SANDIA TECHNOLOGY
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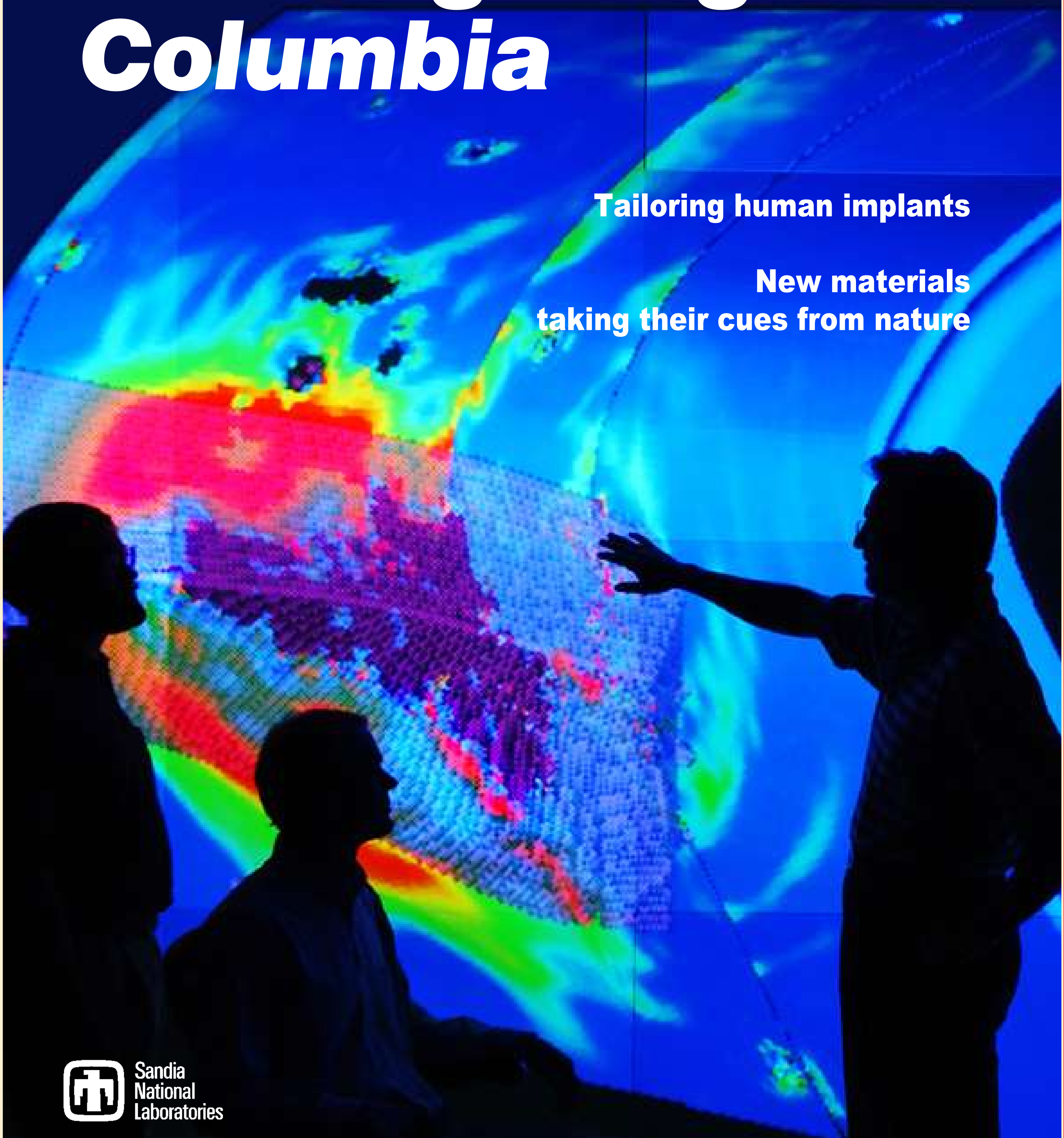
Investigating *Columbia*



Tailoring human implants

New materials taking their cues from nature

Sandia National Laboratories

What is LDRD?

Sandia's world-class science, technology, and engineering work define the Labs' value to the nation. These capabilities must remain on the cutting edge, because the security of the U.S. depends directly upon them. Sandia's Laboratory Directed Research and Development (LDRD) Program provides the flexibility to invest in long-term, high-risk, and potentially high-payoff research and development that stretch the Labs' science and technology capabilities.

LDRD supports Sandia's four primary strategic business objectives: nuclear weapons; nonproliferation and materials assessment; energy and infrastructure assurance; and military technologies and applications; and an emerging strategic objective in homeland security. LDRD also promotes creative and innovative research and development by funding projects that are discretionary, short term, and often high risk, attracting exceptional research talent from across many disciplines.

When the LDRD symbol appears in this issue, it indicates that at some state in the history of the technology or program, LDRD funding played a critical role.

On the Cover:

Researchers at Sandia's Visualization Laboratory discuss a computer simulation and analysis showing the impact of a foam piece along the leading edge of the space shuttle wing. These analyses and subsequent real-world testing helped convince NASA's Columbia Accident Investigation Board that insulating foam, striking the wing during launch, was the likely cause of damage that led to the shuttle's loss. Story on page 2. (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 policies, by ensuring that the nuclear weapon 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.*

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Fall Issue 2003

FROM THE Editor

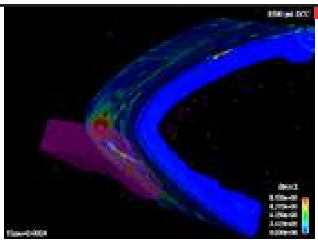
Dear Readers,

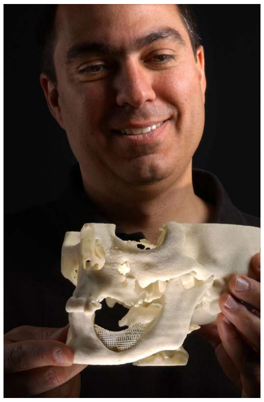
This issue of *Sandia Technology* begins with a look at the Labs' contributions to our national understanding of what went wrong February 1, 2003, when the Space Shuttle *Columbia* plunged from the sky. It details what Sandia did technically, but it reveals little of the personal efforts of team members, who immersed themselves in this intense effort for several months' time. In the scheme of things, Sandia played a small part on the stage of a global drama, but the work of these researchers is certainly worthy of recognition.

Following the *Columbia* article, reported by Sandia's Michael Padilla, are two related pieces, summarizing the Labs' efforts to provide materials and to test technologies for next-generation launch vehicles. These efforts will help to make the U.S. space program safer and stronger.

