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Space Research

Office of Biological and Physical Research
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Green Light for the Red Planet

Research Updates:

- Shining a Light on the Brain
- Bacterial Virulence
- Neutron Spectrometers
- Navigation with Star Tracker

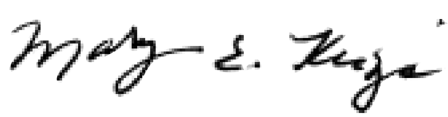
Letter from the Associate Administrator

I have heard it said that change is the most constant thing in the universe. And so it goes at NASA. Along with the entire agency, the Biological and Physical Research Enterprise (BPRE) is undergoing some significant changes to reflect the new national vision for space exploration described by President George W. Bush.

It is an exciting time for BPRE, as we work diligently to align our research in support of exploration to the Moon, Mars, and beyond. It is our task to overcome some significant obstacles — radiation, human health issues, human support systems, and so on — to ensure the safety and well-being of space explorers. It is a difficult task, but then no great task is ever easy.

In our feature article, "Green light for the Red Planet," you'll read about how NASA research will specifically aid the Mission to Mars, and other articles present cutting-edge research in support of space exploration. Future editions of *Space Research* will focus on the vision for exploration and how to overcome the obstacles inherent to the endeavors it will bring.

Sometimes change is a good thing.



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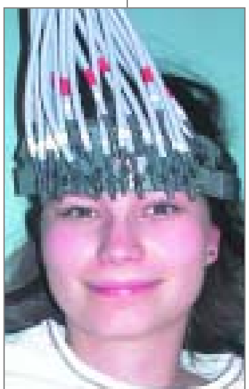

credit: National Space Biomedical Research Institute

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credit: Dimtris Kammer

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On the cover:
Exploration of Mars will be much easier if some supplies and equipment can be produced from raw materials found on the planet. Douglas LeVan and Krista Walton of Vanderbilt University, Nashville, Tennessee, work with a device that separates carbon dioxide from carbon monoxide. The device is part of a system for turning the martian "air" into spacecraft propellant.
credit: Vanderbilt University

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Chiao selected as International Space Station Science Officer for Expedition 10

credit: NASA

Leroy Chiao has been chosen as commander and International Space Station (ISS) science officer for Expedition 10. He is scheduled to fly to the ISS in October 2004 and will remain for 6 months. This expedition will be Chiao's fourth spaceflight but his first long-term mission. As ISS science officer, he will be the link between the research community and the in-flight experiments, helping to ensure that each experiment runs smoothly and gathers the best possible data.

Chiao is a veteran of three space shuttle flights: STS-65 (1994), STS-72 (1996), and STS-92 (2000). STS-65 flew the second International Microgravity Laboratory. During the 15-day flight, crewmembers conducted more than 80 experiments focused on materials and life sciences research. During STS-72, Chiao performed two spacewalks, demonstrating tools and hardware and evaluating techniques to be used in the construction of the ISS. The STS-92 crew attached the Z1 truss and pressurized mating adapter 3 to the ISS, preparing the space station for its first resident crew.

Chiao received a bachelor's degree in chemical engineering from the University of California, Berkeley, in 1983 and a master's degree and a doctorate in chemical engineering from the University of California, Santa Barbara, in 1985 and 1987, respectively. Selected for the astronaut corps in January 1990, Chiao became an astronaut in July 1991. He has worked at the Shuttle Avionics Integration Laboratory and in the Astronaut Office, Mission Development Branch, and has served as chief of the Astronaut Office, Extravehicular Activity Branch (all at Johnson Space Center, Houston, Texas). He is qualified for flight assignment as a mission specialist.

Chiao's crewmate will be Russian cosmonaut Salizhan Sharipov, Expedition 10 flight engineer and Soyuz commander. Chiao and Sharipov have trained together for many years. Keeping in mind the stresses and pressures of an extended stay in orbit, NASA and its partners endeavor to partner crewmembers who know each other well and have worked together extensively in the past.

Introducing the Expedition 9 International Space Station Science Officer

credit: NASA

Expedition 9 Flight Engineer and International Space Station (ISS) Science Officer Edward Michael "Mike" Fincke arrived on the ISS on April 21, 2004, for a 6-month tour of duty. The youngest crewmember to live aboard the ISS, Fincke has twice been a backup expedition crewmember, but this is his first time on the ISS. As ISS science officer, he works with the research community to help each experiment achieve maximum return on research investment.

Fincke received two bachelor's degrees — one in aeronautics and astronautics and the other in earth, atmospheric, and planetary sciences — from the Massachusetts Institute of Technology, Cambridge, in 1989. He then attended a summer exchange program with the Moscow Aviation Institute in the former Soviet Union, where he studied cosmonautics. He received a master's degree in aeronautics and astronautics from Stanford University, Stanford, California, in 1990, then joined the U.S. Air Force. He earned a second master's degree in physical sciences (planetary geology) from the University of Houston, Clear Lake, Texas, in 2001.

Fincke was selected for the astronaut corps in April 1996. After completing two years of training and evaluation, he joined the Astronaut Office, Station Operations Branch (Johnson Space Center, Houston, Texas), and served as an ISS spacecraft communicator, a member of the Crew Test Support Team in Russia, and ISS crew procedures team lead. He is qualified to fly as a left-seat flight engineer (co-pilot) on the Russian Soyuz spacecraft.

Fincke's crewmate is his long-time training partner, Russian cosmonaut Gennady Padalka, Expedition 9 commander and Soyuz commander. European Space Agency astronaut Andre Kuipers of the Netherlands joined the crew in the Soyuz flight to the ISS. He spent several days aboard the ISS conducting scientific experiments and then returned to Earth with Expedition 8 crewmembers Michael Foale and Alexander Kaleri.

Padalka and Fincke have their work cut out for them on the ISS. They will conduct many scientific experiments to add to what researchers already know about the long-term effects on humans living and working in microgravity. They also will improve ISS capabilities through two spacewalks. There is critical work to be done, says Fincke, because the orbiting outpost is crucial in furthering President George W. Bush's vision of sending explorers to the Moon and Mars.

A Honey of an Experiment

The next time you prepare tea, squirt some honey into it and watch what happens. Gooey rivulets, falling downward, twist themselves into curlicues, filaments, and spinning "smoke rings." It's mesmerizing — but only for a split second, then the honey splats at the bottom of the cup. Gravity has no respect for humanity's curiosity.

Take the gravity away, and new rules apply that scientists are only beginning to discover. "How fluids mix in weightlessness is not well understood," explains John Pojman, chemistry professor at the University of Southern Mississippi, Hattiesburg. On Earth, he says, rules of physics are dominated by gravity. Dense fluids sink, light fluids rise, and everything else is a side effect of that basic motion. In microgravity, more subtle phenomena rule. Understanding how fluids behave, singly or in mixtures, is important to the space program, especially now that NASA plans to send people back to the Moon and on to Mars.

How different is teatime in orbit? Expedition 6 ISS Science Officer Don Pettit showed us in 2003 when he filmed himself on board the International Space Station (ISS). Instead of sipping tea from a cup, Pettit used chopsticks to pluck grape-sized blobs of tea from the air, grinning each time he popped one into his mouth. Pojman remembers seeing the video. "I wanted to fly right up there and start experimenting," he says. Because he couldn't go to the ISS himself, Pojman devised an experiment that astronauts could do for him: the Miscible Fluids in Microgravity (MFMG) experiment.

credit: Julia Ogle

"MFMG is a very simple experiment," Pojman says. "It involves two syringes, a drinking straw, honey, and water. All of these things were already on board the ISS." One syringe is filled with honey or a honey–water solution, the other with pure water. The tips of the syringes are connected via the straw. An astronaut gently squirts a blob of honey into water, or vice versa, and films what happens. Expedition 8 ISS Science Officer Michael Foale ran the experiment once and downlinked the video to Earth.

"We've already learned something new," says Pojman. "The fact that we could do this using only odds and ends on board the space station is encouraging."

OBPR Researcher Recognized for Physics Research

credit: NASA

A NASA principal investigator in the Office of Biological and Physical Research has been honored with the Presidential Early Career Award for Scientists and Engineers (PECASE). Eric Weeks, an associate professor in the department of physics at Emory University, Atlanta, Georgia, received the award at the White House in Washington, D.C., on May 4, 2004. PECASE is given by the National Science and Technology Council and represents the highest honor that the U.S. government can bestow on exceptional scientists and engineers who are only beginning their careers. The award recognizes recipients' exceptional potential for leadership as they advance the cutting edge of scientific knowledge and research.

Weeks was honored for his research on colloidal physics (the study of solutions in which very small particles are evenly dispersed throughout a fluid). With his co-investigator Luca Cipelletti, Université Montpellier 2, Montpellier, France, Weeks is researching colloidal glass transitions with the use of a confocal microscope, which allows scientists to build very clear three-dimensional images of their samples.

Most liquids transition to solids without any interim phases; it's either one or the other. Glass, however, transitions from its fluid state as molten glass to a very viscous fluid and eventually to a solid as it cools. The change is a continuous process, without a sudden jump from one phase to another. Scientists use colloidal particles to model glass atoms and help them better understand the fundamental physics involved in the process.

Green Light for the Red Planet

For many years, scientists in NASA's Office of Biological and Physical Research (OBPR) have set their sights on a human trip to deep space. Supporting President George W. Bush's vision for the space agency, OBPR is researching ways to help humans endure the rugged environment of the Red Planet and make Mars a destination within reach.

Turning martian "air" into spacecraft propellant will help provide the first Mars crew with enough fuel for a return trip to Earth. Here, Krista Walton of Vanderbilt University, Nashville, Tennessee, stands in front of a computer that drives the third phase of the three-step process to purify oxygen from the martian atmosphere for propellant. The computer controls the flow of gases and monitors how well they have been separated. The two black boxes that are side-by-side at the bottom of the computer screen allow Walton and Douglas LeVan, system designer, also from Vanderbilt University, to monitor the pressure and the amount of product coming out of the device.

credit: Vanderbilt University

From inside a spacecraft, astronauts press their noses against the window to see Earth or the Moon; on spacewalks, they are treated to a comet's-eye view of the universe. Astronaut Daniel Barry is a veteran of three shuttle missions and four spacewalks. In 2001, during his most recent spacewalk, Barry took in the sights as he rode the robotic arm from Space Shuttle *Discovery* to the International Space Station to attach a supply module. As he looked up to see the red–orange glow of Mars, one thought came to mind: "We've GOT to go explore that place."

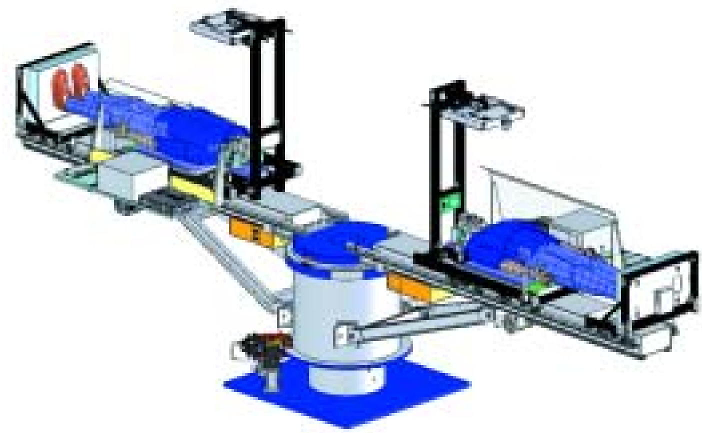
Space fans everywhere share Barry's dream, and in 30 years or so, humans will set foot on the Red Planet. Scientists in NASA's Office of Biological and Physical Research (OBPR) are ready to make it happen. Research to support human extraplanetary travel and colonization has been ongoing, but the commitment to human space exploration recently solidified. In 2003, in response to a request from the NASA Advisory Council, OBPR began tailoring its research agenda to focus on what humans need to explore deep space. In January 2004, President George W. Bush officially endorsed the Mars journey, and OBPR again responded. "The President's announcement adds to our research program specific milestones and destinations. Before it was self-paced; now it's paced by the needs of a very explicit vision and agenda for the agency," comments Howard Ross, OBPR's deputy associate administrator for science at NASA headquarters, Washington, D.C.

This agenda set in motion a research plan to support the first human crew to visit Mars. This journey would take more than 2 years; round-trip travel alone would be at least 12 months. To survive, crewmembers might need artificial gravity to counteract the detrimental effects of microgravity on their bodies; greenhouses that can support crops in the extreme environment of Mars; and local resources (from Mars, the Moon, or possibly both) to produce propellant for the spacecraft, food to eat, and air to breathe.

Providing for these needs will take time, money, and creative brainpower. "OBPR is specifically focused on what we need to be successful in exploring space. Other agencies that might do this type of research are coming from a somewhat different direction, such as trying to cure disease or to understand basic physiology. For us those are important too, but they are not the same focus," comments Barry. But he does expect that some benefits of the Mars research will trickle down to Earth.

