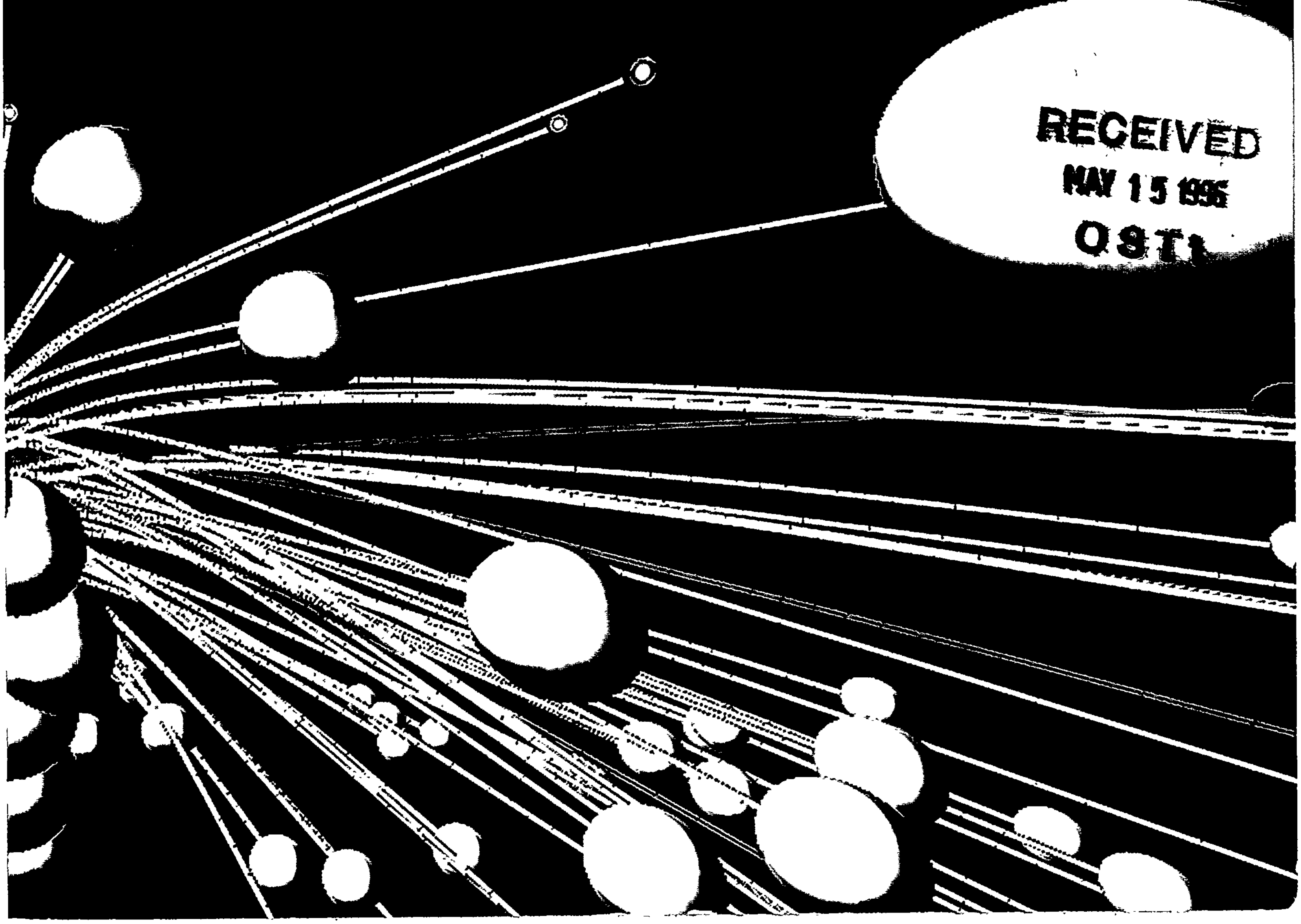
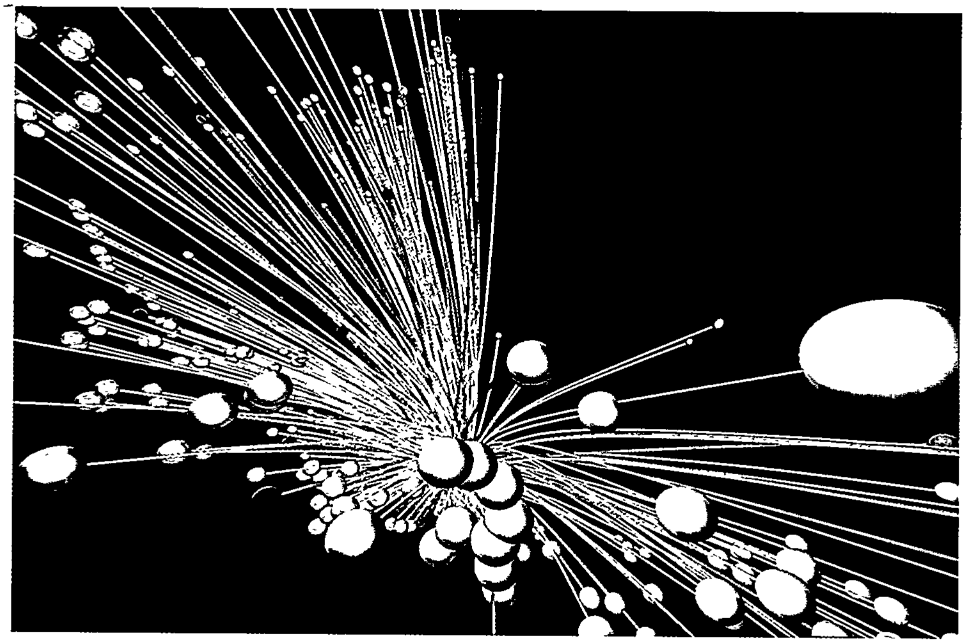
FEBRUARY 1995

Sandia Technology

ENGINEERING & SCIENCE ACCOMPLISHMENTS

Sandia National Laboratories





On the cover:

A simulation of cometary debris from the collision of Shoemaker-Levy 9 with Jupiter in July 1994. Sandia's CTH computer codes accurately predicted the ejection of debris from Jupiter's atmosphere. The MUSE interactive virtual environment created this representation of the back-blast from CTH information.

This work was performed at Sandia National Laboratories, supported by the U.S. Department of Energy under contract DE-AC04-94AL85000.

A note on acronyms

In an effort to make this document easy to read, acronyms are generally avoided. When unfamiliar acronyms must be used, they are explained in the proximate text. Acronyms that occur freely in popular or news publications—acronyms such as DOE, DoD, EPA, and NASA—occur in the document without explanation.

President's message

Sandia National Laboratories is one of the Department of Energy's primary research and development laboratories. Our essential mission is to support the national interests of the United States in defense, energy, and the environment. Managed by Martin Marietta Corporation for DOE, Sandia focuses its resources on problems of national interest that require the integration of science and technology for their solution.

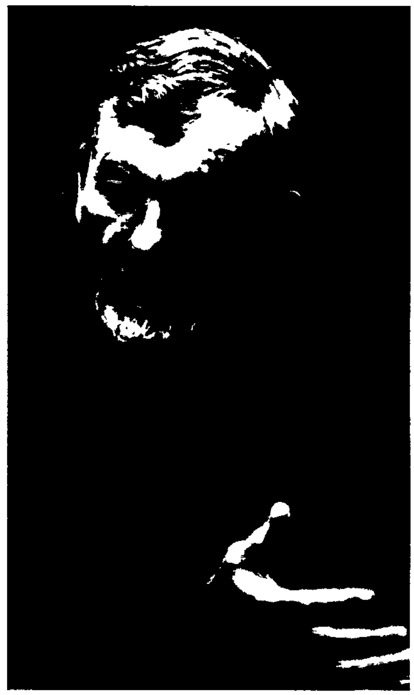
We all hope that this period of sweeping alterations in international affairs will result in a successful transition from the Cold War to a period of sustainable global security and prosperity. In the meantime, our nation's interests are best served by continued commitment to Sandia's traditional responsibilities. Nonetheless, as momentous developments are reshaping the world, Sandia is also changing. From its beginnings as a closed operation concentrating on classified defense programs, Sandia has become a more accessible resource that focuses on research and development partnerships with industry and universities as a way to ensure continued success in DOE's evolving core mission areas of nuclear weapons, energy, environment, and the basic sciences. Through these collaborative efforts, Sandia and its partners are also benefiting the economic competitiveness of our nation.

Sandia places a special emphasis on working with small businesses as both technology transfer partners and suppliers of goods and services. We are also reaching out to the larger community surrounding Sandia, striving to provide technological solutions and accurate information to meet community needs. We believe that the dialogue we are creating will benefit Sandia, the community, and the nation.

This annual review of our accomplishments gives evidence of the growing breadth and depth of our activities. Our accomplishments are deeply rooted in our scientific and technological foundations. Our fundamental technical core competencies are best described as "science-based engineering." As always, our strength derives from the dedication and skills of our people, whose work is represented here. I believe that, as you read this publication, you will agree that Sandia has become a significant part of our nation's research and development infrastructure.

Our goal is to render "Exceptional Service in the National Interest" by returning maximum value on the investment in the Labs. As you review this document, look for new ways in which Sandia can contribute to the solution of problems facing our nation. Contact the technical contributors listed in each article for further information.

Al Narath



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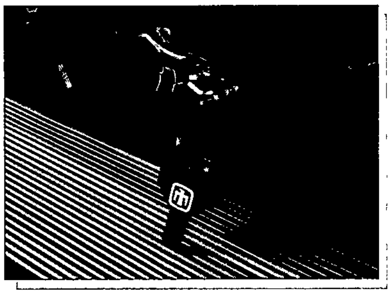

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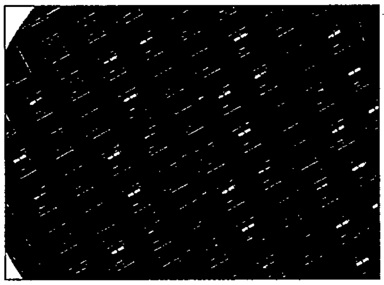

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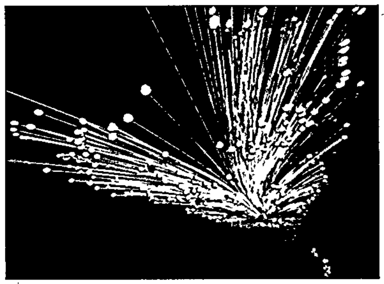

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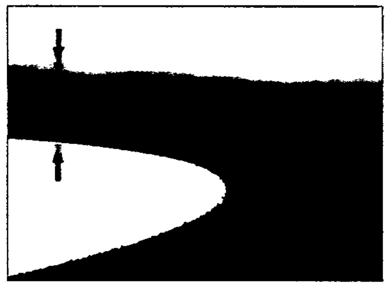

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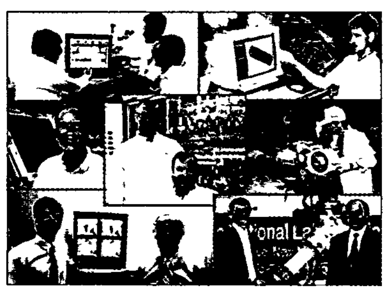
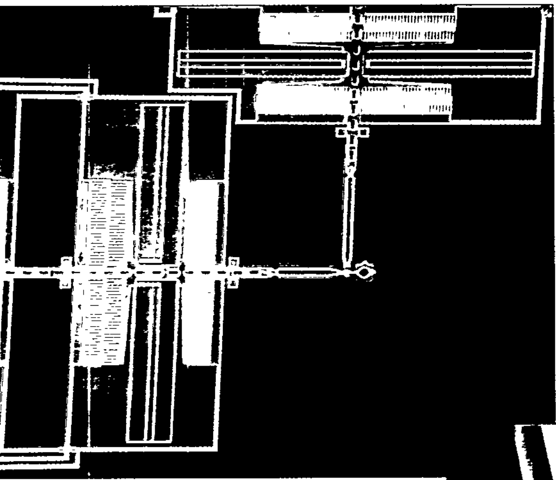


Advanced Manufacturing

Microscopic motors



Tiny engines deliver usable mechanical power

In 1959, Robert Noyce and Jack Kilby independently invented the integrated circuit, the world's first microelectronic device. Less than 10 years later, H. C. Nathanson used microelectronic fabrication techniques to make the world's first micromechanical device, a mechanical resonating transistor switch. Today, micromechanics is on the brink of a revolution that could affect future products in the same way that microelectronics has changed our world.

The Sandia Microengine (above) uses two linear-motion comb drive actuators at right angles to each other to generate rotational motion. The linear motion of each comb drive is converted by the drive linkage into the rotational motion of the output gear (right).

Micromechanical sensors that measure pressure, temperature, and acceleration already form the bulk of a $500 million global market that is projected to reach $8 billion by the year 2000. While microfabricated sensors have become products in the marketplace, mechanically effective microactuators are almost nonexistent. This is due to the difficulty in designing and fabricating devices that can deliver sufficient displacements and forces to be coupled to a mechanical load.

The Sandia Microengine solves some of the major problems limiting the practical application of microactuators. Recently developed by Ernest Garcia and Jeff Sniegowski under DOE Defense Program funding, the Sandia Microengine is the world's first demonstration of a completely batch-fabricated engine capable of delivering power to a mechanical load through a rotating output gear in either clockwise or counterclockwise directions. Rotational speeds to several hundred thousand revolutions per minute have been demonstrated. "Before the Sandia Microengine, devices fabricated entirely by integrated circuit fabrication techniques and capable of delivering continuous rotational motion could not deliver power to mechanical systems," says John Stichman, of Sandia's Surety Components and Instrumentation Center.

"Until the Sandia Microengine was developed, the only rotational output microactuators capable of delivering usable power required piece-part assembly," adds Paul McWhorter, of the Silicon Technologies Department.

Using integrated circuit manufacturing technology to build micromechanisms is called micromachining. To micromachine the Sandia Microengine, a layer of silicon dioxide film is first deposited on a prepared silicon wafer. A photoresist material is spun onto the silicon dioxide layer and then patterned with a desired design. The exposed silcon oxide is selectively etched, with the patterned photoresist protecting the portions of the oxide that are to remain. The photoresist is then removed, and a polycrystalline silicon layer is deposited over the oxide. This layer is similarly patterned and etched to form the desired microscopically small gears, rotors, links, and hubs. This layering and etching process is repeated several times to create all the features desired in the device. Finally, the remaining silicon dioxide films are etched away using hydrofluoric acid, leaving the polycrystalline silicon structures free-standing, except for necessary attachments to the silicon wafer itself.

Ernie Garcia examines a set of Microengines etched onto a silicon wafer. The micromachining techniques applied to Microengine production allow mutiple engines to be produced from a single wafer.

"The beauty of micromachining is that it allows literally thousands of devices to be fabricated at one time," explains Sniegowski. "This mass production capability results in lower costs for individual devices that can be orders of magnitude lower than conventionally produced devices."

The Sandia Microengine, measuring little more than one millimeter by one millimeter, converts motion from linear comb drive actuators into rotating gear output that can drive other micromechanisms (see illustration — the output gear itself is only about 50 microns in diameter.) "The Sandia Microengine drive's output capability is opening doors to many exciting micromechanical applications," says Garcia. In biomedicine, the Microengine could drive microsurgical pincers, cutters, and manipulators, or it could power extremely precise fluid pumps and meters. In manufacturing, it could drive diminutive cutting, slicing, milling, grinding, and drilling tools for creating other microstructures. In computers, the Microengine could steer mirrors that direct laser light for optical computing, or even drive positioning mechanisms for disk read/write heads. The Sandia Miroengine promises to power micromechanical devices to a position as pervasive as microelectronics is today.

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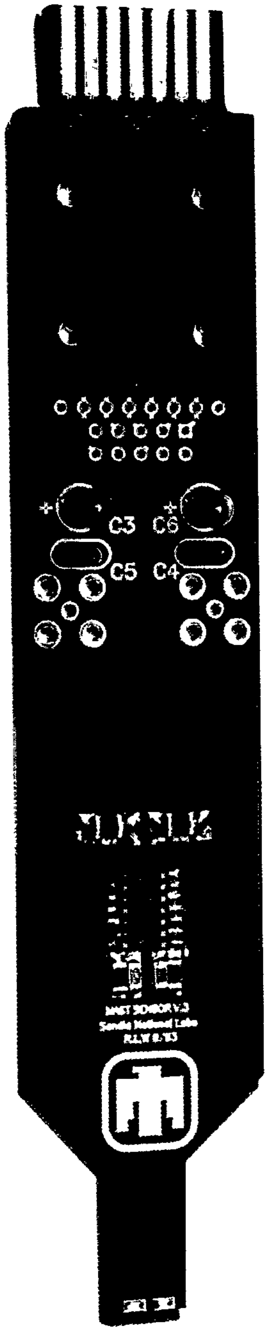
Rocket-building robots

Sandia sensor guides paste-dispensing operation



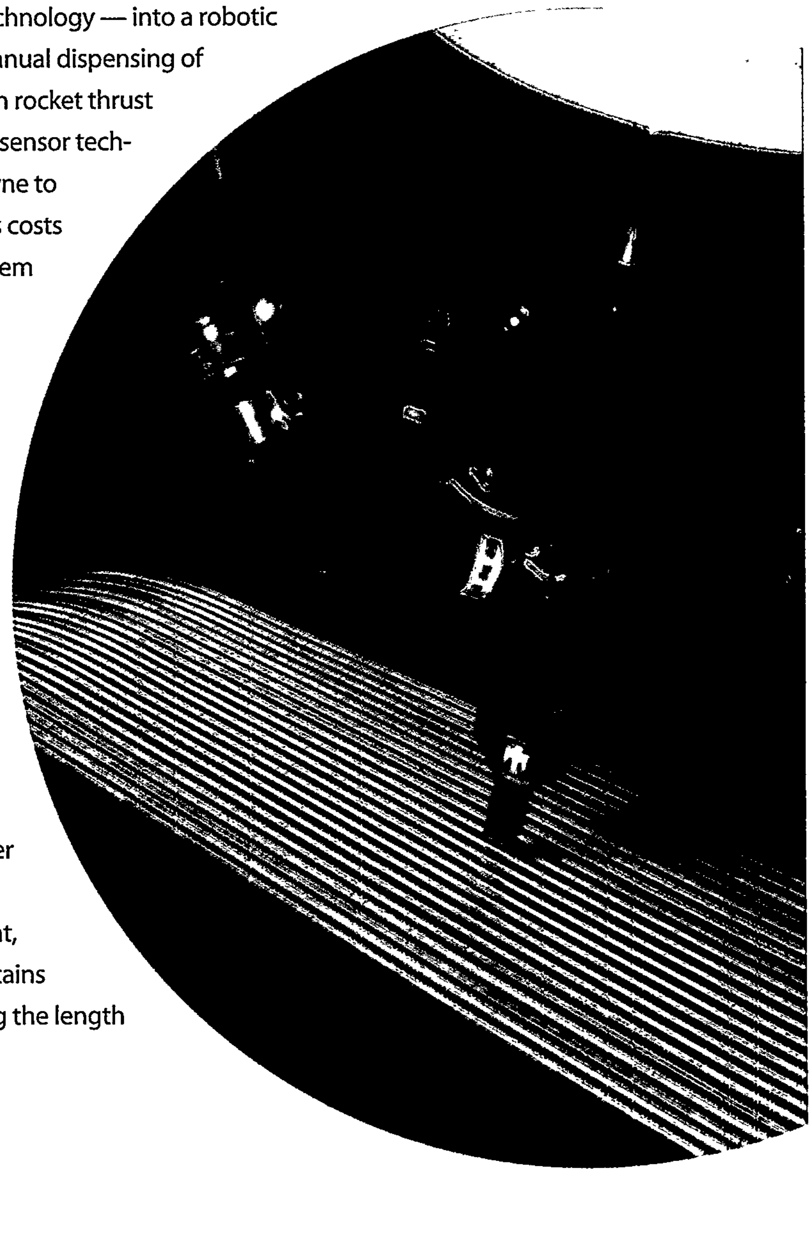
Fabricated from an inexpensive, multilayer printed circuit board, the MAST sensor measures 6 inches long and 1 inch wide. The board's lower tip holds four capacitor electrodes that send tracking information to signal conditioning electronics.

Building rocket engines for the space program is a labor-intensive effort, involving limited-lot manufacture of specialized units. When Rocketdyne, a California-based division of Rockwell International, was looking for a way to automate the process and reduce costs, it found the solution at Sandia: a new sensor for robotic applications.

Through a cooperative research and development agreement, Rocketdyne is now incorporating Multi-Axis Seam Tracking — Sandia's fast, reliable, and inexpensive sensor technology — into a robotic operation that replaces manual dispensing of braze paste and powder on rocket thrust chamber tube seams. This sensor technology will allow Rocketdyne to reduce labor and materials costs significantly when the system begins production.

Rocketdyne is a world leader in the rocket industry, building Delta, Atlas, and space shuttle rocket boosters. "Incorporating robotic equipment into our manufacturing operations is a key strategy for staying competitive," says Rocketdyne robotics engineer John Maslakowski.