Other articles in this issue touch on Sandia research in the medical, materials, risk vulnerability assessment, and energy fields. Finally, the issue reviews some of the very best of Sandia's technology developments for the year, as judged by editors of *R&D Magazine*. Among Sandia's seven winning entries was a collaborative research project with industry and academic colleagues on Extreme Ultraviolet Lithography. Seen as the next wave in computer chip manufacturing, this effort was singled out by *R&D Magazine* editors for one of its very top awards, the Editors' Choice.

Will Keener
Editor





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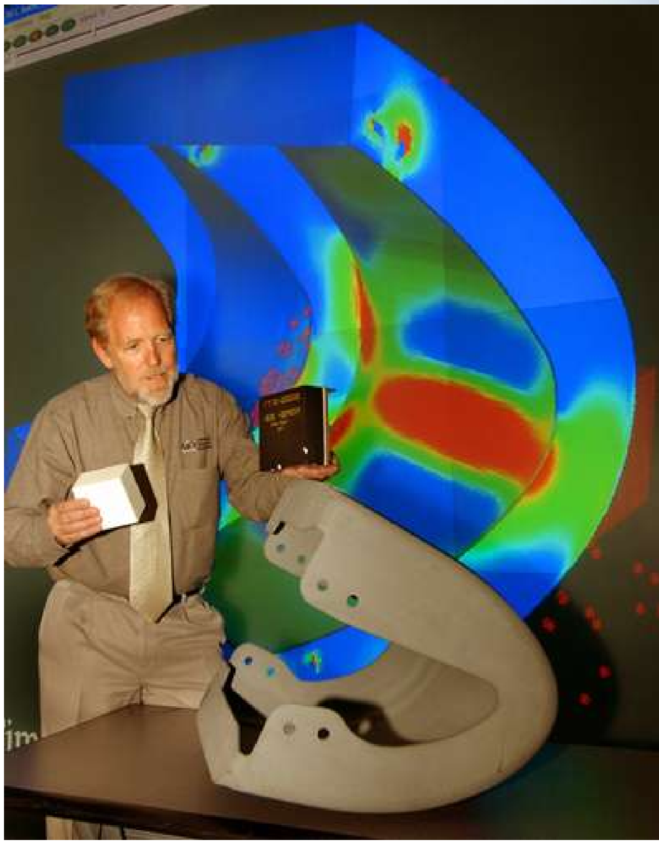
The Shuttle *Columbia*: A probable cause

Sandia researchers faced a very skeptical community of engineers and scientists when they predicted that scraps of foam could penetrate a layer of tough composite material, causing damage that led to Columbia's break-up over Texas. Working closely with NASA engineers and contractors, the researchers set about convincing themselves and their colleagues with real-world materials testing and supercomputer simulations.

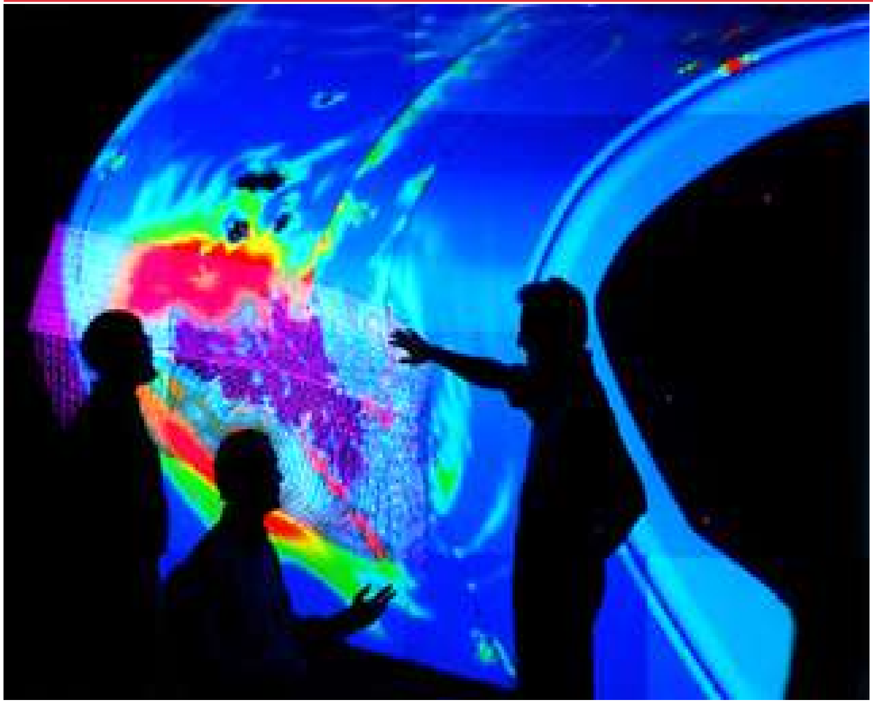


Tom Bickel, director of Sandia's Engineering Sciences Center, with samples of foam and shuttle tile, and a section of the composite leading edge of the shuttle wing. (Photo by Randy Montoya.)

Sandia's expertise in material and engineering science played a key role in helping NASA determine the cause of the February 1 space shuttle *Columbia* disaster. After five months' work, Sandia analyses and experimental studies supported the *Columbia* Accident Investigation Board's position that the most probable cause of the accident was damage to the wing leading edge caused by foam debris. The debris separated from the fuel tank and impacted the orbiter wing during launch.

Just four days after the disaster, Sandia personnel joined a team of engineers from several NASA Centers and their contractors to identify and evaluate credible damage scenarios that might have led to the accident. They analyzed data sent from *Columbia* during reentry, and they reviewed the locations of orbiter debris recovered across Texas during the first month after the accident. Information on *Columbia* damage scenarios, configuration, and material properties was sent back to Albuquerque, where engineering analyses were performed on Sandia's big computers.

Working in partnership with NASA analysts, Sandians assessed the credibility of possible damage to *Columbia* that could have occurred prior to reentry and could have resulted in orbiter breakup during reentry. The researchers used computational



Sandia researchers discuss a computer model analyzing a foam block impacting the leading edge of the shuttle wing. (Photo by Randy Montoya.)

"Our team wanted to use analysis to eliminate as many scenarios as possible and then focus on the remaining ones that seemed the most plausible."

Basil Hassan of Sandia's Engineering Sciences Center

fluid dynamics (CFD) and rarefied gas dynamic computer codes to simulate the orbiter at various altitudes along the trajectory. Other codes, called aerothermodynamic codes, were used to predict the heat transfer for various damaged wing configurations. These codes calculated the thermal and fluid flow properties of plumes, simulating hot gas entering the wing through damage sites.

