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SCIENTIFIC AMERICAN

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THE SPACE STATION:
THIS ORBITING OUTPOST PREPARES FOR LAUNCH AMID MISGIVINGS ABOUT ITS MISSION

SCIENTIFIC AMERICAN

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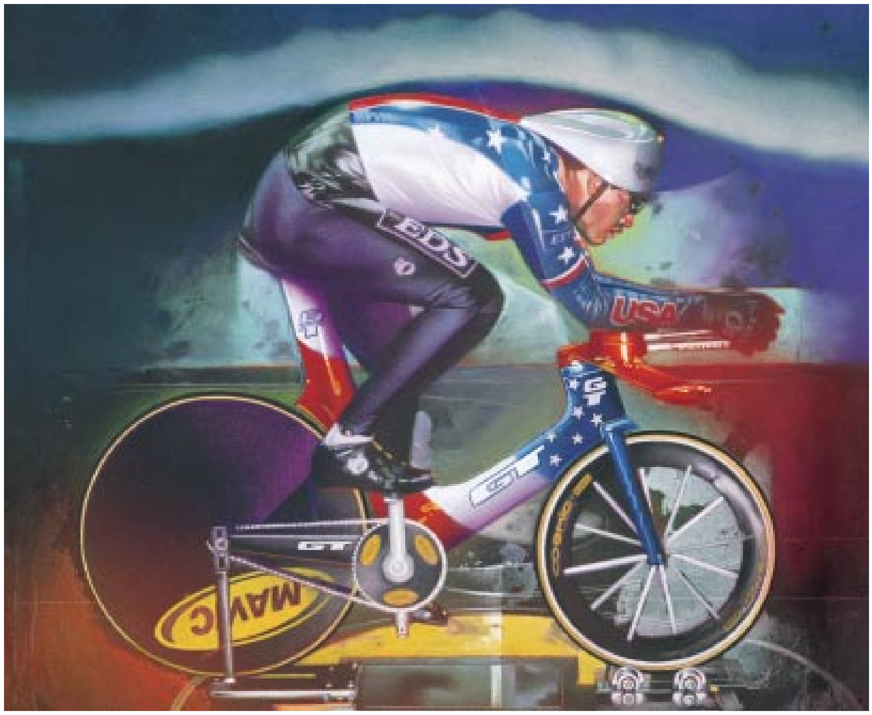
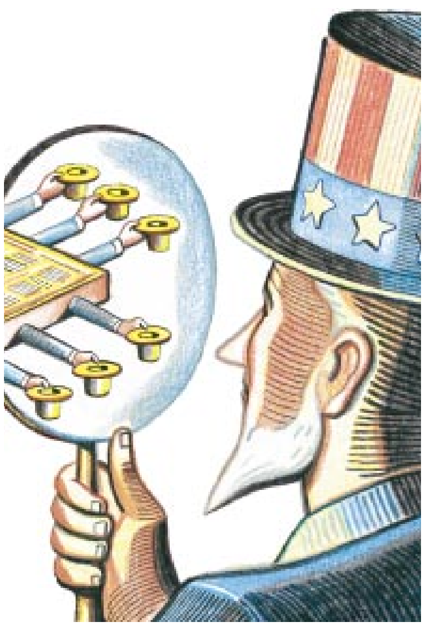


Training the Olympic Athlete 52
Jay T. Kearney

In competitions that push the limits of human performance, victory can hinge on scant centimeters or hundredths of a second. To get the edge they need, modern Olympians and their coaches turn to science and technology. A sports scientist for the U.S. Olympic Committee describes how training programs drawing on physiology, psychology, aerodynamics and other disciplines are boosting the performance of athletes in four events: bicycling, weight lifting, rowing and shooting.



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Lucien P. Randazzese

The federally funded research consortium SEMATECH is often credited with restoring vigor to the U.S. semiconductor industry. The ability of such cooperative efforts to foster competitive technology can be severely limited, however, as illustrated by the noteworthy failure of GCA Corporation. A once successful manufacturer of microlithography tools, GCA hit hard times during the 1980s. SEMATECH tried to resuscitate GCA's business but could not. That experience holds lessons for other public and private policymakers.

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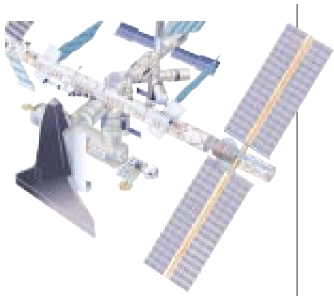
Tim Beardsley, staff writer

The $27-billion International Space Station will not do many of the jobs once conceived for it. Industrial interest in it has ebbed. Uncertainties about Russia's commitment jeopardize its mission. Next year NASA will start building it anyway.



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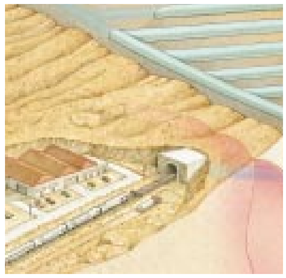

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Jeremy Bernstein

Albert Einstein's general theory of relativity and his invention of quantum-statistical mechanics are the foundation for all speculations about the reality of black holes. Yet Einstein rejected the idea of such bizarre singularities and repeatedly argued against their existence.

SCIENCE IN PICTURES

86 **The Art of Charles R. Knight**
Gregory S. Paul

The conception of dinosaurs as sluggish, pea-brained giants owes as much to art as to science—specifically, the work of this painter, whose murals of the distant past shaped the thinking of paleontologists and the public throughout this century.

94 **Taxoids: New Weapons against Cancer**
K. C. Nicolaou, Rodney K. Guy and Pierre Potier

The bark of the Pacific yew tree contains a chemical, taxol, with remarkable anticancer potency. Early problems with scarcity and side effects have recently been overcome. Now chemists are synthesizing a family of related drugs, called taxoids, that may turn out to be even better than the original.

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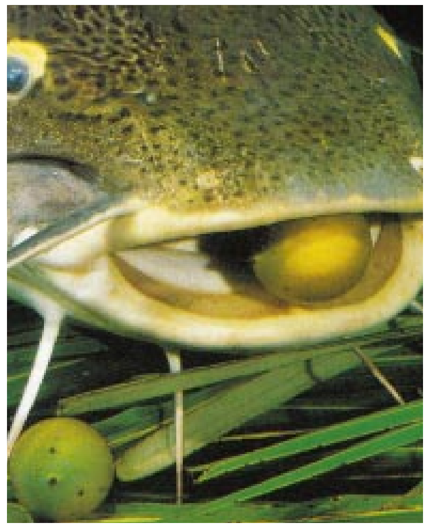

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About the Cover
A cyclist tests the aerodynamics of a new bike design in a wind tunnel. A trail of smoke outlines the wind flow over the rider. Painting by Robert Rodriguez.

FROM THE EDITORS

The Space Station's Disappointing Odyssey

Through three presidential administrations and a dozen years of planning and replanning, advocates of the International Space Station (in all its incarnations) have sold it with pitches ranging from the romantic to the pragmatic. They have called it our stepping-stone to Mars and the other planets. As a laboratory and forerunner of space manufacturing facilities, it would yield potentially marvelous scientific and technological benefits. And work on building the station would pay off in jobs in the aerospace industry and others.

A not so funny thing happened on the way to the launchpad: the middle set of those arguments fell out. As Tim Beardsley details in "Science in the Sky," beginning on page 66, the scientific and technological capabilities of the station have been compromised to the point that many researchers question the worth of the station altogether. Of course, the station is still the only place to learn how people will fare in microgravity. NASA has stated that this is now the station's primary goal, and it is a good one because it does keep alive our dream of exploring the cosmos in the flesh. Still, even the most loyal fans of the space program must admit to the tautology—we should be in space because we want to be in space—in this justification.

UP IN THE AIR are the station's true capabilities.

The economic arguments seem to have had most sway over Washington, which fears killing the station and putting voters out of work. Moreover, the project is now also supposed to keep Russia's scientific establishment well employed and out of mischief. Thus, humankind's greatest adventure reduces to a high-tech jobs program and an instrument of foreign policy.

As a child of the space age, I feel cheated. But should I? The Apollo program was clearly a weapon of national prestige and a technological engine during the cold war, but going to the moon was a glorious adventure nonetheless. Economics and politics have never been alien to the manned space program. Moreover, creating jobs and opportunities to spin off new technologies are desirable ends.

But if enthusiasm for follow-up space missions evaporates, and work on the station has failed to deliver down-to-earth benefits, an angry electorate will be wondering why so much money was wasted. And if keeping the aerospace industry occupied on a meaningless project distracts it from the more economically vital job of reinventing itself for post–cold war competitiveness, the $27-billion price tag of the station may be higher than we imagine.

It will be very nice to have a working space station. It's a pity that we'll be getting this one.

JOHN RENNIE, *Editor in Chief*
editors@sciam.com

SMART FOOD

The excellent review in the February issue of delayed intellectual development of children ["Malnutrition, Poverty and Intellectual Development," by J. Larry Brown and Ernesto Pollitt] did not address the uniqueness of this problem in the U.S. This country is the only industrial democracy with a substantial impoverished and undernourished population. Among this group, iron deficiency, growth retardation, lead poisoning or fetal exposure to alcohol can cause a downward shift in intelligence test scores by approximately five points. This result may have little effect on the life of an individual child, but the overall effect can be profound.

In impoverished, malnourished communities, classes for mentally gifted children (with IQ scores over 130) may be emptied, whereas classes for children with mild mental retardation (IQ scores under 70) may begin to overflow. Simplistic explanations for this phenomenon—such as the notions put forth in the recent book *The Bell Curve*—fail to appreciate the complexity of poverty.

ROBERT J. KARP
Pediatric Resource Center
Kings County Hospital
Brooklyn, N.Y.

MILITARY ADVANTAGE

I was pleased when I first saw your February article "The Global Positioning System," by Thomas A. Herring. As developers and operators of GPS, we in the Department of Defense and our partners in industry are justifiably proud of the technology. GPS represents the best of American scientific and technical ingenuity as well as being an excellent example of cooperation between the military and civilian sectors. But after reading the entire article, I was disappointed by its unbalanced discussion of the national security aspects of GPS.

Yes, the Defense Department does operate GPS with unpopular security features. But these features were not designed to inconvenience the peaceful users of the system, as Herring implies. Rather they were designed to provide U.S. and allied forces with a crucial military edge. Furthermore, the Defense Department is well aware that the security aspects of GPS are an additional burden for many users. And while we believe such measures are still needed at this time to help preserve our military advantage, we have set a goal of discontinuing regular use of the feature known as Selective Availability, the component that degrades GPS accuracy, within a decade.

Both time and resources are needed to replace the advantages Selective Availability provides. In light of the revolutionary contributions of GPS to both military and commercial enterprise, Herring could have portrayed the technology in a more evenhanded manner.

PAUL G. KAMINSKI
Under Secretary
Department of Defense

ALTERNATIVE MEDICINE

On "The Bacteria behind Ulcers," by Martin J. Blaser [February], I offer the following poem:

I'll tell you a terrible story
Of *Helicobacter pylori,*
A minuscule breaker of truces
Between stomach lining and juices.
The lymphoma I got from infection
Was treated by gastric resection,
Supplemented by irradiation;
Nowadays I'd just take medication.
Something soothing and pink, not
exotic,
And two kinds of antibiotic
Would dispose just as well
of the tumor,
And leave me in better humor.

HOWARD M. SHAPIRO
West Newton, Mass.

FIGHTING POLIO

Gary Stix reports in the article "Keeping Vaccines Cold" [Science and the Citizen, February] that efforts to develop a heat-stable oral polio vaccine have "foundered in a morass of bureaucratic confusion" at the World Health Organization. I disagree. The process of improving a vaccine and developing it for general use is quite complex. While research was proceeding in the lab, progress in the field was more rapid than anticipated. Polio was eradicated in the Americas in 1991, and heat-sensitive monitors on vials reduce the need for new vaccines.

Indeed, it remains unclear whether a new vaccine can even be brought to market before polio is eradicated. Simply put, it is apparent to both the WHO and vaccine manufacturers that the efforts required to bring this vaccine to market are not worth the potential benefits.

JONG-WOOK LEE
Director, Global Program
for Vaccines and Immunization
World Health Organization

WHAT'S THE DEAL?

In his essay "The Constraints of Chance" [January], Christian de Duve gives a figure of 5×10^{28} as the number of possible bridge hands. My calculator computes ${}_{52}C_{13}$ as 6.35×10^{11}. How can he be so far off?

ROBERT G. GRISWOLD
University of Hawaii at Hilo

De Duve replies:
Griswold is right. Instead of "hand," I should have written "deal." You will find the two correct figures on page 8 of my book *Vital Dust*. My excuse: I never played bridge in English.

Letters may be edited for length and clarity. Because of the considerable volume of mail received, we cannot answer all correspondence.

ERRATA

The image on the cover of the April issue was incorrectly attributed to David A. Grimaldi. The photograph was taken by Jackie Beckett of the American Museum of Natural History's Photo Studio. Also, in the article by Grimaldi ["Captured in Amber"], the insect shown on page 91, in the New Jersey amber, is a crane-fly (family Tipulidae), not a parasitoid wasp.

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

JUNE 1946

Capable of solving scientific problems so complex that all previous methods of solution were considered impractical, an electronic robot, known as Eniac—Electronic Numerical Integrator and Computer—has been announced by the War Department. It is able to compute 1,000 times faster than the most advanced general-purpose calculating machine, and solves in hours problems which would take years on a mechanical machine. Containing nearly 18,000 vacuum tubes, the 30-ton Eniac occupies a room 30 by 50 feet."

"There is no question that private flying is going to expand rapidly in the near future and that one of the big fields for small planes is going to be their use by industry."

JUNE 1896

The subject of grafting living tissue has been treated facetiously by the lay press, and at last a novel has been based upon it. Mr. H. G. Wells has based the plot of his recent 'Island of Dr. Moreau' on the artificial production of semi-human beings from animals. Dr. Moreau is a ferocious vivisector, with something of the hypnotist thrown in, and has produced a set of amusing creatures, such as ox-hog-men, and a puma-dog-lady who escapes in an incomplete condition, to the subsequent destruction of her artificer. The story is grewsome and exciting to a high degree. Recent work on transplantation and transfusion, however, is conclusively against the success of operations conducted upon animals of different species. So extreme is the aversion of a body to extrinsic material, that transplantations from other individuals, even of the same species, rarely hold. They are treated as foreign bodies."

"Sixteen thousand railroad employees were killed, and 170,000 crippled, in the seven years from 1888 to 1894. The awful record of the killed and injured seems incredible; few battles in history show so ghastly a fatality. A large percentage of these deaths were caused by the use of imperfect equipment by the railroad companies; twenty years ago it was practically demonstrated that cars could be automatically coupled, and that it was no longer necessary for a railroad employee to imperil his life by stepping between two cars about to be connected. In response to appeals from all over, the United States Congress passed the Safety Appliance Act in March 1893. It has or will cost the railroads $50,000,000 to fully comply with the provisions of the law. Such progress has already been made that the death rate has dropped by 35 per cent."

The ingenious and entertaining viviscope

"The crystalline lens in the eye, like the lens of a camera, causes the image of an object to be inverted upon the retina. Psychologists have yet to explain in detail, however, why we see things right side up, though it is believed that the re-inversion is effected mentally, and is determined and controlled by sensations of touch. It has lately been pointed out that many young children draw things upside down. However, if a child who draws things upside down when drawing on a horizontal table, is asked to draw on a blackboard placed vertically, he will draw everything the right way up."

"A great deal of ingenuity is devoted to the production of entertainment devices, but it is seldom that one more interesting, from the scientific as well as amusement standpoint, can be offered to our readers than the one we here illustrate. The viviscope is supplied with a number of endless bands of paper with colored pictures of figures in progressive stages of movement. A perfect zoetrope effect is produced, and the figures seem endowed with life."

JUNE 1846

The mammoth steam-ship Great Britain arrived in New York on Saturday morning, 20 days from Liverpool. Her propellers have been remodelled, but there appears to have been no improvement in her speed. It is truly astonishing that men of capital in England persist in keeping themselves so totally ignorant of the plain philosophical principles of Mechanics, as to suppose that a propeller of any form on the screw principle, can compete with the simple Fultonian paddle-wheel." [*Editors' note: The paddle wheel, theoretically efficient but hard to control and prone to damage in rough seas, is today relegated to calm inland waters.*]

"Among the fancy inventions recently introduced is a genteel bee-hive for the parlor, invented by Mr. J. A. Cutting, of Boston. It is finished in the style of elegant cabinet furniture, and about the size of a bureau, with glass doors in front, through which the operations of the 'busy bee' can be observed. Meanwhile, the bees, not intimidated by contiguity with equally civil though less industrious society, being furnished with a private entrance through the walls of the house, pursue their avocation with security."

"A Philadelphia paper attributes the recent frequent heavy rains to the electric telegraph wires on the New York and Baltimore lines. It would be quite as rational to attribute them to mesmerism."

NEWS AND ANALYSIS

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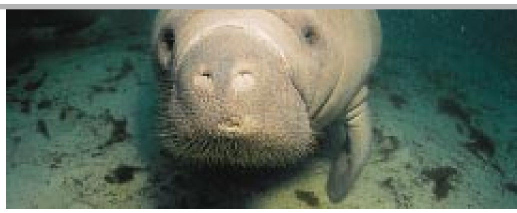

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IN FOCUS

"PEACEFUL" NUCLEAR EXPLOSIONS

China's interest in this technology may scuttle a test-ban treaty

GALEN A. ROWELL *Mountain Light*

TIBET'S BRAHMAPUTRA RIVER
could be diverted northward with nuclear explosions, Chinese officials say.

China's northwest territory, which includes the Gobi Desert, contains almost half of that country's total landmass but only 7 percent of its freshwater. Recently some Chinese engineers proposed diverting water into this arid area from the mighty Brahmaputra River, which skirts China's southern border before dipping into India and Bangladesh. Such a feat would be "impossible" with conventional methods, engineers stated at a meeting held last December at the Chinese Academy of Engineering Physics in Beijing. But they added that "we can certainly accomplish this project"—with nuclear explosives.

This statement is just one of many lately in which Chinese technologists and officials have touted the potential of nuclear blasts for carrying out nonmilitary goals. Now that France has finally pledged to stop testing, the Chinese interest in so-called peaceful nuclear explosions (PNEs) is emerging as the major obstacle to the enactment of a Comprehensive Test Ban Treaty, which arms-control advocates had anticipated might be achieved this year.

The U.S. considers China's position on PNEs to be "totally unacceptable," says Katherine E. Magraw of the U.S. Arms Control and Disarmament Agency. "Other states would view PNEs as a gaping loophole" in a test-ban treaty, she maintains, because any nuclear blast can provide useful information for military purposes. Of the 38 states engaged in test-ban talks, only China is seeking a PNE exclusion.

Some diplomats fear that China secretly intends to sabotage the test ban so that it can upgrade its relatively small, primitive nuclear arsenal without any constraints. China is thought to possess some 300 warheads, compared with 10,000 in the U.S. and 12,000 in the former Soviet republics. China has conducted 43 nuclear tests in all, most recently in August 1995, whereas the U.S. and Russia have detonated 1,030 and 715 devices, respectively.

One Asian diplomat with close ties to China contends privately that Beijing is not trying to scuttle the test ban entirely, but only to delay its enactment long enough for a few more weapons tests. "When push comes to shove," says the diplomat, the Chinese will accept a test ban without an allowance for PNEs. But Chinese officials have denied that they are engaging in negotiating tactics. "As a populous developing country with insufficient energy and mineral resources," declared Qian Shaojun, a test-ban negotiator, in January, "China cannot abandon forever any promising and potentially useful technology." To alleviate concerns that China might carry out weapons research under the guise of PNEs, Wang Xuexian, deputy ambassador to the United Nations, stated in February that China would be willing to accept "stringent international monitoring and verification with prior approval by the treaty organization."

Both the U.S. and the former Soviet Union once supported PNE programs. From the 1950s through 1973, the U.S. detonated 27 nuclear devices in Nevada, Alaska, New Mexico, Colorado and other states as part of its Plowshare program; the tests were aimed primarily at establishing the efficacy of nuclear blasts for the stimulation of oil and gas production and for excavation. (In the late 1950s the U.S. considered blasting a new canal through Central America with PNEs.)

The largest excavation experiment took place in 1962 at the Department of Energy's Nevada Test Site. The so-called Sedan test displaced 12 million tons of earth, creating the largest man-made crater in the world; it also generated a "vast amount of fallout" that drifted beyond Nevada and over Utah, according to Derek S. Scammell, a spokesperson for the Nevada Test Site. Explosions in oil and gas fields did indeed stimulate production, but in some cases they also made the fuel so radioactive that it could not be used. The Plowshare program was discontinued in 1973 after the U.S. decided that the cons of PNEs—including criticism from the growing environmental movement—far outweighed the benefits.

U.S. DEPARTMENT OF ENERGY

1,200-FOOT-WIDE CRATER
in Nevada was created in 1962 by the Sedan test.

The Soviet Union pursued a much more vigorous program, notes Milo D. Nordyke of Lawrence Livermore Laboratory. The Russians detonated 124 PNEs in all, Nordyke says, for many ends: to move earth, to stimulate fossil-fuel production, to blow out oil and gas fires, to create underground cavities for storing fossil fuels and to dispose of toxic waste. With a technique called seismic sounding, the Russians also created images of buried geologic formations by observing how they reflect shock waves from nuclear explosions. The Russians only reluctantly agreed to stop their PNE program in 1988 as a result of then president Mikhail S. Gorbachev's disarmament initiative, Nordyke explains. But he adds that the engineers involved in the Soviet program still take pride in their accomplishments.

Indeed, Robert S. Norris of the Natural Resources Defense Council, a watchdog group, speculates that China's recent interest in PNEs may have been piqued by "Russian mischief-makers" who pine for the return of the technology. PNE experts from the Russian Ministry of Nuclear Energy were active participants at the meeting in Beijing last December. The Russians related their experience with PNEs and provided advice and encouragement to Chinese engineers formulating their own plans, according to a report by He Zuoxiu, one of the participants. Those plans included a scheme for deflecting asteroids away from Earth with nuclear-tipped rockets (an idea also popular among certain members of the U.S. nuclear weapons establishment) and the Brahmaputra River project, which would require blasting a 20-kilometer channel through a mountain range. The Russians hailed this latter proposal as a "wonderful idea," He claimed.

In addition, the Chinese proposed harnessing the energy of underground thermonuclear explosions for generating electricity. The explosions would supposedly take place in a subterranean cavity lined with massive steel tubes, which would conduct steam to turbines on the surface. "It's possible that this kind of controllable nuclear electric station will become the main energy supplier around the world in 30 to 50 years," He wrote.

That scenario is highly unlikely, according to Richard L. Garwin of the IBM Thomas J. Watson Research Center, who participated in a U.S. study of this power-generation concept in the 1970s. The investigation, he says, showed that a minimum of two detonations a day, or more than 700 a year, would be required to keep such a generator running. The costs of this technology, Garwin says, would exceed those for conventional nuclear reactors, which are already hard-pressed to compete economically with hydropower, fossil fuels and other energy sources. Garwin contends that nonnuclear methods are also cheaper, more effective and less damaging to the environment than PNEs for applications such as excavation and oil-well stimulation.

PNEs are simply not worth the risk that they would pose to international security, adds Nordyke of Lawrence Livermore. Even if a nation is prevented by international monitors from extracting detailed information from a PNE, he explains, simply knowing the yield of a nuclear device—and that it works—has military value. In the 1950s, Nordyke recalls, arms-control experts considered establishing an international organization that would stockpile devices for PNEs and oversee their use to ensure that they were not exploited for military advantage. But this plan was soon abandoned as politically and technically unworkable.

Michael Krepon of the Henry L. Stimson Center, a think tank in Washington, D.C., is cautiously hopeful that a Comprehensive Test Ban Treaty can still be achieved this year, even if China continues to insist on a loophole for PNEs. The trick, he observes, will be negotiating a provision that technically allows PNEs but makes them subject to so many restrictions that they are unlikely ever to be employed. "I don't believe this is a treaty-breaker," Krepon says of the Chinese position on PNEs. "But it sure as hell isn't any help." *—John Horgan*

POLICY

URBACULTURE

Cities of the developing world learn to feed themselves

The number of city dwellers in the developing world, a total of 1.5 billion in 1990, will likely triple during the next 30 years. The great migration from the country has become a factor in many of the doomsday scenarios put forward by policy analysts and journalists. In these depictions, the defining image of the 21st century consists of swarming shantytowns populated by children with the swollen bellies emblematic of severe malnutrition.

Counterbalancing such dark visions is the growth of informal economies—barter networks and the Grameen banks that provide credit to small enterprises in developing countries. Perhaps the most important item on this list, though, is a flourishing urban agricultural sector that could achieve a measure of food self-sufficiency for even the poorest of urbanites.

The potential of cities to feed themselves will be one of the themes of the second United Nations Conference on Human Settlements, known as Habitat II, that will meet this month in Istanbul. In preparation for the meeting, the U.N. Development Program (UNDP) issued a report earlier this year—*Urban Agriculture: Food, Jobs and Sustainable Cities*—that assesses the role of city farming in both developing nations and the industrial world.

The document traces the urban approach to cultivation as far back as the Aztec, Inca and Indus River civilizations.

FIELD NOTES

Star-Hopping by the Outhouse

As my headlight-dazzled pupils slowly dilate, I can begin to distinguish the forms scattered across this grassy slope on Mount Tamalpais. Tall knolls block most of the orange glow from San Francisco, so it is quite dark. There seem to be about two dozen tall, thin objects pointing up at the vast canopy of stars. Some of the objects, I presume, are members of the Astronomical Society of the Pacific, assembled to witness Comet Hyakutake's unexpected visit to our part of the solar system. The rest are their telescopes.

Al Stern, a jovial member of the society, points me toward the comet and proceeds to describe, in endearing detail, its position over each of the past seven nights. Tonight it hangs like a drop of milk frozen mid-fall from the handle of the Big Dipper. Hyakutake is just one day from its closest approach to Earth, and its tail seems to grow by the minute. "I believe it stretches halfway to Arcturus," Stern says, tracing a line with his finger to the bright red giant in Boötes.

JERRY SCHAD

My cosmic reverie is interrupted by a whiff of—something very unpleasant. "Someone knocked over the portable john," Stern explains. "It kind of stinks up here. But the seeing is good," he adds enthusiastically.

Two other stargazers, Shelley and Art, also don't seem to mind the fallen latrine. They have set up their scope just downwind of it. As I get a closer look at the comet, Shelley recalls how she and Art met at an ASP star party. "We got married on an observing trip to Yosemite," she says. "The preacher camped out with us at Glacier Point." Stern is checking out that tail again. "I'm not sure, but I think it's three quarters as far as Arcturus," he says. Shelley agrees. Art simply stands and gazes, with an air of contentment. "Star-hopping by the outhouse," he says, apropos of nothing in particular.

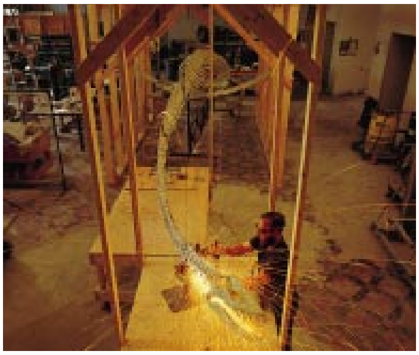
Down the slope a bit, another observer peers through a six-foot-long cylinder resting in an odd cradle that Stern calls a Dobsonian mount: "It's much cheaper and easier to build than the standard equatorial mount." Two sets of bearings allow the scope to move in two directions. "The bearings are just toilet flanges!" Stern points out with great amusement. Local folklore has it that John Dobson, a former monk, invented the design and was consequently kicked out of the brotherhood.

Stern hustles me over to another fellow peering through a 10-inch reflector. When I ask his name, he digs through the pockets of his coat and produces a penlight, which he proceeds to shine for several seconds into a cupped palm. At last he douses the light to reveal a small nameplate with "DENNIS TYE" spelled out in glow-in-the-dark letters. "It's always so hard to tell who's who at these things, so I made this in my basement," he deadpans, as I finally dissolve in laughter.

Tye is one of two amateurs in the club to have run experiments on the *Hubble Space Telescope,* through a NASA extension program. Although the Cassegrain instrument he now uses can't quite make out the quasars he studied with the *Hubble,* Tye boasts that its tracking system has as much processing power as a Macintosh computer. "I would have liked to get a 12-inch scope," he quips, "but I figured it would cost me another $11,000—$1,000 more for the telescope and $10,000 for a new car to carry it."

Indeed, some of the instruments are as tall as their owners and twice as heavy. Gordon Robinson's seven-inch refractor weighs 330 pounds. But it provides the best view of Hyakutake this evening, revealing a brilliant green jet shooting from the nucleus. Robinson, who watched Comet West as a teenager in 1976, recalls that West's fan-shaped tail was brighter. But Hyakutake hardly disappoints. "This is just fascinating," he muses. Tye, remembering the overhyped disappointments of Kohoutek and Halley, is more emphatic. "On a scale of one to 100," he beams, "those others were fours or fives. This is an 80." —*W. Wayt Gibbs in San Francisco*

IN BRIEF



LOUIS PSIHOYOS *Matrix*

Spinal Tap
Seven years under construction, the Hall of Vertebrate Origins at the American Museum of Natural History in New York City opens this month. The collection completes the tour—replete with murals, skeletal mounts and multimedia displays—through evolution and traces the history of vertebrates as they developed true backbones, jaws and limbs. Specimens include Loch Ness monster–like plesiosaurs, 40-foot sharks and giant flying reptiles.

Aging Gene
Scientists in Seattle have characterized the gene responsible for Werner's syndrome, a rare disorder whose course mimics the aging process. Early in adulthood, affected individuals develop gray hair, wrinkles and a number of age-related diseases. Study of this gene may boost knowledge about aging in general.

Heat Shrinker
Doors, streets, feet—all things swell in the heat. Except zirconium tungstate. Researchers have found that this solid actually contracts when warmed. They presume that higher temperatures make the oxygen atoms in the compound vibrate more, pulling the other constituent atoms closer together. The material, which has already received patent approval, should find an array of commercial uses.

Gene Therapy for HIV
Scientists at the National Institute of Allergy and Infectious Diseases inserted antiviral DNA into CD4+ *T* cells and found that these immune cells fared better in the face of HIV infection. The group tested three HIV-positive people; in all, the altered CD4+ *T* cells remained healthier longer.

Continued on page 22

Even a century ago Parisians farmed the *marais,* harvesting six salad crops annually from land that adjoins the Seine River. While Paris picked its greens, the 19th-century idea of the planned modern city as a locus of industrial activity had begun to undermine urban farming in many places. Some contemporary economists question whether farming is the best use for what they perceive as scarce urban land. But the challenge of feeding the flood of migrants to cities of the developing world has begun to reverse these negative perceptions.

For the urban poor of developing nations, farming is a necessity because 60 to 90 percent of household income is spent on nourishment. "Food becomes a form of money," says Jac Smit of the Urban Agriculture Network, a policy group that wrote the report for the UNDP. To date, no global census of urban agriculture exists. But studies of individual countries have shown a marked upswing. In Dar es Salaam, the capital of Tanzania, 67 percent of families had become farmers by 1991, a nearly fourfold increase from 1967.

The impact on food resources can be substantial. China supplies almost all its vegetables within its metropolises. City farming can also achieve surprising efficiency. By raising a variety of crops in a confined area with little water, urban agriculturists obtain yields for produce that are several times as high per square meter of cultivated land as those achieved by rural farmers. At the same time, they deliver fresher produce and avoid transport and distribution costs.

Urban agriculture is the antonym of the monoculture. In Mexico City, potatoes grow in stacked tires; cactus cultivated in yards and on rooftops and patios serves as both food and cash crop. In Port-au-Prince, Haiti, rooftop compost beds sprout fresh vegetables. In Peru, guinea pigs are raised in cages that hang on apartment walls. Farmer cooperatives in Calcutta produce tilapia, carp, rohu and other fish in treated sewage water, supplying one fifth of the fish consumed there. Land is often procured under the legal principle of *usufruct,* the Latin word meaning "to use and enjoy." Farmers agree to maintain a tract or a body of water in exchange for the right to grow food on land they do not own.

These practices do more than just keep stomachs full. According to the UNDP report, women in a cooperative in Bogotá, Colombia, that produces several dozen varieties of hydroponic vegetables earn three times more than their husbands do. Urban farmers also create a closed system in which organic wastes—from food, manufacturing or partially treated animal or human feces—are reused instead of being channeled into dumps, waterways or treatment plants.

Some case histories glow less brightly. Urban farming must be carefully managed to avoid contamination of food with pollutants or raw sewage. Chile and Peru experienced cholera incidents in 1992 from untreated sewage used in irrigation. Salad leaves in Yaoundé, the capital of Cameroon, often contain sump oil or sewage. Wastes can be treated, though, by exposing them to algae or to plants such as duckweed, which digest harmful microorganisms.

If the impact of urban agriculture continues to broaden, the notion of the garden city—the turn-of-the-century dream of urban centers lined with trees and ornamental plants—may take on a new and more pragmatic meaning. *—Gary Stix*

KEITH DANNEMILLER *SABA*

ROOFTOP GARDENS are farmed by Mexico City residents.

In Brief, *continued from page 20*

Cryptographic Lawsuit
Engineer Phil Karn of Qualcomm lost another round in his legal battle to export encoding software on floppy disk. In 1994 Karn received an export license for the book *Applied Cryptography,* by Bruce Schneier, but the State Department deemed that digital copies of the text threatened national security: whereas book buyers would have to retype the source code therein, disk users could merely copy it. Karn's appeal was denied this March.

Herbal X-posé
The Food and Drug Administration now warns that many of the herbal drugs sold in health food stores and nightclubs can be as dangerous as their illegal inspirations. Herbal Ecstasy and other such substances containing ephedra can cause heart attacks, seizures and psychotic episodes. Also called ma huang, ephedra is the herbal form of ephedrine, a stimulant found in some over-the-counter dietary supplements and asthma medications.

JASON GOLTZ

Looking Glass
Dutch physicists have found a way to switch the optical character of certain films. Thin dihydride layers—made from yttrium, lanthanum and other rare elements—reflect mirror images. Once exposed to hydrogen, though, the same films become transparent trihydrides. The process, which is fully reversible at room temperature, may well find applications in architecture, communications and photography.

Gnat Lag
Four teams of researchers have unraveled how light winds a fruit fly's biological clock. The rising sun switches on two genes, period (*per*) and timeless (*tim*). Their messenger RNA accumulates during the day. At dusk, proteins PER and TIM bind together and somehow stop transcription. The mRNA and protein levels then fall through the night until morning, when the cycle starts again. The mechanism may offer clues into sleep and mood disorders, as well as jet lag.

Continued on page 24

ASTRONOMY

FORECAST: DRY AND WINDY

Galileo probe finds elemental mysteries on Jupiter

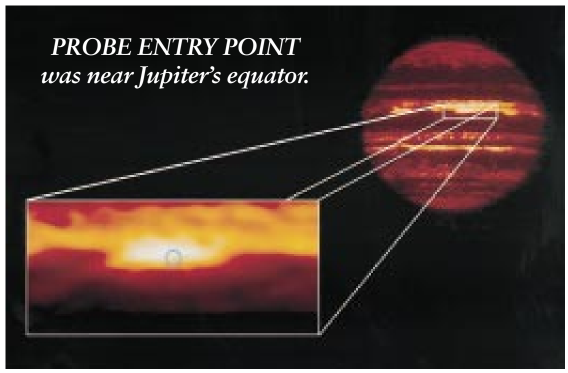
When a probe from the *Galileo* spacecraft perished in a plunge through the crushing Jovian atmosphere last December, it pulled a few assumptions about the gaseous planet down with it. The 339-kilogram craft parachuted through Jupiter's thick, turbulent atmosphere, taking the first samples from an outer planet. Onboard sensors gathered and transmitted a trove of data that scientists have been analyzing ever since. Preliminary results indicate that the great ball of gas that makes up most of Jupiter's volume has far more helium and carbon, but less water, than had been thought. The strength of the planet's winds, too, was surprising: they whip around the planet at up to 200 meters per second.

Overall, however, data from the probe's 57-minute descent did not challenge the prevailing hypothesis of the evolution of the solar system and its largest planet, according to Richard Young of the National Aeronautics and Space Administration Ames Research Center. For example, the notion that the sun and Jupiter coalesced out of the same cloud of space dust is consistent with the probe's measurements of the percentage of helium in the Jovian atmosphere. At 24.24 percent by mass, this ratio closely matches the sun's.

The lack of water in Jupiter's atmosphere tops a list of puzzles likely to keep scientists busy for a while, says David D. Morrison, also of NASA. "It's the biggest surprise, among the unexpected concentrations," he comments. Extrapolating the sun's makeup, at least one researcher had expected to find a Jovian oxygen content as high as one one-hundredth of the hydrogen content. But the actual oxygen concentration measured by the probe was one fiftieth of that.

Several theories have emerged to explain this finding. It may be that water concentrations vary with latitude, Young says, citing the observation that most of Jupiter's lightning occurs at middle latitudes (such electrical activity tends to occur in water clouds). The probe, on the other hand, descended near the planet's equator.

Another working hypothesis, proposed by Tobias C. Owen of the University of Hawaii, is that during Jupiter's formation, oxygen was deposited from rock and ice planetesimals, such as comets, that collided and built up Jupiter's core. This core was later blanketed by gases such as hydrogen and helium drawn in from the surrounding primordial dust cloud. This blanketing, in Owen's theory, tended to confine the water to the planet's core. Later the hydrogen and helium in the great, gaseous ball surrounding the core mixed with carbon- and nitrogen-containing gases given off by the planetoids. This conflation, Owen points out, would also explain the relative abundance of carbon in Jupiter's atmosphere.


PROBE ENTRY POINT was near Jupiter's equator.
JET PROPULSION LABORATORY

In comparison with elemental abundances (or the lack thereof), measurements of the brisk Jovian winds have permitted slightly more conclusive theories about the planet's meteorology. Before the probe plunged, scientists wondered whether the thermal energy that drives the planet's winds resulted mainly from uneven solar heating of the surface or from Jupiter's hot interior.

For many researchers, the new data offer strong evidence that the winds are driven mainly from below. While still at relatively high altitudes, where the pressure was about half an Earth atmosphere, the probe measured wind speeds of some 150 meters per second. Down where the pressure equaled several Earth atmospheres, the wind speed increased to 200 meters per second. It held more or less constant until the craft stopped sending readings, 600 kilometers down, where the pressure was about 24 Earth atmospheres. —*Glenn Zorpette*

In Brief, *continued from page 22*

Comet Caper

When Comet Hyakutake neared Earth this past March, astrophysicists could at last confirm that comets shine in x-rays. For 24 hours, Germany's orbiting *ROSAT* satellite tracked Hyakutake's fluctuating emissions. On occasion, the radiation became some 100 times brighter than predicted. One theory posits that water molecules around the comet's core absorb solar x-rays and later reemit them. Another credits collisions between the comet's components and those streaming away from the sun.

Apoptosis in Plants

New research shows that plant cells, like animal cells, undergo apoptosis—a series of changes causing damaged cells to self-destruct. Scientists observed stages of the process after exposing plants to fungal toxins. The find suggests that bacteria, viruses and fungi may promote disease in plants by triggering programmed cell death. Understanding the mechanism could lead to hardier crops.

FOLLOW-UP

Manatee Mystery

Marine biologists are puzzled by the sudden death of some 128 manatees in Florida. Last year 201 of the gentle sea cows died—most fell victim to boats speeding through shallow waters where the animals swim. These new deaths, however, seem related to an unknown natural cause. Some suspect that a nearby red tide, caused by toxic microorganisms, may explain the situation. But the manatees show none of the ordinary symptoms. (See July 1994, page 66.)

STEPHEN FRINK *The Waterhouse*

Hantavirus

New data show that hantavirus infections have become more prevalent since 1993, when an outbreak struck a Navajo reservation in New Mexico. The figures tally 131 cases nationwide; most have taken place in western states. The virus—spread by several types of rodent—typically infects only isolated individuals in an area. Virologists do not yet know why certain people are more susceptible than others. (See December 1994, page 34.)

—Kristin Leutwyler

SA

ARCHAEOLOGY

ARTFUL DATING

Researchers refine techniques to gauge the age of ancient sites

Throughout history, people have sought to leave their mark by painting on cave walls and scraping designs into rock. Until recently, pinpointing the age of these efforts has been mostly speculative. Now, with advances in radiocarbon-dating techniques, the art of telling the age of rock engravings is becoming a science.

The use of accelerator mass spectrometry (AMS) and improved carbon-extraction methods have transformed the field. "This is the first time we can put numbers on a painting or engraving," says Alan L. Watchman of the Canadian rock-art dating and conservation company Data-Roche Watchman. "Now we can date the art and see how it matches up to archaeological evidence."

Much of the success depends on microorganisms. After humans scrape into rock, microbes inevitably move in. Eventually these colonizers are killed by a layer of varnish that is produced by other microorganisms or inorganic processes. The net effect traps the microorganisms, a carbon source; scientists can then isolate and date this carbon. And this date, it is believed, is when humans chiseled their designs into the rock.

This past year the technique was used on giant figures called geoglyphs, found on the desert floor of the southwestern U.S. The geoglyphs, some of which extend for tens of meters, resemble human stick figures, lizards and dance circles. The new dates are the first solid evidence to give the geoglyphs some historical context. "There was absolutely no clue about the chronology of these things, a total blank," explains Ronald I. Dorn of Arizona State University. "This was the first effort to date them systematically."

The target carbon at the geoglyph sites was contained in lichen trapped under a layer of varnish. The carbon 14 results indicate that the figures were etched between 1,000 and 3,000 years ago. Dorn admits, however, that radiodating of entombed carbon is best at providing only a minimum age for rock art.

"The application involves a lot of complexity and requires refinement," he says. Interpreting the data can be complicated by the variability of biological processes involved. For example, it can take between 80 and 110 years for varnish to start to form. This time lag could make the carbon 14 dates younger than those of the geoglyphs. Another challenge is isolating the carbon that was deposited soon after the creation of the engraving. Contamination by older carbon from soil or from the weathering rind—a layer of organic material between the varnish and the lichen—could push the numbers toward a riper age.

In an attempt to limit error, Dorn pretreated samples with chemicals to remove contamination. He also selected sites with the most defined layers of varnish and organic material to decrease the chance of mixing carbon originating from different times. Adjacent unscraped rocks served as controls; the radio dates of their varnishes, which were older than those of the geoglyphs, confirmed the relative accuracy of the numbers.

Dorn's dates have not upset anyone so far, but some of the new numbers have not been embraced. Watchman stirred up controversy last June in the Côa Valley in Portugal when he declared supposed Paleolithic rock engravings to be modern—that is, created after A.D. 250. Specialists had previously identified the art as approximately 20,000 years old, basing their assessment on its style.

Watchman used radiocarbon to date samples of phytoplankton and algae embedded in a silica skin covering the rock. His numbers revealed only 1,700-year-old carbon. Watchman claims the more modern date is consistent with physical observations of weathering patterns. But he does admit there is room for doubt: "We were dealing with very small samples, so the dating at Côa is at the very limit of radiocarbon dating."

In the future, increasing confidence in dating will depend on the ability to identify and separate various carbon sources on the rock art. Watchman is experimenting with a laser he hopes will help him to achieve that goal. More research on various surfaces in different climates could also help. "AMS and work on the chemistry of the materials that are being dated have made radiocarbon dating a far more powerful tool than it's ever been," says Michael B. Collins of the Texas Archeological Research Laboratory at the University of Texas at Austin. "Archaeologists are going to be skeptical whenever a new dating technique comes out, but I believe the work is heading in the right direction." *—Ken Howard*

Among the Papers in Kaczynski's Cabin

by Anne Eisenberg

Theodore J. Kaczynski, the man suspected of being the Unabomber, did not keep a list in his Montana cabin, according to the Federal Bureau of Investigation. What he did keep were names scribbled on pieces of paper: some were followed by addresses; others had no information beyond the names themselves. One FBI agent told me that Kaczynski packed his handwritten notes into boxes and then stored these in a wooden loft he built. ("Everyone describes that cabin as small," the agent said. "Let me tell you, it's not small when you are sifting through box after box of paper.")

