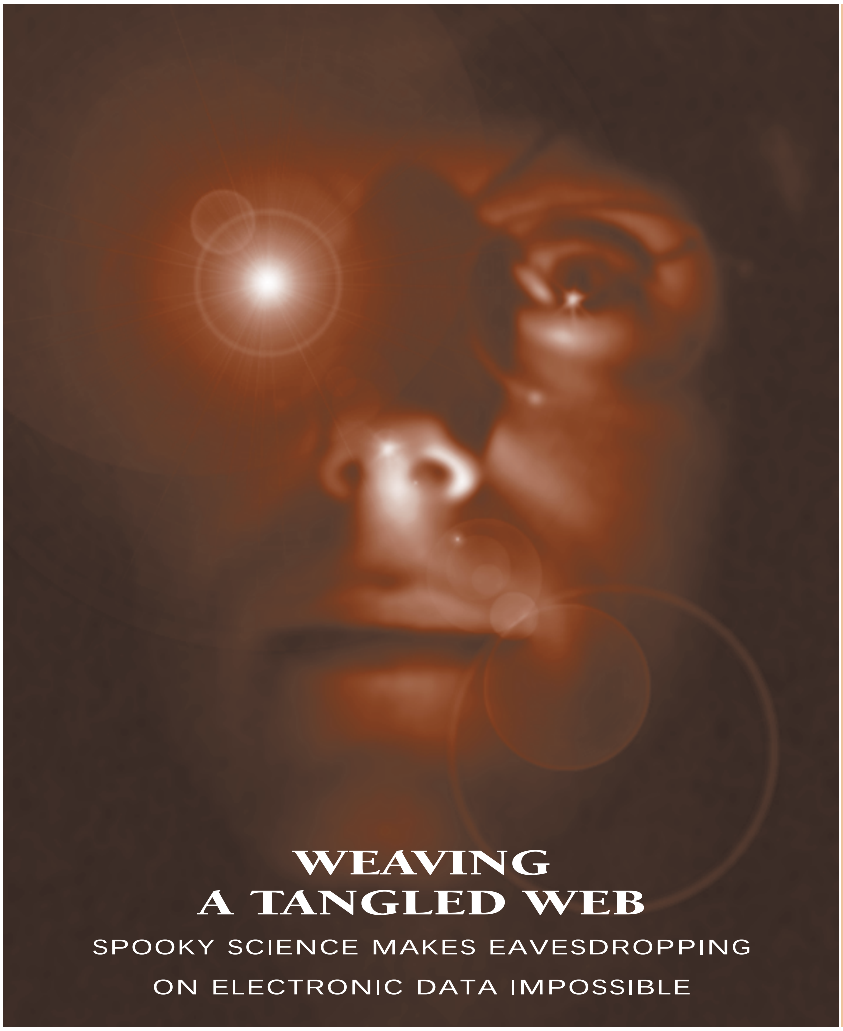
NOVEMBER ISSUE 2000

LOS ALAMOS NATIONAL LABORATORY
WHERE SCIENCE MAKES A DIFFERENCE

DATELINE LOS ALAMOS

U.S. DEPARTMENT OF ENERGY
UNIVERSITY OF CALIFORNIA



The first practical application of the new field of quantum information has been quantum cryptography, which allows for completely secure encryption of electronic information, based on the laws of quantum physics. Recent demonstrations at Los Alamos using entangled photons for quantum cryptography have made this technique even more promising for safeguarding and sending data.

Classical physics describes “big” objects, like baseballs, airplanes and planets. In this realm, our normal intuitions are fairly trustworthy. But scientists have known for three-quarters of a century

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that classical physics is only an approximation of a more correct, if more unfamiliar, picture of reality, described by quantum physics.

In this bizarre realm, particles have no precise location, and can exist in more than one place at a time; watching a system — measuring it — can alter the way it behaves; and distantly separated particles can share nonlocal correlations that Albert Einstein called "spooky action at a distance."

This last feature, known as "quantum entanglement," was described by Erwin Schrödinger, one of the founding fathers of quantum physics, as "the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought."

