LOS ALAMOS SCIENCE AND TECHNOLOGY MAGAZINE

JULY 2009

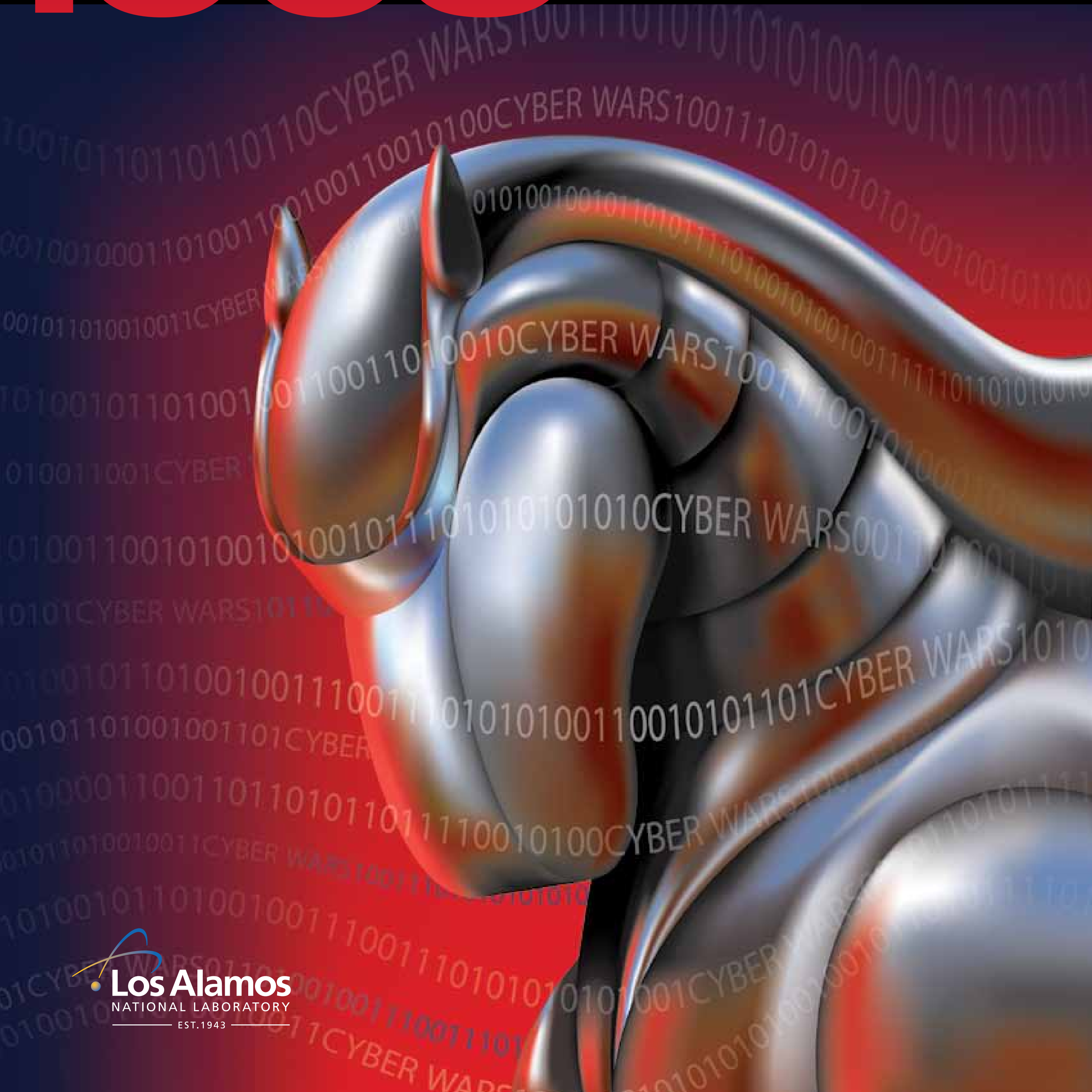
1663

Wired for the Future

Cyber Wars

Have SQUIDs, Will Travel

A Trip to Nuclear North Korea



Los Alamos
NATIONAL LABORATORY
EST. 1943

1663

About Our Name: During World War II, all that the outside world knew of Los Alamos and its top-secret laboratory was the mailing address—P. O. Box 1663, Santa Fe, New Mexico. That box number, still part of our address, symbolizes our historic role in the nation's service.

Located on the high mesas of northern New Mexico, Los Alamos National Laboratory was founded in 1943 to build the first atomic bomb. It remains a premier scientific laboratory, dedicated to national security in its broadest sense. The Laboratory is operated by Los Alamos National Security, LLC, for the Department of Energy's National Nuclear Security Administration.

About the Cover: Artist's conception of a hacker's "Trojan horse," in cyberspace. Los Alamos fights an unending battle against Trojan horses, worms, and other forms of malicious software but is spearheading research to play offense rather than defense in the ongoing cyber wars.

LOS ALAMOS ARCHIVE

During the Manhattan Project, Enrico Fermi, Nobel Laureate and leader of F-Division, meets with San Ildefonso Pueblo's Maria Martinez, famous worldwide for her extraordinary black pottery.

From Terry Wallace

The Scientist Envoy

Since the middle of the nineteenth century and the days of Mendeleev, Darwin, Pasteur, and Maxwell, scientists have helped to better society. Their theories and discoveries underlie all of today's technologies, and increasingly, society is turning to them to help find long-term solutions to tomorrow's environmental, social, and security challenges.

Scientists at Los Alamos National Laboratory readily shoulder this responsibility. Evidence for that can be seen throughout this issue of 1663, *which highlights efforts to develop superconducting transmission lines, perfect new medical imaging technologies, and safeguard computer networks. Each of those efforts has the potential to contribute greatly to society and national security.*

But scientists also form a unique community. All hold a rational view of the natural world and, regardless of their native tongue, speak the universal language of mathematics. They relate to one another so that, on occasion, scientists can play a special role, that of the unofficial envoy, called upon to help society confront a difficult situation.

North Korea's development of nuclear weapons is one example. Since 2004, former Los Alamos Director Sig Hecker has gone to that country several times in the capacity of technical advisor to verify North Korea's ability to make and purify plutonium. His direct experience with both plutonium metallurgy and international diplomacy have allowed him to communicate with the North's weapons scientists, obtain accurate information about the country's plutonium capabilities, and report his findings to the United States government. In an exclusive interview with this magazine, Hecker recalls his experiences in nuclear North Korea.

Today, Los Alamos' scientific staff members continue to support numerous nuclear nonproliferation activities, for example, monitoring seismic activity to detect underground nuclear tests. They design systems to safeguard nuclear facilities, as exemplified by the work of Howard Menlove, the world's expert on measuring neutrons from radioactive materials. Menlove designed instruments to monitor operations and nuclear materials at North Korea's Yongbyon reactor. In the area of diplomacy, George Eccleston was a technical expert at the Six-Party Talks, a role now filled by Los Alamos scientist Kevin Veal.

As the premier national security science Laboratory, Los Alamos is a continuing source of diverse and important contributions. Those contributions, whether technical, social, or diplomatic, will arise from the talents of one of our nation's great assets—its scientists.

TABLE OF CONTENTS

WIRED for the future

Superconducting Wires Might Transform Energy Distribution

The recent successes of underground superconducting power lines and the advent of second-generation, potentially cost-competitive superconducting wires may well be a prelude to a bigger revolution in our nation's power grid.

Steve Ashworth has invented a cooling scheme

The complicated network of transmission lines that brings electricity from energy sources to the user has dramatically changed its topology since the 1970s. Power plants that traditionally served local areas became part of a large interconnecting network of hubs and spokes, with power plants and transmission lines fanning out to multiple population centers, many of which are connected to multiple power plants. The interconnectedness has tended to make the grid more reliable because failures in individual power lines don't bring the system down.

The trouble is that investments in transmission lines have not always kept up with the addition of new power plants, especially in congested areas. No one wants a power line in the backyard, so new lines can take 7 to 10 years to site and string. The National Energy Regulatory Commission reports that 25,000 miles of new high-voltage lines are planned for construction over the next 10 years, but historically, only a small fraction of lines planned are actually built. If renewable sources of electricity (wind farms and solar arrays) increase as expected, most will be located far from major population centers and will require at least another 12,000 miles of new lines.

Steve Ashworth, leader of the applications team at the Los Alamos Superconductivity Technology Center (STC), sees opportunity in these challenges. Superconducting wires, which are just now being produced in kilometer lengths (just over a half mile), can carry massive amounts of electric power with almost no energy loss. Ashworth wants to run these wires overhead to minimize the environmental impact of new high-power lines that must run for hundreds of miles. Superconducting wires would carry much more current and much lower voltage and so could be strung on much shorter, less intrusive poles than are used for conventional high-power lines.

However, superconducting wire has to be cooled below 90 degrees Kelvin (90K), a very chilly –300°F, to become superconducting. To cool an underground cable (current ones typically are only a half mile long), liquid nitrogen enters the cable at 68K and warms to about 72K as it flows along the cable to the other end. It is then taken out of the cable and recooled. This scheme, which uses the specific heat of liquid nitrogen for cooling, requires recooling after no more than a mile, making it uneconomical for long, overhead cable runs.

Ashworth has demonstrated an alternative scheme that requires a cooling plant only once every 40 miles. Each plant takes in air, cools it, and produces liquefied nitrogen at 77K and 4 times atmospheric pressure. In one design, the liquid nitrogen would run through a perforated flexible-metal cooling tube alongside the superconducting wire. All would be encased in a long cryostat (vacuum-walled piping). The pressurized liquid nitrogen would spray out of its piping, vaporizing as it cools the nearby wire to superconducting temperatures. The vapor would then exit from engineered vents every few miles. The conceptual difference is the use of the liquid nitrogen coolant's latent heat of vaporization, as well as its specific heat, and that difference makes overhead lines feasible.

Says Ken Marken, head of the STC, "Steve's out-of-the box thinking is what's needed if superconducting technology is to be a major player in the next 20 years."

Because superconducting lines could transmit power with a significantly lower visual impact than conventional high-voltage power lines, Ashworth thinks they would be more acceptable to the public and would reduce—by years—the delay for obtaining permits. Even more important, bringing one large wind-power generating facility online a year earlier, and using it to replace a coal-fired generator, would eliminate up to 4 million tons of CO_2 emissions. A superconducting grid could help power a green revolution.

First Trials

Almost 100 years ago, mercury was found to be superconducting at 4K (–453°F), and since then, scientists have finessed hundreds of elements and compounds into exhibiting superconductivity.

Starting in 1986 a class of compounds called copper oxide

Three high-temperature superconducting power lines enter an underground right of way on Long Island, New York. Switched on in April 2008, the lines carry almost 600 megawatts of power, as much as all the perovskites were found to become superconducting at temperatures about 100 degrees higher than mercury does. That meant cooling costs would be 1,000 times lower, a giant advantage in any application. These new “high-temperature” superconductors promised to fulfill the dream of lossless power transmission.

The new compounds, however, were ceramic materials, as brittle as chalk. To be used in wires and cables, whether above the ground or under it, they would have to be coaxed into a flexible form that could stand up to real-world torture such as bending, twisting, and the occasional lightning strike.