My name, it turned out, was on one of those pieces of paper. My address was there, too, straight down to the zip code. I discovered this a few days ago, when an FBI agent telephoned and informed me, quite calmly, that I should be careful about U.S. Postal Service deliveries. "You don't need to be overly concerned, though," the agent continued in a steady, polite voice as I absorbed the startling news. "We watched Kaczynski for the four weeks before he was taken in, and he didn't mail a thing." I called my office to warn the staff about packages; one of my colleagues floored me by saying, "I'm a bit jealous. I think I might like to have been chosen, too."

I can't say I found Kaczynski's regard enviable; the news chilled me. Over the years, I had occasionally wondered if my writing would draw the Unabomber's gaze, but the knowledge that it may actually have done so was unsettling. I felt like Frodo, the hobbit in *Lord of the Rings,* just trotting along while from far away Sauron watches with his evil, giant eye.

The details of how I had engaged the alleged Unabomber's attention were of interest to the FBI.

The details of how I had engaged Kaczynski's attention were of interest to the FBI, and we arranged to meet at the agency's New York City office to try to nail the matter down. "You'll feel safe here," one of the agents said, and indeed I did. I entered the interior offices in a series of elaborate, solemn stages, standing beside a bulletproof delivery hatch and negotiating by telephone with a guard behind double sets of glass doors that were also bulletproof. "Every year we have to increase the security," my escort said as we rose in the elevator. A second agent joined us for the interview. "We're in terrorism," they explained.

Kaczynski had put no date next to my name and address. Apparently this was common; the agents said that many of his notations were undated. They hoped that by interviewing people whom Kaczynski had noted—they stressed again that there was no list, just names, and many names at that—they could find out what had attracted him to us. In building a case, they looked for connections between what he jotted down and when he jotted it, what he was reading and when he was reading it. "We're looking for a pattern," they said.

Our conference took several hours; by the time it was done, the jolt I'd felt at learning of my name among Kaczynski's papers had faded. The fear of bombing recedes quickly when you are trying to recall details of the first book you wrote or of your out-of-town speaking engagements over the past 10 years. Letters received, articles anthologized or syndicated, books published, pieces by others in which I was mentioned—all were extracted from me for cross-checking by computer. The agents were thorough, stopping to question and note the possibilities of a connection. What I could not remember I promised to look up and deliver later through the bulletproof hatch.

It was clear the agents were disappointed with many of the scientists they had interviewed. They found them a trying, arrogant lot. One agent said, "They called all the time. 'Did you get a suspicious package?' we asked. No, no package, but they wanted us to protect them anyway. They thought their accomplishments would make them targets."

Paul Saffo of the Institute for the Future shares the FBI's lack of sympathy with people who feared the bomber; he calls them "Unawannas"—those whose "inflated sense of self-importance" led them to conclude that they were likely targets. Since the arrest, he says, Unawannas have sought status by hoping their names were noticed by Kaczynski.

I think Kaczynski noticed me by way of his local library, but however I made my way onto his dance card, I did not seek it, nor do I think my status is going to be increased if I become known as the Unabomber suspect's favorite writer. It's true that the Unabomber has many fans, particularly on the Internet (the Usenet news group is alt.fan.unabomber).

But the scientists I know don't share the free-floating appreciation of him shown by his Internet following. On the contrary, they find him repellent. Their interest in him during the search was confined largely to affixing cautionary notes to their computers or office doors—for instance, photocopies of Institute of Electrical and Electronics Engineers warnings against opening packages with stamps instead of meter strips. They kept an eye on the news not because of the allure of the anonymous figure but because so many of the targets were academics.

When Kaczynski was arrested, people glumly noted the similarities between themselves and him. A computer scientist pointed to the parallels with his usual precision: "We both studied mathematics at Berkeley during the 1960s, we both ride bicycles, we both have a lot of books." But Kaczynski is not admired, and no one finds his attentions status-enhancing; we follow the case because a madman was after us, not out of some appreciation of his counterculture, save-our-planet beliefs.

I never met Kaczynski or knew of his interest in me before the FBI telephoned. But in the blaze of publicity after his arraignment, I recognized where I'd seen him before: in the movies. In Hollywood, scientists star in dramas of destruction. In their quest for power, they bring trouble on us all. If convicted, Kaczynski will be perfect—he'll get top billing in the celluloid pantheon of scientists become monsters, replacing Vincent Price plotting murders in his laboratory or Dr. Strangelove wheeling through the War Room. He will become the apotheosis of the stereotype, the archetype of the scientist run amok.

I don't want him as the governing image of scientists in popular imagination. If I get to pick an embodiment, it will be in the likeness of the numberless people who have extended my leisure time and life expectancy with their intelligent work, people exemplified by Paul Ehrlich or Marie Curie but never by the gaunt face of Theodore J. Kaczynski.

ANNE EISENBERG writes frequently for Scientific American.

ANTI GRAVITY

The Lizard Kings

About halfway between Fresno and San Jose, in California's Merced County, a tiny creature is stuck in an endless cycle, in which winning guarantees imminent defeat, and losing only foreshadows a brighter future. The creature is the side-blotched lizard, *Uta stansburiana,* for which evolution has designed a unique chore: three distinct male types are caught in a living version of the rock-paper-scissors game. In a recent issue of *Nature,* Barry Sinervo and Curtis M. Lively of Indiana University describe this first example of a species in which the population frequency of males is determined by a cycle involving three different forms of male.

In the rock-paper-scissors game, paper always covers rock, scissors always cut paper, and rock always breaks scissors, only to be covered by paper again, and so on. In the lizard version, mating is the objective: orange-throated males beat out blue-throats, blue-throats overpower yellow-striped throats and yellow-striped throats checkmate orange-throats. These relations have generated a six-year cycle in which the three distinct morphs take turns being predominant.

When the temperate blue-throats, which keep harems of three females and defend small territories, are the most common males, even small numbers of aggressive oranges can take over. These lizards are "ultradominant," brimming with testosterone, keeping harems of up to seven females and defending large territories. Just one generation later, oranges dominate.

But then a few yellow-stripes can easily infiltrate the orange camps, passing themselves off as females and secretly copulating. (A related strategy was featured in the movie *Shampoo,* in which Warren Beatty cuckolded husbands by pretending to be a gay hairdresser and thereby gaining easy access to their wives.)

Another generation later the yellow-stripes have become the most populous morph. This change at the top, however, reopens the door for the now sparse blues, who recognize the yellow-throats for what they are and are aggressive enough to do something about it. "One reason that the blue males can see through [the yellows' deception] is that they know all their neighbors very well, because they have a small territory," Sinervo explains. "Whereas an orange may have just a whole slew of males that it's up against. And a whole slew of females to keep track of. It's got way more information to process." Not to mention the fact that the blues, with their lower testosterone levels, can probably think more clearly.

Of course, other cyclical relations exist that define population frequencies. The lynx-hare association is an example of predator-prey linkage in which both players shape the other's numbers. But, Sinervo points out, the lizards "could be the first example of a species almost like a perpetual-motion machine, without any other real external inputs." The possibility of a monospecific population cycling through a rock-paper-scissors scenario was predicted by John Maynard Smith in 1982. Eight years later Sinervo began collecting data on the lizards for general ecological studies, simply because they are widespread and abundant. Using number of females per male as a measure of evolutionary fitness, Sinervo worked up his data in 1995. This exercise proved irritating—at first.

"Then I looked at the data in the right way, by year," Sinervo recalls. "We were in my office, and Curt and I just looked at each other and we said, 'Dude! This is the rock-paper-scissors game!' We both knew it at the same instant." Whether lizards enjoy such moments of simultaneous rapture remains a mystery.

—*Steve Mirsky*

MICHAEL CRAWFORD

NEUROSCIENCE

SENILE WORDS

Susceptibility to dementia may be apparent at an early age

Alzheimer's disease destroys the memory. It kills many older people. Their brains contain so-called senile plaques. Yet some senior citizens, passed over by this capricious angel of death, die at advanced ages with their faculties intact and neural connections free of the ailment's proteinaceous tangles. The root cause of the disease is still unknown.

An ongoing study of some 700 retired midwestern nuns, however, appears to have uncovered an odd correlation between writing style at an early age and senile dementia decades later. All the novices who wrote autobiographical essays in very simple sentences died with symptoms of Alzheimer's (*A*), but none of those whose prose style was more complex succumbed to the disease (*B*).

(*A*) *"I attended the public school until the fifth grade. I started St. John's school when I was in the fifth grade. On September 1, 1925 following graduation, I entered as junior. I reentered on August 29th, 1927. On account of ill health I was a novice for two years."*

(*B*) *"During my junior year I again thought of entering. My father himself gave me the opportunity to express this desire, when he asked me what I intended to make of myself. I told him, 'a Notre Dame.' To my surprise, he said, 'If it's your vocation go to it.' I went to it, with God's grace, and find myself, this very day, happily preparing to take Holy Vows—preparing to be 'a Notre Dame.' "*

Susan J. Kemper of the University of Kansas, who studied the biographical essays, notes that measurements of "idea density" are surprisingly consistent and appear to correspond to some kind of general cognitive skill. Because all the nuns in the study belonged to the teaching order of the School Sisters of Notre Dame, and because many of them were educated in the same schools and classes, it seems reasonable that their preferred writing styles would be similar, Kemper explains. (Cohorts with some subjects brought up to emulate Ernest Hemingway and others nurtured on Anthony Trollope would show too much variability for such an effect to be noticeable.)

The nuns who wrote the simplest sentences probably did so, Kemper argues, because even around age 20, they did not have the short-term memory skills to juggle all the components of more complex wordings. She notes that many people tend to write less densely as they grow older, even while other aspects of their writing style remain the same.

One long-running hypothesis about Alzheimer's holds that people show signs of dementia only when brain damage has eroded their "cognitive reserve"—the smaller the reserve, the earlier the onset. If this extra brain capacity could somehow be enhanced or preserved, it might be possible to stave off the worst phases of Alzheimer's, says David A. Snowdon of the University of Kentucky, the director of the nun study. Martha Storandt, a psychologist at Washington University, notes that some of the subjects at whom she and her colleagues have looked died free of apparent cognitive impairment, but with at least some visible senile plaques in their brain. These elderly patients may have been reaching the end of their cognitive reserve.

Snowdon points out, however, that examinations of the brains of nuns who have died cast doubt on the cognitive reserve theory: those who suffered from dementia before death had numerous neural plaques and tangles characteristic of Alzheimer's; those who died unimpaired had almost none. If the theory were correct, he explains, one would expect to see roughly similar numbers of tangles in both cases.

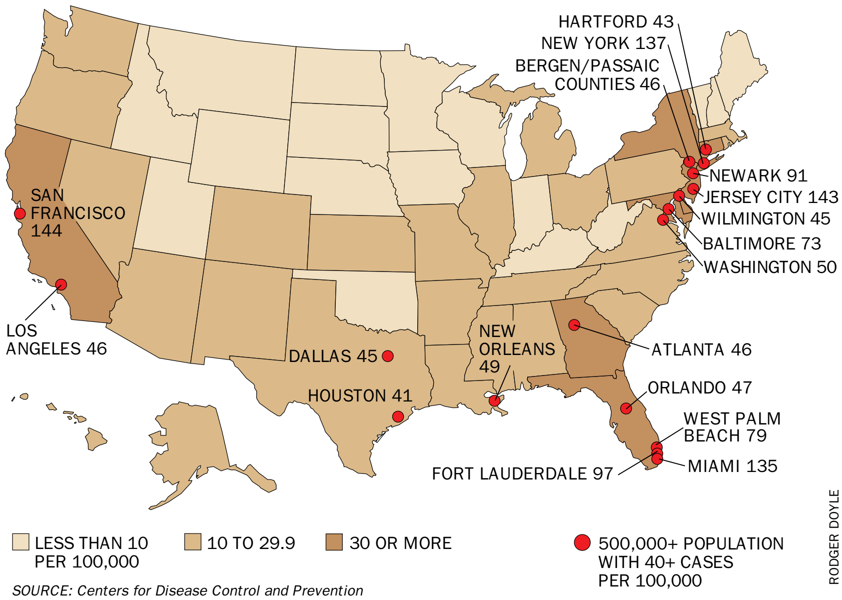
Although the narrow slice of midwestern population covered by the study makes it possible for researchers to see effects that would otherwise be hidden, it also prevents easy generalization. It appears that early in life something may be measurable that distinguishes those at high risk for Alzheimer's from those at low risk, but finding a way to detect it in the general population will be difficult.

Because the nuns have led remarkably similar lives since their early twenties—doing essentially the same work, often living in the same residences and eating the same food—it appears that whatever factors control susceptibility to Alzheimer's are probably fixed at an early age, Snowdon says. Recent studies of people who have tested positive for genes that mark a familial version of the ailment tell a parallel story: scans indicate differences in brain metabolism among subjects in their early fifties, long before any cognitive changes are apparent.

The researchers are currently investigating what is known of their subjects' prenovitiate life to see if any childhood or teenage factors seem to be correlated with the disease. *—Paul Wallich*

BY THE NUMBERS

AIDS Cases Reported, 1994–1995



SOURCE: Centers for Disease Control and Prevention

Since the beginning of the epidemic, more than 500,000 people in the U.S. have been diagnosed with AIDS; of these, about 200,000 are living. Currently there are some one million Americans who are infected with the human immunodeficiency virus (HIV), but most have not yet been diagnosed with AIDS.

The first cases reported from the East and West coasts in 1981 were among males who had had sex with other males. Later in 1981 it became clear that the disease was also spread by exchange of needles among intravenous drug users. And in 1982 it became apparent that people needing blood transfusions, such as hemophiliacs, were vulnerable as well. By 1983 it was known that ordinary heterosexual contact could spread the disease and that women were at risk. In 1995 perhaps half the reported new cases were among gay men, about a third were users of illegal intravenous drugs, and about one of 10 were heterosexuals who did not inject drugs; heterosexual transmission accounted for 38 percent of the cases reported in women. In 1982 AIDS was a mostly white disease, but by 1995, new cases among blacks accounted for 40 percent of the total, or the same as whites. Hispanics accounted for 19 percent.

Geographical aspects of the epidemic have shifted as well. In 1981, 76 percent of reported AIDS cases were in New York and California, but by 1995, these states accounted for only 33 percent. AIDS still remains highly concentrated regionally, with 57 percent of the 1995 cases in only five states—California, New York, New Jersey, Florida and Texas. The incidence of AIDS is far lower in suburban areas, small towns and rural areas than in the central cities of metropolitan areas.

The loci of AIDS reflect the population of intravenous drug users and sexually active gay men, but the importance of these two groups varies by region. In California the epidemic has been driven largely by gay men, who account for three fourths of the cases there, but in New York State the leading group has been intravenous drug users, who account for almost half the cases. (Gay men in New York account for a third.) The above-average rates in the South probably reflect, in part, the high incidence there of other sexually transmitted diseases, such as syphilis, the open lesions of which increase the risk of HIV infection.

In 1993 the one million or so people in the U.S. infected with HIV could be compared with 500,000 in western Europe, 50,000 in the former Soviet bloc countries, one million in Latin America and the Caribbean, 25,000 in East Asia, 1.5 million in South Asia, and 7.5 million in sub-Saharan Africa. The incidence of AIDS is now leveling off in the U.S. and western Europe but is rising steeply in Africa and Asia. *—Rodger Doyle*

CYBER VIEW

Playing Facts and Loose

Databases are the foundries of the information revolution. They provide the raw facts from which arguments are made and decisions taken. Computers have set data free from the bounds of paper and put them at the fingertips of anyone with a keyboard—and by so doing, they have transformed the global economy and the state of human knowledge. In executive circles, it is now fashionable to argue that a company's real assets are its databases, for ultimately the information a company holds about its products and its customers are worth more than any mere production facilities. But amid all the talk and excitement, few have thought much about what a database is and what it might mean to "own" one. A directive from the European Union, which was announced in March, is about to spark a debate.

The EU hopes to encourage Europeans to invest more in creating databases by giving database creators a tighter hold on their information. As the EU's 15 member nations enact this broad policy, the legislators for each country should seize the opportunity to think thoroughly about where the real value of information lies—in keeping it, creating it or communicating it.

Traditionally, databases have fallen through the cracks of intellectual property law. Most such law is designed to protect creativity—the imagination of an author, the lyricism of a composer or the discoveries of a scientist. Yet databases are not meant to be innovative. Good databases are about facts—plain, simple facts, which are best delivered unadorned. Facts can be neither copyrighted nor patented. But for the publishers and executives investing billions to amass facts in the hopes that data can be translated into power, this situation gives them only a very slippery legal grip on the fruit of their labors.

The U.S. is the least strict on this front. In a 1991 case—*Feist Publications v. Rural Telephone Service*—the Supreme Court ruled that Rural Telephone could not control the copying of names and numbers in its white pages. The company could, if it wished, try to prevent anybody else from presenting those data in a similar layout (although in the case of white pages, it would probably be beyond even the highest-priced lawyers to argue that alphabetized columns of text are sufficiently original to merit legal protection). But, the court concluded, facts are facts and belong to everybody and to nobody.

British law lies at the other extreme. While acknowledging that facts want to be free, judges have tried to protect the work put into gathering data. So long as a plaintiff can show that he has expended the sweat of his brow amassing information, judges permit the material to be copyrighted. This allowance prevents would-be Feists from copying the results of another's effort—although anyone can make precisely the same database by expending his own sweat.

The EU is trying to create a middle ground. Some databases, it argues, will be sufficiently creative to qualify for traditional copyright protection. But many, perhaps most, will not.

For the collectors of facts, the EU is devising a new legal privilege. So long as a database creator can show that he has devoted substantial time to reaping and arranging facts, he will for 15 years be able to prevent anyone from copying his product or extracting "substantial" information from it. Simon Chalton, a lawyer with the London firm of Bird & Bird, notes that this wording provides sweeping powers for architects of computerized databases. Loading data from computer disk into memory is itself considered to be copying—whether anyone sees the data or not. So the novel restriction on extracting and copying could ensure a restriction on searching data.

The directive is also extremely broad in its definition of a database, so it could have all kinds of interesting consequences for, among other things, that vast collection of collections of data known as the World Wide Web. This is because, although the actual text of a Web page is copyrighted, the underlying links that connect it to the rest of the Web lie more in the realm of databases than of prose.

The task of determining what consequences the directive will have lies in the hands of the EU's members. They must give the policy force by incorporating it into national law by 1998. Along the way, they have considerable latitude to interpret and adjust it. Most governments will be tempted to construe the directive as broadly as possible so as to protect the work that goes into compiling a database.

But governments will not be doing their citizens any favors if they do so, because the apparent security granted by "ownership" of facts is largely illusory. Information is not like gold or diamonds, which quietly appreciate in value. It grows stale quickly. To the extent that greater control encourages companies to feel content just holding information, it diverts them from the real sources of advantage in the database world. The first and most important of these is the ability to gather new information.

Over the long term, the greatest impact of computers on the availability of information lies not in their power to manipulate it and to distribute it but in the ease with which they enable it to be gathered. Unlike paper records, the flow of transactions through a computer is itself an archive that can be quickly and easily searched. Ultimately, the advantages of holding expensively gathered data will pale in comparison with the advantages of being in a position to gather lots more inexpensively.

Similar arguments hold true for communication. Tempting as it is for companies to keep information close to the vest, some are learning that they can get a tighter rein on their customers by setting it free. The reason is subtle but simple. To benefit from information of any complexity, customers have to make an investment to develop the knowledge necessary to make the most of the data. Without that personal investment, the material is valueless—which is why some firms are giving it away in order to cement paying relations with customers.

Take J. P. Morgan, which has invested tens of millions in collecting data about the relative risks of various financial investments. Corporate treasurers use these data to determine how much they have to hedge their investments. Good data can be worth millions, but only if used intelligently. So J. P. Morgan gives the information away at its Web site (http://www.jpmorgan.com). More than 400 companies now gather data from the site daily. As they do so, they become increasingly attuned to J. P. Morgan's viewpoint on risk and to its language for analyzing it—and thus all the more entrenched in a relation with J. P. Morgan that includes expensive consulting and advice as well as free data. None of that would have happened, of course, if J. P. Morgan had tried to keep a fast grip on its data—which, as the EU tries to make data more grippable, is something Europeans should think about hard.

—John Browning in London

TECHNOLOGY AND BUSINESS

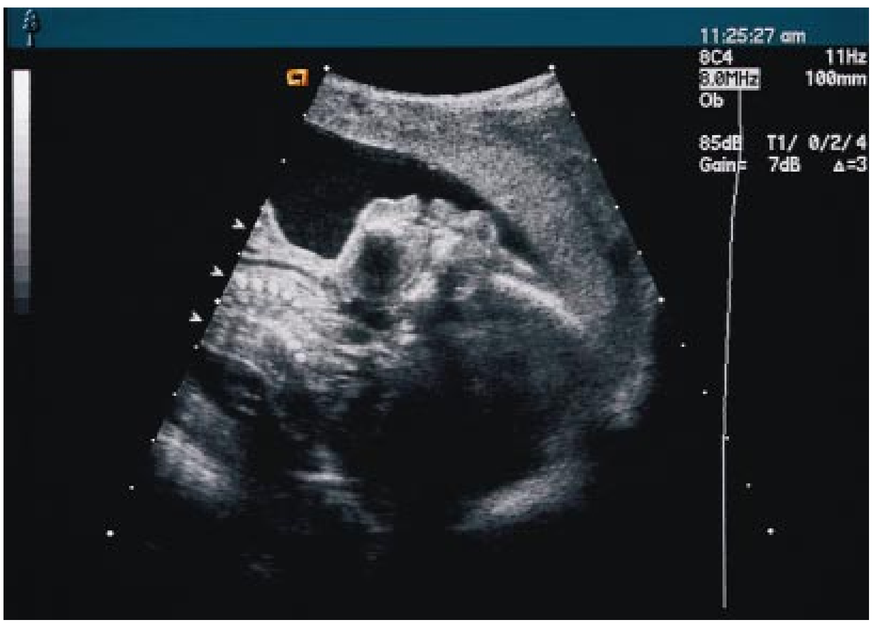
MEDICAL IMAGING

ULTRASOUND'S NEW PHASE

A major advance yields deeper, clearer views of the body

Born into a sea of sound and light, humans develop sophisticated organs to sense and process the waves. Technology has extended the range of our perception, allowing us to discern oscillations as slow as Earth's seismic shudders and as rapid as the x-ray wail of hot gas spinning into a black hole. But like the eyes and ears of the humans who built them, imaging instruments are generally blind to one of the three forms in which waves transport information. We sense a wave's amplitude as brightness or loudness, its frequency as color or pitch. Yet its phase—the position of the waves' crests and troughs in space—falls on deaf ears.

An innovative medical imaging system unveiled in April demonstrates how much we have been missing. By translating the phase information in ultrasound echoes into a form humans can see, the machine gives physicians a significantly clearer window into the inner workings of their patients.



ACUSON CORPORATION

FETUS AT 20 WEEKS
appears much more clearly in the new ultrasound image.

Doctors have been using ultrasonic imaging systems to peer within the body for more than two decades, but it was not until all-electronic machines were introduced in the early 1980s that the technology found widespread use. Since then, all such systems have worked similarly: extremely high pitched sound pulses—at about 250 times the frequency of the highest squeal that human ears can apprehend—are produced by a handheld wand pressed against the patient. As the pulses travel through the body, faint echoes return from spots where the tissue changes in density or stiffness. The wand then picks up the reflected sound and sends the signal to a computer, where it is amplified and processed into a black-and-white image.

Denser surfaces, such as bone, return louder echoes and thus appear brighter than squishier bits, like kidneys. Quickly moving cells, such as blood, change the pitch of the sound they reflect through a phenomenon known as the Doppler effect. Most systems can detect this shift and display blood flows in bright colors.

Converting sonic reflections to visual patterns remains an inexact science, however, complicated by echoes arriving from many different directions and depths at once. To sort out which pulses are returning from where, ultrasound machines try to focus on a slice within the body and scan it one line at a time. But there are trade-offs. Higher-frequency sound returns crisper echoes but does not penetrate as far. Boosting the number of scan lines also increases clarity. But doctors often use ultrasound to look for unusual movement as well as suspicious shapes—a leaking heart valve, for example, or inadequate circulation in an organ. In order to update the image several times a second, the number of lines must be reduced.

The result is often a fuzzy—and sometimes inconclusive—picture. To make accurate diagnoses, physicians have to learn how to read the missing information between the lines. In many cases, they send patients on to get clearer, but considerably more expensive, scans using computed tomography (CT) or magnetic resonance imaging (MRI).

Imaging specialists have long known that half the information returned by an ultrasound echo is coded in its phase, which reflects changes in the stiffness of tissue where the echo originated. Theoretically, that information could be used to produce more distinct images. But because a wave's phase is altered by its journey through the body, no one could figure out how to incorporate phase data in a way meaningful to human eyes.

In 1987 engineers at Acuson, an ultrasound equipment manufacturer in Mountain View, Calif., began work on a solution. The system they developed sends sonic pulses into the body one at a time, as usual; its innovation is on the receiving end. The machine can record the strength and phase of up to four separate echoes, reflected from a row of four closely adjacent spots as each pulse bounces off a cross section of tissue. Because the echoes come from the same initial pulse and follow essentially the same path back to the receiver, the slight differences in their phase are caused only by tissue variations at the spots where they were created.

The four echoes are passed to a device called an imageformer. If one imagines the echo pulses as parallel rays of light, then the imageformer acts like an adjustable lens. It can focus the rays into an image of any of the four spots in the body. But it can also focus them to reproduce an image of any point *between* the spots, thanks to the extra phase information that the echoes carry. Because the system is computerized, it can refocus the same set of echoes over and over to form a nearly continuous band of varying brightness. As successive groups of pulses arrive, the imageformer stacks the bands into image cells and finally converts them into a picture.

After seven years and more than $200 million in research and development, the new system, dubbed Sequoia, is ready for market. For Acuson, a leader in its market that has nonetheless seen the demand for ultrasound equipment fall by 30 percent and has had to cut its prices by up to 50 percent over the past two years, the future rides on Sequoia. Will hospitals and clinics pay a 40 percent premium—raising the price to about $200,000—for this new technology?

Radiologists who have evaluated Sequoia say they might. These doctors are optimistic that the noticeably clearer images may make ultrasound a more reliable diagnostic method for a number of conditions.

"It gives us a tremendous window on the fetal heart, for example," says Donald S. Emerson of the University of Tennessee at Memphis. Recently Emerson examined an expectant mother whose fetus suffered from a rare heart condition. Blood vessels connected one chamber in the fetus's heart to the coronary arteries that feed the heart, resulting in a backwash of blood flooding the arteries. Using a state-of-the-art ultrasound machine, doctors had to sit and stare for a long time in order to make a diagnosis, Emerson says. "With shrinking reimbursements reducing the time physicians can spend on patients, many labs might have missed it. But when we examined this patient with Sequoia," he recalls, "those vessels just jumped out." No doctor could have failed to notice the aberrant blood flow, he says.

Acuson has demonstrated that Sequoia can reveal an impressive list of structures that have been difficult, if not impossible, to see with ultrasound. Blood flow through the coronary arteries stands out clearly on Sequoia's monitor—important because if this flow is blocked it frequently indicates heart disease. Circulation through the brain, kidneys and heart of a tiny fetus is now visible perhaps a month or two earlier than before.

Early adopters, such as the Mayo Clinic, which has ordered eight Sequoia machines, will test Acuson's assertion that the new device can justify its higher cost by reducing the need for more expensive tests. "All we have now," Emerson says, "is tantalizing but preliminary experience that tells us we are seeing more anatomy." He chuckles. "But I was sure disappointed when the evaluation ended, and they took it out of our lab."

—W. Wayt Gibbs in San Francisco

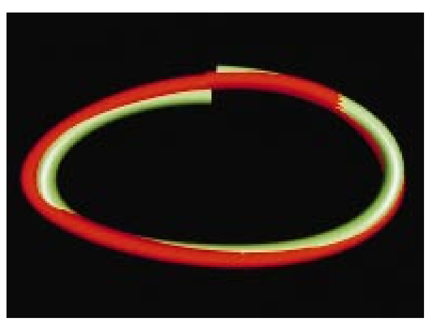
NEUROSCIENCE

MIND READINGS

Researchers can now predict what a monkey will draw—before it even moves

In a laboratory outside San Diego, a rhesus monkey sits and peers through a periscopelike arrangement of mirrors into a computer-generated virtual reality. If monkeys have a sense of wonder, this one must have been in awe at first seeing an elliptical tube float before its eyes. But now the animal has mastered this game. The monkey reaches for the object. When it does, infrared diodes strapped on its arm convey its movement to the computer, which then moves a spherical cursor in the virtual world. As one segment of the tube lights up and spins around the ellipse, the rhesus must follow it, tracing ovals in the air. After months of practicing four hours a day, five days a week, the monkey has this down. Every time it completes five orbits, the creature wins a drink of water.

As the rhesus plays, Andrew B. Schwartz, a senior fellow at the Neuro-



ANDREW B. SCHWARTZ

***PATH PREDICTED* *by brain probe* (red) *closely matches actual arm movement* (green).**

sciences Institute, sits in front of a floor-to-ceiling rack of equipment recording the animal's thoughts—or rather electrical traces of them. His instruments are connected by a wire far thinner than a human hair to a single brain cell lying just below the surface of the animal's primary motor cortex. No electricity goes into the subject's skull. But the moment the monkey decides to move its arm, this neuron starts firing, sending pulses out to the computer, which registers how rapidly they arrive. From the pattern of signals produced by fewer than 100 brain cells sampled as the rhesus repeats its task, Schwartz has all the data he needs to predict where the monkey's arm is going a good tenth of a second before the animal moves a muscle.

Neuroscientists discovered a decade ago that the rate at which a neuron fires in the motor cortex determines the direction the associated muscle will tend to move. Averaging the directions sent by a bunch of brain cells within the region, researchers found that they could predict with uncanny accuracy which way a monkey was going to move its arm—so long as the movement was a straight line. Working with colleagues at Arizona State University, Schwartz has improved the technique to reproduce the spirals and other complex curves the subject draws in three-dimensional space.

The advance is important, explains Gary T. Yamaguchi of Arizona State, "because our long-term goal is to try to figure out how to use these neural signals to move a prosthetic limb in a natural way." Schwartz suggests that within a decade or so it should be possible to fit amputees with thought-controlled robotic arms that move naturally.

"One of the big problems with building devices that replace human function is that they often fail or make the wearer feel conspicuous and then get thrown in the closet," Yamaguchi says. But building a bionic arm involves more than just decoding the path a person intends his or her arm to follow.

"The problem is that there are an essentially infinite number of joint positions and movements you can use to move your hand from point A to point B," Yamaguchi explains. "Fortunately, humans and lower primates almost always make common movements in just one way." At a conference in February, Yamaguchi reported that his group has developed a mathematical model that, given a trajectory, can accurately predict just how a human would move

SCIENTIFIC AMERICAN CORRESPONDENCE

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six of the seven major joints in the arm.

Schwartz found that the key to translating motor cortex signals is to associate neuron firing rates with velocity as well as direction. He improved the accuracy of his decoder further by accounting for what he calls "a time-warping phenomenon" in the brain. When humans and other primates draw straight lines, the lag between brain signal and muscle movement is tiny, just a few hundredths of a second. Curves are harder, however. So the tighter the curve, the slower we draw it, and the further our brains have to race ahead of our hands.

That process complicates movement prediction, however. "If at one moment the lag from neuron firing to movement is 200 milliseconds and then a moment later the lags drops near zero, the two signals might cross, making the movements occur out of order," Schwartz says. "In reality, the change from moment to moment is never so radical that signals actually cross, but you can see how predictions get really messed up unless we take time warping into account."

Although Schwartz's current technique works well on tasks that monkeys have been trained to perform, he has yet to test it when the animals are drawing patterns they have never seen before. His colleagues have constructed an artificial neural net that reorganizes itself to extract as much information as possible from the cortex signals. It should predict new patterns with more accuracy.

The technology still offers more questions than answers. Deciphering the brain signals that produce finer motions like grasping may be much trickier than predicting arm movement. And no one knows whether it will work in humans as well as it does in lower primates.

Schwartz intends to find out. This summer, he says, his group will start testing two new devices. A larger probe will sense the firing rates of many cortex cells simultaneously, producing real-time predictions such as those generated by muscle and brain-wave monitors. And an early prototype of a wireless probe will radio its host's intentions to an external processor. If the device is successful, the researchers will try to shrink and implant it within an animal's skull.

—W. Wayt Gibbs in San Francisco

ENVIRONMENTAL POLICY

GOOD WOOD

Can timber certification save the rain forest?

During the 1980s, concern about Earth's dwindling rain forests and the loss of biodiversity caused some environmentalists to call for boycotts of tropical woods. One organization decided not to threaten the timber industry with a stick but to wield a carrot instead: it would offer formal approval to logging operations that could meet certain standards. So began the Rainforest Alliance's Smart Wood Program in 1990, the first of several ongoing efforts to grant official recognition to environmentally sustainable and socially responsible timber production. Such certification, a market-driven approach to conservation, is gaining momentum worldwide, with more than a dozen sources now approved and big retailers such as Home Depot and IKEA seeking to offer consumers "green" wood products.

Yet the challenges to this strategy remain daunting, particularly for the besieged forests of the tropics. One problem is that certification is not likely to catch on in developing countries any time soon, because the vast majority of timber operations in the U.S. and Europe lack any such credentials. "For this scheme to be credible, it needs to function globally," notes Justin Stead, who coordinates a group of companies that allied with the World Wide Fund for Nature in the U.K. to support certification. Hence, it is understandable that the Rainforest Alliance has certified nearly as many operations in the U.S. (four) as in tropical countries (six), even though the temperate forests of the Northern Hemisphere are roughly stable in area.

***TROPICAL WOOD** from places such as Brazil's Rondonia Province could come under certification. But slash-and-burn practices cause far more deforestation.*

"Stable" does not describe undeveloped tropical lands, where an area the size of Florida is denuded every year. But logging contributes only modestly to this deforestation: according to a United Nations study, nine out of 10 tropical trees are felled for agriculture or cattle ranching. Most trees cut for their wood are used locally for fuel; only 14 percent are taken for timber, and less than a third of that material ever enters international markets. So it is unclear whether consumers in developed countries could slow tropical deforestation even if they demanded that all their wood purchases be certified.

Richard E. Rice of Conservation International argues that many environmental interest groups are too focused on timber certification, which could prove to be too little, too late. He is convinced that the economic pressures threatening the forests of developing countries are impossible to counter with enlightened consumerism alone. And he is concerned that other opportunities are being overlooked.

Rice suggests, for example, that a more effective strategy might be to convince the governments of tropical nations to tax timber producers according to the extent of their holdings rather than by the amount or type of wood extracted. That simple change would provide an economic incentive for the timber companies to place many of their economically marginal lands off-limits to logging. He also says certifiers have overemphasized "sustainability," an often vague term that can be defined in this context as managing the harvesting and replanting of trees so that the amount of any given species removed equals what regenerates. Rice objects because that seemingly virtuous principle can be at odds with preservation.

These complexities are well demonstrated by the conundrum of mahogany. Laura K. Snook of Duke University notes that true mahogany grows naturally only in tropical regions of the new world—such as the forests of Mexico's Yucatán peninsula. The logging operations she studied there, a cooperative enterprise called Plan Piloto Forestal, have been certified by Scientific Certification Systems in Oakland, Calif., and are deemed "well managed" by the Rainforest Alliance.

The certification criteria applied to the Mexican loggers are fundamentally no different from those demanded of other such operations. Approval hinged on satisfying three imperatives: the timber must be harvested sustainably; the health of the ecosystem must be maintained; and the social and economic needs of the community must be respected. Although each organization offering certification defines its requirements differently, most groups have moved toward setting a common framework for certification, established by an umbrella body called the Forest Stewardship Council.

Certification has, however, highlighted certain difficulties for the Plan Piloto. The problem is ecological, Snook explains. The density of mahogany is quite low (typically about one tree per hectare), and mahogany seedlings cannot survive in the shade of other trees. If new mahogany does not grow, sustainability is impossible to achieve. In the past, mahogany regenerated in clearings where trees had been destroyed by fire, blown over by hurricanes or felled by Mayan farmers. Now the only way to harvest this wood sustainably is to remove many other trees that are of little or no economic value.

Although it seems counterintuitive, Debbie Hammel of Scientific Certification Systems asserts that "the removal of more trees is not necessarily a negative thing." The premise is that by taking out additional trees and selling them, the loggers of Plan Piloto might be able to profit indefinitely from the forests, forestalling the influx of farms or ranches.

But Rice points out that such efforts can be considerably more damaging to a forest than simply taking the mahogany and leaving the other trunks alone. After studying the Chimanes Forest of the Bolivian Amazon (where there is little pressure to convert lands to agriculture), he concluded that uncontrolled logging of mahogany is a lesser evil than trying to manage the process sustainably. Rice estimated that the unsustainable pattern (as is now practiced) would in fact do one third the damage to these forests.

Finding the formula to preserve tropical forests in the face of the immense economic and social forces working to clear them remains a difficult assignment. Timber certification may well prove an important tool, particularly if consumer demand mounts and the prerequisites for approval become better tailored to local situations. Yet other conservation measures will undoubtedly need to be applied alongside. As Hammel freely admits, "Certification is not a panacea." *—David Schneider*

MEDICINE

TESTING, TESTING

Unusual proteins could improve cancer diagnosis and reduce deaths

The key to treating cancer is to catch it early. But identifying the subtle changes in cells that betray their turncoat tendencies requires skill—and good luck—on the part of pathologists. Many cancers are not spotted until too late, when the rebel colonies are well enough established to put up a fight and found new mutinous outposts.

Matritech, a Massachusetts-based start-up company, has developed a diagnostic technique that detects bladder cancer more easily—and possibly more effectively—than existing methods can. Matritech's test, which the company expects the Food and Drug Administration to approve by this summer, measures the amount of a particular type of protein in urine. Bladder cancer patients excrete this substance, called a nuclear matrix protein, in greater amounts than healthy subjects do.

All cell nuclei contain matrix proteins, constituents that give the nucleus its shape and organize the chromosomes. Researchers have known of their existence since the 1970s. Their possible value has become apparent just in the past few years, however, since investigators at the Massachusetts Institute of Technology showed that some nuclear matrix proteins in cancer cells are different from those in normal cells. Others are present in elevated amounts.

The unusual proteins seem to explain why the nuclei of cancer cells are often oddly shaped. The proteins escape into body fluids, where they can be identified using antibodies. Thus, the way is opened to tests for abnormal matrix proteins or, as in the case of Matritech's bladder cancer test, a normal one in unusual amounts. "There's been all this hoopla about genetic screening, but nuclear matrix protein testing could have the biggest impact of all," says Lance Willsey of Harvard Medical School.

Stephen D. Chubb, Matritech's chief executive, says his company's test, called NMP22, detected all cases of invasive disease in a trial with 1,000 subjects who had previously been treated for bladder cancer and were being monitored for recurrences—which are very common. Furthermore, it found about 70 percent of cases of bladder cancer that was still localized and in less need of urgent treatment. A negative result meant patients had a 90 percent chance of cancer not developing in the next three to six months—a useful predictive ability, because that is the usual interval between follow-up visits for bladder cancer patients.

Those figures, Chubb notes, indicate that NMP22 could be used instead of current techniques, which involve examining cells from the bladder shed in urine or viewing the inside of the bladder with a fiber-optic device (cystoscopy). Moreover, Matritech's test is one sixth the price of cystoscopy, which is typically billed at $300, and obviates any risk of infection. Matritech is initially seeking approval for NMP22 solely to check for recurrences of bladder cancer. But Chubb is not averse to the idea that NMP22 could be used more widely to screen for the disease in people who have not previously been diagnosed.

NMP22 might be the first of a series of matrix protein–based tests. Although the matrix protein that NMP22 detects is found in low levels in nuclei throughout the body, other nuclear matrix proteins are more specific. In April, Robert H. Getzenberg of the University of Pittsburgh Cancer Institute and his colleagues reported their discovery of five matrix proteins (not yet employed in any test) that occur exclusively in bladder cancer cells—thus suggesting the possibility of even more accurate diagnosis.

Chubb states that Matritech has strong patent protection for all uses of nuclear matrix proteins as cancer diagnostics and that it is working on such tests for early detection of prostate, colon, cervical and breast cancer. Most of these will be based on proteins that occur exclusively in particular cancers. But Willsey wonders whether Matritech has sufficient resources to develop nuclear matrix protein–based tests as fast as the company, and he, would like.

Nuclear matrix proteins could represent targets for therapeutic agents, too. The difficulty is that drugs have trouble penetrating cell nuclei. But Chubb says Matritech is giving the development of such therapeutics serious thought—and about 10 percent of its research budget.

—Tim Beardsley in Washington, D.C.

MILITARY TECHNOLOGY

UP, UP AND AWAY

The U.S. military brings back the balloon

In 1861, at Cloud's Mill, Va., the Union Army took to the air with a reconnaissance balloon to help spot Confederate artillery pieces in one of the first uses of flight in war. Now, in 1996, the U.S. Army is going back to the balloon to identify an emerging, lethal class of cheap, sophisticated missiles. Balloons are not likely to replace high-technology spy planes anytime soon, but forward-thinking military planners see an increasingly important battlefield role for inexpensive, unmanned platforms that cost far less and can stay aloft much longer than conventional aircraft.

U.S. AIR FORCE

SURVEILLANCE BY BLIMP* *is making a military comeback.

These are no ordinary balloons. The Pentagon, being the Pentagon, prefers to call them aerostats—helium-filled craft tied down by thin but incredibly strong fiber-optic cables that transmit missile-tracking and communications data to the ground. Aerostats are not self-propelled: they can be tethered to ground vehicles, ships or even airplanes.

The idea is to float a sensor-laden aerostat high above a battlefield area to increase the range at which soldiers can monitor incoming threats. "The aerostat is a very inexpensive way to have cheap surveillance over a military force," says retired admiral William Owens, until recently the vice chairman of the Joint Chiefs of Staff and the principal sponsor of the new aerostat program.

Specifically, the Pentagon is developing aerostats to spot cruise missiles: remote-controlled aircraft packed with explosives and directed by sophisticated navigation equipment. Because cruise missiles are designed to fly low to the ground, they can get very close to their targets before ground-based radar can detect them. And destroying such missiles close to friendly troops can be dangerous because they may carry biological or chemical materials—perhaps even nuclear weapons. With an aerostat, which can see "over the horizon" beyond the range of ground-based radar, cruise missiles can be located earlier; data passed to missile defense weapons such as the Patriot system can then be used to shoot the missiles down over enemy territory.

Although the Pentagon has spent billions developing so-called Star Wars weapons systems designed to bring down ballistic missiles, it has only recently begun to pay close attention to the threat posed by cruise missiles. The imperative for doing so is obvious: smaller nations are discovering that cruise missiles are easy to build and even easier to buy. The Pentagon's own Global Positioning System satellite network, which was designed for military navigation but which has become a hugely successful commercial tool, has opened the door to more sophisticated remote piloting systems perfect for cruise missiles. For around $50 million, any nation can purchase either a very few fighter aircraft, about four attack helicopters or 15 ballistic missiles. But the same amount buys hundreds of cruise missiles—what the army calls "a poor man's air force."

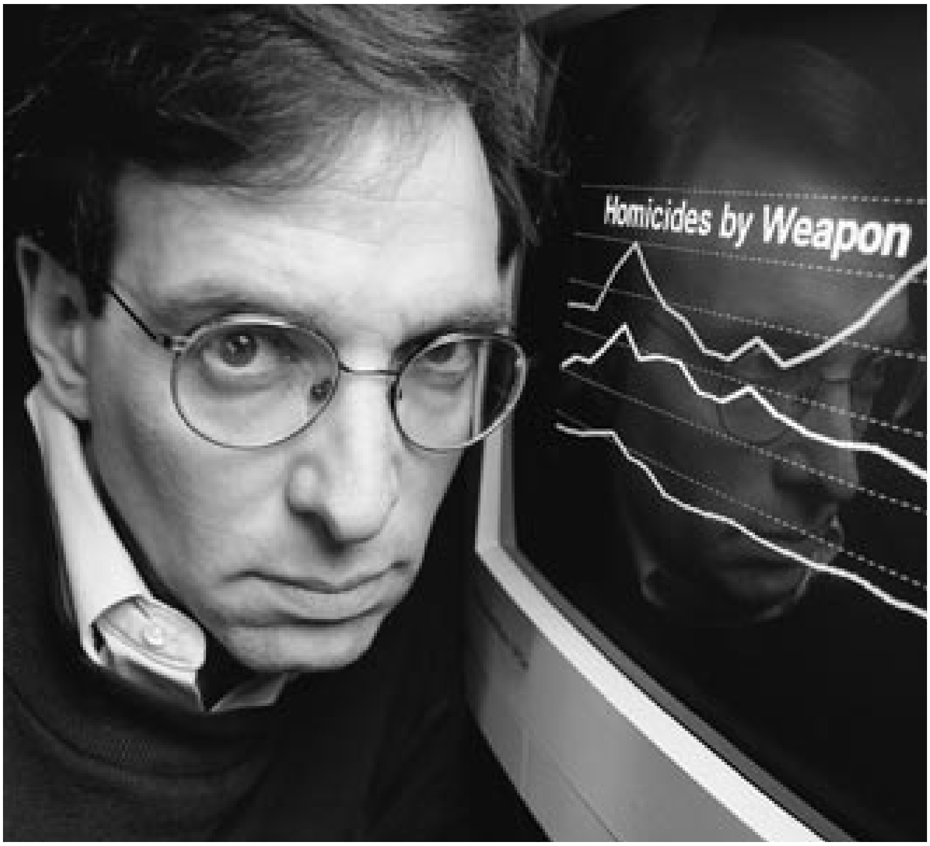
Today and for the foreseeable future, the military can do little about cruise missiles, especially those that attack targets on land. Enter the aerostat. The U.S. Air Force has years of experience operating the balloons along the southern U.S. border, but until last year the Pentagon paid little attention to the "lighter than air" solution. Now, given a high-profile push by top military leaders, the Pentagon has devoted $500 million over the next five years to develop and test aerostats' potential for cruise missile defense.

