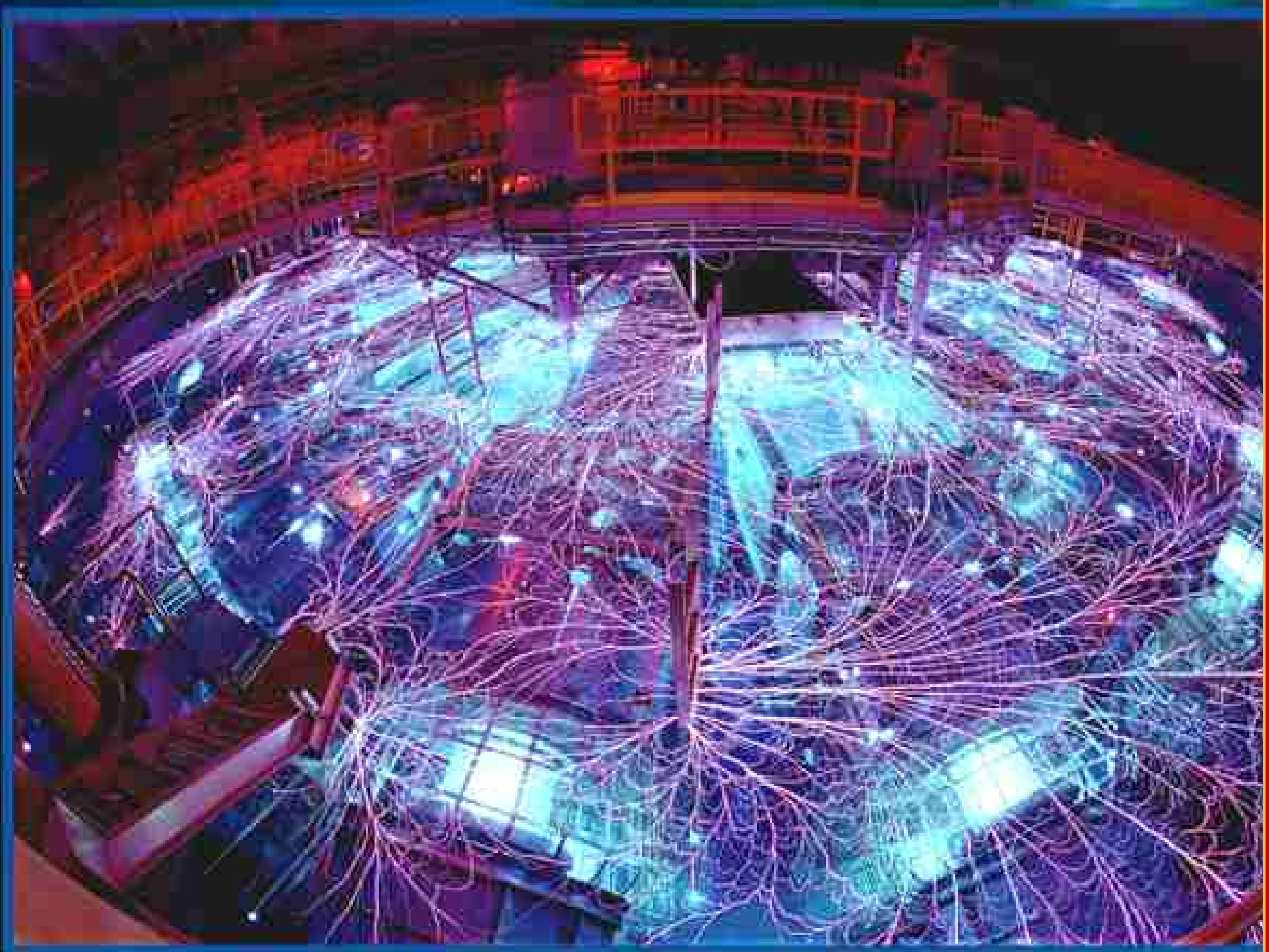
WINTER • 1999 - 2000

SANDIA TECHNOLOGY

A QUARTERLY RESEARCH & DEVELOPMENT JOURNAL
VOLUME 1, NO. 4

Z MACHINE
Providing Clues to Astronomical Mysteries



ALSO:
BUILDING A BETTER MICROSYSTEM

SPRAY IT AGAIN, SAM
VR Tool Helps Prepare for Terrorist Attacks

Sandia National Laboratories

A Department of Energy National Laboratory

From atop a 25-foot ladder, Sandian Larry Shipers examines a pair of cameras that provide feedback to a computer system that controls Sandia's automated painting system for the F-117 Nighthawk, also known as Stealth. The system sprays a thin radar-absorbent coating on the surfaces of the fighters. To test the system, this cardboard mock-up of some of the aircraft's more hard-to-reach surfaces was constructed in a high bay.

"Creating a neutron star or black hole on Earth for scientists to understand distant reactions is something of a problem, since there would be no more Earth. But because "neutron stars and black holes emanate X-rays similar in effect to those emanated by Z, we realized we have a chance to test astrophysical theoretical models that have never been tested experimentally,"

Mark Foord, Physicist

ON THE COVER: Sandia National Laboratories' Z Machine, the most powerful X-ray generator on Earth, is helping scientists better understand astronomical phenomena such as black holes, neutron stars, and the evolution and eventual expiration of the universe.

(Photo by Randy Montoya)

Sandia Technology is a quarterly journal published by Sandia National Laboratories. Sandia is a multiprogram engineering and science laboratory operated by Sandia Corporation, a Lockheed Martin company, for the Department of Energy. With main facilities in Albuquerque, New Mexico, and Livermore, California, Sandia has broad-based research and development responsibilities for nuclear weapons, arms control, energy, the environment, economic competitiveness, and other areas of importance to the needs of the nation. The Laboratories' principal mission is to support national defense policy, by ensuring that the nuclear weapons stockpile meets the highest standards of safety, reliability, security, use control, and military performance. For more information on Sandia, see our Web site at *http://www.sandia.gov.*

To request additional copies or to be added to our mailing list, contact:
Connie Myers
Marketing Communications Dept.
MS 0129
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0129
Voice: (505) 844-4902
Fax: (505) 844-1392
e-mail: cimyers@sandia.gov

Sandia Technology Staff:
Laboratory Directed Research & Development Program
Manager: Chuck Meyers, Sandia National Laboratories
Editor: Chris Miller, Sandia National Laboratories
Research, writing, and design by Technically Write

FROM THE *Editor*

Dear Readers:

This issue of *Sandia Technology* contains articles about a variety of recent Sandia developments in diverse areas of the weapons program. The Labs' Z machine — the most powerful X-ray generator on Earth — continues to make news, this time by helping physicists examine what happens to iron in the grip of black holes and neutron stars. The work could even give scientists a much better understanding of the formation and expiration of the universe. Several stories focus on Sandia's growing field of work in microsystems. A major development is the creation of a new, advanced, five-level polysilicon surface micromachining process that will permit microelectromechanical systems (MEMS) to become more reliable and sophisticated. MEMS, complex machines with micro-size features, can be found in a variety of products, including optical devices, computer game joy sticks, car airbag sensors, ink-jet printers, and projection displays.

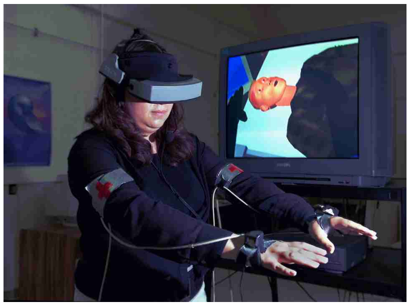
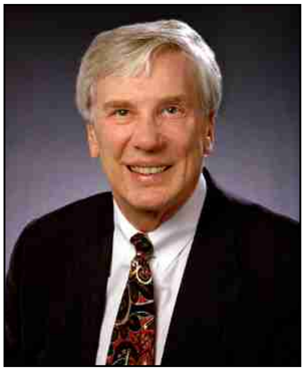
Another article describes the creation of a synthetic product whose need would escape the understanding of most sane people — until you learn it could save lives as well as millions of taxpayer dollars. Synthetic sludge is the product, and it successfully mimics the deadly sludge found in underground nuclear waste storage tanks. Working with the safe sludge will give workers cleaning up nuclear waste sites a better understanding of how best to deal with the product's deadly cousin.

