cells.

Large particles of metal do not burn until heated to the metal's boiling point. At this temperature, metal vapor combusts to form metal oxides. Unfortunately, the process leads to very high combustion temperatures, fouling of the internal surfaces of the combustion chamber, and the production of nitrogen oxide pollutants. Metal nanoparticles, however, burn faster and more completely at lower temperatures with no gas phase combustion. "These particles oxidize fast enough that they never reach the peak combustion temperature," Beach says.

Beach is leading experiments to demonstrate that metal fuels could be developed for both civilian and military transportation. He works with ORNL's Solomon Labinov, who originated the idea; John Thomas, who is designing an engine to run on metal fuels; and Bobby Sumpter, who carries out first-principles modeling of the combustion using the extensive computing resources of ORNL's National Leadership Computing Facility.

They conducted initial experiments with iron nanoparticles for civilian applications. They demonstrated that combustion occurs entirely in the solid state, that nanostructuring is preserved through many cycles of oxidation and reduction, and that the particles are easily reduced with synthetic gas—the mixture of carbon monoxide and hydrogen that comes from heating coal and water in the absence of air.

"We have performed experiments with iron nanoparticles about 50 nanometers in diameter," Beach says. "These nanoparticles are partially oxidized to develop a 2-nanometer-thick oxide coating that keeps the particles from spontaneously combusting. With the oxide coating, which we measured using X-ray diffraction, a temperature exceeding 150°C is required to make the particles ignite. We measured the peak combustion temperatures of these particles, the ignition temperature, and the extent of the reaction. Then we determined the products of the reaction.

"In our radiometry experiment we measured the iron nanoparticles' peak combustion temperature, which is 1100 Kelvin," Beach continues. "The temperature should be hot enough to achieve high energy efficiency but not so high that exotic materials, such as expensive ceramics, are required to contain the combustion. Cast iron can be used as the combustion chamber for nanostructured metal fuels."

Beach says that the exhaust gas of metal fuels in a heat engine, such as a gas turbine or Stirling engine, is very clean. "We take the oxygen out of the air, leaving nearly pure nitrogen," he says. "We recover most of the heat using a recuperator and get much closer to the highest efficiency theoretically achievable in an engine.

"An even better energy carrier would be boron, but only if boron nanoparticles could be made at a reasonable cost. Boron is three times better than gasoline in terms of heat per unit weight and heat per unit volume." ®

Quickly and Accurately

Researchers pursue the goal of a portable detector that instantly identifies a package's radioactive contents.

Hand-held radiation detectors and radiation monitors can sense radioactivity in abandoned packages. Today's security challenges, however, require a portable detector that instantly reveals the precise nature of an unidentified package's radioactive contents.

Such a detector can be built if a material can be identified that captures radiation efficiently and provides highly detailed information about an isotopic source. ORNL researchers are working on this goal.

"The federal government wants radiation detectors that are smaller, simpler, faster, more sensitive, higher resolution, and less expensive than today's instruments," says Lynn Boatner, a materials physicist in ORNL's Condensed Matter Sciences Division who directs the new Center for Radiation Detection Materials and Systems at ORNL. "We are investigating various new materials and systems for detecting radiation and for tracking sensitive items for the Department of Energy's Nuclear Nonproliferation Office, the Department of Homeland Security, and other government agencies."

ORNL researchers are fabricating and characterizing the radiation response of detectors made of innovative "scintillators," including crystalline materials and glasses with high density that give off photons of light when exposed to radiation.

"These materials show the potential for detecting radiation with great efficiency and yielding an ultrafast response on the order of tens of nanoseconds or less," says Boatner, who is an ORNL corporate fellow. "Some of these materials have a relatively high energy resolution, suggesting they could enable a detector to distinguish among radiation emissions from different radioisotopes."

The best of these materials may be strong candidates for portable radiation detectors at airports, train stations, and ports. Other materials might be practical for large-area portal monitors that screen truck containers at weigh-and-inspection stations for radioactive cargo. The goal is to distinguish between benign radioactive products found in normal commerce—such as medical radioisotopes, smoke detectors, ceramic pots, and kitty litter—and potentially dangerous nuclear materials (cesium, strontium, uranium, and plutonium) that could be intended for a terrorist bomb.

