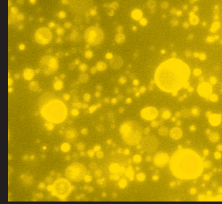
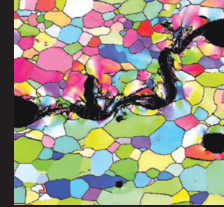
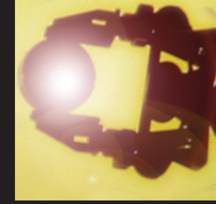
LOS ALAMOS SCIENCE AND TECHNOLOGY MAGAZINE



AUGUST 2007





1663

Los Alamos
NATIONAL LABORATORY

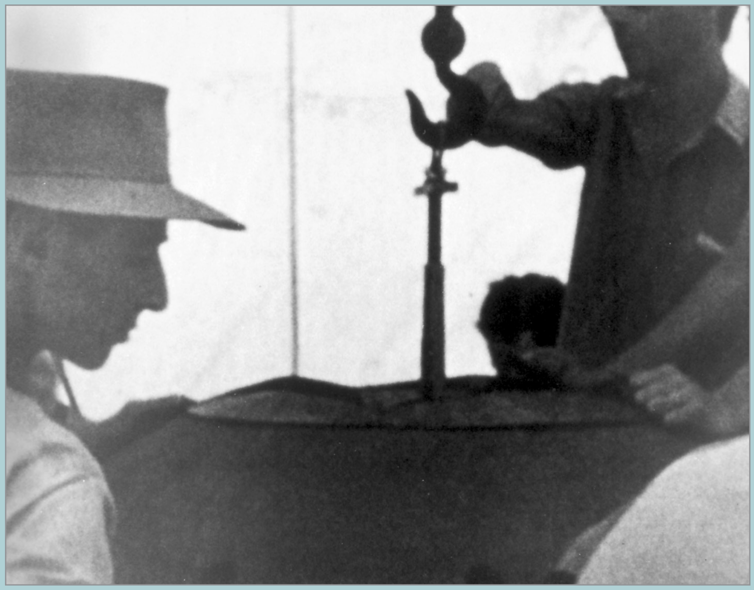
1663

About Our Name: During World War II, all that the outside world knew of Los Alamos and its top-secret laboratory was the mailing address—P. O. Box 1663, Santa Fe, New Mexico. That box number, still part of our address, symbolizes our historic role in the nation's service.

Located on the high mesas of northern New Mexico, Los Alamos National Laboratory was founded in 1943 to build the first atomic bomb. It remains a premier scientific laboratory dedicated to national security in its broadest sense. The Laboratory is operated by Los Alamos National Security, LLC, for the Department of Energy's National Nuclear Security Administration.

About the Cover: Icebergs calve, or break off, from an outlet glacier in the West Antarctic Peninsula. Los Alamos computer models of accelerated melting here and in the Arctic can help to forecast the effects of global warming and lead to mitigation strategies.

Photo by Jeanne M. Bowles.



LOS ALAMOS ARCHIVE

From Glenn Mara

Stockpile Stewardship Ensures National Security

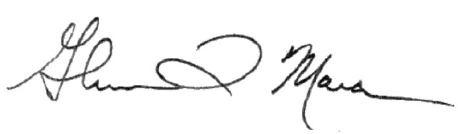
The United States conducted its last underground nuclear test in 1992 and turned to Los Alamos and the other weapons laboratories for a new approach to ensuring the continued safety and reliability of its nuclear deterrent without testing. The chosen approach, "science-based" Stockpile Stewardship, relies on combining scientific data with advanced computing and simulation.

Although few were sure they would succeed, today Stockpile Stewardship tools are delivering astounding results for national security. The Los Alamos Dual Axis Radiographic Hydrotest facility's Axis-1 is delivering x-ray pictures of unimagined quality. Axis-2, combined with the capabilities of the Los Alamos Neutron Science Center (LANSCE), will make Los Alamos the nation's premier imaging center. A new supercomputer, Roadrunner, and its promise of sustaining 1 thousand trillion operations per second, will put the Laboratory in the forefront of supercomputing.

In addition to those signature Los Alamos facilities, materials science and actinide chemistry laboratories, gas guns, and firing sites are making vital contributions to Stockpile Stewardship.

Manufacturing and certifying a pit without testing has been a major challenge of Stockpile Stewardship. As described in this issue of 1663, Los Alamos met that challenge June 6 when the U.S. Department of Energy accepted a Laboratory-produced pit, the first pit accepted since Rocky Flats shut down. This accomplishment resulted from the efforts of employees at all levels across the Laboratory.

Los Alamos has demonstrated the success of Stockpile Stewardship, thereby laying a foundation for the United States to maintain its nuclear deterrent through a capability-based approach. The success of this approach requires moving to a stockpile of reliable replacement warheads, investing in key facilities such as LANSCE-R and the Chemistry and Metallurgy Research replacement building, recruiting and retaining the best technical staff, and integrating more completely with other elements of the weapons complex.



Principal Associate Director
Weapons Programs

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POLAR WARNINGS

Sea Ice, Ice Sheets, and the Threat of Abrupt Climate Change

Los Alamos–based computer models project that by 2040 the Arctic Ocean may be ice-free for part of each year, bringing devastation to Arctic inhabitants. What makes this projection believable? And does it portend other abrupt changes in climate?

At a distance, the vast expanses of polar sea ice seem static and sublime, but they are actually in constant slow motion and internal change. Los Alamos researchers Elizabeth Hunke and Bill Lipscomb know that firsthand. Spending weeks onboard an icebreaker will teach you to read the signs. Ice floe extent, floe thickness, snow cover, and ratio of ice to open ocean—all change with location and season, and now with global warming.

Hunke and Lipscomb are members of the Los Alamos effort, begun nearly 20 years ago, to apply the power of supercomputers to the problem of modeling climate change. Both have contributed for over a decade to accurate computer models of floating sea ice.

Today their models are sought after by worldwide climate modeling groups who are trying to predict how rapid changes in the entire Arctic and parts of the Antarctic will impact Earth's climate.

Sea Ice and Climate

Sea ice plays a sensitive role in Earth's climate system for one simple reason: it is white and therefore has high albedo, or reflective power. While covering only 4 percent of Earth's surface, it accounts for perhaps 8 percent of the planet's total reflected energy, so it contributes significantly to the delicate balance between the energy delivered to Earth as sunlight and the energy radiated from Earth's surface as heat.

Antarctic photo by Jeanne M. Bowles

Today, global warming is causing the sea ice to melt and give way to open ocean. This has caused the Arctic's albedo to decrease, and the increased absorption by the dark ocean surface causes more warming. Thus, melting begets melting in a feedback loop that amplifies the warming trend.

In the Arctic, a second process is also at work. Ice frozen in the Arctic Ocean flows into the North Atlantic and melts, diluting the dense, salty water brought northward by the Gulf Stream and possibly disrupting the density-driven movement of global ocean currents.

Understanding the possible strength and ramifications of these events requires a good sea ice model incorporated into to a full climate-system model.

Tapping Los Alamos' Computing Power

Global warming was already a major concern in 1990, when the Department of Energy challenged climate researchers to ramp up their predictive powers. The department suggested adapting climate models to new, massively parallel supercomputers.

These computers, called "parallel" because they consist of hundreds of individual processors wired together and working simultaneously, had increased computer power by a factor of 10 (now a factor of 1000s). They should, it was argued, be able to handle more-realistic full-climate-system models that included atmosphere, land, ocean, and sea ice components. Of course, the component models would have to be rewritten to work in a parallel mode.

Los Alamos had the computer power, having just acquired a Connection Machine from Thinking Machines, Inc., the first modern parallel computer. But it was a relative newcomer to climate modeling. Nonetheless, Bob Malone of Theoretical Division knew that the Lab's strength in fluid-flow modeling could make a big difference to ocean models. It was a two-part challenge—improve the physics and make the models run efficiently on the new parallel machine.

By 1993 Malone and colleagues had developed the Parallel Ocean Program, or POP, the first model to accurately represent the path of the Gulf Stream. POP also set a new standard in computational efficiency and was soon chosen as the ocean component of one of the world's leading climate models, now known as the U.S. Community Climate System Model.

The sea ice component, however, remained a stumbling block, and Malone suggested that John Dukowicz, a POP developer, team up with newcomer Hunke to develop a fresh approach. "Dukowicz and

Top: A typical icescape near the SHEBA field camp in the Arctic Ocean, May 1998. The snow ridges (sastrugi) are formed by wind action.
Center: Stephen Ackley and Elizabeth Hunke drilling a sea ice core in the Weddell Sea, Antarctica, in 1998.
PHOTO BY MARK SOUTHWELL, H.M.S. ENDURANCE

Hunke were as immune as the rest of us to the 'this is the way we've always done it' mindset," Malone says proudly, "and they completely rethought the traditional methods for calculating sea ice dynamics."

How Arctic Ice Floes Flow

Driven by fierce winds and ocean currents, Arctic sea ice advances across the North Pole from Siberia to northern Greenland in a slow-motion walk known as the Transpolar Drift. About 10 percent annually flows into the North Atlantic through the Fram Strait, between Greenland and Svalbard, Norway.

Some sea ice gets trapped by the huge Beaufort Gyre, north of Canada and Alaska, and circulates for years or piles up near the Canadian coast. That older, thicker ice gradually feeds into the Transpolar Drift, completing the turnover of Arctic sea ice about once every 10 years.

Within the two major drift systems, individual ice floes crash together and deform into ridges. Under tension, they crack and split into many pieces. Sunlight reflects from their surface but also penetrates to warm their interiors and the surrounding ocean, causing summer's melting. Winter's cold, turbulent winds cause freezing. No computer model can account for all the large and small motions and thermal changes of the yearly cycle of melting and freezing—there simply isn't enough computer power. So the important processes must be abstracted—idealized—and converted into equations.

As their biggest abstraction, sea ice models treat the Arctic's millions of square miles of individual floes and ice packs as a continuous flat layer of viscous, plastic material (like tough putty or very dense molasses) that slows down as it stiffens. This two-dimensional layer, sandwiched between atmosphere and ocean, is divided into a grid of computational cells, about 60 miles on a side. When forces push more ice into a given cell and create thick ridges, the increase in thickness makes the ice more rigid in that cell.

The traditional treatment of sea ice as a viscous-plastic sheet imitates reality very well, except where the sheet encounters an obstacle and must stop. In that area the modeled rigidity of the ice pack increases and spreads, and much computational work is required before disturbances in this region die down. Thus, a barrier encountered in one area dramatically slows the entire calculation. That's a disaster when the goal is to simulate decades of sea ice changes and their global consequences.

