PLANETARY SCIENCE

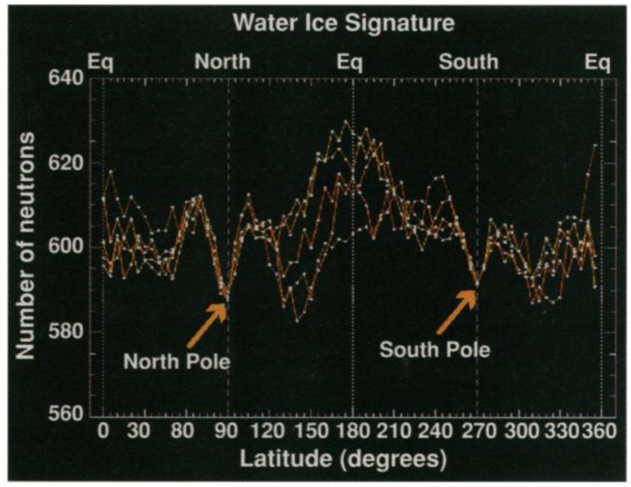
Cheapest Mission Finds Moon's Frozen Water

Lunar Prospector, the cheapest of the NASA Discovery program's "faster, cheaper, better" missions, last week proved itself the equal of more costly spacecraft. After only a month in orbit, the $63 million, five-instrument spacecraft gathered "the first unquestionable result that there is water on the moon," says the mission's principal investigator, Alan Binder of the Lunar Research Institute in Gilroy, California. Developed and launched in just 22 months, the spacecraft "is performing much better than we could have hoped. It's a little gem. This is what the Discovery program is all about." Not only does the detection of water frozen near the lunar poles bolster hopes for eventual colonization of the moon, it strengthens claims that Mercury—innermost and hottest of the planets—has polar water, too.

Despite the extreme dryness of the rocks returned by Apollo astronauts, planetary scientists have speculated for decades that ice might exist on the moon, because comets—balls of dirty ice—have been pelting it for billions of years. In theory, a tiny part of that cometary water could have been secreted away from the sun's heat in the interiors of large craters near the poles, where the sun never rises over the craters' rims and the temperature can drop well below −120°C. Radar probing by the orbiting Clementine spacecraft reported polar ice in 1996, but a subsequent Earth-based radar study contradicted that finding.

Lunar Prospector was designed to settle the question using an instrument new to planetary exploration. The neutron spectrometer, operated by William Feldman of the Los Alamos National Laboratory (LANL) in New Mexico, records neutrons produced by the high-energy cosmic rays that continually strike the lunar surface. These fast-moving neutrons bounce off nearby atoms before ricocheting up to the spacecraft. If they hit a hydrogen atom—two of which are found in every water molecule—they will slow dramatically, signaling the presence of water.

Like the other instruments on Lunar Prospector, the neutron spectrometer was not developed specifically for the mission. Similar instruments have been flying for 35 years on Earth-orbiting satellites that monitor compliance with the 1963 ban on atmospheric nuclear tests. This proven technology kept the cost of Lunar Prospector's instrument to less than $750,000, says Feldman. The total cost of all five of the



W. FELDMAN/LANL

Double dipping. Drops in the abundance of neutrons over both lunar poles reveal the presence of ice.

The Short Life of a Spacecraft

It's been a triumphant week for the Lunar Prospector team, but their moment won't last forever. In these cost-conscious days, NASA missions are supposed to be not only "faster, cheaper, better" but also shorter. For Prospector—at $63 million, the cheapest of the cheap—the clock will run out within 18 months, after the craft is sent into a lower and increasingly unstable orbit, ending in a final, suicidal crash onto the lunar surface.

And while a short life culminating in suicide may be considered a tragedy among humans, NASA considers it a productive option for spacecraft. Other missions are also scheduled, if not for outright termination, then for risky behavior that will probably claim the spacecraft but will also squeeze more data from their final days. "We're taking more risks, clearly," says Guenter Riegler, NASA's overseer of space science mission operations.

Many earlier missions enjoyed seemingly indefinite extensions. Magellan's 8-month orbit of Venus, for example, was repeatedly extended until the spacecraft failed after 5.5 years. But while operating costs continue to mount during an extension, scientific return declines. So the new plan is to have spacecraft achieve their main goals during their "prime phase," then, barring an extraordinary reason for a reprieve, kill them in a crash or simply turn them off. No matter how much data Lunar Prospector gathers from its final low passes (see main text), it's not likely to win much more time in orbit.

Other missions may be headed for a similarly violent end. Take the Near Earth Asteroid Rendezvous (NEAR) spacecraft. After orbiting the asteroid Eros for 10 months starting next January at altitudes as low as 35 kilometers, NEAR is scheduled to end its prime phase by dropping to 100 meters for a closer look or even touching down. But the $210 million NEAR was never designed for landing. "There's a lot of risk involved," says NEAR project scientist Andrew Cheng of the Applied Physics Laboratory in Laurel, Maryland. "If we crash land, that will be the end of the mission."

Farther out in the solar system, the Galileo spacecraft orbiting Jupiter finished its prime phase late last year. To plead the case for extending Galileo's life, team members slashed costs by 80% while offering extra passes by the moon Europa, with its evidence of a subsurface ocean, says Galileo project scientist Torrence Johnson of the Jet Propulsion Laboratory in Pasadena, California. Galileo won a 2-year extension and is continuing to deliver the goods, transmitting the highest resolution images of Europa ever (see p. 1639).

But Galileo has already accumulated more than its nominal design limit of 150 kilorads of radiation by swinging into Jupiter's radiation belts, and its next move is riskier yet: In 1998 it will head further inward and fly by Io. After two passes, Galileo will have absorbed two to three times its design limit for radiation. Sooner or later, its electronics will be disabled by radiation. "It's very definitely a risky endeavor," says Johnson. But in the short life of a spacecraft these days, a little risk is well worth the reward.