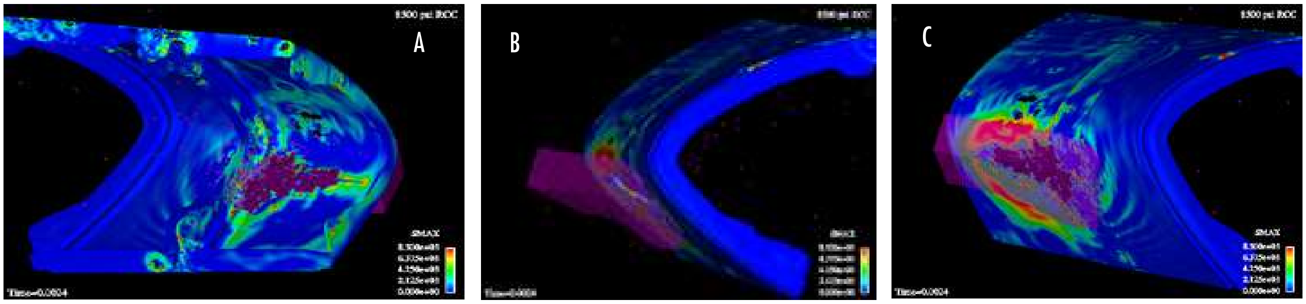
"The difficult part of our work was realizing that many damage scenarios were consistent with the limited data telemetered from *Columbia* during reentry," said Basil Hassan of Sandia's Engineering Sciences Center. "More than one damage scenario could match the data. Our team wanted to use analysis to eliminate as many scenarios as possible and then focus on the remaining ones that seemed the most plausible." When *Columbia's* flight recorder was located late in March, the investigation team received a wealth of additional information that eliminated several accident scenarios and directed its attention to the left wing leading edge and thermal tiles.

Little agreement

Despite video images of foam striking *Columbia's* left wing during lift-off, there was no agreement among investigators that the foam could cause sufficient damage to precipitate the accident. As a result, NASA planned experiments at Southwest Research Institute (SwRI) in San Antonio, Texas, to assess foam impact damage. In late February, NASA asked Sandia for foam impact analysis support to guide the SwRI tests, which used full-scale mockups of parts of the wing. Sandia began preparing computational models of foam impact onto the wing's reinforced carbon composite (RCC) leading edge and lower surface thermal protection system (TPS) tiles.

During the next three months, Sandia experimentalists in California and New Mexico supported the foam impact analysts by providing material characterization data for RCC, TPS tiles, and foam. Data from these material characterization experiments became a major Sandia contribution to the accident investigation. They were used by all of the NASA foam impact analysis teams.

Sandia's foam impact computational results suggested that foam impacting the lower wing tiles would not cause much damage. But impacts to the



A) View from 'inside' the wing area, or a view opposite the impact side.
B) View from 'outside' the wing, or in front of the wing leading edge (shows hole.)
C) View from 'outside' the wing, in a perspective that shows the foam coming at you, as it slides down the leading edge.

All images are from analyses of Southwest Research Institute's test of a 1.9 pound piece of foam at 775 feet/second impact. All plots are at 2.4 milli-seconds of analysis time, or 0.0024 second.

wing's leading edge could actually damage and potentially penetrate the RCC material. "We faced a very skeptical community," said Tom Bickel, who led the Sandia team. This skepticism would remain until full-scale tests of foam impacting a mockup of the orbiter's leading edge proved the point.

SwRI foam impact tests at different wing locations produced damage in the RCC leading edge panels that ranged from localized cracking to full breakage. The most dramatic test at SwRI produced a 16-inch diameter hole in the lower half of a leading edge panel of the orbiter. Such damage would be catastrophic, allowing high-temperature gases to enter the wing and melt the aluminum wing structure during reentry. These data convinced all investigators that the most probable damage location was the leading edge of the left wing.

The *Columbia* Accident Investigation Board subsequently acknowledged the RCC leading edge foam impact scenario as the most likely cause of the disaster. Its full report is scheduled for release at the end of the year.

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Invaluable expertise

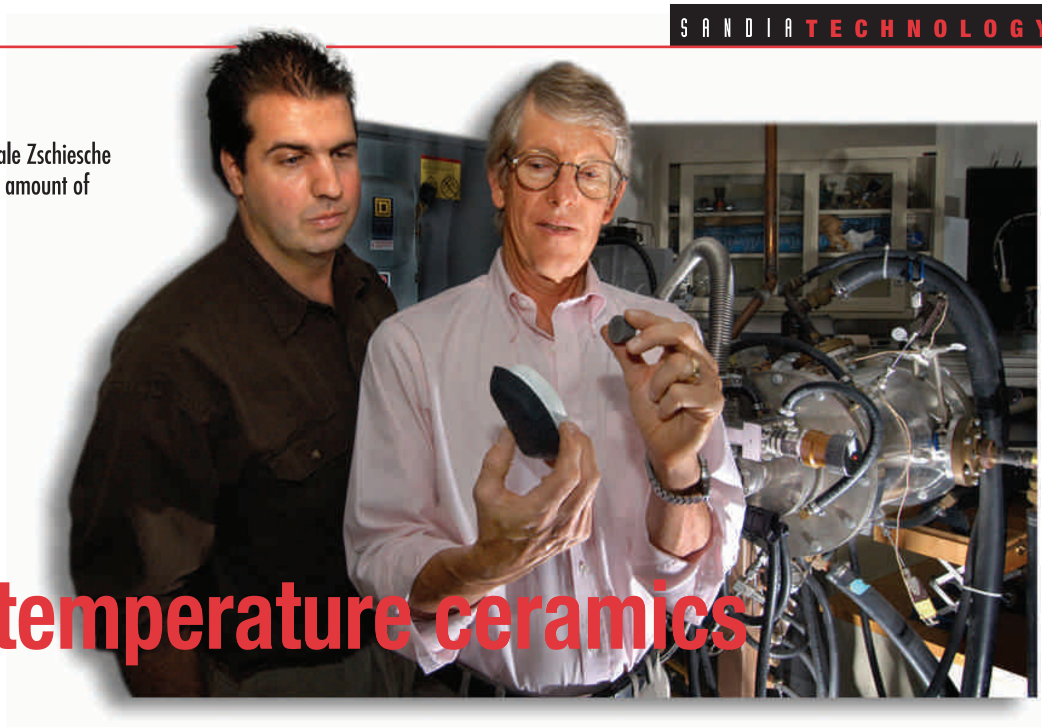
"Sandia's expertise in the areas of impact testing and modeling, material testing, non-continuum aerodynamics, and thermal analysis has been invaluable to our investigation teams. The cooperative effort and sharing of ideas, test methods, and analytical tools have been beneficial to both our organizations."