Breaking the Computational Barrier

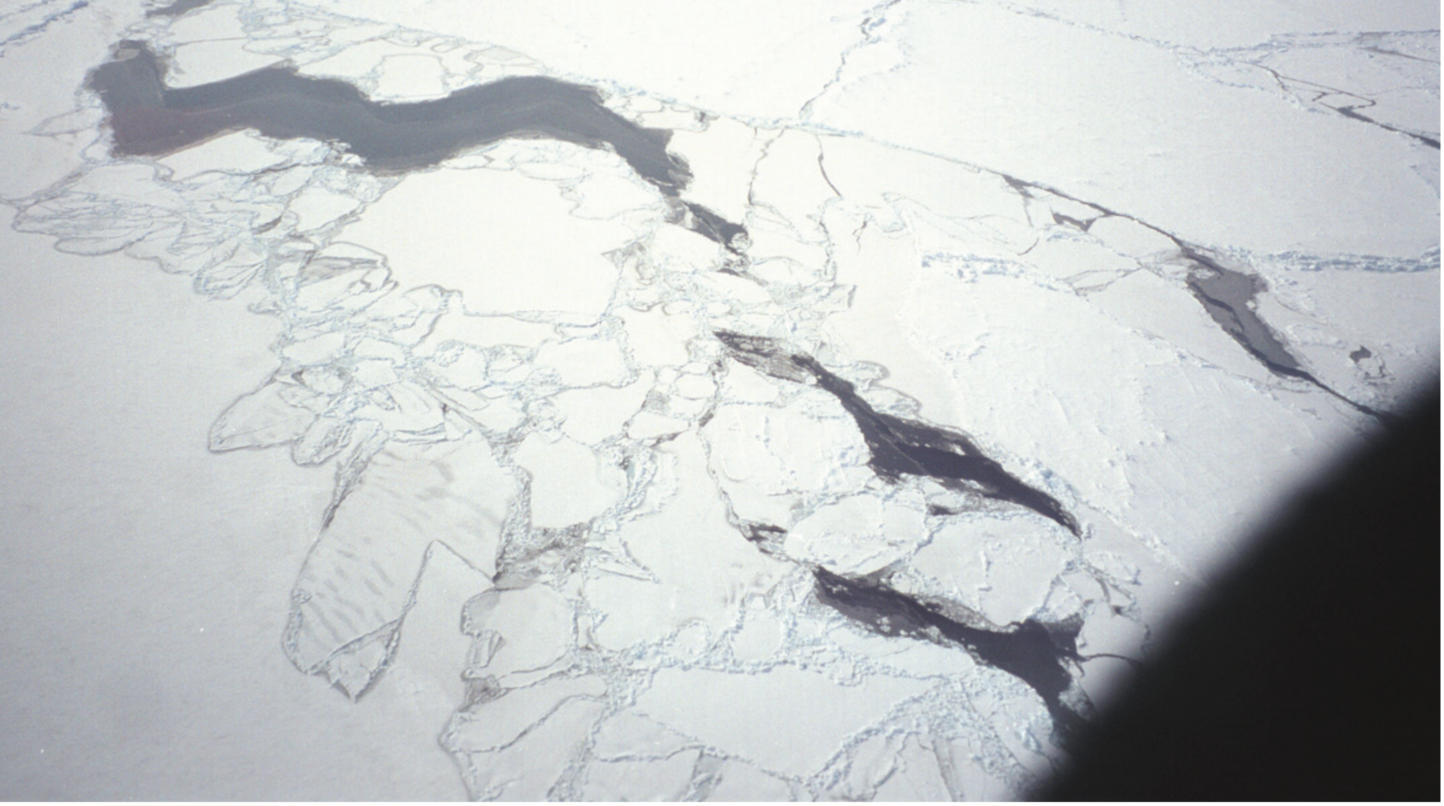
Hunke and Dukowicz broke through the computational barrier by introducing a clever numerical scheme. "When a portion of the material begins slowing down, the energy of its forward motion is converted to elastic waves that, like sound waves in a tuning fork, cause the material to effectively 'vibrate' in place without deforming, while the neighboring ice floes move past," explains Dukowicz, who initiated the scheme.

The new elastic viscous-plastic scheme mimics the real behavior of the ice, affecting only the local region that encounters the barrier. And it is fast and efficient on modern parallel supercomputers.

Similarly, Lipscomb, a newcomer in 1998, worked to model thermal processes more realistically. He improved the model representation of how brine pockets affect heat flow, melting, and freezing within each computational cell.

Also in 1998 Lipscomb traveled to the Arctic as part of the international SHEBA (Surface Heat Budget of the Arctic) project. There he learned that sea ice in the central Arctic had thinned from about 10 feet to 6 feet or less in the 20 years since the previous such project. Anomalies associated with strong winds were part of the explanation, but then in 1999, newly released

Top: Bill Lipscomb's height relative to an Arctic sea ice ridge.
Right: The two main sea ice drift systems in the Arctic Ocean, the Beaufort Gyre and the Transpolar Drift.



An aerial view of Arctic sea ice. Leads (large cracks tens to hundreds of yards across) and smaller cracks form as sea ice moves.

submarine sonar measurements showed that overall Arctic sea ice thickness had decreased about 40 percent from the 1970s to the 1990s.

Since sea ice thinning must affect heat flow between ocean and atmosphere, Lipscomb added to the thermal model the ability to represent variable sea ice thickness within a computational cell.

The improved thermal model fit smoothly with the Hunke-Dukowicz dynamics model, and together they became known as CICE (pronounced "sea ice"). CICE can be downloaded from the Web, and users find it well documented and easy to run.

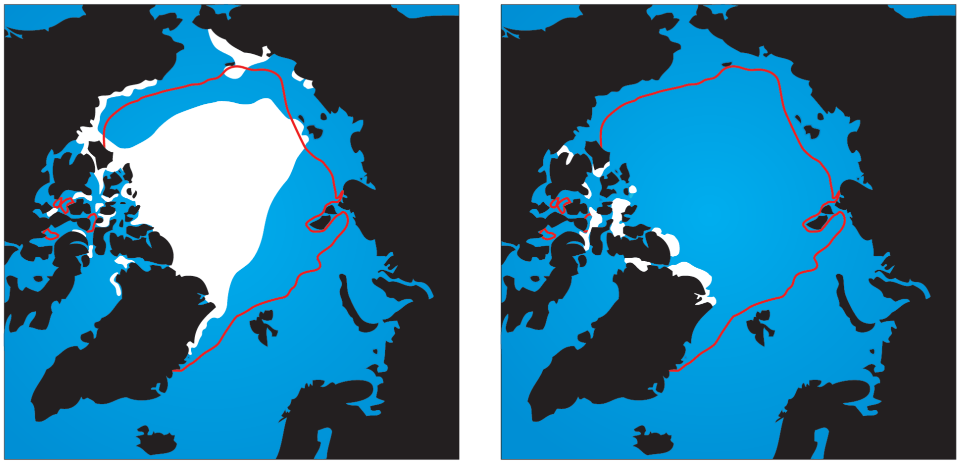
"Our users send us questions when they get funky or suspicious results, and sometimes that leads to improvements in the model. Also, because many people have applied it to different problems, the program is quite trustworthy. I hate to call it 'bug-free,' but 'almost' is OK," says Hunke wryly.

Is CICE a Crystal Ball?

CICE's accuracy has been assessed by comparing "hindcasts" (simulations of past sea ice changes) with observations.

For example, when CICE is used along with POP in the U.S. Community Climate System Model, it accurately reproduces satellite observations of ice pack movements over the cycle of seasons in both the Arctic and Antarctic—including current variations in the expanse of Arctic sea ice from about 2.5 million square miles at summer's end to 6 million square miles at the end of winter.

In addition, when major components of CICE are used in both the Community Climate System Model and the United Kingdom's Hadley Centre Climate Model, those two come much closer than



The U.S. Community Climate System Model forecasts a rapid decline in average September (minimum) sea ice extent. White areas have at least 50 percent ice coverage. The model projections for 2010–2019 (left) and 2040–2049 (right) show the decline relative to the observed September ice extent averaged for the 1990s (red curve).

New Focus—The Greenland Ice Sheet

How fast will it take for the ice covering Greenland to melt? "That's the great unanswered question we'll try to answer next," says Phil Jones, present leader of climate modeling at Los Alamos.

Large outlet glaciers in Greenland have accelerated their movement to the coast and thinned during the past decade. Scientists are concerned that the entire Greenland ice sheet could decay within a few centuries, instead of over several millennia, as previously believed.

The melting would raise sea level by about 20 feet. Melting of the West Antarctic ice sheet could contribute another 15 feet.

Existing ice sheet models, which track the movement of ice on land, are too crude to predict these changes, in particular, the initiation of rapid sliding at the base of the ice sheet. Los Alamos plans to develop a more accurate model to account for processes that enable accelerated sliding, for example, ice melt reaching and lubricating the base of the ice sheet. The model will then be coupled to full-climate-system models to study the feedbacks that might result as the ice sheet retreats.

Could the ice sheet's shrinking trigger local climate changes that further affect the rate of retreat? Could the retreat alter the ocean circulation? What role do ice sheets play in transitions between interglacial and ice age climates?

Modeling is the key to answering these questions.

Surface meltwater flows into a large vertical shaft, or moulin, where it plunges deep into the Greenland ice sheet. Dr. Alberto Behar, California Institute of Technology, Jet Propulsion Laboratory stands by the opening.
IMAGE CREDIT: NASA/JPL.

other models to reproducing the dramatic decline in summer Arctic sea ice from 1957 to the present.

In view of these hindcasting successes, CICE might well be a crystal ball for predicting the Arctic's future.

For a scenario in which greenhouse gas emissions follow a middle-of-the-road projection, the Community Climate System Model, with CICE and POP components, forecasts that Arctic summer ice could decline precipitously in coming decades and almost disappear by 2040.

When the initial conditions of a computer run are varied to represent natural climate variation, the pattern of sea ice decline shows one or two brief periods of abrupt change (30 percent or more), flanked by slower changes. Interestingly, these abrupt events were triggered by unanticipated influxes of warm water from neighboring oceans into the Arctic Ocean.

