MIT Science News in Review

[Biological Sciences]

A Step In the Fight against Cancer

MIT researchers have unexpectedly come across a method to treat a rare abdominal cancer. Although research was intended to be on basic cancer study, Dr. David A. Tuveson, professor of biology at MIT, has found an existing drug that heals those afflicted with Gastrointestinal Stromal Tumor (GIST).


Dr. David A. Tuveson

The drug, Gleevac, has been clinically tested and has dramatically helped people with GIST. Tuveson worked with other colleagues from MIT and other institutions to show that the drug ST1571 stopped GIST. Through an inhibition of genetic mutation in the c-KIT receptor and, in some instances, destruction of cancerous cells, their work has helped to eliminate the disease.

Treatment of leukemia with ST1571 had focused on stopping the kinase enzyme that is responsible for the disease—Tuveson and his colleagues hypothesized that the drug might be effective against a similar mechanism in GIST.

Indeed, the 5,000 Americans that are annually affected by GIST may now have hope. Before current research, GIST could not be treated by any traditional means besides surgery. However, for those in developed stages of illness, such surgery is nearly impossible, and thus they are left with little help for a cure.

The work emphasizes the importance of basic research in finding more effective medical solutions to various illnesses, while also highlighting the importance of using basic observation, analysis, and critical thinking to apply existing solutions to new situations. The application of ST1571 to leukemia also raises support for the targeted approach to cancer, namely, the explicit focus on cancerous cells rather than destroying all the cells.

Thermotherapy Provides New Hope for Breast Cancer Treatment

Radar technology, first developed at MIT to detect missiles, is now being applied to the treatment of breast cancer. According to initial results from a Phase II trial, microwave radiation can kill tumor cells without harming the skin.

This novel therapy—termed "thermotherapy"—is based on technology first invented by Dr. Alan J. Fenn, a senior staff member at MIT Lincoln Laboratory.

The radiation was originally used to detect missiles and to protect against enemy jamming. But its ability to selectively kill cancer cells suggests that it could supplement or even replace more conventional approaches like surgery, x-ray radiation, and chemotherapy, which are less effective and have serious side effects.

Thermotherapy is effective because tumor cells contain unusually large amounts of water and ions, making them more susceptible to microwave energy than normal cells. The cancer cells are therefore preferentially destroyed. "After thermotherapy treatment, we are seeing a significant number of breast cancer cells killed without damage to the skin," said Dr. Robert A. Gardner, a breast surgeon at Columbia Hospital in Florida.

Forty-three women with early-stage breast cancer are participating in the Phase II trials at three hospitals: Martin Luther University (Germany), Harbor-UCLA Medical Center, and Columbia Hospital. The study should be completed in 2002.

Gene Therapy Corrects Sickle-Cell Disease in Mice

In the December 14, 2001, issue of *Science*, Assistant Professor Philippe Leboulch, research affiliate in the Harvard-MIT Division of Health Sciences and Technology, and colleagues reported the development of a gene therapy method that treats sickle-cell anemia in mice.

Sickle-cell disease is caused by a point mutation in the beta globin gene that contributes two protein units to hemoglobin. When the mutation is inherited from both parents, abnormal hemoglobin molecules result. In periods of low oxygen, the mutant protein chains interact and bind to each other, causing red blood cells to collapse into sickle shapes that get caught in blood vessels, blocking blood flow and leading to anemia, stroke, and organ damage.

The therapy utilizes a modified lentivirus (a retrovirus) as a vector to transport an antisickling beta globin gene variant into the resting stem cells in bone marrow. The lentivirus is modified to include a flap of DNA from the HIV-1 virus. This improves the delivery. Furthermore, expression regulation elements surrounding the gene were optimized to increase expression in red blood cells.

"Usually when a copy of a new gene lands in the genome this way, it is strongly influenced by its surroundings and often gets silenced. But when the expression level is very high, and spread evenly through the cells, as it is in this case, the gene can do its work," Leboulch said.

Mice that underwent this treatment after having their bone marrow eliminated by radiation were found to have 99 percent of their red blood cells expressing very high levels of the new gene less than 10 months after transplantation.

