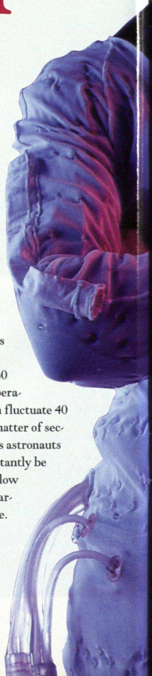
Space Skivvies, Souped-Up Cement and Circulation Secrets

BY DAWN KLINGENSMITH
PHOTO BY ROB HILL



WITH FEWER THAN 500 DAYS left in the 20th century, the countdown to Century 21 incites hope and hysteria. A pesky computer bug threatens to obliterate billions of files come Jan. 1, 2000, downing airplanes, governments and bank accounts. Scholars and the public pore the equally apocalyptic, 500-year-old prophecies of Nostradamus. Yet visions of Mars vacations, two-way telescreens and personal Hovercrafts tantalize, holding out the gee-whiz hope of a Jetson-esque future. With a new and still-enigmatic eon looming, now is a good time to sort the science from the fiction, to anchor the unknown in the terrain of fact.

Travel capsules haven't replaced the family sedan, and we still haven't wiped out death and disease. But MU scientists are working on ways to make our highways a safe system of travel for the 21st century and to reduce the frailty and failing health of old age. We don't keep summer cottages on other planets, but U.S astronauts will plant the flag on Mars as early as 2010, and when they do, they'll be sporting newfangled spacesuits MU scientists helped design. In laboratories all across campus, researchers are working to bring into focus a clear image of what the human race can achieve in a century that grows nearer with every whirl of the analog clock.

THE SKY'S THE LIMIT

NASA plans to send astronauts to Mars by 2010. In cosmic time, that's right around the corner. And they don't have a thing to wear.

The oxygen-filled suits and bubble-shaped headgear that astronauts have sported since the 1960s just won't do for astronauts bound for the red planet. The part that needs the biggest makeover, though, isn't visible at first glance: a spandex garment they wear beneath their spacesuits. It doesn't look much different from long underwear, but the "liquid-cooling and ventilation garment," as it's called, is ribbed with plastic tubing that delivers chilled water to every body part at the twirl of a dial. It suited the men on the moon, but NASA's latest mission calls for some new duds.

Mars is a fickle frontier. The atmosphere is so variable that the air at nose level can be below freezing even as the temperature near the ground registers 60 degrees. Overall temperatures, meanwhile, can fluctuate 40 degrees or more in a matter of seconds. In the spacesuits astronauts use today, they'd constantly be fiddling with water-flow dials to maintain a bearable body temperature. But with a $219,000 grant from NASA, Satish Nair and John Miles, professors of

mechanical engineering, are designing a technologically advanced suit that will adjust automatically to those changes, assuring astronauts moment-to-moment comfort in their sojourns on the fourth orb.

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How will this spiffed-up spacesuit work? Scientists still don't know much about Mars, so no one can say for sure how to tailor a suit for the air up there. But the most pressing questions revolve less around the heavenly body than they do around the human one. "Right now we're trying to unravel the mysteries of how the human being functions thermally," Nair says. "Some things turn out to be very complicated. When we perform certain exercises, where is heat generated? How do we sweat?" Nair and Miles devote their labors to answering such questions.

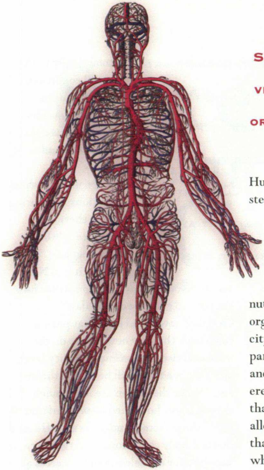
Humans are remarkably well-adapted to this third rock from the sun. We generate heat at all times in every environment, yet our "core temperature" rarely varies by more than a few degrees. Our bodies must stay within this narrow temperature range to survive.

A human thermostat, the hypothalamus, maintains that comfort zone. If this part of the brain detects changes in body temperature above or below the set point, it makes the necessary adjustments: increasing or restricting blood flow, breaking a sweat, inducing shivers. "If we can learn how that system works," says Tony Campbell, a PhD student involved in the project, "we can 'teach' the spacesuit to respond automatically to the thermal conditions of the astronaut in space," just as the hypothalamus does for earth-bound humans.