Ross agrees and points out that space research has created earthly gains in technology and medicine. "If we let history be our guide, the challenge of going to space and doing things that people have never done before has returned tremendous benefits to nearly everyone on Earth," remarks Ross. "I have all of the same hopes for the Moon and Mars missions."

A matter of gravity to OBPR research questions



William Paloski (Johnson Space Center, Houston, Texas) and colleagues will use a short-arm centrifuge with this design as an artificial gravity countermeasure in bed rest experiments slated to begin in August 2004. This device produces a gravity gradient (*g*-gradient) along the body when the subject's head is placed near the center of the centrifuge. Results of *g*-gradient experiments help NASA researchers determine whether different amounts of artificial gravity can protect different body systems against weakening during missions to deep space. In this design, many parameters can be varied so that NASA can develop an optimal "prescription" for artificial gravity. After that prescription is determined, a more compact, less expensive centrifuge would be used for flight.

credit: Wyle Life Sciences

A primary challenge in leaving our home planet is the need to compensate for the adverse effects of microgravity on the body. Humans have evolved in and adapted to the amount of gravitational force experienced on Earth (1*g*). Simply resisting gravity strengthens bone, muscle, and the cardiovascular system. Microgravity (one-millionth of 1*g*) has the opposite effect; it weakens body tissues and systems accustomed to 1*g*. So far, astronauts have spent limited time in microgravity to minimize potential weakening. The long travel time to Mars combined with an extended stay, however, would be too dangerous without new knowledge and countermeasures. One broad countermeasure would be to provide artificial gravitational force; OBPR is studying the effects of artificial gravity on humans.

Scientists do not yet know how much gravity would be needed to keep microgravity-induced weakening at bay; it may well be less than 1*g*. Fortunately, a study that combines bed rest (which mimics the effects of microgravity on the body) and centrifuges (which can create gravity at levels lower than 1*g* via centrifugal force) may begin to give the answer. William Paloski, chief of the Human Adaptation and Countermeasures Office, Johnson Space Center (JSC), Houston, Texas, and colleague Laurence Young, Apollo Program Professor of Astronautics, Massachusetts Institute of Technology (MIT), Cambridge, lead an international multidisciplinary team of scientists from JSC, MIT, Baylor

A trip to and a stay on Mars will expose crewmembers to long periods of variable gravity, which adversely affects many body systems. Thus, the crew might bring a short-arm centrifuge similar to this one to create artificial gravity during spaceflight and while on the Red Planet. William Paloski, Johnson Space Center, Houston, Texas, is using short-arm centrifuges in artificial gravity experiments.

credit: NASA

College of Medicine, Houston, Texas; Mount Sinai School of Medicine, New York, New York; University of California, Irvine; University of Kentucky, Lexington; University of Texas Medical Branch (UTMB), Galveston; Deutsche Forshungs-und Versuchsanstait fur Luft-und Raumfahrt (DLR; the German Aerospace Research Establishment) in Cologne, Germany; and Institute for Biomedical Problems (IBMP) in Moscow, Russia. The team — experts in artificial gravity, engineering, physiology, psychology, immunology, and nutrition — is working to determine what it will take to protect each body system.

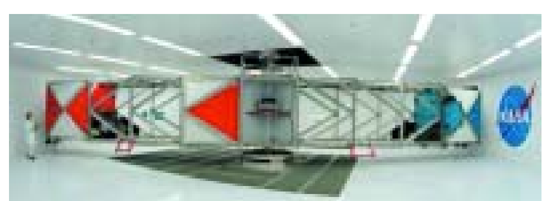
In the first set of studies, slated to begin at UTMB in August 2004, healthy volunteers who closely resemble the astronaut population in age, weight, and fitness level will be confined to 6-degree head-down bed rest — which "unloads" the body in the same way that microgravity does — for 2 weeks. Activity in microgravity requires force to start and stop movement, but when at rest, astronauts do not have constant gravitational forces acting on them. Although gravity will act on the volunteers, its force won't be directed against their legs, hips, and spines, so their bones will weaken as if they were in a microgravity environment.

The volunteers will be divided into two groups. The control group will receive no countermeasures, and the treatment group will receive daily exposure to artificial gravity. For artificial gravity exposure in all experiments, supine volunteers will be laid — two at a time — on a large centrifuge. A centrifuge generates a strong outward force and thus artificial gravity as its arms spin. By varying the subject's distance from the centrifuge's center of rotation, scientists can vary the amount of centrifugal force on the subject's body (because centrifugal force is proportional to the radius of the centrifuge).

Volunteers in Paloski's first study will experience short-radius artificial gravity (SRAG) in a 2.5-meter (8.2-foot) centrifuge at UTMB. When a subject lies in the centrifuge with the head at the center of rotation, gravity will increase continuously down the body, with the most gravity — 2.5*g* in the first study — at the feet. "In a very short radius centrifuge, that's what we call a *g*-gradient" (for gravity gradient), explains Paloski. The results will indicate whether different parts of the body can be protected by different amounts of artificial gravity.

Before bed rest, volunteers will undergo a thorough medical examination that includes determining metabolic (e.g., bone density) and physiological (e.g., muscle fiber) parameters. After bed rest, the same parameters will be measured every few days for 2 weeks. Paloski then will compare the treatment and control groups to determine whether any protection can be attributed to the artificial gravity "prescriptions" and monitor how quickly the volunteers regain bone and muscle strength after returning to normal activity levels.

Findings of the SRAG experiment will be expanded in a similar study in which new volunteers will be subjected to bed rest and artificial gravity produced by a long-arm centrifuge with a 15.85-meter (52-foot) radius at Ames Research Center, Moffett Field, California. One difference between



A long-arm centrifuge exposes the body to a continuous amount of artificial gravity. Scientists like William Paloski, Johnson Space Center, Houston, Texas, can use results of human experiments on long-arm centrifuges to design a rotating spacecraft. If all or part of a spacecraft were built to rotate, then astronauts in microgravity would be exposed to passive artificial gravity similar to the gravitational force humans are accustomed to on Earth.

credit: NASA

short- and long-arm centrifuge systems is the *g*-gradient, explains Paloski; the longer the radius of the centrifuge, the smaller the gradient across the body and the more like gravity the centrifugal force becomes.

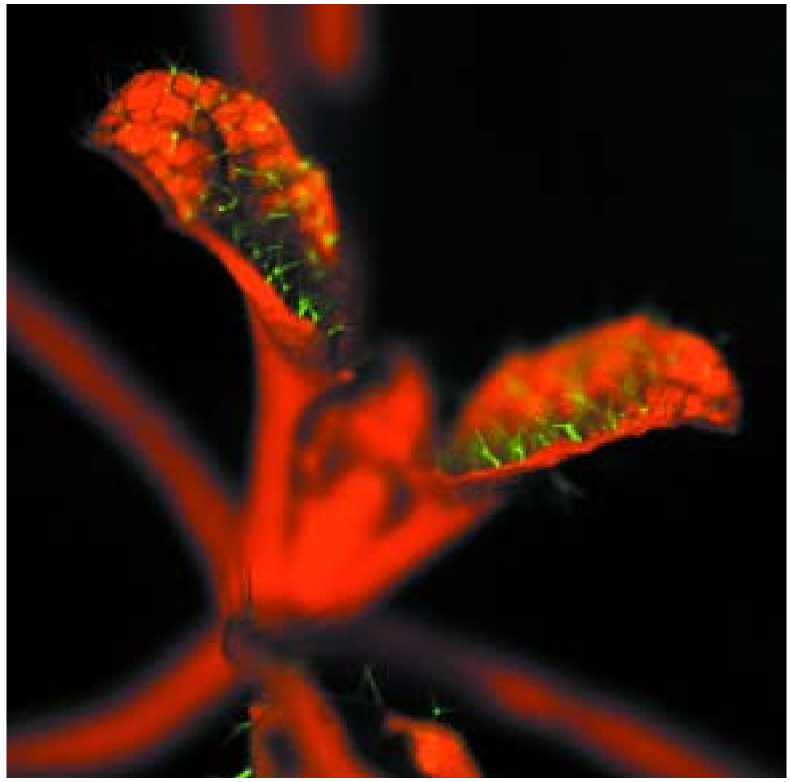
Paloski says space physiologists prefer long-arm centrifuges for providing artificial gravity in space because they can provide continuous gravitational loads at low rotation rates, which is important to the balance and orientation system of the inner ear. Also, if all or part of the spacecraft intended to travel to Mars could be built to rotate — essentially making it a centrifuge — no specialized centrifuge hardware would need to be developed, and no crew time would need to be designated for "gravity replacement therapy." If the cost or complexity of rotating a spacecraft in this way were too high, then the craft might carry a short-arm centrifuge. The dimensions and operating requirements (prescriptions) for short- and long-radius centrifuges determined by Paloski's research will dictate the dimensions of the Mars spacecraft. This research also will help to determine whether the low gravity of the Moon (one-sixth of 1*g*) or Mars (one-third of 1*g*) will be sufficient to protect astronauts from further physiological deconditioning during surface operations or whether some form of artificial gravity will also be required.

For now, says Ross, the OBPR research program assumes NASA will send a crew to Mars in a microgravity environment — the spacecraft won't rotate. In addition to influencing spacecraft design, the results of Paloski's studies "could change our [OBPR] biomedical research program," says Ross, because scientists will begin to understand what's needed for the health of each body system during spaceflight. The regime may even be personalized for each astronaut. Whatever it takes, the program is committed to having astronauts arrive on Mars strong and ready to explore its wonders.

Greenhouses on the Red Planet

Humans won't be the only earthlings visiting Mars; the crew probably will bring plants to grow food, produce oxygen, and recycle waste and water. Research is under way to ensure that the plants can survive and produce on the Red Planet. Even though plants, like humans, will live in an enclosed habitat, that environment will not provide all the comforts of home. Robert Ferl of the University of Florida, Gainesville, is studying how plants adapt to extreme environments (like a Mars greenhouse) and notes that plants are expert adapters: "Plants have to deal with whatever comes their way. Plants can't get up and move and can't change their environments."

The martian greenhouse probably will have low atmospheric pressure — that is, lower than on Earth but higher than on Mars. Low-pressure habitats (for plants or humans) have low leak rates, which minimize the transport of harmful dust and atmospheric mass (gas) into the habitats from the outside. Ferl's current investigation is designed to



Researchers in Robert Ferl's lab at the University of Florida, Gainesville, genetically altered this *Arabidopsis thaliana* (a brassica species) plant to learn how extreme environments, such as the low atmospheric pressure on Mars, affect plant genes. They inserted green fluorescent protein (GFP) near the on/off switches for anoxia and drought genes. When those genes were "turned on" after exposure to reduced atmospheric pressure, GFP was turned on as well, causing cells expressing those genes to glow green under a blue light. The natural fluorescence of chlorophyll accounts for the red glow.

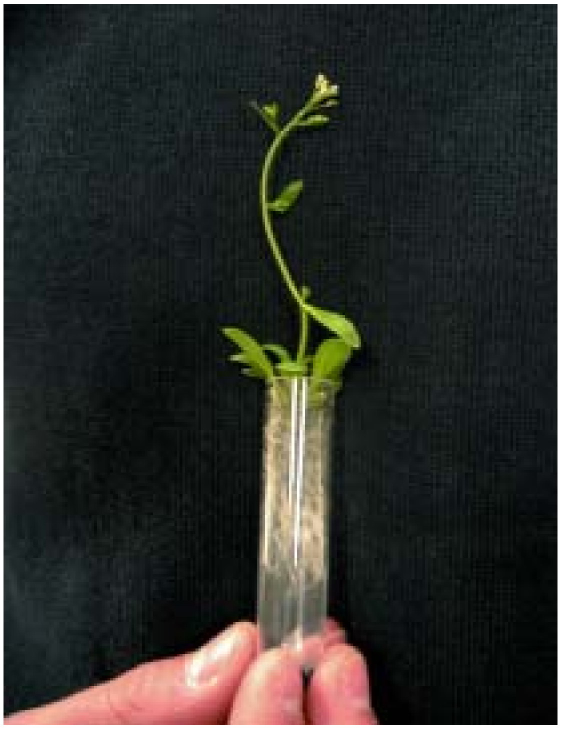
credit: Robert Ferl and Anna-Lisa Paul

determine how plants might react to low atmospheric pressure. He will measure that reaction by examining the plants' genes, because when the environment changes, explains Ferl, so does gene regulation (as the plants adjust to the new environment).

