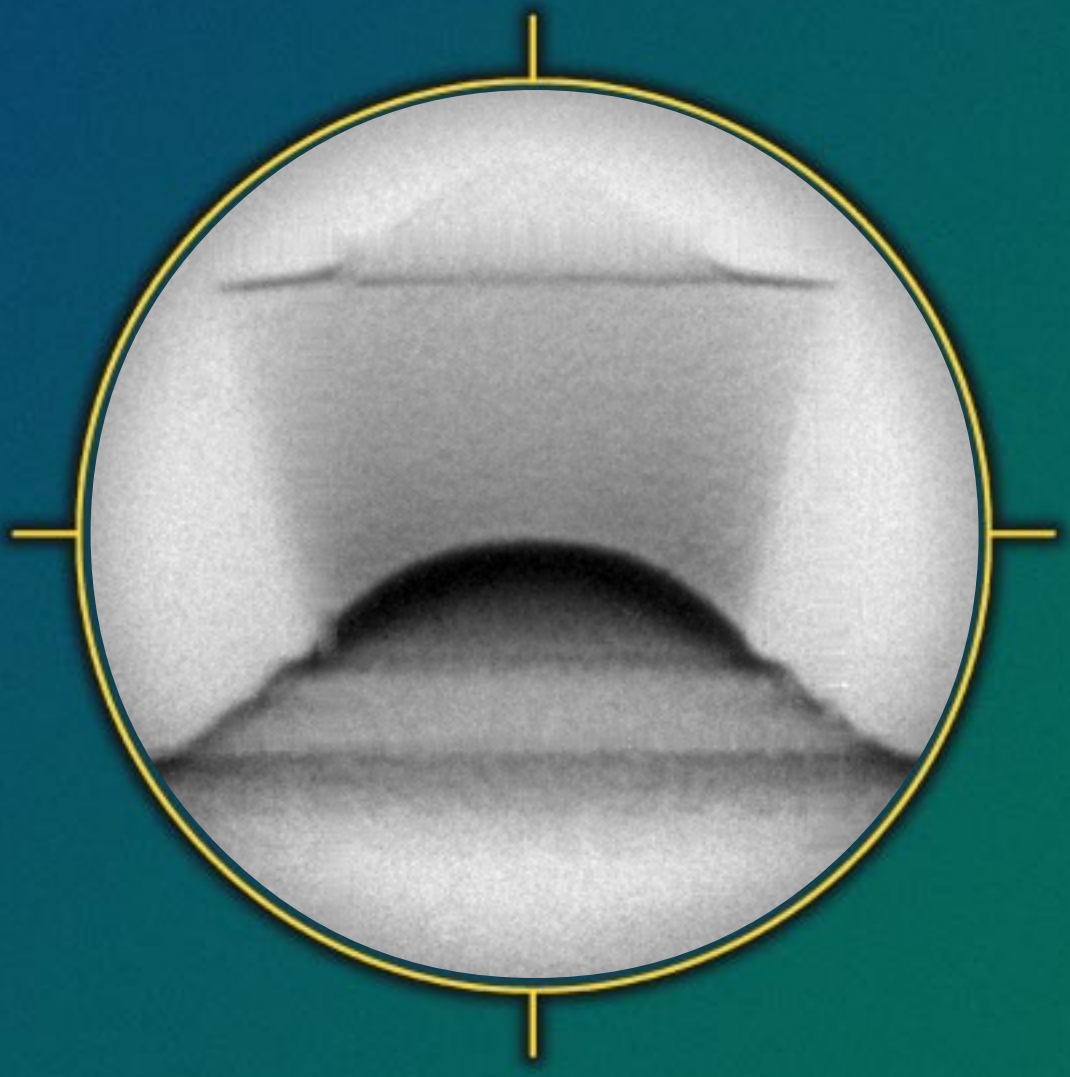
Winter 2003

LOS ALAMOS research QUARTERLY

Proton Radiography



Shelf Life Guaranteed
Modeling Bone Remodeling
Simulation Science

Los Alamos
NATIONAL LABORATORY

About the Quarterly

The *Los Alamos Research Quarterly* is published to communicate the Laboratory's achievements and how they benefit our neighbors, our nation, and the world. Operated by the University of California for the Department of Energy and the National Nuclear Security Administration, Los Alamos has a distinguished record of applying science and technology to meet national needs, a record that stretches back to our founding during the Manhattan Project.

The *Research Quarterly* highlights our ongoing work to enhance global security by ensuring the safety and reliability of the U.S. nuclear weapons stockpile, developing technical solutions to reduce the threat of weapons of mass destruction, and solving problems related to energy, environment, infrastructure, health, and national security. The *Research Quarterly* is available online (http://www.lanl.gov/quarterly/).

Inquiries about this publication should be directed to larq@lanl.gov or to Research Quarterly, Los Alamos National Laboratory, Mail Stop D416, Los Alamos, NM 87545.

About the Cover

The front-cover photo shows a levitating spall layer of shock-melted tin. It is one of sixteen frames in a proton-radiography movie that shows how a tin disk responds to the shock wave produced by detonating a high explosive beneath the disk. First, the detonation's spherical shock wave bulges the disk (about 2 inches in diameter and 0.25 inch thick). Then, when the compressive shock wave reflects from the disk's upper surface, the shock becomes tensile, dislodging and levitating the spall layer (the "flying saucer"). The shock wave's high pressure and temperature also melt the tin (light gray region connecting the flying saucer and bulge). The movie sequence is shown on pages 14 and 15. Proton radiography is a new diagnostic technique that produces detailed movies of high-speed shock and implosion tests. The back cover shows the proton radiograph of a model airplane engine (see page 16).

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Dateline Los Alamos

Healing or Self-Damage: Immunoreceptors' "Split Personality"

Sometimes described as a "liquid brain," the immune system is continually poised at the edge of disaster, required to aggressively attack invading pathogens without damaging its own body. The challenge of understanding the complexity of signaling entailed in such a delicately balanced system has been taken up by Laboratory researchers, who are developing a mathematical model of immunoreceptors, a large and diverse group of proteins that decode regulatory signals.

As recently reported in *Molecular Immunology*, a team led by Byron Goldstein of T-10 (Theoretical Biology and Biophysics), and including Michael Blinov, Jim Faeder, Bill Hlavacek, Antonio Redondo, and Carla Wofsy, is studying the Fc epsilon receptor. This receptor is a mast-cell membrane protein that normally functions in inflammation to help remove pathogenic organisms but which, when regulation goes awry, serves as a signaling intermediary in allergic reactions. The receptor binds the IgE class of antibodies and is activated when foreign substances (antigens) bind to those antibodies. Receptor activation initiates a cascade of biochemical changes that culminates in the secretion of histamine and other inflammatory biochemicals. In allergic reactions, the

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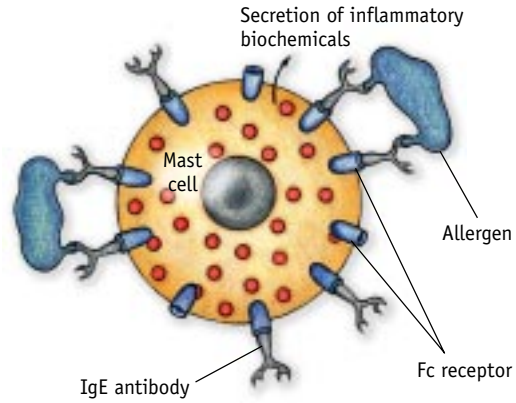

A mast cell with IgE antibodies bound to the Fc receptors on its surface; when a foreign substance binds to those antibodies, the Fc-receptor signaling cascade is triggered and inflammatory biochemicals such as histamine are secreted. When the secretions become excessive, the foreign substance is termed an "allergen."

Two infrasound microphones under white heat shields (about 2 feet tall). The black "wires" in the foreground are porous hoses that reduce wind noise for the microphones.

Improving Meteor Impact Predictions

An array of infrasound detectors used by the Laboratory to "listen" for clandestine nuclear tests has played a key role in helping scientists more accurately determine how often Earth is hammered by giant meteors like the one that flattened 1,900 square miles of forest in Tunguska, Siberia, in 1908.

Previously, scientists believed that very large meteors like the Tunguska one entered Earth's atmosphere every 200 to 300 years. Now, Lab researcher Douglas ReVelle and his colleagues have collected evidence that such catastrophic meteor strikes occur less frequently—about every 1,000 years. Their findings were published in the November 21 issue of *Nature*.

ReVelle teamed up with researchers from Sandia National Laboratories, the University of Western Ontario, ET Space Systems, and the U.S. Space Command to look at both infrasound and light signatures from mid-size meteors that entered Earth's atmosphere over the last eight years. When such meteors—ranging from 3 to 30 feet in

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Mesa View

Science at Los Alamos

Richard Robinson

Thomas J. Meyer,
Associate Director, Strategic Research

Los Alamos is a laboratory with a mission. It began nearly sixty years ago with the Manhattan Project and the first successful nuclear test at Trinity Site. From start to finish, that first mission was accomplished in twenty-seven months, from 1943 to 1945. This remarkable science and engineering feat was the result of the concerted efforts of some of the greatest minds of the century—Bethe, Fermi, Feynman, Oppenheimer, Teller, Ulam, von Neumann, and others. There were eleven Nobel Prize winners from that remarkable group.

The Laboratory's mission has evolved through the years, and the Laboratory has evolved with it—but always in response to national needs and with a national security focus. Our budget is approaching $2 billion, and we have more than 10,000 employees. Los Alamos is now a multipurpose Department of Energy science facility, one of the great research laboratories of the world.

Our core mission remains in nuclear weapons, but now ensuring the reliability of an aging stockpile must be accomplished without nuclear testing. The nation relies on us for solutions in homeland security and for our expertise in assessing and mitigating threats from weapons of mass destruction, whether they are nuclear, chemical, or biological.

We are also a key national R&D facility for energy and environmental studies, the biosciences, analysis of critical infrastructures, and the implications of such research for national security. Key capabilities have evolved from this R&D mission and assumed national importance to U.S. security and the U.S. economy—such as our Superconductivity Technology Center, the Los Alamos Fuel Cell National Resource Initiative, and the National Infrastructure Simulation and Analysis Center (see the article on page 23).

There are other capabilities on the Lab's drawing boards, including ways of coping with global warming as well as with threats from terrorism, mounting water shortages, and the energy demands of a growing world population. All demonstrate the strength of the national laboratory system in providing a diverse pool of exceptional scientists to collaborate on technical problems of national importance.

Nearly everything that we accomplish at Los Alamos relies on maintaining a premier scientific and engineering base. This base must be broad and diverse, capable of rapid response across multiple disciplines. It must be complete, extending from fundamental science to the design and manufacture of specialty devices, components, and instrumentation. It must be outstanding because the problems are challenging. It must be the best because our nation demands excellence.

In many areas, industry has chosen to walk away from developmental science, preferring instead to "buy off the shelf." It is the nature of what we do at Los Alamos that there is often no shelf to buy from. We have our people, our capabilities, and our marching orders. Our science provides the means by which we meet our mission responsibilities for the nation.

John Flower

Shelf Life Guaranteed

Extending the Life of Nuclear Weapons

by Brian Fishbine

No new nuclear weapons have been produced in this country in 10 years. In fact, the average age of a stockpile weapon is now 19 years, and some of the weapons are over 35 years old.

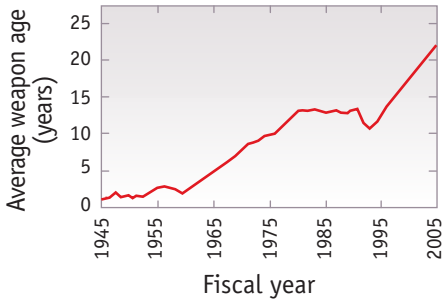
Los Alamos researchers Deniece Korzekwa and Phil Tubesing position a cylindrical graphite funnel over a graphite mold used to cast pieces of uranium alloy. Thermocouples in the mold measure the temperature distribution during casting. (Thermocouple leads protrude from the mold.) Temperature data help researchers refine computer models of the casting process that will be used to improve the process. Proper casting helps produce alloy pieces that do not become brittle over long periods of time.

The nation's nuclear weapons were originally designed to last for 20 to 25 years. Each year, the directors of the Department of Energy's three nuclear weapons labs must certify that the stockpile weapons will perform as designed. If the performance of an older weapon becomes questionable, lab scientists must decide how to replace its aging parts in order to restore its peak performance.

