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THE COMETS' LAIR:
A RING OF ICY DEBRIS BEYOND PLUTO'S ORBIT IS REVISING VIEWS OF THE SOLAR SYSTEM

SCIENTIFIC AMERICAN

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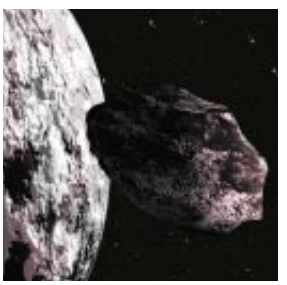
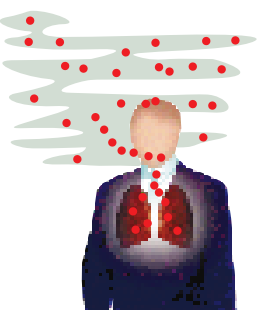
NEWS AND ANALYSIS





About the Cover
Small blast mines of the type pictured can be difficult to see on many terrains, which makes them a severe hazard for unwary civilians returning to former battle sites. Painting by Daniel Adel.

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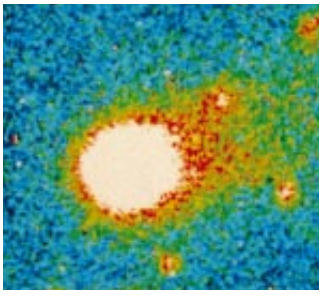
FROM THE EDITORS

Unexpected Thrills

Pursuing what is merely not known, investigators sometimes find what is not supposed to be. For over 30 years, the quark seemed to be the irreducible unit of nuclear matter. Yet recently, when physicists forced collisions between protons and antiprotons, they found hints among the subatomic shrapnel that quarks might have an internal structure, comprising even tinier entities. How far down is the bottom?

Zoology has been rocked during this decade by the capture of several large mammal species, some new to science, others that had been thought extinct, including the Tibetan Riwoche horse and the Vietnamese Vu Quang ox. The pace of these discoveries is astonishing because only a handful of big land beasts had been catalogued previously this century.

Astronomers, meanwhile, have been turning up billions of additional galaxies and the first examples of planets orbiting sunlike stars. Much closer to home, though, surprises have also cropped up within our solar system. Four years ago, after considerable patient effort, Jane X. Luu and David C. Jewitt found an entirely new class of object in the outer solar system. It was no more than an icy orb a few hundred kilometers across, but its existence argued that a huge ring of similar bodies extends out beyond Neptune. Dozens of additional objects have been found since then, confirming the presence of the long-sought Kuiper belt. They have shed light on the origin of comets and even revised some astronomers' thinking about Pluto, which may not be a true planet at all. Luu and Jewitt explain more fully in "The Kuiper Belt," on page 46.



THIS TINY COMET may have recently emerged from the Kuiper belt.

Speaking of finding treasures in uncharted spaces, everyone roaming the Internet is encouraged to visit *Scientific American*'s new World Wide Web site at http://www.sciam.com/ These days it is often hard to confine the contents of our articles to just two dimensions; they keep trying to pop off the page, grow like kudzu and intertwine with the rest of the world. What better place to let articles go, then, than on the Web, where readers can enjoy this magazine in a more interactive, unconfined form. Visitors to our site will discover expanded, enhanced versions of articles in the current issue, including links to other relevant sites on the Web, "Explorations" of recent developments in the news, a "Gallery" of images, sounds and animations that capture the beauty of science, and much more. We think you will find it to be the ideal springboard for conducting your own explorations of the universe. Happy hunting.

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LETTERS TO THE EDITORS

LIVE LONG, BUT PROSPER?

Richard Weindruch rightfully points out that mouse data showing how a restricted diet increases longevity cannot be extended to humans at this time [see "Caloric Restriction and Aging," January]. But if the extrapolation is valid, look out, Social Security trust fund. If aging baby boomers like myself decide to embrace a spartan lifestyle, we'll be around until the year 2060.

ROBERT CORNELL
Lexington, Ky.

Weindruch omitted any reference to work that examined the effect of the compound deprenyl [used in the treatment of Parkinson's disease] on the longevity of male rats. These studies showed an increase in both the average life span and the maximum life span of these rodents. In other words, pharmaceutical intervention can also slow aging in mammals.

WALLACE E. PARR
Stevensville, Md.

Weindruch replies:

The concern raised by Cornell is unwarranted: caloric restriction influences not only the length of life but also the quality of life. If vast numbers of baby boomers turn to caloric restriction, a new society would likely emerge in which energetic 85-year-olds change careers and Social Security would have to be entirely restructured. A Hungarian researcher, Jozsef Knoll, did report greatly extended average and maximum lifetimes in rats given deprenyl. Unfortunately, subsequent studies of the drug have found either a very mild increase in maximum life span or no effect at all. In contrast, caloric restriction extends maximum life span in a repeatable fashion worldwide.

LOW-TECH SOLUTION

In "Resisting Resistance" [Science and the Citizen, January], Tim Beardsley states that "the attention being focused on infectious disease indicates that a turning point may…be in sight in one of humankind's oldest struggles." Absent from the solutions discussed—including new infectious disease laboratories, more intense surveillance and investigation, more prudent use of antibiotics and development of new drugs—is one major preventative component: hand washing. According to the U.S. Centers for Disease Control and Prevention, "Hand washing is the single most important means of preventing the spread of infection."

NOEL SEGAL
President, Compliance Control
Forestville, Md.

MIXED REVIEWS

Thomas E. Lovejoy, who reviewed my book *A Moment on the Earth* ["Rethinking Green Thoughts," Reviews and Commentaries, February], is a prominent proponent of the bleak environmental outlook the book contests. Thus, Lovejoy has a professional self-interest in denying the book's validity: his work was criticized in the book, a point only obliquely disclosed to readers. Lovejoy's enmity is indicated by several inaccurate statements. He writes that I extol the recovery of the bald eagle "while ignoring its previous downward trend." Yet my chapter on species begins by noting that DDT and logging caused the decline of the southern bald eagle. Lovejoy says I do not credit Rachel Carson for inspiring environmental reforms. But on page 82, I write, "Society heeded Carson's warnings, enacted the necessary reforms…and realized such a prompt environmental gain that the day of reckoning Carson foresaw never arrived. This shows that environmental reform works."

Lovejoy accuses me of "innumerable errors" yet cites only two. One is a single-word copyediting glitch, and the other, according to Lovejoy, is an "absurd assertion, building from a misunderstanding of evolutionary biologist Lynn Margulis's work…that cooperation is dominant in nature." In fact, I present this notion as *speculation:* surely a reviewer for a science publication ought to be able to make the distinction between assertion and speculation. And good or bad, it's hard to believe my characterization of Margulis's work is "absurd," as Margulis herself read the book at the galley stage.

Of course, hostile reviews are an occupational hazard for writers. Yet Lovejoy's resort to false claims suggests that he seeks to divert attention from the book's central contention: namely, that most Western environmental trends are improving. The optimism I propose may be right or wrong, but the debate on it will not go forward if magazines such as *Scientific American* hand the concept over to those with a dull ax to grind.

GREGG EASTERBROOK
Brussels, Belgium

Lovejoy replies:

I can understand why Easterbrook would not like my review, but I nonetheless believe it is objective and dispassionate. The review does highlight his main conclusions—positive environmental trends in some industrial nations and the neglect of clean air and water issues in developing countries. The book, in fact, contains little mention of my work (which is mostly about tropical forests and soaring extinction rates) and is critical of it in only one instance. My main lament is that his book, which has some really important points to make, does not make them better. For example, to equate cooperation with Lynn Margulis's work on symbiosis is simply an error.

STRING THEORY

In quoting Pierre M. Ramond, Madhusree Mukerjee ["Explaining Everything," January] deprived him of a superb simile. She has Ramond saying about string theory research, "It's as if you are wandering in the valley of a king, push aside a rock and find an enchanted staircase." Surely what was intended was "wandering in the Valley of the Kings," a reference to the sarcophagal region of Egypt that grudgingly yields its hermetic secrets.

HAROLD P. HANSON
University of Florida at Gainesville

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

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

MAY 1946

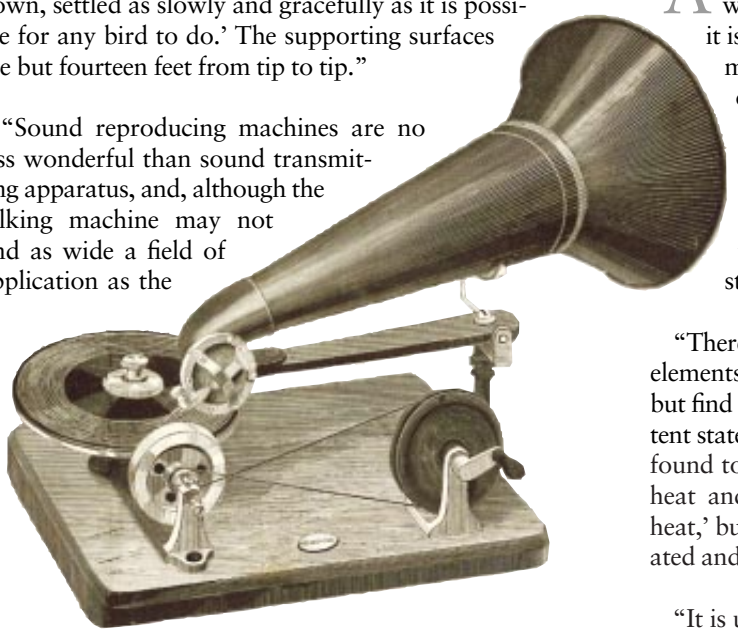
Color television looms large on the radio horizon: RCA has it but calls it impractical as yet; Columbia Broadcasting System is going all-out for color; Zenith Radio says that they will produce only color-television receivers; and the public waits with more or less patience for the final outcome."

"Predicating their conclusions on a price of $15 a ton for coal, atomic energy experts recently predicted that atomic energy might economically come into competition with coal for industrial power production in from three to twenty-five years. According to a director of the Bituminous Coal Institute, this quoted price is greatly excessive, and coal is now being delivered to the power producers at a national average price of less than $6 a ton; therefore it would be 'something like two or three generations before bituminous coal has anything to fear from atomic energy.' "

MAY 1896

The first really practical solution to the problem of artificial flight has been made by Prof. Samuel Langley, the secretary of the Smithsonian Institution. Prof. Alexander Bell describes the successful experiments, which were carried out near Occoquan, Va., on May 6: 'The aerodrome, or flying machine, in question was of steel, driven by a steam engine. It resembled an enormous bird, soaring in the air with extreme regularity in large curves, sweeping steadily upward in a spiral path, until it reached a height of about 100 feet in the air, at the end of a course of about a half mile, when the steam gave out and the propellers which had moved it stopped. Then, to my further surprise, the whole, instead of tumbling down, settled as slowly and gracefully as it is possible for any bird to do.' The supporting surfaces are but fourteen feet from tip to tip."

"Sound reproducing machines are no less wonderful than sound transmitting apparatus, and, although the talking machine may not find as wide a field of application as the telephone, it is perhaps more interesting and instructive. Our present engraving illustrates the gramophone in its latest form, the work of the inventor Mr. Emile Berliner. It is driven by a belt extending around the larger pulley on the crank shaft, which is turned by hand. On the turntable is placed the hard rubber disk bearing the record. The sound box is mounted on a swinging arm, which also supports the conical resonator. With five minutes' practice a child can operate it so as to reproduce a band selection or a song in perfect tune."



The new talking machine

"Each year the laws of sea storms are understood more perfectly through the indefatigable efforts of the United States hydrographic office. The landsman hardly appreciates what has been done by the government to protect ships from danger. In order to measure the storms, it was necessary to obtain reliable data from a wide extent of ocean territory. In the absence of telegraph stations, forms for keeping observations were issued to every captain of a vessel touching any American port, to be filled out and mailed to the headquarters at Washington. In return for this labor every captain received free the Monthly Pilot Chart. From the pile of data received, a map of each storm was constructed, and rules were compiled that are given to mariners when encountering a storm at sea."

"The Medical Society of Berne has inaugurated a plan for the suppression of press notices of suicides, as it has been observed that epidemics of suicides, so called, come from 'suggestion,' acquired through printed accounts of them."

MAY 1846

Audubon's 'Quadrupeds of North America'—This great work, now in course of publication (more than half of it is already completed) is of value to the naturalist, and more than of ordinary interest to general readers. The drawings are Audubon's and are spirited and life-like beyond any thing we have ever seen; not even excepting his other work, the 'Birds of America.' In some animals—the raccoon, for instance—the fur is so exquisitely wrought and transparent as to induce the belief, at first sight, that it has been stuck on, instead of being painted on a flat surface."

"There is evidently an abundance of caloric in the common elements, and which might be had at a cheap rate, could we but find a cheap and ready method of liberating it from its latent state; and the time may yet arrive, in which *water* will be found to be the cheapest fuel, and be made to furnish both heat and light. Latent caloric is commonly called 'latent heat,' but we think it is *not* heat in any sense, until it is liberated and becomes palpable."

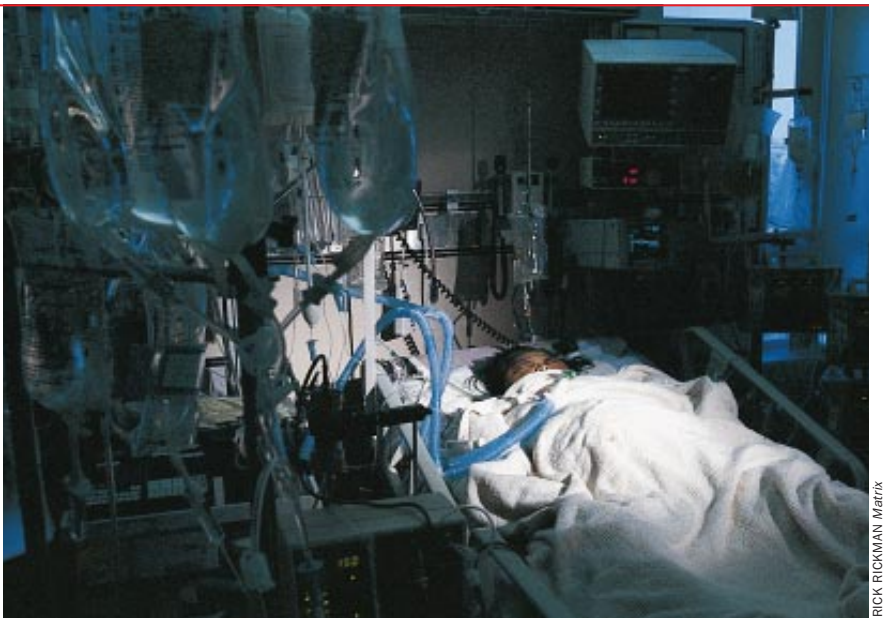
"It is urged upon emigrants to Oregon to take wives with them. There is no supply of the article in that heathen land."

NEWS AND ANALYSIS

IN FOCUS

RIGHT TO DIE

Ethicists debate whether advanced directives have furthered the cause of death with dignity



RICK RICKMAN *Matrix*

***MEDICAL EQUIPMENT** often prolongs the agony of terminally ill patients.*

When the U.S. Congress passed the Patient Self-Determination Act in 1990, many ethicists hailed it as an important step in the right of patients to choose how they are treated—and how they die. The possibility that the act might reduce health care costs by cutting down on futile and unwanted treatments was seen as an added bonus. It has been estimated that almost 40 percent of all deaths in the U.S. take place following the withdrawal of life-sustaining treatments—often from a sedated or comatose patient and after protracted, agonizing indecision on the part of family members and physicians.

The Patient Self-Determination Act was designed to reduce this indecision by giving patients more control over their destiny. It requires hospitals to inform patients and their families—upon a person's admission to the hospital—of their legal right to refuse various life-sustaining technologies and procedures through what are called advanced directives. The two most common advanced directives are living wills, in which individuals specify their choices concerning life-sustaining treatment, and documents authorizing a spouse, relative or other proxy to make such decisions, in the event that an individual becomes mentally incapacitated.

So far the act and advanced directives have not had the impact that proponents had hoped for. Only 10 to 20 percent of American adults, at most, have signed an advanced directive. Moreover, as a number of recent court decisions illustrate, conflicts and misunderstandings still arise between patients, relatives and health care providers over the proper treatment of critically ill patients.

Although some right-to-die advocates say that advanced directives can still fulfill their promise, others have their doubts. Arthur L. Caplan, director of the Center for Bioethics at the University of Pennsylvania, predicted in 1990 that advanced directives and the Patient Self-Determination Act—

and the notion of "patient empowerment" from which they stem—would prove to be a failure. Unfortunately, he says, recent events have proved him right.

The "nail in the coffin," Caplan notes, is a paper published last November in the *Journal of the American Medical Association*. The article presented the results of an experiment called SUPPORT, for Study to Understand Prognoses and Preferences for Outcomes and Risks of Treatments. The four-year study, which involved more than 9,000 patients at five hospitals, had two phases.

The initial, two-year phase of the study revealed "substantial shortcomings in care for seriously ill hospitalized adults." More often than not, patients died in pain, their desires concerning treatment neglected, after spending 10 days or more in an intensive care unit. Less than half of the physicians whose patients had signed orders forbidding cardiopulmonary resuscitation were aware of that fact. During the second phase of the study, each patient was assigned a nurse who had been trained to facilitate communication between patients, their families and physicians in order to make the patients' care more comfortable and dignified. The intervention failed dismally; the 2,652 patients who received this special attention fared no better, statistically speaking, than those in the control group or those in the previous phase of the investigation.

PAUL FUSCO *Magnum Photos*

***RELATIVES OF INCAPACITATED PATIENTS** may disagree over when to withdraw treatment.*

But given that doctors are the supreme authorities in hospitals, says Nancy Dubler, an attorney who heads an ethics committee at the Montefiore Medical Center in Bronx, N.Y., it was inevitable that the nurse-based intervention method employed by the study would fail. She insists that her own experience has shown that advanced directives can work—and particularly those that appoint a proxy, who can provide more guidance in a complex situation than can a "rigid" living will.

"I definitely feel advanced directives are useful," concurs Andrew Broder, an attorney specializing in right-to-die cases. Broder recently served as the lawyer for a Michigan woman, Mary Martin, who wanted to have a feeding tube removed from her husband, Michael Martin, who had suffered severe brain damage in an accident in 1987. Michael Martin's mother and sister opposed the removal of the life-sustaining treatment. Michigan courts turned down Mary Martin's request, and in February the U.S. Supreme Court refused to hear her appeal. An advanced directive "might have made the difference" in the Martin case, Broder says.

Some ethicists fear that the problems revealed by SUPPORT will spur more calls for physician-assisted suicide, the legal status of which has been boosted by two recent decisions. In March a jury ruled that Jack Kevorkian, a retired physician who has admitted helping 27 patients end their lives, had not violated Michigan state law. (Kevorkian still faces another trial on similar charges.) That same week, a federal court of appeals struck down a Washington State law prohibiting euthanasia. Oregon has already passed a law permitting assisted suicide (although it has not come into effect), and eight other states are considering similar legislation.

"I see suicide as a symptom of the problem, not a solution to the problem," says Joseph J. Fins, a physician and director of medical ethics at New York Hospital. The lesson of SUPPORT, he says, is that doctors must learn to view palliative care—which focuses on the relief of suffering rather than on curing disease—as an important part of their job. Many physicians, Fins elaborates, need to become more aware of developments in the treatment of pain, such as alternatives to morphine that do not cause constipation, nausea, grogginess or other unpleasant side effects. If doctors take these steps, Fins contends, horror stories about terminally ill patients being subjected to unwanted treatment should diminish, and so should calls for assisted suicide.

Officials from Choice in Dying—a New York City–based group that created the first living wills almost 30 years ago (but does not advocate assisted suicide)—believe the problems identified by SUPPORT can be rectified through more regulation, litigation and education. According to executive director Karen O. Kaplan, Choice in Dying plans to further its cause with a documentary that will be aired by the Public Broadcasting Service this summer; with a page on the World Wide Web that will include living-will and proxy forms and educational materials; and with an electronic database that hospitals can consult to determine whether a patient has an advanced directive. The group also advocates legislation that would encourage physicians to bring up the issue of advanced directives with patients as a routine part of their care, rather than in a crisis.

Kaplan hopes the threat of lawsuits may force hospitals to pay more heed to the wishes of patients and their relatives. This past February, she notes, a jury in Flint, Mich., found that a hospital had improperly ignored a mother's plea that her comatose daughter not be placed on a respirator. The hospital was ordered to pay $16 million to the family of the woman, who emerged from the coma with severe brain damage.

But there is no "ideal formula" for preventing such incidents, according to Daniel Callahan, president of the Hastings Center, a think tank for biomedical ethics. These situations, he says, stem from certain stubborn realities: most people are reluctant to think about their own death; some patients and relatives insist on aggressive treatment even when the chances of recovery are minuscule; doctors' prognoses for certain patients may be vague or contradictory; and families, patients and health care providers often fail to reach agreement on proper treatment, despite their best efforts.

Callahan notes that these problems can be resolved only by bringing about profound changes in the way that the medical profession and society at large think about dying. "We thought at first we just needed reform," Callahan wrote in a special issue of the *Hastings Center Report* devoted to SUPPORT. "It is now obvious we need a revolution." —*John Horgan*

NEUROSCIENCE

X MARKS THE SPOTS

Researchers find a genetic marker for an uncommon form of epilepsy

Genetic mutations account for a number of neurological disorders, among them certain forms of mental retardation. By studying such illnesses, scientists have learned a great deal about normal brain development. Now they have new material to work with. In a recent issue of *Neuron,* Boston researchers from Beth Israel Hospital and Harvard Medical School described a genetic marker for a rare form of epilepsy called periventricular heterotopia (PH). Some 0.5 percent of the population have epilepsy, and fewer than 1 percent of them have PH.

"The disease seemed to be expressed exclusively in females, and these families seemed to have a shortage of male babies," says team member Christopher Walsh. "So there was the suggestion that it was an X-linked defect." The group examined blood samples from four affected pedigrees and quickly confirmed the hypothesis. They singled out a common stretch of DNA along the X chromosome that contained many well-known genes, including one dubbed *L1*.

Genes such as *L1* that ordinarily help to assemble the brain are strong suspects in the search for PH's source, Walsh adds. Damage to *L1* itself causes an array of developmental disorders often marked by some subset of symptoms, including hydrocephalus (water on the brain), enlarged ventricles, enlarged head, thinning of the corpus callosum, retardation, spasticity in the lower limbs, adducted thumbs and defects in cell migration. PH also produces certain telltale brain defects. In particular, neurons that should travel to the cerebral cortex—the outermost region of the brain—

FIELD NOTES

Plotting the Next Move

I am at the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., talking to four of the six brains behind Deep Blue, perhaps the second-best chess player in the world. Present are Feng-hsiung Hsu and Murray Campbell, who began working on chess-playing computers as graduate students at Carnegie Mellon University in the 1980s; Chung-Jen Tan, manager of the chess project; and software specialist A. Joseph Hoane, Jr. Absent are Jerry Brody, a hardware designer who has been delayed by an ice storm, and Deep Blue's silicon brain—a pair of refrigerator-size, 16-node, parallel-processing computers—which is housed elsewhere in the building.

In one corner of the room stands a case crammed with trophies won by Deep Blue and its ancestors, ChipTest and Deep Thought, which were created by Hsu, Campbell and others. (Deep Thought mutated less than two years ago into Deep Blue, a reference to the color of IBM's trademark.) Draped across one wall is a banner announcing the match between Deep Blue and world champion Garry K. Kasparov in Philadelphia this past February. Deep Blue won the first game but lost the match.

JASON GOLTZ

DEEP BLUE'S HANDLERS:
(from left) *Brody, Hoane, Campbell, Hsu, Tan.*

The IBM team wants to dispel one ugly rumor: Deep Blue did not lose the match because of human error—namely, theirs. They did indeed tinker with Deep Blue's program between its only victory in game one and its loss in game two, but those changes had no adverse effect on the contender's play. Oh, sure, in retrospect they would have been better off if they had accepted Kasparov's offer of a draw in game five (as was the case in games three and four), which he went on to win. "If we'd won, everybody would have said we were brilliant," Campbell says.

When Marcy Holle, an IBM public relations representative, suggests that the team explain why Deep Blue made certain moves in its game-one victory, they look at her dubiously. They remind her that the computer's program is so complex that even they do not really understand how it arrives at a given decision. Indeed, sometimes the machine, when faced with exactly the same position, will make a different move than it made previously.

In three minutes, the time allocated for each move in a formal match, the machine can evaluate a total of about 20 billion moves; that is enough to consider every single possible move and countermove 12 sequences ahead and selected lines of attack as much as 30 moves beyond that. The fact that this ability is still not enough to beat a mere human is "amazing," Campbell says. The lesson, Hoane adds, is that masters such as Kasparov "are doing some mysterious computation we can't figure out."

IBM is now negotiating a rematch with Kasparov, who is apparently eager for it. "He got more exposure out of the match than any other match" he has played, Tan remarks. Kasparov also won $400,000 of the $500,000 prize put up for the event by the Association for Computing Machinery.

In the October 1990 issue of *Scientific American,* Hsu, Campbell and two former colleagues predicted that Deep Thought might beat any human alive "perhaps as early as 1992." Reminded of this prophecy, Campbell grimaces and insists that their editor had elicited this bold statement. Not surprisingly, no one is eager to offer up another such prediction. If they had truly wanted to beat Kasparov, Tan says, they could have boosted Deep Blue's performance by utilizing a 128-node computer, but such a move would have been too expensive. The goal of the Deep Blue team has never been to beat the world champion, he emphasizes, but to conduct *research* that will show how parallel processing can be harnessed for solving such complex problems as airline scheduling or drug design. "This *is* IBM," Holle says. —*John Horgan*

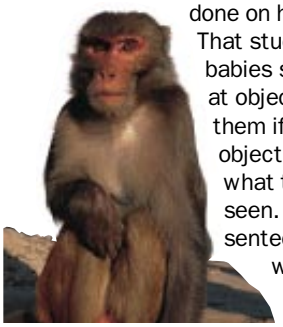
IN BRIEF

Record Time

Far from the Olympic trials, three teams of computer scientists have set a new speed record—one that no one thought would be reached before the year 2000. Each group—from Fujitsu, Nippon Telegraph and Telephone, and AT&T Research and Lucent Technologies—transmitted in a single second one trillion bits of data, or the amount of information contained in 300 years' worth of a daily newspaper. They sent multiple streams of bit-bearing light, each at a different wavelength, through a relatively short optical fiber. The technique should make communications cheaper.

Monkey See, Monkey Count

At least to two, says Marc D. Hauser of Harvard University. He and his colleagues tested how well wild rhesus monkeys could add. To do so, they reenacted an experiment done on human infants. That study found that babies stared longer at objects in front of them if the number of objects differed from what they had just seen. So Hauser presented monkeys with a seemingly empty box, which had one side removed, and then replaced the side panel while they watched. Next he put two eggplants inside the box in such a way that when he lifted the side panel again, only one purple fruit appeared. The monkeys stared in astonishment—proving their arithmetic ability.



R. A. MITTERMEIER *Bruce Coleman Inc.*

DOD's Toxic Totals

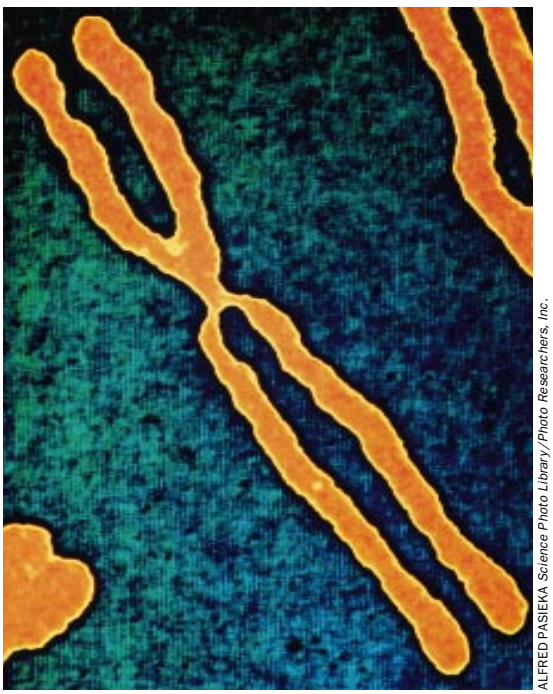
The Department of Defense came clean this past March, announcing that during 1993, 131 military installations around the country released 11.4 million pounds of toxic chemicals. The report was the first of its kind filed under a federal law that also requires private companies to list such releases. The DOD says it has reduced hazardous-waste disposal by half since 1987 and intends to make further cuts. The latest figures compare with some 2.8 billion pounds of toxic waste emitted by civilian manufacturing companies.

Continued on page 20

remain deep inside the organ instead.

"We wondered why some of all cell types [in PH] failed to migrate, as opposed to all of one cell type," Walsh notes. "We think the answer is that the female brain is a mosaic." One of the two X chromosomes in each cell of a female fetus is shut off at random after the first third of gestation, he explains. So those with PH probably express normal X chromosomes in most cells and mutants in a few others. As a result, select representatives of all types of cortical cells are stalled in their movement. In contrast, affected male fetuses, which possess single, flawed X chromosomes in every cell, develop so abnormally that they are miscarried.

Finding the precise gene should make it easier to diagnosis PH, Walsh says. Most patients have no outward symptoms other than frequent epileptic seizures, which are usually atypical. Also, whatever mechanism prompts PH may play some role in other forms of epilepsy. "There may be hundreds of gene mutations that confer risk for epilepsy," Walsh states. (Indeed, geneticists from Stanford and the University of Helsinki reported in March that mutations in the gene encoding for a protein called Cystatin B occurred in another uncommon inherited epilepsy, progressive myclonus epilepsy.) "But perhaps the gene products behind PH do something throughout the brain that causes seizures," Walsh adds, "and perhaps that same thing underlies all forms of epilepsy."



ALFRED PASIEKA *Science Photo Library/Photo Researchers, Inc.*

X CHROMOSOME
is the site of genes controlling many aspects of neurological development.

In fact, the products of X-chromosome genes controlling development may stand behind even more neurological disorders than has been believed. Researchers at the J. C. Self Research Institute of the Greenwood Genetic Center in South Carolina are currently screening for *L1* defects among the 40 to 50 percent of mentally retarded individuals in the state for whom no diagnosis has been found. To narrow the search, the group limited the survey to men having enlarged heads and spasticity in their gait. Already they have found a greater incidence of *L1* mutations than expected. "*L1*-related retardation is not as prevalent as fragile-X [another form of retardation]," says Charles Schwartz, director of the Molecular Studies unit, "but it's probably still more common than previously thought."

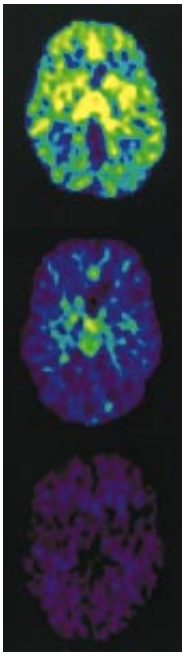
Knowledge of the actual molecular mechanisms behind *L1*-related disorders has recently given workers insight into fetal alcohol syndrome as well. Several years ago Michael E. Charness of Harvard University noted several similarities between certain aspects of fetal alcohol syndrome, his area of expertise, and *L1* disorders. Therefore, he tested the effects of alcohol on the L1 molecule, known to guide axon growth over long distances and connect neurons during development.

Last month, Charness released results showing that alcohol completely abolishes L1's adhesive properties in low doses—namely, amounts that would be present in a pregnant woman's bloodstream after she consumed one or two drinks. "Epidemiologists have suggested that there may be measurable effects of low amounts of alcohol on a fetus," Charness states. "This finding provides us with one potential molecular mechanism behind that observation." The hope is that the unraveling of more such mechanisms will lead to prevention or to better treatment for a wide range of neurological birth defects. —*Kristin Leutwyler*

In Brief, *continued from page 18*

Smoke Screen

Cigarettes, it now seems, snare their catch twice. Not only does nicotine raise levels of dopamine, a chemical linked to addictive behaviors, but another psychoactive substance in cigarette smoke—one not yet identified—reinforces that grip by inhibiting monoamine oxidase B (MAO B), an enzyme that degrades dopamine. Looking at PET scans, Joanna S. Fowler and her colleagues at Brookhaven National Laboratory found that MAO B was 40 percent less active in smokers (*middle*) than in people who had never or no longer smoked (*top*). Further study showed that the MAO B deficiency in smokers was comparable to that seen in patients taking L-deprenyl, a drug used to ameliorate Parkinson's disease (*bottom*). The finding may explain why few smokers acquire the debilitating condition, brought on by low dopamine levels. It could also elucidate the connection between smoking and depression, which is often treated with MAO inhibitors.



BROOKHAVEN NATIONAL LABORATORY

Drafting Ants

Ant fans have always presumed that caste quotas in colonies remained more or less fixed: communities produced however many workers or soldiers were required to fulfill their needs. But it now seems that one species of ant makes more soldiers than normal when threatened by an enemy attack. Luc Passera and his colleagues at Paul Sabatier University in Toulouse, France, separated two colonies of *Pheidole pallidula* using a wire mesh. The structure allowed legs or antennae to pass through but prevented any direct combat. Both colonies quickly churned out more "major" members, larger than the rest and ready to defend them. This reproductive tactic takes more energy and time than would, say, recruiting troops from other castes.

Continued on page 22

MEDICINE

NOT SO BLIND, AFTER ALL

Randomized trials—the linchpin of medicine—may often be rigged

To find out whether a daily dose of aspirin prevents heart attacks, you take 10,000 people from the general population, select half of them at random to take aspirin every day, and follow all 10,000 for five or 10 years to see how their cardiovascular systems hold up. This kind of randomized selection is at the center of the clinical trials used to test all manner of new medical treatments. In practice, however, it may be significantly flawed.

Kenneth P. Schulz of the Centers for Disease Control and Prevention and his colleagues have been raising questions about the quality of "allocation concealment"—the process of hiding information about which patients will be assigned new treatment versus which will get conventional care. For instance, if doctors know that all new patients registered on odd-numbered days get a new drug that is under investigation, whereas those registered on even-numbered days get a placebo, they could easily rearrange their appointment books—with only the best interests of their patients at heart—to undermine the intent of a randomized trial. Even when there is negligible evidence, doctors tend to believe they know what treatment is most effective, Schulz contends.

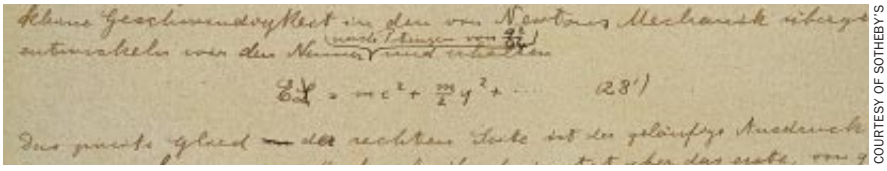
Researchers generally use significantly more sophisticated methods to allocate their patients, but the doctors who actually carry out trials may go to even greater lengths to subvert concealment. Schulz surveyed his co-workers anonymously and found that some will do anything—from opening sealed envelopes or holding them over a strong light to rifling a colleague's desk—for copies of the randomization sequence.

According to work that Schulz and his collaborators published in the *Journal of the American Medical Association,* trials with inadequate concealment—half or more of those studied—yield estimates of effectiveness that on average are roughly 30 percent higher than those where allocation is properly controlled. In some trials, however, the effect of cheating can work against a treatment's apparent effectiveness, Schulz says: medical staff convinced that a new drug would not be in testing if it didn't work may try to help their sickest patients by sneaking them into the treatment group instead of the control group. The drug would then have to be significantly better than conventional treatment just to appear equal in efficacy.

Such irregularities highlight the importance of good statistical analysis of any difference between control and treatment groups. Schulz analyzed one set of papers and found that only 2 percent of tests indicated "statistically significant" differences between control and treatment patients. Because a statistically significant result is defined as one that would appear by chance one time in 20, the 2 percent figure immediately puts those trials' methods in doubt, he says.

Why do doctors who agree to enroll their patients in clinical trials turn around and effectively subvert them? "They un-

PHYSICS



COURTESY OF SOTHEBY'S

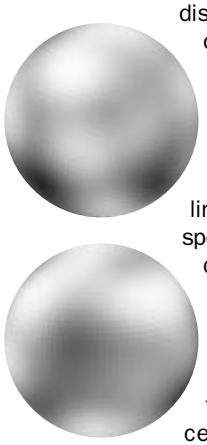
Relatively Expensive

It is the most famous equation of all time: $EL = mc^2$. What is that "L" doing there? Working in 1912, Albert Einstein quickly decided that his equation was weighty enough without superfluous constants, so he crossed the "L" out. But Sotheby's thought Einstein's deletions were quite valuable; it expected the manuscript to fetch $4 million to $6 million. At the auction on March 16, however, the highest bid only broached the $3-million mark, so the document was sold privately—for less—a few days later. It will be donated to the Israel Museum in Jerusalem. —*Charles Seife*

In Brief, *continued from page 20*

A Peek at Pluto

The *Hubble Space Telescope* has captured pictures of Pluto's frosty surface—66 years after the planet was discovered. The smallest, outermost member of our solar system sports a prominent polar ice cap, a dark strip bisecting the cap, a curious bright line, rotating bright spots and a cluster of dark areas. These features suggest that Pluto is not, as had been proposed, a twin of Neptune's moon Triton. A computer processed *Hubble* data to produce these images; other graphics are available at http://www.stsci.edu/pubinfo/PR/96/09.html



NASA and ESA

He Said, She Said

Scientists at Johns Hopkins University have found one reason why women often possess better verbal skills than men do. The group took MRI scans of 43 men and 17 women and compared the gray matter in two brain regions involved in verbal fluency. Although the women's brains were on average much smaller, in both language areas they bore greater concentrations of gray matter than the men did: 23.2 percent higher in the dorsolateral prefrontal cortex and 12.8 percent higher in the superior temporal gyrus.

FOLLOW-UP

Slowing Japan's Fast-Breeder Program

After devoting three decades to development, Japan has had to deactivate its only fast-breeder reactor—one that produces more plutonium fuel than it consumes. The prototype suffered a dangerous leak of sodium coolant last December, confirming many people's fears about its safety. (See January 1996, page 34.)

Summer at the South Pole?

Long ago Antarctica may not have been an icy mound. Recent finds suggest that it was once quite balmy. While searching for fossils some 300 miles from the South Pole, geologists happened on an unusual growth. There, buried under layers of rocks, they found a bed of moss that dates back at least three million years. (See November 1995, page 18.) —*Kristin Leutwyler*

derstand the need for randomization on a cognitive level," but the gut feeling for it eludes them, Schulz explains. As a result, once a treatment has become respectable, it may be impossible to determine whether it actually works. When Canadian physicians explored the effectiveness of episiotomy to aid childbirth, he notes, a third of doctors employed the operation in 90 percent of the patients ostensibly slated for the surgery only as a last resort.

It can be difficult for doctors committed to the best possible care for their patients to give medical decisions over to a roll of the dice, especially if early results from a new treatment are promising, but it may be necessary. "If you think you know what's happening, you'll never allow it to play out, and you'll never know. But your notions aren't based on good data," Schulz observes. He recalls one randomized trial of antibacterial cream given to prevent premature births caused by vaginal infections: after initial indications that the cream was effective, reviewers moved to block the trial on the grounds that it would be unethical to withhold treatment—but when all the results were in, the control group had had fewer premature births.

Schulz and other medical statisticians around the world have developed guidelines, to be published later this year, for reporting safeguards, including the methods used in trials to ensure allocation concealment. Several major medical journals, including the *Lancet* and the *New England Journal of Medicine*, are proposing to reject manuscripts that do not conform, so that trials whose results are easily susceptible to jiggering will not be widely published and become part of what everybody knows. —*Paul Wallich*

ANTI GRAVITY

Pork Barrel Science

Between stints as prime minister, Winston Churchill retired to a country farm, where he was fond of taking walks with his grandson. He especially liked the pigs, his grandson remembered in a recent television interview. One day the elder Churchill stopped to stroke the pigs' backs with the end of his walking stick. "A cat looks down upon a man, and a dog looks up to a man," the Nobel Prize–winner confided to his grandson. "But a pig will look a man in the eye and see his equal."

Stanley E. Curtis, professor of animal sciences at Pennsylvania State University, intends to find out whether Churchill was right. In a pig-nutshell, Curtis wants to know what swine know, and more. "In particular, we want to know how the animals feel, not how a human being might think they feel," Curtis says. "And we have every reason to believe that they don't see the world as we see the world."

MICHAEL CRAWFORD

Curtis plans to explore what goes on in a pig's mind's eye, using a technology already established for the study of the mental capacities of primates, including teenagers: video games. Of course, we can easily operate joysticks; Curtis intends to modify technology so that pigs, using their snouts, can interact with videos. (Because pigs are notoriously nearsighted, a choice of glasses, contacts or radial keratotomy needs to be made.)

Assuming all those problems get pig-ironed out, we can start to fathom what they fathom. Because pigs have at least six calls, Curtis's ultimate dream is to determine the behavioral contexts of their individual yelps: "I would see the day when we could use synthesized calls from computers to engage in conversations with them in their own language." The result could be pig husbandry's version of the kind of enlightened management many credit for the rebound of the Big Three automobile manufacturers. "If we could have the pigs themselves participate on the team that's designing the piece of equipment or the facility that they're living in, that would be great," Curtis says. But what if the communication we get is "Porkers of the World, Unite"? —*Steve Mirsky*

POLICY

SOWING WHERE YOU REAP

Profits from biodiversity are neither easy to pinpoint nor to protect

That biodiversity is valuable enough to pay for itself has long been recognized as a self-evident truth. Roughly half the drugs in clinical use are estimated to derive from nature. The Biodiversity Convention, adopted in 1992 at the United Nations Conference on Environment and Development, tried to ensure that profits from such goods return to the place of origin to aid conservation and local communities. Despite some success, that goal remains elusive. Although bioprospectors—those who seek potential products in biota—number in the hundreds, the returns they promise to peoples in developing countries appear highly variable.

"I've seen genuine outrage in parts of the world," attests Daniel M. Putterman, a consultant who helps developing countries negotiate deals with industry. The anger is cutting off parts of the world to bioprospectors. In Thailand, public ire has forced a British foundation to stop seeking the medicinal secrets of Karen tribes. In India, thousands of insects found in the luggage of two German "tourists" have prompted legislation regulating gene transfer; the Philippines recently passed just such a law.

Even when they agree to the transfer of such resources, some Third World representatives remain uneasy about the power balance with their First World partners. "If you are a small fish swimming with a shark," says Maurice M. Iwu of the Bioresources Development and Conservation Program in Cameroon, "it makes no difference if the shark has good intentions."

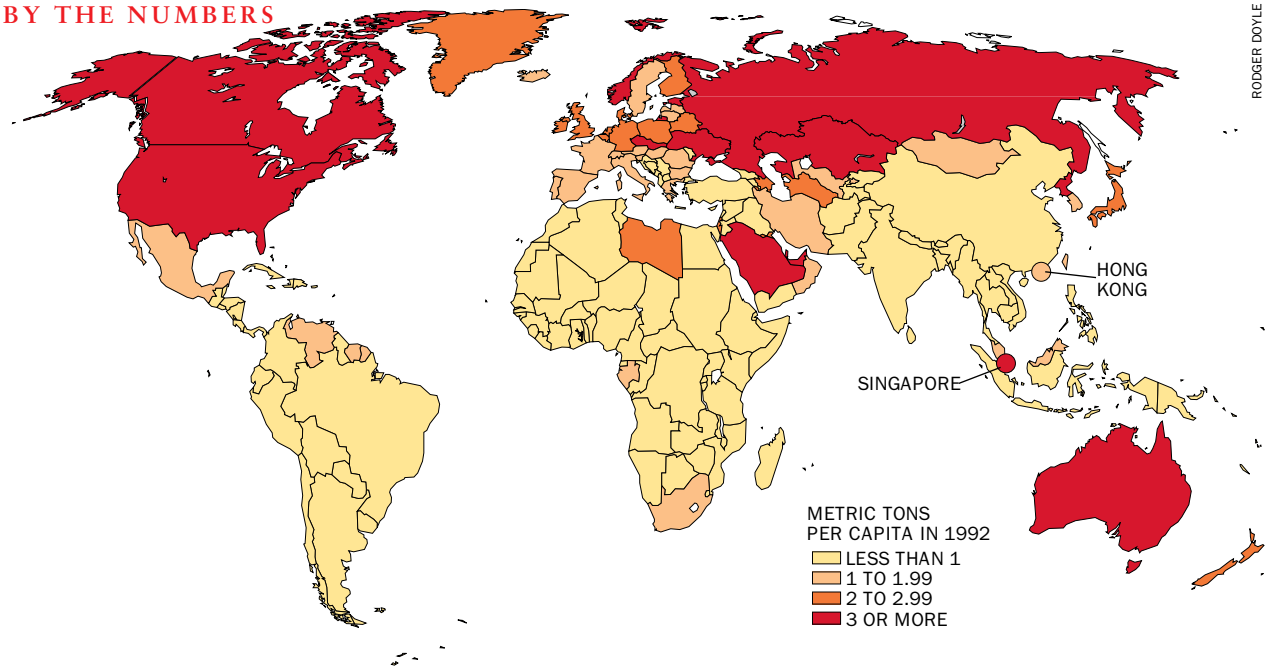
These problems center on that special attribute of biological materials: they reproduce. Thus, a handful of seeds or micrograms of microbes might be enough to carry a genetic resource out of a country. Technological advances allow tiny amounts of material to be screened, so a drug developer may never have to return to the source country. "The trick right now is monitoring the flow of material," explains Walter V. Reid of the World Resources Institute.

When a benefit-sharing agreement is

signed, local institutions must often rely on the integrity of the foreign partner in sharing information. "You have no way of knowing" what happened to a sample, notes Berhanu M. Abegaz of the University of Botswana. On occasion, a drug developer may offer to cultivate a plant in the source country, Abegaz says. Nevertheless, he adds, this arrangement can have a double edge: the firm that holds the patent can also control the price paid to farmers, and the producers are kept at a subsistence level.

The more land brought under cultivation, the greater may be the threat to biodiversity. And if collected from the wild, the plant itself may become endangered. That happened with the Pacific yew, which yields the anticancer agent taxol. If a drug can be synthesized in the laboratory, the pressure on biodiversity

BY THE NUMBERS



SOURCE: Carbon Dioxide Information and Analysis Center

Carbon Dioxide Emissions

Certain gases in the atmosphere allow visible light to pass through, but they block much of the heat reflected from Earth's surface—in the same fashion as the glass windows in a greenhouse. Without this greenhouse effect, worldwide temperatures would be lower by 35 degrees Celsius, most of the oceans would freeze, and life would cease or be totally altered. According to the theory of global warming, an increase in greenhouse gases in the atmosphere will produce unacceptable temperature increases. A doubling of the volume of gases, for example, would cause temperatures to go up by 1.5 degrees C or more, a phenomenal change by historical standards.

The most dramatic consequence of the warming would be a rise in sea level from the melting of polar ice caps, a rise that the Environmental Protection Agency projects to be 20 feet as early as the year 2300—sufficient to submerge large parts of coastal cities. Global warming would result in profound shifts in agriculture and may, as some have suggested, hasten the spread of infectious diseases.

Aside from water vapor, the principal greenhouse gases are carbon dioxide, resulting from the burning of fossil fuels; methane, produced by the breakdown of plant materials by bacteria; nitrous oxide, produced during the burning of fossil fuels and by the decomposition of chemical fertilizers and by bacterial action; and chlorofluorocarbons, used for industrial and commercial purposes, such as air conditioning. Of these, carbon dioxide is the most important. The atmospheric concentration of CO_2 was 280 parts per million before the Industrial Revolution; with the increasing use of fossil fuels, it has risen to more than 350 parts per million today.

The idea of global warming gained support as temperatures soared to record levels in the 1980s and 1990s, but there are several problems with the theory, including doubts about the reliability of the temperature record. Despite this and other questions, a majority of climatologists feel that a risk of global warming exists, although there is much disagreement concerning the extent and timing. (One of the uncertainties is the possibility that large amounts of methane now locked in Arctic tundra and permafrost could be rapidly released if warming reaches a critical point.) At the 1992 United Nations Conference on Environment and Development, more than 150 countries signed the U.N. Framework Convention on Climate Change, which pledges signatories to control emissions of greenhouse gases.