A typical thrust chamber is cone shaped, five feet in diameter at its widest point, and eight feet long. It contains hundreds of tubes running the length



CLERVER goes commercial

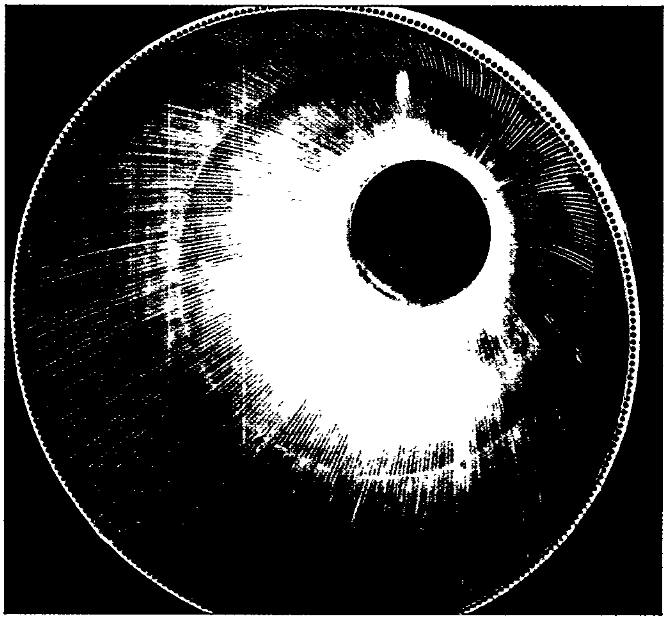
Sun Microsystems builds commercial program on Sandia's ICE

Modern computer communications have created a new universe of working relationships. Megabytes of business information or technical data can stream over phone lines or dedicated computer networks from one workstation to another. Photographs or design graphics can bounce off satellites and appear on computer screens on different continents. However, each data file that holds such information is usually created or modified at one workstation at one location, then sent as a block of data to a different site, where it may be modified independently, then sent on to another site, again and again, until the product may not even be recognizable by the originator.

The ideal solution to the problems created by a complex information system would allow users of the system to speak directly to each other through their computers, see the object of their discussion (whether text, CAD design, or manufactured item) on all their screens simultaneously, manipulate the object in one or more shared programs, and even see each other as they worked. This solution is now available in commercial products from SunSolutions, a division of Sun Microsystems Inc. The SunSolutions ShowMe/SharedApp program is based in large part on Sandia National Laboratories' CLERVER software. CLERVER is an amalgam of CLient-sERVER and is the core of Sandia's own ICE program, the Interactive Collaborative Environment that allows workers in different locations to work on the same file in the same program.

"We wanted to create a system that allowed people to stay in their native environment, and that means both their computer environment and their office environment," said Jim Yoder, of Sandia's Advanced Information Technology Center. "Productivity is directly tied to familiarity, and your own computer in your own office is the best place to work." In the late 1980s and early '90s, workers at Sandia began looking for ways to share information and work collaboratively through their computers. Existing software did not have the needed features or flexibility, so Sandians started the ICE project to create their own environment. The CLERVER software that they developed met their requirements.

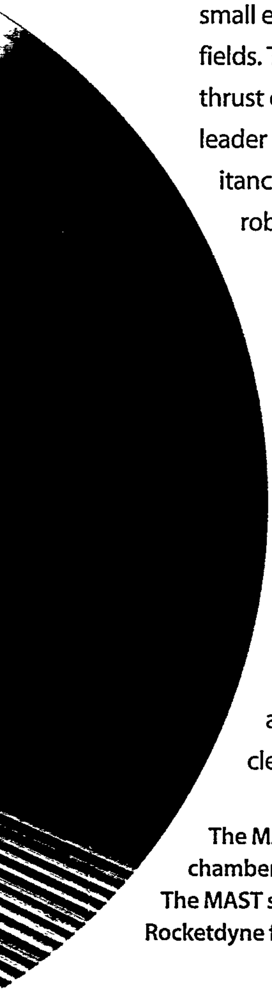
CLERVER operates across platforms using the X protocol. Any platform or any application that uses the protocol (which is simply a set of communications/presentation rules for computer of the inside surface. Fuel circulates through these tubes to cool the thrust chamber jacket and preheat the fuel before combustion. To bond the tubes, an operator currently applies nickel powder and palladium-silver braze paste along each tube seam. After the tubes have been prepared with the powder and braze paste, the entire structure is heated in a large, high-temperature furnace to form a solid assembly. The manual application of the powder and braze paste is expensive, time-consuming, and subject to inconsistency. After evaluating several different robotic approaches for replacing the manual operation, Rocketdyne selected Sandia's Multi-Axis Seam Tracking capacitive sensor approach. "The MAST sensor contains small electrodes that generate multiple electric fields. These fields interact with the surface of the thrust chamber tubes to track the seams between the tubes," explains Sandia project leader Dan Schmitt. "The MAST system detects changes in the electric fields as capacitance variations and converts them into voltages to control the position of the robot arm."



The cone-shaped fuel-tube assembly for thrust chambers manufactured by Rocketdyne. The company anticipates significant reductions in labor and material costs by using MAST.

At Rocketdyne, MAST capacitive sensor technology emerged as the best choice among the competing robotic alternatives: open-loop (no sensor feedback), contact sensors, optical sensors, and MAST sensors. Cost, accuracy, and quality considerations all pointed to MAST as the most effective approach. The MAST system has already been installed into a production version of the robotic seam-tracking dispenser at Rocketdyne's development lab. "We are now prototyping this production system," reports Maslakowski. "We expect to move into a production environment in late 1994."

MAST can excel in many limited-lot manufacturing operations that involve tracking seams. Examples include glue dispensing, welding, and applying potting material. The MAST approach could also be adapted to applications where a robot needs to pinpoint "real world" coordinates for cleaning, coating, or even assembling components.



The MAST sensor, interfaced to a Fanuc S-700 robot arm, tracks tube seams on a thrust chamber section that precisely replicates the geometries of thrust chamber components. The MAST system has been successfully integrated with production robotic equipment at Rocketdyne for dispensing powder and braze paste along tube seams.

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Huong Tran talks to Han Lin (the image in the lower right corner of her screen) as they work together on a component design in Sandia's Interactive Collaborative Environment. ICE allows multiple users to access files simultaneously while communicating over a computer network or communications links. CLERVER is the core of ICE that manages the communications between different computers. Tran and Lin can jointly modify the design as they work together, incorporating their ideas immediately and reducing the time it takes to generate a new or modified design.

operations) can be linked in a network and join the collaborative environment created by CLERVER. "Licensing CLERVER from Sandia let us bring an interactive environment to our customers years earlier than we could have otherwise," said Scott McNealy, chairman and CEO of Sun Microsystems. The SunSolutions ShowMe/Shared App program allows users to work together within an application to make changes and record progress. The ShowMe portion of the program creates a videoconference environment (when video cameras and microphones are installed with the users' computers) in which participants can see each other as well as the objects of collaboration. The SharedApp portion, using CLERVER, manages communications between the multiple users and the shared application, which manages changes to the object (which may be in a CAD program or in a computer-aided manufacturing environment, for example).

"This approach is going to change the way we work," commented Yoder. "Telecommuting becomes a lot easier when you have a collaboration facility that is both platform and application independent." SunSolutions has a nonexclusive license, and Sandia is now talking to communications vendors about adapting ICE or CLERVER to communications environments. There is no theoretical limit to the number of participants in a communications pool, although there are limits due to bandwidth availability. Hsi-Tien Chang, a Sandia researcher, is working on making it possible for smaller, non-Unix computers to join a collaborative environment, and on approaches to solving the bandwidth problem.

ShowMe has become one of the most popular packages that SunSolutions offers. In this application, in communications environments, and in applications and improvements under development at Sandia, computer collaboration will affect electronic communications and computer work styles in ways we cannot yet foresee. Initial applications will probably be in design and manufacturing environments, but the power of collaboration will spread to almost any environment that uses computers.

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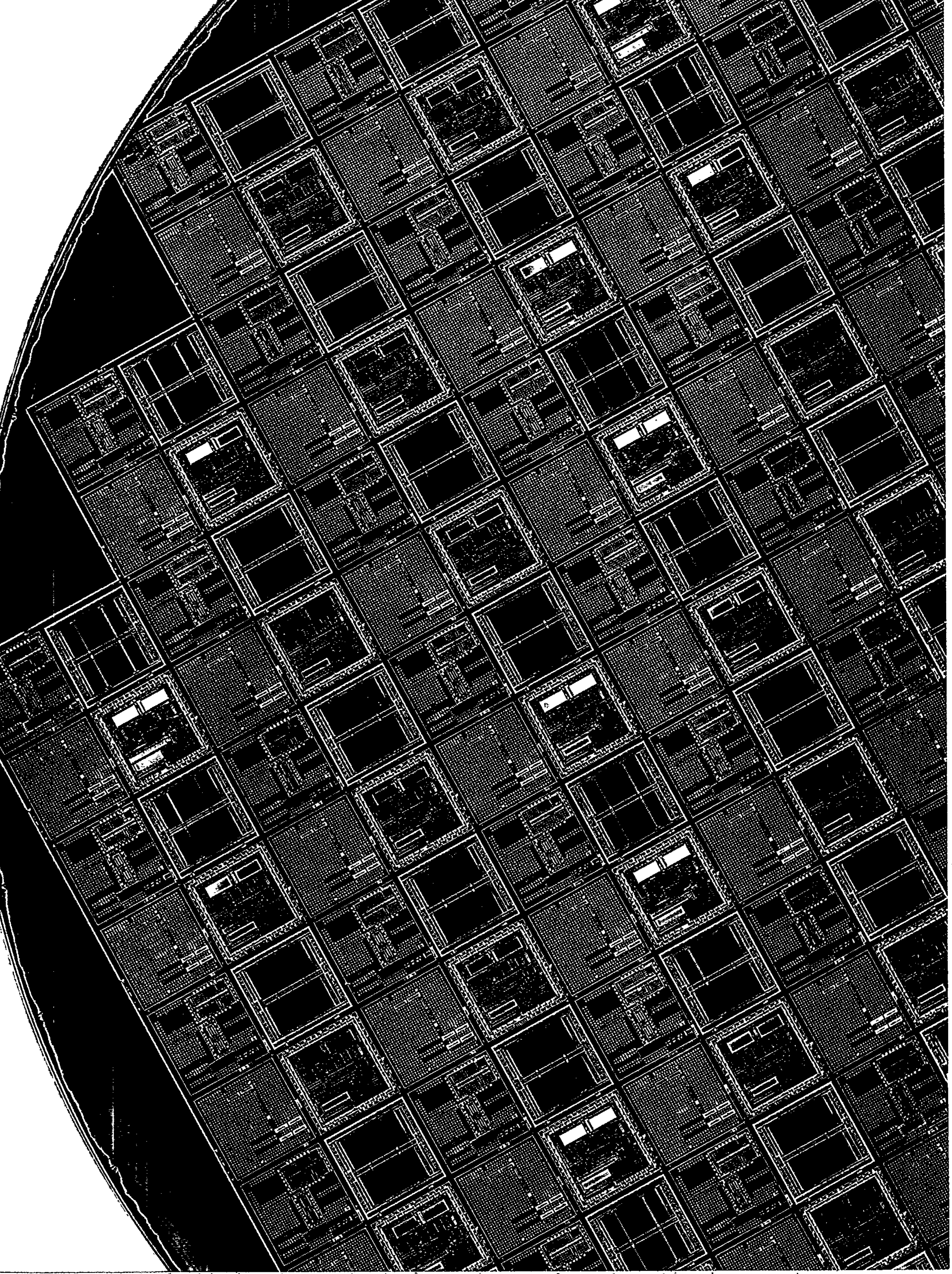
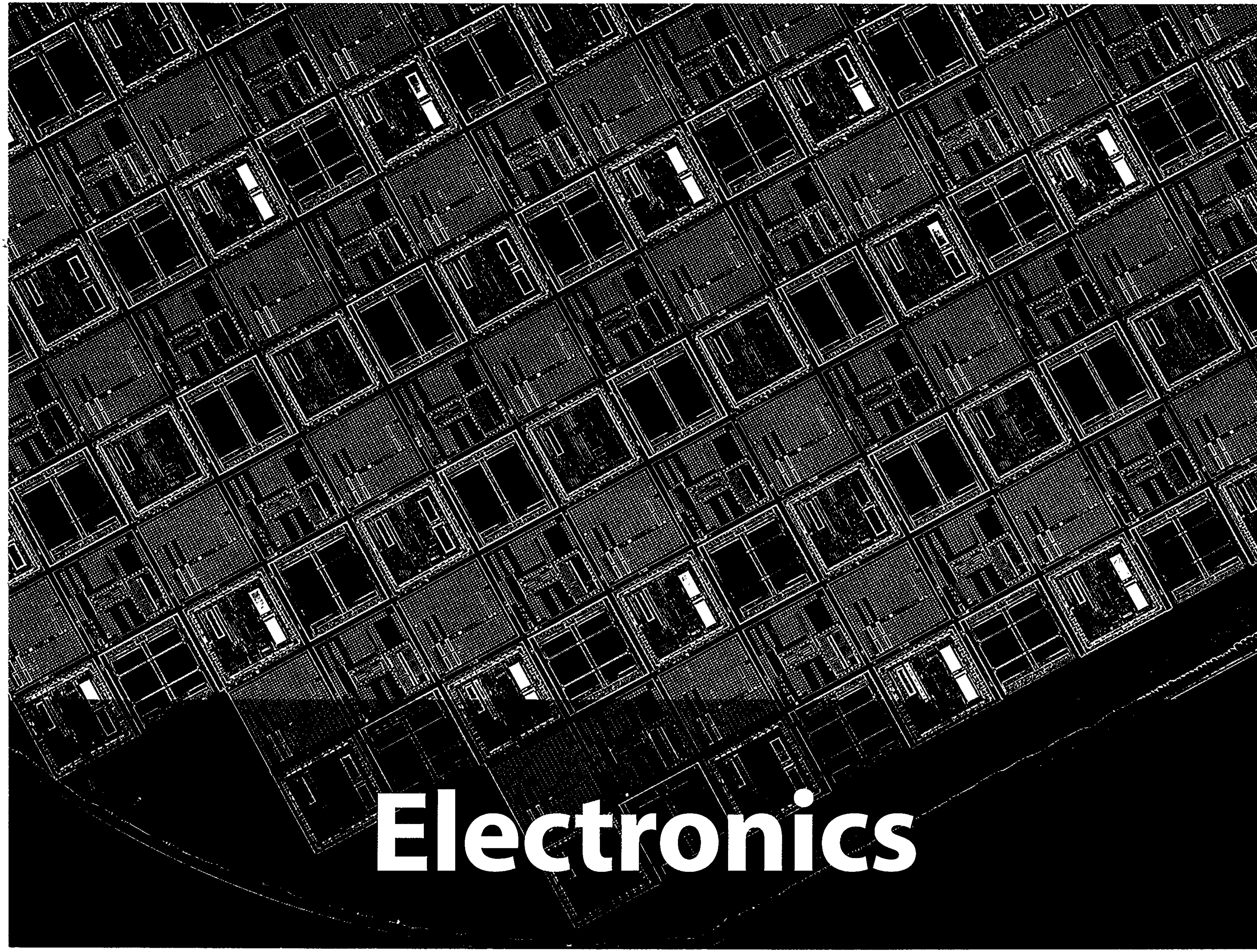
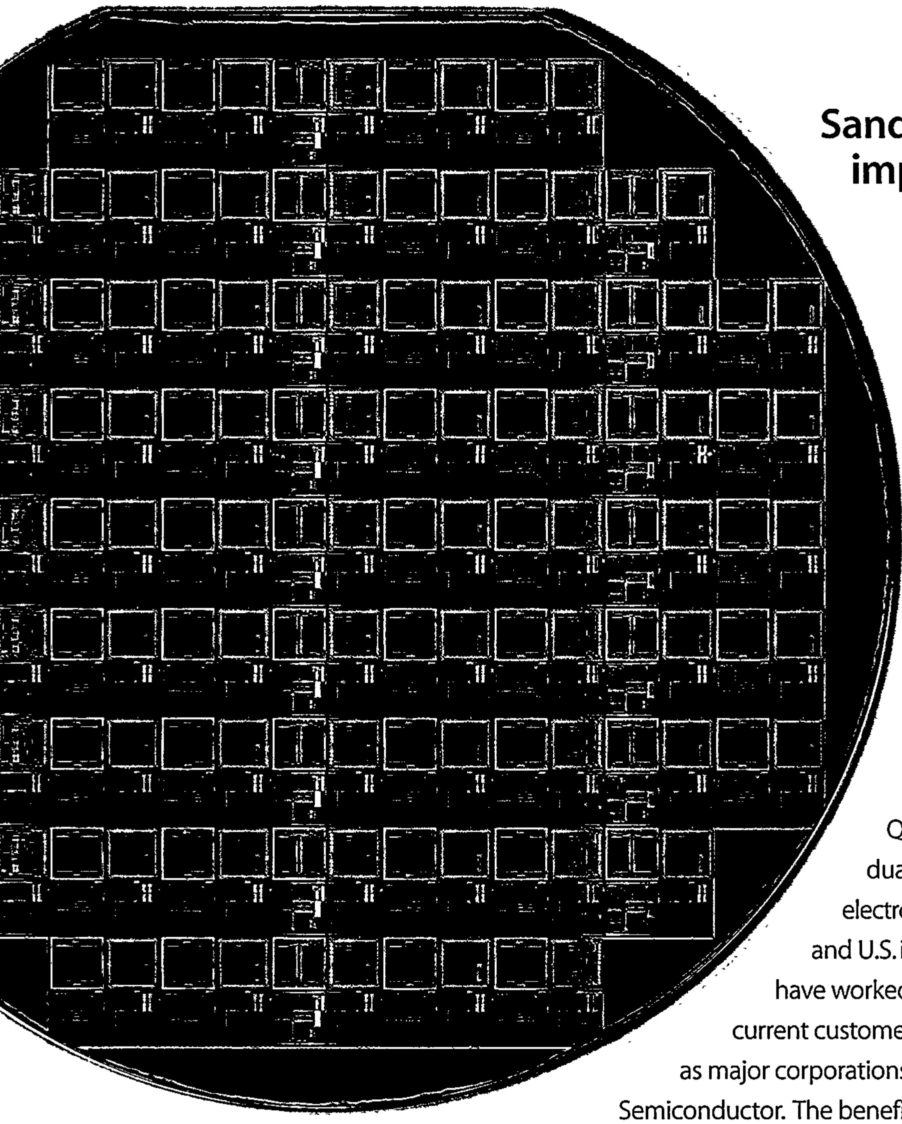




Electronics

Science-based reliability



Sandia is helping industry improve electronics reliability

The state-of-the-art integrated circuits that make up the "brains" of today's computers and intelligent products put millions of interconnected transistors in an area the size of a fingernail. Industry depends so much on these ICs, in both commercial and defense products, that they have to be extremely reliable. However, achieving high reliability is quite a challenge—a small variation on even one transistor out of a million can cause a whole chip to fail.

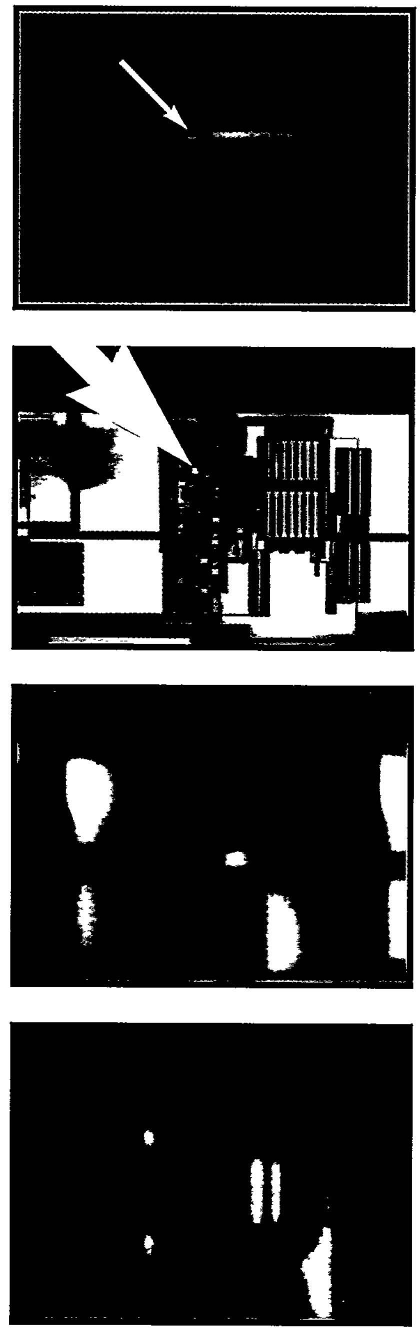
In 1989, Sandia formed the Electronics Quality/Reliability Center as a focal point for dual-benefit partnerships to meet the common electronics reliability needs of DOE Defense Programs and U.S. industry. Since then, over 60 U.S. companies have worked with Sandia on electronics reliability. The current customer base includes many small businesses, as well as major corporations such as Intel, General Motors, and National Semiconductor. The benefit of these partnerships to industry is higher reliability in less time and at a lower cost. The benefit to the U.S. defense effort is improved reliability in stockpile electronics and the ability to use more commercial electronics in defense applications.

A significant EQRC project is its Reliability-Test-Lab-on-a-Chip, which won a 1994 R&D 100 Award. This device replicates the functions of expensive external reliability test systems and ovens on the same silicon wafer that produces the actual ICs being tested. In addition to significant cost savings, this new invention makes it practical to study how ICs fail at the high operating frequencies—hundreds of megaHertz—of state-of-the-art ICs. Invented by Sandia, the Reliability-Test-Lab-on-a-Chip was transferred to industry as part of a cooperative research and development agreement with Philips Semiconductors.