William Readdy
Associate Administrator for Space, National Aeronautics and Space Administration

Service in the national interest

Sandia has been instrumental in assisting in investigating the cause of various national issues including:

- Determining the cause of the 1989 turret explosion that killed 47 men aboard the USS *Iowa*.
- Supporting and helping guide the National Transportation Safety Board to confirm that the TWA Flight 800 accident of July 1997 most likely was the result of an unintended ignition of the fuel-air mixture in a fuel tank.
- Working in solving the Unabomber case in 1996 by assisting FBI and other agents during the search of the Unabomber's cabin in Montana.



Sandia researchers Ron Loehman, right, and Dale Zschiesche check out material that can withstand twice the amount of heat of a conventional piece of a shuttle tile. (Photo by Randy Montoya.)

Sandia developing ultra-high-temperature ceramics

LDRD

Thermal insulation materials for sharp leading edges on hypersonic vehicles, like the space shuttle, must be stable at temperatures near 2000ºC. The materials must resist evaporation, erosion, and oxidation, and limit the heat transfer to support structures.

Researchers at Sandia National Laboratories are developing a new lightweight material to withstand ultra-high temperatures on hypersonic vehicles, such as the space shuttle. The ultra-high-temperature ceramics (UHTCs), created in Sandia's Advanced Materials Laboratory, can withstand up to 2000ºC (about 3,800ºF).

Ron Loehman, a senior scientist in Sandia's Ceramic Materials, said results from the first seven months of the project have exceeded his expectations. "We plan to have demonstrated successful performance at the lab scale in another year with scale-up the next year," Loehman said.

Composite materials

UHTCs are composed of zirconium diboride (ZrB_2) and hafnium diboride (HfB_2), and composites of those ceramics with silicon carbide. These ceramics are extremely hard and have high melting temperatures (3245ºC for ZrB_2 and 3380ºC for HfB_2). When combined, the material forms protective, oxidation-resistant coatings.

"However, in their present state of development, UHTCs have exhibited poor strength and thermal shock behavior, a deficiency that has been attributed to inability to make them as fully dense ceramics with good microstructures," Loehman said.

Loehman said the initial evaluation of UHTC specimens provided by the NASA Thermal Protection Branch about a year ago suggests that the poor properties could be traced to errors in ceramic processing.

During the first seven months, the researchers made UHTCs, using both the zirconium and hafnium systems, that are nearly 100 percent dense. They have favorable microstructures, as indicated by preliminary electron microscopic examination. In addition, the researchers have hot pressed UHTCs with a much wider range of silicon carbide contents than ever before.

This availability of a range of compositions and microstructures will give system engineers added flexibility in optimizing their designs.

Collaborations

The project is part of the Sandia Thermal Protection Materials Program and represents the work of researchers at Sandia and the University of New Mexico.

Sandia's David Kuntz said his primary responsibility is to design thermal protection systems, or heat shields, compute material thermal response on high-speed flight vehicles, and to develop tools to improve these capabilities.

If enough of the wrong contaminants find their way into the process, the material will have no high-temperature strength or stability.

"If a vehicle flies fast enough to get hot, we analyze it," Kuntz said. "Our tools consist of a set of computer codes that compute the flow field around a high-speed flight vehicle, the resultant heating on the surface of the vehicle, and the subsequent temperatures and loss of the materials, which form the surface of the vehicle."

Jill Glass (Sandia's Ceramic Materials Department) works with high-temperature mechanical properties and fracture analysis. Paul Kotula (Materials Characterization department) performs microstructural and microchemical analysis on the ceramic materials. Kotula applies software analysis to the characterization of hafnium and zirconium UHTCs. he looks at these materials at the micron and even smaller scales for problems that can adversely affect their mechanical properties.

(The Automated eXpert Spectral Image Analysis (AXSIA) developed by Kotula and Sandia's Michael Keenan was recently patented and was a winner of a 2002 R&D 100 award. For more on the 2003 winners, see inside back cover.)

Creative analysis

Boron and carbon are difficult to analyze, because they give off low-energy or soft X-rays when excited with an electron beam as typically used for such analyses. Instead of using X-ray analysis, the research team has developed analytical capabilities based on electron energy-loss spectrometry to determine amounts and distributions of the light elements in UHTCs.

Oxygen, in particular, is an important impurity since, in combination with the silicon present in the UHTCs and other impurities, it can form glasses or other phases that typically can't withstand the required high-operation temperatures and would melt or crack in service, causing the material to fail.

"If enough of the wrong contaminants find their way into the process, the material will have no high-temperature strength or stability," Kotula said.

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Sandia assists NASA's HyTEx program

LDRD

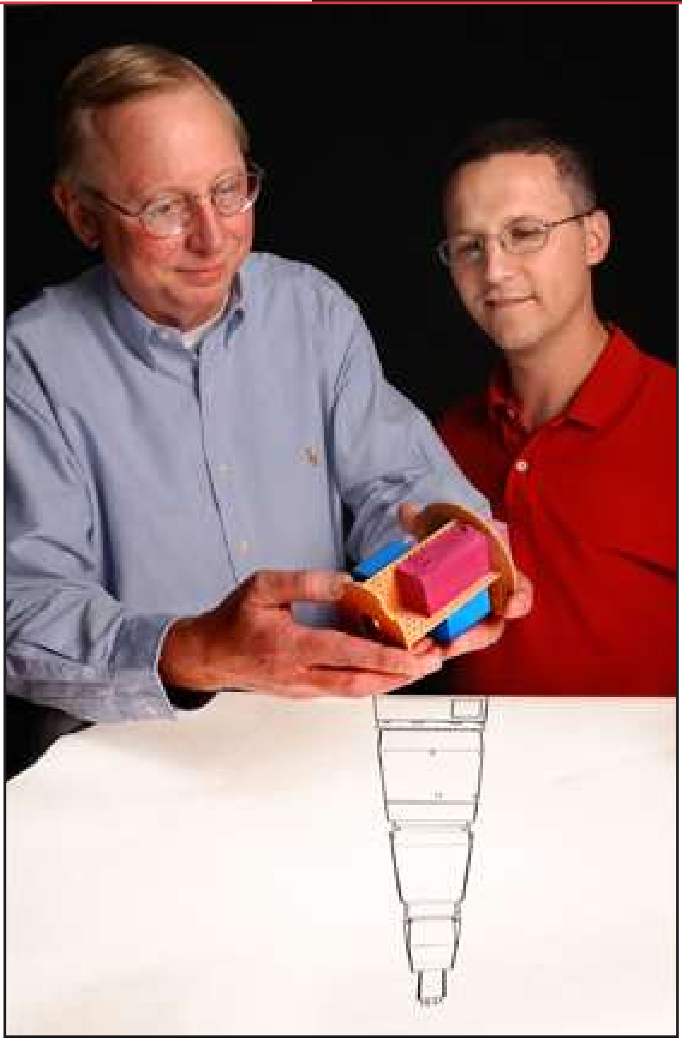
Sandia's Aerospace Systems Development Center will develop the HyTEx re-entry system.