In 1992 the Persian Gulf states of Qatar and the United Arab Emirates had the highest per capita emissions of carbon dioxide—16.9 and 11.5 metric tons, respectively—whereas the U.S. was in eighth highest place with 5.2 metric tons. Overall, the U.S. produced 23 percent of global emissions, western Europe 14 percent, the former communist countries of eastern Europe 20 percent, and Japan 5 percent. Of the developing countries, China was the biggest contributor in 1992 with 12 percent, followed by India with almost 4 percent. Although emissions have more than tripled during the past 40 years, they showed signs of leveling off in the late 1980s and early 1990s. *—Rodger Doyle*

is eased (again, as with the yew), but then it can become hard to ensure that some proceeds return. Roger Kennedy, director of the National Park Service, has proposed that royalties from finds—such as the bacterium *Thermus aquaticus,* which was discovered in Yellowstone National Park and used in the enormously profitable polymerase chain reaction—be used to protect the parks.

This idea is disputed by some pharmaceutical companies and by other observers, who point out the differences between property and intellectual property. In the case of *T. aquaticus,* the counterargument goes, scientists discovered PCR—the technique is the product of their effort and thought. Thus, their intellectual work and financial investment deserve to be protected. Many experts feel that the Biodiversity Convention (which the U.S. has still not ratified) does not adequately protect patents or intellectual property.

At the same time that developing countries are demanding a share of the royalties from drug discovery, many bioprospectors argue that the promise of such revenue is overblown. One profitable drug is developed, after 10 or 15 years, from some 10,000 to 100,000 substances that are screened. "The royalties may never come," points out Ana Sittenfeld of INBio, a Costa Rican organization that supplies extracts to several pharmaceutical firms, including Merck. For instance, the National Cancer Institute (NCI) screened nearly 80,000 biological materials between 1986 and 1991—only one major lead has emerged so far.

Small biotech companies have, however, discovered how to make money not just from the end product—the drug—but also from the steps that lead to it. Some rent out samples to pharmaceutical companies for screening; others do the screening and provide leads to substances. The industry assigns well-defined trade values to each step: extracts sell for $10 to $100, leads sell for $100 to $1,000, and a drug candidate with animal toxicology data sells for $1,000 to $10,000. "Those countries that had access to this market information have negotiated the best deals," Putterman notes.

The most valuable benefit, Sittenfeld states, is technological training. INBio, often cited as an example for future Third World institutions, functions much like a biotech company, with attendant profits. In contrast, Abegaz laments a "failure to build capacity in Africa." Among the bioprospectors in Africa is the NCI, which has been criticized for providing minimal up-front benefits and no guarantee of royalties.

INBio puts 10 percent of its research budget into conservation and trains local parataxonomists, who might otherwise have been using the forests in nonsustainable ways. The International Cooperative Biodiversity Groups Program, set up by three U.S. agencies—the National Institutes of Health, the National Science Foundation and the Agency for International Development—also tries to build local capacity while bioprospecting. Joshua P. Rosenthal, who heads the program for the NIH, comments that such training helps local scientists in identifying areas rich in biodiversity.

A handful of other bioprospectors have set up trust funds that promise returns if royalties ever start to flow. But ensuring that biodiversity survives its value to humanity remains a climb up a slippery slope. *—Madhusree Mukerjee*

This is the second in a two-part series on profiting from biodiversity.

DENTISTRY

ELECTRIC SMILE-AID

There's a new way to stave off cavities

Of all the diseases that afflict humankind, none is more prevalent than tooth rot. By the age of 17, almost 85 percent of adolescents in the U.S. have had multiple cavities, according to a recent article in the journal *Public Health Reports*.

The basic reason for this pervasiveness is that dentists often cannot detect the onset of decay until it is too late. But researchers and dental professionals have high hopes for an experimental diagnostic tool that, if it ever goes into production, could detect problems while there is still time to prevent cavities.

Decay begins just under the tooth's surface, in the enamel coating. Bacterial fermentation of the carbohydrates from food creates acids that cause the loss of mineral in the enamel (which is about 90 percent mineral when healthy). If this demineralization reaches the underlying dentine, the enamel eventually caves in, forming a cavity.

If a dentist can catch demineralization before it becomes too advanced, fluoride treatments can heal the lesion. But dentists seldom can. "Decay has to be advanced to be seen or felt," explains George E. White of the Tufts University School of Dental Medicine. The only tools most dentists have are their eyes, the infamous metal pick—which they use to detect spots made fragile by demineralization—and the x-ray machine.

These methods do not work well. Recent studies have found that even with x-rays, dentists miss at least half of these precavity lesions. Tooth enamel is quite opaque to x-rays, so the demineralized regions are often obscured by adjacent healthy enamel.

Now members of a research group from the universities of Dundee and of St. Andrews, both in Scotland, and the University of Nijmegen in the Netherlands say they have found a much better approach. They describe their findings in a recent issue of *Nature Medicine*. Their technique, which measures the electrical impedance of a tooth surface to determine whether it contains a demineralized region, was 100 percent accurate in trials on extracted teeth.

The method exploits the fact that demineralization opens up pores that fill with a fluid that is much less electrically resistant than enamel. The technique is not new. But the Dundee team increased accuracy considerably by measuring impedance using alternating-current waveforms over a broad spectrum—from one hertz to about 300 kilohertz.

The procedure took 10 to 15 minutes to measure impedances separately on all four sides and the top surface of a single tooth. That time, however, could be cut to seconds by more selective application of the frequency bands used on each tooth, says Christopher Longbottom, one of the Dundee researchers. He and his colleagues are currently seeking funds to produce a version of their system that would be suitable for clinical use. *—Glenn Zorpette*

BIOLOGY

The More Species, the Merrier

Environmentalists often call attention to the erosion of Earth's biodiversity. Yet even the most knowledgeable of them often has difficulty following such warnings with clear statements about the value of what has been lost. Now ecologists have demonstrated at least one benefit of biodiversity: a multiplicity of species makes some lands more productive.

G. David Tilman and Johannes Knops of the University of Minnesota, along with David A. Wedin of the University of Toronto, recently published this report in *Nature*. Their investigation involved a set of 147 grassland plots; each measured three by three meters square and was planted with a controlled mixture of grasses (*right*). Using student labor for the frequent weeding, the researchers allowed only one kind of grass to grow on some squares, whereas in others they maintained many types. In some plots, 24 different species sprouted—seemingly a vast variety but still only a mere fraction of the natural variation. Wedin says native prairies easily have 40 to 50 species.

DAVID A. WEDIN *University of Toronto*

The point of the strangely quilted field was to determine how the richness of species affected the land. Charles Darwin long ago reported that a mixture of different grasses can support higher biological production than can a single type of plant. But according to biologist Peter Kareiva of the University of Washington, no one quite knows which experiments Darwin had in mind.

Tilman and his co-workers demonstrated Darwin's point clearly by monitoring the effect of species richness on the peak standing crop (as measured, for example, by the amount of a plot covered by grass). Plant cover expanded from 33 to 49 percent as the number of species rose from one to six. Interestingly, with greater than six species, further productivity gains were hard to see; the researchers could find no indications of increasing productivity on plots for which the number of grass species surpassed 10.

"So do these results tell the policy maker to worry about preserving the first 10 species of prairie plant but not to bother once that quota has been satisfied?" asked Kareiva in a commentary in *Nature*. Clearly, more work would be necessary to gauge how a greater richness of species might offer other advantages, such as resilience to drought, predatory insects or disease. But Tilman and his team are keen to address such questions. They have established a group of 342 plots, each 13 by 13 meters square. "The bigger plots will be more valuable," Wedin remarks. But new results showing the other values of biodiversity will perhaps take quite a bit more time. As Tilman notes, "Hand weeding 20 acres is a slow process." *—David Schneider*

CYBER VIEW

Television Arrives on the Internet

Someday soon, just about everything will be networked. Television may well be next. Intercasting is a technology developed by Intel that intertwines World Wide Web pages with television broadcasts. With it, video producers can back up their real-time broadcasts with all the resources of the Internet. So a sports fan could call up batting averages to a window in the screen of a baseball game. News programs could provide reams of background analysis for those eager to look beyond the limits of a 30-second spot. And advertisers could offer viewers the chance to buy their product—or to get more information about it.

Station KGW in Portland, Ore.—the local TV station to Intel's Hillsboro plant, which is taking the lead in Intercast development—ran a successful demonstration last year. PC makers Gateway, Packard Bell and others promise a full range of Intercast-equipped computers over the course of 1996. The hope is that the broadcasting will begin in earnest as soon as the machines start hitting the shops.

And as it does, one of the easy assumptions made about the new media will be shown to be hopelessly wrong. New media do not replace old: they complement them. We won't all be reading our newspapers on-screen and watching interactive TV on our PCs. But the expanded media of the Net will enrich print and broadcast with their own unique capabilities, and vice versa. The process has already begun, and Intercast may well accelerate it.

The technology is simple. Television signals contain pauses, called vertical blanking intervals, to provide time for the electron beam that creates the picture to scoot back up from the bottom of the screen to the top. In America, those gaps are already used to transmit data that create captions for the deaf; in Europe, they transmit teletext information. Intercast takes up about half of the remaining capacity, and it uses it to transmit Web pages at about 96,000 bits a second—about three times faster than today's quickest modem. The Web pages are stored on a hard disk on the Intercast PC/TV and displayed in a window on the screen. Nothing fancy is required. Many PCs already receive and display video signals. The only special element needed for Intercast is a $50 chip for decoding the broadcast Web pages.

The interesting stuff begins when the Web pages hit the hard disk. At the simplest level, those pages can contain background information about the broadcast—which can be pretty dull But if the PC/TV is connected to the Internet, the pages can bring an interactive dimension to the broadcast. Instead of just passively watching what's beamed to the screen, the viewer can follow the links from the Intercast Web pages to the Internet. Bingo: instant interactive TV, using infrastructure and technology that already exist.

TOERGE

***WATCHING PC/TV** allows viewers to surf the Internet simultaneously. Here Ron Perkes of NetTV demonstrates the WorldVision system.*

Want to know about the movie you are watching? An Intercast old-movies link could connect you to a database of film information containing everything from biographies of the cast to copies of the reviews the film received. Want to play along with a game show? You could pick an answer, or buy a vowel. Because Web pages can connect to computer programs or to people (via e-mail, say, or videoconferencing), the only limit on the interactivity is the bandwidth of the link from PC/TV and the Net. In practice, most people will have "fast" modems, capable of transmitting about 28,800 bits a second, fast enough for text and simple (still) graphics. But in theory, cable companies promise this year to start rolling out speedy modems that can transmit more than one million bits a second, fast enough for rudimentary video.

But if Intercast is to fulfill this potential, TV program makers will have to get smart about the ways in which new media can complement old. There's no point in simply doing slowly what can already be done well via broadcasting—like shoveling out prepackaged information. Three of the new media's capabilities will prove crucial in making the marriage work:

- Richness. There is more information on the Web than could be broadcast over decades of television, let alone in a single half-hour show. So whereas TV necessarily has to aim for the broad middle ground, the Web can cater to individual whims and interests.
- Interactivity. The Net is a two-way channel, allowing people to talk back to the makers of TV programs and their subjects—and to participate in the program rather than just watch it.
- Ubiquity. Cyberspace is a shared space: viewers interact with one another as well as program makers. So they can create true communities of interest and action—and perhaps resolve one of the basic dilemmas of new media versus old. Although TV watchers all share the same experience, they can only sit back and watch. But on the Net, people can interact. Intercast just might create an interesting meeting ground that fosters true community.

And if not Intercast, then somebody else will push forward with connectivity. The possibilities of networking the world have only begun to be explored. Many magazines and newspapers already carry Web page addresses that will provide more information about their articles—even Playboy bunnies now have Web pages.

There is no reason why appliances could not also be linked. The oven could be linked to recipes and cooking hints, preferably via a wireless link to a waterproof, handheld computer. The office photocopier could hook up both to the maker's repair service and to an on-line manual and help system. Anything you've ever kicked, cursed or switched off just for being so determinedly and inanimately stupid could be improved by bringing more information to it—and it's only a connection away. After all, if the Net can make television smart, just think what it could do for a vacuum cleaner. *—John Browning in London*

INFORMATION TECHNOLOGY

SYSTEMATIC ERRORS

A new law aims to prevent software meltdown in federal agencies

SPENCER GRANT *Gamma Liaison*

Several hundred tons of plutonium, enriched uranium and other highly radioactive materials have been produced within the U.S. over the past two decades. For every ounce created, transported or sold, Department of Energy officials entered a record into a database. The tracking system ensures that no weapons-grade nuclear materials are stolen or misplaced and provides evidence that the U.S. is complying with international treaties. But in 1993 the software, written 20 years ago for an obsolete mainframe, had become impractical to maintain, so the DOE ordered a replacement.

Because of the importance of the system, Congress asked the General Accounting Office (GAO) to check up on the project a year later. The GAO's report was disturbing. It warned that the DOE's contractor had started programming without adequately analyzing whether the new design would work as well as alternatives, meet users' needs or even save money. Despite the GAO's admonition, construction continued.

Last fall the GAO issued a follow-up review raising more serious concerns. The contractors, it found, could provide no specifications, no test results, no status reports. The DOE had no way of knowing whether the project was on track. Agency managers could not even estimate the size of the new system. Nevertheless, in September the DOE switched off the old tracking system and turned on the new one without ever requiring that the software pass a final test demonstrating that all its reports are accurate. GAO reviewers have recommended canceling the project, warning that "the history of software development is littered with systems that failed under similar circumstances."

Indeed, in the history of federal software procurement, expensive, time-consuming failures are the rule. The costs to taxpayers are threefold. First are direct losses from investments in technology that is never used, such as a Federal

Bureau of Investigation fingerprint-scanning system ordered in 1993. Already late and more than 50 percent over budget, the system uses technology so outdated that police advisers recently voted to reject and rebid the contract.

Secondary costs go to pay salaries and maintenance fees to keep obsolete systems running while modernization projects drag on. The National Weather Service's upgrade of its observation and forecasting systems, for example, has slipped five years and doubled in cost because of poor design and management.

Most painful, however, are the lost savings that could have been realized had agencies applied technology effectively. While the Internal Revenue Service has frittered eight years and $2.5 billion trying, with little success, to modernize its systems in order to combat fraud and noncompliance, an estimated $70 billion in uncollected taxes has slipped through the government's fingers.

No one knows what return executive agencies can expect from the $26.5 billion they plan to spend on information technology in 1996. But many industry experts are certain that it is lower than it ought to be. One major reason, an outdated law known as the Brooks Act, vanished in February, when President Bill Clinton signed a bill that radically reorganizes the way federal agencies purchase large software systems.

The 1965 Brooks Act funneled nearly all computer purchases through the General Services Administration (GSA) and forced agencies to pick contractors through a lengthy competition. The idea was to ensure that the government paid the lowest price for expensive mainframes. But as large machines yielded to the market for personal computers, the law became a costly anachronism.

The legislation that repeals the Brooks Act will require each federal agency to appoint a chief information officer (CIO). Although agencies will no longer need the GSA's (typically rubber-stamped) permission to buy information technology, they will have to report on the cost, status and success of their projects to the Office of Management and Budget (OMB). The OMB will have the authority to kill runaway systems by withholding their funding—and the duty to send an annual report to Congress comparing the performance of the agencies.

In place of the Brooks Act's intricate rules is a new set of detailed directions. Big systems must be split into small independent chunks so that later sections can incorporate newer technology. Segments are supposed to be finished within 18 months—faster than most current projects. Perhaps the law's most ambitious provision insists that agencies analyze and redesign operations *before* investing in systems to automate them.

Senator William Cohen of Maine, who sponsored the legislation, maintains that it could save up to $175 billion over five years. Industry veterans suggest that estimate may be wildly optimistic, although they generally agree with Larry E. Druffel, head of the Software Engineering Institute, that "repeal of the Brooks Act has to be positive." Appointing CIOs, splitting projects into pieces and enforcing risk management could produce a more logical approach, he says. But Druffel warns that "these components could also produce a bureaucratic system in which the CIO becomes a bottleneck, security concerns inhibit the use of commercial products, and increments are built without any unifying framework, so that nothing works with anything else."

Richard A. DeMillo, former head of the Software Engineering Research Consortium, points out that the law "recycles old ideas that have always sounded good but haven't been followed by contractors." Indeed, the act gives agencies no new leverage to deal with firms that deliver poor work, fall behind schedule or raise their cost estimates midstream.

If Congress has neglected oversight in the past, "this goes to the other extreme, of micromanagement," complains Paul Strassmann, former CIO for Xerox, Kraft and General Foods. "The fundamental flaw here is that [Congress] prescribes inputs yet has very little interest in results." Congress, he suggests, should demand reductions in overall agency costs, not in the price of technology.

"Treating each systems acquisition as a separate [technological] solution," Strassmann testified in a Senate hearing, "has resulted in thousands of unintegrated, hard-to-maintain, impossible-to-manage, contractor-dependent islands of automation." Because the law "does not articulate what to do with what is already in place and what happens after new systems are installed," Strassmann warns, "this act may succeed in eliminating much of the existing regulatory chaos of acquisition only to become saddled with a more costly chaos of operations."

—W. Wayt Gibbs in San Francisco

This is the second in a continuing series on computing and government.

COMPUTING

Recently Netted…

Migrating Metaphors. The terminology of computer networks is gradually making its way into the general lexicon. For example, low bandwidth, as in the disparaging "He has very low bandwidth" or "What a low bandwidth group," is a putdown of mental capacity. Bookmark, as in the approving "I bookmarked them," is a verb for people one might wish to telephone or e-mail in the future, perhaps after a successful business presentation. And mostly digital, as in "I'm mostly digital," is said of the reading habits of those who prefer e-mail, news groups, chat lines and Web sites to books.

Licensed to CyberNotarize. The American Bar Association is working on a new legal specialization—the CyberNotary. Those licensed in the field will authenticate and certify commercial electronic documents destined for abroad, where legal procedures and content differ substantially and where transactions are made still trickier by the advent of electronic commerce. CyberNotaries will be expert not only in international law but also in digital-signature technology, attesting to electronic identities on corporate share transfers and establishing that parties of the first part truly possess the public keys that they purport to possess. The ABA CyberNotary Project World Wide Web page is at http://www.intermarket.com/ecl

Carpet Tunnel Syndrome? During the 1980s, bemused operators on computer help-lines fielded calls from people unable to work their mouse buttons. It turned out that new users were placing the devices below their desks and trying to operate them by foot. Nowadays, though, a tapping foot may be just right. Hoping to eliminate the hazards of carpal tunnel syndrome, manufacturers have begun introducing a foot-pedal mouse that sits on the floor, freeing hands. In one two-pedal model, users tap the left pedal to click. They rotate their foot on the right pedal to direct the cursor, pressing down for speed. *—Anne Eisenberg (aeisenb@duke.poly.edu)*

IMAGING

ON PERMANENT DISPLAYS

Low-power, low-cost liquid crystals move to market

The failings of conventional flat-panel display technology are familiar to anyone who has used—or priced—laptop computers. Inexpensive models are limited to shades of gray or dim colors. More advanced versions capable of bright, fast-changing hues carry dizzying price tags. And all liquid-crystal screens suffer from a voracious appetite for power, sucking batteries dry within a few hours.

Researchers at the Liquid Crystal Institute of Kent State University have recently demonstrated a new kind of inexpensive liquid-crystal display (LCD) that can produce clearer images using much less energy. Commercial production of a high-resolution gray-scale version has already begun at Kent Display Systems. The researchers are now engineering a similar color device.

The displays do more with less because they affect light in a different way than conventional LCDs do. A standard liquid-crystal panel filters the light both going in and coming out. Dots, or pixels, of liquid crystal inside the panel naturally twist the light so that it can pass through the second filter. But when a pixel is turned on, it untwists, and the dot goes dark. Unfortunately, such polarized filters cut the light going in by half; changing bright pixels into colored ones requires yet another filter. LCDs are consequently too dim to use as computer displays unless lit by a lamp from behind. And lamps devour power.

Liang-Chy Chien and his colleagues got around this problem using a so-called cholesteric liquid-crystal material. Rather than twisting light, this material breaks incoming rays into two parts. One ray is reflected; the other is transmitted. Electrifying the chemical turns it clear. Because cholesteric LCDs reflect light without the need for polarizing filters, they can be as bright and legible in ambient light as conventional LCDs are when backlit.

Early cholesteric LCDs were limited to single colors, but Chien found that if he added small amounts of a second material, he could tune the color to anything from deep red to brilliant blue by shining various amounts of bright ultraviolet light on the panel. Mixing in a bit of polymer then locks in the chosen color. The engineers are now adapting masks such as those used to etch microscopic patterns onto computer chips to create millions of red, blue and green pixels on a cholesteric LCD panel.

At present, cholesteric LCDs are about 20 percent more expensive than conventional "passive matrix" displays, but their effects are worth far more. Pixels in the new displays stay on once they are turned on, eliminating the need to redraw the display several times each second, thus saving power. These panels should run more than 10 times longer on batteries than present displays can.

The stability also allows pixels to be much smaller—one prototype boasts 200 dots per inch—and it eliminates the flicker that makes laptop screens wearisome to read. But the biggest advantage of the new LCDs is that they do not require the "active matrix" electronics that triple the price of conventional panels in order to maintain high contrast and resolution. A wide range of electronics makers, including IBM, Sony and Toshiba, have reportedly expressed interest in licensing the technology.

—W. Wayt Gibbs in San Francisco

PETER YATES *SABA*

NEW LIQUID-CRYSTAL DISPLAYS reflect rather than polarize light.

BIOTECHNOLOGY

ADVANTAGE: NATURE

Could escaped genes from bioengineered crops give weeds a crucial boost?

During the past two years, a dozen varieties of cotton, squash, soybeans, potatoes and tomatoes created by gene splicing have been approved for sale in the U.S. The added genes confer traits ranging from longer shelf life to pest resistance. The plants seem safe, but environmental watchdog groups fear that the spliced genes might spread into the crops' wild relatives. In such hosts, the genes might be less benign—and harder to control.

Researchers have long known that transgenic plants can form sterile hybrids with wild relatives. Now researchers in Denmark have shown that these hybrids can be fertile and can transmit a genetically engineered trait to subsequent generations in field conditions. Health concerns have also emerged: a report in the *New England Journal of Medicine* indicates that a gene taken from Brazil nuts and engineered into soybeans made the beans allergenic.

The Danish researchers, Thomas R. Mikkelsen and his colleagues at the Risø National Laboratory in Roskilde, crossed oilseed rape (also known as canola) that had genetically engineered resistance to a common herbicide, glufosinate, with a weedy relative of the crop, *Brassica campestris*. They then bred the hybrids with wild *B. campestris* to create glufosinate-resistant plants. Furthermore, the plants transmitted glufosinate resistance to the next generation. "I have been waiting for something like this to happen," comments Norman C. Ellstrand of the University of California at Riverside. "This demonstrates that you can get expression of a novel gene in a weed plant, and it has high fitness."

Resistance to herbicides has been a popular trait for genetic engineering, because the plant developers can sell the seeds with the promise that the crop will not be harmed by use of the proper herbicide. Plant Genetic Systems in Belgium has obtained marketing approval in Britain for glufosinate-resistant oilseed rape, and Monsanto sells soybeans that are resistant to the herbicide glyphosate. But if weeds acquire resistance genes from the crop, the commercial advantage will quickly evaporate.

That scenario is plausible only if there are weedy relatives in the area where the crop is grown. Gene spread from soybeans in North America seems unlikely, because the crop has no wild relatives. But soybeans in Asia do have such neighbors, and canola and squash have numerous wild relatives in North America.

Genes for herbicide resistance probably will not get far outside of a controlled agricultural setting, because they offer no advantage where the herbicide is not used. Genes for pest resistance are a different matter. Even seemingly innocuous traits such as altered oil composition might give a weed a boost if the traits were to spread. The Union of Concerned Scientists has called for more research on a virus-resistant crookneck squash marketed by Asgrow and a modified canola, sold by Calgene, that produces seeds with oil rich in lauric acid.

Beyond the threat of the spread of resistance lies the worry that other harmful attributes could be transferred between transgenic crops. Scientists have long been aware, for instance, that if a plant is given new genes, it produces new proteins, and some proteins can cause life-threatening allergic reactions in people. This possibility just became reality for Pioneer Hi-Bred International, which had engineered a Brazil-nut gene into soybeans intended for animal feed in order to provide extra methionine to supplement the animals' diet. The company called off the project before any beans were sold, after tests showed that the Brazil-nut protein it had used caused allergic reactions when extracts of the soybeans were tested on people.

Despite the discovery that transgenes can spread by hybridization into weedy relatives of crops, the U.S. Department of Agriculture has proposed streamlining the procedure companies follow to get approval for field tests of genetically engineered crops. "Sex does happen, and we know about it," says Arnold Foudin of the Animal and Plant Health Inspection Service. "The question is: Does it pose risk elements that have not traditionally existed? The answer is, not really." Others are less sanguine. "I don't think there should be a class of genes or species that we assume are never going to cause problems," says C. Randal Linder of the University of Illinois. "The USDA is taking a bit of a fast track."

—Tim Beardsley in Washington, D.C.

MATERIALS

Make a Muscle

Artificial muscles twice as strong and nearly as fast as human muscle have been constructed by Mo Shahinpoor, an engineer at the University of New Mexico. The devices encapsulate fibers of polyacrylonitrile inside latex sheaths through which a chemical solution is pumped. By changing the pH of the solution, the researchers can make the fibers contract to as little as one tenth their original length, the professor reports. In February, Shahinpoor and graduate student Mehran Mojarrad demonstrated a platinum-coated ion-exchange membrane that runs on electricity instead of a chemical solution. Mojarrad has created sheets of the plastic material that curl when electrodes are charged on either side. So far the researchers have constructed only demonstration toys from the material: a boat propelled by a waving fin of polymer, and a flapping machine that they believe may yet get off the ground. But more practical uses for a cheap, noiseless and highly efficient artificial muscle are probably not far off.

—W. Wayt Gibbs in San Francisco

ERIC O'CONNELL

INFORMATION TECHNOLOGY

REMOTE REPAIR

Internet technology may allow equipment to be fixed from afar

Your computer system is down, and you don't know why. Wouldn't it be convenient if the manufacturer could diagnose and fix the problem over the telephone lines or send you the needed spare even before your system bombed? Such a scheme could be in place within a year, at least for industrial manufacturing equipment. The idea is to have a kind of data recorder within a piece of equipment that would transmit information on operating conditions to the original manufacturer. The firm can use the data to dispatch a replacement or even send commands that restart the device.

That is the hope of Richard S. Post, head of Applied Science and Technology (ASTeX), a company in Woburn, Mass., that supplies components, such as plasma sources and microwave power generators, for semiconductor manufacturing. Currently semiconductor-making equipment remains down about 15 percent of the time for maintenance. To construct more durable machinery, Post says, one needs to know the conditions under which the machine failed, such as the temperature it reached or the voltage it drew. But that kind of information is rarely available. "You just get the component back in a bag with a note saying it doesn't work," Post complains. Monitoring over the Internet might also obviate the need for a return shipment: a command could be sent that simply resets the device or that confirms it has actually malfunctioned.

The idea of using networks to monitor a piece of equipment is not new. Telephone companies already employ a similar strategy, notes Ralph Wyndrum of AT&T Bell Laboratories. They routinely test their lines and reroute calls around glitches before any disruption occurs.

The value of the Internet, however, is its economical utility: it is virtually free and has global reach. Moreover, no hardware needs to be invented. Microprocessors are often embedded in equipment (for every one personal computer, there are 10 home and business machines with a processor chip), and many of these chips can do diagnostic tests.

And software exists to connect these "intelligent" devices. For the past year, Novell in Orem, Utah, has been touting software called NEST, which links office machines so that, say, a single fax transmission can be dispersed to several locales. More important, it can collect real-time data about the devices and generate statistics on their use. At the end of March, Novell began selling a version that is compatible with the Internet. With the hardware and software available, the principle of remote monitoring over the Internet can be demonstrated in a matter of weeks, claims Post, who has only just begun floating the idea to colleagues and customers. Real systems could be had in a year.

Unfortunately, the ability to determine what a device is doing also suggests that information flow can be reversed, making sabotage a possibility. And sending proprietary operating data across the Internet makes it game for industrial espionage. Such security issues, though, are not that different from dealing with credit-card and other sensitive transactions over the Internet, Post remarks. He thinks that even a 5 percent increase in productivity would be worth the attempt: "We just have to decide what kinds of things to include in the next generation of devices." —*Philip Yam*

ENGINEERING

Winging It

From the Red Baron's Fokker to the stealthy, state-of-the-art F-22, fighter aircraft have always sported a tail. But for rear fins, the end may be in sight.

On March 19 the National Aeronautics and Space Administration unveiled the X-36—the first high-performance jet with no tail at all. Remotely controlled and powered by a cruise-missile engine, the 5.4-meter-long, 600-kilogram scale model represents "a major breakthrough in our ability to couple aerodynamic surfaces with thrust vectoring and flight-control laws to achieve truly tailless, agile flight," says Larry Birckelbaw, who led the X-36 project at the NASA Ames Research Center at Moffett Field, Calif.

Why go tailless? Because it can make a jet much more stealthy, Birckelbaw notes. And that's not all: a finless posterior can significantly improve performance. As much as 30 or 40 percent of the drag on a conventional jet fighter comes from the tail, Birckelbaw estimates. In a typical design, though, the tail is crucial for aerodynamic stability and maneuverability. The X-36 does without one by making extensive use of thrust vectoring—the ability to change the direction of the engine's thrust. The trick, Birckelbaw explains, was designing the X-36's aerodynamics so that the airplane would not spin out of control if the vectoring capability failed.

If Birckelbaw has his way, the diminutive X-36 will change the shape of high-performance airplanes. "I'm very hopeful that these technologies will make a major impact on fighters in the future," he says. —*Glenn Zorpette*

ROGER RENKEN *McDonnell Douglas Corporation*

PROFILE: MIRIAM ROTHSCHILD

A Natural History of Fleas and Butterflies

The house at Ashton Wold is wild, outside and in. Although it is muddy midwinter and the twisting branches and vines are bare, it is clear that the garden is a lush, unruly tangle in the spring and summer, that things are just let be. In the large living room, too, things are everywhere: an imposing pine tree hung only with its own cones, a sideboard with cakes and coffee, walls of bookshelves as well as long tables piled high with books—about fleas, birds in Israel, mother-daughter relations, Beatrix Potter's botanical drawings, and memory. There are pictures of birds and butterflies and photographs of the children and grandchildren and one of Walter Rothschild on the back of his giant tortoise Rotumah, a stuffed owl, vases of yellow flowers and star lilies, many small jars of seeds, two barking dogs, myriad couches.

CLIVE BOURSNELL

And Miriam Rothschild, whose interests, accomplishments and moods are as diverse as her sitting room. She even has another last name, Lane, that she uses when it suits her—sometimes when callers ask if they are speaking to Miriam Rothschild, she will answer, "It depends. Who are you?" ("Lane" was what the British Commandos dubbed her husband during World War II, because his Hungarian name sounded so decidedly un-English.) It is the name "Rothschild," however, that appears on her some 350 papers about entomology, neurophysiology, chemistry and zoology and on the roster of the Royal Society.

And it is as a Rothschild that she is known for her dozen books, much of her conservation work, her advocacy for the better treatment of animals, her gallery devoted to the artwork of schizophrenics, her political activism on behalf of homosexuals, and all the other hundreds of things she has done in her nearly 90 years. "I am a tilter at windmills," Rothschild asserts from her wheelchair, where she is temporarily stuck because of an injury. No matter that the furniture has been rearranged to accommodate the large Christmas tree, Rothschild takes the same path as ever to the ever ringing telephone, pushing chairs and small tables out of her way. "I always have had some cause or other which I really get terribly steamed up about."

Her expansive interests, her energy and her activism are in keeping with her lineage. The Rothschild family—famous for banking and politics—has produced astounding naturalists: Walter, whose collections included 2.25 million butterflies, 30,000 birds and 300,000 beetles; and Charles, Miriam's father, who assembled the most comprehensive flea inventory in the world. Rothschild's first memories are of being obsessed with nature and with collecting specimens. Her parents believed that a formal education would be too stifling, so she was free to pursue her interests and to read widely. At 17 she decided to take some courses.

"Right in the beginning of my university life, if you call it that, I tried to take two degrees at once: English literature and one in zoology. But it became impossible. You could never get the lectures synchronized. You always wanted to hear somebody talk on Ruskin, and at the same time you had to dissect the entrails of a sea urchin. It was hopeless."

Rothschild ultimately chose marine biology because of a field trip to Plymouth and a chance meeting with naturalist G. C. Robson. "He offered me the world if I would stick with his marine snails," she recalls—and he packed her off to Italy to do so, as the winner of an all-paid position. "I went home to my mother and said, 'You will be very pleased to hear that I have been awarded the London University Table in Naples.' I didn't tell her I was the only applicant. I thought it was high time she thought I was clever, instead of being the stupid one in the family."

There were no such snails, but Rothschild had a wonderful time: "My trouble at Naples was that I merely went into everything because it was all so fascinating." She returned to England, working on snail-borne parasites for seven years, until her lab at Plymouth was bombed in 1940. Rothschild has written about the sudden destruction as horrible but also liberating: "Without realizing it I had gradually become an appendage of my trematode life cycles." She then did some wartime work. "I made a food for chickens out of seaweed, and I was asked, 'Do you think this is a success?' And I said, 'I don't know. It gives me the hiccups.' " Rothschild stops and listens as the dogs begin to bark, high-pitched and persistent; when they calm down, she continues.

Rothschild was asked in the early 1940s to join Enigma (or Ultra, a project to decode German communications) with, oddly, a bevy of marine biologists. "There was the champion chess player of Ireland, and there were all these top mathematicians. But on the whole the marine biologists came out way ahead. It was very funny." The work was worrying, she says tersely. "Look, I can sum up my views on Enigma: we didn't win the war, but we shortened it."

She left Enigma to marry her husband and to work on an agricultural council, studying wood pigeons. She discovered that the birds carried bovine tuberculosis. "People said there was a different breed of wood pigeon, a different strain, that came to this country in the winter, which had darker plumage." To her, the coloring suggested addisonism, which people have when their adrenal glands are infected with TB. "I went to the meat market, and I dissected an awful lot of pigeons there. And then I found this TB in the adrenals." (She was not allowed to publish her results, because, she confides, "it gave the enemy information, which I thought was remarkably funny.")

Rothschild does not characterize her hunch about the TB—or any of her remarkable hunches—as intuitive. "I think if you had to describe any talent I might have, it is that I am a good observer. And that means that you don't only notice things, but you think about what you have noticed."

"I am a tilter at windmills."

After the war, at the age of 44, she wrote her first book, *Fleas, Flukes and Cuckoos,* about parasites, and then concentrated on the family fetish: fleas. Charles, who, among other things, identified the flea that carried the plague, had housed his tiny millions at the Natural History Museum in London, but they had yet to be catalogued. Being the mother of six posed no challenge to Rothschild. "I guess roughly I gave up 10 years to the children. And I have always been quite honest about this: I much prefer children to the fleas. It was not a sacrifice to me at all. And I never really believed a word of these women who said they could not give up their careers; it is obvious the children are more interesting than the careers."

She does admit that she is a chronic insomniac. "One thing that made it easy was you could look after the children in the daytime, and you could do your morphology and your microscopy at night." She apparently also dispenses with time-consuming chores like choosing clothes by wearing one outfit that she designed and had made up in various fabrics.

Working with a collaborator for 20 years, Rothschild catalogued and investigated the peculiarities of fleas: "I discovered, just by accident, that if you knew the histology of the flea you could pretty much know the histology of any other insect." She points to some drawings. "Look at their lovely mouthparts. They have got such beautiful mouthparts, fleas. Really, they have." Rothschild also discovered how fleas jump so well. They have a ball of resilin between their back legs; this elasticlike substance allows them to jump from bended knee off the ground at more than 140 times the force of gravity. Some do this 30,000 times without stopping.

In the midst of studying rabbit overpopulation in Australia, Rothschild discovered the first example of a parasite relying on its host's hormones. "I was able to show that the flea has turned over the control of its breeding cycle to the rabbit. Its ovaries only mature under the influence of the pregnant rabbit's hormones," she explains in crisp, clear manner. "During copulation between adult rabbits, the fleas all move off the buck onto the doe—she seems to attract them at that stage. Then, when she becomes pregnant and begins to mature her baby, so to speak, the fleas gradually go through her cycle. And their ovaries begin to develop. By the time she is ready to give birth, the fleas respond to this and instead of remaining attached to the rabbit ear, as they do normally, they break loose, run down the rabbit's nose and drop off on the babies just as they are born. There they receive another set of hormones that enables them to copulate." (Rothschild has said that this synchronicity may explain why women are more often bitten by fleas than men are.)

She stopped her work on hormones when her collaborator at the University of Oxford, Geoffrey W. Harris, died. "Somehow the gilt was off the gingerbread, you know." Rothschild attributes much of her luck to collaborators. "Without the enthusiasm, I mean, you know. I am an amateur, I have no degrees." With Nobel laureate Tadeus Reichstein, Rothschild determined that the poison of monarch butterflies comes from their diet of milkweed. She continues to study butterflies—her first love, she says, and the subject of her most recent book, *Butterfly Cooing like a Dove*—as well as toxins and chemical signaling in insects and plants.

Plants, in fact, are a current obsession. Rothschild is revisiting 180 of 280 sites in the British Isles that her father described in 1912 as areas vital to preserve. She hopes to determine which forms of land management failed. She has also devoted 150 acres of her estate to rare wildflowers and is selling the seeds so as to preserve genetic diversity. Generally, population growth and the destruction of the natural world depress her. But "there is only one single, slight good thing. And that is that a different class of person now is interested. I hate the word 'lower classes,' it is a horrible word, but it is true," she says. There are "more uneducated people who have become interested in the environment."

Her other concerns of the moment are memory (how certain chemicals trigger recall) and the plight of animals. Rothschild argues compellingly for animal consciousness and is trying to reform how farm animals are housed and slaughtered in England. She is remorseful about some of the experiments she conducted in the past. "People should be taught when they are young that they *have* to consider the value of the experiment before they start in on it. It is absolutely not enough to be interested. But you get so carried away with interest that you lose all sense of proportion."

Further, Rothschild is studying telepathy in several dogs and cats that appear to be able to tell when their owners are returning from a trip or are telephoning, even though no one else in the household knows of these events. She has put out ads ("Anyone whose dog or cat anticipates their return, please communicate") and is trying to design experiments to test her theory. "There are quite a few funny things about dogs and telepathy," Rothschild remarks and recounts how early one morning she was awakened in London, far from home, by her dog barking. She called her staff at Ashton Wold and discovered the dog had been barking for a while. "Probably coincidence, but now I feel as though I need to look into it."

And then there is the paper on ladybirds she needs to look into, as well as lost papers of her father's that have just been found and the meadow of Biblical flowers she would like to create and the book she is writing about Proust and the weather. "There comes a moment when counting the bristles on fleas becomes a bore," Rothschild says, explaining why she has always veered off into "corny" writing. But then art and science are not really so far apart. "My great thing is that I believe the two are very similar and should go together," she says. "You see, I am an amateur, not a professional zoologist. Because if I was one, life would have made me specialize more severely." —*Marguerite Holloway*

The Horror of Land Mines

Land mines kill or maim more than 15,000 people each year. Most victims are innocent civilians. Many are children. Still, mines are planted by the thousands every day

by Gino Strada

Finally, the terrible bloodshed in Rwanda had come to an end. Alphonsine and her family were returning to their house when Alphonsine stepped on an unseen mine. At the hospital in Kigali, run by the surgical team of the relief organization EMERGENCY, *I and other physicians did what we could to repair the damage. The explosion had smashed Alphonsine's legs and fractured her left forearm. We had to amputate both legs above the knee. Her sister sustained a penetrating brain injury from a metallic fragment; she never regained consciousness and died six hours after surgery. Their father, who had been meters away from the two girls, had only multiple small wounds in his chest.*

As a surgeon for EMERGENCY, I have treated many children such as Alphonsine and her sister—victims of a new kind of war. The great majority of modern conflicts are now internal rather than international: they are civil wars, struggles for independence, ethnic and racial "cleansings," terrorist campaigns. Today armies of irregulars without uniforms routinely fight with devastating weapons in the midst of crowded areas. Many armed groups deliberately mix with the population to avoid identification. Sometimes they actually use civilians as shields. Quite often, targeting and terrorizing large civilian groups are part of an army's primary military strategy.

Accordingly, civilians have increasingly become victims of war. During World War I, they represented only 15 percent of all fatalities, but by the end of World War II the percentage had risen to 65 percent, including Holocaust casualties. In today's hostilities, more than 90 percent of all of those injured are civilians. Numerous research institutes, among them the Stockholm International Peace Research Institute and the International Peace Research Institute in Oslo, and humanitarian organizations involved in victim assistance have confirmed these figures.

One of the most dramatic aspects of this catastrophic change is the ever more widespread use of inhumane weapons

such as antipersonnel mines. They characteristically pose an indiscriminate and persistent threat. Land mines do not distinguish the foot of a combatant from that of a playing child. Land mines do not recognize cease-fires or peace agreements. And once laid, they can maim or kill for many decades after any hostilities have ended. For this reason, the antipersonnel mine has been referred to as "a weapon of mass destruction in slow motion."

Mine Pollution

Mines have been used in various guises since the beginning of the century, but military philosophy has evolved over the years to make more cunning use of them. They are no longer seen simply as weapons for denying an enemy certain lands, or for channeling an enemy's troop movements, or for protecting key installations. Instead they are now often laid to deprive a local population access to water sources, wood, fuel, pathways and even burial grounds. In many countries, in fact, helicopters, artillery and other remote means have been used to scatter mines randomly over villages or agricultural land as deliberate acts of terrorism against the civilian population.

In technical terms, an antipersonnel mine (also known as an AP mine) can be defined as a device designed to kill or maim the person who triggers it. (In contrast, antitank mines, usually called ATMs, are specifically designed for blowing up tanks and vehicles. They explode only when compressed by something weighing hundreds of kilograms.) AP mines are generally rather small in diameter, frequently less than 10 centimeters across, and difficult to detect. In some cases, the color and shape of the mine help to camouflage it so that it becomes virtually invisible at a glance.

A land mine is activated when the victim triggers the firing mechanism, usually by applying direct pressure to the mine itself or by putting tension on a trip wire. That action sets off the detonator, which in turn ignites the booster charge, a small amount of high-quality explosive. The detonation of the booster charge detonates the land mine's main charge, completing the explosive chain.

In recent years, mine technology has evolved significantly. The development of plastic mines, as well as those containing a minimum amount of metal, has made these weapons cheaper, more reliable, more durable and harder to detect and dismantle. In addition, remote deployment systems (such as helicopters) have made it possible to deliver thousands of mines to a broad territory within just a few minutes. Laying mines in this way also makes it impossible to record exactly where they land, so recovering them is all the more difficult.

Unfortunately, land-mine technology is quite simple and its price very low—most weapons cost in the range of $3 to $15. As a result, they have been profitably manufactured and sold by a rising number of countries in past years, including many in the developing world. Approximately 50 nations have produced and exported antipersonnel mines, and at least 350 models are currently available, not only to official armies but essentially to all fighting groups and armed factions worldwide.

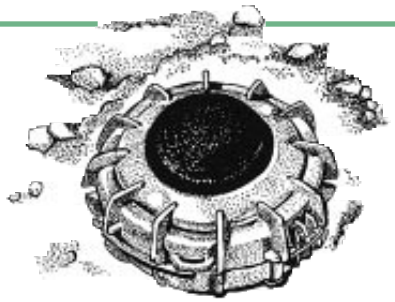
The number of unexploded mines in place around the globe is not known. According to several sources (including the United Nations, the U.S. State Department and various humanitarian

EMERGENCY ARCHIVE

SMALL SB-33 MINE, shown at its actual size below, blends with these stones so well that it becomes virtually invisible. When a person steps on such a blast mine, the resulting explosion typically blows off a foot or leg. Many antipersonnel mines are currently made in colors and shapes that help to camouflage them once laid.

Patterns of Injuries

PATTERN A INJURIES, suffered by the boy below, are most often caused by small blast mines, such as the VS-50 mine shown at the right. These weapons, less than 10 centimeters in diameter, most often amputate a foot or leg, depending on how they are stepped on. Rarely do they produce wounds higher than the knee or on the opposite leg.



agencies), at least 100 million are now scattered across 64 countries. Because neither manufacturers nor users typically keep records, though, these figures very likely underestimate the real situation. Whatever the case, a significant portion of the world undeniably suffers from what might be considered "landmine pollution."

The agencies offering victim assistance or operations to clear mines estimate that during the past two decades these weapons have killed or maimed approximately 15,000 people each year. Of these victims, about 80 percent were civilians. In fact, the actual number is probably even higher given that many accidents occur in remote areas without medical facilities and so are not documented. In a mined area, many everyday activities—gathering wood or food, drawing water, farming, playing, tending livestock—become highly risky. I have personally treated 1,950 people injured by mines; of them, 93 percent were civilians, and 29 percent were children younger than the age of 14.

The Damage Mines Inflict

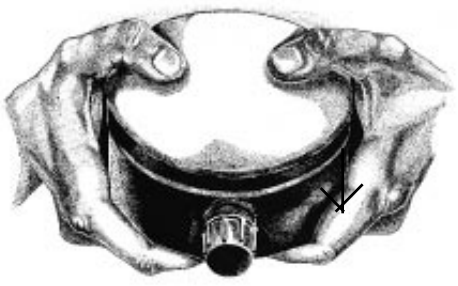
Practically speaking, antipersonnel mines can be divided into two large groups: blast mines and fragmentation mines. Blast mines usually respond to pressure—for example, from a descending foot on a sensitive plate. The injuries to the body from blast mines are direct consequences of the explosion itself. In contrast, fragmentation mines are usually activated by trip wires. When they explode, a large number of metallic fragments fly outward for a considerable distance. These fragments are either contained inside the mine or result from the rupture of its segmented outer case.

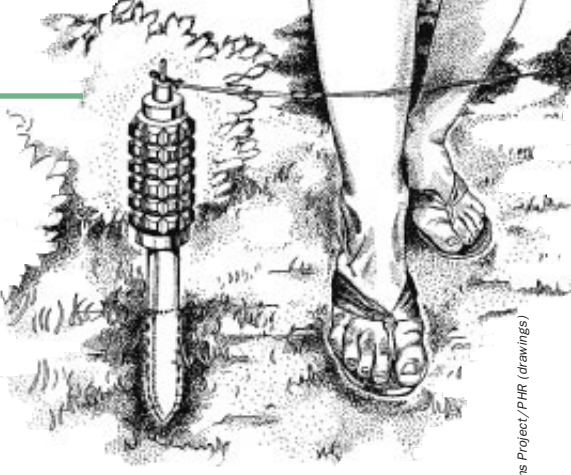
The type of mine, the specifics of its operation, its position on the ground, the position of the victim and the characteristics of the environment at the explosion site all affect the nature and extent of the damage a mine causes. Victims suffer from a broad range of injuries. Nevertheless, four general patterns are recognizable. I apologize if the description I shall offer of those injuries is disturbing to many readers. Yet to grasp how truly awful these weapons are, one must be aware of what they do and how they do it.

Small blast mines, having diameters of less than 10 centimeters, produce a very common pattern of injury that we call Pattern A. Among the most common mines in this group are the Italian scatterable mines TS-50 and SB-33 and the hand-laid VS-50 and VAR-40, the U.S.-made M14, and the Chinese Type 72. Typically, these weapons amputate the foot or leg. In some cases, only part of the foot may be blown off, depending on how the mine was placed and how it was stepped on. In most cases, the injuries from these types of mines occur below the knee, and no major wounds are present higher on the body or on the opposite leg.

Larger antipersonnel blast mines, such as those in the Russian PMN series, usually cause a different type of injury (Pattern B). This difference arises in part simply from the discrepancy in the size of the weapon. The diameter of the "small" VS-50 is 9.0 centimeters, whereas a PMN is 11.2 centimeters. The shock waves from both mines explode outward at the same high speed, approximately 6,800 meters per second, seven times the speed of a high-velocity bullet. But the cone of the explosion—the volume carrying the explosive force—is much wider for the larger mine. The large mines also contain much more high-quality explosive material. A VS-50, for instance, has 42 grams of RDX-TNT; a PMN-2 carries 150 grams of TNT; and a PMN contains 240 grams.

Victims stepping on these large antipersonnel mines invariably suffer a traumatic amputation. Quite often the lower part of the leg is blown off. A piece of the tibia (the large bone in the shin) may protrude from the stump, and the remaining muscles are smashed and pushed upward, giving the injury a grotesque cauliflowerlike appearance.