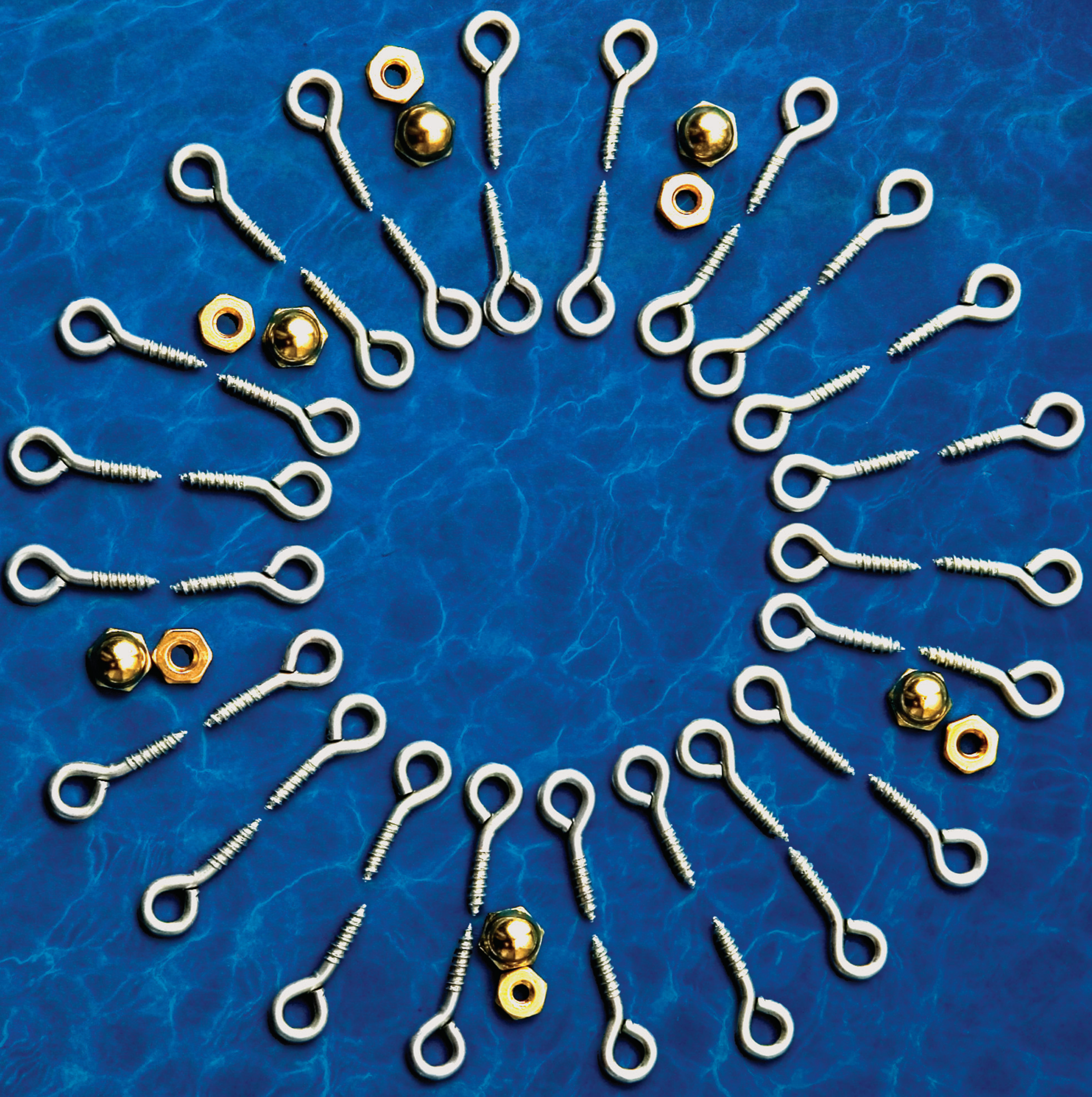
The complete disappearance of Arctic sea ice for part of the year would destroy the habitat of polar bears and other species dependent on floating ice. In addition, the associated Arctic warming could trigger the onset of other major changes, including accelerated melting of the mile-thick ice sheet covering Greenland. The melting of so much ice from a land mass would cause a rapid rise in sea level. (Sea ice already displaces its weight in water and does not raise the sea level when it melts.)

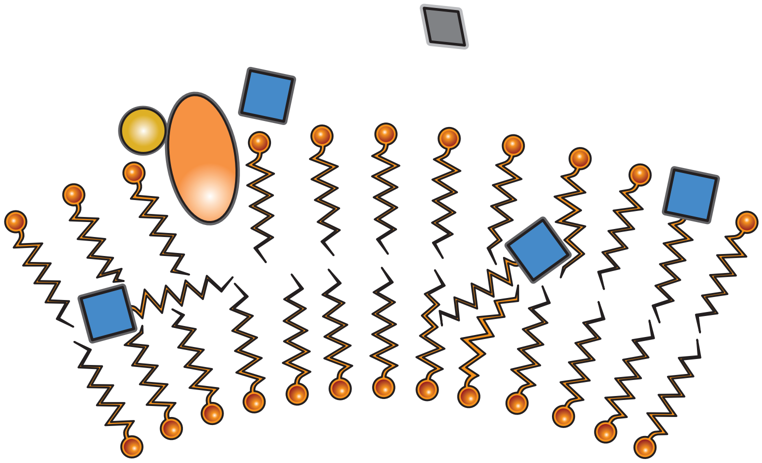
Arctic sea ice melting may be a warning for the whole planet: if greenhouse gases double or triple by the end of this century, global warming could wreak havoc on our only home in the universe.

It seems climate modeling has come of age just in the nick of time, allowing humanity to project into the future the consequences of its actions and to develop and evaluate strategies for both adapting to and mitigating the changes that are already in motion. ❖

A unique approach to making "nano-machines" that mimic living cells is beginning to bear fruit. It could usher in an age of incredibly useful technologies.

A Lifelike Machine





The current version of the Los Alamos protocell consists of a "sensitizer" molecule (orange oval) and an information molecule (gold circle) within a membrane-like container. The two molecules work together, along with a consumable resource (black diamond) to convert nutrients (blue box with squiggly tail) into container material.

Imagine a computer chip that, when damaged, "heals itself" by replicating and making new, undamaged copies of itself. Or a swarm of microbe-sized machines that dissolve rocks as part of their "metabolism" and, in the process, remove planet-warming carbon dioxide from the atmosphere. Or a nanoscale device that extracts plutonium from the environment and evolves to become even more efficient at doing the task. Science fiction? Maybe.

Or maybe not. Although the ability to self-replicate, metabolize, and evolve into new forms is considered the defining characteristic of living cells, fundamentally there are no reasons a human-made "machine" couldn't have those abilities as well. Indeed, the Department of Commerce, the National Science Foundation, and the European Commission already predict that so-called "convergent, or living, technologies" will have a large impact on our technology and economy within the next 25 years and as such will become key to our technological leadership and national security.

Now, collaborating teams of scientists from Los Alamos National Laboratory and across Europe are close to developing the "protocell," a system of molecules that exhibits living cell-like behavior. The microscopic protocell would be the first step toward making lifelike devices that perform specific, useful functions.

"Our goal is not to modify existing living cells and turn them into little machines," says Steen Rasmussen, leader of the Los Alamos Protocell Assembly project. "Our goal is to take those features that make living cells so successful and apply them to something new."

"Because we're starting from scratch," adds Rasmussen, "we can design our protocell to do things that living cells cannot. In theory, we can make it so different that it can operate in any environment—toxic, radioactive, or otherwise. Protocells can also be designed so they don't interact directly with the biosphere, which would make them less controversial to use than genetically modified cells."

The Protocell Different

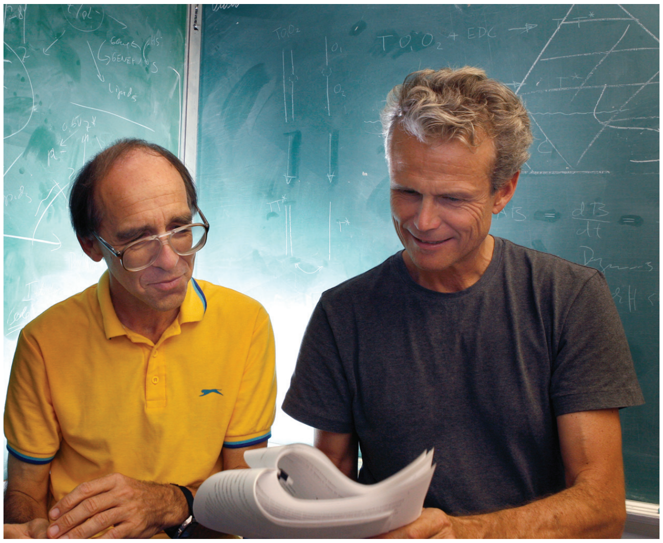
Taking its cues from living cells, the simple protocell has just three components:

- A metabolism (the chemical processes used to obtain energy and create the protocell's building blocks).
- An information system (which instructs the metabolism). Like DNA, the molecules that make up the information system have the ability to copy themselves.
- A container (which keeps everything together).

These components interact strongly with each other—the information system participates in the metabolism, while parts of the metabolism produce copies of the information system and more container material.

The Los Alamos team has already built a pared-down version of a protocell. While not yet able to replicate all of itself, it has nonetheless achieved the team's major milestone: it used its information system to control a metabolic pathway that converted external resources into container material. This machine built its own container!

This early form of protocell is strikingly simple. Its information system (in its most rudimentary form) is actually a single molecule—a modified DNA base. The information molecule works with a second molecule, known as the "sensitizer," to carry out the metabolic pathway (see "The Protocell's Metabolism").



Steen Rasmussen (right) and Hans Ziock are part of a team of some 23 researchers in the Los Alamos Protocell Assembly project. Team members are listed at www.lanl.gov/science/1663

The Protocell's Metabolism: Simple as ABCD

Together, the sensitizer and information molecule function as a light-sensitive catalyst to carry out the metabolism.

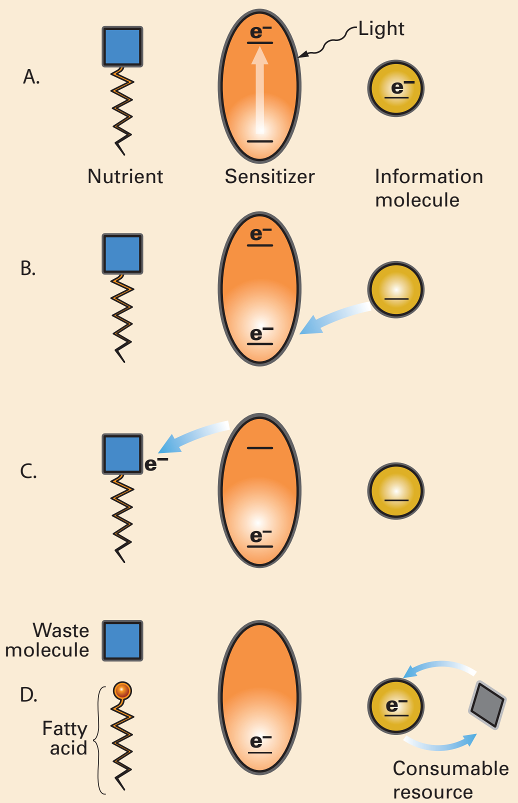
A. When the sensitizer absorbs light, an electron (e^-) is excited from its resting energy level to an energetically higher level.

B. Normally, the excited electron would rapidly return to the lower energy level, and the light energy would be lost. The information molecule, however, transfers one of its electrons to the lower level. The excited electron is then trapped.

C. The excited electron jumps to a nutrient, and its energy breaks the nutrient into a fatty acid (used to build the protocell's container) and a waste product. The sensitizer is restored to its original state, but the information molecule is still missing an electron.

D. The information molecule gets its electron back after it interacts with a consumable resource. The spent resource becomes another waste product.