Another dual-benefit project with a high impact is Sandia's Wafer-level sOftware for Reliable Devices. SWORD provides rapid, low-cost reliability characterization and is a key part of manufacturers' efforts to build in reliability by understanding and controlling manufacturing processes. Sandia researchers worked with Hewlett-Packard on a CRADA to develop a commercial version of SWORD, which is now being used by ten major U.S. electronics manufacturers, including IBM and AT&T. "We could not have developed our reliability testing software alone," says Greg Miller, an applications engineer for Hewlett-Packard who worked with the EQRC on this project.

Another major area for cooperation is investigating integrated circuit failures. Sandia has developed a whole suite of techniques for significantly reducing the time to find where a failure occurred. One example is Light-Induced Voltage Alteration, which uses an infrared laser to do failure analysis through the back of an integrated circuit. LIVA examines chips in advanced packaging technologies and complex, leading-edge ICs.

To facilitate an even wider range of dual-benefit partnerships, DOE has designated the EQRC as a Defense Programs Technology Deployment Center and User Facility. This user facility will make it even easier for industry—especially small businesses—to utilize Sandia's unique capabilities and expertise.



Failure analysis using Light-Induced Voltage Alteration can pinpoint open metal-to-silicon contacts and show logic states as well. In the top image, the LIVA process identifies a failure area. Next, a reflected-light image is superimposed to show the specific location of the fault. In the bottom two images, LIVA shows the changed logic states of transistor operation.

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This six-inch silicon wafer includes Sandia's Reliability-Test-Lab-on-a-Chip as structures on the wafer. These structures generate stress signals on-chip using inexpensive DC components. This approach permits high-frequency reliability stress testing of circuit elements while reducing costs and qualification time for integrated circuit manufacturing processes.

Plasma does colors

Sandia researcher Willard Hareland adjusts the optical train used for spectrographic analysis of a set of plasma cells. The analysis is part of an effort to improve plasma displays in several areas, including the lifetime of the displays, color quality, and electrical efficiency. Spectrographic information from these tests will also be used in modeling studies.

Orange screens give way to full-color displays

Plasma displays. The image that might come to mind is a laptop computer with an orange screen, neon plasma glowing as the individual cells of the screen are ionized. Think instead of a 60-inch full-color video display, flicker free, with a pixel size and density that supports high-definition television. This is the hoped-for future of plasma flat-panel displays, and Sandia researchers are trying to make that future come true.

Sandia is working closely with Photonics Imaging Inc., the leading manufacturer of plasma displays in the U.S., to develop the technology to bring improved plasma displays to the market as soon as possible. Sandia has over a dozen research projects in flat-panel displays, and seven of these projects are in plasma display technology. These projects are sponsored by cooperative research and development agreements, and by the National Center for Advanced Information Components Manufacturing at Sandia. "It is easy to see the potential of this technology," explains Walt Worobey, one of the lead researchers on plasma displays at Sandia. "The need for high-resolution, low-weight, thin-cabinet displays is widespread. HDTV is coming, and it will be the main market, but there will be major needs for high-resolution medical imaging, aircraft cockpit displays, and high-tech automobile dashboard displays."

One research area focuses on glass substrates. These substrates contain the plasma cells that create the images on the screen. Sandians are starting to characterize new areas of glass technology for plasma displays. In the course of applying electronic features and layers of chemicals to the glass substrates of a plasma display, the glass may be fired several times to ensure the bonding of the chemical layers to the glass.

Sandians are characterizing the reactions of the glass plates to these firing cycles, which frequently cause warping and distortion. Using precision measuring equipment, researchers measure the viscosity, shrinkage, and stress/strain properties of the glass, fit this data into a computerized viscoelastic model, and run a finite-element analysis to predict residual stress and deformation. The viscoelastic model is a new capability that supports both the analysis and design of actual manufacturing processes by predicting the effect of temperature history (empirical or modeled) on the residual stress state of the glass.

In another project, researchers are developing computer models to understand the complex physics of the reactions inside a plasma cell. When a voltage pulse is applied to a cell at the intersection of electrodes placed on the glass substrate, an electrical discharge occurs. This ionizes the gas mixture in the cell, which emits a burst of ultraviolet light, exciting a phosphor coating on the cell walls to produce a red, green, or blue response. By modeling the electrons, ions, and excited atoms in a plasma cell to understand the physics of the plasma screen, Sandia researchers aim to improve plasma display technology and help the U.S. flat-panel display industry. As project leader Bob McGrath says, "Alternating current-based plasma screens are not a thoroughly studied area, especially in relation to exciting phosphors in emissive cells. If we can understand and improve this technology, we will help plasma color displays fill an important niche in the display market."

Plasma color screens have great potential as a less expensive alternative to CRT and liquid crystal technologies for large-area displays. Over large areas, they exhibit no loss of intensity or resolution, are highly dependable, and weigh less than their competition. "The goal of all our projects in plasma displays is to help the production effort," says Worobey. "We want to improve materials, reduce production costs, improve quality and reliability, and optimize the performance of flat-panel displays."

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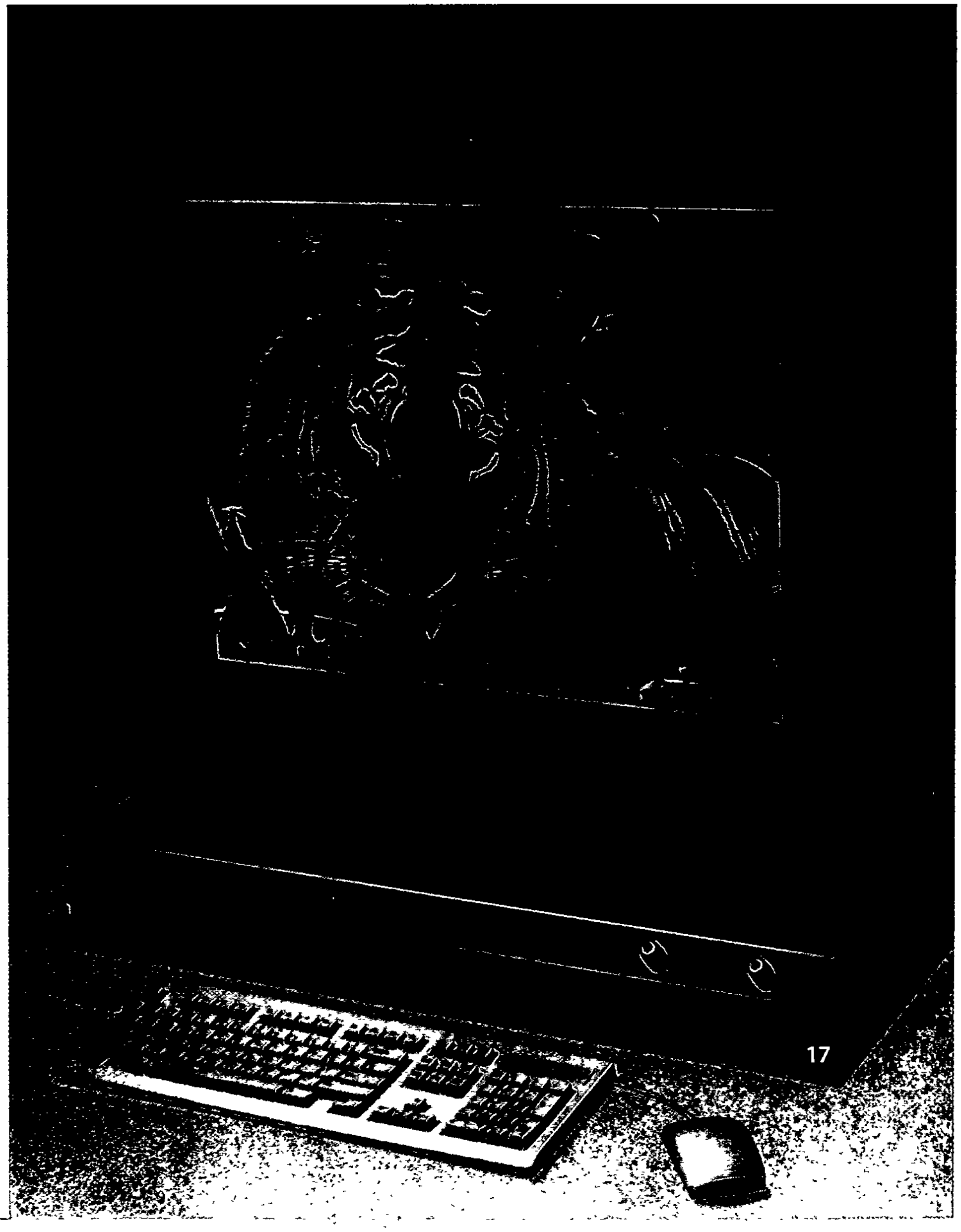
A 30-inch full-color plasma display from Photonics Imaging. The 1024 x 768 color pixel image provides a high-resolution image in a flat-panel format. The size (volume) and weight advantages of flat panels are important in both military and commercial uses.



Putting down copper

Sandia's copper films hit world-record deposition rate

Remember aluminum house wiring? It was marketed in the mid-1960s as an economical alternative to copper wiring. But aluminum household wiring was short-lived. Aluminum's tendency to expand when exposed to heat or electrical current sometimes caused loose connections, creating overheating and even fires. Aluminum's characteristics are also beginning to cause problems in the microelectronics industry, where aluminum is used for the microscopic interconnecting lines inside computer chips. As the technology for building integrated circuits pushes line widths toward 0.25 micron, aluminum migration induced by current and stress can create disabling electrical opens and shorts.

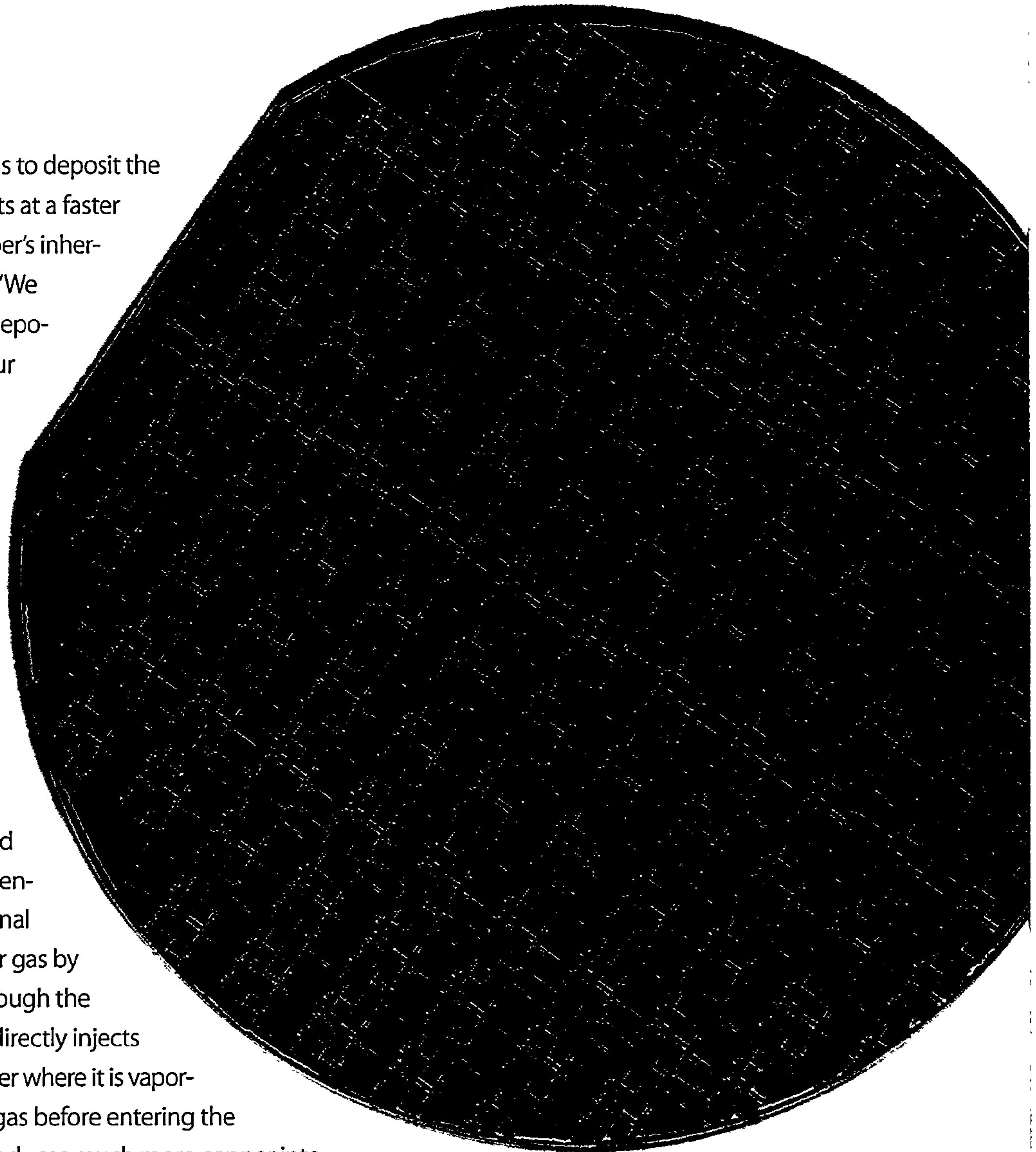
The reaction chamber of the Watkins-Johnson CVD machine. Using a new approach to vaporizing a copper precursor, Sandia researchers achieved a record copper deposition rate.

Among the alternatives to aluminum, copper is a promising candidate. "Copper doesn't seem to suffer from electromigration and thermal migration nearly as much as aluminum does," says Sandia's Paul Smith. As an added benefit, copper's resistivity is much lower than aluminum's. "Lower resistivity decreases signal propagation delays," explains co-researcher Chris Apblett. "In other words, copper allows you to speed up your chips."

Smith and Apblett—working through cooperative research and development agreements with equipment manufacturer Watkins-Johnson and chemical supplier Schumacher—have overcome several of the initial obstacles to copper's use in microelectronics.

"One of our first challenges was to deposit the copper films for the interconnects at a faster rate without compromising copper's inherently low resistivity," says Smith. "We devised a novel chemical vapor deposition approach that is two to four times faster than previous efforts and that yields copper films with extremely low resistivity."

This approach uses Schumacher's Cupra Select, a liquid precursor containing chemically bound copper. Under precisely controlled conditions inside the Watkins-Johnson CVD system, some of the copper atoms chemically dissociate from the precursor and deposit on the substrate as elemental copper. Unlike the conventional technique that saturates a carrier gas by forcing or "bubbling" the gas through the liquid precursor, this technique directly injects the liquid precursor into a chamber where it is vaporized and mixed with the carrier gas before entering the CVD system. "Our approach introduces much more copper into the CVD system, dramatically increasing copper deposition rates," says Apblett.



A patterned silicon wafer after copper deposition using the new CVD technique.

Their process yields copper films with a resistivity of 1.85 microhm-centimeter at a rate of 150 nanometers (thickness) per minute—a world-record deposition rate for this type of system. Smith and Apblett also have deposited copper in holes and grooves with submicron widths. Non-CVD copper deposition techniques, such as sputtering and evaporation, cannot fill the bottoms of these holes. "Like snow covering a deep hole, the copper piles up at the edges of these openings, leaving a void in the bottom," explains Smith. "This action is called 'keyholing.' By using chemical vapor deposition to react preferentially on the walls and base of the opening, our process can avoid keyholing."

Fast deposition of high-purity copper that avoids keyholing has bolstered copper as a contender material for tomorrow's ultraminiaturized microcircuits. While other challenges remain, Sandia has helped bring the advantages that copper interconnects offer—low resistivity and resistance to thermal migration and electromigration—closer to reality.

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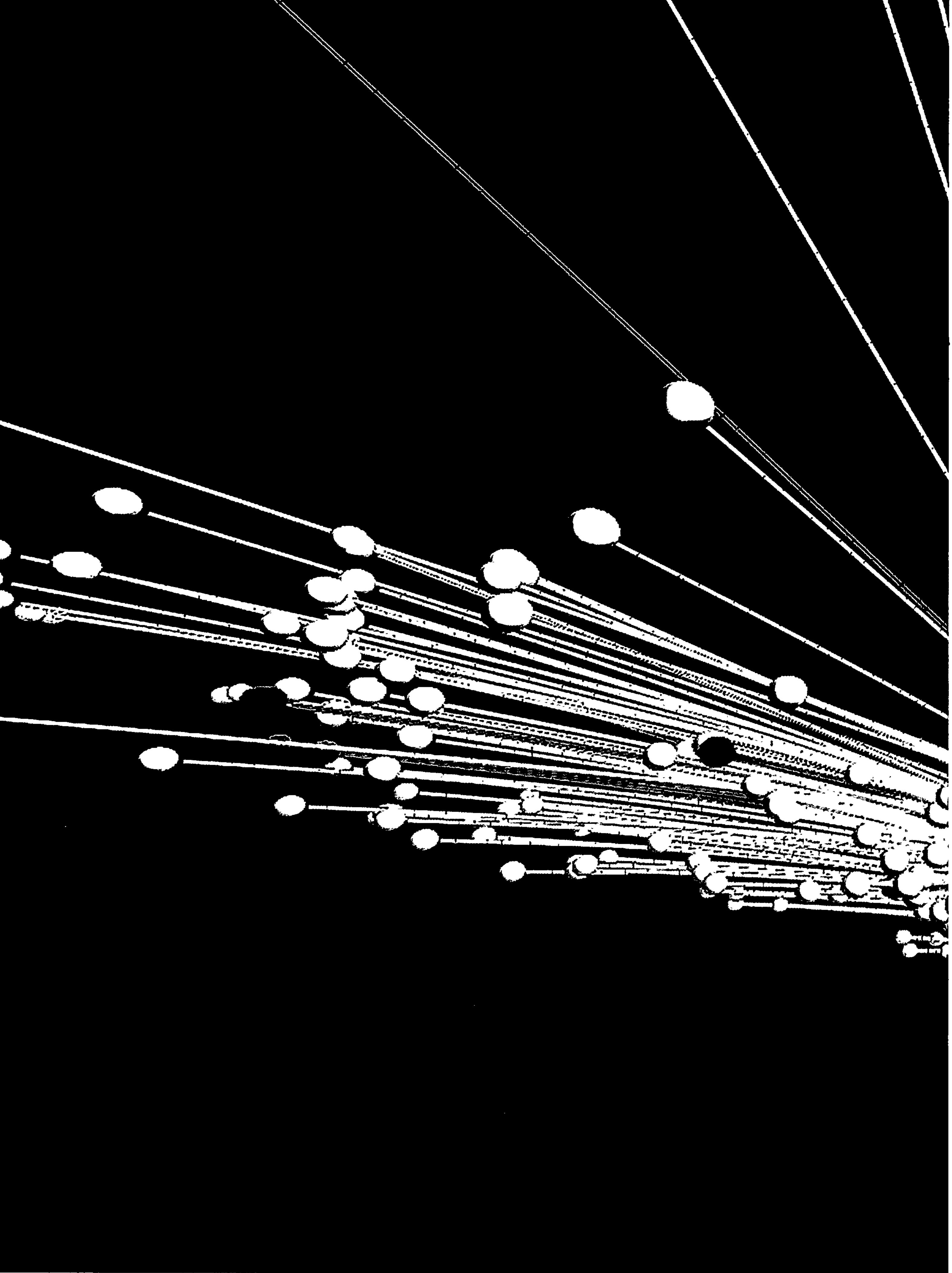

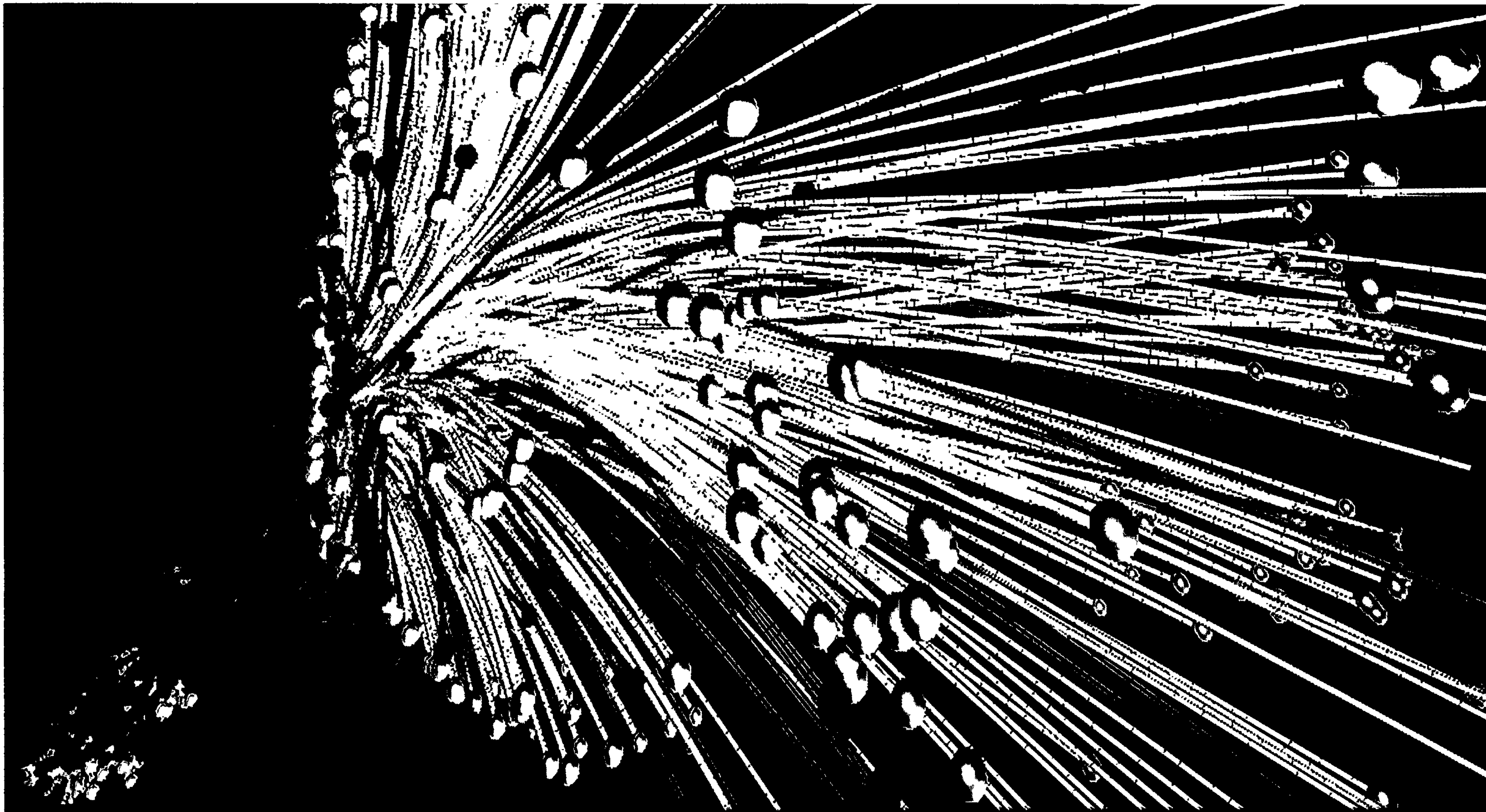

Information & Computation

Laying tracks

Sandia computer technology helps build information superhighway

On May 10, 1869, the last spike — a golden one — was driven into the first transcontinental railroad connecting the Pacific and Atlantic oceans. Just as the cross-country rail system linked the East and West coasts, fiber-optic routes are creating a transcontinental communications highway.

