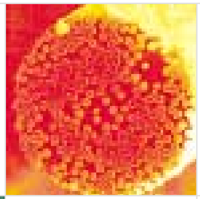
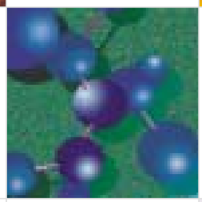
NC STATE UNIVERSITY





Volume II, Number 2

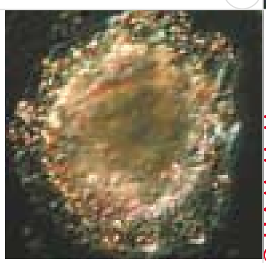
RESULTS

SUMMER 2002

RESEARCH AND GRADUATE STUDIES AT NORTH CAROLINA STATE UNIVERSITY

NANOMEDICINE: Special Delivery for Cancer Patients

For decades, scientists have envisioned creating nanodevices that would, for example, be able to travel through the human circulatory system tracking down and destroying cancer cells and tumors. In a chemistry lab in NC State's College of Physical and Mathematical Sciences, professors Dan Feldheim and Stefan Franzen are turning that vision into a literal dose of reality.

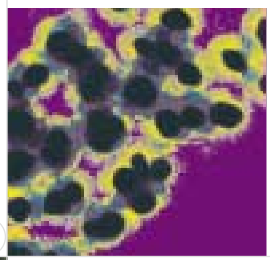


Cervical cell; gold particles delivered to nucleus by customized nanocapsules

Feldheim and Franzen, along with five chemistry graduate students, have developed a method for making nanoscopic polymer capsules that can identify cancer cells and deliver DNA fragments with destruction instructions to the cell's nucleus. Having been proven in the laboratory, and soon to enter animal trials, the discovery could provide cancer patients with more effective intravenous treatments without today's cruel side effects.

Keys to the capsule's effectiveness are its selectivity for cancer cells and its ability to get to their DNA before the cell pumps the therapeutic agent back out. Typical chemotherapy drugs attack not only cancer cells but all fast-growing cells in the body, such as those in hair follicles, bone marrow and stomach lining—causing baldness, immune deficiencies, and nausea—often making the cure worse than the disease. "There are available cancer drugs that work," says Feldheim. "The problem is in targeting the drug delivery."

"We've learned a lot from viruses," he explains. "They have certain proteins on their coatings that allow them to find a specific cell, unlock the door and go right into the cell nucleus. We've attached to our capsule coating small peptide fragments from virus proteins that can detect and enter cancer cells while leaving other types of cells alone."



Hollow nanocapsules

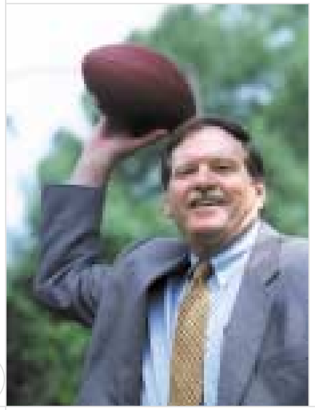
Funded by the National Science Foundation and the North Carolina Biotechnology Center, Feldheim and Franzen are working with researchers at the UNC Lineberger Cancer Center and the Duke Comprehensive Cancer Center. The UNC and Duke collaborators are providing the DNA fragments for NC State's proprietary delivery technology, and will eventually provide test therapeutics for other diseases as well. Feldheim believes that intracellular sensors could be positioned in specific cells through the same method, perhaps affording earlier cancer detection. ■

www.ncsu.edu/chemistry/dlf.html

Dr. Stefan Franzen and Dr. Dan Feldheim

www.ncsu.edu/research/results

NANOTECHNOLOGY



Dr. Charles Moreland

RESEARCH ADMINISTRATION

RETIRING Vice Chancellor Advises: "GO LONG"

"Focus on the future. Be tenacious. And be patient."

As Vice Chancellor Charles Moreland retires this summer after a 38-year career at NC State including ten years as quarterback for research and graduate studies, he calls one last play. "Go long," he advises. "Focus on the future. Be tenacious. And be patient." It's his version of Wayne Gretzky's famous quote about skating to where the puck is going to be.