I hope you will take a look at the "Insights" column at the back of this issue. The column is a reprint of a message written by Sandia President and Laboratories Director C. Paul Robinson from the *Sandia Lab News* – Sandia's in-house newspaper . The column was published on Sandia's 50th anniversary, an occasion observed by employees as well as by many VIPs who joined us at the Labs for a day of reflection and celebration.

Chris Miller
Editor

TABLE OF *Contents*



2 *Z Provides Clues to Astronomical Mysteries*

4 *VR Tool Helps Prepare for Terrorist Attacks*

7 *A Dirty Task Gets Cleaner*

8 *Building a Better Microsystem*

10 *Remote Sensors Analyze Gases From Afar*

13 *Controlling Quantum Dots*

15 *Fine Resolution, Real Time Images*

INSIGHTS

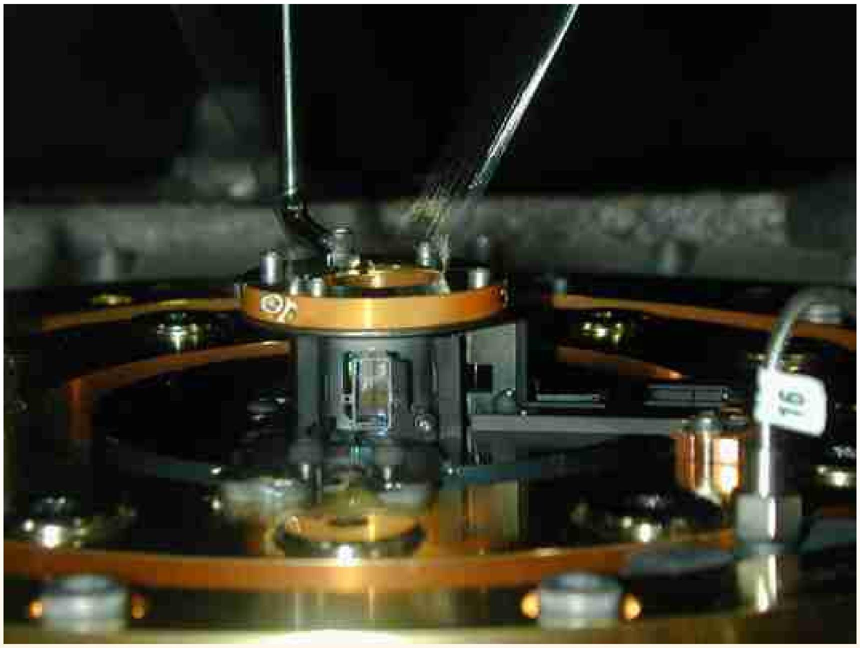
by C. Paul Robinson
President and Laboratories Director
Sandia National Laboratories

Black Holes, Neutron Stars, Evolution of the Universe:

Z PROVIDING CLUES TO ASTRONOMICAL MYSTERIES

The results will further human understanding of black holes, neutron stars, and the evolution and eventual expiration of the universe.

In an inconspicuous, flat-roofed building on the high desert of New Mexico, a machine that creates temperatures rivaling those of the sun is helping physicists examine up-close what happens to iron in the grip of black holes and neutron stars.



In front of a containment can at the center of Sandia's Z machine, a small window-like frame holds a shining foil containing a layer of mixed iron and sodium fluoride only 500 angstroms thick, sandwiched between micron-thick plastic substrates.

Experiments on Sandia National Laboratories' Z machine — the most powerful X-ray generator on Earth — usually focus on the defense of the United States and harnessing nuclear fusion for electrical power.

But data from recent tests undertaken there by researchers from the Department of Energy's Lawrence Livermore and Sandia national laboratories should help astronomers trying to interpret images from the billion-dollar Chandra X-ray observatory now orbiting Earth. (Also benefiting will be two billion-dollar X-ray orbiting observatories expected to be sent aloft from Europe and Japan in the next year.)

Creating a neutron star or black hole on Earth for scientists to understand distant reactions is something of a problem since there would be no more Earth.

The results will further human understanding of black holes, neutron stars, and the evolution and eventual expiration of the universe, predicts Livermore physicist Mark Foord, one of the leaders of the joint Sandia-Livermore project. The methods developed in the work also can be used in weapons physics, says Sandia project collaborator and physicist Jim Bailey.

Apprentice cooks in empty kitchens

Iron is of interest to astronomers because it is among the most complicated of elements widespread in the universe, and, therefore, among the hardest to understand. Several explanations are possible for the effects it creates on images taken by the recently launched Chandra orbiting telescope.

The problem for astronomers, who now hold bleacher seats to watch titanic energies that are transforming elements on a scale never before seen, is somewhat similar to that faced by apprentice cooks in empty kitchens who watch master chefs cook on TV: Without being able to cook along, many fine points of the process can only be guessed at.

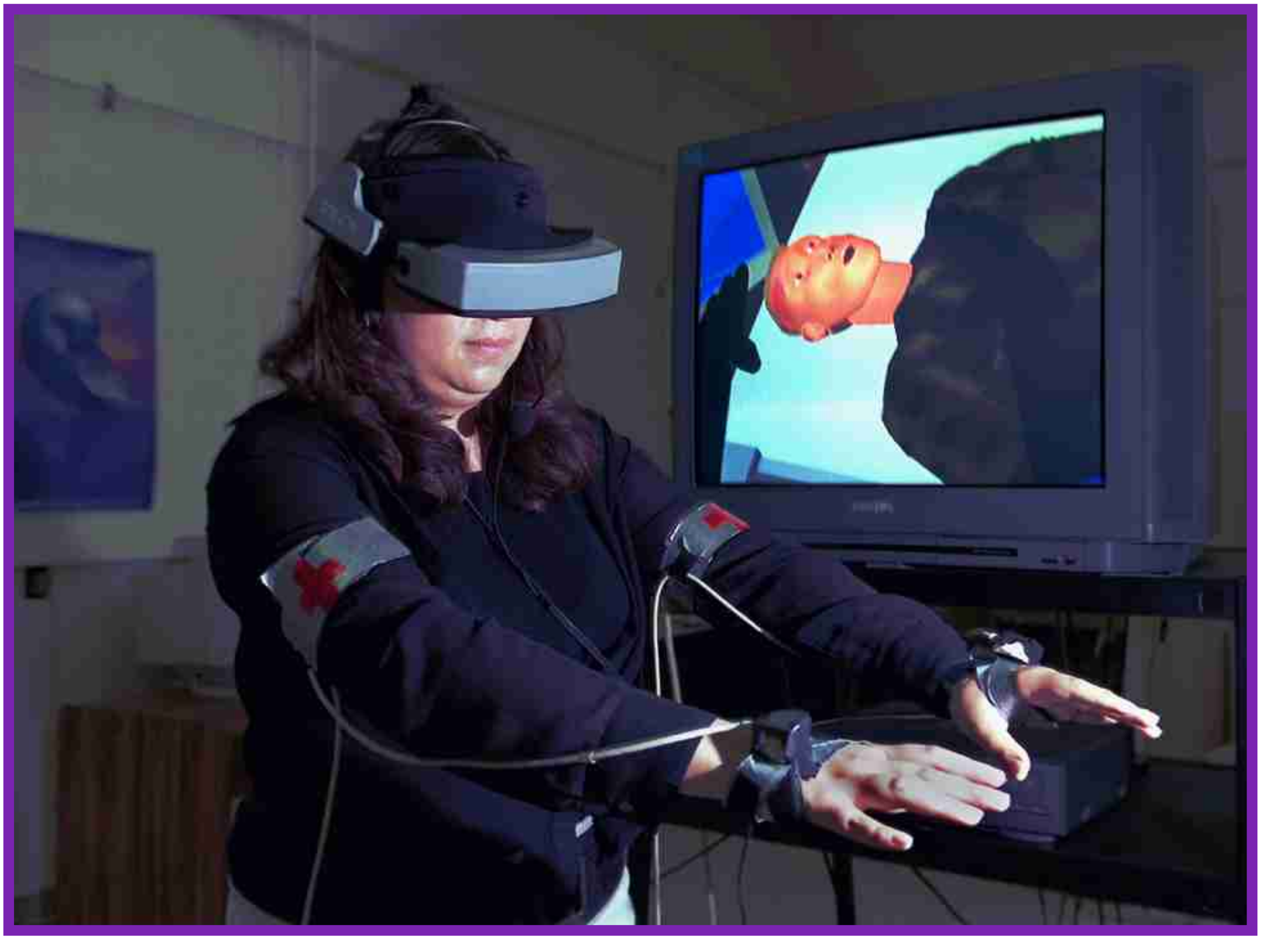
Creating a neutron star or black hole on Earth for scientists to understand distant reactions is something of a problem since there would be no more Earth. But because "neutron stars and black holes emanate X-rays similar in effect to those emanated by Z, we realized we have a chance to test astrophysical theoretical models that have never been tested experimentally," says Foord.