Both parts of the complex have now been restored to their original states. The protocell can continue producing fatty acids as long as light, nutrients, and consumable resources are supplied.



"In a living cell, the DNA creates proteins that control the metabolism's chemical reactions," says Hans Ziock, a Los Alamos physicist and member of the protocell project. "In our protocell, the information molecule participates directly in the metabolic pathway, so no protein synthesis is necessary. It's a great simplification."

Ziock continues, "Our simplistic information molecule nonetheless captures the essential features of an information system. It makes the reaction work and, in that sense, controls or instructs the metabolism. Though it's a *modified* DNA base, it can still pair with another base and, in principle, copy itself the way DNA does. Lastly, it can join with other bases and become more complex. That might allow for more-efficient metabolic pathways, thereby opening up a way for the protocell to evolve."

Building a Container

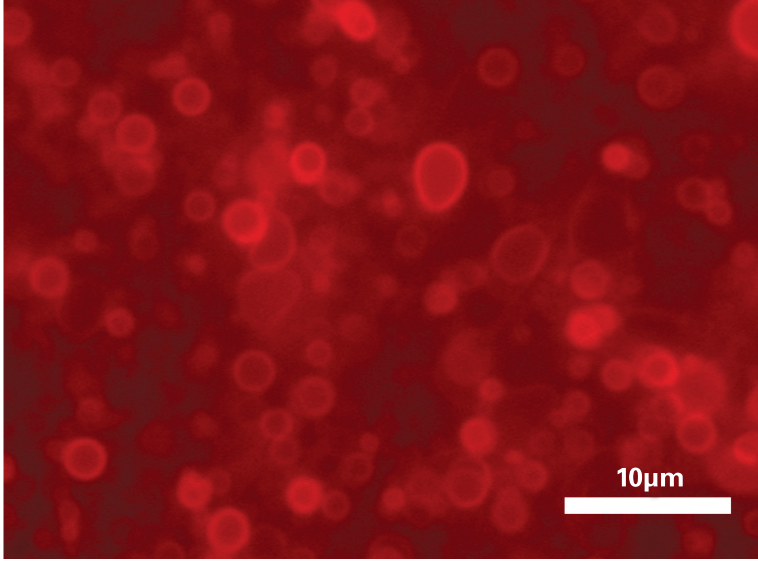
But how did the protocell build its own container? It did so by exploiting the wonderful properties of fatty acids. Fatty acid molecules have large-diameter "heads" that are comfortable in water and long, narrow "tails" that have the characteristics of an oil molecule. The tails dislike being in water.

In a watery environment, fatty acids will try to get their tails out of water by spontaneously forming aggregate structures—in this case bi-layered membranes that have curled up into cell-like vesicles, wherein the membrane encloses a pocket of water. The bi-layer structure satisfies the fatty acid's dual preferences: the water-loving heads face toward and touch water, while the oily tails face each other and are shielded from water. (See the illustration on the previous page.) The tail arrangement creates an oil-like environment in the bi-layer's interior.

This bi-layer is the protocell's container. Unlike a living cell, where the vast majority of the metabolic and genetic processes occur in the watery volume enclosed by the cell membrane, the Los Alamos protocell conducts all of its business within the oily part of the bi-layer or at its surface. This makes it possible for the protocell to freely exchange nutrients and wastes with the environment and eliminates the complex process used by a cell to transport resources through its membrane.

To build the container, researchers mix sensitizer molecules and informational molecules together with chemical nutrients in a water-based soup. The mixture is then exposed to a bright light.

The sensitizer absorbs the light energy and, together with the information molecule, catalyzes the breakup of a nutrient into a fatty acid and a waste product.



These spheroidal vesicles—with their (bright) bi-layer membrane enclosing a (dark) pocket of water—were created as a result of the protocell's metabolism. Each vesicle is a potential new protocell.

After some time, enough fatty acids have been produced to spontaneously form a bi-layer. At that point, the metabolism has built the protocell's container!

The process continues, however. A part of the sensitizer and information molecule prefers to reside in an oily environment, so when they bump into the container, they tend to "stick" to it. Likewise, the nutrient is designed to be oil-loving, so it too will associate with the container. With a ready supply of resources, the protocell—a sensitizer and information molecule in a container—produces more fatty acids and grows. But when a fatty-acid aggregate grows too large, it splits in two, that is, it replicates.

"On paper, this pared-down protocell has all the features of a complete system" notes Ziock. "However, we still need to demonstrate experimentally that the protocell's *information molecule* can replicate. This is the critical missing link for completing the first human-made, fully functional protocell."

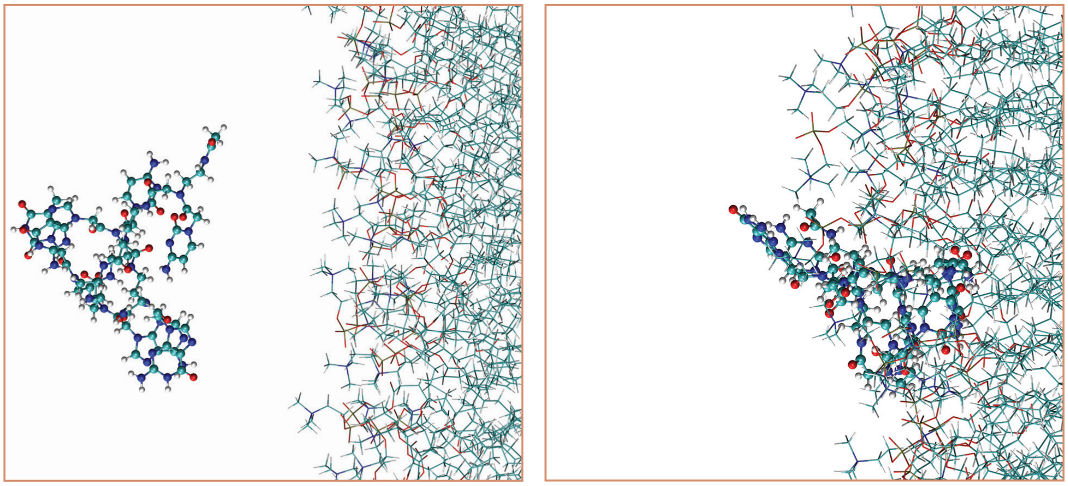
Multiscale Modeling

To help understand and build a more complex system, the team has developed a computational version of all key protocell processes, combining different simulation methods to provide different levels of detail.

The computations have already helped answer what had been an open question about the protocell's growth process. If the container, sensitizer, and information molecule are produced at different rates, will one component be produced far in excess of the others? Theoretical and computational work indicates the answer is "no": the protocell's three components automatically regulate each other's duplication rate, thereby achieving coordinated growth. This is one of the cleverer features of the protocell's design.

Still, it has been surprisingly difficult to simulate the protocell's full life cycle, as there are numerous cross interactions between the molecules. The complexity of the system initially made its behavior difficult to predict.

"Those times when our simulations differ from our experiments are nonetheless the times when we learn the most," observes Rasmussen. "We then have to revise our thinking and change our approach."



Results from a computer simulation showing an information molecule "sticking" to the protocell's container.

Vision

The fruit of all its labor is the Los Alamos team's greater understanding of how to make self-replicating materials, which is the first step toward creating living technology that will benefit society in fundamental ways.

"When your computer crashes or when your car breaks down, somebody has to repair it," says Rasmussen. "In contrast, when you scratch your hand, it heals itself. I predict that, in the future, this distinction between nonliving and living systems will slowly disappear as our technology becomes more and more lifelike." ❖

W88 Certification without Testing

Los Alamos has built the first nuclear trigger in 20 years and has demonstrated, without a nuclear test, that it will work if needed.

Almost everything about it is secret.

It inspires awe, but not from its outward, unremarkable appearance.

The raw power than can be released from its compact, technologically advanced design boggles the mind of even those with detailed knowledge of its form and function.

It is the pit for the W88, the most modern nuclear warhead in the U.S. arsenal, designed by Los Alamos National Laboratory in 1988 to be placed on ballistic missiles carried by the U.S. Navy's submarine fleet.

The pit, which lies at the core of the W88's first stage (the primary), is a hollow sphere of plutonium. When the pit is squeezed into a supercritical mass, it undergoes an uncontrolled chain reaction that triggers the second stage (the secondary), culminating in release of the warhead's full power (see "How a Nuclear Weapon Works").

In June 2007, Los Alamos delivered a newly manufactured W88 pit that is interchangeable with those produced in an earlier era.

The delivery was the fulfillment of a two-part promise the Lab made in the early 1990s: (1) to recover the nation's capability, lost for nearly two decades, to fabricate a plutonium pit to W88 design specifications, and (2) to give unequivocal scientific proof (certify), without a full-scale nuclear test, that the warhead would work as specified with its new pit. Certification without nuclear testing had never before been done.

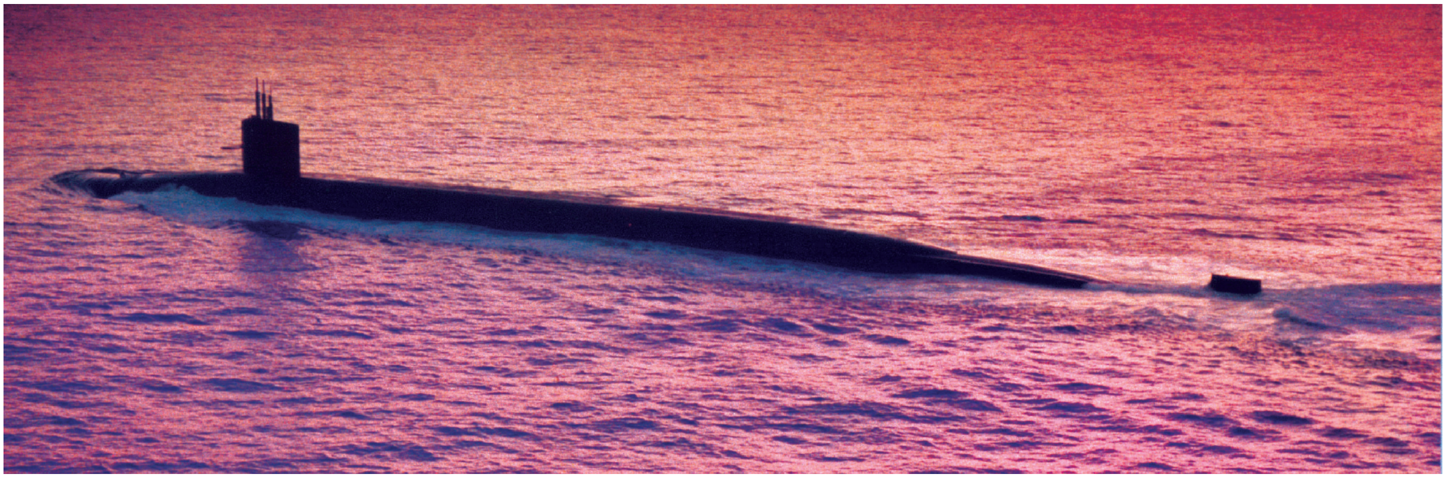
Bob Putnam of the Los Alamos Pit Manufacturing Program Office near the cone-shaped re-entry vehicle for the W88 warhead.