The first transcontinental rail system had uniform standards, but computer systems don't. They talk to different routers, run at different speeds, and operate on independent platforms. And there are problems related to sending and receiving huge amounts of information over long distances quickly and securely.

Three years ago, Sandia computer communications engineer Steve Gossage realized that combining and advancing transmission and switching technologies could solve these problems. Based on cooperative research that began in 1992 between Sandia, AT&T, and other partners, Sandia achieved significant network advantages by deploying Synchronous Optical NETwork technology for standard long-distance telephone transmission and Asynchronous Transfer Mode technology for switching.

By segmenting information into small, fixed-size cells, Sandia and industry scientists found that ATM had the capability to quickly and efficiently transmit large amounts of data over computer networks. "An ATM cell is analogous to a brick. Just as you need a lot of bricks to build a wall, you need a lot of cells to pass information," says Gossage. The ATM switch gear sorts and routes the cells over SONET trunks, directing them to their correct destinations. ATM technology also adapts, or scales, to different speeds, distances, platforms, and storage sizes, solving the problem of communications compatibility.

Further pioneering work by Sandia and its industry partners showed that

SONET — typically used to form "long distance trunks" between switches — could also be used for "optical trunking." By electro-optically packaging, synchronizing, and transmitting ATM information cells over optical fiber cable, high-speed data, video, and voice can be sent through a single communications system directly to the customer's desktop.

"We want to have a highly reliable, expandable, scalable system," says Gossage. "ATM brought us the ability to transmit large amounts of data. SONET brought us high reliability, high speed, insensitivity to distance, and standardization. Together, these technologies are the building blocks of future networks."

To keep the data secure during transit, Sandia researcher Lyndon Pierson is extending security methods that initially supported defense programs. Recently, Pierson's group won an R&D 100 Award for work on Crypto Sync Loss Detection, an important component of end-to-end encryption, a method of protecting data from theft or fraud. Crypto Sync Loss Detection detects problems with decrypted message integrity so that a synchronization recovery procedure can begin. It also scales to different applications and data rates.

"We are now trying to identify the missing pieces of technology to communicate at 10 to 100 billion bits per second," says Pierson. Currently, computers communicate at no more than a few million bits per second — less than one percent of Pierson's goal.

ATM, SONET, and Crypto Sync Loss Detection are all emerging technologies Sandia is helping to advance. These communications technologies will help make the information superhighway as integral a part of the economy as the railroads have been since that golden spike linked the coasts.

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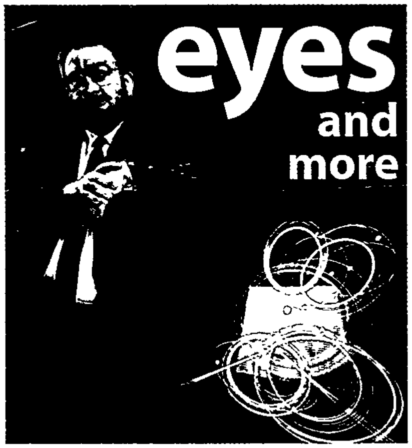
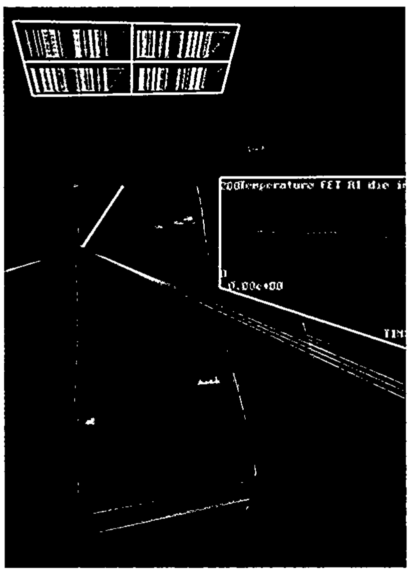
New MUSE provides new ways of perceiving

multi-dimensional user-oriented synthetic environment



Creve Maples, MUSE project head, with a representation of the solar system created by the computer program.



For a chip developed at Sandia, MUSE integrates the CAD design, the thermal analysis of the component, and a circuit simulation. This data fusion allows different sets of information to be viewed together.

Seeing is believing. Participation leads to understanding. The representation of data is an essential part of its analysis. When experimental data can be linked in different media using appropriate symbols or analogs, human beings can focus their tremendous skills in pattern recognition, trend analysis, and novelty discrimination on data that could only be poorly comprehended through more traditional data analysis.

These principles helped Sandia computer specialists develop a new interface between information and the people who use information. They began by asking what computers could do to enhance the best skills of the human brain. Their answer is MUSE, the Multi-dimensional, User-oriented, Synthetic Environment.

MUSE is a device-independent software shell that can accept data from many different sources and create a meaningful sensory representation of that data. For instance, MUSE can take the visual CAD-developed design of an integrated circuit, the thermal analysis of that circuit (performed in a program that is not linked to the CAD program), and a circuit analysis of the device, and show the temperature of the miniature component as it operates over time, creating a visual representation of two sets of data, while "sonifying" the circuit analysis, so that voltage levels are presented as varying volume and pitch in an audible signal. Now an observer can "see" the chip heating up during operation, note the points of most intense thermal increase, and "hear" the circuit analysis. This allows the observer to perceive any links between electrical operation, heat, and possible component failure.

"Everyone who has put information on their products or experiments into MUSE has found something they simply had not perceived before," said Creve Maples, head of the Synthetic Environment Lab and designer of MUSE. For example, a design team that wanted to create an explosively formed copper seal around an opening in a steel plate (as part of a heat exchange system) brought their numerical data to MUSE. MUSE showed the steel plate with its opening, the copper pipe that would be formed into a seal, and the explosive, all as they moved through time; the explosive blasted the pipe into a seal around a beveled portion of the steel plate's opening just as the designers expected. What was unexpected was what they saw when they "sliced" the steel plate, saw the edge of the solid steel wall bulging around the opening, and then traveled inside the plate to see the effect of the bulge.

MUSE generated all these activities in real time by relating and manipulating sets of data. "One of the unique features of MUSE is the 'craft' that we've created," noted Maples. The craft, or vehicle, is a three-dimensional virtual office that travels with the observer through information space. The craft exists as a transparent shell with boundary outlines, which provide the user with a local frame of reference. If the observer is using a stereoscopic headset, for instance, the craft provides a position and orientation reference, while the user is free to look in any direction, even while moving. The craft also allows the observer to place other representations of the data (such as voltage analysis graphs, or a two-dimensional view of the object being navigated) on the transparent "walls" of the office.

MUSE sliced the steel plate in the explosive welding experiment, showing the bulge caused by the explosion, and then represented the plate as hollow, permitting the craft to fly into it, while the model still responded to the explosion as a solid material. When the designers "flew" into the plate, they saw that the bulge indicated that the opening in the plate was enlarged by the explosion. By participating in a moving visual representation, the design team gained new insight into the nature of the dynamic processes that formed the seal and made appropriate design changes. In the same way, any project that analyzes an object or a process could find new understanding in a complex representation that links different kinds of data.

MUSE is not a virtual reality machine; it does create a synthetic environment in which data is represented in perceivable ways. Companies engaged in manufacturing and in information-intensive applications are beginning to use MUSE to develop new ways of presenting data, and educational institutions are finding new ways of teaching students in a computer environment that represents knowledge as sensory data with perceivable relationships. "MUSE is about three years ahead of the rest of the computer world in its human-computer interaction and its virtual presentation of information," said Maples. MUSE is available on license from Sandia National Laboratories, and major corporations are already using it. The program promises to have a significant impact on any area that depends upon information and information analysis to understand the world.

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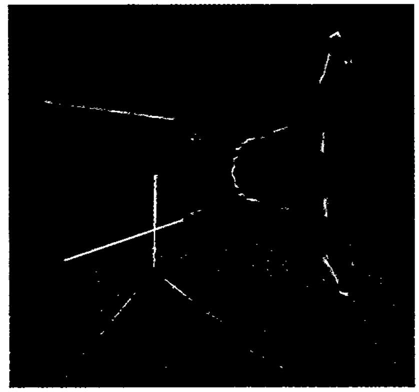
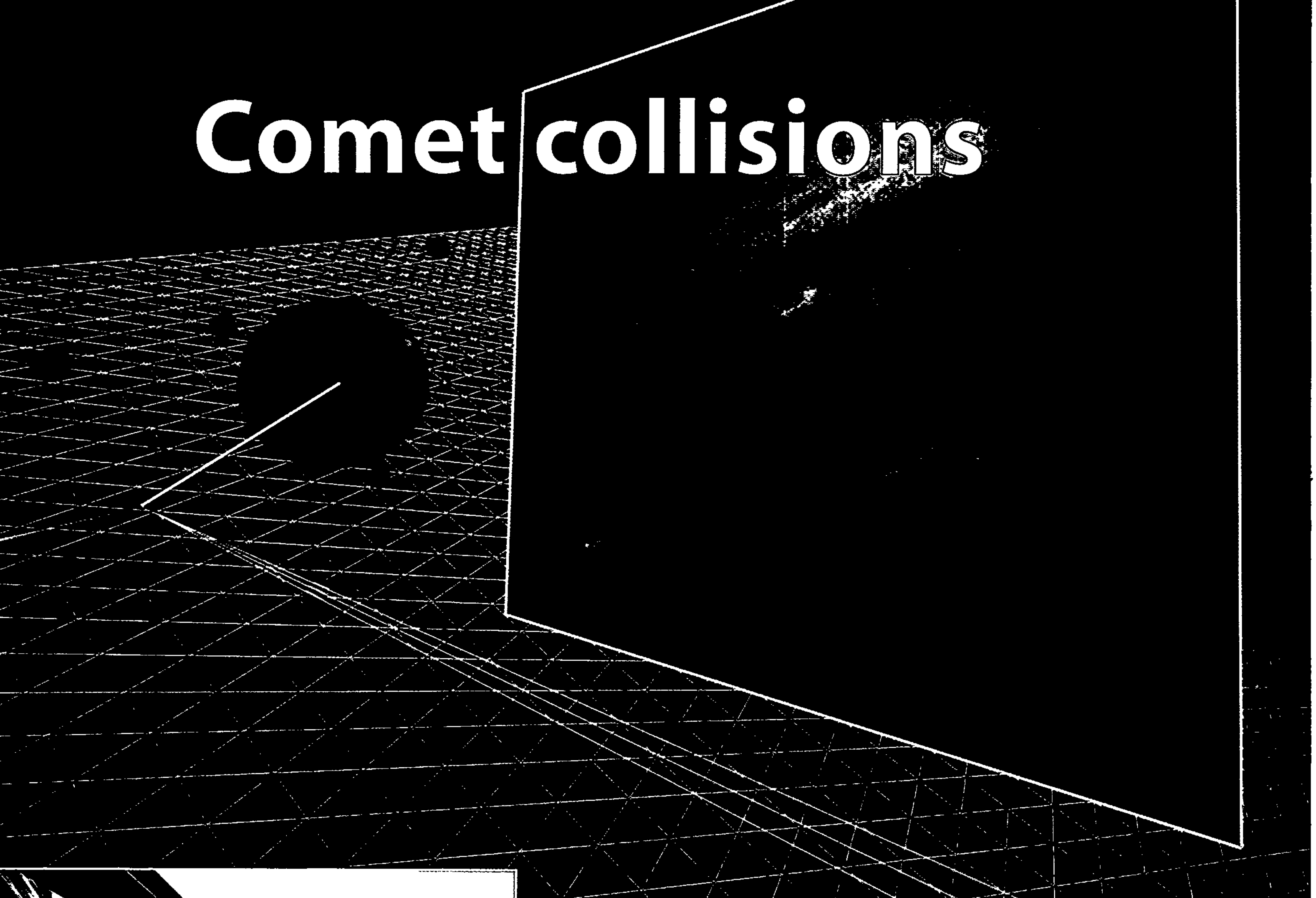


The explosive welding experiment, with its dynamic elements spatially separated. MUSE shows the steel wall, the copper pipe, and the explosion itself as distinct elements here; MUSE can also integrate the same elements to represent a unified process. This flexibility is part of how MUSE leads users to new perceptions of data.

Eugene Shoemaker, one of the discoverers of the Shoemaker-Levy comet that struck Jupiter in 1994, talks to Craig Peterson, Sandia contractor, about how MUSE represents data (see the following article, "Comet collisions"). Behind Shoemaker are Sandia's Jim Asay and Mark Boslough. Boslough was part of the Sandia effort to predict the effects of the comet impact on Jupiter.

Comet collisions



Eugene and Carolyn Shoemaker, discoverers (with David Levy) of the Shoemaker-Levy 9 comet, view a MUSE simulation of the CTH code's calculations of cometary and atmospheric debris ejected from Jupiter's atmosphere. (See previous article on MUSE and its interaction with computer data.) The CTH code provided accurate predictions of the explosive reactions within Jupiter's atmosphere to the powerful impact of the comet's fragments.

In 1992, Shoemaker-Levy 9, a comet perhaps 5 miles in diameter, passed close to Jupiter. Torn by the giant planet's gravity, the comet broke into 21 mountain-sized fragments that lined up "like a string of pearls." The encounter put the fragments on a collision course with Jupiter when they returned in July 1994. Using telescopes around the world, astronomers witnessed the effects of comet fragments bombarding the back side of Jupiter (out of Earth's line of sight) for six days. Brilliant fireballs rocketed thousands of miles over Jupiter's rim and into the sunlight, providing evidence of the immense forces generated by the impacts.

The impending collisions also riveted the attention of Sandia planetary scientist David Crawford and other Sandians studying high-velocity impacts. Using a family of computer codes originally developed to model the effects of nuclear explosions, they simulated the cosmic collisions. Today, data from the collisions — infrared photographs and images from the Earth-orbiting Hubble observatory and cameras on the Galileo spacecraft — are corroborating Sandia's computer simulations. "Never before has an object been discovered, its orbit calculated, and an impact prediction

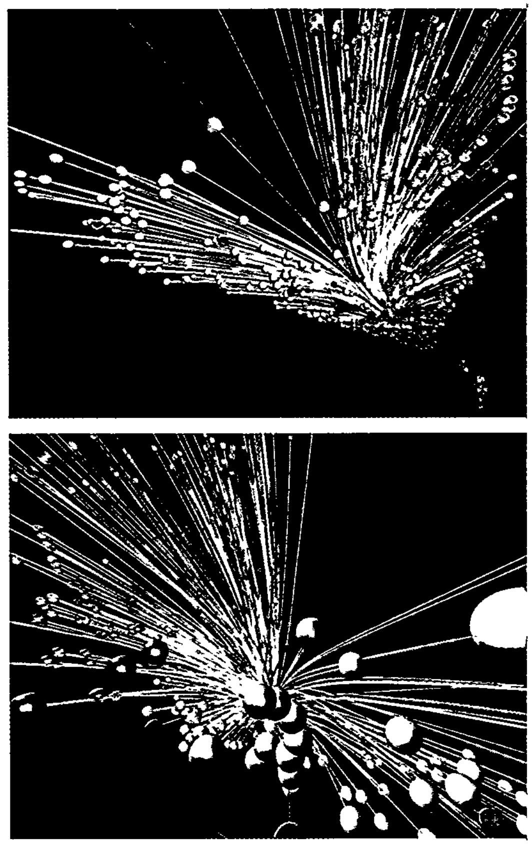
(Far left) Hubble Space Telescope images of the plume from the impact of fragment G on July 18, 1994. (Images courtesy of NASA Space Telescope Science Institute.) (Left) Sandia CTH simulation of a plume generated by impact on Jupiter of an ice sphere three kilometers in diameter. Information from the actual impacts of comet fragments on Jupiter have validated the accuracy of the CTH codes.

made. Astronomers often cite Sandia's work as alerting them to the possibility of seeing fireballs over the limb of Jupiter, and the event itself gave us the chance to validate Sandia's computer models," says Crawford.

To simulate the collisions, Crawford used a computer code named CTH. For years, Sandia scientists developed and refined CTH to simulate responses to strong shocks and large deformations under conditions of high pressures and temperatures, such as in nuclear explosions. By running CTH on Sandia's 1,840-node Intel Paragon massively parallel computer, Crawford and colleague Allen Robinson were able to simulate the distribution of pressure, density, and temperature within the expanding fireball.

During the week of July 16, David Crawford and Mark Boslough joined astronomers in Hawaii and, beginning July 19, witnessed early validation of their CTH calculations. The fireball size and asymmetric shape (visible in the infrared) and the comet debris carried up and over the planet's rim and into the sunlight had been predicted. "These are the most highly resolved three-dimensional calculations ever done on such problems. The CTH simulations, combined with the observational data, allow us to assess the accuracy of CTH in an energy regime not accessible in the laboratory," notes Crawford.

The validation of the CTH code has far-reaching effects. With continued funding from the National Science Foundation, Crawford, Boslough, Robinson, Tim Trucano, and others are helping astronomers analyze the data from the comet/Jupiter collision. This work will help astronomers improve their knowledge of comets and of Jupiter, the largest planet in the solar system. Because comets are thought to be over 4.5 billion years old, this analysis will provide insight into the origins of the solar system. CTH is also being used to analyze the effects of asteroids and comets that have struck Earth in the past or may impact in the future, including the effects of the collision 65 million years ago that may have caused the extinction of the dinosaurs. "Studying the impact of Shoemaker-Levy 9 on Jupiter will help us understand what could happen if comets hit Earth," says Crawford. If that were to occur, CTH could provide vital predictive information about the effects such impacts could have.



(Above) Two MUSE simulations of cometary and atmospheric debris streaming out of Jupiter's atmosphere after a comet fragment's impact.