PATTERN B INJURIES, sustained by some of the children shown at the left at the Red Cross hospital in Kabul, Afghanistan, result from stepping on antipersonnel mines such as the PMN (*above*). These mines are not much larger than small blast mines, but they pack far more explosive material. As a result, they often blow off the lower leg and cause further harm to the thighs, genitals or buttocks.

PATTERN D INJURIES indicate that a person has tripped a fragmentation mine, such as the POMZ-2 "stake" mine above. These mines usually kill anyone who comes into direct contact with them by discharging metallic shards over a wide area.

PATTERN C INJURIES are produced by the PFM-1, the so-called butterfly mine (*left*). These mines explode only after cumulative pressure has been applied to their wings, which help them initially to glide to the ground after being released from a helicopter. Because they are usually being handled when they go off, these mines amputate fingers or hands and damage the face and chest as well. Almost all victims are children, such as the one shown above, who treat the mines as toys.

EMERGENCY ARCHIVE (*photographs*); PAMELA BLOTNER *The Arms Project/PHR* (*drawings*)

Occasionally, the lower leg is blown off completely, along with the knee. Large wounds are often sustained in the thigh, the genitals or the buttocks. In many patients the opposite leg is also damaged, bearing gaping wounds or open fractures. As a result, sometimes parts of both legs are lost. Penetrating injuries of the abdomen or chest are also fairly common.

The Russian PFM-1, the so-called butterfly mine, causes a third pattern of injury (Pattern C). This mine earned its nickname because it sports small wings that enable it to glide to the ground after it is released from a helicopter. A huge number of them were dropped during the conflict in Afghanistan. As has often been pointed out, the PFM-1 is particularly fiendish because it is a "toy mine"—a weapon masquerading as a plaything. Specialists insist that the shape of the PFM-1 is dictated by function, but the fact remains that it is attractive to children.

A unique feature of these mines is that they are activated by distortion or cumulative pressure on their wings; in other words, they do not necessarily go off when first touched. In Afghanistan my co-workers and I were told several times that a child had taken the butterfly—or "green parrot," as the Afghans call it—and played with it for hours with friends before any explosion occurred. The term "toy mine" therefore seems totally justified. In our group's surgical experience of treating more than 150 victims of this type of mine, we have never seen a single injured adult.

Technically, the PFM-1 is just another type of small, scatterable blast mine, but because of the peculiar damage it causes, it deserves a separate description. The PFM-1 is usually being held when it goes off, so it traumatically amputates one or both hands at the wrist. In less severe cases, only two or three fingers are destroyed. Very often the blast does further harm to the chest and the face. Injuries to one or both eyes are very common, producing partial or complete blindness.

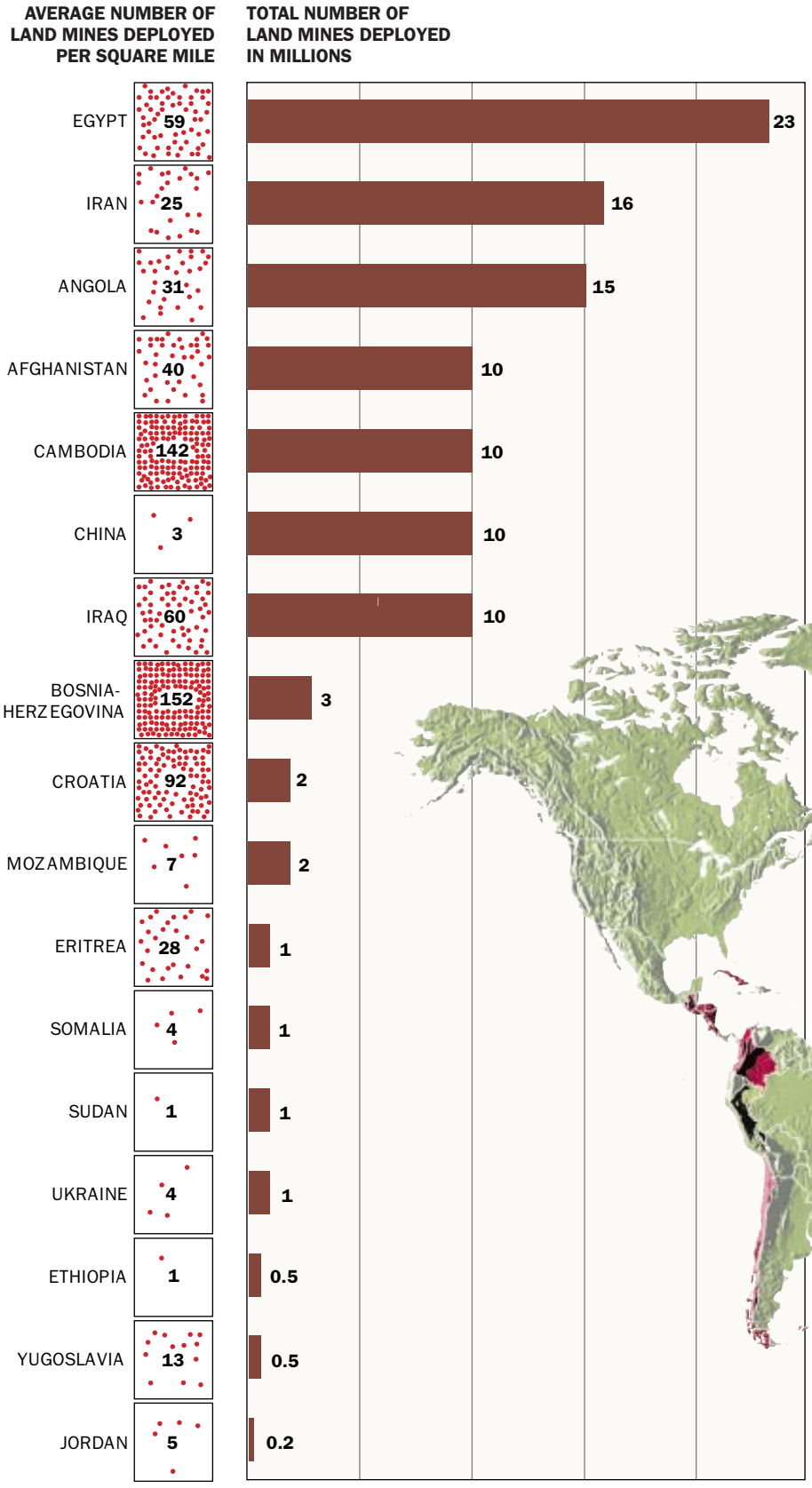
Antipersonnel fragmentation mines cause the fourth pattern of injury (Pattern D). Within this group are the "bounding" fragmentation mines, such as the Italian Valmara-69, the U.S.-manufactured M16 series and the Russian OZM series. These weapons are laid on the ground but, when triggered, jump into the air before exploding so that they can disperse their fragments over the maximum range and to the most lethal effect. Directional fragmentation mines—including the U.S.-made M18A1 (or "Claymore") and the Russian MON and POMZ "stake" mines, which aim their projectiles toward a target—are also in this class of weapon. All these mines are typically operated by trip wires.

The defining feature of fragmentation mines is that they fire metallic shards over a wide area. The Valmara-69, for example, explodes at a height of 50 to 100 centimeters—roughly the level of a man's waist—and projects some 1,000 bits of metallic shrapnel across a 360-degree spread. Mine specialists consider this mine to have a "killing zone" with a 25-meter radius and an "injury zone" of up to 200 meters.

Fragmentation mines produce injuries throughout the body. The size of the wound depends in part on the size of the penetrating splinter. If the victim is meters away from the site of the explosion, the fragments will frequently penetrate the abdomen, the chest or the brain, particularly if a bounding mine is involved. For shorter distances, the injuries resemble those of Pattern B. Still, doctors rarely treat traumatic amputations caused by fragmentation mines because the weapons usually kill in an instant anyone who activates them by direct contact.

In northern Iraq, during the Persian Gulf War, for instance, we observed six casualties from the explosion of a Valmara-69. The two persons who were trying to defuse the mine to recover its aluminum content—worth about $1 on the local market—were immediately killed. At the same time, four other peo-

COUNTRIES reporting land-mine incidents are shaded on the map at the right. The bar chart shows the number of mines planted in regions only where such estimates are known. The boxes (*left*) indicate the density of deployed land mines in those regions, measured as the average number of mines per square mile.



ple nearby, including two young shepherds, were severely injured. Only two of them survived.

The Challenge of Treating Victims

The injury patterns I have described identify the prevalent distribution of wounds that a patient may suffer, but they do not correspond cleanly to levels of severity. A traumatic amputation of the foot with only a small wound in the thigh—a Pattern A casualty—might be life-threatening if the thigh injury involves the femoral artery. Commonly, the patient who sustains a land-mine injury is in critical condition. Often a vital structure is directly damaged, or the wounds (including the traumatic amputations) are so extensive that the patient is imperiled by hemorrhagic shock. In such an emergency situation, identifying a pattern of injury with a specific category of land mine can provide useful information to the surgical team (and also to any personnel involved in clearing the area of mines).

For several reasons, surgery on mine injuries is a complex and challenging discipline. Often the medical team has to work in hazardous areas where the fighting is ongoing. The available facilities are typically primitive. Scarce resources, the lack of proper hygiene, and sometimes even the absence of water and electricity make the job extremely difficult. Furthermore, the surgeons must be trained to deal with all kinds of emergencies: vascular, thoracic, abdominal, orthopedic and so on. Fragments of bone, for example, can become "secondary bullets." I once had to reconstruct the axillary artery in the shoulder of a patient that had been completely severed by a piece of bone from the patient's traumatically amputated foot.

From the technical point of view, the keystone operation is the debridement, or surgical cleansing, of the wound. When a blast mine goes off, stones, mud, grass and even pieces of the patient's clothes or shoes can be pushed deep into the tissues by the ascending explosion. The removal of all foreign

bodies and, even more important, the excision of all dead, dying or weakened tissue from the lesions are of paramount importance in preventing life-threatening postsurgical infections.

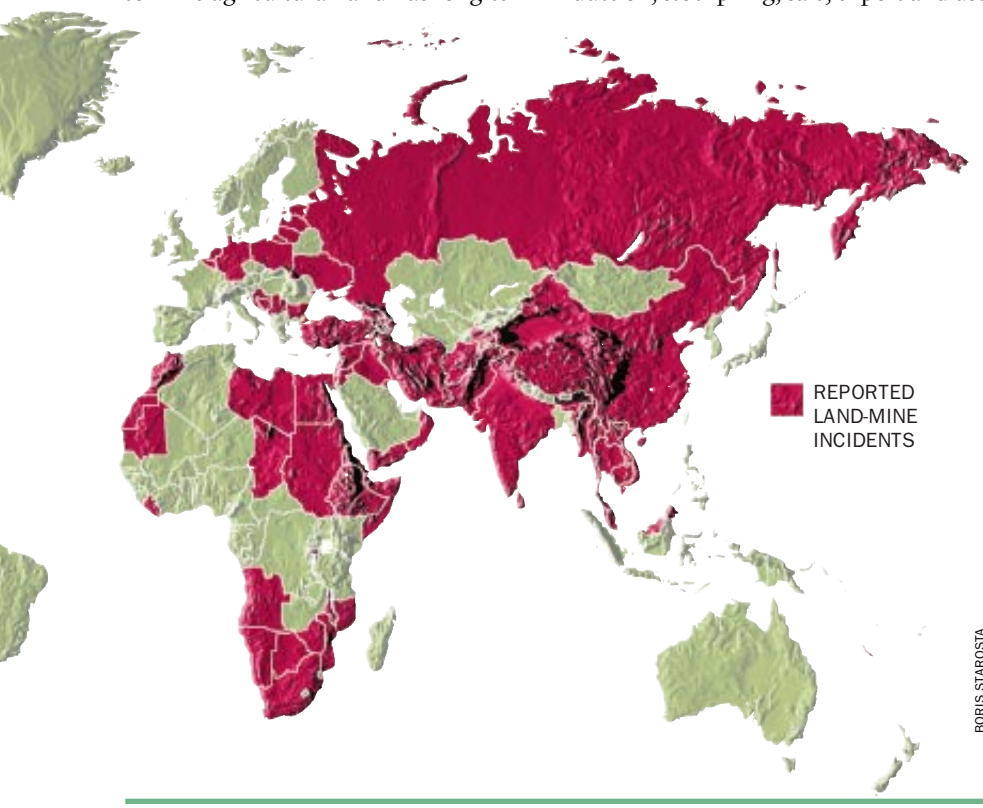
A Deadly Legacy

Most patients who recover from land-mine accidents never truly regain their ability to take an active part in family life or society. Rehabilitating these patients under the best circumstances is often immensely problematic. And many victims live in developing countries, where poor living conditions make it even more difficult to overcome physical and psychological handicaps. Moreover, beyond the tremendous human cost that mines claim in lives and suffering, they also impose a severe social and economic burden on entire societies and nations. An army's decision to mine agricultural land has long-term devastating effects on farming communities, who rely on the land for survival. The presence of land mines also deters many wartime refugees from returning to their homes. The displaced people tend to become permanent refugees who overload the economic and social structures of the regions to which they flee.

In 1980 the U.N. adopted what is commonly known as the Convention on Inhumane Weapons. Although this convention and its protocols were supposed to guarantee protection to civilians, events during the rest of that decade demonstrated all too clearly the inadequacy of those regulations. In recent years, more than 400 humanitarian organizations in nearly 30 countries have launched a campaign to raise the international community's awareness of the devastating effects of antipersonnel mines. They have urged the U.N. and national governments to ban the production, stockpiling, sale, export and use of mines. The campaign has had significant results, and several countries have decided to stop the production or export of land mines, at least temporarily.

In September 1995 a U.N. review conference of the convention gathered in Vienna. International diplomacy focused the discussion on various technical and military aspects of land-mine use. From a humanitarian point of view, the Vienna conference was a fiasco. A total ban on these indiscriminate weapons—the only real solution—was not even taken into consideration. Moreover, it seems unlikely that a ban will be proposed in the session of the conference that is currently under way in Geneva. Certainly most countries and citizens of the world now realize the horrors of nuclear bombs. It is astonishing that those same countries do not object to the daily massacre of innocent civilians by way of antipersonnel mines.

Still, the world in the next century faces a terrible legacy. Many of the mines dropped decades ago may have effective lifetimes of centuries. Indeed, even if no more mines are laid in the future, those that are already in place will cause colossal tragedy and will challenge relief organizations of tomorrow. We may hope that the international community will soon make the issue of land mines a top priority and provide the funds needed to carry on essential humanitarian activities. Emergency surgical assistance and the subsequent rehabilitation of victims, as well as operations to clear mines and to educate people about their dangers, will in fact remain the only options for easing the suffering of hundreds of thousands of people. Even for a veteran war surgeon, looking at the body of a child torn to pieces by these inhumane weapons is startling and upsetting. This carnage has nothing to do with military strategy. It is a deliberate choice to inflict monstruous pain and mutilation. It is a crime against humanity. SA



BORIS STAROSTA

The Author

GINO STRADA received his medical degree from the University of Milan. In 1988 he joined the International Committee of the Red Cross mission in Pakistan and has worked as a war surgeon ever since. He has treated land-mine victims in Afghanistan, Cambodia, Peru, Bosnia, Djibouti, Somalia, Ethiopia, Rwanda and northern Iraq. In 1994 Strada founded EMERGENCY, a humanitarian association serving civilian war victims. For more information, contact EMERGENCY, via Bagutta 12, 20121 Milan, Italy; telephone: 39-2-7600-1104; fax: 39-2-7600-3719.

Further Reading

HIDDEN KILLERS: THE GLOBAL PROBLEM WITH UNCLEARED LANDMINES: A REPORT ON INTERNATIONAL DEMINING. Political-Military Affairs Bureau Office of International Security Operations. U.S. Department of State, 1993.

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The Kuiper Belt

Rather than ending abruptly at the orbit of Pluto, the outer solar system contains an extended belt of small bodies

by Jane X. Luu and David C. Jewitt

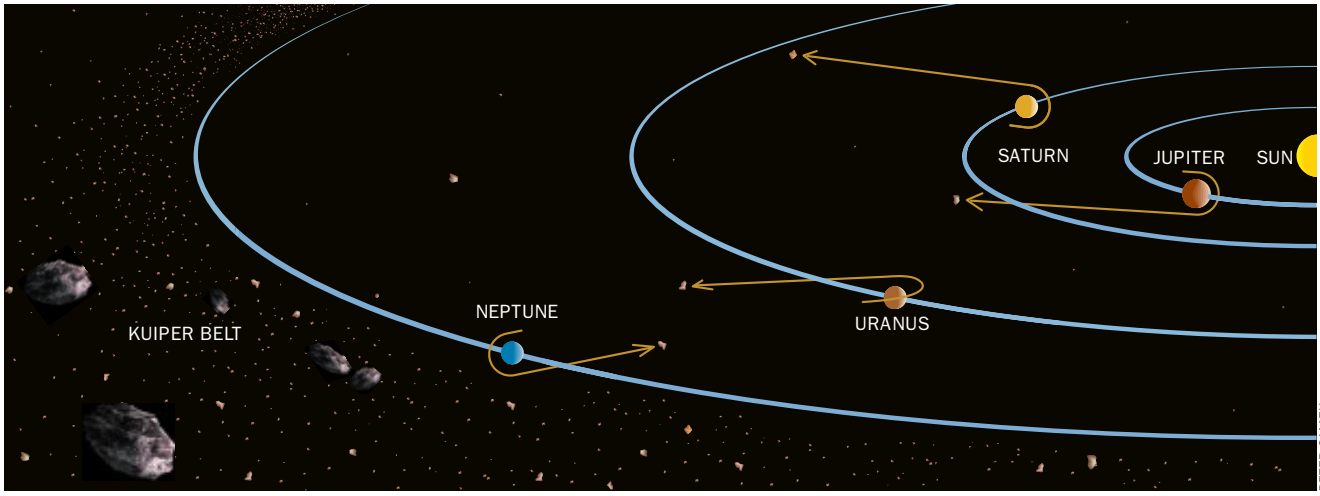
After the discovery of Pluto in 1930, many astronomers became intrigued by the possibility of finding a 10th planet circling the sun. Cloaked by the vast distances of interplanetary space, the mysterious "Planet X" might have remained hidden from even the best telescopic sight, or so these scientists reasoned. Yet decades passed without detection, and most researchers began to accept that the solar system was restricted to the familiar set of nine planets.

But many scientists began seriously rethinking their notions of the solar system in 1992, when we identified a small celestial body—just a few hundred kilometers across—sited farther from the sun than any of the known planets. Since that time, we have identified nearly three dozen such objects circling through the outer solar system. A host of similar objects is likely to be traveling with them, making up the so-called Kuiper belt, a region named for Dutch-American astronomer Gerard P. Kuiper, who, in 1951, championed the idea that the solar system contains this distant family.

What led Kuiper, nearly half a century ago, to believe the disk of the solar system was populated with numerous small bodies orbiting at great distances from the sun?

OUTER EXTREMITIES of the solar system preserve primordial material remaining from the time the planets first formed. During that early era, Pluto (*foreground*) may have captured its satellite, Charon (*right*), while casting a third body (*top*) away into space. At the time, the region would have been thick with dust and rife with growing Kuiper belt objects.

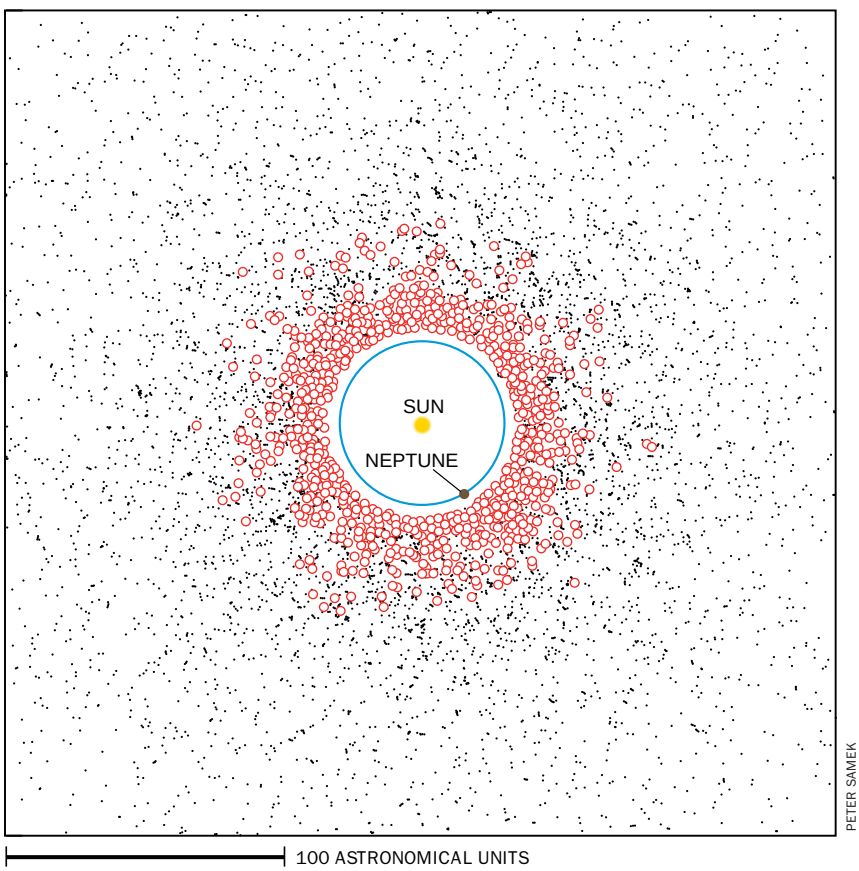
ALFRED T. KAMAJIAN



GRAVITY OF THE PLANETS acted during the early stages of the solar system to sweep away small bodies within the orbit of Neptune. Some of these objects plummeted toward the sun; others sped outward toward the distant Oort cloud (*not shown*).

His conviction grew from a fundamental knowledge of the behavior of certain comets—masses of ice and rock that on a regular schedule plunge from the outer reaches of the solar system inward toward the sun. Many of these comparatively small objects periodically provide spectacular appearances when the sun's rays warm them enough to drive dust and gas off their surfaces into luminous halos (creating large "comae") and elongate tails.

Astronomers have long realized that such active comets must be relatively new members of the inner solar system. A body such as Halley's comet, which swings into view every 76 years, loses about one ten-thousandth of its mass on each visit near the sun. That comet will survive for only about 10,000 orbits, lasting perhaps half a million years in all. Such comets were created during the formation of the solar system 4.5 billion years ago and should have completely lost their volatile constituents by now, leaving behind either inactive, rocky nuclei or diffuse streams of dust. Why then are so many comets still around to dazzle onlookers with their displays?



COUNTLESS OBJECTS in the Kuiper belt may orbit far from the sun, but not all of those bodies can be seen from Earth. Objects (*circles*) that could reasonably be detected with the telescope on Mauna Kea in Hawaii typically lie near the inner border of the belt, as seen in this computer simulation of the distribution of distant matter.

Guiding Lights

The comets that are currently active formed in the earliest days of the solar system, but they have since been stored in an inactive state—most of them preserved within a celestial deep freeze called the Oort cloud. The Dutch astronomer Jan H. Oort proposed the existence of this sphere of cometary material in 1950. He believed that this cloud had a diameter of about 100,000 astronomical units (AU—a distance defined as the average separation between Earth and the sun, about 150 million kilometers) and that it contained several hundred billion individual comets. In Oort's conception, the random gravitational jostling of stars passing nearby knocks some of the outer comets in the cloud from their stable orbits and gradually deflects their paths to dip toward the sun.

For most of the past half a century, Oort's hypothesis neatly explained the size and orientation of the trajectories that the so-called long-period comets

(those that take more than 200 years to circle the sun) follow. Astronomers find that those bodies fall into the planetary region from random directions—as would be expected for comets originating in a spherical repository like the Oort cloud. In contrast, Oort's hypothesis could not explain short-period comets that normally occupy smaller orbits tilted only slightly from the orbital plane of Earth—a plane that astronomers call the ecliptic.

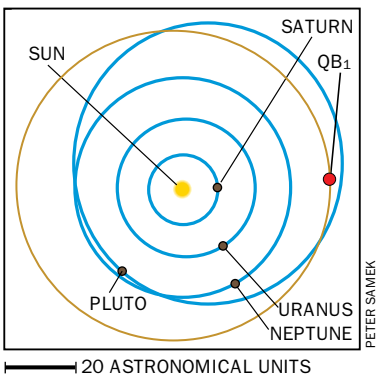
Most astronomers believed that the short-period comets originally traveled in immense, randomly oriented orbits (as the long-period comets do today) but that they were diverted by the gravity of the planets—primarily Jupiter—into their current orbital configuration. Yet not all scientists subscribed to this idea. As early as 1949, Kenneth Essex Edgeworth, an Irish gentleman-scientist (who was not affiliated with any research institution) wrote a scholarly article suggesting that there could be a flat ring of comets in the outer solar system. In his 1951 paper, Kuiper also discussed such a belt of comets, but he did not refer to Edgeworth's previous work.

Kuiper and others reasoned that the disk of the solar system should not end abruptly at Neptune or Pluto (which vie with each other for the distinction of being the planet most distant from the sun). He envisioned instead a belt beyond Neptune and Pluto consisting of residual material left over from the formation of the planets. The density of matter in this outer region would be so low that large planets could not have accreted there, but smaller objects, perhaps of asteroidal dimensions, might exist. Because these scattered remnants of primordial material were so far from the sun, they would maintain low surface temperatures. It thus seemed likely that these distant objects would be composed of water ice and various frozen gases—making them quite similar (if not identical) to the nuclei of comets.

Kuiper's hypothesis languished until the 1970s, when Paul C. Joss of the Massachusetts Institute of Technology began to question whether Jupiter's gravity could in fact efficiently transform long-period comets into short-period ones. He noted that the probability of gravitational capture was so small that the large number of short-period comets that now exists simply did not make sense. Other researchers were, however, unable to confirm this result, and the Oort cloud remained the accepted source of the comets, long and short period alike.

But Joss had sown a seed of doubt, and eventually other astronomers started to question the accepted view. In 1980 Julio A. Fernández (then at the Max Planck Institute for Aeronomy in Katlenburg-Lindau) had, for example, done calculations that suggested that short-period comets could come from Kuiper's proposed trans-Neptunian source. In 1988 Martin J. Duncan of the University of Toronto, Thomas Quinn and Scott D. Tremaine (both at the Canadian Institute for Theoretical Astrophysics) used computer simulations to investigate how the giant gaseous planets could capture comets. Like Joss, they found that the process worked rather poorly, raising doubts about the veracity of this well-established concept for the origin of short-period comets. Indeed, their studies sounded a new alarm because they noted that the few comets that could be drawn from the Oort cloud by the gravitational tug of the major planets should be traveling in a spherical swarm, whereas the orbits of the short-period comets tend to lie in planes close to the ecliptic.

Duncan, Quinn and Tremaine reasoned that short-period comets must have been captured from original orbits



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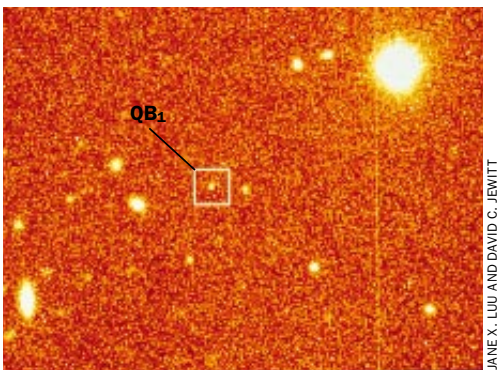
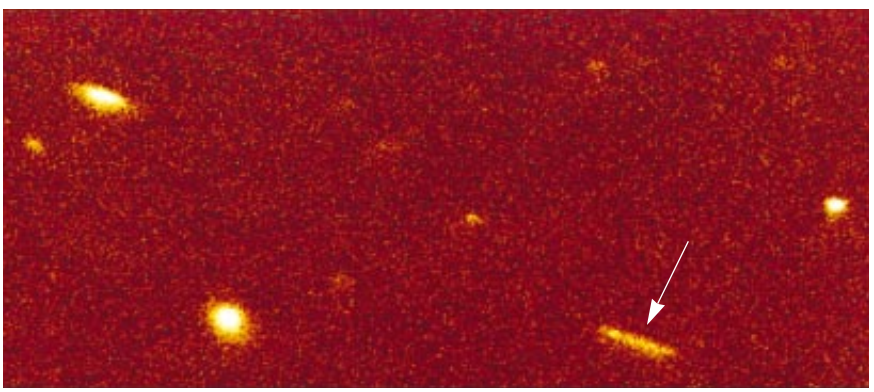
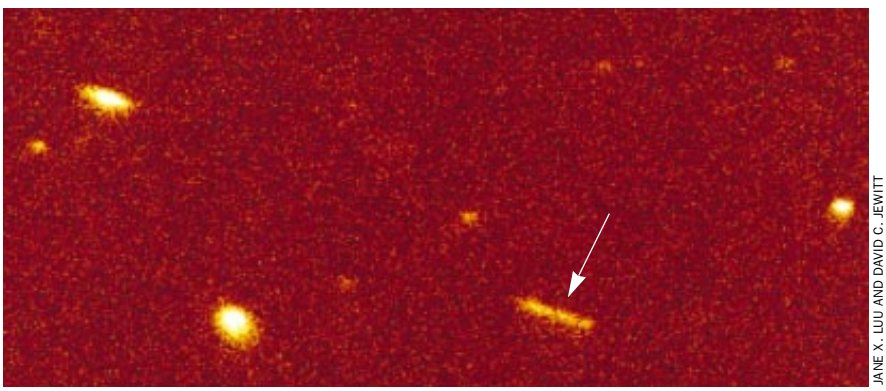


JANE X. LUU AND DAVID C. JEWITT





JANE X. LUU AND DAVID C. JEWITT

SEQUENTIAL CCD EXPOSURES from 1992 revealed Kuiper belt object QB_1 clearly against the background of fixed stars (*middle* and *bottom*). This pair of images covers only a small part of the complete CCD frame (*top right*) that had to be analyzed before the authors could identify QB_1 (*arrows*) and determine its orbit (*top left*).

that were canted only slightly from the ecliptic, perhaps from a flattened belt of comets in the outer solar system. But their so-called Kuiper belt hypothesis was not beyond question. In order to make their calculations tractable, they had exaggerated the masses of the outer planets as much as 40 times (thereby increasing the amount of gravitational attraction and speeding up the orbital evolution they desired to examine). Other astrophysicists wondered whether this computational sleight of hand might have led to an incorrect conclusion.

Why Not Just Look?

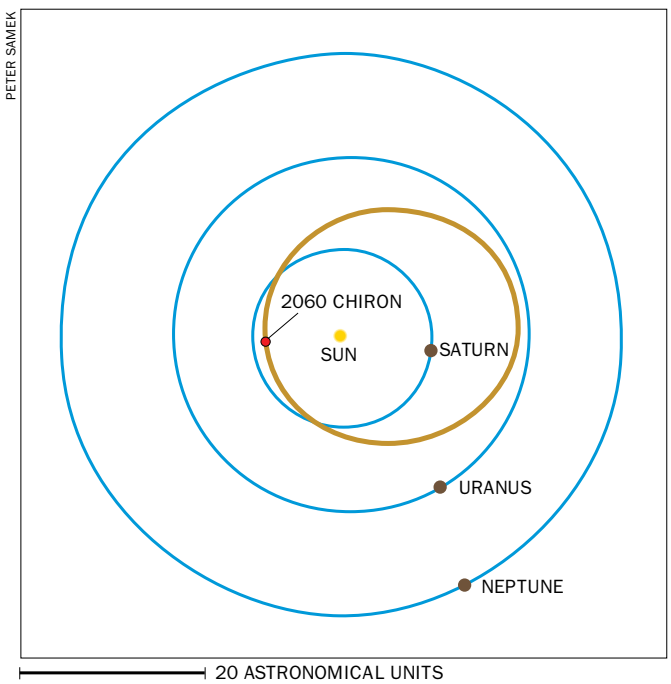
Even before Duncan, Quinn and Tremaine published their work, we wondered whether the outer solar system was truly empty or instead full of small, unseen bodies. In 1987 we began a telescopic survey intended to address exactly that question. Our plan was to look for any objects that might be present in the outer solar system using the meager amount of sunlight that would be reflected back from such great distances. Although our initial efforts employed photographic plates, we soon decided that a more promising approach was to use an electronic detector (a charge-coupled device, or CCD) attached to one of the larger telescopes.

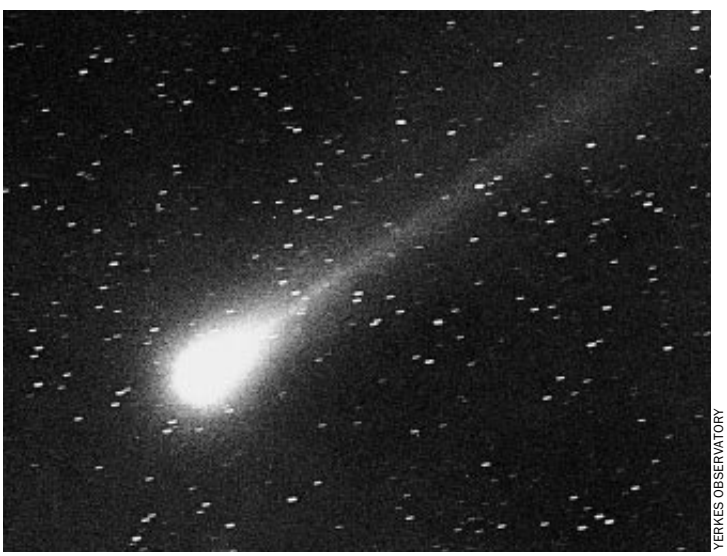
We conducted the bulk of our survey using the University of Hawaii's 2.2-meter telescope on Mauna Kea. Our strategy was to use a CCD array with this instrument to take four sequential, 15-minute exposures of a particular segment of the sky. We then enlisted a computer to display the images in the sequence in quick succession—a process astronomers call "blinking." An object that shifts slightly in the image against the background of stars (which appear fixed) will reveal itself as a member of the solar system.

For five years, we continued the search with only negative results. But the technology available to us was improving so rapidly that it was easy to maintain enthusiasm (if not funds) in the continuing hunt for our elusive quarry. On August 30, 1992, we were taking the third of a four-exposure sequence while blinking the first two images on a computer. We noticed that the position of one faint "star" appeared to move slightly between the successive frames. We both fell silent. The motion was quite subtle, but it seemed definite. When we compared the first two images with the third, we realized that we had indeed found something out of the ordinary. Its slow motion across the sky indicated that the newly discovered object could be traveling beyond even the outer reaches of Pluto's distant orbit. Still, we were suspicious that the mysterious object might be a near-Earth asteroid moving in parallel with Earth (which might also cause a slow apparent motion). But further measurements ruled out that possibility.

We observed the curious body again on the next two nights and obtained accurate measurements of its position, brightness and color. We then communicated these data to Brian G. Marsden, director of the International Astronomical Union's Central Bureau of Astronomical Telegrams at the Smithsonian Astrophysical Observatory in Cambridge, Mass. His calculations indicated that the object we had discovered was indeed orbiting the sun at a vast distance (40 AU)—only slightly less remote than we had first supposed. He assigned the newly discovered body a formal, if somewhat drab, name based on the date of discovery: he christened it "1992 QB_1." (We preferred to call it "Smiley," after John Le Carré's fictional spy, but that name did not take hold within the conservative astronomical community.)

Our observations showed that QB_1 reflects light that is quite rich in red hues compared with the sunlight that illuminates it. This odd coloring matched only one other object in the solar system—a peculiar asteroid or comet called 5145 Pholus. Planetary astronomers attribute the red color of 5145 Pholus to the presence of dark, carbon-rich material on its surface. The similarity between QB_1 and 5145 Pholus thus heightened our excitement during the first days after the discovery. Perhaps the object we had just located was coated by some kind of red material abundant in organic compounds. How big was this ruddy new world? From our first series of measurements, we estimated that QB_1 was be-





2060 CHIRON may have escaped from the Kuiper belt into its current planet-crossing orbit (*left*). Although quite faint, the subtle glow surrounding 2060 Chiron (*far right*) marks this object as a celestial cousin to other "active" bodies, such as Comet Peltier (*above*).

tween 200 and 250 kilometers across—about 15 times the size of the nucleus of Halley's comet.

Some astronomers initially doubted whether our discovery of QB_1 truly signified the existence of a population of objects in the outer solar system, as Kuiper and others had hypothesized. But such questioning began to fade when we found a second body in March 1993. This object is as far from the sun as QB_1 but is located on the opposite side of the solar system. During the past three years, several other research groups have joined the effort, and a steady stream of discoveries has ensued. The current count of trans-Neptunian, Kuiper belt objects is 32.

The known members of the Kuiper belt share a number of characteristics. They are, for example, all located beyond the orbit of Neptune, suggesting that the inner edge of the belt may be defined by this planet. All these newly found celestial bodies travel in orbits that are only slightly tilted from the ecliptic—an observation consistent with the existence of a flat belt of comets. Each of the Kuiper belt objects is millions of times fainter than can be seen with the naked eye. The 32 objects range in diameter from 100 to 400 kilometers, making them considerably smaller than both Pluto (which is about 2,300 kilometers wide) and its satellite, Charon, (which measures about 1,100 kilometers across).

The current sampling is still quite modest, but the number of new solar system bodies found so far is sufficient to establish beyond doubt the existence of the Kuiper belt. It is also clear that the belt's total population must be substantial. We estimate that the Kuiper belt contains at least 35,000 objects larger than 100 kilometers in diameter. Hence, the Kuiper belt probably has a total mass that is hundreds of times larger than the well-known asteroid belt between the orbits of Mars and Jupiter.

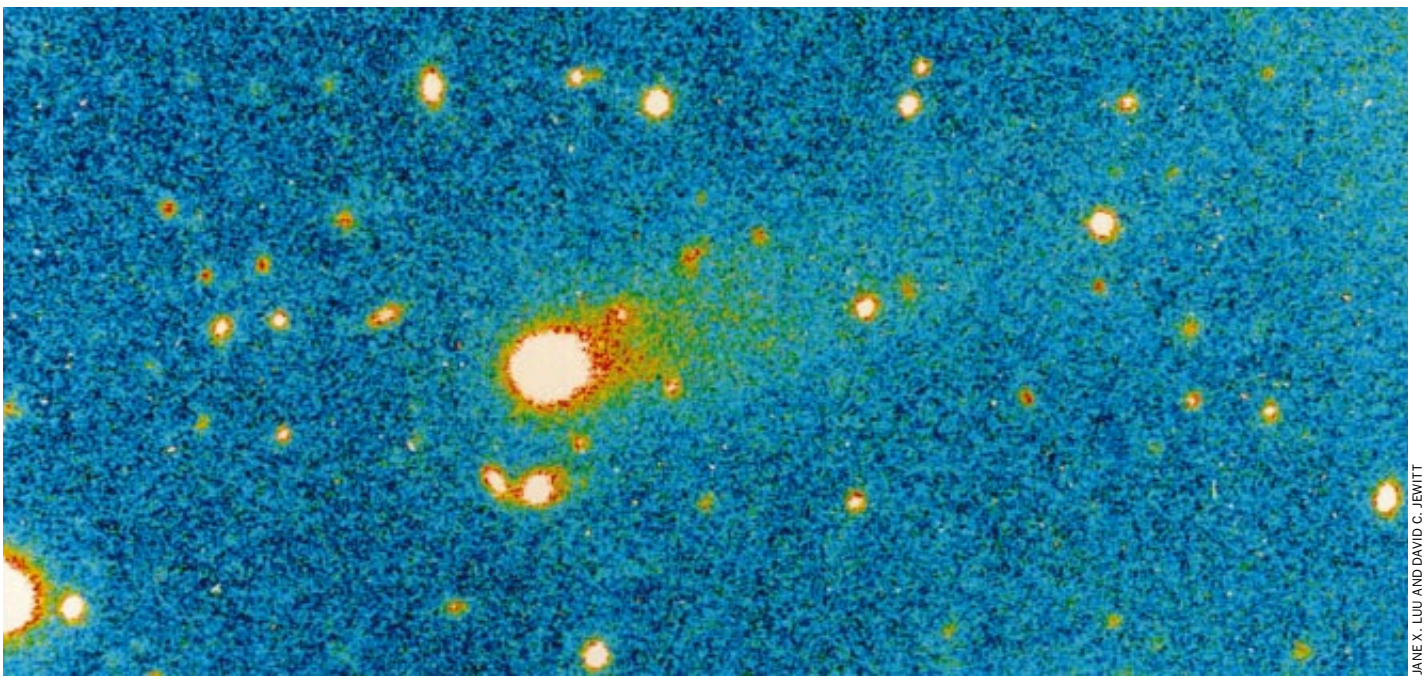
Cold Storage for Comets

The Kuiper belt may be rich in material, but can it in fact serve as the supply source for the rapidly consumed short-period comets? Matthew J. Holman and Jack L. Wisdom, both then at M.I.T., addressed this problem using computer simulations. They showed that within a span of 100,000 years the gravitational influence of the giant gaseous planets (Jupiter, Saturn, Uranus and Neptune) ejects comets orbiting in their vicinity, sending them out to the farthest reaches of the solar system. But a substantial percentage of trans-Neptunian comets can escape this fate and remain in the belt even after 4.5 billion years. Hence, Kuiper belt objects located more than 40 AU from the sun are likely to have held in stable orbits since the formation of the solar system.

Astronomers also believe there has been sufficient mass in the Kuiper belt to supply all the short-period comets that have ever been formed. So the Kuiper belt seems to be a good candidate for a cometary storehouse. And the mechanics of the transfer out of storage is now well understood. Computer simulations have shown that Neptune's gravity slowly erodes the inner edge of the Kuiper belt (the region within 40 AU of the sun), launching objects from that zone into the inner solar system. Ultimately, many of these small bodies slowly burn up as comets. Some—such as Comet Shoemaker-Levy 9, which collided with Jupiter in July 1994—may end their lives suddenly by striking a planet (or perhaps the sun). Others will be caught in a gravitational slingshot that ejects them into the far reaches of interstellar space.

If the Kuiper belt is the source of short-period comets, another obvious question emerges: Are any comets now on their way from the Kuiper belt into the inner solar system? The answer may lie in the Centaurs, a group of objects that includes the extremely red 5145 Pholus. Centaurs travel in huge planet-crossing orbits that are fundamentally unstable. They can remain among the giant planets for only a few million years before gravitational interactions either send them out of the solar system or transfer them into tighter orbits.

With orbital lifetimes that are far shorter than the age of the solar system, the Centaurs could not have formed where they currently are found. Yet the nature of their orbits makes it practical-



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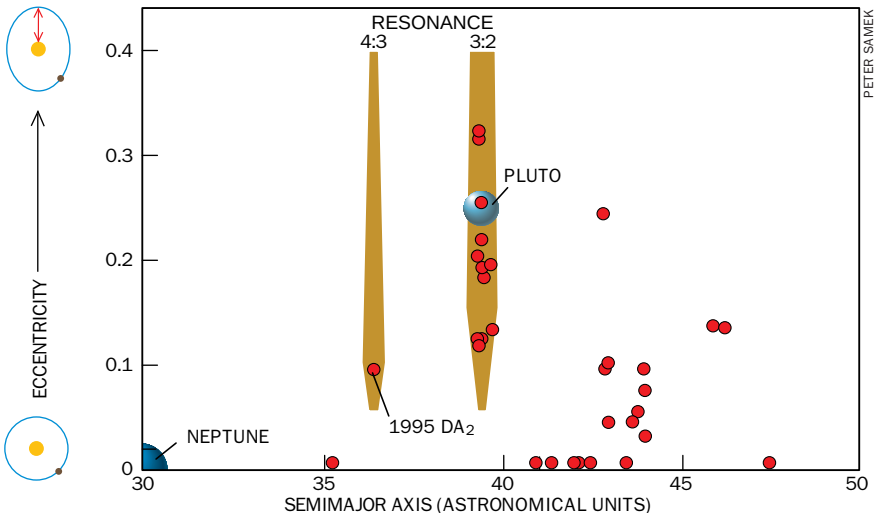

MEAN-MOTION RESONANCE governs the size and shape of the orbits of many Kuiper belt objects. Orbits are described by eccentricity (deviation from circularity) and semimajor axis (*red arrow*). Like Pluto, about half the known Kuiper belt bodies (*red points*) circle the sun twice while Neptune completes three orbits—a 3:2 resonance. The object 1995 DA_2 orbits in one of the other resonances. Renu Malhotra of the Lunar and Planetary Institute in Houston suggests that this pattern reflects the early evolution of the solar system, when many small bodies were ejected and the major planets migrated away from the sun. During these outward movements, Neptune could have drawn Pluto and a variety of smaller bodies into the resonant orbits that are now observed.

ly impossible to deduce their place of origin with certainty. Nevertheless, the nearest (and most likely) reservoir is the Kuiper belt. The Centaurs may thus be "transition comets," former Kuiper belt objects heading toward short but showy lives within the inner solar system. The strongest evidence supporting this hypothesis comes from one particular Centaur—2060 Chiron. Although its discoverers first thought it was just an unusual asteroid, 2060 Chiron is now firmly established as an active comet with a weak but persistent coma.

As astronomers continue to study the Kuiper belt, some have started to wonder whether this reservoir might have yielded more than just comets. Is it coincidence that Pluto, its satellite, Charon, and the Neptunian satellite Triton lie in the vicinity of the Kuiper belt? This question stems from the realization that Pluto, Charon and Triton share similarities in their own basic properties but differ drastically from their neighbors.

A Peculiar Trio

The densities of both Pluto and Triton, for instance, are much higher than any of the giant gaseous planets of the outer solar system. The orbital motions of these bodies are also quite strange. Triton revolves around Neptune in the "retrograde" direction—opposite to the orbital direction of all planets and most satellites. Pluto's orbit slants highly from the ecliptic, and it is so far from circular that it actually crosses the orbit of Neptune. Pluto is, however, protected from possible collision with the larger planet by a special orbital relationship known as a 3:2 mean-motion resonance. Simply put, for every three orbits of Neptune around the sun, Pluto completes two.

The pieces of the celestial puzzle may fit together if one postulates that Pluto, Charon and Triton are the last survivors of a once much larger set of similarly sized objects. S. Alan Stern of the Southwest Research Institute in Boulder first suggested this idea in 1991. These three bodies may have been swept up by Neptune, which captured Triton and locked Pluto—perhaps with Charon in tow—into its present orbital resonance.

Interestingly, orbital resonances appear to influence the position of many Kuiper belt objects as well. Up to one half of the newly discovered bodies have the same 3:2 mean-motion resonance as Pluto and, like that planet, may orbit serenely for billions of years. (The resonance prevents Neptune from approaching too closely and disturbing the orbit of the smaller body.) We have dubbed such Kuiper belt objects Plutinos—"little Plutos." Judging from the small part of the sky we have examined, we estimate that there must be several thousand Plutinos larger than 100 kilometers across.

The recent discoveries of objects in the Kuiper belt provide a new perspective on the outer solar system. Pluto now appears special only because it is larger than any other member of the Kuiper belt. One might even question whether Pluto deserves the status of a full-fledged planet. Strangely, a line of research that began with attempts to find a 10th planet may, in a sense, have succeeded in reducing the final count to eight. This irony, along with the many intriguing observations we have made of Kuiper belt objects, reminds us that our solar system contains countless surprises. SA

The Authors

JANE X. LUU and DAVID C. JEWITT came to study astronomy in different ways. For Jewitt, astronomy was a passion he developed as a youngster in England. Luu's childhood years were filled with more practical concerns: as a refugee from Vietnam, she had to learn to speak English and adjust to life in southern California. She became enamored of astronomy almost by accident, during a summer spent at the Jet Propulsion Laboratory in Pasadena. Luu and Jewitt began their collaborative work in 1986 at the Massachusetts Institute of Technology. Jewitt was a professor there when Luu became a graduate student. Jewitt moved to the University of Hawaii in 1988. It was during Luu's postdoctoral fellowship at the Harvard-Smithsonian Center for Astrophysics that Luu and Jewitt discovered the first Kuiper belt object. In 1994 Luu joined the faculty of Harvard University.