Ferl's subject is a species called *Arabidopsis thaliana* (*A. thaliana*), a member of the same plant family as cultivated broccoli. Like rice and maize, *A. thaliana* is a workhorse for plant biologists. It grows to maturity quickly (6 weeks) and is compact (only 20.3 to 30.5 centimeters [8 to 12 inches] tall), so it requires little physical space; all the plant's genes have been identified and sequenced; and the plant's relatively few genes are easy to manipulate.

Ferl began his study by observing changes in two genes that would be affected by an extreme environment: one responsive to anoxia (extremely low oxygen levels) and one responsive to drought. He wanted to know whether these particular genes would be expressed ("turned on") under low-pressure conditions. Because he did not want to kill the plants to find out, he used a reporter gene called green fluorescent protein (GFP).

Reporter genes show scientists whether a particular gene has been expressed and in which cells that gene is active. Scientists insert a reporter gene near the on/off switch for the gene they want to study. When that gene is turned on



For Robert Ferl, a plant biologist at the University of Florida, Gainesville, *Arabidopsis thaliana* plants are good research models because they have a rapid life cycle and are small, so they take up little space.

credit: Robert Ferl and Anna-Lisa Paul

— for instance, by an environmental factor — the reporter gene is turned on as well. When used as the reporter gene, GFP glows green under a blue light in each of the plant's cells where the environment causes the gene to be expressed. Ferl inserted GFP near the anoxia genes and the drought genes and exposed *A. thaliana* to 10 kilopascals (100 millibars) — about one-tenth of Earth's atmospheric pressure — for 24 hours.

Because low-pressure environments reduce atmospheric oxygen levels, Ferl expected the anoxia gene to be turned on, and it was. But the results of the drought gene surprised him. "When *Arabidopsis* [*thaliana* plants] were exposed to low pressure, they acted as if they were being exposed to drought," remarks Ferl. "This was a bit of a surprise, because the plants were in a highly humid environment, so they had plenty of water. The question was, why would they be expressing genes associated with drought?" The answer lay in the leaves. Water evaporates from leaves quickly at low pressure, he explains, triggering the movement of water from the roots toward the leaves. On Earth, water is evaporated by heat instead of low pressure, but either way, plants interpret this water movement as an indicator of dry conditions.

In future work, Ferl will expose *A. thaliana* to even lower pressures to determine its lowest survivable pressure limits and then study genes that are expressed under those more demanding conditions. He wants to determine the levels of pressure that plants can tolerate and the point at which they begin to show genetic response.

Ferl explains that the results of his basic research with *A. thaliana* will quickly be applied to understanding the pressure limits of possible gas compositions of a martian greenhouse and also should provide a starting point for other plant species that might be cultivated on Mars. He adds that although humans are already good at growing crops on Earth, any understanding of growing crops in extreme environments might be useful to farmers here, too.

Ferl plans to extend his plant investigations to include other environmental stressors, such as radiation, and would like to determine whether martian regolith (surface soil) will support or be toxic to *A. thaliana* growth. Transporting soil to Mars would be costly because of its weight, so finding a way to use resources on Mars to sustain plants would be helpful. In the coming years, Ferl would like to see how *A. thaliana* fares in a greenhouse on the Moon, where some conditions, including soil, are similar to those on Mars. Results will help researchers design a martian plant habitat.

The fate of the first plants sent to Mars probably will demonstrate whether future plants can survive the pressure, atmosphere, and soil. In a sense, any plant sent on a Mars mission also would serve as a canary in a coal mine:

Douglas LeVan and Krista Walton, both of Vanderbilt University, Nashville, Tennessee, work with a device that separates carbon dioxide from carbon monoxide. The device is part of a system for turning the martian "air" into spacecraft propellant.

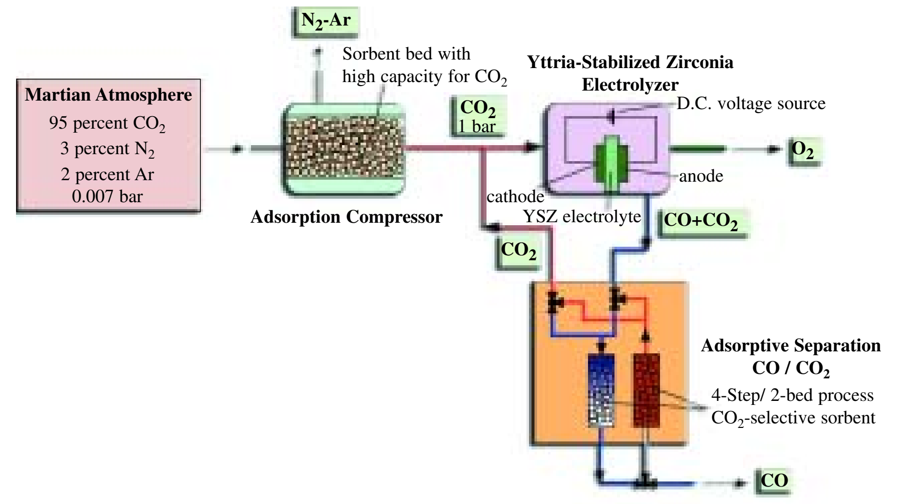
credit: Vanderbilt University

If plants can survive in a specialized habitat on Mars, then humans probably can, too, says Ferl. “The real question is when we’ll get an opportunity to actually send plants there. That’s what we’re really ready for.”

Tanking up on martian air

When people and plants blast off for Mars, the weight and volume of fuel for the mission are serious considerations. Carrying only enough propellant for a one-way trip could ease mission costs and allow crews to transport extra equipment. For that to happen, though, enough propellant for combustion to fuel a launch back to Earth will have to be on the Red Planet when the visitors arrive.

Martian air is no good for humans to breathe — 95 percent carbon dioxide (CO_2) with traces of nitrogen and argon — but offers potential for fueling rockets. CO_2 can provide a plentiful source of oxygen (O_2) for combustion as well as human life support, if necessary.



This flow chart illustrates a three-phase system that Douglas LeVan’s research group at Vanderbilt University, Nashville, Tennessee, helped design. The system converts carbon dioxide (CO_2) in the martian atmosphere to pure oxygen (O_2), a propellant that would fuel a launch back to Earth, and carbon monoxide (CO), which could be used to produce plastics or low-grade fuel. The atmosphere on Mars contains 95 percent CO_2 and trace amounts of nitrogen (N_2) and argon (Ar). D.C., direct current. YSZ, YSZ electrolyzer (a solid electrolysis cell).

credit: Krista Walton

Douglas LeVan, the J. Lawrence Wilson Professor and Chair of chemical engineering at Vanderbilt University, Nashville, Tennessee, is part of a collaborative effort among scientists at Ames Research Center (ARC), Moffett Field, California, and the University of Arizona, Tucson, to design a system to purify O_2 from the martian atmosphere. The system, which would be sent to Mars well ahead of humans, could purify enough O_2 propellant for a trip home.

To fuel a martian gas station, three steps are required: CO_2 collection, O_2 purification, and CO_2 separation from carbon monoxide (CO) for reuse. First, atmospheric CO_2 is collected from the martian atmosphere; in this step, CO_2 molecules naturally adsorb onto solid surfaces. Synthetic zeolites — molecular sieves made of silicon and aluminum oxides that form caged structures — are ideal for this application. Their structure provides a large surface area in a small volume, so zeolites bind large amounts of CO_2 effectively, says LeVan.

The CO_2 is collected and adsorbed in an adsorption compressor developed at ARC. Adsorption compressors use zeolites to collect and release CO_2. First, a valve opens to the martian atmosphere and allows CO_2 to collect on the zeolite within the compressor. Next, the valve closes, and the compressor is heated. As the system warms, CO_2 is released from the zeolite, and pressure increases dramatically. When the pressure reaches 1 atmosphere, another valve opens, and the CO_2 is diverted to a storage tank or routed to the next processing step.

The second step generates O_2 from CO_2 by using a system designed at the University of Arizona, Tucson. CO_2 passes out of the adsorption compressor and moves through a solid electrolysis cell that breaks down the CO_2 to release pure O_2 when an electric current is applied.

Not all of the CO_2 reacts in the electrolysis cell during the second step. Unreacted CO_2 and CO produced as a by-product of the purification process must be separated. LeVan is principal investigator for this third part of the process. Along with graduate student Krista Walton, LeVan designed an adsorption/separation device that separates CO from CO_2. The CO_2 recycles back to the electrolysis cell for processing, and the CO may be used for low-grade fuel or plastics. “You don’t want to waste anything,” remarks Walton.

Walton and LeVan estimate that 2.75 kilograms (6.06 pounds) of CO_2 can be compressed each day from the martian atmosphere to produce 1.0 kilogram (2.20 pounds) of O_2. Many orders of magnitude more than this amount of propellant would be required for a return trip, says LeVan, so the equipment would have to be up and running on Mars long before a crew arrived. Le Van says that remote control of the process would not be difficult, and the three steps could be monitored from Earth. “You just need to send back a few readings,” he explains.

LeVan comments that although the technology is being developed to operate on Mars, improving any aspect of separation technology may provide benefits on Earth, too. For example, people with lung disease use portable O_2-delivery devices that contain small-scale separation devices; although such devices are powered with electricity, they contain a zeolite adsorber. Also, adsorption compressors are used in some hotel room refrigerators — because they are quieter than typical refrigerator compressors — to give patrons a peaceful night’s sleep.

At 0.91 meters (3 feet) long, this prototype excavator is the same size as the finished product intended to be sent to the Moon to purify lunar soil for use as propellant. According to Michael Duke, director of the Center for Commercial Applications of Combustion at the Colorado School of Mines in Golden, the wheel on the end of the boom can dig up several times the weight of the device — 45.36 kilograms (100 pounds) — in dirt each hour.

credit: Michael Duke

The primary goal of the research remains to shave some pounds off the Mars launch payload. "If you can mine the martian atmosphere to produce your O_2," says LeVan, "you're saving a whole lot of payload."

Gas station in space

Michael Duke, director of the Center for Commercial Applications of Combustion at the Colorado School of Mines in Golden, also is working on ways to fuel spacecraft after launching from Earth. But he envisions spacecraft refueling at orbiting depots instead of a gas station on Mars's surface.

Orbiting refueling depots will need to be filled with propellant. Duke is developing "space architectures" to extract fuel from the Moon, Mars, or even asteroids. Right now, his focus is on mining hydrogen or O_2 propellant from the Moon and then devising new ways for that propellant to be used.

So far, Duke's lab has designed and built a prototype bucket-wheel excavator to scoop soil and transfer it to a reactor where useful products could be extracted. The prototype weighs about 45.36 kilograms (100 pounds), is 0.91 meters (3 feet) long, and can dig up several times its weight in dirt each hour.

The excavator would have to work constantly for months without failing. Mining equipment on Earth occasionally breaks down, says Duke, but his design poses a more difficult challenge. "Once the bucket excavator lands on the Moon, it's not coming back to Earth," he remarks.

Duke is equipping the prototype excavator for extreme conditions, because he doesn't yet know where lunar mining operations would begin. There might be ice (and thus water, providing a source of O_2 and hydrogen) in permanently shadowed craters near the lunar poles, so the excavator might need to operate in dark, very cold conditions where solar panels could not provide power — unless they were located elsewhere on the Moon and beamed energy to the site. Duke and his lab also need to design the heat chamber of the reactor to extract propellant and want the excavator to be remotely controlled. Duke hopes to have an opportunity to test the excavator on the Moon during the next 10 years.

Extracting propellant from in situ resources would require equipment that is expensive to build and launch, so the cost of producing and launching the technology must not be more than that of producing the propellant on Earth and launching it into space. "Right now, the cost of lifting payload to Earth orbit is about $5,000 per pound [0.453 kilogram]. Duke anticipates that it would cost about 10 times that amount to deliver payload to the Moon. He accounts for these considerations in his architecture designs and performs mathematical feasibility studies.

One way to make extracting lunar propellant cost-effective, says Duke, would be to place propellant in an orbiting refueling station. Duke's calculations indicate that such a station is both feasible and plausible, but the steps to create it are many. Duke envisions launching a propellant production plant to the Moon, mining and purifying propellant, then launching the fuel from the Moon's surface to orbit at one of the two lagrange points — locations of gravitational balance — between it and Earth. Any spacecraft placed in orbit at a lagrange point would remain in orbit; objects in orbit at other locations would gradually fall toward the Moon or Earth.

It may seem that two launches (equipment from Earth and fuel from the Moon to an orbiting depot) could not be more economical than launching the propellant from Earth in a spacecraft bound for Mars. But according to Duke, with Mars as a destination, it would be less expensive to launch from Earth with less fuel than is needed and then top it off en route.

Duke says that developing orbiting propellant stations could change spaceflight. And if the demand is high enough and using lunar propellants is economically beneficial, then there might be a commercial market for space travel, which could offset part of NASA's mission costs, he adds. "There are going to be new ways of operating in space if you have propellants in space."