The most promising superconductor was a copper oxide compound containing bismuth, strontium, calcium, copper, and oxygen—BSCCO (pronounced “bisco”). Silver tubes were loaded with BSCCO powder, sealed, and drawn into long, thin filaments that were then rolled into very thin tape. The tiny platelike BSCCO crystallites naturally formed a layered structure like mica, with their planes of copper and oxygen atoms (the layers where current flows) running parallel to the flat tape.

Through the 1990s this method produced longer and longer tapes, and by 2001 American Superconductor was planning a production facility to make 10,000 kilometers of tape per year for commercial applications.

But BSCCO wire has two Achilles heels. First, the metal used to form the tape must not react with the superconducting material, and silver is the cheapest metal that qualifies; therefore, BSCCO will always be prohibitively expensive. Second, BSCCO’s current-carrying capacity in liquid nitrogen is very low in high magnetic fields, so it could never be used in commercially attractive applications like oil-free transformers and high-efficiency motors, whose wiring must operate in high magnetic fields.

The Long Shot

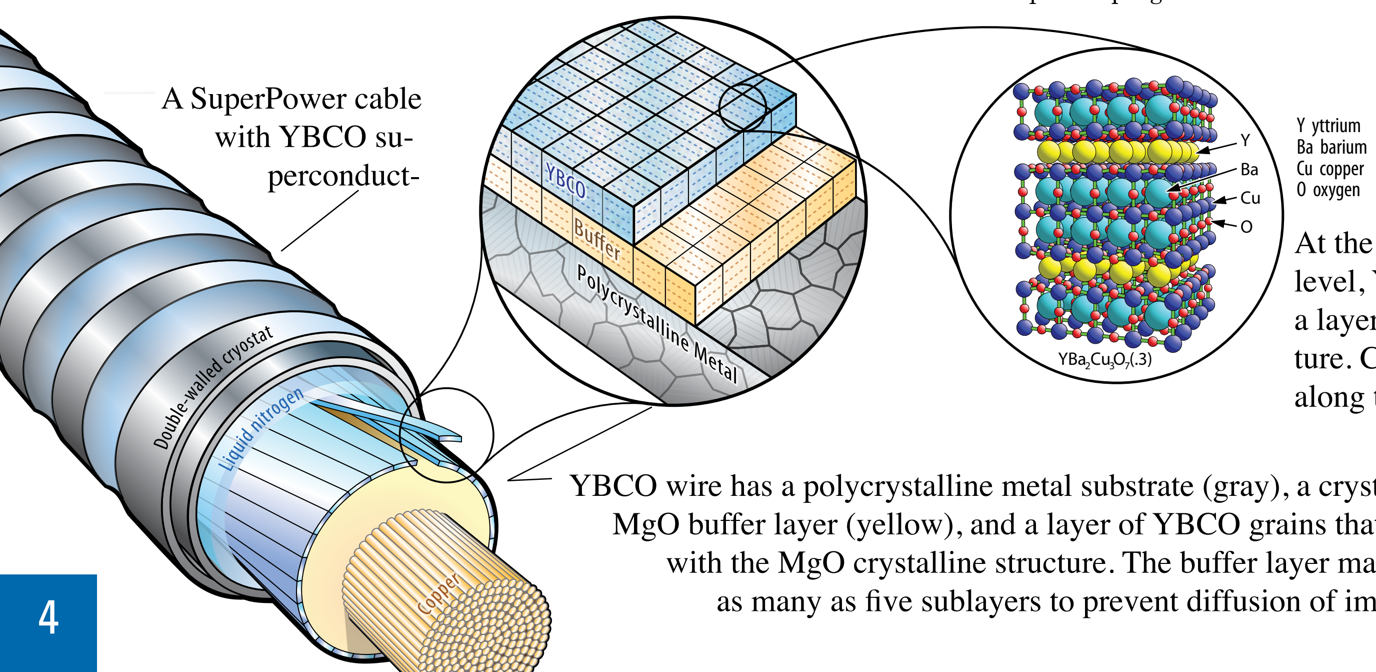
Another possible high-temperature superconductor was yttrium barium copper oxide (YBCO), discovered in 1987. This was the first compound found to be superconducting at temperatures above that of liquid nitrogen. But it was a long shot for superconducting wire because on the microscopic scale, current would not flow from one YBCO grain to another unless the two grains were almost perfectly aligned, an arrangement not achievable through the powder-in-tube manufacturing method.

STC’s Steve Foltyn, Xindi Wu, and Paul Arendt all had experience growing thin films of YBCO for electronics applications, and they did it on single-crystal substrates—substrates in which the crystal lattice is continuous (no boundaries). The single-crystal surface served as a template for growing YBCO crystallites that were aligned sufficiently to allow superconducting currents to flow easily. In 1993 the three decided to apply the same technique to making YBCO into superconducting wires.

They needed to grow the YBCO thin film on something flexible, strong, inexpensive, and available in long lengths—in other words, on metal strips. But metal strips are polycrystalline, with the crystal grains facing every which way, making them poor templates for aligning YBCO grains.

Their search for a solution took the STC researchers to a technique discovered in 1991: coating the polycrystalline metal with a single-crystalline-like surface that would serve as a buffer. The team tried a method called ion-beam-assisted deposition, or IBAD, which uses a beam of argon atoms to bombard a film of a YSZ (a yttrium-stabilized form of zirconium oxide) as the film grows on a metal strip. IBAD causes misoriented grains to sputter from the surface, leaving a crystalline-like surface. A thin YBCO coating grown on top of YSZ was able to carry significant current.

Starting with funds from the Laboratory Directed Research and Development program at Los Alamos,



A SuperPower cable with YBCO su-perconduct-

At the atomic level, YBCO has a layered struc-ture. Current flows along the copper-

YBCO wire has a polycrystalline metal substrate (gray), a crystalline MgO buffer layer (yellow), and a layer of YBCO grains that align with the MgO crystalline structure. The buffer layer may have as many as five sublayers to prevent diffusion of impurities,

Los Alamos’ Yates Coulter checks the quality and uniformity of long tapes for a number of compa-nies. His cassettelike machine passes each tape, inch by inch, through two external magnetic fields, the first in the plane of the tape and the second vertical to it, automatically measuring current flow through each segment. Reduced current flow in

team members began making YBCO/YSZ-coated samples. By 1995 they had made a 1-centimeter-long sample that carried current at over a million amperes per square centimeter—1,000 times the current density carried by household wiring.

When they announced their achievement, they were met with snickers. No one believed that their 1-centimeter-long sample could ever be scaled up to commercial lengths. But they didn’t give up. By the end of 1995, they had the growth process under control and could quadruple the length of their product. By 1997 they had produced their first meter-long superconducting tape—just over 3 feet.

In that same year, they speeded up the process by replacing the YSZ with a much thinner film of magnesium oxide (MgO), which could be laid down with IBAD much faster. Foltyn says, “Magnesium oxide has a better texture than YSZ for achieving alignment of the YBCO grains. So MgO made the tapes cheaper to manufacture and improved their performance.”

By 1999, the STC team had a continuous process that produced meter-long, superconducting-coated conductors with very high current-carrying capacity. It wasn’t long before a leading high-temperature superconductor company negotiated a license to adapt the technology for commercial purposes. That same company eventually created SuperPower.

Quanxi Jia (left) and his colleagues have focused on reducing the number of buffer layers, an im-portant step toward low-cost 2G wires. Leonardo Civale (right) has shown that the right distribution of imperfections grown in the YBCO layer will

2G Hot Wire

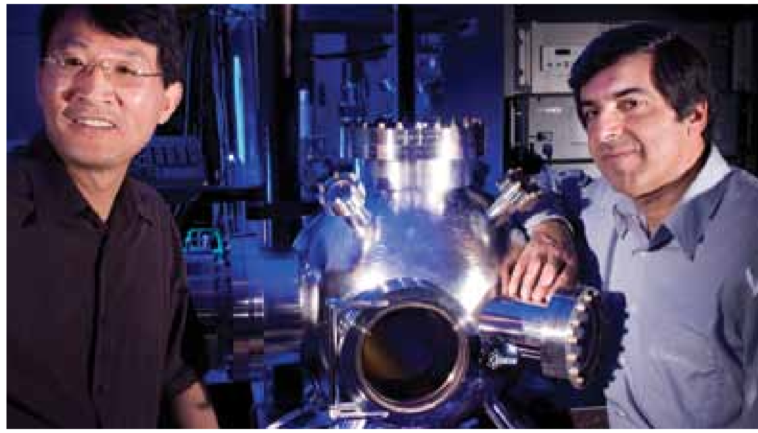
Today, YBCO wire has overtaken BSCCO, becoming the second-generation (2G) superconducting wire and the hope for the future. About 10 companies are making 2G wires longer and longer, and SuperPower leads the pack, having manufactured the first mile-long wire with a high current-carrying capacity.

In 2006 a 100-foot cable made from YBCO wire was spliced into an underground superconducting BSCCO cable in Albany and performed very well. Now YBCO wire cables up to a mile long will be used in a new round of government-sponsored superconducting power line projects in New Orleans, New York City, and Long Island. And Ashworth is set to try his overhead cable idea with a 100-foot cable strung at Los Alamos.

On the development front, STC scientists are now collaborating with SuperPower, American Superconductor, and other companies to simplify the design of 2G wire, get better control over the processing, and improve performance in high magnetic fields. If 2G wire becomes cost competitive with copper wire, it could eventually be in widespread use.

Ken Marken states, “DOE’s Office of Electricity sees high-temperature superconducting wire as a key enabler for high-efficiency power transmission cables with 3 to 5 times the capacity of conventional underground AC cables and up to 10 times the capacity of DC cables. Given the immense potential of this wire, we need to face the remaining challenges and support the research to overcome them.” ❖

—*Necia Grant Cooper*



cyber wars

The unending battle for CONTROL

More than employees and authorized visitors seek entrance to Los Alamos. Computer hackers are always trying to break in, but the Laboratory fights back against their “worms,” “Trojan horses,” and other forms of malicious software.

In the war between network professionals and computer hackers, the professionals know they have little advantage over their hacker adversaries, who have roughly the same programming skills, use the same software, speak the same language, and know the same tricks as the professionals.

The professionals also know that their current role is a defensive one, *reacting* to hackers’ attacks instead of mounting an offense against them, their formidable defenses doing little to stop the onslaught. Most of all, the pros know they can’t stop fighting back. Once an outsider has gained access to secure files, the information in those files, whether personal information or state secrets, is forever compromised.

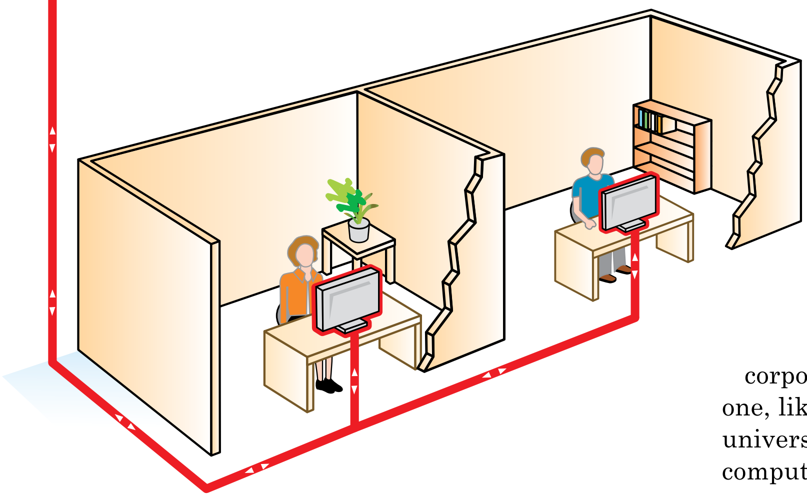
The need for constant vigilance is especially true at Los Alamos National Laboratory, whose famous name, substantial Internet presence, state-of-the-art computer systems, and huge stores of proprietary information make it a hacker’s dream target.