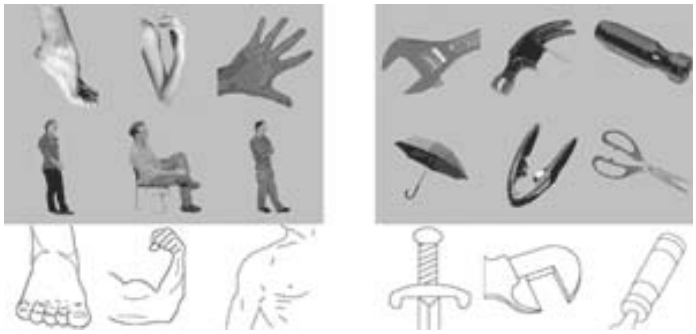
Two different models of sickle-cell disease were tested in mice. In one model the gene therapy caused an eightfold reduction in sickled cells. In the other model, sickled cells were completely eliminated. Other symptoms of sickle-cell disease were also corrected in mice, such as enlarged spleens, urine concentration defects, and dehydration of red blood cells.

Future research includes the development of large-scale production of nonreplicating viral vectors and the investigation into bypassing the toxic irradiation of bone marrow for the success of the therapy.

Brain Region Identified that Responds to Human Form

In consortium with the University of Wales, researchers at MIT have identified a region of the brain that responds strongly and primarily to images of the body and its parts.

The Extrastriate Body Area (EBA) is located in the lateral surface of the brain called the posterior superior temporal sulcus. It



may be part of a larger network of close areas that are key in social perception and cognition.

This discovery highlights why human brains have regions that process "faces, places, and bodies, but apparently not spiders, cars or food." Neuroscientists are attempting to determine whether the mind exists as a single multipurpose system or as part of a complicated web of distinct systems for mental tasks.

Researchers are excited about the technology, which made possible the explorations of brain activity and are "now making progress at a historically unprecedented rate in understanding the functional organization of the mind and brain" (Professor Nancy Kanwisher).

[Physical Sciences]

MIT Researcher on Team for Possible 2006 Pluto Mission

Professor Richard P. Binzel of the Department of Earth, Atmospheric and Planetary Sciences was chosen by NASA as a member of the Pluto-Kuiper Belt (PKB) mission sciences team slated to visit Pluto and the Kuiper Belt in 2006.

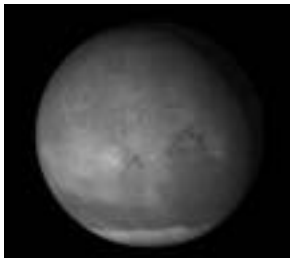
Pluto is the last planet in the solar system to be visited by a spacecraft. The goal of the mission is to observe global geology and morphology, map the planetary surface composition, and characterize Pluto's neutral atmosphere and its escape rates. "One of the most exciting aspects of this mission is that it will complete the first reconnaissance of our solar system by closely examining Pluto and one or more Kuiper Belt Objects," Binzel said.

The PKB mission aims to reach Pluto before 2020, simply because as the planet moves farther from the sun its atmosphere may freeze out and to catch the planet before it moves into shadow, impeding the chance to take photographs in reflected sunlight. The 2006 launch date facilitates the slingshot trajectory of the spacecraft past Jupiter toward the outer solar system to fly by Pluto and Charon between 2016 and 2018. By 2026, the spacecraft will pass the Kuiper Belt, the distant home of comets believed to be the source of Earth's water and the chemical building blocks of life. Kuiper Belt Objects (KBOs) are small, icy bodies with diameters of approximately 100 kilometers (62 miles), which make them difficult to study from Earth.

"Visiting Pluto and other Kuiper Belt Objects would be like visiting a deep freeze containing samples of the most ancient material in our solar system, the stuff that all the other planets including Earth were made of," said Colleen Hartman, solar system exploration director in NASA's Office of Space Science. "But the most exciting thing about going to an unexplored planet is what we may find there that we're not expecting."

MIT, NASA Scientists Team Up to Track Ice on Mars

Years ago, then–Vice President Dan Quayle made the humorous but inaccurate remark, "We have seen pictures where there are canals, we believe, and water [on Mars]. If there is water that means there is oxygen. If oxygen, that means we can breathe." Although that remark appeared quite premature, MIT and NASA scientists have since investigated more about the "water" (actually ice and snow) on Mars and what it might implicate.