Further Reading

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Uncovering New Clues to Cancer Risk

A growing discipline called molecular epidemiology is attempting to find early biological signposts for heightened risk of cancer. The research should enhance prevention of the disease

by Frederica P. Perera

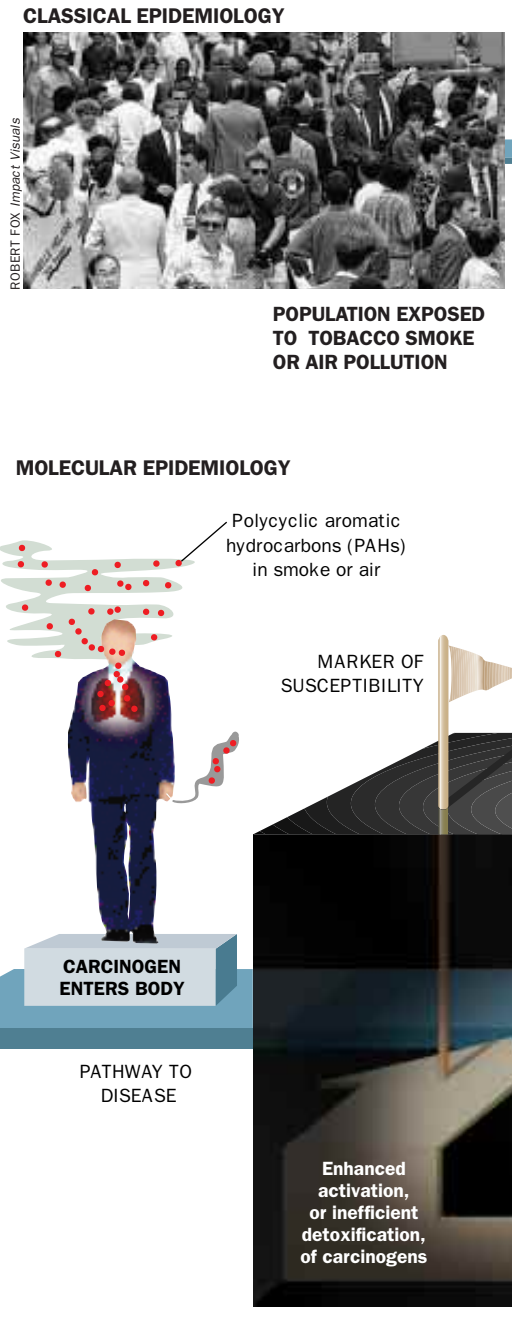
Imagine that well before tumors arose in people, a laboratory could detect biological clues, or biomarkers, indicating that tissues had been assaulted by specific cancer-causing agents or, worse, were beginning to undergo precancerous changes. And suppose it were possible to identify biomarkers of special vulnerability to the effects of carcinogens in the environment. (These agents can include tobacco smoke, radiation, certain microbes, and natural and synthetic chemicals in our food, water and air.) Discovery of such markers could help affected individuals to prevent cancer, in part because they would know which carcinogens they most needed to avoid. Use of markers to demonstrate heightened risk in certain groups, such as children, might also spur public health officials to take new measures to reduce exposures that are beyond an individual's control.

With such aims in mind, researchers in a burgeoning discipline called molecular epidemiology have begun looking for biomarkers that can signal enhanced risk for cancer. The field is still young. Scientists cannot yet screen for a panel of markers in an individual and then offer a meaningful assessment of the person's likelihood of acquiring cancer. Nevertheless, such testing should one day be feasible. (The delay is not all bad. People who undergo screening will need to be carefully protected from discrimination by insurance companies and employers, but the needed safeguards are not yet in place.)

In the meantime, the available data are proving to be informative in other ways. In particular, they are lending support to the view that current methods for determining "acceptable" levels of exposure to environmental carcinogens may seriously underestimate the danger faced by some segments of society. Biomarkers may also soon be useful to researchers interested in developing new approaches to preventing cancer. Instead of waiting years or decades to learn whether exposure to some chemical increases cancer rates in humans or whether an experimental intervention reduces incidence, investigators may be able to attain relatively quick answers by monitoring selected signs of precancerous damage in the body.

Epidemiology with a Difference

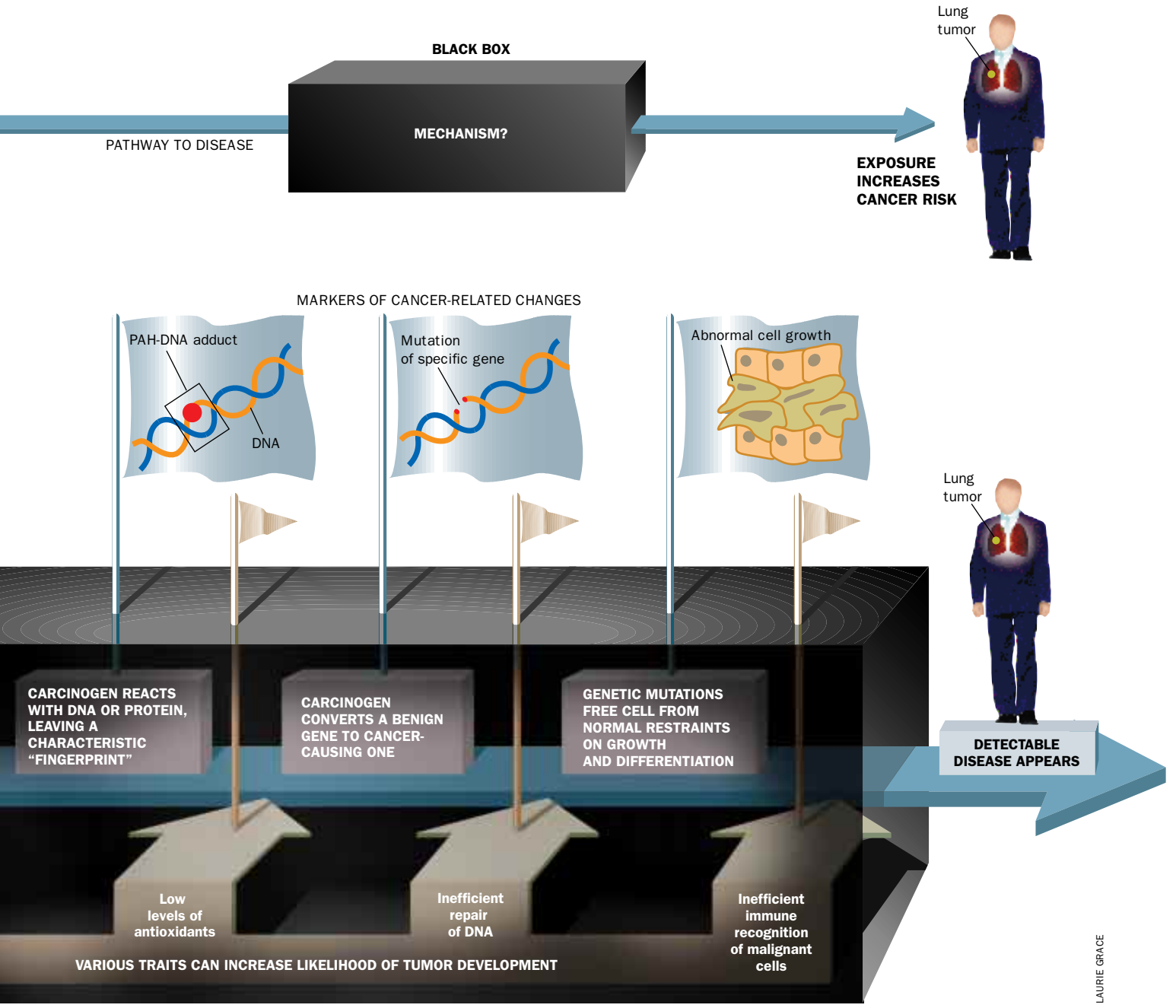
Molecular epidemiology resembles conventional epidemiology but differs in important ways as well. It combines the tools of standard epidemiology (such as case histories, questionnaires, and monitoring of exposure) with the sensitive laboratory techniques of molecular biology. The conventional approach by itself has made major contributions to the understanding of cancer risk. For instance, traditional epidemiology has shown that high-fat diets can play a part in colon cancer, has linked benzene to leukemia and has established that cigarette smoking profoundly increases the chance of acquiring lung cancer. It has even quantified risks: one in 10 heavy smokers is likely to get lung cancer. But such research reveals nothing about the precise continuum of events leading from exposure to overt disease. Molecular epidemiology aims to uncover critical precancerous events taking place inside the body and to identify measurable biologic flags signaling their occurrence.



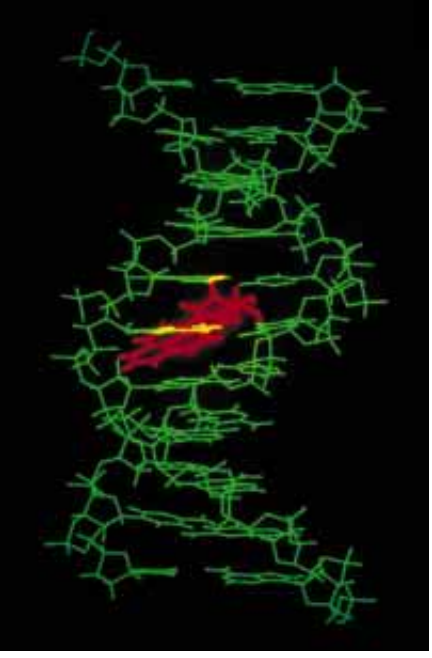
This work is informed by, and is contributing to, a growing understanding of how cancer develops. It now seems clear that malignancies generally arise through the serial accumulation of damage to genes in a single cell. When the collected defects finally free the cell from normal restraints on growth, tumors develop and, all too often, invade nearby tissue and establish lethal satellites (metastases) elsewhere in the body.

The discovery that genetic damage lies at the root of cancer does not mean most malignancies stem from the inheritance of seriously flawed genes. In fact, such inheritance probably explains no more than 5 percent of all cancers in the U.S. The genetic disruptions that transform a normal cell into a malignant one typically arise in the course of living—via complex interactions between carcinogens and the body's systems for contending with them. (The offending carcinogens include those in the environment and those, called oxidants, that our bodies generate during normal metabolism.) Indeed, whether any agent

MOLECULAR EPIDEMIOLOGY supplies information that classical epidemiology cannot, as is illustrated here by the example of lung cancer. Classical epidemiology (*top*) identifies factors that increase risk for cancer (such as inhalation of polluted air or tobacco smoke), but it does not address how the disease arises. Molecular epidemiology (*bottom*) looks into the black box to uncover important steps leading from carcinogenic exposures to disease. It also identifies biological signs, or biomarkers, that may indicate increased risk. Some markers (*rectangular flags*) reflect exposure or advancement along the pathway to cancer. Others reflect innate or acquired susceptibility to the effects of carcinogens (*small banners*). By detecting such markers, researchers may one day be able to pinpoint groups or individuals who most need preventive interventions.

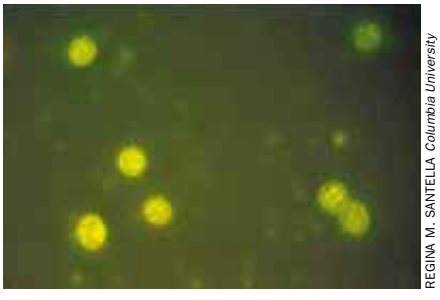


LAURIE GRACE



A. M. JEFFREY AND I. B. WEINSTEIN ET AL. *Columbia University*

FOUNDRY WORKERS (*photograph*), smokers and people who live in highly industrial regions often breathe in high levels of combustion products, including carcinogens known as polycyclic aromatic hydrocarbons (PAHs). "Fingerprints" of this exposure can be detected in lung and blood cells, in the form of PAH-DNA adducts: DNA-damaging complexes arising when such hydrocarbons (*red in computer-generated image at left*) bind to DNA (*green*). Adducts in white blood cells of one exposed individual appear as green fluorescence in the micrograph at the right.



REGINA M. SANTELLA *Columbia University*

contributes to cancer depends not only on the extent of an individual's exposure but also on the effectiveness of the body's defensive responses—responses now known to vary from one individual to another, sometimes profoundly.

In the early 1980s my colleagues and I at Columbia University laid out the basic conceptual framework for molecular epidemiological investigations of cancer after we detected a new molecular marker indicating that a specific carcinogen had damaged DNA in human tissue. Simply put, molecular epidemiologists probe samples of human tissue for biologic markers that reflect exposure to a carcinogen, cancer-inducing damage to cells or tissue, or special vulnerability to carcinogens. Through a series of steps, these markers are "validated," tested to show that they indicate an increased risk for cancer well before clinical signs appear. Valid markers (those that pass many such tests) can then be measured in selected groups and can signal a need for intervention.

The steps by which we found a new marker and established its potential value as a warning of increased risk for lung cancer serve to exemplify the overall approach. In 1982, working with I. Bernard Weinstein of Columbia and Miriam C. Poirier of the National Cancer Institute, I noted that a well-known class of carcinogens—polycyclic aromatic hydrocarbons (PAHs)—left a unique "fingerprint" in human lung and blood cells. These hydrocarbons are among the approximately 400 chemicals that have been shown to be carcinogenic in studies of animals or humans; they are combustion products found mainly in tobacco smoke, polluted air, and barbecued, grilled or smoked foods. The fingerprint took the form of an adduct, a complex that results when a chemical attaches to a biological molecule, usually to DNA or a protein in a cell.

Intrigued by the presence of PAH-DNA adducts in blood—which would be easy to obtain for use in widespread screening—we set out to determine whether these fingerprints could serve as early markers of an increased propensity for lung cancer. My colleagues and I, including Regina M. Santella of Columbia and Kari Hemminki of the Karolinska Institute in Stockholm, demonstrated that people known to have been exposed to high levels of PAHs in tobacco smoke, in polluted air and at certain work sites displayed markedly higher levels of PAH-DNA adducts in their blood than did people whose exposure was lower.

These findings could not by themselves tell us whether the adducts signified a heightened likelihood that lung cancer would develop, but subsequent studies supported that idea. Subjects who harbored high levels of PAH-DNA complexes and related adducts in the blood also suffered greater than normal levels of genetic mutations and other chromosomal disturbances in blood cells. Because such changes are common in malignant cells, the results were consistent with the notion that increased quantities of the adducts could reflect added liability for cancer.

Further circumstantial evidence came from our finding that blood samples from patients with lung cancer contain markedly higher amounts of PAH-DNA adducts than do samples drawn from cancer-free individuals who have been exposed to similar doses of lung carcinogens. We are now analyzing stored blood samples from volunteers enrolled in a long-term study to determine whether PAH-DNA adducts and other markers are able to predict lung cancer years before diagnosis.

Markers of Exposure and Damage

A number of other biomarkers show promise for detecting heightened risk of cancer, including that of the liver and the bladder. For instance, it is well known that a natural substance called aflatoxin B1 (common in moldy corn

and peanuts) can play a part in liver cancer. Molecular epidemiological studies by John D. Groopman and his colleagues at Johns Hopkins University and elsewhere have established that this carcinogen, too, leaves fingerprints in the form of adducts on DNA. Furthermore, Chinese subjects with detectable aflatoxin B1-DNA complexes or aflatoxin derivatives in their urine proved three to four times more likely to fall ill with liver cancer than were people whose urine contained no such substances. If the subjects were also infected with the hepatitis B virus, another known carcinogen, they were 60 times more likely to acquire the cancer.

Like adducts, mutations in cancer-related genes can constitute biomarkers of incipient tumor formation, but these signposts reflect later occurrences in the chain of events that culminates in cancer. If a gene disrupted in many cancers is found to be damaged, the information may say little about the causative agent. But the precise type of mutation may well be revealing, as seems to be the case with the *p53* gene, one of the most frequently mutated in cancer. In its healthy state, *p53* is a tumor suppressor; it blocks the growth and division of cells harboring damaged genes. When the *p53* gene itself is mutated, disturbed cells are allowed to transmit potentially carcinogenic genetic derangements to their progeny.

Evidence compiled by Curtis C. Harris and his co-workers at the National Cancer Institute suggests that some patterns of mutation in *p53* reflect exposure to specific substances. Lung tumors in smokers commonly display a *p53* mutation that is characteristic of exposure to PAHs or to oxidants and occurs at many sites in the gene. In contrast, a single, "hot spot" mutation in *p53* appears in lung tumors of radon-exposed uranium miners. In geographical areas where aflatoxin B1 and hepatitis B virus yield high rates of liver cancer, *p53* mutations in liver tumors tend to congregate at yet another, single site on the gene.

Distinct *p53* mutations are also seen in a rare liver tumor (angiosarcoma) induced by occupational exposure to vinyl chloride, in colon cancer presumably caused by carcinogens in food, and in skin tumors that result from exposure to ultraviolet light. As is true of carcinogen-DNA adducts, mutational patterns do not conclusively reveal the identity of the agent that caused them. But when combined with other data, such patterns can help spotlight the carcinogens at fault and send a warning that exposure must be reduced.

Biomarkers of Susceptibility

Of course, an individual's own traits can also influence cancer development, and these characteristics undoubtedly help to explain why a given "dose" of carcinogen will cause only some people to get cancer, whereas others escape the disease. Consequently, in addition to searching for biomarkers of exposure and of early damage from carcinogenic agents, molecular epidemiologists try to uncover biomarkers of heightened inborn and acquired susceptibility.

Certain rare inherited mutations in genes seriously elevate a person's risk for cancer. A child normally inherits two versions, or alleles, of a gene—one from each parent. Occasionally, a youngster may be born with one defective allele of a tumor suppressor known as the *retinoblastoma* gene and subsequently sustain a mutation in the normal allele. This unlucky series of events almost single-handedly releases the brakes on cell growth and accounts for a sight-robbing childhood cancer called retinoblastoma (hence, the name of the gene). And wom-

Some Biomarkers under Study

	Tissue or Fluid Usually Examined	What Marker Indicates
Markers of exposure to or damage by a carcinogen		
Aflatoxin B1-DNA adduct*	Urine, liver	Genetic damage from aflatoxin in moldy peanuts or corn; increased risk for liver cancer
PAH-DNA adduct	Blood, lung, placenta	Genetic damage from polycyclic aromatic hydrocarbons (PAHs) in polluted air, in workplace or in cigarette smoke (being assessed as marker of lung cancer risk)
4-Aminobiphenyl-hemoglobin adduct	Blood	Active or passive exposure to cigarette smoke (being assessed as marker of increased risk for bladder cancer)
Thymine glycol (oxidized DNA base)	Urine	Genetic damage from oxidizing agents (being assessed as marker of increased risk for various cancers)
Mutation in *p53* tumor suppressor gene	Breast, liver, lung, among others	Increased risk for various cancers; pattern of mutation may help reveal carcinogen that caused the damage
Markers of inherited susceptibility to cancer		
Certain (fairly common) variations in *cytochrome p4501A1* gene or its activity	Blood	(Being assessed as marker of increased risk for lung cancer)
Absence of *glutathione-S-transferase M1* gene (absence very common; occurs in almost half of whites, 35 percent of African-Americans)	Blood	Increased risk for lung and bladder cancer
H-ras-VTR variant of *H-ras* gene (common in African-Americans)	Blood	Increased risk for breast and other cancers
Mutation in *BRCA1* gene (mutation rare; occurs in fewer than 1 percent of people)	Blood	Greatly increased risk for breast and ovarian cancer
Markers of acquired susceptibility to cancer		
Low blood levels of antioxidants or vitamins	Blood	(Being assessed as marker of increased risk for lung, esophageal, cervical, breast and other cancers)
Immunosuppression	Blood	Increased risk for various cancers

**An adduct is a complex formed when a carcinogen combines with DNA or a protein.*

MICHEL MAIOFISS *Gamma Liaison*

LISA BURNETT

en born with a mutated *breast cancer 1* (*BRCA1*) gene face a very high (greater than 70 percent) lifetime risk for breast cancer. Inheritance of the damaged gene can be devastating to the individual but probably accounts for only about 5 percent of all breast cancers.

Yet the inherited traits that most often predispose people to cancer act more subtly and indirectly, generally by modulating the body's reaction to carcinogens. (The characteristics may therefore be harmless if exposure to the offending agents is limited.) These traits may lead to rapid conversion of fairly quiescent carcinogens into active forms, or they may render a person relatively ineffective at detoxifying carcinogens or repairing the damage they do. Any of these attributes could facilitate cancer development by increasing adduct formation and subsequent genetic mutations. People differ in their responses to carcinogens because our gene pool contains multiple forms of certain genes that control these responses; the forms one person inherits may be more or less helpful than those another person receives.

Variations in genes that encode, or carry the instructions for manufacturing, a family of enzymes known as cytochrome p450 have been linked to a propensity for cancer. As a group, cytochrome p450 molecules generally render harmless a wide range of internally produced and foreign chemicals. Unfortunately, in the process they can sometimes generate intermediate products capable of damaging DNA and other cellular components. It is these "activated" intermediates that are the true carcinogens; left unprocessed, many so-called carcinogens would be innocuous.

One cytochrome p450 enzyme—CYP1A1—acts on polycyclic aromatic hydrocarbons. Molecular epidemiological studies suggest that smokers who harbor certain forms of the *CYP1A1* gene have an increased chance of ending up with lung cancer. Presumably the risk is elevated because the gene variants lead to enhanced activation of PAHs by CYP1A1 proteins. Small differences in genes coding for other cytochrome p450 enzymes appear to influence the extent to which additional carcinogens, such as aflatoxins, benzene and carbon tetrachloride, can contribute to tumors. These differences, too, might thus serve as markers of susceptibility to cancer.

Certain classes of detoxifying enzymes are more consistently beneficial than the cytochrome p450 family. Among these are the glutathione-*S*-transferases (GSTs), one variant of which, named GSTM1, efficiently detoxifies PAHs, ethylene oxide and styrene (all found in tobacco smoke, in certain workplaces and in urban air). Roughly half of all whites entirely lack the gene for GSTM1. This deficiency has been consistently associated with an increased tendency to bladder and lung cancer, and so the absence of this gene might reasonably be monitored as a biomarker of innate susceptibility.

Another enzyme, NAT2 (*N*-acetyltransferase), deactivates carcinogenic aromatic amines—chemicals present in air pollution, tobacco smoke and certain cooked foods. Various findings suggest that a slow-acting form of NAT2 contributes to bladder cancer. Patients with this cancer are more likely than their healthier counterparts to have the gene encoding the slow enzyme. And Paolo Vineis of the University of Turin in Italy and Steven R. Tannenbaum of the Massachusetts Institute of Technology have demonstrated that blood of individuals possessing the slow NAT2 enzyme contains elevated levels of protein bound by aromatic amines.

Beyond genetic signposts of vulnerability, scientists are searching for markers of acquired vulnerability to carcinogenic agents. The likelihood of tumor development is increased by impairment of the immune system and by such disorders as hormonal imbalances, hepatitis and chronic lung disease. Convincing evidence also indicates that a diet low in fruits and vegetables containing antioxidants and other nutrients (such as vitamins A, C and E) increases the probability of acquiring diverse cancers, including lung, esophageal, oral, laryngeal, cervical and breast. Through a variety of mechanisms, antioxidants can block oxygen radicals, PAHs and other chemicals from damaging DNA.

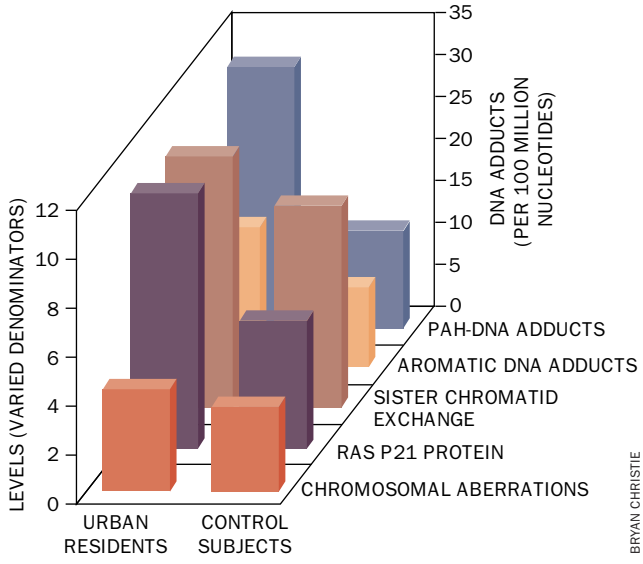
Molecular epidemiology promises to refine greatly estimates of cancer risk by considering variations in innate and acquired susceptibility within a popula-

Anatomy of a Molecular Epidemiological Study

Airborne carcinogens have long been suspected of contributing to the increased rates of lung cancer in heavily industrial regions. This suspicion has been bolstered by the finding that certain products of combustion in polluted air—such as polycyclic aromatic hydrocarbons (PAHs)—can cause lung cancer in test animals and in people exposed to high amounts of those substances in the workplace.

Yet the link between air pollution and cancer in the general population has been difficult to demonstrate, in part because residents in polluted environments, usually urban, tend to follow living patterns that differ from those of their counterparts in cleaner, more rural areas. Ruling out the importance of those differences has proved extremely difficult.

In 1990 my colleagues and I at Columbia University, Mieczyslaw Chorazy of the Institute of Oncology in Gliwice, Poland, and others carried out a molecular epidemiological study that attempted to trace the influence of polluted air on lung cancer. We showed for the first time that contaminants inhaled in extremely dirty air leave their "fingerprints" on DNA.



Markers in two Polish populations

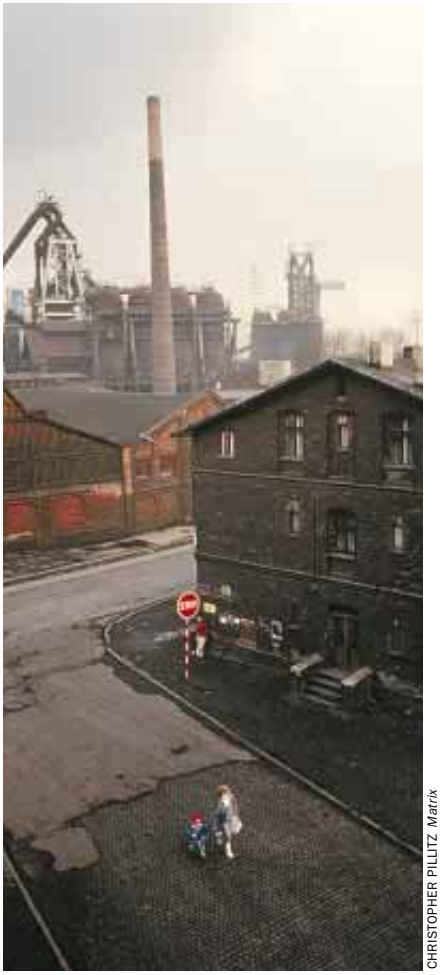
Moreover, elevations in these fingerprints accompany rises in irreversible damage to chromosomes. Because such damage enhances the probability that cancer will develop, these findings strongly suggested that severe air pollution could indeed help induce lung cancer.

To conduct this study, we examined two populations. One set of subjects

lived in Gliwice in the Silesia region, which is one of the most polluted areas of the world and has a high death rate from cancer. The other subjects lived in Biala Podlaska, a rural province in northeastern Poland, where the air is much cleaner and the cancer incidence is lower.

We measured the levels in the blood of biomarkers reflecting exposure to PAHs and other aromatic compounds. We also measured cellular changes more directly indicative of enhanced cancer risk. The markers of exposure, which also reflected the biologically effective dose of carcinogen, were PAH-DNA and related aromatic adducts. The other markers included chromosomal aberrations, a specific chromosomal disturbance known as sister chromatid exchange, and excess production of a protein (called ras p21) encoded by the gene *H-ras*.

The results (*graph*) showed that compared with the rural residents, those of Gliwice had much higher levels of PAH-DNA and aromatic adducts, chromosomal aberrations, sister chromatid exchanges, and *ras* activity. In other words, it appeared that carcinogens in dirty air could contribute to lung cancer, and their cancer-inducing effects were heralded by the formation of adducts on DNA. Since then, other studies have linked high levels of PAH-DNA adducts to an elevated risk for lung cancer. —*F.P.P.*



CHRISTOPHER PILLITZ *Matrix*

A street in the highly polluted Silesia region of Poland

tion. I would emphasize, however, that in most cases, calculations of risk based on single genetic characteristics will be incomplete and could even be misleading. The effect of any one, subtly acting gene can be modulated by environmental influences, by other genes, by health and nutritional status, and by an array of other host characteristics. To add to the complexity, certain genetic traits may protect against one type of cancer but may predispose to another. (NAT2, for example, both detoxifies bladder carcinogens and activates colon carcinogens.) But assessment of multiple traits, combined with biological assessments of exposure and early damage, should eventually yield meaningful estimates of risk.

Risks in Special Populations

Molecular epidemiologists may not yet be poised to assess precisely the odds for cancer in any given individual, but the research is already helping to clarify some of the variation in cancer risk seen across races and ages. For instance, classical epidemiology has shown that cancer incidence and death rates are often higher for black Americans than for whites. The U.S. incidence for a form of esophageal cancer (squamous cell cancer) is more than three times higher among black men than white men; lung cancer incidence is about 50 percent higher in black males. Black women younger than 40 years experience more breast cancer than white women of the same age do, although the situation is reversed in women older than 40.

A review of many studies provides compelling evidence that at least some of the excess risk in blacks and other minorities may stem from increased exposure to carcinogens. People of color and of lower incomes in the U.S. are disproportionately exposed to certain environmental toxic substances, including lead, air pollution and hazardous waste. Moreover, individuals who live in poverty often eat foods low in vitamins and other protective nutrients.

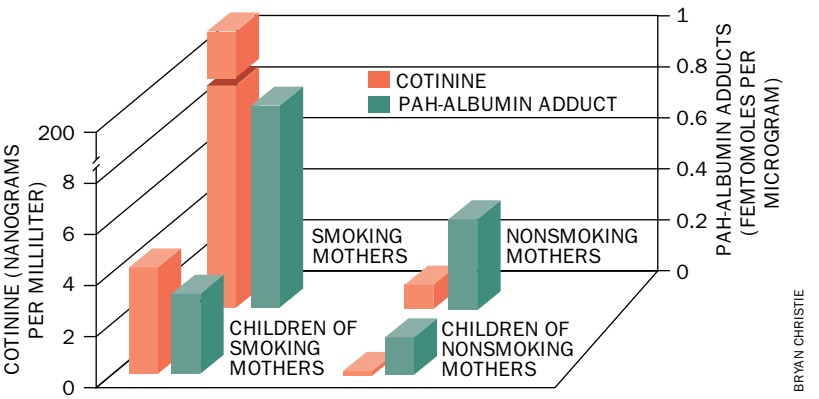
Molecular epidemiology suggests that the effects of environmental exposure and of poor nutrition can be exacerbated in these groups by inborn differences in internal processing of carcinogens. For example, a variant of the carcinogen-activating *CYP1A1* gene found only in African-Americans has been linked in one study to an increased risk for a form of lung cancer (adenocarcinoma): black smokers with this variant were two to three times more likely to have lung cancer than were black smokers who lacked the variant. DNA damage from PAHs also appears to be greater in African-Americans than in Mexican-Americans. Another genetic variant, this time affecting a gene called *H-ras,* is found more frequently in blacks than in whites; this variant is associated with increased risk of leukemia as well as cancers of the lung, breast, colon and bladder, through mechanisms not yet understood.

No racial or ethnic group appears to be consistently more susceptible to cancer as a whole than any other group. But each population seems to display a relatively high frequency of certain genetic traits thought to increase their propensity for one malignancy or another.

Investigators have long known that, as is true of ethnicity, a person's age at the time of exposure to a carcinogenic agent can influence the probability that cancer will result. Data from studies of both animals and humans suggest that fetuses, infants and children may be at greater risk than adults from a variety of environmental carcinogens. Studies of air pollution, tobacco smoke, PAHs, pesticides, nitrosamines, aflatoxin B1 and radiation all show that the lifetime risk of cancer can be heightened if exposure begins in utero or in childhood rather than in adulthood. A longer incubation time and higher rates of cell proliferation during early development presumably play a part in this outcome (proliferating cells are more prone to genetic damage than resting cells are). Molecular epidemiological studies indicate that young children are also less efficient than adults at detoxifying certain carcinogens and repairing molecular injury. Moreover, children frequently absorb higher amounts of some carcinogens relative to body weight than adults do.

As evidence of these last points, nursing infants are estimated to ingest 10 to 20 times more dioxin for their weight than adults do in the course of a day. My colleagues and I have recently found that

RICHARD ELKINS *Gamma Liaison*



BRYAN CHRISTIE

SECONDHAND SMOKE in the home may raise the odds that youngsters will acquire lung cancer later in life. A study by the author and her colleagues has contributed to this understanding. Blood levels of cotinine (a derivative of nicotine and a marker of smoke inhalation) and of an adduct called PAH-albumin (an indirect marker of DNA damage) were higher not only in mothers who smoked than in nonsmoking mothers but also in children of smokers than in children of nonsmokers (*graph*). Because all the women smoked less than a pack a day, the findings suggest that even light use of cigarettes by parents can harm children.

levels of PAH-DNA adducts in the blood of newborns in a polluted area of eastern Europe exceeded those of their mothers, even though a fetus is thought to be exposed to only a tenth of the PAH dose absorbed by its mother. We have also shown that young children whose mothers were fairly light smokers (smoking an average of 10 cigarettes a day) had markedly higher PAH-protein adducts in their blood than children of nonsmoking mothers did.

Implications for Policy

Two general themes emerging from molecular epidemiological research on cancer have strong implications for public health policy. First, the work confirms an already impressive body of evidence indicating that most cancer has an environmental component and thus can be prevented by the dual approach of modifying hazardous behaviors and, at the governmental level, reducing involuntary exposure to carcinogenic substances in the air, water, food supply and workplace. Indeed, it has been estimated that in the absence of environmental exposures, cancer incidence would be reduced by up to 90 percent.

Second, the collected data reinforce other convincing evidence that carcinogenic agents in the environment are more harmful to certain members of society than to others who are similarly exposed. It follows, therefore, that significant gains in cancer prevention will come only from ensuring—through regulation, education and other measures—that these more vulnerable people are protected.

At the moment, the government is not paying adequate attention to the fact that people can differ markedly in their susceptibility to carcinogens. Governmental agencies use a tool called risk assessment to determine the levels of carcinogenic exposures that would cause an "unacceptable" number of future cancers. That goal is reasonable, but most of the current approaches rest on the mistaken assumption that all individuals in a population have an identical response to a cancer-causing agent. Hence, the results can seriously underestimate risk for certain groups. Dale B. Hattis and his colleagues at Clark University have calculated that possession of only a few susceptibility factors could increase a group's risk of cancer by an order of magnitude or more over that predicted for the mythical "standard" population.

To remedy this problem, policy makers should determine, and present to the public, the estimated risks to specific groups thought to be most sensitive to the carcinogenic agent in question (such as particular ethnic groups, women, children, the elderly). Failure of regulatory decisions to account for individual variability could lead to environmental standards and public health policies that cause the most susceptible subsets of the population to bear the greatest risks.

Prevention of cancer is the best "treatment." Avoiding even 20 percent of cases in the U.S. would translate into more than 270,000 people spared from the disease every year. Molecular epidemiology can help guide the development of preventive strategies, and it is already providing new scientific impetus for protecting the most vulnerable members of society. SA

The Author

FREDERICA P. PERERA has pioneered the application of molecular epidemiological methods to the study of cancer. She is a professor at the Columbia University School of Public Health and associate director of the Columbia-Presbyterian Cancer Center. She received a B.A. from Radcliffe College in 1963 and a doctorate in public health from Columbia in 1981.

Further Reading

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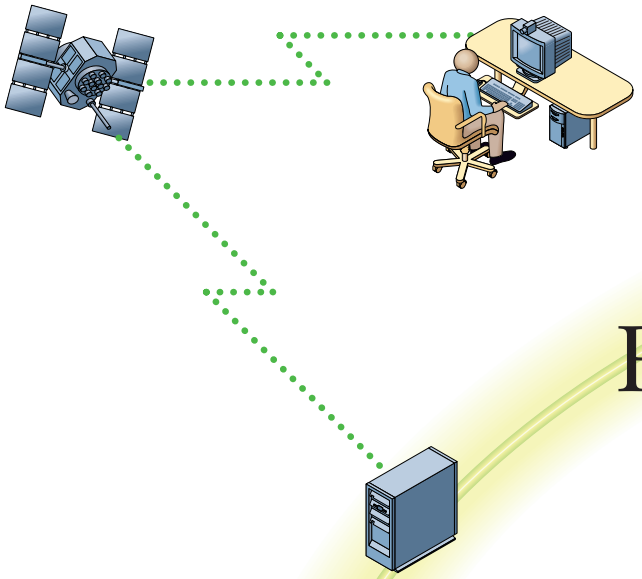


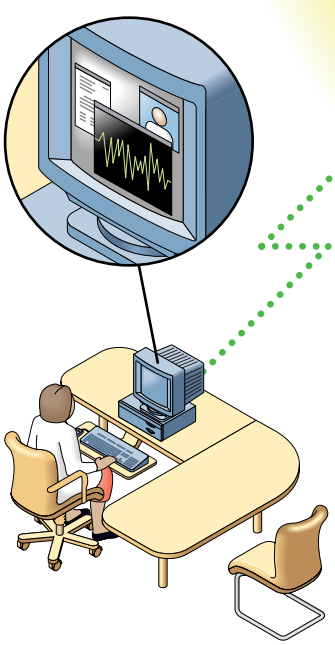
REMOTE CONSULTATION
Videoconferencing server allows doctors to consult other experts for additional information about cases.

Software for Reliable Networks

Techniques that enable distributed computing systems to reorganize themselves can restore operation when one part crashes

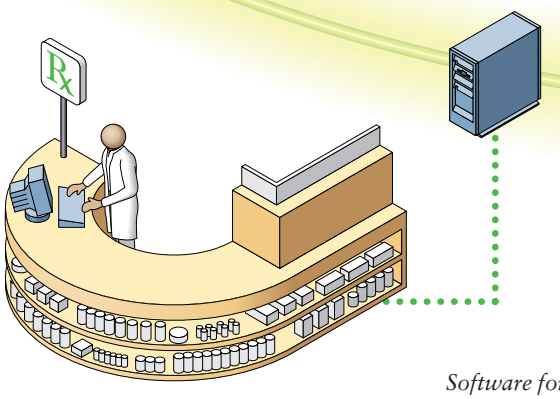
by Kenneth P. Birman and Robbert van Renesse

PHYSICIAN
From a private office in another building, a physician can monitor patients in the hospital. The physician can access vital signs, such as breathing and heart rate, laboratory results and current medical records.



Surfing the Internet is no longer just a seductive pastime. In rising numbers, organizations of all kinds, from computer companies to publishing firms, are turning to on-line services that operate much like the World Wide Web. These services can help manage important information, speed decision making and improve efficiency. But as more and more enterprises become dependent on this new technology, many are also exposed to the downside of computer networking. The drawbacks are particularly evident to users of distributed computing systems, which link programs, servers and data files dispersed across an extended network of computers and terminals.

As every computer user knows, programs that operate across networks are prone to failure. Indeed, Leslie B. Lamport, a pioneer in distributed computing at Digital Equipment Corporation, defined a distributed computing system as "one in which the failure of a computer you didn't even know existed can render your own computer unusable." The Web is certainly not exempt from breakdowns [*see box on page 68*]. During late 1995, users of the Web reported several "brownouts," when communication on the Internet was largely impossible. Such lapses have been variously attributed to software errors, excessive traffic on transmission lines, and overload or complete failure of the Web servers, which are computers that



PHARMACY
The hospital pharmacist also adds information to patients' records, noting when requested medications were dispensed. Accurate data about all medications a patient receives help to prevent dangerous drug interactions.

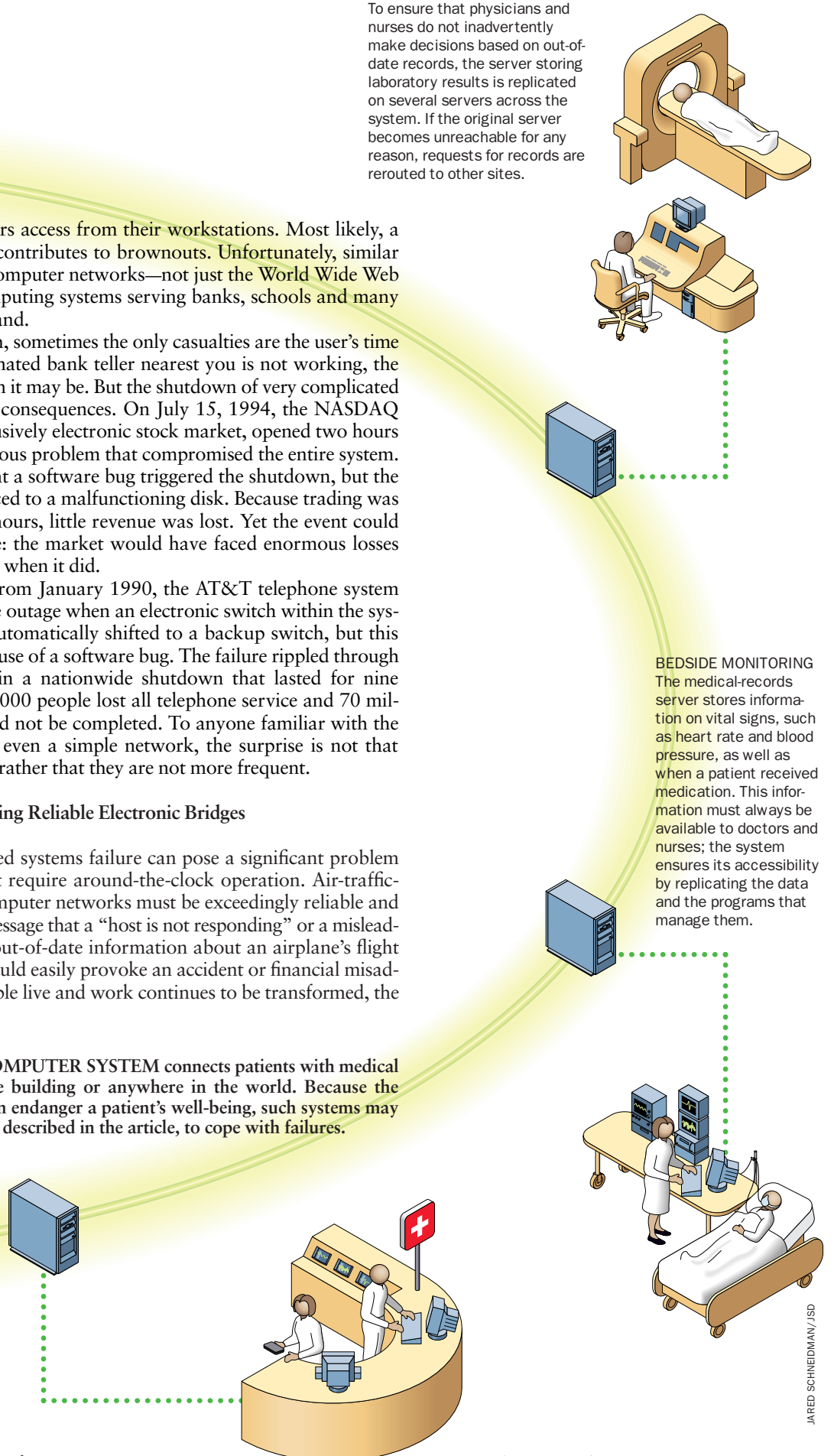
store the documents users access from their workstations. Most likely, a combination of factors contributes to brownouts. Unfortunately, similar events will multiply as computer networks—not just the World Wide Web but also distributed computing systems serving banks, schools and many offices—continue to expand.

When computers crash, sometimes the only casualties are the user's time and temper. If the automated bank teller nearest you is not working, the one across the street from it may be. But the shutdown of very complicated networks can have dire consequences. On July 15, 1994, the NASDAQ stock exchange, an exclusively electronic stock market, opened two hours late because of a mysterious problem that compromised the entire system. Initially, workers thought a software bug triggered the shutdown, but the error was ultimately traced to a malfunctioning disk. Because trading was delayed only for a few hours, little revenue was lost. Yet the event could have been a catastrophe: the market would have faced enormous losses had trading not resumed when it did.

In another example, from January 1990, the AT&T telephone system experienced a large-scale outage when an electronic switch within the system failed. Calls were automatically shifted to a backup switch, but this switch also crashed because of a software bug. The failure rippled through the network, resulting in a nationwide shutdown that lasted for nine hours, during which 60,000 people lost all telephone service and 70 million telephone calls could not be completed. To anyone familiar with the challenges of managing even a simple network, the surprise is not that these mishaps occur but rather that they are not more frequent.

Building Reliable Electronic Bridges

Even a brief distributed systems failure can pose a significant problem for applications that require around-the-clock operation. Air-traffic-control and financial computer networks must be exceedingly reliable and constantly updated. A message that a "host is not responding" or a misleading display that shows out-of-date information about an airplane's flight path or a stock's price could easily provoke an accident or financial misadventure. As the way people live and work continues to be transformed, the



FUTURE HOSPITAL COMPUTER SYSTEM connects patients with medical personnel throughout the building or anywhere in the world. Because the crash of one computer can endanger a patient's well-being, such systems may employ active replication, described in the article, to cope with failures.

security and stability of their finances, property and even health will increasingly depend on distributed computer systems. Thus, although it is easy to talk about the potential benefits of the information superhighway, we believe the bridges that link computers must be inspected more closely. Various computer scientists, including the two of us, have been working since the late 1970s on developing software to improve distributed computer networks, making them more secure and resistant to failure—an activity that people in the field refer to as designing robust distributed computing systems.

Why do distributed systems crash? If we exclude systems that fail because they were mismanaged or poorly designed, the most common scenario involves an isolated problem at one site that triggers a chain of events in which program after program throughout the network eventually shuts down. One response to this threat might be to strengthen individual components—incorporating computers and disks specially designed to tolerate faults, for example. But ceilings can still leak, causing short circuits; power can fluctuate; and communications connections can be inadvertently cut. Acts of sabotage by hackers or disgruntled employees can also endanger distributed systems. Although engineers and computer programmers can improve the durability of hardware and software, no computer can ever be made completely reliable.

Even if every component of a system were extremely dependable, the story would not end there. Merely interconnecting reliable computers and bug-free programs does not yield a robust distributed system. Instead it produces a network that works well under most conditions. Electronic-mail programs, bulletin boards and the Web were designed using components that, considered individually, are very trustworthy. Yet these systems frequently freeze when anything unexpected happens to an individual component of the system; for instance, the system may crash when one machine or a communications line becomes overloaded. Some additional form of protection is therefore needed.

During the past two decades, programmers have attacked the dependability problem by developing fault-tolerant software—programs that allow computer systems to restore normal operation even when problems occur. The technique eliminates the chains of internal dependencies that link the operation of a system as a whole to the operation of any single component. The resulting systems do not need to shut down even if some sites go off-line. Instead they resume service by rapidly reconfiguring to work around crashed servers.

OLA RØE *Røe Foto (background photograph and computer screen photograph)*

WEATHER MONITORING NETWORK alerts Norwegian fishermen to dangerous storms (*left*) or hazardous oil spills (*right*). The computer system StormCast links re-

Saved by the Backup

Computer scientists refer to these arrangements as highly available distributed systems. Because these systems are designed to replicate critical information continuously and to distribute multiple backup copies among their individual computers, they can adapt to changing conditions—a malfunctioning disk drive at one site, an overload at another, a broken communications connection and so forth. As long as failures do not occur so often that the software lacks time to react, these systems can respond by pulling up from elsewhere a duplicate copy of a needed file or a replica of an on-line program. In this way, a system as a whole remains available and, ideally, provides uninterrupted service to the users still connected.

A simple and popular method of building a highly available distributed system involves a primary and a backup system. If the primary machine fails, the backup can be called into service. Switching between the two is easy if the data never change. The conversion becomes difficult, however, if data or files change while the system is running. And in an extensive network of servers, data, files and programs, it can be difficult to distinguish between a system that has genuinely crashed and one that is merely experiencing communications difficulties.

Suppose that a computer is trying to update information on both the primary and backup servers, but one of them stops responding to messages. If the problem is merely in the communications lines, the messages will get through, given enough time. But if the server has actually failed, the computer doing the updating would wait indefinitely; in the meantime, the system would be unavailable. If the computer trying to carry out the update inappropriately stops waiting and sends the update to only one server, however, the primary and the backup will no longer be identical. Errors will arise if the system attempts to use the outdated server.

The NASDAQ financial market illustrates one way to resolve this conundrum. The network has two central trading servers. To prevent confusion, only one is active at any given time. The NASDAQ operators themselves decide when to switch to the replacement server. Unfortunately, very few distributed systems can rely on the wisdom of a human operator to detect failures and then to switch the entire network from one server to another. Rather programmers must automate this decision so that the transition can occur seamlessly.

JOHN PAUL *Gamma Liaison (background photograph)*; OLA RØE *Røe Foto (computer screen photograph)*

mote video cameras, weather stations and satellites to provide reliably updated reports. StormCast can be accessed on the World Wide Web at http://www.cs.uit.no/

Moreover, highly available distributed systems often have large numbers of servers and programs. Consequently, these systems typically maintain a membership list, which keeps track of every program, noting whether it is working or not. If a program is unresponsive for any reason, it is marked as faulty. By recognizing a failure at one site, the system can then reconfigure itself and redirect work to operational sites.