For a Mars mission, Duke foresees a spacecraft blasting off from Earth, refueling with lunar propellant, and then refueling again on Mars with propellant extracted from resources there. This scenario could be applied to many kinds of deep space missions.

Blastoff to the new world

One day — perhaps 30 years from now — the first crew to blast off for the Red Planet will be strapped in their seats, seconds before liftoff. Countermeasures for microgravity

On Mars, the colonists' survival will be uniquely interdependent. …. "Your survival depends on the other guy not cracking a window at the wrong time."

— Daniel Barry, astronaut

will be in place. Plants hardy enough to thrive in a martian greenhouse will be on board. Fuel for the return trip will be waiting on Mars.

That first trip to Mars may change space travel in ways that now can only be imagined. Astronaut Barry expects the journey will affect the way humans think about themselves by shedding some light on some big questions many people ask: Are humans alone in the universe? Specifically, is there life on Mars? And if so, is that life based on deoxyribonucleic acid (DNA), like ours? After all, he says, Mars could have supported life because at one time, the temperatures were right and there was water. If evidence of life is not found on Mars, he wonders, then what is the likelihood that other planets support life?

But that first flight to Mars will be risky. Why would humans risk their lives for such a journey? Barry knows why he would go: to start answering those big questions. If Mars supports life that isn't DNA based, then humans could firmly establish that life evolved independently in two different places. This discovery alone would affect the way humans think about themselves, he suggests. "Then … we really have to start listening hard," he remarks, because "there are creatures out there who can communicate with us."

But if no evidence of life is found on Mars, then perhaps earthlings are alone, and colonizing Mars is our obligation. "Our existence becomes a lot more important to the grand scheme of things if we're really the only ones," states Barry. "It becomes our job to survive and get past these petty differences we have and make *Star Trek* a reality in the rest of the universe."

When many robotic missions and human visits to the Red Planet morph into a martian colony of humans from Earth living and raising children on Mars, a new culture will evolve in much the same way that cultures integrated and developed among settlers in the Americas. It may be those new-world martians who will figure out how to explore the rest of the Solar System because they will live that life every day, comments Barry. And that possibility is another reason to make the trip.

On Mars, the colonists' survival will be uniquely interdependent. They will rely on each other as they adapt and survive whatever onslaughts come their way. As Barry says, on Mars, "your survival depends on the other guy not cracking a window at the wrong time." And to him, this kind of living foretells growth for all of us.

"We will see whole new developments on how human beings relate to each other, and that will strengthen and revitalize the human spirit."

Jeanne Erdmann

President George W. Bush's goals for space exploration are posted at *http://www.nasa.gov/missions/solarsystem/bush_vision.html*. To learn more about artificial gravity, visit the Web site of the Ohio Chapter of the Mars Society at *http://mars.complete-isp.com/aero2.htm*. For more information about Robert Ferl's research on Arabidopsis thaliana, see *http://www.hos.ufl.edu/ferllab/*. To learn what types of crops might be grown on Mars, visit *http://advlifesupport.jsc.nasa.gov/baselinecrops.html*. For more information about Douglas LeVan's work to develop a propellant purifier for Mars, click the Research link at *http://www.vuse.vanderbilt.edu/~cheinfo/levan2.htm*. Michael Duke's space architectures are described in a downloadable document at *http://www.spaceagepub.com/pdfs/Duke_1.pdf*.

Diggin' the Moon

The Moon is a hot destination again. With NASA's sights set on a human visit to Mars, extending Earth's laboratories to the lunar surface will help make the journey possible. The Moon will become a test bed, says Howard Ross, deputy associate administrator for science in the Office of Biological and Physical Research, NASA Headquarters, Washington, D.C. "The beauty of the Moon is it's only 3 days away from Earth. And it's a much safer approach from the human side to test all the equipment and human–machine interactions," he remarks. For example, investigating how equipment, life support systems, habitats, and life forms are affected by one-sixth of the Earth's gravitational pull (which is 1*g*) on the Moon will help determine designs to support and protect people in three-eighths of 1*g* on Mars.

The lunar surface also will provide a way to test NASA's plan to use in situ resources on the Moon and Mars to support the crews who visit deep space. Lunar and martian regolith (soil) are not very different, says Ross. Michael Duke, director of the Center for Commercial Applications of Combustion at the Colorado School of Mines, Golden, plans to mine lunar resources for rocket fuel that will fill orbiting "gas stations."

The Moon is back in the national limelight, and Duke is pleased about its recognition as a route to improving NASA's space systems. "For those of us who are interested in space resource development, the fact that the President of the United States in his definition of the exploration initiative actually said we should develop resources on the Moon is very stimulating," he comments.

Shining a Light on the Brain

New optical techniques enable researchers to see how the brain functions in the real world.

Most children love to play with flashlights in the dark. Inevitably, they cover the lens with a hand and see their fingers illuminated as light passes through. If they look closely, they may even see their bones. Jeffrey Sutton, director of the National Space Biomedical Research Institute (NSBRI) in Houston, Texas, hopes to use the same phenomenon — the ability of light to pass through skin and bone — to record the brain activity of astronauts in space and of patients on Earth who require emergency treatment.

Optical fibers carrying near-infrared laser light dangle from the diffuse optical tomography (DOT) imaging device worn by this volunteer. Researchers can measure blood activity and deduce brain functions by measuring the scatter and absorption of light shining on the brain.

credit: National Space Biomedical Research Institute

The emerging technology, called diffuse optical tomography (DOT), could provide researchers and doctors with a unique diagnostic tool that is much smaller, lighter, and more portable than X-ray, magnetic resonance imaging (MRI), and other imaging systems, says Sutton. It also is relatively insensitive to motion. In space, DOT could help astronauts diagnose head injuries and determine mental alertness before performing mission-critical tasks. On Earth, it may help doctors quickly evaluate neurological conditions and monitor real-time brain activity.

A new old standard

Using light as a diagnostic tool is not a new idea. “Doctors learn it in the second year of medical school,” explains Sutton. “Clinically, transilluminating the skull with a flashlight is a very quick way to see if a baby has significant internal bleeding or other problems. If a child comes in with pain on one side of the face, doctors can transilluminate the sinuses in a dark room. If the sinuses are opaque, the child may have an infection.”

Sutton knows about these tests because he was an emergency room doctor before completing a master’s degree in neuroscience and doctorate in theoretical physics. In the early 1990s, he moved to Boston’s Massachusetts General Hospital, a pioneering research center in brain imaging.

At the time, Sutton was learning about brain activity by measuring changes in blood oxygenation with a technique called functional MRI (fMRI). Like conventional MRI, fMRI uses superconducting magnets to generate powerful magnetic fields. The fields interact with the iron in hemoglobin (the oxygen-carrying component of red blood cells), causing it to resonate. Just as empty and full glasses of water sound different tones when struck, hemoglobin’s resonance differs depending on whether it carries an oxygen molecule. fMRI uses these vibrations to paint a picture of the flow, volume, and oxygenation levels of blood in the brain.

Although fMRI works like MRI, it is much faster. Whereas an MRI scan may take 20 minutes or longer, fMRI generates images in seconds. By comparing sequential images of changes in blood properties, researchers can determine which regions of the brain are active as subjects perform specific tasks. The result is a map of the pathways that link physical and mental performance with brain activity.

Yet fMRI has limitations. One second is an eternity relative to the speed of rapid molecular interactions taking place at the cellular level, and fMRI images blur crucial details. fMRI systems are also massive. If researchers had portable devices, they might be able to observe brain activity in active children or people with motion disorders who cannot remain perfectly still.

Sutton was intrigued when he first learned about DOT’s speed and portability from Gary Strangman, then a postdoctoral student in his laboratory. Strangman introduced Sutton to David Boas, who had joined Massachusetts General to develop ways to image the brain optically.

Light

Although the use of near-infrared (NIR) light to collect information from the brain dates back more than 25 years, most scientists use optical techniques to analyze only the most superficial layers of skin. Just as a flashlight shines through a child's fingers, NIR light penetrates layers of surface skin relatively easily. It is another matter to shine a light through the scalp and skull, 1 to 2 centimeters (0.4 to 0.8 inches) into the cerebral cortex, and capture the light after it arcs back to light detectors on the scalp's surface. DOT works by measuring the absorption and scattering of NIR light after it makes this journey.

Along the way, some light scatters and some is absorbed by certain molecules in the brain. Sutton generally uses one or more NIR light sources between 700 and 900 nanometers because these wavelengths are preferentially absorbed by hemoglobin. By measuring the absorption of different wavelengths as light exits the skull, Sutton can determine the flow, volume, and oxygenation level of blood in the brain.

Scientists have used light absorption to identify chemicals since 1832. Applying the technique to a human skull, however, presents challenges. By the time the light exits the brain, it is seven to eight orders of magnitude less bright than when it entered; only sophisticated optoelectronic sensors can detect it. DOT also requires computational power. Software must not only correlate absorption spectra with changes in hemoglobin but also map those changes spatially within the brain. Finally, researchers must validate DOT data by comparing them with known fMRI results to ensure accuracy.

DOT's advantages have been worth the development effort. Because the technique relies on light pulses and electronics, DOT is fast enough to measure molecular processes that take place in thousandths of a second. Although it does not capture fine details as well as fMRI, it provides enough resolution to be useful for diagnosis. Most important, like MP3 players and other semiconductor-based products, DOT imagers are small, portable, and impervious to motion.

NASA investigator Jeffrey Sutton, director of the National Space Biomedical Research Institute (NSBRI) in Houston, Texas, readies a volunteer who will undergo simultaneous functional magnetic resonance imaging (fMRI) and diffuse optical tomography (DOT) brain scanning while performing various motor tasks. By comparing images, Sutton validates those produced by DOT against those created by fMRI, a more mature technology.

credit: National Space Biomedical Research Institute

Intrigued

From the start, Sutton was intrigued. "NSBRI had invited me to participate in workshops on neurobehavioral issues and smart medical systems," he recalls. "It struck me that this emerging capability to perform noninvasive, real-time imaging in a harsh environment might help NASA assess physiological changes and diagnose injuries that may occur in microgravity."

A key issue for NASA, says Sutton, is that astronauts perform lots of construction work during missions. Although the objects they move have minimal weight in microgravity, they retain all their mass, so an accident can cause serious trauma. "If an astronaut bangs his or her head hard and has an intractable headache, DOT could help diagnose whether there's a contusion or a hemorrhage," says Sutton. "We can then determine whether the injury is serious and make a decision on how to treat it based on available resources and the impact on crew and mission."

Since 2000, Sutton, Strangman, and Boas have collaborated to ready a DOT device for space use. Their latest prototypes send a laser diode pulse through a fiber-optic cable to the scalp. "There's no special preparation," says Sutton. "People just put on the cap so the light source makes contact with the skin. You don't even need to cut your hair."

Interestingly, DOT is designed to work with the same laser-driven spectroscopic system under development for tissue analysis during long-term NASA missions. "It is part of a larger investment in the use of lasers to perform multiple functions aboard NASA vehicles," says Sutton.

Astronaut performance

In addition to diagnosing injuries, DOT scans could warn astronauts when their mental alertness begins to deteriorate, like other sensors that now monitor vital signs for signs of physical stress.

The problem is very real, cautions Sutton. On Earth, sleep is tied to the 24-hour day–night cycle. In space, astronauts are no longer anchored to this circadian rhythm. "They often have some difficulty sleeping, especially when low-Earth orbit exposes them to 15 to 16 sunrises and sunsets every 24 hours. This is a high-risk, high-stress job, and fatigue is an issue."

Sleep deprivation appears on DOT images as a dramatic change in blood flow at the front of the brain. To correlate this change with performance, Sutton's team developed software to simulate docking a spacecraft using two joysticks. The task requires a challenging combination of mental and physical coordination. Subjects wearing the DOT cap performed the task

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A Tiny Threat Packs a Big Punch

Understanding the virulence of bacteria and the effectiveness of treatments against these microbes is of critical importance to improving the health and safety of both flight crews in microgravity and people on Earth.

Most bacteria are harmless; in fact, many are beneficial. However, some bacteria — the ones people usually hear about — can cause disease in people and animals. On Earth, many bacterial infections are easily treated with antibiotics. But in microgravity, recovery is not as simple as applying an ointment or taking a few pills. Research has shown that some bacteria reproduce faster and have a more efficient metabolism in microgravity, so they may be more difficult to control than on Earth; meanwhile, astronauts are more susceptible to infection because spaceflight suppresses their immune systems.

NASA is not treating these findings lightly; experiments planned for the International Space Station (ISS) may help give astronauts the advantage over this invisible threat. Principal Investigator Barry Pyle and his team at Montana State University, Bozeman, have designed studies to better understand the physiology and virulence of *Pseudomonas aeruginosa* (*P. aeruginosa*) as well as the effectiveness of treatments against it. Normally, this common bacterium and the toxins it produces have little or no effect on healthy people; when it does, it usually infects the skin. It also causes ear infections and can cause eye infections in people who use extended-wear contact lenses.