The team of David E. Smith of NASA's Goddard Space Flight Center; Maria T. Zuber, professor of Earth, Atmospheric and Planetary Sciences (EAPS) at MIT; and EAPS research scientist Gregory A. Neumann has collaborated to provide for the first time measurements of the density and thickness of seasonal snow and frost on Mars. As published in the December 7 issue of *Science*, Smith, Zuber, and Neumann found that they could make extremely precise observations of seasonal frost deposits on Mars using NASA's Mars Global Surveyor (MGS) spacecraft.

"Snow on Mars is denser than it is on Earth, being more ice-like than powdery," Zuber told *Tech Talk* reporters. He and his colleagues chose the MGS craft so that they could use a laser-based altimeter and a radio tracking system to determine minute changes in elevation and gravity on Mars, allowing the team to make the first direct measurement of frost density on the planet. The group reported that over the course of one Martian year

(about 687 Earth days), about one-third of Mars' carbon dioxide atmosphere freezes in the northern and southern hemispheres. By measuring changes in the height of the Martian surface every two weeks, the NASA and MIT researchers showed that even minute changes in surface height correlate with the expected times of deposition and evaporation of carbon dioxide from the planet's surface. By tracking small changes in the gravity field of Mars, the team was also able to measure the density of surface frost deposits.

"Snow on Mars is composed of dry ice, and last year it reached a maximum depth of 1.5 to 2 meters near both the north and south poles," said Smith, who was lead author of the study. Smith's results, along with those of his colleagues, will likely provide a better understanding of Mars' atmosphere, as well as make it easier to design future spacecraft intended to land on the surface of Mars. The MGS spacecraft used in the experiment is already being used for this purpose and is now engaged in an extended mapping mission of the surface of Mars.

In addition to offering clues for future lander design, the results from this experiment offer the "first step toward understanding past climates on Mars," said Neumann. Using data from this study, scientists might be able to track what the atmosphere on Mars was like hundreds of years ago or even offer clues to the origins of Dan Quayle's notorious canals.

"Quantum weirdness" Provides More Accurate Measurement of Position

Instead of relying on the accuracy of researchers' measurements of the initiation and arrival times of a pulse, scientists can find the position of an object using quantum mechanics, the accuracy of which is based on how many photons can be prepared within a quantum pulse. Postdoctoral associates in MIT's Research Laboratory of Electronics call this process "quantum positioning system" (QPS).

Current techniques for locating the position of an object use clock synchronization; one can determine an object's position by sending pulses of light or sound from one place to another or by determining the arrival time of the pulses at a certain reference point.

According to Seth Lloyd, associate professor of mechanical engineering, "Counterintuitive features of quantum mechanics such as entanglement and squeezing can be employed to overcome the classical limits in these procedures."

Entanglement occurs when quantum correlations are greater than classical mechanics, while squeezing brings quantum noise levels below their original limit.

The accuracy of conventional techniques is proportional to the bandwidth of the pulse multiplied by the square root of the power in the pulse. Since it depends on the number of photons in a quantum pulse, in the "quantum quirk," 100 photons increased the result by 10 over the classical limit, and a million photons yields a thousand times better result.

Another use would be to implement quantum cryptographic schemes that would not allow an eavesdropper to obtain information on an object's position, benefiting high-security users. In the near future, people could be using basic quantum building blocks in order to measure various objects' whereabouts.

Nepal Water Project

In 2000, some 1.7 billion people worldwide lacked access to clean drinking water, according to UNICEF. About 44,000 children under 5 die every year in Nepal from waterborne diseases. The poor quality of the water has caused developmental diseases in children. The women who run the families are saddled with carrying much needed water in rural areas, knowing that the very water they tote is causing illness in their families.

An MIT project in consortium with local Nepalese agencies and organizations is working to develop a solution to the water problem. Water engineer Susan Murcott spearheaded the project, which has become a large Masters of Engineering program with thesis projects in Nepal.

The problem has two main sides: removal of particles and microorganisms that cause diseases and finding a viable water-treatment system for a developing country with technical performance, "low or no" cost, sustainability, and social acceptance and adoption.

