mation with them that you can't get with an EEG. But whether that's going to justify the enormous expense to a hospital, say, of laying out $2 million on something that complements a $20,000 EEG system is another question. Quite crudely, it will depend on how many lives you can save. And whether you can save any lives or not isn't clear right now." Indeed, some of the commercial companies seem to be waiting for successful clinical applications before committing themselves to full-scale production of the large arrays.

As a research tool, however, biomagnetism unquestionably has enormous significance. The study of high brain functions such as mental imaging, language production, and memorization, for instance, up to now has had to rely primarily on case studies of individuals who have suffered various forms of brain damage, often incurred during wartime. Moreover, conventional EEG and positron emission tomography techniques look only for point sources of current. To understand higher brain functions, however, one has to look at a sequence of activity—how each area communicates with several others over time—and MEGs may allow you to do that. New York University is an important center for such research, and an NYU team announced at the conference results in which differences between how the brain processes visual and linguistic tasks had been detected. Another breakthrough was announced by a team of British scientists at the Open University who had developed computer methods of graphically presenting in three dimensions and in real time brain current densities picked up by MEGs.

Meanwhile, research is shooting out in so many directions that biomagnetism may not be a unified discipline much longer; indeed, researchers sometimes liken its probable fate to that of the discipline once spawned by the Mössbauer effect, the phenomenon of recoilless emission and absorption of gamma rays by certain nuclei which is widely used in many fields. "Of itself," Cohen says, "the Mössbauer effect isn't all that interesting anymore, but it does have applications. You don't see Mössbauer conferences like you used to, but you do see Mössbauer people using it in different fields. The same may happen to biomagnetism." Indeed, MPG researchers were less prominent at the NYU conference than in previous years, suggesting that they have gone elsewhere and that the process of fragmentation has already begun. ■ ROBERT CREASE

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The (Liquid) Breath of Life

Fluid in the lungs is a bad sign—unless the fluid is perfluorocarbon, which could save many premature infants and lung-damaged adults

AFTER 2 WEEKS it was clear that nothing more was going to help: the infant girl, born prematurely at 28 weeks and under intensive care at Saint Christopher's Hospital for Children in Philadelphia, had failed to respond to any of the conventional therapies. Indeed, the high-pressure oxygen that made it possible for her to breathe at all had slowly ruptured the membranes of her lungs beyond healing.

And so on 10 May, when the doctors agreed that the end was probably minutes away, the parents gave their permission for the first human test of a treatment as radical as it was bizarre. Through a thin plastic tube, researchers flooded the girl's damaged lungs with the kind of "perfluorocarbon" fluid that is widely used to cool electronics gear—and that just happens to be capable of carrying more oxygen than air itself.

Within minutes, her condition improved markedly, and she lived for another 19 hours.

"Just seeing that fluid go into a human lung was a very intense experience emotionally," says team leader Thomas H. Shaffer, who has spent the past decade and a half testing the procedure on animals. "We were very nervous. A baby this sick could die just from having you walk up to it."

Nervous or not, Shaffer has become something of a hero in the tiny community of liquid breathing researchers. "So many things in medicine require a psychological breakthrough," says Leland C. Clark of the Children's Hospital Medical Center in Cincinnati, the chemist who first discovered perfluorocarbons' application for liquid breathing. There have been abundant animal tests demonstrating the technique's potential for saving many premature babies who would otherwise die—and for treating adults suffering from smoke inhalation and other types of lung damage. "[But] Shaffer deserves a lot of credit for breaking through that barrier and trying it on humans."

Shaffer has been working his way to this point since the early 1970s, when he was an undergraduate engineering student at Drexel University. Clark had demonstrated perfluorocarbon breathing only a few years before, in 1966, and the concept was still enjoying something of a vogue. Not only were perfluorocarbons known to be extremely stable and generally nontoxic—the name denotes an organic molecule in which

Temple University

Perfluorocarbon pioneers. *After 15 years of experiments with animals, engineer-cum-physiologist Thomas Shaffer and colleague Marla Wolfson conducted the first human test of liquid breathing.*

every possible hydrogen atom has been replaced by a fluorine—but they were capable of carrying even more dissolved oxygen than air. People were imagining all kinds of applications for deep-sea diving and space travel. (They still are: the newly released science fiction film, *The Abyss*, features an "aquanaut" breathing liquid in a special diving suit.)

"I had won a science prize for an engineering project," Shaffer recalls. "So one of the faculty members [engineer Gordon Moskowitz] asked me to design a controller for a liquid-breathing apparatus he was working on."