Says Bailey, "We're looking with spectroscopic eyes at the atomic physics of ionized iron so that these can be compared with theoretical calculations. Astrophysicists will have to consider what implications our figures have for their models."

Continued on page 6

SPRAY IT AGAIN, SAM

VR Tool Helps Prepare for Terrorist Attacks



Lydia Tapia of Sandia National Laboratories demonstrates BioSimMER, a virtual reality application that allows rescue personnel to practice responding to a terrorist attack involving release of a biological agent.

[*"With virtual reality, you can practice over and over again, like in a video game," Stansfield said. "You make mistakes; you learn. If someone dies, you can hit the reset button."*]

In future emergencies — when rescue personnel may need to treat mass casualties following the release of a nerve agent in a shopping mall, theme park, or subway — there will be no second chances. Rescuers who become victims of a terrorist attack can't save lives.

Soon emergency medical technicians (EMTs) and firefighters may be able to practice responding to such attacks using a virtual reality (VR) training tool under development at Sandia National Laboratories.

Sandia computer scientists have combined seven years of virtual reality research into BioSimMER, a VR application that immerses first responders in a 3-D, computer-simulated emergency setting — a small airport in which a biological warfare agent has been dispersed following a terrorist bombing. Simulated casualties with a variety of symptoms are found throughout the airport. BioSimMER can help emergency personnel make better decisions if they are ever called to respond in a real chem-bio attack, says project leader Sharon Stansfield.

"With virtual reality, you can practice

over and over again, like in a video game," she said. "You make mistakes; you learn. If someone dies, you can hit the reset button."

Saving 'cyber casualties'

The computer simulation engages the rescuer's eyes, ears, and decision-making abilities through goggles that display the scene's images. The rescuer wears sensors on the arms, legs, and waist, allowing the player's motions to be fed back into the simulation.

The researchers worked closely with Dr. Annette Sobel, a Sandia physician and researcher, to create "cyber casualties" with realistic symptoms and real-time changes in their conditions. One virtual casualty has a visible chest wound. Another has symptoms that indicate head trauma. Another suffers from inhalation of *staphylococcal enterotoxin B* (SEB), the airborne bio agent used in the simulation. And a fourth appears to exhibit the symptoms of SEB exposure, but closer examination shows him to be suffering from psychological shock.

During a simulation, the player must triage, diagnose, and attend to the medical needs of each casualty. Visual indicators, such as a victim's movements, labored breathing, skin color, and vital signs, give clues to each victim's condition. If the rescuer is wrong or not fast enough, the victim or patient could die.

After making a diagnosis, a player can administer medical treatment by reaching for and using tools in a virtual medical kit. Players may need to attend to initial decontamination procedures, place masks over a patient's nose and mouth, or place sensors or other monitoring equipment near the patient. Most important, they need to learn to protect themselves.

"A player who dies a quick cyber death will not likely forget the importance of personal protective equipment in the future," Stansfield said.

> ***"We tend to understand what we see with our eyes and do with our hands. The strength of VR is being able to train on things you can't do otherwise, particularly in highly contaminated or highly stressful situations."***

Although textbook-style preparation and live-training exercises are valuable pursuits as the nation's emergency personnel prepare for future emergencies, BioSimMER offers some advantages.

"We tend to understand what we see with our eyes and do with our hands. The strength of VR is being able to train on things you can't do otherwise, particularly in highly contaminated or highly stressful situations," Stansfield said. "We don't think BioSimMER should replace live exercises, but it can provide an inexpensive way for emergency personnel to practice."

Achieving a suspension of disbelief

Although BioSimMER's graphics aren't as refined as the latest 3-D video games, the VR application does offer some realism that video games can't.

"In video games, the world is imaginary," Stansfield said. "But a VR world is a representation of a real place with representations of real people moving in real-time. Everything in that world must move and respond as if it were real and bound by the laws of physics."

Creating a virtual world with such physical realism does require some trade-offs, she said, but the ultimate goal is to create a suspension of disbelief. "You've got to make the player believe, at least temporarily, that he or she is in the situation you are presenting," she said.

The airport used in BioSimMER is a fictitious one-story, three-gate airport based loosely on a real airport in central New York. The research team modeled how the airborne biological agent would spread through the airport following an explosion that dispersed the agent.

More than 20 first responders got their first chance in July to test drive BioSimMER at the National Emergency Response and Rescue Training Center at Texas A&M University .

"Those people out there — the police, the firefighters, the EMTs — they do important jobs. They are telling us they want this. If we can do something to help them, then we are using technology to make a real contribution to society," Stansfield said.

Development of BioSimMER was funded by the Defense Advanced Research Projects Agency. BioSimMER also builds on previous Sandia VR work, including applications for training battlefield medics and for law enforcement small-teams tactical training. Although BioSimMER is a research prototype, the researchers hope to continue development and refinement of the system and scenarios, with the goal of making a version of BioSimMER available to users in the not-too-distant future.

Currently, work is focusing on making the user's interaction with the BioSimMER virtual world easier and more realistic with funding from DOE's Office of Science and Technology Pilot Projects in Biomedical Engineering Program.

Technical contact:
Sharon Stansfield,
(505) 844-1396
sastans@sandia.gov

A machine that creates temperatures rivaling those of the sun is helping physicsts examine up-close what happens to iron in the grip of black holes and neutron stars.

Continued from page 3

"We have a collaboration with four or five groups around the world whose main job is to analyze data from Chandra using their own codes," says Foord. "They have made some predictions that we're going to compare to our data." If necessary, the codes will be modified.

The results will be compared with astrophysical calculations embedded in computer codes of how neutron stars affect the widespread element.

Interpreting data from the stars

The experiments proceed by placing square centimeters of iron, a few hundred angstroms thick, close to the Z-pinch at the heart of Z. (A Z-pinch achieves its output by generating a powerful magnetic field that collides ions at an appreciable fraction of the speed of light.)

"It appears that we were successful at producing highly ionized iron and were able to obtain an accurate measurement of the radiation produced from the Z-pinch. We hope to be back in a few months to do follow-up experiments and then return again in the summer to explore different regimes."