Now a group led by quantum physicist Paul Kwiat at Los Alamos has come up with a much-improved method for creating such entangled states and using them to implement a version of quantum cryptography. The correlated particles in this case are photons – the basic particles of light — engineered in such a way that they always have the same polarization — the direction in which the electric field vibrates.

A simplified, classical analogy of the concept of entangled photons would be two coins that are each equally likely to give heads or tails, but which somehow always give the identical result, even if they are very far apart and flipped by different people. For encryption purposes these heads and

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LOS ALAMOS NATIONAL LABORATORY, AN AFFIRMATIVE ACTION / EQUAL OPPORTUNITY EMPLOYER, IS OPERATED BY THE UNIVERSITY OF CALIFORNIA FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. W-7405-ENG-36

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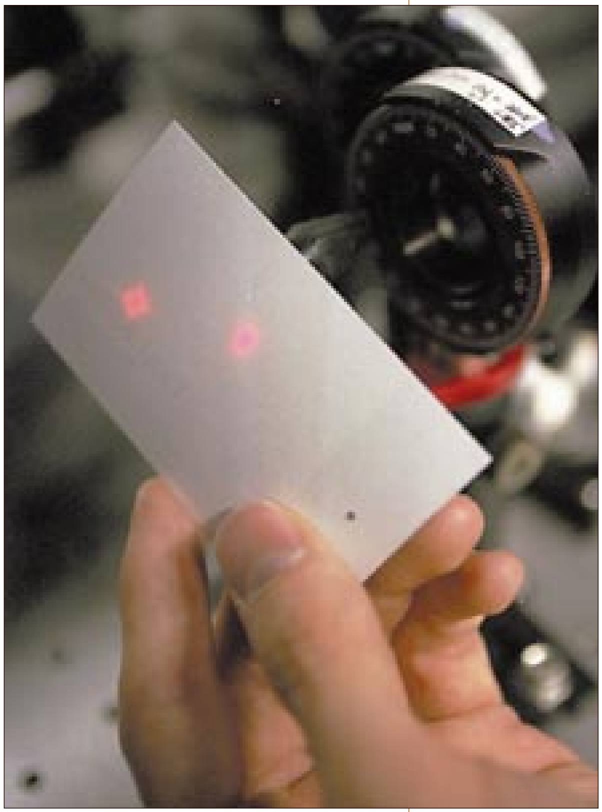
tails represent the 0's and 1's that make up a cryptographic key that two people might use to lock or unlock encrypted messages sent via normal communication channels.



The two laser spots on the card indicate where the magical entangled photons would be going to "Alice" and "Bob."

Quantum cryptographers have already employed weak pulses of light, which are dimmed until they contain less than one photon on average, to send quantum keys. Just last year, Los Alamos researchers led by Kwiat's colleague Richard Hughes set a world record when they sent such a single-photon quantum key over 30 miles of underground optical fiber at Los Alamos.

While this distance would be enough to connect closely spaced government offices or local branches of a bank, at greater distances the signal loss in optical fiber increases since some individual photons are more likely to be absorbed. And unlike conventional signals, the quantum transmissions cannot be amplified without completely distorting them. Therefore, to access longer distances, researchers here developed free-space quantum cryptography, which allows codes to be sent through the air.

Recently Hughes' group demonstrated free-space code transmissions over a mile, with the eventual goal of earth-to-satellite communication. This free-space transmission set a world record.

A potential drawback to the weak-pulse method is that occasionally the pulses contain more than one photon, which a technologically advanced eavesdropper might be able to use to gain information about the secret key by skimming off the information-bearing extraneous photons. Using entangled photons, whose pair-like nature allows the receivers to more easily account for any missing photons, reduces this problem.

Artur Ekert of Oxford University was the first person to suggest using entangled photons for quantum cryptography, in the early 1990s, but Ekert's process had never been demonstrated until it was accomplished

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simultaneously last year by Kwiat's group and collaborators led by Anton Zeilinger of Austria.

In the Los Alamos implementation of Ekert's cryptography protocol, researchers used a pair of special optical crystals placed in a beam of ultraviolet light from a laser. Occasionally an ultraviolet photon from the laser is converted into two infrared photons. These daughter photons share the almost magical correlations of entanglement.