Sandia National Laboratories researchers are assisting with NASA's HyTEx (Hypersonic Technology Experiment) program to benefit next-generation launch vehicles, following in the footsteps of the space shuttle.

With the first flight scheduled for May 2005, HyTEx is expected to provide a dedicated, timely, and cost-effective means of advancing the readiness level of vehicle system technologies through flight demonstrations in a relevant reentry environment.

Involvement in HyTEx is in keeping with Sandia's long-range goal of developing advanced technologies and integrated capabilities for hypersonic flight systems, applicable to a wide range of military and access-to-space requirements.

David Keese, deputy director for Strike Systems in Sandia's Aerospace Systems Development Center, said the NASA HyTEx technology flight demonstration is a perfect fit with Sandia's goal of supporting the design, development, and demonstration of the next generation of hypersonic vehicles. "Our most important role in the HyTEx program is to use our integrated design, development, and flight experience to produce a capability to obtain hypersonic flight evaluation of these new technologies," Keese said.



Mike Macha (left) and Mark Howard check out a scale model of the internal experiment assembly that will be flown on the HyTEx reentry vehicle. The model was created by using a 3-D printer. (Photo by Randy Montoya.)

Labs researchers are also working to advance key enabling technologies that will give even greater capabilities to programs like HyTEx in the future.

He described four basic design challenges in the HyTEx program:

- Provide a robust — low-risk and effective — vehicle to function as a flying test-bed.
- Incorporate technology experiments into this test-bed design in a fail-safe approach.
- Collect and transmit in-flight data from these experiments.
- Adapt the flight vehicle design to a variety of potential booster designs, including a recovery system that will allow post-flight examination of the integrated experiments.

Sandia's next major steps in the project involve developing detailed plans and organizing Sandia's resources to produce an actual flight system for the HyTEx proof-of-concept mission. Labs researchers are also working to advance key enabling technologies that will give even greater capabilities to programs like HyTEx in the future.

Mike Macha, HyTEx project manager, said he sees the project as an opportunity for Sandia to have a significant impact on a spectrum of emerging U.S. hypersonic technology initiatives. "There is a resurgent interest in developing a new generation of vehicles for rapid, affordable access to space," Macha said.

Fortunately, Sandia already has a foothold in a wide range of potential hypersonic technology areas — from high-temperature materials, to robust non-GPS-dependent navigation and guidance methods, to modeling and simulation capabilities.

"One immediate major challenge is deciding which subset of candidate technology areas to invest in," Macha said. "During the first year we have gone through a discovery phase that includes understanding the current level of development and the time frame for maturation of these technologies."

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Tailoring human implants
with new technology

The problem: how to create synthetic weight-bearing scaffolds that will encourage the growth of natural bone, blood vessels, and soft tissue to repair damaged bone within the human body.

The solution: use data from medical CAT scans and Robocasting technology to create implants with tailored microstructures and precise macrostructures.

It has been known for some time that bone mass can be generated by encouraging cells to grow around three-dimensional synthetic structures, such as sponges that are impregnated with a growth medium. With time, the body fills in the scaffold-like structure with bone and blood vessels. Currently, however, it is difficult to produce a tailor-made, individualized "scaffold" that precisely fits into the shape of a specific implant site. Additionally, the sponge-like replicas are weak and have uncontrolled and non-optimized porous structures.

Researchers at the University of Illinois are teaming with Sandia National Laboratories colleagues to find a solution with Robocasting. A computer model of an implant may be generated from a medical scan of a region of damaged bone. Using a combination of Robocasting and precise machining, researchers produce an implant that fits perfectly into the damaged region and promotes healing and growth of the surrounding healthy bone.

The implant requires a mesh-like structure with mechanical properties similar to living bone and made with a biocompatible material. The Robocasting system is ideally suited to precisely fabricate the mesh-like scaffolds out of a precursor ceramic material, hydroxyapatite. The hydroxyapatite scaffolds are strong enough to remain in place until natural bone grows into and ultimately replaces the scaffold. Approval for use in people is expected to be swift since the Food and Drug Administration (FDA) has already accepted hydroxyapatite as a suitable bio-material for use in humans.

Pain-saving device brings pleasure to creator: Sandia researcher Joe Cesarano admires the perfect fit of his team's Robocast implant set in the jawbone of a model skull. (Photo by Randy Montoya.)

Testing the concept

Recently, at a hospital in Urbana, Illinois, an elderly woman was briefly fitted with a Robocast scaffold to see if it fit her jaw as well as expected. She had lost most of her teeth and much of the bone of her lower jaw and was about to undergo a conventional bone replacement procedure, using bone harvested from her pelvis. The ceramic implant — created a thousand miles away at Sandia facilities in Albuquerque — was designed in great detail, from its overall shape to the inclusion of a nerve groove. An earlier medical scan had enabled the generation of a computer-derived model of an implant that would mate perfectly with the healthy remaining bone. Surgical expertise was provided to give computer programmers the dimensions of "what should be there but wasn't."

Once it is approved by the FDA, it's believed that use of the ceramic scaffolding

The computer-controlled machine dispenses liquefied ceramic pastes, like toothpaste squeezed from a tube, to form shapes of varying complexity along a prearranged path.

technique would reduce the pain, recovery time, and chances of infection of those needing repair or augmentation of the jaw, skull, spine, or other bony areas. Other benefits include avoidance of longer surgeries, greater predictability of outcome, and eventually lower health care costs.

A patent for the implant process is pending. The original Sandia-patented Robocasting process was conceived and built to fashion defense components on a battlefield, instead of medical parts in a hospital. Robocasting also is being developed to form advanced catalyst supports to increase chemical reactivity. The computer-controlled machine dispenses liquefied ceramic pastes, like toothpaste squeezed from a tube, to form shapes of varying complexity along a prearranged path.

To create the simulated bone scaffolding, the machine dispensed a hydroxyapatite mixture in a child's Lincoln Log-like arrangement, in cross-laid slivers each about as thick and as far apart as the diameters of ten human hairs. "Bone, blood vessels, and collagen love to grow into a structure with pores of that size (about 500 microns)," says Sandia scientist Joe Cesarano. "The material becomes a hard-tissue scaffold for promoting new bone growth."