This exposes the metal to temperatures of more than one million degrees for a few billionths of a second, ionizing the metal.

"Iron has thousands of spectral lines," says Foord. "We know their positions (on a spectroscopic scale), but they differ in intensity depending on which electrons, or how many, have been stripped away in the ionizing heat of a neutron star. Calculating these relative intensities is uncertain. This makes it difficult to predict how highly ionized iron is, or should be, in other star systems. If we can measure in the lab what the actual figures are, we learn how to interpret our data from the stars."

A Sandia instrument that takes seven images temporally and a Livermore instrument that takes one image in time and two images spatially will help determine effects of the intense X-ray pulse from Z on iron samples in terms of spectrum, temperature, density, and ionization.

"Our first two shots were in late October and we are now analyzing the data," says Foord. "It appears that we were successful at producing highly ionized iron and were able to obtain an accurate measurement of the radiation produced from the Z-pinch. We hope to be back in a few months to do follow up experiments and then return again in the summer to explore different regimes."

Other collaborators in the experiments are Livermore's Bob Heeter, Bob Thoe, and Jim Emig. Heeter, a recent Princeton graduate and Livermore postdoctoral fellow, is the lead experimentalist for the project.

Sandia's Tom Nash, Gordon Chandler, Dan Nielsen, Dan Jobe, and Pat Ryan also contributed to the experiments.

Technical contacts:
Jim Bailey,
(505) 845-7203
jebaile@sandia.gov

Mark Foord,
(925) 422-0990
foord1@llnl.gov

Bob Heeter,
(925) 423-3761
heeter@llnl.gov

A Dirty Task Gets Cleaner

Synthetic Sludge Permits Safer, Less Expensive Cleanup

Synthetic goods are generally modeled on scarce but desirable materials — diamonds, fine wools, even fruit juices.

Jim Krumhansl is offering the world something a bit different: synthetic sludge. The unusual product, which harmlessly mimics the deadly sludge found in underground nuclear waste storage tanks, could save taxpayers hundreds of millions of dollars in cleanup costs around the United States. It will provide researchers with a safer and less costly way to determine which radioactive wastes will remain embedded in, and which will migrate from, the sludge found in waste storage tanks.

This should permit easier and more cost-effective decommissioning of some tanks at a cost of $10 million each, rather than worst-case disposal, with maximum safeguards for every tank of $65 million each. There are approximately 180 such tanks at Washington state's Hanford Reservation alone. Far fewer are at the Savannah River Site in South Carolina.

The work is an outgrowth of the February 1995 Galvin Report's suggestion that national laboratories find new science to cut down on the very large costs of projected environmental clean-up bills.

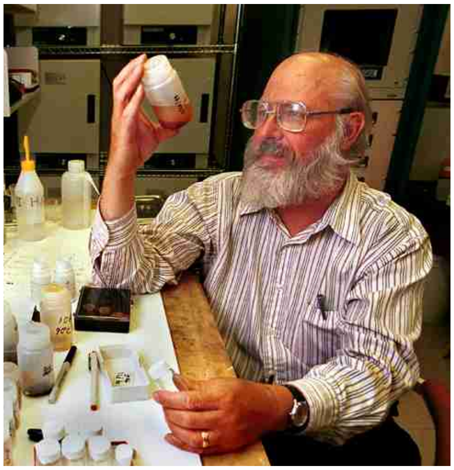
The artificial sludges consist of "non-radioactive representations of screamingly radioactive materials" that precipitate as a matter of course during storage in giant underground tanks that may contain up to a million gallons of nuclear waste, said Krumhansl, a Sandia researcher.

The sludges created by Krumhansl's research group are part of a joint project among the Department of Energy's Sandia National Laboratories, Pacific Northwest National Laboratory (PNNL), and the University of Colorado.

Sludge that won't budge

Naturally occurring sludge sticks to the walls of tanks and could serve as a long-term source of radioactive contamination in the environment.

"When the tanks are emptied, some of the sludge won't budge," said Krumhansl. "The tanks will be sluiced, sloshed, and squirted, but people won't be sent inside to clean them up."



Sandia researcher Jim Krumhansl believes the use of synthetic sludge could reduce the cost of decommissioning some radioactive waste storage tanks at several DOE facilities.

While purists might prefer that scientists experiment on real sludge, workers feel differently. Many of these materials are so radioactive that working with them is both costly and requires taking extreme measures to protect the health of researchers performing the work.

Synthetic sludges, while chemically similar to radioactive ones, are not radioactive and can be handled without danger by lab workers attempting to quantify how much radioactive material sludges will store or release, and for how long.

Costs of decommissioning tanks, treating every material as a worst case in its potential to escape into the environment, could amount to hundreds of millions of dollars. "The decision how to treat these tanks ultimately depends on how much hazard there is from their residual radioactivity being able to move about. If virtually none of it goes any place, then you're a lot freer to do simple decommissioning techniques," Krumhansl said.

"The question is what fraction of radionuclides in the sludge will stay there indefinitely and what fraction could become mobile and enter the groundwater."

The worst-case alternative is removing to a new location potentially corroded radioactive tanks that are 70 feet across and 55 feet high, with tops seven feet below the ground. The simpler alternative is to leave the tanks in place and seal them off, said Krumhansl.

Wanted: the sludgehammer

"Imagine being the one to dig up seven feet of radioactive earth just to reach the top of the tank," said Krumhansl, describing the worst-case ordeal. "Where do you put the dirt? How do you cut the tank into small enough pieces to move? Working in a lead-lined (hazardous materials) suit is like working in a sauna. It's awkward, uncomfortable, you need a respirator, you need a cutting torch, you have to make sure the pieces you're cutting don't fall down and hit you. The job may take robots because the radiation levels are so high. It's a difficult and expensive task to do."

To judge whether the synthetic sludges are realistic representations of their more lethal counterparts, group member Jun Liu of PNNL has done transmission electron microscope (TEM) work comparing the atomic structure of a small number of actual radioactive sludges with the group's synthetic version. (The TEM uses such a small sample that the radioactivity constitutes no danger.)

In some cases, the synthetic sludges contain nonradioactive elements from the periodic table that "weren't exact matches for radioisotopes, but provide useful insights into the way these things work," said Krumhansl. Examples of this include substituting rhenium for technetium and neodymium for americium. Other elements, like strontium, cesium, and selenium have nonradioactive isotopes that behave identically to the radioactive isotopes in the actual waste. Finally, the artificial sludges also contain nonradioactive components, such as lead and cadmium present in the actual wastes, that are of concern because of their heavy-metal toxicity.

Technical contact:
Jim Krumhansl,
(505) 844-9093
jlkrumh@sandia.gov

BUILDING A BETTER MICROSYSTEM

Five-Level Process Could Become Industry Standard

This image shows a ratcheting system fabricated in the five-level technology. Twenty of these gears fit on a period in a newspaper sentence.

A new, advanced, five-level polysilicon surface micromachining process pioneered at Sandia National Laboratories promises that microelectromechanical systems (MEMS) of the future will be more reliable and capable of doing increasingly complex tasks.