And the military might not stop there. Owens, keeping an eye on what he calls the "smart front edge of warfare," thinks balloons have potential far beyond the detection of cruise missiles. Current aerostats fly as high as 15,000 feet; for cruise missile defense, 20,000 feet is a likely ceiling. But Owens believes an aerostat flying at 60,000 feet could one day keep watch over an area the size of Bosnia for days or even weeks without maintenance or fuel, providing surveillance and communications for troops on the ground. Given the soaring costs of constructing and flying high-tech surveillance airplanes, the balloon may have a lofty place on the battlefield of the future. *—Daniel G. Dupont*

PROFILE: James Alan Fox

Catching a Coming Crime Wave

College deans do not seem to make suitable protagonists in movies, unless they are the butt of fraternity pranks. So the idea of an academic who moonlights as a sleuth of serial murder might appear downright improbable. Still, the script is being written, an actor is lined up, and in a year, James Alan Fox, the dean of the College of Criminal Justice at Northeastern University, will likely see himself portrayed in a movie made for television.



BRUCE DAVIDSON *Magnum*

Television and Fox are hardly strangers. The criminologist has studied serial killings and mass murders for almost 20 years. Whenever bodies turn up or some multiple shooting occurs, the media look to Fox for the usual commentary. In addition to being quoted in thousands of articles, he has appeared hundreds of times on network programs, from *Good Morning America* to the *Late Late Show with Tom Snyder.* "I've done the *Oprah* show eight times," Fox states.

"Not all my colleagues think it's a good idea to appear on television," he adds. "There's a gut feeling that it's not appropriate, that it's beneath the role of a serious academic. I don't agree with that. The way I look at it, I'm teaching a class of millions. It's an opportunity lost and a responsibility shirked if we don't publicize important research findings."

That's why Fox freely gives out his beeper and home numbers to journalists, returns their calls promptly and answers the telephone that frequently interrupts our conversation in his office. He even pauses midsentence to allow me to flip the recording tape. "Academics don't know how to say things in a concise manner. Most people want straightforward answers. I know, sound bites," Fox winces. "But they're not always bites. Sometimes they're whole meals."

Wearing an Italian suit and a Movado watch, the boyish 44-year-old media maven is a far cry from the shy, short, fat teenager with Coke-bottle glasses. Back then, he was a math whiz, although by the end of his college years at the University of Pennsylvania, he had turned to sociology in the search for a topic that had more immediate applicability. Inspired by a summer course in criminology, Fox earned master's degrees in criminology and statistics before completing his doctorate in sociology at Pennsylvania at the age of 24.

Soon after, he assumed a professorship at Northeastern. There he combined criminology with his love of mathematics and computers—programming is a hobby of his, and he says he would be a computer scientist if he had to do it all over again. Fox began to use statistics and demographics to forecast crime patterns, showing, for example, how trends in homicide depend largely on the number of 18- to 24-year-olds, the most crime-prone age group.

His interest in multiple killings developed when his colleague Jack Levin approached him at a party with the idea to conduct a study on mass murder. Their first effort was published in 1985, and since then the two have collaborated on several other books and articles.

Fox began honing his media skills with Levin as well, when they broadcast an interview program from the campus radio station. "I worked hard at getting rid of my Boston accent in that show," Fox—who grew up in the city's suburbs—recalls. The thick eyeglasses are gone as well. The only obvious indications of his legal blindness—resulting from the high oxygen content in his incubator after his premature birth—are the size of the fonts displayed on his monitor and the fact that he brings reading material to the tip of his nose.

The television movie (appropriately, to appear on the Fox network) is based on the criminologist's involvement with a 1990 case in Gainesville, Fla., in which five college students were brutally slain. The news broke while Fox and his wife were vacationing in Maine, and Fox soon found himself in Florida appearing on a talk show. On it, he stated that the suspect in custody was the wrong man, even though he matched the profile supplied by the Federal Bureau of Investigation. "He was an impulsive, young hothead who could not control himself. Someone as impulsive as he could not carry out such a methodical, meticulous crime," Fox explained, noting how the killer carefully mutilated the corpses. Moreover, the suspect was only 18, rather young for a serial killer.

Harboring their own doubts about the

suspect, the local police hired Fox as a consultant. Culling records of previous murders in the area, Fox was struck by crime-scene photographs of a murder in Shreveport, La., months earlier. "The FBI did not think the connection was so strong," Fox says, but he was not misled by the differences, pointing out similarities in the way the killer had cleaned up, then posed the corpses in both cases.

So he told the police to look for someone who had a connection between the two towns. After compiling hospital records, college rosters and other lists, the police came across a man from Shreveport who was in custody in Ocala, Fla., for stealing a car from Gainesville near the time of the murders. Soon, the authorities genetically matched Danny Harold Rolling to the crimes.

Although the study of mass murder seems to have made Fox the country's most quoted criminologist, it no longer holds the same fascination for him. "It got to a point that it was not satisfying, because there's not much you can do about it," Fox confesses, remarking that there is no real way to identify potential mass killers. So he branched out to research violence in the workplace and among juveniles. These topics have led him back to number crunching to explain and predict patterns. He and others have recently used statistics to argue that the current downturn of crime rates in many cities reflects the drop in the population of young adults.

Such conclusions agitate law-enforcement officials, most notably William J. Bratton, until this past April the New York City police commissioner. Bratton claims that his revamping of the department and aggressive policing sparked the 39 percent drop in homicide from 1993 to 1995, with equally impressive double-digit declines in most other major crimes. Last year Bratton set out to disprove the theories of Fox and his academic ilk, promising to "knock them down like ducks in a row" and declaring that the police are winning the war on crime.

The ducks quack right back. "I hate that stuff," Fox groans. "We're not winning the war on crime. Bratton deserves a lot of credit in terms of expanding community policing and bringing a greater sense of order to the city. But he doesn't deserve all the credit."

In fact, Fox's studies of homicide lead him to conclude that the U.S. is headed for a crime wave. "Hidden beneath the overall drop in crime is this tremendous surge in youth crime," Fox asserts. Historically, young adults—between the ages of 18 and 24—were responsible for the vast majority of murders. But since the mid-1980s, when the crack epidemic struck, juveniles began committing more murder: the rate among those in the 14- to 17-year-old group more than doubled between 1985 and 1994, from seven to 19.1 per 100,000.

The baby-boom generation has produced 39 million people who are now under the age of 10. During the next decade, this "baby boomerang," as Fox calls it, will enter their most crime-prone years. Unless steps are taken immediately, "the next crime wave will get so bad that it will make 1995 look like the good old days." Although some investigators disagree with his conclusions and choice of language, few argue with his statistical analyses.

"Kids face violence and death… by their peers."

The notoriety he has achieved with media appearances has helped him gain an audience for his glum forecast. During the past year, he has testified before members of Congress, dined with President Bill Clinton and briefed U.S. Attorney General Janet Reno. "People are listening. I hear the president talking about it, the senators. And now Janet Reno is appointing a juvenile violence czar," the criminologist enthuses.

Fox rattles off several reasons why teenagers are more violent today, such as access to weapons, lack of parental supervision (crime among juveniles peaks at 3 P.M.) and the brutal aspects of American society. "We have a culture that glorifies violence," Fox complains, citing as an example serial killing, which is mostly a U.S. phenomenon. Killers often become celebrities, their visages appearing on trading cards and on the covers of entertainment magazines.

Videocassettes have made it easy for children to view violence. And the proposed ratings system for television and the incorporation of the V-chip (a device that can block out adult-oriented programming) provides an incentive for producers to include more gratuitous scenes to achieve higher ratings, Fox comments. "It's a myth that parents will be able to tune this stuff out," he opines, arguing that parents would not know how to manage the technology.

Threats of severe punishment will not stem the coming tide. "Many kids face violence and death in the classrooms by their peers," Fox emphasizes. "As far as they're concerned, the criminal justice system might as well take a number and stand in line with all the other people who want to get them.

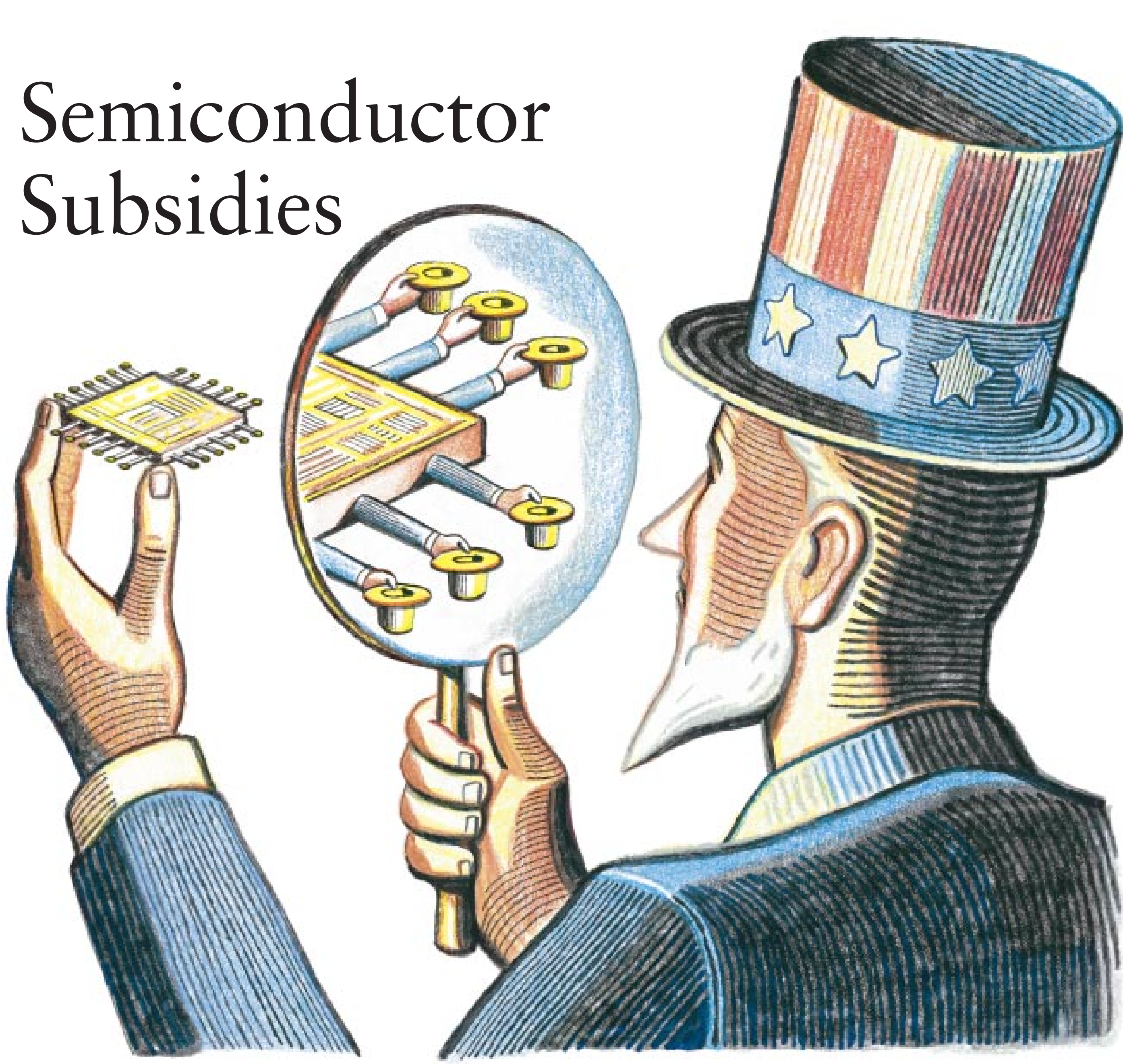
"It might make us feel better that an offender is getting a hard sentence," he continues, "but that's not accomplishing anything. We need to put him in an environment that is therapeutic." Given that many working parents cannot afford child care, Fox thinks government and corporations should develop programs that keep teens engaged, rather than try to hold parents responsible for their children's crimes.

Not surprisingly, he is vociferously opposed to the death penalty. "Nothing is gained by execution, and a lot is lost," Fox maintains. It costs more, largely because of the legal machinery needed to ensure a fair trial and not, as many people believe, because of repeated appeals. Given the sentence, prosecutors take more care in preparation, and judges give the defense a wider latitude. The argument that it is expensive to lock up murderers for life does not wash with Fox, either. He disputes the typically cited estimate of $30,000 to $40,000 a year, which comes from dividing the correctional budget by the number of inmates. Most costs are fixed and do not drop when prisoners are executed. "You can't call up the commissioner and tell him we're going to cut his salary because there is one fewer inmate," Fox sneers. "The actual expendable cost for incarcerating that one person is probably a couple of thousand dollars."

"We have a very good alternative to the death penalty, which is life in prison," he explains. "One reason so many Americans thirst for the death penalty is that they don't trust the criminal justice system." They fear that such offenders will be given parole after only a brief jail term. But to Fox, the system works pretty well, given the millions of people that pass through it. It is the rare instance of a corrupt judge or a recidivist parolee that captures the front pages. "Good news is no news," he concludes, "and bad news is big news."

A reporter from *USA Today* calls for the second time. Fox obliges with more of his statistics and prognostications. And of course, he speaks in concise, brief statements, sure to read well on the front page. *—Philip Yam*

Semiconductor Subsidies



DAVID SUTER

Did the U.S. government spend more than $700 million to achieve a goal that might have been attained for much less?

by Lucien P. Randazzese

During the early and mid-1980s, the U.S. semiconductor industry lost about half of its global market share—particularly in memory chips—to Japanese integrated-circuit producers. The decline in semiconductor manufacturing equipment by domestic makers was equally precipitous. Their global market share fell from 78 percent in 1978 to 48 percent by 1989. That was the background against which the principal American chip manufacturers organized the SEMATECH (Semiconductor Manufacturing Technology) consortium in 1987 to foster research and development on advanced semiconductor technology. Fearing that the integrity of the U.S. defense apparatus was threatened by a growing dependence on foreign semiconductors, the federal government agreed to contribute $100 million annually to SEMATECH's operations.

SEMATECH is one of hundreds of consortia that have sprung up since the 1984 passage of the National Cooperative Research Act, which gives companies engaged in cooperative research and development partial exemption from antitrust laws. Through cooperation on "generic" or "precompetitive" research, companies may be able to reduce wasteful duplicative effort, take advantage of complementary resources in different firms and augment their own research investment with that of their partners.

Although cooperative research sounds good in theory, it is often difficult in practice, as SEMATECH found out. After struggling unsuccessfully for more than a year to organize a research program suitable to its diverse membership, the consortium decided that the best opportunity it had to aid the U.S. semiconductor industry was not to emphasize direct cooperation between its members but rather to concentrate on improving the position of the domestic companies that make semiconductor manufacturing equipment. SEMATECH thereby changed the nature of the cooperative task at hand in important ways. No one appears to have fully appreciated the organizational implications of these changes at the time.

The consortium focused in particular on lithography technology, which is used to print microscopic circuit patterns on silicon wafers. The U.S. share of the lithography market had slid from 71 percent in 1983 to just 29 percent by 1988. Although this sector is relatively small, it is indispensable to the $150-billion global semiconductor industry.

Most of the dramatic decline was accounted for by GCA Corporation. In the late 1970s GCA had invented the step-and-repeat (or stepper) technology that soon became the workhorse of the semiconductor manufacturing industry. After an early period of enormous success, the company's poor quality control and customer field support began to catch up with it. A global downturn in the semiconductor manufacturing equipment industry and the rapid emergence of Japanese competition brought the company to the brink of bankruptcy. In March 1988 GCA was bought by the General Signal conglomerate. During the next few years, GCA received an estimated $60 million from SEMATECH in an attempt to restore its technological and commercial leadership.

Despite eventual technological improvements, however, GCA failed to win more than one major customer, and General Signal continued to lose money on its purchase. As part of its exit from the semiconductor manufacturing equipment industry, General Signal put GCA up for sale in January 1993 and, unable to find a buyer, shut it down by the summer of that year. SEMATECH's members and the federal government were left with little to show for their cooperative experiment. Given the increasing number of R&D consortia and the widely expressed hopes that they will improve the competitiveness of the nation's high-technology sectors, this spectacular failure raises questions about how such consortia should be organized and managed, especially when large amounts of money are at stake.

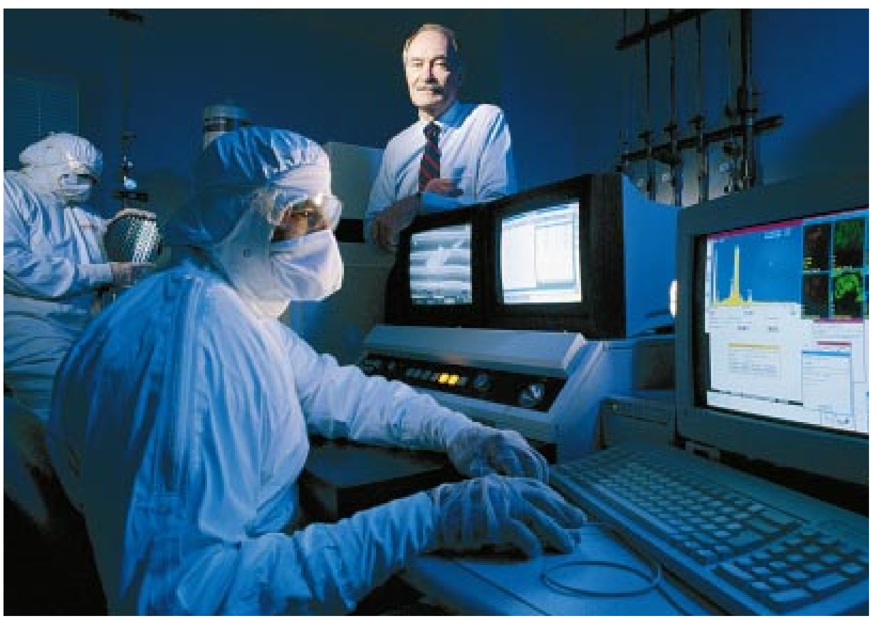
A Fated Effort

Most observers have blamed GCA's management for the company's closure. They claim that despite SEMATECH's subsidies, the company's executives continued to run the company into the ground, as they had been doing before General Signal purchased the firm. Management, these observers argue, had simply been unable to commercialize the technology that SEMATECH helped to develop. These observers contend that agencies participating in cooperative technology initiatives must address the managerial competence as well as the technical potential of the companies they subsidize. Although this prescription has merit, a closer look at the GCA case suggests a richer set of lessons.

Instead of simply coordinating research among companies all engaged in the same business—as most similar research consortia did—SEMATECH was trying to promote cooperation between customers and suppliers. The consortium had to succeed not only in managing a cooperative R&D project—which it appears to have done well—but ultimately in establishing the commitment of its members to buy the product of a supplier that they had lost faith in. The organizational costs of achieving this goal, assuming that it was possible at all, appear to have been dramatically underestimated.

SEMATECH's patronage of GCA began in earnest in May 1989, when GCA won the consortium's contract to develop the next generation of stepper, capable of imprinting chips with lines half a micron wide. Chipmakers require prototype tools for evaluation about two years before starting full production so that they can optimize their manufacturing processes; chips containing half-micron line widths were scheduled to start rolling off assembly lines in 1992. As a result, companies intended to start selecting their lithography vendors by the middle of 1990.

Semiconductor equipment suppliers generally experience cyclical sales patterns: chipmakers introduce major new products roughly every three years, for which they must buy equipment to retool their manufacturing lines. Between investment seasons, sales are much lower. SEMATECH selected GCA despite its poor image largely because no other do-



ZIGY KALUZNY *Gamma Liaison*

SEMATECH PRESIDENT William J. Spencer poses in the consortium's chip-inspection laboratory. Workers are in clean-room suits to prevent dust and other contaminants from reaching silicon wafers and equipment. An electron microscope image of an integrated circuit is visible on the monitor screen at the right.

mestic company was in a position to develop or manufacture high-end lithography equipment in volume.

Throughout 1989, 1990 and 1991, lithography consumed the majority of SEMATECH's expenditures, with at least $50 million going to GCA. In early 1990 SEMATECH took an unprecedented step by purchasing 14 GCA steppers for $19 million and delivering them to four member companies for evaluation and joint development work. SEMATECH had decided that this unusual effort was required because GCA had gone several years without major customers and so had not had the opportunity to pursue collaborative development. Despite this effort, however, GCA was not able to perfect its equipment in time for the 1990 investment season and so won no customers.

Undaunted, SEMATECH embarked on an effort to achieve market acceptance for GCA's next generation of technology. With technical, financial and managerial assistance from SEMATECH, GCA eventually produced what many engineers believed to be some of the most promising lithography equipment in the world. In April 1992 Digital Equipment Corporation chose GCA's new stepper over Nikon's for the production of its flagship Alpha microprocessor chip. The proximity of GCA's Andover, Mass., site to Digital's Hudson facility allowed GCA workers to establish close relations with people at Digital.

Yet Digital remained the only company to commit to purchasing any meaningful numbers of steppers. Although GCA finally appeared to have come up with a very competitive technology, almost none of SEMATECH's members were willing to buy it. The reason for this apparent paradox is that the technical capabilities of a stepper have become only part of the basis for purchasing decisions. Chipmakers are dependent on vendor support to upgrade equipment and keep it running at top efficiency. During the 1970s, lithographic tools cost perhaps $20,000 each; now top-of-the-line steppers go for between $4 million and $6 million. They are the most expensive single components of fabrication lines that may cost well over $1 billion. The prospect of losing support, should a supplier go out of business, would be unpalatable to risk-averse managers trying to maintain their manufacturing investments.

By 1990 GCA had already gone several years with very little revenue, and so the company's failure to win any customers at that point created doubt that the company would survive. General Signal's ownership, which might have provided some degree of insulation from financial difficulties, afforded little reassurance, however, because U.S. conglomerates are well known for closing their semiconductor equipment operations during downturns. As a result, many managers in SEMATECH member companies appear to have decided as early as 1990 or 1991 that GCA equipment would not be seriously considered, no matter how good it might become. The effects of this lack of coordination between the procurement decisions of SEMATECH members and the goal of the consortium's largest single project—restoring GCA—is what I believe to be the most important lesson to come from SEMATECH's experience with GCA.

Although SEMATECH correctly claimed that it could not interfere with a business decision made by General Signal, GCA's owner, the latter's divestiture illustrates another valuable lesson: the importance, and apparent difficulty, of maintaining the long-term commitment of parent companies to cooperative ventures of their subsidiaries.

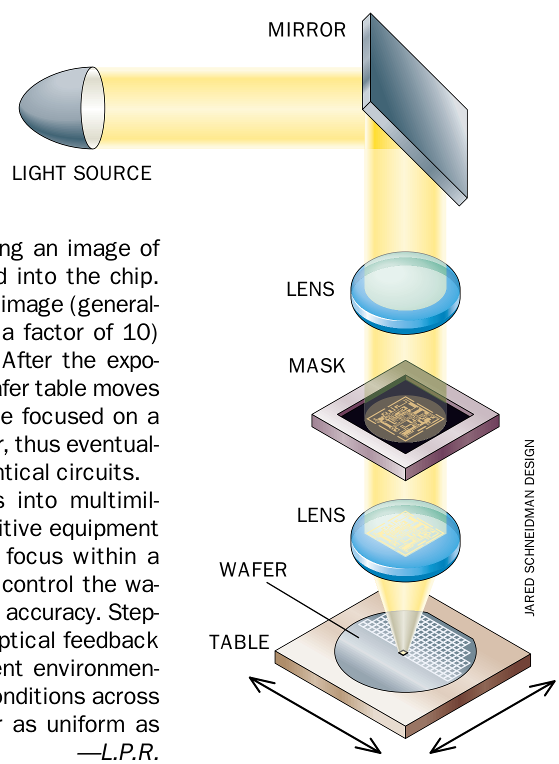
To its credit, SEMATECH was not entirely unaware of the nature of the problems it faced in restoring GCA, but the consortium was never equipped, organizationally or legally, to effect the requisite coordination among its member companies in order to make the investment in GCA pay off. Even with the broadened antitrust exemption that consortia enjoy, a consortium-wide agreement to buy GCA products might have faced serious legal stumbling blocks. (Furthermore, SEMATECH's membership never reached consensus on the issue.)

In October 1994 SEMATECH invested about $8 million in what is essentially the last remaining mainstream lithography company in the U.S.—Silicon Valley Group Lithography Systems (SVGL). Three of SEMATECH's principal members invested another $30 million, all in the form of stock rather than subsidies. The arrangement provided SVGL with the working capital it needed to manufacture steppers in higher volumes, but, more important, it alleviated the fear among SEMATECH's members that the supplier might disappear. Companies

The Anatomy of a Stepper

Step-and-repeat lithography is deceptively simple in principle. A high-intensity, short-wavelength light source is collimated and focused onto a transparent mask carrying an image of the pattern to be etched into the chip. Another lens focuses the image (generally reducing it in size by a factor of 10) onto the wafer surface. After the exposure is completed, the wafer table moves so that the image can be focused on a different part of the wafer, thus eventually producing multiple identical circuits.

What makes steppers into multimillion-dollar pieces of sensitive equipment is the need to maintain focus within a fraction of a micron and control the wafer's position with similar accuracy. Steppers use sophisticated optical feedback mechanisms and stringent environmental control to keep the conditions across the surface of the wafer as uniform as possible. —*L.P.R.*



need not fear the closure of suppliers that they themselves own.

This arrangement with SVGL was, at least in part, made in response to efforts by Canon—one of the two Japanese firms that now dominate the lithography market—to license SVGL technology. The very same month GCA was shut down in 1993, SVGL had begun negotiating with Canon for financial support in return for rights to SVGL's advanced technology. Paradoxically, U.S. chipmakers had warmly greeted this intended arrangement. They claimed that the alliance with Canon would strengthen the small lithography company enough to give them confidence in SVGL's technology. The industry's later investments in SVGL rescued it from its dependence on Canon and contributed to the collapse in November 1994 of the SVGL-Canon negotiations.

Consortia and Public Policy

Despite the highly visible failure of GCA, the years since SEMATECH was founded have seen an improvement in the competitive position of the U.S. semiconductor industry. In 1993 American companies captured 43.4 percent of the global semiconductor market, surpassing the Japanese share for the first time in eight years, and U.S. semiconductor manufacturing equipment companies once again held 50 percent of the global market, compared with Japan's 42.9 percent. Something of a consensus has emerged that SEMATECH deserves much of the credit for these gains, even though a number of other factors contributed to the recovery. These include an extended recession in Japan, the rising value of the yen, trade agreements in which Japan conceded that imports should account for 20 percent of its domestic semiconductor market, competition from low-cost Korean makers of memory chips, and the continued dominance of U.S. semiconductor companies in the microprocessor market.

"Don't fund it if you don't want to buy it."

—Papken S. Der Torossian CEO, Silicon Valley Group Lithography Systems

SEMATECH's greatest accomplishment was probably not its technical achievements by themselves but rather its role in improving relations between chipmakers and their suppliers. Once almost antagonistic, these companies are now cooperating closely. Observers have universally considered these accomplishments, along with the consortium's ostensible contribution to the fortunes of the U.S. semiconductor industry, as the gauge to measure SEMATECH's success as a model for public policy.

These achievements alone, however, are not the proper basis on which to evaluate the consortium's value. SEMATECH's work must be compared to what might have been achieved in the absence of federal support. The consortium has received well over $700 million from the federal government since 1988. From 1988 to 1994 SEMATECH's members (not counting giants IBM and AT&T) spent approximately $45 *billion* of their own money on research and development. In the face of these enormous expenditures, the argument that SEMATECH would not have worked without substantial federal funds is highly questionable.

Federal participation provided a critical anchor for activities that facilitated cooperation between SEMATECH's diverse membership. The question, then, is what level of federal financial support is required to achieve this coordination. In my opinion, a few million taxpayer dollars a year, for the first few years of SEMATECH's operations, would have been adequate for this function. Continuing subsidies of $90 million to $100 million a year do not appear justified given the enormous profits the industry has recently been enjoying. Similarly, SEMATECH's plan for keeping SVGL competitive offers no more lucid a rationale for the public money involved. As part of the deal by which three SEMATECH members made their $30-million equity investment in SVGL, the federal government agreed to provide SVGL with another $30 million in subsidies through SEMATECH and the Department of Defense. If maintaining a domestic source of lithography is so important to these profitable companies, they should be willing to provide the additional money themselves; if it is not, taxpayers should not be guaranteeing the additional return on the companies' investment.

Of course, decisions regarding the allocation of taxpayers' resources are often more strongly shaped by political compulsion than by analyses of economic efficacy. Although federal support of SEMATECH officially ends in fiscal year 1997, the lessons we can cull from its history continue to be relevant, especially as consortia continue to be formed. Perhaps the most important lesson for both public and private policymakers is to be sure that proposed consortia will be legally, financially and organizationally equipped to meet their goals. Attempting a job that is beyond an institution's charter may produce little of lasting value—and even that at great cost. SA

The Author

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Further Reading

THE REAL LESSONS OF JAPANESE RESEARCH CONSORTIA. Gerald J. Hane in *Issues in Science and Technology,* Vol. 10, No. 2, pages 56–62; Winter 1993–1994.

PRIVATIZING PUBLIC RESEARCH. Linda R. Cohen and Roger G. Noll in *Scientific American,* Vol. 271, No. 3, pages 72–77; September 1994.

R&D COLLABORATION ON TRIAL: THE MICROELECTRONICS AND COMPUTER TECHNOLOGY CORPORATION. David V. Gibson and Everett M. Rogers. Harvard Business School Press, 1994.

SEMATECH AND COLLABORATIVE RESEARCH: LESSONS IN THE DESIGN OF HIGH-TECHNOLOGY CONSORTIA. Peter Grindley, David C. Mowery and Brian Silverman in *Journal of Policy Analysis and Management,* Vol. 13, No. 4, pages 723–758; Fall 1994.

Training the Olympic Athlete

Sports science and technology are today providing elite competitors with the tiny margins needed to win in world-class competition

by Jay T. Kearney

CAMERAPHOTO-ARTE / ART RESOURCE

The lore of ancient Greece recalls an Olympic athlete who was determined to become the strongest person in the world. Every day Milon of Croton (*above*) would pick up a calf, raise it above his head and carry it around a stable. As the calf grew, so did Milon's strength, until eventually he was able to lift the full-grown cow.

Milon, who won the wrestling contest five times, intuitively grasped one of the basic tenets of contemporary sports science. Progressive resistance training—the stressing of muscles with steadily increasing loads—is something well understood by the more than 10,000 athletes from 197 countries who will go to Atlanta, Ga., next month for the centennial of the modern Olympic Games.

During the past half century, however, sports science has refined the basic principles of training beyond the understanding of the Greeks. Exercise physiologists and coaches draw on new scientific knowledge to help athletes develop a balance of muscular and metabolic fitness for each of the 29 sports in the Olympic Games. Biomechanical experts employ computers, video and specialized sensors to study the dynamics of movement. Design engineers incorporate advances in materials and aerodynamics to fashion streamlined bobsleds or racing bicycles. Sports psychologists build confidence through mental-training techniques. The integration of these approaches affords the small gains in performance that can translate into victory.

Working the Body

Understanding how training builds the strength and stamina needed for Olympic events requires basic knowledge of how the body produces energy. All human motion depends on the use and resynthesis of adenosine triphosphate (ATP), a high-energy molecule consisting of a base (adenine), a sugar

(ribose) and three phosphate groups. The breaking of the bond between two phosphate units releases energy that powers muscle contractions and other cellular reactions. Humans have a very limited capacity for storing ATP. At a maximum rate of work, the five millimoles of ATP available for each kilogram of muscle is completely depleted in a few seconds. To sustain activity, the body has three interrelated metabolic processes for continually resupplying the molecule. Which one predominates depends on the muscles' power requirements at a given moment and on the duration of the activity.

The most immediately available source for reconstructing ATP is phosphocreatine, itself a high-energy, phosphate-bearing molecule. The energy released by the breakdown of the phosphocreatine molecule is used to resynthesize ATP. The phosphocreatine system can recharge ATP for only a short while—just five to 10 seconds during a sprint. When the supply of this molecule is exhausted, the body must rely on two other ATP-generating processes—one that does not require oxygen (anaerobic) and one that does (aerobic).

The anaerobic process, also known as glycolysis, is usually the first to kick in. Cells break down specific carbohydrates (glucose or glycogen in muscle) to release the energy for resynthesizing ATP. Unfortunately for the athlete, the anaerobic metabolism of carbohydrates can yield a buildup of lactic acid, which accumulates in the muscles within two minutes. Lactic acid and associated hydrogen ions cause burning muscle pain. But lactic acid and its metabolite, lactate, which accumulates in muscle, do not always degrade performance. Through training, the muscles of elite competitors adapt so that they can tolerate the elevated levels of lactate produced during high-intensity exercise.

Even so, lactic acid and lactate eventually inhibit muscles from contracting. So anaerobic glycolysis can be relied on only for short bursts of exercise. It cannot supply the ATP needed for the sustained activity in endurance events. That task falls to aerobic metabolism—the breakdown of carbohydrate, fat and protein in the presence of oxygen. In contrast with anaerobic glycolysis, the aerobic system cannot be switched on quickly. At least one to two minutes of hard exercise must pass until the increase in breathing and heart rate ensures delivery of oxygen to a muscle cell. During that interval, the athlete depends on a combination of stored ATP, the phosphocreatine system or anaerobic glycolysis to provide energy. With the activation of the aerobic processes, these other systems function at a lower level. In the aerobic phase, for instance, lactic acid and lactate are still produced, but they are consumed by less active muscles or metabolized in the liver and so do not accumulate.

Although the aerobic system is highly efficient, its ability to supply the muscles with energy reaches an upper threshold. If still more ATP is needed, the muscles must step up the use of various other energy sources. A soccer player in the middle of a 45-minute half, for example, would depend mostly on aerobic metabolism. But if he needed to sprint briefly at full speed, his body would immediately call on stored ATP or ATP reconstituted by the phosphocreatine system to supplement the aerobic system. Similarly, if this high-intensity sprint continued for five to 15 seconds, the player would experience a rapid increase in the rate of anaerobic glycolysis. As the play ended, the body would return to its reliance on the aerobic metabolic system, while the capacities of the other energy systems regenerated themselves.

Coaches must understand the requirements of their sports and adjust the intensity or duration of training to improve an athlete's aerobic or anaerobic functioning. The fundamental principle of training is that sustained activity will result in adaptation of the muscles to

PHOTOGRAPHS BY KEN REGAN *Camera 5*

OLYMPIC HOPEFULS Betsy and Mary McCagg train together at the headquarters of the U.S. national rowing team in Chattanooga, Tenn. Although the twins often train and compete as a pair, they will participate in the Olympics as members of an eight-woman crew.

Photography by Ken Regan

ever increasing levels of stress—an idea sometimes referred to as the stimulus-response model. Over time, training will induce physiological changes, which are adapted to the needs of a specific sport. The distance runner's training, for example, focuses on enhancing the capabilities of the aerobic system. In contrast, a weight lifter would concentrate on strength and power instead of the endurance requirements of the distance events.

Going the Distance

For the Olympic coach, training also becomes the judicious management of diminishing returns. During the first year, an athlete might invest 50 to 100 hours of training to improve 10 to 15 percent in a season. At the peak of his or her career, the same athlete might put in 1,000 hours of intense and concentrated effort to achieve an improvement of a single percentage point. Such a small gain appears to be a seemingly poor return on investment. But consider that the margin of victory in the track sprint events in the 1992 Olympics—the average difference between a gold and silver medal—was only 0.86 percent, little more than two tenths of a second.

The details of how coaches and athletes tailor training to specific sports are perhaps best illustrated by the examples of competitors in widely differing events. At the Atlanta Games, the longest competition will be the men's cycling race, which lasts about five hours. The 228-kilometer road race will bring together rivals whose training is optimized for sustained aerobic effort, while taking advantage of extraordinary advances in the aerodynamics of cycling technology. Lance Armstrong of Austin, Tex., is expected to be a strong contender for a medal. Although he did not bring home any medals in the 1992 Olympics, he won the world championship in 1993 and, in 1995, a day-long segment of the Tour de France.

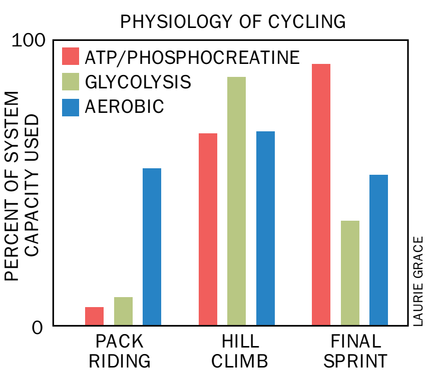
Armstrong's innate ability was evident from an early age. At age 15, he demonstrated the aerobic capacity that places him among the upper 1 to 2 percent of athletes worldwide. A measure of overall cardiorespiratory fitness, aerobic capacity is the maximum amount of oxygen that can be taken up and delivered to muscle cells for use in making ATP. It also goes by the name of maximum oxygen uptake, or VO_2 max. Armstrong registered a maximum oxygen uptake of 80 milliliters of oxygen per kilogram of body weight per minute, a rate he continues to maintain at the age of 24. This measurement is almost double that of the average fit male.

As part of his preparation for the Olympics, Armstrong has made several trips to the U.S. Olympic Committee's largest training center, located at the committee's headquarters in Colorado Springs. I am part of the sports science team there that evaluates and advises athletes and their coaches on training improvements.

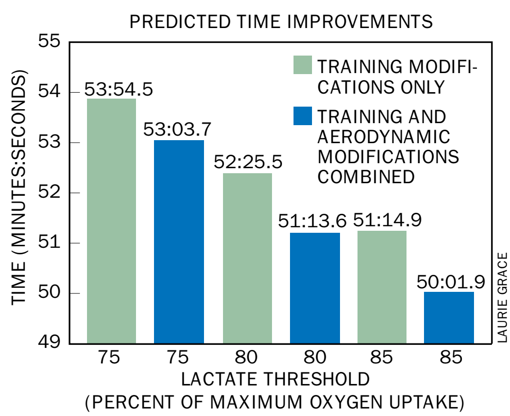

MIKE POWELL *Allsport*


PASCAL RONDEAU *Allsport*

LANCE ARMSTRONG, who will compete in the Olympics, won a stage (a day-long segment) of the Tour de France in 1995 (*above* and *right*).



PHYSIOLOGICAL DEMANDS for cycling vary throughout the event. A rider will tap stored ATP or the phosphocreatine system or will depend on anaerobic glycolysis to provide the additional energy needed for a hill climb or a final sprint.



ANALYSIS of Armstrong's cycling was performed at the U.S. Olympic Training Center in Colorado Springs. Recommendations included changing his riding position to enhance aerodynamics and training so that he increased his lactate threshold, thereby delaying an accumulation of lactate. By following both suggestions, he could reduce his time in a race spanning 40 kilometers by nearly four minutes.

During one of his stays, Armstrong completed a metabolic assessment on a cycling ergometer, a machine in the sports physiology laboratory that precisely controls workload (how hard and fast an athlete pedals). Tests conducted while Armstrong labored on the ergometer measured VO_2max, heart rate and lactic acid levels. Armstrong registered the highest VO_2max of any U.S. cycler. When performing at this peak level, he was able to marshal a world-class 525 watts of pedaling power.

Physiologists also assess two other benchmarks of performance—how efficiently the athlete uses oxygen and how quickly lactate builds up in the muscles. This latter measurement, the lactate threshold, is represented as a percentage of VO_2max. It is at the threshold that lactate begins to accumulate, causing pain and burning.

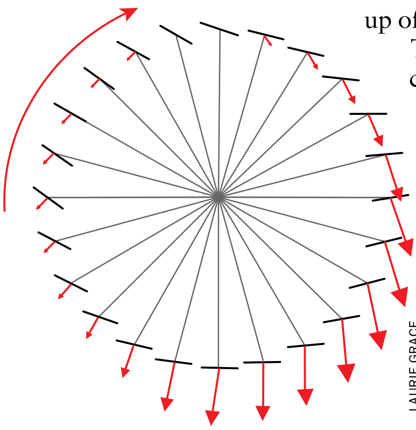
At the training center, Armstrong's lactate threshold measured 75 percent, which was 10 percentage points less than the average for the best cyclists on the U.S. national team. The evaluation team recommended that he train more often at close to or slightly above his threshold. Training at this intensity produces changes in circulatory, nervous and enzymatic functions that can raise the lactate threshold, thereby delaying a buildup of lactate.

Training to improve physiological capacity is only one variable—and sometimes not even the most important one—in streamlining performance in a sport that relies as much on technology as cycling does. During Armstrong's visits to Colorado Springs, we have also assessed his pedaling technique, riding position and bicycle design.

In our biomechanics laboratory Armstrong rode a stationary bicycle that measured the direction and magnitude of the forces on the pedals [*see illustration at left*]. Jeffrey P. Broker, a biomechanics specialist at the center, determined that Armstrong pedaled almost identically with the left and right leg. The only flaws identified were minor weaknesses in propulsive force at the top and bottom of the pedaling cycle.

An analysis of Armstrong's body po-

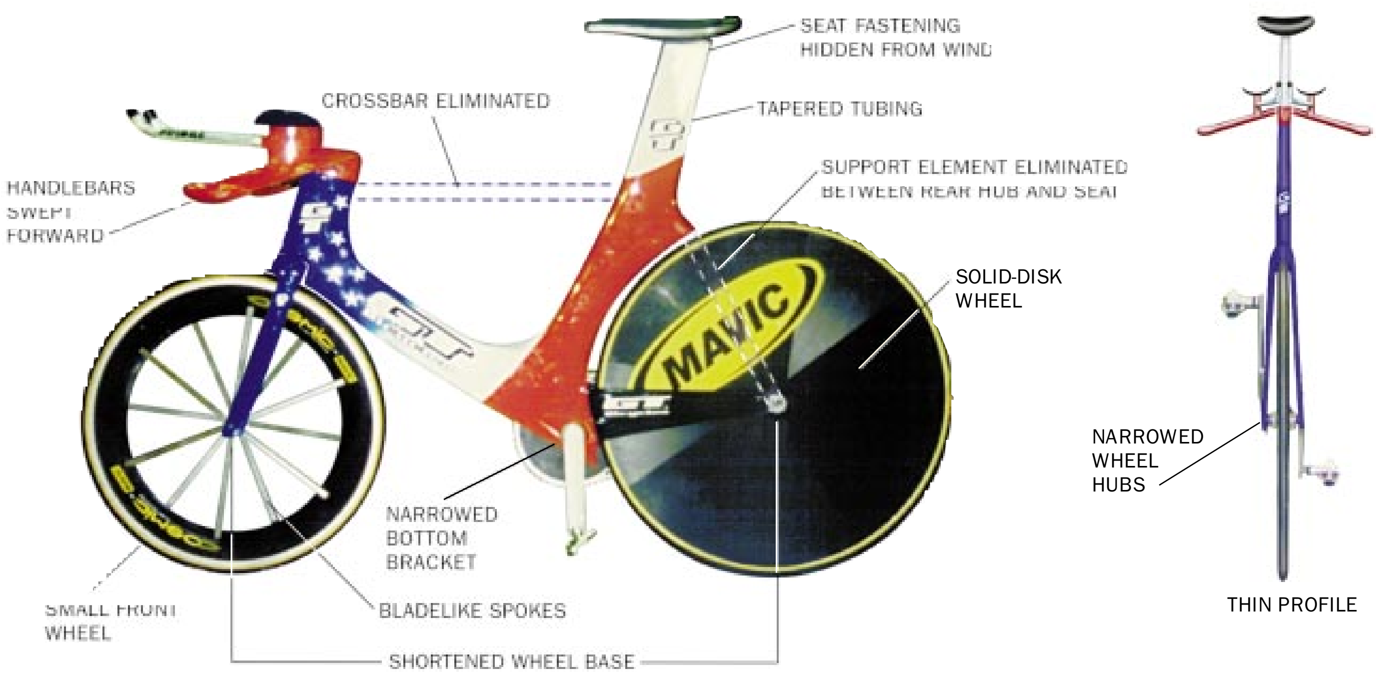
PEDAL MOTION of Armstrong was analyzed at the U.S. training center. The length and angle of the arrows indicate the magnitude and direction of forces applied by Armstrong's left foot. The diagram revealed that he needed to exert force on the pedal at both the top and bottom of the cycle in the direction of the rotation.