Unprecedented Challenges

The United States lost its pit-manufacturing capability in 1989 when the Rocky Flats production plant south of Boulder, Colorado, was shut down. The plant was closed in the middle of the production run for the W88, and the run was never completed.

Only three years later, in 1992, the United States began a self-imposed, informal ban on nuclear testing.

Nuclear testing had always been the ultimate means of validating the technical judgment of weapons designers that a warhead would perform reliably and would be safe against accidental detonation.



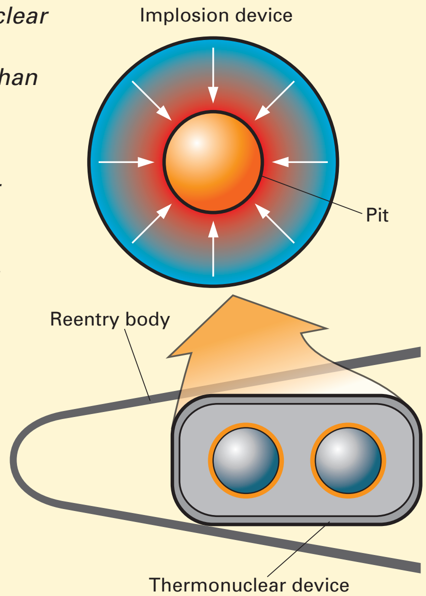
A U.S. Navy submarine going out to sea at sunrise. The W88 warheads are placed on ballistic missiles designed to be launched from submarines.

How Nuclear Weapons Work

Modern thermonuclear weapons have two main stages: the primary and the secondary. The primary, which resembles an old-fashioned fission bomb, delivers energy to the secondary, which uses thermonuclear fusion to release hundreds to thousands of times more energy than a fission bomb would.

The nuclear core of the primary is the hollow sphere of plutonium or enriched uranium known as the pit. Chemical explosives surround the pit and, when detonated, send shock waves inward, squeezing ("imploding") the pit from a subcritical to a supercritical mass—one that will sustain an uncontrolled nuclear fission chain reaction ending in a nuclear explosion.

The x-rays from this nuclear explosion trigger the secondary by compressing and igniting the thermonuclear fuel. The entire process, from detonation of the explosives in the primary to the release of fusion energy in the secondary happens in less than a thousandth of a second.



"Because Los Alamos has the only fully functional plutonium facility in the United States, it fell to us to figure out how to make a Rocky Flats W88 pit and then guarantee it would work if needed," says Glenn Mara, principal associate director for nuclear weapons programs. "As usual, the Laboratory rose to the task, delivering both a high-quality product and a high-quality, high-efficiency process."

To carry out the work, the Lab had to develop new machining, welding, and inspection capabilities, along with processing methods that met modern regulatory standards. This development phase ended in 2003 with the delivery of "Qual 1," the first Los Alamos pit that had the right W88 material properties, size, weight, and shape and that was built using "qualified" processes and "quality" systems—ones that met DOE's quality-control standards for manufacturing and assembly.

The completion of Qual 1 kicked off the next stage of operations: refinement of the manufacturing processes and certification that the new pits would work.

After 1992, validation became the province of a Department of Energy (DOE) program called Stockpile Stewardship. The program was to supply a new set of tools—a collection of experimental and computational capabilities and scientific data, including the results of past nuclear tests, that would enable weapons designers to make technically sound judgments about nuclear performance without any new nuclear tests.

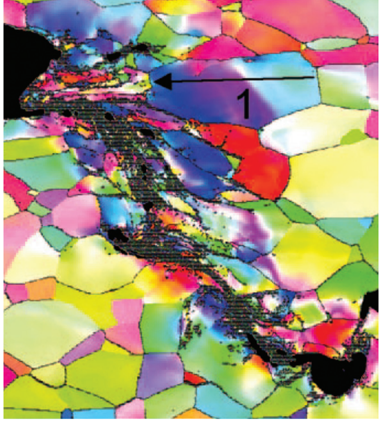
One of the key elements of Stockpile Stewardship is stockpile surveillance, through which a few of each type of weapons system are examined annually to monitor how they age and to determine if there are problems that need fixing.

As part of surveillance, one W88 pit per year was being analyzed—and destroyed in the process. Eventually, the Navy, already deprived of its originally desired number of W88 pits, balked at providing more until replacements could be made.

More Than Just Pits

"Actually, it's not just the pit we certify, it's the warhead, with the pit as a key component," says Gary Wall, leader of the certification team, Laboratory Fellow, and stalwart member of the weapons design community. "From the physics side, we certify that it will deliver a certain yield [nuclear energy release] and, from the engineering side, that it will survive all the mechanical stresses and thermal environments it might eventually encounter."

Performance of the Rocky Flats pit, including its yield, had been measured directly in the underground testing program at the Nevada Test Site. Nuclear explosions were set off hundreds of feet underground and performance information teased out of the



This metal sample, containing many tiny crystalline grains (colored regions), was exposed to strong shocks. The highly strained regions produced by the shocks have coalesced into tiny cracks (black).

explosion byproducts (radiation, debris, and so on). There was visceral validation too—measured by how much the ground shook.

Without nuclear testing, performance of the Los Alamos pit had to be assessed indirectly.

The pressure was on, as never before, to apply the scientific tools of Stockpile Stewardship.

The plan for the new W88 pit was first to measure the differences between small plutonium samples taken from the Rocky Flats and Los Alamos pits and to use the results to build accurate physics models describing the pit material's behavior. Those models would then be used in the full-system codes developed by another DOE program, the Advanced Simulation and Computing (ASC) program.

Starting with the detonation of high explosives and ending with the final energy release of the entire warhead, those full-system codes would simulate beginning-to-end performance, including the differences between the Rocky Flats and Los Alamos pits. Then the code predictions would be assessed through comparisons with past nuclear tests. Plutonium experiments would also be used to inform and validate the computer physics models supporting W88 certification.

Wrought versus Cast

The most glaring difference between the old and new pits? Rocky Flats pits were wrought; Los Alamos pits are cast. Rocky Flats was large enough to house the machinery used to form solid metals into the required configurations and was devoted entirely to pit production. In contrast, the Laboratory's plutonium facility at Technical Area 55 is much smaller and accommodates many other activities. It has to rely on the more-compact method of casting, in which molten plutonium is poured into molds to make rough versions that are then machined into their final shapes.

"Ninety percent of why the W88 certification process was so extensive was the change from a wrought to a cast pit," says Paul Dunn, leader of the Lab's metallurgy group. "It's a philosophical principle that if you change the processing, you change the material's performance. There *would* be differences between the two pits."

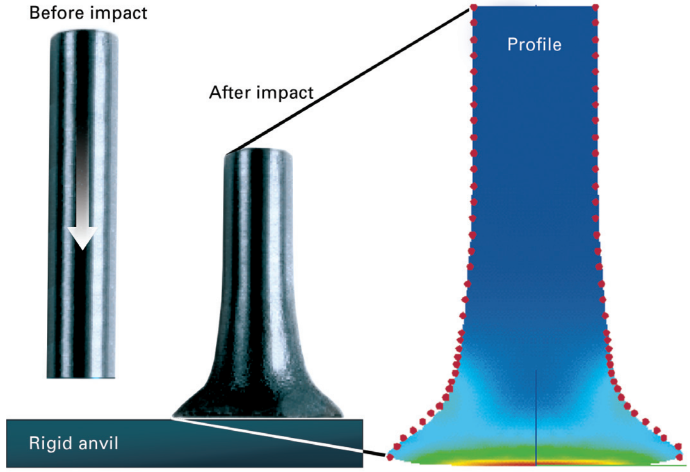
Wrought materials tend to be stronger than cast ones, so designers needed to develop very accurate computer models of plutonium strength from

Towers at the Nevada Test Site, where the test rack for a subcritical test was assembled before being placed downhole precision measurements of both kinds of pit.

Measurements and models had to describe pit responses to a millionfold range of potential "strain rates" (fractional changes in material length, area, or volume per second) that a W88 could encounter. Strain rates would be lowest during shipping and assembly, a thousand times higher during ballistic-missile liftoff, and yet another thousand times higher during pit implosion.

Responses to low strain rates were measured by "simply" squeezing, stretching, and twisting the plutonium metal, while the effects of higher strain rates were measured using a gas gun that sends a projectile into the sample at speeds of up to 18,000 miles per hour.

Finally, responses to the highest strain rates and the highest pressure and temperature changes were measured in "subcritical" (non-nuclear) experiments in deep underground laboratories at the Nevada Test Site, where high explosives delivered strong shocks to the plutonium samples.



When a cylindrical sample hits a rigid anvil at high velocity, it deforms. Computer simulations using the new materials-strength models can predict the final shape after deformation. Compare the colored region (predicted) with the experimental shape (outlined by red dots). Color variations represent the predicted variation of internal strain.

Experiment–Computer Modeling Seesaw

The higher strain rates produce small cracks and voids, which coalesce into fractured surfaces and finally into deep cracks throughout the material. Theorist Paul Maudlin and experimentalists Rusty Gray and Rob Hixson evolved materials models that reproduce such deformations with great fidelity. They also developed equations of state that quantify the density changes resulting from wide variations in pressure and temperature.

Such analysis is difficult enough with normal metals, but plutonium sends the difficulty through the roof. This most complex of all chemical elements is always changing. Small increases in temperature or pressure dramatically alter its density and its atoms' crystalline arrangement. It reacts chemically with most other elements, and it accumulates internal damage through its own radioactivity.

Gary Wall explains, "We needed to control how the plutonium samples where produced and handled so any measured differences between Rocky Flats and Los Alamos samples were not artifacts of our fabrication and testing procedures but were instead real differences derived from the two manufacturing processes."

Some experiments were laid out in the initial certification plan, but as the physics models evolved, new experiments were needed to improve or validate the models. "Experiments drove model development, and then models drove new experiments," notes Wall.

The final physics models for materials in the Rocky Flats and Los Alamos pits were put into the full-system ASC codes to predict whether each primary and the full system would deliver a yield in the desired range.

"We got slightly different performance results for the two types of pit. But the point was not to determine the differences but to show that the performance with the new pit was indeed within the range of yields specified by the National Nuclear Security Administration [NNSA] and the military," explains Wall.

Simulations Confirmed

To confirm the positive results of the full-system simulations, Wall and his colleagues designed

Gary Wall, leader of the W88 certification team. The backdrop shows test preparations.

experiments that examined the behavior of plutonium as it is strongly shocked by forces produced by high explosives. All the measurements—the performance of the high explosives, the velocities at which the plutonium surfaces moved, and the properties of the materials released (the ejecta)—confirmed the results of the simulations.