Perfection regained: the perfect fit of the Sandia ceramic scaffolding in the model jaw also recreates the upper line of the original jawbone. The scaffold layerings, which criss-cross each other, expedite passage of new bone and blood vessels. (Photo by Randy Montoya.)

Improving the process

The hospital experience helped demonstrate that scientists and doctors using computer programs, modern communications, and machines at large distances from each other can produce a prosthetic device that will fit virtually seamlessly in a patient's body. As University of Illinois surgeon Michael Goldwasser put it, "What we want is a method by which I can see a patient in Illinois, transmit X-ray information to someone who can make a substitute part that would have the porous properties that would allow bone to grow into it, yet be strong enough for normal function."

"Surgeons and patients would love to eliminate both the bone retrieval and implant preparation processes," adds Cesarano, whose team fashioned the demonstration implant. "This test showed we can make artificial porous implants prior to surgery that will fit perfectly into the damaged region. The reconstructive procedure would then only require attaching the implant and closing the wound.

"There is nothing inherently expensive about either the materials or the process," said Cesarano. However, delineating the exact dimensions of what the bone would have looked like, were it healthy, currently requires the potentially expensive presence of a surgeon. Goldwasser looks forward to the time when a simple and cost-effective method could be used through electronic means. For example, a piece might quickly and inexpensively take shape at a remote site, if there were a computer-aided drawing program, by which the surgeon needed only to begin the process by sketching the shape needed.

"We'll see if the clinician, the bioresearcher, and the engineer can come up with a method to implement it," Goldwasser says.

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New way to make white light

Lauren Rohwer displays the two solid-state light-emitting devices using quantum dots her team has developed.
(Photos by Randy Montoya.)

LDRD

Quantum dots: nanoscience provides a contender in the quest for a high-efficiency, low-cost white light source. It can come in other colors, too.

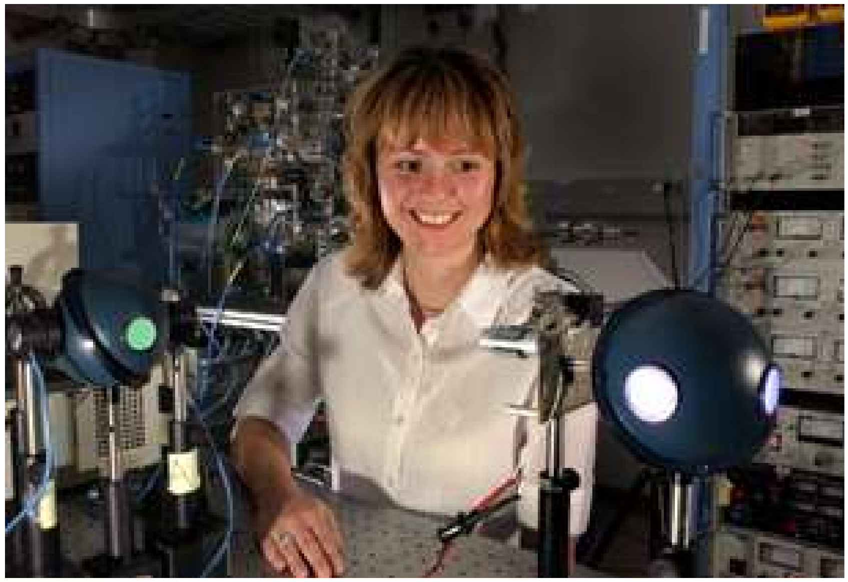
In a different approach to creating white light, a Sandia research group has developed the first solid-state, white light-emitting device that uses quantum dots. In the future, the use of quantum dots as light-emitting phosphors may represent a major application of nanotechnology.

"Highly efficient, low-cost quantum dot-based lighting would represent a revolution in lighting technology through nanoscience," says Lauren Rohwer, principal Sandia investigator. "Understanding the physics of luminescence at the nanoscale and applying this knowledge to develop quantum dot-based light sources is the focus of this work."

Conventional phosphors used in fluorescent lighting are not ideal for solid-state lighting, because they have poor absorption in the near ultraviolet wavelength range. So researchers worldwide have been investigating other chemical compounds for their suitability as phosphors for solid-state lighting.

The new Sandia approach is based on encapsulating semiconductor quantum dots — nanoparticles approximately one billionth of a meter in size — and engineering their surfaces so they efficiently emit visible light when excited by near-ultraviolet (UV) light-emitting diodes (LEDs). The quantum dots strongly absorb light in the near UV range

This nanophosphor-based device is quite different from an alternative approach based upon growth of blue-, green-, and red-emitting semiconductor materials that require careful mixing to produce white illumination.



Lauren Rohwer is the principal investigator of a research team developing the first solid-state white light-emitting device using quantum dots.

and re-emit visible light that has its color determined by both dot size and surface chemistry.

While the optical properties of conventional bulk phosphor powders are determined solely by the phosphor's chemical composition, in quantum dots the optical properties such as light absorbance are determined by the size of the dot. Changing the size produces dramatic changes in color.

Alternative approach

This nanophosphor-based device is quite different from an alternative approach based upon growth of blue-, green-, and red-emitting semiconductor materials that require careful mixing to produce white illumination.

Efficiently extracting all three colors in such a device requires costly chip designs, which likely cannot compete with conventional fluorescent lighting but can be attractive for more specialized lighting applications.

Rohwer and the quantum dot team — Jess Wilcoxon, Stephen Woessner, Billie Abrams, Steven Thoma, and Arturo Sanchez — started on the project two-and-a-half years ago. "This accomplishment brings quantum dot technology from the laboratory demonstration phase to a packaged component," Rohwer says.

By making a key innovation in the encapsulation process, the team achieved an increase in efficiency from the 10-20 percent range to an amazing 60 percent, Thoma says. While others working in the field of quantum dots have reported conversion efficiencies of nearly 50 percent in dilute solutions, the Sandia team is believed to be the first to make an encapsulated quantum dot device with such high efficiencies.

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Sandia, GTI address natural gas supply security

America needs a secure and reliable gas distribution system for the future. Sandia and a private-sector leader are teaming to see what's needed to make it a reality.

Sandia National Laboratories and GTI have agreed to work together over the next two years to address concerns about the security, reliability, integrity, and resiliency of the nation's natural gas supply and delivery system.

"This coordinated effort will require a strong, constructive relationship among the natural gas industry, government, the nation's research laboratories, and academia in the areas of policy, regulation, training, and technology development," said John Riordan, GTI's president and CEO, in announcing the pact.

GTI is a leading energy research, development and training organization.