While the astounding pace of change on NC State's research scene during Moreland's tenure might make one question his patience, he has clearly proven his focus and tenacity. NC State's research expenditures increased 70% on his watch, now topping $290 million—exceptional for a university without a medical school. Ranked in the top 50 public and private universities in research and development expenditures ten years ago, NC State now ranks in the top 30. Moreland has also transformed the university's technology transfer operation which today holds a premier national ranking with 235 patents and 35 spin-off companies.

Always pushing for new initiatives, Moreland led the creation of "The NC State Model" for industry partnerships in innovation, entrepreneurship and economic development—so successful that NC State received a $500,000 grant from the National Science Foundation to disseminate the model to other universities. Moreland's key challenges in building the model were convincing university foundations to invest in a seed venture capital fund for university-affiliated start-up companies and getting office and lab incubators open on the Centennial Campus.

Under Moreland's leadership, the university also began taking equity in lieu of part of the license fees for companies that commercialize university patents, giving the institution an upside benefit when those companies are profitable. With a legendary sense of humor and an aversion for both micro-management and unnecessary meetings, Moreland also catalyzed a cross-campus effort to streamline the research proposal and administration process, now electronically based.

"It should not be forgotten that Charlie has also been a fantastic classroom teacher who was so important to bringing excellence to what was not a very strong chemistry department when he came here in 1964," remembers longtime friend Bill Tucker, who joined the chemistry faculty one year before Moreland arrived. "His satisfaction comes from accomplishment, not recognition. That's what makes him such a great team player."

Moreland has played a key role in promoting faculty research in nanotechnology. His persistence is credited for persuading university officials to begin construction of Partners Building III, a new building for nanotechnology researchers to break ground on Centennial Campus this fall.

While he credits the success to an outstanding faculty and administrative team, his staff and his boss are unanimous in their praise for his decision-making skill.

> "Charlie Moreland is amazing. His strongest quality is his ability to think quickly, to analyze a situation, and to speak the truth clearly and forcefully."
>
> — Chancellor Marye Anne Fox

Moreland proudly points to industry and government partnership development on the Centennial Campus as some of the most fun he's had. He has paid careful attention to creating meaningful research and workforce partnerships, rather than merely leasing real estate—a "no-brainer," he claims—but one that has propelled the exponential growth of the new campus for the past ten years.

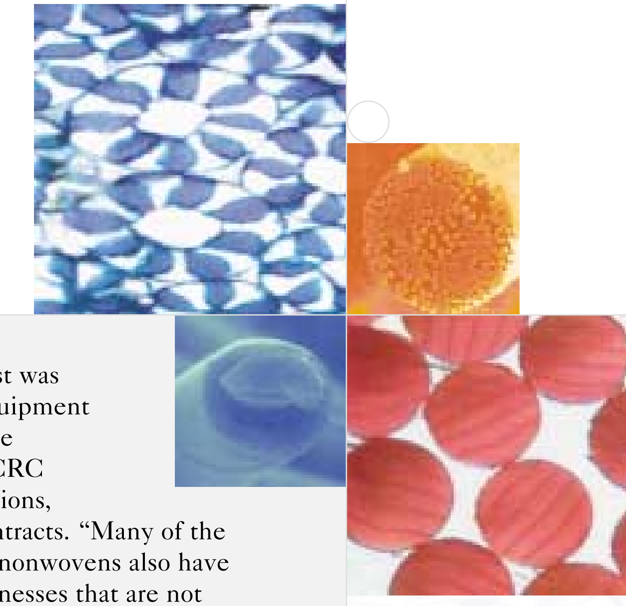
Will he miss all the fun after retirement? "Sure," he says. "How many people can spend the last ten years of their careers working in a place where there's something this great happening every day?" ■

NANOMETER: (năn′ ə-mē′tər)
One billionth of a meter • The width of 3-4 atoms • One thousandth the width of a human hair.

NANOTECHNOLOGY: (năn′ ə-tĕk-nŏl′ ə-jē)
Using materials at the molecular level, atom by atom, to create large structures with fundamentally new and extraordinary properties and functions • The "manufacturing technology of the 21st century."

NANOMANUFACTURING

New Partners Lab Gives High-Tech Boost to Nonwovens Industry



Nanofiber cross-sections (l. to r.): segmented pie; islands-in-the-sea; sheath-core; side-by-side.