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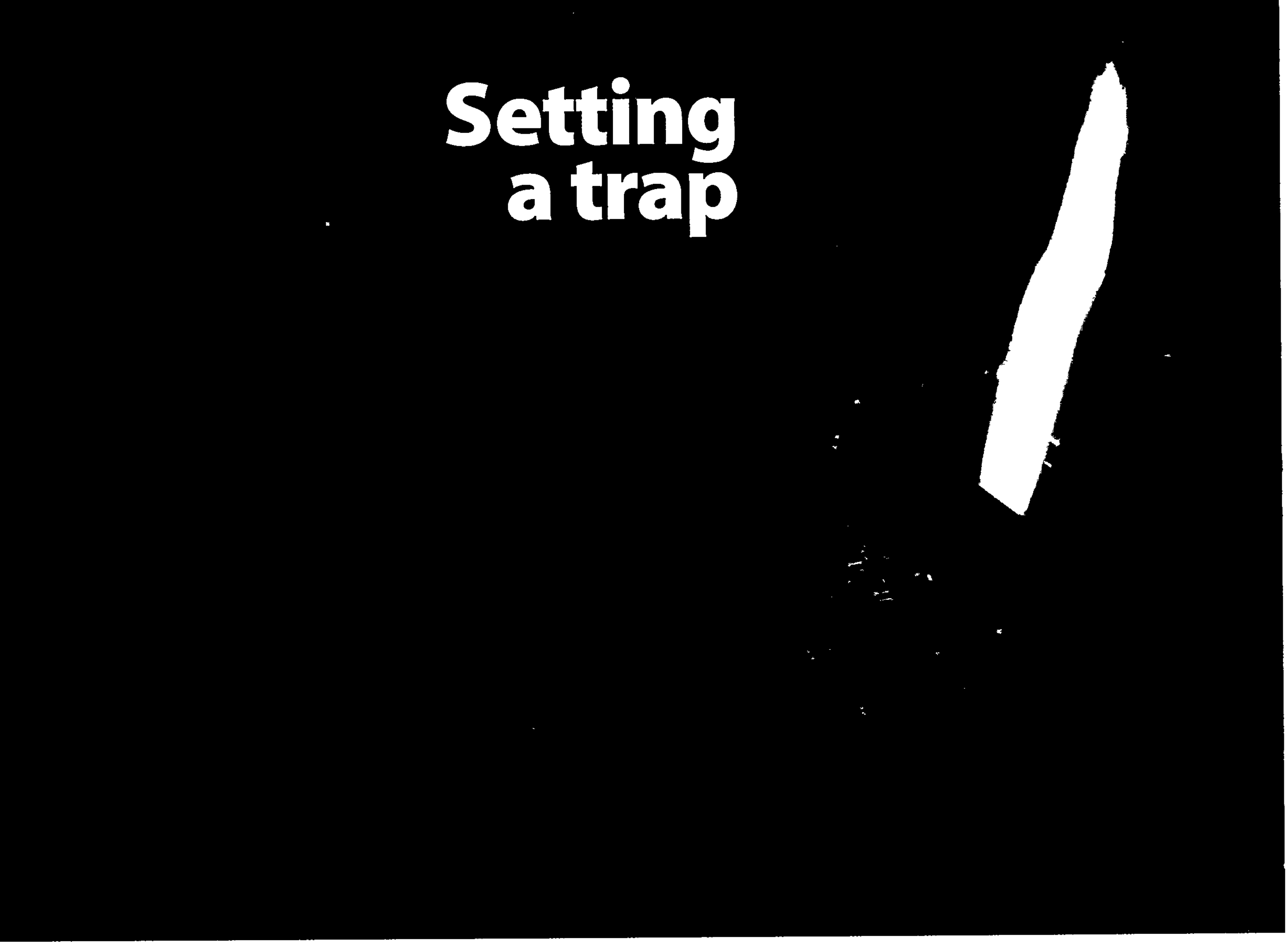
Environment

Setting a trap



Using an atomic absorption spectrometer, Dan Trudell checks whether a solution contains cesium.

Cagelike molecules remove cesium from radwaste

It's hard to imagine fractions of an angstrom making much of a difference. After all, an angstrom — the tiny unit of measure that describes wavelengths of light — spans a mere ten-millionth of a millimeter.

But deep inside a decades-old storage tank containing radioactive waste, even fractions of an angstrom can make a big difference. Sandia researchers, working with materials specialists at Texas A&M University, have developed materials known as crystalline silicotitanates that can extract cesium — one of the most difficult radioisotopes to remove — from the nonradioactive constituents of radioactive waste. The CSTs' unique cesium-trapping properties are based on subtle atomic-level spatial differences between crystalline lattice planes, or layers. CSTs show great promise for removing cesium and other radionuclides from both defense and commercial nuclear wastes. Through a cooperative research and development agreement with UOP (a company in Des Plaines, Illinois), CSTs are scheduled to be commercially available this year.

Silicotitanates are ion exchangers: they can swap ions (charged atomic particles) from within their molecular structures for similarly charged ions of a different species. The crystalline material acts as a trap; rejecting larger ions, its cagelike structure captures ions small enough to reach vacant bonding sites. By varying the composition of a CST, openings can be adjusted by fractions of an angstrom, thereby determining which ions fit and which don't.

That's particularly valuable for a situation like that at DOE's Westinghouse Hanford site, where radioactive cesium is stored in 177 underground tanks containing a total of about 60 million gallons of waste. Every radioactive cesium ion in the tanks is accompanied by 100,000 chemically similar sodium atoms. Traditional ion exchangers can't efficiently distinguish between the two.

Fortunately, says Sandia researcher Elmer Klavetter, cesium and sodium don't appear by themselves. Each combines with water to form a different-sized molecule. "The sodium-with-water molecules are slightly larger than the cesium-with-water molecules," he says. The new CSTs are designed so that cesium ions from waste must travel down narrow channels in the CST molecular structure to reach vacant bonding sites. The slightly larger sodium atoms don't fit. The researchers found that a CST with 7.8 angstroms between lattice planes exhibits the greatest selectivity for cesium. That wasn't an instant discovery, says Klavetter: "We ran through dozens of formulations."

Waste inside tanks can be treated in two ways, says Sandia researcher Norm Brown. One method is to pump a tank's liquid contents out through a column containing the CSTs, trapping the radioisotopes in the column. The other is to dilute the waste, then mix in powdered CSTs and other ion exchangers. The CSTs would trap the radioisotopes and sink to the bottom.

CSTs have potential uses across the DOE complex and at commercial nuclear reactors. Besides their cleanup potential, they could serve as retardation barriers and seals to prevent radionuclide releases from repositories and other storage sites.

Radwaste applications were initially developed with internal R&D funding. CSTs will be manufactured commercially by UOP, which was competitively selected as Sandia's partner for a project funded by Sandia's internal R&D program, DOE, and Westinghouse Hanford.

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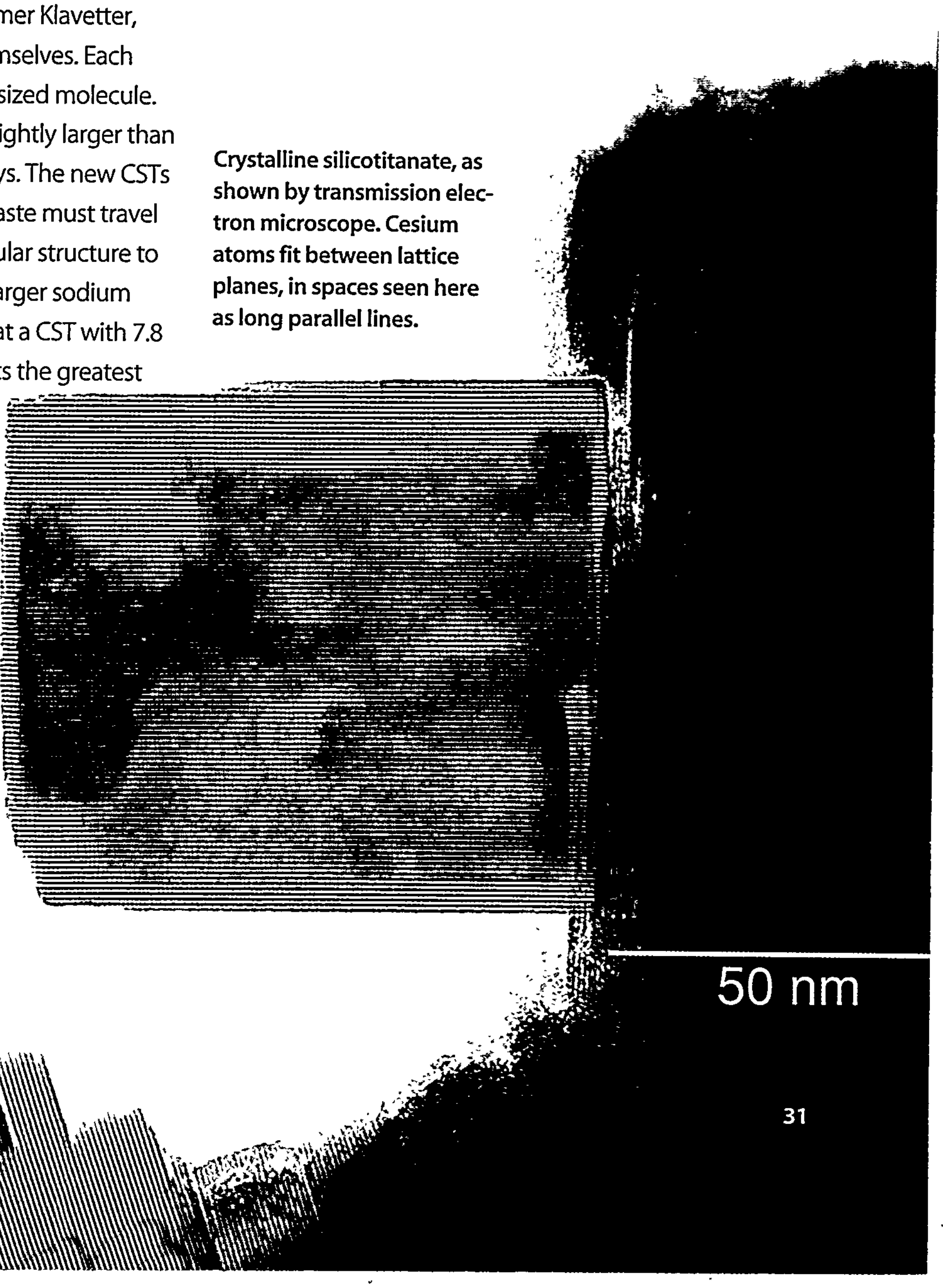


Crystalline silicotitanate, as shown by transmission electron microscope. Cesium atoms fit between lattice planes, in spaces seen here as long parallel lines.

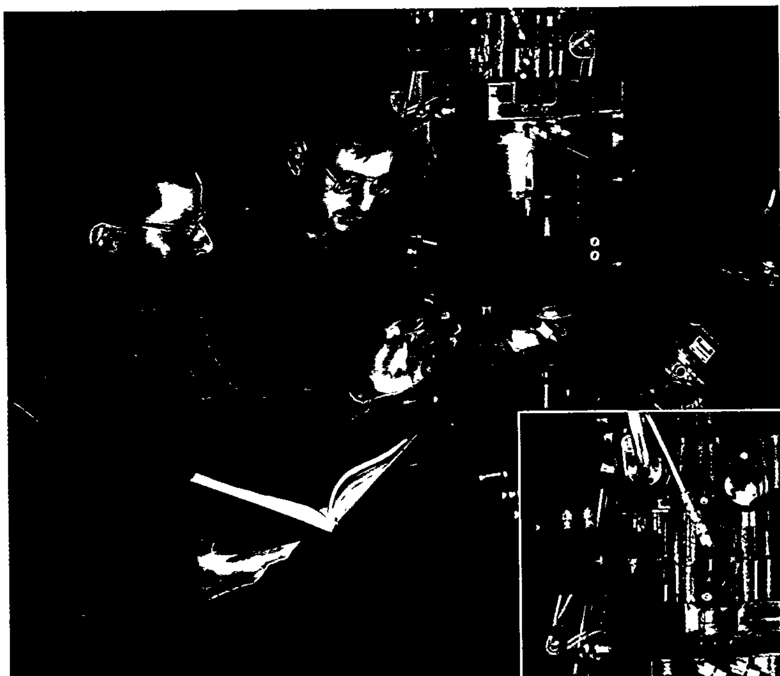
Inside a diesel engine

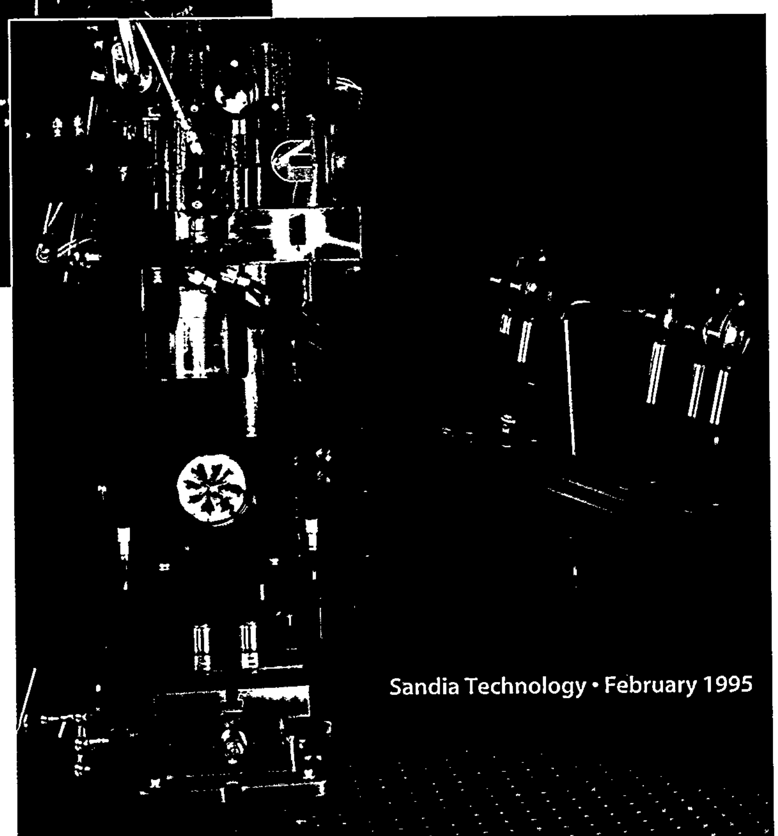
Sandia/Cummins optical-access engine reveals secrets of soot formation

Diesel engines are the most fuel-efficient power plants available for surface transportation, but they also produce emissions that contribute to urban smog. Reducing emissions without a loss in performance is a major challenge for diesel engine makers. To help make the diesel engine more environmentally friendly, Sandia's Combustion Research Facility has formed a partnership with Cummins Engine Company, the world's largest producer of engines over 200 horsepower.

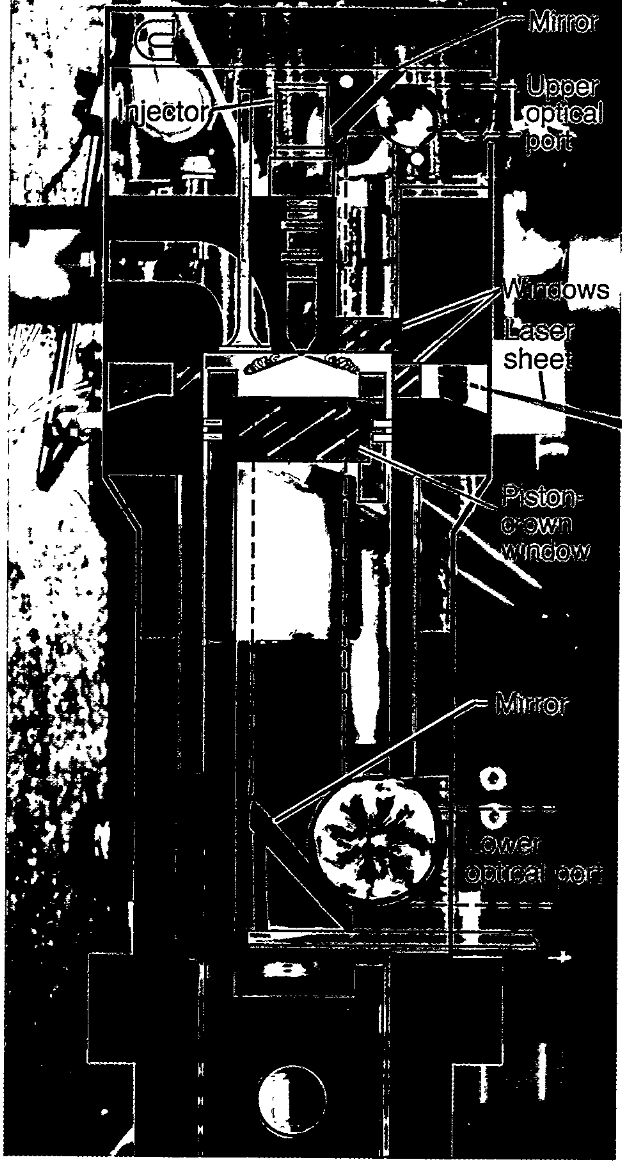
To apply laser diagnostics to diesel combustion, Sandia (in cooperation with Cummins) designed and built a special research engine with windows in the combustion chamber. The engine design provides optical access while retaining the basic geometry of a production Cummins heavy-duty diesel engine. Using advanced laser-based imaging diagnostics, as well as more conventional techniques, researchers have determined that diesel combustion progresses in a very different manner than was previously thought.

Fuel-jet penetration, vaporization, and mixing-process studies with the optical-access engine show that, under typical conditions, the fuel vaporizes by the time it travels about 25 millimeters from the injector. Beyond this point, in the main combustion zone, all the fuel is in the vapor phase. Quantitative fuel-vapor concentration images show that just downstream of the maximum liquid penetration, the fuel vapor is well mixed with air. "These findings contrast sharply with the previously held belief that liquid fuel penetrated far out into the

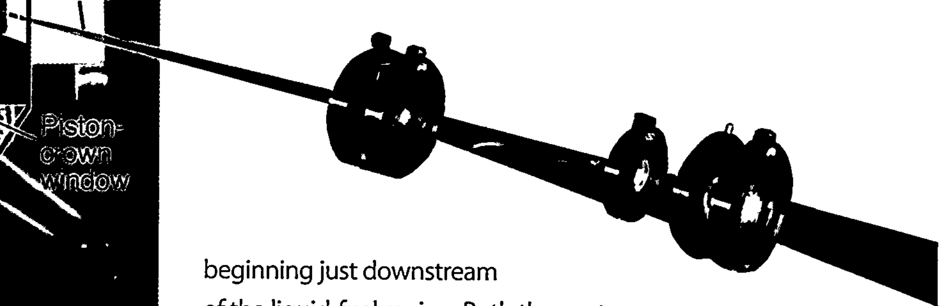




John Dec and Cristoph Espey (above) prepare the optical-access diesel engine for a test run. They are adjusting a video camera to record laser-induced images of combustion activity through an optical port in the engine. (Right) A laser beam (as a planar sheet) enters the combustion chamber along the axis of the fuel jet. The optical port near the bottom of the engine shows all eight fuel jets as they burn.



A schematic of the optical-access diesel engine, showing the mirrors and optical ports that permit viewing the combustion process. The optical-access engine has refined understanding of diesel combustion, providing information that can lead to improved engine design.



combustion chamber and that the diesel jet had a nonreacting core of pure fuel," says John Dec, Sandia's principal investigator on this project, who has worked closely with Cummins-sponsored graduate student Christoph Espey on the studies.

Researchers used a combination of planar Rayleigh scatter imaging (two-dimensional imaging of submicroscopic particles) and planar laser-induced incandescence imaging (imaging of induced thermal radiation) to measure relative soot concentrations and particle-size distributions. Laser-induced incandescence imaging is a relatively new soot imaging technique pioneered on this project and is becoming widely accepted for its advantages over more classic techniques. The soot studies in the Sandia/Cummins engine show that soot occurs throughout the cross section of the combusting fuel jet beginning just downstream of the liquid-fuel region. Both the soot concentration and particle size increase toward the leading edge of the jet, with the highest soot concentrations and largest soot particles occurring at the front of the jet in a region called the head vortex. Clusters of large soot particles from the head vortex persist late into combustion, which means they may never oxidize and may eventually come out the exhaust pipe.

Like the results of the fuel distribution studies, these soot measurements show that the classic model of diesel combustion is incorrect. This model held that diesel combustion occurred as a simple diffusion flame at the interface of the pure fuel core of the jet and the surrounding air. Soot was believed to occur only in a shell-like region around the periphery of the jet. The Sandia/Cummins engine studies show that there is no pure fuel core and that soot occurs throughout the cross section of the combusting fuel jet.

This project is providing a new understanding of diesel combustion, based on laser diagnostics from the optical-access engine and Sandia's data analysis. Sandia is transferring this information to Cummins design engineers to help them develop cleaner and more efficient diesel engines. The information is also being used to guide the development of a predictive computer model that may revolutionize the process of designing diesel engines.

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Containing wastes and costs

Practical new technologies improve waste containment

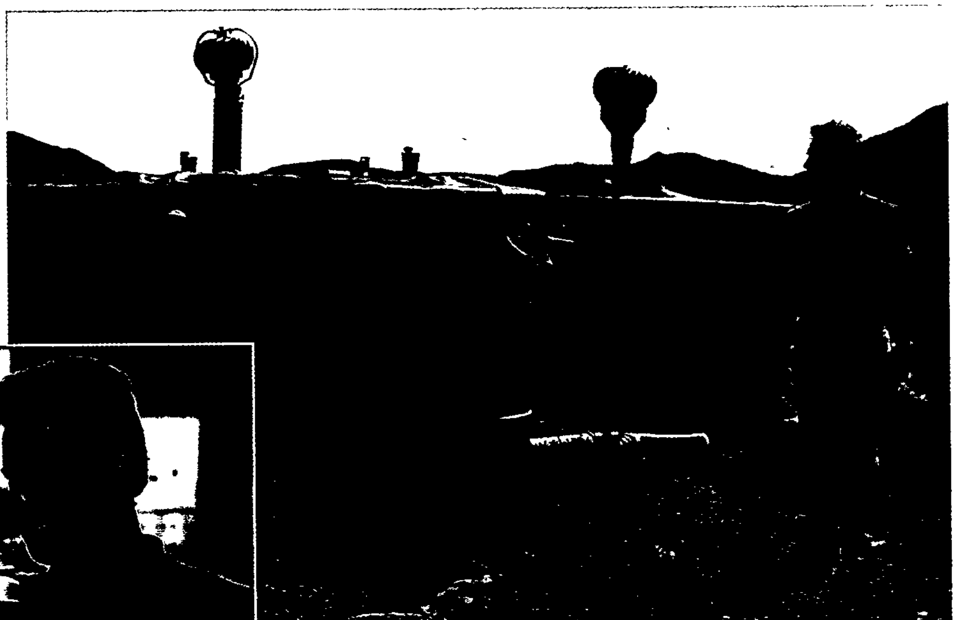
"Suck, muck, and truck" is what people in the environmental remediation business call it. First you excavate and treat (suck and muck), then you dispose (truck), then you pay — a lot. "It costs a fortune to dig up contaminated land, it's difficult to remediate, and then you have to put it someplace else," says Cecelia Williams of the Mixed Waste Landfill Integrated Demonstration program at Sandia.