From the beginning, the scientists knew that the new physics models would need to be validated by comparison with experiments and that uncertainties in the model predictions would need to be determined through statistical sampling of both experimental and computational results—all before the physics models were added to the ASC codes.

The pieces came together at the right time. The scientists used the ASC codes, the new materials models, and the results of experiments to make quantitative predictions of system performance and associated uncertainties. Together, those results were used to back up the statement, “If the warhead were taken out of the stockpile and tested, we are 95 percent confident that it would perform within this predicted range.”

Los Alamos science-based certification of the W88 tells the Navy unequivocally, “You can safely place the new warheads aboard your submarines and trust that they will perform as specified if needed.”

Delivering the Product

With the physics goal achieved, the manufacturing team now has to deliver the pits the Navy needs.

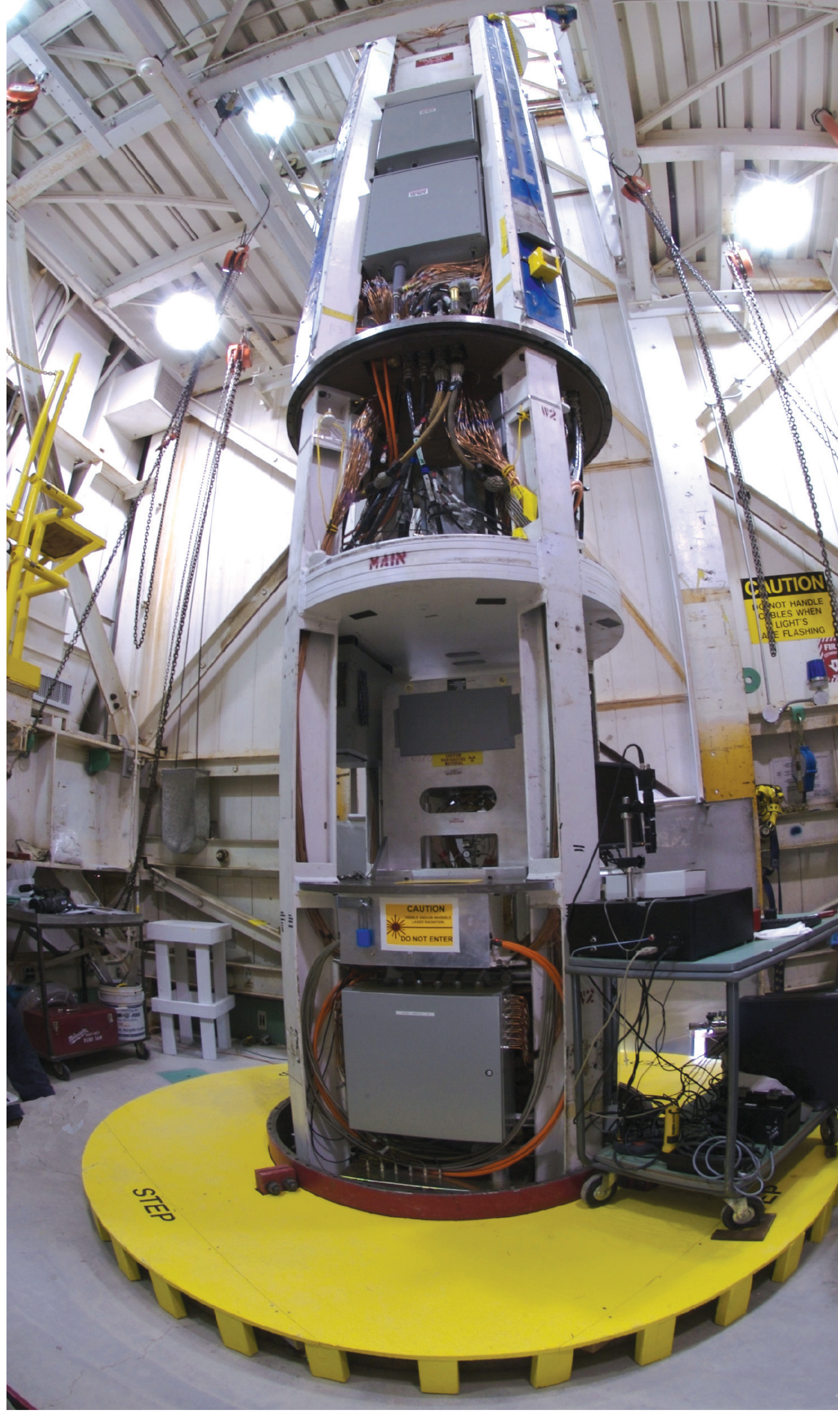
“We have already delivered 15 Qual pits as part of the certification process, and our goal is always repeatability—to make the same pit, with the same strict specifications, every time so the product meets extremely high standards,” says Bob Putnam of the Laboratory’s Pit Manufacturing Program Office.

This past year, processes were streamlined, in part by removing hazardous and environmentally unfriendly steps. Paradoxically, some rather small changes resulted in momentous improvements in quality, productivity, and worker safety.

“We’ve tripled the number of pits we can make in a given time while our budget has remained the same,” says Putnam.

Los Alamos delivered the first pit to the NNSA for its quality review on May 2, 2007, and in June the NNSA accepted it, giving it the so-called “Diamond Stamp” of approval, meaning it’s accepted for insertion into the U.S. stockpile. That first diamond-stamped pit has been delivered to the Pantex Plant near Amarillo, Texas, for assembly into a W88 warhead. The rest will follow on schedule.

As Putnam aptly notes, “It’s no secret that this is the best team Los Alamos could have put together. It would not have been possible without the great scientific and technical expertise of the whole Laboratory.” ❖



The large test rack for a subcritical underground experiment, including diagnostic detectors and the cables that send signals from the detectors to aboveground stations.

The Life-Saving Business of Radioisotopes

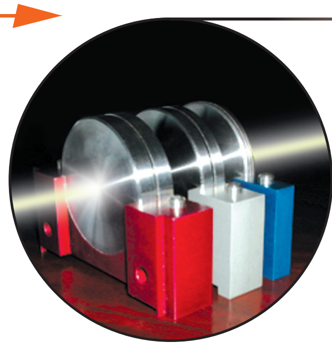
Every month, Los Alamos produces enough radioactive strontium-82 to permit an estimated 6,000 heart diagnoses via PET scans. Spurred on by an invigorated national program, the Lab plans new research.

Some 40 feet beneath the mesa top that rims Los Alamos canyon, in a heavily shielded room appropriately dubbed "the cave," atoms are being transformed. Energetic protons from an accelerator are sent smashing through a series of targets. When a proton slams into the nucleus of one of the target's constituent atoms, it transforms that ordinary, stable bit of matter into something extraordinary: a radioactive nucleus made specifically to serve society.

Radioactive nuclei, also called radioisotopes (or radioactive isotopes), emit energetic particles and/or gamma rays as they decay and become other nuclei. These radiations, while potentially dangerous, nonetheless make radioisotopes uniquely useful.

Days 1–2: *The radioisotope strontium-82 starts life as rubidium-chloride powder, which technicians melt, cast into a target, and seal into a metal capsule.*

Days 3–14: *Inside the Lab's Isotope Production Facility, protons irradiate the encapsulated target material. Some rubidium is transmuted into radioactive strontium-82.*



Day 14: *Technicians remotely retrieve the dangerously radioactive target and transport it to the Lab's dedicated hot cell facility.*

Uniquely Useful

Home smoke detectors work because they contain americium-241 (the number refers to the radioisotope's mass). Radiation from the radioisotope creates an electric current that weakens when smoke is present and triggers an alarm. Security personnel use the neutrons emitted from californium-252 to inspect airline luggage for hidden explosives, while technicians use the gamma rays from iridium-192 to test the integrity of pipelines. Even polonium-210, the radioisotope that killed former KGB agent Alexander Litvinenko, is used as an anti-static brush to, say, neutralize static electricity on photographic films.

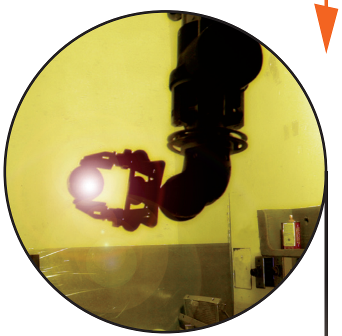
Even more important are the dozens of life-saving radioisotopes used for medical diagnostics and treatments. An estimated 16 million nuclear medicine procedures are performed annually in the United States, primarily to identify cardiovascular disorders, but also to diagnose and treat cancer.

These commercial applications merely hint at the business of radioisotopes, which is also useful for the military, research, and space exploration. Although the private sector conducts most of the commerce, four national laboratories, and in particular Los Alamos, are also players, providing critical radioisotopes that neither industry nor the universities can manufacture.

Guaranteed on Time

Radioactive nuclei need to be created, but then the atoms that contain the unstable nuclei must be chemically extracted from the target material, purified, packaged safely, and distributed in compliance with Department of Transportation regulations. This production requires a specialized infrastructure: an accelerator or nuclear reactor, where the radioisotopes are made; hot cells, where the radioactive goods are remotely processed and

Days 14–17: *Within the hot cells, the strontium-82 is extracted from the target material and chemically purified.*



Days 18–19: *General Electric Healthcare in New Jersey manufactures the CardioGen-82 generator within which long-lived strontium-82 generates short-lived rubidium-82 through radioactive decay. The rubidium is used for PET scans.*

Days 20–46: *Injected into a PET-scan patient, the rubidium-82 is preferentially absorbed by heart muscle. The rubidium decays by emitting positrons, which combine with electrons to produce gamma rays that are detected by the scanner. Doctors rely on the data to determine the condition of the patient's heart. The spent generator is returned to Los Alamos, where its remaining strontium is properly disposed.*

the isotope product purified; and facilities where the radioactive and chemical waste streams are handled.

Los Alamos has been producing radioisotopes since the early 1970s, and its biggest success story has been developing a steady supply of strontium-82 for medical purposes. (See the timeline on the previous page.) The radioisotope decays to radioactive rubidium-82, a short-lived radioisotope that is used in positron emission tomography (PET) scans to diagnose the condition of a patient's heart.

The Laboratory also produces germanium-68, which is used to calibrate the PET scanners and without which the sophisticated scanners would quickly become less useful.

Up until 1998, those two radioisotopes and others were made using high-energy protons from the accelerator at what is now the Los Alamos Neutron Science Center (LANSCE). The isotope production station was located at the end of the accelerator beam line, so when the accelerator went down for maintenance, radioisotope production ceased.

The situation changed with the 2004 commissioning of the Isotope Production Facility (IPF).

"The LANSCE accelerator is actually two linear accelerators joined together," says Gene Peterson, the Chemistry Division leader and driving force behind the IPF. "Someone had the foresight to put a 'spigot' where the two join. We can remove protons after the first accelerator stage and send them into the IPF's cave. Our operation is effectively decoupled from the other accelerator and from LANSCE."