Boatner and colleagues John Neal, Joanne Ramey, and Jim Kolopus are striving to develop a powerful, versatile, alternative method for producing large, transparent inorganic scintillators without the need to grow large single crystals, a task that is often time consuming and difficult to accomplish. They have recently synthesized zinc oxide nanoparticles doped with gallium using urea precipitation methods and were able to produce translucent ZnO ceramics by techniques based on hot pressing.

ORNL researchers developed silicone rubber bonded with boron compounds that emits blue light in the presence of neutrons.

Sheng Dai of ORNL's Chemical Sciences Division is investigating nanocrystalline and glass scintillators formed by sol-gel processes. Dai and Zane Bell of ORNL's Nuclear Science and Technology Division have been fabricating and characterizing neutron scintillators that are high in lithium or boron. Bell has been investigating new types of mercury-containing scintillators.

Bell has led the development of a new radiation detector material and detector prototype, both of which have been licensed to NucSafe, an Oak Ridge manufacturer of radiation detectors. Bell's research team developed a silicone rubber laced with boron that emits a blue-green light in the presence of alpha, beta, gamma, and neutron radiation. Having an 18% boron content makes the silicone rubber material an excellent detector of neutrons that indicate the presence of uranium and plutonium. Researchers believe the silicone rubber could be incorporated into another invention, the HotSpotter, an inexpensive, handheld gamma-ray spectrometer.

The heart of the HotSpotter is a scintillator made of cadmium tungstate, whose extremely high density increases the probability that gamma rays will interact with the crystal's light-emitting molecules. The HotSpotter software analyzes the gamma-ray spectrum to identify the radioisotope present.

Other ORNL work in the new center includes research on cerium-doped, rare-earth double phosphates for radiation detectors, as well as related research on new phosphor materials for possible use in tagging, tracking, and locating sensitive items.

The collective goal for all of these projects is the ability to prevent an increasing array of dangerous materials from reaching the hands of America's adversaries. ®

...and the WINNERS are...

Accomplishments of Distinction at Oak Ridge National Laboratory

At the 2005 ORNL Awards Night ceremony, **Lynn Boatner**, who had been elected a ***fellow of the Mineralogical Society of America*** and bestowed second prize in the ***American Conference on Crystal Growth and Epitaxy's 16th Annual Crystal Photograph Competition,*** was named ***Distinguished Scientist.*** At the same ceremony, **Steve Pennycook** received the ***Director's Award for Outstanding Individual Accomplishment in Science and Technology***.

Everett Bloom, retired director of the Metal and Ceramics Division, has received the ***2005 Mishima Award*** of the ***American Nuclear Society*** for outstanding achievements in nuclear fuels and materials development. At the 2005 ORNL Awards Night ceremony, ORNL Director Jeff Wadsworth presented Bloom with a trophy and gave him special recognition, citing "his outstanding research and leadership in materials science at Oak Ridge National Laboratory."

ORNL has again made an impressive showing in the competition of the Southeast Region of the Federal Laboratory Consortium for Technology Transfer. Winners of the ***Excellence in Technology Transfer Award*** are the Polyelectrolyte Thin-Film Array Slide, whose developers include **Jizhong Zhou** and **Xichon Zhou;** Flame Doctor Burner–Monitoring System, whose developers include **Charles Finney** and **Stuart Daw**; and the Laser-Based Item Monitoring System, whose team includes **Peter Chiaro**, **Curt Maxey**, **Tim McIntyre**, and **Fred Gibson**. ORNL also shares the Southeast FLC's first partnership award with USEC Inc. for cooperative efforts to develop and demonstrate USEC's American Centrifuge uranium enrichment technology.

Amit Goyal, a Battelle Distinguished Inventor, is the inventor on 50 issued patents. He received his latest patent in a portfolio of processes and products relating to the development of high-temperature superconducting wires.