The polarization-entangled photons are then transmitted to the communicating parties — historically called "Alice" and "Bob" by cryptographers — to create a random string of 0's and 1's known only to them. This string of numbers becomes the quantum cryptographic key. Because the photons cannot be intercepted without tipping off Alice and Bob, the key is secure, as is any data subsequently encrypted with it.

The eavesdropper, called "Eve," cannot simply intercept a photon going to Bob, because then Bob will not receive it, and it won't be used as part of the key. The best strategy an eavesdropper can hope to have is to make a measurement on the photon as it flies by.

However, according to the laws of quantum mechanics, Eve's activities will necessarily produce an irreversible change in the fragile quantum states — a collapse of the quantum wave function — when they arrive at Bob. These changes, in turn, lead to an unusually high error rate in the comparison of Alice's and Bob's results, sending a clear message that there is an eavesdropper.

To test the Ekert protocol against eavesdropping, Los Alamos researchers simulated a potential eavesdropper between the source and Bob by passing the entangled photons through a polarization filter and then performing precise measurements to detect disturbances in the transmissions. In every experiment the transmission errors produced by the filter exposed the presence of an eavesdropper, even when researchers used only minimally invasive eavesdropping techniques.

By combining the correlated-photon work with the long-distance free-space cryptography efforts, we may someday have entangled particles flying to satellites and circling the globe as they pass secrets safely between parties and weave the tangled web of quantum cryptography even tighter. "Spooky," indeed.

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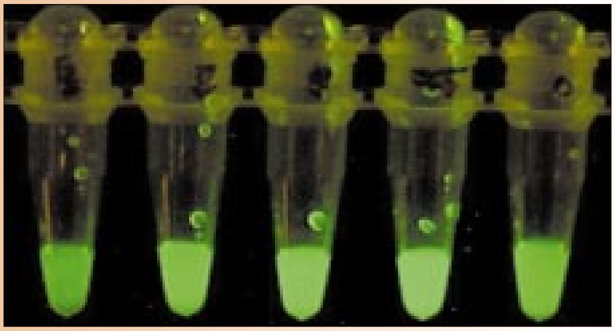
LOS ALAMOS RECEIVES NIH GRANT

$28.5 MILLION TO HELP FIGHT TUBERCULOSIS

Los Alamos will lead an international consortium to perform research that someday may help eradicate tuberculosis under a $28.5 million grant from the National Institutes of Health. The five-year grant for the TB Structural Genomics Consortium was awarded by the NIH's National Institute of General Medical Sciences and National Institute of Allergy and Infectious Diseases. Los Alamos will receive the grant, distribute the funds and coordinate the work among all the institutions.



These tubes of cell-free extracts of bacterial proteins fused to fluorescent protein illustrate the technology developed to engineer target proteins to fold better, be more soluble and amenable to study by X-ray crystallography. Determining the structure of tuberculosis proteins will enable researchers to better understand how they work and allow them to design drugs and vaccines.

Tuberculosis is the world's number-one infectious disease, claiming about two million lives each year. About one-third of all people in the world are infected with TB, and, in fact, many people who die of complications caused by AIDS actually die from TB. Most infected people do not get the disease as long as their immune systems are strong, but Mycobacterium tuberculosis, which causes the disease, takes advantage of weakened immune systems and grows into full-blown disease in about 5 to 10 percent of infected people.

The new consortium's goal is to determine the structures and shapes of approximately 400 functional proteins from Mycobacterium tuberculosis. By determining the structures and shapes of these proteins, researchers can determine how M. tuberculosis works and design drugs that bind to the proteins and inhibit their activity, killing the organism, and design vaccines that protect against the disease.

All information obtained from the project will be placed online at http://www.doe-mbi.ucla.edu/TB for other researchers and companies to use for free.

Consortium members Lawrence Livermore National Laboratory; University of California, Los Angeles; University of California, Berkeley; Texas A&M University; and the Albert Einstein School of Medicine will receive direct funding from Los Alamos.