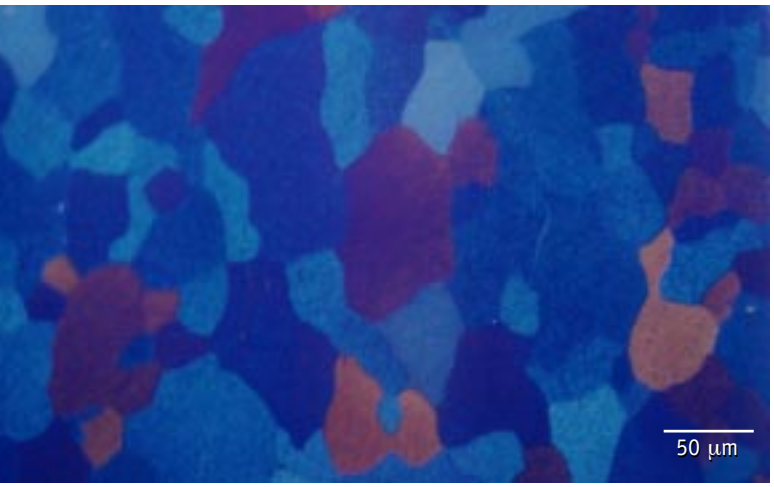
Aging weapon parts are a major topic for materials scientists Paul Dunn, Rusty Gray, Dave Teter, and Dan Thoma, who are working to extend the lifetimes of stockpile weapons in two of Los Alamos' highest-priority programs. The goal of one of these programs is to extend the lifetime of a 25-year-old weapon system to 75 years, which will guarantee its performance until at least 2042. Materials science is key to these efforts because, as Thoma says, "The only things that change in a stockpiled nuclear weapon are the materials." These scientists must determine how the materials are changing so they can predict when a part will fail.

Materials science has become more central to the weapons program because of a change in how weapons research is done. During the Cold War, researchers designed and built nuclear weapons without completely understanding the materials. They simply used the materials and fabrication processes that made a weapon explode at its nominal yield when tested at the Nevada Test Site. However, the end of the Cold War brought a ban on nuclear testing. Now, nuclear weapons are "tested" in computer simulations, which do require a full understanding of weapon materials, because a simulation must accurately predict how weapon parts will behave during the detonation.

However, there are many materials in a nuclear weapon, including metals, high explosives, polymers, and ceramics. The aging of any one of these materials could affect weapon performance, which is why scientists with a wide range of materials



No new warheads have been produced for over 10 years, a hiatus that is rapidly increasing the average age of stockpiled weapons.



Ann M. Kelly

Micrograph of pure uranium. Each colored region in this mosaic is a single microscopic crystal, or grain, of uranium. When the polished surface of this uranium sample was exposed to air, thin oxide films formed overnight. Oxidation is undesirable for a weapon part because it weakens the part. The colors here are produced by the interference of light in the oxide films. Different colors correspond to different oxide thicknesses and are shown as they actually appear.

expertise are working to understand aging processes. The challenges these scientists face are illustrated by the aging issues for uranium, the specialty of Dunn, Gray, Teter, and Thoma.

Old Uranium

Uranium is the main heavy metal used in a weapon's "rad case" to redirect the x-ray radiation produced by the weapon's fission primary. It is also sometimes used in other weapon parts.

Uranium and its alloys age in several ways. Like steel, pure uranium "rusts" when exposed to the oxygen in air. It is also corroded by hydrogen. Although nuclear warheads are sealed in airtight metal containers to reduce oxidation and corrosion, the high explosives, plastics, and other organic materials also in the container emit tiny amounts of oxygen, hydrogen, and water vapor that, over time, can cause problems.

Uranium alloys also change their crystal structures, or phases, over time, which also presents aging problems. Materials scientists manufacture a part to have a specific phase in order to optimize its strength, density, or corrosion resistance. However, the strain a part accumulates during fabrication and the temperature variations a weapon experiences in the field can, over time, change the phase, thereby degrading a part's properties.

Subjected to the considerable heat given off by a weapon's radioactive plutonium, for example, a uranium part—and all other weapon parts—can reach temperatures as high as 40°C (about 100°F). A weapon can also experience temperature extremes in its storage environment, such as a desert. Temperature-induced phase changes that degrade uranium's mechanical properties are a major concern.

Predicting the Future

A logical first step in deciding when to replace a weapon's parts is to examine the parts. Each year, technicians randomly select ten or eleven stockpiled weapons for each weapon system, take them apart, and inspect, weigh, and x-ray their parts. Some of the parts are then sent to the weapons labs for further study. From an analysis of the parts, materials scientists must predict when they will fail. Predictions may have to extend many decades into the future.

For example, Thoma has developed a model to predict long-term changes in the ductility of a rad case. (Ductility measures a material's ability to inelastically deform without fracturing. It is important because rad cases become brittle with age.) Thoma has modeled the thermal migration of uranium atoms within the case material, which leads to phase changes that embrittle it. The model's predictions agree well with mechanical measurements on rad cases 2 to 9 years old. Thus, there is good reason to believe the model's predictions for rad cases many decades old. Extrapolating much further into the future, however, requires accelerated aging tests. For example, the aging of uranium alloys may be accelerated by heating them in the presence of various gases.

To predict a part's lifetime, scientists must also know how the part was made, because a material's properties strongly depend on how it is processed. For the older weapons, details on part fabrication now considered important were not always recorded. Often, however, scientists can retrieve the missing information by applying knowledge and techniques developed through decades of weapon materials research. Thoma points to this sort of detective work as an excellent example of how studies whose goals are to clarify everything possible about a material—without an immediate payoff—can help solve problems that arise later. This is the nature of *science-based* stockpile stewardship.

Replacing Old Parts

Once they have decided that a part must be replaced, materials scientists must decide how to manufacture its replacement, since many of the nation's weapons plants have been dismantled. For small numbers of parts, they may be able to use existing small-scale fabrication facilities.

For example, Los Alamos has several sophisticated small-scale facilities for processing uranium and plutonium parts, including uranium- and plutonium-casting facilities. The Lab also has the specialized expertise needed to work with these and other weapon materials and, in fact, has begun developing the capability to manufacture replacement pits, the main component of a fission primary.

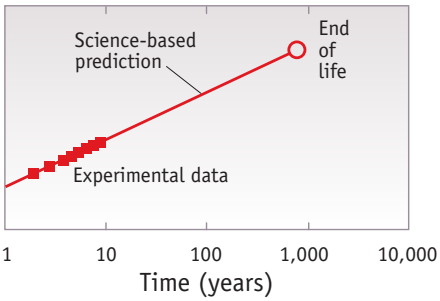
However, a process used to produce replacement parts must be cost-effective and must comply with environmental regulations that did not exist during the Cold War. Further, because the material properties depend on processing steps, the parts produced by a new process may not be exact replacements. Although newer technology may produce better parts, the fact that the parts are different can lead to changes in their performance and aging.

Gray illustrates the problem with potato chips. The same ingredients are found in traditional chips sliced from potatoes and in the injection-molded chips that stack snugly inside a can. But the chips' properties—their appearances, textures, tensile and bending strengths, even their tastes—differ because of their different processing.

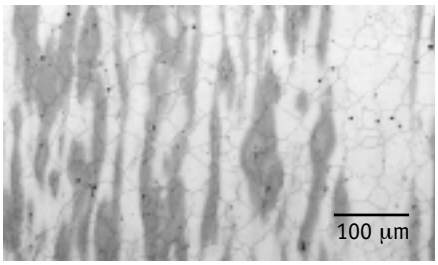
Dunn uses this analogy in discussing the replacement of rad cases. During the Cold War, rad cases were forged. To replace them now, it would be cheaper to cast new cases from the uranium melted down from old cases. However, casting produces a different microstructure in the uranium than forging does, which could produce compositional inhomogeneities that alter phase stability. Dunn and his co-workers are working to determine if such microstructural differences could have serious adverse effects.

In addition, many materials—particularly the weapons' polymers—are no longer available, or the processes used to make them have changed so much that the materials' properties are quite different from those of the original polymers. Lab scientists must also find solutions to these problems.

It was, of course, much easier to determine the effects of a new fabrication process during the Cold War: a weapon containing parts made with the process was simply tested. But with weapon testing no longer an



The effects of aging on a uranium rad case. The squares represent measurements of the mechanical strengths of rad cases that were pulled from the stockpile for inspection. Higher mechanical strength means that a rad case is more brittle. When the case becomes too brittle, it has reached the end of its life. The line represents the mechanical strength predicted by a theoretical model developed at Los Alamos. The close agreement between theory and measurement implies that the cases will not have to be replaced for many decades.



Ann M. Kelly

Micrograph of a uranium alloy used in rad cases. A small percentage of niobium is added to the uranium to prevent oxidation. Each banded region started out as a compositional inhomogeneity formed when a molten mixture of the two metals solidified. In time, inhomogeneities can change the alloy's crystalline structure, making the alloy brittle. Understanding how to minimize inhomogeneities is important in extending the shelf life of rad cases.

John Flower

Before (top) and after (bottom) photos show the effects of aging on the plastic binder used in many high explosives. As part of accelerated-aging experiments conducted by the Lab's Polymers and Coatings Group, cast cylinders of the plastic were stored for 59 days at 70° C (160° F) and 75 percent humidity. Over this time, the plastic changed color, became misshapen, and turned brittle, with cracks forming at the base of some cylinders.

option, the complete effects of a new process can now be studied only with computer simulations.

Guaranteeing Shelf Life

The challenge of extending the lifetimes of nuclear weapons is complex and requires the coordination of many varied research efforts focused on how the properties of weapon materials change over time. These efforts include studying how aging and processing affect a material's microstructure and, in turn, how microstructure affects the material's bulk properties; extracting data on material properties under conditions that resemble those of a nuclear detonation; and accurately modeling the material properties in computer simulations of weapon performance.

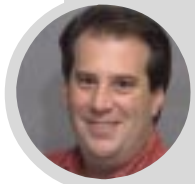
Cost-effectively extending the shelf lives of weapons is critical to maintaining the nation's nuclear deterrent. It would cost about $1 billion to build a new facility to manufacture rad cases or other uranium replacement parts. A new facility for making plutonium parts would cost even more. These costs make it important to analyze all the options available for extending weapon shelf life. ■

The Researchers

Paul S. Dunn earned a B.S. in engineering from Northern Arizona University and an M.S. in metallurgical engineering from the Colorado School of Mines. He is the deputy group leader of the Metallurgy Group in the Materials Science and Technology Division.

George T. "Rusty" Gray III earned a B.S. and M.S. at the South Dakota School of Mines and a Ph.D. at Carnegie Mellon University, all in metallurgical engineering and materials science. He became a Laboratory Fellow in 2002.

David F. Teter earned a B.S. and Ph.D. at the University of Illinois, both in metallurgical engineering. His speciality is the study of environmental effects on materials.



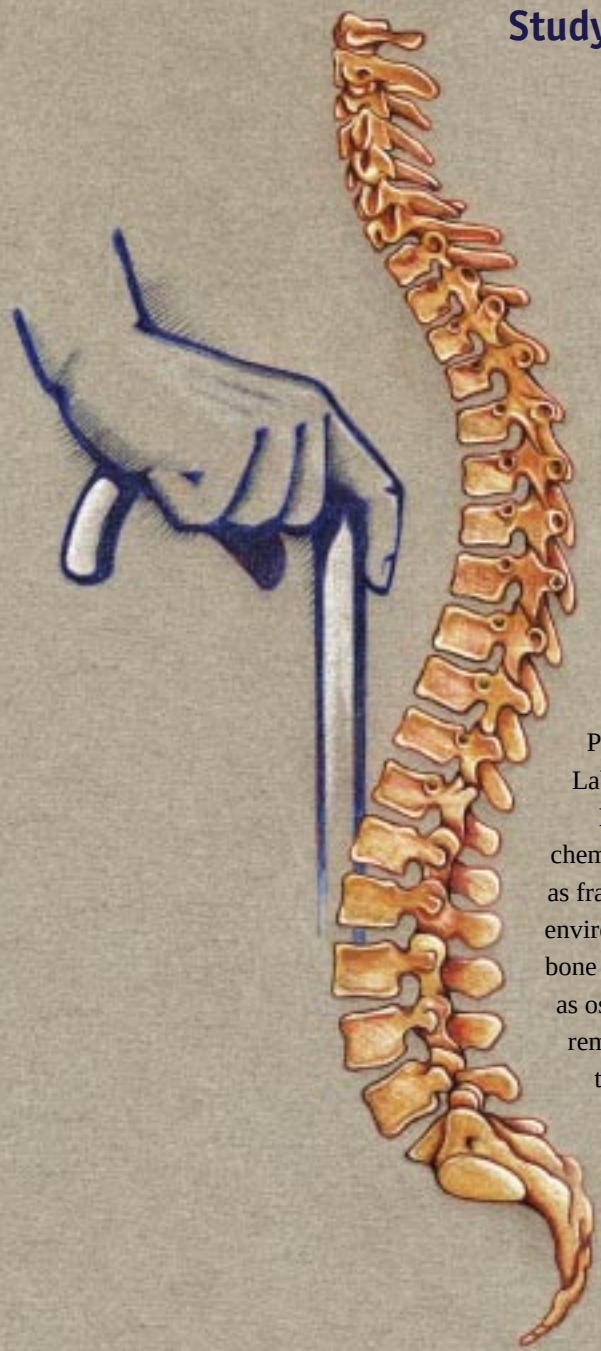
Dan J. Thoma earned a B.S. and M.S. at the University of Cincinnati and a Ph.D. at the University of Wisconsin, all in metallurgical engineering. He is the 2003 president of the Minerals, Metals and Materials Society, the youngest president in the society's history.