The search for a solution to the water contamination problem included exploring other MIT scientists' research. Amy Smith (MIT Edgerton Center instructor and graduate) invented a nonelectric-powered incubator for detecting microbial contamination. Nepal does not possess a reliable electrical source to power the standard microbial incubator. And Junko Sagara has studied the filtration methods in Nepal and examined the use of a stainless steel unit that works but is too expensive for the Nepalese to afford.

The best recommendation so far is SODIS (household solar disinfection). This is promising but still limited by the inclement weather in Nepal because the system runs on solar power. Work by other institutes includes a BioSand Water Filter (BSF) created by Professor David Manz of the University of Calgary, Canada. This system strains water through layers of sand, removing the sand and microbes; it is promising but requires much calibration and maintenance.

Carbon Credit Policy Examined

A feature of the Kyoto Protocol on Climate Change could irrevocably damage the welfare of the world's oceans. Carbon trading limits the amount of the greenhouse gas carbon dioxide that a country may emit. A country that has exceeded its quota can buy carbon credits from another country that has not reached its emissions quota. The purchase of such credits from commercial industries that have found ways to remove carbon from the atmosphere makes the credit policy dangerous.

One technique for removing atmospheric carbon is known as ocean fertilization. Experiments over the last 10 years show that fertilizing parts of the ocean increases phytoplankton, which as part of their normal life cycle remove carbon dioxide from the atmosphere.

MIT Professor Sallie W. Chisholm objects to this technique because "a fertilized part in turbulent ocean currents is not like a plot of land."

She contests claims that ocean fertilization is easily controlled or a process that occurs naturally in nature or environmentally harmless in the long term. She worries about the slippery slope that the current interest in ocean fertilization would lead to. "If it's profitable for one, it would be profitable for many, leading to exploitation and a classic tragedy of the commons," she said.

Rhodium-Based Molecule Leads to Photosynthesis in a Beaker

The August 31, 2001, issue of *Science* covered the advent of a potentially cheap and clean future energy source through the creation of a rhodium-based molecule that produces hydrogen gas when submitted to a catalyst and a zap of light. "We have been seeking a future alternative fuel source by studying the principles that govern the conversion of photon energy into chemical potential," said Professor of Chemistry Daniel G. Nocera and former MIT graduate student Alan F. Heyduk. "Our strategy is to use the energy of sunlight to drive reactants uphill to energy-rich products, thus harnessing the sun's energy to create a renewable energy source in the future."

When rhodium is dissolved in a hydrohalic acid solution and bombarded with light, the metal acts as a photocatalyst. The structure of the rhodium compound allows it to break chemical bonds in the hydrohalic acid to release hydrogen gas and halogen by-products. The halogen by-products are trapped and recycled into the reaction. "In the leaf, sugar and oxygen are energy-rich products. In our beaker, the sought-after fuels are hydrogen and a halogen, produced catalytically from the photochemical splitting of hydrohalic acid," Nocera said.

Professor Daniel G. Nocera

The goal of the research reported in *Science* was to convert light into hydrogen by trapping photon energy in a structurally well-defined molecule. Although this system is not as complete or efficient as photosynthesis, it has surpassed the use of massive solid photocatalysts previously developed to achieve the goal of cleanly converting sunlight into chemical energy. "As it stands, we have performed half of the photosynthetic reaction by generating hydrogen. If we can now get the other half of the process to work [getting the halogen], we would have a framework for future energy production," Nocera said.

[Technological Sciences]

2.009, a One-of-a-Kind Course

2.009 "Product Engineering Processes," the mechanical engineering senior design course, is one of the most exciting and demanding courses at MIT. Working in teams, students are challenged to use both their engineering skills and their interpersonal skills to build several wireless, remote-controlled products. In addition to designing and building the products, the students are also required to draw upon their knowledge of business and marketing in order to present their products to a group of invited guests.

In this year's 2.009 class, students from six different teams came up with a snowblower, a wheeled and turreted water gun, an amphibious tanklike toy that shoots foam discs, a water rescue vehicle, a bartending machine, and a rock-climbing device. Although the process of building these products can be grueling, students generally have a positive attitude toward the course. One of the 2.009 students, Greg Townsend, believes that the course is "an immense challenge, but it teaches you more than any of the other courses."