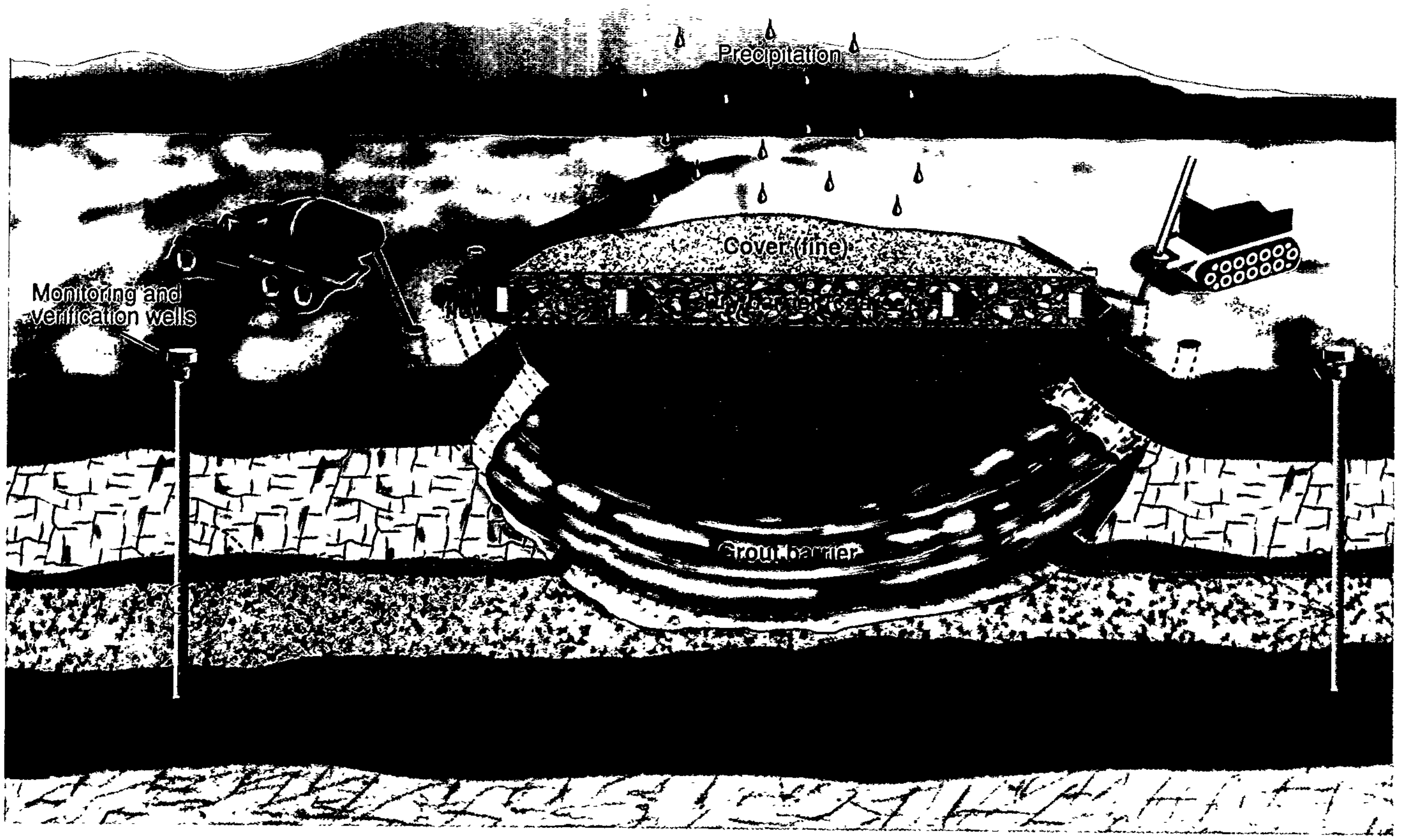
"Our nation can't afford to excavate, treat, and dispose of all the contaminated soil at its 20,000-plus hazardous waste sites," continues Williams. "We're developing a better way." Funded by the Department of Energy's Office of Technology Development, MWLID demonstrates, assesses, and transfers technologies and systems that lead to faster, more effective, cheaper, and safer in-situ remediation of landfills in arid environments.

Few in-situ technologies exist for removing many types of contaminants, especially mobile heavy metals. Fast-moving pollutants, such as volatile organic compounds, can be removed without disturbing the soil before they reach groundwater, using techniques such as thermally enhanced vapor extraction. Slow-moving contaminants, however, are hard to remove, but they can be contained. "Containment allows us to keep the waste immobilized until more effective treatment options emerge," explains Williams. "It does not preclude future treatment options."

MWLID is developing a number of technologies, including subsurface barriers and dry barriers, to contain slow-moving wastes in arid climates where an unsaturated "vadose zone" separates contaminated soil from underlying groundwater. Subsurface barrier technology uses directional drilling to create vertical, angled, and horizontal rows of boreholes in the vadose zone around the waste. The boreholes are injected

(Right) Dry barrier experiments using wind turbines to induce air flow in tanks. (Below) John Stormont checks the water system that adds water to a barrier test. (Opposite page) Artist's concept of how a dry barrier using air flow for drying could be combined with an underlying grout barrier to prevent migration of contaminants to groundwater.





with grout to form a basin-shaped barrier to pollutants. Brian Dwyer, Sandia's principal investigator on the grout barrier project, is demonstrating subsurface barrier technology using two approaches: 1) injection of a low viscosity grout into the soil at low pressure that fills voids surrounding the boreholes; and 2) grout injection at high pressure and velocity that mixes the grout and soil to form a barrier composed of continuous, interconnected soil-grout columns.

Dry barriers feature a fine layer — usually native soil — that limits downward water flow, plus an underlying, coarser layer through which air flows laterally to evaporate any water that reaches it. "The air-enhanced dry barrier can underlie the waste, functioning as a final barrier to contaminant leaching and as a method for stripping away denser-than-air contaminant gases, such as trichloroethylene," explains John Stormont, principal investigator for the dry barrier project. "It can also be a component of a cap or cover system that limits vertical infiltration through the cap."

While commercialization of subsurface barrier technology — the basin-shaped barrier made of grout — is probably two years down the road, MWLID is already transferring air-enhanced dry-barrier technology to commercial use through Daniel B. Stephens and Associates Inc., an Albuquerque environmental firm. In addition, MWLID is actively involved in a landfill cover demonstration project to help the Environmental Protection Agency develop landfill cover designs suited for the arid climate of the southwestern United States. "Because every hazardous waste landfill in the Western states will require closure with a cover system, there is a tremendous commercialization potential for advanced landfill cover technology," notes Williams. "Just in New Mexico, there are 156 known landfills."

For these and thousands of other landfills across the Southwest, barrier technologies are welcome alternatives to costly excavation, treatment, and disposal. Subsurface barriers and dry barriers can not only contain wastes effectively; they can also contain the costs associated with environmental remediation.

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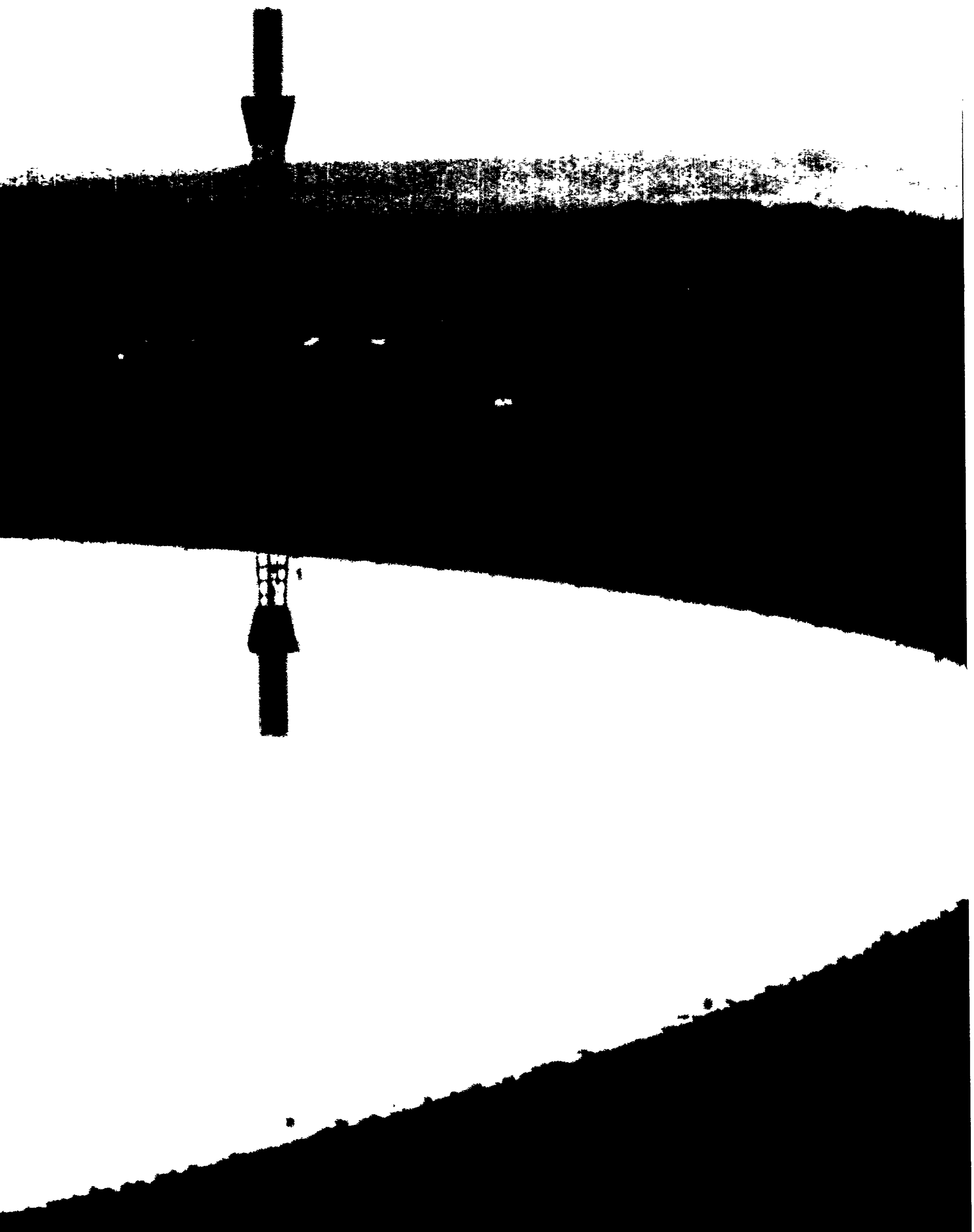
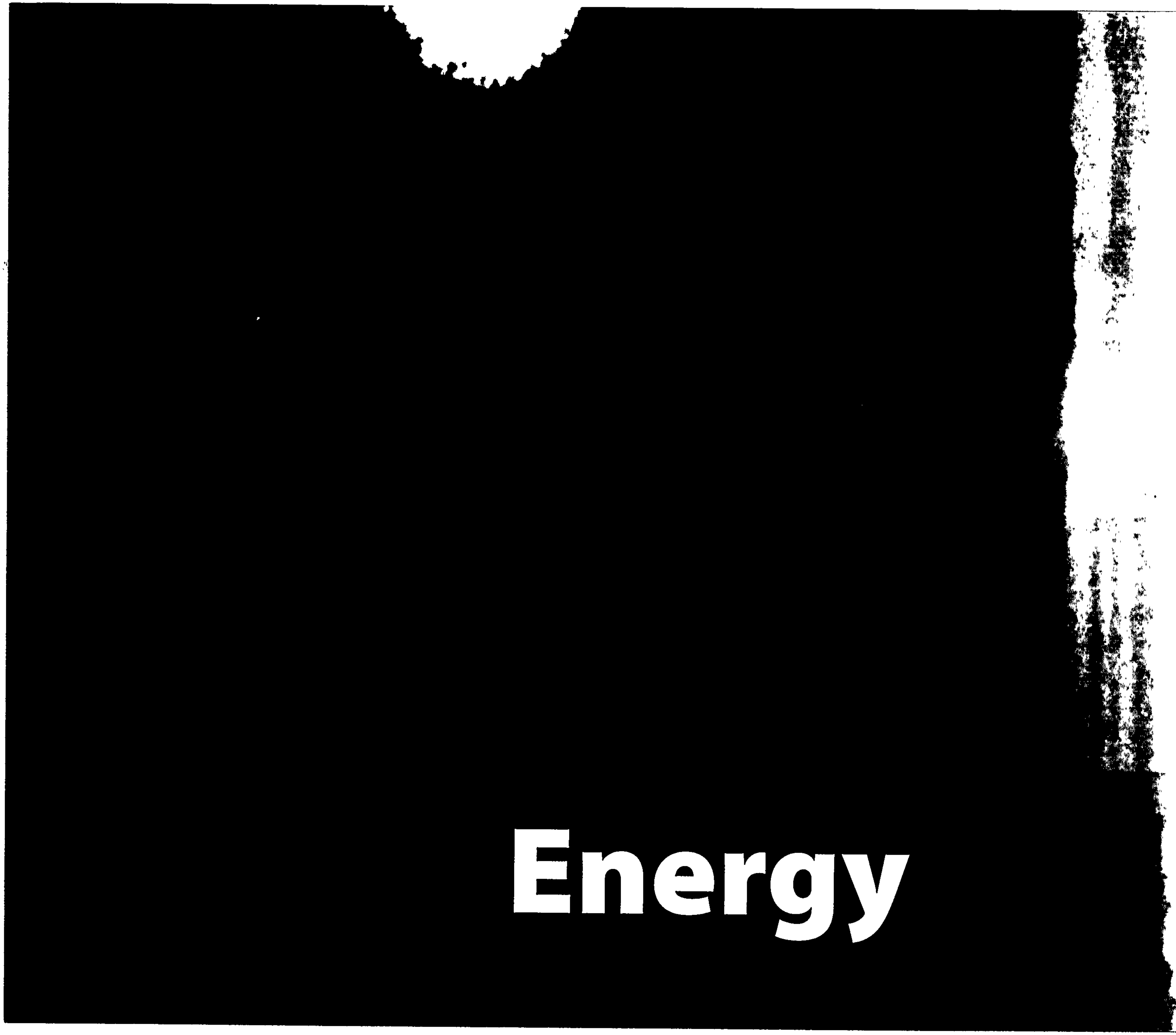



Energy

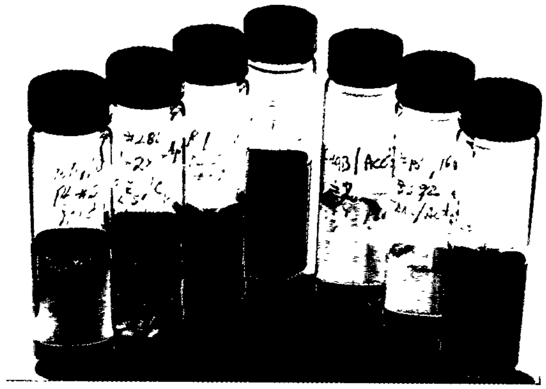
Tiny chunks of catalysts

Sharon Craft works with nanocluster solutions.

Nanoclusters could boost coal liquefaction

Nanoclusters — tiny chunks of matter containing from a few to several thousand atoms — range from a few nanometers to tens of nanometers in size. Too small to form bulk material, too large to be understood as atoms or molecules, nanoclusters have peculiar properties that make them ideal catalysts. Sandia researchers are exploring the intriguing possibilities these odd particles offer, such as creating liquid fuels from coal.

In a nanocluster, a large fraction of the atoms are near the surface (simply because of the small size), and the surface atoms can't arrange themselves into a complete crystalline structure. Instead, atoms are packed into faceted shapes, with extra vacancies at some spots where atoms might normally be located in a crystal. These vacancies are believed to be important in catalysis. The small size also affects electronic structure:



electrons can't move about as freely as in bulk material, and thus can't settle into their lowest energy state. That makes nanoclusters unstable and difficult to fabricate, especially in large quantities.

A patented method developed by Sandia researchers overcomes the difficulty by growing nanoclusters inside molecular "cages." The cages form when surfactant (essentially, soap) molecules group together in oil and create what's called an inverse micelle, a tiny space whose dimensions control the size of nanoclusters that grow inside.

Among the nanocluster catalysts studied by Sandia scientists are inexpensive materials such as iron, iron sulfide, and molybdenum disulfide. These inexpensive materials might substitute for precious-metal catalysts. They are cheap enough to be disposable, an important feature when a catalyst can't be recovered after use, as is the case in a number of potential coal liquefaction processes.

In one set of liquefaction experiments, the presence of iron sulfide nanoclusters increased the yield of useful hydrocarbon materials from coal samples by 50 percent, while decreasing the amount of undesirable products. In a study of direct coal pyrolysis, another coal liquefaction process, iron was effective only in nanocluster form. "It didn't work as well as commercial palladium catalysts," says researcher Jess Wilcoxon, "but iron is much cheaper. These results suggest trying an alloy of an inexpensive material like iron and a more traditional catalyst such as palladium. We're beginning work on nanoclusters made of such alloys." In other experiments, using molybdenum disulfide nanoclusters, the nanoclusters were six times more active than a commercial palladium catalyst.

How close are these results to producing a commercially useful catalyst for liquefying coal? At the current low price of crude oil, says Wilcoxon, liquefied coal fuels can't compete. But he and his fellow researchers have their eyes on an inevitable future. "We're trying to do work that will be valuable later, as oil supplies are exhausted and the price rises," says Wilcoxon. A shorter-term use, he adds, might be to use nanoclusters to help remove sulfur from coal to be burned in power plants.

Possible uses for nanoclusters are just beginning to open up. Their unique properties could make them useful in cleaning up pollutants, creating new types of semiconductor materials for information storage in extremely small spaces, or developing lasers that operate at desired wavelengths.

Right now, though, Wilcoxon is most interested in energy. "We've chosen a hard problem," he says, "one that's worth working on for a long time, because it has so many implications for our long-term energy supply."

Left: Properties of nanoclusters depend largely on particle size. Thus, solutions that are chemically the same can have different colors and different catalytic effectiveness because they contain nanoclusters of different sizes.

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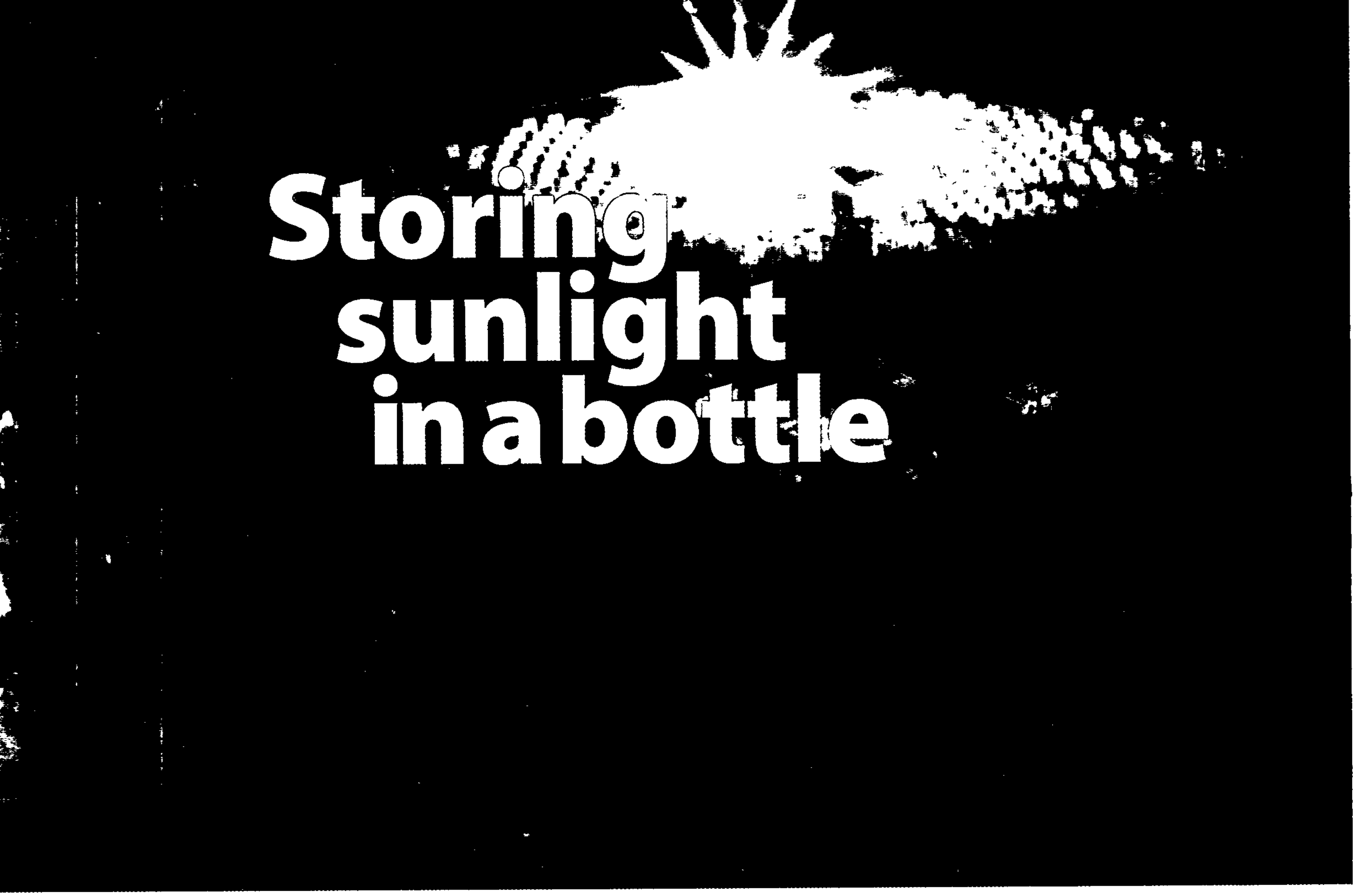