Even under normal conditions, measuring human thermal dynamics is "totally mind-boggling" in its complexity, in Nair's words. "You can have someone come into the lab and exercise on one day," Campbell says, "and have that person come back the very next day to do the same exercise at the same intensity level, and your readings will be totally different." What the person ate, how much sleep she got, how hard he worked that day—these factors and more all influence thermal body conditions. And those are variables for a single subject. "Across all subjects," Campbell continues, "we have to figure differences in metabolic rate, height, weight, overall conditioning and so on."

Such factors make the human system hard to replicate in a laboratory. The research team is trying, though, through a so-called "dynamic computer model" of the human body. That model gauges sweating, temperature and other physiological changes that occur at various activity levels. They are also designing a computer model of a spacesuit cooling system. At some point, the human and hardware models will work together to demonstrate how a suit can provide a comfortable environment for work in hellish conditions like those on Mars.

Unraveling the intricacies of human thermoregulation could easily go on "for one year, two years, maybe forever," Campbell says. But the researchers have a date to keep. NASA wants a prototype for the spacesuit in plenty of time for its planned 2010 Mars mission. In the end, their small step toward understanding our own bodily universe could prove a giant



one for the exploration of space in the coming century.

Gray Areas of Study

As the new millennium nears, we still haven't stumbled onto Ponce de Leon's fountain of youth, but people are living longer than they ever have. According to the World Health Report, the average life expectancy worldwide will be 73 in the year 2025, compared with 48 in 1955. In the United States, the average life expectancy will climb to 80 by that time. Our graying population faces some difficult health problems.

As new medical technologies are applied to the aged, doctors will need to keep an eye on the incidence of blood poisoning, which occurs far more frequently in patients with suppressed immune systems. Blood poisoning, or sepsis, is a bacterial infection that triggers a cascade of events, the most dangerous of which is excessive leakage from the blood vessels. This condition kills roughly 50 percent of its victims. The research of Virginia

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Huxley, a professor of physiology, aims at stemming sepsis and other life-threatening diseases associated with vessel leaks.

A certain amount of seepage through vessel walls is normal and good, Huxley says. That's how blood traveling through vessels transfers its nutrients to surrounding tissues and organs. Huxley likens the process to a city's distribution system. "Almost every part of a city needs supplies like water and food," she says, "and they're delivered through a transportation system" that includes main highways, streets, alleys and sidewalks. In human beings, that network is the circulatory system, which comprises some 60,000 miles of vessels. In a process called exchange, blood looping through capillaries—the tiniest of all vessels—delivers its goods.

Capillary walls are so thin that blood-borne oxygen and nutrients can easily pass through them into surrounding tissue, says Huxley, who studies this process. At the same time, surrounding tissue deposits waste—including carbon dioxide—through the capillary wall so it can be disposed of. Scientists once believed this two-way exchange was a passive phenomenon, like water running through a sieve. But research like Huxley's has shown, to scientists' amazement, that vessel walls grow "leakier" or "tighter" depending on the body's needs at a given time. The process occurs through the so-called "endothelials"—muscle cells that line the capillary walls and create expansion and contraction on demand.

Most of the time, the gate-keeping endothelial cells mind their duties with amazing efficiency, says Huxley, much as the automated doors on a smooth-running subway open and close to discharge and take on passengers. But sepsis and other pathologic stimuli throw the movement out of whack, flinging open the gates at the wrong times. Excessive "leakiness" can overwhelm neighboring organs and cause a complete shutdown. There is no cure for such problems in so-called permeability. "That's because we don't understand exactly how exchange occurs in normal states, let alone diseased ones," Huxley says.

Endothelial cells release biochemicals that affect leakiness. Nitric oxide is one, but scientists have yet to pinpoint its effect on permeability. To see how the subway doors respond to this biochemical, Huxley removes a bowel loop from an anesthetized frog or rat and places the live tissue under a microscope connected to a video monitor. She injects nitric oxide, tagged with fluorescent dye, into the capillaries. These little vessels appear on the monitor like lines on a road map. A computer-assisted image analysis program calculates the fluid flux across the capillary wall to see how the biochemical affects permeability.

In both species, Huxley has found, the nitric oxide increases blood flow, and a simultaneous increase in permeability allows solutes to pass more easily across the capillary wall. In a healthy subject, this ensures that the supply of water and nutrients keeps pace with the tissues' demands. But nitric oxide can also stimulate pathologic increases in permeability. The participation of this biochemical in the body's trade system is an area that merits further investigation, Huxley says.