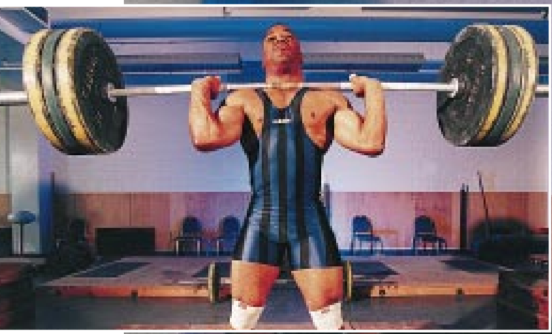
LAURIE GRACE

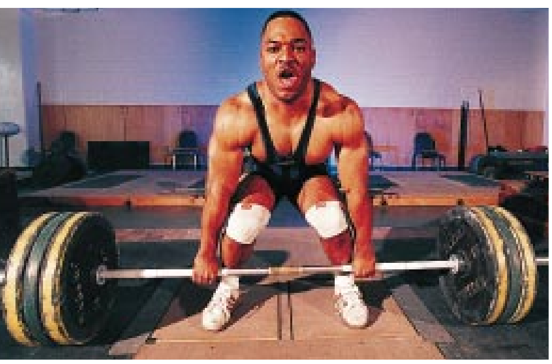
COURTESY OF JAY T. KEARNEY

AERODYNAMICS have preoccupied bicycle designers since the early part of this century, as is evident in early racing bicycles equipped with canopies, called fairings, that helped to reduce drag (*above*). The most advanced bicycles today are deployed in track racing. The recently unveiled SB II, or Superbike II (*below*), has a lightweight carbon-fiber frame. It also has a range of aerodynamic design elements. Similar features are incorporated into bicycles for some road-racing events in which Armstrong competes.



LAURIE GRACE





sition proved more constructive. The wind drag encountered by rider and bicycle increases as the square of velocity and can dramatically affect speed. The position of the rider on the bike becomes so critical that some cyclists have assumed bizarre postures. Graeme Obree, who won the 1995 world championship in the individual pursuit race and set the one-hour record in 1994, contrived a position in which his head was pitched far in front of the handlebars. His arms were completely tucked under his chest, which was resting on the handlebars. Obree's unconventional riding position, one that was difficult for other cyclists to master, was banned by the International Cycling Union because it was unstable and dangerous.

The U.S. Olympic Committee evaluation team assessed Armstrong's riding position through videotapes taken during competitions and at the training center. The footage revealed that Armstrong's trunk needed to be lower to reduce drag. His relatively wide arm spacing permitted wind to stall against his upper torso, requiring more power at any given speed than a flatter, more streamlined position would. Moreover, his head position allowed his helmet to project up into the airstream. We suggested he move his seat forward and up slightly, his handlebars forward and down and his hands further forward on the "aero" bars—aerodynamic extensions of the standard drop handlebars.

We also recommended design changes to his helmet, including a longer, tail-like extension in the rear (to keep the wind flowing in a smooth stream over his head and onto his back). Testing with power-monitoring equipment showed that Armstrong's new position resulted in an increase in speed of 1.44 kilometers per hour relative to his old position. If combined with the various physiological improvements recommended, Armstrong could cut nearly four minutes off his 40-kilometer race time [*see graph at bottom right on page 54*].

No matter how they train, Armstrong and other cyclists in Atlanta are sure to come equipped with bicycles incorporating the latest designs. To a great extent, these innovations have come out of Project '96, a collaboration between the U.S. Cycling Federation, the U.S. Olympic Committee and corporate America, with the mission of combining advanced training and technology to prepare athletes for the games in Atlanta.

Designers have inspected every square inch of the frame to boost aerodynamics. They have made the front wheel smaller and narrower to cut wind resistance and to allow teammates to ride closer to one another. In addition, by using high-strength composite materials, they have minimized the amount of structural support needed. The tubing

TIM MCRAE, a member of the U.S. national weight-lifting team, executes a 130-kilogram lift called the clean and jerk at the U.S. training center (*bottom to top*). Two high-speed cameras photograph the athlete to make an assessment of the pattern of motion (*below right*). Combining the videos provides a three-dimensional stick-figure image for analysis of lifting technique (*inset*).

found on an ordinary bicycle has been replaced by structural members that taper off from front to back in a teardrop shape, as does the wing of an airplane [*see bottom illustration on page 55*].

Examining every aspect of Armstrong's performance has improved his readiness for the Olympics. His lactate threshold has increased from 75 to 79 percent. He now practices or competes up to 40,000 kilometers every year. (This performance contrasts with the 1,600 kilometers or so he cycled at the age of 15.) Armstrong has also logged better results in recent races. In 1995 he won the U.S. Tour DuPont, and his training helps to explain why he scored an astonishing breakaway victory in a 167-kilometer stretch of the Tour de France, from Montpon-Menesterol to Limoges.

Weight lifting is at the opposite end of the physiological spectrum from cycling. Whereas cycling is the longest event in the Olympics, weight lifting is the shortest. Weight lifters require extreme muscular strength and power, as opposed to endurance. The act of lifting a 120- to 250-kilogram barbell demands up to 3,000 watts of power, enough to illuminate 50 lightbulbs, each 60 watts, for a second. For these events, the athlete relies on ATP stored in the muscles and the regeneration of ATP by the breakdown of phosphocreatine. During the long recovery period in training between each set of five or fewer lifts, these energy systems replenish themselves aerobically.

Eastern European Training

The U.S. has but a slight chance to win a medal in Atlanta, because the championship eastern European weight-lifting programs have endured in the newly independent countries that survived the fracturing of the Soviet bloc. Nevertheless, U.S. athletes have begun to adopt some of the same training methods embraced by their competition.

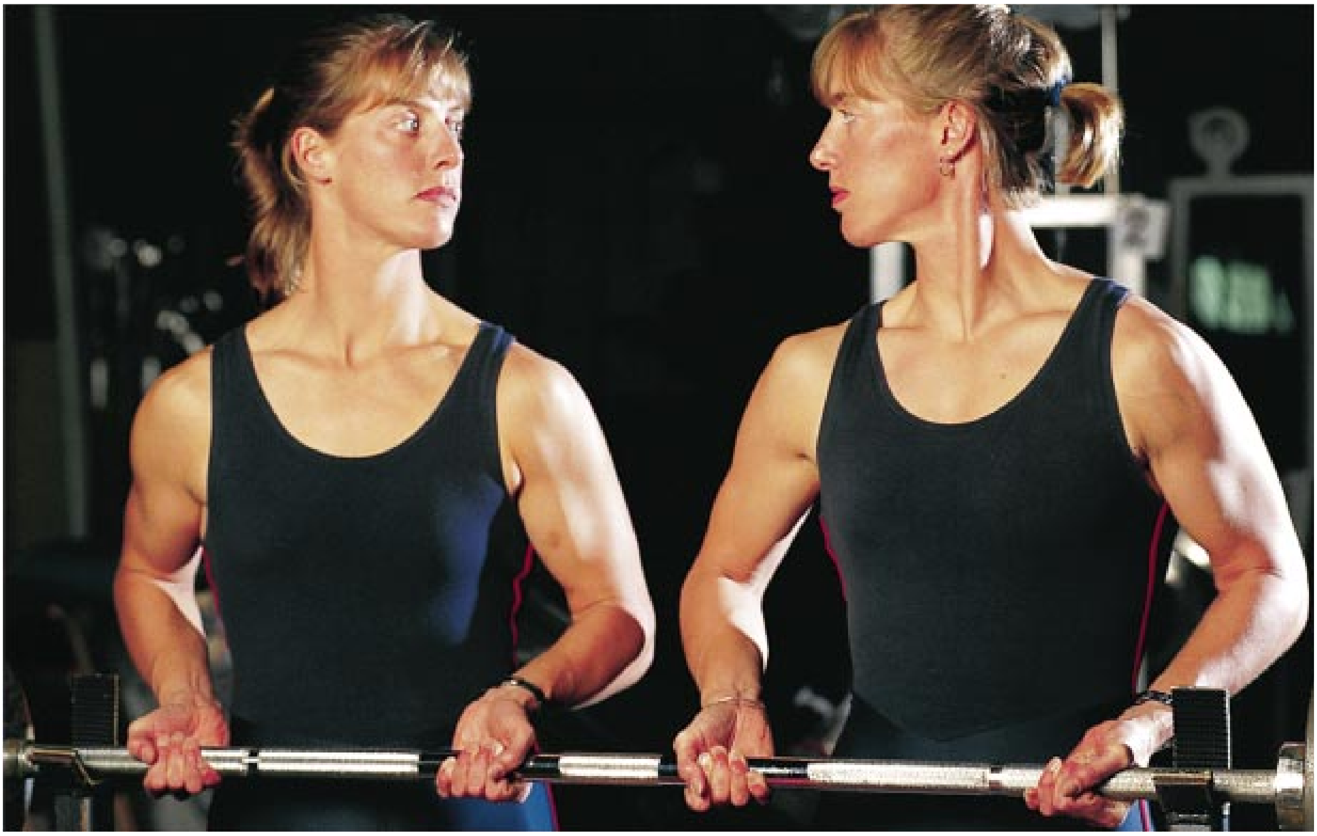
During the past five years, Dragomir Cioroslan, a Romanian-educated coach who won a bronze medal for that country in the 1984 Olympics, has taken over as the resident weight-lifting coach at the U.S. Olympic Training Center. Cioroslan has instituted a highly structured, year-round program based on his eastern European training. Tim McRae is one of the coach's protégés. With his anvillike upper body, McRae might have been tapped for the National Football League instead of the U.S. national weight-lifting team if he had not stopped growing at 160 centimeters (five feet three inches). McRae, in fact, took up weight lifting because he hoped it would make him grow taller and more competitive in football.

McRae can lift more than twice his body weight, a feat that has helped make him national champion five times and the U.S. record holder in three weight classes for the two main competitive events—the snatch and the clean and jerk. In the snatch, an athlete grips the bar with hands placed two to three times shoulder width. He then pulls it to chest level. He squats under the bar, catching it overhead with straightened arms. Then he returns to a standing position with the bar above his head. The clean and jerk proceeds with hands at shoulder width. The athlete brings the bar to chest level, squatting underneath to secure it on the shoulders before standing. After a pause, he finishes with the jerk, a full extension of the arms. An explosive vertical thrust from the legs aids him in lifting the bar.

McRae's stature—short limbs, long torso and muscular build—suits him well for weight lifting. For one, his height means that he need lift the bar only a relatively short distance. Perhaps McRae's most remarkable physical skill can be seen when he jumps straight up nearly a meter from a standing position, a demonstration of the kind of leg power needed in lifting.

Weight lifting is the ideal sport to illustrate another fundamental concept of modern athletic training. Periodization, as it is known, is the structured, sequential development of athletic skill or physiological capacity through organizing training into blocks of time. The time periods involved range from an individual lesson to annual cycles. Weight lifters prepare two to four months for a competition through a macrocycle, a period that itself includes several shorter segments called mesocycles.

Cioroslan takes the athletes on the national team through three to four macrocycles during the year, each leading up to a major competition. A macrocycle begins with a preparatory phase, a mesocycle that lasts about eight to 10 weeks. Each week during this mesocycle, McRae and other athletes will perform 600 lifting repetitions at 80 to 90 percent of the maximum amount they are able to lift. The high-volume, medium-intensity workouts elicit changes in muscle, connective tissue, ligaments and other soft tissues. These changes enable the athletes



to tolerate heavier lifting in the next training phase.

In the second mesocycle, which lasts another four to five weeks, the team's training objective is to bolster strength and power by doing fewer repetitions (200 to 300 per week) but using heavier weights that require 90 to 100 percent of an athlete's lifting capacity. The strongest of Cioroslan's athletes might lift more than three million kilograms a year.

The final mesocycle includes two phases leading up to the event. During the first phase, the athlete works at maximum intensity to ensure that the strength and power gains from earlier training periods translate into competitive performances. The last week or so of this mesocycle focuses on tapering: the reduction of the volume and intensity of exercise to allow the athlete to recover from the stresses of training without losing the benefits of intensive preparation.

In addition to applying physiological principles to training, weight lifters, like cyclists, take advantage of an array of sophisticated monitoring equipment. Weight lifting is one of the most technically demanding sports, requiring use of a specific sequence of muscles. If each muscle group, from the knee and hip extensors to the shoulder and arm muscles, does not activate in sequence, the lifter may not raise the bar high enough, or else it may sway precariously back and forth.

Sarah L. Smith, a biomechanical specialist at the Colorado Springs training center, tested McRae to track the smoothness of the S-shaped trajectory that the bar must trace from ground to full extension. The analysis involves two cameras and two platforms containing sensors that record the forces applied through each foot. If the load on each foot differs, the lifter may lose symmetry between his hands—that is, he may raise one side of the bar faster than the other. Testing showed that asymmetries in McRae's lifting made it difficult to catch and stabilize the bar during the snatch, a finding that led to several refinements in technique.

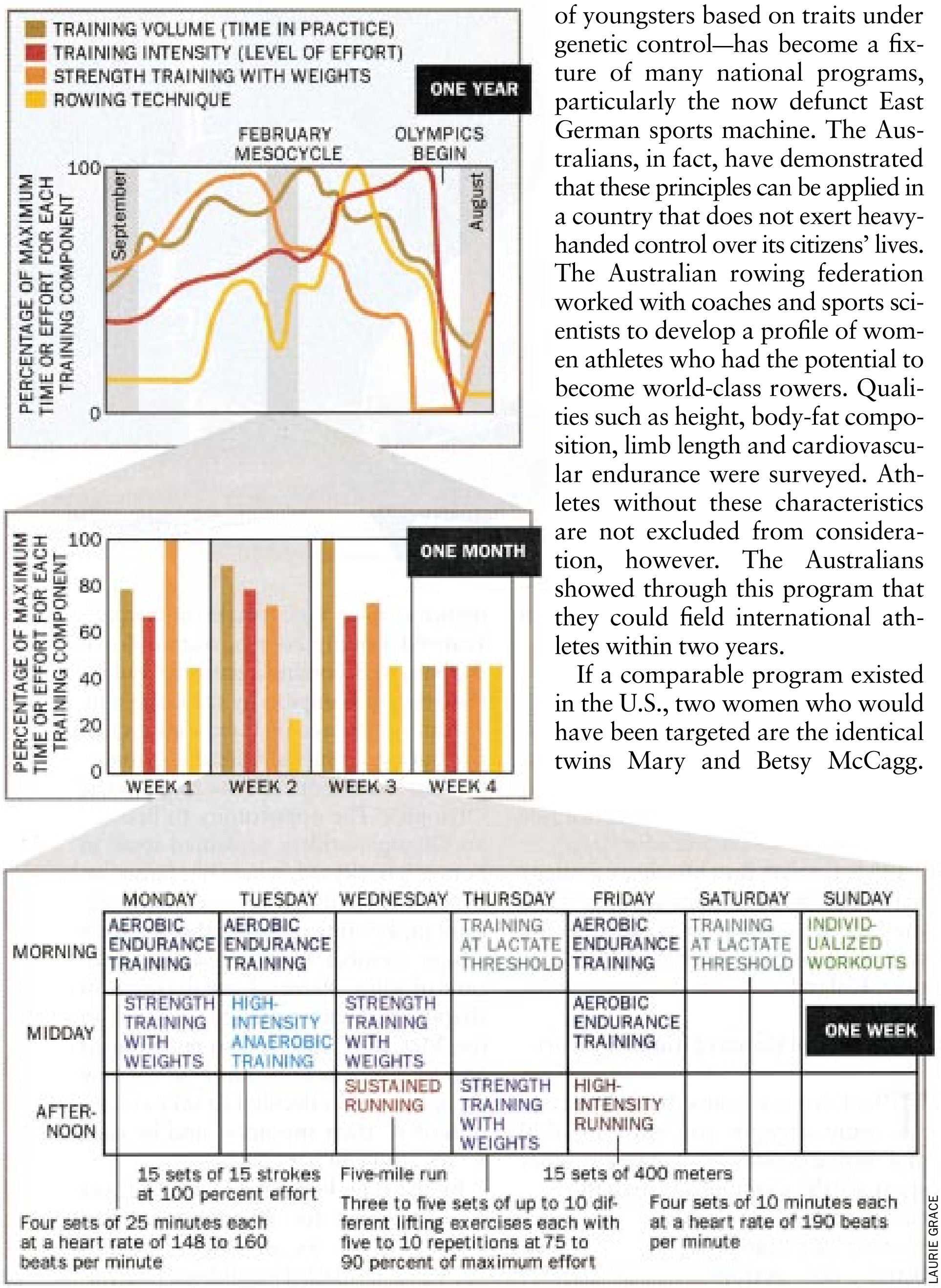
Choosing One's Parents

McRae's ability to lift more than twice his body weight may be a matter of birthright or his early exposure to the sport—or perhaps a little of both. Sports scientists often ponder the role of genes and environment in the makeup of the elite athlete.

The physiologist Per-Olof Åstrand coined the often repeated maxim: to become an Olympic athlete, choose your parents well. That genetics probably plays at least some role has been demonstrated by Claude Bouchard, an anthropological geneticist and exercise physiologist at Laval University in Quebec. In the 1980s Bouchard studied paternal and identical twins. He found that some pairs of sedentary twins were able to nearly double their maximum oxygen uptake after 15 to 20 weeks of physical training, whereas others showed minimal gains in fitness. These findings suggested a genetic basis for the superior physiology of top-notch athletes. Bouchard is now looking for genetic markers that would distinguish between those with a high response to training and those who adapt less well.

As yet, no elite training programs seek out competitors with specific "athletic" genes. But they often do the next best thing. The physical typing of a prospective athlete—the systematic recruitment

STRENGTH TRAINING with weights is a critical part of the regimen of the McCagg sisters and the rest of the U.S. rowing team. But this type of training is just part of their periodization routine: the programmed scheduling of training by year, quarter (macrocycle, which is not shown), month (mesocycle), week and day (*graphs and table on opposite page*). The volume, intensity and type of training are carefully varied until the tapering-off period just before the Olympic Games begin.



of youngsters based on traits under genetic control—has become a fixture of many national programs, particularly the now defunct East German sports machine. The Australians, in fact, have demonstrated that these principles can be applied in a country that does not exert heavy-handed control over its citizens' lives. The Australian rowing federation worked with coaches and sports scientists to develop a profile of women athletes who had the potential to become world-class rowers. Qualities such as height, body-fat composition, limb length and cardiovascular endurance were surveyed. Athletes without these characteristics are not excluded from consideration, however. The Australians showed through this program that they could field international athletes within two years.

If a comparable program existed in the U.S., two women who would have been targeted are the identical twins Mary and Betsy McCagg. The McCagg sisters, stalwarts of the U.S. women's rowing team, are perfectly endowed for their sport. Both are 188 centimeters (six feet two inches) tall and weigh 79 kilograms (175 pounds). Both have body-fat compositions lower than that of the average college-age male (meaning most of that weight is muscle) as well as long legs that facilitate the execution of a long, powerful stroke.

The McCaggs also demonstrate that genes are only of value in an environment that permits development of one's natural physical assets through training. The family also had a multigenerational tradition of involvement in the sport. The McCaggs' father and grandfather—as well as many other family members—rowed competitively while attending Harvard University and other eastern establishment colleges.

After finishing their rowing careers in an exceptional high school program, the sisters attended Radcliffe College, with its long tradition in women's rowing. Expectations for the twins remained high from the outset: they joined the Radcliffe varsity team as freshmen. In their sophomore and junior years, the team went undefeated. Both sisters made the Olympic team in 1992; their crew of eight scored a sixth-place finish.

Improving the Best Rowers

The McCaggs compete in either eight- or two-woman crews for sweep rowing, in which each crew member pulls one long oar with both arms. As much as any event, the 2,000-meter distance they traverse in six to seven minutes requires a balance of athletic physical capabilities: muscular power combined with a highly honed aerobic capacity, and an ability to tap into one's anaerobic pathway for more muscle power.

The McCaggs and the rest of the national team came to the training center in Colorado Springs in 1991 for a physiological and biomechanical assessment to determine why they encountered difficulties in the last 500 meters of a race. To their coaches, it appeared that they had failed to develop the requisite anaerobic capacity—and so were unable to achieve the increase in rowing power required in a final sprint.

Testing at the training center showed that, in actuality, the team had attained a level of anaerobic fitness matching that of the best rowers in the world. What the members lacked was sufficient aero-

McCAGG SISTERS ready their oars for a daily training session on the Tennessee River; their coach, Hartmut Buschbacher, watches a video of the two women rowing.

TAMMY FORSTER prepared for the Olympic trials at the 50-meter shooting range at the U.S. training center. Forster did not qualify for the Olympic team.

bic capacity to carry them through the first 1,500 meters of a race without accumulating debilitating levels of lactate.

Later in 1991 someone with ideas about how to solve the problem of the anemic finishes arrived in the U.S. That year Hartmut Buschbacher, the former coach of the East German women rowers, took charge of the U.S. national team. Ironically, it was an East German junior women's team coached by Buschbacher that had beaten a U.S. team on which the McCaggs had rowed in 1985—an event that stiffened the sisters' resolve to become more competitive.

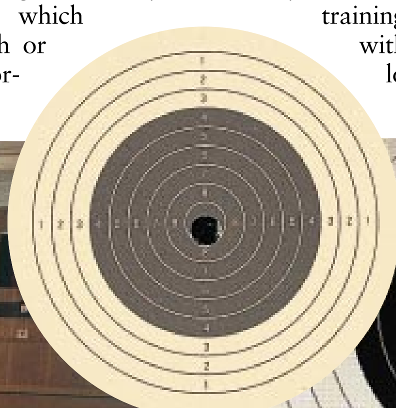
Buschbacher soon established a full-time resident athlete program in Chattanooga, Tenn., with a group of 15 carefully screened women. His philosophy of coaching borrows extensively from the systematic training principles for which the East Germans were known. Buschbacher applied concepts of periodization, alternating different mixes of volume and intensity of training that helped to correct the aerobic deficit [*see graphs and table on preceding page*].

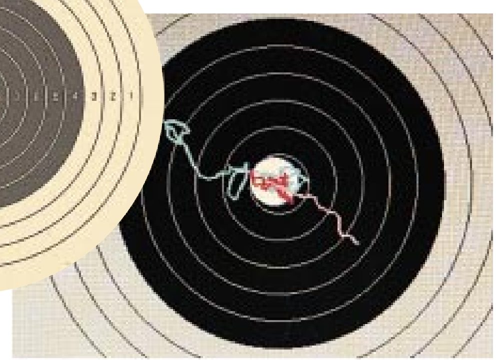
Evidence that Buschbacher's strategy may be helping came last summer when the McCaggs, racing in a team of eight, won the world championships in Tampere, Finland.

The Mental Game of Target Practice

The Olympic events that rely less on brute strength and more on skill and mental conditioning than any other sport are the shooting and archery competitions, in which women can match or better the performance of men. One female shooter, 27-year-old Tammy Forster, started down the path to becoming a national and international champion by watching television. At the age of four, seeing Olga Korbut's gold-medal-winning gymnastic feats made Forster vow to go to the Olympics. The opportunity to become an Olympic athlete presented itself in Forster's backyard, where her father, an expert rifleman and an occasional entrant in shooting contests, showed each family member how to use and take care of guns. Parental involvement in shaping the young athlete, a theme in the McCaggs' career, also encouraged Forster. Once her commitment became clear, her father decided to take classes in how to train shooters—and he now serves as one of her coaches.

By the time Forster was 15, she was training for 90 minutes a day with an air rifle or an unloaded small-bore (.22 cal-





ACTUAL TARGET SIZE (*above left*) for an event in which athletes aim a rifle without a scope from 10 meters (*left*). A laser tracking system detects where Forster aims the rifle (*above*).

SHOOTING SHOES provide a stable base to fire from a standing position.

iber) rifle indoors. She is a testament to the benefits of perseverance, showing that intensive training can in some sports make up for a lack of innate ability. Not a natural talent, Forster observed her sister shoot equally well while spending only a quarter of the time in practice. Forster nonetheless stayed with it. By 1985 she had won a silver medal at the junior national competition, and she chose to go to West Virginia University to train with Ed Etzel, an Olympic gold medalist in 1984.

In 1991 Forster took up residency at the Colorado Springs training center. Her stay has allowed her to devote full time to training for the 10-meter air-rifle contest and the three-position shooting event. The latter contest requires firing a small-bore rifle (one shooting a small-diameter bullet) at targets 50 meters away while lying, kneeling and standing. She has especially labored on the mental-rehearsal techniques she needs in order to muster the focused concentration essential to excelling in this event. Her efforts have improved her skills, although she fell short of winning one of the two open spots on the women's Olympic shooting team in the 10- and 50-meter events. Forster's training, however, provides an illustration of the benefits psychology brings to sports.

The roots of the sports psychology field that are the basis for Forster's skills extend back almost a century, when Norman Triplett discovered that athletes performed better when competing against one another than when competing against the clock. Sports psychology began to gain a broad appeal in the 1970s, when the profession started applying a set of cognitive and behavioral techniques to athletic training. At that time, new research showed that mental practice alone could improve motor performance.

As elements of her rehearsal training, she combines a number of techniques—among them, muscle relaxation exercises, mental visualization of a performance, and recording of her accomplishments and day-to-day emotions in a journal. She also sets out a series of realistic objectives that she can accomplish during each practice.

Relaxation exercises allow the shooter to heighten concentration and to recognize sources of muscle tension in the shoulders and back that can affect the accuracy of a shot. During visualization, Forster may picture herself aiming and shooting; at other times, she sees herself as a bystander watching the event from the sidelines. The more active imagery, when she actually imagines holding the rifle, seems to yield more of a performance gain.

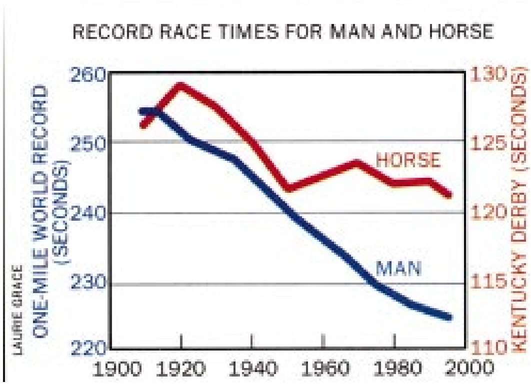
Forster repeats a visualization routine before each shot she takes in competition. In her mind, she moves slowly through each step, from standing on the firing line to bringing the rifle into position to firing an actual shot. She goes through this mental exercise before each of the 60 shots in the three-position competition. Invoking this state of focused calm before each shot, a shooter may spend up to two and a half hours in preparation and firing, the time limit for a shooting event. The winner, who is gauged on accuracy, not speed, will hit the bull's-eye with more than 90 percent of the shots made in the two events.

Forster has also worked directly with U.S. Olympic sports psychologist Sean McCann to allay the perfectionism that has sometimes caused her to lose confidence in the accuracy of her aim. To assess her technique, she shot a rifle equipped with an infrared laser. An analysis of the placement of the beam on the target showed that her aim was nearly flawless. But she continually tried to make adjustments, and so her ability to remain steadily fixed on the target deteriorated after five or six seconds.

McCann helped Forster develop visualization routines that included a series of verbal cues to quell these fears—the repeating of simple words like "relax" or "ready." Persistence has yielded some payoffs. During her residency, Forster has won two world cups, and last year she placed second at the national championships—a testament to the accomplishments that accrue from the slow, deliberate pace that characterizes this most cerebral of sporting events.

The combination of physical and mental training employed by the rower or shooter applies across the full range of the 29 Olympic sports, from swimming to baseball. Sports science and technology have contributed to a trend in which world records in all sports keep falling. Winning times for horses in the Kentucky Derby have declined at a slower rate than records in the one-mile run have. It is certain, moreover, that the Olympic Games in Atlanta this summer will once again challenge the limits of human performance. SA

LAURIE GRACE



The Author

JAY T. KEARNEY, who holds a doctorate degree in exercise physiology from the University of Maryland, is a senior sports physiologist for the U.S. Olympic Committee. From 1974 to 1986 he was professor of physiology at the University of Kentucky, and from 1988 to 1992 he served as director of the sports science and technology division of the U.S. Olympic Training Center in Colorado Springs. He was on the flat-water canoeing team slated to go to the 1980 Olympic Games in Moscow, but the team stayed home because of the Carter administration's boycott protesting the Soviet invasion of Afghanistan. Professionals from the U.S. Olympic Committee's sports science and technology division contributed to this article—in particular, research assistant Susan Mulligan.

Further Reading

TRAINING FOR SPORT AND ACTIVITY: THE PHYSIOLOGICAL BASIS OF THE CONDITIONING PROCESS. Jack H. Wilmore and David L. Costill. Human Kinetics Publishers, 1988.

THEORY AND METHODOLOGY OF TRAINING: THE KEY TO ATHLETIC PERFORMANCE. Tudor O. Bompa. Kendall/Hunt Publishing, 1994.

THE OLYMPIC FACTBOOK: A SPECTATOR'S GUIDE TO THE SUMMER GAMES. Edited by Rebecca Nelson and Marie J. MacNee. Visible Ink, 1996.

Science in the Sky

by Tim Beardsley, *staff writer*

It's about life on Earth!" gushes an advertising slogan for the International Space Station, the $27-billion orbiting laboratory now taking shape at a Boeing plant in Huntsville, Ala., at the Khrunichev works in Moscow and at other locations around the globe. Truer words were probably never spoken about the 400-ton space behemoth, which after 12 years of redesigns, reviews and cliff-hanging votes, seems finally to have reached political escape velocity.

The space station's brightening prospects have less to do with its scientific potential than with terrestrial politics. Space station boosters have for years claimed that research in orbit will generate huge scientific and commercial rewards. But the scientific returns from more than a decade of experiments in weightless conditions on space shuttle flights, while sometimes intriguing, have not generated fundamental insights. Scientific panels, such as the National Research Council's space studies board, have warned that although some interesting research will be possible on the station, the expected returns cannot justify the facility's overall cost.

Commercial interest, too, is cool, even though the National Aeronautics and Space Administration has provided substantial incentives for businesses to conduct research and to manufacture high-tech products in space. To date, no large companies are planning major research or manufacturing efforts on the space station. James Ferris of Rensselaer Polytechnic Institute insists that "nothing has come out of microgravity research to convince me that a material can be fabricated in orbit that is going to be better than what you can make on Earth."

Daniel S. Goldin, NASA's administrator, tacitly acknowledges such criticisms in stating the agency's rationale for the project. Science and commerce are not the reason for building the space station after all. "The space station is being built to see how people can live and work safely and efficiently in space," Goldin intones. "We can do stunning science," he adds as an afterthought, in fields ranging from biotechnology to materials processing, but "that isn't the justification."

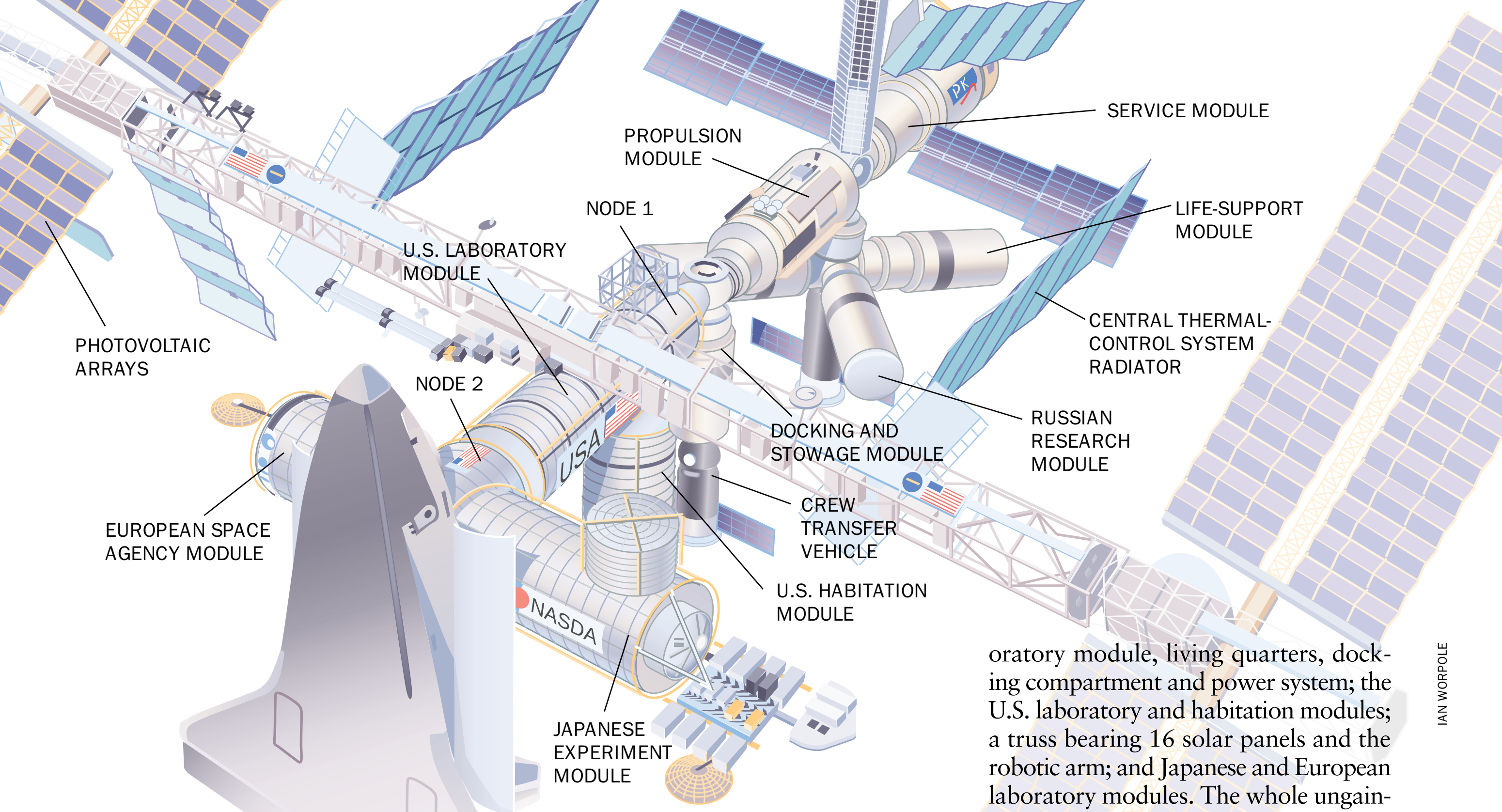
Why exactly the world needs to learn how people can live and work in space is a question Goldin glosses over. Nevertheless, ministers in Europe and Russia have been cajoled and bullied into promising funds to support their share of the station, lured by the prospect of providing jobs for defense-industry workers and cementing peaceful ties between former geopolitical rivals. The U.S. House of Representatives, which three years ago came within one vote of canceling the project, has approved spending $2.1 billion a year to complete it by June 2002.

Many researchers fear that the station is draining funds from science at a time when research budgets are everywhere in decline. NASA quotes a price tag of $17.4 billion. A further $9 billion-plus will be contributed by international partners, excluding Russia's share. But shuttle launches to build the station and keep it supplied will amount to an additional $19.6 billion until 2002 and $46 billion thereafter, according to the General Accounting Office (GAO).

All told, the GAO's numbers make it clear that the station will soak up more than $100 billion over its lifetime (which is designed to be 10 years). Even so, there are no spares for the major station components. If one were lost in an accident or if (for example) an increasingly nationalistic Russia fell out of the coalition, costs would soar still further, and the schedule would be pushed back by years. NASA's 1995 research and development outlay of $9.5 billion, bloated by the space station, represents almost 40 percent of the nation's total nonhealth, nonmilitary research and development. "I am concerned that the space station may represent an excessive allo-

SPACE STATION is depicted as it will appear when completed in June 2002, orbiting 248 miles above Earth.

The International Space Station will be the most expensive object ever built. Although many scientists oppose the grandiose scheme, its political momentum now appears unstoppable



IAN WORPOLE

PROFUSION OF COMPONENTS—from the U.S., Russia, Japan, Canada and Europe—will compose the space station. The central truss will support solar panels to generate power and radiators to dispose of excess heat.

cation, which is one reason why we need to think about the sources of the nation's R&D funding," states Louis J. Lanzerotti, a physicist at AT&T Bell Laboratories and a former chairman of the space studies board.

Barring a last-minute change of heart on Capitol Hill or a technical showstopper, the space station's first component, the Russian-built propulsion module, should be launched on a Proton rocket from Baikonur Cosmodrome in Kazakhstan in November 1997. When in 1984 President Ronald Reagan invited allies of the U.S. to participate in building an orbital laboratory, a Russian launching would have been unthinkable. The cold war was still icy, and as far as Moscow was concerned, containment rather than collaboration was the objective.

But in 1986 the *Challenger* disaster forced a radical rethinking of the station's design, and the $8-billion sticker price was soon spiraling upward. After Reagan named the project Space Station Freedom in 1988, the design started changing each year as Congress called for cost reductions. By 1993 the program had consumed $11.2 billion, with nothing launched.

The incoming Clinton administration gave the space station a hard look, redesigned it yet again and decided to save money and make Russia a strategic ally by giving it a central role. Russian rockets have a good safety record, and the country has a decade of experience with its *Mir* space station. The current plan, which was briefly known as Alpha but is now simply the International Space Station, calls for Russia to build three of the first four modules, including the all-important propulsion module. This unit, which the U.S. is buying from Russia, will keep the station on its trajectory 248 miles above Earth.

The unilateral U.S. initiative to bring Russia into the charmed circle caused consternation in Europe. But after some intense politicking, European ministers voted last October to go along with the new plan. Europe will supply its own experimental module, and negotiations are under way with the U.S. about a collaboration on an emergency crew return vehicle. Canada is providing a robotic manipulator arm like that used on the shuttle, and Japan will build an experimental module.

An Architect's Nightmare

The space station might be a masterpiece of functional design, but it looks like an architect's nightmare. Sprouting from the propulsion module will be a Russian wing with its own laboratory module, living quarters, docking compartment and power system; the U.S. laboratory and habitation modules; a truss bearing 16 solar panels and the robotic arm; and Japanese and European laboratory modules. The whole ungainly hybrid, which on the ground would cover 14 tennis courts, will be assembled over five years and after 44 launches of U.S. space shuttles and European, Japanese and Russian rockets. On completion, the complex will support a crew of six, who will enjoy a pressurized volume equivalent to the passenger compartments of two jumbo jets.

A single primary contractor, Boeing, is responsible for the U.S. share, with Rocketdyne and McDonnell Douglas as subcontractors. In March the U.S. laboratory and habitat modules, aluminum cylinders 28 feet long and 14.5 feet across, were being machined and outfitted in Boeing's assembly buildings at the NASA Marshall Space Flight Center in Huntsville. Laser measuring devices were checking that the connecting surfaces that will mate the modules to adjacent units are accurately machined to within two hundredths of an inch. The accuracy is essential to minimize air leaks. Many space station supplies, including air to breathe, will be carried into orbit on shuttle flights, which cost $10,000 to $20,000 per pound of payload delivered.

NASA officials say collaborative relations with their foreign counterparts are generally good. But several of the teams planning station research facilities acknowledge special difficulties working with the Russians, who are not yet fully participating in joint science planning for the station. Russian health research has not impressed NASA's investigators, who say it lacks statistical rigor. Some on the U.S. side complain that the shortage of funds for science in Russia leads that country's investigators to look continually for financial arrangements that minimize Russia's outlays. U.S. shuttle flights to *Mir* are paving the way to better scientific working relations.

Nevertheless, late last year top Russian space officials startled NASA by proposing a plan to scale back their participation, suggesting that the international partners instead modify the existing *Mir* station for the next few years. NASA quickly squelched that plan, but the panic it triggered gave the Russians leverage to renegotiate the complex agreement it has with its space station partners. NASA had previously agreed to launch several shuttle flights to supply *Mir.* Russia now demanded, and got, an extra flight.

Then this spring saw a reshuffling of the assembly sequence that will delay orbiting of the Japanese module and a centrifuge unit by several months. The European module will now not be flown until 2003, after the nominal assembly-complete date. "We will have to be flexible," says Wilbur C. Trafton, NASA's director of space flight.

Even though last year's scare was contained, Russian industry sources have since indicated to NASA officials that Russian government funding for the third element of the station, known as the service module, has been held up. NASA has now "received assurances from the Russians that the project will be fully funded," Trafton declares. But anxiety over Russia's reliability is palpable. In March, Vice President Al Gore sent a strongly worded letter to Russian prime minister Viktor Chernomyrdin warning that if Russia failed to provide full funding for its part of the station, opponents of the project in Congress might yet decide to end the partnership.

Vibrations and Vapors

The station will probably survive this latest political flap. But many scientists remain dubious about the venture. The planned racks of research equipment, which will be launched after the laboratory modules and then installed in orbit, are now in various stages of design. Expert groups are providing advice on the facilities that will be needed to attract investigators. Yet the long lead time required to design and qualify apparatus for flight—up to seven years—limits the enthusiasm of scientists anxious to stay at the forefront of their fields.

Planning of the research facilities is disrupted every time the station assembly schedule is altered, because apparatus delivered on one flight might be useless without an item assigned to a different launch slot. And there are still unanswered questions about how much time the space station crew will have for research and about the amount of vibration during the five-year assembly period.

Originally, the station was advertised in part as a platform for remote sensing of Earth. NASA still boasts that the station's orbit, which sweeps over more of Earth's surface than *Freedom*'s would have done, "provides excellent Earth observation." Yet there are currently no plans to study the terrestrial surface from the station: crew movements mean it will be too jittery for precise measurements. And a cloud of gases that will be vented from the station and will follow it in orbit makes it a poor platform for studying the space environment.

Instead the emphasis has switched to studying the effects of weightlessness on humans and on physical and biological processes. Trafton says he is building "a world-class laboratory" to explore microgravity. (Even in the absence of vibrations, zero-gravity conditions in orbit can be approached only at a "sweet spot" that is the station's center of mass; other locations have levels that are measured in units of millionths of Earth-gravity, hence the term "microgravity.")

A special fund of $2.6 billion has been set aside to support space station research. "Microgravity research…will lay the foundation for important advances in medicine, food, safety, shelter, communications, transportation and environment," a Boeing brochure advises. "The program will create tens of thousands of high-technology U.S. jobs directly, and thousands more in spin-off fields, thereby improving America's competitive posture."

In the 1980s NASA drummed up support for the station as well as the shuttle by touting the opportunities for commercial materials processing. The phenomenon that was seen as most promising for exploitation was crystal growth, which occurs more slowly in microgravity because convection currents are greatly reduced. As a consequence, crystals of some materials, notably proteins, form more perfectly in space than they do on Earth. When probed by x-rays, they therefore yield better data about their composition, which could make it easier to design drugs that work by targeting the protein in the body. In addition, interest focused on the observation that liquids in microgravity are strongly affected by forces such as surface tension, which suggested possible advantages for separating mixtures of materials. Microgravity also seemed to offer benefits for creating extremely thin coatings of polymers or semiconductors.

BULKHEAD is lowered into position (*right*) on one of the connecting "nodes" of the space station at the Boeing assembly building at the NASA Marshall Space Flight Center in Huntsville, Ala. The main structure of the U.S. laboratory module (*below*), weighing 6,000 pounds, is lifted by crane after the completion of welding. The module will later be machined and a woven Kevlar jacket put around it to protect against space debris.