To the delight of the nonwoven fabrics industry—the only growing segment of the U.S. textile market—the Nonwovens Cooperative Research Center (NCRC) in the NC State's College of Textiles opened a dream R&D facility on May 28th. The new NCRC Partners Lab is a state-of-the-art spunbond and meltblown installation capable of blowing and stretching microfibers into webs of nanofibers incorporating high-performance characteristics.

The NCRC Partners Laboratory adds new R&D capabilities for use by industry as well as faculty and graduate students from any of the eight affiliated universities whose nonwovens activities are coordinated by the NCRC. "There is no other facility in the world that can combine these processes in one continuous line," says Dr. Benham Pourdeyhimi, NCRC director. "Because we can operate at commercial speeds and throughputs, we offer companies of any size the opportunity to develop and test products before they invest in their own plant and equipment."

> "The NCRC Partners Lab, valued at about $12 million, was financed with only $1.3 million in university funds"

"We're pushing the envelope in terms of how many nanofibers with various functions can be combined using melt blowing," says Pourdehimi. Photomicroscopy of fiber cross-sections (see illustration at top right) reveals the precision of the technology, even at the nanoscale. Fibers can be positioned with enough accuracy to earn their descriptive labels—side-by-side, sheath-core, segmented pie, and islands-in-the-sea. Already, the NCRC has combined an astounding 1,080 nanofibers in a single extrusion with a diameter less than 200 nanometers using the islands-in-the-sea method.

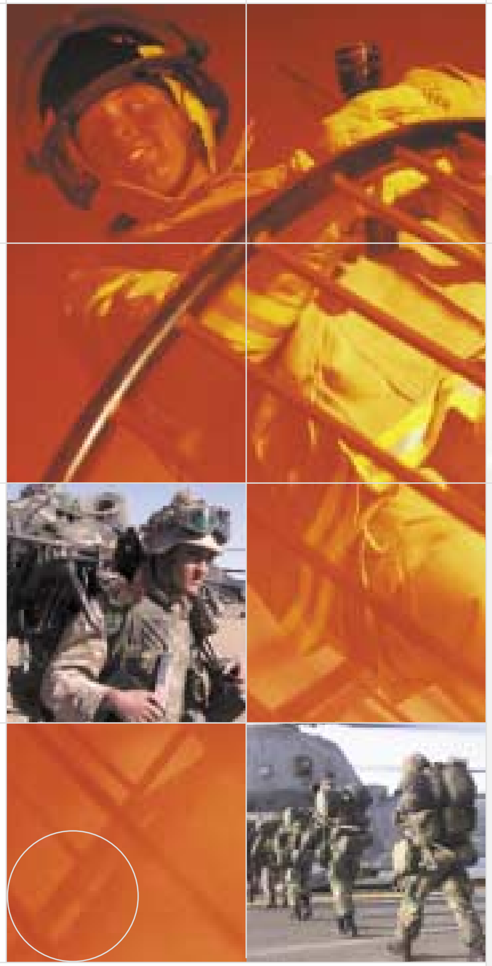
The NCRC Partners Lab, valued at about $12 million, was financed with only $1.3 million in university funds—the rest was leveraged as cash and equipment from the National Science Foundation and from NCRC industry members' donations, discounts and service contracts. "Many of the companies who produce nonwovens also have other textile-related businesses that are not growing," says Pourdeyhimi. "But our members recognize that by pooling funds for research and development, they can increase the profitability of their nonwovens operations.

Most of us are familiar with nonwovens, from disposable diapers and air filters to Tyvek™ house wrap, disposable medical gowns and those untearable Federal Express envelopes. The industry is now shifting to include durable products such as furnishings and automobile seats, as well as protective apparel for soldiers, firefighters and police.

The U.S. leads the world in technology and production of nonwovens, despite declining trends in the textile industry as a whole. Nonwovens are produced at high speed, in high volumes and at low cost, generating over $38 billion in annual revenues and 160,000 jobs in the U.S. Because the equipment is expensive and the technology is sophisticated, nonwovens jobs tend to stay on shore, leading to an industry growth rate of eight to ten percent annually. North Carolina has 29 nonwoven firms—almost twice as many as any other state—employing 16,000 and producing over $3 billion in annual revenues. Pourdeyhimi is bullish. "Our center is committed to maintaining America's premier position in the market for high-tech textiles." ■

Dr. Benham Pourdeyhimi and Rory Holmes at new NCRC Partners Laboratory on the Centennial Campus

www.ncrc.ncsu.edu/



NANOTEXTILES

LIGHTENING THE LOAD ON SOLDIERS, FIREFIGHTERS

Faculty and graduate students in NC State's Colleges of Textiles (COT) are applying nanotechnology to add new technological capabilities to protective clothing while lightening the burden shouldered by public safety and defense professionals. In partnership with faculty in the Colleges of Engineering and Physical and Mathematical Sciences, textiles researchers are leveraging their unique and complementary strengths in nanoscience, materials science and polymer, fiber and textile sciences to the good of tomorrow's heroes.