She continues to do just that. In her medical-school laboratory, she plumbs another pink-tailed patient. The monitor shows blood coursing through the vast network of vessels conjoining the rat's innards. Huxley traces her finger along the screen, eagerly following the fluorescent dye as it makes its way around a capillary loop-the-loop. It won't lead her to a panacea, perhaps, but this vascular pathway might one day lead to the eradication of sepsis and other deadly permeability problems.

A Modern Stone Age

Engineers know the future will call for an extraordinary building material. It must be tough enough to build durable superhighways, yet elastic enough to mold into any shape and size. Ideally, it would never rust, rot or call for a coat of paint. The raw material for society's infrastructure in the 21st century should be abundant and easily found in nature.

Luckily, we don't need to hire any inventors to concoct the stuff. In fact, the future's already here. It's set in cement.

Cement has been the very foundation of civilization for thousands of years. Egyptians built the pyramids using cement-like mortar, the Greeks lined water tanks with concrete, and Romans built the Colosseum and the Pantheon with volcanic ash-enriched cement. Today, this age-old substance is the world's most widely used building material, forming our roads, runways, bridges, buildings, dams, sidewalks, silos, water and sewage pipes, and more.

The right material is there. The problem is, it isn't perfect—yet. Corrosion and poor construction are threatening our concrete world, due in part to our sketchy understanding of how cement works, says Ron Berliner, a physicist at the MU Research Reactor. Cement is the binding ingredient in concrete, and when a bag of it is mixed with water, it dries into a rock-like mass. But the hardening process that looks so simple depends on chemical reactions that even the experts have never understood. "It's like you take this stuff and you mix it with water, and then a miracle happens," Berliner says. "People don't know what's going on there."

At present, ignorance about concrete puts builders between a rock and a hard place. "Sometimes you'll whip up a batch and it looks fine; it's just not very durable," Berliner says. For mysterious reasons, "It will break up quickly, and then you have to go through the whole process again." That's why the Federal Highway Administration in 1996 spent a total of $3 billion on road resurfacing, restoration and rehabilitation; state and local expenditures compounded that figure. Some have estimated that if scientists could upgrade the durability of cement by 1 percent, it would save $5 billion to $10 billion every five years in the United States alone.

A souped-up cement wouldn't just save money; it would help the environment, too. Making cement calls for temperatures in excess of 1,400 degrees C (2,700 degrees F), or more heat than the average daytime temperature on Mercury. Finite fossil fuels generate that heat, and every ton of cement made releases a half-ton of carbon dioxide into the atmosphere. The 350 million metric tons of cement produced every year account for about 10 percent of all greenhouse gases—a quantity scientists like Berliner hope to shrink.

To do so, they'll have to get to know the familiar stuff better. Berliner has brought the physicist's tools to bear on the problem, using "the marvelous properties of the neutron" to map out molecular structure and trace out the chemical reactions that take place when it's mixed with water. He utilizes, in effect, the same principles a pool player calls upon when making a shot: He fires neutrons into a slice of cement, then measures the angles at which they exit the sample. Those angles give Berliner information about how its atoms and molecules are arranged.

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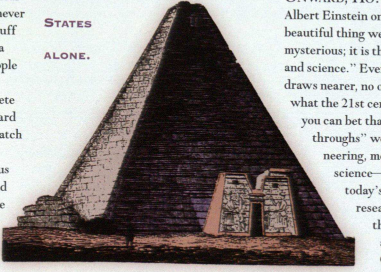

Studying cement's structure might reveal why it's susceptible to degradation and "disease." Common problems are "concrete cancer"—internal disintegration caused by chemical reactions—and potholes, which dot our aging interstates like a pox gone berserk. Berliner has recently been studying one culprit: a compound that "grows" in the little pockets of air and water dispersed throughout a slab of concrete, like holes in a sponge. This compound expands and contracts as the temperature changes and may be one of the contributors to concrete deterioration.

Once Berliner understands the secrets of cement, he and others in his field can brainstorm ways to make it a fit foundation for the 21st century. There's still a long, rocky road to travel, but with the MU physicist paving the way, a modern Stone Age awaits.

Onward, Ho!

Albert Einstein once said, "The most beautiful thing we can experience is the mysterious; it is the source of all true art and science." Even as the year 2000 draws nearer, no one can say for sure what the 21st century will offer. But you can bet that some of the "breakthroughs" we will witness—in engineering, medicine and materials science—will date back to today's forward-thinking MU researchers. Brick by brick, they're building a better and brighter future for Generation 2K. ❋