"This is an important agreement between two institutions ideally suited to improve the security and reliability of the natural gas infrastructure in this nation," said Bob Eagan, Sandia vice president for Energy, Information and Infrastructure Surety. The project will tap into the science, technology and engineering strengths at Sandia, he said. "It will allow us to use tools we have developed as part of the National Infrastructure Simulation and Analysis Center as well."

Sandia's role will involve development and application of a risk assessment approach for physical protection of pipelines and gas storage facilities. Adapting its experience in other industries, Sandia will also look at interdependencies between natural gas infrastructures and those involving electric power and telecommunications, said David Borns, of the Labs' Geophysical Technology Department.

Researchers at the Labs will look at the security of information technologies used in gas pipeline control and in gas business transactions, he said. Sandia will also provide technical advice about needed technologies or processes as they are identified during the analysis and implementation stages.

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New materials

taking their cues from nature

LDRD

Jim Voigt, left, and Jun Liu discuss complex nanomaterials developed to mimic nature. (Photo by Chris Burroughs.)

Complex micromaterials that look strikingly similar to diatoms and seashells are emerging from Sandia's nanotechnology labs.

The physical and chemical principles behind the formation of natural materials are helping Sandia's scientists to develop ways of using environmentally benign processes for producing nano-materials. The goal is to take tips from nature in devising synthetic routes to achieve structural control for reliable and scalable production.

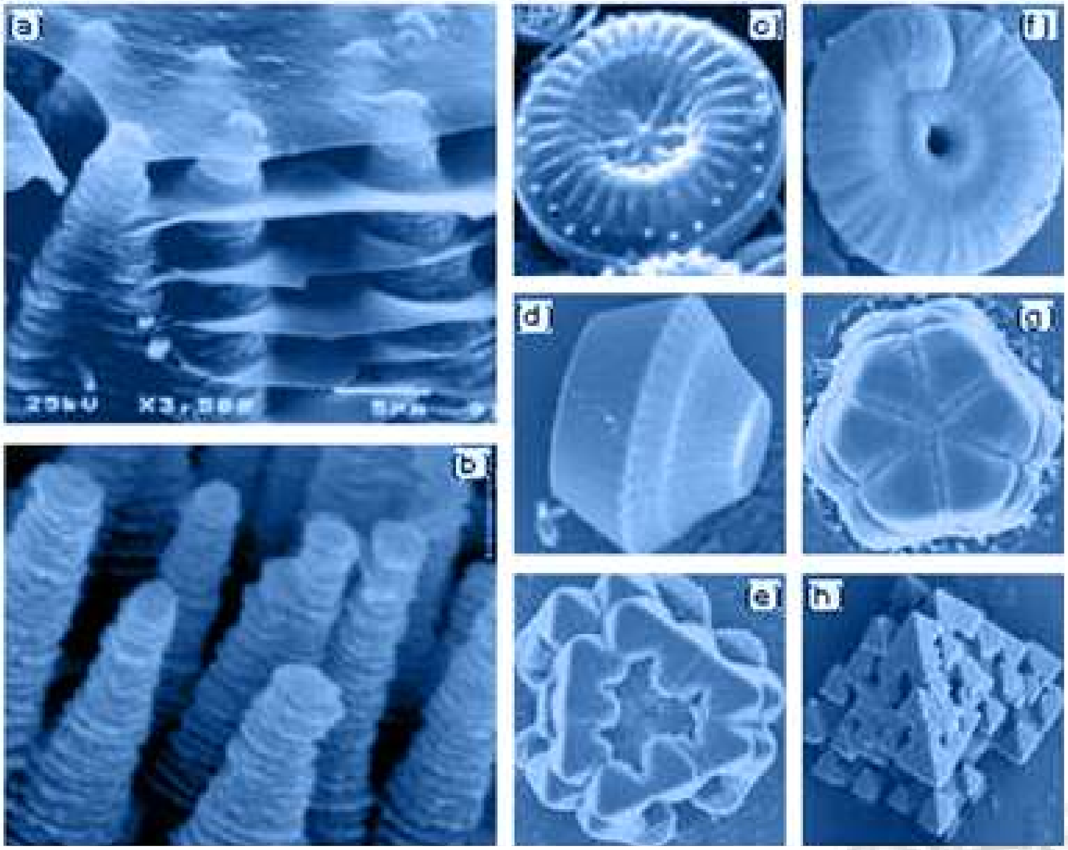
Nanomaterials are likely to find applications in microelectronic devices, chemical and biological sensing and diagnosis, catalysis, and energy conversion and storage, including photovoltaic cells, batteries, capacitors, and hydrogen storage devices. These structures could also have potential for light-emitting display, drug delivery and optical storage.

A group of scientists, mainly from Sandia's Chemical Synthesis and Nanomaterials Department, aim to precisely control and predict a wide range of materials properties. These include composition, particle size and shape, crystalline structure, orientation, particle morphology, surface and interface chemistry. The team has already made new chemical sensor devices with its materials.

The team has demonstrated complete control of where and how crystals are formed. The process they have developed selectively activates the specific surface they desire to grow, and then spontaneously produces complicated three-dimensional structures that cannot be formed by other means.

Controlling growth

Natural systems use sophisticated protein molecules to precisely control the growth direction and structure of the biominerals. In general, the proteins play two important tricks. First, they control where the mineral is deposited. Second, they control how the minerals are formed. In red abalone, a marine snail, water-soluble proteins control mineralization of calcium carbonate. Some of these proteins are responsible for the formation of calcium carbonate architectures



Complex nanocrystals have been prepared showing striking similarities with those observed in biominerals. (a) is the inner layer of a shell in red-abalone. (b) is synthetic zinc oxide crystals. (c) is a diatom. (d) to (h) are different types of synthetic silica crystals. The structure depends on the growth conditions and can be controlled.

Studies of low-temperature, low-chemical-concentration conditions in aqueous environments are helping the team control the speed with which the materials grow from solution.

– for example column-like calcite and plate-like aragonite. A highly ordered nanocomposite formed of these minerals confers optimal mechanical properties to the hard tissue.

The first step of the process is to understand and control the solution chemistry. Studies of low-temperature, low-chemical-concentration conditions in aqueous environments are helping the team control the speed with which the materials grow from solution. This avoids the precipitations commonly encountered.

Surface chemistry

Modifying the surface chemistry is often used to stimulate the formation of the minerals on specific locations. At other times, nanoparticles are used as nucleation seeds. Computer modeling helps understand how the organic molecules bind to the crystals.