Shaffer did so (it was cited explicitly in the novelization of *The Abyss*) and, in the process, formed an interest in the lung that proved enduring. For his Ph.D. in applied mechanics, Shaffer wrote his thesis on the lung as a control system; then, realizing that he really didn't know very much about the physiology of the lung, he went off to the University of Pennsylvania for postdoctoral work in that field. While there, he says, "I became interested in how a baby's lungs develop, and then it hit me: 'This is the application here!' Liquid breathing made a lot more sense with distressed lungs than with healthy lungs."

In a healthy lung, he explains, the moist inner membranes are coated with a kind of natural detergent, a "surfactant" that lowers the water's surface tension. This is what makes it possible for the lungs to fill with air in the first place: if the surface tension on the membranes were as high as that of ordinary water, the myriad tiny alveoli, or air sacs, would simply collapse.

Unfortunately, he says, this is exactly what sometimes happens in the lungs of infants born before about 35 weeks. The natural surfactant is inadequate, which is why high-pressure oxygen is required to keep many of these babies alive, despite its potential for devastating the lung tissues.

Liquid breathing, Shaffer realized, has one potential major advantage over the use of high-pressure oxygen: The perfluorocarbons, which happen to have a very low surface tension, could easily penetrate into the tiniest cavity of the lungs and keep them inflated at normal atmospheric pressure, thus delivering the vital oxygen without causing damage.

The trick was to turn this idea into a viable therapy. Starting in the late 1970s, Shaffer and his co-workers systematically began to research such nitty-gritty factors as the rate of gas exchange inside a perfluorocarbon-filled lung (slow) and optimum breathing rates for the liquid (about four times per minute.) The bulk of the experiments were done on premature sheep, he says, since these animals are about the right size and provide a good model of human lung development.

It was often lonely work. Clark and most of the other pioneers in liquid breathing

Phobos at Mars: A Dramatic View—and Then Failure

When the Soviet Union's Phobos 2 satellite tumbled out of control at the end of March, researchers' hopes for a close-up view of Mars and its largest moon seemed dashed. But, as Soviet scientists reported at a recent solar system conference held at Caltech in conjunction with the Voyager encounter with Neptune,* all was not lost. A good deal of scientific data was returned during the doomed satellite's short life in Mars orbit. One of the most spectacular results was the first temperature map of the Martian surface ever made, shown below.

The image, one of four similar strips of the Martian equatorial regions mapped by Phobos' thermal scanning instrument, has a resolution of 2 kilometers, and covers the vast, 5000-kilometer rift valley known as Valles Marineris. Starting on the right, just above the great shield volcano Arsia Mons, the image clearly shows the cool track left by the shadow of the moon Phobos.

According to astronomer Margarita K. Naraeva of Glavkosmos, the Soviet space operations agency that is roughly equivalent to NASA, these maps will allow the Phobos scientists to learn something about the surface composition of Mars by measuring how rapidly the rocks and soil at each point heat up during the day and cool down at night. Ultimately, she said, Phobos was to have mapped virtually all of Mars. It is unfortunate that most of the surface scans had been scheduled for *after* the encounter with Phobos, she said, so that they were lost.

In the meantime, however, the spacecraft was able to take 37 color pictures of Phobos itself. Several of them provide new high-resolution coverage of areas that were poorly imaged by the U.S. Viking orbiters in the mid-1970s. In addition, said Leonid Ksanfomality of the Space Research Institute (IKI), data from the infrared spectrometer suggest that the Phobian rocks hold considerably less water in their crystalline structure than Martian surface rocks do. Such a level of hydration is consistent with that found in carbonaceous chondrites, meteorites thought to have remained largely unchanged since the origin of the solar system 4.6 billion years ago. This finding, in turn, is consistent with planetologists' widely held view that Phobos, like its companion satellite, Deimos, was not originally a moon at all but an asteroid that Mars somehow captured from the nearby asteroid belt.

Equally intriguing is the fact that the infrared data suggest strong variations in composition from one point to another on Phobos, said Ksanfomality. This may mean that Phobos was originally formed not as a single mass but as a loose conglomerate of several large pieces.

The scientists would have been able to learn much more about Phobos if the spacecraft had been able to rendezvous with the satellite and drop a pair of surface landers as planned. But it was not to be. Roald Kremnev, director of the Soviet Union's

* The Second AIAA/JPL Conference on Solar System Exploration, 22 to 24 August 1989, California Institute of Technology, Pasadena, CA.

research had long since gone off to pursue perfluorocarbons as an artificial blood substitute. (At least four companies are currently seeking Food and Drug Administration approval for artificial blood products.) Nonetheless, the culmination of this phase of the research came with an experiment presented in the spring of 1989 to the Society of Pediatric Research. Shaffer and his colleagues demonstrated that premature lambs could survive on perfluorocarbon breathing at a stage of lung development equivalent to a human baby's at 20 weeks.