John Flower and LeRoy N. Sanchez

Modeling Bone Remodeling

Studying Bone Dynamics with Monte Carlo Codes

by Vin LoPresti



Often viewed as static support beams, human bones are in fact dynamic organs enmeshed in the network chatter—the complex information processing—that characterizes human physiology. Continually remodeling through processes that remove existing bone and deposit new bone, a young adult's skeleton replaces one-fifth of its bone tissue each year.

This dynamic remodeling serves both to subtly adjust structure in response to changing stresses and to maintain the proper level of blood calcium, a mineral essential to the functioning of all cells. To create more informative—and ultimately more medically useful—models of bone dynamics, a team from the Theoretical and the Applied Physics Divisions is drawing on time-tested algorithms and the Laboratory's supercomputing capability.

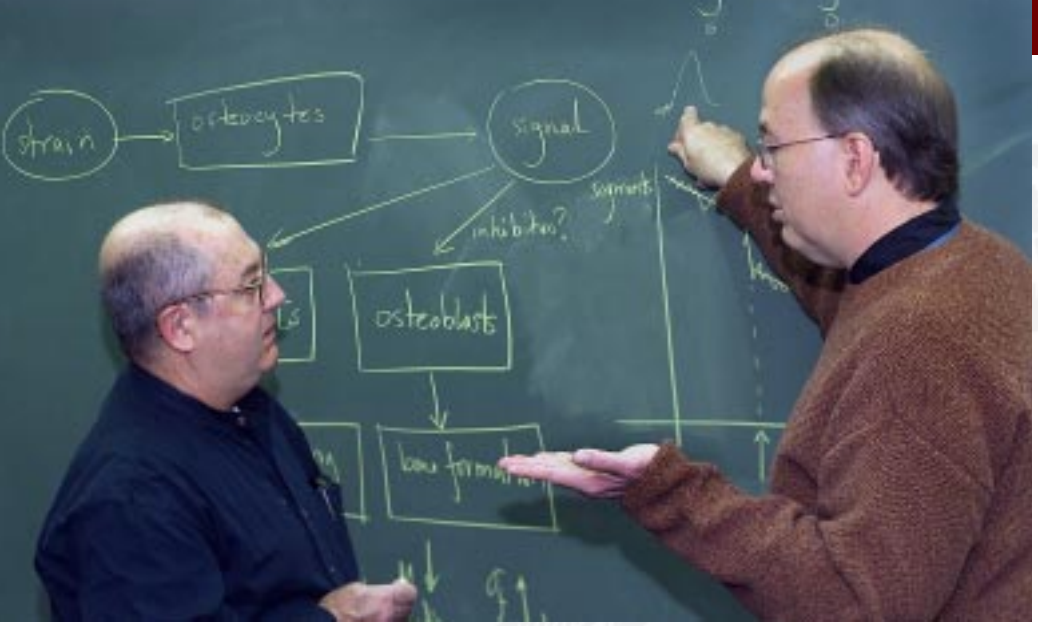
Remodeling normally occurs during bone growth, in response to physico-chemical factors such as stresses from exercise, during repair of injuries such as fractures, and during hormonal changes. Remodeling includes the sensing of environmental changes, the formation of new bone, and the removal of existing bone ("resorption"). Because of bone remodeling's complexity, illnesses such as osteoporosis—which result from disturbances in the control of remodeling—are poorly understood. Existing treatments for such illnesses therefore relieve symptoms rather than address underlying causes.

To firmly ground their research in the real world of biomedicine, the Los Alamos team is collaborating with a local orthopedic surgeon, Wayne Augé.

Modeling Complex Systems

The team is using simulation techniques that have proved valuable in materials science, mechanical engineering, chemistry, and physics and that were originated at the Laboratory during the 1950s by Nicholas

Illustration by Donald Montoya



John Flower

Investigators Antonio Redondo and Richard LeSar discuss a modeling strategy.

Metropolis and his collaborators. Exemplified by the well-known Monte Carlo method, these computational approaches lend themselves to analyzing any complex system that exhibits multiple states and nonlinear competing interactions.

Since biological systems are characterized by multistate nonlinearity, they are amenable to Monte Carlo analysis. Moreover, enough is known about the competing processes in bone remodeling to make it a logical candidate for study. Monte Carlo methods tend to find preferred paths for a system's evolution of states, ignoring irrelevant ones. They are, therefore, well suited for modeling living systems, which clearly cannot "visit" any chemical configuration that would be incompatible with continued life.

Honing In on Bone

In some respects, bone tissue closely resembles reinforced concrete: its hard, inflexible calcium phosphate matrix is reinforced by flexible fibers of collagen, a protein that plays a role similar to that of steel "rebars." However, bone matrix is also quite different from concrete in that it is populated by three types of living cells and crisscrossed by blood vessels. This dense cellularity and blood supply enable bone to renew its components at a microscopic level—by resorbing existing bone and forming new bone—while remaining stable at the macroscopic level. Such processes of self-renewal are characteristic of all living tissue. In bone, they are carried out by a grouping of three varieties of bone cells collectively referred to as a basic multicellular unit, or BMU (see the sidebar on page 12 for details).

Bones are also organs whose design incorporates the best in biological engineering know-how. Although on their exterior surfaces, bones appear to be solid matrix with few interruptions, this so-called compact bone is merely a shell. For under the surface, most bones resemble a rigid sponge, a meshwork of thin beams of bone tissue. Such an arrangement is analogous to the exterior-wall construction of homes—internally composed of regularly spaced studs, externally faced with particle-board sheets. This design in both houses and bones confers strength while minimizing weight.

Osteoporosis

Osteoporosis results from an imbalance in which bone resorption outstrips bone formation. The net loss of bone matrix renders bones weaker and more susceptible to fracture, with the fracture risk doubling for every 10 percent bone loss. Well known as an illness of older women, osteoporosis is also on the rise for men.

The effects of osteoporosis are most readily seen in x-rays of the spongelike interiors of bone. The erosion or thinning of the individual beams of this rigid meshwork is both an important clinical indicator and a key mechanical problem, weakening weight-bearing bones and predisposing them to fracture and collapse. Just as progressive termite damage to the supporting studs in a house's wall will eventually produce disastrous results, so too will the erosion of this spongy bone tissue.

Modeling Bone Dynamics on Three Levels

Because of the complex signaling network that regulates bone cells, counteracting illnesses such as osteoporosis or the bone losses accompanying cancer requires an improved ability to predict how changes in that network will affect the physical composition of bones. From signaling substances referred to as "bone morphogenetic proteins" to immune-system inflammatory proteins to hormones like estrogens, there are many signaling configurations to which bone cells respond.

In addition, any set of signals will produce not only a physiological response (such as remodeling) but also feedback signals that tend to modulate the effect of the initial signals. Factor in information communicated locally among neighboring bone cells, and the need to use high-performance computers to model such interactions becomes obvious. Therefore,

developing computational models of signaling is a core focus of this research.

The microscopic scale of the BMU comprises the first level of the team's modeling. The model incorporates the three BMU bone cells, the signaling molecules by which they interact, and known triggers of remodeling such as altered stress on a bone. All interactions between pairs of cells are written in the general form used to describe a chemical reaction: $A + B \rightarrow C + D$, where A + B describes the particular interaction and C + D, the outcome of that interaction. The entire set of such "reactions" constitutes the input to the model. The algorithms that solve the equations by predicting most-probable BMU behaviors are identical to those developed to study the progress of chemical reactions.

A second modeling level examines the effects of many BMUs reshaping the individual beams of spongy bone. Model parameters include rates of BMU activation and of bone resorption and formation. Using a Monte Carlo sampling allows researchers to examine

John Flower

Dr. Wayne Augé, an orthopedic surgeon from Española, NM, is helping the team sort through contradictory experimental findings in bone-research literature. His experience should prove invaluable in evaluating the team's choices for configuring its models.

Bone Structure and Osteoporosis

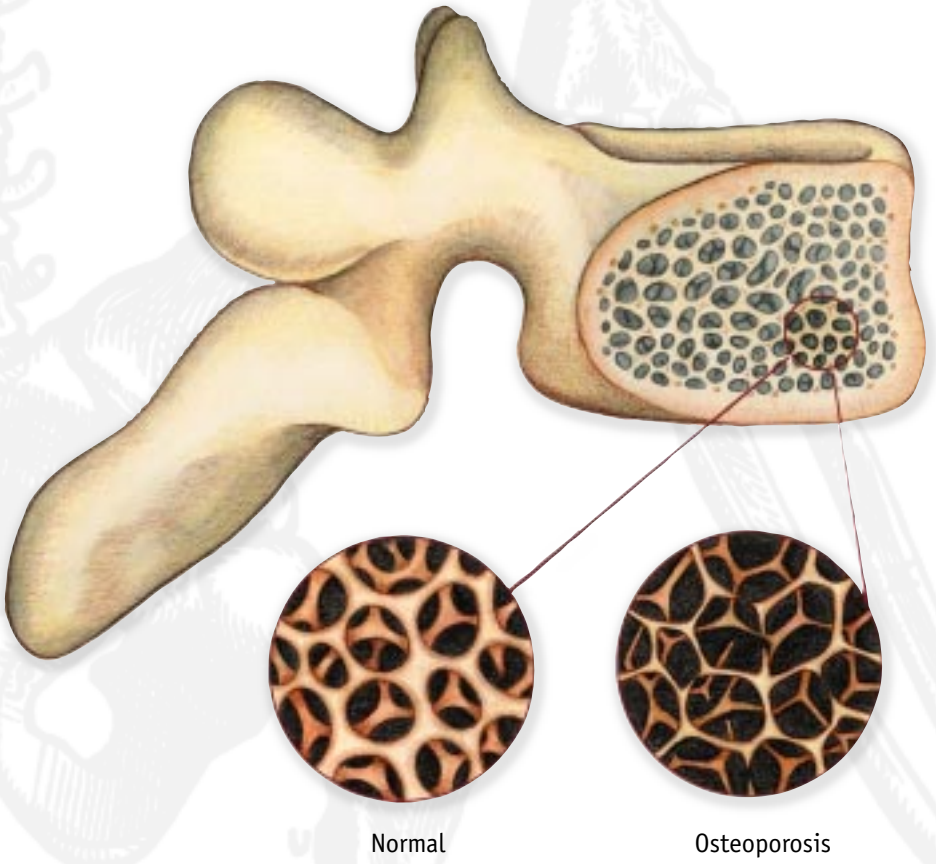
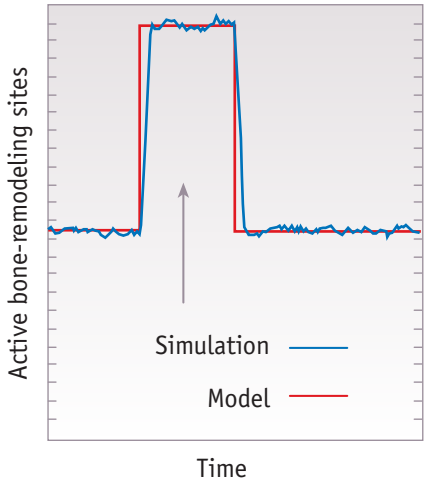


Illustration by Donald Montoya

This drawing of a spinal vertebra illustrates the exterior shell of compact bone with its interior beams of bone—a meshwork akin to a rigid sponge. The magnifications of this so-called spongy bone show a typical appearance for normal anatomy (left) and the thinner and incomplete beams of bone seen in osteoporosis (right). Such bone loss weakens the weight-bearing capacity of vertebrae, potentially leading to their compression and the "shrinking," or abnormal curvature, of the entire spine over time. In addition, all osteoporotic bones demonstrate an increased propensity to fracture, often described as brittleness.



An analytical model developed by the investigators closely coincides with their Monte Carlo simulation in describing the increase in bone remodeling that occurs during menopause (arrow).

Bone-Remodeling Dynamics

Bone dynamics encompass a continuous building up and tearing down (resorption) of bone matrix. This ongoing remodeling results from the interplay of three bone cell types collectively referred to as a basic multicellular unit, or BMU.