Los Alamos fends off several million cyber attacks a day, mostly from worms—highly virulent, self-reproducing programs that send themselves through a network from one computer to another. Other types of malicious software (malware) arrive attached to email, encoded into documents or PDFs, or in the form of a Trojan horse, a program that carries another “hidden” program, often harmful, that is ready to be activated by an unwary user.

The Laboratory’s primary defense is its “firewall,” a sophisticated program that intercepts and inspects all incoming communications. The firewall is continually maintained and improved by a large contingent of network, systems, and day-to-day operations people. Hackers, however, can be remarkably adept at finding ways to get through the barrier.

“The firewall tends to drive the evolution of more-sophisticated attack strategies,” says Alex Kent, the head of the Advanced Computing Solutions Program Office (ACS-PO). “As a result, firewalls get breached more often than network administrators like to admit. Unfortunately, the response is often to make the firewall more restrictive and systems less ‘user friendly.’”

Artist’s depiction of a hacker’s Trojan horse, attempting to



Kent's small ACS team has other ideas. It's building an understanding of the relationships between users, technology, and security; tapping into new research and technology; and coming up with solutions that both enhance security and foster a more favorable work environment. Kent also takes every opportunity to leverage the unique problem-solving skills of other Laboratory specialists, such as theoreticians, mathematicians, and statisticians. Says Kent, "My reward is having people come to me and say, 'I think this idea I've had for my own work has got some applicability to the problem that you're describing.'"

One of those people is Joanne Wendelberger, a statistician with the Computer, Computational, and Statistical Sciences Division and a relative newcomer to the cyber wars. "I had a view of cyber security as this compliance-driven, necessary evil that made it difficult for us to do our jobs," she confesses. "But after looking at the threats, I understood why some policies get implemented. Then I wanted to help."

Wendelberger and colleagues are beginning to apply statistical methods to the analysis of network traffic streaming into the Laboratory. The large, time-ordered datasets need to be reorganized and analyzed in a way that identifies statistical anomalies. "Then we'd be in a better position to characterize normal versus unusual behavior," she says. "Understanding why data deviates from normal might allow us to design a system that recognizes an intrusion as it is happening."

A Hacking Incident

Like every institution worth targeting, the Laboratory has been infiltrated. Kent keeps the details of those events close to his chest, but an exception is the Stakkato incident, a sustained attack perpetrated by a 14-year old Swedish boy who called himself "Stakkato." The details of that incident won't help any hacker but do give the uninitiated a taste of battle.

From August 2003 to March 2005, Stakkato (and maybe others) compromised roughly 1,000 computers, including unclassified supercomputers belonging to Los Alamos, NASA, the U.S. military, the National Supercomputing Center in Linköping (Sweden), and many of the world's leading universities and corporations. But he started by breaking into just one, likely a Unix-based computer at a Swedish university. From there, he was able to jump to other computers because he had found a way to steal passwords.

On a Unix-based machine, the "ssh" protocol opens a secure (encrypted) connection between the user's computer and another one. The user can then log onto the second computer by entering an assigned username and password.

Stakkato modified the Swedish computer's ssh protocol, turning it into a Trojan horse. Whenever a user on the Swedish computer accessed another computer (say, computer B), the Trojan ssh surreptitiously recorded that person's username and password as he logged on. The Trojan then sent those credentials to a third machine that the hacker could access.

Using the stolen credentials, the hacker could log onto computer B on his own. Right out of the gate, he hid his tracks by disabling B's history log (type "unset HISTFILE"). Then he looked for users with administrative privileges (they tend to own lots of system files) and identified other computers networked with B (look in the "/etc/hosts" file). Again using the pilfered username and password, he tried logging onto each network computer and, if successful, got the new machine to tell him all about itself (with the command "uname") and its users (the Unix "w" command).

His goal was to find a computer (B or any other) with vulnerabilities that would gain him administrative control of the computer. His bigger goal was to steal the "root" password, which would make him a "superuser," with *total* control of the computer. One technique he used was to deploy his Trojan ssh in a system administrator's account, hoping the administrator would log onto a machine using the root password.

In the end, he hoped to gain control of one of the network file system (NFS) servers, computers where everyone on the network stores data files. Often he had to bootstrap his way and first control the computers

continued on page 10

Super VTR: Reducing the Insider Threat

In the summer of 2006, a young woman, trained and sanctioned by the Laboratory to scan secret documents into a computer, but behind in her work, allegedly wanted to catch up by taking work home. She walked into a document storage vault, copied secret documents to a removable flash memory drive, printed pages of secret material, placed the flash drive and copies in her knapsack, and walked out the door. Her actions were consistent with what every cyber expert knows to be true: the greatest threat to computer and information security is the insider—the person authorized to use the system and/or access classified material.

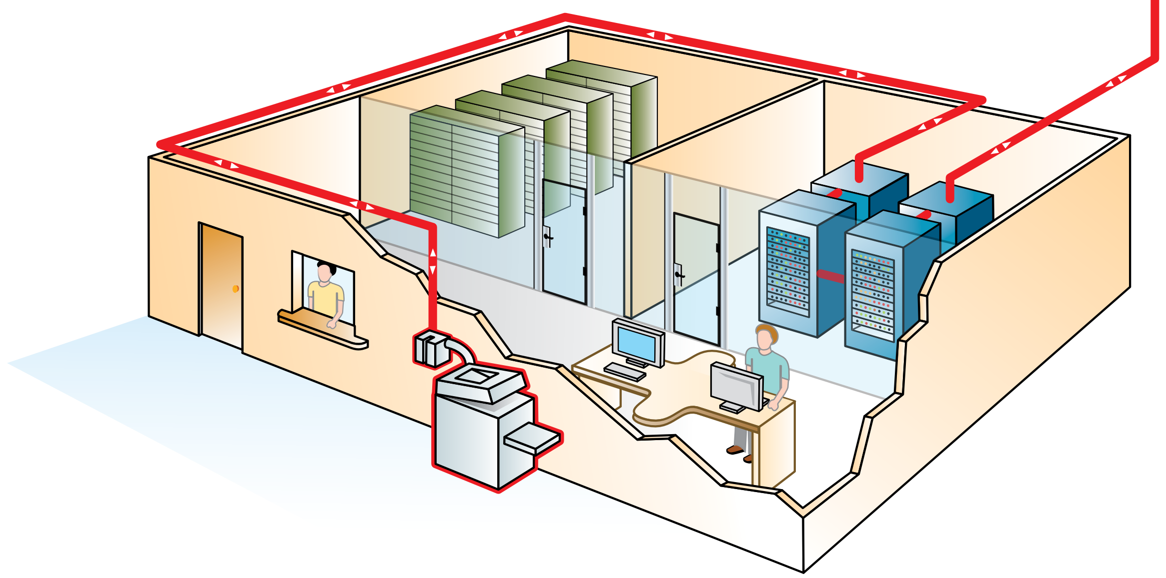
Mike Fisk, Scott Miller, and Alex Kent, of ACS-PO, argue that the majority of insider attacks, and almost all inadvertent security violations, can be eliminated by concentrating classified materials into a small number of rooms and conducting all aspects of classified computing on centralized computer servers. Their plan, currently being implemented at the Laboratory, houses both the media room and server inside a physically secure, restricted-access area known as a super vault-type room, or S-VTR.

The existing fiber-optic network connects the S-VTR to the numerous protected areas (scattered across the Laboratory) where classified work is conducted. A staffer in one of those areas still uses a mouse, monitor, and keyboard, but those devices aren't connected to a computer beneath the desk. Instead, they're connected, through the network, to a server in the S-VTR.

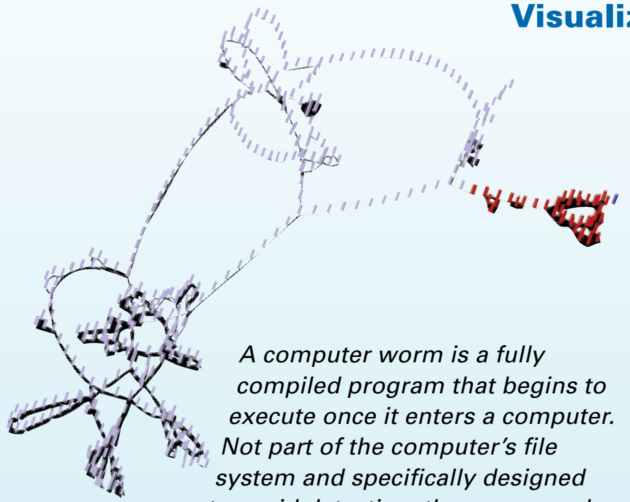
"What we're doing is connecting each user to a protected server 24-7," says Kent. "All files and data reside on the server, and every calculation, all data storage—everything—is done on the server. There's never any tangible classified material in the user's office. An insider who tries to remove information from the server instantly triggers an alert."

No users are allowed inside the S-VTR, which is manned by special personnel trained to handle classified media. Any user who wants to physically retrieve materials, must submit a request to an S-VTR worker, who records the removal and return of the material. Eventually, few users will ever need to carry classified documents around because every protected area will be connected to the server. Materials will be printed onsite and destroyed after each use.

The print jobs themselves will go to a queue on the secure server and won't print until the user swipes his or her security badge in a reader attached to the printer. The Laboratory is also looking into technology for placing an individual bar code or watermark on each page of the job. In both cases, users will know they are accountable for what's printed, which will help prevent casual misuse, or clandestine abuse, of the material.



Visualizing a Worm



A computer worm is a fully compiled program that begins to execute once it enters a computer. Not part of the computer's file system and specifically designed to avoid detection, the worm can be difficult to find within the host system and even more difficult to reverse engineer to figure out what it does.

Laboratory scientists have devised a complete system for rapidly dissecting a worm. The worm is allowed to infect a mock network computer containing analysis software that includes a visualization package developed by Danny Quist of the ACS-PO. That package automatically creates a graphic representation of the worm's execution path (the program's flow chart). Because different subroutines or program units have distinctly different patterns, the graphic provides a quick way to classify the worm and begin figuring out what it does.

The graphic shown here illustrates the structure of the Conficker V3 worm, which is likely to become the most widespread infection to date. The program unfolds from right to left. Each mark along the lines corresponds to a small block of program steps, so a line of marks represents a sequential set of steps. Forks indicate decision points and alternate ways for the program to proceed. The tangle of loops in the middle shows the many paths the worm can follow, depending on instructions from its creator. The bundle on the lower left is a spam engine, indicating that one purpose for this worm is to send spam from the infected computer to every email address it finds on the machine.

that talked to the servers (the NFS clients). But once he gained control of the server, his invasion was complete, for he essentially ruled the local network. He then gathered more usernames and passwords, jumped to a new machine on a different network, and did it all again.