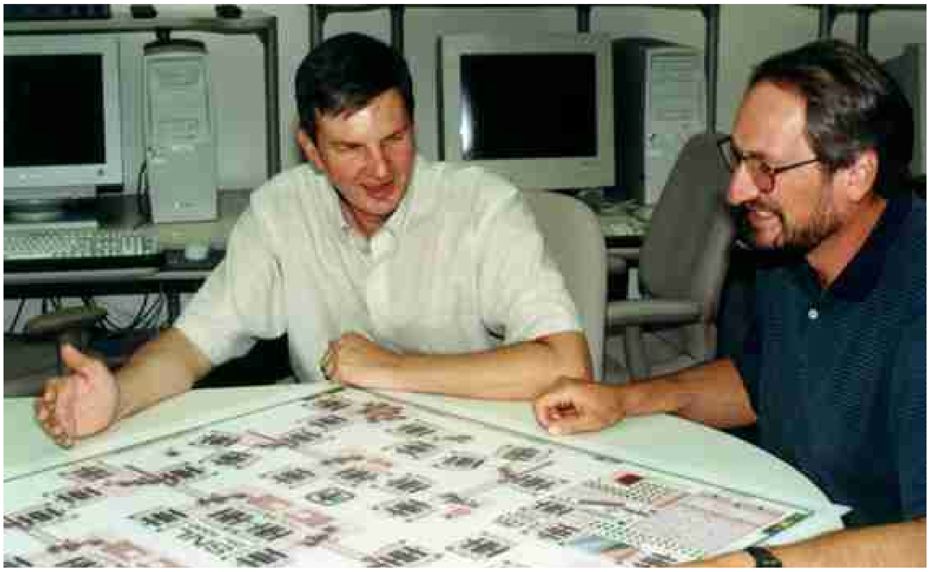
"This five-level polysilicon surface micromachining technology has the potential of becoming the industry standard, replacing the more commonly used two- or three-level polysilicon surface micromachining approaches," said Sandia engineer Steve Rodgers, who with colleague Jeff Sniegowski has spent the past several years prototyping designs and developing the innovative process. "We have been working hard to baseline the technology as a reproducible manufacturing process, and we're getting there." The new technology was developed at Sandia's Microelectronics Development Laboratory. MEMS devices made from the five-level process eventually will be manufactured in the new Microsystems and Engineering Sciences Application (MESA) facility being planned for construction at Sandia.

MEMS, complex machines with micron-size features, can be found in a variety of products, including optical devices, computer-game joy sticks, car-airbag sensors, ink-jet printers, projection displays, and more. They are so small that they are almost imperceptible to the human eye and have moving parts no bigger than a red blood cell.

> ***They are so small that they are almost imperceptible to the human eye and have moving parts no bigger than a red blood cell.***

Sandia will begin offering the five-level technology next spring to external customers for prototyping purposes. Information about all MEMS courses is available on Sandia's micromachine Web page located at *http://www.mdl.sandia.gov/micromachine.*

Almost all of today's surface micromachine components are designed for and fabricated in technologies that incorporate three or fewer levels of structural materials. The levels are typically deposited as thin films of polysilicon that are about one to two microns thick. These films are separated by air gaps that initially are defined



Sandia's Steve Rodgers (left) and Jeff Sniegowski look over a computer schematic of a five-level polysilicon surface micromachine.

by layers of sacrificial silicon dioxide (sacrificial because they will eventually be eliminated) of about the same thickness. Processes with thicker polysilicon film — up to tens of microns — exist, but are typically limited to only that layer.

"In general, the more layers of structural material that a designer has to work with, the more complicated the device that can be fabricated," said Sniegowski, who developed the fabrication technology for the five-level layering method. "Therefore, surface micromachined components have greater functionality than bulk micromachined parts."

That's why, he added, the five-level polysilicon surface micromachine process that incorporates four layers of structural films, plus an electrical interconnect layer, is so attractive.

"This technology permits mechanical functionality that only a five- or more layer process could offer," Sniegowski said. "It provides a base for designing truly sophisticated multilevel microelectromechanical systems, while simultaneously offering much of the yield and robustness that typically is associated with single-level micromachining technology."

A two-level polysilicon process has only one layer of structural material, with the other level defining the ground plane. Such a technology is useful for fabricating simple sensors and actuators. With three levels, it is possible to create gears with hubs, while the four-level technology provides an additional layer of material that can be used to define linkage arms that move above the plane of the gears, enabling a continuous 360-degree rotation. The five-level technology expands on this to permit complex interacting mechanisms to be fabricated on moving platforms.

"This technology permits mechanical functionality that only a five- or more layer process could offer," Sniegowski said. "It provides a base for designing truly sophisticated multilevel microelectromechanical systems, while simultaneously offering much of the yield and robustness that is typically associated with single-level micromachining technology."

But to do this, several challenges had to be overcome, which Sniegowski and Rodgers have met. For example, as additional layers are added, more texture appears on the surface. This occurs because the top layer acquires the characteristics of all the lower layers, including high and low spots. The result is the creation of protrusions, called mechanical parasitics, that extend from the upper mechanical layer to lower areas. They can interfere with operation.

These parasitics, Sniegowski said, can significantly "constrain the design." If the design doesn't take them into account, they could easily "collide with the teeth and prevent rotation of the gear."

To eliminate this problem, a Sandia team led by process engineer Dale Hetherington modified and patented a process commonly used in manufacturing integrated circuits — chemical mechanical polishing — to planarize (flatten) the surface. High spots are eliminated after a very thick layer of sacrificial oxide covers all previous layers. Through chemical mechanical polishing, the high spots are eroded, producing a uniform flat surface.

Rodgers said the new five-layer process provides a foundation for fabricating components that offer high performance, reliability, and robustness. However, work continues to improve the process even further. "We are now adding the final touches before offering it for widespread use," he said.

Technical contacts:
Steve Rodgers,
(505) 844-1784
rodgersm@sandia.gov

Jeff Sniegowski,
(505) 844-2718
sniegojj@sandia.gov

Functioning Prototype Expected by 2001

TINY SENSOR TO ANALYZE GASES FROM AFAR

This computer image simulates a soldier on a battlefield looking remotely at a gas cloud through a pair of binoculars containing the Polychromator chip.

A new remote sensor the size of a dime being developed by the Department of Energy's Sandia National Laboratories should allow users to rapidly detect dangerous gases from up to two miles away.

Called Polychromator, the device will use a combination of optics and microelectromechanical systems (MEMS) to determine gas types. It is a joint effort of Honeywell, Massachusetts Institute of Technology (MIT), and Sandia. MIT is designing the MEMS structures that are being fabricated by Honeywell.

"Imagine a soldier on a battlefield looking through a pair of binoculars with the Polychromator chip built into it and detecting from afar the nature of gas being emitted in a smoke cloud," says Sandia researcher Mike Butler, one of Polychromator's inventors. "There's no need to obtain a sample of the gas or even get close to it. Instead, the detection is made from a safe one or two miles away."

He adds, "It promises that in a matter of seconds you can tell the nature of a gas and whether it's toxic without having an actual sample. It has all kinds of possibilities."

Butler, together with Mike Sinclair, also a Sandia researcher; former Sandian Tony Ricco; and MIT professor Steve Senturia have obtained two patents on the device, the most recent one in May. The researchers expect to have a functioning prototype by 2001, the end of a four-and-a-half-year funding period for the project by the Defense Advanced Research Projects Agency.

The Polychromator is a variation of a conventional gas-analysis technique, correlation spectroscopy. Infrared radiation is passed through a sample gas that imparts a spectral pattern to the radiation. This pattern then is correlated with the spectrum of a reference gas to provide the identification. Each gas has its own distinct spectral pattern, which can be used to identify the gas.

Butler says the standard method is limited because it requires a reference cell of the gas and the testing equipment is bulky.

The Polychromator chip, however, is small — about the size of a dime — and does not need a reference cell. It consists of thousands of microscopic MEMS grating elements on a silicon wafer manufactured with standard microlithographic "mask and etch" techniques. Each element is 10 microns wide and one-centimeter long, looks

It promises that in a matter of seconds you can tell the nature of a gas and whether it's toxic without having an actual sample.

like a long flat beam, and is designed to move up and down. Light from the gas cloud shines on the chip after being collected by an optical device, such as a telescope or binoculars.