–R.A.K.

instruments totaled only $3.6 million, says mission manager Scott Hubbard of NASA's Ames Research Center in Mountain View, California—well below the $10 million to $30 million that a single instrument on other missions can cost, he says.

After Lunar Prospector had crossed the poles repeatedly for a month, researchers "were certain water is there," says Binder. "The uncertainty is in how much." About 0.5% to 1% of the lunar soil near the poles appears to be fine particles of ice. That means a cubic meter of soil would contain about 5 to 20 liters of water, which might add up to a total of 10 to 300 million metric tons of water, says Binder. Although the amount is tiny by terrestrial standards and is still uncertain by a factor of 10, "that's a significant quantity," he says.

Extracting the water would in theory be simple: Take some soil and heat it a little. The resulting "moonshine" would allow "a modest amount of colonization for centuries," says Feldman, assuming a reasonable cost for distilling it. The water could also be split into hydrogen and oxygen—the perfect combination for rocket fuel. "For the first time, when you go to the moon, you [know] you can fuel up," says Binder.

Mining the moon would require a practical means of operating in the extreme cold, however, as well as a far better understanding of lunar geology, says Binder. "There's a lot of questions to be answered," he says. Lunar Prospector will be helping to answer those questions this year and next as it continues its explorations. It has already completed a much improved gravity map of the moon, which will offer insights into the moon's internal structure and improve planning for future orbiting spacecraft. Mapping of the moon's major chemical elements is progressing very well, Feldman reports. And once the spacecraft drops to a lower orbit next year (see sidebar), it is expected to get a better fix on the location of the ice.

The mission even has implications for other planets. Earth-based radar detected possible signs of ice on Mercury in the early 1990s (*Science*, 15 November 1991, p. 935). Although Mercury is closer to the sun, its polar craters are even colder than the moon's because the planet wobbles less on its axis. Still, many researchers were skeptical, thinking that the putative ice was volatile sulfur instead, which would give a similar signal. But having water on the moon "means almost for sure there's ice on Mercury too," says planetary scientist David Page of the University of California, Los Angeles. Don't expect mining missions to Mercury anytime soon, however. Even faster, cheaper, better has its limits.

–Richard A. Kerr

EMERGING DISEASES

Celebrated Virus Hunters Set Up Shop in France

PARIS AND LYONS—Joseph McCormick has a history of setting up laboratories under tough conditions. During the 1970s and '80s, he studied the deadly Lassa and Ebola viruses in remote African villages, some reachable only by dirt tracks. And when Projet SIDA, a program to study AIDS in Zaire, started up in 1984, McCormick flew into Kinshasa with an entire AIDS lab packed in boxes. But some supplies were hard to come by. "We didn't know where we were going to find liquid nitrogen," recalls Jonathan Mann, Projet SIDA's first director. "Then Joe located some at a Kinshasa brewery. He could always find a way."

McCormick, an American epidemiologist formerly with the Centers for Disease Control and Prevention (CDC) in Atlanta, won't have to knock on brewery doors in his new job. As head of a recently created epidemiology and biostatistics unit at the Pasteur Institute in Paris, the veteran virus hunter will be able to carry on his research in relative scientific luxury. And he is joined in France by his British wife and virus-hunting colleague, former CDC physician Susan Fisher-Hoch, who is overseeing the construction of Europe's first full-scale, top-security microbiology lab in Lyons (see sidebar).

R. BENALI AND R. GAILLARDE/GAMMA LIAISON

Dynamic duo. Susan Fisher-Hoch dons microbe-proof suit while Joseph McCormick looks on.

It may seem strange that this duo, whose adventures in Africa and Asia have been featured in several recent books and television documentaries, has traded the hardships of the developing world for the advanced scientific environment of France and the bistros of Paris and Lyons. "I was a little bit surprised that they went to France," says Mann, who is now dean of the Allegheny University School of Public Health in Philadelphia. "They are entering a citadel of modern medicine with a message about public health" in the developing world. But McCormick and Fisher-Hoch intend to continue focusing on problems of the Third World countries in which they spent much of their careers. One of McCormick's key tasks will be to create an epidemiology training program for the worldwide network of Pasteur institutes, most of which are in Asia, Africa, and South America. And among the first projects Fisher-Hoch hopes to carry out at the new lab she is setting up in Lyons is the development of a vaccine against Lassa fever, which infects at least 100,000 people in Africa each year and causes up to 5000 deaths.

The couple's journey from Atlanta to France followed a circuitous route. In 1993, they left the CDC and moved to Karachi, Pakistan, when the Aga Khan University offered McCormick a position as head of its community health sciences department. They left the CDC in part because they felt that over the years the agency had become "political and bureaucratic," McCormick says. "The big watershed," Fisher-Hoch adds, was a falling-out with some colleagues at CDC over how best to handle a 1989–90 outbreak of Ebola at a private monkey facility in Reston, Virginia, that received widespread media coverage. McCormick—who was head of CDC's special pathogens branch at the time—believes the dangers to the public were greatly exaggerated. In Karachi, the two were in their element, training medical students to track down hepatitis C and cholera and trying to boost the underdeveloped public health system in Pakistan.

Then, in late 1996, as their contract at Aga Khan University was coming to an end, McCormick learned from a former colleague at CDC that the Pasteur Institute was looking for someone to create a new epidemiology unit. McCormick sent an e-mail message to Pasteur medical director Philippe Sansonetti expressing interest. The e-mail never went through, but Pasteur officials, it turns out, were already interested in McCormick. At