P. aeruginosa is an opportunistic pathogen, which means that it infects people when their immune defenses are down — in other words, when they are already sick, stressed, or injured. *P. aeruginosa* is a major cause of secondary infections in hospitalized patients; it commonly infects wounds and burns and can be deadly to patients in intensive care units who have throat tubes to aid breathing. The bacterium also can cause persistent lung infections in people who have cystic fibrosis.

P. aeruginosa is of particular concern to NASA because it is so widespread that it is impossible to keep it out of spacecraft. Indeed, it has been detected at times in the space shuttle's water system. For healthy people on Earth, *P. aeruginosa*'s presence usually is not a problem; however, for astronauts during spaceflight, it could pose a significant threat. In adapting to microgravity, radiation exposure, and cramped conditions, the human body is subjected to a great deal of stress. It experiences fluid shifts, changes in physiology, and even metabolic changes at the cellular level. As a result, crewmembers' immune systems are weakened; their susceptibility to infection is greater than that of healthy people on the ground.

A study in slime

Research begun several years ago by Pyle and colleagues is helping scientists better understand the effects of microgravity on bacteria. With an experiment that flew on STS-81 (January 1997), Pyle focused on *Burkholderia cepacia* (*B. cepacia*), a bacterium related to *P. aeruginosa*; both bacteria are opportunistic pathogens found in spacecraft water systems. The experiment studied the ability of *B. cepacia* to form biofilm, commonly known as slime, on stainless steel. It also studied the resistance of biofilm to iodine, a water disinfectant often used on Earth and in spacecraft.

Biofilm is a layer of bacterial growth on a surface. Minimizing and eliminating such growth is important from an engineering standpoint because biofilm can reduce flow rates, lower heat transfer in heat exchangers and condensers, and promote the corrosion of metal parts. In microgravity and on Earth, biofilms can be quite difficult to remove from surfaces because they form particularly strong attachments. They also may resist disinfection.

For Pyle's STS-81 experiment, three groups of cultures were grown directly in microgravity in water, diluted nutrient broth, or iodine solution; in-flight control cultures were grown in a centrifuge that simulated Earth's gravity while in orbit. Another control experiment was conducted on Earth.

The samples were examined after the flight to determine cell growth and health, enzyme activity, and cell membrane integrity. Many of the determinations required staining cells with chemicals that fluoresce (glow) under certain conditions. For example, staining techniques allowed researchers to count and compare the number of respiring cells. A different stain was used to determine cell membrane integrity and activity, giving another view of metabolism and viability.

The primary focus of Pyle's research was on bacterial growth. "There appeared to be enhanced growth of the bacteria in the flight samples in all three media," he reports, but the difference was not statistically significant because the results were variable. Data comparisons were difficult because the centrifuge had to be stopped and started for other experiments, so the in-flight controls may have been affected by microgravity. Pyle adds, "The experiment also proved that biofilms do form in microgravity, as suspected, so … on any spacecraft where you want to maintain a clean water system, the need for microbial control is about the same as on Earth. Once they [biofilms] are on the surface of a system, it is very difficult to remove them or to disinfect them."

Learning through genetics

After confirming the formation of biofilms and the difficulty of disinfecting biofilms in microgravity, Pyle's group decided to study the effects of spaceflight on bacterial virulence and physiology. They focused particularly on *P. aeruginosa*'s production of a toxin called Exotoxin A (ETA), which is one factor that determines the microbe's virulence. When released within a host cell, ETA disrupts metabolism and eventually kills the cell.

Working on research to determine the effects of microgravity on *Pseudomonas aeruginosa*, a common bacterium, research assistant Susan Broadaway (left) and post-doctoral scholar Elinor Pulcini (right), both of Montana State University, Bozeman, check cultures of clinostat samples for changes in the proteins the bacterium produces. Such changes are clues to understanding if and how microgravity causes increased growth or ability to infect.

credit: Barry Pyle

"The regulation of this toxin production within this bacterium is much more complex than we previously thought," explains Pyle. Studying toxin production in microgravity also would provide insights into the same process on Earth.

Pyle and his team designed a flight experiment that would detect changes in the expression of genes of *P. aeruginosa*. All of an organism's functions are regulated by its genes, which carry out many tasks — including sending messages that direct the production of particular proteins that carry out specific activities for the cell, such as toxin production or growth.

Pyle's plan was to use nucleotide microarrays (a new kind of analysis that identifies genes and indicates their activity) to determine whether the same genes were expressed in microgravity as in Earth's gravity and two-dimensional gel electrophoresis to capture, identify, and separate proteins based on their charge and molecular weight (size). With results from ground and flight cultures, the analysts then could compare the proteins that the bacteria produced in orbit with those produced on Earth and use this knowledge to detect changes in many proteins, including those that affect virulence factors. The results also could be compared with published data to determine how cultures responded to the particular growth conditions.

Pyle's *P. aeruginosa* experiment flew on STS-107 in January and February 2003. However, with the tragic loss of Space Shuttle *Columbia*, the experiment was lost. "We didn't get anything back from STS-107," he explains, "because we did not get any observations or data downlinked from the samples on board." Although some canisters containing experiments were later recovered, none were Pyle's.

Next stop, the ISS

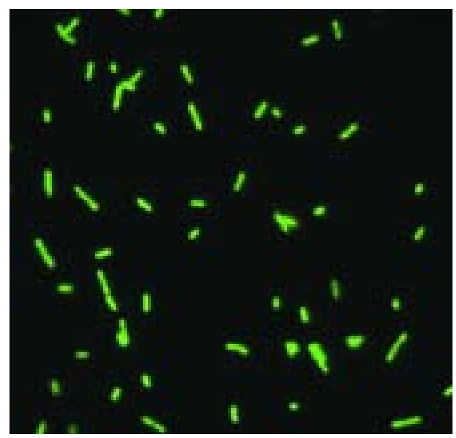
Pyle and his team are readying an experiment to fly to the ISS, but they must wait out the existing backlog. Because their original experiment was designed for flight only, not a stay on the ISS, "it will require some changes," he explains. For example, they are adapting the experiment to the longer time between launch and recovery and to take advantage of the greater capabilities for life science experiments aboard the ISS.

Despite modifications to the experiment, the goals remain the same. "We will be looking at very similar parameters," says Pyle. "We will focus on the Exotoxin A production and on the proteomics [the study of the proteins of an organism] and genomics [the study of the genes of an organism]" to determine changes in gene expression. Proteomic assays will allow the analysis of the protein products; genomic assays will help determine which genes have been expressed more, less, or the same as they are on Earth.

As preparation of this experiment continues, Pyle has some idea how the bacteria might respond to spaceflight. In ground-based experiments, *P. aeruginosa* has produced ETA both in Earth's normal gravity and in a clinostat, which is a device that simulates microgravity by rotating the organism sample to expose it to the gravity vector from all directions. Although he is not predicting results yet, Pyle ventures to say, "It is possible that there will be no effect on Exotoxin A expression." He adds that his group has observed an increased expression of other virulence-related proteins in samples subjected to simulated microgravity in the clinostat, "and we would expect similar changes in spaceflight samples. But this is yet to be demonstrated."

In ground-based research, Pyle and colleagues have already discovered that cells of *P. aeruginosa* stored in sterilized water for several years not only survive but also grow within 24 hours when inoculated into a culture medium incubated at human body temperature. The resulting cultured cells produce ETA, too. This disturbing finding indicates that "contaminants of a water system could remain viable [and infectious] for long periods," says Pyle, possibly posing trouble for a crew on a long-duration space mission.

Pyle mentions that the study of opportunistic pathogens like *P. aeruginosa* is also important to the growing number of people who have weakened immune systems due to infection — for example, with human immunodeficiency virus (HIV), the cause of acquired immune deficiency syndrome (AIDS) — chemotherapy, organ transplant, or simply the effects of aging. "The protein and gene analyses of *P. aeruginosa* may lead to new insights into the infection process and its control on Earth and in spaceflight," he adds. And that is good news for everyone at risk for bacterial infection.



These microscopic cells of *Pseudomonas aeruginosa*, a bacterium found in soil and water, are stained green with a fluorescent chemical so they can be counted. This sample was grown in a lab under the same conditions as the samples that flew on STS-107 in 2003.

credit: Susan Broadaway

For more information about Barry Pyle's research, read NASA's "The effect of microgravity on the smallest space travelers: Bacterial physiology and virulence on Earth and in microgravity" (*http://spaceresearch. nasa.gov/sts-107/107_pyle.pdf*).

Neutron Spectrometers: To Detect and Protect

A new device provides information about astronauts' exposure to high-energy neutrons, a potentially harmful form of radiation.

To the human eye, space appears mostly empty, with just the occasional star, planet, and comet. However, between and among these large, isolated celestial bodies, space is filled with radiation in the form of cosmic rays. In our solar system, these rays primarily consist of charged atomic particles that are emitted by the Sun and by supernova explosions. Each square centimeter of apparently "empty" space may contain a per-second flow of as many as 10 protons plus the occasional atomic nucleus. In addition, when cosmic rays hit a material, their interactions with the material's atoms can knock out high-energy neutrons, creating yet another form of radiation. For space travelers, exposure to all these particles increases their risk of developing cancer.

Astronauts' exposure to cosmic radiation has been carefully studied and monitored, but high-energy neutrons defy easy detection. Richard Maurer, a principal investigator at Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, is developing a compact, portable device to measure real-time exposure to high-energy neutron radiation in spacecraft, in space habitats, and on the surfaces of planets other than Earth.

Neutrons at home and in space

Neutrons are elementary particles that, along with protons, make up the nuclei of atoms. High-energy neutrons penetrate the human body fairly easily. Because the human body is mostly water — a good material for shielding neutrons — high-energy neutrons are quickly slowed down. The slowed neutrons are then likely to interact with atoms in the internal organs, such as the kidneys and spleen, rather than just pass through the body. These kinds of interactions can increase cancer risk.

On Earth, the risk of exposure to cosmic radiation is minimal for two reasons: Neutrons entering Earth's atmosphere are slowed by collisions with the nuclei of nitrogen and oxygen atoms in air molecules, and Earth's magnetic field deflects a fraction of the incoming cosmic rays (so they do not interact with material in the atmosphere to produce neutrons). Beyond Earth's atmosphere, however, the situation is quite different. People in space or on another planet receive little or no natural atmospheric shielding against cosmic rays.

As the lengths of missions have grown, astronauts have been exposed to increasingly larger doses of high-energy neutrons per spaceflight. Whereas the Apollo missions of the 1960s and early 1970s and even shuttle flights typically were less than 2 weeks each, stays on the International Space Station usually are much longer — about 6 months. In addition, newer, larger spacecraft have more structural material for the impinging high-energy particles to interact with, which means that more high-energy neutrons can be produced. A trip to Mars, which would require a large spacecraft and a lengthy stay outside Earth's atmosphere, would expose astronauts to higher amounts of radiation than on any missions to date.

According to Maurer, scientists have been doing a reasonable job of monitoring charged particles during travel outside Earth's atmosphere since the first spaceflights. However, high-energy neutrons have no charge, so they are more difficult to detect than the positively charged protons and nuclei of cosmic rays. Because most of the current instruments for measuring radiation dosages are not very sensitive to neutrons, the actual radiation dose may be underestimated by 20 to 30 percent, he says.

Maurer and colleagues are developing a neutron energy spectrometer to measure the previously undetected radiation. For an interplanetary mission, the compact, portable spectrometer would be carried inside the spacecraft to measure radiation exposure; after the journey, it would be moved to a space habitat or a planet's surface along with the astronauts. The instrument could be set to warn personnel of radiation fluxes above a given threshold so they could seek shelter in a protected area (such as a structure shielded by water or a cave on a planet's surface).

A wide spectrum

A neutron energy spectrometer measures the number of neutrons present of various energies. Neutron energies can range from fractions of an electron volt to millions of electron volts. Making one detector that is sensitive to the whole range of possible energies is technically difficult, so Maurer's group has developed different detectors for neutrons of different energy ranges.

As Maurer's colleague David Roth explains, scientists typically use indirect means to measure neutrons. Rather than measuring the neutrons directly, the equipment detects atomic interactions that the neutrons cause in the detector itself.

Dick Maurer (left) and Dave Roth (right) of the Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, check the response of neutron detector systems designed to measure previously unmonitored radiation that could be dangerous to astronauts. The detectors are mounted in the case that carried them approximately 26,000 meters (85,000 feet) into Earth's atmosphere during a balloon flight experiment, a test readying them for use in space.

credit: Johns Hopkins University Applied Physics Laboratory

Maurer and Roth use this indirect type of measurement to detect very high energy neutrons in the range of 20–600 megaelectron volts (MeV). Although the detection method is common, their group is the only one to use a silicon detector to measure the neutrons: The neutrons collide with the silicon nuclei and create charged particles that the detector counts.