System administrators were lucky (as far as they know) in that Stakkato was more egotistical than malicious. For example, after an administrator tried (but failed) to eradicate the hacker from his machines, Stakkato sent every user on the administrator's network an insulting message, but he didn't destroy any data. Still, the attacks cost millions of dollars, mostly for the time needed by administrators to check, diagnose, and fix their systems.

Stakkato Hits the Lab

Stakkato's infiltration of Los Alamos was different. A few years before the attacks started, the Laboratory had gone to a "one-time" password system. This security measure negated the hacker's attack because a user's password (generated by a "cryptocard") is valid for only one use. So the hacker adapted his strategy.

"He hid in a computer outside the Los Alamos network and monitored the user's activities," says Mike Fisk of ACS-PO. "He then waited for the user to log onto a Los Alamos machine. Apparently the user took a short break and left his computer without closing the connection, allowing Stakkato access to the Los Alamos machine. Once he had this foothold, Stakkato never left, discretely maintaining a connection to the machine even after the original user logged out."

Upon learning that it had been cracked, Los Alamos closed all ssh connections from outside computers and mitigated several vulnerabilities, thus locking the hacker out. A similar, Stakkato-type attack couldn't happen today at the Laboratory.

But Fisk stresses that hackers are experts at finding and exploiting new vulnerabilities and getting around firewalls. "And there will always be vulnerabilities," he states matter-of-factly. "That's just the nature of the computer beast."

The Secure Enterprise Network Consortium

One reason cyberspace is so vulnerable is that when the initial Internet infrastructure was cobbled together, no one foresaw the vast array of commercial services, variations of network hardware, and volumes of digital information that it would need to support, integrate, and transmit. The infrastructure grew too fast and became peppered with incompatibilities and vulnerabilities that are now easy pickings for hackers.

But a different future may be possible because of the Secure Enterprise Network Consortium (SEN-C), a partnership between Accenture, a global technology management company; industry-leading provider companies Cisco, Sun Microsystems, and Computer Associates (CA); and Los Alamos, a premier national security research institution. The SEN-C was formed because collaborative development is key to designing truly unified, secure information systems that are deployable across the country.

The SEN-C intends to do away with the usual "general contractor" model of systems development, wherein a "service integrator" contracts with individual software, hardware, and network providers and constructs a customer's product. Instead, a product will essentially be designed, developed, and deployed jointly by all members of the consortium, with Accenture overseeing and coordinating the effort.

Says David Seigel, the Laboratory liaison for the SEN-C, "By coming together as one team, we can maximize our R&D efforts, reduce the time it takes to deploy solutions, and thereby ensure that those solutions are not obsolete upon installation because adversaries have already designed around them."

Los Alamos' role will be to inject new technology and concepts into the SEN-C and to conceptualize defensive measures as rapidly as hackers evolve offensive methods. To do so will require that the Laboratory bring into the cyber realm its expertise in data visualization, algorithm development, statistical analysis, and high-performance computing. It will need to call upon its experience in modeling and simulating national infrastructures, along with their interdependencies, in order to place cyber security within the bigger picture of national security.

To Turn the Worm

Accenture chose Los Alamos to join the consortium based on the Laboratory's reputation for initiating inventive and effective solutions to cyber security. An example is the Network Automated Response and Quarantine (NARQ) software, designed to shut down a worm infestation.

A computer worm will enter a vulnerable computer, rapidly copy itself, and then send its clones out over a network to infect other computers. Because the number of worms grows exponentially, the network, or even large portions of the Internet, can become so clogged that it has to be shut down. The cost can be enormous: the various Code Red worms, launched in 2001, cost businesses roughly $2.6 billion in lost productivity.

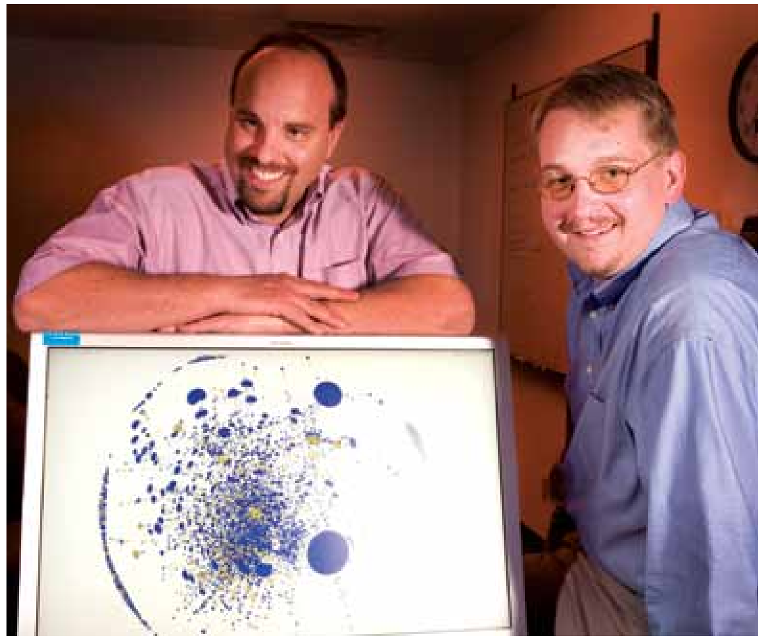
NARQ efficiently stops the worms' spread by locating each infected computer and then removing it from the network by switching off its network ports. It's easier said than done. Los Alamos alone has over 10,000 computing devices tied to more than 33 square miles of network infrastructure. The semiautomated software, however, is several orders of magnitude faster than other solutions, and after a year's use at the Laboratory, the response time to remove a worm infection has been reduced from over 3 weeks to less than 1 day.

Solutions such as NARQ are coming none too soon. Hackers are sophisticated and bold, and they grow more numerous by the hour. By compromising the integrity of computers and the Internet, they literally threaten the foundation of our society.

The good news is that there's a heightened awareness of the cyber security problem on the national level. President Obama's announcement of a cyber security coordinator is recognition that computer security is of central importance to the United States, on a par with traditional military concerns.

Short of disconnecting completely from the Internet, there will always be a risk of hackers stealing proprietary or personal information. Indeed, a tenet of cyber security is that you can never win; you only hope not to lose something today. Eventually, Los Alamos would like to disprove that belief and is prepared to create and deploy multidisciplinary teams of scientists to help make it happen. Until then, the cyber war will rage on, and the Laboratory stands ready. ❖

—Jay Schecker



Alex Kent (left) and Michael Fisk are helping the Laboratory defend computer systems against malicious cyber attacks. The screen shows a graphic representation of attacks on Los Alamos. Blue and yellow splotches are clusters of computers' IP addresses that were attacked during an incident. Analysis

HAVE SQUIDS, WILL TRAVEL

Los Alamos researchers are using the world's most sensitive magnetic-field detector to pinpoint seizure-generating tissue in epileptics' brains and to screen carry-on liquids at airports.

Andrei Matlashov, a member of the SQUID team, with the apparatus used to study magnetic resonance imaging at ultralow magnetic fields. The copper coils that produce the magnetic fields are wound on wooden armatures to avoid the magnetic distortions caused by metal.

This research is supported in part by LDRD funding.

It was 2002, and the Los Alamos SQUID team had a problem. The team had just invented and tested a helmetlike system incorporating the world's most sensitive magnetic-field detectors: superconducting quantum interference devices (SQUIDs). Placed just above the skull, the SQUIDs measured magnetic fields generated by neural electrical currents in the brain and pinpointed the currents' locations to within a quarter millimeter. Such spatial precision would be good enough to guide doctors' attempts to electrically quell or surgically remove "epileptogenic" tissue—the small, localized regions of the brain where epileptic seizures begin—but only if the reference frame in which the positions of this tissue were measured could be made to closely coincide (coregister) with the reference frame of a magnetic resonance image (MRI) of the same brain. An MRI shows the detailed structure a surgeon needs to see.

At the time, however, the two reference frames couldn't be coregistered precisely enough because the images were being produced by two different instruments—the team's helmet and a hospital MRI machine. Each instrument separately produced images with the required spatial precision, but a set of two images, one from each machine, could be coregistered to only 5 millimeters.

When you treat epilepsy surgically, you want all the precision you can get. Brain tissue is highly folded and densely packed with neurons, so even a slight surgical misstep can have disastrous results. Or as Bob Kraus, former SQUID team leader, says, "If someone is cutting into your brain, you want them to know where to cut as precisely as possible."

A Magnetic Disparity

The solution to the coregistration problem might seem obvious: combine the SQUIDs and the MRI machinery into one instrument. The problem is that hospital MRI machines use a powerful magnetic field that will destroy SQUIDs.

SQUIDs are really the only way of measuring the brain's magnetic fields, with a technique called magnetoencephalography, or MEG. These fields have a strength of about 1 picotesla, some 50 million times weaker than Earth's magnetic field. A SQUID can detect a magnetic field as small as half a femtotesla, or one 2,000th of a picotesla. The helmet, the team's crowning achievement after 20 years of MEG research, uses 155 SQUIDs arranged on a curved supporting surface that conforms generally to the top of the skull.

An MRI is created from measurements of nuclear magnetic resonance (NMR) signals, which are magnetic signals emitted by certain nuclei—including hydrogen nuclei (protons)—when their quantum-mechanical “spins” are manipulated in certain ways. Since hydrogen is a major atomic component of water and fat (two of the body’s main ingredients), proton NMR signals are commonly used to produce images of organs, muscles, and so forth, that is, to produce MRIs. To produce a hospital MRI, some of the spins are first aligned by the powerful magnetic field of a large superconducting electromagnet, and therein lay the team’s dilemma: an instrument combining MRI and MEG imaging would self-destruct the first time it was turned on because the powerful magnet used to produce MRIs would destroy the SQUIDs used to produce MEG images.

Finding Aberrant Brain Tissue

Nonetheless, in and of itself, the MEG helmet is a stunning success. As a method of localizing epileptogenic tissue, MEG is completely noninvasive. In fact, the helmet’s SQUIDs do not even touch the skull. And that’s a very good thing because, to operate, they must be kept extremely cold—a few degrees above absolute zero. To chill them out, the team immerses them in liquid helium that has been poured into a large thermos supported by a sturdy gantry above a person’s head. The thermos is so well insulated that the outer surface—only an inch or so from the subject’s skull—is at room temperature.

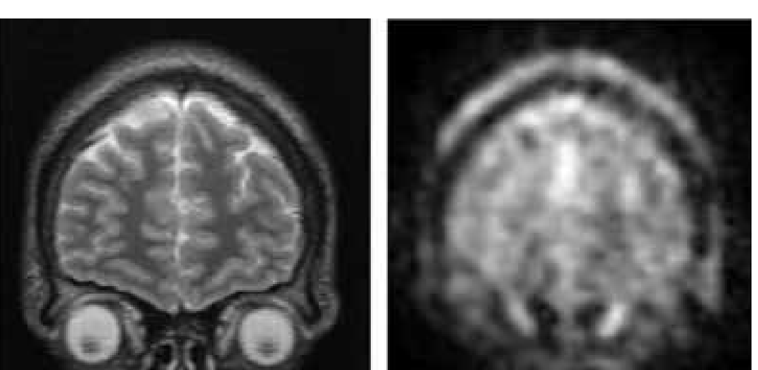
The helmet’s MEG measurements are also extremely precise with respect to time. The SQUIDs have a temporal resolution of about 100 microseconds—short enough to distinguish between electrical signals that occur at almost the same time but arise from patches of epileptogenic tissue in different parts of the brain.