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DATELINE: LOS ALAMOS

NEW FACILITY WILL ENSURE STEADY SUPPLY OF MEDICAL ISOTOPES

CONSTRUCTION UNDER WAY AT LOS ALAMOS

Artist's conception of a section of the Isotope Production Facility. The targets will be irradiated underground, then raised about 40 feet to ground level via a specially designed transport system and placed in shipping containers. The targets then will be shipped to another technical area for isotope processing and recovery.

To ensure that U.S. researchers have a steady supply of medical isotopes, Los Alamos is building a new Isotope Production Facility to replace an existing facility. Construction of the $16.5 million IPF began earlier this year, and the project should be completed in June 2002.

Once operational, the IPF will support eight months of isotope production annually. Combining its output with similar isotope production capabilities at Brookhaven National Laboratory in New York will ensure doctors and researchers an adequate, year-round supply of accelerator-produced medical isotopes.

U.S. researchers use medical isotopes to perform 36,000 diagnostic procedures daily and 50,000 therapies annually, along with 100 million lab tests annually. The Department of Energy's Office of Isotopes for Medicine and Sciences estimates the annual value of these procedures to the medical industry at between $7 billion and $10 billion.

Los Alamos' Neutron Science Center Division and Chemistry Division have produced some of these medical isotopes, such as strontium-82 and germanium-68, for more than 20 years under DOE's Isotope Production and Distribution Program.

Need for isotopes didn't stop during Cerro Grande Fire

There's no such thing as a good time for anything as devastating as the Cerro Grande Fire to occur, but its timing created potential crises for two companies and their clients and patients. Fortunately, Los Alamos' Chemistry Division prevented those crises from coming to fruition.

The first company, CTI Inc. in Knoxville, Tenn., provides products and services for positron emission tomography, or PET, scanners used primarily for diagnosing and treating cancer, epilepsy, coronary artery disease and other ailments. Los Alamos is the company's sole supplier of germanium-68 to manufacture the scanners' calibration sources. But CTI had exhausted its current supply at about the time the fire broke out last May, shutting down the Laboratory for two weeks.

continued on next page

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"The program is an essential element of the nation's overall health-care system, and Los Alamos' ability to deliver key medical isotopes to customers is a critical part of the DOE program," said Carol Burns, deputy director for Los Alamos' Chemistry Division.

Researchers use radioisotopes in clinical trials; to diagnose and treat diseases such as cancer, epilepsy and coronary artery disease; to perform research and development of new pharmaceuticals; and in other medical research and treatment applications. Millions of patients would be adversely affected if medical isotopes weren't available.

In the past, targets were irradiated with LANSCE's half-mile-long linear accelerator, then shipped to a Chemistry Division facility for processing. Los Alamos processes irradiated targets obtained from other sources worldwide as well.

Needed upgrades to LANSCE's facility and accelerator eventually will make it impossible for Los Alamos to continue using the former isotope production facility.

To avoid interruption of the nation's medical isotope supply and continue serving this important mission, the DOE's Office of Nuclear Energy funded construction of the new IPF, which will not only replace the former facility but will significantly upgrade the isotope production capability at LANSCE.

The new facility will irradiate a wide range of materials underground, including rubidium chloride, gallium and other targets, using a portion of the LANSCE proton beam.

The irradiated targets will be raised to ground level via a specially designed transport system and placed in certified shipping containers. Los Alamos then will ship the targets to another Lab area for isotope processing and recovery via chemical processes.

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The Laboratory obviously could not access the processed Ge-68 stored in its vault and CTI could not find a substitute source. Without operational scanners, dozens of patients potentially could be denied adequate diagnosis and treatment.

An emergency request was put in to enter the Hot Cell Facility where the radioisotope is produced and on May 18 four employees were allowed into the building for an hour-and-a-half to gather up six weeks' worth of Ge-68 and ship it to CTI.

The second potential crisis involved health and personal care giant Bristol-Myers Squibb, which gets a monthly supply of strontium-82 from Los Alamos for use in a biomedical generator called CardioGen. Unlike the CTI case, however, the Laboratory did not have this radioisotope in stock, much less the irradiated target needed to process and extract it.