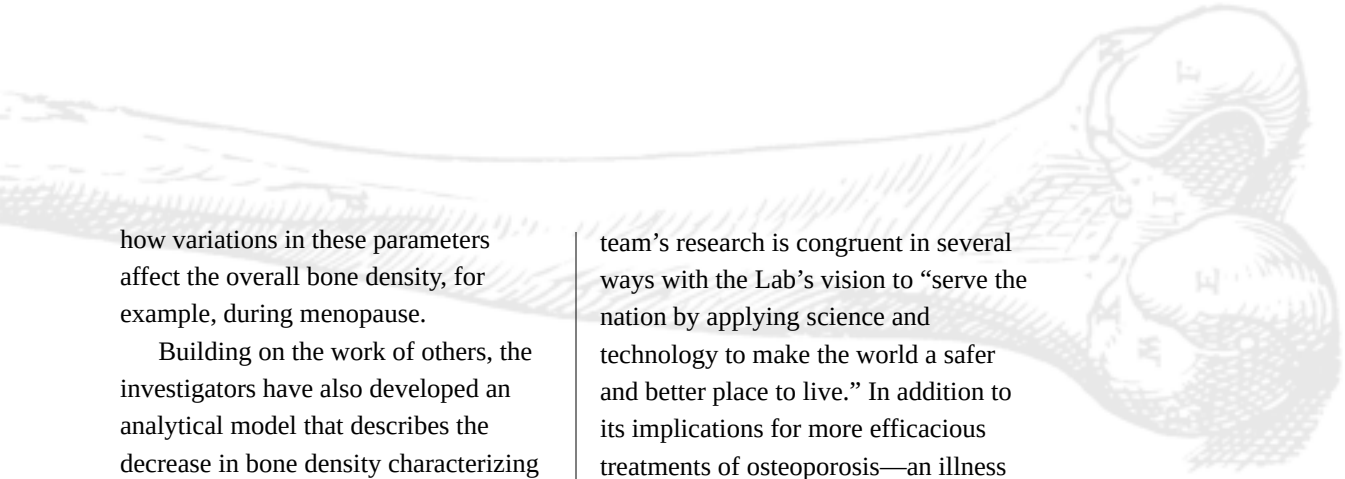
Osteocytes live in fluid-filled hollows within the bone matrix and are interconnected by fingerlike extensions through microscopic tunnels. They are believed to be the cells that sense mechanical strain—either piezoelectrically through ionic currents induced when bone is deformed or by detecting fluid flow in the tunnels. Osteocytes are presumed to respond to this strain by sending signals that either cause new bone formation or existing bone removal.

A second bone cell, the osteoblast, is responsible for forming and depositing new matrix. A third cell, the osteoclast, is charged with resorbing bone matrix by dissolving its calcium and phosphate and releasing them into blood. Much as acid rain increases the weathering of rocks, so osteoclasts create an acidic microenvironment that is necessary to dissolve bone minerals and to activate enzymes that break down collagen fibers.

Both osteoclasts and osteoblasts play a role in the repair work that follows fractures. The net gain or loss of bone depends on a delicate balance between the activity and number of these two cell types. When osteoclasts remove bone more rapidly than osteoblasts create new bone, a net bone loss occurs. For example, when muscle-generated mechanical stress is abnormally low, such as for a bedridden person, there tends to be an overall loss of bone from the skeleton. This is likewise a problem for astronauts, for whom extended weightlessness greatly diminishes the natural mechanical stress produced when muscles hold the skeleton upright against the force of gravity.

NASA

In a talk at Los Alamos, astronaut and physician Jerry Linenger said that during his four months in space, he lost 13 percent of his bone mass (enough to more than double his probability of bone fractures). Linenger also reported that after a year of vigorous musculoskeletal-stressing exercise such as swimming, he had regained only half the lost bone mass. These numbers emphasize the importance of physical activity in maintaining healthy bones.



how variations in these parameters affect the overall bone density, for example, during menopause.

Building on the work of others, the investigators have also developed an analytical model that describes the decrease in bone density characterizing menopause. Their two-equation model is in agreement both with the results of the simulation and with experimental observation. However, it yields rapid solutions as compared with the time-consuming simulations and permits a deeper understanding of the relationships among the variables governing remodeling.

The team's third level of bone modeling will examine how changes in bone structure (such as BMU reshaping) affect bone's mechanical properties. This study will use the finite-element method to examine the response of large pieces of bone to macroscopic external stresses.

The finite-element method is commonly used in industrial applications such as modeling the crashworthiness of automobiles and designing commercial aircraft. The key to using the method is to know the properties of the relevant materials. Since bone's mechanical properties are clearly linked to the porosity of its internal rigid-sponge structure and since previous model levels characterize this porosity, the finite-element method should prove a fruitful approach. During this study, the calculated mechanical properties will be validated by comparing them with experimental data.

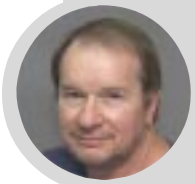
Human Health and Beyond

Funded by a Laboratory Directed Research and Development grant, the team's research is congruent in several ways with the Lab's vision to "serve the nation by applying science and technology to make the world a safer and better place to live." In addition to its implications for more efficacious treatments of osteoporosis—an illness threatening millions of Americans—the research is also relevant to materials development. Imagine a new material that, like bone, could respond to environmental changes by altering its properties to maximize functionality and minimize the probability of failure under extreme conditions. Previously the stuff of animated cartoons, such a vision has far more pragmatic significance for these Los Alamos researchers. ■

The Researchers

Antonio Redondo received an M.Sc. and a Ph.D. in applied physics from the California Institute of Technology. Before joining the Laboratory, he served as an associate professor of physics at the Universidad de Los Andes in Venezuela.

Richard LeSar holds an A.M. in physics and a Ph.D. in chemical physics from Harvard. He serves as adjunct professor at the University of California, Santa Barbara. In addition to simulation methods, he has broad research experience in the area of material microstructure.



William Wray holds a B.S., M.S., and Ph.D. in aerospace engineering and engineering mechanics from The University of Texas. His bioengineering research includes a patent for a noncontact method of determining intraocular pressure.

Yi Jiang received a Ph.D. in physics from Notre Dame after earning a B.S. in physics in China. In addition to biophysics, her research interests include soft condensed matter and complex fluids.

John Flower

PROTON RADIOGRAPHY

Sharper "X-Ray Vision" for Hydrotests

by Brian Fishbine

Researchers are now using protons to probe the details of imploding weapon mock-ups. Proton radiography is enhancing the Lab's ability to predict the performance of stockpiled nuclear weapons.

The first step in detonating a modern nuclear weapon is to rapidly compress, or implode, a sphere of fissile material such as plutonium. Imploding the sphere, also called a pit, forces the fissile atoms closer together so they can sustain a chain reaction, thereby releasing a huge burst of nuclear energy. The pit is imploded by shock waves produced by a shell of high explosives surrounding the pit.

Because the implosion geometry is crucial, implosion tests are needed to ensure that the weapons in the nation's nuclear stockpile will perform as expected—one of the goals of stockpile stewardship. These tests also help validate computer simulations of nuclear weapon performance, confirmation that is vital in the absence of nuclear testing. (See "Code Validation Experiments" in the Fall 2002 issue of *Research Quarterly*.)

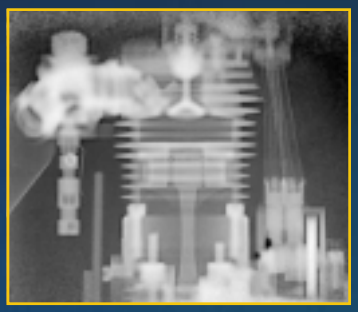
In most implosion tests, scientists study a full-scale weapon mock-up. The pit of the mock-up is made of a surrogate metal that has mechanical properties similar to those of the fissile material but that is not fissile and so cannot produce nuclear reactions. During an implosion, the shock waves' high pressures and temperatures cause metals and other materials to flow like liquids. Because liquid behavior can be described by hydrodynamic equations, implosion tests are called hydrotests.

To see what happens during a hydrotest requires "x-ray vision," that is, the ability to see through the mock-up's thick, dense metal parts. In the first hydrotests, performed during the Manhattan Project, scientists took snapshots of imploding mock-ups with intense flashes of high-energy x-rays,

Los Alamos researcher Peter Pazuchanics inspects a 3-ton steel vessel used to confine the explosions involved in many proton-radiography experiments. The large orange electromagnets flanking the confinement vessel focus the protons to produce sharp radiographs. The protons travel within the stainless-steel vacuum tubing that passes through the centers of the electromagnets and the confinement vessel.

John Flower

John Flower



A 150-cubic-centimeter model airplane engine (top) and radiographs of it produced by 800-million-electronvolt protons (middle) and ~100-thousand-electronvolt x-rays (bottom). Because the x-ray attenuation length is much shorter than the engine's thickness and because the engine strongly scatters the x-rays—producing "scatter background"—the x-ray radiograph is less detailed. The details of the thicker parts of the engine are clearer in the proton radiograph because the proton attenuation length is longer and because the lens used to produce the radiograph greatly reduces proton scattering.

much as medical x-rays are taken of bones or teeth. X-rays have been used for hydrotests ever since.

In 1995, however, Los Alamos physicist Chris Morris thought of a way to use protons instead of x-rays for hydrotest radiography. "The extraordinary quality of the first proton radiographs made at Los Alamos surprised even the inventors—us," says Morris. Later experiments confirmed the technique's potential.

Proton radiography is now being proposed as the key diagnostic technique for an Advanced Hydrotest Facility, or AHF. In the view of Los Alamos Director John Browne, experiments conducted at this facility would "represent a focusing of all the predictive capability developed through stewardship and would validate our designers' abilities to predict, with greatest confidence, the nuclear performance of weapons. In short, AHF would represent the 'last stop' taken by stewardship before technical issues would lead us to demanding a nuclear test."

Protons versus X-Rays

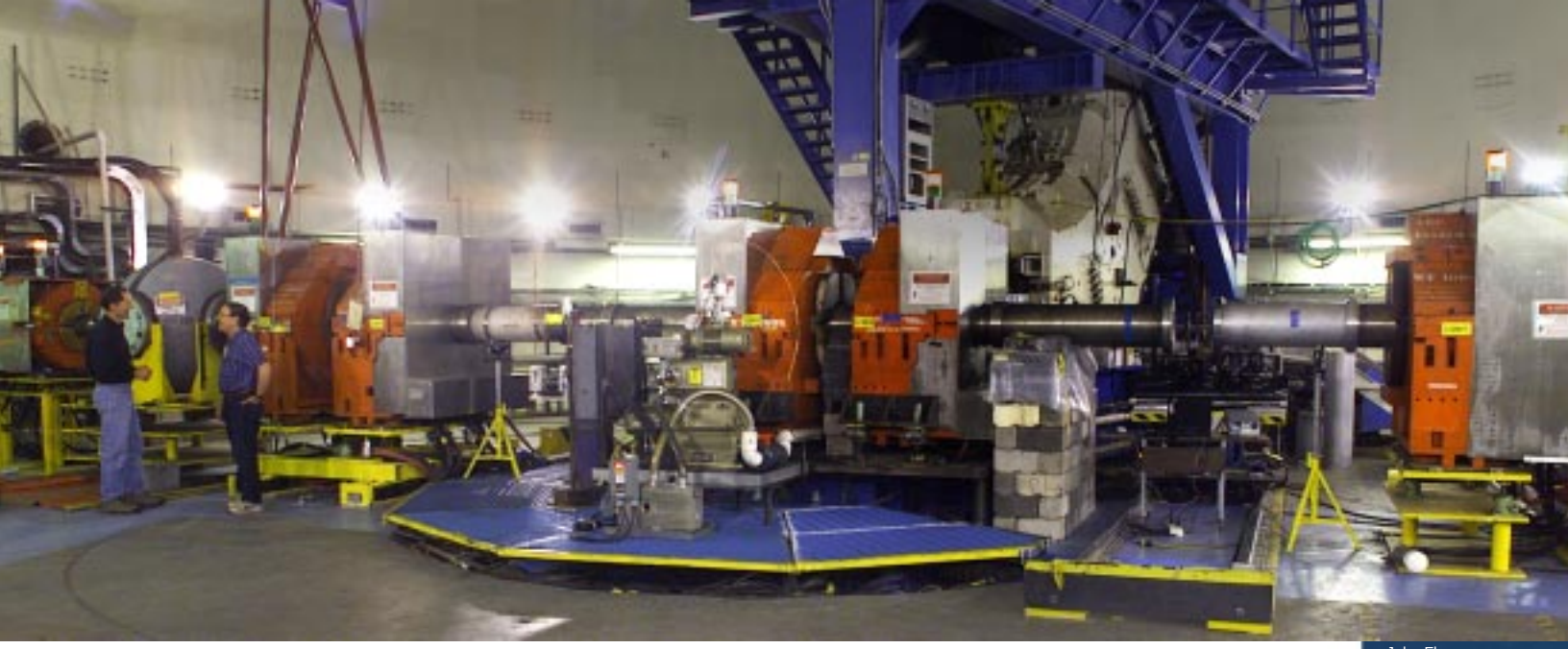
The promise of proton radiography is best illustrated by comparison with the Lab's present state-of-the-art hydrotest facility, the Dual-Axis Radiographic Hydrodynamic Test facility, or DARHT. Recently completed at Los Alamos, DARHT will be fully operational in 2004 and is expected to be the centerpiece of the nation's hydrotest program for at least a decade.