The NASDAQ system also demonstrates a second concern about reliability in distributed systems. The two-hour trading delay in 1994 could have been avoided if the operators had switched immediately to the backup. They opted to wait, however, because of concerns that a software bug might have caused the primary system to malfunction. If such a bug were present, the backup might also crash, just as the AT&T backup system did. Because it is impossible to guarantee that software is completely free of bugs, some form of protection is needed to reduce the risk that backup versions of a critical server will crash following the failure of a primary server.

Programmers have responded to this challenge with an approach known as active replication. In active replication, a system's software establishes redundant copies of vital programs or servers through the use of so-called process groups. A process group links a set of programs that cooperate closely. A distributed system may contain many process groups, and programs can belong to several of these groups. Each group is known by a name much like a file name and has its own list of current members. Most important, the process group provides a means for sending messages to its members. This message-passing function ensures that each member of the group receives every message in the same order, even if the sender crashes while transmitting the message.

If a particular program is necessary for maintaining availability, the system introduces a group of programs, each of which replicates the original. To update the data managed by the replicated program, the system sends a message to the process group. Each member reacts by updating its particular replica. Because all the programs see the same updates in the same order, they will remain in mutually consistent states.

Active replication enables a system to tolerate faults because any group member can handle any request: if one machine crashes, work can be redirected to an operational site. Furthermore, if a request does not alter data, one site can process the query rather than tie up the entire system. In this way, multiple tasks can be worked on at once by different programs, speeding up the application by employing parallel processing.

Of course, if all members of a process group handle an incoming message in the same erroneous manner, all the members could, in theory, crash simultaneously. Although it would seem that active replication should be vulnerable to such failures, this turns out not to be the case. Programmers have often observed that the errors most likely to be missed in testing software are those involving the order in which data are received. These bugs can be provoked only by unlikely sequences or timings of events. When a system employs active replication, the replicas do see the same updates in the same order; however, updates are only a small part of the requests a program sees. Most of the time, replicated programs work in parallel, with each program handling its own set of queries in a unique order. Thus, even if a software bug slips through testing and interferes with a few parts of a networked application, it is unlikely to cause all the members of any particular process group to crash at the same time.

The idea behind active replication is simple, but the software needed to support it is not. Managing dynamically changing membership lists and communicating with process groups is difficult, particularly in the face of inevitable crashes and lost messages. Although distributed computing has become commonplace over the past decade, active replication has only recently emerged from the laboratory.

Tool Kits for Robust Networks

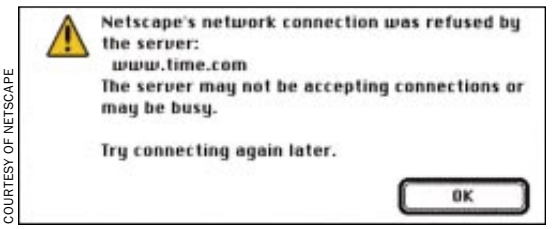
Over the past few years, more than a dozen software teams have developed packages for robust distributed computing systems. All provide high availability through active replication, although they each differ somewhat in their emphasis. Some packages focus on speed, for example; others on the need for security.

Our research efforts at Cornell University contributed two such packages. One of us (Birman) headed the team that introduced Isis in 1987; more recently, the two of us worked on Horus, introduced in 1994. The names "Isis" and "Horus" allude to Egyptian mythology. The goddess Isis helped to revive the god Osiris after he was torn to pieces in a battle with the war god Set; Horus was Isis's son, who eventually triumphed over Set. By analogy, the Isis and Horus packages can help restore a distributed system that has been disrupted by a failure.

Packages such as Isis employ a set of software functions, or "tools," that replicate and update data, keep track of

The Tangled Web

Most of the World Wide Web is invisible. For many users, the Web appears to have only two components: a browser program and remote servers where documents to be downloaded are stored. But the Web—and the Internet, which provides the medium of communication that connects Web sites—consists of millions of additional programs and servers; dozens cooperate to fetch a single document. For example, to fetch an item from a server at Cornell University, the name "www.cornell.edu" must be translated, or mapped, to a numerical address that the software recognizes.This task may be handled by a series of mapping programs before the correct address is located. Furthermore, a request to connect to a Web site typically passes through a number of so-called proxies—programs that save copies of frequently accessed documents as a way of reducing the load on remote Web servers. If a nearby proxy has stored a needed document, the user can avoid a lengthy file transfer over the Internet.



COURTESY OF NETSCAPE

Such hidden dependence on intermediate programs is common in distributed systems, but it can contribute to system failures. If a name-mapping program does not respond, if a proxy fails or if the Web server crashes, the initial request will not go through. So the ubiquitous error message that the Web server has failed or is busy (*above*) can be misleading: the overload or failure of any number of intermediate programs can result in such an outcome.

The Internet as a whole can experience "brownouts" somewhat akin to a telephone or power outage. For instance, in late 1995 a major Internet name service, located in Atlanta, became intermittently overloaded. During these periods, no one on the Web could fetch documents from servers whose addresses were not already known to the local system. This type of brownout can affect large numbers of people worldwide. Even when a connection is made to a server, errors can still occur. Copies saved by Web proxies are not updated when the original document is, so there is no guarantee that users will see the most up-to-date version of a Web page. In many situations, this possibility does not cause significant problems, but some time-sensitive applications can become untrustworthy if the necessary documents are not kept current. Web proxies improve the Internet's reliability in one sense, by reducing the processing load on the network. But proxies decrease reliability by creating the possibility that people will see outdated information.

Critical projects on the Web or other distributed computing systems will require stronger guarantees that information retrieved from the system is accurate, current and always available when needed. One way to avoid such mistakes is to arrange for saved copies of vital information to be managed by the process of active replication described in the accompanying article. —*K.P.B.*

process groups and assist in handling membership changes. Isis can also parcel out data processing among servers (a procedure known as load sharing). Distributed systems that make use of load sharing exhibit many of the advantages of parallel computing but without requiring special-purpose parallel computers. By dividing up incoming work among multiple servers functioning in concert, Isis enables systems to manage large tasks quickly. Also, if a particular application requires additional computing power, one can add an extra server, and the load-sharing technique will adapt itself to the new group size. The possibility, offered by such tool kits as Isis and Horus, of improving both performance and reliability often surprises developers: they tend to assume that making a system more robust will also make it slower and more expensive.

Active replication has been applied in a number of settings, including several telecommunications networks, stock markets, banks and brokerages. In Norway, researchers have developed an environmental monitoring system based on the technology [*see illustrations on preceding two pages*]. The French air-traffic-control agency is also exploring the technique for use in a new generation of air-traffic-control software. And manufacturing plants have used process groups to coordinate work and to reconfigure assembly lines when equipment is taken off-line to be serviced.

As computer scientists look to ever more demanding applications, however, they discover that active replication has important limitations. Load sharing is not always possible or desirable: some systems (notably, those in which data stored at a server change very rapidly) slow down when components are replicated. For example, in videoconferencing technology, active replication does improve the fault tolerance of the network of servers that must keep running even when some participants are cut off. But the technique would slow down the system—without improving dependability—if applied to the transmission of video data to remote users.

The need for flexibility motivated us to develop Horus. Like the Isis tool kit, Horus supports active replication, but it also provides much greater versatility. The basic strategy behind Horus is modularity, resembling that of a child's set of Legos: different building blocks of Horus can fit together in any combination to support the specific needs of a particular process group. One block might encrypt data so that hackers cannot break into the system. Another block might address potential communications failures that can arise when messages are lost or corrupted. Programmers using Horus decide which properties their system actually needs, permitting them to customize the system for its intended use. Furthermore, Horus can be extended with custom-designed blocks for special needs that we may not have encountered or anticipated in our own work.

Horus has a growing group of users worldwide. At Cornell, Brian C. Smith has used it to build a videoconferencing system for "groupware" applications. Horus information is available from http://www.cs.cornell.edu/Info/Projects/HORUS/

A Crisis of Will?

Our work on Isis and Horus has convinced us that careful planning can ensure the dependability of computer networks. But making the information superhighway robust may take more

time and money than computer makers and users are willing to commit. Software for distributed applications is typically built with existing technology that was not designed for dependability. Moreover, researchers need to seek better methods for designing large-scale systems that are robust and that provide very high performance: a system that is extremely robust when accessed by 50 users simultaneously may turn out to be unacceptably slow and hence unreliable if 5,000 people do so.

Although programmers have applied the technology for robust distributed computing successfully in some instances, the public hears more about failures of nonrobust systems. For example, over the past few years, there have been dozens of reports on the problems with the current air-traffic-control system. In the fall of 1995 the Los Angeles system failed, leaving controllers unable to communicate with aircraft; a midair collision was avoided by seconds.

To make matters worse, updated air-traffic-control software, commissioned in 1982 by the Federal Aviation Administration, has been repeatedly delayed and scaled back. The FAA selected the original proposal precisely because of its innovative approach to distributed computing; now it seems the highly available and distributed aspects of the proposed software have been almost entirely eliminated. Yet air-traffic controllers criticize the existing system as dangerously inadequate, particularly because it lacks a distributed software architecture and has become undependable with age. Highly publicized fiascoes such as these have fueled a common perception that there is a crisis in computer software [see "Software's Chronic Crisis," by W. Wayt Gibbs; SCIENTIFIC AMERICAN, September 1994].

But if we are really in the midst of a software development crisis, it is perhaps as much a crisis of will as of means. Not all developers are concerned with making their networking software robust, and the public pressure for reliability does not seem to extend beyond a few especially sensitive applications. Indeed, companies that market distributed computing packages often state in product licenses that their technologies may not be dependable enough for use in critical applications—implying that reliability is not a reasonable objective. In our opinion, this situation is analogous to the unlikely prospect of automakers selling cars with the warning that vehicles are unsafe for use on highways. The computer equivalents of safety belts and air bags are infrequently applied to software development. And the desire for sophisticated, user-friendly interfaces as well as improved speed and performance tends to dominate the attention both of the software developers and the people who use the programs.

Reliability often conjures up an image of slow, ponderous computer systems that is incompatible with the allure of effortless and instantaneous access to information on the data superhighway. Yet robust technology does not have to be slow and unpleasant to use: the Golden Gate Bridge is a model of stability as well as grace. With each passing hour, more and more uses are being found for the information bridges that link computers. Our enthusiasm to incorporate elegant electronic bridges in every conceivable application should not overshadow a reasonable degree of concern about whether or not such bridges will be able to support the resulting traffic of information. We believe that robust distributed systems provide a valuable tool for connecting computers quickly and dependably, creating opportunities for business and pleasure in the information society. But we also believe that in many cases, unless a distributed system can be engineered to function robustly, it may be better not to build—or use—one at all. SA

ANDREW LICHTENSTEIN

AIRLINE PASSENGERS waited for delayed flights in New York City's La Guardia Airport in May 1995 after a power failure triggered a shutdown of the local air-traffic-control system. The effort to rejuvenate aging U.S. air-traffic-control software using distributed systems dates back to the 1980s.

The Authors

KENNETH P. BIRMAN and ROBBERT VAN RENESSE have worked together on distributed computing systems for the past five years. Birman is professor of computer science at Cornell University. After developing the Isis tool kit in the 1980s, he founded a company to commercialize the technology. Isis Distributed Systems now operates as a division of Stratus Computer, Inc. Van Renesse entered the field of distributed computing after deciding not to pursue a career as a circus acrobat. He is now a senior research associate at Cornell and is the primary architect and developer of the Horus system.

Further Reading

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The Pursuit of Happiness

New research uncovers some anti-intuitive insights into how many people are happy—and why

by David G. Myers and Ed Diener

DIMITRY SCHIDLOVSKY

Compared with misery, happiness is relatively unexplored terrain for social scientists. Between 1967 and 1994, 46,380 articles indexed in *Psychological Abstracts* mentioned depression, 36,851 anxiety, and 5,099 anger. Only 2,389 spoke of happiness, 2,340 life satisfaction, and 405 joy.

Recently we and other researchers have begun a systematic study of happiness. During the past two decades, dozens of investigators throughout the world have asked several hundred thousand representatively sampled people to reflect on their happiness and satisfaction with life—or what psychologists call "subjective well-being." In the U.S. the National Opinion Research Center at the University of Chicago has surveyed a representative sample of roughly 1,500 people a year since 1957; the Institute for Social Research at the University of Michigan has carried out similar studies on a less regular basis, as has the Gallup Organization. Government-funded efforts have also probed the moods of European countries.

We have uncovered some surprising findings. People are happier than one might expect, and happiness does not appear to depend significantly on external circumstances. Although viewing life as a tragedy has a long and honorable history, the responses of random samples of people around the world about their happiness paints a much rosier picture.

In the University of Chicago surveys, three in 10 Americans say they are very happy, for example. Only one in 10 chooses the most negative description, "not too happy." The majority describe themselves as "pretty happy." (The few exceptions to global reports of reasonable happiness include hospitalized alcoholics, new inmates, new psychotherapy clients, South African blacks during apartheid, and students living under conditions of economic and political oppression.)

How can social scientists measure something as hard to pin down as happiness? Most researchers simply ask people to report their feelings of happiness or unhappiness and to assess how satisfying their lives are. Such self-reported well-being is moderately consistent over years of retesting. Furthermore, those who say they are happy and satisfied seem happy to their close friends and family members and to a psychologist-interviewer. Their daily mood ratings reveal more positive emotions, and they smile more than those who call themselves unhappy. Self-reported happiness also predicts other indicators of well-being. Compared with the depressed, happy people are less self-focused, less hostile and abusive, and less susceptible to disease.

We have found that the even distribution of happiness cuts across almost all demographic classifications of age, economic class, race and educational level. In addition, almost all strategies for assessing subjective well-being—including those that sample people's experience by polling them at random times with beepers—turn up similar findings.

Interviews with representative samples of people of all ages, for example, reveal that no time of life is notably happier or unhappier. Similarly, men and women are equally likely to declare themselves "very happy" and "satisfied" with life, according to a statistical digest of 146 studies by Marilyn J. Haring, William Stock and Morris A. Okun, all then at Arizona State University. Alex Michalos of the University of Northern British Columbia and Ronald Inglehart of the University of Michigan, summarizing newer surveys of 18,000 university students in 39 countries and 170,000 adults in 16 countries, corroborate these findings.

Knowing someone's ethnicity also gives little clue to subjective well-being. African-Americans are only slightly less likely than European-Americans to feel very happy. The National Institute of Mental Health found that rates of depression and alcoholism among blacks and whites are roughly equal. Social psychologists Jennifer K. Crocker of the University of Michigan and Brenda Major of the University of California at Santa Barbara assert that people in disadvantaged groups maintain self-esteem by valuing things at which they excel, by making comparisons within their own groups and by blaming problems on external sources such as prejudice.

What Money Can't Buy

Wealth is also a poor predictor of happiness. People have not become happier over time as their cultures have become more affluent. Even though Americans earn twice as much in today's dollars as they did in 1957, the proportion of those telling surveyors from the National Opinion Research Center that they are "very happy" has declined from 35 to 29 percent.

Even very rich people—those surveyed among *Forbes* magazine's 100 wealthiest Americans—are only slightly happier than the average American. Those whose income has increased over a 10-year period are not happier than those whose income is stagnant. Indeed, in most nations the correlation between income and happiness is negligible—only in the poorest countries, such as Bangladesh and India, is income a good measure of emotional well-being.

Are people in rich countries happier, by and large, than people in not so rich countries? It appears in general that they are, but the margin may be slim. In Portugal, for example, only one in 10 people reports being very happy, whereas in the much more prosperous Netherlands

Probing for Happiness

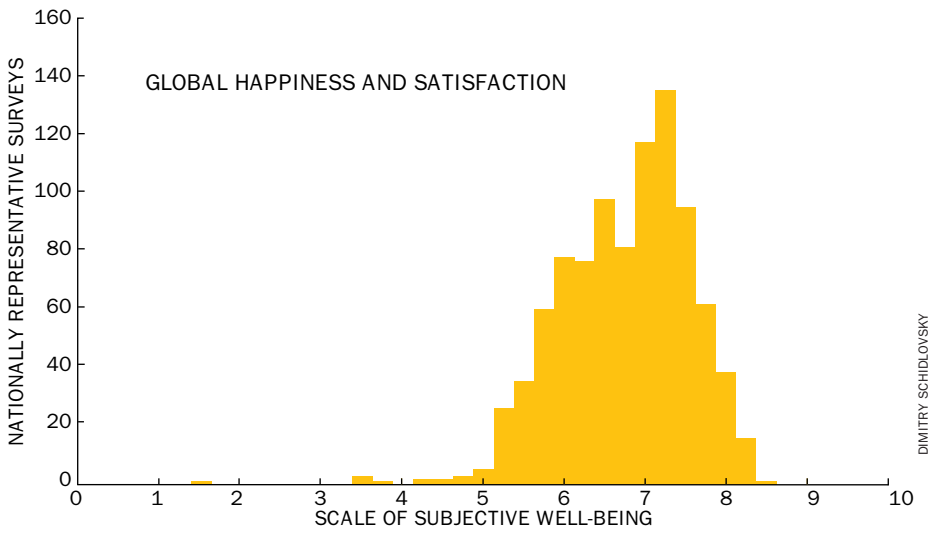
Researchers use various methods to survey people's subjective sense of well-being. Some employ images (*top*), others use words (*middle*), but all questions essentially come down to asking people how they feel about their lives. Different techniques yield remarkably similar results; we have collated data from almost 1,000 surveys of 1.1 million people to arrive at a global estimate of reported subjective well-being (*bottom*). *—D.G.M. and E.D.*

WHICH OF THESE FACES REPRESENTS
THE WAY YOU FEEL ABOUT YOUR LIFE AS A WHOLE?

20% 46% 27% 4% 2% 1% 0%

"In most ways my life is close to my ideal."
"The conditions of my life are excellent."
"I am satisfied with my life."
"So far I have gotten the important things I want in life."
"If I could live my life over, I would change almost nothing."

Do you strongly disagree, disagree, slightly disagree, neither agree nor disagree, slightly agree, agree or strongly agree?



DIMITRY SCHIDLOVSKY

the proportion of very happy is four in 10. Yet there are curious reversals in this correlation between national wealth and well-being—the Irish during the 1980s consistently reported greater life satisfaction than the wealthier West Germans. Furthermore, other factors, such as civil rights, literacy and duration of democratic government, all of which also promote reported life satisfaction, tend to go hand in hand with national wealth. As a result, it is impossible to tell whether the happiness of people in wealthier nations is based on money or is a by-product of other felicities.

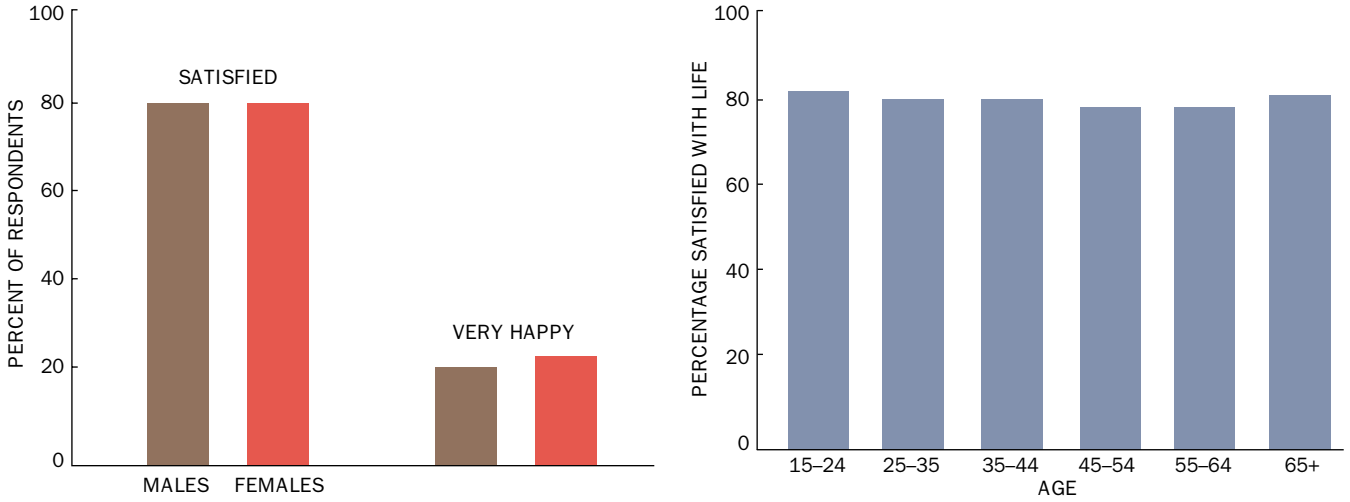
Habits of Happy People

Although happiness is not easy to predict from material circumstances, it seems consistent for those who have it. In one National Institute on Aging study of 5,000 adults, the happiest people in 1973 were still relatively happy a decade later, despite changes in work, residence and family status.

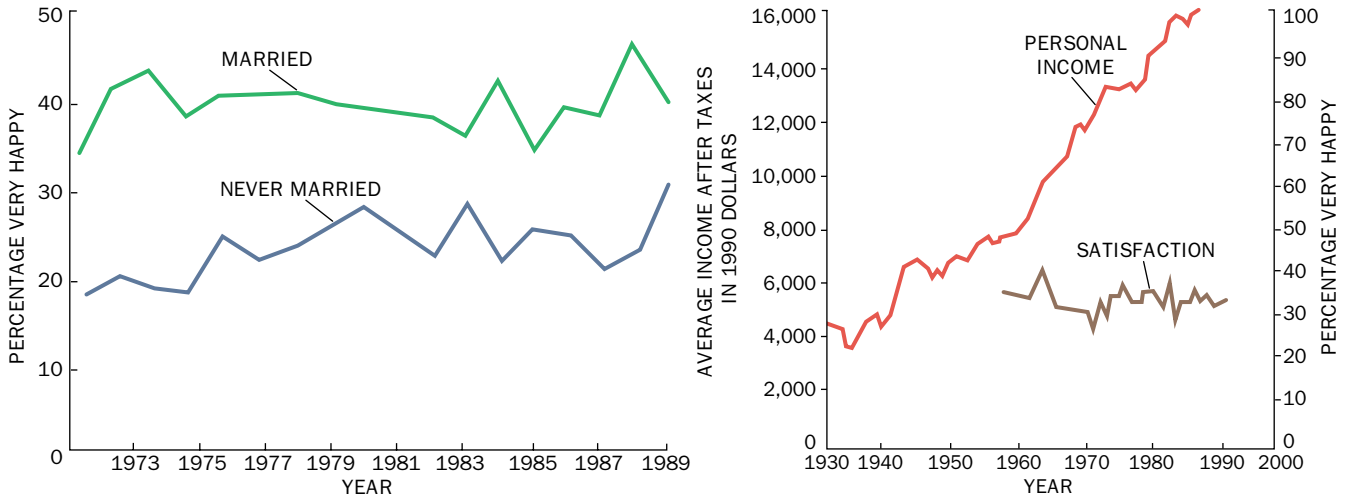
In study after study, four traits characterize happy people. First, especially in individualistic Western cultures, they like themselves. They have high self-esteem and usually believe themselves to be more ethical, more intelligent, less prejudiced, better able to get along with others, and healthier than the average person. (Such findings bring to mind Sigmund Freud's joke about the man who told his wife, "If one of us should die, I think I would go live in Paris.")

Second, happy people typically feel personal control. Those with little or no control over their lives—such as prisoners, nursing home patients, severely impoverished groups or individuals, and citizens of totalitarian regimes—suffer lower morale and worse health. Third, happy people are usually optimistic. Fourth, most happy people are extroverted. Although one might expect that introverts would live more happily in the serenity of their less stressed, contemplative lives, extroverts are happier—whether alone or with others.

The causal arrows for these correlations are uncertain. Does happiness make people more outgoing, or are outgoing people more likely to be happy, perhaps explaining why they marry sooner, get better jobs and make more friends? If these traits indeed predispose their carriers to happiness, people might become happier by acting in certain ways. In experiments, people who feign high self-esteem report feeling more pos-



SOURCE: Based on data reported by Ronald Inglehart in Culture Shift in Advanced Industrial Society, *Princeton University Press, 1989* (top graphs)



SOURCE: National Opinion Research Center, University of Chicago (bottom graphs)

DIMITRY SCHIDLOVSKY

HAPPINESS APPEARS CONSISTENT across many different sectors of the population. Both sexes report roughly the same satisfaction with life (*top left*), as do various age groups (*top right*). Among the few consistent differentials is that between married and never-married people (*bottom left*); other data indicate that divorced people are less happy than either of these two groups. Happiness has remained relatively constant over time in the U.S., even as national income has increased (*bottom right*).

itively about themselves, for example.

Whatever the reason, the close personal relationships that characterize happy lives are also correlated with health. Compared with loners, those who can name several intimate friends are healthier and less likely to die prematurely. For more than nine out of 10 people, the most significant alternative to aloneness is marriage. Although broken marital relationships can cause much misery, a good marriage apparently is a strong source of support. During the 1970s and 1980s, 39 percent of married adults told the National Opinion Research Center they were "very happy," as compared with 24 percent of those who had never married. In other surveys, only 12 percent of those who had divorced perceived themselves to be "very happy." The happiness gap between the married and the never-married was similar for women and men.

Religiously active people also report greater happiness. One Gallup survey found that highly religious people were twice as likely as those lowest in spiritual commitment to declare themselves very happy. Other surveys, including a 16-nation collaborative study of 166,000 people in 14 nations, have found that reported happiness and life satisfaction rise with strength of religious affiliation and frequency of attendance at worship services. Some researchers believe that religious affiliation entails greater social support and hopefulness.

Students of happiness are now beginning to examine happy people's exercise patterns, worldviews and goals. It is possible that some of the patterns discovered in the research may offer clues for transforming circumstances and behaviors that work against well-being into ones that promote it. Ultimately, then, the scientific study of happiness could help us understand how to build a world that enhances human well-being and to aid people in getting the most satisfaction from their circumstances. SA

The Authors

DAVID G. MYERS and ED DIENER have been studying happiness for more than 10 years. Myers is professor of psychology at Hope College in Michigan and author of *The Pursuit of Happiness: Who Is Happy and Why* (William Morrow, 1992). He won the Gordon Allport Prize for his studies of group influence. Diener is professor of psychology at the University of Illinois and investigates the definition and measurement of subjective well-being. His current work focuses on cultural differences in subjective well-being and on adaptation to life events.

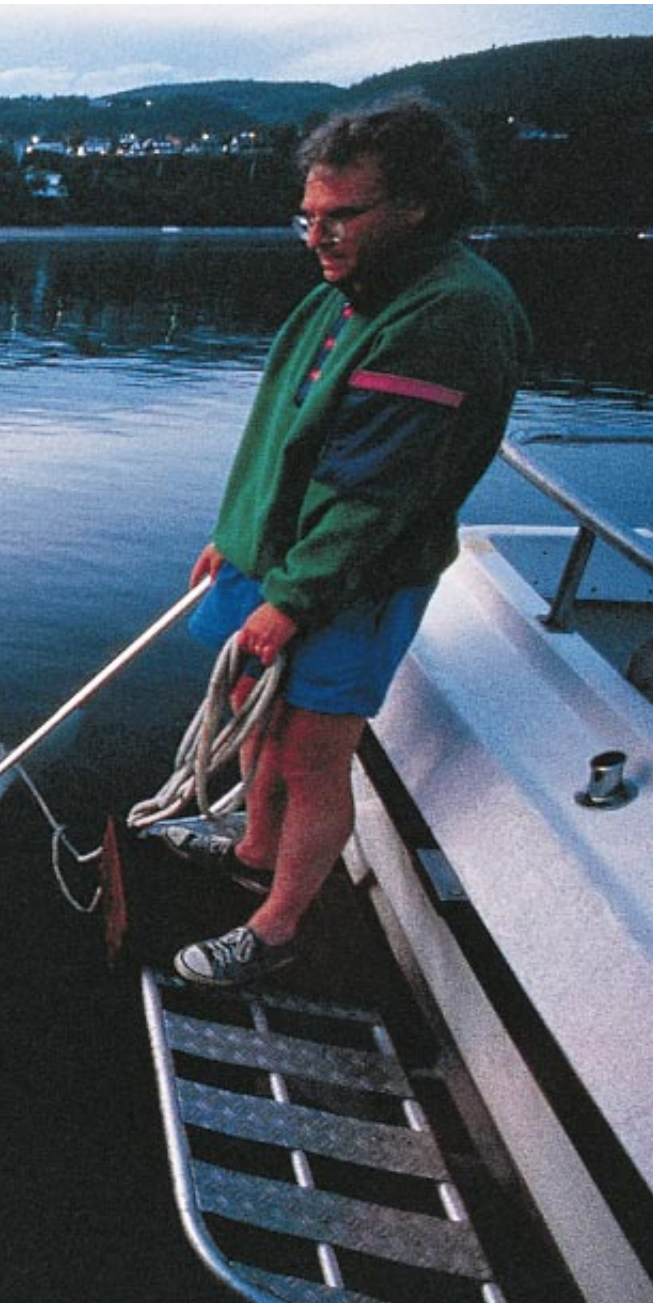
The Beluga Whales of the St. Lawrence River

FLIP NICKLIN *Minden Pictures*

by Pierre Béland

Although they are protected by law from hunters, these whales must struggle to survive the threat of industrial pollution

In 1535, on his second voyage to America, the French explorer Jacques Cartier sailed up the St. Lawrence River, guided by two Amerindians. Beyond the mouth of the Saguenay River, adverse winds and tidal currents stalled his progress for a full day. Cartier was forced to moor for the night near a low-lying island in the middle of the river. In the morning, he was startled to see large white porpoises surrounding the ship. The native pilots said they were good to eat and called them *Adothuys*. The animals were beluga whales, an Arctic species that had lived in the St. Lawrence for millennia.



BELUGA WHALES that die in the St. Lawrence, such as the one the author has roped in the photograph, are most often victims of toxic chemical waste from the area's industries. Fourteen of the whales that Béland's group has autopsied bore cancerous tumors—representing more than half of all malignancies ever reported among whales, dolphins and porpoises.

These small, toothed whales first came to the river from the Atlantic Ocean, shortly after the Ice Age ended. When the climate warmed, the Atlantic rose, flooding much of North America's eastern seaboard. The water washed over a huge area of land beyond the Gulf of St. Lawrence, almost as far as the Great Lakes and into New York and Vermont. Many species of seals and whales ventured into this inland sea, called the Champlain. In time, the land reemerged, the basin dried and the St. Lawrence took form.

Belugas and other whales continued to swim up the estuary and the river as far as they could, but they did not roam undisturbed for long. About 8,500 years ago nomadic tribes came to the edge of the river from the southwest and gathered next to shores where the belugas passed in the summer. There the people made seasonal dwellings, remnants of which are now buried under the grass and soil, along with bones from the seals and belugas they hunted.

In the 1600s Basque sailors came ashore near the Saguenay to render right whales and probably beluga whales as well. The sailors were followed in the next century by fur traders and settlers, for whom fishing provided a good income. The representative for the king of France gave concessions for catching belugas to a few hunters, who typically used fixed weir nets. These giant meshings took advantage of the falling tides to trap belugas over the river's extensive mudflats. By 1721 there were 15 such fisheries on both shores of the St. Lawrence.

For some communities, hunting belugas became a way of life, and the whale became a subject of lore. One tale has it that after catching more than 100 belugas in a single day, a village held a party in a barn near the river. Rum, whiskey and wine kept everyone lively, and laughter and music wafted over the beach, where the rising tide had started to lap at the dead whales. Around midnight, one reveler saw fleshless hands trying to seize the dancers. Everyone fled from the barn to find with dismay that the tide had reclaimed their catch. Rising from the moonlit waves, human ghosts appeared, riding the whales. The belugas' eyes shone like hot coals, and their blowholes spit flames as they swam away into the night, leaving glowing trails on the dark water.

No one knows how many belugas were killed before the 1800s. It has been estimated, though, that between 1866 and 1960 some 16,200 belugas, or an average of 172 a year, were landed. This annual yield suggests that the population must have been 5,000 to 10,000 strong near the turn of the 20th century. When catches became sparse and the demand for whale products waned, the St. Lawrence beluga was almost forgotten. By the 1970s, it is now believed, there were only 500 of the whales left.

In 1979 the Canadian government afforded the whales total protection from hunters. Despite that measure, the population has not recovered. There are still only 500 whales in the St. Lawrence today. Why this number fails to increase has been a mystery. Some marine biologists have pointed to low reproductive rates among the small population or to the degradation of their habitat by hydroelectric projects. But over the past dozen years, my colleagues and I have uncovered another reason.

Victims of Pollution

My investigations began in the fall of 1982, when I went with a local veterinarian, Daniel Martineau, to see a dead beluga beached on the St. Lawrence shore. The whale was relatively small but stood out clearly on a bed of dark pebbles in the late afternoon sun. It seemed smooth as plastic and whiter than the froth on the breaking surf. "Let's open it," Martineau suggested. The subsequent laboratory work showed that the whale had probably died from renal

failure. Tissue samples revealed that it was heavily contaminated with mercury and lead as well as polychlorobiphenyls (PCBs), DDT, Mirex and other pesticides. Two dead belugas found later that same season were similarly poisoned.

In a way, the discovery was nothing new. Many scientists had documented high levels of PCBs and DDT in harbor seals and harbor porpoises elsewhere. These compounds, known as organohalogens, are highly soluble in lipids. Because they are not broken down in an animal's body, they accumulate in fatty tissues. The chemicals travel up the food chain, ultimately reaching the highest levels in top predators. A vast literature described sundry diseases associated with organohalogens—among them liver damage, gastric erosions, lesions of the skin and glands, and hormonal imbalances. But during the early 1980s, most experts believed that organohalogens posed little threat to marine mammals.

LAURIE GRACE

FLIP NICKLIN *Minden Pictures*

ST. LAWRENCE SHORES support numerous chemical manufacturers (*photograph*). Some 25 potentially toxic compounds—including PCBs and DDT—have been found in belugas living in the river. Many whales are further laden with Mirex. The pesticide was made throughout the 1970s near Lake Ontario. Mirex contaminated eels that migrated down the St. Lawrence (*map*), where they were taken as food by the belugas. The whales stay near the mouth of the Saguenay in summer (*red*) and spread out in winter (*blue*).

Still, curious as to why the population of St. Lawrence belugas had remained low despite protective measures, we continued our studies. Over the next 15 years or so, we recorded 179 deaths and examined 73 carcasses at the Faculty of Veterinary Medicine of the University of Montreal. Subsequent analyses confirmed that the entire population was highly contaminated with an array of chemicals. The salient pathological observations were stunning. Forty percent of the animals bore tumors, 14 of which were cancerous, representing more than half of all malignancies ever reported in cetaceans. There was also a high incidence of stomach ulcers, including three cases of perforated ulcers, a condition never before documented in whales. Forty-five percent of the females produced only small amounts of milk because of infection, necrosis or tumors in their mammary glands. Lesions of the thyroid and adrenal glands were common. And many animals seemed to suffer from compromised immunity: a disproportionate number had opportunistic bacterial and protozoan infections; others had multisystemic diseases; and several had lost teeth. One whale we examined was a true hermaphrodite.

In comparison, other species of Arctic belugas did not display any of these conditions. Nor did other species of whales or seals living in the St. Lawrence. Both groups did, however, contain the same toxic substances as the belugas, albeit in lesser amounts. The maximum levels of PCBs in Arctic belugas

COURTESY OF PIERRE BÉLAND

EXTENSIVE HUNTING of beluga whales once took place along the St. Lawrence River, as this photograph from 1918 shows. Whaling records indicate that more than 16,000 belugas were landed between 1866 and 1960.

were only some five parts per million (ppm), whereas St. Lawrence belugas had concentrations up to 100 times greater. Most tissue contained more than 50 ppm, which, according to Canadian regulations, made it toxic waste! We also discovered that the toxics were not confined to the fat in the blubber, as had been expected. Small amounts were found in the lipids present in other tissues, where they might have more readily injured vital organs.

Ill Effects of Organohalogens

Despite our findings, many marine biologists maintained that toxics were not at fault. They argued that even though the diseases and lesions we observed in the belugas matched the known effects of toxic chemicals, we had not yet demonstrated a cause-and-effect relationship. To do so, we had to single out a specific compound and the mechanism by which it might lead to disease. We turned our attention to the most striking disorder, cancer. Its incidence in the belugas was twice as high as in humans, higher than in horses and cats and only slightly lower than in dogs. If we restricted our comparison to cancers in the organs most often affected in whales—those of the gastrointestinal tract—the prevalence was more startling. It was exceeded only by that seen in sheep in Australia and New Zealand. There the high disease rate was attributed to treating pastures with carcinogenic herbicides.

We proposed that we had found a parallel situation of sorts. The sediments of the Saguenay contain tons of an extremely potent carcinogen, benzo(a)pyrene (BaP), which collects in invertebrates. For decades, one of the world's largest aluminum-producing complexes released BaP into the Saguenay.

We were able to demonstrate its presence in the belugas, but we were not certain how the BaP had entered their systems. The belugas are, however, unique among toothed whales in that in addition to eating fish, they dig into sediments to feed on bottom-dwelling invertebrates. Thus, it seemed reasonable to suggest that BaP had entered their systems in this way and had caused the higher rates of cancer found among the St. Lawrence belugas, ultimately

FLIP NICKLIN *Minden Pictures*

PHOTOGRAPHIC RECORDS have helped researchers Robert Michaud and Natalie Boudreau to identify more than 150 animals living in the St. Lawrence. By monitoring known whales, they hope to learn how often the females give birth and how many of those calves survive. They can also estimate the size of the herds and study their social structure and preferred habitats.

contributing to their decreased numbers overall.

Industry officials, of course, disagreed with our suggestions, and, to be fair, the cancer data were confounding. A variety of organs—the stomach, intestine, bladder, salivary gland, liver, ovary and mammary gland—were affected. But exposure to a given carcinogen usually harms a specific tissue. So it seemed probable that other toxics might be at work. We looked first to organohalogens, the chemicals that were most abundant in the whales. Although they were not directly carcinogenic, there was evidence that they could disrupt the expression of certain genes. Also, in many animals, organohalogens impeded the activity of killer *T* cells, immune cells that ordinarily destroy malignant tumor cells.

Moreover, when given to experimental animals during embryonic, fetal and early postnatal stages, the chemicals caused defects in the nervous, endocrine and reproductive systems. They further stunted the production of needed immune proteins and immune cells. It was highly likely that organohalogens had such effects on whales, which would explain why the St. Lawrence belugas had been susceptible to various cancers and many other types of disease as well. Some lesions observed among our samples indeed appeared to result from immunodeficiency.

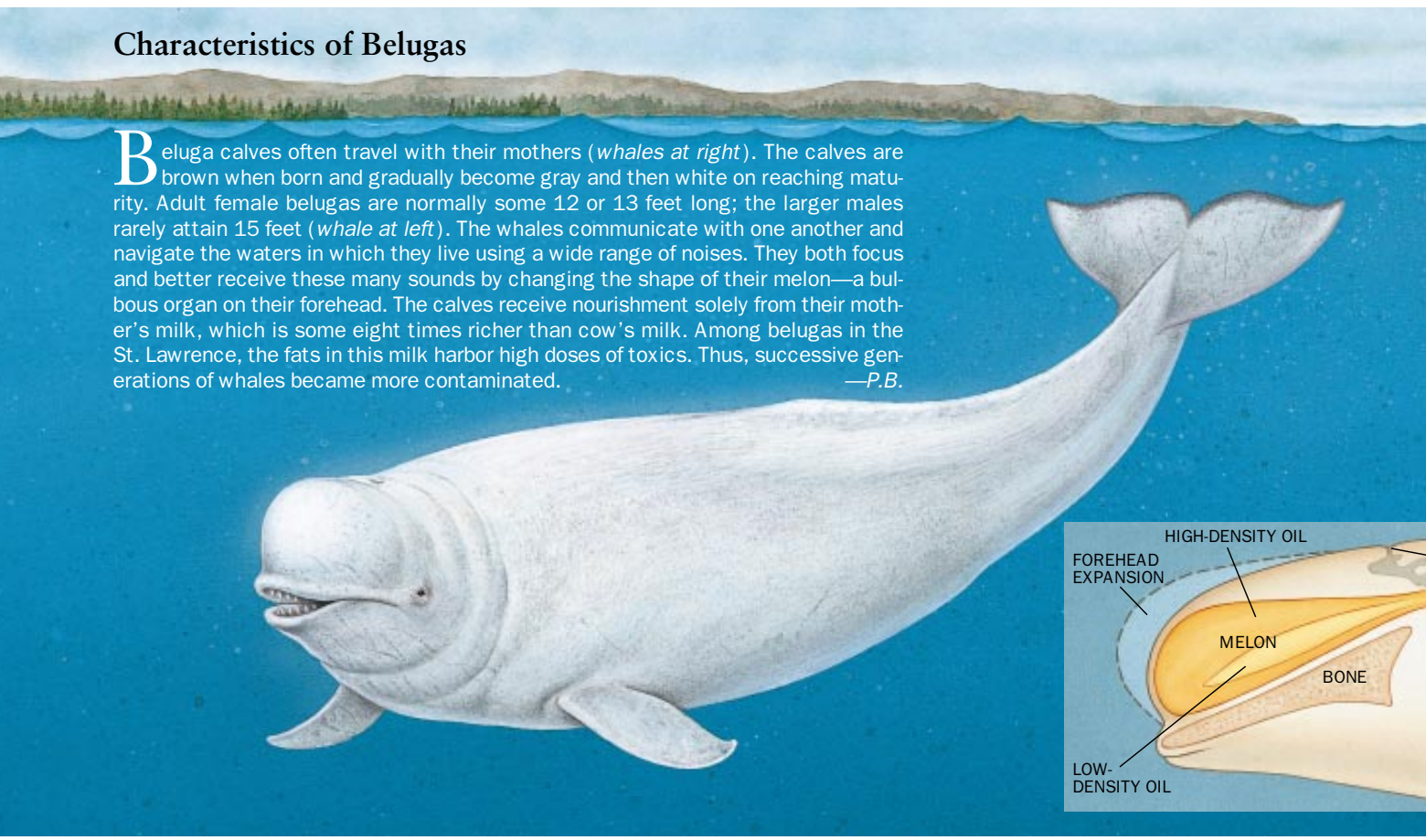
Pathologist Sylvain De Guise, who had already autopsied dozens of the whales we found, joined a team directed by Michel Fournier at the University of Quebec in Montreal. This group was analyzing blood samples from live animals to count the types of immune cells present and to test whether these cells were functional. We decided to use similar methods to examine blood samples from the contaminated whales to look for a relation between the levels of organohalogens in the plasma and the numbers and response of immune cells.

First, we needed to describe the immune cells in a beluga's blood and adapt the tests to them. For this, we used blood samples from Arctic whales held captive at the Shedd Aquarium in Chicago and from wild ones that we momentarily restrained in their natural habitat. Then we adapted our analytical methods to measure minute amounts of toxics in the plasma. In cultures from Arctic beluga, we saw that their immune cells underwent changes when they were exposed to organohalogens in the laboratory. A recent study in the Netherlands also showed that captive seals suffered a suppression in immune function when fed naturally contaminated fish. The chemical levels in these fish were comparable to those in the St. Lawrence fish. We hope to get a definitive answer by sampling a number of live whales in the St. Lawrence in the near future.

We are particularly interested in determining the minimum levels at which the ill effects of organohalogens arise. All the whales and seals in the St. Lawrence system carry organohalogens to various degrees, but not all experience as much trouble as do the beluga. We know that the larger animals typically have lower levels of toxics. For instance, the smallest whale, the harbor porpoise, is the most contaminated, whereas the largest, the blue whale, is the least affected. The reason is that the smaller whale requires more food per pound of its body weight than does the larger whale. Moreover, the harbor porpoise takes

Characteristics of Belugas

Beluga calves often travel with their mothers (*whales at right*). The calves are brown when born and gradually become gray and then white on reaching maturity. Adult female belugas are normally some 12 or 13 feet long; the larger males rarely attain 15 feet (*whale at left*). The whales communicate with one another and navigate the waters in which they live using a wide range of noises. They both focus and better receive these many sounds by changing the shape of their melon—a bulbous organ on their forehead. The calves receive nourishment solely from their mother's milk, which is some eight times richer than cow's milk. Among belugas in the St. Lawrence, the fats in this milk harbor high doses of toxics. Thus, successive generations of whales became more contaminated. —*P.B.*



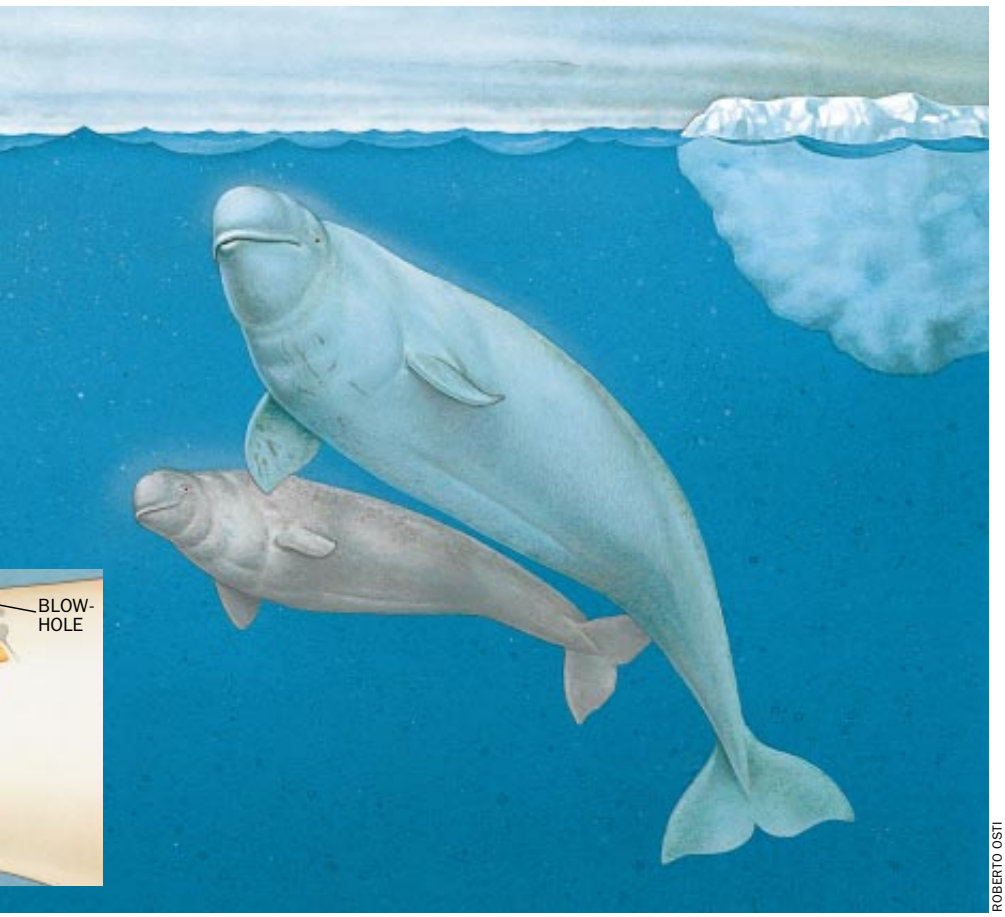
fish from high in the food chain, where organohalogens accrete. The blue whale consumes base-level plankton.

Beluga whales are in fact far more contaminated than their size would indicate, which we originally found quite puzzling. Knowing the typical chemical contents in a pound of blubber, we estimated the total amount of each chemical within the entire population of 500 animals. Allowing for all the food they have taken in over 15 years, our model showed that the concentrations of toxics in local fish were much too low to account for the total burden we saw. So there was very likely another source.

We found that source by researching one particular chemical, called Mirex. We had been surprised earlier in the 1980s to find this insecticide—used against fire ants in the southern U.S.—in whales in eastern Canada. A follow-up study revealed that all the Mirex detected in the belugas was made at a chemical plant in New York State near Lake Ontario. It had seeped into the lake, where eels collected it in their tissues. Every October the adult eels migrated to the Atlantic to reproduce, first swimming down the St. Lawrence through the beluga habitat.

Turning back to our model, we found that if the belugas had fed on eels for only 10 days each year over the course of 15 years, they would have taken in the amounts of Mirex we were measuring in their tissues. The model also indicated that other chemicals in the eels—such as PCBs and DDT—explained half of the total organohalogen concentration seen in the whales. At this juncture, I felt like a naive detective who had been trying to figure out how packages move between cities by searching highway vehicles at random. I got nowhere until I chanced on a mail truck.