Shaffer is wary of overselling this experiment, especially considering the sensitivities surrounding the abortion issue and the question of just when a fetus can survive outside the womb. (The ragged edge of viability is usually considered to be 24 weeks.) "All we can say is that we can get gas exchange," he says, "and we can get the fluid in and out with no damage."

Still, the demonstration was dramatic enough to convince the Saint Christopher's human review board to approve a test of perfluorocarbon breathing in a human baby. "It was a tough protocol," says Shaffer. "The baby would have to fail all other conventional therapies before we could try this."

But that was exactly what happened on 10 May. Shaffer filled the little girl's lungs for 15 minutes and then drained them again; enough fluid remained behind in the alveoli to keep them expanded and to keep the oxygen moving into her blood. "The most important thing is that her physiological responses to the fluid mimicked exactly what happened in the animals," says Shaffer. This suggests that the technique does work as expected in humans. Moreover, if this finding is confirmed in subsequent tests—the current plan is to test liquid breathing in five to ten more babies under the same protocol—then Shaffer and his colleagues hope to get permission to intervene before lung damage has progressed so far, so that they have a chance to save some of these babies.

Meanwhile, Shaffer and his team are equally excited about applying perfluorocarbon breathing to adults as well. Pulmonary edema, aspiration of food or vomit, smoke inhalation, lung burns, even some kinds of autoimmune diseases—"perfluorocarbons are very good for cleaning the lung," says physiologist Marla Wolfson, a co-principal investigator on Shaffer's project for the past 8 years. "With this low surface tension they get in everywhere, even around mucus plugs. And they don't remove the natural surfactants when they do it."

And then there is a less obvious application: helping preserve rare mammals in captivity. Premature birth is a severe problem among some captive animals, and for some species, saving even one or two would make a big difference. "There's no doubt in my mind that we could support those pandas they're losing," declares Wolfson.

■ M. Mitchell Waldrop

spacecraft manufacturing plant, the Babakin Center, told the Caltech meeting what happened.

On 27 March, he said through a translator, the spacecraft was passing near Phobos for what was, by then, a routine session of imaging. "It was on automatic operation," he said. "To conserve energy, the transmitter was off during imaging. But at the time it was due to restart, no signal was heard on Earth." The control group hurriedly sent up emergency commands, Kremnev said, and they indeed were able to reestablish contact. "They got 17 minutes of telemetry data. But the spacecraft was tumbling so that the only communication was through the spacecraft's small antenna. Therefore they couldn't decipher the telemetry. Then they lost the telemetry." Phobos 2 was never heard from again.

But since then, said Kremnev, "Considerable time has been taken, and we have been successful in deciphering the telemetry." There is now no doubt that the failure lay in the spacecraft's on-board computer, he said, and was not due to, say, a meteoroid collision. "After the failure of Phobos," he said, "People at Babakin said, 'We have luck only with women—not spacecraft!' "

In any case, he said, the Babakin team is attempting to increase the reliability of the spacecraft for future missions, the most urgent being the Mars 94 mission that is already undergoing intensive development. In particular, future versions of the spacecraft will have enough power to carry out their operations without switching off their antennas, so that they can be controlled full time from Earth. "We have no doubt we can use the spacecraft for future flights to Mars," he declared.

Kremnev also offered new details as to how the Phobos 1 spacecraft was lost last year on the way to Mars. As part of the ground checkout prior to launch, he said, the spacecraft computer had been loaded with a program for testing its steering. Once the test was completed, of course, the program was no long needed. However, it was in "firmware"—read-only memory—which could only be cleared with special electronics equipment. "We would have had to remove the computer from the spacecraft and take it to the people who could do it," said Kremnev. "[But] we had *very* little time before the voyage. So the program was 'locked in a safe.' " That is, it was sealed off and rendered harmless by other software in the spacecraft computer.

Unfortunately, said Kremnev, "the key was found to unlock the safe." On 29 August 1988, not long after launch, a ground controller omitted a single letter in a series of digital commands sent to the spacecraft. And by malignant bad luck, that omission caused the code to be mistranslated in just such a way as to trigger the test sequence. Phobos 1 went into a tumble that was not noticed until the next attempt at contact, 2 days later. It was never recovered. Kremnev said that future versions will have more on-board safeguards.

And what happened to the controller who made the error? Well, Kremnev told *Science* with a dour expression, he did not go to jail or to Siberia. In fact, it was he who eventually tracked down the error in the code. Nonetheless, said Kremnev, "he was not able to participate in the later operation of Phobos."

■ M. Mitchell Waldrop

Margarita K. Naraeva/Glavkosmos

The Great Martian Rift. *In this image of the vast Valles Marineris rift, the Phobos spacecraft's thermal scanner shows warmer areas as bright and cooler areas as dark. The cool, dark track of the moon Phobos runs along the right center.*