During a hydrotest, DARHT will take four sequential x-ray radiographs along one axis and one radiograph along a perpendicular axis, providing the first-ever simultaneous views of an implosion from two directions. The radiographs' exposure time—60 nanoseconds, or 60 billionths of a second—will freeze the action of an imploding mock-up to within a millimeter. (The exposure time required is determined by the radiograph's spatial resolution and by the implosion speed, which can exceed 4.4 millimeters per microsecond, or 10,000 miles per hour.)

> The extraordinary quality of the first proton radiographs surprised even the inventors—us.

One of proton radiography's many advantages over x-ray radiography is its ability to take twenty or more sequential radiographs per hydrotest (as shown across the top of the previous pages), as opposed to DARHT's four. This multiframe capability will allow weapon scientists to make detailed motion pictures of implosions for the first time.

In addition, proton radiography will be able to provide simultaneous views from many directions during an implosion. Using the same computerized-tomography methods that produce three-dimensional medical images of the brain or other organs (commonly called CT scans), researchers can convert proton radiography's multiple two-dimensional images into a single three-dimensional view for each frame of an implosion movie. Such views will help scientists



John Flower

Panoramic view of the proton-radiography facility. The confinement vessel is at the far left. During an experiment, radiographic images appear on a scintillator plate placed in the proton beam at the break in the vacuum tubing between the last two orange electromagnets on the right. The scintillator plate and the cameras used to record the images are not shown in the photo because it was taken before the experiment had been completely set up.

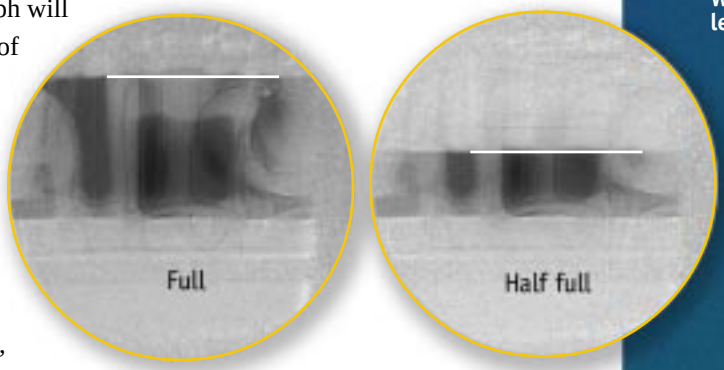
validate three-dimensional weapon codes as well as determine if the implosion geometry is correct.

Protons can also image subtle effects impossible to see with x-rays. For example, Lab researchers have made proton radiographs of water coolant levels inside an internal combustion engine. The ability to distinguish between parts of an object with different densities will help researchers track the behavior of specific weapon components during implosion tests.

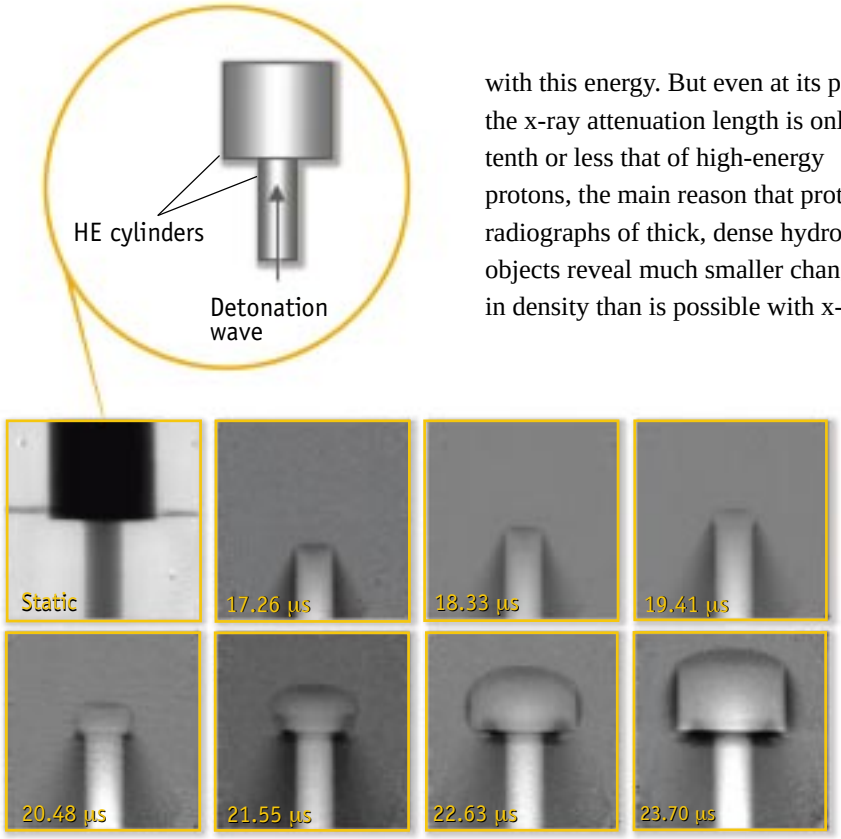
To image such effects, researchers must sensitively measure how a test object reduces (or attenuates) the intensity of the imaging radiation, which, generally speaking, means measuring small changes in density within the object. To do so, researchers must match the proton's attenuation length in the test object to half the object's thickness.

The attenuation length is the distance in which the intensity of a proton beam decreases to about a third of its initial value as the beam passes through the test object. If the attenuation length is much shorter than the object's thickness, the protons will not penetrate the object, and the resulting radiograph will show a silhouette of the object but nothing inside it. If the attenuation length is much greater than this thickness, all the protons will sail through the object, leaving no trace of it in the radiograph. The optimum attenuation length is between these two extremes.

For most elements in the periodic table, a proton's attenuation length increases with its energy. Fortunately, modern accelerators can produce protons with the high energies required to match their attenuation lengths to the thickness of a hydrotest mock-up. The attenuation lengths for x-rays, however, peak at about 4 million electronvolts, the reason that DARHT produces x-rays



A demonstration of proton radiography's ability to measure small density differences inside a test object. Two levels of coolant water in an engine block are clearly visible in these radiographs. The ability to discriminate between small changes in density will help scientists track individual weapon parts during implosion.



A seven-frame proton-radiography movie of a high-explosive burn. The "static" frame, taken before the detonation, shows a large-diameter cylinder of high explosive (HE) on top of a narrower HE cylinder. Movie frames show how the densities of the two cylinders change as the detonation wave moves upward from the bottom of the smaller cylinder. A swept-back shadow is produced by the detonation's reaction products. The ignition of the upper cylinder is of particular interest. Dark regions near the interface between the two cylinders—but slightly beyond the edge of the smaller cylinder—are where the explosive burns inefficiently as it "turns the corner" from the narrower to the wider HE cylinder. Such inefficiencies are of interest in explosives research.

with this energy. But even at its peak, the x-ray attenuation length is only a tenth or less that of high-energy protons, the main reason that proton radiographs of thick, dense hydrotest objects reveal much smaller changes in density than is possible with x-rays.

The longer attenuation lengths of high-energy protons also allow a much larger fraction of the protons to pass through the test object than is possible with x-rays, while still producing radiographs that detect small changes in density. Thus, the total amount of radiation, or dose, required to produce a proton radiograph is much less than that required for an x-ray radiograph.

For DARHT, the x-ray dose per radiograph will reach 1,000 roentgens—the equivalent of 60,000 chest x-rays. For a proton radiograph, the dose is currently about 2 roentgens per radiograph. In fact, the first proton radiographs were taken in 1973 to explore their potential for low-dose medical radiography, but the radiographs were unacceptably blurred by proton scattering.

In addition, the intensity of an accelerator-produced proton beam is so high that billions of protons can be focused on a test object in 50 nanoseconds. The resulting radiographs have excellent detail and tonal range and are not "snowy," as they would be if too few protons were used. In fact, Morris says that proton radiography owes much of its success to the ability of modern accelerators to provide high beam intensities as well as high proton energies.

Another reason proton radiography can measure small changes in density is that proton scattering can be controlled. Whereas a test object scatters x-rays uncontrollably into a wide range of angles—producing a diffuse background that reduces the radiograph's accuracy and sensitivity—scattered protons can be focused to form a sharp image with virtually no background. In fact, rather than being a hindrance, proton scattering can be used to identify the chemical elements in a radiograph, which will also help scientists track specific weapon parts during implosion tests.

In addition to these advantages, the proton-radiography technique proposed for hydrotests has a spatial resolution of several hundred micrometers, compared with DARHT's millimeter resolution. And recent proton-radiography experiments have demonstrated a spatial resolution of 15 micrometers, with the potential for 1 to 2 micrometers, making possible a new type of microscopic "x-ray vision."

Finally, researchers can arbitrarily select the time at which a proton radiograph is exposed, a great advantage for hydrotests. For example, researchers can use longer time

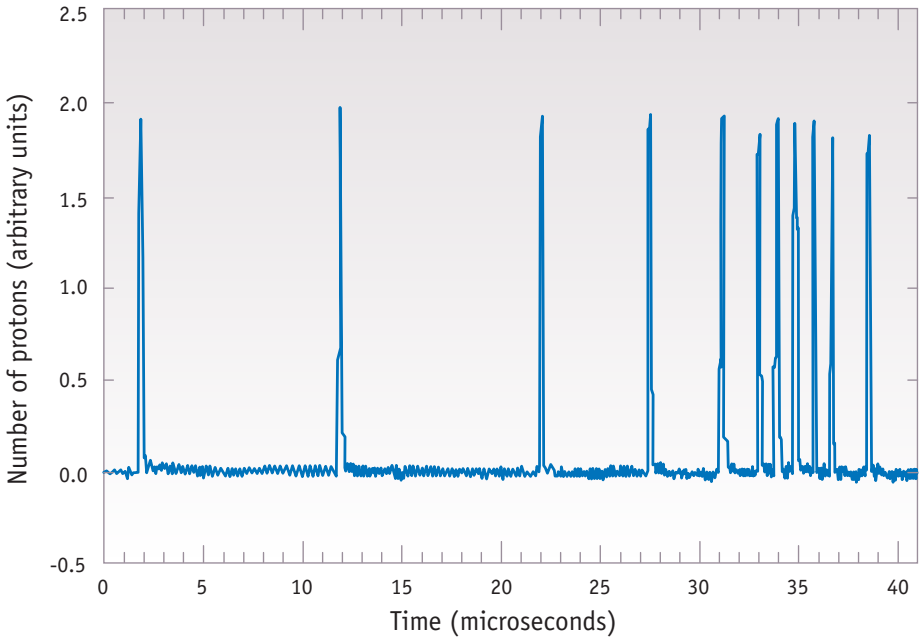
intervals between successive radiographs to freeze the mock-up's slower motion during the early phases of an implosion. However, in the later phases, when implosion speeds are higher, they can use shorter time intervals to freeze the motion. In this way, they can obtain the most important information about the implosion using a limited number of radiographs.

This timing flexibility is possible because the Los Alamos accelerator used for proton radiography produces protons in a continuous succession of "microbunches," each lasting about 100 picoseconds and spaced 5 nanoseconds apart. (Other accelerators may have slightly different parameters but operate in basically the same way.) Typically, a series of eight to twenty microbunches is used to expose each radiograph.

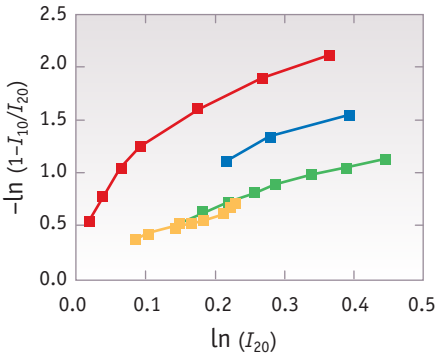
In contrast, the timing of DARHT's radiographs is determined by electrical circuits that produce x-ray pulses whose temporal separations and durations are fixed. Thus, DARHT's radiographs will be taken at set intervals, and researchers will be able to specify only the time of the first radiograph.