Los Alamos gets its irradiated targets from LANSCE Division and other institutions worldwide. For this particular shipment of strontium-82, the targets came from South Africa and Russia, and they already had been shipped to Los Alamos.

But no one could accept the shipment because of the Lab closure. And, if Los Alamos couldn't accept the shipment, the targets would be returned to South Africa and Russia, which would have resulted in an even later delivery date.

Fortunately, it all worked out. The Hot Cell Facility reopened in time and the company received the shipment May 30, right on schedule.

Both companies were grateful. In fact, John Hoffman, director of Quality, Regulatory Affairs and Sources with CTI, wrote C Division to thank those who contributed to the effort.

"We were going to have to tell hospitals that they would have to wait to put their scanners in use. Because of your efforts, that won't be necessary... Los Alamos National Laboratory is truly a national treasure," Hoffman wrote.

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LOS ALAMOS SPECTROMETERS PART OF "CLUSTER" MISSION

SATELLITE CONSTELLATION WILL EXAMINE HOW THE SUN'S PARTICLES INTERACT WITH EARTH'S MAGNETIC FIELD

The second Cluster pair, Tango and Rumba, are placed on the Fregat assembly.

Image courtesy of the European Space Agency

Imaging spectrometers developed at Los Alamos are among the science tools aboard the four-satellite Cluster II mission. Together, the four satellites dancing in a tetrahedral formation during their two-year mission will give three-dimensional views of the near-Earth particle, field and plasma environments.

The first two satellites, Salsa and Samba, were launched in July from the Baikonur Cosmodrome in Kazakstan. The satellites, a project of the European Space Agency, were launched on a Soyuz-Fregat launch vehicle provided by the French-Russian consortium, Starsem. Another pair of identical satellites, Tango and Rumba, were launched several weeks later.

The four satellites are orbiting in an elliptical polar orbit. The first two, Samba and Salsa have been turned on and are measuring the fluxes of energetic electrons encountered at their locations. Tango and Rumba are in the process of being turned on.

When fully commissioned, the constellation will examine how particles from the sun interact with Earth's magnetic field, observing magnetic and electrical interactions through direct measurements of the fields and particles trapped in Earth's magnetic field. For the first time, small-scale fluctuations in interplanetary space will be measured between each of the four spacecraft as they orbit Earth.

Los Alamos Cluster team leader Richard Belian and his colleagues have invested years in the research and development of their equipment.

Their current success is all the more poignant in the wake of the disastrous failure of the Arianne IV rocket during the original launch of the Cluster I mission in 1996.

The instrument packages aboard the satellites will gather information on the magnetic storms, electric currents and particle accelerations that take place in the space surrounding Earth. These features produce events such as the aurorae in the polar regions, and under extreme conditions can create power outages, breakdowns in telecommunication systems, satellite malfunctions and perhaps even changes in climate.

“The Cluster formation will remove, for the first time, temporal and spatial ambiguities in the interpretation of magnetospheric data,” said Belian. “Until now, with single or even double satellites, we have been unable to determine whether an event, say an enhancement of the energetic-particle flux, was due to the passage of a structure (a spatial event), or whether the flux simply changed (a temporal event). This aspect pertains to every kind of measurement that Cluster will make.”

The Los Alamos spectrometer was built as part of the instrument called RAPID (Research with Adaptive Particle Imaging Detectors). RAPID measures very energetic electrons and ions, which need separate instruments, and Los Alamos was tasked with building the electron part — the Imaging Electron Spectrometer.

Up until now most space physics missions have been based on single satellites that can only measure a single point in space and then infer the conditions in the surrounding area. This is the first mission designed to use multiple satellites to simultaneously measure the conditions across an entire region of space. That should give researchers their first good look at the three-dimensional structure of the magnetosphere and how charged particles and energy flow through Earth’s space environment.

Work on such projects not only advances space science in general, but applies to the Laboratory’s nonproliferation mission as well. The instrumentation itself in some cases is applicable as new tools for detecting proliferation efforts, and the scientists develop new expertise that can be applied to threat-reduction challenges.

Work on both the Cluster I and Cluster II missions was jointly sponsored by the European Space Agency and NASA.