In fact, MEG’s temporal resolution is comparable to that of the “gold standard” for localizing epileptogenic activity—electrocorticography (ECoG), which measures the electrical potential of electrodes implanted in or on the brain. However, ECoG has the clear drawback of being about as invasive as it gets.

Jonatan Mattson, a former graduate student on the SQUID team, inspects the helmetlike system the team developed to measure the tiny magnetic fields produced by the brain’s neural currents.

The only other technique with comparable temporal resolution is electroencephalography, or EEG, which uses electrodes taped to the scalp and parts of the face to measure changes in electrical potential. EEG is only mildly invasive (the discomfort of tape and conductive gel) but has a more important problem. The signals it detects must pass through various types of tissue and the bone of the skull, all of which have different electrical conductivities that distort the signals. The distortion is worst near openings in the skull, such as eye sockets and ears, and introduces errors in measuring the locations of the epileptogenic tissue. In contrast, magnetic fields measured by the MEG helmet pass through the skull undistorted because there are no magnetic materials within a normal skull.

“However, EEG is cheaper to use than MEG is,” Kraus says, “and patients can ‘wear’ EEG electrodes for a long time to permit near-continuous monitoring of neural activity.” In contrast, during a MEG measurement, the patient has to stay put, like a beauty shop patron sitting under a hair dryer.



Images obtained with traditional MRI (left) and ultralow-field (ULF) MRI (right). The ULF MRI image is fuzzier because the signals used to produce it have relatively more noise than those producing traditional MRIs. However, unlike traditional MRI, ULF MRI can be done in the presence of metals, allowing a surgeon to operate and view an MRI of his/her work at the same time. Moreover, ULF MRI can image some types of tissue better than traditional MRI can.

For those reasons, in spite of the distortion, EEG is currently the diagnostic tool of choice at epilepsy treatment centers, although the most-reliable, most-accurate results for diagnosing epilepsy are actually obtained by combining MEG and EEG, Kraus says.

Shutting Out the Noise

However, two new concepts the SQUID team developed and then proved with the helmet could provide significant improvements that make MEG’s use more common. Both concepts aim to reduce the interference with MEG measurements caused by magnetic “noise,” that is, ambient magnetic fields such as Earth’s magnetic field and magnetic fields produced by power lines, electric appliances, and even passing cars. The new concepts so effectively reduce ambient magnetic noise that MEG measurements can be made in a room that has only one layer of magnetic shielding instead of two, as is usually required. A single-layer room is much simpler and therefore less expensive than is a double-layer room.

The first new concept is to use a lead sheet, shaped roughly like a conquistador’s helmet, to shield the SQUIDs from ambient magnetic fields. When bathed in liquid helium, the same medium used to cool the SQUIDs, the lead sheet becomes a superconducting “magnetic mirror” that reflects the ambient fields away from the SQUIDs.

The second concept is to use additional SQUIDs outside the shaped lead sheet to measure ambient fields that are not completely reflected by the magnetic mirror. When the data are later processed, the residual magnetic noise is cancelled out by subtracting the signals of these residual fields from the signals measured by the 155 SQUIDs.

Initial tests established that the helmet’s novel design put it well ahead of its time and that it was a potential steppingstone to cheaper MEG systems that could be used to help more people who have epilepsy or other brain disorders. But there was still that pesky coregistration problem.

A bottle of Perrier about to pass, on a conveyor belt, into the heart of MagViz, a ULF MRI machine developed for use at airport security portals. MagViz provides MRIs of airline carry-on liquids and identifies the liquids.

Way Less Is More

Then in 2002, the same year the coregistration problem stymied the SQUID team, a potential solution was announced by scientists in California. Berkeley researchers published a paper describing the first use of SQUIDs to perform a new kind of MRI. In this new variant, proton spins are aligned by a relatively weak electromagnet that is turned on for only about a second. Subsequent spin manipulations with even weaker pulsed electromagnets produce NMR signals that are detected by the SQUIDs (see box, next page).

The use of magnetic fields much weaker than that associated with traditional MRI led researchers to christen the new discipline “ultralow-field” (ULF) magnetic resonance imaging, or ULF MRI. This approach clearly provides a way for a single SQUID-based instrument to perform both MRI and MEG imaging and thereby solve the coregistration problem.

Excited by this development, the Los Alamos SQUID team repeated some of the Berkeley group’s results and soon went beyond them.

From Brains to Cokes

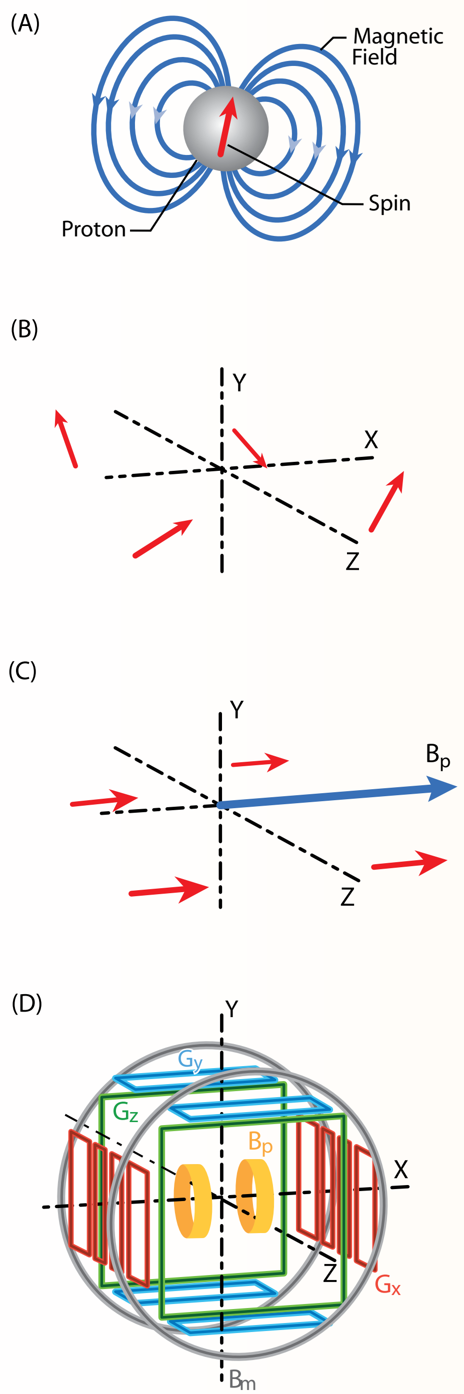
The team started its ULF MRI odyssey simply, using a single SQUID to measure the NMR signals of whatever happened to be lying around in the laboratory—Coke, V8, and sports drink, for example. “Some of our ‘research’ was driven by idle curiosity,” Kraus admits. Whatever the motivation, the team soon found it was easy to positively identify a liquid from its ULF NMR signal. The team filed these results away and went on to other experiments.

One early experiment measured an NMR signal and a MEG signal from the same brain at the same time—a first step to using a single SQUID-based instrument to image both the brain’s structure and its MEG-derived electrical activity. Within a couple of years, the team had also used an array of seven SQUIDs to produce ULF MRI images of a preserved sheep brain, a living postdoctoral researcher’s hand, and a living team leader’s knees.

Increasing the number of SQUIDs—from one to seven, in this case—is one way to increase the “signal-to-noise” ratios of the NMR signals. A signal with a high signal-to-noise ratio can produce an image with a given quality in a shorter time than can a signal with a lower ratio.

Last year, the team published a paper describing experiments in which they used seven SQUIDs to capture the first ULF MRI images of a living human brain and, at nearly the same time, to record seven channels of MEG data as that brain responded to audio tones. Team members also considered using the SQUIDs

Ultralow-Field MRI



About 63 percent of the atoms in the body are hydrogen, mostly in fat and water. Magnetic resonance imaging (MRI) measures the concentration of those atoms at many points in the body and converts the data into a map, or picture, of the body's tissues.

The hydrogen atoms can be detected because each atom's nucleus—a single proton—has a tiny magnetic field produced by the proton's quantum-mechanical "spin," as shown in Figure A. Normally, the spins point in random directions (Fig. B), so the total magnetic field measured by a detector far from the spins is zero. MRI manipulates the spins so the protons' magnetic fields combine into a field large enough to be measured.

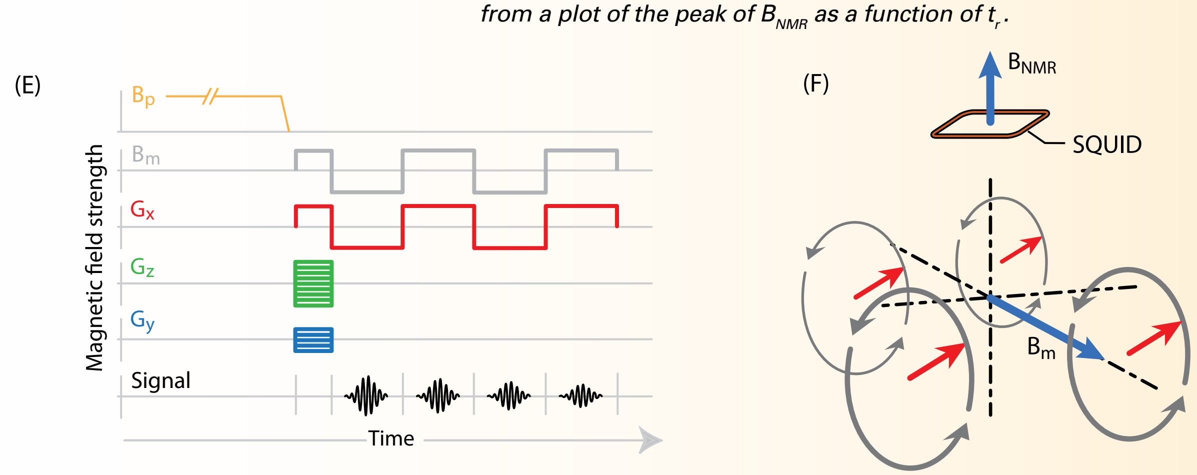
The first step in this process is to align some of the spins in the region of interest with a relatively weak uniform magnetic field B_p (Fig. C). In ultralow-field (ULF) MRI, B_p is produced by an electromagnet that is turned on for a second or two. Figure D is a schematic drawing of the electromagnets that produce B_p (yellow) and another, much weaker magnetic field B_m (gray), as well as three magnetic-field gradients G_x (red), G_y (blue), and G_z (green), which are discussed below. The timing diagrams (Fig. E) show when the electromagnets are turned on and off relative to each other.