Maurer and Roth's silicon detector is well-suited to space travel because it is light, compact, and small — only about one-tenth the volume of a typical neutron radiation detector. It is intended to be carried from a transport spacecraft to a habitation facility or wherever it may be needed. Despite its small size, the detector has a relatively large detection area of 2 square centimeters (0.31 square inches).

Neutrons in a slightly lower energy range — 100 kiloelectron volts (keV) to 20 MeV —also can be damaging to humans. For this range, Maurer and Roth use a plastic scintillator, which gives off light when subatomic particles hit it. When a neutron enters the scintillator, it bounces off nuclei until it slows down enough to be captured by a nucleus; the bouncing process and the capture create a pair of characteristic pulses in the detector.

Getting off the ground

After the detectors were built and calibrated, Maurer's group began testing the equipment for effectiveness on future spaceflight missions and possible trips to Mars. They needed to reduce the shielding effects of Earth's atmosphere to accomplish this task. Flying their detectors underneath jet aircraft provided valuable information to fine-tune the spectrometer.

To further test the devices, Maurer's group sent the detectors up, up, and away on balloon flights. Although the aircraft test flights were only 1 or 2 hours long, each balloon flight provided about 20 hours' worth of data. And because the balloons fly higher than aircraft at about 26,000 meters (85,000 feet), the equipment they carry can measure neutrons in an environment with even less atmosphere than that of the jet flights.

The balloon flights provide what Roth calls a "poor man's simulation of the surface of Mars" because the amount of atmosphere at such a high altitude is about the same as on Mars' surface. Maurer and Roth expect the incident or downward neutron spectrum on Mars to look similar to the data they have gathered from balloon flights.

The payload for balloon flight testing, including Maurer's spectrometer (the gold-wrapped box on top), awaits takeoff. A balloon flight allows Maurer to collect neutron data at high altitudes where the amount of atmosphere is about the same as on the surface of Mars. One day the spectrometer may be used on Mars to monitor radiation inside habitats.

credit: Shaun White, SW Video Productions, Inc.

Choosing the right material

Whereas high-altitude testing allows Maurer to fine-tune the spectrometer for use on future space missions, ground-based research with a known neutron beam yields crucial information about how to build better spacecraft. At particle accelerator facilities, Maurer and colleagues have studied common spacecraft materials to determine what kind of neutron spectrum each material produces when hit with high-energy particles. So far, they have concentrated their studies on aluminum, graphite, and polyethylene. Aluminum is currently the most common structural material used in spacecraft because it is strong and extremely lightweight; graphite also is light and strong and coming into use as a spacecraft material. Polyethylene contains lots of hydrogen atoms and thus is particularly good for shielding neutrons. Maurer's group is now analyzing the spectra from these materials to determine which materials are more prone to produce neutrons that could be damaging to astronauts. This information will affect materials decisions for building spacecraft and Mars habitats.

A potential next step in this study is to determine the neutron radiation produced from a mixture of materials. For example, if polyethylene is an excellent shielding material but must be combined with graphite for structural strength, then Maurer's spectrometer could help radiobiologists determine the proportions that maximize the desired end features in the building material. Because all materials let through some types of radiation while filtering out others, the goal is to identify the structure composition that minimizes the doses of the most harmful particles. As Maurer explains, they "do not try to reduce the radiation to zero, but just try to minimize it."

Benefits on Earth, too

Maurer's research has two exciting potential applications within Earth's atmosphere. On the homeland security front, the neutron detectors could be used in systems to detect the presence of nuclear or radioactive materials; the compact devices could easily be taken to the scene of a potential threat.

An impressive medical application also might benefit. A technique to treat brain tumors called boron neutron capture therapy involves injecting boron into the tumor and then shooting low-energy neutrons into it. The neutrons interact with the boron more strongly than with the body tissues and effectively "burn" the tumor. Maurer's neutron detectors could be used in conjunction with other measurement techniques to precisely characterize neutron sources and thus maximize the effect on the tumor while minimizing the effect on surrounding tissues.

Although Maurer is enthusiastic about these possible uses for the detectors, he and his colleagues are most eager about sending the neutron spectrometers into space. The testing that Maurer's team has done to date has progressed far enough that the detectors are, in Roth's words, "ready for that next big step."

Paige Varner

For a technical description of some of Maurer's research, see "Mars neutron energy spectrometer (MANES): An instrument for the Mars 2003 lander" (R. H. Maurer, D. R. Roth, J. D. Kinnison, J. O. Goldsten, R. E. Gold, and R. Fainchtein, *Acta Astronautica,* **52**(2-6), January–March 2003, pages 405–410).

Navigating through the Stars, by the Stars

Many spacecraft use a "smart" camera called a star tracker that helps them navigate by reading the stars as if they were a map. New technology has improved the device, making it lighter and more accurate — because the first rule of exploration is "Don't get lost!"

On May 5, 1961, astronaut Alan Shepard became the first American in space with a suborbital flight that lasted just over 15 minutes. Since then, humanity has visited many of Earth's planetary neighbors through the means of satellites and probes and is now exploring black holes, planets, and stars well outside of Earth's solar system.

As NASA gears up to make the jump from low Earth orbit to planetary and long-duration exploration — including sending astronauts to the Moon and to Mars — new challenges must be met. One of these challenges is to aim the sensors and antennas on spacecraft with greater accuracy than is currently possible. David Boyle, director of the Spacecraft Technology Center (STC) at Texas A&M University, College Station, is working with principal investigators from the university's Aerospace Engineering Department on the development of a new-and-improved star tracker that promises to raise the technology to new heights: StarNavII.

Star-tracking technology has been in use for many years; is available in many configurations from several manufacturers; and is invaluable in steering spacecraft of all sorts, from satellites to space shuttles. The generic term *star tracker* describes any device that uses the stars to determine a spacecraft's spatial orientation, referred to as attitude (e.g., an airplane flying upside down is said to be in an inverted attitude), and the direction in which a camera or antenna is aimed, referred to as pointing knowledge. The device is in essence a "smart" camera linked to a comprehensive database of astronomical information (names, locations, and relative angles of all the stars that can be seen from low Earth orbit).

"Imagine you're a communications satellite orbiting Earth," says Boyle. "You need to point your antennas at a certain place. How do you know where you're pointing? Astronomers have mapped every visible star, and we know the interstellar angle between every two stars. If your [star tracker's] camera were clever enough to look at two stars, identify which ones they were, and measure very accurately the viewing angle between them, then repeat this for three or four [more pairs of] stars, there's only one direction you could be pointing and have those angles be true. Satellites can reorient themselves and point [their antennas or sensors] in different directions, but the 'knowledge' of where they're pointing comes from the star tracker."

In addition, Boyle and his team have set their sights on building a handheld version of StarNavII. "When astronauts are walking on the surface of the Moon or Mars, there are no road signs. A handheld device would be like a star-based Global Positioning System. It would tell you where you are and where you're headed, just by looking at the stars."

Star trackers are linked to a comprehensive database of astronomical information. Built by astronomers over years of observing starry skies like this one, the database includes the names and locations of all the stars visible from low Earth orbit as well as the angles between any two stars. After a star tracker determines the angles of several pairs of stars, it searches its database to determine its location.

On a new track

A few years ago, John Junkins and Tom Pollock, two professors from the Aerospace Engineering Department at Texas A&M, had some great ideas for improving the already-existing star-tracking technology. "Between the two of them," recollects Boyle, "they came up with a clever way to do the optics, to focus the stars from two different fields of view simultaneously, and then … to do the mathematical algorithms to find the angles in the star catalog very quickly. You've got to do this quickly if you're going to make this work."

STC's prototype, StarNavI, was built to demonstrate some of Junkins and Pollock's improvements. Computer algorithms enabled the device to process the angles between stars more quickly and more accurately than commercial star trackers available at that time. StarNavI flew on STS-107 in January 2003, and although it was lost when Space Shuttle *Columbia* was tragically destroyed on reentry, the device operated successfully during the flight and downlinked valuable information to researchers on the ground.

Two heads are better than one

In the months after the STS-107 flight, Boyle and the Texas A&M team built StarNavII, incorporating many of the lessons learned from StarNavI. Its mathematical algorithms are more advanced than those of its predecessor, and most important, StarNavII has one camera but two fields of view. “When converting the interstellar angles between stars into a pointing vector for a camera,” explains Boyle, “the accuracy suffers a little bit if the camera is rotated left or right.” Rotation disrupts the bore sight line, which is the invisible line extending from the camera along the exact center of the view — much like a targeting laser beam — toward the target, which in this case is a star. When the camera is rotated, even though the bore sight appears to “touch” the same point in the sky, the pointing information is no longer as reliable.

Having two fields of view is advantageous because one field “looks” in one direction; the other is oriented orthogonally to the first. When the bore sight of one view is rotated, the other view moves to adjust for the rotation. The result is a significant increase in the accuracy of results over a device with a single field of view.

Another innovative feature of StarNavII is that a single set of electronics serves both fields of view. So, in essence, the device offers the accuracy of two star trackers but has the weight, cost, and power needs of closer to one. Because weight, cost, and power requirements are limiting factors to spacecraft cargo, improvements to StarNavII can increase the value and commercial viability of the device.

For centuries, sailors have used the stars to navigate the seas with the help of tools like this sextant. Now that ships sail the skies as well, pilots also can rely entirely on celestial bodies to determine their locations and chart their courses. New star-tracking technology developed at the Spacecraft Technology Center (Texas A&M University, College Station) will greatly increase the accuracy of navigation using the stars.

Partners in success

Developing technology for use in spacecraft is technically and financially challenging. To increase its technical knowledge base and share development costs, NASA has established and manages several research partnership centers. Based at major research institutions throughout the country, these centers bring together the cutting-edge ideas and inventions of researchers and scientists with the expertise of NASA and the commercial talent of industry. The result is a winning situation for all involved. STC at Texas A&M is such a center.

Junkins and Pollock brought their ideas for improving space-tracking technology to STC for development back in 2000. “Professors and inventors have interesting ideas that could potentially lead to a very good, useful product,” explains Boyle. “But usually, they’re not developed enough that someone is sure they’re going to work. So, we build prototypes and models and test items, and [we] make real hardware to learn whether or not this nifty idea will actually work. We start with a professor’s laboratory experiment and develop it into a real, usable product flying on someone’s satellite.”

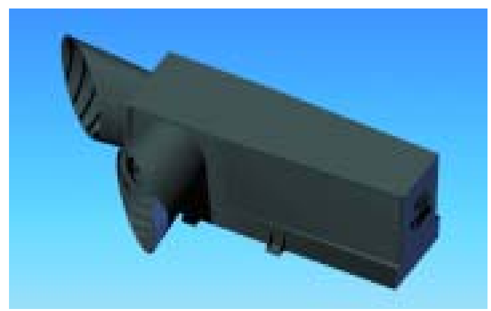
The other side of the partnership is industry. The industry partner for StarNavII is Broad Reach Engineering (BRE), a company in Denver, Colorado, that builds custom electronics for satellites. Already working with STC on other projects, BRE had been on the lookout for intellectual property that it could develop into a product to manufacture and sell; BRE is now investing money and labor to build part of this device. BRE has licensed the StarNavII star-tracking technology and will market it commercially under the name Khalstar.

StarNav — the first project that STC has taken through all stages of development, from experiment to usable product — demonstrates the best feature of research partnership centers. “It is a good model for what the research partnership centers are supposed to be doing,” enthuses Boyle. “We’re building technology that NASA needs, but because we have an industry partner that is contributing to the cost, NASA is getting technology developed at a lower cost. At the same time, a commercial company is getting a new product developed that they can then go out and sell, boosting the American economy. And that’s exactly the role we want to play.”

Tracking the future

When Khalstar is ready to be put into service, its first task will be to work with the Geosynchronous Imaging Fourier-Transform Spectrometer (GIFTS) project. Flying as part of a stand-alone satellite in geosynchronous orbit (that is, it follows Earth’s orbit and rotation so it always stays over the same location), GIFTS will demonstrate new and emerging sensor- and data-processing technology that will measure various meteorological characteristics in the atmosphere. The antennas of the GIFTS sensor must be pointed with exceptional accuracy, so this pairing will provide an excellent opportunity for Khalstar to prove its talents. GIFTS is currently waiting to be assigned a flight date and vehicle.