SMALLER, LIGHTER, STRONGER

We've all seen the images of the World Trade Center firefighters and police trudging slowly up the endless stairways lugging equipment and weighed down by heavy fire suits and helmets. TV carries footage of our soldiers shivering in the mountains of Afghanistan but reluctant to add the weight of warmer clothes to the burden of the 130 pounds of weapons, ammunition, rations, water, gas masks, communications equipment and protective clothing they are already carrying. The technology is available for soldiers and firefighters to protect themselves from almost anything, if only they could carry it all. A typical firefighter's flameproof suit now weighs about 30 pounds without the addition the air tank (another 30 pounds), axe, ropes, radio, or other gear. Hazardous chemical and biological protection requires yet another heavy layer. Weight reduction is a matter of life and death for the people who risk their lives to protect the rest of us.

Illustration by Bill Baverstock

Stacked cyclodextrin molecules with polymer chain in center channel

CHANNELING THE SCIENCE

The mix of strengths in the COT provides a unique ability to develop and adapt new classes of functional nanofibers, and to shape them into lightweight, high-performance protective clothing. In an example of fundamental research undergirding such new-age textiles, polymer chemist Dr. Alan Tonelli has recently filed a patent for use of nanoscience to create high-strength, lightweight nanofibers with multifunctional properties. "We're figuring out how to organize polymer chain molecules—the basic stuff of textile fiber—for higher strength, higher melting points, and chemical and antibacterial impermeability," says Tonelli. He and his graduate students are stacking cyclodextrin molecules to form a nano-tubular compound that attracts polymer chains and loads them down its middle channel (see illustration at left).

"Dissolving the cyclodextrin coating then allows the stretched and aligned polymers to crystallize on themselves and make very high-strength fibers," Tonelli continues. "Using this technique, we can intimately mix polymers with different properties for the first time, embedding other features such as fire retardancy or antibacterial protection. These embedded features are superior to coatings, which are not only heavy but also tend to wear or wash off."

> "NANOTECHNOLOGY IS USHERING IN A NEW PHASE OF THE TEXTILE INDUSTRY WITH A BRIGHTER FUTURE."
>
> —DR. TUSHAR GHOSH

SCALING-UP

While such mind-boggling nanoscience is happening in laboratory test tubes, the next challenge is to scale up nanomaterials manufacturing while preserving the embedded nano features. Scientists in the high-tech manufacturing facilities in COT's Nonwovens Cooperative Research Center (NCRC) are working on making Tonelli's nanofibers into fabric. NCRC director Dr. Benham Pourdeyhimi, explains the difficulty. "We can't process nanofibers by themselves because they are invisible. It's like trying to weave spider webs." With highly specialized NCRC equipment, Pourdeyhimi and colleague Dr. Trevor Little can extrude the nanofibers in various combinations with other polymers (see story on previous page), using hot air to blow and stretch them into webs of nonwoven fabric.

Robotic Fiber Assembly and Control system can mold a non-woven fabric of meltblown nanofibers to a mannequin, manufacturing a garment without cutting or sewing

www.tx.ncsu.edu/extension/service/appres/appres.htm

But why the push to get the size of fibers down to the nanoscale? "It's all about porosity and the surface-area-to-weight ratio," says Pourdeyhimi. The tiny pores between the tightly packed nanofibers stop all but the very smallest molecules from getting through. Also, the thinner the fabric, the less weight it adds."

NO CUTTING. NO SEWING.

In a related project with the NCRC, Drs. Tushar Ghosh and Abdelfattah Seyam are finishing up work on a $2.1 million research grant from the Army Research Office. They have created a process for generating lightweight battlefield chem-bio protection in just one step from polymer extrusion to garment. A system called Robotic Fiber Assembly and Control melt-blows fibers onto a mannequin, custom-molding a garment with no seams. Further research is underway to incorporate electrospinning technology with the system to reduce garment weights while increasing protection.