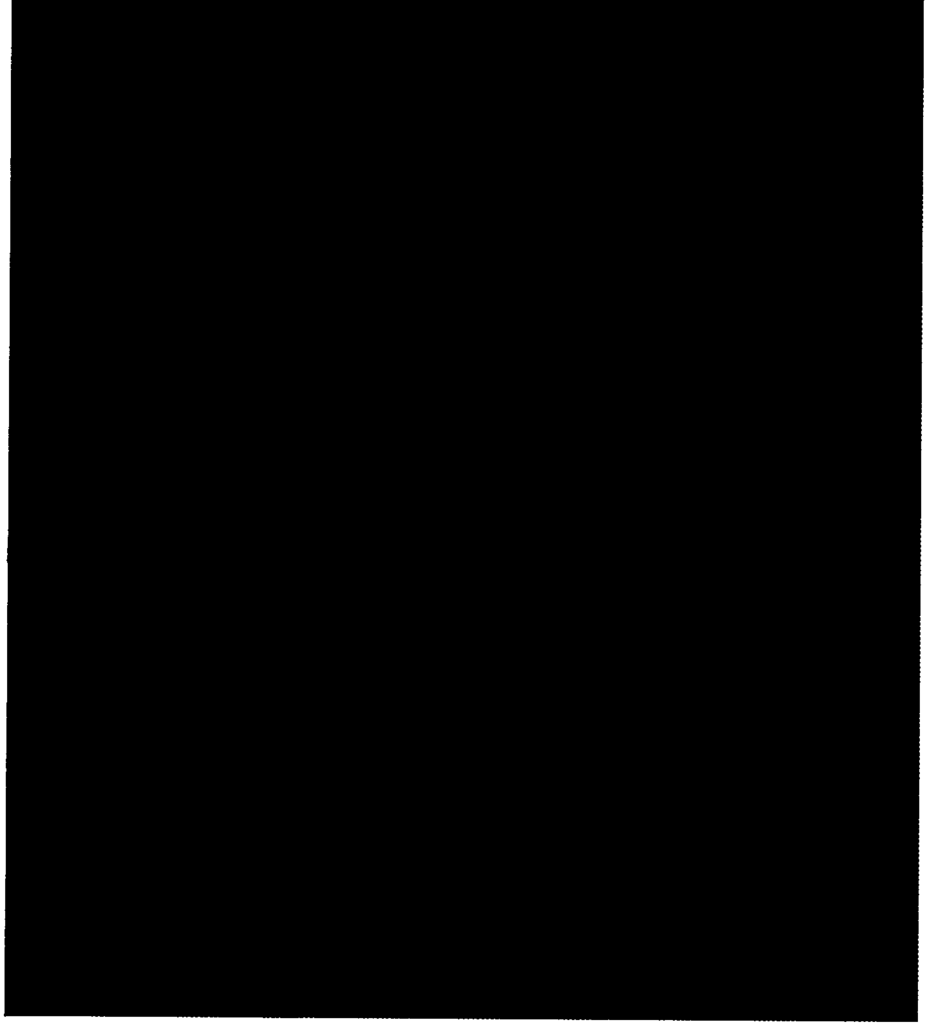
Storing sunlight in a bottle

Sandia transfers molten-salt technology to Solar Two demonstration plant

There's a bridge that must be built before utility-scale solar power becomes reality. Don Brundage of Southern California Edison calls it the "confidence bridge." That bridge is Solar Two, a 10-megawatt solar power plant under construction in Barstow, California. Southern California Edison, supported by Sandia National Laboratories, leads a consortium of utilities, industry, and government agencies that is building the central receiver power plant. The Solar Two project will help create the confidence that utility executives and investors need to commercialize solar central receiver plants 10 to 20 times the size of Solar Two.

A lot of that confidence is already there, thanks to years of work by solar engineers at Sandia, a key Department of Energy laboratory for solar thermal electric technology. "Sandia is the keeper and purveyor of this technology," says Brundage. "Sandia has demonstrated the technology's key components, and is helping transfer this technology to industry through its technical advisory role in the Solar Two project." Sandia also supports DOE management for Solar Two and provides design input as a member of the Solar Two project team.

Solar central receiver technology has been under development since the mid-1970s. A central receiver system consists of a field of sun-tracking mirrors that concen-



The Solar One demonstration plant at Barstow, California. Solar One is being converted to Solar Two, a molten salt electrical power plant.

trate sunlight onto a central receiver on the top of a tall tower. The thermal energy from the receiver makes steam that powers a turbine generator.

Solar central receivers, also called power towers, promise to provide our nation a clean, inexhaustible, and secure supply of electricity. Experts project that power towers will be economically competitive with conventional power plants, especially when environmental costs are considered. U.S.-built power towers could also find their way into foreign markets where conventional electric power is more expensive.

Solar Two is a retrofit of Solar One, which came on-line in 1982 and operated successfully for six years. However, Solar One was unable to store energy efficiently. In Solar Two, molten nitrate salt — similar to the nitrate salt found in common chemical fertilizer — will be used instead of water to transfer heat from the receiver. Molten salt, because it stores heat more efficiently than water, can be used to make steam hours after sunset or even while clouds block the sunlight.

Sandia has worked with industry since the late 1970s to develop a practical molten nitrate salt system. "We tested three salt receivers at Sandia," explains Sandia solar engineer Jim Chavez, chairman of the Solar Two technical advisory committee. "We also tested and proved a commercial-scale salt thermal storage system — the pumps, valves, piping, and all the associated equipment required to make the system work."

Aside from new equipment for the molten salt storage system, Solar Two will reuse many components originally built for Solar One. This retrofit approach means that costs for Solar Two will be less than a third of the original $150 million invested in Solar One. The conversion costs are paid for through a 50-50 cost sharing arrangement between DOE and the consortium led by Southern California Edison. Scheduled to begin operation in 1996, Solar Two will provide 10 megawatts of electrical power, enough for as many as 10,000 homes. But more important than its size, Solar Two will give the consortium the opportunity to evaluate and build confidence in this emerging technology. If all goes as planned, Solar Two will be a bridge to large-scale, cost-effective, pollution-free solar energy.

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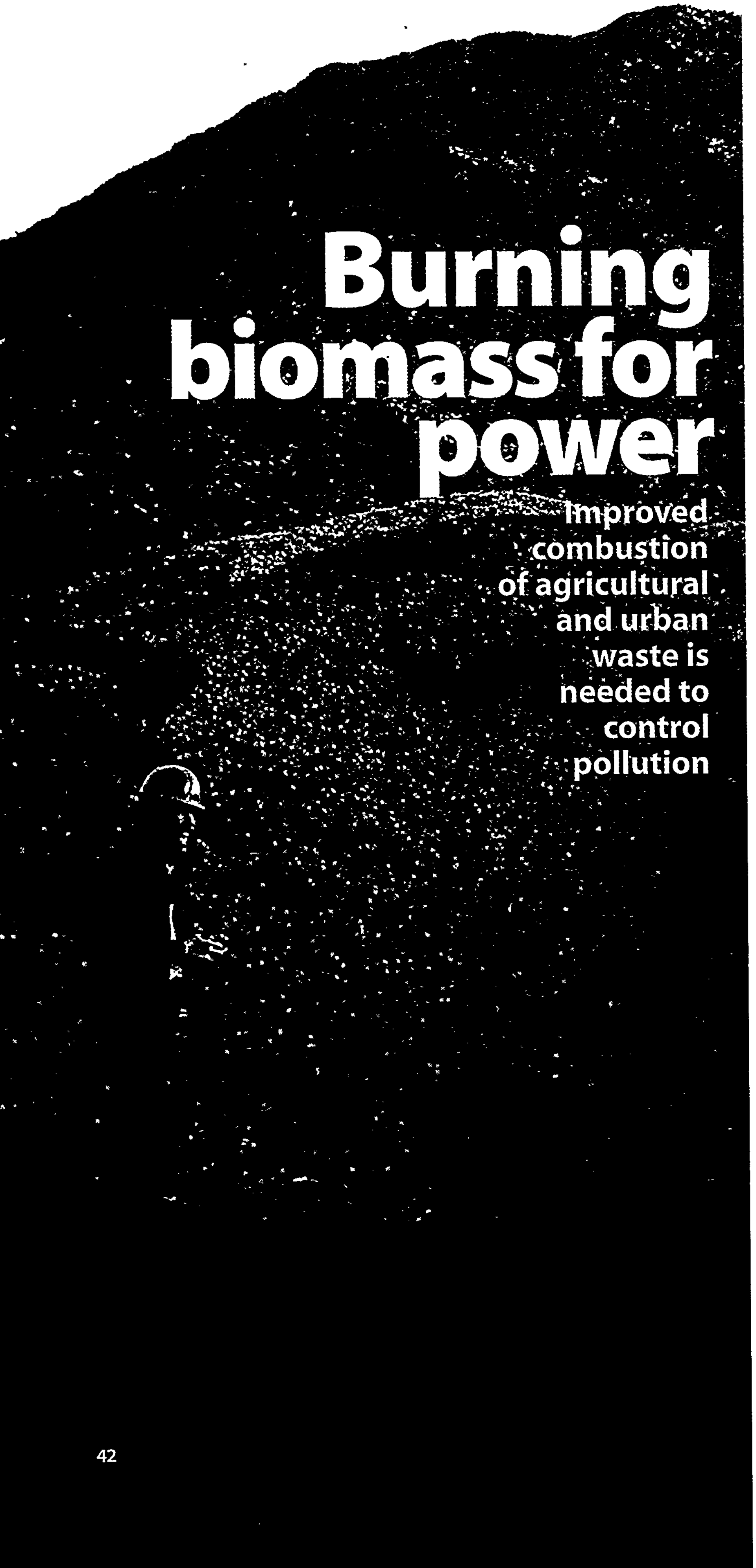


Burning biomass for power

Improved combustion of agricultural and urban waste is needed to control pollution

Domestic energy resources are ending up in our nation's landfills and going up in smoke. Farmers burn straw from their fields. Nut and fruit processors send their pits, hulls, and shells to landfills or burn them in the field. Tree branches, lumber from demolished buildings, and nonrecyclable paper are being burned or buried.

Instead of being wasted, these biomass materials can be used as fuel by independent energy producers to generate electricity. And because carbon dioxide produced by combusting biomass fuels is recaptured by growing new biomass fuels that consume carbon dioxide, biomass energy production does not significantly increase the net amount of carbon dioxide, a greenhouse gas, in our atmosphere.

Realizing these advantages, and spurred by price guarantees and other incentives, California power producers lead the nation in biomass power generation. However, the state's incentives will soon expire, forcing direct competition with traditional sources of electricity. To survive, California biomass power producers must find fuel blends that minimize boiler fouling, a serious problem that leads to significant down time. Producers are doing this through collaborations with Sandia/California's Combustion Research Facility.

Sandia's work is sponsored by a group of 10 biomass industry participants, the National Renewable Energy Laboratory, and DOE's Energy Efficiency and Renewable Energy Office. The research team includes members from government, industry, and universities.

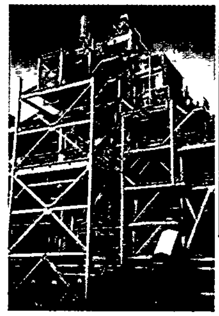
One important biomass resource, straw, is particularly prone to ash deposition that fouls boilers. "Straw has a high fraction of inorganic material in its structure," says Larry Baxter, Sandia's principal investigator on the project. Three-fourths of the inorganic material is silica; one-fifth is potassium. "Modeling and testing at our Multifuel Combustion Laboratory, corroborated by field tests, show that silica by itself poses no real problem," adds Baxter. "But the potassium in straw lowers the ash melting temperature, promoting the formation of glassy molten deposits that force operators to shut down too often for cleaning."

Baxter and his co-workers diagnosed the causes of straw ash deposition using analytical tools originally developed for modeling coal combustion. "Our generalized approach embraces a wide range of fuel variations, combustor types, and operating conditions, so we do not need to develop extensive databases or testing procedures for each new situation," says Baxter. He notes that this approach is also the basis for a new computer program that will model ash deposition in biomass boilers.

To comply with the Clean Air Act in California, operators of some newly built biomass boilers have promised to use straw for about 20 percent of their fuel, because burning the straw as a biomass fuel generates much less pollution than field burning, creating a net reduction in emissions. Solving the straw ash problem is essential to meet this requirement, and Sandia researchers are now investigating solutions.

As Baxter says, "We are looking at several possibilities, including decreasing operating temperature, improving boiler design, and finding appropriate fuel blends that minimize potassium levels."

Other projects undertaken by the consortium include laboratory analyses of over a dozen biomass fuels (wood, nutshells, fruit pits, etc.), as well as field tests of many major commercial boiler designs for biomass combustion. As Bill Carlson, general manager of the Wheelabrator-Shasta Energy Company, a biomass industry participant, says, "To compete with other energy sources, today's biomass industry needs models that predict how different fuel blends perform in our boilers. Sandia is providing us the capability to predict performance of fuel blends, which will avoid costly trial and error."




(Left) The bubbling fluid bed biomass combustor at Delano, California, operated by ThermoElectron Energy Systems. (Right) Sandia's Multifuel Combustor in operation, using lasers and other instrumentation to study ash deposition rates for biomass materials and other fuels. Sandia's laboratory and field research is looking for ways to improve biomass combustion. (Opposite page) Bryan Jenkins, on sabbatical to Sandia from UC Davis, examines a supply of walnut shells, one of the fuels tested at Wheelabrator's biomass combustor in northern California.

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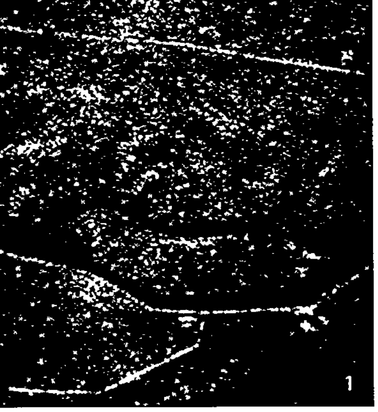
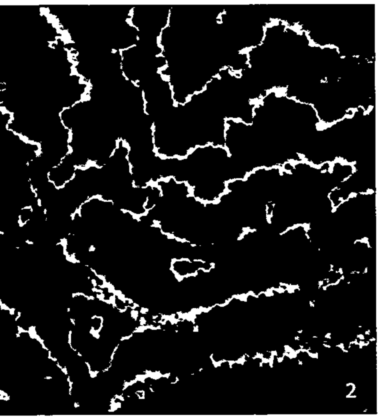
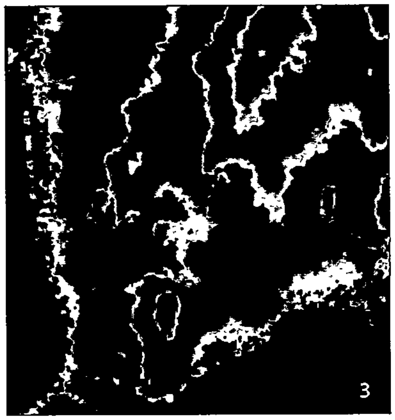
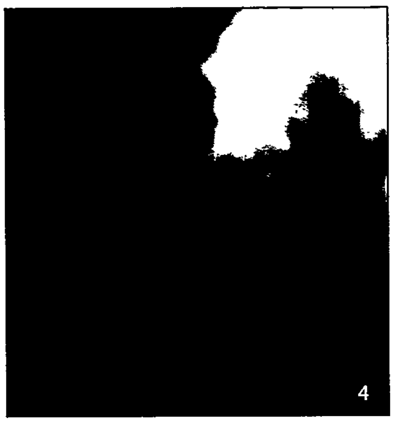
Nonproliferation

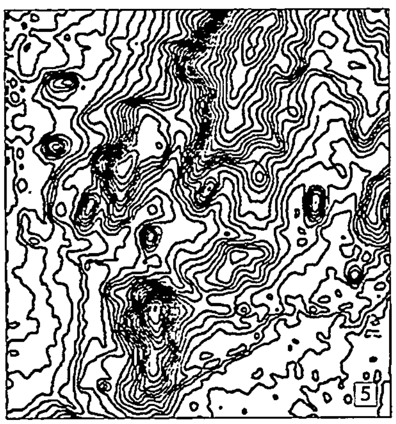
Mapping
molehills











(1) A synthetic aperture radar image. Two SAR images can be combined to provide accurate terrain-height information.

(2) An interferometric fringe image created by processing two SAR images.

(3) An interferometric fringe image corrected for wavefront curvature.

(4) A digital terrain height map in which lighter shades show higher elevation.

(5) A contour map calculated from IFSAR data.

Terrain height accurate within centimeters

How high is that hill — really? The question isn't as simple as it seems, especially when dealing with inaccessible terrain. Measuring elevations accurately —within centimeters — is virtually impossible with conventional methods. Techniques approaching that accuracy, such as low-level aerial surveys, don't work in clouds or darkness and usually aren't practical for large expanses. But a new Sandia technique using interferometric synthetic aperture radar can, even in bad weather, create maps in which height is accurate to within a few centimeters.

Interferometric SAR compares two radar images made at slightly different angles and uses them to create three-dimensional information. The images can be obtained in two passes by an aircraft carrying a single antenna, or in a single pass by an aircraft with two antennas. IFSAR builds on conventional SAR, in which a radar system moves across an area, receiving echoes that are processed to produce an image resembling an aerial photo.

The mathematics of the Sandia method treats radar scans like medical CAT scans, explains Charles Jakowatz, leader of a Sandia group working on IFSAR. "We extended what other people had noted about the CAT scan analogy, and we found a better way to describe IFSAR mathematically and do the computations." The improvements include a spotlight mode of image processing for ultrahigh resolution, the ability to handle two-pass data collection even when the collection platform follows ground tracks that cross at an angle, and a simple way to relate phase difference between two SAR images to terrain height. The work was funded by DOE's Office of Arms Control.

In effect, IFSAR creates a grid of an area and finds the elevation of each cell of the grid — whether natural landforms or artificial objects such as buildings. Contour maps or perspective views are typical products. But once captured and processed by computer, the IFSAR data can be used in many ways. "For example," says Jakowatz, "two images obtained at different times can be processed to highlight changes between the two passes — even small changes, such as vehicle tracks, not detectable in either SAR image alone."

Using high-resolution SAR hardware, the Sandia team creates maps and other displays with a horizontal resolution of 1 meter. Most IFSAR work has previously been done with radar systems whose resolution is tens of meters, sufficient for an ecologist mapping the extent of rain forests or urban development, but not good enough for many military uses.

According to Rick Fellerhoff, of Sandia's Aided Navigation and Remote Sensing Systems Department, IFSAR could be used as part of an interferometric terrain-aided guidance system. Such a system would let a cruise missile or reentry vehicle deliver a conventional weapon with an accuracy potentially better than three meters. Or the guidance system could be used for precise delivery of other weapons, such as air-dropped bombs. "This ability could be valuable in destroying an adversary's ability to produce or deliver weapons of mass destruction," says Fellerhoff. "A strike could be made in any weather, with a minimum of collateral damage." The concept for such a guidance system, relying on Sandia's advanced radar alti-metry, high-accuracy navigation systems, and IFSAR, is being validated in flight tests.

Jakowatz points out other uses for extremely accurate IFSAR. "People going on a rescue mission — military or civilian — in difficult terrain could rehearse the mission with simulators. Helicopter pilots would get a realistic preview of how to fly in, and ground personnel being dropped off by helicopter would see in advance the details of the terrain they were to operate in."

Jakowatz believes that satellite-borne SAR could map the entire Earth, with elevations accurate to within about a meter. That information would be valuable both for defense purposes and for civilian applications such as oil exploration or geological research — reflecting a truly global potential for IFSAR.

(Top) Synthetic aperture radar image of a landfill with vehicles, equipment, and an excavated trench.

(Bottom) If a second SAR image of the same area is obtained later, combining the two images can reveal changes caused by intervening activity. Here, soil disturbances appear as dark areas where vehicles have traveled and bulldozers have moved earth.

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Cold war gives way to hot projects

Former adversaries cooperate on high temperature technologies

It's cold in Russia, no doubt about it. The ubiquitous fur hats seen in outdoor photos during the Russian winter are functional, not decorative. But relations between Russian weapons labs and U.S. weapons labs are getting warmer all the time. Visits to Russia in the spring of 1994 by Sandia representatives have resulted in several partnership agreements with Arzamas-16 and Chelyabinsk-70, the major Russian nuclear weapons institutes. Sandia's efforts are supported by Congressional programs designed to find useful work for Russian weapons experts and thus support the goals of nonproliferation.

One such effort is the Industrial Partnership Program, in which Sandia scientists and engineers work with their Russian counterparts to identify technologies with good potential for commercialization. Sandians and Russians then work together to demonstrate the capabilities of the selected technologies. The next step brings U.S. companies into contact with the Russian technology, through the U.S. Industry Coalition, part of the partnership program. With industry involved, specific applications can be developed that benefit the U.S. partner's technology base and provide economic benefits to the Russian labs.

Two current projects under development in the IPP involve different technologies operating at high temperatures. One project focuses on deep drilling in the Earth's crust; the other brings in technology developed for the Russian space program.