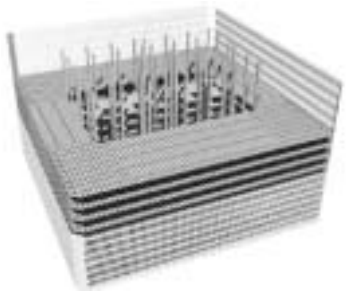
The lead instructor is Professor David Wallace of mechanical engineering. The section instructors are professors Woodie Flowers and San-Gook Kim; lecturers Richard Fenner, Hamid Hashemi, David Meeker, and Doug Vincent; and visiting engineer Chris Magee. The course sponsors are the Lemelson Foundation, United Technologies, Ford Motor Co., and General Motors.

Unveiling the Myths behind the Collapse of the World Trade Center

The collapse of the World Trade Center (WTC) towers on September 11, 2001, was a tragic yet scientifically intriguing event. In its December, 2001, issue, *JOM: The Member Journal of The Minerals, Metals, Materials Society* attempts to elucidate the events that brought about the eventual complete destruction of the twin towers.

There were three major events that occurred throughout the incident. They were the airplane impact with damage to the columns, the ensuing fire with loss of steel strength and distortion, and the collapse, which occurred inward without significant tipping. Although the towers were built in the mid-1960s through the early 1970s, they represented a new approach to building skyscrapers because they were extremely lightweight and involved modular construction methods that accelerated the

building schedule and reduced the cost. In any event, the buildings were designed to withstand a 225-km/hr hurricane and resist 2- kPa wind load, a lateral load of 5,000 t. So, while the airplane impact destroyed several columns in the WTC towers, the ensuing fire was the principal cause of the collapse. The temperature of the fire caused the WTC's steel columns to lose strength, and it also made the building lose its structural integrity due to the distortion of the steel from the nonuniform temperature in the fire.



Although the authors of the article claim that the towers were not defectively designed, they point out that there will undoubtedly be a number of changes in the building codes as a result of the WTC catastrophe.

MIT Program Works toward Sustainable Development in China

By 2094, scientists predict that housing in China will consume one out of every nine units of energy available to the world. Hoping to lower future energy consumption, MIT is collaborating with groups from Switzerland, China, and Japan to increase Chinese building efficiency.

The MIT program is designing and evaluating prototypes for urban housing sites in Beijing, Shanghai, and Shenzhen. The goal is to use passive and natural means to develop sustainable improvements in Chinese buildings.

For example, natural cooling due to wind and low nocturnal temperatures can theoretically replace air-conditioning. Similarly, glass-covered terraces can serve as "buffer zones" that trap solar heat during the winter, thus reducing the energy required for mechanical heating.

The researchers use computer simulations of air velocity around the buildings, taking into account open windows, roof slope and edges, building geometry, and vent placement. The results are incorporated into designs that optimize ventilation during the summer and insulation during the winter. The site in Shenzhen, for instance, is designed to promote natural airflow due to pressure differences between the buildings.

In Beijing and Shanghai, the planned buildings will also include skip-stop elevators, which stop only once every three floors and therefore use less energy.

Although the MIT program is focusing on China, the resulting nascent technology should be useful in developing countries all over the world. This ambitious project is therefore poised to significantly decrease global energy consumption.

MilliWave Viscometer Wins R&D Award

Paul Woskov's MilliWave Viscometer wins him his fifth R&D award in seven years. The MIT Plasma Science and Fusion Center principal research engineer developed the instrument to aid in the cleanup of cold war remnants of radioactive waste deposits. The cleanup of such wastes is the largest civil works project in U. S. history with over $40 billion already spent in its cause.

The MilliWave Viscometer measures the viscosity of molten materials. The new instrument is unique because it is able to function at the high temperatures of molten glass and metals. "Its maximum temperature of operation is more than 1,000 degrees Celsius high than viscometers currently on the market." Woskov's colleagues believe that the invention will reduce the costs of environmental cleanup and the manufacturing of many material products.

Converting Heat to Energy without a Generator

For years, scientists have attempted to convert heat directly to electricity without using the moving parts of a generator. Associate Professor Peter Hagelstein of the MIT Department of Electrical Engineering and Computer Science along with Dr. Yan Kucherov of ENECO, Inc., have announced the first such device, which is virtually silent, vibration-free, and low in maintenance costs.