BOEING DEFENSE AND SPACE GROUP

BOEING DEFENSE AND SPACE GROUP

For the past decade, NASA has provided funds for the Centers for the Commercial Development of Space, research units dotted around the country that help companies develop projects to fly on the shuttle. Originally intended to be self-supporting after five years, the centers are still being bankrolled by NASA to the tune of about $15 million a year. NASA also provides launch space gratis, which has induced many adventurous companies to conduct experiments. NASA hopes they will eventually be prepared to pay full costs and make use of the larger facilities available on the space station, where experiments can continue for longer than the two weeks' duration of a shuttle flight.

But NASA's commercial centers have come under fire because the experiments they fly are not reviewed by disinterested experts. Robert F. Sekerka of Carnegie Mellon University, who chaired a study of microgravity research for the National Research Council, says that as long as an experiment is being given a ride into space at public expense it should be subject to independent scrutiny.

Lawrence J. DeLucas, who runs a commercial center at the University of Alabama at Birmingham that specializes in growing protein crystals in microgravity, counters that the commercial centers impose their own business discipline. "We have made samples for lots of companies," DeLucas states. "We help them design the drug. In return, they give us a share of the royalties," he explains. So far, though, the greater part of the receipts has been "in-kind contributions"—which include the value of the company's samples.

Skepticism over Costs

There seems to be little disagreement that NASA has improved the quality of its science programs over the past decade. "All of NASA's research fields have used rigorous peer review for quite a while," remarks John-David F. Bartoe, chief station research manager. Skepticism about research on the space station focuses on whether the returns can possibly be worth the extraordinary expense.

Gregory K. Farber of Pennsylvania State University, who studies protein crystals grown on Earth, acknowledges that some complex space-grown crystals are bigger or produce better x-ray data than their terrestrial counterparts do. But dozens of tests must be made to discover the best conditions for growing each crystal, Farber points out, so a specimen represents an investment in the region of $1 million. "What would you have achieved if you had spent that money to improve crystal growth on Earth?" he demands. And Eric Cross, a materials researcher at Penn State, points out that "success in growing simple crystals on Earth has been staggering."

MIKE McCORMICK *Boeing*

MODULAR EXPERIMENT RACKS will line the walls of the space station's laboratories, as in this mockup of the U.S. module. One wall is an arbitrary "ceiling," surrounded by lights to help astronauts orient themselves in microgravity.

The budget-blowing cost of sending anything into orbit has largely extinguished enthusiasm for space-based manufacturing. Indeed, some big corporations that were at one time interested have given up on the idea. The 3M company, reputedly one of the most imaginative of materials firms, was for a time excited about making thin films and polymers in microgravity but abandoned its efforts several years ago.

One beam of hope for space manufacturing appeared to be Schering-Plough Corporation, which makes alpha-interferon, a protein used to treat hepatitis and other disorders. A 1996 paper by Paul Reichert and Tattanahalli L. Nagabhushan of Schering-Plough Research Institute and others describes how a microcrystalline form of interferon made on a space shuttle flight stayed in the bloodstream of monkeys several hours longer than the interferon solution now in use, a possible therapeutic advantage. Four flasks of the preparation could meet the $750-million annual demand for the drug, DeLucas notes.

But Nagabhushan, who is Schering-Plough's senior vice president for biotechnology, maintains he has no plans to do further research on microcrystalline interferon on the space station. The space-grown crystals "were not different enough to jump up and down" about, he says, adding that he knows of nobody else in the pharmaceutical industry who is planning to make drugs in space.

Another commercial space idea is molecular-beam epitaxy, a technique for producing thin, single-crystal layers of materials such as semiconductors. The method has been investigated for the past decade by the Space Vacuum Epitaxy Center, one of NASA's commercial centers, based at the University of Houston. This notion depends on the high vacuum that exists in the wake of an orbiting satellite, rather than on microgravity. A recent shuttle flight demonstrated that pure semiconductor layers can be made in orbit behind a special shield.

Yet no facility for orbital molecular-beam epitaxy could operate within 50 miles of the space station because of its surrounding gas cloud, and the Houston center has so far not persuaded any business to fund epitaxy research in space. The National Research Council's space studies board, in an unusually blunt assessment, concluded last year that it "discards the idea that epitaxial layers will be manufactured in space."

Even when research in orbit identifies a novel phenomenon, commercial interest is not assured. Randall M. German, another materials researcher at Penn State, says his studies of liquid-phase sintering of tungsten-based alloys on the shuttle produced startling findings that have initiated an unexpected line of inquiry. But German is not convinced that the space station will offer him research opportunities that the shuttle cannot, and he foresees no commercial interest "in the short term."

Fizzy Drinks

The only commercial enterprises still talking about making things in orbit are bit players. Krist Jani of Paragon Vision Sciences in Arizona professes to be enthusiastic about making better permeable contact lenses in space. As of April, Paragon had flown only two experiments on the shuttle—one of which did not work—so manufacturing is still some way off. Coca-Cola has conducted experiments on how to dispense fizzy drinks in orbit. Yet a Coca-Cola consultant who gave a presentation to NASA earlier this year frankly admitted that the company's effort is driven by the publicity value.

If space-based manufacturing is a bust, some research-oriented companies remain optimistic about microgravity studies that might show them how to make things better on terra firma. By probing space-grown insulin crystals with x-rays, G. David Smith of the Hauptman-Woodward Medical Research Institute in Buffalo, N.Y., has created images with unprecedented resolution of complexes formed between insulin and a possible drug for diabetics. The images could guide chemists attempting to devise better drugs. Howmet, a company in Michigan, wants to study how liquid metals flow in microgravity, in the hope of refining its computer models of casting.

Daniel C. Carter, a NASA protein crystal scientist at the Marshall Space Flight Center, is assisting several companies to grow crystals of medically important proteins in orbit. The list includes an enzyme from the AIDS virus crystallized with a drug, a protein produced by an oncogene and a blood-clotting protein. At least 38 percent of proteins crystallize more successfully in microgravity, he maintains, and with more sophisticated temperature-controlled apparatus recently available the proportion is approaching 100 percent.

Studies of combustion are another important part of the research scheduled for the station. Materials burn completely differently in microgravity because of the lack of convection currents: a candle flame, for example, is spherical and quickly extinguishes itself. If basic studies of combustion showed how to increase the efficiency of automobiles or power plants, notes NASA's Robert Rhome, the economic consequences could be vast. For the time being, though, it is mainly NASA that is interested in the practical applications, which bear on safety in spacecraft.

The number of phenomena that might be studied in microgravity is huge, but Cross notes that within the space station it will be impossible to reach temperatures as low as those that can routinely be achieved on Earth. Nor will it be possible to make such high vacuums.

Tremors caused by equipment and the crew on the space station will further limit opportunities for a lot of precise research, Cross asserts, despite NASA's efforts to design vibration-resisting equipment. Cross, who has designed space hardware and flown an orbital experiment, says materials research opportunities on the station impress him "not one bit." Critics argue that robotic spacecraft custom-built for specific purposes could investigate the surprising behavior of liquids in the near absence of gravity, as well as some of the biological effects, for far less than the cost of the space station.

Biology has increasingly become the focus of those who hope to exploit the

What Good Is the Space Station?

	PROS/CONS	STATUS
HIGH-TECH PRODUCTS	Novel processes can be exploited in microgravity No products have been found that justify \$10,000 to \$20,000 per pound for shuttle launch costs	No large companies are currently interested in manufacturing in space
ASTRONOMY; REMOTE TERRESTRIAL SENSING	Clear view above Earth's atmosphere is good for both astronomy and environmental studies Space station is too jittery for high-precision measurements	No research currently planned
MATERIALS AND FLUID MECHANICS	Many interesting phenomena are known to occur in microgravity Aircraft flying parabolic trajectories and automated spacecraft can do a lot now, for far less expense	NASA and its partners are planning experiments
ANIMAL AND PLANT DEVELOPMENT	Many experiments can be done only on a space station because they are of long duration It is unclear whether the findings would be useful	NASA and its partners are planning experiments
BIOTECHNOLOGY (for example, growing protein crystals and cells)	Some crystals grow better in microgravity; cells grow differently Good progress has been made using terrestrial techniques	NASA and its partners are planning experiments; commercial interest limited to subsidized research
MOLECULAR-BEAM EPITAXY (MBE)	Vacuum in the wake of a spacecraft is higher than can be achieved on Earth; manufacturing of high-value products possible Gases near the space station rule out MBE within 50 miles	NASA has assigned this area low priority; no commercial interest
WAYS HUMANS LIVE AND WORK IN SPACE	Long-term observations can be made on the space station; fortuitous medical discoveries possible Answers may be important only if another long-duration mission is planned, such as one to Mars	NASA now identifies this area as the station's major mission

COURTESY OF NASA AND RUSSIAN SPACE AGENCY

COSMONAUT Gennady Strekalov entertains three American astronauts during a *Mir*-shuttle linkup last year.

The Pressures of Weightless Life

Living on the space station will be no picnic. When astronaut Norman Thagard returned to Earth last year after 110 days in orbit on *Mir* with a Russian crew, he noted that "the cultural isolation was extreme." It remains to be seen how well Russian and U.S. spacefarers will work together for months at a time in the more demanding environment of a space station under construction. Good politics will be crucial: the first station commander, William M. Shepherd, will be ordering around two Russian cosmonauts on what will be initially an all-Russian spacecraft.

The psychological pressure of a rigorously controlled schedule can be severe. In a famous incident during a Skylab mission in 1973, astronauts rebelled against a mission controller whom they felt was being too demanding. Productivity increased after crew members were granted greater autonomy.

The National Aeronautics and Space Administration is planning to give space station astronauts more flexibility than it currently grants shuttle crews, which will bring its policies more into line with Russian practice. To make the space station crew feel less cut off from the world, NASA is providing facilities for private telephone calls.

A substantial part of each day must be spent exercising to try to counter the effects of prolonged weightlessness. Planners at the Johnson Space Center in Houston are now choosing exercise equipment that will avoid vibrations.

Still unresolved is the matter of the vodka that Russian cosmonauts like to drink and the Europeans' fondness for good wine. NASA does not generally allow alcohol to be taken into space. But what if U.S. astronauts were invited over to the Russian wing or the European laboratory for a quick "tube" of something?

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space station's scientific promise. Results from shuttle experiments indicate that microgravity has significant effects on the development of plants and animals. Cells grow differently in culture, and there are indications it may be easier to grow human tissues. Plants lay down less of an important structural material called lignin, and one result suggests bacteria divide 50 percent faster in microgravity, which would be "astounding if true," comments Maurice M. Averner, a microbiologist with NASA.

Studying Life in Space

Results so far are sparse, because experimenting with animals and plants demands a lot of an astronaut's time. Joan Vernikos, NASA's life science head, says the superior facilities planned on the space station will allow researchers to repeat and modify biology experiments far more easily than they can on the shuttle. Moreover, a centrifuge that can spin animal cages will enable researchers to study for the first time the effects of different gravity levels on developing organisms. (The centrifuge is a divisive issue on the space station, because it will produce vibrations.)

The strongest new emphasis in space station science, however, is human health. The human frame is affected by the absence of gravity in ways more serious than might be supposed from watching the fun and games broadcast from the shuttle. Bones lose calcium, muscles atrophy and immunity may diminish. Health research on station astronauts will be conducted in a special facility boasting instruments to weigh people (not trivial without gravity), to measure their muscle strength and to analyze their blood and expired gases, among other vital signs.

But the value of biological and health research in orbit has been challenged by Elliott C. Levinthal, a former program director of the Defense Advanced Research Projects Agency who worked on the Viking robotic missions to Mars. Levinthal, who has been a professor of genetics and mechanical engineering at Stanford University, asserts that no neutral committee handing out funds for basic research in biology would support microgravity studies. Levinthal argues that giving priority to such investigations would make sense only if the space station is being built to prepare for some other long-duration mission.

NASA's answer is that humans will one day want to go to Mars. Levinthal insists, however, that building the space station is premature even if people will eventually visit the red planet. Long before astronauts could make such a perilous journey—which would cost far more than the space station—robotic craft should first explore the planet in detail and return samples from its surface, Levinthal contends. That exploration might take decades.

Levinthal is also doubtful about the space station's supposed purpose of keeping Russian technologists in peaceful employment. That country's scientists would actually rather spend research rubles on more down-to-earth work, he suggests: the U.S. could keep Russian scientific unemployment lines short for far less than the cost of the space station by simply sending money for science. Levinthal recognizes that Russian politicians are caught in the same bind as those in the U.S.; they are wedded to human space flight as a symbol of technological prestige, and they fear the wrath in the polling booth of unemployed former defense workers. Levinthal nonetheless concludes that the space station is "essentially purposeless."

The choice for scientists, it appears, is whether or not to make use of a one-of-a-kind microgravity laboratory that is going to be built with or without their approval. And as long as there are research grants, investigators will probably find something to do in the high-priced facility. "The reason the space station got into trouble in the first place is that we kept debating it," NASA chief Goldin says. "It is no longer a debatable issue. We are saying no to redesign and no to changes. We are going to build the space station." SA

Further Reading

MICROGRAVITY RESEARCH OPPORTUNITIES FOR THE 1990s. Committee on Microgravity Research, Space Studies Board. National Research Council, 1995.

For information on the International Space Station, visit Web site http://issa-www.jsc.nasa.gov/ss/prgview/prgview.html

For information on the federal R&D budget, visit Web site gopher://sunny.stat-usa.gov:70/00/BudgetFY96/Perspectives/bud96p08.txt

Can Nuclear Waste Be Stored Safely at Yucca Mountain?

Studies of the mountain's history and geology can contribute useful insights but not unequivocal conclusions

by Chris G. Whipple

In the half century of the nuclear age, the U.S. has accumulated some 30,000 metric tons of spent fuel rods from power reactors and another 380,000 cubic meters of high-level radioactive waste, a by-product of producing plutonium for nuclear weapons. None of these materials have found anything more than interim accommodation, despite decades of study and expenditures in the billions of dollars on research, development and storage.

The fuel rods, which accumulate at the rate of six tons a day, have for the most part remained at the nuclear reactors where they were irradiated, in water-filled basins and, in some cases, in steel containers on concrete pads. The high-level waste occupies huge, aging tanks at government sites in Washington State, South Carolina, Idaho and New York State. Some tanks have leaked, making conspicuous the lack of a more permanent, efficient and coherent solution for the nuclear waste problem.

In 1987 the federal government narrowed to one its long-term options for disposing of this waste: storing it permanently in a series of caverns excavated out of the rock deep below Yucca Mountain in southern Nevada. Since then, the U.S. Department of Energy, which is responsible for the handling of practically all the high-level nuclear waste in the U.S., has spent $1.7 billion on scientific and technical studies of whether such a repository below the mountain might safely store waste.

From the very beginning, however, the state of Nevada has strongly opposed the project, hiring its own scientists to study the mountain. Whether the state can block the project altogether is uncertain; its active opposition, though, is sure to complicate an undertaking that is already very difficult.

At the same time, legal issues make it necessary that something be done. Since 1982, nuclear utilities in the U.S. have paid $12 billion into a Nuclear Waste Fund and a related escrow account. In return, the DOE pledged to build a national repository and begin accepting the utilities' waste in 1998. Yet even if a repository is actually built at Yucca Mountain, it could not begin accepting waste until after 2015, according to the latest estimates. This has prompted the utilities to file suit in the U.S. Court of Appeals in Washington, D.C., to find out exactly what they are owed in two years' time. In addition, legal agreements with the states of Washington and South Carolina oblige the DOE to process the high-level tank waste into glass logs, for eventual disposal in a repository.

Whether it makes sense at this time to dispose permanently of spent fuel and radioactive waste in a deep geologic repository is hotly disputed. But the Nuclear Waste Policy Act amendments of 1987 decree that waste be consolidated in Yucca Mountain if the mountain is found suitable. Meanwhile the spent fuel continues to pile up across the country, and 1998 looms, adding urgency to the question: What can science tell us about the ability of Yucca Mountain to store nuclear waste safely?

PASSAGE OF TIME and its effects on container materials and nuclear wastes are at the heart of studies aimed at determining how likely it is that Yucca Mountain can safely contain the wastes. The latest guidelines suggest that a repository built underneath the mountain should be capable of isolating its contents for as many as one million years—long enough for the stars overhead, seen here in a timed exposure, to stray somewhat from today's constellations. A swath of yellow lights marks one of the footpaths over the mountain.

Tuff Enough?

The answer, or at least part of it, is to be found deep under that barren mound of rock, where preliminary work has already begun on an exploratory tunnel. Yucca Mountain, about 160 kilometers northwest of Las Vegas, is adjacent to the Nevada Test Site, where until recently, the DOE tested nuclear weapons. The mountain might more accurately be described as a ridge, about 29 kilome-

ROGER RESSMEYER *Starlight*

ROGER RESSMEYER *Starlight*

ters long and jutting up several hundred meters above the surrounding land. It is composed of tuff, a rock formed from volcanic ash, estimated to be between 11 million and 13 million years old.

Although many design details have not yet been made final, the plan is for canisters containing spent fuel to be arranged horizontally in chambers 300 meters below the surface and 240 to 370 meters above the water table. Once the repository was full, it would be monitored for at least 50 years and then sealed.

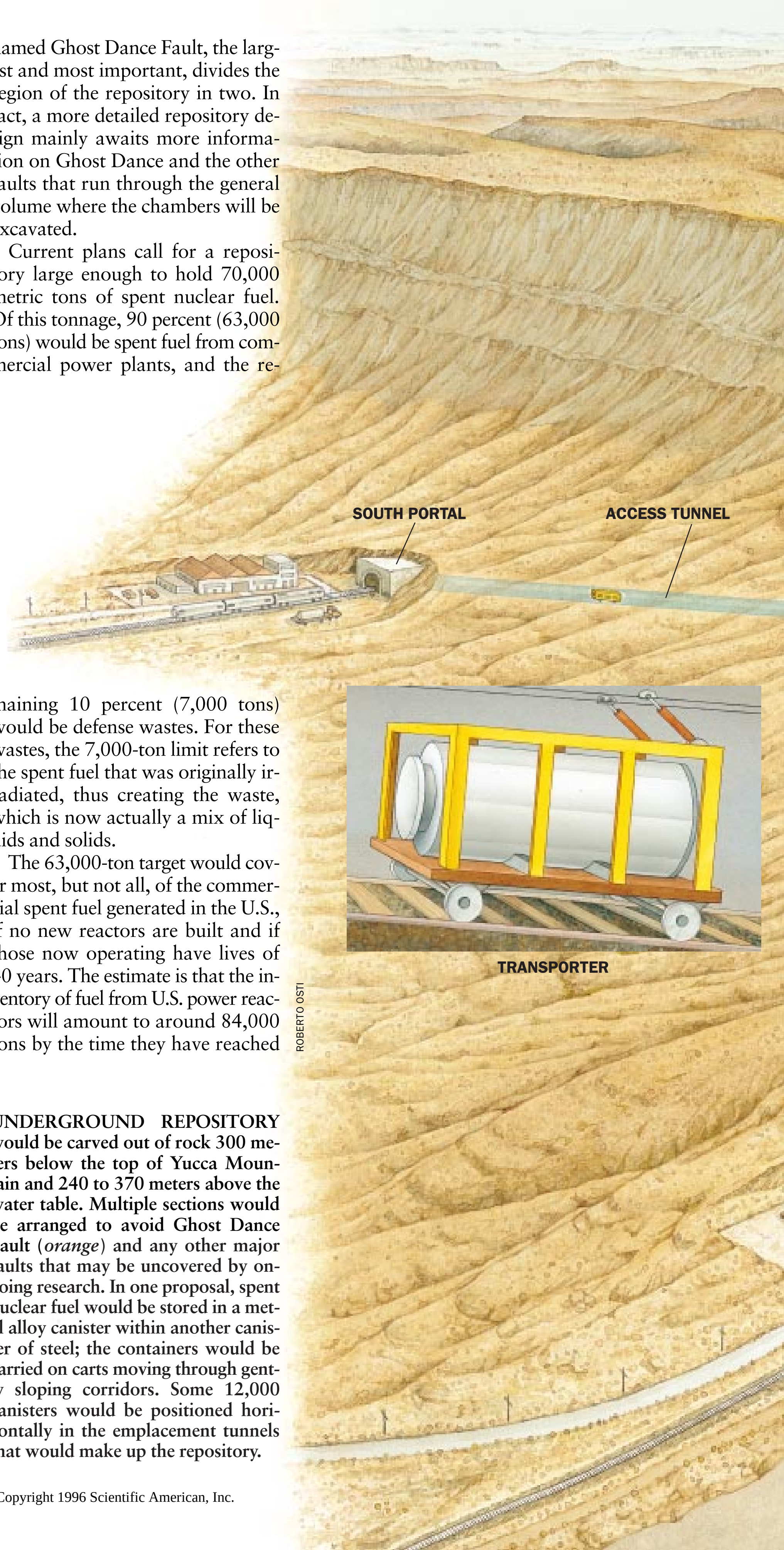
Although alternatives, such as disposing of radioactive waste beneath the ocean floor or even in outer space, have been considered, the U.S. and all other countries with high-level waste disposal programs have chosen to pursue deep geologic repositories, such as the one planned for Yucca Mountain. Still, no country has yet disposed of any spent fuel or high-level waste in such a repository. At this time, the only real alternative to a repository is long-term storage above ground; while less expensive, such storage is not a means of disposal, because the materials still have to be maintained and continuously secured. A hybrid proposal—to store spent fuel and high-level waste in a subterranean repository but to keep the facility open indefinitely—has also been suggested.

The Yucca Mountain repository would be accessed through a pair of tunnels comprising the sides of a U-shaped loop through the mountain, with the repository at the trough [*see illustration on these two pages*]. The gently sloping tunnels are an attractive feature made possible by the site's mountainous topography. Half of the U-shaped loop has been excavated, providing access for studies of the mountain's interior. The sloping tunnel has penetrated about five kilometers into the mountain and has reached the location of the proposed repository. Rapid progress is now being made with a 7.6-meter-diameter tunnel-boring machine, which excavates up to 30 meters of rock a day.

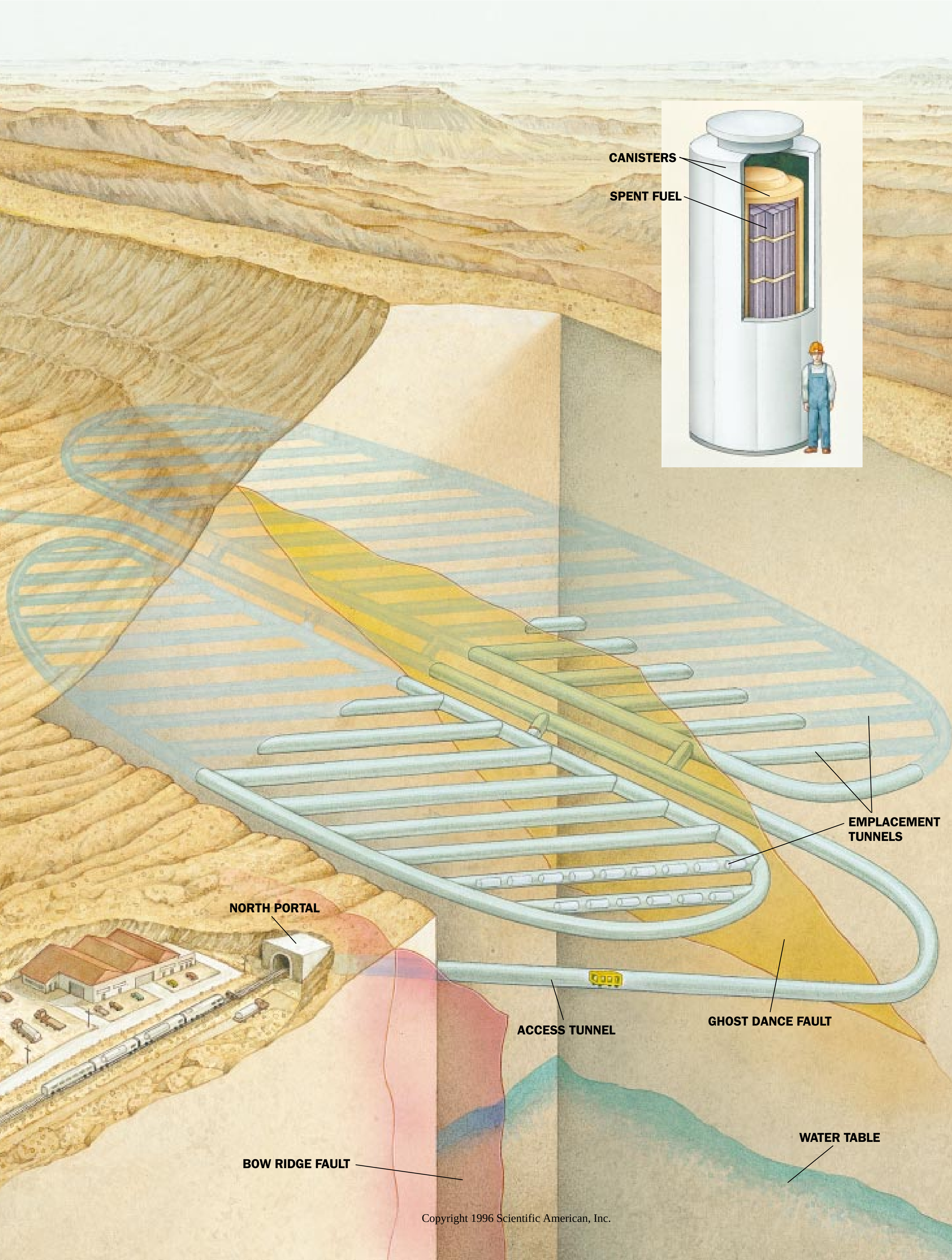
Designers anticipate dividing the repository into two sections laid out to avoid major geologic faults. Finding and characterizing those faults is the goal of several projects that are about to begin. The poetically named Ghost Dance Fault, the largest and most important, divides the region of the repository in two. In fact, a more detailed repository design mainly awaits more information on Ghost Dance and the other faults that run through the general volume where the chambers will be excavated.

Current plans call for a repository large enough to hold 70,000 metric tons of spent nuclear fuel. Of this tonnage, 90 percent (63,000 tons) would be spent fuel from commercial power plants, and the remaining 10 percent (7,000 tons) would be defense wastes. For these wastes, the 7,000-ton limit refers to the spent fuel that was originally irradiated, thus creating the waste, which is now actually a mix of liquids and solids.

The 63,000-ton target would cover most, but not all, of the commercial spent fuel generated in the U.S., if no new reactors are built and if those now operating have lives of 40 years. The estimate is that the inventory of fuel from U.S. power reactors will amount to around 84,000 tons by the time they have reached



UNDERGROUND REPOSITORY would be carved out of rock 300 meters below the top of Yucca Mountain and 240 to 370 meters above the water table. Multiple sections would be arranged to avoid Ghost Dance Fault (*orange*) and any other major faults that may be uncovered by ongoing research. In one proposal, spent nuclear fuel would be stored in a metal alloy canister within another canister of steel; the containers would be carried on carts moving through gently sloping corridors. Some 12,000 canisters would be positioned horizontally in the emplacement tunnels that would make up the repository.


CANISTERS
SPENT FUEL
EMPLACEMENT TUNNELS
NORTH PORTAL
ACCESS TUNNEL
GHOST DANCE FAULT
WATER TABLE
BOW RIDGE FAULT

the limit of their licensed operating life. Yet the 7,000-ton allocation for defense wastes would not even contain the DOE's inventory of wastes and spent fuel from Hanford alone. Currently no policy exists to designate a site for a second repository.

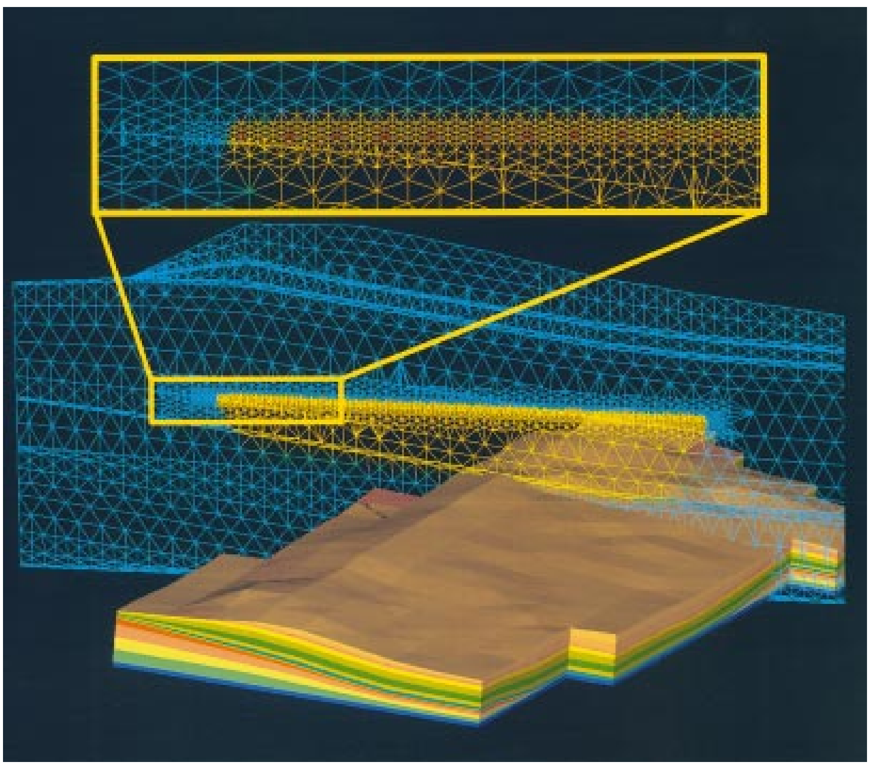
Besides the activities aimed at revealing the geologic features and properties of Yucca Mountain, DOE scientists are evaluating how alternative repository designs would affect long-term performance and how various waste-package designs and materials would contribute to the repository's ability to isolate hazardous wastes from the environment.

How People Might Be Exposed

A great deal of effort has gone into discovering and analyzing the ways in which humans could be exposed to radioactive materials from a waste repository. Dozens of scenarios have been offered. In the one that has received the most attention, waste canisters corrode, and water leaches radioactive elements (radionuclides) out of the spent fuel or vitrified high-level waste, then carries them into the groundwater. People would be exposed if they used the water for any of the usual purposes: drinking, washing or irrigation.

A repository at Yucca Mountain, however, would have some inherent resistance to such occurrences. The repository would store the waste above the groundwater, in what is known as unsaturated rock. Depending on how much water flows down through the mountain and contacts the waste, the movement of radioactive materials into groundwater can be delayed for a long time and can occur at a limited rate in comparison to what might occur at a site below the water table.

An additional advantage is that repository operations, including the possibility of retrieval of the spent fuel or repair of the repository if needed, would be simpler in unsaturated rock. Whereas the prospects for intentional retrieval of spent fuel are seen by some as remote or threatening to nonproliferation, to others the discarding of spent fuel is extremely profligate. Given the enormous energy content of the plutonium and uranium in the spent fuel, intentional retrieval of these materials at some distant time is a reasonable possibility that must be recognized. Retrieval of spent fuel would be easier from Yucca Mountain than from some of the other types of repositories that have been considered.



NUCLEAR WASTE MANAGEMENT R&D GROUP, LOS ALAMOS NATIONAL LABORATORY

MIGRATION OF RADIOACTIVE ELEMENT, neptunium 237, into Yucca Mountain after one million years is shown in this computer simulation. Blue computational mesh shows a cross section of the mountain; yellow indicates rock suffused with neptunium. The expanded view shows former locations of canisters, which have long since decayed away. The solid figure, at the bottom, reveals geologic strata.

The probability that people will some day come into contact with radionuclides from Yucca Mountain, and the magnitude of the dose they might receive, depends on many factors. Some factors can be fairly well quantified for any future time; others cannot. In the former category is the content of the waste, determined by taking into account the radioactive decay of some isotopes and the consequent growth of others. Similarly, the dilution and dispersion of the radionuclides in groundwater as the water seeps away from the repository is believed to be calculable with reasonable accuracy, based on well-understood mechanisms and knowledge of many existing contamination plumes.

On the other hand, a significant unknown at this time is the infiltration rate—the rate at which water percolates down through the mountain. Only about 16 centimeters of rain falls on Yucca Mountain every year. Most of this water evaporates, although some does penetrate the ground. Its movement is the single most important factor in determining how long the buried canisters might survive—their rate of corrosion depends strongly on how much moisture they encounter. Flow rates are estimated from the age of water found in the zone above the water table; the age of the water is calculated from carbon, chlorine and uranium isotope ratios.

Still, the variability in the rainwater infiltration rate throughout the mountain may prove difficult to characterize, and the possibility that climate changes will produce a higher flux cannot be dismissed. On the other hand, layers of caliche, a form of calcium carbonate, or other comparatively impermeable materials could serve as barriers to restrict the downward migration of water.

Projections of how radionuclides might move from the repository into groundwater are also complex and uncertain. If water flows primarily through fractures in the rock, the transportation time would be relatively short, with little retardation of radionuclides by zeolites—silicate-based rock that tends to retain many chemicals. But if the downward flow is largely through the rock itself, the travel time and retardation of radionuclides would be greater. The actual mix of fracture flow and through-rock seepage cannot be known precisely, because the entire mountain cannot be analyzed in the fine detail needed.

Human settlement patterns present an even greater challenge. One of the most significant uncertainties in risk calculations for a planned repository such as at Yucca Mountain comes from the need to make assumptions about where people will live and work. What will occur in far-future times is of course unknowable, but assumptions can be made for purposes of hypothetical projections. Basically, for a Yucca Mountain repository to pose a hazard, people must live over or near a plume of groundwater contaminated by leakage from the repository, use water wells sunk into the plume and fail to detect that the water has been contaminated.

Other release scenarios have also been considered. They include events that might result from volcanism near Yucca Mountain and from inadvertent human intrusion in connection with, for example, mining. The U.S. Geological Survey and other DOE contractors have been studying volcanoes in the vicinity to try to estimate the likelihood of future activity, which appears improbable. Earthquakes are also being studied, but the historical evidence indicates that earthquakes tend to be much less harmful to underground structures than to surface ones. The speculation about whether and how inadvertent human intrusion might occur is much like attempts to determine the type of society that might occupy Yucca Mountain: interesting to think about but unknowable.


U.S. DEPARTMENT OF ENERGY

TUNNEL-BORING MACHINE has drilled five kilometers into Yucca Mountain thus far. This photograph was shot in the same general direction as the excavation, so only the back side of the 73-meter-long boring assembly is visible (*upper right*). Right now the tunnel is used primarily for studies of seismicity and water movements.

How Safe Is "Safe"?

Difficulties in making realistic projections are exacerbated by uncertainties about standards. The question of whether nuclear waste can be stored safely at Yucca Mountain naturally prompts another query: What exactly is meant by "safe?" That question cannot yet be answered; from a regulatory viewpoint, the DOE is working toward an as yet undefined standard. In 1992 Congress directed the Environmental Protection Agency and the National Research Council (NRC) to develop new standards, specific to Yucca Mountain, based on recommendations from the National Academy of Sciences. The academy's guidelines have been published, and the EPA's new standards are still being developed. The NRC is expected to put forth its proposals after the EPA does.

One of the most fundamental unresolved questions concerns the length of time that the repository would be required to contain the waste. Until recently, the timescale under consideration was the EPA's limit of 10,000 years. But for Yucca Mountain, that limit has been challenged by the National Academy of Sciences's recent recommendations to the EPA and NRC. The academy's view is that the repository should contain the waste until its risk begins to decline—even if that means a million years. How the EPA and NRC will respond to this recommendation is not yet known.

It appears quite plausible that if the canisters and other packaging were appropriately designed, a Yucca Mountain repository could prevent waste from migrating in significant quantities into the environment for 10,000 years. The projected life of a waste package is based on corrosion rates for different package materials and repository conditions. For Yucca Mountain, experts are considering various alloys of steel and titanium, as well as ceramic materials.

It is in waste-package life that, unfortunately, some of the advantages of an unsaturated repository are offset. Specifically, the chemical conditions in an unsaturated repository favor oxidation—that is, they tend to promote reaction with oxygen. A well-chosen saturated site, in contrast, could be a reducing environment; it would tend to prevent reactions between metals and oxygen.

The challenges of developing long-lived waste packages in an oxidizing environment appear to be more difficult than for a reducing environment. For example, the Swedish program for spent-fuel disposal plans to use copper-coated canisters in a saturated repository near a seacoast. The Swedes estimate that a million-year canister life can be anticipated. An added "benefit" of the Swedish approach is that if the repository does eventually begin to leak, it will do so into the ocean, not into a potable aquifer.

For an unsaturated, oxidizing environment, ceramics may be the best choice for packaging waste because they have the advantage of already being oxidized. Cathodic protection of multiple-layer canisters, in which an outer layer electrically shields an inner layer, also appears to extend waste-package life significantly.

Research into the deterioration of

Living with High-Level Radioactive Waste

Created by nuclear fission, high-level radioactive waste comes from two different sources: the commercial generation of nuclear power, as well as the production of plutonium for nuclear weapons.

Commercial and military wastes differ in several respects, which are relevant to their long-term safety in a repository. Military waste includes many different types, among them spent fuel. By far the largest component of defense waste is the reprocessing residue stored in underground tanks at the Hanford complex in Washington State and at the Savannah River site in South Carolina. These wastes have had most of their plutonium and uranium extracted through chemical reprocessing; their current hazardous nature comes from the presence of other radioactive elements produced by fission. In contrast, spent commercial powerplant fuel contains substantial quantities of uranium and plutonium, in addition to fission products.

JASON GOLTZ

VITRIFIED WASTE traps materials in glass; sample here is not radioactive.

Because of these differences, military nuclear wastes will decay to a safe level more rapidly than spent fuel will. For spent fuel or military waste that has been stored for more than a decade, the dominant radionuclides at the time of disposal are cesium 137 and strontium 90, both with half-lives of around 30 years. Initially, cesium and strontium generate most of the heat in a sample of waste and set the requirements for shielding to protect workers. After several centuries, the cesium and strontium will have decayed to levels that are too low to worry about.

After the strontium and cesium are gone, the fission product of concern in both spent fuel and defense waste is technetium 99, with a half-life of 211,100 years. Unlike high-level defense waste, spent fuel also contains americium 241 (with a 432.2-year half-life), carbon 14 (5,730 years), plutonium 239 (24,110 years), neptunium 237 (2.14 million years) and a variety of less important isotopes. Carbon 14 has received much attention because, unlike most other radioisotopes in the waste, it could be released directly from the repository as gaseous carbon dioxide.

A second major difference between the two wastes is their physical form at the time of disposal. Before the Department of Energy's tank wastes are put into a repository, highly radioactive components will be separated from the bulk of the tank wastes, vitrified (melted with other ingredients to make glass) and poured into stainless-steel cans. The Hanford wastes are expected to produce between 10,000 and 60,000 of these glass "logs," each 3 meters long by two thirds of a meter in diameter.

Commercial spent fuel consists of the fuel itself, which is a uranium dioxide ceramic, encased in a zirconium alloy fuel cladding. For disposal in a repository, assemblies of these fuels will be fitted into large waste canisters. *—C.G.W.*

waste packages has found that corrosion occurs most rapidly to canisters in contact with liquid water, such as a recurrent drip onto the waste package or the accumulation of a puddle under a package. If the repository design can eliminate direct water contact, the next most important factor is humidity. Tests indicate that the corrosion rate for candidate materials is very low—almost zero—below a threshold humidity but that corrosion progresses faster at higher humidities. Unfortunately, the ambient humidity inside Yucca Mountain is high, around 98 to 99 percent, and therefore corrosive for most candidate waste-package materials.

The observation that liquid water and high humidity accelerate waste-package failure has led to what is known as the hot, dry repository concept. Raising the temperature of the surrounding rock to above the boiling point of water, using heat from the waste itself, would effectively eliminate levels of humidity or accumulations of liquid water that could cause corrosion of waste packages. Calculations indicate that for comparatively high waste-packing densities, above 200 tons of uranium per hectare, for example, the repository temperature could be kept above boiling for more than 10,000 years.

The downside is that such elevated temperatures may also adversely affect materials in the repository and the mountain—for example, more heat may increase the rate of canister degradation. The DOE is currently considering this trade-off and has not yet determined what operating temperature it would seek to maintain in the repository.

Over a timescale of hundreds of thousands of years, all safety analyses presume that canisters have failed and that the rock between the repository and the groundwater has achieved equilibrium with the waste products migrating through. In this case, the capability of the rock to retard the movement of waste has been fully taxed. Radionuclide concentrations in water flowing down from the repository and the radiation exposures resulting from use of this water are both in a steady state. The key factors in this process are the water's rate of flow through the mountain, the solubility of key isotopes in that water, localized barriers to prevent free access of water to the waste, and the dilution of waste once it reaches groundwater.

For limited amounts of water flowing past the waste, solubility is likely to limit the movement of radionuclides to groundwater, although it is possible that some radionuclides could be transported as colloids, particles less than a micron across suspended in liquids. Projections of performance out to a million years indicate that the peak dose to a hypothetical individual who drinks water from a well 25 kilometers from the repository would not occur until several hundred thousand years hence.

Red Herrings

In recent years, there have been a few controversies over the stability of a Yucca Mountain repository. The most sensational one concerned the potential for a nuclear criticality—that is, a self-sustaining nuclear chain reaction—as the waste dissolved and migrated through the mountain. Another one was related to the potential for groundwater to rise up and engulf the repository.

Both of these hypothetical situations have been addressed at length elsewhere. My view, briefly, is that they are technical "red herrings." While the possibility of criticality at some time far into the future cannot be completely ruled out, simple technical fixes could render its probability negligible. The simple addition of depleted uranium to waste canisters would be one such approach. If wastes were contained long enough for the plutonium 239 to decay to uranium 235, the depleted uranium would prevent a criticality. This process would take quite a while; plutonium 239 has a half-life of 24,110 years. The depleted uranium would, in effect, prevent the plutonium from becoming concentrated enough to go critical.

The possibility of groundwater reaching the repository level at Yucca Mountain also seems a very small concern. A National Academy of Sciences committee studied the issue in detail and concluded that there were no plausible mechanisms that could cause the water table to rise to such an extent and that there was no physical evidence that this had ever occurred before.

Although these two concerns may not seem to have much merit in and of themselves, they do underscore the uncertainty inherent in any analytical projection so far into the future. For a Yucca Mountain repository, even the phrase "far into the future" is ambiguous; it can be taken to mean 10,000 or as many as one million years.

Experiments may be conducted to generate input for models of how a repository might behave, but predictions of very long-term behavior from short-term tests are always suspect. Unfortunately, few, if any, experiments could feasibly be done to provide a basis for the long-term projections required to assess repository performance for the practical life of the waste.

One of the very few such efforts so far uses natural analogues such as deposits of uranium ore to predict repository performance. Because the major component of spent fuel is uranium, and because plutonium 239 decays to uranium, the behavior of uranium in a natural setting is relevant to how a repository might perform. The fact that such ore deposits have existed for many millions of years without dissolving away provides evidence that, at least in some geologic settings, it is possible to isolate such materials over extended timescales. But what is not known is how many uranium deposits have not survived.

Hazy Future

The Yucca Mountain project has an uncertain future. Officially, if the DOE determines that Yucca Mountain is a suitable place to build a repository, the department will apply to the U.S. Nuclear Regulatory Commission for a license to construct and operate one there. If the commission grants the license, the state of Nevada can refuse the project, but the rejection can be overridden by a congressional vote.

It may never even make it that far, however. Although the investigatory and exploratory phase of the Yucca Mountain project is already almost a decade old, the anticipated time when a repository could be ready to receive nuclear waste is no closer than it was when work began. This year's federal financial allocation, $315 million, is about half of what was requested, and 1,100 fewer people are working on the project than a year ago. The most effective congressional supporter of a radioactive waste repository, Senator J. Bennett Johnston of Louisiana, has announced his plans to retire after this term.

The forces in the early 1980s that gave rise to the present policy were an unusual alignment of nuclear power industry and environmental group interests. The electric utility industry wanted to implement waste disposal rapidly, so that this critical obstacle to the rebirth of nuclear power was removed, and the environmentalists' desire was to ensure that spent reactor fuel was not reprocessed and that the proliferation threat that they associated with plutonium recycling and breeder reactors be avoided.