The protons taken from the spigot have less energy than those that travel the accelerator's full length. The lower-energy acutally allowed for more specific control of the nuclear reactions that create the radioisotopes. The decoupling greatly increased the reliability of Los Alamos products and guaranteed the Lab a stake in the national radioisotope market. The Laboratory's Isotope Production and Distribution Program, under which the radioisotopes are produced, is the first business-like operation at Los Alamos.

A National Production Program

As soon as they are created, radioactive nuclei begin to decay and disappear. Part of staying in business is maintaining production to ensure a steady supply.

At the national level, the isotope program, administered by the U.S. Department of Energy's (DOE) Office of Nuclear Energy, is responsible for radioisotope production at Los Alamos, Brookhaven, Oak Ridge, and Idaho national laboratories and ensures the supply through the coordination of production schedules. For example, Brookhaven and Los Alamos—the sole producers of strontium-82 in the country—stagger their schedules so one is producing while the other is down for maintenance.

The national program has been remarkably successful, in recent years serving about 170 hospitals and companies worldwide and making about 450 isotope shipments annually.

However, the demand for radioisotopes is steadily increasing, with medical isotopes being one of the fastest growing markets. The increased demand has been a significant strain on the enterprise, especially with respect to the supply of radioisotopes used in research.

In response, DOE recently shifted to a contractor-based system, managed out of the newly created National Isotope Program Office. In addition to contracting with the national laboratories, the national program will be keeping the supplies coming through contracts with reactor facilities at the University of California, Davis, and the University of Missouri, as well as with facilities in Russia and South Africa.

"We're trying to establish an integrated production schedule with all the contracted facilities, even those located halfway around the world," says Wolfgang

Above: Wolfgang Runde is the new manager of the National Isotope Program, part of which aims to revitalize research into radioisotope products.

Runde, a Los Alamos chemist and the national program manager. “Plus, we plan to re-invigorate research and development for new radioisotopes, as well as educate the next generation of nuclear physicists, engineers, and chemists. We’re investing in the future.”

New Life Savers

Los Alamos is already working with several partners to make other life-saving radioisotopes, for example, copper-67, widely available to the medical community. A brief human trial during the 1990s showed that copper-67 was effective for treating non-Hodgkin’s lymphoma.

At the time of the trial, it was difficult to consistently produce the radioisotope. Laboratory scientists are investigating using a target enriched in zinc-68 to produce the copper isotope. The reaction is ideally suited for the proton energy range available at the IPF.

The zinc target would also produce copper-64, a gamma-ray emitter that can be used for medical imaging applications. Used together, the two copper radioisotopes offer the possibility of simultaneously diagnosing and treating cancer cells.

Los Alamos is also partnering with the New Mexico Center for Isotopes in Medicine, part of the University of New Mexico, to develop a new and improved gallium-68 generator. The positron-emitting gallium-68 is a short-lived radioisotope that can be used for PET imaging of cancerous tissue. The manufactured generator would contain the long-lived radioisotope germanium-68 which decays to the short-lived gallium-68. A hospital or research institution would use the generator as an on-site source of gallium-68.

The gallium radioisotope can be quickly linked to different cancer-targeting agents.

Together with its New Mexico partners, Los Alamos will develop commercial kits that researchers can use to evaluate the gallium-labeled agents in animal studies and experimental models of cancer.

In Runde’s opinion, Los Alamos, with its Isotope Production Facility, hot cell facilities, the proposed Materials Test Station (see sidebar), and expertise in nuclear chemistry, radiochemistry, and physics, can be at the forefront of radioisotope research.

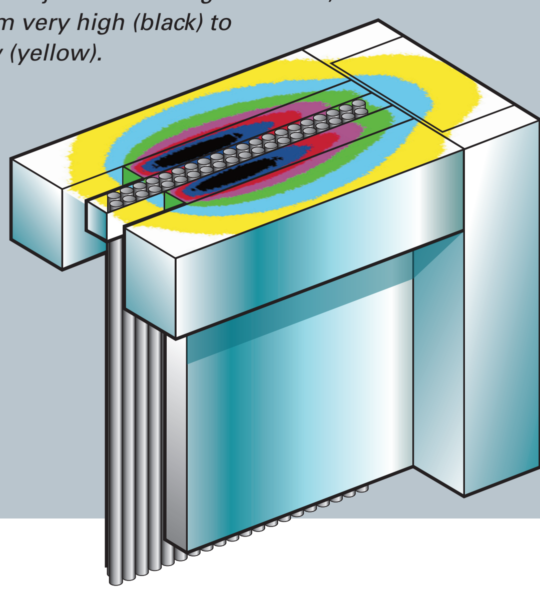
“New nuclei will be needed to tackle tomorrow’s problems,” he says. “We need to start discovering and producing those nuclei today.” ❖

Above: Cleo Naranjo with a CardioGen-82 generator containing strontium-82.

The Materials Test Station

The proposed Materials Test Station (MTS) is designed to test the behavior of nuclear fuels and materials being considered for advanced nuclear power reactors. It will use high-energy protons from the LANSCE accelerator to create high-energy neutrons, and thereby mimic conditions found inside the reactors. The neutrons and protons would also be available to irradiate radioisotope targets, making MTS the only dual-source radioisotope facility in the world.

The figure shows the MTS target assembly. Fuels and materials in the gray cylindrical tubes are exposed to neutrons and/or protons. A simulation of the neutron flux (neutrons per cubic centimeter per second) that would be present at the middle of the assembly has been superimposed. Targets are subjected to a range of fluxes, from very high (black) to low (yellow).



The Global Energy Challenge

Rajan Gupta, chairman of the Los Alamos National Laboratory Energy Council, and Hans Ziock, an expert on zero-emission coal and carbon-dioxide sequestration, discuss their ideas on providing clean energy to an energy-hungry world.

1663: How would you define the global energy challenge?

GUPTA: First, we have to recognize that growth in energy use goes hand in hand with development—whether it is measured using gross domestic product, education, or the human development index. The challenge facing us is that every child growing up in an industrialized nation today expects to flick a switch and have the lights turn on, or the TV, or whatever. And every child in a developing nation is beginning to have the same expectation. To facilitate development globally, we need cheap energy, clean energy, and energy for all.

ZIOCK: But with so many people in the world today using energy, the environmental impacts are beginning to show up on a global scale. Carbon dioxide (CO_2), which is produced by burning fossil fuels such as oil, gasoline, natural gas, or coal, is a known greenhouse gas that contributes to global warming.

Since the start of the industrial age, the CO_2 levels in the atmosphere have increased by some 35 percent. If everyone had the standard of living we have in the United States today, and the population of the world doubled, as is possible in this century, energy use worldwide would grow to ten times what it is today. And past greenhouse emissions would be completely dwarfed by those of the future.

1663: So what can be done?

GUPTA: The problem has both a short-term and a long-term challenge. In the short-term, the world needs a lot more energy, especially for rapidly developing countries like China and India. And there are no immediate large-scale solutions other than fossil fuels. The long-term aspect of the energy problem is, as Hans said, global climate change. Fossil fuels supply over 80 percent of the energy used today. Even if the use of fossil fuels levels out, the level of CO_2 will grow and persist for hundreds of years, and there will be substantial warming over what we're seeing now.

1663: But energy use is likely to increase, not level out.

GUPTA: Right. The global energy demand is growing at about 2 percent per year, which translates to a fossil-fuel energy equivalent of an extra three million barrels of oil per day, and proportionately more every year. There is no easy or quick way to develop this extra energy capacity using today's "carbon neutral" systems—systems like solar, wind, or nuclear, which don't increase the atmosphere's CO_2 load.

If you tried to meet the growing energy demand by burning more oil, it would take at least five years to bring an extra three million barrels of oil online, and the cost of oil may continue to rise. Analyzing the scale of the global energy problem leads to a very pessimistic scenario: either the world burns a lot more coal, because that's the most abundant fuel among both developed and developing nations, or economic development will stall.

ZIOCK: It truly is the *scale* of our energy use that's the problem. For example biofuels, which are made from corn and other crops, are carbon neutral. When burned as ethanol (or biodiesel), they release only as much CO_2 as they took in while growing. They also provide economic opportunity, since ethanol is a high-value liquid fuel. Biofuels would seem to be an ideal fuel source. Yet, to meet the world's likely energy demand at the end of the century, nearly all of the planet's land area, including its agricultural areas, would have to be converted into biofuel farms.

> As daunting as the energy challenges are, they are thousands of times cheaper than the possible consequences of doing nothing.

One could turn coal into a carbon-neutral energy source by capturing the CO_2 it produces and storing it underground or in the form of rocks—CO_2 sequestration. While a relatively low-cost solution, sequestration still adds to the overall price of the fuel. At this time, all carbon-neutral energy systems are more expensive than fossil fuels. For poor countries, that's sort of a double-edged sword. To afford to go carbon neutral, they have to develop economically, which requires them to use a lot of cheap energy.

The only solution is for society as a whole to come to grips with the cost issue and take action on it.

GUPTA: The problem is easier in Europe, Japan, and many other developed countries, where there is essentially zero population growth. They do not need significantly larger amounts of energy, and they can more easily absorb the extra costs of transitioning to carbon-neutral systems. When a coal plant becomes decrepit or a liability, they can just replace it with a clean coal system, a nuclear plant, or even a large photovoltaic farm or wind farm.

1663: So Europe will be shifting more toward renewables?

ZIOCK: Perhaps, but there are problems. Renewables are not yet cheap enough, and there's no cheap and compact way to store the energy for times when the winds are down or the sun is obscured. You would need huge banks of batteries or even another fuel that you could burn when you need to. That's why coal is so good. When you need it, you shovel it into the oven, put a match to it, and it burns and releases tremendous amounts of energy. Burning just one ounce of coal in a second generates about as much raw energy as you get from sunlight falling on a 30-by-30-yard area for one second. And you can burn coal anytime, not just when the sun shines.

1663: So what are the options?

GUPTA: The first, obvious one is to become more energy efficient. Efficiency alone can cut U.S. gasoline consumption by about 50 percent, and today's technology allows us to increase the average fuel efficiency from 23 to 35 miles per gallon without restricting mobility. Similarly, going from incandescent light bulbs to compact fluorescent bulbs would reduce the lighting budget to 25 percent of what it is now. Efficiency measures taken by the developed world could buy the world about 10 years of projected energy growth, during which time we could develop sequestration and alternate fuels technology.

Next, we need to develop global solutions for nuclear waste and proliferation problems so we can rapidly ramp up nuclear power. The third option is to invest very heavily in research and development of alternative energy systems. We need to bring the price of solar panels down to one-fifth or one-tenth of what it is today.

ZIOCK: We also need to start capturing CO_2 from power plants and sequestering it underground at a large scale. Although today's projects inject about 25 million tons of CO_2 underground per year, the world produces 25 *billion* tons per year. Furthermore, most of the CO_2 being injected is from natural CO_2 sources and hence does not represent sequestration.

GUPTA: Yes, fast ramp-up of CO_2 sequestration is essential.