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DATELINE: LOS ALAMOS

NEW RADIATION-TOLERANT MATERIALS SHOW PROMISE FOR NUCLEAR WASTE STORAGE

RESEARCH PUBLISHED IN 'SCIENCE'

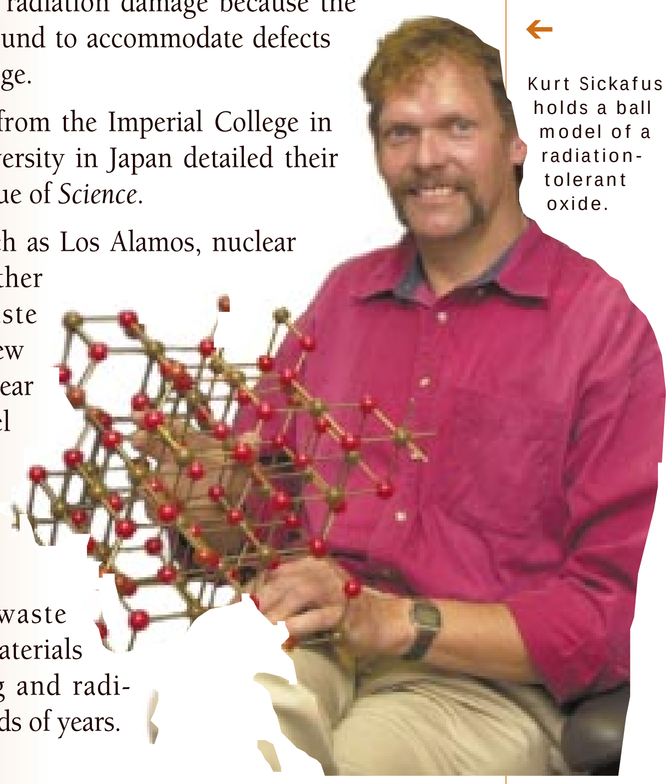
A continual issue in the handling of nuclear waste is long-term storage, because internal radiation can cause radioactive host materials to swell or crack, making the stored waste unstable and susceptible to leaching.

Now, a team led by Los Alamos' Kurt Sickafus has demonstrated that certain ceramic materials with structures similar to fluorite crystals hold up well to radiation damage because the materials' atoms shift around to accommodate defects caused by radiation damage.

Sickafus and colleagues from the Imperial College in London and Osaka University in Japan detailed their research in the Aug. 4 issue of *Science*.

National laboratories such as Los Alamos, nuclear reactor operators and other creators of nuclear waste could benefit from the new findings. High-level nuclear waste, such as spent fuel from nuclear reactors, is currently stored in containers designed to last 100 years.

But storing nuclear waste requires containment materials that can resist leaching and radiation damage for thousands of years.



Kurt Sickafus holds a ball model of a radiation-tolerant oxide.

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Sickafus says fluorite-type ceramic materials show promise as safe, radiation-resistant materials and should be further developed for containing nuclear wastes.

For years researchers have been looking for better storage materials for storing high-level radioactive waste. Recent research has centered on a class of materials that are part of a larger group of ceramics called complex oxides.

To test their theory, researchers tested pyrochlore and fluorite structures. Pyrochlore is a brownish-black mineral oxide found in granitic rocks and pegmatites, coarse-grained igneous rocks. Fluorite is a bluish-green mineral used in the smelting of iron and in the ceramic and chemical industry.

The researchers tested several combinations and discovered that radiation resistance increases when relatively large metallic ions such as zirconium are included in the compound's atomic structure.

"Preliminary radiation damage experiments substantiate the prediction that fluorites are inherently more radiation resistant than pyrochlores. These results may permit the chemical durability and radiation tolerance of potential hosts for actinides and radioactive wastes to be tailored," the researchers wrote.

Funding for the work was provided by the Department of Energy's Office of Basic Energy Sciences.

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DATELINE FOLLOWUP

LIBS PASSES ANOTHER NASA TEST

A Los Alamos multi-award-winning technology discussed in the May 1999 issue of *Dateline: Los Alamos* has passed another NASA test to determine its suitability for use in future space missions, including a planned mission to Mars.