One challenge now is to fundamentally understand how organic molecules affect crystal growth. Another is developing general rules to guide the production of a wide range of nanomaterials. The team is also in the process of developing tools to control the delivery, diffusion, and transport of the chemical species in reaction chambers,

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Lowering the cost of wind energy

LDRD

As the popularity of wind energy rapidly grows worldwide, researchers at Sandia National Laboratories are developing ways to lower the cost of this alternative energy and enable turbines to produce more power.

Turbines spin at the New Mexico Wind Energy Center, located 170 miles southeast of Albuquerque and 20 miles northeast of Fort Sumner. The site began producing electricity for Public Service Company of New Mexico (PNM) this fall. The center is the world's third-largest wind generation project. (Photo by Norman Johnson courtesy of PNM.)

Current wind turbines are cost effective in very windy sites. The goal of the Department of Energy's wind program is to extend that cost effectiveness to convenient sites that are not as windy. This can be done by making the rotor swept area as long as possible with out increasing system costs.

"We are looking at methods of building larger, stronger blades for turbines using a hybrid of carbon graphite fibers and fiberglass that sweep a greater area without greater cost," says Paul Veers, manager of Sandia's Wind Energy Technology Department. "By next summer we expect to have experimental blades ready for testing we believe will be lighter and stiffer than blades currently used in the industry."

Sandia has been researching wind energy since the 1970s, but it's only now that the alternative energy source has become economical enough to find widespread use. Over the past ten years the cost of wind energy has fallen dramatically — to 2.5-4 cents a kilowatt-hour in the windiest sites. However, further cost reductions are necessary in critical subcomponents in design, manufacturing, and system integration, Veers says, to make wind turbines cost effective in sites with modest winds.

Wind farms

Wind farms — fields of wind turbines — can be found in California, Southwest Texas, Minnesota, the Washington-Oregon border, Iowa, West Virginia, Pennsylvania, Kansas, and several other states. A newly developed wind farm recently began operations at a Public Service Company of New Mexico Wind Energy Center near Fort Sumner, New Mexico.

Veers says that in Europe, where wind energy has become particularly popular, turbine manufacturers are starting to produce very large machines. They are frequently used for offshore applications where winds are steady and strong.

Today, the most popular commercial wind turbines have 35-meter blades on towers that are 65 to 80 meters tall.

(Photos courtesy of Sandia Wind Energy Department.)

"However, as machines have grown larger, issues of scaling and loads have made detailed engineering even more important," Veers says.

That's where Sandia comes in — researching how to overcome some of these issues.

Today, the most popular commercial wind turbines have 35-meter blades on towers that are 65 to 80 meters tall. They produce about 1.5 megawatts each, and the blades are primarily made of fiberglass, although at least one European manufacturer uses wood.

Scaling up the blades

Tom Ashwill, who leads the blade development team, says that the research blades will be built at sub-scale sizes of nine to ten meters in order for the researchers to cost-effectively grapple with issues such as fiber material form, degree of carbon/glass hybridization, manufacturability and other traditional issues like aerodynamics, structural strength, and reliability. Researchers believe that qualities of successful subscale blades can be scaled up to blades 50 meters long. These blades would reside on turbines with 100-meter towers and produce 2 to 5 megawatts each.

Sandia is working with both manufacturers and designers to bring the findings of these subscale blade studies up to full-scale application in commercial prototypes. Public-private partnerships are being funded through the Department of Energy's Low Wind Speed Turbine program.

By next summer the researchers hope to have six to 12 blades to test at the National Wind Technology Center near Boulder, Colorado, using its large blade test facilities, and at the Department of Agriculture's research station in Bushland, Texas, using three experimental turbines.

"We expect over the next few months to make some real inroads to developing better blades for turbines," Ashwill said. "It's a project we are all looking forward to."

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Kevin Krenz, an engineer in Sandia's Advanced Lithography department, inspects components in a first-generation EUV Lithography tool.

Sandia researchers earn R&D 100 Awards

Sandia National Laboratories researchers won seven R&D 100 Awards this year, plus a "best of the best" Editor's Choice recognition. The contest, sponsored by the Chicago-based trade magazine *R&D Magazine,* uses technical experts to determine the best new technologies. One hundred winners are chosen from an international pool. Sandia won many of the awards in partnership with private companies, other labs, or universities.

Members of the Extreme Ultraviolet Lithography Full-Field Step-Scan System team were singled out for special recognition at the recent R&D 100 Awards banquet in Chicago. The editors described the team's achievement as "the 'moon shot' of technology in the semiconductor industry."

The team of more than 50 collaborators from Sandia, other national laboratories and industry were recognized for advances that will lead to dramatic improvements in the speed and memory of future computer systems. Researchers created a system that can pattern full chip-size areas on silicon wafers with features as small as 50 nanometers.

The R&D 100 Awards were created in 1963. The sole criterion for winning is "demonstrable technological significance compared with competing products and technologies." Here are brief descriptions of other winning technologies:

SnifferStar

An extremely lightweight mobile chemical sensor created by seven Sandia researchers and a Lockheed Martin staff member, SnifferStar™ mounts on a drone aircraft for remote surveillance of battlefield situations where suspect plumes or clouds are present.

Acoustic telemetry technology

Acoustic telemetry technology, developed at Sandia in cooperation with a Canadian engineering company from Calgary, Alberta, allows real-time measurements while drilling. Acoustic telemetry technology uses the well-drilling tubing as the data transmission medium and sound waves as the data carrier.

Low Emissions Atmospheric Metering Separator

The Low Emissions Atmospheric Metering Separator (LEAMS) is a family of atmospheric geothermal separators used to safely contain and clean the atmospheric vented steam of polluting solids, liquids, and noxious gasses. This system is designed to be environmentally friendly, safe, and easy to transport and assemble. LEAMS can be used in geothermal drilling, well testing, and power plant start-up.

Adaptive Optics Phoropter

Two Sandia researchers helped design and integrate a compact, transportable adaptive optics system that determines correction needed for near-sightedness or far-sightedness, astigmatism, and high-order aberrations that can interfere with night vision. The Adaptive Optics Phoropter combines technologies from astronomy and micromachining.

Mitigating electrical network problems

A fast-response semiconductor device developed under Sandia direction allows a utility to rapidly convert energy stored in a DC device into AC power to minimize the negative effects of lightning strikes or equipment failures. The component could become a critical part of inverters, motor controllers, and many other electronics systems that require medium voltage and high current switches.

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"Sandia's expertise in the areas of impact testing and modeling, material testing, non-continuum aerodynamics, and thermal analysis has been invaluable to our investigation teams. The cooperative effort and sharing of ideas, test methods,and analytical tools have been beneficial to both our organizations."

William Readdy
Associate Administrator for Space,
National Aeronautics and Space Administration

Sandia National Laboratories

LOCKHEED MARTIN

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

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