Carolyn Carter Snare



This rendering is of a star-tracking device, StarNavII, developed at the Spacecraft Technology Center (Texas A&M University, College Station). The device, which will be marketed as Khalstar by Broad Reach Engineering, Denver, Colorado, features a patented system that determines the orientation of the spacecraft (attitude) as well as the direction in which a camera or an antenna is aimed (pointing knowledge) with high accuracy by using height, width, and length measurements. This innovative device has dual fields of view, which provide the accuracy of two star trackers at the weight, cost, and power needs of closer to one.

credit: Spacecraft Technology Center

For more information about the Spacecraft Technology Center, visit *http://stc.tamu.edu/*. To learn more about Broad Reach Engineering, go to *http://www.broad-reach. net/*. A list of NASA’s research partnership centers is posted at *http://spd.nasa.gov/csc.html*. Texas A&M University’s main Web site is *http://www.tamu.edu/*.

Staying Alive: On Mars — and on Earth

A specialized NASA center for research in advanced life support for missions to Mars — a cooperative venture of three universities — is exciting the younger generation by involving students from middle school through college in real-world research.

Hungry? Go to the nearest restaurant or grocery store. Thirsty? Fill a glass of water from the faucet. Need some fresh air? Take a walk outdoors. Got trash? Switch on the garbage disposal, flush the toilet, or put a bag out on the curb.

In our modern society, the necessities of life (food, water, and air) and waste disposal are so smoothly provided by stores, plumbing, green plants, and sanitation trucks that we scarcely give them thought. But on a round-trip mission to Mars, astronauts will have to live within entirely closed systems for several years while growing crops, cleaning air and water, and recycling waste into usable foodstuffs. How they will carry out all these tasks necessary to human survival has not yet been determined.

Purdue University (West Lafayette, Indiana) heads a university consortium that operates a NASA specialized center with the goal of developing advanced life support technologies for a mission to Mars while engaging college undergraduates and high school students in the fundamental research and middle school students in defining the basic challenges. “It’s part of our mission to inspire and excite the next generation of explorers,” explains Julia Hains-Allen, outreach coordinator for the NASA Specialized Center of Research and Training (NSCORT) in Advanced Life Support (ALS), commonly known as ALS/NSCORT and headquartered at Purdue.

Innovative research on life support

ALS/NSCORT — one of about a dozen NSCORTs founded since 1990, each focusing on a major interdisciplinary challenge related to long-duration space missions — is the only center in the nation devoted to advanced life support. Begun in 2002 with a 5-year grant of $10 million from NASA, ALS/NSCORT consists of 24 researchers from a consortium of three universities: Purdue, Alabama A&M (Normal), and Howard University (Washington, D.C.). NASA wanted consortia competing for the grant to include at least one minority university with essential expertise. Purdue selected not one but two minority universities — Howard for its engineering researchers and Alabama A&M for its food scientists and agriculturalists.

Growing plants in a spacecraft or on Mars will be more complicated than on Earth, not only because of confined growing space but also because of sunlight considerations. The Sun’s rays would be harsher everywhere outside of Earth’s atmosphere (because ultraviolet rays would not be filtered), and the light would be less bright on Mars than on Earth (because of Mars’ greater distance from the Sun). Researchers at Purdue are thus investigating energy- and space-saving ways to provide light sources for food crops. Instead of conventional incandescent or fluorescent lighting, vertical strips of colored, light-emitting diodes might hang among crops. The colors would match the wavelengths absorbed by the plants’ photosynthetic pigments, and the diodes are cool enough that they can touch leaves without damage.

In waste-recycling projects, Alabama A&M horticulturalists are experimenting with growing edible mushrooms from the roots, stems, and leaves of other plants as a method of recycling inedible plant waste. Howard engineers are researching membranes to filter waste water into gray water (suitable for showering, laundry, or dishwashing) or even into drinking water (which would require further sanitization). Meanwhile, Purdue scientists are studying the usefulness of the whitefish tilapia, a bottom feeder, in eating plant, human, and food waste and adding variety to astronauts’ largely vegetarian diet. They also have observed that tilapia become sluggish and hide in response to environmental changes (e.g., in oxygen levels or water quality) and are trying to determine how such behavioral signals could make the fish useful as the equivalent of miners’ canaries in warning of deteriorating conditions well before human astronauts might be endangered.

Getting college students to reach out

Equally important to ALS/NSCORT’s advanced life support research is its commitment to educate students from middle school through college. Today, ALS/NSCORT conducts three unique programs: 8-week summer fellowships in education and outreach for college undergraduates; a cooperative program with a high school in Indianapolis, Indiana, to engage students in fundamental NASA research; and an 11-week program to encourage elementary and middle school students to think through the challenges of living on Mars — and what those challenges mean for Earth.

In 2003, ALS/NSCORT inaugurated the summer fellowships program in which six undergraduate students from the three universities work alongside researchers on some of the consortium’s 19 projects (See Table 1, page 26). At the end of the summer, the students present their research in an ALS/NSCORT symposium. This program continues in 2004.

One major innovation for 2004 is the introduction of two additional 8-week undergraduate summer fellowships for education and outreach, awarded to two students who are majoring in elementary or secondary education. The students learn about various science hands-on activities that can be taught in the classroom and are coached on “how to teach teachers, 4-H extension educators, and kids about those activities,” Hains-Allen says.

Surprisingly, getting the word out about ALS/NSCORT, even to undergraduates at Purdue's partner universities, has "been a big problem," Hains-Allen reports. "But within the directives of NASA, outreach has been elevated to the importance of research. We are doing the same here at ALS/NSCORT." Therefore, each undergraduate education major who completes a fellowship and returns to Howard or Alabama will "serve as the ALS/NSCORT outreach person at the home university as well as do outreach in local schools."

Students Dora Price, Adrielle Banet, and Elizabeth Jensen (from left to right) from the Key Learning Community in Indianapolis, Indiana, look over the cowpea plants they will take to their school for research. With them is Gioia Massa (far right), a Purdue University (West Lafayette, Indiana) postdoctoral student in plant research at the NASA Specialized Center of Research and Training in Advanced Life Support (ALS/NSCORT).

credit: Mark Simon

One important benefit to the undergraduates in the outreach fellowships is that they will learn about science. "Education majors often have very little science background, in part because they themselves may have been turned off to it in school," Hains-Allen points out. "So we teach them the science they'll need for NASA outreach — but not in the way it was likely presented in school. If it's chemistry about acids and bases, we don't teach them balancing equations or stoichiometry. We teach them fundamentals using household objects such as pennies and lemons and challenge them to design experiments to answer fun questions that relate to everyday life, like 'Why does Alka-Seltzer fizz?' Experiments are simple dump–pour–explain activities yet are inquiry based, like real science. When fellowship participants understand the concepts, they feel successful and can convey that thrill to both their students and other teachers."

Mars inspiring younger students

Another outreach activity is the Explore Mars pilot program being conducted at ALS/NSCORT and Key Learning Community in Indianapolis. The Key Learning Community is an innovative public school that has been teaching kindergarten through grade 8 in inner-city Indianapolis for two decades and now also includes high school. Its educational approach of teaching the whole child is premised on psychologist Howard Gardner's theory that each person has seven types of intelligence, which include five (musical, spatial, bodily-kinesthetic, interpersonal, and intrapersonal) in addition to the verbal-linguistic and logical-mathematical types that are the focus of most schools.

Located in Key Learning's science laboratory is a prototype bioreactor designed by Purdue's researchers to remove surfactants (sudsing agents) from gray water in the Mars habitat. "Key Learning students are doing actual ALS/NSCORT experiments in cleaning water, mirroring research at Purdue," Hains-Allen explains. "This is authentic, relevant research, not a simulation," she adds.

New in August 2004 will be an Explore Mars Camp on the Purdue campus, where Key Learning students in grades 9–12 will have additional opportunities (still being defined) to learn about and conduct research in other areas of ALS/NSCORT. They also will produce a 10-minute documentary film about ALS/NSCORT and Explore Mars to use in education and outreach efforts.

For students from other schools, ALS/NSCORT has been pilot testing an 11-week program called Mission to Mars at the Imagination Station family science center in Lafayette, Indiana. Aimed at students in grades 5 through 8 (but also accessible to gifted and talented children in grades 3 and 4), the program challenges children to think about what astronauts would need to live on Mars. Children first consider the necessities people must have to live on Earth, then explore how some of those needs could be adapted for Mars. "The program is structured around four concepts: producers, consumers, decomposers, and energy, all within the big picture of an ecosystem," Hains-Allen explains. "Every week [students] are asked a central question, such as 'What will we drink?' Then they are challenged to design a water-cleaning system from household supplies and test the system with simulated gray water."

Although the Mission to Mars program meets defined educational standards, "our goal is not to deliver content," Hains-Allen cautions. "Our goal is to fulfill NASA's aim to 'inspire and excite the next generation of explorers' — a difficult

continued on page 26

Students Laureka Robinson, Heather Smith, and Marta Ream (left to right) from the Key Learning Community in Indianapolis, Indiana, construct Winogradsky columns (clear containers of mud that, when exposed to light, become self-contained recycling systems) during a field trip to Purdue University, West Lafayette, Indiana. Various microbes that grow in the mud will be used for waste treatment experiments.

credit: Mark Simon

What's Happening on the ISS?: Expedition 9

Two viscosity studies, one on the capillary flow of fluids and one on colloids, have joined several ongoing life and physical science experiments already on the ISS to keep the Expedition 9 crew's science schedule full.

Expedition 8 Commander and Science Officer Michael Foale uses a digital still camera to photograph a Slow Growth sample module for the Binary Colloidal Alloy Test (BCAT)-3. In BCAT-3, Principal Investigator David Weitz of Harvard University, Cambridge, Massachusetts, is studying the long-term behavior of three classes of colloids to better understand their assembly and thermodynamics and how to engineer their properties.

credit: NASA

On April 29, 2004, Expedition 8 crewmembers Michael Foale and Alexander Kaleri returned to Earth, replaced by Expedition 9 Commander Gennady Padalka and Flight Engineer and Science Officer Michael Fincke, who had arrived on the International Space Station (ISS) 8 days earlier. Meanwhile, several new physical science experiments have reached the ISS via Russian Progress ships: two viscosity studies, one on the capillary flow of fluids, and one on colloids. These new experiments joined several ongoing life and physical science experiments already on the ISS to keep the Expedition 9 crew's science schedule full.

The Viscous Liquid Foam–Bulk Metallic Glass experiment uses a unique family of glass known as bulk metallic glasses to study bubble formation, foaming, and foam viscosity in microgravity. Viscosity is difficult to model in foam, yet understanding this property can help scientists better control the formation of structural foams (materials that flow but are stiff enough to hold a shape) on Earth. Bulk metallic glasses are formed by undercooling a metal alloy — cooling it to a temperature below which it would normally solidify. Deep undercooling sometimes allows solidification without the usual crystal formation, creating a material much stronger than standard metal alloys and ceramics.

Principal Investigator (PI) William Johnson and his research team at the California Institute of Technology, Pasadena, prepared bulk metallic glass samples on Earth. Aboard the ISS, the samples will be heated until they foam. When subsequently cooled, the solidified samples will retain their foam shape.

Because bulk metallic glasses are high-viscosity liquids, they capture bubbles when they foam and are useful for studying both foaming and bubble behavior. Microgravity prevents bubbles from rising and liquid from sinking, an important consideration for metal foams, in which the densities of the gas (bubbles) and the liquid (metal) are very different.

Johnson and his team will compare the bulk metallic foams created in microgravity with foams created on Earth to determine differences in wall thickness, bubble size, distribution, and shape effects. This knowledge ultimately will allow scientists to develop specific foam formulations to improve various materials used in the processing of paints, emulsions, and polymer melts as well as foams used to produce food, pharmaceutical, and cosmetic products.

In the Fluid Merging Viscosity Measurement (FMVM) experiment, PI Edwin Ethridge of Marshall Space Flight Center, Huntsville, Alabama, and his team are observing the coalescence of two liquid spherical drops into a single spherical drop. They hope to verify this process for measuring the viscosity of extremely viscous materials (e.g., high-temperature liquids such as certain high-performance glasses) in a containerless system. This technique avoids the contamination that otherwise would take place from contact between such liquids and the vessels used to hold them. The current containerless method for determining the viscosity of low-viscosity liquids (such as molten metal) is to measure the decay rate of oscillations of molten drops; however, the oscillation method is unsuitable for high-viscosity liquids.

Two drops close to each other eventually coalesce to form one drop. After they make contact, a "neck" forms between them and thickens until the drops merge completely. For the FMVM experiment, ISS crewmembers will release two drops of liquid with known viscosity (honey, corn syrup, glycerin, or silicone oil) from a syringe onto strings, then record digital images as the drops coalesce. By viewing the digital video, the research team will observe how the neck forms and grows between drops and measure the rate of shape change as the drops coalesce.

On Earth, gravity distorts liquid spheres, and drops are too heavy to be supported by strings; some liquids (molten glass, for example, and glasses created by undercooling in particular) crystallize when they touch a container wall, and viscosity cannot be measured after a liquid crystallizes. In microgravity, however, the movement and coalescence of drops should be controlled strictly by surface tension and viscosity, and Ethridge can study unencumbered, free-floating drops.