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LASER PROBES PLANETARY SURFACES

PROTOTYPE INSTRUMENT CAN ANALYZE SAMPLES FROM A DISTANCE

Zap! With a spark from a small laser, researchers can analyze soils and rocks from more than 50 feet away. Los Alamos is developing a prototype instrument for planetary exploration that combines a laser the size of a small flashlight, optics and a spectral analyzer into a compact, low-power package.

The laser can be fired every five seconds and within three minutes sends enough data for an accurate measurement. "The scientific returns for planetary exploration increase dramatically when you can conduct such rapid analyses," said David Cremers, Los Alamos principal investigator on the NASA-funded development effort.

Cremers' laser-induced breakdown spectroscopy technology — or LIBS — has been under development at Los Alamos for 18 years, but up to now has been applied to Earth-based purposes. It has been field tested

An artist's conception of a Martian rover equipped with LIBS analyzing a sample. The laser beam is projected from the mast on the rover and the light is collected back along the same path.

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Laser-induced breakdown spectroscopy, or LIBS, uses a laser that strikes and evaporates soil, air or water samples to form a hot microplasma and excite the samples' atoms so they emit light. A small telescope mounted on top of the laser picks up the light and feeds it to a spectrometer, which analyzes the samples' unique spectral signatures to determine their compositions. The technique even works on rocks with weathered veneer. Since its initial development back in 1981, the technology has been licensed several times for various terrestrial applications.

The test took place just outside Black Rock Summit in the Nevada desert. Fitted atop a NASA remote rover, the prototype LIBS instrument fired its laser at several rock types — basalt, tuff, limestone and others — from about seven to eight feet away. Test results, later confirmed at the University of Washington, showed that LIBS accurately identified the rocks' elemental compositions. Los Alamos researchers presented the field test results this past summer at a NASA meeting on Concepts and Approaches for Mars Exploration in Houston.

The prototype LIBS used for the test is 14 inches long and 3 1/2 inches wide and weighs a little more than 2 pounds. Researchers are working to further reduce its size, weight and power requirements and increase its ruggedness and laser firing distance. The near-term goal for firing distance in the open environment is at least 11 yards. In laboratory tests, LIBS has successfully obtained elemental rock compositions from distances as far away as 20 yards.

Future NASA tests for LIBS and other techniques under consideration are scheduled for next summer.

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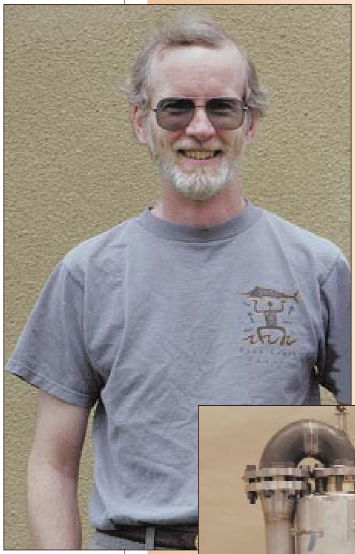
PEOPLE IN THE NEWS

GREG SWIFT HONORED BY ACOUSTICAL SOCIETY OF AMERICA

Los Alamos physicist Greg Swift will receive the Silver Medal in Physical Acoustics from the Acoustical Society of America at a meeting next month of the society. The medal is presented for contributions to the advancement of science, engineering or human welfare through the application of acoustic principles or through research accomplishments in acoustics. The Silver Medal in Physical Acoustics has been awarded to only eight other people during the award's 25-year history.



Greg Swift and the Acoustic Stirling Heat Engine (inset).

Last year, Swift, of the Condensed Matter and Thermal Physics Group, along with Chris Espinoza and Scott Backhaus of the same group, received an R&D 100 Award from R&D Magazine for their Acoustic Stirling Heat Engine.

The Acoustic Stirling Heat Engine consists of a long, baseball-bat-shaped resonator with an oval "handle" on one end. Filled with compressed helium and constructed of inexpensive steel pipe, the device creates acoustic energy in the form of sound waves by applying heat to the compressed helium contained within the system through a heat exchanger located on the handle.