The Right Source

Many of the advantages of protons over x-rays arise from differences in the sources of radiation. At an x-ray hydrotest facility, an intense "point" source projects x-rays through the weapon mock-up onto a scintillator

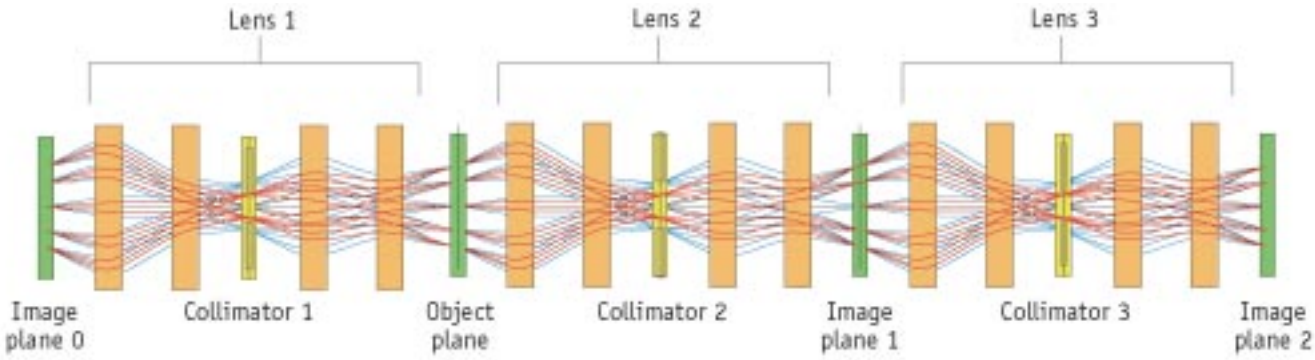


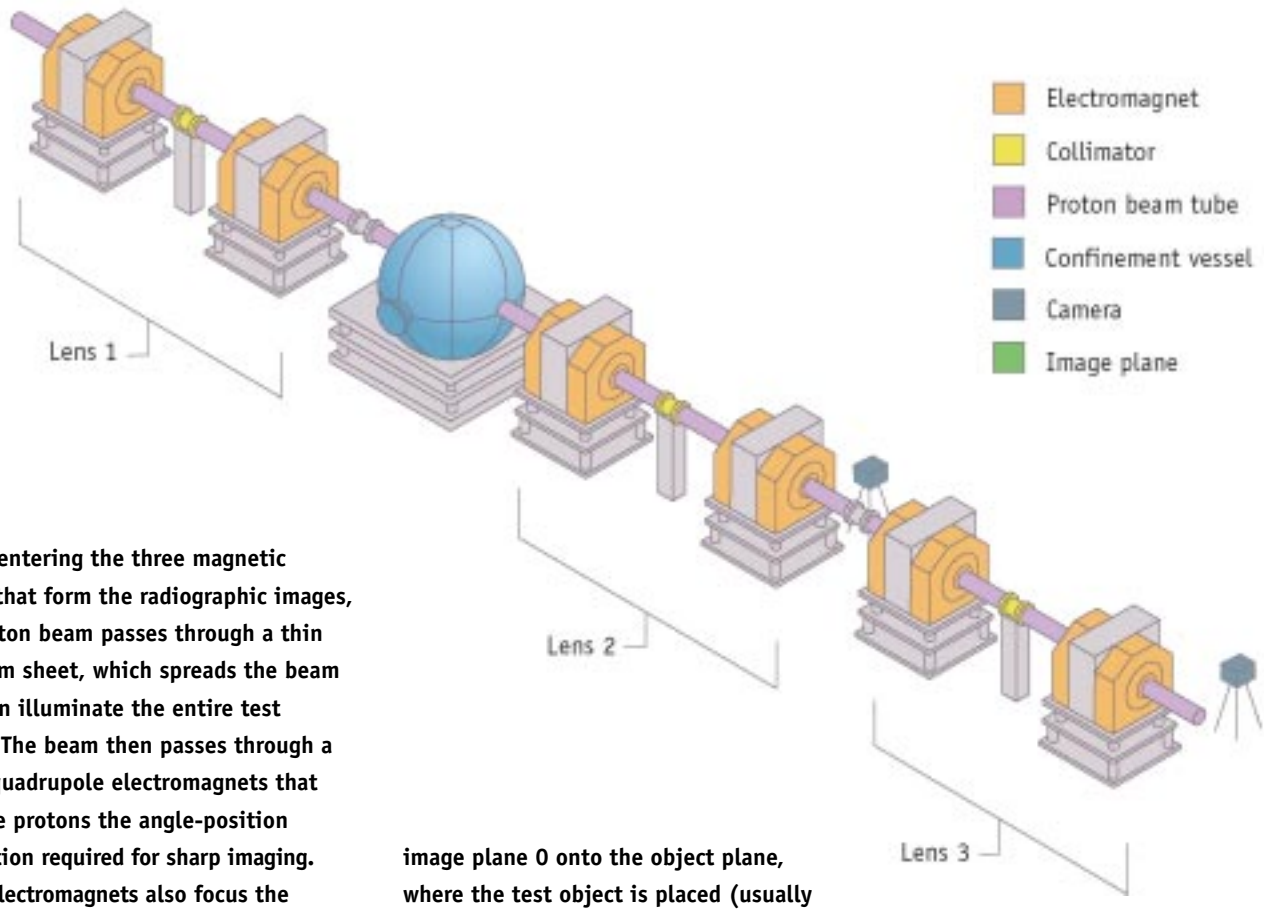
To resolve a mock-up's motion throughout an implosion, radiographs must be taken more frequently as the implosion proceeds. This plot demonstrates proton radiography's ability to take a sequence of radiographs exposed by proton bursts (spikes) with varying time intervals between exposures.



The separations between these plots demonstrate proton radiography's ability to distinguish between different materials, in this case, silver (red), aluminum (blue), carbon (green), and polyethylene (gold). The data were obtained from a radiograph of side-by-side strips of these materials. The thickness of a strip increased incrementally with its length in a direction parallel to the incident proton beam. In the plot, the horizontal axis corresponds to a strip's thickness divided by the proton attenuation length in the strip. The vertical axis corresponds to a strips's thickness divided by the proton radiation length in the strip.

Proton-Radiography Beam Line





Ward Zaelke and Chris Brigman

Before entering the three magnetic lenses that form the radiographic images, the proton beam passes through a thin tantalum sheet, which spreads the beam so it can illuminate the entire test object. The beam then passes through a set of quadrupole electromagnets that give the protons the angle-position correlation required for sharp imaging. These electromagnets also focus the protons to a plane called image plane 0, where small fiducial markers are placed. The markers appear on all the downstream images and are used to align the imaging apparatus. Each of the three proton lenses consists of four quadrupole electromagnets, with a collimator at the midplane of each lens. Lens 1 focuses image plane 0 onto the object plane, where the test object is placed (usually inside a confinement vessel). Lens 2 focuses the object plane onto image plane 1, where digital cameras record radiographic images of the object produced on a scintillator in the proton beam's path. Lens 3 focuses image plane 1 (and its replica of the object plane's image) onto image plane 2, where a second scintillator plate captures a second set of radiographs. The two sets of radiographs can be taken at different magnifications or compared at the same magnification to determine the test object's composition.

plate. The radiograph is produced without using lenses or mirrors to focus the x-rays. In fact, there is no known way to focus the 4-million-electronvolt x-rays required for hydrotests. As a result, the radiograph's sharpness, or spatial resolution, is determined by the diameter of the source.

But the source's diameter cannot be reduced arbitrarily because of the way the x-rays are produced: an intense, pulsed electron beam impinges on a tungsten plate, and the electrons emit x-rays as they are deflected by the tungsten's positively charged nuclei. However, since the electrons have like charges, they repel one other and try to expand the beam radially, increasing the beam's cross section. As a result, the minimum possible beam diameter is 1 to 2 millimeters.

The radiation source for the proton radiographs produced at Los Alamos is a beam of 800-million-electronvolt protons generated by the half-mile-long linear accelerator at the Los Alamos Neutron Science Center (LANSCE). Although the beam is used primarily to produce neutrons, it can also be diverted to produce radiographs. The protons in the beam move at about 84 percent of the speed of light, and about 4 billion protons pass through the radiograph's field of view in 50 nanoseconds.

Los Alamos scientists have also made radiographs with 12- and 24-billion-electronvolt protons produced by a synchrotron accelerator at Brookhaven National Laboratory in Upton, New York. These energies are closer to the Advanced Hydrotest Facility's 50-billion-electronvolt design energy, which is in the range required for hydrotest radiography.

The Right Prescription

Proton radiography's potential would never have been realized if the blurring evident in early proton radiographs had persisted. In 1995, however, Morris realized that a magnetic lens could focus the protons and eliminate the blurring. Initial experiments with an existing lens design proved him right. Later, John Zumbro, another Los Alamos physicist, improved this lens design. The resulting Zumbro lens has been used for proton radiography ever since.

According to Morris, the main virtue of the Zumbro lens is its low

On the Frontiers of Science

By Ray Juzaitis, Associate Director, Weapons Physics

Richard Robinson

We at Los Alamos like to call ourselves the science laboratory. This epithet speaks to how we see ourselves and how we value science and the scientific approach. Since the Lab's founding, science has been the organizing principle and powering force behind our mission success. Our passion is driven by the satisfaction we get from exploration, from the resulting fundamental understanding, and from applying that understanding to the tough problems within and beyond our national security mission.

A central component of science is innovation—the search for new ideas, new approaches, new insights—and more than ever, that innovation must be applied to the weapons program just as much as to quantum science, genomics, or nanoscience. Not by accident, today, such scientific innovation has given stockpile stewardship a new and extraordinarily effective capability—proton radiography—a diagnostic concept that, perhaps like all revolutionary ideas, was initially thought of as stretching credibility. But as is often the case, a few passionate and committed individuals have now brought proton radiography to operational reality, giving us high-speed, high-resolution movies of rapid implosion events that enable us to validate and refine our predictions of weapon performance.

And the researchers aren't done yet; they now talk about muon radiography, stretching credibility again—but actually not. They are exploring what is likely to be a sound approach to using cosmic rays to peek inside dense weapon systems for early detection and mitigation of the effects of materials aging. So the innovative science continues.

chromatic aberration. Chromatic aberration causes protons with different energies to be focused differently, blurring the radiograph. The protons in an accelerator beam do not have quite the same energy. In addition, proton scattering by the test object increases the spread in proton energies, which is why chromatic aberration could have been a showstopper.

The Zumbro lens minimizes proton blurring, which could have been a showstopper.

For the Zumbro lens to minimize chromatic aberration, however, the protons must have an "angle-position correlation," which means that the angle a proton makes with the optical axis of the lens is proportional to the proton's radial distance from the axis. A series of quadrupole electromagnets, common at accelerator facilities such as LANSCE, gives the protons the necessary correlation.

Because the Zumbro lens preserves the correlation, several Zumbro lenses can be used in series without one of the lenses degrading the images produced by later lenses, an essential feature for elemental identification. The correlation also simplifies sorting protons by their scattering angles, which is also required for elemental identification.

With the basic setup shown in the figure on page 20, many proton-radiography studies have been performed at Los Alamos and Brookhaven in the last few years. About 150 of these studies have been done at LANSCE in collaboration with scientists from Sandia National Laboratories in New Mexico, Lawrence Livermore National Laboratory in California, and the Atomic Weapons Establishment in the United Kingdom.

The studies have focused on the propagation of detonation waves in high explosives, the response of metals and other materials to shock waves generated by high explosives, the performance of explosive neutron generators, and the implosions of half-scale weapon mock-ups with aluminum pits. (Because of the energy of LANSCE protons, their attenuation length is better matched to the thickness of a half-scale mock-up with an aluminum pit than to that of a full-scale mock-up with a surrogate pit.)