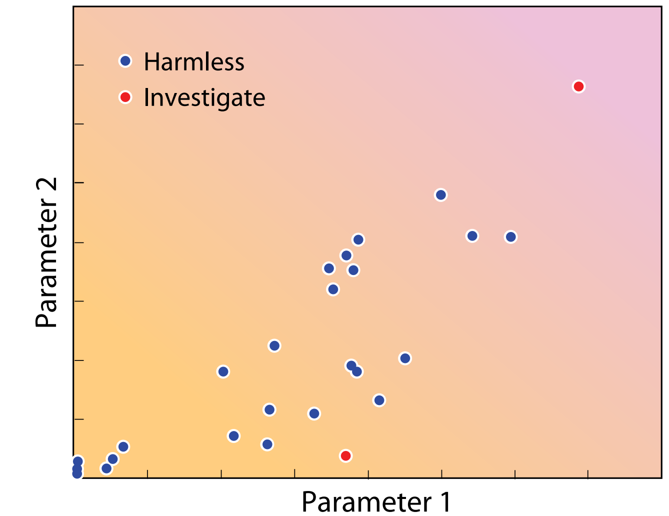
Signals are obtained when B_p is off. The field B_m, which points perpendicular to the aligned spins, is applied to the region for a few seconds. The spins start rotating together ("precessing" in phase) around B_m with a frequency proportional to B_m's strength (Fig. F). The magnetic fields of the precessing spins combine to produce a net magnetic field, B_{NMR}, that is vastly larger than that of a single proton, but still much weaker than B_m. This nuclear magnetic resonance (NMR) signal oscillates at the precession frequency and can be measured by SQUIDs located some distance from the spins.

The strengths of G_x, G_y, and G_z vary linearly with distance in the x, y, and z directions. The total magnetic field then has a slightly different value at each point, so the spins at different points precess at slightly different frequencies. A 3-D map can be produced because each tiny measurement volume in the patient's body produces an NMR signal with a unique frequency that is determined by the volume's position.

As time passes, very slight differences in the frequencies of the spins' rotations, arising from interactions with neighboring spins, cause the spins to rotate out of phase with each other, so B_{NMR} fades away. For B_{NMR} to be measured, the spins' rotations are reversed by reversing B_m. As the spins come back into phase and then fall out of it again, they produce a measurable "echo" signal (bottom of Fig. E). The time it takes an echo signal to rise and fall gives the first of two characteristic times used to distinguish between different types of tissue or different chemicals.

The second characteristic time arises from the fact that after B_p is turned on, the spins take some time to realign. To measure how fast they do, B_p is turned on and off in the usual way, and then an echo signal is measured at a time t_r after B_p is turned off. This procedure is repeated for several different values of t_r. The second characteristic time is obtained from a plot of the peak of B_{NMR} as a function of t_r.





MagViz discriminates between harmless liquids and those requiring further investigation, by security personnel, based on a liquid's position in a space determined by two ULF MRI parameters.

in the MEG helmet to simultaneously image brain structure and MEG sources. They were well on their way to brilliantly solving the coregistration problem—when they were suddenly diverted by world events.

A "Slight" Side Trip

In August 2006 British authorities foiled a terrorist plot to set off liquid explosives onboard an aircraft in flight, and what is known in the air-travel industry as the "3-1-1" rule was born. All carry-on liquids are now limited to 3 ounces each and must be packed together in a single quart-size plastic bag—one per traveler. The delays and inconveniences caused by this rule have been irking millions of air travelers ever since.

One particular air traveler, Michelle Espy, the current head of the SQUID team, would like to see the rule go away so she can take fruit juice on the plane when she travels with her two young children. She's also one of the few people in the world who can probably do something about the rule, thanks to the team's old data on Coke and other liquids. Suddenly what had once been playfulness in the laboratory took on a very serious purpose that drew the attention of the Department of Homeland Security (DHS).

Well aware of the 3-1-1 rule's unpopularity, DHS is actively seeking ways to modify or rescind it. So when a Los Alamos program manager briefed Washington on the team's successes with ULF MRI, the department came calling. Could ULF MRI be used to screen carry-on liquids at airports? Soon DHS was funding a major program at Los Alamos to develop a technology called MagViz.

That program has occupied the team for the last two years, and the results have been spectacular. MagViz provides MRIs of the scanned liquids and, at the same time, identifies them and classifies them as harmless or "threats," even if the liquids are inside metal cans or metal-foil-lined containers. "This would be impossible for traditional MRI," says Espy. In tests last December at Albuquerque's international airport, the Sunport, MagViz took under a minute to scan the liquids in six containers placed in an airport coin tray 4 inches deep.

Because it uses the weak pulsed electromagnets of ULF MRI, MagViz is also safer than a traditional MRI machine would be in a crowded public environment. The superconducting electromagnet used for traditional MRIs is powerful enough to violently suck up nearby steel objects—sometimes with lethal effect, which is why hospitals carefully control what people wear or carry in and around their MRI facilities.

Scanning in the Boondocks, Etc.

MagViz's pulsed electromagnets are also lighter, smaller, and cheaper than the magnet in a hospital MRI machine, which means MagViz's basic design could be used to build portable, inexpensive MRI machines for use in third-world nations and rural areas, as well as at aid stations on the battlefield. Such a machine could even be used by emergency medical technicians to treat a patient and/or perform triage on the way to the hospital, Kraus says.

Team members are excited by the humanitarian potential of portable MRI and by the fact that ULF MRI could jump-start MEG research. But first they must finish MagViz. DHS doesn't want the technology to be commercialized until it can scan an unopened piece of luggage 1 foot deep in less than 1 minute.

The team is working hard to reach that goal and feels it will succeed in another year or so. When that day comes, air travelers around the globe—especially Espy's kids—will be deeply grateful, although most of them will not know that the odious 3-1-1 rule was finally toppled by brain research. ❖

—Brian Fishbine

Former leader of the SQUID team, Bob Kraus is the deputy program director of the Los Alamos Laboratory Directed Research and Development (LDRD) Office. Michelle Espy (not shown) currently heads the SQUID team.

A Trip to Nuclear North Korea

Siegfried Hecker, co-director of the Center for International Security and Cooperation (CISAC) at Stanford University and former director of Los Alamos National Laboratory, has worked directly with the Russian nuclear laboratories for the last 17 years to secure the vast stockpile of ex-Soviet fissile materials. His current interests include nuclear India, Pakistan, North Korea, and the nuclear aspirations of Iran. Hecker is a member of the Nonproliferation panel of the National Academies' Committee on International Security and Arms Control. He has traveled to North Korea five times, beginning in 2004. Here he discusses his first trip and the way the technical expertise of our national labs opens doors, providing a basis for building cooperation.

1663: Sig, you started combining technical and policy interests in your work with Russian nuclear scientists, but now you're into the North Korean situation.

Hecker: Yes, in the spirit of reducing the nuclear danger, many of us from Los Alamos and the other national labs get involved whenever we're needed, and North Korea is a great example of a situation in which our expertise becomes useful.

1663: So how did you get involved?

Hecker: Through John Lewis, a political science professor at Stanford. John is a China expert and author of *China and the Bomb*. Back in 2002 he had asked me to be a technical expert in CISAC's Five-Nation Project, which brought India and Pakistan together with the U.S., Russia, and China to discuss nuclear proliferation issues.

Then in October 2002, tensions rose between North Korea and the U.S. After accusing the North Koreans of taking the uranium path to the bomb while observing the two countries' 1994 Agreed Framework to freeze the plutonium path, the Bush administration cut off our part of the Agreed Framework. Namely, we stopped delivering heavy fuel oil to North Korea and asked Japan and South Korea to stop construction of two commercial light-water nuclear reactors. The North Korean response was to expel the IAEA (International Atomic Energy Agency) inspectors who had been there since 1994 and say, "We're going to strengthen our deterrent." We knew they'd restarted the 5-megawatt plutonium-producing reactor they'd shut down in 1994—the steam from the cooling tower was visible from space—but we didn't know if they'd also begun reprocessing the reactor's spent-fuel rods, which had been stored in a cooling pond since 1994. Those rods contained weapons-grade plutonium.

In late November 2003, John Lewis, who had been to North Korea nine previous times, got an invitation to come back. Typically he would talk to diplomatic and military people in Pyongyang, the North Korean capital, carrying on what is called a "track-two" dialogue, a nongovernmental, nonofficial dialogue to maintain communications when governments are at loggerheads.

This time the North Koreans wanted John to visit their Yongbyon nuclear center, and John asked me to be his technical expert, the person who would know the difference between a centrifuge for enriching uranium and a reactor for making plutonium. The North Koreans were impressed that a former director of Los Alamos would be visiting their nuclear facilities. And the U.S. State Department also approved my trip. We were scheduled to arrive on January 4, 2004.

Hecker and Ambassador Li Gun, director of the North American Bureau of North Korea's Ministry of Foreign Affairs.

It was an important opportunity. Yongbyon was off limits to almost everyone. In fact, one of the North Korean diplomats who accompanied us said to me at the end of the visit, "I have to thank you, Dr. Hecker. If it weren't for you, I never would have been able to come

here." So this is a place where not even members of the North Korean government are invited to visit.

1663: Was our government interested in what you would learn there?

Hecker: Actually the State Department was concerned that I would be used by the North Koreans for propaganda purposes, that I'd become their mouthpiece.

But Linton Brooks, the head of the NNSA (National Nuclear Security Administration), wanted me to find out what had happened to the 8,000 fuel rods from the North Korean reactor. The cladding on the rods had been corroding in the containment pond, and we had been helping to repackage the highly radioactive fuel into stainless steel canisters backfilled with argon. But in early 2003, with the inspectors gone, the North Koreans could easily have diverted those rods to their reprocessing center without our knowing it by putting them in steel-lined casks and transporting them by truck. They'd only have to make the transfers when our satellites weren't overhead. The reprocessing steps themselves release some krypton-85, and planes can sniff for that stuff, but it's difficult to get definitive information. The bottom line was that we didn't know what they'd done, and people like Linton Brooks wanted me to find out.

1663: Who went with you on the trip?

Hecker: There were five of us who traveled together—John Lewis and I; Jack Pritchard, a former envoy to North Korea; and two congressional staffers who had planned to go separately but decided to join us. One was Keith Luse, the principal staffer for Senator Richard Lugar, then chairman of the Senate Foreign Relations Committee. The other was Frank Januzzi, principal staffer for former Senator Joe Biden, who was the senior minority member of the committee.

The press was also a constant presence. At 7 a.m. on January 2, the day we were to fly to China, ABC News called me at home and said, "We just read in *USA Today* that you're going to North Korea. Is it true?" I did some fast thinking and said, "Well, I'm leaving for China today, and I don't know yet whether I'll be going to North Korea because you never know if you're going to get in." Then I called Linton Brooks to inform him that our trip had been leaked to the press, and he said, "I already talked to the White House and explained that I gave the okay for you to go."

The press kept chasing us down no matter how hard we tried to avoid them. They were at our hotel in China and at the airport before we took off for North Korea. When we arrived, our North Korean hosts laughed and said, "We understand you had a lot of publicity coming out of Beijing." Pressure from the news media continued in North Korea, and finally we agreed to a press conference in the Beijing airport on our return trip. At least 100 reporters were there.

The North Koreans got a big kick out of all the news coverage because in the end that's actually what they wanted, whereas we wanted our trip to be below the radar.

1663: Why did they want the coverage?

Hecker: I think they wanted us to know they were serious about building a deterrent. Their message was, "Look, we've taken out these fuel rods, we've reprocessed the plutonium, and we have the bomb. Now that we have it, you ought to be paying us some respect." And they were quite happy to have that message delivered by a former director of Los Alamos National Laboratory instead of a political scientist.

1663: What kind of greeting did you get?

Hecker: We arrived on Air Koryo, the North Korean airline, at a 1950s-style airport in Pyongyang and went through Soviet-style customs. We were greeted by none other than Ambassador Li Gun, director of the North American Bureau at the North Korean Ministry of Foreign Affairs, so John Lewis immediately knew that this would be an important meeting.