The intense acoustic energy can be used directly in acoustically powered refrigerators or to generate electricity. Because the acoustic Stirling heat engine contains no moving parts and is constructed of common materials, it requires little or no maintenance and can be manufactured inexpensively.

Swift has been at Los Alamos since 1981, when he arrived as a postdoctoral fellow.

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SCIENCE FOR THE 21ST CENTURY

LIGHTNING

RESEARCH INTO THE ELECTRODYNAMICS, ELECTRIC FIELDS AND HIGH-FREQUENCY RADIO SIGNALS ASSOCIATED WITH LIGHTNING

Striking Earth 100 times every second, lightning may be not only the most spectacular weather phenomenon we know, but the most familiar as well. Lightning bolts can go from cloud to ground, within and between clouds or from ground to cloud. The bolts can carry electrical charges of 100 million volts and can be deadly. Approximately 100 people are killed by lightning in the United States every year, hundreds more are seriously injured and property damage amounts to millions of dollars.

The FORTE satellite (left), launched in 1997 to study optical and radio frequency signals, also is being used by researchers to study lightning. To date it has collected data on more than three million lightning discharges.

In the early 1990s researchers recorded the first visual proof of a

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strange and beautiful electrical phenomenon, upward lightning — so-called jets, sprites and elves — that, in slow-motion video, seemed to puff vividly colored light upward high above the tops of thunderstorms in the stratosphere. Los Alamos scientists plan to use high-altitude scientific balloons to further the research of this mysterious phenomenon.

The primary lightning research tool used by Los Alamos is FORTE, a satellite launched in 1997 to study optical and radio frequency signals. FORTE's capabilities also make it an outstanding platform for the study of lightning. To date FORTE has compiled data on more than three million individual lightning discharges.

Los Alamos coordinates optical observation of lightning with radio-frequency observations, continues compiling extensive statistical data on a wide variety of weather and electric field conditions associated with lightning and is developing and expanding a ground-based electric field change detection system, called the Sferic Array.

Electric field changes are used to explore the mechanism thought to be at the heart of lightning. Strong bipolar impulses measured inside clouds reveal these emissions as a function of altitude, total charge produced in a thunderstorm, charge density, charge separation and charging rate. These and other factors must be understood together to build a complete picture of lightning.

Changes in the electric field of clouds also give rise to CIDs, or compact intercloud discharges, which are detected by the Sferic Array. These allow scientists to examine the characteristics of thunderstorms that are prolific producers of CIDs and compare them to thunderstorms that produce few, if any, CIDs and correlate that to the amount of lightning produced by a given thunderstorm. This information can begin the process of understanding why one thunderstorm produces a vast amount of lightning while another yields no lightning at all.

Using the optical and radio-frequency detectors on FORTE in concert with ground-based detection and characterization technologies, scientists are building the ability to pinpoint the location of lightning strikes and correlate the electrodynamics and atmospheric conditions that are present with lightning.

Researchers hope to one day build a large enough data set so that an accurate predictive model can be created to provide a space-based global early warning capability that can help protect people during severe weather anywhere on Earth.

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BRIEFLY ...

LOS ALAMOS SCIENTIST LARRY WINTER HAS BEEN APPOINTED SCIENCE ADVISER TO NEW MEXICO GOV. GARY JOHNSON. In his role as science adviser to the governor, Winter provides advice and assistance to the governor and state government on general science and technology matters. Winter said one of his first efforts will be to help the State Engineer's Office to become a partner in the National Science Foundation's Science and Technology Center. The Laboratory already is a major partner in a $16 million, five-year project focusing on sustainability of water resources in semi-arid regions such as the southwestern United States. Winter also is organizing a workshop on carbon sequestration — scientific efforts to isolate and dispose of carbon dioxide before it ever reaches the air, and also to directly remove carbon dioxide from the atmosphere — this fall at Los Alamos for state and university employees, and personnel from New Mexico's national laboratories.

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DATELINE LOS ALAMOS

A Monthly Publication of the Public Affairs Office of Los Alamos National Laboratory

Nonprofit Organization
U.S. Postage Paid
Albuquerque, NM
Permit No.532

LALP 00-1-11

Los Alamos NATIONAL LABORATORY