From the present perspective, these motivations and objectives seem almost irrelevant. Nuclear power has many problems, of which waste disposal is only one. Were the waste problem settled tomorrow, orders for new U.S. power reactors are unlikely for many economic reasons. Similarly, the hundreds of metric tons of bomb-grade plutonium released by the post–cold war decommissioning of nuclear weapons in the U.S. and former Soviet Union has made concerns about spent power-reactor fuel as a proliferation threat seem insignificant. The DOE is gathering nearly 100 metric tons of plutonium from decommissioned nuclear weapons and from other sources; no decisions have been made on its ultimate disposition, but the issue will likely overlap somehow with policies for managing spent nuclear fuel and high-level nuclear waste.

Significant though they are, such issues should not be permitted to distract attention from the basic facts. Storage of spent nuclear fuels above ground is an economic and technically proven interim measure. But such a measure is not up to the task of safely and efficiently securing dangerous materials that will exist for thousands of years to come. SA

The Author

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Further Reading

GROUND WATER AT YUCCA MOUNTAIN: HOW HIGH CAN IT RISE? Panel on Coupled Hydrologic/Tectonic/Hydrothermal Systems at Yucca Mountain. National Research Council, 1992.

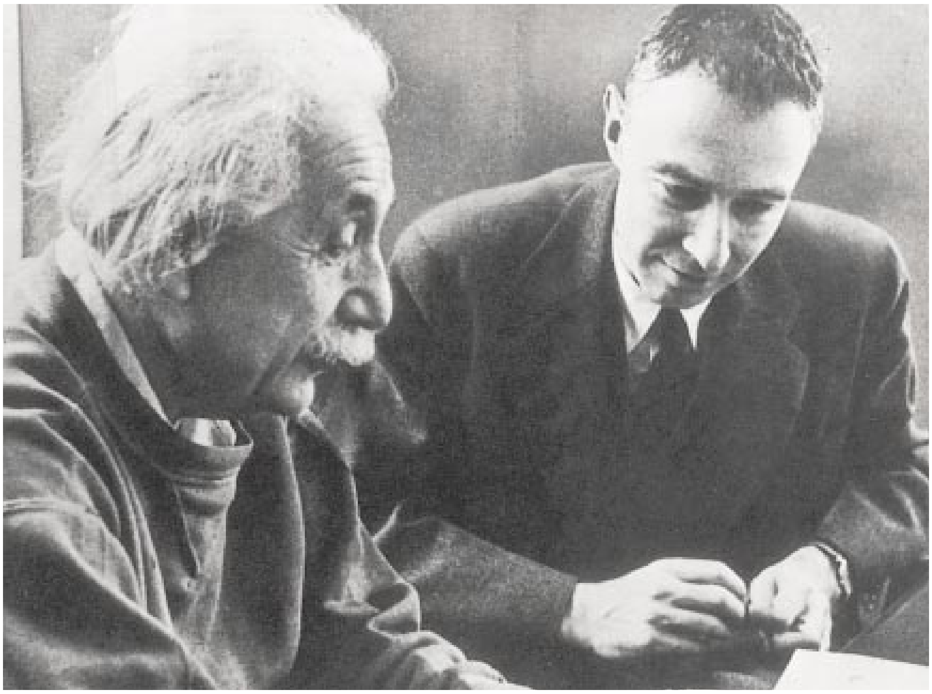
THE NUCLEAR WASTE PRIMER. League of Women Voters Education Fund. Lyons & Burford, 1993.

TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS. National Research Council Committee on the Technical Bases for Yucca Mountain Standards. National Academy Press, 1995.

TOTAL SYSTEMS PERFORMANCE ASSESSMENT-1995: AN EVALUATION OF THE POTENTIAL YUCCA MOUNTAIN REPOSITORY. Civilian Radioactive Waste Management System (Management and Operating Contractor), B00000000-01717-2200-00136, Las Vegas, 1995.

CONSIDERATIONS OF AUTOCATALYTIC CRITICALITY OF FISSILE MATERIALS IN GEOLOGIC REPOSITORIES. Report by the Department of Nuclear Engineering and the Department of Materials Science and Mineral Engineering, University of California, Berkeley, January 22, 1996.

LOCALIZED DRYOUT: AN APPROACH FOR MANAGING THE THERMAL-HYDROLOGICAL EFFECTS OF DECAY HEAT AT YUCCA MOUNTAIN. T. A. Buscheck, J. J. Nitao and L. D. Ramspott [available as Lawrence Livermore National Laboratory offprint UCRL-JC-121232] in *Scientific Basis for Nuclear Waste Management XIX*. Edited by W. M. Murphy and D. A. Knecht. Materials Research Society, Vol. 412, 1996.



INTERNATIONAL COMMUNICATION AGENCY *courtesy of Emilio Segrè Visual Archive*

The Reluctant Father of Black Holes

Albert Einstein's equations of gravity are the foundation of the modern view of black holes; ironically, he used the equations in trying to prove these objects cannot exist

by Jeremy Bernstein

Great science sometimes produces a legacy that outstrips not only the imagination of its practitioners but also their intentions. A case in point is the early development of the theory of black holes and, above all, the role played in it by Albert Einstein. In 1939 Einstein published a paper in the journal *Annals of Mathematics* with the daunting title "On a Stationary System with Spherical Symmetry Consisting of Many Gravitating Masses." With it, Einstein sought to prove that black holes—celestial objects so dense that their gravity prevents even light from escaping—were impossible.

The irony is that, to make his case, he used his own general theory of relativity and gravitation, published in 1916—the very theory that is now used to argue that black holes are not only possible but, for many astronomical objects, inevitable. Indeed, a few months after Einstein's rejection of black holes appeared—and with no reference to it—J. Robert Oppenheimer and his student Hartland S. Snyder published a paper entitled "On Continued Gravitational Contraction." That work used Einstein's general theory of relativity to show, for the first time in the context of modern physics, how black holes could form.

PRO AND CON: In 1939 J. Robert Oppenheimer (*right*) argued for the existence of black holes, at the same time Albert Einstein tried to disprove them. Their careers crossed paths at the Institute for Advanced Study in Princeton, N.J., in the late 1940s, when this photograph was taken, but it is unknown whether they ever discussed black holes.

Perhaps even more ironically, the modern study of black holes, and more generally that of collapsing stars, builds on a completely different aspect of Einstein's legacy—namely, his invention of quantum-statistical mechanics. Without the effects predicted by quantum statistics, every astronomical object would eventually collapse into a black hole, yielding a universe that would bear no resemblance to the one we actually live in.

Bose, Einstein and Statistics

Einstein's creation of quantum statistics was inspired by a letter he received in June 1924 from a then unknown young Indian physicist named Satyendra Nath Bose. Along with Bose's letter came a manuscript that had already been rejected by one British scientific publication. After reading the manuscript, Einstein translated it himself into German and arranged to have it published in the prestigious journal *Zeitschrift für Physik*.

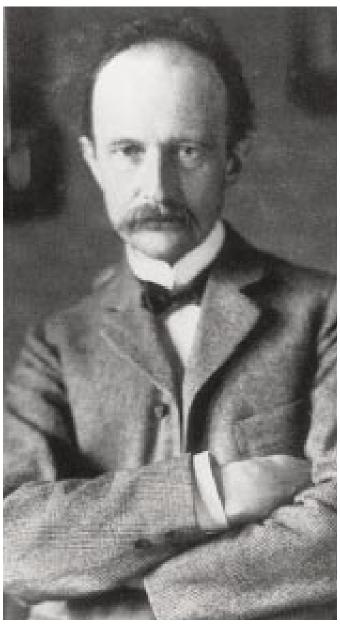
Why did Einstein think that this manuscript was so important? For two decades, he had been struggling with the nature of electromagnetic radiation—especially the radiation trapped inside a heated container that attains the same temperature as its walls. At the turn of the century the German physicist Max Planck had discovered the mathematical function that describes how the various wavelengths, or colors, of this "black body" radiation vary in intensity. It turns out that the form of this spectrum does not depend on the material of the container walls. Only the temperature of the radiation matters. (A striking example of black-body radiation is the photons left over from the big bang, in which case the entire universe is the "container." The temperature of these photons was recently measured at 2.726 ± 0.002 kelvins.)

Somewhat serendipitously, Bose had worked out the statistical mechanics of black-body radiation—that is, he derived the Planck law from a mathematical, quantum-mechanical perspective. That outcome caught Einstein's attention. But being Einstein, he took the matter a step further. He used the same methods to examine the statistical mechanics of a gas of massive molecules obeying the same kinds of rules that Bose had used for the photons. He derived the analogue of the Planck law for this case and noticed something absolutely remarkable. If one cools the gas of particles obeying so-called Bose-Einstein statistics, then at a certain critical temperature all the molecules suddenly collect themselves into a "degenerate," or single, state. That state is now known as Bose-Einstein condensation (although Bose had nothing to do with it).

An interesting example is a gas made up of the common isotope helium 4, whose nucleus consists of two protons and two neutrons. At a temperature of 2.18 kelvins, this gas turns into a liquid that has the most uncanny properties one can imagine, including frictionless flow (that is, superfluidity). U.S. researchers in the past year accomplished the difficult task of cooling other kinds of atoms to several billionths of a kelvin to achieve a Bose-Einstein condensate.

Not all the particles in nature, how-

An Early History of Black Holes

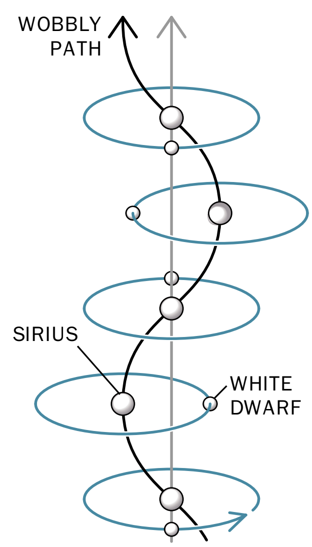


AMERICAN INSTITUTE OF PHYSICS EMILIO SEGRÈ VISUAL ARCHIVE

1900
Max Planck discovers black-body radiation.

BETTMANN ARCHIVE

1905
In a paper on black-body radiation, **Albert Einstein** shows that light can be viewed as particles (photons).



JARED SCHNEIDMAN DESIGN

1915
Through spectroscopic studies, astronomer Walter S. Adams identifies Sirius's faint companion (which causes Sirius to wobble slightly as it moves) as a small, hot, dense star—a white dwarf.

UPI/BETTMANN

1916
Einstein publishes his general theory of relativity, producing equations that describe gravity.

ever, show this condensation. In 1925, just after Einstein published his papers on the condensation, the Austrian-born physicist Wolfgang Pauli identified a second class of particles, which includes the electron, proton and neutron, that obeyed different properties. He found that no two such identical particles—two electrons, for example—can ever be in exactly the same quantum-mechanical state, a property that has since become known as the Pauli exclusion principle. In 1926 Enrico Fermi and P.A.M. Dirac invented the quantum statistics of these particles, making them the analogue of the Bose-Einstein statistics.

Because of the Pauli principle, the last thing in the world these particles want to do at low temperatures is to condense. In fact, they exhibit just the opposite tendency. If you compress, say, a gas of electrons, cooling it to very low temperatures and shrinking its volume, the electrons are forced to begin invading one another's space. But Pauli's principle forbids this, so they dart away from one another at speeds that can approach that of light. For electrons and the other Pauli particles, the pressure created by these fleeing particles—the "degeneracy pressure"—persists even if the gas is cooled to absolute zero. It has nothing to do with the fact that the electrons repel one another electrically. Neutrons, which have no charge, do the same thing. It is pure quantum physics.

Quantum Statistics and White Dwarfs

But what has quantum statistics got to do with the stars? Before the turn of the century, astronomers had begun to identify a class of peculiar stars that are small and dim: white dwarfs. The one that accompanies Sirius, the brightest star in the heavens, has the mass of the sun but emits about 1/360 the light. Given their mass and size, white dwarfs must be humongously dense. Sirius's companion is some 61,000 times denser than water. What are these bizarre objects? Enter Sir Arthur Eddington.

When I began studying physics in the late 1940s, Eddington was a hero of mine but for the wrong reasons. I knew nothing about his great work in astronomy. I admired his popular books (which, since I have learned more about physics, now seem rather silly to me). Eddington, who died in 1944, was a neo-Kantian who believed that everything of significance about the universe could be learned by examining what went on inside one's head. But starting in the late 1910s, when Eddington led one of the two expeditions that confirmed Einstein's prediction that the sun bends starlight, until the late 1930s, when Eddington really started going off the deep end, he was truly one of the giants of 20th-century science. He practically created the discipline that led to the first understanding of the internal constitution of stars, the title of his classic 1926 book. To him, white dwarfs were an affront, at least from an aesthetic point of view. But he studied them nonetheless and came up with a liberating idea.

In 1924 Eddington proposed that the gravitational pressure that was squeezing the dwarf might strip some of the electrons off protons. The atoms would then lose their "boundaries" and might be squeezed together into a small, dense package. The dwarf would eventually stop collapsing because of the Fermi-Dirac degeneracy pressure—that is, when the Pauli exclusion principle forced the electrons to recoil from one another.

The understanding of white dwarfs took another step forward in July 1930, when Subrahmanyan Chandrasekhar, who was 19, was on board a ship sail-

ROBERT BEIN *AIP Emilio Segrè Visual Archive*

1916
Karl Schwarzschild shows that a radius of a collapsing object exists at which Einstein's gravity equations become "singular"—time vanishes, and space becomes infinite.

MAX PLANCK INSTITUTE *courtesy of AIP*

1924
Einstein publishes **Satyendra Nath Bose**'s work on black-body radiation, developing so-called quantum statistics for one class of particles (such as photons).

UPI/BETTMANN

1924
Sir Arthur Eddington proposes that gravity can strip away electrons from protons in a white dwarf.

AIP EMILIO SEGRÈ VISUAL ARCHIVE

1925
Wolfgang Pauli formulates the exclusion principle, which states that certain particles cannot be in exactly the same quantum-mechanical state.

ing from Madras to Southampton. He had been accepted by the British physicist R. H. Fowler to study with him at the University of Cambridge (where Eddington was, too). Having read Eddington's book on the stars and Fowler's book on quantum-statistical mechanics, Chandrasekhar had become fascinated by white dwarfs. To pass the time during the voyage, Chandrasekhar asked himself: Is there any upper limit to how massive a white dwarf can be before it collapses under the force of its own gravitation? His answer set off a revolution.

A white dwarf as a whole is electrically neutral, so all the electrons must have a corresponding proton, which is some 2,000 times more massive. Consequently, protons must supply the bulk of the gravitational compression. If the dwarf is not collapsing, the degeneracy pressure of the electrons and the gravitational collapse of the protons must just balance. This balance, it turns out, limits the number of protons and hence the mass of the dwarf. This maximum is known as the Chandrasekhar limit and equals about 1.4 times the mass of the sun. Any dwarf more massive than this number cannot be stable.

Chandrasekhar's result deeply disturbed Eddington. What happens if the mass is more than 1.4 times that of the sun? He was not pleased with the answer. Unless some mechanism could be found for limiting the mass of any star that was eventually going to compress itself into a dwarf, or unless Chandrasekhar's result was wrong, massive stars were fated to collapse gravitationally into oblivion.

To Eddington, white dwarfs were an affront.

Eddington found this intolerable and proceeded to attack Chandrasekhar's use of quantum statistics—both publicly and privately. The criticism devastated Chandrasekhar. But he held his ground, bolstered by people such as the Danish physicist Niels Bohr, who assured him that Eddington was simply wrong and should be ignored.

A Singular Sensation

As researchers explored quantum statistics and white dwarfs, others tackled Einstein's work on gravitation, his general theory of relativity. As far as I know, Einstein never spent a great deal of time looking for exact solutions to his gravitational equations. The part that described gravity around matter was extremely complicated, because gravity distorts the geometry of space and time, causing a particle to move from point to point along a curved path. More important to Einstein, the source of gravity—matter—could not be described by the gravitational equations alone. It had to be put in by hand, leaving Einstein to feel the equations were incomplete. Still, approximate solutions could describe with sufficient accuracy phenomena such as the bending of starlight. Nevertheless, he was impressed when, in 1916, the German astronomer Karl Schwarzschild came up with an exact solution for a realistic situation—in particular, the case of a planet orbiting a star.

In the process, Schwarzschild found something disturbing. There is a distance from the center of the star at which the mathematics goes berserk. At this distance, now known as the Schwarzschild radius, time vanishes, and space becomes infinite. The equation becomes what mathematicians call singular. The Schwarzschild radius is usually much smaller than the radius of the object. For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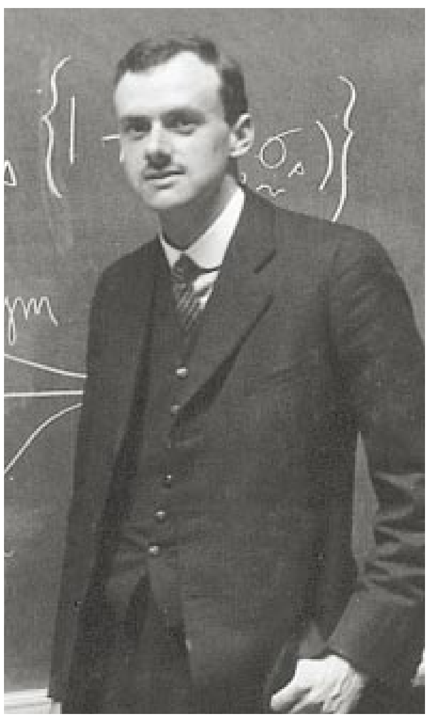

AIP EMILIO SEGRÈ VISUAL ARCHIVE


UPI/BETTMANN

1926

Enrico Fermi and **P.A.M. Dirac** develop quantum statistics for particles that obey Pauli's exclusion principle (such as electrons and protons). When compressed, such particles fly away from one another, creating a so-called degeneracy pressure.

1930

Using quantum statistics and Eddington's work on stars, **Subrahmanyan Chandrasekhar** finds that the upper mass limit for white dwarfs is 1.4 times the mass of the sun, suggesting that more massive stars collapse into oblivion. Eddington makes fun of him.

the sun, for example, it is three kilometers, whereas for a one-gram marble it is 10^{-28} centimeter.

Schwarzschild was, of course, aware that his formula went crazy at this radius, but he decided that it did not matter. He constructed a simplified model of a star and showed that it would take an infinite gradient of pressure to compress it to his radius. The finding, he argued, served no practical interest.

But his analysis did not appease everybody. It bothered Einstein, because Schwarzschild's model star did not satisfy certain technical requirements of relativity theory. Various people, however, showed that one could rewrite Schwarzschild's solutions so that they avoided the singularity. But was the result really nonsingular? It would be incorrect to say that a debate raged, because most physicists had rather little regard for these matters—at least until 1939.

In his 1939 paper Einstein credits his renewed concern about the Schwarzschild radius to discussions with the Princeton cosmologist Harold P. Robertson and with his assistant Peter G. Bergmann, who is now professor emeritus at Syracuse University. It was certainly Einstein's intention in this paper to kill off the Schwarzschild singularity once and for all. At the end of it he writes, "The essential result of this investigation is a clear understanding as to why 'Schwarzschild singularities' do not exist in physical reality." In other words, black holes cannot exist.

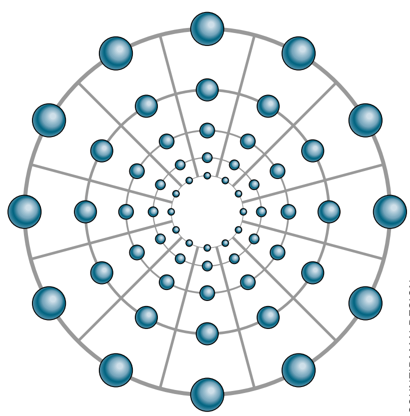
To make his point, Einstein focused on a collection of small particles moving in circular orbits under the influence of one another's gravitation—in effect, a system resembling a spherical star cluster. He then asked whether such a configuration could collapse under its own gravity into a stable star with a radius equal to its Schwarzschild radius. He concluded that it could not, because at a somewhat larger radius the stars in the cluster would have to move faster than light in order to keep the configuration stable. Although Einstein's reasoning is correct, his point is irrelevant: it does not matter that a collapsing star at the Schwarzschild radius is unstable, because the star collapses past that radius anyway. I was much taken by the fact that the then 60-year-old Einstein presents in this paper tables of numerical results, which he must have gotten by using a slide rule. But the paper, like the slide rule, is now a historical artifact.

From Neutrons to Black Holes

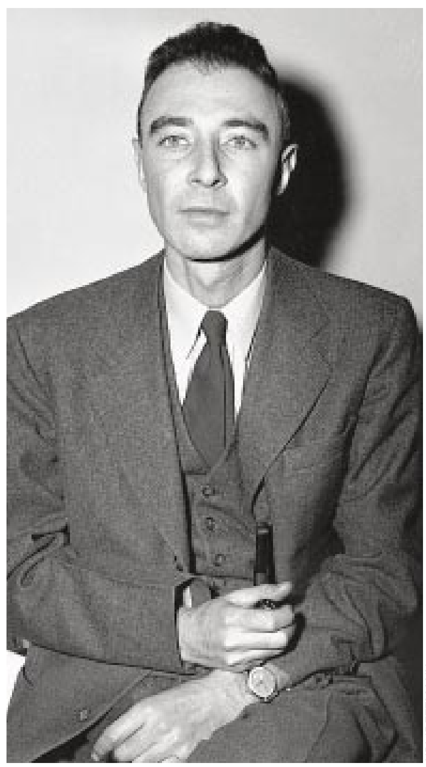
While Einstein was doing this research, an entirely different enterprise was unfolding in California. Oppenheimer and his students were creating the modern theory of black holes [see "J. Robert Oppenheimer: Before the War," by John S. Rigden; Scientific American, July 1995]. The curious thing about the black-hole research is that it was inspired by an idea that turned out to be entirely wrong. In 1932 the British experimental physicist James Chadwick found the neutron, the neutral component of the atomic nucleus. Soon thereafter speculation began—most notably by Fritz Zwicky of the California Institute of Technology and independently by the brilliant Soviet theoretical physicist Lev D. Landau—that neutrons could lead to an alternative to white dwarfs.

1932
James Chadwick discovers the neutron. Its existence leads researchers to wonder if "neutron stars" could be an alternative to white dwarfs.

"On a Stationary System with Spherical Symmetry Consisting of Many Gravitating Masses"
– Albert Einstein in *Annals of Mathematics*, 1939



1939
Sparked by conversations with colleagues, Einstein tries to kill off the Schwarzschild radius once and for all: he concludes that black holes are impossible in a paper published in *Annals of Mathematics.*



1939
Using ideas of collapsing neutron stars and white dwarfs, **J. Robert Oppenheimer** and his student Hartland S. Snyder show how a black hole can form.

When the gravitational pressure got large enough, they argued, an electron in a star could react with a proton to produce a neutron. (Zwicky even conjectured that this process would happen in supernova explosions; he was right, and these "neutron stars" we now identify as pulsars.) At the time of this work, the actual mechanism for generating the energy in ordinary stars was not known. One solution placed a neutron star at the center of ordinary stars, in somewhat the same spirit that many astrophysicists now conjecture that black holes power quasars.

Although Einstein's reasoning was correct, his point is irrelevant.

The question then arose: What was the equivalent of the Chandrasekhar mass limit for these stars? Determining this answer is much harder than finding the limit for the white dwarfs. The reason is that the neutrons interact with one another with a strong force whose specifics we still do not fully understand. Gravity will eventually overcome this force, but the precise limiting mass is sensitive to the details. Oppenheimer published two papers on this subject with his students Robert Serber and George M. Volkoff and concluded that the mass limit here is comparable to the Chandrasekhar limit for white dwarfs. The first of these papers was published in 1938, and the second in 1939. (The real source of stellar energy—fusion—was discovered in 1938 by Hans Bethe and Carl Friedrich von Weizsäcker, but it took a few years to be accepted, and so astrophysicists continued to pursue alternative theories.)

Oppenheimer went on to ask exactly what Eddington had wondered about white dwarfs: What would happen if one had a collapsing star whose mass exceeded any of the limits? Einstein's 1939 rejection of black holes—to which Oppenheimer and his students were certainly oblivious, for they were working concurrently, 3,000 miles away—was of no relevance. But Oppenheimer did not want to construct a stable star with a radius equal to its Schwarzschild radius. He wanted to see what would happen if one let the star collapse through its Schwarzschild radius. He suggested that Snyder work out this problem in detail.

To simplify matters, Oppenheimer told Snyder to make certain assumptions and to neglect technical considerations such as the degeneracy pressure or the possible rotation of the star. Oppenheimer's intuition told him that these factors would not change anything essential. (These assumptions were challenged many years later by a new generation of researchers using sophisticated high-speed computers—poor Snyder had an old-fashioned mechanical desk calculator—but Oppenheimer was right. Nothing essential changes.) With the simplified assumptions, Snyder found out that what happens to a collapsing star depends dramatically on the vantage point of the observer.

Two Views of a Collapse

Let us start with an observer at rest a safe distance from the star. Let us also suppose that there is another observer attached to the surface of the star—"co-moving" with its collapse—who can send light signals back to his stationary colleague. The stationary observer will see the signals from his moving counterpart gradually shift to the red end of the electromagnetic spectrum. If the frequency of the signals is thought of as a clock, the stationary observer will say that the moving observer's clock is gradually slowing down.

Indeed, at the Schwarzschild radius the clock will slow down to zero. The stationary observer will argue that it took an infinite amount of time for the star to collapse to its Schwarzschild radius. What happens after that we cannot say, because, according to the stationary observer, there is no "after." As far as this observer is concerned, the star is frozen at its Schwarzschild radius.

Indeed, until December 1967, when the physicist John A. Wheeler, now at Princeton University, coined the name "black hole" in a lecture he presented, these objects were often referred to in the literature as frozen stars. This frozen state is the real significance of the singularity in the Schwarzschild geometry. As Oppenheimer and Snyder observed in their paper, the collapsing star "tends to close itself off from any communication with a distant observer; only its gravitational field persists." In other words, a black hole has been formed.

But what about observers riding with collapsing stars? These observers, Oppenheimer and Snyder pointed out, have a completely different sense of things. To them, the Schwarzschild radius has no special significance. They pass right through it and on to the center in a matter of hours, as measured by their watches. They would, however, be subject to monstrous tidal gravitational forces that would tear them to pieces.

The year was 1939, and the world itself was about to be torn to pieces. Oppenheimer was soon to go off to war to build the most destructive weapon ever devised by humans. He never worked on the subject of black holes again. As far as I know, Einstein never did, either. In peacetime, in 1947, Oppenheimer became the director of the Institute for Advanced Study in Princeton, N.J., where Einstein was still a professor. From time to time they talked. There is no record of their ever having discussed black holes. Further progress would have to wait until the 1960s, when discoveries of quasars, pulsars and compact x-ray sources reinvigorated thinking about the mysterious fate of stars. SA

The Author

JEREMY BERNSTEIN is professor emeritus of physics at the Stevens Institute of Technology, an adjunct professor at the Rockefeller University and a vice president of the board of trustees of the Aspen Center for Physics. He is a former staff writer for the *New Yorker* and the recipient of many science-writing awards. This article is adapted from his collection of essays, *A Theory for Everything,* to be published in August by Copernicus (Springer-Verlag). He wrote about Niels Bohr and the atomic bomb in the May 1995 issue of *Scientific American.*

Further Reading

SUBTLE IS THE LORD: THE SCIENCE AND THE LIFE OF ALBERT EINSTEIN. Abraham Pais. Oxford University Press, 1982.

DARK STARS: THE EVOLUTION OF AN IDEA. Werner Israel in *300 Years of Gravitation.* Edited by S. W. Hawking and W. Israel. Cambridge University Press, 1987.

CHANDRA: A BIOGRAPHY OF S. CHANDRASEKHAR. Kameshwar C. Wali. University of Chicago Press, 1991.

BLACK HOLES. J.-P. Luminet et al. Cambridge University Press, 1992.

BLACK HOLES AND TIME WARPS. Kip Thorne. W. W. Norton, 1994.

The Art of Charles R. Knight

Long before the film Jurassic Park, *Knight's illustrations brought dinosaurs to life in the public's mind*

by Gregory S. Paul

During the first half of the 20th century, paleontologists typically thought of dinosaurs as small-brained, tail-dragging reptiles that practiced little socialization and parenting. In recent years it has become increasingly apparent to some researchers that many dinosaurs were quite active and communal. But the earlier view, which Stephen Jay Gould of Harvard University has dubbed the Modern Consensus, held for many decades. Although paleontologists were responsible for this trend, the American artist Charles R. Knight (1874–1953) popularized it. The murals he painted for museums around the country dominated the way people viewed prehistoric life not only during his professional career—which extended from the turn of the century to the 1940s—but for several decades after his death as well. Indeed, the current generation of dinosaur illustrators, including myself, grew up admiring his renditions. And these images will very likely continue to inspire paleoartists in the years to come.

Knight's influence prevails in large part because he was both a superb artist and a naturalist who possessed a deep understanding of anatomy. He had the ability to apply his vast knowl-

DEADLY ENEMIES,
a horned *Triceratops* and towering *Tyrannosaurus,* meet face to face in Charles R. Knight's most influential mural (*below*), painted in the late 1920s. Such paintings still set high standards for today's paleo-artists. Relying on his vast knowledge of anatomy and his vivid imagination, Knight rendered many detailed images of prehistoric animals. For example, although the model *Stegosaurus* he created in 1899 (*photograph at right*) bears too many plates by current standards, it carries them in the alternating pattern now accepted.

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RON TESTA *Field Museum of Natural History*

edge of anatomical structure to make prehistoric creatures come alive again. His paintings remain on display at many museums, including the Field Museum of Natural History in Chicago and the Natural History Museum of Los Angeles County, and they form an important part of the new dinosaur halls at the American Museum of Natural History in New York City.

The first published account of fossils that today are believed to be from a dinosaur appeared in 1824. Throughout the 1800s, scientists collected numerous teeth and bones from excavations in Europe and the U.S. The public naturally clamored for descriptions of the long-gone giants. But the jumbled skeletons the fossil hunters found offered only sketchy information to artists hoping to re-create the prehistoric animals. The most notable effort to satisfy society's curiosity came from Richard Owen, the preeminent paleontologist who coined the name "Dinosauria" in 1841. In 1854 he commissioned full-size dinosaur sculptures—which are still standing today—for the grounds of the Crystal Palace in London.

The only complete skeleton unearthed before the 1880s

came from Germany: a small, carnivorous, birdlike animal named *Compsognathus*. The situation improved dramatically during the 1870s and 1880s, when scientists began to excavate the dinosaur-rich sediments in the arid western U.S. There they uncovered whole skeletons of sauropods, predaceous allosaurs and plated stegosaurs from the Jurassic period. Knowledge about the shape and size of dinosaurs quickly started to accumulate. Shortly thereafter, in the 1890s, Knight began painting them.

Despite his good timing, it is somewhat remarkable that he became the most famous dinosaur artist of his time. Knight was a sensitive character prone to phobias. And although he showed early promise—he began drawing animals and landscapes at age five or six—he was very nearsighted. In addition, a severe injury to his right eye during

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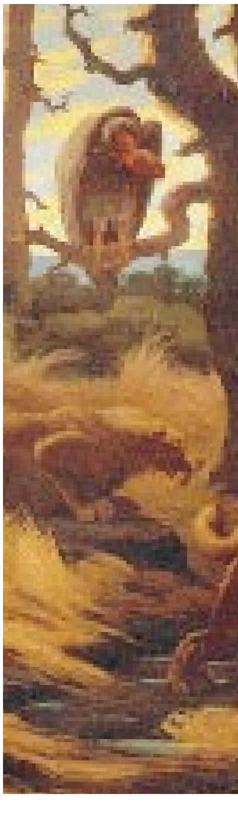

TAR PITS AT RANCHO LA BREA in California were painted by Knight in the 1920s, some 15 years after their excavation in 1906. The deposit yielded a vast number of Ice Age fossils, including those from saber-toothed cats, cave lions, elephants, mastodons, sloths, camels, horses, coyote, bison, antelope and birds. Unlike his drawings of dinosaurs, Knight's paintings of mammals typically showed a great deal of action. So, too, skeletal mounts of mammals made in conjunction with Knight's murals, such as the sloths at the American Museum of Natural History in New York City (*photograph*), took animated poses.

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DUCK-BILLED DINOSAURS of the genus *Anatosaurus* were painted by Knight in 1909 (*painting at left*). He based the composition on two skeletons mounted at the American Museum of Natural History. In the museum's newly renovated dinosaur halls, the mounts and Knight's painting are on display side by side.

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childhood further impaired his vision. All the same, encouraged by the adults around him, including an artistic stepmother and a talented family friend, Knight attended a series of art schools in and around New York City as he grew older. At age 16, he got his first, and only, full-time job, painting nature scenes for church decorations.

Quickly thereafter, Knight moved from Brooklyn—and away from his increasingly jealous stepmother—to Manhattan. He soon launched a successful freelance career as an illustrator for several natural history publications. He enjoyed going to the city's zoos and parks and chronicled his trips by making numerous, meticulous sketches of animals, plants and other objects. The exercise enhanced his work, as did his habit of visiting the American Museum of Natural History. There he honed his knowledge of anatomy by dissecting carcasses. It was also at the museum that Knight found his calling, when a paleontologist there asked him as a favor to create a replica of an extinct mammal.

After an extended trip to Europe—during which he studied art and visited even more zoos—Knight turned his attention to dinosaurs almost exclusively. He went to work for a short while under Edward Drinker Cope, just before the renowned vertebrate paleontologist died. Cope and his rival, Othniel C. Marsh of Yale College, had brought about the first great rush of American interest in dinosaurs during the 1870s.

But Knight formed his most important association again at the American Museum of Natural History, collaborating with the aristocratic paleontologist Henry Fairfield Osborn. As director of the museum, Osborn wanted someone to translate his collections of dry bones into captivating, living images. Such pictures, he thought, could draw

crowds and make his museum the leading center of natural science.

Knight quickly won attention for the museum and for himself, fashioning restorations that reflected many of Osborn's early ideas. Osborn proposed, for example, that sauropods may have been terrestrial high browsers, and so, under Osborn's direction, Knight painted just such a sauropod—a brontosaur—rearing up on its hind legs as though in search of foliage [*see illustration at right*]. Knight also showed large theropods—the most successful predatory dinosaurs—leaping into the air [*see upper illustration on opposite page*]. Although he was correct to characterize these theropods as agile hunters, most paleontologists of the time rejected that notion.

During the early 20th century, digs in North America and Asia produced remnants of remarkable dinosaurs from the Late Cretaceous period—among them terrible tyrannosaurs, horned ceratopsians, duck-billed hadrosaurs and armored ankylosaurs. Knight's paintings from this time—primarily murals for the American Museum of Natural History and for the Field Museum of Natural History—were sophisticated works of art. He typically painted misty scenes, possibly because of his poor long-range vision, filled with finely rendered, highly realistic figures of well-known dinosaurs. These were Knight's most productive years, and his illustrations became the world's most celebrated.

Knight's personal life was also at its zenith during the 1920s. He and his wife, the spirited Annie Hardcastle, were a popular couple on New York's social scene. Annie secured a comfortable life for them, managing all Knight's money matters, from his pocket change to his payments for paintings (he was notoriously absentminded about finances). At age 13, their daughter, Lucy, took charge. Seven years later, she successfully obtained $150,000 from the Field Museum for her father's murals on display there. In the 1930s Knight augmented his income by giving lectures, and his authority expanded even further. Today dinosaur restoration is a minor industry, practiced around the world. Necessarily, much of the romance that Knight enjoyed—having been almost alone in the field—has disappeared.

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DON HAMERMAN *American Museum of Natural History*

REARING SAUROPOD, which Knight painted early in his career, near the turn of the century, was influenced by one of the theories of the paleontologist Henry Fairfield Osborn—namely, that such dinosaurs might have been terrestrial high browsers (*painting*). Most paleontologists rejected the idea at the time; even so, the famed barosaur installed in 1991 in the entry hall of the American Museum of Natural History to greet visitors is mounted in the same position (*photograph*).

AMERICAN MUSEUM OF NATURAL HISTORY

FIGHTING CARNIVORES
of the genus *Dryptosaurus* are shown here as they were described by the paleontologist Edward Drinker Cope. Knight completed the painting in 1897, shortly after Cope died. Within a decade, most scientists frowned on the idea that these dinosaurs leaped into the air. Some scientists now think these theropods may have been quite aggressive hunters.

RON TESTA *Field Museum of Natural History*

SMALL *PROTOCERATOPS*
were painted by Knight in 1922, shortly after the first dinosaur nests were uncovered in Mongolia. At Osborn's suggestion, Knight depicted the ceratopsian dinosaurs protecting their eggs. (Recently experts at the American Museum of Natural History demonstrated that these eggs actually belonged to *Oviraptor.*) The painting can now be seen at the Field Museum of Natural History in Chicago.

JOHN WEINSTEIN *Field Museum of Natural History*

Knight worked in close collaboration with paleontologists. Thus, his art reflects the scientific dogmatism of his times. This dogmatism was by no means absolute, however. For example, in *Life through the Ages*—a catalogue of dinosaurs Knight compiled in 1946—he called dinosaurs "unadaptable and unprogressive" and "slow-moving dunces" that were well suited for extinction in favor of "alert, little warm-blooded" mammals. But on the same page he noted that one predaceous dinosaur was "lightly constructed for quick action, and fairly sagacious for a reptile." And he did not always draw dinosaurs as "typical" reptiles. In one painting he depicted a pair of *Triceratops* watching over a youngster. On occasion he placed social groups of plant-eating dinosaurs in his work. And after the discovery of dinosaur nests in Central Asia, he painted, at Osborn's suggestion, diminutive protoceratopsids guarding their eggs.

The limitations of the time are most apparent in Knight's best-known piece, showing a lone, horned *Triceratops* facing down two *Tyrannosaurus* [*see illustration on pages 86 and 87*]. Knight did not know that enormous beds of bones would eventually reveal that some horned dinosaurs lived in herds. Moreover, in Knight's picture, little action takes place between the herbivore and its predators. Every foot is planted firmly on the ground. In fact, the "every-foot-on-the-ground" rule is true of almost all Knight's dino-

AMERICAN MUSEUM OF NATURAL HISTORY

HORNED *AGATHAUMAS,* one of Knight's earliest works, was finished under the direction of Cope in 1897 for the American Museum of Natural History. During Cope's day, paleontologists offered many fanciful and unsubstantiated descriptions of dinosaurs. The animal shown at the left sports what would seem by current standards to be an extreme number of adornments.

NORTH AMERICAN DINOSAURS from the Upper Cretaceous period are seen in this mural, which Knight painted in the late 1920s for the Field Museum of Natural History. Moving through this somewhat misty scene, a variety of creatures stand out, including, from left to right, a helmet-crested *Corythosaurus*, a herd of *Parasaurolophus,* an armored *Palaeoscincus,* several *Struthiomimus* and a few flat-headed hadrosaurs (called *Edmontosaurus*).

saur figures. Although he frequently drew mammals, even large ones, walking and running, he almost never depicted dinosaurs doing so. Knight most often colored dinosaurs in rather drab shades of solid dun and green. Dinosaurs may have been such hues, but they probably had color vision much like reptiles and birds, and their scaly skins would have been suitable bases for more intense pigmentation. For these reasons, most of today's artists often apply vivid colors to their dinosaurs.

Knight used his vast knowledge of anatomy to make extinct forms appear so real that his viewers could easily believe he had seen them. This ability no doubt explains why his pictures continue to look plausible today. But this seeming realism was in some ways superficial. Although Knight sketched detailed musculoskeletal studies of living animals, he did not produce similar studies of dinosaurs—in part because skeletons reveal limited information about an animal's musculature. Instead Knight drew skeletal mounts, made rough sculptures or composed life restorations freehand—a tradition in which many dinosaur artists have followed.

One particular anatomical convention that Knight practiced perplexed me when I was a budding dinosaur artist in the late 1960s—back in the days before the idea that dinosaurs were energetic had gained any popularity. I knew that dinosaurs were considered to be reptiles and that lizards and crocodilians have narrow thigh muscles attached to small hips. Consistent with this theory, Knight made his dinosaurs with narrow, reptilelike thighs. Yet looking at skeletons, I thought that dinosaurs seemed to be built more like birds and mammals, with large hips anchoring broad thigh muscles. What was a teenage dino-artist to do? I copied my hero Knight, even though Alfred S. Romer, the esteemed vertebrate paleontologist of Harvard, had correctly depicted big-hipped dinosaurs with broad, birdlike thigh muscles in his classic 1920s studies of the evolution of tetrapod musculature. The paradox was resolved in the 1970s, when the new hypothesis that dinosaurs were "warm-blooded" at last emerged. An animal having broad hips and large thigh muscles would need to have an aerobic system capable of sustaining high levels of activity for extended periods.

Artists are a bit like magicians: we use optical illusions to fool people into thinking they are seeing a version of reality. Because one's bag of optical tricks gets bigger with time, most artists tend to get better with age. Knight's last decade of restorations, however, did not meet his earlier standards. Deteriorating eyesight may have been the culprit. Also, Osborn was long departed, and the Great Depression and World War II had sent dinosaurology into an era of quiescence that did not lift for 30 years. Knight never knew of dinosaur nesting grounds, the mass migration of herds, polar habitats, the shape of *Apatosaurus*'s head, giant meteoritic impacts, or the fact that birds are living dinosaurs. Even so, his re-creations currently set the highest standards for artistic quality—and they keep motivating those of us who follow in his footsteps. SA

The Author

GREGORY S. PAUL has published his artwork in *Nature, Smithsonian* and *Science News* and has written articles for many professional journals. A freelance dinosaur scholar and illustrator, Paul studied at Johns Hopkins University and resides in Baltimore, Md.

Further Reading

LIFE THROUGH THE AGES. Charles R. Knight. Alfred A. Knopf, 1946.
DINOSAURS, MAMMOTHS, AND CAVEMEN. S. M. Czerkas and D. F. Glut. E. P. Dutton, 1982.
DINOSAURS PAST AND PRESENT. Edited by S. J. Czerkas and E. C. Olson. University of Washington Press, 1987.
THE DINOSAUR SOCIETY'S DINOSAUR ENCYCLOPEDIA. Don Lessem and Donald F. Glut. Random House, 1993.

Taxoids: New Weapons against Cancer

The chemists who developed the cancer-fighting agent taxol are creating a family of similar compounds that may one day help combat the disease

by K. C. Nicolaou, Rodney K. Guy and Pierre Potier

ERIK S. LESSER

Just five years ago the chemical known as taxol made headlines as a breakthrough treatment for ovarian cancer. There was only one problem—the drug was incredibly hard to come by. Researchers had to extract the substance from the bark of the Pacific yew (*Taxus brevifolia*) in a process that inevitably killed the tree. Even more frustrating, yews grow slowly (a full-grown tree is around 25 feet tall), and each plant yields little bark. A 100-year-old tree provides only a gram of the compound, about half the amount needed for a single treatment. In addition, yews that produce taxol exist within the delicate old-growth forest of the Pacific Northwest, and harvesting the endangered trees would cause irreparable harm to this ecosystem. As the number of Pacific yews dwindled, environmentalists argued to protect the few remaining trees, while cancer patients and their families pleaded for more of the drug.