"The Russians are the experts at deep hard-rock drilling," explains Dennis Croessmann, project manager for Sandia's IPP efforts. "They have the specialized equipment to drill and maintain holes 12 kilometers deep." Major oil and gas companies as well as small businesses in the U.S. are interested in this Russian technology, which includes cements to seal the boreholes along their lengths. The sides of the drilled shafts have to be sealed to keep oil or gas from contaminating freshwater aquifers along the length of the borehole; the cements used in such deep wells have to be effective at high temperatures to

Al Narath, president of Sandia, and Yuli Khariton, scientific director emeritus of Arzamas-16, met by chance on the way to Arzamas-16. Such a meeting would have been impossible just a few years ago.

prevent collapse of unstable borehole walls. In addition to oil and gas exploration and production, this technology may be useful in other deep drilling applications, such as sealing the shafts of wellbores drilled to test waste disposal sites.

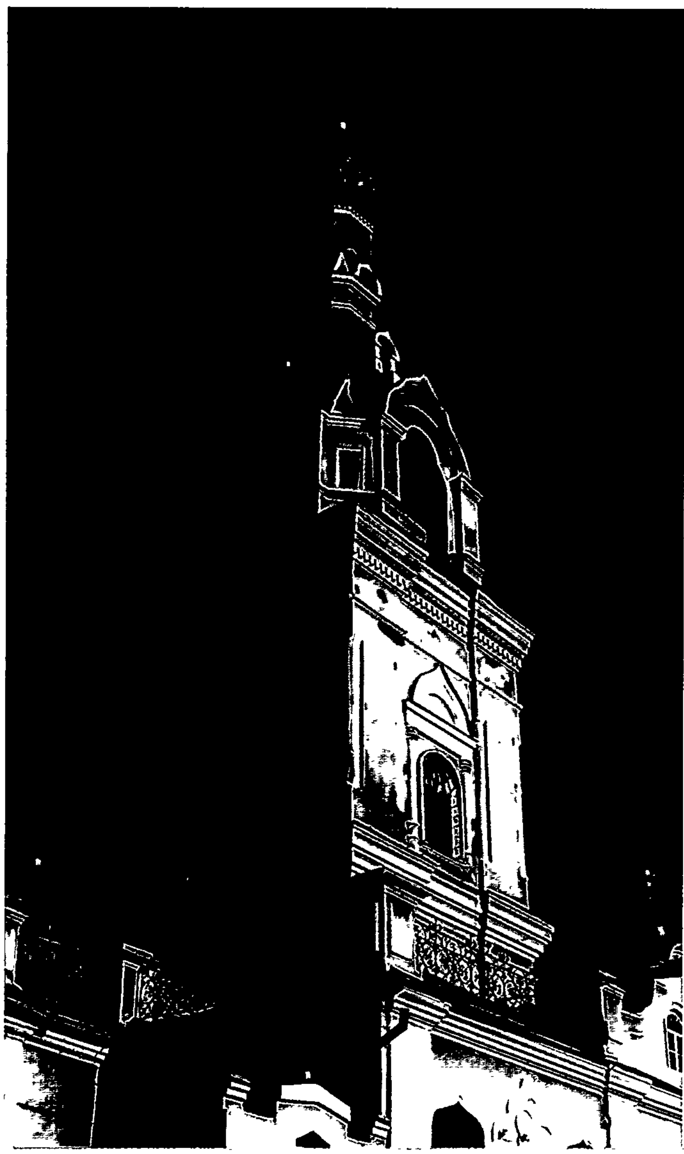
Another Russian technology for high-temperature applications comes from their space program. The Russians are ahead of the rest of the world in nuclear reactors for space applications, and this includes the electronics for sensing reactor conditions. The material on which these electronics are based is silicon carbide, and it could form the basis for sensors in many extreme environments, including combustion engines, turbines, and geoscience applications. U.S. electronics firms are now working with the Russians to develop applications for this technology.

"Just as our U.S. national labs and defense companies are looking at dual-use (commercial and defense) technologies, the IPP is working with Russian defense technologies in commercial applications," says Croessmann. "Getting the Russian labs involved in commercializing technology keeps their weapons experts working on projects that help the Russian economy and help our own nonproliferation goals."

Wide-ranging agreements between United States and Russian laboratories support technology transfer and commercialization

Sandia National Laboratories has signed As Ordered Agreements with Arzamas-16, Chelyabinsk-70, and the Kurchatov Institute, a nuclear research center. These AOAs are umbrella agreements that shelter a number of projects, including work with the Industrial Partnership Program. Sandia President Al Narath visited Russia in May 1994 to sign the agreements with Arzamas-16 and Chelyabinsk-70; the agreement with the Kurchatov Institute was signed later that summer. Even before IPP began moving Russian technology into commercial areas, projects in energy, the environment, biotechnology, and nuclear reactor safety had helped develop good relations between the Russian labs and Sandia.

(Previous page)
Anatoly Agapov, a research physicist at Arzamas-16, guided many Sandians around the area on impromptu historical and archaeological tours.



The steeple of the monastery in the city of Arzamas-16. During the Cold War, the Russians nearly razed the building, fearing it could aid U.S. targeting of the research center in the event of war.

For more information, call
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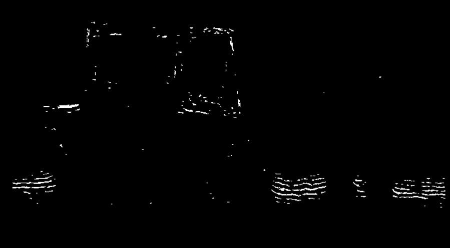

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Sandia's scannerless laser radar system produces images that provide distances to everything in the field of view. (1) Color enhancing with contour lines similar to those on a topographical map shows gradations in distance; the person in the photo is 57 feet from the camera, the cart 62 feet. (2) In the grayscale image, the dark foreground is closest to the camera, the light background farthest. (3) Data for the images was collected by actively illuminating the scene with a laser. (4) A nighttime photo shows how closely the ladar data corresponds to a camera view.

Automated eyes are watching

Laser radar sees what humans miss

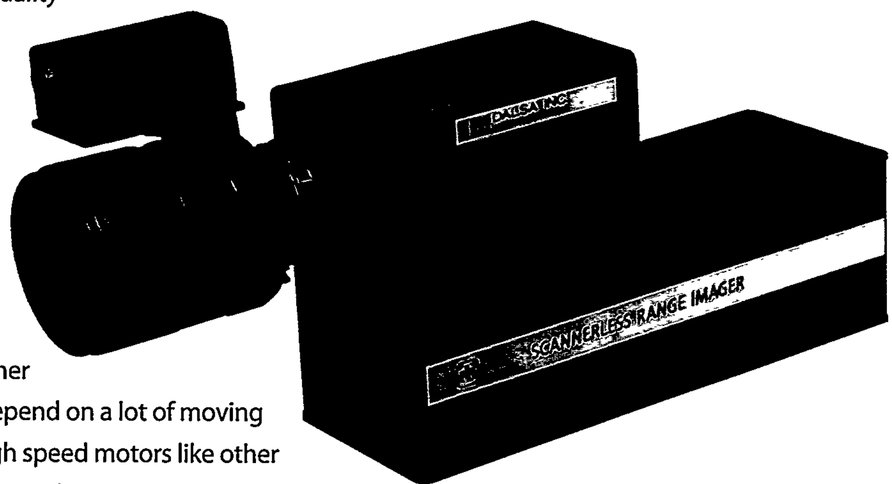
The intruder, the sniper, and the mine layer all have one thing in common: for their work to succeed, it must be hidden.

But a new Sandia technology makes it possible to uncover their activities without being noticed. It can detect an intruder breaching a fence, a hidden sniper, or an underwater mine. Scannerless laser radar can record images much faster than the unaided human eye can interpret a flash of light used to illuminate a scene, and it can "see" a wavelength to which the human eye is not very sensitive. Because the technology combines both radar and light, it accurately measures the distance to all objects in the field of view, improving detection and reducing false alarms.

Currently being developed for the Department of Energy for perimeter surveillance and for the Department of Defense for smart weapon applications, scannerless ladar (ladar is short for laser radar) also has a variety of potential nonmilitary uses. It could be used to help spacecraft "see" the contours of a space station and land and dock autonomously. It could map and monitor the pavement condition of highways and check them for wear and tear. It could survey and assess hazards or unknown environments, such as underwater mines, damaged nuclear reactors, or collapsed buildings.

In an advanced manufacturing environment, scannerless ladar could be coupled with computer codes to enable a robot to manipulate objects in its workspace. "The system collects and processes data so quickly that it could actually inspect every part on an assembly line and stop the machinery immediately if something goes wrong," says researcher Randy Schmitt. "This is far more effective than inspecting only every 1,000th part, for instance, after hundreds of parts might have been damaged."

Ever since scannerless ladar was invented by Sandia engineer Marion Scott in 1990 and patented by DOE, researchers have been working hard to perfect it. Their goal has been to develop a cheap, fast, reliable system for identifying targets and measuring distance that is easy to operate and produces high-quality images. The result: a system built with parts costing one-tenth to one-fifth as much as those used in conventional scanner systems and that is as useful for guiding a missile as it is for guiding a robot.



Sandia's portable laser radar system consists of a laser transmitter and receiver, along with a personal computer.

What's unique about the technology, says Sandia researcher Tim Cooley, is that it does not depend on a lot of moving parts, expensive mirrors, and high speed motors like other scanning systems. In fact, the scannerless ladar is sometimes called a "staring" system, notes researcher John Sackos, because its image-sensing CCD (charge-coupled device) camera doesn't move. Instead, the system floods the field of view with laser light and registers the return signals all at once to produce an image divided into picture elements much like the image on a television screen.

Each picture element, or pixel, has a range determined by distance measurements taken with an inexpensive light source (either a laser or light-emitting diode). The system can collect data for 65,536 pixels simultaneously (in rows of 256), and the sensor can be moving or stationary when it registers an image. Distance measurements make it possible to distinguish, for instance, an intruder from background clutter and know when the intruder passes a certain boundary.

Perhaps best of all, the system is portable. It consists of three basic parts: a laser transmitter, an image-intensified receiver (the camera), and a computerized signal processor. Currently, the whole system is the size of a video camera and a personal computer. Future versions will have even smaller components. Eventually, researchers hope, both the image intensifier and the CCD camera will fit inside a cup, making the product the size of a camcorder.

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John Sackos
Electronic Fuzing and Sensors
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SiXTRON
CSRL

Awards and Patents

Awards

Professional society and prestigious awards

Jim Asay	Aeroballistic Range Association 1994 Aeroballistic Award
Richard Brow	American Ceramic Society Karl Schwartzwalder-Professional Achievement in Ceramic Engineering (PACE) award for his study on the short-range structure of novel glasses and how that structure can be manipulated to obtain specific thermal, optical, and chemical properties
Bob Easterling	American Statistical Association/National Science Foundation/National Institute of Standards and Technology Research Fellowship
Blase Gaude	*Careers & the disAbled* magazine Disabled Engineer of the Year
James Gee Electric Power Research Institute U.S. Department of Energy Amonix, Inc. SunPower Corporation	R&D 100 Award for development of a high-performance silicon photovoltaic cell
Dan Hartley	Georgia Institute of Technology Academy of Distinguished Engineering Alumni
Jack Houston Terry Michalske	R&D 100 Award for development of an interfacial force microscope
Yong Hwang Pang Chen	R&D 100 Award for development of a computer code (SANDROS) for planning paths for robotic controllers
Bob Luna	American Society of Mechanical Engineers fellow
Tom Mancini	American Society of Mechanical Engineers fellow
Sam Martin	Academy of Mechanical Engineers at Texas Tech University
Nestor Ortiz	*Hispanic Engineer* magazine Professional Achievement Award
Jose Rodriguez	*Hispanic Engineer* magazine Outstanding Technical Achievement Award
Richard Schneider Jeffrey Figiel James Lott (U.S.A.F.)	R&D 100 Award for development of red-light vertical-cavity surface-emitting laser (VCSEL)
Eric Snyder Donald Pierce Scot Swanson David Campbell (Analog ASICS) Sandia IC Simulation Modeling Dept.	R&D 100 Award for development of a SHIELD™ test chip that allows reliability characterization at the full operating frequency of a semiconductor technology using only a few inexpensive direct-current components
Jim Schwank	Institute of Electrical and Electronics Engineers fellow

Cecil Sonnier	Institute of Nuclear Materials Management Distinguished Service Award for leadership in the international safeguards community by fostering the role of containment and surveillance technology, which has greatly enhanced the INMM international safeguards
John Stormont	International Association for Computer Methods and Advances in Geomechanics, Junior Researchers, Constitutive Laws and Applications Significant Contribution Award for co-authoring a paper titled "Prediction of Dilation and Permeability Changes in Rock Salt"
Tamara Ulibarri	*Hispanic Engineer* magazine Most Promising Scientist Award
Cecelia Williams **Science and Engineering Associates** **Eastman Cherrington Environmental**	R&D 100 Award for development of SEAMIST™ (Science and Engineering Associates Membrane Instrumentation and Sampling Technique) system that uses an impermeable tubular membrane to deploy sensors or samples in boreholes for studying subsurface environments or monitoring them for hazardous materials
Jan Williams	Society of Women Engineers Distinguished New Engineer Award
David Womble	R&D 100 Award for development of a software package for solving linear systems of equations on parallel computers
Robert Woods	American Society of Mechanical Engineers fellow

DOE/DoD awards

Bob Biefeld, Ralph Dawson, Ian Fritz, Paul Gourley, Eric Jones, Sungkwun Lyo, Jeff Nelson, Gordon Osbourn, Rich Schneider	DOE Basic Energy Sciences Materials Science Award for sustained outstanding research in metallurgy and ceramics for "strained-layer and artificially structured materials"
Mark Dickinson	Secretary of Defense Medal for Outstanding Public Service for applying his nuclear weapons technical and programmatic expertise to make significant improvements in the Nuclear Command and Control System interagency process
Jack Houston **Terry Michalske**	DOE Basic Energy Sciences Materials Science Award for significant implication for DOE-related technologies in metallurgy and ceramics for "interfacial force microscope"
Greg Mann **John Didlake** **Terry Olascoaga** **Tom Poteat** **Anton West**	DOE Exceptional Service Award for reengineering a DOE departmental directive system for DOE Orders and Directives
Sandia Labs	Secretary of Defense "Pro Patria" award for distinguished contributions to the national defense through exceptional support of the Guard and Reserve

Patents

Anisotropic fiber alignment in composite structures
L. A. Mondy
Patent #5,262,106

Automated quadrilateral surface discretization method and apparatus usable to generate mesh in a finite element analysis system
T. D. Blacker
Patent #5,315,537

Automatic rapid attachable warhead section
A. J. Trennel
Patent #5,311,436

Coherent optical monolithic phased-array antenna steering system
V. C. Hietala, S. H. Kravitz, G. A. Vawter
Patent #5,333,000

Crash resistant container
J. D. Pierce
Patent #5,337,917

Downhole material injector for lost circulation control
D. A. Glowka
Patent #5,343,968

Dual manifold heat pipe evaporator
D. R. Adkins, K. S. Rawlinson
Patent #5,275,232

Electrochemical thinning of silicon
J. W. Medernach
Patent #5,277,769

Extended range chemical sensing apparatus
R. C. Hughes, W. K. Schubert
Patent #5,279,795

Fault-tolerant correction/detector chip for high speed data processing
D. D. Andaleon, L. M. Napolitano, Jr., G. R. Redinbo, W. O. Shreeve
Patent #5,291,496

Ferroelectric optical image comparator
M. A. Butler, S. J. Martin, K. B. Pfeifer, C. E. Land
Patent #5,267,179

High performance static latches with complete single event upset immunity
W. T. Corbett, H. T. Weaver
Patent #5,307,142

High resolution time interval counter
K. J. Condreva
Patent #5,333,162

High thermal expansion sealing glass
R. K. Brow, L. Kovacic
Patent #5,262,364

Inorganic volumetric light source excited by ultraviolet light
S. Reed, R. J. Walko, C. S. Ashley, C. J. Brinker
Patent #5,306,445

Luminescent light source for laser pumping and laser system containing same
R. A. Hamil, C. S. Ashley, C. J. Brinker, S. Reed, R. J. Walko
Patent #5,313,485

Method and apparatus for collaborative use of application program
C. D. Dean
Patent #5,293,619

Method and apparatus for controlling electroslag remelting
M. C. Maguire, F. J. Zanner, B. K. Damkroger, M. E. Miszkiel, E. A. Aronson
Patent #5,331,661

Method for exponentiating in cryptographic systems
E. F. Brickell, D. M. Gordon, K. S. McCurley
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Method for minimizing decarburization and other high temperature oxygen reactions in a plasma sprayed material
J. A. Henfling, M. F. Smith, W. Lenling
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Patent #5,315,430

Tandem resonator reflectance modulator
I. J. Fritz, J. R. Wendth
Patent #5,345,328

X-ray transmissive debris shield
R. B. Spielman
Patent #5,329,569

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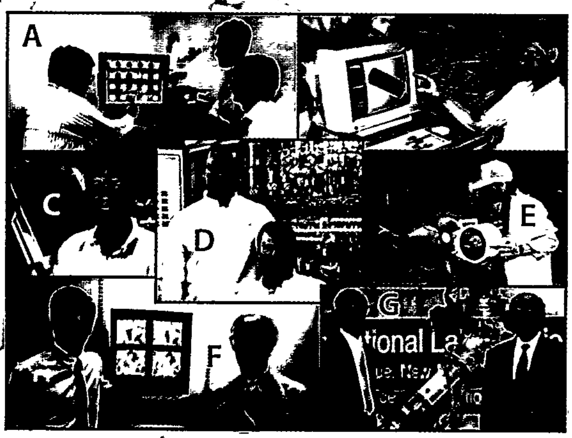

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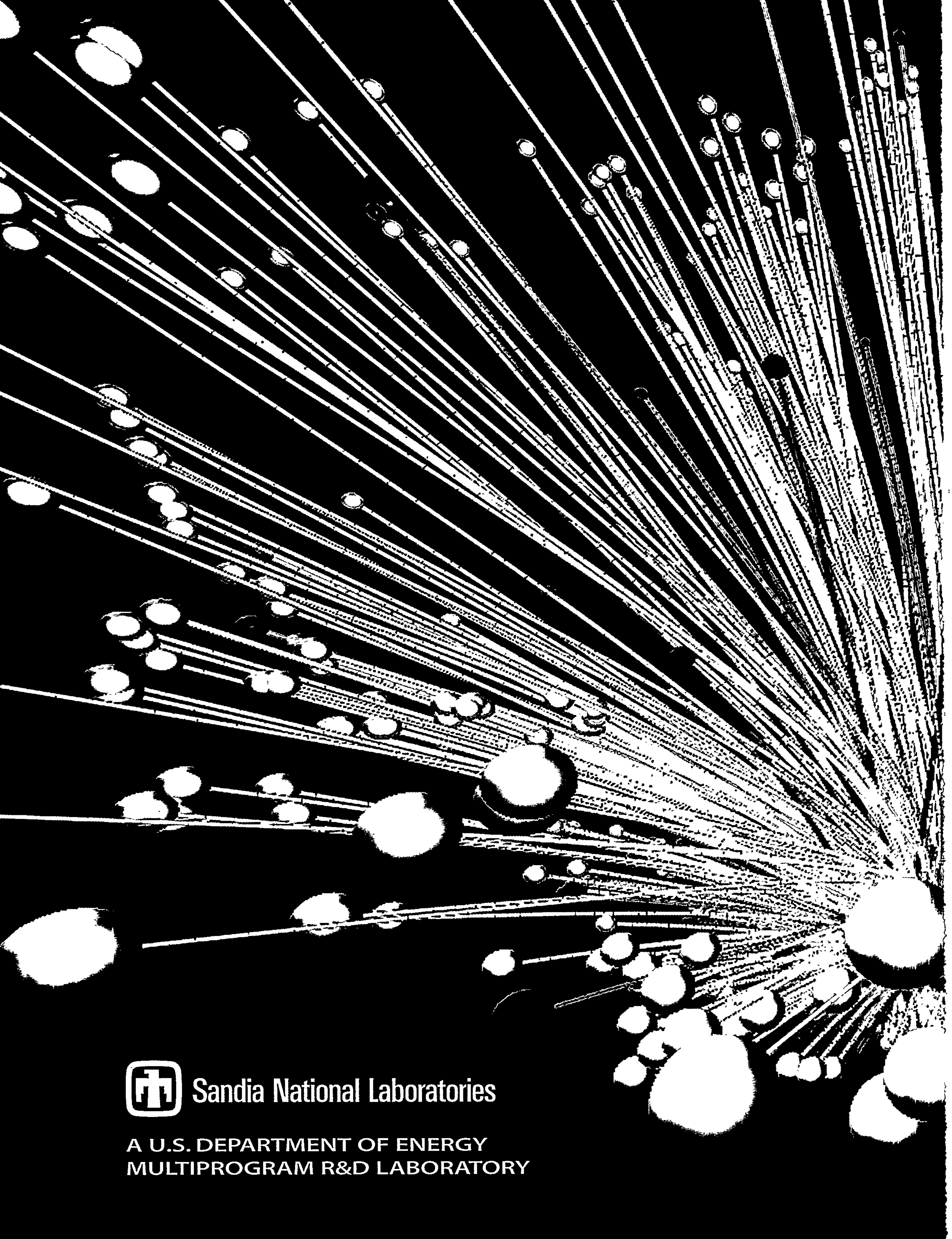

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