By the late 1980s the amount of organohalogens measured in Great Lakes fauna had decreased substantially. But we saw no similar reduction in the belugas. At first we assumed that perhaps improvements in the whales would occur only after some delay. They are, after all, removed from the Great Lakes, both geographically and in terms of the food chain. But eventually, an alternative explanation came to mind, and it does not bode very well for the future.



ROBERTO OSTI

Up to 40 percent of the body weight of a beluga is blubber, and some 85 percent of that blubber is fat tissue, in which organohalogens concentrate. We noticed that organohalogen levels were often higher in very young animals than in older ones, contradicting the normal assumption that the toxics accumulated over the course of an animal's lifetime. We also found that the females were consistently less contaminated than the males. Taken together, these facts implied that the females passed significant amounts of chemicals on to their calves. We were able to prove the supposition by happening on a few females who had died shortly after giving birth. They were still producing milk, and it was some 35 percent fat. When tested, this fat held on average 10 ppm of PCBs, as well as other toxics.

Toxic Legacy of the St. Lawrence

The amount of toxics in the milk was only about a third of that normally found in the blubber of a female beluga. Still, it was an astounding amount—by human standards, anything containing more than 2 ppm of PCBs is considered unfit for consumption. It also meant that the toxics were transferred rapidly from mother to calf. The calf grows from about 50 kilograms at birth to 150 kilograms in one year by feeding on about four kilograms of milk each day. Assuming that the mother's blubber had 30 ppm of PCBs (and many adult females have more than three times that), that her milk fat had 10 ppm of PCBs and that roughly 70 percent of the PCBs were being passed on, over one year the mother would deliver to her calf about 3.8 grams of PCBs—translating into a concentration of 60 ppm in the blubber of the calf, or twice that found in the mother. All the while, the mother would consume 10 kilograms of fish a day, replenishing her own PCB load.

The milk provided the explanation. The suckling calf ingests food that is far more contaminated than its mother's food. In ecological terms, the calves feed at a higher echelon in the food chain, where the toxics have been further concentrated. Toxics first entered the St. Lawrence system in the 1930s and 1940s. We have a sample of beluga blubber oil from the early 1950s that contains 5 ppm of PCBs. We now know that every new wave of calves started out with a blubber level of toxics above that of their mothers. They then took in

Canaries of the Arctic Seas

Because belugas make an extraordinary range of noises—from whistles and creaks to clicks and warbles—the seafarers who first heard them named them sea canaries.

Although the number of belugas living in the St. Lawrence River has remained below 500 since the 1970s, experts estimate that some 100,000 belugas roam the Arctic seas around Alaska, Canada, Greenland, Scandinavia and Russia. One herd is shown in the bottom photograph at the right.

By tracking individual whales, scientists have learned that the whales often travel great distances, sometimes for several miles under the Arctic ice (*photograph below*). In place of a dorsal fin, belugas sport a long ridge of fibrous tissue on their back (*top photograph at right*). Using this ridge, they can break through several inches of ice to create a breathing hole. *—P.B.*

FLIP NICKLIN *Minden Pictures*

FLIP NICKLIN *Minden Pictures*

FLIP NICKLIN *Minden Pictures*

fish that also contained progressively higher levels of toxics every year. So each new generation started from a less advantageous position than had the one before it.

This reasoning should apply to all predatory aquatic mammals, depending to some extent on their strategy regarding fat reserves and lactation. Lipids are a valuable substance—especially in cold seas—to be hoarded and passed on to the next generation. But when fats contain nonbiodegradable toxics, this legacy may be as poisonous as bad genes. In theory, the young animals should show more evidence of the acute effects of toxics in the St. Lawrence. But unfortunately, few belugas in their first years have been found.

In fact, we believe not many calves are being produced. The females, and perhaps the males as well, may not be as fertile as expected. The toxics they were exposed to in the womb could have stunted their reproductive development. And the toxics they ingest as adults could be disrupting hormonal cycles essential for reproduction. Some years ago it was shown that captive seals fed naturally contaminated fish did not produce offspring. The seals had low levels of vitamin A and its precursors—elements that are necessary for growth, reproduction and infection resistance.

Obviously, calving and maturing of the young to adulthood are the keys to a population's survival. Robert Michaud and Daniel Lefebvre of the St. Lawrence National Institute of Ecotoxicology spend months on the St. Lawrence every year, observing the lives of belugas. They conduct surveys from the air, estimating the sizes of herds and identifying their preferred habitats. They also work from a small boat, calculating the proportion of young whales. They have used photographs to identify more than 150 animals, several of whom are females with offspring of various ages. It is hoped in the years ahead that they will be resighted, giving us some measure of how often the females give birth and how many of these calves survive. Also, by following known whales, we can study the social structure of the population and, using skin biopsies as well, assess the degree of genetic relatedness in social groups.

We have no definite answers yet, but all the evidence indicates that the St. Lawrence belugas have failed to increase in number because of long-term exposure to a complex mixture of toxic chemicals. We have approached the problem from various angles and intend to pursue each one further. Studying whales anywhere requires a great deal of dedication. On the St. Lawrence, it also takes a strong heart and some degree of aloofness. Because we know many of the belugas individually, sailing among them is somewhat like visiting relatives. We do not find ourselves in foreign waters surrounded by swarms of whales as in the days of Jacques Cartier. They come to greet us in small groups, and we realize how important each one is for the future. We can afford to spend time with them, for there are no new lands to be discovered—only old ones to be understood and preserved, a task for which there is no one to guide us. SA

The Author

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The Lost Technology of Ancient Greek Rowing

The navies of classical Greece took advantage of the sliding stroke, a technique that 19th-century competitive rowers later reinvented

by John R. Hale

In the classic age of oared galleys, Greek navies dominated the Mediterranean, and the Athenians dominated the other Greeks. While most states were relying on aristocratic cavalry or yeoman infantry for their military force, Athens mobilized thousands of lower-class citizens to serve as rowers in the fleet. Themistocles, the mastermind of this naval policy, endured rhetorical attacks from conservative rivals who said he had "robbed the Athenians of the shield and spear, and degraded them to cushion and oar." The reference to oars is sufficiently clear: 170 rowers were required to propel each of Athens's trireme warships (galleys with three tiers of rowers). But why mention cushions?

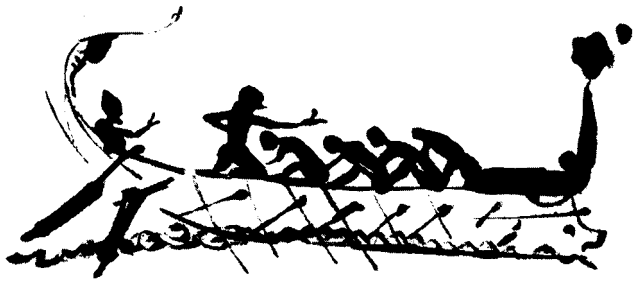
This cushion, or rowing pad, presents a riddle, one of many in the history of technology. I have proposed a solution to this mystery that suggests the cushions used by Greek rowers were in fact one of those modest technical advances—like the cavalry stirrup or the medieval longbow—that can decide the fate of empires. An enigma today, the rowing cushion was once so familiar that when the Greek geographer Eratosthenes wanted to describe Mesopotamia, he stated that it was shaped like a rowing cushion. Yet further written description of this object is lacking, and historians must depend on chance clues that have survived the wreck of the ancient world. Like so many items of technical apparatus, the device may never have been described or drawn in detail.

Fortunately, there is more information than the fact that the cushion was shaped like Mesopotamia—that is, broad in the middle with tapering ends. The rowing pad (*hyperesion* in Greek, meaning "under the rower") was indeed a cushion. The Roman and Byzantine scholars who wrote dictionaries to explain obscure terms in Greek texts variously defined the *hyperesion* as a fleece, a hide or a pillow that kept the rower from wearing out his rump. It is clear that the rowing cushion was tied to the rower: an Athenian orator complained of the ridiculous figure cut by his countrymen abroad when they went ashore wearing their rowing pads. And it is apparent that the cushion was a necessity. When the Spartans launched an amphibious attack against Athens in 429 B.C., each rower had to carry a rowing cushion along with his oar as he walked overland to the ships. Such descriptions are, however, uniquely Greek.

CRAIG MAUZY AND MARIE MAUZY; COURTESY OF THE ACROPOLIS MUSEUM

STONE RELIEF, discovered on the Athenian acropolis, depicts a triple-tiered Greek galley of the fifth century B.C. called a trireme. The posture of the rower with knees angled upward (*center*) suggests ancient Greek oarsmen used a sliding stroke to take advantage of the power of the rowers' leg muscles.

The Romans manned warships like those of the Greeks, yet Roman oarsmen used no rowing cushions. Indeed, the Latin language does not even have a word for such an object. Rowing cushions were also unknown on Venetian galleys in the Middle Ages and the Renaissance. Had they been used, it would surely have been recorded. The obsessively complete naval inventories of Venice detail every item, down to the rowers' caps. Is one to believe that the Greeks, including the famously austere Spartans, were so soft that they alone could not row on a bare bench?



COURTESY OF CAMBRIDGE UNIVERSITY PRESS

CORINTHIAN VASE DECORATION from the sixth century B.C. shows Greek rowers positioned with their knees raised.

To solve this puzzle, one must realize that different rowing techniques have evolved throughout history. Initially, some prehistoric inventor must have discovered that he could use his paddle as a lever if he tied it to the side of a boat and pulled. Thereafter, the efficiency of propulsion offered by rowing, as opposed to paddling, inspired the development of a vast family of rowing strokes. Techniques range from the "sculling" stroke of a Venetian gondolier, who sweeps a single oar back and forth in the manner of a fish's tail, to the "walking" stroke of medieval galleys, which required oars so immense that the rowers had to step forward and back as they worked. Rowing helped to carry the Vikings across the Atlantic and the Phoenicians around Africa. Human power was particularly critical to the navies of the ancient Greeks, whose warships were torpedolike galleys with heavy bronze rams affixed to their bows [see "Ancient Oared Warships," by Vernard Foley and Werner Soedel; Scientific American, April 1981].

Buckskin and Butter

Among the different rowing techniques that have evolved over time, there is one from the 19th century that, like the ancient Greek stroke, depended on the use of a leather pad. In the 1850s and 1860s, competitive rowers and scullers in the U.S., Canada and Britain began to experiment with a pad of "wash leather" (a soft, pliant leather) sewn to the seat of their rowing trousers. When these pads were greased, the rower could slide forward and back on his thwart (the flat board that served as the rower's seat), increasing the length of his stroke and adding the pistonlike thrust of powerful leg muscles to the motion of his arms and back.

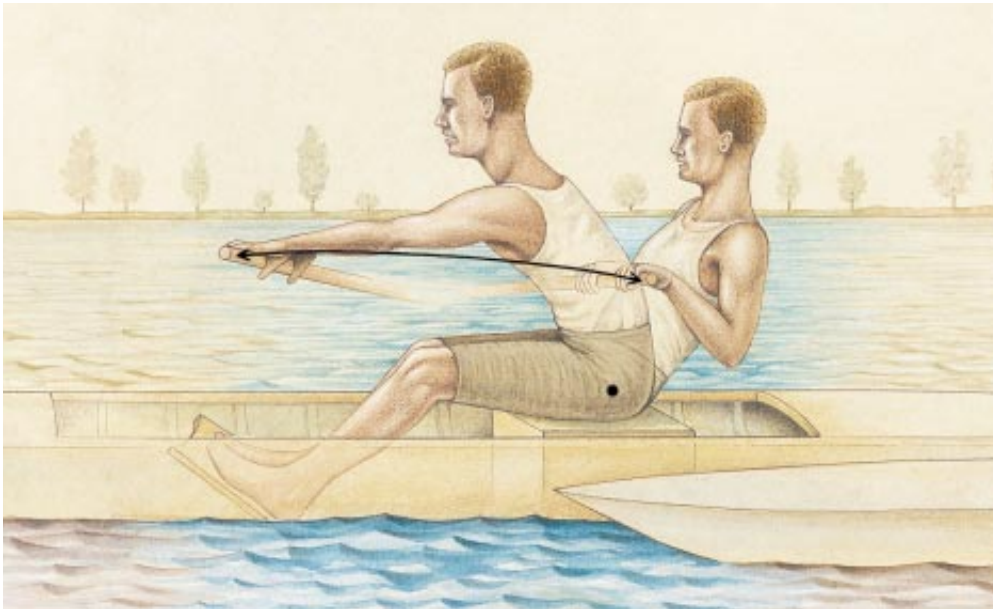
The 1871 edition of the *Annual Illustrated Catalogue and Oarsman's Manual,* by George T. Balch, sang the praises of this innovation. "The seat is made of a thin plank of hard, close-grained wood, usually cherry, the grain running fore and aft, and the surface smoothly polished. To reduce the friction still more, this surface and the oarsman's pantaloons, which should be reinforced with wash-leather, are lubricated with grease." Balch referred to this rowing technique as the "buckskin and butter plan." His catalogue of rowing equipment also advertised various medicinal potions to deal with the boils and blisters that resulted from the repeated sliding.

Because championship races of the day awarded as much as $4,000 to the winner, rowers eagerly sought new techniques that might give them a competitive edge in speed. Experiments have shown that every inch of forward movement on the handle of the oar translates to double that distance in the water. A sliding motion of only six inches adds a full foot to the beginning of the stroke—the most critical point in terms of leverage. Such performance was unattainable with a fixed seat, which forces a rower to use a sharp, dipping movement.

Nineteenth-century rowing races also resembled some naval contests of antiquity in the sense that the ability to make a sharp turn at high speed could mean

COMPETITIVE OARSMEN in England and North America rediscovered the advantages of the sliding stroke in the mid-19th century. An early 20th-century lithograph of a rowing race shows the bent-knee posture at the start of the stroke (*rowers in foreground*) and the full extension of the leg at the end (*rowers in background*).

AFTER HIBBERD V. B. KLINE; COURTESY OF THOMAS E. WEIL, JR.



ROBERTO OSTI

FIXED-POSITION ROWER uses arm and back muscles to work the oar through a relatively short stroke (*arrow*). The legs serve only to brace the rower, and knees cannot be raised too high without interfering with the rower's motions.

the difference between winning and losing. Victorian competitors normally dashed out to a fixed stake, doubled quickly around it and then rowed back over the same course to finish where they had started. A famous American painting of 1873 by Thomas Eakins, "The Biglin Brothers Turning the Stake," shows how a longer stroke from the rower on the outside of the curve could pry the boat around the turn. The sliding stroke—Balch's buckskin-and-butter method—offered the greatest advantage during such a maneuver.

The greased leather pad of the 19th century was eventually replaced by mechanical means to make the sliding motion even longer and easier: a seat mounted on wheels that rolled forward and backward on a wooden track. Such mechanical slides are now essential equipment on collegiate, club and Olympic racing shells. Even today, however, Australian lifeboat crews who race in heavy surf are unwilling to risk jamming or breaking a mechanical slide. Instead they sit on molded thwarts with a smooth polymer coating so that, like rowers of an earlier century, they can slide on a fixed surface.

Truth in Comedy

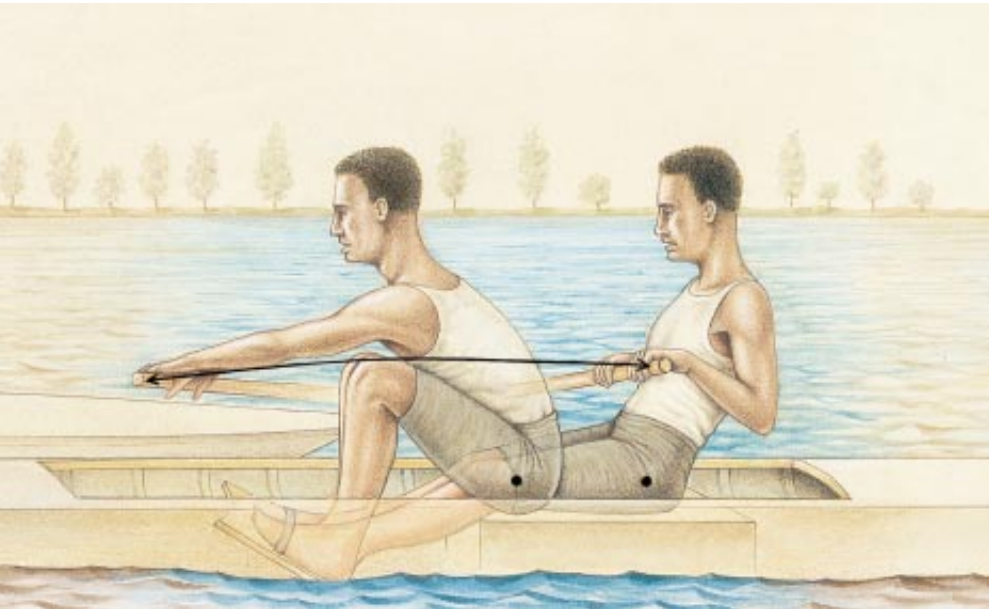
It is logical, then, that ancient Greek rowers used their cushions just as 19th-century rowers used greased wash leather: to allow a more powerful, sliding stroke. Is there evidence other than the use of a rowing pad that the Greeks employed a sliding technique? Indeed, artistic renderings, literary accounts and shipbuilding techniques all bear witness to this type of rowing. For example, painted pottery and sculptured reliefs show Greek rowers sitting with their knees bent upward—a strong visual clue to the use of the sliding stroke. These images also prove that the Greek rowers did not sit on raised benches but rather on low planks set at the same level as their feet. In this position, upper body movements are severely restricted, and sliding becomes the best method of delivering an effective stroke.

EVERETT COLLECTION

ROMAN GALLEYS had raised benches for the rowers (who were typically freemen, not slaves as pictured in the film *Ben-Hur*). These oarsmen thus could not have used the sliding stroke developed earlier by the Greeks.

Curiously, much information about the details of ancient rowing comes not from histories or technical manuals but from Athenian comic plays. These satirical comedies originally entertained audiences made up in large part of the poor citizens who manned the oars in the Athenian fleet. (The depiction in the popular 1959 film *Ben-Hur* notwithstanding, most rowers in classical navies were freemen, not slaves.) Aristophanes, for example, created a chorus of frogs that mocks the cries of a novice rower complaining of the blisters on his buttocks. The playwright Eupolis also wrote a scene intended to be familiar to rowers in which the tough old general Phormio taught an unwilling recruit how to row. "Stop splashing!"—the first of the angry general's commands—could apply to any rowing style. But his second shouted order—"Extend your leg!"—identifies the sliding stroke, in which the legs begin bent and then extend straight as the rower pulls through.

Greek naval engineers and shipbuilders developed designs that reflect the use of a sliding stroke. Greek triremes were



SLIDING-POSITION ROWER benefits from the added thrust of leg muscles, giving a longer stroke (*arrow*) and increased leverage. The sliding stroke begins with the knees flexed tightly and ends with the legs fully extended.

fitted with wooden "outriggers" on each side to carry the wooden pins to which the oars were secured. The outrigger was a point of vulnerability in battle, but it was necessary to accommodate the longer reach a sliding stroke requires. During the 19th century, the reintroduction of the sliding stroke brought with it a 30 percent increase in the distance between the rower and the oar's hinge point.

Nineteenth-century boat designers ultimately developed a low, streamlined hull in the quest for more speed. In the process, the rowing bench disappeared, and the oarsman's seat was lowered to the level of his feet. Ancient Greek naval engineers achieved the same result, but from an entirely different motivation. In order to squeeze more men into the hull, additional tiers of rowers were added above and below the original line of oars. This close packing required the legs of the upper rowers to be lifted so as to clear the oars of the men below.

For centuries, the evidence that rowers in Greek triremes sat at different levels was challenged by doubting scholars who considered the arrangement impractical. The reality of multitiered galleys, however, was triumphantly proved by John S. Morrison of the University of Cambridge, whose theories were brought to life in the reconstructed trireme *Olympias* [see "The Trireme Sails Again," by John F. Coates; Scientific American, April 1989]. The sea trials of this ambitious experiment in nautical archaeology validated a number of ancient claims, including the statement that these galleys made their fastest speed under a combination of oars and sails. It is clear, however, that during actual battles the trireme and other such ships were powered by rowers alone. The masts and sails were removed and left on shore, and most naval battles were fought at dawn, when calm seas favored optimal working of the oars.

Full Slide Ahead

Classic trireme warfare was one of the simplest forms of combat ever devised. It had but a single tactic: to smash and disable enemy warships by ramming them. This result could be achieved through two different maneuvers. Both were techniques for gaining an advantageous position off the stern or the rear quarter of the enemy vessel, and both required the ability to make a quick, sharp turn. Commanders avoided prow-to-prow ramming because such head-on collisions might cause as much damage to one's own ship as to the opponent's.

In a stratagem called the *diekplous* (Greek for "rowing through"), a ship broke the enemy's line by charging straight through the gaps between opposing vessels into the open water behind. Once clear, the attacker wheeled quickly around to strike its rival's exposed stern or quarter. The second popular maneuver was the *periplous* ("rowing around"). If the enemy attempted to close ranks or double its line to prevent a *diekplous*, the attacker could take advantage of the shorter line by simply rowing around it at either end. Both the *diekplous* and the *periplous* required the attacker to execute a hairpin turn behind the enemy line without losing so much speed as to become itself a sitting, broadside target.

One readily sees the advantages con-

AFTER SYDNEY HALL; COURTESY OF JOHN R. HALE

NINETEENTH-CENTURY ROWERS, such as the world champion James Renforth of Newcastle (depicted in this wood engraving), adopted the sliding stroke in the 1850s and 1860s. These rowers initially used greased leather patches sewn to the seats of their pantaloons to slide freely. Later, movable mechanical seats were devised.

ferred by a sliding stroke in the duel fought between two Greek galleys in late October of 429 B.C., during the early stages of the Peloponnesian War. The Spartan commander Timocrates was chasing into port the Athenian Phormio in the flagship *Paralos*. Phormio could not turn to confront his pursuer without exposing the vulnerable flank of his own trireme to the Spartan's ram. But by chance a merchant ship had anchored outside the harbor. As the *Paralos* drew abreast of this stationary vessel, Phormio gave the command to turn.

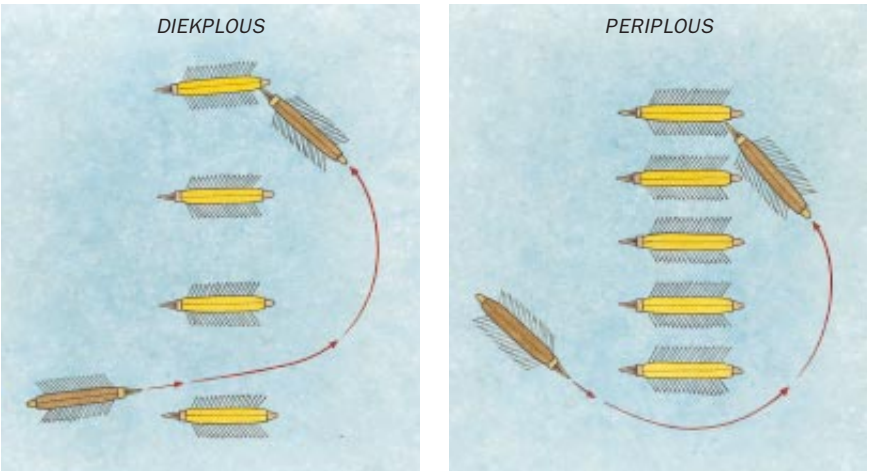
Using the anchored merchantman as a screen, the Athenian crew executed a tight 270-degree turn so quickly that the Spartan ship had no time to take evasive action. Phormio struck the enemy amidships with his ram, destroying the Spartan trireme. Timocrates was so shamed by the sudden reversal of fortune that he killed himself on the spot. The Athenians had indeed capitalized on the advantages afforded by the sliding stroke. Phormio and his highly trained crew had brought the full-speed turn to the point of perfection.

In certain ancient naval engagements, neither the *diekplous* nor the *periplous* was effective. The advantage then remained with the ship that could execute the most rapid 90-degree turn in the smallest space. Such agility allowed a straight dash at the enemy line to terminate in an abrupt swerve intended to drive the attacker's ram against the flank of the opponent's vessel.

The most famous use of such an abbreviated turn occurred at Salamis in late September of 480 B.C. That island was the site of a fierce battle between an alliance of free Greek cities led by Athens and the invading armada of King Xerxes of Persia. The core of Xerxes' naval strength was a Phoenician fleet from Tyre and Sidon (ancient cities situated in what is now southern Lebanon). The Phoenician triremes lacked outriggers, which strongly suggests that, unlike their Greek adversaries, they did not use a sliding stroke.

At Salamis, the heavily outnumbered Greeks could not use the *diekplous* or the *periplous,* because the huge Persian fleet jammed the straits from shore to shore. Indeed, the Greeks were more vulnerable to both maneuvers because of their smaller numbers. So they seized the initiative and attacked before the Persians had a chance to break or encircle the Greek line. An eyewitness reported that the first Greek ship to engage the enemy carried out a sharp turn to such good effect that its ram entirely sheared off the enemy's prow. Many other Greek advances were similarly successful, and the Persian line was soon clogged with disabled ships attempting to turn and escape into the crush behind. So many ships on the Persian left wing were disabled that the Athenians were finally able to force their way around in a rudimentary *periplous,* thus surrounding the enemy fleet. Had the Persian ships and crews been capable of the same sharp turns at high speed, the Greeks could never have won the critical initial advantage.

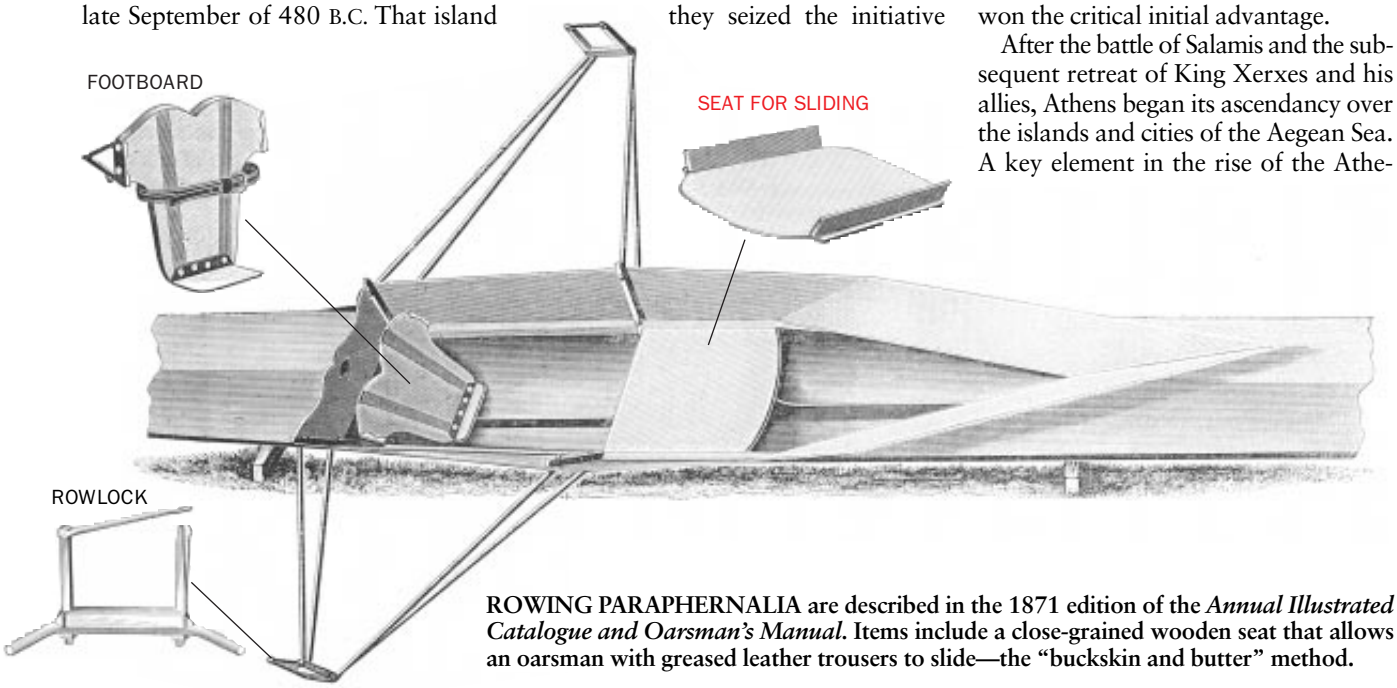
After the battle of Salamis and the subsequent retreat of King Xerxes and his allies, Athens began its ascendancy over the islands and cities of the Aegean Sea. A key element in the rise of the Athe-



ROBERTO OSTI

GREEK TRIREME WARFARE in the fifth and fourth centuries B.C. used ramming as the primary offensive weapon during naval engagements (*far right*). An attacking vessel frequently positioned itself on the vulnerable side of the enemy's line, using one of two maneuvers, the *diekplous* or the *periplous* (*panels above*).

MARK MYERS



COURTESY OF THOMAS E. WEIL, JR.

ROWING PARAPHERNALIA are described in the 1871 edition of the *Annual Illustrated Catalogue and Oarsman's Manual.* Items include a close-grained wooden seat that allows an oarsman with greased leather trousers to slide—the "buckskin and butter" method.

nian empire was the willingness to commit the time, money and manpower to build a standing navy. Athenians paid 12,000 rowers to train for a full eight months of the year, in part because the sliding stroke required extensive practice for complete mastery.

Technology Lost and Found

Given the superiority of a sliding technique for trireme warfare, why was it ever abandoned? The Athenians themselves saw no reason to meddle with an effective method. Inevitably, though, states that found themselves unable to compete with Athenian ships developed innovative techniques of their own. In 400 B.C. the Carthaginians launched the first quadriremes, or "fours." This new type of galley initiated an arms race in which the means to success lay in multiplying the number of rowers on each oar. (The trireme had always used just one man per oar.) As ships and crews grew larger, the brute force of unskilled muscle superseded the finesse of the Athenian professionals, with their long and intense periods of training. Tactics also changed. Pulling enemy ships alongside with grappling hooks and boarding replaced ramming as the chief offensive maneuver, and warships became little more than mobile platforms for small armies of foot soldiers. The sliding stroke seems to have survived only in a few backwaters. Mention of the rowing cushion appears for the last time in a papyrus document that lists gear for a small Greek galley operating on the Nile River, several centuries after triremes had given way to larger ships carrying more men.

During the period when highly skilled rowing had been appreciated and rewarded, its benefits had made Athens the greatest naval power in the ancient world. The Athenians themselves were well aware of the part that their rowing technique played in the victory over the armada of King Xerxes—the beginning of their naval dominance. In a scene from a comedy by Aristophanes, an old man named Demos (in the satire he represents the "Everyman" of Athens) starts to take a seat on a rough stony surface. A fellow Athenian immediately offers him a cushion, so that Demos will be in no danger of wearing away the rump that "served so well at Salamis."

The means may have been humble, even comical. But the end result was a century of naval supremacy that built Athenian hegemony in the Aegean. The tribute from this maritime empire built the Parthenon, financed Athenian democracy, sponsored the plays of Sophocles and Aristophanes, and laid the cornerstone for the Academy of Plato and Aristotle. Yet the Golden Age of Athens was in fact founded on the sweat of a few thousand skilled rowers—and a little buckskin and butter. SA

The Author

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Hanford's Nuclear Wasteland

by Glenn Zorpette, *staff writer*

Over the next 75 years, the U.S. government will undertake what has been called the largest civil works project in world history in an expansive desert in southeast Washington State. When the project is over, at a cost of well over $50 billion, there will be no sprawling rocket-launch center or string of advanced electricity-generating plants or other inspiring monuments to progress. What there will be, mostly, is radioactive detritus, millions of tons of it, ranging from contaminated soil to entire nuclear reactors. It will all be on a large plateau, buried in vast landfills or stashed away in a collection of nondescript buildings. And there it will stay, probably for thousands of years to come.

Such is the future of the Department of Energy's Hanford site, the original U.S. plutonium-production complex and the source of the plutonium used in the bomb detonated over Nagasaki, Japan, during World War II. From those early days of military and technological glory, the 1,450-square-kilometer Hanford site has slowly devolved into a nightmarish agglomeration of decaying, contaminated facilities that each consume tens of millions of dollars a year just to be kept stable or safe.

In 1989 the DOE began deactivating and cleaning up Hanford. At last count, there were about 14,300 contractor workers and 550 DOE employees at the complex, and an estimated 1,400 different places where environmental work had begun or was needed. At several hundred of these sites, liquid or solid nuclear wastes had been intentionally dumped: since 1944 the DOE and its predecessors are believed to have pumped 1.3 billion cubic meters of liquid waste and contaminated effluents into Hanford's soil.

Over the past seven years, the DOE has spent $7.5 billion cleaning up Hanford. It expects to spend at least $1 billion at Hanford every year for the next four decades. The cleanup has attracted far-flung interest, and not just because of the sums involved. "This is absolutely brand-new—not only to industrial society but to humankind," says Roy E. Gephart, a program manager in the environmental and energy sciences division of Battelle Pacific Northwest National Laboratory in Richland, Wash. "There will be difficult political, social and technical trade-offs as we approach cleaning up this site."

In an effort to determine how well the cleanup is proceeding, SCIENTIFIC AMERICAN examined several dozen recent reports and other documents, some not yet officially released, and conducted scores of interviews with cleanup workers, administrators and scientists at Hanford as well as with key DOE officials and others in Washington, D.C. The picture that emerges from this research is not encouraging. In addition to the contaminated soil and water, dozens of potential disasters vie for attention, including:

- 177 huge underground tanks of high-level nuclear waste, some of which have leaked or are building up heat or flammable gases;
- At least a dozen tons of dangerous plutonium, some of it in the soil or otherwise unsecured;
- Five gigantic and profoundly contaminated buildings where plutonium was extracted from irradiated nuclear fuel;
- 2,100 tons of irradiated fuel, in basins that in an earthquake could become lethal, radioactive dustbins.

Not surprisingly, questions have been raised about virtually every aspect of the Hanford project. They concern whether the work is being done properly and efficiently, how cleanup contracts are being written and the possibility that a mishap could cause a radiological disaster. The most significant accomplishment of the past seven years may be an arrangement that has enabled parties with conflicting interests—principally the state, the DOE and the Environmental Protection Agency—to begin working with one another. Unfortunately, adherence to the agreement has hindered planning and priority setting, several studies have found.

"We've been on this cleanup effort for six years, and we're still not out of the starting block," states a scientist who has worked at Hanford for two decades. "No program—for tank cleanup, groundwater remediation or anything else—has lasted more than about two years. We're not sustaining a long-term vision, and investment in that vision, long enough to make any progress."

U.S. DEPARTMENT OF ENERGY/BOEING

Cold War Leftovers

Huge as the Hanford project is, it is just one piece—about a fifth—of a DOE program to close down a large part of its vast nuclear-weapons enterprise over the next century, give or take a few decades. Estimates of cleanup costs range from $230 billion to more than half a trillion dollars—well in excess of the $375 billion it cost, in current dollars, to research and build the tens of thousands of weapons that were assembled in the U.S. and to detonate the 1,000 or so that were tested. Government officials expect to spend fully 70 percent of the money on just five DOE sites, including Hanford.

The imprecision of the time and cost estimates results in part from the lack of agreement on how "clean" the former weapons sites will need to be on that far-off and probably chimerical day when they are formally declared rehabilitated. "There can't be

The U.S. is spending billions to clean up its nuclear weapons complexes. At one of the most contaminated sites, no one knows how much the project will cost, how long it will take or how much good it will do

cleanup in the traditional sense, like you clean up a kitchen floor or a hazardous chemical site in the civil sector," notes James D. Werner, director of strategic planning and analysis in the DOE's Office of Environmental Management. "The stuff we're dealing with can't go away until it decays. You can containerize it, solidify it, immobilize it and move it, but you can't make it go away."

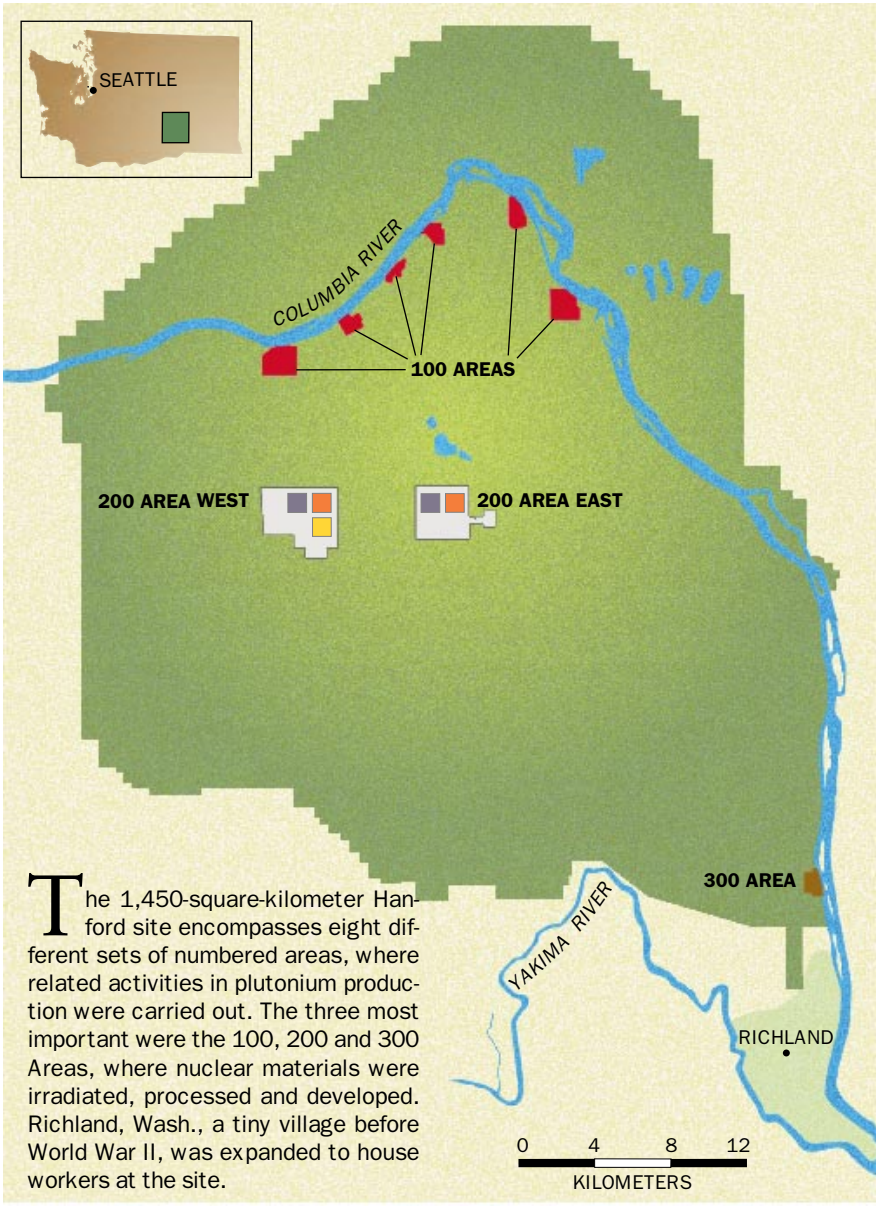
Understanding how and why this colossal mess was created requires a bit of history. Starting with the Manhattan Project, the U.S. assembled an enormous industry for manufacturing nuclear weapons. A great deal of the enterprise was devoted to making plutonium, a basic element of nuclear weapons and the cold war's coin of the realm. The metal is derived from uranium, which was processed or fashioned into nuclear fuel at complexes in the states of Idaho, Kentucky, Ohio and Tennessee.

The uranium was irradiated and chemically treated to create plutonium at sites near Hanford, Wash., and Aiken, S.C.; the plutonium metal was machined into bomb components at Rocky Flats, Colo. Those parts came together with hundreds of others into finished weapons at a plant called Pantex in the Texas Panhandle.

At these sites, the cold war ethos em-

HIGH-LEVEL NUCLEAR WASTE TANK sits about three meters underground. Ports and risers admit instruments for monitoring and sampling of the waste. These entry tubes are normally sealed by the plates visible in the photograph.

How Hanford Became Contaminated: Some Examples



The 1,450-square-kilometer Hanford site encompasses eight different sets of numbered areas, where related activities in plutonium production were carried out. The three most important were the 100, 200 and 300 Areas, where nuclear materials were irradiated, processed and developed. Richland, Wash., a tiny village before World War II, was expanded to house workers at the site.

MICHAEL GOODMAN

NUCLEAR REACTORS
All but one of Hanford's nine nuclear reactors, which created plutonium in fuel rods, drew water from the nearby Columbia River, ran it through the reactor to cool it and then discharged the water back into the river. When fuel claddings ruptured, radioactive elements contaminated the water, which was diverted to the soil and flowed back to the river. All the reactors also had nearby burial grounds, where workers dumped solid objects, including some extremely radioactive ones.

REPROCESSING CANYONS
Five reprocessing canyons were built (three in 200 Area West and two in 200 Area East) to extract plutonium from irradiated nuclear fuel. Workers poured millions of cubic meters of relatively lightly radioactive and chemically contaminated wastewater into the soil. In the 1940s and early 1950s, more strongly radioactive wastes from one plant were injected hundreds of feet below ground. At the same time, large quantities of radioactive iodine were released into the air from two plants.

HIGH-LEVEL WASTE TANKS
A total of 177 tanks (91 in 200 Area East and 86 in 200 Area West) store 210,000 cubic meters of highly radioactive nuclear waste, a by-product of reprocessing. Sixty-seven of the tanks are known or suspected of having leaked an estimated 3,700 cubic meters of the intensely radioactive waste into the soil.

PLUTONIUM FINISHING PLANT
From this plant, wastes containing transuranic elements, such as plutonium and americium, were pumped into the ground. Many industrial solvents and other chemical contaminants were also discharged, including carbon tetrachloride, tributyl phosphate, aluminum fluoride nitride, and lard oil (the latter was used as a cutting oil in the machining of plutonium metal).

EXPERIMENTAL FACILITIES
A plutonium laboratory, nuclear-fuel fabrication facilities and six small test reactors all occupy what is known as the 300 Area. Waste and uranium-bearing liquids were sometimes discharged into the soil from the laboratories and facilities, as were contaminated coolants from the reactors.

phasized production above all else. Starting with the Atomic Energy Commission in the 1940s, the agencies that oversaw the weapons complexes were essentially unconcerned with environmental degradation. (Nor, it seems, did Congress pay it much heed.) The DOE and its predecessors answered to no outside regulators and, it is now known, obscured or lied about operations and conditions inside the complexes.

A turnaround began in the mid-1980s, when a series of landmark rulings in federal courts established the applicability of state and federal environmental laws and regulations to DOE activities. (Notably, however, the DOE continues to regulate itself where certain nuclear materials, such as uranium and plutonium, are concerned.) During the late 1980s, newspaper investigations began offering the first hints of the extent of the contamination inside some of the complexes, intensifying the pressure on the department to fundamentally change its activities with regard to the environment and safety.

For the DOE, becoming an externally regulated entity was difficult and sometimes traumatic. At the Rocky Flats complex near Denver, where the department's contractors machined plutonium, allegations of secret violations of environmental laws and dangerously deteriorating conditions prompted a federal raid in 1989 and a subsequent lawsuit against the plant's main contractor, Rockwell International. In a plea bargain, Rockwell paid $18.5 million, and the charges were dropped.

At about the time of the Rocky Flats episode, the DOE formally faced the inevitable by creating the Office of Environmental Management (which expanded on the existing Office of Waste Management). This year Environmental Management will receive $6.026 billion of the DOE's total budget of $16.3 billion ($3.4 billion still goes toward weapons work). In comparison, the entire 1996 budget of the EPA (not

finalized at press time because of the federal budget impasse) is likely to be $5.7 billion. In effect, the DOE is being painfully transformed into a huge environmental agency that has so far shown little aptitude for its core mission.

Only lately, as part of Energy Secretary Hazel R. O'Leary's initiative to make the DOE more open about its past and present, has the department begun revealing the extent of its transgressions. The DOE and its contractors generated hundreds of thousands of cubic meters of highly radioactive and hazardous waste and billions of cubic meters of less radioactive effluents. The DOE now admits that enormous amounts of the liquids and solids were simply pumped or dumped into the ground. Most of the wastes contain both radioactive and chemical contaminants.

At some places where releases were intentional, scientists tried to estimate how much contaminant the soil above the groundwater could adsorb; operators were then supposed to limit discharges to 10 percent of that amount. Judging from the groundwater problems at most large DOE complexes, the technique was rarely or inadequately applied. In recent years, a series of liquid-effluent treatment plants have begun operating to clean up the discharges before they go into the ground.

There were accidental releases of waste, too. Almost all are attributable to carelessness: high-level radioactive wastes sometimes leaked from aging storage tanks into the soil, as did contaminated water from basins containing spent nuclear fuel or other materials. Millions of curies of potentially harmful radioactive materials were also released into the air and nearby river water at Hanford and other sites, sometimes intentionally.

Some of the damage is permanent; cleanup technologies either do not exist or could never make a dent in the level of contamination. For example, at Hanford, a plume of groundwater containing tritium, nitrates and other contaminants occupies at least 250 square kilometers and is leaching into the Columbia River, which runs for 82 kilometers through Hanford. It is practically impossible to separate tritium, a radioactive isotope of hydrogen, from water. The contaminated plume is only one of dozens below the site.

The DOE estimates that throughout all the weapons complexes, billions of cubic meters of soil, groundwater and surface water are contaminated. Along with their counterparts in the former Soviet Union, these are the grievously disturbed battlefields of the cold war.

Nightmare in 177 Tanks

The DOE has been working longest to stabilize and remediate Hanford, making the site a proving grounds of sorts for the many other complexes where work is less advanced—including those in the former Soviet Union. This year $1.353 billion of the Environmental Management budget, the largest share, will go to Hanford; by the end of this fiscal year, almost $9 billion will have been spent at Hanford on work designated as environmental. The lack of apparent progress, however, has prompted many observers to wonder where exactly the money has gone.

The simplest reason why so little progress is apparent is that, unfortunately, the remediation of contaminated soil and water is one of the least urgent items on Hanford's agenda. Of the many other, more pressing issues, the 177 high-level waste tanks are the biggest, most complex and most costly by far. One contractor has estimated that this job alone could cost $50 billion. Nevertheless, until quite recently, the tank farm was tended by some of Hanford's worst workers. It was "a Siberia for a lot of derelicts on the site," says Roger F. Bacon, Westinghouse Hanford Company vice president in charge of the tank program.

To instill discipline in the program, Westinghouse Hanford recently brought in Bacon, a tall, broad-shouldered former navy admiral and submarine commander who looks the part. Bacon, who wrote the forward to one of Tom Clancy's books, now has in the tank-waste project a mission far more daunting than anything ever dreamed up for a techno-thriller. The tanks, many the size of the U.S. Capitol dome, store 210,000 cubic meters of intensely radioactive, high-level nuclear waste. Almost half of Hanford's known accumulation of roughly 450 million curies of radioactivity sit in the tanks—a hellish mixture of liquids, gases, peanut-butter-like sludges and rocklike "salt cake."

Sixty-seven of the 177 tanks are known or suspected of having leaked an estimated 3,700 cubic meters of waste into the soil. Fifty-four tanks are continuously monitored, about half because they occasionally build up flammable gases inside—creating the possibility, though slight, of a radiation-releasing chemical explosion. The DOE spends $80 million a year just to maintain the tanks and keep them safe.

Almost all the tank waste was generated as a by-product of the isolation of plutonium from spent nuclear fuel. Single steel shells covered by reinforced concrete make up 149 of the tanks, including the 67 that have or may have leaked; the rest have more leak-resistant double shells. Although they were intended to hold some radioactive products with half-lives of thousands of years, the tanks were designed to last only 25 years—and were built without any means for draining the waste.

The first of the single-shell tanks were finished in 1944. By 1959, weapons officials at the DOE's predecessor agency knew that some of them had leaked. "Yet they kept building them until 1964 and kept introducing waste into them until 1980," notes Andrew P. Caputo, an attorney with the Natural Resources Defense Council, a watchdog group. "It's hard to explain this history in a rational way."

The tanks contain waste from three different reprocessing technologies. Intermittently, other chemical processes were used to mine the tanks of useful or troublesome isotopes. When some of the tanks started leaking, waste was shifted around from tank to tank—and, inevitably, mixed together—to avoid the leaking vessels.

The DOE is being transformed into a huge environmental agency that has shown little aptitude for its core mission.