At the Supercomputing 2005 conference in Seattle, Washington, **Thomas Zacharia** received an ***Editor's Choice Award*** and the University of Tennessee's **Jack Dongarra** received a ***Readers' Choice Award*** from *HPCwire* for ***"Communicating the Importance of High-performance Computing Technology and Raising Public Awareness."***

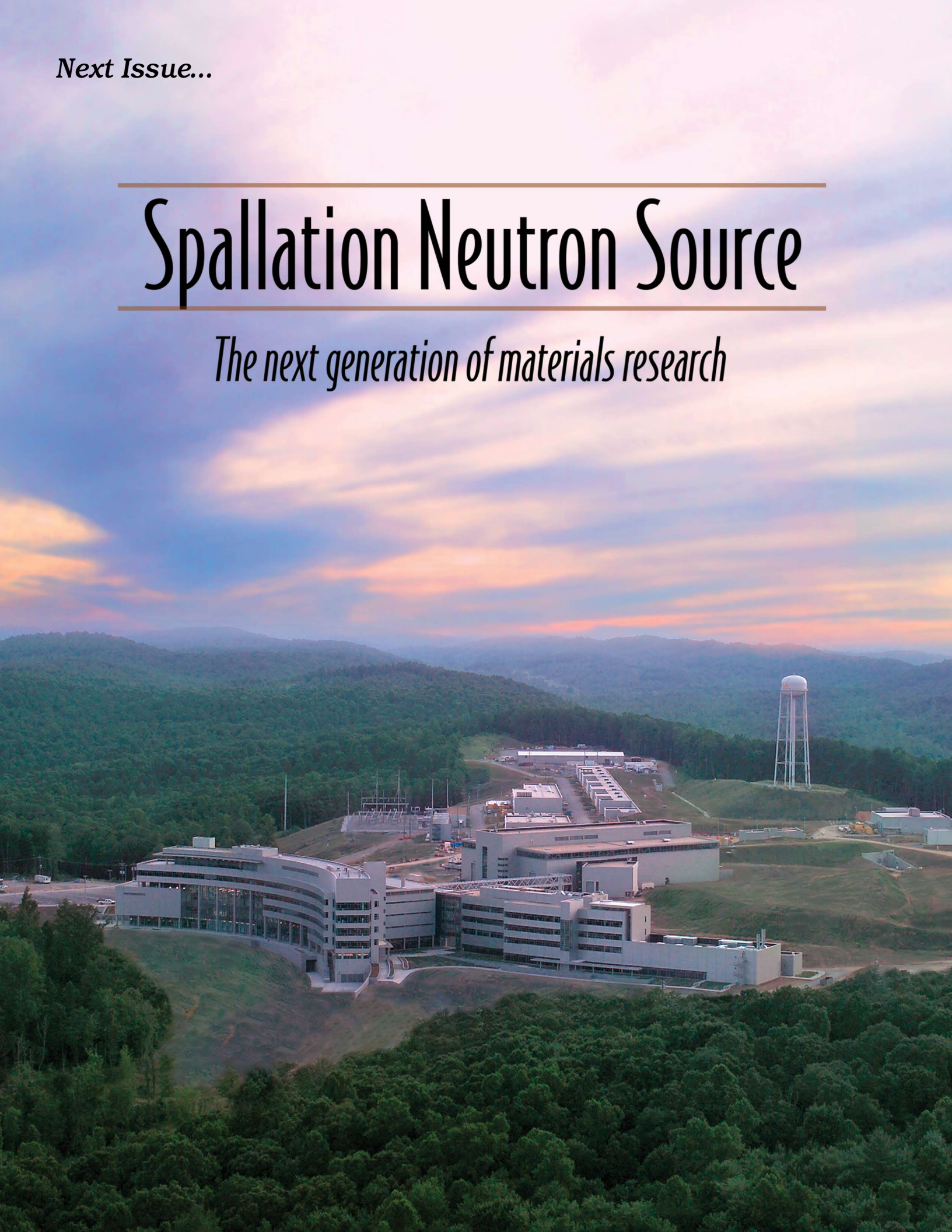
The ORNL *Review* received a ***silver award*** in the science category of *Folio:* magazine's 2005 ***Eddie*** and ***Ozzie Awards*** competition held in New York City. The award is the first ever for the *Review* in one of the nation's leading magazine competitions. ®

Steve Pennycook accepts the Director's Award for Science and Technology from ORNL Director Jeff Wadsworth at the 2005 ORNL Awards Night ceremony.

Next Issue...

Spallation Neutron Source

The next generation of materials research



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