Estimates of additional costs to the end user vary between 30 and 50 percent. The real show stopper is that we have not done the research, nor the risk analysis, on sequestering 25 billion tons of CO_2 each year. But if we could ramp up and sequester one billion tons every year by 2017 and ten billion tons annually by 2030, that would be a phenomenal advance.

ZIOCK: We've been working on sequestration for some time, but there are no miracle solutions at hand. So the public has to demand that we stop emitting CO_2 to the atmosphere and be willing to pay for the technology needed to achieve that.

1663: What are the national labs doing about this problem?

GUPTA: The national labs remain our biggest resource for the development of safe, clean energy. They should lead in developing safe nuclear power and direct the long-term research on alternative technologies and CO_2 sequestration. They need to work with industry to quickly deploy these technologies. The labs should also lead the large-scale systems analysis for each type of energy and help determine life-cycle costs, environmental impacts, and the interactions between energy sectors. This can happen quickly if there is funding and a clear mandate for the national labs to work on energy—and if achieving carbon-neutral energy systems is a national and global priority.

1663: How would you summarize what lies ahead?

GUPTA: As daunting as the energy challenges are, they are thousands of times cheaper than the possible consequences of doing nothing. If we don't start today, we are being very, very short-sighted. The solutions will take time, sacrifice, and global cooperation, but clean, cheap energy for all must be our goal for, say, 2050.

ZIOCK: That's right. I often liken the issue of energy and CO_2 to buying an insurance policy: buying the policy after the accident does no good, especially when the potential long-term costs resulting from inaction are so large. That 2050 goal can be achieved, but only if we start right now in a serious way. ❖

SPOTLIGHT

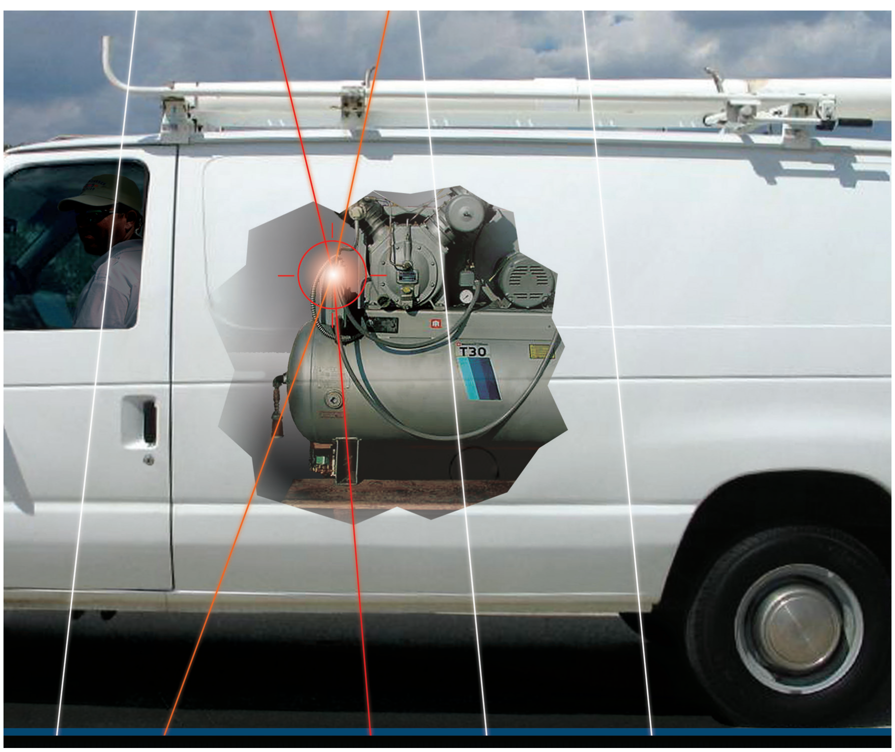
Terrorists Beware!

Now and then, there really is such a thing as a free lunch. This one—served up by Mother Nature—could foil terrorist attempts to smuggle an atomic bomb, or its parts, into the country.

In collaboration with Decision Sciences Corporation, Los Alamos researchers have found a way to use cosmic-ray muons—subatomic particles that constantly stream down from the heavens—to detect plutonium or uranium hidden in a vehicle or shipping container. Unlike current x-ray inspection methods, which expose a vehicle's occupants or a container's contents to a manufactured dose of x-rays, muon inspection involves only the natural muon exposure from cosmic rays that are already part of background radiation.

About 10,000 cosmic-ray muons rain down on every square yard of Earth's surface each minute. Most of them have enough energy to penetrate several feet of lead, which means they are only slightly deflected from their downward path as they pass through the thin steel roof of a car or truck. However, chunks of plutonium or uranium deflect the muons more noticeably: their highly charged atomic nuclei produce large electrostatic forces that bend the path of the electrically charged muons.

A vehicle-scanning system, including panels of charged-particle detectors above, below, and at the sides of a vehicle, determines the path of each muon before and after it passes through the vehicle. Computers analyze the paths, looking for bomb materials and their tell-tale deflections and flagging many suspicious objects in about a minute or more. The panels can be built into a structure and/or otherwise camouflaged so that smugglers will not even know they're being scanned.



Big City's Life on the Line

A "New York minute," slang for "a very short time," refers to the common feeling that life is faster in big cities. This perception was recently borne out in studies that show how urban indicators, which include "social currencies" such as wealth creation, innovation, and information, but also crime rates and how fast people walk, vary with urban population size.

Using data from hundreds of cities worldwide, a team of researchers, including two Los Alamos theorists, found that social currencies increase per capita with population, while material infrastructure (the size of the energy grid, transportation network, etc.) grows more slowly than population. These findings apply to all urban systems studied, from the U.S. to China.

The researchers also introduced a new "urban growth equation" that relates urban population to the availability of resources and their consumption. The equation shows that, as populations grow, social life accelerates because many more contacts become possible between people.

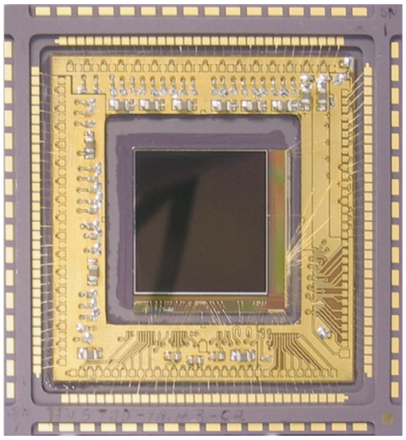
Furthermore, the researchers found that when urban development is driven by social interactions, the relative growth rate steadily increases, which leads inexorably to crises. Sustainable growth can nevertheless be achieved through periodic resetting of the growth trajectory via major adaptations, leading to successive growth cycles. Historically in the U.S., such adaptations have resulted from shifts in immigration, the Civil War, the Great Depression, and the result of urban interventions.

The study's conclusions—that cities are predictable accelerators of social life and that the rate of urban population growth periodically undergoes abrupt changes, which must occur more often as the city's population increases—are confirmed by the analysis of New York City's historic growth. Such insights could help guide new policies on sustainable development in a world that is becoming predominantly urbanized. The work is published in the *Proceedings of the National Academy of Sciences,* Vol. 104, pp. 7301–7306, 2007.

Protons, Camera—Action!

Lab researchers, working with Teledyne Imaging Sensors, have built the world's fastest camera, and it has just won an R&D 100 Award from *R&D Magazine* as one of the 100 most technologically significant products of 2007.

Made from two bonded microelectronic chips, the "Camera on a Chip" can capture 2.8 million frames per second. A normal motion picture camera captures 24 frames per second.



The camera produces movies of ultra-short (sub-microsecond) processes, mostly induced by powerful high explosives. These processes are studied using a remarkable imaging technique known as proton radiography, in which high-energy protons pass through an explosives-driven object to a screen, where they produce a blue "shadowgraph," essentially a two-dimensional representation of the object.

The camera takes pictures of the shadowgraphs in as little as 50 billionths of a second per frame, freezing images of the object's high-speed motions and storing up to three of them "on-chip" at one time. Several cameras can be used together to make a movie of tens of frames or more.

With very high sensitivity in both the visible and near-visible frequencies, the camera can also be used for many other applications, including studies of internal-combustion engines, vehicle-impact tests, and armor-penetration experiments; laser-beam identification of minerals on Mars; and location of fast-moving targets in space.

PHOTO COURTESY OF PAUL RILEY, WWW.SCORE.UK.COM/RESEARCH

A Big SCORE

Across the globe, two billion people use open fires as their primary cooking method—with 93 percent of the energy produced going up in smoke. A simple appliance being developed by a consortium that includes Los Alamos scientists could change all that.

The Stove for COoking, Refrigeration, and Electricity supply (SCORE) would employ thermoacoustic technology to capture some of the energy left in the flue gases after cooking to provide refrigeration and electricity. The flue gases from the burning biomass will unevenly heat air contained in specially shaped pipes; some in the stove's chimney and others behind the stove. Temperature differences produced by the uneven heating will cause the air in the pipes to oscillate, generating intense sound waves. These will produce electricity by moving a diaphragm attached to a coil of wire near a permanent magnet—like a loudspeaker in reverse.

Other sections of the piping form an acoustically powered refrigerator. The sound waves entering those pipes provide cooling by compressing and expanding the air while moving it between cold and ambient heat exchangers.

Led by the University of Nottingham in the United Kingdom, the consortium also includes other universities, industry, and a charity. Scott Backhaus, at Los Alamos, says the consortium would like to produce about a million SCOREs within five years for about $40 per unit and train villagers to build most of the stove's parts themselves—largely from local sources of scrap metal—and then maintain the appliance.

Backhaus notes that SCORE will improve cooking efficiency and provide refrigeration for rural inhabitants of Africa, Asia, and other parts of the world. But by providing enough electricity to charge cell-phone batteries and run computers, SCORE may actually help the Third World catch up to the First.

High-Altitude Dowsing

Since forever, dowsers have searched for groundwater by walking through fields and observing the twitchings of a Y- or L-shaped divining rod. Los Alamos scientists have advanced that ancient art by replacing the rod with large, electrically energized coils of wire, carried not by hand, but aboard a four-engine aircraft.

In 2001, the scientists flew the coils over parts of the Pajarito Plateau in northern New Mexico, the Laboratory's home base, and conducted an electromagnetic survey to characterize local aquifers and contamination pathways. They collected data on the electrical resistivity of Earth's surface layer, a measurement that is highly sensitive to groundwater. When that data was combined with existing geochemical and geophysical borehole data, the results revealed "wet" and "dry" areas of the plateau to depths of 1,000 feet or more. The survey, an important case study of the method, is being published in *Geophysics*, Vol. 72, pp. B31–B45, 2007.

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Address mail to
1663
Mail Stop M711
Los Alamos National Laboratory
Los Alamos, NM 87545

e-mail: 1663magazine@lanl.gov
Tel: 505-667-1447
Fax: 505-665-4408
www.lanl.gov/science/1663/