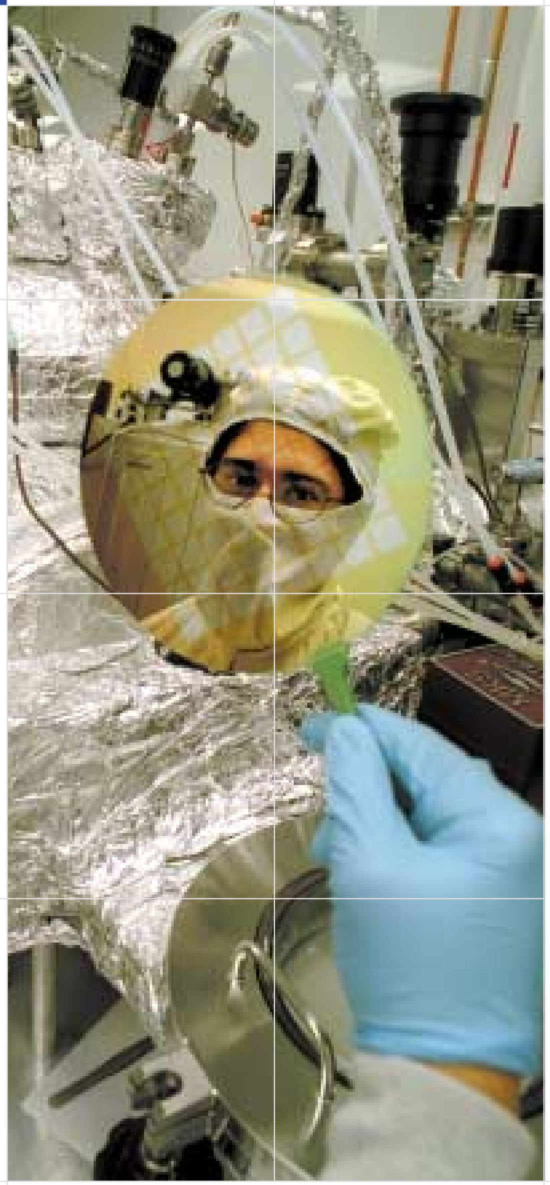
Ghosh says the manufacturing scale-up of such a process would provide a high-strength, low-cost, disposable, head-to-toe barrier that a soldier could carry in his pocket—donning it over other clothing in the event of a chemical or biological threat. With special polymers such as those developed by Tonelli and a host of other top materials scientists at NC State, such a garment might also provide flame resistance, passive heating or cooling, or even chameleon-like camouflage. Additional funding will be needed to improve the robotic process and deal with scale-up issues related to manufacturing safety. But Ghosh and Seyam already see other applications for the one-step process as diverse as custom-fit shoes, car linings and industrial filters.

Dr. Abdelfattah Seyam demonstrates formation of a web of meltblown nanofibers

"Most of the research in the College of Textiles is moving toward 'new' textiles rather than traditional manufacturing," says Ghosh. "There will be a day when what we now know as the U.S. textile industry will be married to other high-technology areas such as aerospace, electronics and transportation. Nanotechnology is ushering in a new phase of the textile industry with a brighter future." ■

> "WE'RE FIGURING OUT HOW TO ORGANIZE MOLECULES FOR HIGHER STRENGTH, HIGHER MELTING POINT, AND CHEMICAL AND ANTIBACTERIAL IMPERMEABILITY."
>
> —DR. ALAN TONELLI

Breaking the Memory Barrier



Dr. Veena Misra examines memory chip fabrication on wafer in Centennial Campus clean room

The team believes it can create tiny supercomputers by incorporating "molecular storage" into standard microelectronic circuitry, using molecules synthesized in a lab at NC State.

www.zettacore.com

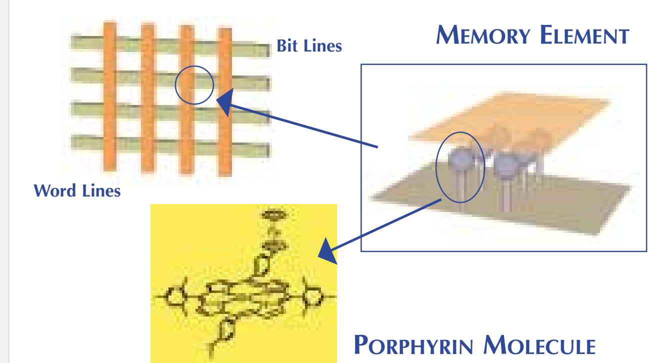
If nanotechnology experts are correct, within the next several years, all the text in the Library of Congress could be stored on a device the size of a sugar cube. But in order for that to happen, some infinitesimally small miracles have to happen first.