As a soldier or other user peers through the binoculars, with light striking the Polychromator chip, a microprocessor inside would direct in a matter of seconds the MEMS grating through a series of movements . Each

Sandia's Mike Sinclair (left) and Mike Butler prepare to put the dime-size Polychromator remote sensor chip into a testing unit.

movement would result in a different grating designed to detect a specific gas. When the grating matches and identifies the gas, the device would alert the soldier.

One of the developments making the Polychromator possible was a computer program created by Sinclair to design the gratings. He came up with the program in 1994, shortly after he and the other future patent holders began talking about the possibility of combining a hologram with a spectrometer to remotely analyze gas clouds. Senturia, the MIT professor, was a Sandia consultant at the time.

"The infrared spectra of various gases have been known for years," Sinclair says. "My computer program uses these known spectra to calculate the grating profiles for each of the gases."

Another computer program then uses these grating profiles to control the movement of the MEMS grating elements. So far, Sinclair has generated grating profiles for about 10 gases, but more profiles are on the way.

While the team is still perfecting the movable MEMS grating, they already have completed silicon wafers containing fixed gratings. Sandia's Compound Semiconductor Research Laboratory fabricated the fixed gratings that can detect 10 different gases, mostly those used in chemical warfare. Unlike the Polychromator, these gratings don't move.

Sinclair notes that remote chemical sensors are nothing new — some have even been developed at Sandia in the past. This sensor, however, promises to have several unique characteristics.

"Unlike conventional spectrometers, the Polychromator will do a lot of the spectral processing up front, making it work faster that other types," Sinclair says. "In addition, it will be very sensitive and selective — able to discern quickly chemicals that have similar infrared spectra."

The researchers are already on the road to a functioning Polychromator prototype. They have an optics package in-hand and are waiting on the production of a refined prototype chip from Honeywell and electronics from an outside contractor. Both are expected in the next few months.

"All we'll have to do then is integrate everything, test, and see how well it works," Sinclair says.

Technical contacts:
Mike Butler,
(505) 844-6897
mabutler@sandia.gov

Mike Sinclair,
(505) 844-5506
mbsinc@sandia.gov

Planned MESA Facility Gets DOE Nod

The Department of Energy has given Sandia National Laboratories the go-ahead to develop a conceptual design for a $300 million Microsystems and Engineering Sciences Application (MESA) facility. The purpose of the project is to join Sandia's expertise in weapons design, very fast computing, and microsystems into an immersive environment in which scientists can imagine, design, and create the 21st century's best non-nuclear components for nuclear weapons.

Other benefits include offering American businesses and universities new opportunities to advance through use of the cutting-edge science that the facility and its programs will provide in microsystems and computer-aided design and simulations.

One military advantage of the new microsystems will be that they are expected to reduce the likelihood of malfunction in the event of an unexpected event, like a crash involving nuclear weapons.

"A big arming or safety device involved in an accident severe enough to destroy or fire off a missile would most likely be damaged as much as the explosive device," said David Plummer, nuclear weapons representative for MESA.

Microsystems designed by high-speed computers are smaller than postage stamps. Their components have little mass, so they have little inertia — the force that keeps an object moving once it is put in motion. Inertia throws passengers forward, for example, when a car comes to a sudden stop. The amount of inertia an object possesses is a key factor in how much damage it may suffer. Devices of extremely low mass, having almost no inertia, have no problem stopping very suddenly and thus are difficult to destroy impact.

"As the magnitudes of potential accidents increase — as jet fuel gets hotter, as air speeds get faster — so do the possibilities of accidents exceeding our current controls. We need more rugged safety devices," said Plummer. "MESA will produce them."

The primary function of the facility will be the defense of the United States, said Tom Hunter, senior vice-president of nuclear weapons. The facility also will include weapon component modeling and simulation, weapon certification, and embedded microsystems.

However, MESA also represents the leading edge of industry's interest in intelligent microsystems, said Dan Hartley, vice president for laboratory development. "The demand for less expensive, more intelligent, smaller systems is ubiquitous in industry, and we believe that what we're doing here represents the birth of a new field of business endeavor."

Al Romig, Sandia vice president for science, technology, and components, said, "This will create a capability to do our business in a new way. It'll revolutionize the way we'll refurbish the nuclear stockpile and build new space satellites. It also will be an opportunity to drive the creation of entirely new industries in the United States, using our Science and Technology Park."

"Conceptually, MESA is a new way of designing intelligent, autonomous, reliable microsystems from the outset and will be the wave of the future for all complex commercial products that will incorporate microsystems, such as cars, planes, and computers," said David Goldheim, director for Sandia's corporate business development and partnerships. "At an appropriate time, we plan to ask businesses to become involved in the design of portions of the program. Industry will help design and use parts of the new facility."

MESA is also of interest to universities "because in our meetings with deans, microsystems are a high priority with them as well, and they want to have more to do with us because we will be defining the leading edge," added Hartley.

Regarding students, Don Cook, director of the MESA project said, "Students in school are being trained in new technologies. We can't expect to train the brightest graduates on old technology. We want them to advance new technology even further. That's why we're a national lab."

Approximately $95 million is slated to be funneled into new equipment for MESA, said Cook.

Said John Stichman, director of weapons systems engineering in New Mexico for Sandia, "As we refurbish weapons, we need to know that those weapons we return to the stockpile meet our safety and capability requirements. These requirements pertain to the next several decades of life these weapons would have in the stockpile. Microsystems hold the promise to provide the most capable implementation of the safety of refurbished weapons. The nuclear weapon systems organization is working closely with the MESA planning staff to assure that MESA is well-aligned with weapons systems design and development."

The tentative schedule is to begin engineering design in fiscal year 2000 and construction in 2001. The project is scheduled for completion by 2003, and to be fully operational by 2004. MESA eventually will house 600 employees.

Technical contact:
Don Cook
(505) 845-7446
dlcook@sandia.gov

Doting Dots These Are Not

Controlling Quantum Dots Key to Producing Effective Solid-state Lasers

The term quantum dots has a nice ring to it, like or a special version of connect-the-dots games that absorb the attention of children. But while the tiny entities may sound amiable, they find each other repulsive, and in that just-discovered knowledge may lie the secret of controlling their formation.

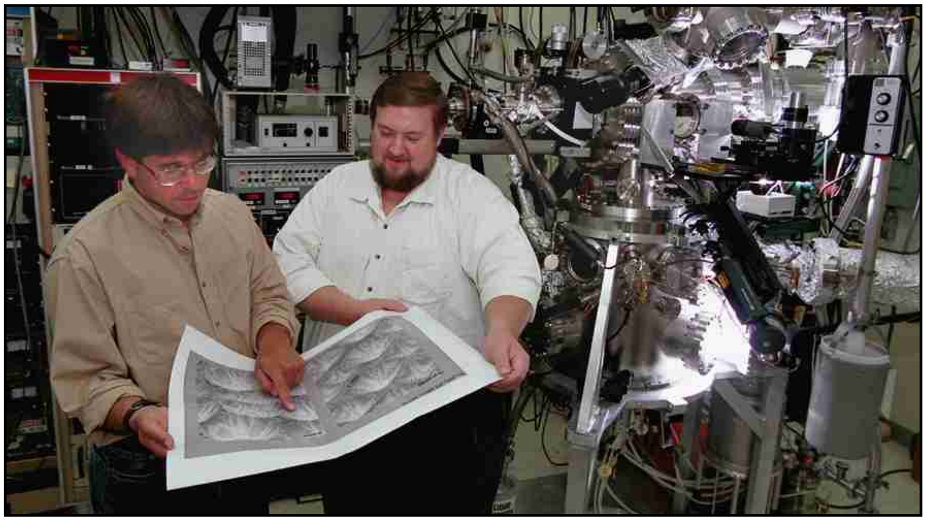
Effective control would turn assemblages of dots containing a few thousand atoms (by comparison a pencil dot contains millions of atoms) into the world's most effective solid-state lasers, said principal investigator Jerry Floro. He leads a research team using probes developed at Sandia National Laboratories.