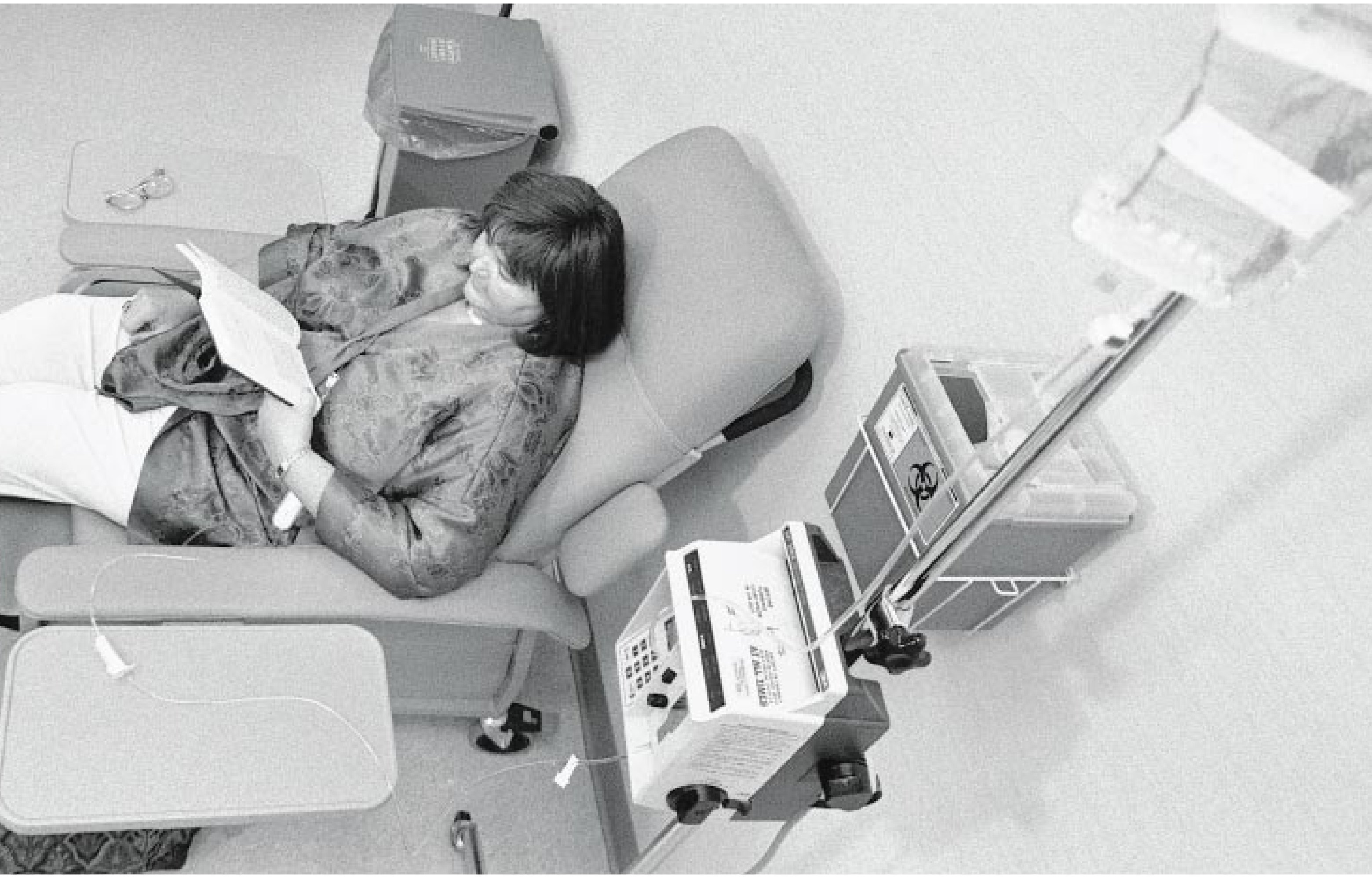
Today the headlines about taxol are quite different. In 1994 the U.S. Food and Drug Administration approved semisynthetic taxol, made in the laboratory and available in unlimited quantities, for use in the treatment of various cancers. Early this year a team of physicians based at Emory University announced results from an extensive study of the drug. Instead of lamenting its scarcity, the researchers emphasized its unexpected potency. According to the findings, women suffering from advanced ovarian cancer who took taxol in combination with another anticancer medication lived an average of 14 months longer than patients who received other therapies. Taxol is now considered one of the most promising treatments for breast and ovarian cancer. Other studies have demonstrated its effectiveness against lung cancer and melanoma. How did taxol, an agent initially known mainly for its absence, become renowned for its powerful presence?

The story of taxol provides an important lesson about how scientists discover and develop new drugs. Chemists first identified the compound almost 30 years ago. Since that time, biologists have determined how taxol works, and physicians have explored its healing properties. Many researchers, including the three of us, are pursuing the challenges of developing an entire family of taxol-like compounds—known as taxoids—that may eventually be easier to manufacture and that may also afford more and better therapeutic options than the parent molecule taxol.

Discovering Taxol, Again

Modern pharmaceutical interest in taxol extends back to the 1960s, but the medicinal properties of the yew tree have been known for centuries. In one of his seven books, collectively entitled *On the Gallic Wars,* published in 51 B.C., Julius Caesar recorded the death of the chieftain Catuvolcus, who committed suicide by drinking tea made from yew bark. In the northwestern U.S., Native American tribes such as the Quinault, Multnomah and Nez Percé utilized the Pacific yew's bark as a disinfectant, an abortifacient and a treatment for skin cancer. Over the past 100 years, however, yew trees attracted little attention—at least until very recently. In the Pacific Northwest, for instance, logging companies simply burned yews after clear-cutting the towering pine and fir trees that surrounded the much smaller yews.

But in 1962 the botanist Arthur Barclay of the U.S. Department of Agriculture started the yew on a long and circuitous journey back to being one of the most valuable trees in the Pacific Northwestern forest. At the time, the National Cancer Institute (NCI) had requested that researchers sample natural sources—such as plants, bacteria and marine life—in hopes of finding substances that might be useful as pharmaceuticals.



CANCER THERAPY WITH TAXOL involves repeated intravenous transfusions, each of which may last up to six hours. Here a woman at the Winship Cancer Center of Emory University receives taxol intravenously for ovarian cancer. Researchers hope derivatives of taxol, known as taxoids, will be easier to administer with simple injections or even tablets.

Barclay collected bark from Pacific yew trees in the Gifford Pinchot National Forest, located in Washington State.

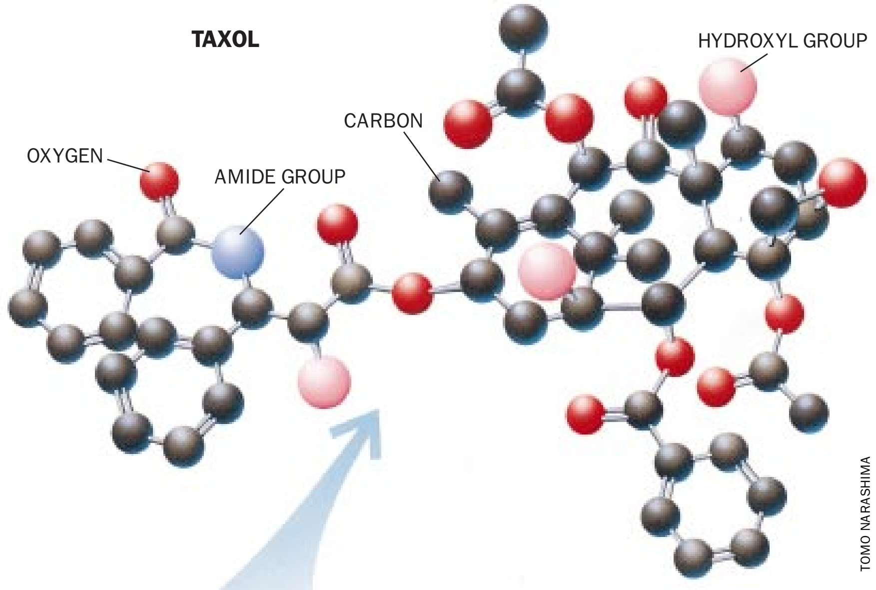
Barclay's yew samples eventually ended up at the Research Triangle Institute in North Carolina. There two chemists, Mansukh C. Wani and Monroe E. Wall, discovered that a mixture containing the yew's bark killed artificially preserved leukemia cells. By 1967 Wani and Wall had isolated the active ingredient from this mixture: a previously unknown chemical that they christened taxol because of its similarities to the family of chemicals known as taxanes and because the substance was found in plants of the genus *Taxus*. (Although the name "taxol" is still widely used generically, the pharmaceutical company Bristol-Myers Squibb has registered "Taxol" as a trademark and wants the scientific community to use "paclitaxel" instead.)

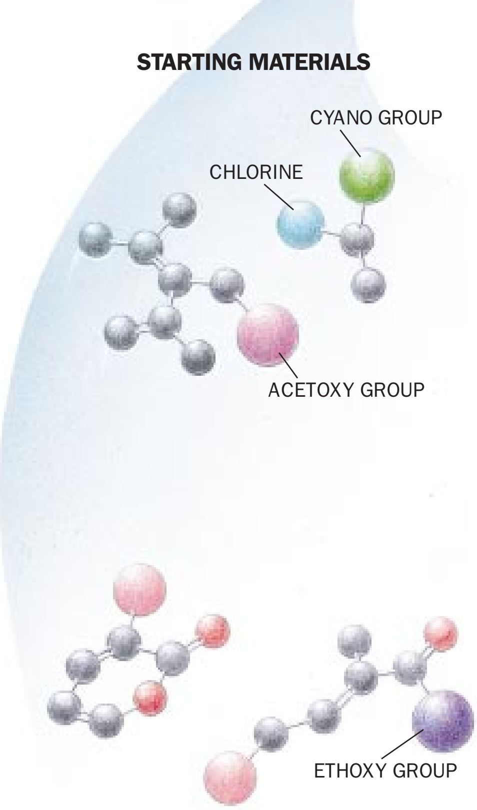
Over the next several years, taxol almost faded back into the forest. The NCI did not consider the compound particularly promising. In early tests, other drugs worked just as well or better than taxol for the treatment of cancer. Taxol was also rare and difficult to obtain. But Wall, acting on a strong belief about its potential, continued to champion the substance to the NCI. In 1977 the agency agreed to investigate the matter further. But even after additional study, taxol still did not stand out from drugs already in the anticancer pipeline.

Rigid Microtubules

Soon after the second round of tests at the NCI, however, a pair of biologists at the Albert Einstein College of Medicine in Bronx, N.Y., uncovered a new facet of taxol. In 1978 Susan B. Horwitz and one of her graduate students, Peter B. Schiff, demonstrated that taxol killed cancer cells in a manner unlike any other drug known at the time. Over the next 10 years, Horwitz's group probed the details of how taxol functions in the human body. In particular, the team found that taxol binds to structures in the cell known as microtubules, which serve as part of the cell's internal skeleton, or cytoskeleton.

Normally, microtubules are flexible constructions that play a crucial role in the dynamic process of cell division. For example, microtubules are the major constituents of the cellular apparatus known as the mitotic spindle, which helps to separate the chromosomes during cell mitosis. When taxol attaches to microtubules, they become extremely stable and static, making cell division impossible, thus killing the cells just as they begin to divide. Cancer cells divide more frequently than healthy cells, so the drug primarily attacks tumors, in which runaway cell division occurs. But other rapidly dividing cells, such as white blood cells or hair cells, can also be affected; consequently, taxol is not without side effects when used to treat cancer. For example, taxol can suppress





SYNTHETIC TAXOL can be produced from simple starting materials. Chemists at Scripps Research Institute combined four small molecules and added additional fragments in a series of 39 steps to produce taxol in a process known as total synthesis. By substituting different molecular fragments at any stage in the process, researchers can potentially make hundreds of derivatives of taxol, or taxoids.

patients' immune systems, deaden sensory nerves or cause nausea and hair loss.

The news of taxol's unusual method of attacking cancerous cells excited the research community. Cancer tends to become resistant to treatment over time; because taxol killed tumor cells in a novel fashion, it might offer hope to patients whose disease was not responding to current therapy. By 1984 physicians at a number of hospitals, including the Dana-Farber Cancer Institute in Boston, the Johns Hopkins Oncology Center in Baltimore, and Memorial Sloan-Kettering Cancer Center in New York City, had begun the first stage of human clinical trials to assess the safety of taxol. In one of these surveys, Eric K. Rowinsky and his associates at Johns Hopkins reported unprecedented results. In more than 30 percent of patients whose tumors had previously defied conventional chemotherapy, taxol reduced the size of the growths. One patient was even cured. Other studies soon echoed these findings, and taxol quickly slipped onto the pharmaceutical fast track.

(Unfortunately, taxol did have potentially serious drawbacks: many people experienced severe allergiclike reactions to treatment, and one person died from this response. The cause of such complications remains unclear, but doctors have adjusted the dosage of the drug and how it is administered to minimize the risk of adverse reactions. Nevertheless, as with all chemotherapies, the side effects of taxol continue to trouble physicians and patients.)

When the promising stories of taxol's benefits surfaced, the NCI found itself faced with two challenges. First, although taxol appeared to be excitingly effective, it was far from perfect. But this problem was typical for new drugs. Second, and more unusual, the supply of taxol was running short. Consequently, between 1984 and 1989 physicians could conduct only a limited number of extensive clinical trials. In 1989 the NCI and Bristol-Myers Squibb established a contract that arranged for the company to produce the compound for the NCI in exchange for gaining access to the results of the NCI's clinical trials. Soon after, Bristol-Myers Squibb began large-scale harvesting of the Pacific yew but predicted that supplies would last only five years. Faced with this impending shortage, scientists in many fields, including horticulture, forestry, cellular biology and chemistry, scrambled to find new ways to produce taxol.

Conquering a Molecular Mount Everest

Chemists in particular exhibited a serious interest in taxol. To them, molecules as large and complex as taxol, which contains 112 atoms, are aesthetically as well as scientifically appealing. Its intricate architecture presented a unique challenge to researchers—such as the three of us—who specialize in synthesizing natural products. We knew that the task of making artificial taxol would be a lengthy one, requiring years of work. In the course of the project, we would most likely come to understand the compound's idiosyncrasies—what parts of the structure were particularly stable or fragile and how the molecule interacted with other chemicals. Such information would help us address broader questions about the precise molecular function of taxol in the body of a cancer patient. Eventually, we hope scientists will understand the architecture of taxol and how the compound attaches to microtubules so thoroughly that they will be able to custom-design new drugs with the benefits of taxol but with fewer harmful side effects.

Between 1983 and 1993, more than 30 research groups struggled to synthesize taxol or simpler, related compounds. But taxol proved to be an exceedingly difficult molecule to construct; at times, it seemed unconquerable. Initially, many groups explored the technique known as semisynthesis in their attempts. In this process, chemists essentially start at about the halfway point in the synthesis; rather than joining many small fragments together to produce the final product, they begin with a substance that is very similar to the desired structure (and that is, ideally, cheap and available in large quantities). Then, by slightly altering this molecule, they obtain the compound of interest in only a few steps.

In the early 1980s one of us (Potier) at the National Center of Scientific Research in France, along with Andrew E. Greene and his colleagues at the Joseph Fourier University in Grenoble, carried out the first successful semisynthesis of taxol. The investigators observed that taxol could be dissected into two parts: the complex center of the molecule, known as the taxane core, and a simpler structure known as the side chain, which is connected to the core. While Potier and his group were screening the European yew (*T. baccata*) for taxollike substances, they realized that the taxane core could be isolated from the needles of this plant. They then figured out a straightforward way to attach the side chain. Because the team obtained the taxane core from the needles, which grow back after harvesting, the procedure offered hope that supplies of taxol might not always be limited.

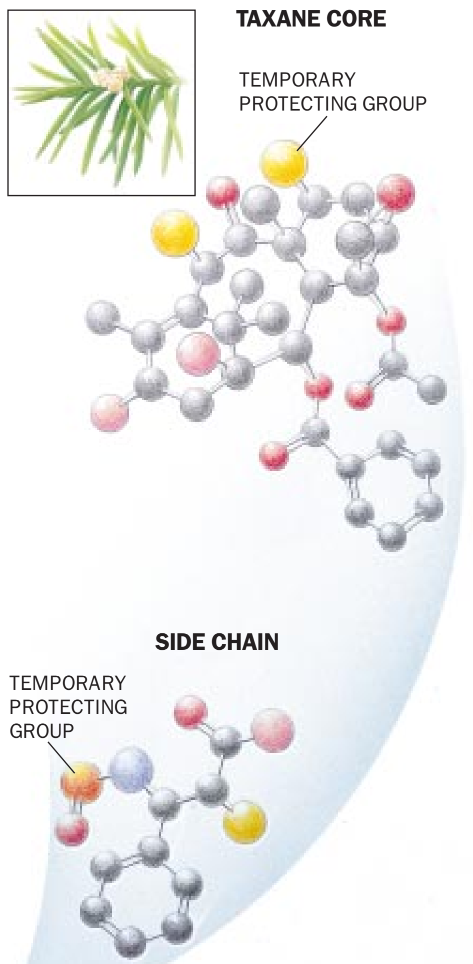
Such hope proved justified when, in 1993, Bristol-Myers Squibb announced that it would no longer harvest Pacific yews. The company had adopted a process for the commercial production of taxol that was initially developed independently by Iwao Ojima of the State University of New York at Stony Brook and by Robert A. Holton of Florida State University. These two researchers also employed a semisynthesis, but their side chain and the method they used to attach it to the core differed from the French version.

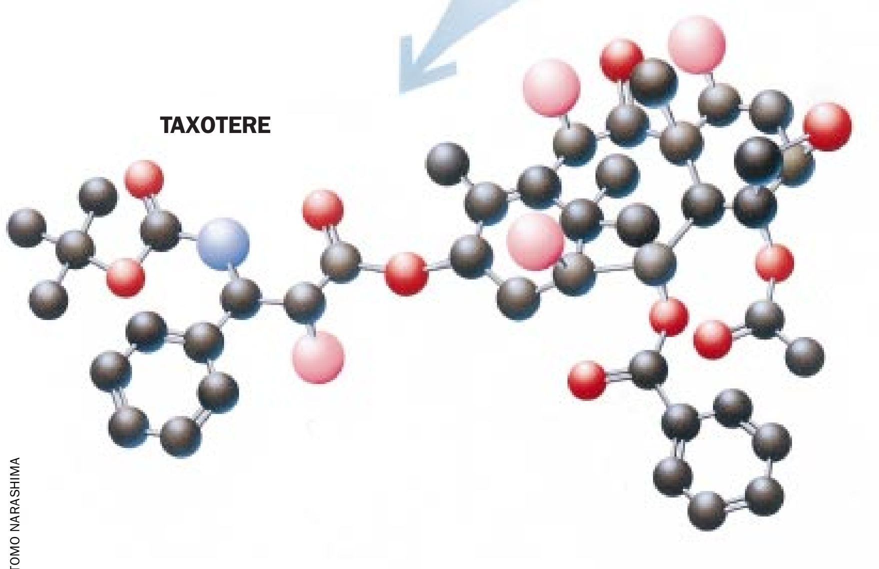
Starting from Scratch

As Potier, Greene and others focused their efforts on producing taxol by semisynthesis, researchers elsewhere, including the two of us—Nicolaou and Guy—at Scripps Research Institute, continued to work on a total synthesis. By constructing taxol with simple building blocks, we would be able to modify the compound's structure at any position, thereby creating a variety of taxol derivatives, or taxoids, some of which might prove less expensive and more potent than taxol itself. In early 1994 two groups almost simultaneously reported a total synthesis of taxol. Nicolaou, Guy and their colleagues first published the results of their work in the journal *Nature;* Holton's group recounted its success in the *Journal of the American Chemical Society.*

Any synthesis of taxol must take into account the inherent symmetry, or "handedness," of natural products. Structures with this property—like our two hands—exist as mirror images of each other; we refer to each mirror image as an enantiomer. But often only one enantiomer can produce an effect in the human body. Not surprisingly then, scientists believe only one form of taxol can combat cancer. The proper enantiomer can be selected early on, by starting with chemicals of the appropriate configuration and then maintaining this orientation at every step of the synthesis. This approach restricts the choice of starting material, however, and thereby limits the versatility of the synthesis. To avoid such constraints and to reserve the option of constructing both enantiomers, our group at Scripps employed the technique known as resolution, which allowed us to distinguish between enantiomers. We were then free to work with a mixture of enantiomers and to select the relevant configuration near the end of the synthesis.

To further streamline the efficiency of our method, we assembled taxol using what is called convergent synthesis. Using this approach, one begins with several small pieces and joins them together to obtain the desired product; in contrast, linear synthesis involves modifying a single starting compound sequentially. The final structure can be altered in





MAKING TAXOTERE from a complex substance similar to both taxol and Taxotere, which is found in the needles of the European yew (*inset*), offered a method of producing a taxollike compound in a few steps. Scientists at the National Center of Scientific Research in France combined the taxane core with a small side chain in a technique known as semisynthesis. Although semisynthesis provides a quick way to produce taxol and Taxotere, it does not lend itself as easily to making a variety of taxoids.

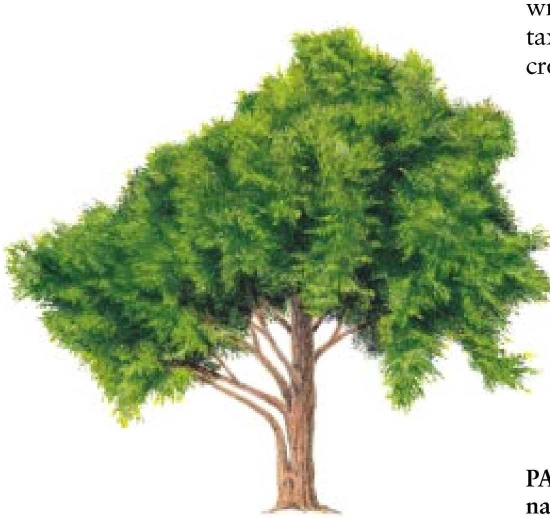
TOMO NARASHIMA

a convergent synthesis fairly easily by introducing different building blocks at any stage of the process; in a linear synthesis, the choice of building blocks is much more restricted. In this way, we could make small, systematic changes in taxol's central core or side chain.

Chemists routinely make these kinds of changes in a compound's structure to evaluate how the molecular framework of the drug influences its potency. For example, suppose that for some hypothetical drug, replacing a hydroxyl group (–OH) with a hydrogen atom makes the substance much less effective. One would then assume that the hydroxyl group is directly involved in the chemical's interaction with the body. Drawing on this information, researchers can make new molecules by altering or eliminating segments that either do not influence potency or cause harmful side effects. Or parts of the structure that reduce potency can be altered or eliminated to improve the drug.

For example, Potier and his colleagues produced the first notable taxoid, which they named Taxotere. The structure of Taxotere differs from taxol at two sites, but fortunately the taxoid also combats the growth of tumors. Physicians in Japan and Europe commonly use Taxotere as a therapy for breast and ovarian cancers; in late 1995 the FDA approved Taxotere for women with drug-resistant or metastatic breast cancer. Taxotere and taxol appear to have subtle differences in their ability to treat certain cancers. Extensive use of both drugs in clinical trials should allow scientists to define any advantages that one may have over the other.

Nicolaou, Guy and their colleagues at Scripps have produced two important classes of taxol derivatives that might one day yield functional pharmaceuticals. First, they simplified taxol's structure and produced a taxoid that is somewhat easier to make than taxol but, in preliminary tests, can still kill certain types of cancer cells. Second, the group has developed a class of taxoids that differs slightly at what seems to be the region of taxol that attaches to microtubules. Scientists are continuing work to improve taxol's potency by tinkering with this binding site and thus making taxol more efficient at connecting to microtubules and preventing cell division.



TOMO NARASHIMA

PACIFIC YEW TREE provided the original source of the anticancer agent taxol.

Improving Taxol

All three of us have also been attempting to solve one of taxol's major pharmacological drawbacks: its inability to dissolve in water. This property makes administering taxol to patients complex and difficult. Currently doctors administer taxol intravenously over several hours; the liquid medium used in this process, Cremophor El, has caused complications in some patients. A water-soluble compound would be much easier to handle. One new taxoid developed at Scripps dissolves in water and could possibly be administered with fewer side effects.

Other water-soluble taxoids produced in the laboratory allow us to examine in greater detail how taxol actually attaches to microtubules. Because taxol itself is so resistant to solubility, investigators have typically analyzed its crystalline, or solid, structure. Unfortunately, the solid form of a molecule does not always accurately reflect the way the compound exists in the aqueous environment of the cell. By observing how dissolved taxoids attach to microtubules, we can get a sense of which segments of the taxoid molecules are most likely to interact with cells. Obviously, if we want to manipulate taxol's structure to better its effectiveness, we need to know where and how this binding occurs. We may be able to enhance taxol's ability to latch onto microtubules and thus kill cells. At the very least, we would not want to alter the binding site in such a way as to diminish taxol's potency.

Clearly, the story of taxol is not complete. But in the discovery of new drugs, one rarely cries "Eureka!" Rather the process takes years of detailed research to determine how a drug works and how to improve its potency. In the case of taxol, scientists have made significant progress, not only figuring out how to produce large quantities of the originally scarce drug but also finding new applications for its use in cancer therapy. Now we have turned to yet another challenge—tinkering with taxol's structure until we find a less expensive, more effective medication. SA

The Authors

K. C. NICOLAOU, RODNEY K. GUY and PIERRE POTIER share an interest in the molecular design and chemistry of natural products. Nicolaou, who holds joint appointments at Scripps Research Institute and the University of California, San Diego, began investigating taxoids in 1992. Guy started his doctoral studies at Scripps in 1991; after graduation, he will move to Southwestern Medical Center in Dallas. Potier began his research on taxol in 1980 at the National Center of Scientific Research in Gif-sur-Yvette, France, where he is currently the director.

Further Reading

THE YEW TREE: A THOUSAND WHISPERS. Hal Hartzell, Jr. Hulogosi Communications, Eugene, Ore., 1991.

TAXOL AND TAXOTERE: DISCOVERY, CHEMISTRY, AND STRUCTURE-ACTIVITY RELATIONSHIPS. D. Guenard, F. Gueritte-Voegelein and P. Potier in *Accounts of Chemical Research,* Vol. 26, No. 4, pages 160–167; April 1993.

AN OVERVIEW OF EXPERIENCE WITH TAXOL (PACLITAXEL) IN THE U.S.A. R. C. Donehower and E. K. Rowinsky in *Cancer Treatment Reviews,* Vol. 19, Supplement C, pages 63–78; October 1993.

CHEMISTRY AND BIOLOGY OF TAXOL. K. C. Nicolaou, W.-M. Dai and R. K. Guy in *Angewandte Chemie, International Edition in English,* Vol. 33, No. 1, pages 45–66; January 17, 1994.

TOTAL SYNTHESIS OF TAXOL. K. C. Nicolaou, Z. Yang, J. J. Liu, H. Ueno, P. G. Nantermet, R. K. Guy, C. F. Claiborne, J. Renaud, E. A. Couladouros, K. Paulvannan and E. J. Sorensen in *Nature,* Vol. 367, pages 630–634; February 17, 1994.

by Shawn Carlson

Homemade Microgram Electrobalances

Microgram balances are clever devices that can measure fantastically tiny masses. Top-of-the-line models employ an ingenious combination of mechanical isolation, thermal insulation and electronic wizardry to produce repeatable measurements down to one tenth of a millionth of one gram. With their elaborate glass enclosures and polished gold-plated fixtures, these balances look more like works of art than scientific instruments. New models can cost more than $10,000 and often require a master's touch to coax reliable data from background noise.

But for all their cost and outward complexity, these devices are in essence quite simple. One common type uses a magnetic coil to provide a torque that delicately balances a specimen at the end of a lever arm. Increasing the electric current in the coil increases the torque. The current required to offset the weight of the specimen is therefore a direct measure of its mass. The coils in commercial balances ride on pivots of polished blue sapphire. Sapphires are used because their extreme hardness (only diamonds are harder) keeps the pivots from wearing. Sophisticated sensing devices and circuitry control the current in the coil—which is why microgram electrobalances are so pricey.

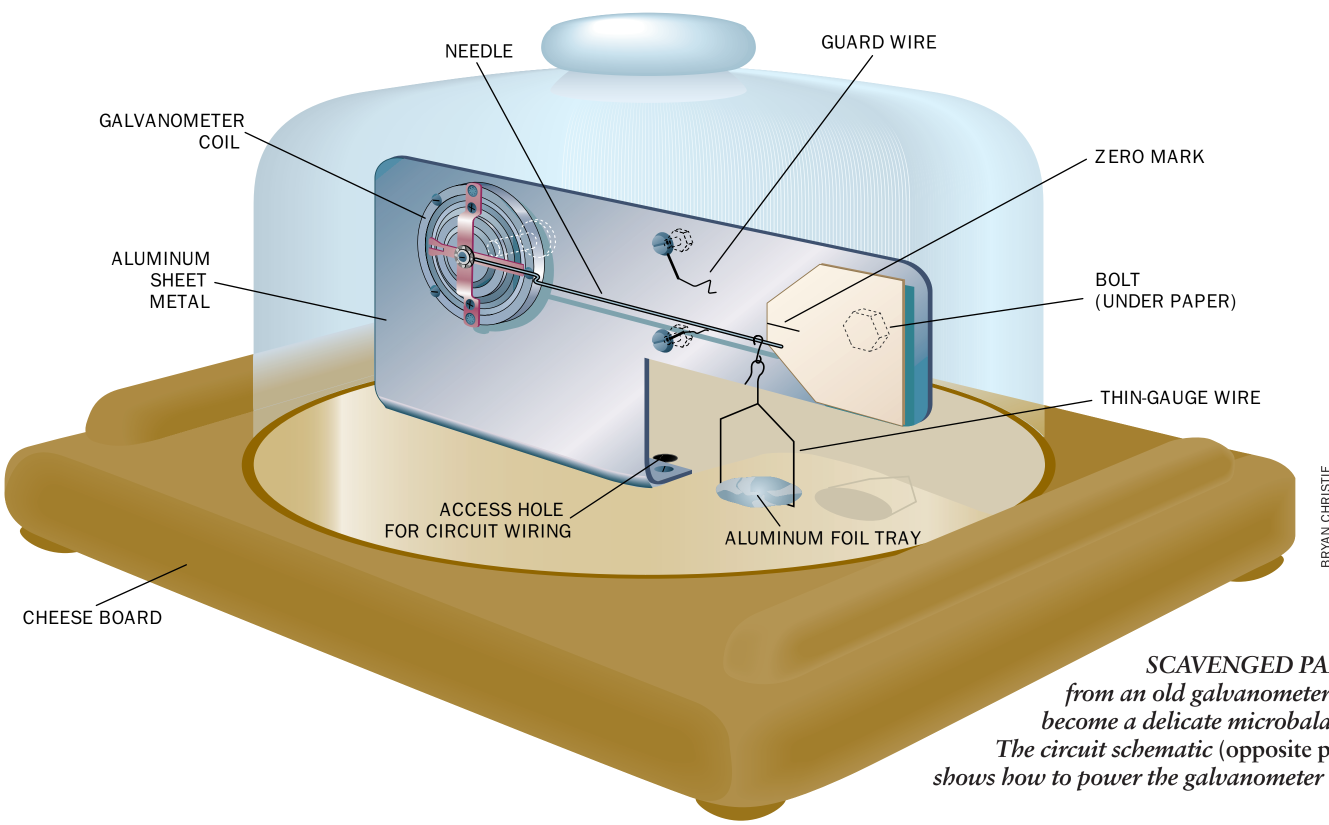
And that is good news for amateurs. If you are willing to substitute your eyes for the sensors and your hands for the control circuits, you can build a delicate electrobalance for less than $30.

George Schmermund of Vista, Calif., made this fact clear to me. For more than 20 years, Schmermund has run a small company called Science Resources, which buys, repairs and customizes scientific equipment. Although he may be an austere professional to his clients, I know him to be quite the free spirit who spends time in the business world only so he can make enough money to indulge his true passion—amateur science.

Schmermund already owns four expensive commercial microgram balances. But in the interest of advancing amateur science, he decided to see how well he could do on the cheap. His ingenious ploy was to combine a cheese board and an old galvanometer, a device that measures current. The result was an electrobalance that can determine weights from about 10 micrograms all the way up to 500,000 micrograms (0.5 gram).

The precision of the measurements is quite impressive. I personally confirmed that his design can measure to 1 percent masses exceeding one milligram. Furthermore, it can distinguish between masses in the 100-microgram range that differ by as little as two micrograms. And calculations suggest that the instrument can measure single masses as slight as 10 micrograms (I didn't have a weight this small to test).

The crucial component, the galvanometer, is easy to come by. These devices are the centerpiece of most old analog electric meters—the kind that use a needle mounted on a coil. Current flowing through the coil creates a magnetic field



SCAVENGED PARTS from an old galvanometer can become a delicate microbalance. The circuit schematic (opposite page) *shows how to power the galvanometer coil.*

that deflects the needle. Schmermund's design calls for the needle, mounted in the vertical plane, to act as the lever arm: specimens hang from the needle's tip.

Electronic surplus stores will probably have several analog galvanometers on hand. A good way to judge the quality is to shake the meter gently from side to side. If the needle stays in place, you're holding a suitable coil. Beyond this test, a strange sense of aesthetics guides me in selecting a good meter. It is frustratingly difficult to describe this sense, but if I'm moved to say, "Now this is a beautiful meter!" when I look it over, I buy it. There is a practical benefit to this aesthetic fuzziness. Finely crafted and carefully designed meters usually house exquisite coils that are every bit as good as the coils used in fine electrobalances, sapphire bearings and all.

To build the balance, gently liberate the coil from the meter housing, being careful not to damage the needle. Mount the coil on a scrap sheet of aluminum [*see illustration on opposite page*]. If you can't use aluminum sheet metal, mount the coil inside a plastic project box. To isolate the balance from air currents, secure the entire assembly in a glass-covered cheese board, with the aluminum sheet standing upright so that the needle moves up and down. The two heavy guard wires cannibalized from the meter are mounted on the aluminum support to constrain the needle's range of motion.

Epoxy a small bolt to the aluminum support, just behind the needle's tip. The needle should cross just in front of the bolt without touching. Cover the bolt with a small piece of construction paper, then draw a thin horizontal line across the center of the paper. This line defines the zero position of the scale.

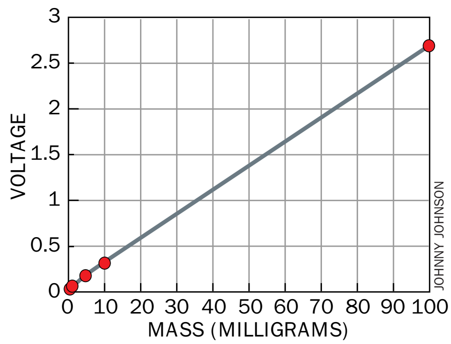
The specimen tray that hangs from the needle is merely a small frame homefashioned by bending noninsulated wire. The exact diameter of the wire is not critical, but keep it thin: 28-gauge wire works well. A tiny circle of aluminum foil rests at the base of the wire frame and serves as the tray pan. To avoid contamination with body oils, never touch the tray (or the specimen) with your fingers; rather always use a pair of tweezers.

To energize the galvanometer coil, you'll need a circuit that supplies a stable five volts [*see illustration below*]. Do not substitute an AC-to-DC adapter for the batteries unless you are willing to add filters that can suppress low-frequency voltage fluctuations.

The device uses two precision, 100-kilohm, 10-turn, variable resistors (also called potentiometers or rheostats)—the first to adjust the voltage across the coil and the second to provide a zero reference. A 20-microfarad capacitor buffers the coil against any jerkiness in the resistors' response and helps in making any delicate adjustments to the needle's position. To measure the voltage across the coil, you'll need a digital voltmeter that reads down to 0.1 millivolt. Radio Shack sells handheld versions for less than $80. Using a five-volt power supply, Schmermund's scale can lift 150 milligrams. For larger weights, replace the type 7805 voltage-regulator chip with a 7812 chip. It will produce a stable 12 volts and will lift objects weighing nearly half a gram.

To calibrate the scale, you'll need a set of known microgram weights. A single high-precision calibrated weight between one and 100 micrograms typically costs $75, and you'll need at least two. There is, however, a cheaper way. The Society for Amateur Scientists is making available for $10 sets of two calibrated microgram weights suitable for this project. Note that these two weights enable you to calibrate your balance with four known masses: zero, weight one, weight two and the sum of the two weights.

To make a measurement, begin with the scale pan empty. Cover the device with the glass enclosure. Choke down the electric current by setting the first resistor to its highest value. Next, adjust the second resistor until the voltage reads as close to zero as possible. Write down this voltage and don't touch this resistor until you have finished all your measurements. Now turn up the first resistor until the needle sinks down to the lower stop, then turn it back so that the needle returns to the zero mark. Note the voltage reading again. Use the average of three voltage measurements to define the zero point of the scale.



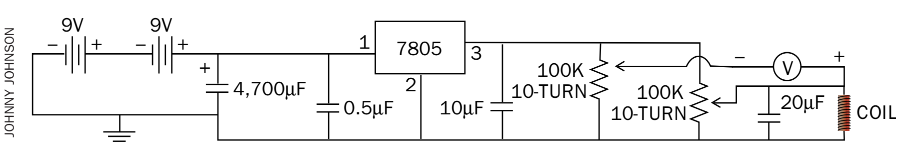
***CALIBRATION OF BALANCE** is accomplished by plotting known masses against the amount of voltage needed to lift each weight.*

Next, increase the resistance until the needle comes to rest on the lower wire support. Place a weight in the tray and reduce the resistance until the armature once more obscures the line. Record the voltage. Again, repeat the measurement three times and take the average. The difference between these two average voltages is a direct measure of the specimen's weight.

Once you have measured the calibrated weights, plot the mass lifted against the voltage applied. The data should fall on a straight line. The mass corresponding to any intermediate voltage can then be read straight off the curve.

Schmermund's balance is extremely linear above 10 milligrams. The slope of the calibration line decreased by only 4 percent at 500 micrograms, the smallest calibrated weight we had available. Nevertheless, I strongly suggest that you calibrate your balance every time you use it and always compare your specimens directly with your calibrated weights.

To receive the two calibrated weights, send $10 and a self-addressed, stamped envelope to the Society for Amateur Scientists, 4951 D Clairemont Square, Suite 179, San Diego, CA 92117. For more information about this project, send $5 to the address above or download it for free from the SAS Web page at http://www.thesphere.com/SAS/ or Scientific American's *area on America Online.*



Editors' note: *A printing problem mislabeled capacitance values in the circuit schematic for "Detecting Natural Electromagnetic Waves" (May). They should be microfarads (µF).*

by Ian Stewart

Tales of a Neglected Number

Last month I described the mathematical sculptures of Alan St. George, who often makes use of the well-known "golden number." The catalogue of his Lisbon exhibition mentions a less glamorous relative, referring to a series of articles in which "the architect Richard Padovan revealed the glories of the 'plastic number.'" The plastic number has little history, which is strange considering its great virtues as a design tool, but its provenance in mathematics is almost as respectable as that of its golden cousin. It doesn't seem to occur so much in nature, but, then, no one's been looking for it.

For purposes of comparison, let me start with the golden number: $\varphi = 1 + 1/\varphi = 1.618034$, approximately. The golden number has close connections with the celebrated Fibonacci numbers. This series can be illustrated by a spiraling system of squares [*see upper illustration on this page*]. The initial square (in gray) has side 1, as does its neighbor to the left. A square of side 2 is added above the first two, followed in turn by squares of side 3, 5, 8, 13, 21 and so on. These numbers, each of which is the sum of the previous two, form the Fibonacci series. The ratio of consecutive Fibonacci numbers tends to the golden number. For example, $21/13 = 1.615384$.

This fact is a consequence of the rule for generating Fibonacci numbers: for large numbers, it leads to the equation $\varphi = 1 + 1/\varphi$. If a quarter circle is added inside each square, the arcs fit together into an elegant spiral. This spiral is a good approximation to the so-called logarithmic spiral often found in nature, such as in the shell of a nautilus mollusk. Successive turns of the spiral grow at a rate approximately equal to the golden number.

That's the golden tale; now for the plastic one. We start with a similar diagram, but composed of equilateral triangles [*see lower illustration on this page*]. The initial triangle is marked in gray; successive triangles are added in a clockwise direction. The spiral generated is again roughly logarithmic. In order to make the shapes fit, the first three triangles all have side 1. The next two have side 2; then the numbers go 3, 4, 5, 7, 9, 12, 16, 21 and so on. Again there is a simple rule of formation: each number is obtained by skipping the previous one and adding the two before that. Let me call this sequence the Padovan sequence in honor of Richard Padovan. (It is curious that Padova is the Italian form of Padua, and Fibonacci was from Pisa—roughly 100 miles from Padua.)

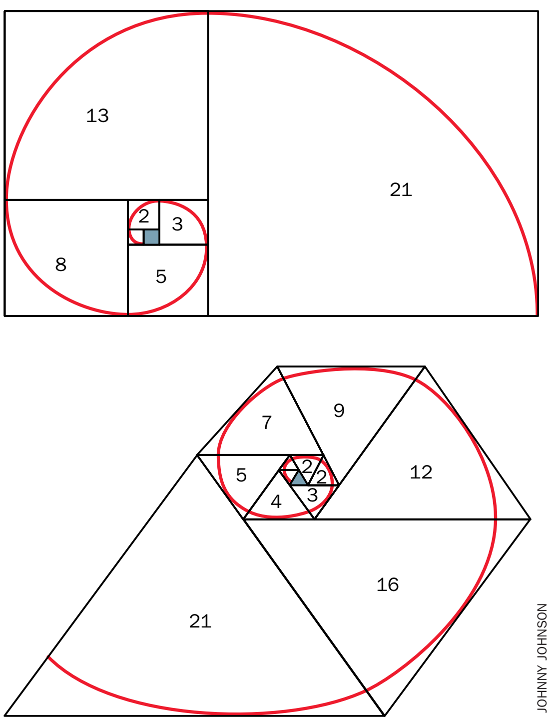
In algebraic form the generating rules for the Fibonacci sequence $F(n)$ and the Padovan sequence $P(n)$ are given as follows: $F(n + 1) = F(n) + F(n - 1)$ where $F(0) = F(1) = 1$, and $P(n + 1) = P(n - 1) + P(n - 2)$ where $P(0) = P(1) = P(2) = 1$. The family resemblance is very apparent. The plastic number, which from now on I shall call p and whose approximate value is 1.324718, arises as the limit of the ratio of successive Padovan numbers—just as the golden number arises from the Fibonacci sequence. The formation rule leads to the equation $p = 1/p + 1/p^2$, or equivalently $p^3 - p - 1 = 0$; the number p is the unique real solution of this equation.

The Padovan sequence increases much more slowly than the Fibonacci sequence, because p is smaller than φ. There are many interesting patterns in the Padovan sequence. For example, the figure shows that 21 = 16 + 5, because adjacent triangles on the same edge have to fit together. Thus, an alternative rule for deriving more terms for the sequence is $P(n + 1) = P(n) + P(n - 4)$.

Some numbers, such as 3, 5 and 21, are both Fibonacci and Padovan. Are there others? If so, how many, and is that count finite or infinite? Some Padovan numbers, such as 9, 16 and 49, are perfect squares—are there others? The square roots here are 3, 4 and 7—also Padovan numbers. Is this a coincidence or a general rule? These and many other questions deserve further study.

Another way to generate the Padovan numbers is to mimic the use of squares for Fibonacci numbers, but with cuboid structures, boxes with rectangular faces. Now we get a kind of three-dimensional spiral of boxes [*see illustration on opposite page*]. Start with a cube of side 1, placing another adjacent to it. The result is a 1 × 1 × 2 cuboid. On the 1 × 2 face, add another 1 × 1 × 2, getting a 1 × 2 × 2 cuboid. Then on a 2 × 2 face, add a 2 × 2 × 2 cube, to form a 2 × 2 × 3 cuboid overall. To a 2 × 3 face, add a 2 × 2 × 3 to get a 2 × 3 × 4 overall, and so on. Continue the process, always adding cuboids in the sequence east, south, down, west, north and up. At each stage the new cuboid formed will have as its sides three consecutive Padovan numbers.

Moreover, if you connect successive

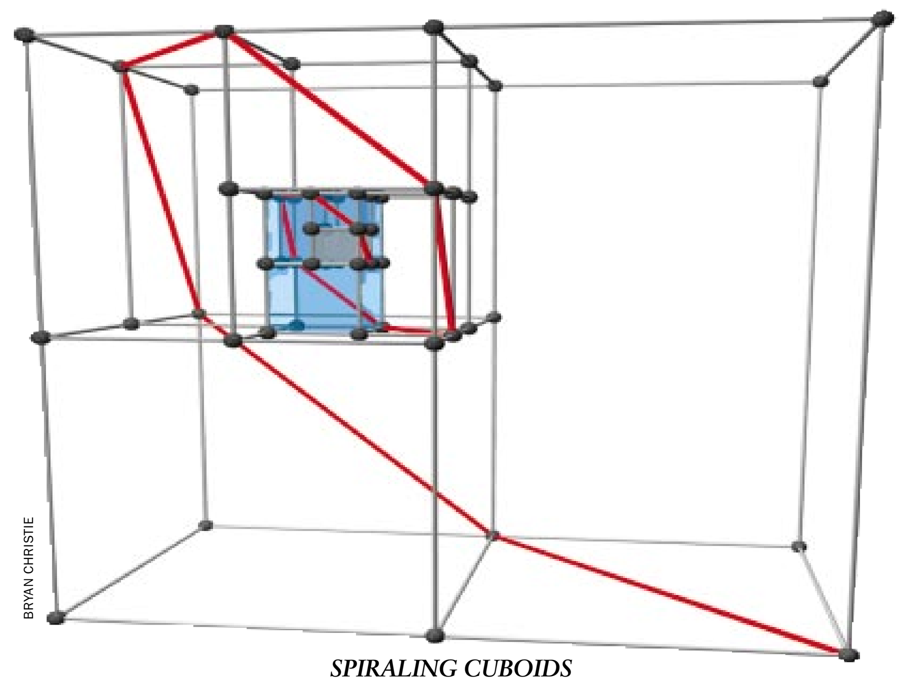


JOHNNY JOHNSON

***SPIRALING SYSTEMS illustrate the Fibonacci numbers* (top) *and the Padovan sequence* (bottom).**

square faces of the added cuboids by straight lines, you get a spiral. It even turns out that this spiral lies in a plane. St. George has based a sculpture on this construction, made from rigid rods connected by drilled balls at their corners. (What diagram does the intersection of the system of cuboids with this plane form?)