NC State professors Jonathan Lindsey, Veena Misra, Wentai Liu and Eric Rotenberg, along with two colleagues at the University of California at Riverside, are betting on just such miracles. The team believes it can speed up the practical use of nanotechnology to create tiny supercomputers by incorporating "molecular storage" into standard microelectronic circuitry, using molecules synthesized in a lab at NC State.

The make-up of the research team proving the concept demonstrates the interdisciplinary nature of the challenge. Lindsey, the Glaxo Distinguished Professor of Chemistry in the NC State's College of Physical and Mathematical Sciences, synthesizes the molecules. UC Riverside chemists Drs. Werner Kuhr and David Bocian (who earned a degree at NC State) characterize the materials. Liu, an engineer, is the circuit designer. Misra, also an engineer, fabricates the memory devices. And Rotenberg, a computer architect, is looking at how computers themselves might be redesigned if they had all that memory.

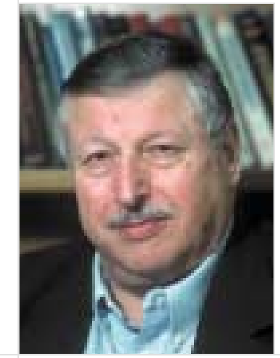
Misra is a recipient of a 2001 NSF Presidential Early Career Award for Scientists and Engineers—the highest honor given by the U.S. government to young scientists and engineers who show exceptional potential for leadership in their fields—for her work with silicon nanoelectronics. She explains that although the number of components the industry can put on a chip doubles every 18 months, there is a limit to how far miniaturization of silicon devices can go. "We will hit the wall at about 10 nanometers," says Misra. "The devices just won't work smaller than that. So instead of using silicon devices as memory storage elements, our team is using porphyrin molecules with functional properties that remain the same at any scale." At only two nanometers across, these molecules can be much more densely and inexpensively packed on a chip.

The highly innovative group has racked up an impressive 11 molecular memory patents at NC State, seven jointly held with UC Riverside. In 1999, the three chemists launched a start-up company called ZettaCore, which has licensed all 11 inventions for commercialization and leased incubator space on NC State's Centennial Campus and in Denver, Colorado. Lindsey allows that most of molecular electronics' promise is at least a generation away from the store shelf. But ZettaCore's technology will allow accelerated development of "hybrid" chips that leverage both the advantages of molecular storage (using stable molecules as capacitors to store a charge) and the substantial capital investment of the existing silicon semiconductor manufacturing industry. Lindsey thinks the hybrid approach is a near-term proposition, maybe only four or five years away. "The industry won't have to change much to use molecular materials in the memory portion of existing chip technology," he says, "and there appears to be no end to the demand for memory." With the worldwide market for computer chips at $35 billion and growing, both universities and ZettaCore's venture capital investors are beaming.



Although ZettaCore expects its products to be both ubiquitous and highly profitable, don't expect to see the company building large manufacturing plants. Instead, it will likely sell its powerful molecules to the big chip fabrication players. Besides, Lindsey says that all the molecular material needed by the chip industry for several hundred thousand computers—or about a million chips—would fit in an ice cream scoop. Small miracles, indeed. ▪

"The industry won't have to change much to use molecular materials in the memory portion of existing chip technology, and there appears to be no end to the demand for memory."
— Dr. Jonathan Lindsey



The Age of Nanoscience has Arrived

by Gerald J. Iafrate, Ph.D., NC State Professor of Electrical and Computer Engineering

Driven by a federal executive order with an inspiring budget, the visionary challenge put forth by Richard Feynman in his well known 1959 presentation *Plenty of Room at the Bottom* is now on its way to becoming reality. Feynman's prediction of an age of nanoscience served as a lightening rod for innovative thinking about "what might be," and set the pace for the evolution of nanotechnology. Today, the National Nanotechnology Initiative (NNI) is pushing the pervasive application of nanoscience to technological advancements in health improvement, information technology, agricultural advancement, materials and energy conservation, and environmental sustainability.