The next day we met with Vice Minister Kim Kye Gwan, who now heads the Six-Party Talks that involve China, South Korea, North Korea, the U.S., the Russian Federation, and Japan. He said, "Because Dr. Hecker is here, we're going to show you everything." Of course that's not what happened. But they did show us a lot.

Statue of Kim Il-sung, founder of North Korea and father of Kim Jong Il.

A day later all of us, along with Ambassador Li Gun and about five others from the North Korean ministry, piled into two Toyota Land Cruisers and rode off to Yongbyon, about 60 miles north of Pyongyang. We arrived at a guest house and were greeted by Ri Hong Sop, the director of the nuclear facility. Director Ri was our host throughout the visit. He carried on the chief technical discussions with me and was very knowledgeable.

1663: What did they show you?

Hecker: In the morning, we saw the production reactor and its control room, where we could see that the reactor definitely was operating. Then they took us to another building, to the pool where the spent-fuel rods were stored. It was a big pool, about 130 feet long and 24 feet deep, with canisters stored row after row and two layers deep in a metal grid. As I looked down into the pool, they said, "Look, the fuel rods are gone," but it looked like only one-third of the grid spaces were empty. About one-third held canisters with their tops missing, and another third had canisters with their tops still on. It was the only place where I was uncomfortable in terms of health and safety. There must have been nasty fission products around. We had dressed up in protective smocks and booties, but there was no radiation barrier.

The 5-magawatt reactor building at Yongbyon.

Then they sat us down in a conference room. Five of us sat on one side of a large table, and five of them sat on the other side. There were always about 10 or so of their people with us. Some were from the General Department of Atomic Energy (the most senior of whom was the head of its International Department), and others were security people. None of them ever spoke.

Director Ri said, "Okay, now we've shown you that the fuel rods are gone." I said, "Well, I can't really say what's in the closed canisters." So the director looked

Hecker visits the Yongbyon reactor control room.

Hecker (center) listens to Chief Engineer Ri at the spent-fuel pool .

at me and said, "Well, why don't you pick one of the closed canisters, and we'll open it up." So we went back to the pool, and I indicated one seven rows up and three columns over. Technicians walking along the edge of the pool used special tools to move the canister to an underwater work station, where they loosened all the bolts and took the lid off. They brought over a light to illuminate the inside of the canister, and all I saw was some crud down at the bottom. So I agreed it was empty. Then at my request, they took me around a barrier to the back of the pool, where I saw empty canisters that seemed to have been hastily discarded in the water.

After lunch, we went to the reprocessing facility, where they said they had reprocessed the fuel, beginning in February 2003 and finishing by June. None of the material was there, but they showed me the hot cells, the sealed chambers where they had presumably removed the plutonium from the rest of the spent fuel. As we walked through, I asked for details about their separation chemistry, which they gave me, and then we reached a door we were not authorized to pass through. It wasn't until 2007 that I learned that the plutonium facility was through that door.

We then went to a nearby conference room, and they said, "Now we've shown you our deterrent, Dr. Hecker." And I said, "Well, no, you really haven't. To have a deterrent, you must have the plutonium, you must make the bomb, and then you must have the means to deliver the bomb. So far you've shown me facilities that are certainly adequate to make the plutonium, but I haven't actually seen any plutonium," to which they said, "Do you want to see our product?" Now, you don't just go get some plutonium at the spur of the moment. They had obviously thought all this through.

In less than 5 minutes, they brought in a red metal box and placed it on the table. Inside was a white wooden box with a lid that they slid off to show me what looked like two glass marmalade jars with screw-on tops. They said that one contained 150 grams of plutonium oxalate (a yellowish greenish powder—a precursor to plutonium metal) and that the other held 200 grams of what they said was plutonium metal—a funnel-shaped piece with a wall about one-eighth of an inch thick. In 1992 they declared that all the plutonium they'd ever made was 62 grams. They showed the IAEA inspectors about 90 grams of plutonium oxide that contained that much plutonium in 1993.

The metal piece in the jar was the right color—dark gray black—and the rough surface suggested that it had been cast in a graphite mold, not machined. Because it was thin walled, I knew right away it was alloyed, ductile plutonium (delta plutonium) and not pure plutonium (alpha plutonium), which is brittle. They let me hold it, after bringing me Playtex kitchen gloves to wear, and when I lifted the jar with the metal piece, it was heavy but only slightly warm. "Director Ri," I said, "it's not very warm." He smiled and said, "Well, Dr. Hecker, that's because the plutonium-240 content is low." Plutonium with a low content of the isotope 240 is good bomb-grade material, and it's also less warm. So I asked, "How low is it?" and Director Ri said, "Well, Dr. Hecker, I'm not authorized to tell you that. Why don't you ask the IAEA. They know."

"But why this shape?" I asked, and the director said, "It's a scrap piece from our most recent casting." They may have cast it especially for me to demonstrate that they can cast something thin walled. That would be proof to me that they have significant plutonium fabrication capability.

Then I asked about the density of the piece. And the director said, "Between 15 and 16," which was an incredibly clever answer because he was telling me it was alloyed (alpha plutonium has a density close to 20) but not giving away how much of the alloying element it contained. A more exact number, like 15.76, would have given me that information. I raised my eyebrows, and he said, "Well, it's alloyed." "But alloyed with what?" I asked. "Well, Dr. Hecker, I'm not authorized to tell you that, but you know something about plutonium. It's the same stuff you use."

1663: This is so amazing.

Hecker: Yes, but not amazing in that he knew what we use. It was amazing for a North Korean to express that sort of sense of humor. At that point, I gave back the jar of "plutonium" and, with the gloves still on and my hands extended, asked Director Ri, "Can I get my hands monitored?" I hadn't seen a single detector of any sort anywhere. He agreed, and in a few minutes, two technicians came back with a little radiation counter.

One technician turned on the electronics, and the counter went brrrr, which is typical if a counter hasn't been used for a long time. My American colleagues stood back, looking worried, and the other technician must have said something like, "Get the plutonium the hell out of here!" So the other technician took away the box with the jars, and the counter settled down. It didn't pick up anything from my gloves, but it was a Geiger counter, which detects gamma rays and not alpha particles, so the lack of a reading didn't necessarily mean the gloves weren't contaminated. I carefully peeled one off, inside out, and used it to peel off the other one. I never did get to check further because there were no other counters to be seen.

1663: Was that the end of your first visit to Yongbyon?

Hecker: Yes. Back in Pyongyang, Ambassador Li Gun said to me, "Well, now you know we have a deterrent." And I repeated my statement that you need three things for the deterrent. I said that I still wasn't sure it was plutonium I saw but that I certainly had seen that they have the people and the facilities to make it.

Among ourselves we immediately started thinking about what we would say to the media waiting for us in Beijing. Keith Luse suggested that Senator Lugar ask me to testify to Congress, and I realized that if I told the media nothing until my congressional testimony, I could make sure the media got it right. I would be presenting my findings in writing. And that's exactly what I did. In Beijing I told the reporters

Director Ri (right front) guides Hecker through the reprocessing facility at Yongbyon.

Fruit vendors at the Tong il Street Market.

A live performance of gymnastics and dancing.

A February 2005 performance at Children's Palace.

that I couldn't tell them anything until after my testimony, and then after the January 21 testimony, I met with them and said, "Look, here's what they told us was there, here's what I found, and here's my assessment."

But back to the night of our visit, at dinner Vice Minister Kim Kye Gwan wanted to know what I thought of Yongbyon. I told him that before giving my testimony in the Senate, I'd say nothing to anyone except him. Then I went through my observations for him: yes, I'm convinced that the fuel rods are gone, and yes, I believe that you've reprocessed the fuel rods. I'm still not absolutely positive that what I saw was plutonium, and even if it was, I couldn't know if it's the plutonium from this reprocessing campaign without testing samples of it. And as far as deterrent goes, I repeated that there are three things needed for a deterrent. "You showed me something credible for the first part but nothing for the other two."

He said, "I had hoped you would be able to say more than that. But I understand that as a scientist you have to say it the way you saw it. When you give testimony, tell them everything you just told me. Don't add or subtract anything." That's what he said, right there at dinner.

In my congressional testimony, I never did say for sure that I'd seen plutonium. I just said it looked like plutonium. By the time I wrote a paper for *The Bridge*, the National Academy of Engineering journal, in May, I was able to say that it was plutonium. By then I had gone back to Los Alamos and met with Howard Menlove, a Los Alamos safeguards expert who's been tracking the North Korean program for 17 years. He used a plutonium-238 source with the equivalent gamma activity of 200 grams of plutonium-239 and the same heat output to duplicate everything I'd seen. At that point I was convinced that the North Koreans had actually shown me plutonium.

In looking back it's clear that the North Koreans were completely prepared. They must have decided that, within a certain envelope, the technical people at Yongbyon should just answer my questions fully and honestly. But they were not to let me get past the edge of that envelope. Also, they had carefully decided what they had to show me to convince me that they have the bomb.

1663: Why were the North Koreans so determined to convince the United States they have the bomb?

Hecker: To them we were, and are, an existential threat. They reasoned, "Saddam Hussein didn't have the bomb, and look what happened to him."

On our trip we met an army general who had been head of the DMZ for 30-some years, and he said outright, "We know you're going to bomb us, and in fact, we believe that you're going to use nuclear weapons on us." Most of the folks I dealt with were from the Ministry of Foreign Affairs, but I would not be surprised if my visit was approved by Kim Jong Il. The North Koreans watch our politics extremely closely. They know how our government works better than a lot of Americans do. They depend on that knowledge for their existence.

1663: So they were disappointed?

Hecker: Yes, but they invited me back the following year. Actually, they never specifically invite you back. John Lewis just goes back and says that we're ready to go back in. So far, I've been there six times, every year starting in 2004. What's important to them is that I told them what I was going to say and then did exactly that. I didn't make up anything. That's what you have to do.

1663: You earned their respect.

Hecker: Yes, and during the second or third visit, they were essentially saying that I was their technical guy for getting nuclear matters communicated to the outside world. In 2005, during an impasse in the denuclearization negotiations, Kim Kye Gwan said, "We're going to have you back to help us try to make progress. And if we make progress in the negotiations, then we're going to have you back because we've got a lot of work to do on denuclearization." That was incredibly candid, and our conversations have continued in that vein.

1663: Have you invited him to this country?

Hecker: Kim Kye Gwan visited the Bay Area in 2007, and there was a whole army of newspeople waiting at the San Francisco airport. John Lewis had scouted all this out and worked with the FBI internally, and they got Kim Gye Gwan from the tarmac into a limousine and ushered him away. The news media followed, but at our destination, the FBI provided protection.

A paper I had written with one of my students was going to appear on the day that Kim Gye Gwan was going from the Bay Area to Washington, D.C. In it we had laid out our best assessment of the nuclear situation in North Korea and concluded that our greatest concern was cooperation between North Korea and Iran—diversion of plutonium or nuclear technologies to Iran. The North Koreans really know uranium metallurgy and know how to make uranium fuel. Well, Iran would love to know the uranium metallurgy because if they're going to build the bomb, they'll go the uranium route.

After checking with my Stanford colleagues, I decided to

A popular food kiosk in Pyongyang.