A sequence with the same rule of formation, but starting with different values, was studied in 1876 by the French mathematician Édouard Lucas. In 1899 his ideas were further developed by R. Perrin, and the sequence is now known as the Perrin sequence $A(n)$. The Perrin numbers differ from the Padovan numbers in that $A(0) = 3$, $A(1) = 0$ and $A(2) = 2$. Again the ratio of consecutive Perrin numbers tends to become p, but Lucas noticed a more subtle property. Whenever n is a prime number, it divides $A(n)$ exactly. For example, 19 is prime, $A(19) = 209$ and $^{209}/_{19} = 11$.



BRYAN CHRISTIE

SPIRALING CUBOIDS
also form Padovan numbers.

This theorem provides a curious test for a number to be composite—that is, not prime. For instance, when $n = 18$, we have $A(18) = 158$ and $^{158}/_{18} = 8.777$, which is not a whole number. Therefore, 18 must be composite. So we can use Perrin numbers to test for nonprimality: any number n that does not divide $A(n)$ is composite.

If n divides $A(n)$, must n always be prime? This does not follow from Lucas's theorem—any more than "if it rains, then I get wet" implies "if I get wet, then it rains." (I might have fallen into a pond on a perfectly dry day.) Still, it is a fascinating open question. Nobody has ever found a composite n that divides $A(n)$, but nobody has shown that such numbers—known as Perrin pseudoprimes—do not exist. In 1991 Steven Arno of the Supercomputing Research Center in Bowie, Md., proved that Perrin pseudoprimes must have at least 15 digits. I would be delighted to hear of any more recent progress.

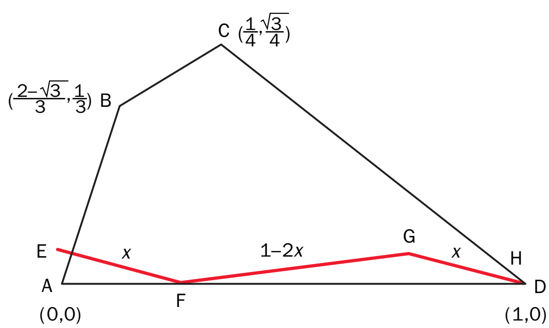
The conjecture that no Perrin pseudoprimes exist is important, because the remainder on dividing $A(n)$ by n can be calculated very rapidly. If the conjecture is true, this remainder will be 0 if and only if n is prime, thereby providing a speedy primality test. (Indeed, in 1982 William W. Adams and Daniel Shanks of the University of Maryland found a way to calculate this remainder in log n steps.) Thus, the conjecture should have useful applications to secret codes, which nowadays often hinge on properties of large primes.

Just like its glittering golden cousin, the plebeian plastic number generates rich spirals of ideas. SA

FEEDBACK

This month's feedback burrows under "Mother Worm's Blanket" [January]. Richard Delaware of the University of Missouri at Kansas City pointed out that in 1992 Rick Norwood, George Poole and Michael Laidacker found a worm blanket of area 0.27523 (from "The Worm Problem of Leo Moser," in *Discrete and Computational Geometry,* Vol. 7, No. 2, pages 153–162; 1992). This blanket is smaller than the 1973 result of Gerriets and Poole that I cited.

This result may still hold the record, because there seems to be a problem with the new blanket that I reported—the quadrilateral ABCD (*right*). Richard D. Kendon of Lowdham, Nottingham, England, found a worm that this blanket fails to cover. He notes that angles DAB and ADC are 75 and 30 degrees, respectively. His worm EFGH is composed of three straight segments. Point G lies distance x along a line that makes angle GDA = 15 degrees, and point F lies distance $1 - 2x$ from G on the line AD. Point E lies distance x from F so that angle EFA = 15 degrees, again. Kendon calculates that when $x = 0.01$, for example, angle EAD is 75.177 degrees. This angle is larger than 75 degrees, so that E lies outside the blanket.



JOHNNY JOHNSON

In and of itself this result is not necessarily fatal. Similar calculations, however, rule out any other position for this particular worm—even if the blanket is flipped over. So it looks as though ABCD must leave some baby worms with cold noses. —*I.S.*

James Stewart in the 1958 film *Bell, Book and Candle*; courtesy of Everett Collection

A BRIGHT LIGHT

Review by Joe Nickell

The Demon-Haunted World: Science as a Candle in the Dark
BY CARL SAGAN
Random House, 1996 ($25.95)

Books promoting pseudoscience are often popular and profitable—James Redfield's *The Celestine Prophecy* has sat on the best-seller list for more than two years. Skeptical books are much less marketable and so are comparatively rare. Rarer still are those of the caliber of Carl Sagan's new work, which joins a small but distinguished group that includes such classics as Charles Mackay's *Extraordinary Popular Delusions and the Madness of Crowds* (published in 1843) and Martin Gardner's *Fads and Fallacies in the Name of Science* (1957).

Sagan, director of the Laboratory for Planetary Studies at Cornell University, is perhaps the best known popularizer of science today. Moreover, he has written and lectured extensively on the paranormal and is an active fellow—as am I—of the Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP), one of the better known investigative organizations in the field.

The Demon-Haunted World is impressively comprehensive: it discusses topics from alien abductions to witchcraft, making stops at astrology, crop circles, dowsing, faith healing, ghosts, past-life regression and telepathy. (Sagan has an edge here, having recently written the foreword to Gordon Stein's 860-page *Encyclopedia of the Paranormal.*) Sagan even cites the recent evidence unmasking the 1947 Roswell Incident—firmly entrenched in UFO mythology as a flying-saucer cover-up—as the crash of a secret reconnaissance balloon. He also manages a debunking discussion of the infamous "alien autopsy" film shown on network television late in 1995.

Taking his title from the ancient Indian text *Isa Upanishad,* Sagan draws persuasive parallels between the oldest demon stories of the human mind and modern paranormal phenomena of spirit haunting and alien abduction. The vocabulary changes, he notes, but the underlying experiences appear to remain the same. "For much of our history," Sagan explains, "we were so fearful of the outside world, with its unpredictable dangers, that we gladly embraced anything that promised to soften or explain away the terror." Even ghosts and demons were better than nameless fear.

Sagan finds an impending threat not only in the New Age mania for the paranormal and religious miracles but also in that much broader realm known as pseudoscience. He takes a swipe at such jargon-clad follies as "facilitated communication" with autistic children, claims of hereditary racial differences in IQ and billions spent on the fanciful Star Wars antimissile umbrella. Amid these "regions of utter darkness," however, Sagan sees scientific reason as a candle lighting the way to sense. Like superstition, "science is an attempt...to understand the world, to get a grip on things, to get hold of ourselves, to steer a safe course," he writes. In contrast to pseudoscience, the scientific method has been mostly successful: "Microbiology and meteorology now explain what only a few centuries ago was considered sufficient cause to burn women to death."

Although his sympathies clearly lie with the debunkers, Sagan bravely acknowledges his own fallible humanity while attempting to coax readers to his point of view. He agrees that some unsupported beliefs have a strong and quite understandable attraction:

> My parents died years ago. I was very close to them. I still miss them terribly. I know I always will. I long to believe that their essence, their personalities, what I loved so much about them, are—really and truly—still in existence somewhere. I wouldn't ask very much, just five or ten minutes a year, say, to tell them about their grandchildren, to catch them up on the latest news, to remind them that I love them. There's a part of me—no matter how childish it sounds—that wonders how they are. "Is everything all right?" I want to ask. The last words I found myself saying to my father, at the moment of his death, were "Take care."
>
> Sometimes I dream that I'm talking to my parents, and suddenly—still immersed in the dreamwork—I'm seized by the overpowering realization that

they didn't really die, that it's all been some kind of horrible mistake.... When I wake up I go through an abbreviated process of mourning all over again. Plainly, there's something within me that's ready to believe in life after death.

Sagan occasionally stumbles, however, when preaching the gospel of modern technology. In one passage, he comments that "we can pray over the cholera victim, or we can give her 500 milligrams of tetracycline every 12 hours." In reality, antibiotics only slightly shorten the course of the disease. One would do better providing abundant fluids while the infection burns itself out—during which time emotional support and other intangibles clearly aid recovery—rather than contributing to the forces of unnatural selection that are rapidly rendering many antibiotics ineffective.

Elsewhere, Sagan does offer perfectly sound guidance for seeing through mediums, channelers and other such charlatans. How is it, he asks, that they never provide information from their spiritual "sources" that is both verifiable and unavailable by other means? "Why don't Sophocles, Democritus and Aristarchus dictate their lost books? Don't they wish future generations to have access to their masterpieces?"

There are practical means for warding off the demons of superstition and ignorance. In a chapter entitled "The

THE ILLUSTRATED PAGE

Floods of Fortune: Ecology and Economy along the Amazon
BY MICHAEL GOULDING, NIGEL J. H. SMITH AND DENNIS J. MAHAR
Columbia University Press, 1996 ($29.95)

Oversize and beautifully illustrated, it is nonetheless smarter than your average coffee-table book. The three authors (who are affiliated with the Rainforest Alliance, the University of Florida and the World Bank, respectively) offer a thoughtful balance of academic and pragmatic insights into one of the world's most celebrated ecosystems. A historical section describes the fundamental elements—wood, gold, hydropower, cattle—that have shaped the economy and ecology of the Amazon basin. From there, the book creatively and energetically explores the myriad life-forms that represent the region's natural wealth, along with the human forces that disrupt them, often to our detriment. Stunning photographs reinforce the message; fruit-eating fish, such as the pirarara catfish (*above*), are a surprising but economically vital part of life in the Amazon's flooded forests. The book's only blemishes are its occasional pedantic touches: the bibliography, for instance, contains seven pages of mostly obscure references unlikely to aid most readers. *—Corey S. Powell*

BRIEFLY NOTED

ENGINEERS OF DREAMS, *by Henry Petroski. Alfred A. Knopf, 1995 ($30).*
Underneath this volume's efficient prose lurks a love poem to the American bridge builders of the 19th century. Henry Petroski has a rare talent for finding the miraculous in the seemingly mundane; his chapter-length biographies of five of the most successful bridge engineers touch on everything from the human impulse to build to the social implications of infrastructure. The result is an unexpected page-turner, rich in technical detail and quietly passionate in tone.

A BEDSIDE *NATURE:* GENIUS AND ECCENTRICITY IN SCIENCE, 1869–1953, *edited by Walter Gratzer. Macmillan Magazines, 1996 ($29.95; $24.95 for subscribers).*
Fully living up to its title, this eclectic volume gathers together highlights and curiosities—letters, editorials, obituaries and so on—from the first 84 years of the journal *Nature.* It begins with a poetic tribute to the fascination of science, attributed to Thomas H. Huxley, and ends with Francis Crick and James D. Watson modestly putting forth "A Structure for Deoxyribose Nucleic Acid." It is a dense and often revealing document of science and the scientific mind.

BLIND WATCHERS OF THE SKY, *by Rocky Kolb. Addison-Wesley, 1996 ($25).*
Rocky Kolb runs squarely against fashion, starting the story of cosmology in 1572 (when Tycho Brahe spotted the supernova that still bears his name) and sticking for the most part to a textbooklike "great men" history of science. What makes it work—despite some stylistic excesses—is Kolb's relentless enthusiasm as a storyteller and his deliberately anachronistic use of language. He manages to breathe new life into familiar characters such as Newton and Galileo and to lead the reader fairly painlessly into the intricacies of modern astrophysics.

Continued on page 111

Fine Art of Baloney Detection," Sagan offers a kit of effective procedures, including Occam's razor (always choosing the simplest hypothesis that explains the data at hand) and the concept of falsifiability. "Propositions that are untestable, unfalsifiable are not worth much," he cautions. His kit also provides lessons on what not to do, including such rhetorical fallacies as the ad hominem argument, the "confusion of correlation and causation" and the fallacy of the excluded middle.

Sagan's book is, of course, only an introduction to the enlightenment that he hopes to help spread. The final chapters are devoted to the importance of education, especially education in critical thinking. He cites the case of Frederick Bailey, a 10-year-old black child sold into slavery in 1828. The slave owner's wife helped Bailey learn the rudiments of reading until her husband forbade it, explaining that such knowledge would "forever unfit him to be a slave." But the boy persevered in private.

Bailey escaped to New England, changed his name to Frederick Douglass, eluded the bounty hunters who tracked down runaway slaves and became one of the greatest orators, writers and political leaders of his century. "All his life," Sagan writes, "he understood that literacy had been the way out."

So it is today, for people hungry for real knowledge but largely bereft of the tools to acquire it. "In every country we should be teaching our children the scientific method and the reasons for a Bill of Rights," Sagan concludes, pointing out that an educated citizenry faces the best chance of constraining those in power to work for the people's interests. "In the demon-haunted world that we inhabit by virtue of being human, this may be all that stands between us and the enveloping darkness."

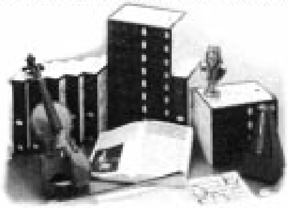
JOE NICKELL is a senior research fellow for the Committee for the Scientific Investigation of Claims of the Paranormal. He is a former stage magician and has spent more than 20 years looking into paranormal claims.

THROUGH THE WIRE

Twisted Pairs
At Performance Works in San Francisco (February 14–March 30)
World Wide Web site (http://www.georgecoates.org/)

The performance artist and techno-wizard George Coates hit on an interesting premise: to stage semi-improvisational performances that incorporate material from USENET news groups, giving visible form to the culture of the Internet. Coates's group also makes use of innovative "soft sets" that project a mixture of photography, film and computer-generated animation onto stage backdrops in lieu of conventional painted sets. The predictable problem is that in focusing so much attention on form, the producers completely lose sight of the need for substance. The actors mainly capture the tendency of some news groups to degenerate into inane banter, sophomoric humor and shouting matches.

Fortunately, *Twisted Pairs* has left behind an extensive and technically impressive Web site, which re-creates many of the production's highlights but mercifully omits the painfully repetitive technopop soundtrack. —*W. Wayt Gibbs*



CHEMICAL COMMUNICATIONS

Review by Peter Atkins

The Same and Not the Same
BY ROALD HOFFMANN
Columbia University Press, 1995
($34.95)

Chemistry needs passionate advocates. It is an essential component of our daily lives, and yet it is, by its very nature, always hidden from view. The discipline's bright side is so pervasive as to go almost unnoticed—and hence readily ignored by those who thrive on drama, inconvenience and death. Where would we be without the fuels, pharmaceuticals, fibers and fertilizers that have been made available by chemistry? Daedalus cannot invent without risk, however, and to the delight of the drama-mongers who feed the media, the dark side of chemistry is readily dressed up as "news."

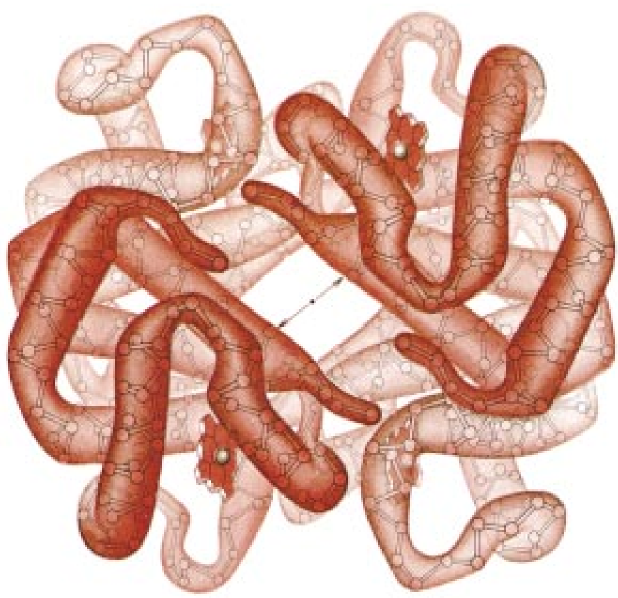
Paradoxically, the subject that deals with all that is material finds its basis in the seemingly abstract: chemical explanations are couched in terms of entropy, energy, atoms, electrons. Few chemists are able, or even willing, to straddle this chasm and relate the abstractions to the mundane. Yet to comprehend the material world in terms of the underworld of atoms and their accompaniments adds richness and delight to our understanding of everything around us.

Roald Hoffmann, a professor of physical science at Cornell University, is certainly a passionate advocate for his field. The title of his book recognizes the discipline's dialectic tensions. In addition to taking on harm versus benefit, Hoffmann confronts the other paradoxical bedfellows of chemistry, including static versus dynamic, creation versus discovery, natural versus unnatural, and revealed versus concealed—explaining how the opposites in each case may be so entwined as to be indistinguishable.

Hoffmann points out, for example, one of the great conceptions of chemistry—that chemistry is dynamic even when everything is in equilibrium: although nothing appears to be happening, at a molecular level there is incessant turmoil. Reaction products form at precisely the same rate at which they decompose into reactants. This dynamic equilibrium below the surface of the ostensibly static ultimately results in the subtle network of responses that we recognize as life.

A poet as well as a Nobel Prize–winning chemist, Hoffmann is well aware of the apparent dichotomy between the practice of chemistry—indeed, of science in general—which primarily involves discovery, and the practice of art, which is mostly creation. Yet he argues convincingly that the progress of chemistry depends also on creative thinking. And much of the power of art stems from presenting what is already there to the eyes of hitherto unseeing minds.

In his discussions of the natural and unnatural, Hoffmann tells of the ambiguity of our—and of chemists'—attempts to make a distinction between products harvested from nature and their synthetic counterparts (the latter often inspiring public suspicion). One of chemistry's major roles is to identify possibly vital contributions to the pharmacy that lie scattered sparsely throughout the natural world and to make them widely and generally available by developing methods for their synthesis. Here it seems to me that Hoffmann loses the

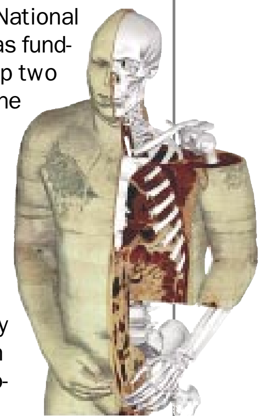


The complex symmetry of hemoglobin

BRIEFLY NOTED

Continued from page 109

DIGITAL HUMANS. *Multimedia Medical Systems, 1996. (CD-ROM for Windows, $19.95).*
In one of the most remarkable triumphs of anatomy since Andreas Vesalius, the U.S. National Library of Medicine has funded a project to slice up two cadavers (one male, one female) and photograph and digitize the cross sections. The results are presented here as a collection of slices and as a set of three-dimensional models. These brutally honest views are both scientifically and philosophically riveting.



THE ARTFUL UNIVERSE, *by John D. Barrow. Clarendon (Oxford University Press), 1995 ($27.50).*
Everyone knows that the starry sky is beautiful; nobody knows why. John D. Barrow's intent is nothing less than "to appreciate how the cosmic environment imprints itself upon our minds and bodies." In addition to dissecting evolutionary explanations for aesthetics, he considers, for instance, why computer art is interesting even when it is bad. Nearly living up to its ambitious goal, Barrow's book makes a consistently provocative case for the innate connection between science and art.

HEALTH AND HAPPINESS IN 20TH-CENTURY AVANT-GARDE ART, *by Donald Kuspit and Lynn Gamwell. Cornell University Press, 1996 ($29.95). Exhibit at the New York Academy of Sciences ends June 21.*
Taking a very different approach from Barrow's, Donald Kuspit and Lynn Gamwell have arrived at iconoclastic readings of 20th-century painting. Kuspit focuses on the often overlooked happy psychological core in the works of this century's "mature" avant-garde artists. Gamwell bravely searches for links between art and modern cosmological and atomic discoveries. The two essays succeed in part because of their inconclusiveness. Simply by stripping away preconceived ideas, they help the viewer bring a fresh eye to the surrounding modern masterworks.

THE CD EXAMINED

Kon-Tiki Interactive
Voyager, 1995 (Windows or Macintosh compatible, $39.95)

The explorer Thor Heyerdahl's career has spanned half a century since his epic balsa-raft journey across the Pacific Ocean bolstered his contention that sea travel helped to shape ancient civilizations. This CD-ROM highlights his voyages across the Atlantic, Pacific and Indian oceans, as well as excavations in Peru and Easter Island. Video and audio recollections from Heyerdahl himself, still hale at age 81, add spice to the text and pictures.

Viewers should be warned that an idiosyncratic design sometimes makes the search for the disc's treasures almost as daunting as the adventures it chronicles. —*Paul Wallich*

grip on his argument; by invoking the belief that "our soul has an innate need for the chanced, the unique, the growing that is life," his analysis seems empty. Elsewhere, however, he admits that he has a distaste for reductionism, so perhaps we must expect an unnatural measure of failure in these trickier regions of the natural.

I have found it harder to discern in the book what Hoffmann had in mind when he identified revelation and concealment as an essential dichotomy of chemistry. The closest I can come is his analysis of the art of scientific publication, where the purported aim is to reveal. Yet, according to Hoffmann, the way journal articles are written conceals the true process of false steps and intuitive leaps by which scientists proceed. Hoffmann argues that each scientific article is endowed with a suppressed tension and that the revelation of that tension is "a recognition of the deep humanity of the creative act in science."

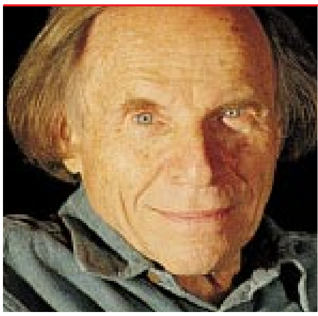
Although there is much more in *The Same and Not the Same* than I have been able to illustrate in these few paragraphs, there is also, I'm afraid, much less. As a chemist, I applaud Hoffmann's sensitivity for the science to which he has contributed so much, but as a critic I sometimes writhe. In striving to be a "humanist," Hoffmann overleaps and lands too often in patches of tortured prose: "...natural ores, unnatural smelting and alloying technology, are used by natural man in the patently unnatural act of sculpture to manipulate the most natural of elements, water...." At other times, he is lax in his choice of words. The unexplained use of terms like "adsorbed," "eluted," "dichloromethane," "fraction" and "gas chromatograph" early in the book might alienate the general reader.

The book consists of many short chapters or miniature essays. Although many of these might be regarded as thought-provoking vignettes when presented alone, in unbroken succession they give the impression of banality. Maybe, as with a Chinese bun, one should nibble at the contents of the book rather than attempt to swallow it whole.

It would be wrong to conclude without a word of warning to Hoffmann's many fans. The title is well chosen, for 18 of the 51 chapters have appeared in print before and were first presented as a series of lectures in 1990.

Hoffmann's writing may be an acquired taste. Overall, though, his book will appeal to those who like to know how scientists think and those who like to gather evidence for the nonexistence of the dichotomy of culture.

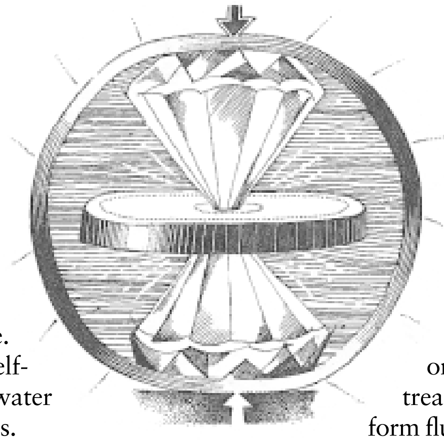
PETER ATKINS is a Fellow of Lincoln College, Oxford, and a university lecturer in physical chemistry. He has written a number of books presenting science, and particularly chemistry, to the general public.



WONDERS

by Philip Morrison

Under Pressure



VLAD GUZNER

In Victorian times Michael Faraday gingerly liquefied gases inside thick-walled glass tubing. By World War I, ingenuity and boldness of design allowed Harvard's Percy W. Bridgman to reach much higher pressures along semi-industrial lines. His large press disclosed innumerable new phases in familiar condensed matter, most famously several new crystalline phases of H_2O. Eventually he came to water ice VI, which at the highest pressures of the time remained an icy solid even at the temperature of a very hot kitchen oven.

The price of this mastery was not low: in 1922 a pressure container failed, steel flew like shrapnel and two men were killed, although the Harvard laboratory went on safely for decades more. Step by step, industry developed high-pressure technology for large-scale syntheses. The most important early product was ammonia, made in the millions of tons by reacting hydrogen and nitrogen gases at modest pressure. The most celebrated is synthetic diamond, by now a high-pressure commodity.

Set some simple markers along the pressure scale. Infants breathe and puff their cheeks, displaying small changes in local air pressure. Mountaintops lure others among us into pressures lower by a factor of two or so. The weather brings stay-at-homes incessant, less noticeable variations in pressure, but sea-level air still affords us a meaningful natural unit. Call the typical pressure at sea level one atmosphere.

A small-scale apparatus produces pressure to match a planet's core by hand-tightening a single bolt!

Like many another kid, I was disappointed years ago by the poor results of taking a long rubber tube into the pool, in an attempt to tap surface air for breathing on the bottom. No way! The added weight of even a foot of water is too much for chest muscles. To breathe at any depth underwater, you need either to be housed within some sealed submersible or to sip breaths of air fed from a portable tank at regulated matching pressure. That is SCUBA—self-contained underwater breathing apparatus.

The ocean defines a second natural pressure marker. Call 1,000 atmospheres one "ocean," by analogy. That value is a ballpark fit to seawater pressure six miles down in the deepest undersea trenches. The earliest physical successes called for pressures reaching one ocean or so, and the ices for pressures half a dozen times greater. The diamonds appeared after World War II up at 50 or 100 oceans, at which graphite dissolved in molten metal at white heat crystallizes to diamond. Such conditions have become routine in the special multiton presses that yield synthetic diamonds around the world.

Solid rock is denser than water, and our planet's center lies a decisive 1,000 times deeper than the average-depth sea bottom. We can plausibly define a third natural benchmark for core pressures, one equal to 1,000 oceans of 1,000 atmospheres each, or a million atmospheres. Calling one atmosphere by the crisper name "bar," its informal equivalent, we use its multiple, one megabar, as a convenient unit for describing the tremendous pressures at the core.

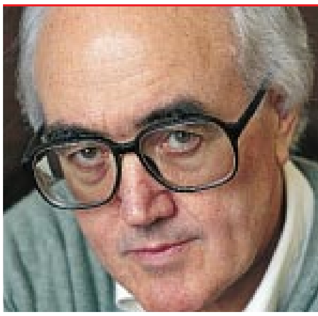
It turns out to be surprisingly easy to estimate the pressures so deep down. The symmetrical Newtonian pull of all the interior parts on all the layers above compacts Earth into a near sphere. Even the expected increase in density as depth approaches the center has at most a modest effect on a calculation that treats the globe as a uniform fluid. The central pressure approximates the simple product of three well-known quantities: the average density of Earth; the planet's radius; and the familiar constant g, the value of surface gravity signaled by every apple that falls. That central pressure is reliably estimated at about four megabars whatever the internal composition, if only all the strata are both stable (not undermined by vast buried caverns) and uniform from place to place, differing only as their depth differs. What is down there anyhow? This rich question bears strongly on the literal roots of all geology.

Can we proceed with theory alone as guide? Can we ignore unknown minerals and fluids, some sure to be as strange as hot ice was? The geophysicists wisely chose to experiment. One megabar of pressure was first reached 20 years ago at the Geophysical Laboratory of the Carnegie Institution of Washington. That lab and others can now summon the conditions of Hades itself right to the bench top.

The megabar apparatus in no way resembles the heavy, house-size hydraulic presses of old, stowed behind safety walls and served by a team of cautious engineers. It resembles more a top-of-the-line research microscope in the precision machining of its minute, elegant parts and is not unlike it as well in bulk, weight and cost. No monster machine at all, this device is mostly made in house by a few master machinists as the prized tool of a few physicists.

How do they evade danger, weight

Continued on page 115



CONNECTIONS

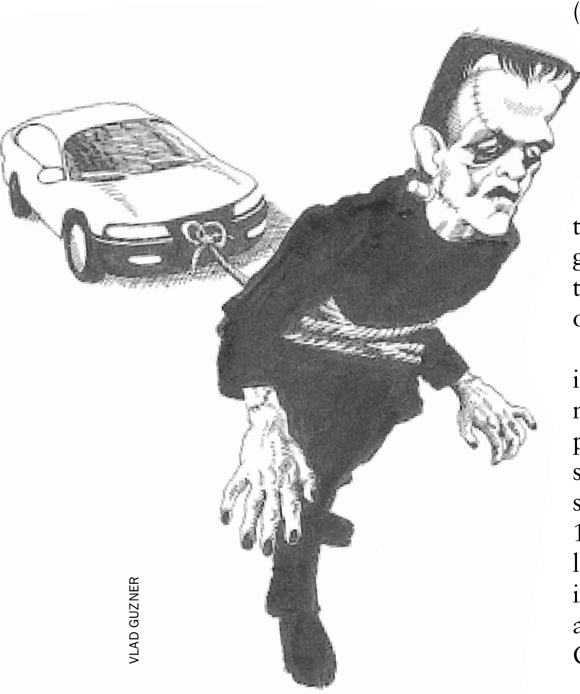
by James Burke

Out of Gas

I was taking some time off in Switzerland recently, driving along the Geneva lakeside, when my rental car announced that it needed gas. Things being the way they are nowadays, a talking automobile didn't strike me as science fiction. Which was ironic, given that at that moment, I was passing Villa Deodati, the very place another Brit vacationer had invented the genre.

Back in 1816 Mary Godwin holidayed there with her poet lover Percy Shelley (they would marry the next year), smoking hemp and having a generally unconventional time, joined by their new pal Lord Byron and his mistress, Claire (née Jane), Mary's stepsister. One evening the dinner conversation got around to rejuvenating corpses and whether artificial human beings could be made from separate parts. And to the mind-boggling rumor that the esteemed Erasmus Darwin had electrically "galvanized" some vermicelli and made it come alive.

Well. Those science dingbats were starting to tamper with the fundamental forces of the universe, and where would it all end? So Mary, probably also influenced by the Humphry Davy chemistry lecture she'd been reading—and his remarks about scientists being able one day to discover the hidden secrets of nature—decided to write a cautionary tale about a Swiss nerd, name of Victor, whose experimental mix of chemistry, physiology and electricity goes horribly wrong and creates a monster Victor can't control. You must have seen one of the film renditions of the story. I prefer Boris Karloff's.



VLAD GUZNER

Mary got many of her technophobe views from her novelist and ex-preacher father, William Godwin, a fountainhead of socialism and political guru to such other left-wingers as Samuel Taylor Coleridge and Charles Lamb. Godwin and most of his Romantic fans reckoned the new factory lifestyle, being introduced everywhere by the Industrial Revolution and its juggernaut machines, would degrade the workers (only just arrived from their idyllic life in country villages) with diabolical and unnatural practices, including shift work and wages. Godwin wrote yards of visionary scribble on the subject of individuals being (mis)shaped by their environment and how the thing to aim for was not mass production and gigantic conurbations but decentralization and egalitarian communities built on the human scale.

Science dingbats were tampering with the forces of the universe. Where would it end?

One of Godwin's most devoted groupies was Robert Owen, a young Welshman who was to take Godwin's principles quite far afield. Owen supervised a spinning mill in Manchester, so he'd seen the worst effects of factory life. In 1800 Owen became part owner of the largest single manufacturing enterprise in Scotland, a water-powered textile mill at New Lanark, a village on the river Clyde. Two thirds of the machine operators were orphans. Extraordinary as it may sound now, this use of pauper children was considered real charitable stuff, because if they hadn't been given jobs at the mill those kids would have been starving, criminal or worse. Which is why, when Owen and his partners took over New Lanark, by the standards of the time it was a dangerously liberal place: the children's bed straw was changed once a month; they had two hours of schooling a day; their clothing was washed every two weeks; and they slept only three to a bed, 75 to a room.

It was a real socialist utopia, with intervals for music and dance, an Institute for the Formation of Character, a company store and a canteen. (Owen also upped the working day to 14 hours.) By 1824 these libertarian ideas were catching on, and Owen was heading a national labor movement, hobnobbing with such admirers as Grand Duke Nicholas of Russia, the reformer Jeremy Bentham and the archbishop of Canterbury.

The fellow who'd sold him New Lanark, and whose daughter he married, was David Dale, a successful textile maker, who counted among his very few failures a partnership in a Scottish cotton mill with one George Macintosh. In 1777 Macintosh had made a scarlet dye called cudbear. Principal ingredients: ammonia (from urine he collected from friends and factory workers) and lichen (mostly imported later on, after he'd scraped the Highlands bare, from Scandinavia and Sardinia). Cudbear was a cheap alternative to a much more expensive coloring, made from cochineal beetles all the way from Mexico. The other thing about the cudbear dye was that alkali made it blue. In acid, it went back to scarlet. Paper dyers knew it as litmus.

It was probably the cudbear link with ammonia that got George's son, Charles, involved with the Glasgow gasworks. In 1819 he cut a deal for all the coal tar they were throwing away there. Coal tar was a by-product of the manufacture of coal gas, which involved cooking coal to obtain the gas. The tar was then disposed of in quarries, rivers and ponds. From this foul-smelling and, for the moment, virtually free gunk, Charles distilled ammonia for the cudbear works, where production was far outpacing the supplies of urine. He also recovered another chemical that would change the meaning of rainy days: naphtha, which, Charles found, dissolved rubber. In 1822, after taking out a patent for this technique, he spread liquefied rubber between sheets of cotton and invented the raincoat, which, in Britain, is still known—and wrongly spelled—as the mackintosh.

Not long after Macintosh was finding wet-weather ways to make money out of muck, a German chemist called von Hoffman got his doctorate in coal tar. So with the nasty stuff thus made academically respectable, more experimental things began to happen. In 1856 one of von Hoffman's pupils at the new Royal College of Chemistry in London, William Perkin, discovered the first artificial aniline dye (mauve) in coal tar while trying to make artificial quinine—but that's another story.

Meanwhile a colleague of von Hoffman's, name of Runge, also experimenting with coal tar, produced creosote, which ended up saving American forests because it preserved railroad ties so well they didn't need replacing so often. Creosote prevented other rots, too. By 1857 in Carlisle, England, a form of creosote called carbolic acid was being mixed with sewage to prevent decomposition.

Eight years later the professor of surgery at the Royal Infirmary in Edinburgh, Joseph Lister, heard about this trick, got hold of some from the Glasgow University chemistry lab and combined it with paraffin. Thus armed, Lister did the unthinkable: he premeditatedly broke the skin of a patient who had a nonlife-threatening complex fracture. When the usually fatal festering appeared, Lister slapped his carbolic goo on it, and, miracle of miracles, the patient survived!

Soon Lister was shooting a carbolic mist into his operating theaters and accomplishing daring antiseptic things. He even did it to Queen Victoria (she had an abscess). In next to no time, surgeons, who like a good laugh, were leaping into the operating theater with cries of "Let us spray!" Previously, appealing to the Almighty had been about their only hope for success in a profession whose other standard joke had been: "Good operation, but the patient died."

Sprays also became popular for local anesthesia and perfume bottles. Then, in 1883, a German engineer called Wilhelm Maybach teamed up with an ex-gunsmith friend, and they used the spray in a way that would literally change the way the world worked (and played). Maybach atomized gasoline into a fine mist that more readily ignited inside a cylinder and so drove the piston up and down. The machine this gizmo was attached to eventually took the name of the daughter of one of their major investors and a favorite of Maybach's partner. The partner was Daimler, and the girl was Mercedes. And Maybach's carburetor is, I suppose, ultimately responsible for me driving along the Geneva lakeside and running out of gas. Like this column (for now). SA

Wonders, *continued from page 113*
and expense? Pressure is a local quantity. Even a handheld steel sewing needle pushed firmly into a surface can exert oceanic pressures if only over a tiny area. Megabars of pressure in a minute container, a tenth of a millimeter on edge, store up something like the energy released by a pencil falling off the workbench. If that holder fractures, expect only a small pop, a source more of sharp fiscal pain than of physical injury. Work small; a miniature-scale apparatus produces pressure to match a planet's core simply by hand-tightening a single bolt!

But can you learn about Earth's center from so small a sample? Indeed you can, for matter is atomic. Its properties are well developed whenever sufficient atoms are present long enough to arrange themselves as the laws require. That small pressure vessel holds some million billion atoms, more than enough to allow matter to fulfill its subtlest intentions. A few micrograms are ineffective for making diamonds commercially but brilliantly suited to yield knowledge.

How will you learn what happens to matter compressed under megabars? First, use a transparent container, just as Faraday did. Probe it adroitly with infrared and optical lasers, with x-rays, neutrons, microwaves, even sound. Tight, high-intensity beams may be needed for a scant sample; for x-ray diffraction studies, the geophysicists often subject their pressure cell to a fierce synchrotron source. The limits are set mainly by the changing state of condensed-matter physics.

How to contain the sample? Squeeze it inside a tiny box of the hardest stuff known, diamond. Find two flawless gems—single crystals selected for purity and extratransparency—then cut in facets to order. Less than one carat in weight, they will be dear but affordable. Align the tip ends of the two truncated diamond cones with a thin ring gasket of steel alloy held between the two tiny flattened tips. The sample is confined within the hole in the gasket. Press diamond hard against diamond, and the whole assembly seals tight.

Megabars come easily. A diamond-diamond total force of only a couple of hundred kilograms is adequate, for that force is concentrated over an extremely small area. Up-to-date diamond-anvil cells may have contact faces only a thirtieth of a millimeter across. Sophisticated mounting design and virtuoso fabrication keep the gems nearly parallel for final optical alignment. Cryogenic cooling and resistance heating are both quite manageable.

The theorists opine that at about 12 megabars, diamond undergoes a change in phase, and some anvil will break. That limit is still ahead. About half that pressure is expected to be enough to press molecular hydrogen into hydrogen metal, a goal that has long eluded the labs. In the past few months there has been a credible report of making the metal hydrogen using a big, noisy gas gun, but the stuff lasted the mere microseconds it took a shock wave to cross the cryogenic hydrogen target.

Fortune may favor us with some new anvil substance harder than pure diamond, so we will be able to see the luster of that simplest of metals. In this subtle corner of condensed-matter physics, the pressure of a planet's core is literally at hand, through an art once awkward but now as harmonious as a quiet song. SA

WORKING KNOWLEDGE

AIR BAGS

by Robert E. Resh

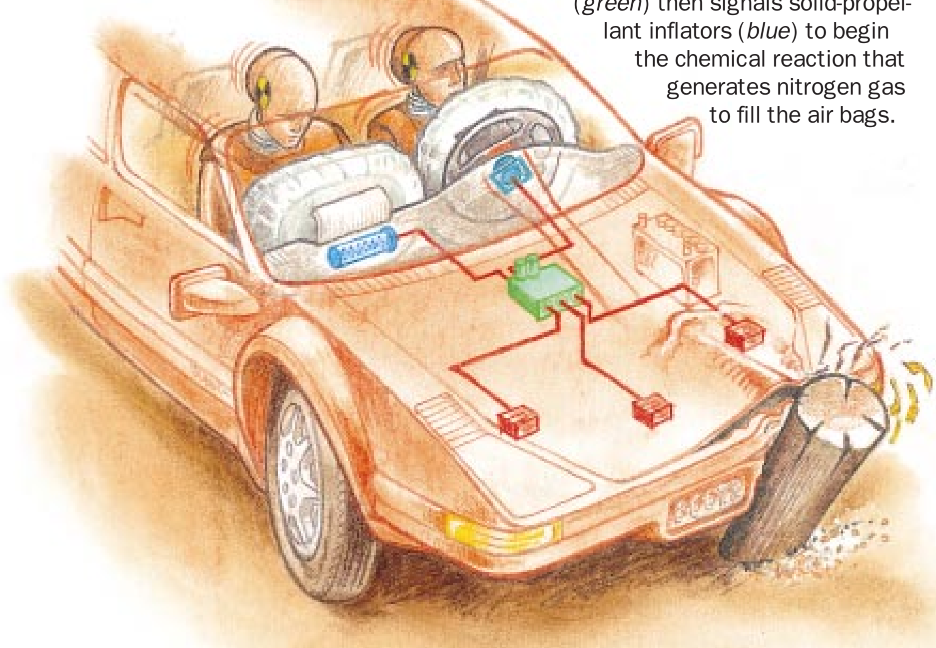
The notion of using a rapidly inflating cushion to prevent crash injuries enjoyed a long history before the U.S. Department of Transportation called for such equipment in automobiles during the 1980s. Indeed, the first patent on an "inflatable crash landing device for airplanes" was filed during World War II.

The automotive air bags that evolved in the next two decades contained many of the features found in their modern counterparts. Yet these early air bags all remained impractical and extremely expensive. The chief technical hurdles involved the storage and release of compressed air. Was there room enough for a gas canister? Would the gas stay contained at high pressure for the entire life of the car? And how could it be made to expand quickly and predictably at a variety of operating temperatures—and without creating an earsplitting bang?

The answers came in the 1970s with the advent of small solid-propellant inflators. These devices initiate a chemical reaction that releases hot nitrogen gas into the bag. This innovation allowed many vehicles to begin sporting air bags on the highway during the 1980s.

The National Highway Traffic Safety Administration estimates that air bags prevented about 600 fatalities in 1995 alone. As the number of air-bag-equipped cars grows, so, too, will the count of lives saved by this technology. Engineers continue designing bags that might better protect automobile passengers as they also explore alternative gas sources that may permit the devices to become smaller and to be recycled more easily.

ROBERT E. RESH is a senior staff technologist at TRW Vehicle Safety Systems in Washington, Mich.

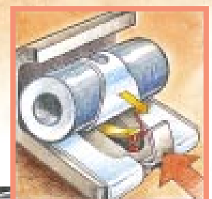


IMPACT is registered by sensing devices (*red*) in the front of the car. The electronic circuitry monitoring these sensors (*green*) then signals solid-propellant inflators (*blue*) to begin the chemical reaction that generates nitrogen gas to fill the air bags.

JAN ADKINS (*drawings*)

SENSORS detect the crash using a mechanical switch that closes when a mass shifts and an electrical contact is made. Electronic sensors use a tiny accelerometer that has been etched on a silicon chip.

MECHANICAL



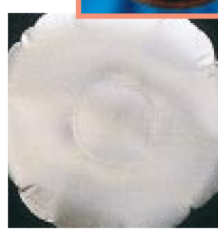
ELECTRONIC

ANALOG DEVICES

25 MILLISECONDS

30 MILLISECONDS

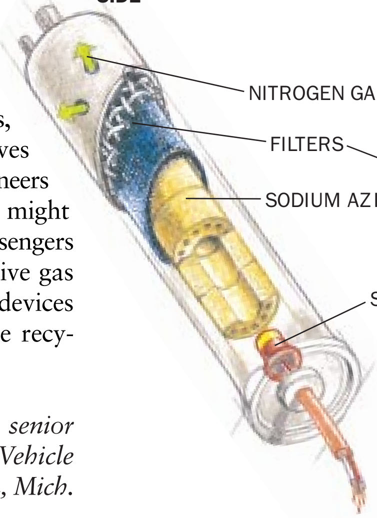
40 MILLISECONDS



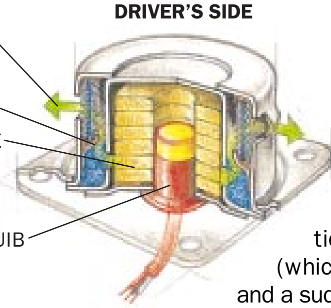
55 MILLISECONDS

TRW VEHICLE SAFETY SYSTEMS

PASSENGER'S SIDE



DRIVER'S SIDE



INFLATORS contain a squib that ignites solid grains of sodium azide along with an oxidant. These materials burn within the metal canister, producing solid particles of sodium oxide (which are trapped by filters) and a sudden pulse of hot nitrogen gas. Inflators on the passenger's side are typically cylindrical, whereas those on the driver's side are shaped to fit in the center of the steering wheel.