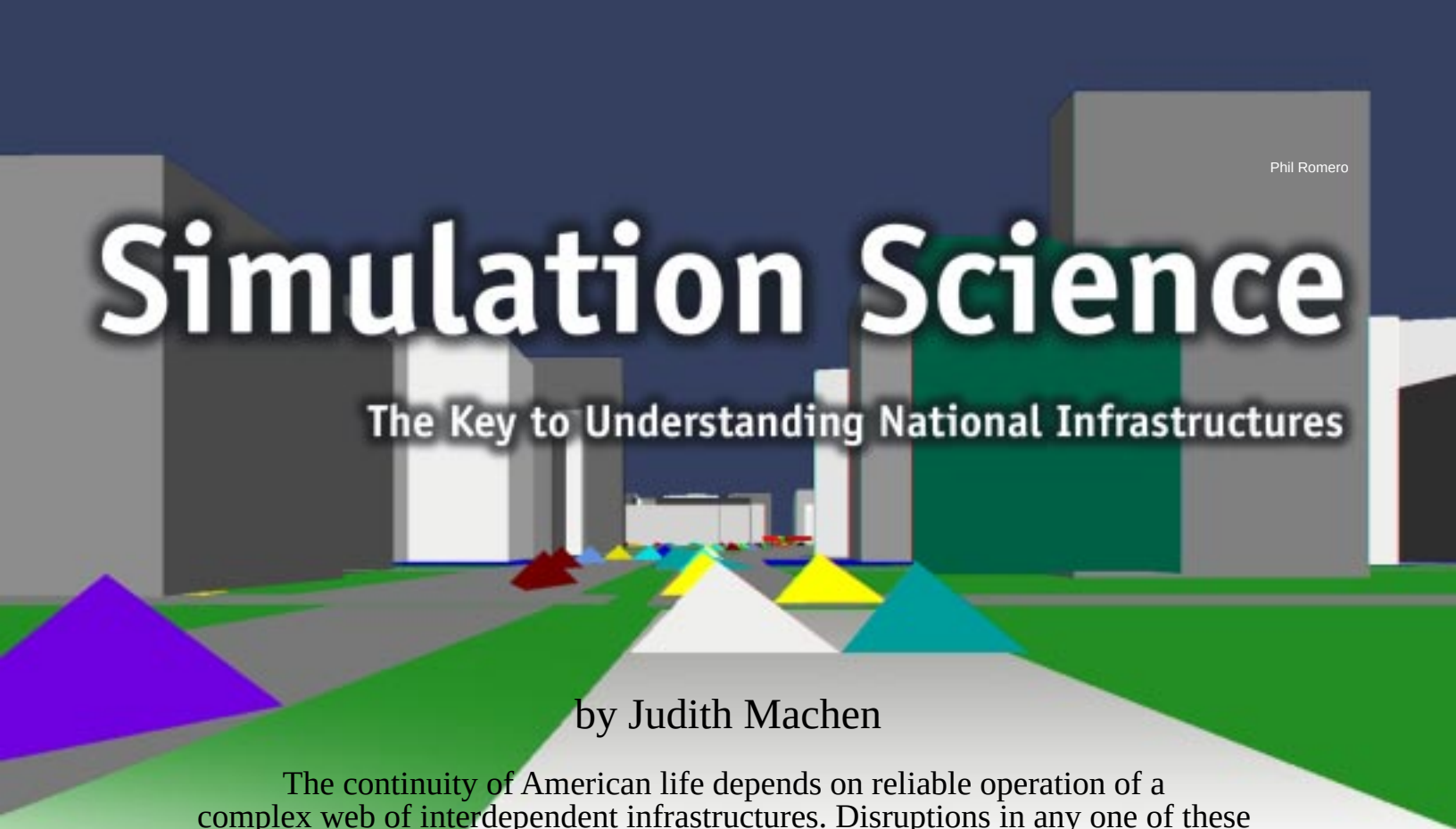
These experiments have confirmed proton radiography's ability to meet the demanding goals of stockpile stewardship for decades to come. In fact, proton-radiography data have already influenced stockpile decisions, prompting conceptual designs for the Advanced Hydrotest Facility. The current schedule calls for the facility's preliminary design to begin in 2006, with facility construction starting in 2008 and full facility operation set for 2016. The new facility would be built near LANSCE, possibly using a second accelerator to boost LANSCE protons to the energies required for full-scale hydrotest mock-ups. The facility's main proton beam would be split into twelve subbeams, which would illuminate a mock-up from twelve angles, providing the data needed for tomographic reconstruction of high-resolution three-dimensional implosion movies.

By giving weapons scientists "x-ray vision" that is more versatile and precise than now possible, proton radiography promises to meet stockpile stewardship needs well into the twenty-first century. ■

The Researcher

John Flower

Christopher Morris received a B.S. in physics from Lehigh University and a Ph.D. in medium-energy nuclear physics from the University of Virginia. In addition to developing a variety of charged-particle radiographic techniques at Los Alamos—using protons, electrons, and, most recently, muons—Morris has also studied pion-nucleus interactions and is currently developing an ultracold-neutron source to measure neutron beta decay. He is the author of more than 250 refereed journal papers and has given over 50 invited talks. He is a fellow of the American Physical Society and received the Los Alamos Inventors Award in 1985 and 1987 for two patents. In 1996, Morris became a Laboratory Fellow.



Phil Romero

Simulation Science

The Key to Understanding National Infrastructures

by Judith Machen

The continuity of American life depends on reliable operation of a complex web of interdependent infrastructures. Disruptions in any one of these could jeopardize our society. A collaboration between Los Alamos and Sandia National Laboratories is helping policymakers understand how the nation's infrastructures work, are linked, and can be protected.

Since September 11, 2001, homeland security has moved to the forefront of domestic issues. Crucial to homeland security is the continuous operation of a complex web of interdependent infrastructures such as transportation, the public health system, and telecommunications. While it is easy to appreciate that these systems constitute the basic fabric of our society, understanding their complexities is much more difficult.

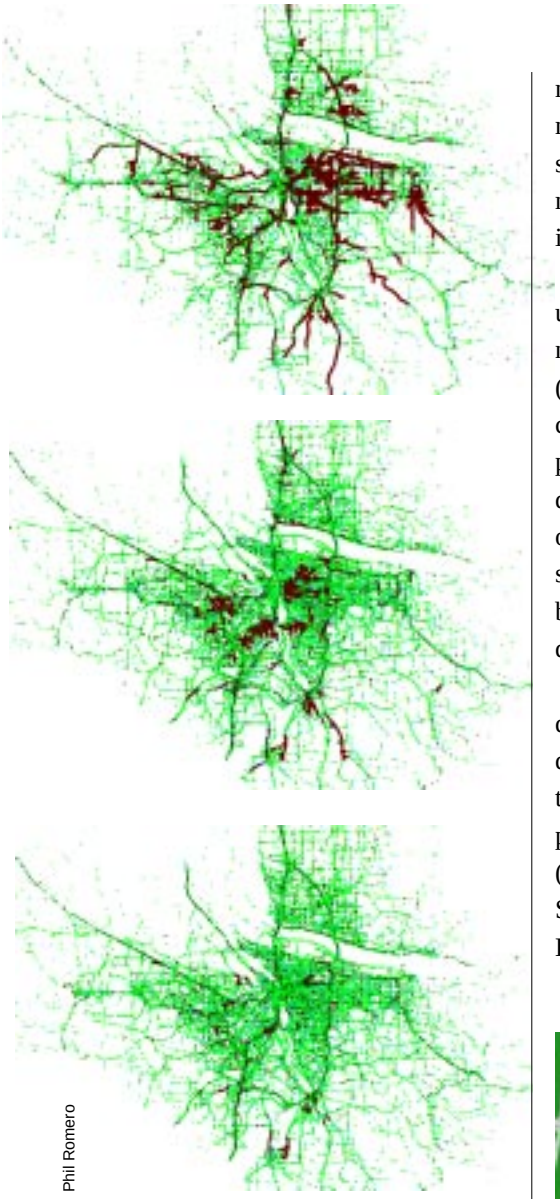
Yet that understanding is being required of the nation's newly created Department of Homeland Security. The White House National Strategy for Homeland Security specifically cites the need for state-of-the-art, high-end modeling and simulation of the nation's critical infrastructures. Meeting that need requires innovative analytical tools, many of which are being developed through collaborative work between Los Alamos and Sandia National Laboratories on modeling, simulating, and analyzing the infrastructures and their interdependencies.

Chris Barrett, a simulation scientist, leads the Los Alamos research and development effort to provide the new department with tools for assessing the complex sociotechnical systems that constitute infrastructure. Developing these advanced technical capabilities is the mission of the National Infrastructure Simulation and Analysis Center (NISAC), the partnership between Los Alamos and Sandia. "Our policymakers need new simulation and information-sharing tools to help them represent and understand complex, interdependent infrastructure systems and to support decision-making for better planning, monitoring, and response to disruption," comments Barrett.

The challenge is daunting, similar to that of simulating the performance of a nuclear weapon but more difficult in certain aspects. Laws of physics determine the performance of a nuclear weapon. In contrast, sociotechnical systems are affected not only by physical laws but also by human factors—such as the decisions and actions of individuals, private industry, governments, and regulatory agencies.

Simulation Capabilities

Powerful simulation tools are the only adequate analytical means for representing and assessing this kind of complexity. Los Alamos NISAC researchers are developing infrastructure-simulation capabilities that are firmly based on contemporary mathematical and computer science theory and designed for use on modern, high-performance computing platforms. These simulations incorporate census and mobility data for entire urban populations. "We can represent systems



Phil Romero

TRANSIMS uses a synthetic population, activity plans, and feedback to simulate route choices made by urban travelers in response to congestion. Above, red denotes congestion and green, free flow. Snapshots are for traffic in Portland, Oregon, at 9 A.M. Three iterations (top to bottom) show how traffic spreads and congestion is reduced as simulated drivers choose new routes to avoid delays encountered in previous iterations. TRANSIMS can also show traffic down to street-level details (right and previous page).

much larger than any previously modeled by other methods because our simulations can be scaled up to include millions, or tens of millions, of interacting variables," says Barrett.

NISAC simulations are unprecedented as well because they are not confined to using aggregated (summed) values for key variables. In contrast, they are designed to use urban population-mobility data that are disaggregated to the level of individuals on a second-by-second basis. Such simulations let analysts search the data by demographics, activities, time of day, or any other parameter of interest.

NISAC researchers have already demonstrated their unique approach by developing prototype simulations for two infrastructures: transportation and public health. The first, TRANSIMS (Transportation Analysis and Simulation System), has been used in Albuquerque, Dallas, and Portland, Oregon.

Phil Romero

Analyzing Transportation

With TRANSIMS, researchers use census data to create a statistically valid, synthetic population of millions of travelers. Drawing on such data, TRANSIMS modules assign daily activities and routes for each traveler and insert these variables into the urban traffic network. A microsimulation moves travelers to their destinations on the basis of these activities and route plans.

Urban traffic patterns emerge from the microsimulation. Automated feedback between the modules and the microsimulation accounts for travelers' responses to traffic congestion and continues until all travelers reach their destinations. Thus, TRANSIMS simulates a region's traffic movement over the transportation infrastructure and the traveling patterns of virtual residents. The result: planners can better estimate the effects of modifying the transportation infrastructure, from simply adding a new traffic light to building a new transit system.

Analyzing Epidemics

A derivative of TRANSIMS is the Epidemiological Simulation System (EpiSIMS), which couples the transmission of disease with the mobility of urban populations as developed by TRANSIMS. By coupling disease and epidemiological models to population-mobility simulation data, researchers have developed an urban simulation that helps planners understand how a disease spreads during an epidemic, what resources would be required to respond to the epidemic, and how effective various response strategies would be.

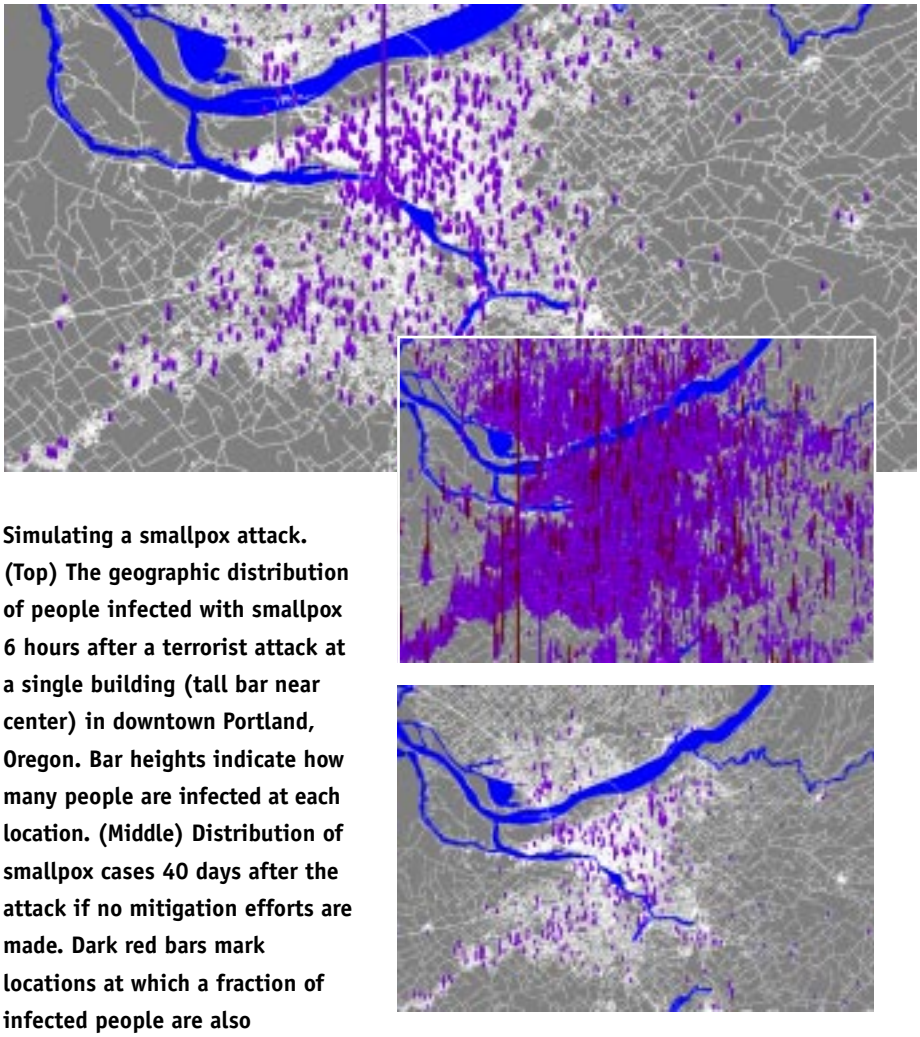
Infrastructure Interdependencies

In the real world, no infrastructure stands alone. Suppose, for example, that electrical power distribution is disrupted. When the power goes off, traffic lights go off as well, causing traffic jams. Thus, the electric power and the transportation infrastructures are linked and interdependent, compounding the complexities researchers face in analyzing these large, national networks.