Nanoscience is the study of materials manipulation at the molecular scale—on the order of a few hundred angstroms—less than one-thousandth the width of a human hair. The extraordinary feature of nanoscience is that it allows for the tailoring and combining of the physical, biological, and engineering properties of matter at a common level of control.

The emerging fields of nanoscale science, engineering, and technology—the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new properties and functions—are leading to unprecedented understanding and control over the basic building blocks and properties of all natural and man-made things.

— M.C. Roco, Chair
National Science and Technology Council's Subcommittee on Nanoscale Science, Engineering and Technology

Critical to progress in nanosciences have been the stunning new achievements in fabrication, processing and tool development in the last several decades, driven in large part by the microelectronics revolution. These developments today allow for molecular-level tailoring of materials not heretofore explorable except through naturally occurring atomic processes.

The NNI, with a mission to promote basic and applied research and educational initiatives in nanoscience and technology, budgeted $422 million in 2001 and $604 million in 2002 across several federal agencies. The President's budget request for 2003 is $710 million. With NNI funding, nanoscience knowledge generation and engineering concepts are emerging across a broad spectrum of science and engineering disciplines. Examples include information technology, nanoelectromechanical components, interactive and smart textiles, medical sensors and probes, and super-efficient engines. It comes as no surprise that one of the new application areas included in the President's 2003 request is chemical-biological-radioactive-explosive detection and protection.

NC State's faculty and equipment resources in nanotechnology stack up against those of the top universities in the country. Increased federal support for nanotechnology research at NC State is producing interdisciplinary results cutting across engineering, physics, chemistry and biology—all strengths on our campus. The NNI presents a tremendous opportunity for NC State—where multi- and interdisciplinary university-industry partnerships are the coin of the realm—to be a leader in the emerging field of nanoscience and technology, now termed "the next industrial revolution." ▪

Dr. Iafrate served 24 years in the U.S. Army Electronics Technology and Device Laboratory and eight years as the director of the U.S. Army Research Office. He recently served on a National Academy of Science team to review the progress of the National Nanotechnology Initiative.

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TECHNOLOGY TRANSFER

48 PATENTS AWARDED

At its April 11, 2002 Annual Inventors Luncheon, NC State honored 40 faculty inventors who received 48 U.S. patents in 2001. Eight of the 2001 patents awarded are in the fields of micro- and nanotechnology. There have been approximately 100 nanotechnology invention disclosures and 50 patents filed in the past three years.

Luncheon speaker Dr. Charles Moreland, Vice Chancellor for Research and Graduate Studies, presented an overview of the phenomenal growth in patents and spin-off companies at NC State over the past eight years. "It's important that our research yields innovative results that pass the uniqueness tests for patents—but more important that most of our patents either have been licensed by industry or have been sufficiently pioneering to serve as the basis for forming new companies and attracting venture capital. These are some of the clearest signs of a research university's economic value."

The following faculty members received awards: Jonathan C. Allen, B. Jayant Baliga,* Frank A. Blazich, Medwick V. Byrd, Ruben G. Carbonell,* Denis R. Cormier, Robert T. Croswell, Christopher R. Daubert, Robert F. Davis,** Joseph M. DeSimone,** Edward A. Foegeding, Ronald S. Gyurcsik,, John A. Heitmann, Jr., Walter A. Hendrix, Andrew K. Hotchkiss, Heather M. Hudson, Robert M. Kelly, Saad A. Khan, Peter Kilpatrick, Todd R. Klaenhammer, Jacob A. Konzelmann, Jonathan S. Lindsey,* Gerardo A. Montero, H. Troy Nagle, James N. Petitte, Arnold Reisman, Injong Rhee, George W. Roberts, Edward C. Sisler, Robert C. Smart, Brent Smith, Steven L. Spiker, Kenneth R. Swartzel, James B. Taylor, William F. Thompson, Mary B. Tompkins, Wayne A. Tompkins, John G. Vandenbergh, Qiwu Wang, Harvey A. West, Tsvetanka S. Zheleva ■

* *Two patents awarded*
***Three patents awarded*

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RESEARCH AND GRADUATE STUDIES AT NCSU **RESULTS**

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