As they reported during the November 27 poster session of the Materials Research Society, the new device is two times more efficient than the next best converter of heat to electricity, which means that the technology could greatly impact the conversion of heat to electricity in power plants or automobiles. "That such good results were obtained in the first generation of the new device technology," write Hagelstein and Kucherov, "indicates that the general approach has great promise for improved performance in more mature implementations." For instance, the device might be used to convert a car engine's heat exhaust into usable electricity for the air-conditioning system.

Hagelstein and Kucherov based the design of their converter on the basic vacuum tube, in which heat causes electrons to boil off a cathode and absorb onto a cooler anode, converting heat to electricity as electrons travel "uphill" against the electric field gradient. The high manufacturing costs and high operating temperature of vacuum tubes reduced their applicability, but Hagelstein and Kucherov's new technology uses a semiconductor to traverse the gap between the cathode and anode in the tube and make the system more efficient.

"I believe that these new devices represent the first big step in performance of these devices," said Professor Louis Smullin of the Department of Electrical Engineering. "In the '50s there was much hope that direct conversion of heat to electricity would open up a new era, but it was not to be. With these new devices, maybe these dreams will come true."

ENECO will develop the device, and one patent has already been issued.

Transportation Challenging Environmental Sustainability

The growing number of pollutants emitted from transportation vehicles is leading the world into environmental degradation. MIT researchers and Charles River Associates have conducted the "Mobility 2001" project (see http://lfee.mit.edu for more information), which is the first stage of a three-year study authorized by the World Business Council for Sustainable Development (WBCSD). This study was designed to find the amount of transportation that the environment could sustain in 2030, as well as methods for attaining this goal.

Drawing on passenger, freight, ground, air, and water transport, the study examined the effect of people's mobile tendencies on economic development, social welfare, and environmental quality. Researchers found that the automobile is the preferred mode of transportation for many people in urban and suburban areas. With a rapidly growing, richer population, the large number of cars and pollutants clog the small number of roads, resulting in environmental damage, high-energy usage, and safety hazards. Other concerns include the construction and usage of roads, bridges, airports, and harbors, as well as the efficiency of consumer transport and airplanes' high-altitude release of carbon compounds. Also, more than 96 percent of the world's transportation depends on petroleum, which yields high-energy fuels, but hugely contaminates the air.

The researchers reasoned that they must solve seven problems in order to maximize the environment's capability to sustain mobility. These problems include ensuring that transport meets people's needs while enhancing quality of life and supporting economic development; modifying vehicles to meet new standards concerning air-pollutant emissions, amount of fuel used, load-carrying capacity, and ownership structure; reconstructing public transportation; creating a more efficient infrastructure for planning, building, and managing mobility; reducing carbon dioxide emissions; fixing problems between passenger and freight transport; and providing options for eradicating congestion.

Combined with technology, political determination, and institutional capability, human beings must help resolve the conflict between their mobility and their environment.

Commodified Light

Like the recent crisis in California, the Northeastern states and electricity corporations may soon face massive energy shortages. New regulations from the Federal Energy Regulatory Committee require the three major energy grids of the Northeast (New York, New England, and "PJM" [a limited-liability-company]) to integrate their services. Despite the intent of such rules, implementation may be difficult.

However, MIT scientist Dr. Marija Ilic of the Department of Electrical Engineering and Computer Science and her colleague, Leonard Hyman of Salomon Smith Barney, suggest an alternative. Their approach would focus on an "Interregional Transmission Organization" (IRTO) as the operator of a network between the grids. This trading system, similar to a pollution credit scheme, would allow companies to buy or sell transmission capacity.

This market solution would maintain flexibility and maximize the decision-making abilities of all companies involved. Ilic and Hyman used computer modeling to show the inexpensive and relative reliable nature of their approach. In contrast to the current solution, which proposes to use the PJM grid as an industry standard, their idea would focus on newly developed software and protocols. This would prevent reliance on old industry standards, helping all parties involved.

Despite the promising outlook for this approach, continued work by scientists, engineers, and economists is necessary for future success and progress toward implementing FERC regulations. Ilic and her research associates are working toward more alternative solutions that might facilitate implementation of a more integrated electricity grid system.