The bottom line is that DOE officials do not know exactly what is in the tanks. That information is necessary for several reasons. A legal agreement with the state of Washington obligates the federal government to mix the waste with glass (a technique called vitrification) for eventual disposal in a high-level nuclear-waste repository. But the waste cannot be safely or efficiently vitrified until the DOE and its contractors know its composition. The waste's in-

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PLUTONIUM "BUTTON" was Hanford's sole product. Consisting mainly of the isotope plutonium 239, the buttons were sent to be machined into bomb parts in Colorado. The metal must be handled in glove boxes, such as the one shown here, because extremely minute quantities of the metal in the lung can induce cancer. Currently the DOE has no long-term plans for its plutonium.

gredients may be different even in different parts of individual tanks.

The "tank-waste characterization" program, which seeks to specify what is in the tanks, has been a lightning rod for criticism. "They've been doing this for 10 years and have spent $260 million, and only now are they at a point where they can take samples at a reasonable rate," says William R. Swick, senior evaluator for energy and science issues at the Richland bureau of the General Accounting Office (GAO). Sampling of the tanks is hindered by the high radioactivity and toxicity, which make access difficult and dangerous, and by the waste's multiplicity of physical states and ongoing chemical activity.

Deadly Bullion

Until recently, plutonium was Hanford's raison d'être, but now it is just another big and expensive headache. For 40 years, plutonium nitrate solutions were brought from the reprocessing facilities to the on-site plutonium-finishing plant, where the element was converted into dull, leadlike "buttons," about the size of hockey pucks, for further machining. Eleven tons of plutonium sit in storage at Hanford, much of it under tight security in vaults at the finishing plant. In addition, an estimated 1.5 tons are believed to be in waste dispersed in the soil around the site or in pipes and filters in its facilities.

Plutonium exists in many forms at Hanford. There are tiny scraps of it, and it is present in sludges and in 3,500 liters of nitrate and other solutions. At the finishing plant, workers have begun cleaning out countless air ducts, filters and "glove boxes" where the metal was extracted and handled. They are also bringing plutonium to the finishing plant from other Hanford sites, to consolidate the element in one place. Most of it will be baked into oxides or other reasonably stable, powdery forms for long-term storage. The work is slow and expensive because plutonium is extremely dangerous; a mere 27 micrograms in the lung can bring about cancer.

Workers must also be mindful of the metal's critical mass—which can be as little as 11 kilograms. If the critical mass is allowed to accumulate in one place, a spontaneous fission chain reaction known as a criticality can occur, releasing a lethal shower of neutron and gamma radiation. In the history of the U.S. nuclear weapons program, there have been eight known accidental criticalities and two fatalities, both in New Mexico in the mid-1940s.

Lately, there have been a few close calls (technically, "criticality infractions"). In late September 1994 a worker drained liquid from a tank at Rocky Flats, leaving five liters of highly concentrated plutonium solution in what the Defense Nuclear Facilities Safety Board called "a potentially unsafe geometry." There was also a near miss several years ago at the Idaho site, when some fuel bundles suspended in a pool fell to the bottom near one another.

During the mid-1980s, Hanford's plutonium-finishing plant was declared a serious earthquake risk. One analysis found that a temblor could rend a construction joint, possibly releasing plutonium compounds into the air. This threat has been pushed into the background by other risks and changing priorities.

Plans for disposing of the scavenged plutonium—not only at Hanford but also at Rocky Flats, Savannah River and Pantex—have been stymied by the DOE's inability to decide whether plutonium should be hoarded for possible future use. "The largest factor affecting the cleanup scope relative to plutonium is the absence of a national policy on whether some or all of the plutonium at Hanford is an asset to be maintained in inventory or a waste to be disposed of," wrote analysts Steven M. Blush and Thomas H. Heitman in a recent congressional report on Hanford's cleanup. The DOE spends about $82 million a year maintaining the plutonium just at Hanford's finishing plant.

Costly Canyons

The reprocessing plants, where plutonium was extracted from irradiated fuel before being sent to the finishing plant, are another financial burden. Hanford has five of them, each in concrete buildings called canyons. Some of the canyons are comparable in size to the Empire State Building, if it were ly-

ing on its side. Each has internal radiation levels ranging from slight to deadly. Their inner surfaces, air filters and duct systems contain large quantities of dangerous radioactive elements.

In one of the canyons, known as B-plant, room-size air filters may have collected as many as 100 million curies of radioactive cesium and strontium, SCIENTIFIC AMERICAN has learned. Such a vast accumulation of radioactivity will make demolition of the building—as required by an agreement between the federal government and the state—extremely difficult. A better estimate of the radioactivity is not available, because it is so high that "we don't have instruments to measure it precisely," a Hanford scientist admits.

The canyons are heavily reinforced to withstand bombing and have massive shields in the walls to keep the radiation in. Currently maintenance and surveillance at each of the five reprocessing plants costs $35 million to $45 million a year. The DOE and Westinghouse Hanford, however, are attempting to decontaminate B-plant and another canyon, called Purex; they hope to put them into a state requiring relatively little maintenance. (The catchphrase at Hanford is "controlled, clean and stable.") The three-year projects aim to reduce annual expenses to $1 or $2 million a year.

At B-plant, though, about $10 million a year will still be needed to sustain the attached Waste Encapsulation Storage Facility. It houses water-filled pools that cool and shield some 1,900 capsules, each containing either cesium 137 or strontium 90. The isotopes were removed from the high-level waste tanks years ago to make the waste less thermally and radiologically hot.

The isotopes have half-lives of about three decades, but the radiation level at the surface of one of the capsules is enough to deliver a fatal dose in four seconds. The radiation is so intense that its interaction with the water around the canisters causes a bright blue glow, like a gaudy effect in a science-fiction movie. Some analysts have questioned how long the capsules can be kept as they are. Blush and Heitman, for example, wrote last year that "Hanford has no technical basis for assuring that WESF [the encapsulation storage facility] may be relied upon for long-term safe storage of these capsules."

The cesium and strontium capsules are the proverbial tip of the iceberg, in terms of Hanford's inventory of solid radioactive waste. In 40-year-old, water-filled basins near the Columbia River, the DOE and its contractors have been storing 2,100 tons of spent nuclear fuel, much of it corroded and releasing radioactive elements into the basin water. A strong earthquake, it was realized, could release up to 9,000 cubic meters of contaminated water from the basins into the soil and river, allowing radiation in the area above the basins to soar to lethal levels and dispersing fine radioactive particles into the air. In fact, in the 1970s a large quantity of contaminated water did leak from the basins, as did a lesser amount in 1993. (No radiation was dispersed into the air, because the leaks were slow, enabling additional water to be pumped in to keep the fuel bundles submerged.)

The DOE spends about $30 million a year maintaining the basins in this unsettling state. But a $700-million crash program to convert the fuel for stable, dry storage in an interim repository on high ground is about to begin. When completed, around the year 2000, the maintenance costs are expected to drop to about $1 million a year. As with Hanford's plutonium and cesium and strontium capsules, the ultimate disposition of the spent fuel is uncertain.

A New "Cleanup"

All told, about $600 million of Hanford's annual budget goes toward paying what cleanup officials call the cold war "mortgage"—safely maintaining buildings and plants, many old and decaying, and keeping them from leaking more radiation into the air, water and soil. In addition to the need to spend vast sums paying the mortgage, there are more complex reasons why so little actual cleanup has been achieved.

When the DOE's contractors at Hanford are not trying to keep urgent risks from becoming disasters, they are generally rounding up contaminants that were improperly disposed of or that are near groundwater or the river—for the sole purpose of redisposing of them more carefully and systematically in what is known as the 200 Area. This area, which includes the reprocessing plants and the high-level waste tanks, is on a plateau about 75 meters above the water table. Roughly 70 percent of Hanford's waste sites are already on the plateau, so the plan basically involves getting waste from the other 30 percent up there. In some cases, though, "what they are doing is moving a problem and giving it to someone else a generation later," one Hanford scientist says.

Besides being the destination for thousands of tons of waste and contaminants from the soil, the 200 Area will be the site of a storage building, a kind of interim repository, for the 2,100 tons of stabilized spent fuel, as well as another such facility for the immobilized, high-level waste from the 177 giant tanks. Currently an agreement

PHIL SCHOFIELD

TRANSPORTING PLUTONIUM is not child's play, appearances to the contrary. The handle allows workers to be more than a meter from the wagon's contents while pulling it, minimizing exposure to radiation. In addition, the wagon's cylindrical pedestals securely separate cans containing the material, so that an upset cannot trigger a spontaneous nuclear chain reaction.

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DRUMS OF CONTAMINATED SOLVENT were simply buried in the soil 35 years ago; most of them decayed and leaked their contents. Unlike many of Hanford's 1,400 waste sites, though, the contamination in the case shown here was relatively confined.

with the state legally requires the DOE to bury in the 200 Area eight of the nine reactor blocks (the cores of the production reactors where the uranium rods were inserted) and their concrete pedestals, sometime around 2070.

Each reactor block and its pedestal comprise an enormous, highly radioactive pair of slabs weighing 15,000 tons. The leading plan for hauling them to the 200 Area involves the use of a $40-million crawling transporter; according to the Blush and Heitman report, one DOE official called the idea "lunatic." The additional costs of moving the reactors—rather than entombing them in place, as many technical analysts favor—have been put at $500 million.

When the hundreds of thousands of tons of waste have been consolidated, stabilized, packaged and redisposed in the 200 Area, basically all the plateau's 130 square kilometers will become a de facto repository, in all likelihood for thousands of years to come. (The short-lived DOE euphemism for such regions was "national sacrifice areas.")

And once this consolidation has been accomplished, how clean will Hanford be? So far specific levels of decontamination, consistent with an intended ultimate use, have not been set at most sites. In fact, the U.S. government still has no standards that can be used to determine when a radiological cleanup is complete. The goal of returning all of Hanford to pristine condition—an utter impossibility made plain by the most rudimentary analysis—has only recently fallen by the wayside. As spokesman Michael V. Berriochoa of Westinghouse Hanford puts it, "There isn't enough money in the world."

Improved Contracting?

Although the peculiar nature of Hanford often defies conventional metrics of cleanup, there is also ample evidence that much of the work done so far has been grossly inefficient. By the DOE's own estimates, cleanup projects started between 1989 and 1994 were 30 to 50 percent more expensive than their equivalents in the private sector.

Because virtually all work at the weapons sites is done by private contracting companies hired by the DOE, the ways contracts are written and structured can strongly influence the cost of work. Unfortunately, the DOE's traditional contracting method, known as a cost-plus or cost-reimbursal system, penalizes efficiency and thrift. Under this scheme, the DOE reimburses a contractor for all its expenses in making a product or performing a service.

Additionally, the DOE gives the contractor a percentage as profit; the more spent, the greater the profit. The system is a holdover from the early weapons days, when the risks and costs were largely unknown and constantly changing. Cleanup personnel may also fear that the harder they work, the sooner they will be unemployed. At Hanford, DOE spokesman Terry L. Brown notes, "you hear a lot of talk: 'I'm working myself out of a job.'"

In 1994, to try to deal with these problems, the DOE and Westinghouse Hanford switched to performance-based contracts. The approach separates huge tasks into a series of more manageable milestones leading to a specific outcome. The contractor's compensation depends partly or wholly on when and how well it meets the milestones. Similar versions are also being implemented at other DOE complexes besides Hanford and also in the contract the DOE has with Bechtel Hanford, another large contractor at the site.

Thomas P. Grumbly, who was assistant secretary in charge of the Environmental Management program until his recent promotion to undersecretary of energy, has high hopes for the techniques. The idea, he adds, is to "work on the economics first and realize that the economics, over time, will really change the system. How much time? I don't know. Four or five years."

Although most observers say performance-based contracting is too new to judge, a former DOE official intimately familiar with the Environmental Management program is pessimistic. To decontaminate a building, the former official explains, a contract would have to specify that "the building contains the following contaminants in the following concentrations. If you don't know what they are, you would have to issue a separate contract just to do the assessment, so you can write a specific enough contract to do the job right. I have no confidence that the DOE can get all the detailed knowledge to make it work. They would have to rely on the contractors themselves to do those assessments, in all probability."

John D. Wagoner, the manager of the DOE's Richland Operations Office, says that the DOE has called in the consulting firm Arthur Andersen to help write the next round of performance-based contracts. (Ironically, the contract with Andersen is not performance-based.)

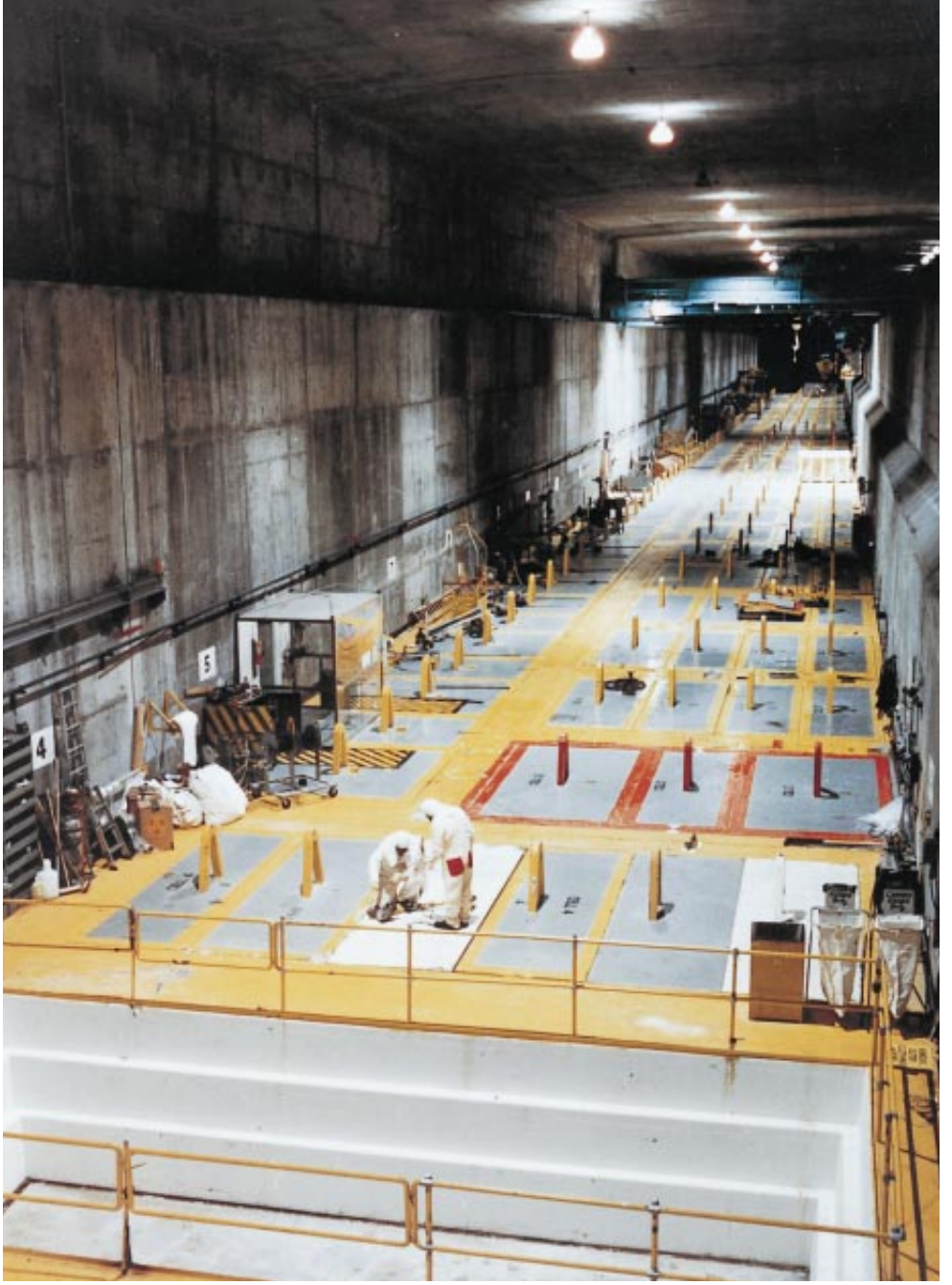
Whatever its current difficulties, performance-based contracting cannot be worse than the cost-plus system, many observers insist. "Contracting has been at the heart of the problems they've had," notes James Noël, assistant director for energy issues of the GAO.

Legal Hammer

Contracting, though, is not all that ails Hanford by any means. In 1989, around the time of the Rocky Flats crackdown, the DOE, the EPA and the state of Washington signed an exhaustive Tri-Party Agreement (TPA), which governs almost all aspects of en-

vironmental work at the site. The TPA, which lists specific activities and milestones and can fine the DOE for missing them, was the template for many other documents, called compliance agreements, governing environmental work on a number of DOE sites. Other than the federal deficit, the cost of the work that the DOE has committed itself to in the compliance agreements at all of its cleanup sites represents the single greatest liability of the U.S. government.

By all accounts, the TPA was a landmark that enabled the DOE and Washington State to begin working together despite deep mistrust. Because it is a legally enforceable document, the TPA also makes it less likely that the DOE—or Congress—will simply give up on the Hanford site in, say, 10 or 20 years. But possibly because of its accomplishments, the TPA's flaws are now apparently being overlooked. When it was drafted seven years ago, the TPA imposed on the DOE a hodgepodge of overlapping and sometimes conflicting state and federal environmental regulations. "The TPA was a punitive agreement," explains a Hanford veteran who witnessed its creation.



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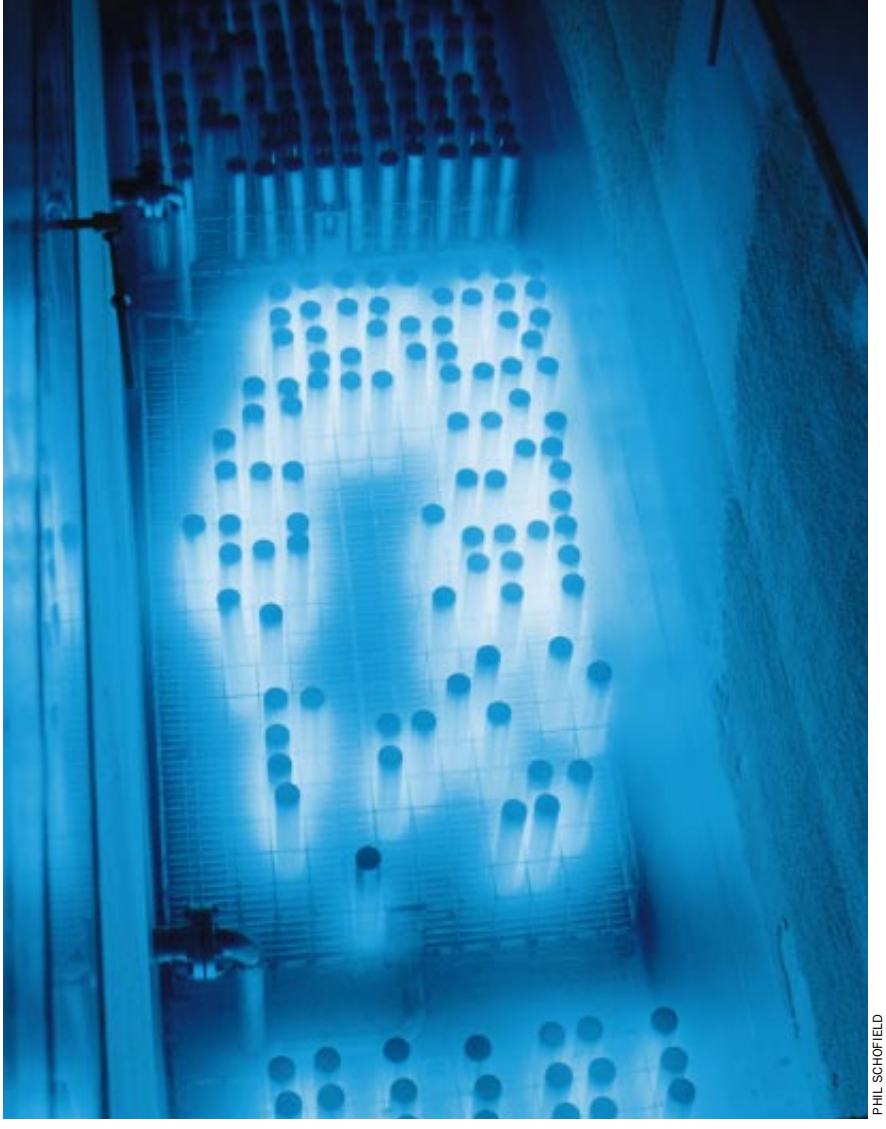
REPROCESSING CANYON was where irradiated nuclear fuel was dissolved in nitric acid and chemically treated in successive "process cells" to extract its minute quantities of plutonium. The rectangular plates in the floor are the cover blocks for the cells. All the work was done by remotely operated cranes and other machinery to shield workers from lethal levels of radioactivity.

Besides the state and federal laws, the DOE's contractors have to continue complying with existing DOE "orders," which dictate how work must be performed. The 466 orders, says Caputo, the attorney at the Natural Resources Defense Council, are "byzantine and overlapping. They're from another era." In addition, the department and its contractors picked up further oversight in the late 1980s in the form of the Defense Nuclear Facilities Safety Board, an executive-branch agency that reports to Congress and also advises the secretary of energy. More recently, a Hanford advisory board has consolidated community oversight and input. "No one has ever tried to superimpose all these regulations simultaneously, let alone on the type of site we have," notes Gephart of the Battelle laboratory.

What the tangle of regulations and external oversight has apparently precluded is a coherent, rational and risk-based set of priorities for the complex as a whole. Many priorities were established by the compliance agreements, which set a legally binding timetable for projects and achievements at the sites. But the DOE, its contractors and the state eventually realized that the schedule set forth in Hanford's original TPA was "wildly unrealistic," as Caputo puts it. So far the state of Washington and the federal government have renegotiated the document four times to try to bring it more in line with reality. Each renegotiation is "an agonizing process, and lots of trade-offs are made," says Chris Abraham of the GAO's Richland bureau.

The absence of a consistent and complex-wide approach to setting priorities has been costly. Any problem becomes an urgent priority at Hanford—and the subject of hundreds of millions of dollars in funding—for largely political or regulatory reasons. "The history of Han-



PHIL SCHOFIELD

RADIATION from capsules of waste cesium and strontium is so intense that its interaction with water creates a glow bright enough to be seen with the naked eye. Radiation at the surface of the canisters is high enough to deliver a fatal dose in four seconds; the water in the pool shields the room above from the deadly emanations.

ford over the past 10 years has been: declare an idea, get started on it, and then someone stops you," says John Fulton, director of the spent-fuel project for Westinghouse Hanford.

Vestiges of various aborted projects are still visible at Hanford. They include the foundation of a huge facility to vitrify high-level waste ($286 million was spent on the project before it was terminated) and a plant to mix low-level liquid waste with cement, as well as associated storage facilities for the resulting blocks of grout ($197 million was spent). Constantly shifting priorities have also thwarted technology development efforts. "Unfortunately, the time cycles for program changes have been much shorter than the time cycles for technology development," says Billy D. Shipp, associate laboratory director in the environmental technology division of the Battelle laboratory.

There are also simpler examples of TPA flaws. In accordance with TPA provisions, the DOE spends about $23 million a year on experimental treatments of Hanford's groundwater. Yet several studies have found that current technologies—all variants of a method called pump and treat—are inadequate. At best, experts say, pump-and-treat techniques could only modestly improve or contain some of Hanford's existing plumes of contamination. "We could pump and treat Hanford's groundwater for the next century, and it would cost tens of billions of dollars, and we still would not have clean groundwater," Gephart explains.

One project seeks to curtail the seepage of strontium into a naturally occurring spring near the "N" reactor and the Columbia River. In conformance with the TPA and the demands of the state, DOE contractor Bechtel Hanford spent $4.8 million pumping and treating water from the spring to remove strontium. Over the next few years, Bechtel expects to build, for $1.5 million, an underground barrier of a material called clinoptilolite, to absorb and hold the strontium.

The sole purpose of all this work is to block from the river an utterly minuscule amount of strontium—its yearly radioactivity was last estimated to be a quarter of a curie. To put the radioactivity in perspective, the Columbia picks up an estimated 6,000 curies every year from natural sources in Canada and northern Washington.

A Jurisdictional Jumble

The TPA further complicates matters by placing Hanford under the jurisdiction of several environmental statutes, the two most important being the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, also known as Superfund). Both laws specify how a contaminated site must be cleaned up. RCRA, however, which is usually administered by the state, pertains mainly to sites where hazardous waste was, or is being, treated, stored or deposited. Superfund, implemented by the EPA, covers contaminated sites that are no longer active. Superfund, unlike RCRA, can be applied to radioactive as well as chemical wastes. RCRA and Superfund also require different procedures and documentation.

Because of the way the TPA applies regulations to Hanford, any site that has both active and inactive hazardous-waste-producing components is technically covered by *both* RCRA and Superfund. Such dual coverage has seriously complicated hundreds of environmental projects at Hanford alone, the GAO and other investigators have found. For example, deactivation and decontamination of the nuclear reactors on the site are now covered by both RCRA and Superfund. In an attempt to avoid duplication, some reactors will be handled primarily under RCRA and the others mainly under Superfund, SCIENTIFIC AMERICAN has found. Thus, exactly the same task, being carried out by the same contractor, will be done and documented in two different ways, and the tons of debris will be disposed of in different waste facilities.

The TPA also applies both RCRA and

Superfund to the 177 tanks of high-level waste. The DOE's acquiescence to this dual coverage "foreclosed significant technological options in the cleanup of the Hanford tanks and created the possibility of a potential cost increase in the range of billions of dollars," according to a January 1996 report by the National Research Council. The DOE and its regulators have been attempting to solve the RCRA/Superfund problem since 1988, with little success.

Troubles Ahead

Serious as they are, the difficulties the DOE now faces seem to pale in comparison with the ones just ahead. For example, the TPA requires the DOE to vitrify the high-level waste in the 177 tanks. A big vitrification plant, the first ever in the U.S., was built at the Savannah River site in South Carolina; it is $2 billion over budget and six years behind schedule, according to the Institute for Energy and Environmental Research, a Takoma Park, Md., public-interest organization. (After innumerable delays, the plant was finally opened on March 12.)

Aware of the difficulty it would have in convincing Congress to underwrite another such venture, but obligated by the TPA to vitrify the waste, the DOE is now seeking one or more private companies to vitrify Hanford's waste. The companies would have to build and operate the vitrification plant, adhere to strict safety standards and assume all financial risk. The DOE would pay for the finished glass logs, enabling the firms—in theory—to profit. Most observers like the idea but are skeptical: "One of the big problems the DOE has had is inability to shift risk to a private company, so that if there is an unanticipated expense, or a catastrophic event, the private company suffers," notes Abraham of the GAO.

After the waste is vitrified, the DOE must take away all the glass logs, as well as part of Hanford's transuranic waste, and place them in permanent repositories in other states. That is what Washington State desires and the TPA stipulates. Standing in the way of this outcome, though, are tremendous obstacles. State opposition has blocked the opening of a repository for transuranic waste (containing plutonium or other elements with atomic numbers greater than 92) in New Mexico and the construction of a repository for high-level waste under Yucca Mountain in Nevada. The DOE now says a Yucca repository could not be ready before 2015; some experts suspect the opening will not take place for decades after that—if at all.

Even if the repositories can be put into use it is unlikely that they could contain more than a small fraction of Hanford's waste. Hanford's allocation of the hypothetical Yucca repository would hold about 6,000 vitrified logs. But the high-level waste in Hanford's tanks would occupy 20,000 to 60,000 such logs, according to the Battelle laboratory's latest estimates. Hanford's quantities of transuranic waste have been estimated to exceed the total capacity of the New Mexico transuranic repository—which, like Yucca, would have to take such waste from dozens of other sources besides Hanford.

Vitrification is one of several crucial issues whose resolution has been precluded by the precarious relationship between the state of Washington and the DOE. Analysts and, privately, site officials ponder such questions as: Should all the tank waste be vitrified? Should the reprocessing buildings be knocked down? Should the 15,000-ton reactor blocks and pedestals be hauled to the 200 Area and buried? Should hundreds of millions of dollars be spent pumping and treating groundwater that will never be clean?

The TPA requires that these questions be answered in the affirmative—even though rigorous technical analyses have argued against such moves. For example, some studies have suggested converting the gargantuan reprocessing buildings to low-level waste repositories. But the TPA currently rules out the possibility. Other problems also await solutions, including finding an ultimate destination for Hanford's many tons of spent nuclear fuel and plutonium.

What may finally force the issues is, as always, money. "A big vitrification plant will be real money," says Westinghouse Hanford president LaMar Trego. "So it will have to compete with plutonium disposition, Medicare, everything—I believe that, in their hearts, the regulators know there will be a big discussion on this in the end," he says.

That end, however, is fast approaching. DOE budgets, like those throughout the federal government, are being reduced. An unreleased study by Battelle considered cleanup strategies in light of an anticipated decrease in annual funding "from current levels [around $1.4 billion] to $1.05 billion in fiscal year 1998." After that year, funding would hold more or less constant for about 40 years. The Battelle report found that "a 50 percent reduction in the cost of cleanup must be immediately achieved and sustained to meet existing commitments and schedules with the projected $1.05-billion budget."

Given the unlikelihood of trimming the price of cleanup so much and, especially, the legally binding nature of the compliance agreements, the U.S. may have to reexamine its national priorities. For example, the $6 billion the DOE will spend this year to maintain, stabilize and clean up its weapons complexes is dwarfed by other budgets. The cold war has been over for years, but the U.S. will spend about $28 billion this year on intelligence alone—including $8 billion for reconnaissance and eavesdropping satellites and related programs. At $270 billion, this year's military budget roughly equals the anticipated cost of the entire DOE environmental management effort over the next half a century.

"While I understand the need to cut back on government programs and make them more efficient, shortchanging the DOE's cleanup budget will only increase the deficit in the long run," says Senator John Glenn of Ohio, whose state has numerous DOE weapons sites. "It may look good on paper, but it will only put off the day of reckoning. If we don't get a handle on this mess now, future generations will be left with a balloon payment constituting both an environmental and budgetary disaster." SA

Further Reading

ON THE HOME FRONT: THE COLD WAR LEGACY OF THE HANFORD NUCLEAR SITE. Michele S. Gerber. University of Nebraska Press, 1992.

HANFORD TANK CLEAN UP: A GUIDE TO UNDERSTANDING THE TECHNICAL ISSUES. Roy E. Gephart and Regina E. Lundgren. Technical Report PNL-10773, 1995. Available from Pacific Northwest Laboratory.

IMPROVING THE ENVIRONMENT: AN EVALUATION OF THE DOE'S ENVIRONMENTAL MANAGEMENT PROGRAM. National Research Council, 1995.

TRAIN WRECK ALONG THE RIVER OF MONEY: AN EVALUATION OF THE HANFORD CLEANUP. Steven M. Blush and Thomas H. Heitman. Report for the U.S. Senate Committee on Energy and Natural Resources, March 1995.

by Shawn Carlson

Detecting Natural Electromagnetic Waves

October 17, 1989, was going to be a banner day for Bay Area baseball. For the first time, the two cross-Bay rivals, the San Francisco Giants and the Oakland Athletics, were preparing to do battle in the World Series. Like millions of other San Franciscans, I was just settling in to watch the game on television when, without warning, it hit us all with the cold relentlessness of a crashing train. My whole house lurched violently and rolled as if being tossed on the crests of 10-foot-high waves. You didn't have to be a California native to know at once that this earthquake was a bad one.

Science quickly added a curious footnote to the Loma Prieta quake's destruction. Antony C. Fraser-Smith, an atmospheric scientist at Stanford University, issued a fascinating report. According to Fraser-Smith, the Hayward fault, which caused the earthquake, had tipped its hand. It had been sending out extremely long wavelength electromagnetic energy beginning almost a month before slipping and continuing right up until the quake. Three hours before the devastation began, Fraser-Smith's detectors were saturated with more than 300 times the normal background. A similar burst was observed on January 17, 1995, just 40 minutes before a magnitude 6.9 quake devastated Kobe, Japan.

The idea that low-frequency electromagnetic waves could be precursors to temblors remains controversial. Not all earthquakes release telltale electromagnetic signals before striking, and many researchers consider the data statistically unconvincing.

Amateur scientists might be able to contribute to this debate with the easy-to-build detector described here. If the low-frequency electromagnetic waves really do precede some earthquakes, this device will detect them. Indeed, it complements the seismometer described last month. Together they make a more sophisticated earthquake-observing station than most professionals have.

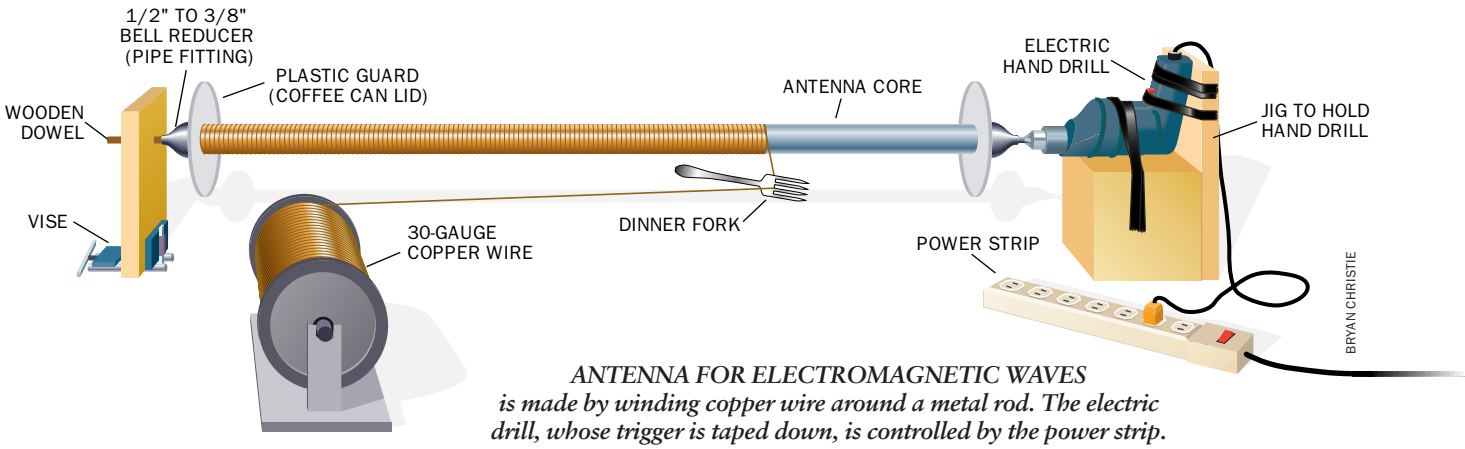
This detector will also enable you to investigate other sources of natural radio waves. About 100 or so lightning bolts strike the surface of Earth every second. Many of the electromagnetic waves associated with the storms (the vast majority occurring near the equator) travel around the globe by bouncing off the ionosphere. With the detector, you can record the signals; data taken over a long period can reveal how storm activity changes over the months. The solar wind bumping into the atmosphere is also a reasonable target.

The electromagnetic waves from all these phenomena are incredibly long. Some stretch three million kilometers from crest to crest—almost 10 times the distance between Earth and the moon. Despite their extreme size, they are still just radio signals and so can be picked up by a properly designed radio tuned to the right frequency band—0.1 to about 20 hertz.

As its name suggests, an electromagnetic wave has both an electrical and a magnetic component. To catch the electric field, as conventional radios do, you usually need an antenna that is at least about one quarter the size of the wave—not too practical when the wave is a million kilometers long. Fortunately, the slowly varying magnetic component can be more easily detected because, by Faraday's law of induction, a changing magnetic field induces voltage inside a loop of wire.

The antenna described here is hence just a solenoid—a cylindrical coil of wire wrapped around a long core. The core consists of a half-inch-diameter (12.8-millimeter) metal rod two feet (0.61 meter) long and wrapped with at least 50,000 turns of 30-gauge copper wire.

Rebar, an iron rod obtainable at any construction supply house, is inexpensive and makes a suitable core. Some alloys of iron, nickel and molybdenum, however, perform much better. Mu-metal and HyMu 80, for example, have exquisite magnetic properties that make an antenna constructed from them 20 times more sensitive than one crafted from rebar. Carefully annealing these rods in a vacuum furnace can boost this performance another 10-fold. But you'll pay for the improvement. Cores suitable for this project are available from Scientific Alloys in Westerly, R.I. (401-596-4947), for $107 apiece; having these



ANTENNA FOR ELECTROMAGNETIC WAVES is made by winding copper wire around a metal rod. The electric drill, whose trigger is taped down, is controlled by the power strip.

Calibrating Your Antenna

You must determine the relation between an oscillating electromagnetic wave and the voltage your system generates when it detects the wave. Select a plastic pipe 2.5 feet (0.74 meter) long and wide enough to slip easily over your antenna. Uniformly wrap it with 100 turns of copper wire, then connect that wire to a signal generator through a 100-ohm resistor. If you do not have a signal generator, check out *Build Your Own Low-Cost Signal Generator,* by Delton T. Horn (TAB Books, 1994).

Center your antenna inside the pipe and set the signal generator to produce a 10-hertz sine wave. The current surging in the wire creates an oscillating magnetic field that your coil will detect. Calculate the maximum magnetic-field strength with the equation

$$B = 0.89 \times 4\pi \times 10^{-7} (N/L)(V/R) = 1.12 \times 10^{-6} (N/L)(V/R)$$

where B is the maximum magnetic-field strength in teslas, N is the number of coils on the pipe, L is the distance in meters between the first and last coil, V is the maximum voltage applied in volts, and R is the resistor value in ohms. Then plot B versus the signal voltage you measure from the antenna.

To discover the smallest signal detectable at 10 hertz, you will need to repeat the procedure, replacing the 100-ohm resistor with resistors of one kilohm, then 10 kilohms and even 100 kilohms. Because your coil is less sensitive at lower frequencies, you'll also need to redo the measurements with the signal generator set to one hertz and then to 0.1 hertz. With the data, you should be able to establish a relation between the signal voltage and the frequency of electromagnetic waves in hertz.

cores annealed could double the cost.

Some shops that repair electric motors will wind your coil for about $80. Alternatively, you can wind it yourself in an afternoon using the setup shown on page 82. A half-inch-diameter core is too wide to be gripped by the three-eighths-inch-wide chuck found on most electric hand drills, so you will need bell reducers, which are fittings that link pipes of different diameters. They also provide an easy way to support the far end of the core while it is rotating.

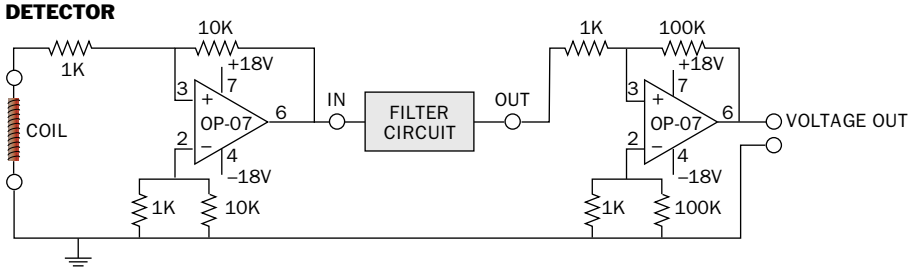
To keep the wire from slipping off the core, you need to cap the ends. Drill half-inch-diameter holes into two plastic coffee can lids. Slip them over the rod and epoxy them into place to support the ends of the winding. Use the tines of a dinner fork to guide the wire into snug coils. When the coil is completely wound (in about 20 layers), carefully trim the lids down to the wires.

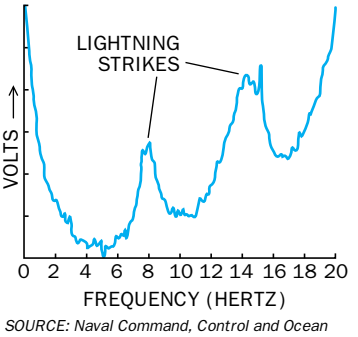
You can estimate the number of turns you've wound by knowing how fast the drill chuck rotates and multiplying by the time the drill remained on. With a little practice, you can wind 10,000 turns an hour. Encase each completed coil inside a plastic pipe to protect it from the elements.

These antennas are highly directional. If your budget allows for only one coil, mount it vertically to search for earthquake precursors and horizontally, with its axis east-west, to detect waves from distant storms. With two coils, mount one vertically and the second with an east-west axis. For complete coverage, add a third coil aligned along the north-south axis. These antennas are so sensitive that they will detect passing cars 100 feet (30 meters) away, so try to set them up at least that far from roads or machinery.

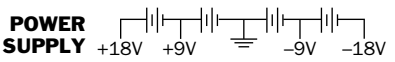
The circuit uses two low-noise operational amplifiers to boost the signal and

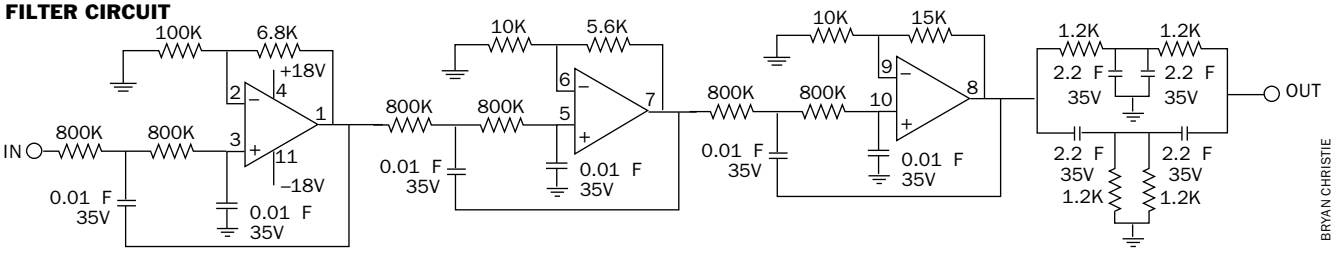
CIRCUITRY TO AMPLIFY ANTENNA SIGNALS includes a filter that requires three of the four op-amps contained within an OP-470Y chip (below). *Plotting the amount of energy detected at different frequencies* (right) *can show peaks created by distant lightning strikes. Earthquakes reportedly produce waves at about four hertz.*





SOURCE: Naval Command, Control and Ocean Surveillance Center, San Diego





BRYAN CHRISTIE

a filter circuit to cut out human-made radio noise. If you have an analog-to-digital interface, you can read the data directly into your home computer. Keep it at least 30 meters away so that its magnetic field does not interfere with the antenna. With a computer, you can identify the individual sources by applying a little mathematical chicanery known as a fast Fourier transform, or FFT. Many data-analysis software packages will do this procedure for you. The graph on the opposite page shows the FFT of a data file in which the output was recorded 30 times each second continuously over 24 hours. The Schumann peak, created by lightning strikes thousands of miles away, is clear at about eight hertz, along with a secondary component near 15 hertz. Earthquake waves seem to appear at around four hertz.

If you do not have a computer, you will need a chart recorder [see The Amateur Scientist, SCIENTIFIC AMERICAN, November 1955, July 1966, May 1970 or March 1972]. Different radio sources will add energy into your system at different frequencies. If you are using a chart recorder, you can only measure this total—you can't unravel how much energy came from each frequency.

The Society for Amateur Scientists is organizing a network of amateur observers to contribute to our understanding of natural radio. It is also offering complete detector stations that are ready to be plugged into your personal computer. For more information or to get involved in the detecting network, send $5 to the Society for Amateur Scientists, 4951 D Clairemont Square, Suite 179, San Diego, CA 92117. Or download the information for free from its World Wide Web site—http://www.thesphere.com/SAS/ or from Scientific American*'s area on America Online. I am grateful to Ugo Conti of Electromagnetic Instruments in Richmond, Calif., Jack Dea of the Naval Command, Control and Ocean Surveillance Center in San Diego, and Tom Liu and Antony C. Fraser-Smith of Stanford University for valuable discussions.*

Editors' note: *In the circuit schematic in the March issue, "Exploring Chemical Bonds," the two resistors between the op-amps and the light-emitting diodes are incorrectly labeled as 330 kilohms. They should be 330 ohms.* SA

by Ian Stewart

The Sculptures of Alan St. George

Alan St. George is a retired British-born architect who lives in Portugal and makes mathematical sculptures. I first came across his work in the catalogue to his exhibition *The Shape of Number,* which opened in Lisbon in December 1995. One of St. George's many themes makes use of fractal or spiral variations of the regular solids. Although his originals are made from acrylic sheet or metal, most of them can be reproduced only using cardboard and wood blocks—or, for those who like their sculpture virtual, computer graphics. The underlying principles can be exploited at will to yield unique variations.

In his *Elements,* Euclid proved that there are precisely five solids whose faces are regular polygons, arranged in exactly the same manner at each vertex. These solids—the cube, tetrahedron, octahedron, dodecahedron and icosahedron—are made of six squares, four triangles, eight triangles, 12 pentagons and 20 triangles, respectively. To make fractal sculptures, St. George begins with one of these solids, gluing onto its faces a series of ever smaller solids—in such a manner that the result resembles a different regular solid.

For example, in order to turn a cube into a fractal octahedron, start with a single cube and divide each face into nine equal squares, so that it looks like a Rubik's cube. Next, make a cross-shaped unit from six smaller cubes, each with faces the size of these squares. Five of these smaller cubes become arranged in a Greek cross, whereas the sixth sits atop the central cube to form a kind of stepped pyramid. Glue one such unit onto each of the six faces of the original cube. Then subdivide each square face of the resulting structure into nine smaller subsquares, gluing on smaller copies of the stepped pyramidal unit.

You will probably want to stop here. The original cube has six faces, so the first stage requires 36 smaller cubes grouped into six pyramidal units. Each unit creates 21 new square faces, while leaving four of the subdivisions of the original face uncovered. Thus, each face of the original cube converts into 25 smaller surfaces. The resulting object has $25 \times 6 = 150$ square surfaces. It might seem that at the next stage you have to attach $6 \times 150 = 900$ even smaller minicubes. But some of the pieces overlap, and according to the fractal scheme you need only 708.

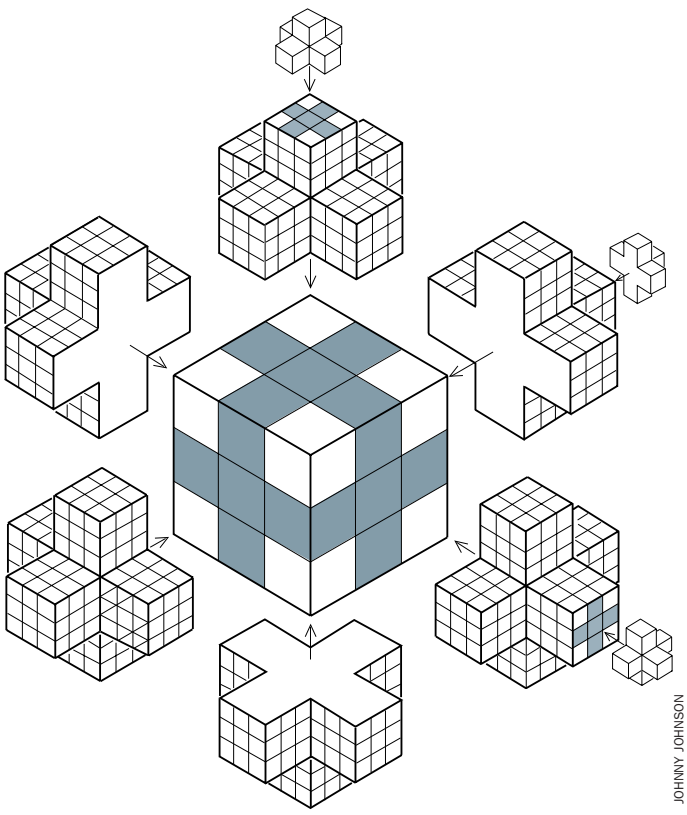
It is also possible to fractalize an octahedron to a tetrahedron. In this case, a triangular face of the original octahedron is subdivided into four equal triangles, and a half-size octahedron is glued onto the central triangle on every other face, the process being repeated several times. If the small octahedron is stuck to each face instead of to every other face, one gets a cube. In fact, St. George's sculptures fractalize the tetrahedron, cube or octahedron to any other one of those three solids.

Fractalizations involving the dodecahedron are difficult because a pentagonal face does not subdivide into smaller, regular polygons. The procedure can be applied to the icosahedron; however, the results do not resemble other regular solids. This problem can also be traced to the pentagonal geometry of the icosahedron, in which five faces surround each vertex.

Still, the territory is wide open for exploration. It might be possible to extend these ideas to the "semiregular" solids, whose faces constitute several different kinds of regular polygons. The easiest way to make most of these sculptures is to assemble the component polyhedrons from cardboard and glue them together. A simple "jig," such as a piece of cardboard with pinholes in appropriate places, can ensure that identical subunits are truly identical.