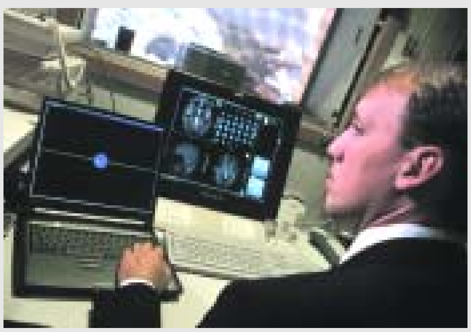
Also on the ISS is the Capillary Flow Experiment. Fluid behavior in low gravity is different from on Earth, and PI Mark M. Weislogel of Portland State University, Oregon, hopes this experiment will help researchers gain insight into the mechanics of capillary flow that can be immediately applied to the design of low-gravity fluid systems, specifically, systems for spacecraft cooling and life support. The experiment is expected to produce conclusive data about long-length capillary flows, flow phenomena in complex geometries, and critical damping resulting from moving contact lines.

In the Binary Colloidal Alloy Test (BCAT) 3, a follow-on to BCAT-2 and BCAT (flown on Russian Space Station *Mir*), PI David Weitz of Harvard University, Cambridge, Massachusetts, is studying the long-term behavior of three classes of colloids (systems of fine particles suspended in a fluid). In microgravity, the effects of sedimentation and convection are greatly reduced. BCAT-3 should lead to a better fundamental understanding of colloids, their assembly and thermodynamics, and how to engineer their properties, which may someday form the foundation of new classes of optical switches and displays as well as other optical devices for communications and computer applications.

Julie K. Poudrier

For additional information about these experiments and others that have been conducted on the International Space Station, visit http://spaceresearch.nasa.gov/research_projects/ros/ros.html.

***Shining* continued from page 15**



credit: National Space Biomedical Research Institute

A simulated spacecraft-docking task was developed to assess whether diffuse optical tomography (DOT) could be used to predict how subjects would perform on difficult tasks. Here, computer screens display task progress and brain activity. With the results of the DOT scan, researchers were able to project when skills would decline, even when volunteers said they were fully alert and ready.

when alert and when sleep-deprived. "We found it was possible to noninvasively measure brain function and predict an upcoming decrement in performance even though the individual felt fine and the EEG [electroencephalogram], the standard means of looking at wakefulness and sleep, looked normal," says Sutton.

"[DOT] may let us create a warning system that astronauts can use when they have to perform mission-critical tasks that require significant cognitive loads," he adds. DOT could supplement an astronaut's self-evaluation with a more objective measurement of readiness to perform a complex task.

Emergencies

On Earth, Sutton sees great promise for DOT in emergency rooms and doctors' offices. Readily available, low-cost, portable units could enable clinicians to scan a patient's brain for neurological damage on the spot rather than order testing that might take hours. For example, 600,000 people have strokes every year in the United States. "Physicians could use DOT to monitor a stroke in progress," suggests Sutton. "Sometimes conditions change overnight and we don't pick it up until the person is comatose the next day. We could do ongoing monitoring with DOT to identify those changes so we could treat them aggressively." He says DOT is already being tested for monitoring stroke progression.

Portable DOT devices also could make it easier to evaluate and diagnose active children who have had a head injury. Clinicians routinely anesthetize children to keep them still for special neurological evaluations, but the procedures would be safer if the patients were conscious, Sutton explains. "Instead, we can have the parent hold the child and monitor brain activity in real time." Finally, DOT could illuminate how the brain controls motor skills in healthy subjects or shine light on how the brains of people with Alzheimer's disease, Parkinson's disease, or schizophrenia function as they go about their daily tasks.

DOT is only one of many noninvasive diagnostic techniques. Yet its advantages — speed, portability, and insensitivity to motion — give it outstanding flexibility for use both in space and on Earth. One day, it may become as ubiquitous in doctors' offices as a flashlight.

Alan S. Brown

For more information about Sutton's research, visit *http://www.nsbri.org/Research/2001-2003/MedSysProj6.html*. G. Strangman, D. A. Boas, and J. P. Sutton have published an excellent review of diffuse optical tomography: "Non-invasive neuroimaging using near-infrared light" (Biological Psychiatry, 52, 2002, pages 679–693).

Staying Alive **continued from page 23**

goal to measure." Difficult, perhaps; but if attendance rolls and students' rapt attention and alert, bright eyes are any indication, "they learn an amazing amount about science — and they absolutely love it."

Trudy E. Bell

Learn more about the NASA Specialized Center of Research and Training in Advanced Life Support (ALS/NSCORT) at *http://www.alsnscort.org*. In April 2004, ALS/NSCORT began offering curriculum materials for teachers that can be downloaded from *http://www.purdue.edu/ DiscoveryPark/ spaceplace*. To request specific information about the program, contact Julia Hains-Allen at *hains@purdue.edu*.

Table 1. Research projects and faculty involved in the NASA Specialized Center of Research and Training in Advanced Life Support (ALS/NSCORT) program

Research Section	*Research Project*	*Faculty*
	Howard University, Washington, D.C.	
Water and Air Processing_1	Membrane Processes in ALS, Phase II: Water Treatment	Kimberly L. Jones
Solids and Water Processing_4	Nitrogen Cycling in ALS	Charles Glass
Systems_2	A System Dynamics Approach to Modeling the ALS System Knowledge Management, System Dynamics, and the Semantic Web	John Trimble
	Alabama A&M, Normal	
Plant Systems_1	Use of Edible White Rot Fungi to Enhance Cellulose, Hemicellulose, and Lignin Degradation of Crop Residues	Caula A. Beyl, R. Pacumbaba, G. Sharma
Food Processing & Safety_3	Optimal Food Safety in ALS	Leonard L. Williams
	Purdue University, West Lafayette, Indiana	
Solids and Water Processing_1	Solids Thermophilic Aerobic Reactor for ESM-Enhanced Solids Processing	James E. Alleman
Solids and Water Processing_2	Solids Separation Water Removal from STAR Biosolids Using Plants	Jeffrey Volenec, Brad Joern
Solids and Water Processing_3	LiFT for ESM-Enhanced Urine Water Recovery	James E. Alleman
Solids and Water Processing_5	Fish in Space: Use of Fish to Reduce System Biomass	Paul Brown
Water and Air Processing_2	Process Optimization of Physical and Chemical Disinfection Processes Subject to Extended Space Travel Constraints	Ernest R. Blatchley III
Water and Air Processing_3	BREATHe, Phase I: Gas Treatment	Albert J. Heber
Water and Air Processing_4	BREATHe, Phase II: Water Treatment	M. Kathy Banks
Food Processing & Safety_1	Advanced Detection of Pathogens in Potable Water and Food	Bruce Applegate, Michael Ladisch
Food Processing & Safety_2	Novel Food Processing and Packaging Operations	Lisa Mauer
Plant Systems_2	Minimizing ESM for ALS Crop Production	Cary A. Mitchell
Systems_1	SIMOPT-Based Integrated ALS System Modeling and Operation/Resource Management	George Chiu, Joseph Pekny, John Trimble, Yuehwern Yih, Bin Yao
Systems_3	SIMOPT-Based Integrated ALS System Modeling and Operation/Resource Management, Part I	George Chiu, Joseph Pekny, John Trimble, Yuehwern Yih, Bin Yao
Systems_4	SIMOPT-Based Integrated ALS System Modeling and Operation/Resource Management, Part II	George Chiu, Joseph Pekny, John Trimble, Yuehwern Yih, Bin Yao
Education and Outreach	Education and Outreach Provides an Avenue to Engage and Educate K–12 Students in the Centers' Investigation of the Principles Required for Life Support in Extended Space Exploration	Julia Hains-Allen

Notes: ALS, Advanced Life Support; BREATHe, Bio-Regenerative Environmental Air Treatment for Health; ESM, Equivalent Systems Mass; K–12, kindergarten through grade 12; LiFT, Liquid Freeze–Thaw Treatment; SIMOPT, Simulation Optimization Model; STAR, Solid-Phase Thermophilic Aerobic Reactor.
Source: ALS/NSCORT

Peter Voorhees

In microgravity experiments, Peter Voorhees compares theoretical calculations of changes in the structure of alloys with real-world data — a task that is impossible on Earth but may lead to advances in materials development.

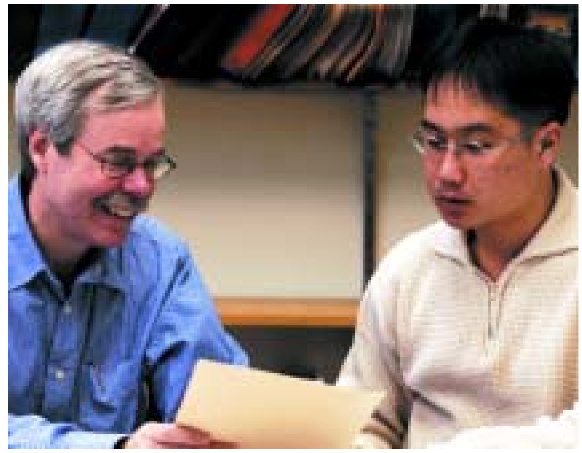
"I have always been fascinated with the way things work, and with physical phenomena," states Peter Voorhees, explaining why he gravitated toward a career in science. "I like the nitty-gritty of solving a problem for the first time." Yet the researcher, who is now chair of the materials science and engineering department at Northwestern University (Evanston, Illinois) and the Frank C. Engelhart Professor of Materials Science and Engineering, almost made a career of his other passion: photography.

"Back in the olden days, I did fine art photography. My big decision in high school was 'Art school or college?'" says Voorhees. Although academic duties and preparations for research on the International Space Station (ISS) don't leave Voorhees much time for hobbies these days, he still enjoys attending museum exhibits, including those at the nearby Art Institute of Chicago, Illinois, and reading photography magazines.

Originally from Staten Island, New York, Voorhees attended Rensselaer Polytechnic Institute (Troy, New York), where he earned a bachelor's degree in physics and a doctorate in materials engineering. He served a 2-year postdoctoral fellowship at the National Institute of Standards and Technology in Gaithersburg, Maryland, before accepting a teaching position at Northwestern. Sixteen years there — along with various visiting professorships around the world — have allowed him to pursue his research as well as work with students, which he very much enjoys.

Early in his career, Voorhees began working on theoretical calculations about coarsening, a process whereby particles in an alloy change size. Smaller particles give up atoms to the larger particles and eventually disappear. This process continues even after an alloy solidifies and can cause various problems. For example, the coarsening of particles in high-temperature turbine blades can cause the blades to weaken and break, and the coarsening of materials in a nuclear reactor can compromise the properties and safety of those materials.

However, coarsening also can be used to tailor the properties of materials. For example, many aluminum alloys obtain their strength via a controlled coarsening process. Better understanding of the process could lead to developments to strengthen everyday materials such as dental fillings, porcelain, machine tools, and electrical capacitors.



One aspect of work that Peter Voorhees (left) particularly enjoys is working with students.

credit: Dimtris Kammer

For Voorhees and colleagues in his field, the problem lies in comparing theory with reality. "When we completed these theoretical calculations and looked through the literature for experimental results with which to compare them, I discovered that there weren't data that could be directly compared. It wasn't that the experimenters had not tried hard; it was that they had not chosen a system that satisfied all the assumptions of the theory."

This lack of feasible comparisons led him to search for a system that would encompass all the conditions. The ideal system turned out to be solid particles embedded in a liquid. The fly in the ointment, however, was gravity: The solid particles would float to the surface of the liquid if they were less dense than the liquid and sink to the bottom if they were more dense. In short, Earth's gravity makes it impossible to achieve an even spatial distribution of particles, thus invalidating the otherwise perfect way to compare data with theory.

"We needed to find an environment that was gravity free in order to do the experiment. That's why I went to NASA," explains Voorhees. NASA approved the Coarsening in Solid–Liquid Mixtures experiment to be conducted during the Microgravity Science Laboratory (MSL)-1 mission on board Space Shuttle *Columbia*. The mission was forced to land shortly after launch because of orbiter problems but was relaunched (as MSL-1R) in July 1997, and Voorhees' experiment was completed.

Interestingly, the data obtained from that flight experiment did not match expectations. "We expected to find that the classical theory of coarsening, developed nearly 40 years ago, would predict the rate at which the coarsening process proceeded," says Voorhees. "It did not. The experiments on the ISS will, I hope, provide the insight as to why."

Two furnaces and two electrical control units are already on board the ISS, ready to be used for more experiments, the results of which are likely to refine theories of coarsening and lead to the development of new and improved materials. Along the way, they will also allow Voorhees to enjoy what he likes most: the nitty-gritty of solving a problem for the first time.

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