Students at the University for Foreign Studies in Pyongyang, February 2008.

give Kim Kye Gwan the paper over dinner in a nice Bay Area restaurant. I said, "Vice Minister Kim, you've shown me a lot of things in North Korea, and so I've written a paper with a student of mine to answer the questions that folks in this country ask. We believe the greatest single risk is your cooperating with Iran." He took his glass of red wine, picked it up, and said, "You're right, Dr. Hecker, we should avoid that." Just like that.

Now, this conversation was around the beginning of March 2007, before anyone knew that the North Koreans had built a reactor in Syria, and of course Syria and Iran have many ties.

The North Koreans built this plutonium-producing reactor in the Syrian desert where there were no reprocessing facilities to extract the plutonium and no fabrication facilities to make the fuel. Who was the customer for that plutonium? There are actually news reports now that Iran paid North Korea to build that facility. So my greatest concern today is still a potential collaboration in nuclear and missile technologies between North Korea and Iran.

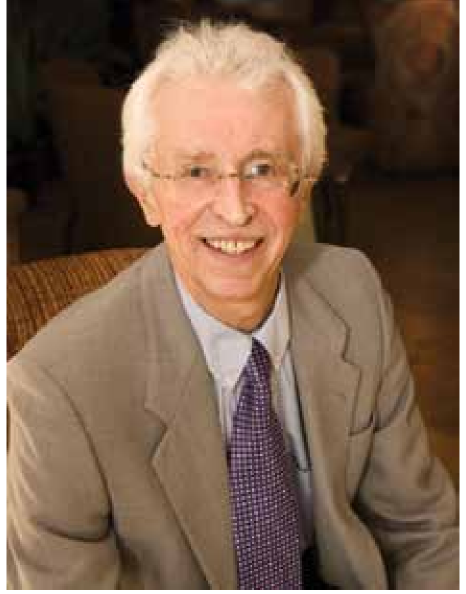
1663: At the time of your conversation, did you think he was being candid with you?

Hecker: No, I know that the North Koreans never tell you the whole story. That's why you have to see them many times in different settings. I always assume that all the North Koreans, even the technical people, are extremely disciplined about getting their country's message across. Whereas the Russians, when I was speaking with them, were more like Americans, speaking their own minds rather than the official line.

Nevertheless, we need to talk to these folks at every opportunity. They already know everything that we do because they have thousands of people studying the Congressional Record. So if we get an opportunity to sit across the dinner table, we learn so much, not anything specifically set aside as secret, but you don't need to know all the secrets.

1663: Did you anticipate the turn of events over the last few months?

Hecker: Over the past 5 years, we've watched the pendulum of power swing back and forth from the Ministry of Foreign Affairs to the military. The military obviously has had the upper hand recently, especially regarding testing. The Ministry of Foreign Affairs is probably against testing because they know it upsets China, and the Chinese are really important to North Korea.



Sig Hecker at a Los Alamos conference in 2009.

If you read the September 19, 2005, Joint Statement on the Denuclearization of the Korean Peninsula, which is the guiding-principles document for the Six-Party Talks, the one thing you take away from the Chinese side is that they want peace and stability on the Korean peninsula. Nuclear weapons, per se, don't bother them that much unless their presence gets the Americans upset enough to do a regime change in North Korea. That would put the Chinese in a very difficult position because they have a mutual defense agreement with North Korea.

In truth, the Chinese were willing to sanction North Korea after their first nuclear test and after their missile tests but in a less severe way than the Americans and Japanese wanted. But their intent is not to bring North Korea to its knees but to bring North Korea back to the diplomatic table, and it did that. On the other hand, the Bush administration, during 2005/2006, wanted to do the opposite.

The Chinese say, "The main difference between you and us, is that we do sanctions in order to have diplomacy. *You* do diplomacy in order to have sanctions."

1663: How do you assess the present situation after the nuclear test of May 25, 2009?

Hecker: We were back in North Korea in February 2009, and that visit foreshadowed what has happened since. This time even the Ministry of Foreign Affairs towed the hard line. They told us they would launch a rocket and halt the disablement of the Yongbyon nuclear complex. They launched the rocket in April, got a slight slap on the hand from the United Nations, and then walked away from all agreements. It was clear to us that they would reprocess more spent fuel and conduct another nuclear test. The May test was more successful than the one in 2006 and, hence, gives them greater confidence in their small arsenal. That arsenal still doesn't represent a direct threat to the U.S., but the potential transfer of nuclear technologies to Iran or other countries does. So, it looks like we are in for another negative cycle. At the end of the February visit, they told me that we had better get used to their being a nuclear power.

1663: You're spending a tremendous amount of time and energy working on nonproliferation issues. Why do you do it?

Hecker: I'm not the only one who does it. Many people from Los Alamos are involved in such work. We feel a great responsibility about nuclear weapons because they started here, and we've developed most of the weapons currently in the U.S. stockpile. Los Alamos is the nuclear Mecca, and people listen to us, all over the world. They respect what we have to say.

I'm reminded of a conversation I had in 2008 with then ex-Director Ri Hong Sop and the head of the International Department in the North Korean Ministry, whom I had met on my first visit. I wanted to talk to them about worker reorientation, what might happen to the employees of the nuclear facilities under a denuclearization regime, and they said the subject was off limits—premature. I said I wanted to give my ideas anyway, so we spent two hours together, and during that time, the head of the International Department remained expressionless, stoic. Later, when we got back to Pyongyong, he stuck out his hand, and said, "We really appreciate what you're trying to do."

That's the sort of impact you can have if you're from the Laboratory. Whether in Kazakhstan or North Korea or India, the name "Los Alamos" opens doors. Everyone can do something to save the world, and if you're from Los Alamos, you can do even more.

1663: Your commitment seems to have a very personal flavor as well.

Hecker: Yes, it does. This country took me in as a teenage kid from Austria and did so much for me. I feel I ought to pay it back. My association with Los Alamos helps me do that. ❖

—*Necia Grant Cooper and Eileen Patterson*

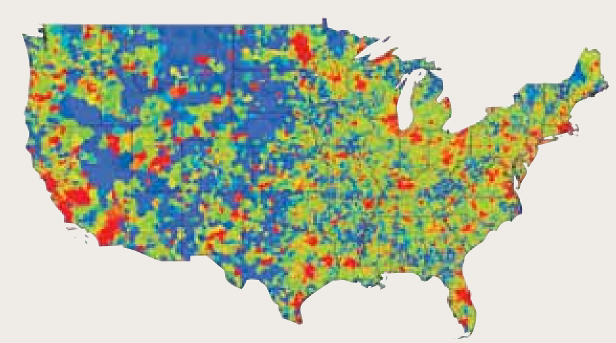
SPOTLIGHT

How to Brake an Epidemic

This spring's swine flu outbreak, which quickly affected several countries, had the news media calling Theoretical Division scientists Tim Germann and Catherine Macken to ask, "How do you slow an epidemic?"

Germann and Macken had used sophisticated supercomputer models to simulate viral transmission through city- and country-size populations while gauging the impact of mitigating strategies. The results, published in the *Proceedings of the National Academy of Sciences USA* (2006 and 2008), showed that school closings, careful hygiene, and antiviral drugs were most effective

Although the simulations dealt with avian flu (the H5N1 subtype) rather than swine flu (H1N1), they were still relevant because, as Germann explains, both forms move similarly through a population. But this year's outbreak has redirected society's attention to H1N1, and the questions about how to fight it will not stop because swine flu may return this coming fall and winter.



Prevalence of influenza cases—low (blue), moderate (green), and high (red)—in a

That possibility has the attention of the Department of Homeland Security (DHS), so at DHS's request, the Laboratory's National Infrastructure Simulation and Analysis Center (NISAC) is completing a 30-day study of H1N1, running new simulations of how the virus may behave if it reappears this year.

In work that began June 8, NISAC scientists are using epidemiological models to track the potential spread of H1N1 through the United States and 214 other countries. With other models, they are evaluating medical supply logistics and the impact of such measures as closing schools, restricting travel, encouraging self-isolation, and using antiviral drugs, vaccines, and protective masks. NISAC is also using models of the U.S. health care system to evaluate the implications of these measures on hospital capacity in an emergency.

Beyond NISAC, many Laboratory staff members have long researched influenza, and Gary Resnick, leader of the Bioscience Division, has proposed that Los Alamos integrate these disparate activities—studies of everything from the virus's genetic/molecular characteristics to its epidemiological behavior—into a Laboratory-wide effort.

With such an approach, says Resnick, Los Alamos could have both a national and an international impact. His proposal will certainly keep the phone ringing.

Measuring the Variable Stars

"Teach me your mood, O patient stars!" wrote poet Ralph Waldo Emerson, but four Los Alamos scientists hope to learn much more, courtesy of NASA's Kepler space telescope, launched March 6. Joyce A. Guzik, Paul Bradley, Arthur N. Cox, and Kim Simmons are part of the multinational Kepler Asteroseismic Science Consortium, which will analyze data from Kepler over the next 3.5 years.

Kepler will measure the light from more than 100,000 stars in part of the Milky Way, mainly to find out if some have Earth-size planets. Such "exoplanets" (outside our solar system) would be found through the "transit" method—detection of light variations caused by an orbiting planet's passage in front of the star, as seen from the spacecraft.

The Los Alamos scientists will focus on the stars themselves. Guzik, Bradley, and Cox are on working groups that will do computer modeling and make follow-up observations of stars that swell and shrink, brighten and dim because of internal changes. Simmons will lend his expertise in applying new modeling codes.

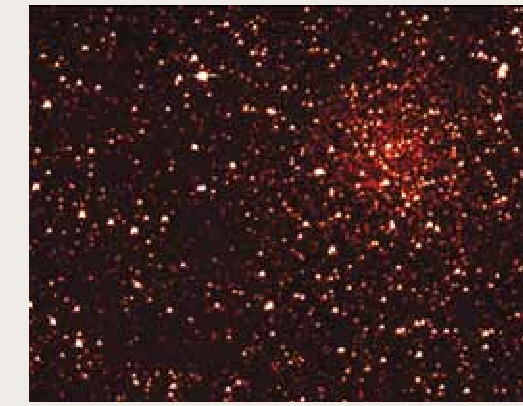


Photo taken April 8 of a small portion of Kepler's field of view, showing stars in the constellation Lyra.

Additionally, as part of the Kepler Guest Observer program, Guzik will observe 14 stars that, in temperature and mass, are on the cusp between two types of variable stars, delta Scuti and gamma Doradus, which pulsate over different time scales: a few hours (delta Scuti) because of the ionization of helium near the surface and 1 to 3 days (gamma Doradus) because, as the Los Alamos team has proposed, of emergent radiation being blocked at the bottom of deep convection zones.

"A 'hybrid' star, having both time scales, should be difficult to find," says Guzik. The delta Scuti stars may not have deep-enough convection zones to produce days-long pulsations, while most gamma Doradus stars should have such efficient convection that helium ionization can't cause short-term variations. Nevertheless, some recent publications have reported observations of up to four potentially hybrid stars.

Guzik wants to find such stars for herself. If they exist, they will be particularly useful for probing the stars' interior structure and testing stellar pulsation theories.

—*Eileen Patterson*

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Frank Addessio of the Theoretical Division enjoys an early summer ride along the Valles Caldera National Preserve, west of Los Alamos.

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