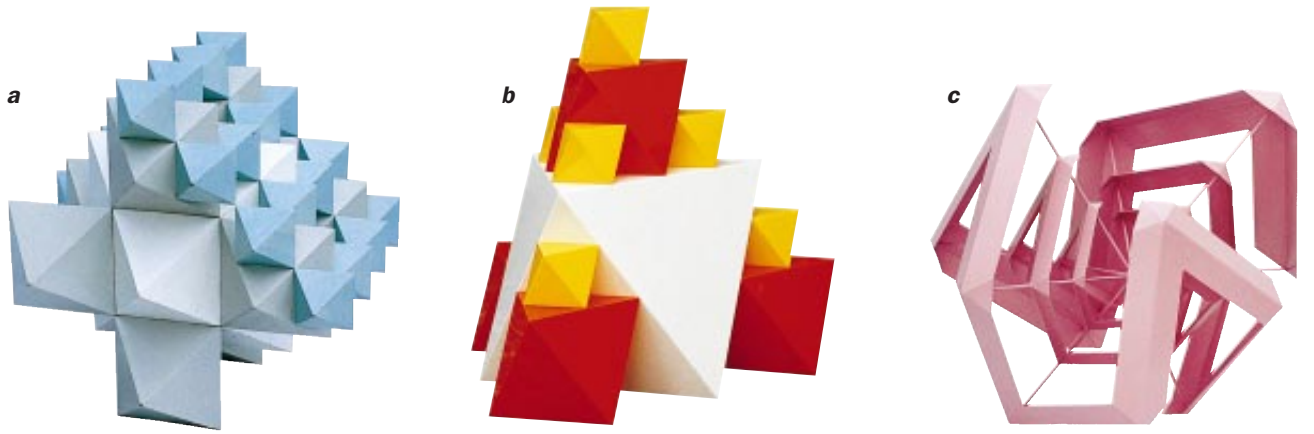
St. George's spirals are based on equally simple geometric principles, but their construction is more intricate and involves some trial and error. I will describe one of the most elaborate spirals, based on the icosahedron.

The construction depends on a closed, geometrically regular circuit that runs along the edges of the icosahedron and visits each vertex exactly once. Imagine an ant that uses



JOHNNY JOHNSON

OCTAHEDRON CAN BE CREATED from a cube by adding smaller cubes in fractal steps.



ALAN ST. GEORGE

JOHN ANNONSON

SCULPTED CUBE
(a) *and tetrahedron* **(b)** *were created by Alan St. George from an octahedron. "Spiral 9"* **(c)** *reveals an icosahedon* **(d)** *were it traversed by an ant, starting at the vertex marked* **A.** *The ant follows a specific path* **(dashed lines);** *the choices it faces at each vertex are labeled* **(e).**

the edges as a network of highways. On approaching a new vertex, the ant can choose between any of the five roads that meet there. It can reverse direction and go back along the same edge, or it can take a sharp right, a gentle right, a gentle left or a sharp left. Symbolize the last four choices as *R, r, l, L* (we won't need the first). Then moving upward from the point marked *A*, the ant follows a circuit prescribed by the sequence of turns *RlLrRlLrRlLr*. Note that the subsequence *RlLr* repeats three times, revealing an obvious pattern.

For aesthetic reasons, St. George employs the famous "golden number," $\varphi = (1+\sqrt{5})/2 = 1.618034$, in the construction. This number has many harmonious properties; for example, $1/\varphi = \varphi - 1$; $\varphi^2 = \varphi + 1$; and so on. Employing this number, beloved of the ancient Greeks, one obtains a structure of pleasing proportions.

The spiral icosahedron is constructed out of a series of "legs" that correspond to the 12 edges of the ant's tour. Each leg is joined to the previous one and runs parallel to an edge. But successive legs have different lengths, each being $\varphi^{1/12} = 1.040916$ times as long as its predecessor. Why choose this strange number? The reason is that after 12 edges have been added to a given one, the last edge runs parallel to the original, and its size has grown by a factor of $(\varphi^{1/12})^{12} = \varphi$.

To make a model of this spiral, you should first calculate a list of powers of $\varphi^{1/12}$ in order to find the lengths of successive sides. The first 25 numbers in the list (correct to two decimal places) are 1.00, 1.04, 1.08, 1.13, 1.17, 1.22, 1.27, 1.32, 1.38, 1.43, 1.49, 1.55, 1.62 = φ, 1.68, 1.75, 1.82, 1.90, 1.98, 2.06, 2.14, 2.23, 2.32, 2.41, 2.52, 2.62 = $1 + \varphi$. Start with a side of, say, two inches (or five centimeters) and multiply that by the numbers in your list.

The easiest way to construct the spiral is to begin with strips of cardboard, with each strip folded down the middle. The ends are cut to create "arrowhead" shapes, with angles of 60 degrees on either side of the fold. At a corner where two legs meet, paste together the adjoining edges of the arrowheads and fill in two small equilateral triangles.

So that the resulting construction is rigid, you must ensure that the five triangular pieces of cardboard meeting at each corner have the same spatial arrangement as the five faces of a pentagonal pyramid. One way to do this is to affix a tiny rigid pyramid to each corner, complete with a pentagonal base. You will still need some struts for support, and inevitable inaccuracies require a certain amount of adjustment. If these design problems are solved—and I'm leaving that pleasant, though lengthy, task to you—you will have an elegant three-dimensional sculpture that will grace the abode of any mathematically minded person. SA

FEEDBACK

The Anthropomurphic Principle" [December 1995] attracted an unprecedented level of comment, including alternative histories of "Murphy's Law" and objections to its use. David D. Carson of the Mississippi University for Women reported a series of experiments conducted by a group of faculty and students, in which toast was (a) tossed randomly from waist height, (b) pushed off the edge of a table and (c) pushed off a 10-foot aluminum ladder. In the first and last cases, the observed frequency of toast landing buttered side down was 47 and 48 percent, respectively, but in the second case, it was 78 percent. Gratifying!

Carlo Séquin of the University of California at Berkeley pointed out that the source of the problem is not God's design of the universe, but the "American Standards Committee for Toast Dimensions," which has clearly decreed that toast be made the wrong size. John S. Steadman of St. John's College provided convincing arguments to the effect that "not only is Murphy's Law a deep consequence of the laws of nature but also that the laws of nature are a deep consequence of Murphy's Law." For example, the Second Law of Thermodynamics is "actions have irretrievable consequences," which is Murphy with a moral dimension, and quantum physics is just a pessimistic version of Murphy's: "If anything can go wrong, it already has." —*I.S.*

From *Frontiers of Complexity*

COMPLEXITY SIMPLIFIED

Review by Seth Lloyd

Frontiers of Complexity: The Search for Order in a Chaotic World
BY PETER COVENEY AND ROGER HIGHFIELD
Fawcett Columbine, Ballantine Books, 1995 ($27.50)

Hidden Order: How Adaptation Builds Complexity
BY JOHN H. HOLLAND
Helix Books, Addison-Wesley, 1995 ($24)

At Home in the Universe: The Search for the Laws of Self-Organization and Complexity
BY STUART KAUFFMAN
Oxford University Press, 1995 ($25)

Fire in the Mind: Science, Faith, and the Search for Order
BY GEORGE JOHNSON
Alfred A. Knopf, 1996 ($27.50)

Complexity" is a word much heard in scientific circles these days, but there is little consensus on the significance or even the exact meaning of the term. The Latin *complexus* comes from the Greek *pleko,* meaning "to plait or twine." Complex systems are woven out of many parts, and the sciences of complexity try to understand the patterns of the weave. Whether this underlying order admits systematic study or whether complexity arises from a lawless variety that tolerates few generalizations, however, is open to question. The orator Cicero used *complexus* to describe an intricate rhetorical argument, whereas the bawdy playwright Plautus preferred it to describe intertwined limbs in a sexual embrace. Plautus's meaning is more helpful in making sense of the current debate on complexity.

The field of complexity studies promiscuously takes in almost every subject that calls itself science and a few that do not. A search of the Massachusetts Institute of Technology library database reveals that the word "complexity" has been tied to anthropology, biology, cosmology, dentistry, economics, geology, historical studies, Islamic architecture, Japanese calligraphy, knapsack problems, linguistics, music, numismatics, operations research, portfolio management, radiology, statistics, telecommunications, urban planning, wavelets and zoology, to name but a handful out of thousands of references. The same mathematical techniques simply cannot apply rigorously to all these subjects. Like Don Juan, the sciences of complexity sometimes must strike out. Nevertheless, in some fields, complexity studies not only have proved useful but also seem to offer the only possible way to succeed. The differing perspectives of the four books reviewed here give a flavor of the promise and the pitfalls of the current fixation on complexity.

The techniques developed for studying complex systems are useful at the hazy boundaries between conventional fields, where well-understood laws give rise to equally well documented phenomena in a complicated manner that no one fully understands. The most stunning example is the way that seemingly straightforward chemical laws lead to life. Even when the parts of a system are perfectly understood, woven together they can exhibit behavior that is too intricate to be easily explained.

Studies of complexity emphasize distinctive methods and questions to get at emergent behavior. They focus on information: How do complex systems acquire information, and what do they do with it? They use detailed computer models for generating and testing hypotheses: When artificial stockbrokers buy and sell artificial stocks, does the resulting market exhibit booms and busts? And they emphasize "emergent properties": How do the laws of chemistry arise from the laws of physics, or the laws of biology from the laws of chemistry? In general, how do complex, specific laws arise from simple, generic ones?

These basic questions are hardly new. Even Aristotle's *Physics* (from the Greek *physis,* "begetting or becoming") can be regarded as an abortive attempt to understand the laws of emergence. Montesquieu's *Spirit of the Laws* and Auguste Comte's *Positivism,* Siméon D. Poisson's probabilistic analyses of the fairness of trial by jury, as well as the sociological theorizing of Léon Walras and Vilfredo Pareto span 200 years of attempts to create for complex social systems analogues of Newton's ironclad physical laws. What is new is the computer. During the past 50 years, the exponentially increasing ability of machines to process information has allowed researchers to explore realms of complexity that were previously inaccessible.

Not that computers are so smart. It is just that human beings are relatively dumb, at least when it comes to performing mind-numbingly repetitive mathematical manipulations. Now, however, the economist need not assume that agents are omniscient, that markets clear instantaneously or that money is the only thing that matters. Although computer models are still necessarily simplified, they can include much more detail than was previously possible.

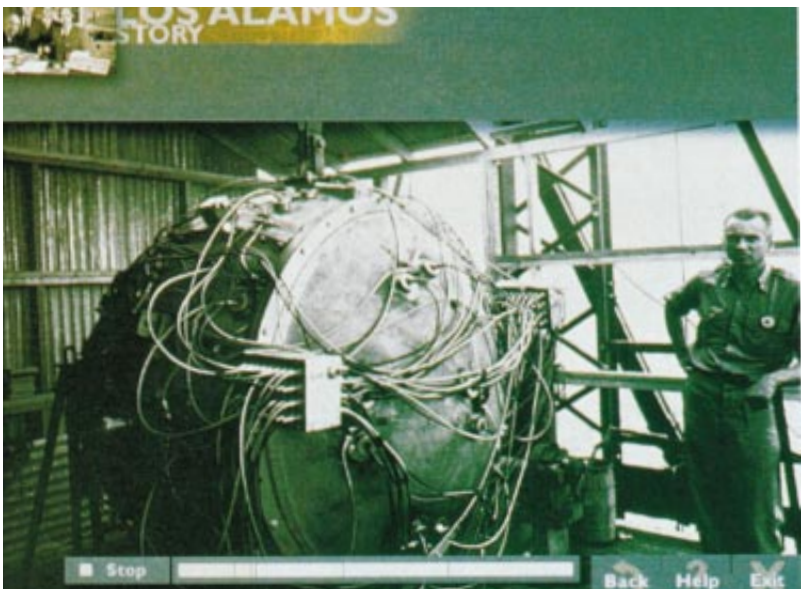
The power of computers is a central theme of *Frontiers of Complexity.* Peter Coveney and Roger Highfield (both trained as scientists) provide a lucid account of lines of research in which the techniques of complexity have yielded surprising and fascinating results. The book is a bestiary of complex systems, complete with color prints of artificial

THE CD ILLUSTRATED

The Day after Trinity:
J. Robert Oppenheimer and the Atomic Bomb
Voyager, 1995 (hybrid CD-ROM for Macintosh and Windows) ($29.95)

Critical Mass: America's Race to Build the Atomic Bomb
Corbis, 1996 (CD-ROM for Windows) ($49.95)

The Day after Trinity, Jon Else's fine documentary film, has been both reduced and enhanced by its translation onto CD-ROM. A search feature allows the user to jump to a specific event or person, partly compensating for the low-quality Quicktime video. And a glossary and biographical index, despite their awkward design, add valuable background on the creation of the A-bomb. *Critical Mass* (*below*) is a slicker but shallower effort; it is not even searchable. Nevertheless, younger users may be captivated by the disk's state-of-the-art graphics and gamelike, nonlinear structure. In the course of their play, they will also find a number of small treasures, including clips of atomic tests and reproductions of declassified documents. —*Corey S. Powell*



From *Critical Mass*

BRIEFLY NOTED

THE CAMBRIDGE ENCYCLOPEDIA OF THE ENGLISH LANGUAGE,
by David Crystal. Cambridge University Press, 1995 ($49.95).
Thoroughly British in its dry wit and relentlessly omnivorous in its erudition, this is not your average reference source. There is hardly a page that will not leave you thinking a bit differently about the way you employ words. The book's structure grows a wee thorny after the initial section on the history of the language, but not to worry: an extensive index, references and glossary will lead you to the right spot. Or you can just browse—which you'll probably end up doing regardless.

THE OCTOPUS'S GARDEN: HYDROTHERMAL VENTS AND OTHER MYSTERIES OF THE DEEP SEA,
by Cindy Lee Van Dover. Helix Books, Addison-Wesley, 1996 ($20).
This slim volume tells of Cindy Lee Van Dover's time as pilot of the *Alvin,* the research submarine whose voyages are responsible for much of what we know about the remarkable life-forms of the seafloor. It is also a story of success in the face of opposition from an almost exclusively male clique of submariners. But the feel of doing science firsthand is what stands out here. Van Dover's lucid descriptions of vent creatures and the bizarre world they inhabit are complemented by pen-and-ink drawings.

ANGELS AND INSECTS,
directed by Philip Haas. Samuel Goldwyn Company, 1996.
Although set at the height of the Victorian era, animal brutality lurks around every corner in this cinematic adaptation of A. S. Byatt's novella *Morpho Eugenia.* At the heart of the film is William Adamson, an impoverished naturalist enamored with Darwin's new theory of evolution. Taken in by a wealthy but mysterious family, Adamson undergoes his own struggle of natural selection in career and in love. The movie works as an enjoyable, if occasionally heavy-handed, cross between *Masterpiece Theater* and *National Geographic.*

Continued on page 107

life-forms and packed with information, including an extensive bibliography and glossary. Each subject is clearly explained on its own, so that—like any good bestiary—the book rewards curious exploration. (The downside of having stand-alone sections is that a topic may be explained again and again, always as if it is being discussed for the first time.)

Coveney and Highfield introduce the reader to Alan M. Turing and John von Neumann, who can be thought of as the parents of the modern digital computer. *Frontiers of Complexity* incorporates a particularly detailed discourse on the subject of artificial life. In the 1950s von Neumann analyzed computer-generated organisms, or automata, that were capable of creating copies of themselves. He noted several features that a self-reproducing automaton must possess, all of which turned out to be features shared by living cells once DNA was identified as the genetic material, the analogue of an automaton's program.

Stanislaw M. Ulam collaborated with von Neumann on his artificial-life project. A pioneer of the sciences of complexity, Ulam contributed to many branches of mathematics and invented the now ubiquitous Monte Carlo technique for simulating the behavior of complex systems by using random numbers. It is appropriate, then, that John H. Holland's *Hidden Order* should be based on the Stanislaw M. Ulam Memorial Lectures Holland delivered at the Santa Fe Institute, a hotbed of complexity research.

Although it is narrower in scope than Coveney and Highfield's book, *Hidden Order* provides a considerably deeper insight into the connection between complexity and life. *Hidden Order* recapitulates some of Holland's MacArthur Foundation award–winning work on genetic algorithms—computer programs that enact analogies of the processes of mutation and recombination that underlie biological evolution—and considers the extent to which automata can behave as if they were actually alive. Holland shows how computers can learn to cope with complexity in software settings by imitating how living creatures cope with the real world. He articulates clearly how computer models can be used to study complex adaptive systems and points out that such modeling accomplishes nothing unless it is supplemented with insight and reflection.

Richard Feynman said that people who wish to analyze nature without using math-

THE ILLUSTRATED PAGE

Vanishing Flora: Endangered Plants around the World
BY DUGALD STERMER
Harry N. Abrams, 1995 ($49.50)

The term "endangered species" usually conjures an image of a bald eagle or a blue whale, but the present biodiversity crunch is not restricted to animals. Wielding graphite pencil and watercolor brush, Stermer gives faces to 82 species of plant whose future is in jeopardy. Some of these, such as the Venus flytrap shown here, are familiar. (Perhaps too familiar—wild populations of the flytrap have nearly been picked to death because of the plant's popularity as a household novelty.) Others are exotic species: the dabaobai shan cha, a variety of camellia, exists only in remote areas of southern China and may already be extinct. In his well-crafted introduction, Stermer provides a temperate overview of why plants are vanishing and why we should care. Although he emphatically downplays the aesthetic argument in favor of an ecological one, his meticulous drawings evince a more emotional attitude toward our planet's natural beauty. —*C.S.P.*

"We must discipline ourselves to step more lightly on the planet."

ematics must settle for a reduced understanding. In that vein, Holland introduces simple equations to illustrate his points. For the reader who is reasonably comfortable with the math learned in eighth grade, the equations should prove no obstacle, and they greatly increase the understanding of how artificial organisms adapt or fail to adapt to their environment.

A considerable part of *Hidden Order* is devoted to an in-depth description of an ambitious and as yet incomplete artificial ecosystem called Echo. Some readers may find more compelling the brief section on an artificial stock exchange that Holland created with the economist W. Brian Arthur and the physicist Richard Palmer, along the lines suggested in discussions with the Nobel laureates Kenneth J. Arrow (economics) and Philip W. Anderson (physics). In this electronic arena, mindless but greedy automata bid against one another's strategies, giving rise to speculative bubbles, crashes and other real-life phenomena that classical economics has difficulty reproducing.

As suggested by the list of contributors to the artificial stock-exchange experiment, the study of complex systems is fundamentally an interdisciplinary exercise. That breadth can be a strength or a weakness. Research that weaves together ideas from many fields often faces opposition from natives of a particular domain. The logic of academic turf battles demands that interlopers be challenged, just as do the logics of the dominance hierarchy in primate groups or of presidential primaries.

Life is, by definition, the provenance of biologists, so it comes as little surprise that many of them are suspicious of computer-based simulations of the origin of life carried out by "theoretical biologists." In *At Home in the Universe,* Stuart Kauffman makes his case for the validity of that work, as he lays out his account of how life might have arisen from nonlife and how complex order might have arisen from the edge of chaos. Kauffman (who, like Holland, is a MacArthur Fellow and a frequent participant at the Sante Fe Institute) has been one of the most productive of the theoretical biologists, and his book gives a fascinating, if abstruse, glimpse of how complexity research is migrating from the computer into the physical world.

Particularly relevant to studies of the origins of life is the notion of an "autocatalytic set," which arises when a group of chemicals react with one another to produce other chemicals, which, in turn, encourage or catalyze the original reactions. Starting at almost negligible concentrations, such a set of chemicals and reactions can, through mutual encouragement, rapidly come to dominate their environment. Eventually, the story goes, the evolving set will hit on the chemical reactions that make up life. Melvin Calvin of the University of California at Berkeley originally suggested this notion; the theoretical biologists Otto Rössler, Manfred Eigen and Kauffman have since explored it independently. Eigen received a Nobel Prize in part for his work on autocatalytic sets involving RNA.

The theory of autocatalysis is potentially a convincing explanation for how life began, lacking only a detailed analysis of the chemical kinetics. Doyne Farmer and Norman Packard of Santa Fe and Richard Bagley of Los Alamos National Laboratory managed to program a computer with an artificial chemistry that exhibited autocatalytic sets. Unfortunately, the actual processes are too complicated to be analyzed even by the fastest computer available.

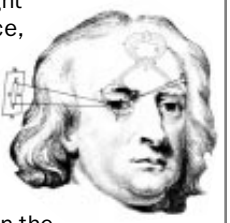
Kauffman's explanations of his scientific work are concise and convincing. The prose that surrounds those explanations is less so. Like Anglo-Saxon epic poets, Kauffman is fond of alliteration and internal rhyme: "physics, cold in its calculus," "coyote crafty across the ridgetop" or "the fleeter-flying fly decreases the fitness of the frog." Some may enjoy this wordplay; others may think of *Beowulf* on bad acid. Whoever reads *At Home in the Universe* for its account of Kauffman's insightful models of adaptation and self-organization will find that the scientific results speak for themselves.

The most remarkable and eloquent of these four books on complexity is the only one not written by a scientist. George Johnson's *Fire in the Mind* examines not only how people search for order but why. Scientists are usually too consumed with their own search for order to step back and ask, "Why bother to search at all?" As to how to search, researchers answer with one voice: by Science! Scientists have an unquestioned faith in questioning everything. But this faith in reason and experiment is as im-

BRIEFLY NOTED

Continued from page 105

PSYCHOLOGISTS IN WORD AND IMAGE, *by Nicholas Wade. MIT Press, 1995 ($42.50; $22.50, paperbound).*



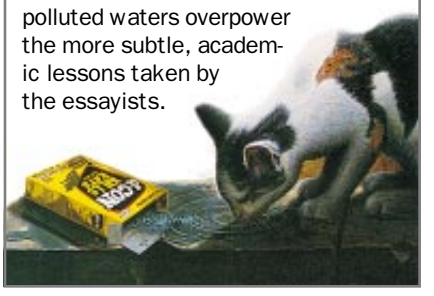
In a left brain–right brain tour de force, Nicholas Wade has created a unique biographical encyclopedia of 104 of the most influential figures in the history of psychology, including Isaac Newton (*above*). The right-hand pages deliver concise essays describing each psychologist's life and work. The left-hand pages offer portraits that graphically summarize the same information.

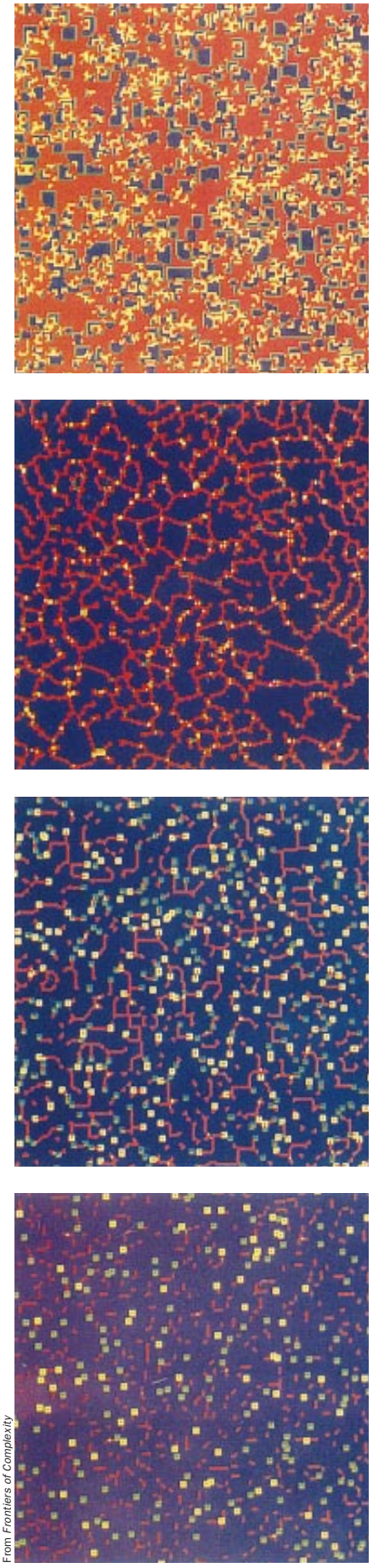
LUCK: THE BRILLIANT RANDOMNESS OF EVERYDAY LIFE, *by Nicholas Rescher. Farrar, Straus and Giroux, 1995 ($19).*

Nicholas Rescher reclaims "chaos" from the scientists and reminds us that the concept is central to everyday unpredictability. That observation, simultaneously profound and banal, is typical of this intriguing and frustrating book. Its numerous philosophical and logical arguments provide abundant food for thought but little in the way of fresh insights into life's capriciousness.

ALEXIS ROCKMAN: SECOND NATURE, *with essays by Douglas Blau, Barry Blinderman, Stephen Jay Gould, Prudence Roberts and Peter Douglas Ward. University Galleries of Illinois State University, 1995 ($25).*

In a well-intentioned meeting of the "two cultures," the writers in this collection reflect on the artistic and scientific meaning of Alexis Rockman's surreal nature paintings, beautifully reproduced here. In the end, however, the surface messages of Rockman's mutant creatures and polluted waters overpower the more subtle, academic lessons taken by the essayists.





From *Frontiers of Complexity*

portant for science as faith in God is for religion. Both founded on faith, science and religion ask many of the same questions. *Fire in the Mind* compares point by point the stories that science and religion tell of how the world began, what it is made of, where life came from and what the future holds.

Taking the landscape of northern New Mexico as a backdrop, Johnson fills his stage with scientists from the Santa Fe Institute, Indians from San Ildefonso pueblo, bomb makers from Los Alamos and flagellants from the Catholic sect Hermanos Penitentes, then lets them speak, to the extent that their vows of secrecy permit.

Johnson's years as a science reporter for the *New York Times* have made him adept at succinct explanation. But his desire not only to explain but to understand the urge to explain infuses *Fire in the Mind* with its own fire. The book is at its most original and revealing when it discusses the social functions of knowledge and understanding. Johnson examines the ways in which three cultures—Indian, Hispanic and Anglo—overlap to shape life in northern New Mexico, and he explores at length the problems faced by communities and individuals who wish to preserve traditional ideas that conflict with contemporary culture or with scientific knowledge. Secret knowledge is fragile; open knowledge is robust. In the end, the dominance of scientific knowledge derives primarily from its drive to make itself accessible to everyone.

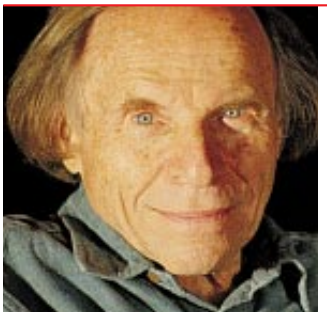
That same drive for accessibility has led science to become a kind of pop culture. The books reviewed here owe their lush production values and large press runs, if not their very existence, to the well-deserved popularity of books such as James Gleick's *Chaos,* Stephen W. Hawking's *A Brief History of Time* and Murray Gell-Mann's *The Quark and the Jaguar.* In this atmosphere, there is a tendency to hype science. Much of the current debate over complexity revolves around whether provocative-sounding (and hence commercially viable) ideas such as "the edge of chaos" and "self-organized criticality" have been oversold, both to the public and to other scientists. If they have been, we soon will know.

In the meantime, the techniques of complexity have quietly pervaded everyday science and engineering. Almost a decade ago, having just received my Ph.D., I attended the first Santa Fe Institute summer school for the study of complex systems. The techniques people described seemed to me far out, abstract and not necessarily practical. Now I am a professor of mechanical engineering at M.I.T. As I write this, graduate students are applying genetic algorithms to find the least wasteful way to stamp parts out of sheet metal, programming cellular automata to analyze air-conditioning systems and using simulated annealing programs to optimize designs for engines. Engineers have taken ideas from the theories of information and computation, woven them together into a method called axiomatic design and put them to work making better freezers and injection molds.

Despite the new contenders, one of the best books on the sciences of complexity is still one of the first, *The Dreams of Reason: The Rise of the Sciences of Complexity,* by Heinz R. Pagels. Published in 1988, shortly before Pagels's tragic death in a climbing accident, the book explores the role of reason in the often irrational human need to understand. Noting that, throughout history, this urge has co-opted all available rational tools, Pagels argues that the future of science lies in the synthesis of multiple disciplines and computational tools. Tall, flamboyant and fond of a good intellectual dustup, Pagels was the real-life model for the chaotician Ian Malcolm in the book *Jurassic Park*. Unlike Malcolm, he cannot be resurrected for a sequel, but if he could read these books and their reports on what the study of complex systems has accomplished recently, he'd probably smile, and he'd certainly say, "I told you so."

***PRISONER'S DILEMMA MAPS** show the proportion of players defecting* (red) *or cooperating* (blue) *depending on the payoff for defection* (highest at top; lowest at bottom). *Yellow and green colors mark players who have just switched from cooperation to defection, or vice versa.*

SETH LLOYD is Finmeccanica Assistant Professor of Mechanical Engineering at the Massachusetts Institute of Technology.



WONDERS

by Philip Morrison

Planet-tude

VLAD GUZNER

The *East London Daily Dispatch* enlightens many readers far from its city desk in that busy South African port. On the rural Fort Hare campus one Monday last October, I was exhilarated by a laconic front-page *Dispatch* story. It told of a planet orbiting the faintly visible sunlike star 51 Pegasi, a credible discovery just announced by two Geneva Observatory astronomers, Michel Mayor and Didier Queloz. Long wistful for just such a find, I eagerly queried my astronomical friends in California by e-mail. Did they believe this report? My ingenuous question from the far-off Eastern Cape put me into the loop; expert opinions and data poured overseas into our node @ufh.ac.za.

Within the month the Californians—R. Paul Butler, Geoffrey W. Marcy and their team at San Francisco State University, Berkeley and Lick Observatory—had fully verified the Geneva data during a sleepless week at their own telescope. By January 1996 that group had twice lengthened the planet tally. Now we can point to three sunlike stars that shine upon giant planets, as does our sun. All are on the lists of the few hundred candidate stars in our galactic neighborhood, rather freely dubbed sunlike. Observers have been searching these for indirect signs of planets. Groups are hard at work in several countries. The count of systems is sure to grow swiftly, maybe even to plenitude (planet-tude?).

Once I filled in the implications, tilting only a little toward optimism, I stood breathless. Star counts of the Milky Way offer quite adequate reason to set the total number of long-lived, stable, sunlike stars at a few percent of the entire star population of this galaxy's disk. You may prudently exclude from consideration sunlike stars much older or younger than the sun, as well as many more stars in binary systems. I estimate that easily a billion stars in our own galaxy resemble Sol. The sample of planets among them is still very small, yet it supports a reasonable bet that unless the stars nearby are somehow exceptional, *10 million* such suns illuminate recognizable planets.

Why were the planets so hidden from us? Our own experience as planet dwellers allows a direct answer. In your sky after dusk this spring, an exceptional evening star blazes forth. This jewel of the wanderers, after the sun and the moon the brightest body of all, is still the "Lady of the Evening, radiant on the horizon," as she was for ancient Ur. Consider what you see. Bright Venus is roughly as far from us as is our sun. Her nature should not be assessed by comparison to the remote stars she so outshines, but to the dazzling disk of the sun hidden at night below the horizon. Imagine moving our sun out among the stars a few light-years away. That will transform its appearance from the hot disk we live by to a mere point of light in a dark sky, like its kin.

Then suppose Venus were sent to orbit that sun-star. The two lights, Venus and the sun, would still be at the same distance from you. If the sunlight is so dimmed by distance, the light of Venus is diminished in the same ratio. Venus placed near any other star will vanish, a point of light far fainter than the stars we see, a billion times dimmer than the starlike sun. It is patent that even with big telescopes we will have a hard time viewing directly the planets of other stars: someday, yes. Our news of distant planets has not come from seeing them. Planets are "dark matter"; all we can spot are silvery cloud tops or sunstruck lands passively returning a small amount of the light of their own glowing star. It is their suns we must watch, faintly visible proxies for their own much too faint satellites.

We tyros cannot yet decide what is commonplace among planets and what is rare.

Our present success exploits the gravitational influence exerted by every planet on its more massive sun. Today's searchers ably detect minute changes in a star's speed as a planet pulls feebly against it. Indeed, the first credible extrasolar planets were well established in 1992 and 1993 by exquisitely timing the natural radio pulses emitted every six milliseconds by a certain very rapid pulsar. Timing those near uniform pulses, collected by the billion, allowed the precise measurement of very slight irregularities.

The recurring advances and delays in pulse arrival time could be fitted well by the pulsar response to forces produced by two planetary masses, plausibly near the pulsar. But a pulsar is a neutron star, a creature of catastrophic collapse. Its nature and history are so unlike our sun's that its ménage seems less than clearly relevant to our solar system. Those pulsar planets may even

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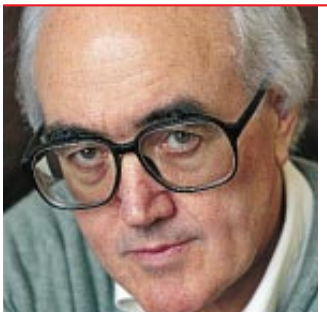


CONNECTIONS

by James Burke

Highbrow Stuff

I got one of those junk-mail fliers through the post the other day, urging me to sign up for study-by-mail on the subject of memory improvement. If only I knew where or what my memory *was,* I thought, I'd do anything to improve it!

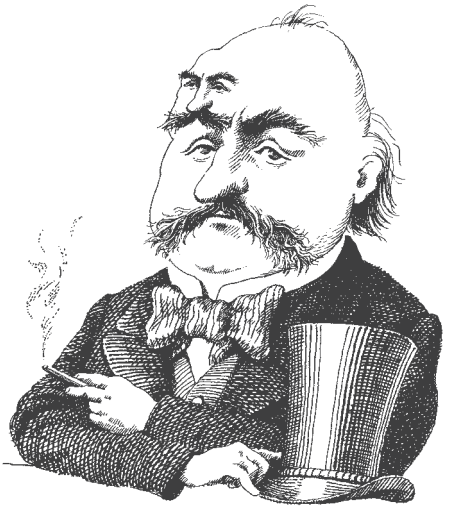
Still, we know more than we used to about such neurophysiological matters, thanks in part to the kind of junk mail that was sent out in the 1850s by Isaac Pitman and his business partners in their efforts to promote a totali nu wei uv speling Inglish. Alas, their efforts came to naught (or nought), and they switched instead to selling correspondence courses for a phonetically based writing technique we now know as shorthand.

Pitman's original reason for attempting to turn English into WYSIWYG was because it isn't. Try pronouncing "Featherstonehaugh," if your mother tongue isn't British English. Go ahead and try, even if you speak English from parts American, Australian, New Zealander, Canadian or South African. (Give up? It's "Fanshaw.") Pitman believed that world peace would be more rapidly achieved if, by making words such as "Featherstonehaugh" simpler to read and pronounce, all those foreign "johnnies" could be more easily exposed to the "civilizing" influence of English English.

If you had a bump behind the left ear, you were a good lover. (Did you just check?)

Harrumph. The idea took root, although on a much grander scale than the single-minded Pitman might have hoped for, and in 1897 it flowered as the International Phonetic Alphabet. Which made *every* language easier to read and pronounce.

Top gun in phonetics was Henry Sweet, after whom George Bernard Shaw modeled Professor Higgins in *Pygmalion* (a.k.a. *My Fair Lady*). As it happens, in the play, Higgins notes down the character Eliza's speech patterns using "visible speech," another set of symbols that had been developed long before by Alexander Graham Bell's father, an elocution teacher who had been a founding member of the British Phonetics Council. By the 1870s Bell, Jr., was busy visualizing sound, too, for the deaf students he was teaching in Boston.



VLAD GUZNER

It was at this juncture that he came across a thing called a phonautograph, developed by the otherwise entirely forgotten E. Leon Scott de Martinville. The device was fairly primitive: a membrane vibrated in reaction to speech, and a bristle attached to the other side of the membrane traced wiggly marks on a moving piece of smoked glass. With the phonautograph, Bell was able to show his pupils the correct "shape" of the sound they were trying to make, so that they could then compare their own attempts to imitate it.

The whole wiggly-line phenomenon probably had its origin in an invention years earlier by a French physiologist by the name of Etienne J. Marey, who fitted a membrane on a tiny drum (a "tambour") and placed this device wherever he wanted vital rhythms to be turned into graphs. When pressure of any kind depressed the membrane, the air in the tambour would be forced along a tube to push against a membrane fitted to another tambour at the far end of the tube. A stylus mounted on this second membrane would move in response and trace a line. With the tambour, still in general medical use as late as 1955, Marey could reduce virtually any kind of physiological vibrations to lines. He called his squiggles "the language of life."

That the innovation should have come from France made sense because in the early 1800s, Parisian hospitals were far in advance of those anywhere else. Even the English came over to take notes. Harrumph.

Paris was where ward rounds and charts and stethoscopic diagnosis and medical statistics first became commonly accepted. And along with all that, the unquestioned authority of doctors, stemming in part from Napoleon and his idea of winning wars by numbers. His million-strong army was the first to be established by nationwide conscription; inevitably, droves of young soldiers went from battlefield to hospital, ever obedient to discipline.

Numbers also did the trick for medical technology, because there were so many war-wounded that hospital staff could now easily gather really large-scale, statistically meaningful amounts of data on the efficacy of patient evaluation and treatment. And so those wiggly lines began to appear at the foot of the bed, charting the course of a patient's temperature, respiration and heart rate, or any other physical condition that could be reduced to lines and figures.

Which, late in the century, left the uncharted field of psychological disorders and their treatment with a brand-new

Viennese technique touted as "Mesmerism." Franz A. Mesmer's assistants would first examine patients to locate their "magnetic poles," whereupon Mesmer himself would appear (in feathered hat and long robes) to stroke relevant areas of their body, transmitting a mysterious, curative "influence" to the sufferer.

Despite the fact that such hardheads as Benjamin Franklin officially pronounced Mesmer a fake, the concept of this influence persisted. The idea had, after all, already been around for 300 years. Even Descartes had thought a "vital spirit" flowed down the nerves from the pineal gland. For this reason, by 1820 two more hucksters, Franz J. Gall and Johann C. Spurzheim, were parlaying the new "science" of phrenology. This was based on the theory that an "influential liquid" originated in 37 separate organs in the brain, each responsible for a moral, sexual or intellectual trait; your character could be assessed by feeling the bumps in the skull above them. If you had a bump behind the left ear, for instance, you were a good lover. (Did you just check?)

By 1876 a fellow called Cesare Lombroso, director of a lunatic asylum, had studied thousands of heads (living and dead) and had arrived at the conclusion that Charles Darwin's theory of human descent from apes was right. It was Lombroso who spread the word about criminals and the insane being "throwbacks" with sloping foreheads. "Neanderthal" had become the new buzzword occasioned by the recent German discovery of ancient human bones in the Neander Valley.

Conservatives took Lombroso's remarks about "criminal characteristics" to mean that criminality was innate and from this inferred that for the "born" criminal, a life-term sentence or execution was the only option. Liberals saw in bump-reading the opportunity for rehabilitation and prison reform. The new welfare agencies found themselves with an extra tool for investigation and self-improvement.

Perhaps the most startling outcome of Lombroso's work was the effect it had on a young man who was briefly Lombroso's assistant in 1872. The job required him to carry out postmortem dissections, and intrigued by talk about bumps of knowledge and lowbrows, he began to slice brains in his kitchen and peer at them with the microscope that his pathologist uncle-by-marriage happened to have.

Sometime in 1873, perhaps stimulated by reading about the new chemistry of photography, he left a piece of brain to harden in a mix of potassium bichromate and osmium chloride, then dunked it in a solution of silver nitrate. When he cut very fine sections of the material, dried them and lit them from behind, he found something that would change how we think about how we think. What Camillo Golgi saw was a golden-yellow background of tissue, within which were visible, in glorious and finely detailed black, the brain cells that today bear his name. From that single experiment, the whole of modern neurophysiology was to emerge.

So if somebody ever does succeed in discovering where your memory resides and how it can be improved, it'll probably be thanks to Golgi and the phrenology freaks. And that junk mail I mentioned at the start (remember?). SA

Wonders, *continued from page 109*
have been formed somehow during the explosive supernova event itself.

Normal stars emit no sharp ticks. The successful planet finders have been at work for years with simple starlight to measure the Doppler shifts of the familiar dark lines in the usual stellar spectrum, but now with startling sensitivity. Our account will draw on the procedure used by the Californians, but its virtuoso performance and that of other groups depend alike on modern instrumentation and similar insights into principles.

At the big Lick reflector (3.5 meters in diameter), a very fast, grating spectrograph accepts only a small range of the optical spectrum, albeit with very high resolution. All detection is done by counting the photons with a large charge-coupled device, or CCD. The positions of hundreds of absorption lines are compared with those of reference lines introduced by passing the incoming starlight through a cell filled with a little absorbing iodine vapor. The numerous sharp molecular lines of iodine throng every spectral chunk. They provide a constant basis for comparison with many closely adjoining lines from the star. The changing motions of Earth and the sun are corrected for, and the best fits to the observed Doppler speeds of the star lines are computed from the large sample of shifts.

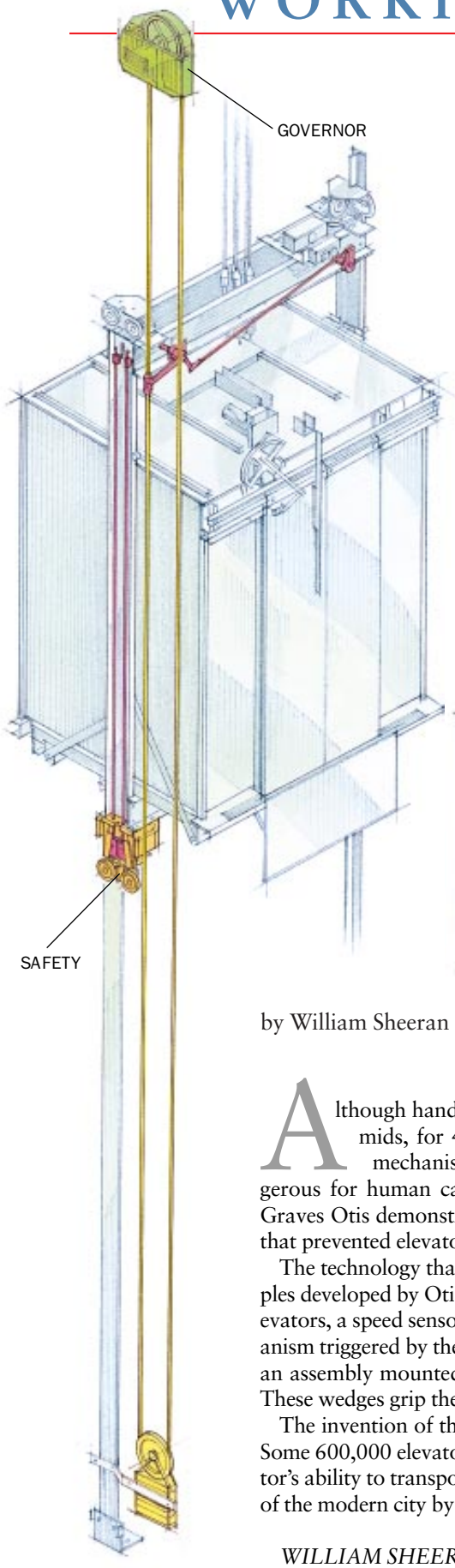
The spectral lines of a star all shift together as its motion responds to the planet's force. No single line shift is very significant, but abundant statistics cancel random error in the atmosphere and within the instrument, while opening unprecedented sensitivity to small accelerations. Isolated stars nearby typically move through space toward or away from us at a constant rate of 10 or 20 kilometers per second, about the speed of a space probe. Only changes in that steady speed count.

For example, Jupiter enforces a changing reflex motion as it orbits our sun, because between the two, gravitational action and reaction are equal. Because the sun outweighs Jupiter 1,000-fold, its response to Jupiter is grudging, so its solar recoil orbit is both tiny and slow. The sun's speed changes are at most that of a racing cyclist, a minor change in any star drift. Note that rocky Earth, only 1/300 of Jupiter's gassy mass, can disturb the sun's speed only by the trifling speed of a running ant.

The Lick setup now checks distant star speed with a well-documented uncertainty no greater than the speed of a brisk walk! That limit is set mainly by photon noise; target stars must be close enough to supply the many photons needed in a reasonable time. The method inherently favors finding giant planets that can pull hard on their stars and close-circling planets that unfold their orbits quickly. The ones we have tagged so far are both: big planets in smallish orbits. We tyros, knowing only one solar system in detail, cannot yet decide what is commonplace among planets and what is rare. Even once we have compiled a thick field guide, we will yearn for answers that transcend astronomy.

For detecting communicative counterparts, we need more than the biochemistry that detailed planet spectra will someday offer. We seek not mere algae nor oxygenated life, but detectable artifices of technology, probably real signals across space, whether sent by inadvertence or by design. Will we not search patiently for such signals from the millions of planetary systems where some finite creatures may share our curious wondering? SA

VERTICAL SAFETY



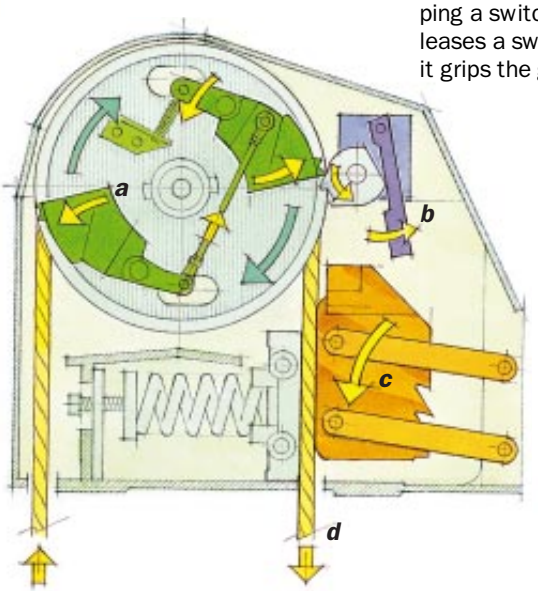
OTIS ELEVATOR COMPANY HISTORIC ARCHIVES

OTIS SUSPENDED

In 1854 at the Crystal Palace Exposition in New York City, Elisha Graves Otis had an assistant cut the rope supporting the platform on which he stood above a gawking crowd. Otis's invention of a safety mechanism prevented the platform from falling. Three years later the first passenger elevator, driven by steam, debuted at the E. V. Haughwout & Company store in New York.

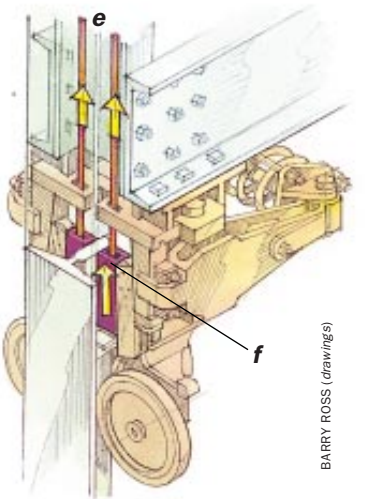
GOVERNOR

When an elevator's speed of descent surpasses a defined limit, weights mounted to a spinning disk move outward (*a*), tripping a switch (*b*) that unlatches and releases a swinging jaw (*c*). As the jaw falls, it grips the governor rope (*d*).



SAFETY

Tension on the governor rope pulls up lift rods (*e*), releasing a pair of wedges (*f*) that grip the guide rail, thereby braking the car's motion.



BARRY ROSS (*drawings*)

by William Sheeran

Although hand-operated hoists date to the building of the pyramids, for 4,500 years the absence of any fail-safe braking mechanism left these earliest elevators unreliable and dangerous for human cargo. That changed in May 1854, when Elisha Graves Otis demonstrated a mechanical system of springs and clamps that prevented elevator cars from going into a free fall.

The technology that ensures elevator safety has advanced greatly since then. Nevertheless, the principles developed by Otis remain in use today, even in the tallest buildings in the world. In most modern elevators, a speed sensor called a governor monitors the rate of descent. If the car moves too fast, a mechanism triggered by the governor first cuts the power and applies the brakes. If the car still does not stop, an assembly mounted below the passenger compartment, called a safety, actuates wedgelike clamps. These wedges grip the rails on which the car rides, bringing it to a halt in a second or two.

The invention of the safety has made the elevator one of the world's safest forms of transportation. Some 600,000 elevators are in use in the U.S., carrying nearly 45 billion passengers annually. The elevator's ability to transport people up and down a vertical shaft without incident has helped etch the profile of the modern city by allowing buildings to grow skyward.

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