"We developed novel probes that uncovered a repulsion effect between quantum dots. This effect may completely govern the way they organize themselves. Understanding this self-organization is critical if we are to control dot characteristics for lasing devices," Floro said.

The probes, one of which was recently patented, have made unique real-time measurements of atoms clustering to form relatively large three-dimensional dots, called islands. Scientists for the first time observed the role of mutual repulsion in causing dots to change shape and self-organize as they grow.

Understanding these factors is an important step in basic science. The smaller the dot, the shorter the emission wavelength; the more tightly the dots are packed, the more intense the beam; and the more uniform their size, the more uniform the frequencies.

The ongoing work was done in collaboration with researchers now at Brown University and the University of Illinois at Urbana-Champaign.



Sandia's Jerry Floro (left) and John Hunter examine an atomic force micrograph image of semiconductor quantum dots.

Buckling up to relieve stress

Quantum dots form when very thin semiconductor films buckle due to the stress of having lattice structures slightly different in size from those of the material upon which the films are grown. Just a few percent difference in lattice size creates stresses (or pressures) in a film that are 10 times larger than those present in the deepest oceans of Earth. These huge pressures, as new layers are deposited, force the initially flat film to separate into dots and then pop up into the third dimension to relieve stress, rather than continue to grow against resistance in two dimensions. This extra dimension, combined with the extremely small size of the dots, gives them different properties from when the material was in its original flat-film shape.

Semiconductor quantum dots have the potential to produce laser-light output at wavelengths where, in a manner of speaking, no flat film has gone before, depending on the size of the dots. But while crude collections of quantum dots have been grown and set lasing, knowledge of the conditions needed to influence the dots so that they form more regularly in size, shape, and pattern — thus improving control of their lasing frequency and intensity — has been only a dream.

Techniques of physical etching — even nanolithography — can't be used to make them because the dots are so small that they do not manifest the continuous nature of a solid. "People have made crude devices," said Floro. "But to make them reliably, we need to understand the ground rules."

The collaboration between Sandia and Brown University makes use of optical and stress measurements to observe dot formation as it happens on silicon germanium. Stress in the film causes the substrate to bend, which the researchers measure by bouncing laser beams off the sample. When the dots form and change shape, the stress changes and so does the amount of bend in the substrate. So, mapping the sub-

continued on page 14

Understanding this self-organization is critical if we are to control dot characteristics for lasing devices.

Quantum Dots (continued)

strate as it bends reveals when dots first form and how their shapes evolve.

Said Floro, "Tiny dots cause detectable bending in a substrate that is 10,000 times thicker than the dots themselves."

The conventional laboratory approach, by contrast, has been to artificially stutter dot formation into separate time intervals and bring intermediate results to powerful microscopes to observe formations at each stage.

As more film layers are deposited, the dots grow closer and closer, and, because they repel each other, they are forced to become more uniform in size, line up in orderly fashion, and change their shape. Some dots are even "eaten" by their neighbors in an attempt to reduce overcrowding, a process known as coarsening.

Working with larger entities

But how does one "see" dots so small? The researchers were clever and used bigger dots, called islands, thousands rather than hundreds of angstroms in size and made of silicon germanium, since the larger ones could be more easily examined. The researchers earlier had shown that groups of larger semiconductor entities interact the same way as smaller semiconductor entities.

According to Dennis Deppe, an electrical engineering professor at the University of Texas at Austin working in the field but unconnected with the Sandia-Brown effort: "Many of the same basic growth phenomena are seen in different material systems. So it is possible to learn some important physical principles concerning nucleation and dot formation in one semiconductor system (and have some of them) carry over to another."

Observing the process of dots going from one shape to another to relieve stress has provided insight into the physics governing island formation.

"We directly measure the kinetics of nucleation, coarsening, self-organization, and phase transformations within growing island arrays," said Floro. "All these processes are explained within a unified model that works with ensembles of islands rather than individual islands in isolation."

In terms of actual formation, the process characteristically went like this: 10 atomic layers of film would form smoothly. As more layers were deposited, the film broke up into tiny pyramid-shaped islands. With more layers, the pyramids self-organized and coarsened, and then became dome-shaped islands.

Quantum dots as diffraction gratings

But there's more. The researchers, not content with one novel tool to examine dots, realized they had another.

Floro—along with Bob Hwang (a California-based Sandia researcher), Ray Twesten at the University of Illinois at Urbana-Champaign, Eric Chason (a former Sandia researcher), and Ben Freund of Brown University—made measurements that treat dots as the originators of light-interference patterns. Since light's direction and intensity varies depending on the size, shape, and spacing of the islands, the results offer information in real-time to determine what is happening to the tiny islands as temperatures, material compositions, and stresses change.

"We realized that if we could produce islands more than 1,000 angstroms across, the spacing between islands was like that of a diffraction grating," said Floro. "Combined with our real-time stress observations, this allowed us to measure stress, shape, and size simultaneously instead of having to stop the process, take the dots out, and measure them. A key ingredient was our ability to show that the basic physics of the large islands mimics that of the much smaller dots."

Observing the process of dots going from one shape to another to relieve stress has provided insight into the physics governing island formation. "It showed us what controls dot evolution and how process conditions like temperature and strain enhance or suppress dots."

Silicon germanium is not a good laser emitter, but it is simple enough to derive the applicable physics. "We need to find out next how much of the physics learned in silicon germanium will apply to real laser materials like indium gallium arsenide," said Floro. "If we can understand the physics, we can make better quantum dots."

The Department of Energy's Office of Basic Energy Sciences, Division of Materials Sciences, is funding this work.

Technical contact:
Jerry Floro,
(505) 844-1197
jafloro@sandia.gov

Sandia researcher Bill Hensley checks the Lynx synthetic-aperture radar (SAR) installed on a General Atomics I-GNAT unmanned aerial vehicle.

Fine-Resolution, Real-time Images
20/20 Vision Even On a Cloudy Day

Lynx, a new fine-resolution, real-time synthetic-aperture radar (SAR) system, has been unveiled by Sandia National Laboratories and General Atomics of San Diego.

Designed to be mounted on both manned aircraft and unmanned aerial vehicles (UAVs), the 115-pound SAR is a sophisticated all-weather sensor capable of providing photographic-like images through clouds, rain or fog and in daytime or nighttime conditions, all in real-time. The SAR produces images of extremely fine resolution, far surpassing current industry standards for synthetic-aperture radar resolution. Depending on weather conditions and imaging resolution, the sensor can operate at a range of up to 85 kilometers.

"The Lynx represents a breakthrough on many fronts," said Bill Hensley, Sandia project leader. "Because the image resolution is so fine and the instrument itself is so lightweight, it represents a technology breakthrough. The real-time, interactive nature of the radar and the innovative operator interface make it a breakthrough for meeting the ease-of-use needs of front-line military users. And because Sandia developed the technology and successfully transferred it to General

Atomics, the Lynx radar also is a technology-transfer success story."

Mike Reed, Lynx program manager at General Atomics, said that Sandia and General Atomics joined forces in 1996 when the San Diego-based company (whose Aeronautical Systems, Inc. affiliate builds a line of unmanned aerial vehicles) wanted to develop an advanced, lightweight SAR system. General Atomics provided the funds to Sandia, which already had a sophisticated SAR, to implement an enhanced design as a commercial product and deliver two prototype units together with licenses and manufacturing information to produce the unit.

General Atomics and Sandia spent the next three years working together to refine and enhance the SAR into a lightweight, user-friendly system with extended range and much higher resolution. General Atomics has commenced production of subsequent units for commercial sales.