Here, too, TRANSIMS has introduced new capabilities, because the traffic-light system is explicitly part of the urban traffic network module in the TRANSIMS design. Researchers can insert the disruption of traffic signals from whatever cause, and TRANSIMS will simulate the resulting behavior of travelers. EpiSIMS and other infrastructure simulations are similarly designed to represent the interdependencies among infrastructure sectors.

Today, Laboratory NISAC scientists are leveraging their expertise by extending their modeling, simulation, and analysis capabilities to other critical systems such as the energy and the banking and finance infrastructures. They have created an evolving and interoperable set of new analytical tools that are essential to the support of the Department of Homeland Security.

Says Barrett, "Our focus is on providing three capabilities to the department's functions of information analysis and infrastructure protection: studies of key technical issues, new tools for assessing infrastructure systems, and external outreach to help ensure that our work is responsive to the needs of our users." ■



Stephen Eubank

Simulating a smallpox attack. (Top) The geographic distribution of people infected with smallpox 6 hours after a terrorist attack at a single building (tall bar near center) in downtown Portland, Oregon. Bar heights indicate how many people are infected at each location. (Middle) Distribution of smallpox cases 40 days after the attack if no mitigation efforts are made. Dark red bars mark locations at which a fraction of infected people are also contagious. (Bottom) Same as above except infected and contagious victims have been isolated and vaccinated. Not only are fewer people infected, but far fewer are contagious, implying that the outbreak has been contained.

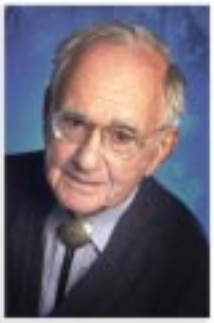
The Researcher

John Flower

Christopher L. Barrett leads NISAC at Los Alamos. His research background is in simulation, scientific computation, algorithm theory and development, system science and control, engineering and decision science, and cognitive human factors. He has received Distinguished Service Awards from the Lab, the Alliance for Transportation Research, the Royal Institute of Technology in Stockholm, and Japan's Oita University. Barrett received his Ph.D. in bioinformation systems from the California Institute of Technology.

Spotlight

Los Alamos in the News



LeRoy N. Sanchez

Louis Rosen **George Cowan**

Richard Robinson

Rosen and Cowan Awarded Laboratory Medals

Recipients of the 2002 Los Alamos National Laboratory Medal are Laboratory Fellow Louis Rosen and Senior Fellow Emeritus George Cowan. “Both recipients have earned international accolades for their scientific and professional accomplishments,” said Laboratory Director John Browne.

Established in 2001, the new medal is the highest honor the Laboratory can bestow on an individual or small group. Noble Laureate Hans Bethe and former Laboratory Director Harold Agnew were the first to receive this annual award.

Louis Rosen began his career at the Laboratory in 1944, when he joined the Manhattan Project. “My long association with the Lab has been as intellectually rewarding as any job can be, due in good measure to my very gifted colleagues as well as to a highly supportive spouse. I was fortunate to have both,” said Rosen.

Rosen is being recognized for his outstanding scientific contributions to the Laboratory and to the nation. His early work in neutron cross-section measurements and nuclear test diagnostics set the standard for the Laboratory. From the early 1960s through the 1980s, Rosen’s leadership in diversifying Los Alamos led to development of the Los Alamos Meson Physics Facility (LAMPF) as a premier nuclear-physics facility for the nation and the world. Throughout the Cold War years, Rosen also advocated that relationships with scientists from Russia and China be continued as a means of reducing tensions and improving understanding. Rosen received the E. O. Lawrence Award in 1963 and many other awards and honors throughout his career.

George Cowan came to the Laboratory in late 1945, when he also joined those working on the Manhattan Project. “I was lucky to have worked at the Lab during a historic period, and I never lacked resources or competent associates,” he added.

Cowan is being recognized as the driving force in the early radiochemical evaluations of nuclear weapons and for undertaking key scientific investigations during nuclear tests. He was awarded the E. O. Lawrence Award in 1965 and the prestigious Fermi Award in 1990 for contributions during his career as a nuclear scientist. Throughout his career, Cowan was an avid spokesman for science at the Laboratory. His service on the White House Science Council from 1982 to 1986 was invaluable to the debates on national security. Cowan also was a past president and founder of the Santa Fe Institute. He became a Senior Fellow at the Laboratory in 1981 and is currently a Laboratory Senior Fellow Emeritus.

Rosen and Cowan will be honored at an award ceremony in 2003 to be held in conjunction with the Laboratory’s 60th anniversary celebration.—*Kathryn Ostic*

Spectra Gases Reopens Lab Facility

In October, the Laboratory and Los Alamos Commerce and Development Corp. joined Spectra Gases in celebrating its new production facility for stable isotopes. The New Jersey company has leased and renovated the Lab's Isotopes of Carbon, Oxygen, and Nitrogen (ICON) facility, where it is now producing high-purity carbon-13, oxygen-17, and oxygen-18. Production of these gases for nuclear medicine and biomedical research will minimize U.S. dependence on foreign sources.

In the late 1960s, Lab scientists pioneered the use cryogenic columns to produce stable isotopes (i.e., isotopes that do not undergo spontaneous radioactive decay). Cooled almost to the point of liquefying in 200- to 700-foot-long columns, the naturally occurring gases stratify, with the heavier isotopes settling to the bottom and the lighter ones rising to the top. Once separated, the stable isotopes are then collected. After operating ICON in the 1970s and 1980s, the Laboratory mothballed the facility in 1989, transferring the technology to the private sector.

In August 2001, the Department of Energy signed a long-term lease that turned the facility over to Los Alamos Commerce and Development Corp., which in turn subleased ICON to Spectra Gases. Over the next thirteen months, Spectra Gases revitalized the facility, designing, fabricating, and installing new process equipment and upgrading the facility's ventilation system to meet current industry standards. The ICON facility is now operated by Spectra Stable Isotopes, a subsidiary of Spectra Gases.

Tom Mills adjusts a gas-sampling panel at the ICON facility. Mills, a retired Lab employee who worked at ICON in the 1970s and 1980s, is a consultant for Spectra Gases, Inc.

Spectra Gases is a leading international supplier of high-purity, rare, and isotopic gases. In addition to supplying the Lab with stable isotopes for biomedical research, the company will use the isotopes to make labeled biochemicals—such as amino acids, carbohydrates, and nucleic acids—for research into the atomic structure of these compounds. Spectra Gases expects to hire fifty people for its northern New Mexico operations over the next five years.—*Judyth Prono*

Immunoreceptor Modeling

inflammatory process becomes excessive, leading to discomfort (as in hay fever) or even to death by asphyxiation (as in extreme insect-sting reactions).

By creating and studying a mathematical model of this signaling cascade, the investigators hope to understand the behavior of the signaling system as a whole. In the process, they should also be able to glean more insight into the complex subcellular networks that regulate this form of receptor-mediated signaling. As emphasized by Faeder, "Signaling has been thought of as a linear chain of events, but it's not like that at all."

The investigators hope to expand the model to include additional components of the signaling cascade. Another goal is to find reduced models that encompass only the key biochemical interactions in this cascade to make it easier for experimentalists to identify critical points for potential drug treatments. Currently available drugs like antihistamines and ibuprofen tend to intervene after the fact, that is, after this signaling cascade has run its course, and therefore relieve symptoms rather than address causes.

"A detailed mathematical model of a signaling cascade for an immune system receptor has never been done before," adds Goldstein. "What's amazing is that as complicated as the system is, our model works. It's consistent with a wide array of experimental observations." This, of course, is potentially good news for allergy sufferers, since researchers may some day be able to use the findings of this model to design more efficacious medications that intervene in the allergic process at an earlier stage.
—*Kevin N. Roark and Vin LoPresti*

Meteor Predictions

diameter—plunge into the atmosphere, they explode, creating a brilliant flash of light and a blast equivalent to many kilotons of TNT.

Because their arrival is heralded by a fireball and a burst of shock-induced sound waves below the range of human hearing, the meteors are easily detected by satellites that look for flashes from incoming missiles or nuclear blasts and by the Lab's infrasound arrays, which are tuned to detect ultralow-frequency and very small amplitude waves. Typical amplitudes are only one-millionth those of normal sea-level atmospheric pressure readings. The satellite and infrasound systems were designed to detect clandestine nuclear weapons tests and other military activities. ReVelle and his colleagues, however, discovered that by combining the optical and infrasonic data, they could also more precisely calculate the size and energy of large incoming meteors.

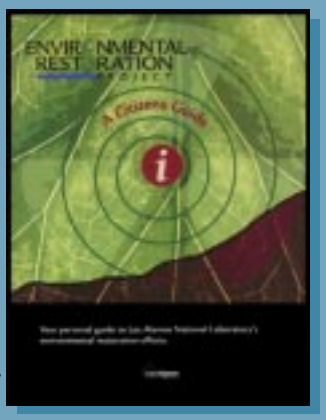
The team examined optical data for 300 meteors that "exploded" in Earth's atmosphere between 1994 and 2002. From those data, they evaluated the meteors' total optical energy and converted that energy into an equivalent impact energy. As part of their conversion work, they calibrated the optical data with independent source-energy estimates for a dozen well-observed, large meteors. Most of these estimates came from data from the Los Alamos infrasound arrays. Funded by the Department of Energy, the Earth and Environmental Sciences Division operates five infrasound arrays across the western United States that routinely monitor and locate global atmospheric explosions.

From the satellite and infrasound analyses, ReVelle produced a graph that relates the number of meteors colliding with Earth in a year to their impact energy and corresponding size. Over twelve magnitudes of energy, a single distribution fits the data from mid-size meteors to giants like the one that leveled the Tunguska forest.

"What is exciting about this work for me is that without the data from Los Alamos' infrasound arrays, this probably would not have been possible," said ReVelle. "Infrasound provided the key to unraveling the source energy of 75 percent of these collision events."

In addition to providing impact estimates for large meteors, the team's work also holds promise for accurately distinguishing between meteoric fireballs and other atmospheric phenomena, such as volcanic eruptions, accidental explosions, and incoming missiles. Combining satellite and infrasound data offers a means of definitively identifying such events, a capability that could prove critical during times of heightened regional or global tension.—*James Rickman*

Recent Publications



Kelly Parker

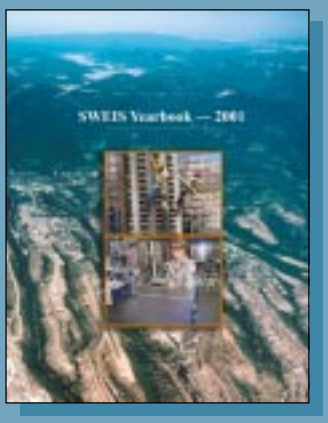
Environmental Restoration Project: A Citizens Guide

The Laboratory's Environmental Restoration (ER) Project is tasked with investigating the presence of hazardous chemical and/or radioactive materials in the environment due to Lab operations, assessing their risk to human health, and cleaning them up. This Citizens Guide updates the public on ER Project work and answers commonly asked questions about restoration issues. To request a copy, send e-mail to erproject@lanl.gov.

Kelly Parker

UCDRD Activities for Fiscal Year 2001

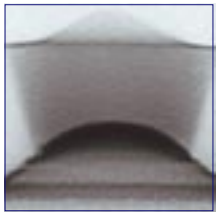
The University of California Directed Research and Development (UCDRD) activities involve collaborative research between the Laboratory, UC campuses, and New Mexico universities that is conducted in support of Lab missions. This report highlights the accomplishments of FY 2001 research. For a copy, contact Deborah Wilke (dwilke@lanl.gov).



Gail Flower

SWEIS Yearbook—2001

The fifth in an annual series, the SWEIS Yearbook—2001 compares data on the environmental impact of operations at key Lab facilities with their original impact projections. Such annual comparisons are made to ensure that Lab activities remain within the boundary conditions set by our sitewide environmental impact statement (SWEIS). The report is available on the Web (http://lib-www.lanl.gov/la-pubs/00818857.pdf).



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