The new SAR will enhance the surveillance capability of the General Atomics Aeronautical Systems UAVs and other reconnaissance aircraft, which previously were equipped only with cameras, infrared sensors, and older-generation SAR equipment. "Cameras provided good data, but they don't work at night or in rainy, foggy, and cloudy situations," Hensley said. "Fine-resolution-image SAR radar is perfect for these circumstances because it can 'see' in the dark and peer through clouds and fog."

Flying at an altitude of 25,000 feet, the Lynx SAR can produce one-foot-resolution imagery at standoff distances of up to 55 kilometers. At a resolution of four inches, the radar can make images of scenes 25 kilometers away (about 16 miles) even through clouds and light rain.

The radar operates in Ku band with a center frequency of about 16.7 GHz, although the precise value can be tuned to prevent interference with other emitters.

Lynx introduces several new characteristics and functions. In addition to being very lightweight, the radar can detect very small changes in a scene by using a technique called coherent change detection. It also will be able to detect moving targets.

The Lynx radar image shows the Rio Grande Valley .

Flying at an altitude of 25,000 feet, the Lynx SAR can produce one-foot resolution imagery at standoff distances of up to 55 kilometers.

Sandia and General Atomics worked to make Lynx as much like an optical system to use as possible. The radar forms an image covering an area larger than that displayed, storing it in cache memory. This allows the operator to pan around within the total scene to concentrate on a particular area of interest. The radar's fine resolution allows it to detect small surface penetrations — even footprints in a soft terrain.

Lynx has been flown successfully for more than 140 hours on a Department of Energy plane and on the General Atomics I-GNAT. In all testing, the SAR worked with the precision expected.

Sandia and General Atomics continue to explore ways to improve the Lynx. Future upgrades could include an inverse SAR mode for imaging of seaborne targets, interferometric SAR (requiring the use of two antennas) for three-dimensional imaging, the ability to cue other sensors, and radio-frequency tagging — both for combat identification and for precision-strike applications. Additional "cognitive" enhancements are planned to make interpretation of the radar image more user friendly.

General Atomics, founded in 1955, is involved in high-technology nuclear energy, commercial, and defense-related research and development. Affiliated manufacturing and commercial service companies include General Atomics Aeronautical Systems Inc., which builds the family of Predator, GNAT, Prowler, and Altus UAVs.

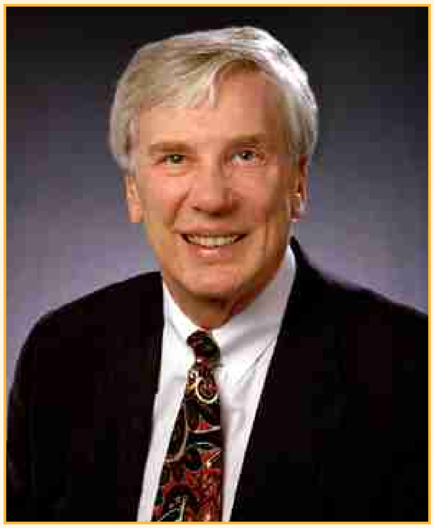
Sandia technical contact:
Bill Hensley, (505) 845-8112
whhensl@sandia.gov

General Atomics contact:
Mike Reed, (858) 455-2446
mike.reed@gat.com

INSIGHTS

by C. Paul Robinson
President and Laboratories Director
Sandia National Laboratories

Sandia National Laboratories Celebrates 50 Years of "Exceptional Service"



Although Sandia began as a part of the Los Alamos laboratory during the Manhattan Project to develop the first atomic weapons, the decision to make it a stand-alone laboratory — on Nov. 1, 1949 — launched an exciting endeavor whose history is still being written after 50 years.

Sandia has grown to be the nation's largest science and engineering laboratory, with impressive facilities in New Mexico and California, and at smaller sites scattered around the United States. Yet the laboratory, then as now, is most distinguished for our staff. Indeed, Sandians' sense of service to the nation has always been a major part of our laboratory's character. We have a deep faith in the power of technology — applied with wisdom — to change the world for the better, and we are continuing to build an impressive record of success through fundamental inventions, scientific discoveries, applications of technology, and major national projects.

Our primary mission has always been the ordnance engineering of all U.S. nuclear weapons, including system safety, security, and use-control for the weapons systems. We have achieved extraordinary levels of reliability and safety for U.S. nuclear weapons, while in storage or in military deployment. Over the years, we have put the skills and capabilities developed for the weapons mission to good use in a wide spectrum of other fields.

Achievements span many domains

Sandia's achievements span many domains — in the basic sciences of fission and fusion, in the creation of leading-edge electronic and microelectronic devices, in the creation and flight of advanced experimental satellites, in the pioneering of new sources of energy and greater efficiency in its use, in the development of some of the world's fastest computers, in the development of new medical instruments, and through the creation of environmentally conscious manufacturing techniques now adopted by industries around the world.

Most of Sandia's major advances could likely never have been achieved if approached within the confines of a single scientific or engineering discipline. If there is a "secret of success" for Sandia's past 50 years, it is this coming-together of world-class experts from a variety of training and experience to merge their unique contributions in technically challenging endeavors.

Credit for the entire laboratory

We began as a more narrowly focused copy of Bell Labs and have emerged since as one of the world's most diverse science and engineering laboratories, numbering more than 1,500 PhD researchers in a total staff of about 7,500. Although Sandians make extraordinary individual contributions, our culture is primarily world-wise technologists working together and understanding that "the job gets done better if you don't care who gets the credit." Thus, over the years, the name most often credited and remembered by the world for our major advances has been simply "Sandia."

Our history, like all history, moves with fits and starts, and today's challenges for the laboratories are no less daunting than ever. The tensions of the Cold War have now receded, with many Americans hardly remembering our role in helping to ensure a peaceful outcome. The current period of greater peace and stability has led to the inevitable questioning of the value of maintaining such a large laboratory for national security.

To Sandians, the greatest lesson of history is that pressures for wars of national aggression are inevitable, until such time as we can change the very nature of man — a doubtful and certainly long-term aspiration. Until that daunting challenge is met, if ever, it is only through maintaining strength that the United States and its allies can hope to deter aggression and defend their vital interests. Therefore, we must be conscientiously pursuing the advancement of defense science and the perpetual strengthening of the U.S. deterrent — the best hope to prevent major wars in the future.

Saying what we believe... regardless

It is thus that the nearly 30,000 Sandia employees over these 50 years have found their place — working in comfortable harmony on larger-than-life national security missions. Not surprisingly, Sandians are profoundly patriotic people. There is a tradition at our laboratories that even though we serve the national government, we always place service to the nation above service to any political party. Thus, we provide each administration and each Congress the very best advice of which we are capable. Similarly, we must always say what we believe to be right, regardless of what potential consequences may result from it. Recently, a Sandian on assignment in Washington told me that a senior government official, whom he described as one of the real "movers and shakers," said he believed Sandians could be counted on to give the best advice, even if that advice could hurt the laboratory. I don't know of a higher compliment we could be paid.

Truman's phrase still motivates

Indeed, Sandia National Laboratories began with a request by President Harry Truman which contained the phrase "you have here an opportunity to render an exceptional service in the national interest." That simple but very profound phrase has been taken to heart by every Sandian, and they have used it as a catechism to motivate themselves and each other ever since. To understand this simple phrase in all of its complexity, its challenges, and its opportunities — from inventing a new technology to figuring out how to counter major threats to our people and our way of life — is to fully appreciate the call we have each answered in serving the nation through service in this laboratory.

Nov. 1, 1999

If there is a “secret of success” for Sandia’s past 50 years, it is this coming-together of world-class experts from a variety of training and experience to merge their unique contributions in technically challenging endeavors.

C. Paul Robinson
President and Laboratories Director
Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000

SAND 99-3107

Sandia National Laboratories

Marketing Communications Dept.
MS 0129
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0129