The prefix “nano-” simply means one billionth. So, one nanometer is one billionth of a meter. To help put this in perspective, one-tenth of one nanometer is approximately the size of an atom. So why should fundamental branches of science and engineering be named after the “nano-” prefix? What is so special about this length scale? The answer lies in the physical properties of any substance that is this small. Let’s consider the melting point of gold. Look up this property in any reference book for metals, and you will find that gold’s melting point is listed at exactly 1064°C (1947°F). Surprisingly, the melting temperature recorded in the case of a gold particle only a few nanometers in diameter is 427°C (800°F). In fact, in the smallest size ranges, the melting temperature of gold particles depends on the size of the particles that are being heated.

This example allows us to easily and precisely define nanoscience and nanoengineering. Nanoscience is the field of science that measures and explains the changes of the properties of substances as a function of size. Like the melting of gold, the properties of any substance will remain constant as its size gets smaller and smaller, that is until the size is reduced into the nano-range (depending on the substance and the property being measured, roughly 10 to 100 nanometers). In the dimensional nano-range, any property measured may continuously change with size, and often dramatically so. Nanoengineering (or nanotechnology) simply takes advantage of this phenomenon by applying property modifications of this nature to some beneficial endeavor — and what a warehouse of beneficial endeavors there are. Nanoengineering involves the manipulation of matter at the nanoscale, a remarkable feat that scientists and engineers have been mastering over the last 30 years or so. Take for example a modern microprocessor or mass storage chip; each one has billions of solid state transistors, all built on the nanoscale.
IMAGES FROM ICTAS DOCTORAL SCHOLARS
POSTER SESSION

APRIL 18, 2011
ICTAS 310

full versions of the doctoral scholars’ posters are available at http://www.ictas.vt.edu/downloads.
In the ICTAS discovery domain, Nanotechnology is perhaps the most revolutionary among the convergent technologies expected to usher in a third industrial wave. Dealing with the understanding and control of matter at the nanoscale, it has led to rapidly evolving new developments that may revolutionize many aspects of our lives, including healthcare, communication, national security, consumer products, and transportation, to name only a few.

Given the scope of nanoscale scientific discovery and its growing impact, it is not surprising that the first of the three ICTAS building designed and commissioned for research was a state-of-the-art Nanoscale Characterization and Fabrication Facility (NCFL), equipped to fabricate and characterize engineering and biological materials at the nanoscale and cellular dimensions. Since its inauguration in November 2007, the facility has acted as an enabler in promoting discovery in a number of research areas including, among others, targeted delivery of nano-medicine, fuel cells, nanoscale engineering and the environment, self-assembled nanostructures, nano-metrology and nano-manufacturing, polymer photovoltaics, nano-devices and the application of nano-materials covering carbon nanotubes, carbon nanohorns, “buckyballs” and nanofibers. Our researchers are pushing the envelope of science and technology in these areas and are leading or poised to lead the nation in these fields. As Professor Mike Hochella, ICTAS Thrust leader on Nanoscale Science & Engineering, notes in his lead article, “there is nothing nano about VT’s efforts in nanoscale science and engineering”.

In addition to highlighting ICTAS-supported research in nanoscale science and engineering, this issue of the newsletter also includes a stream of pictures from a poster session hosted by the ICTAS Doctoral Scholar Program on April 18. As a collaborative effort among participating colleges and their departments, the graduate school and ICTAS, this program was established in 2007 to honor exceptional Ph. D. candidates with a Graduate Research Assistantship through the Ph.D. qualifying period. The inaugural class consisted of 11 doctoral scholars representing 5 colleges and 10 departments. This elite group has since grown to a cohort of 43 scholars representing 5 colleges and 23 departments. Of these, 25 students presented posters on a variety of research topics ranging from behaviors in urban and rural song sparrows to energy harvesting for powering pacemakers from heartbeat vibrations. I was very impressed by the quality of research presented and am proud of our scholar’s dedication and hard work. I would like to take this opportunity to thank all of the scholars and the organizers for making this event highly successful. Additional information related to the doctoral scholars program, scholar accomplishments, and posters may be accessed at http://www.ictas.vt.edu/education/docscholars.html.

Finally, I am pleased to note that the construction of our third building, ICTAS II, located on Washington Street in the Life Sciences District of the Virginia Tech Blacksburg campus was completed on time. This building encompasses 42,190 square feet and is home to research laboratories, office space and conference rooms. Researchers began moving soon after the certificate of occupancy was granted, and it is now nearly fully occupied with a number of research laboratories. These are: applied environmental biochemistry, fluvial processes, nanobiology, nonlinear imaging and spectroscopy, organic nanostructures, pathogen ecology, pipeline corrosion, sustainable water, a global laboratory for bio-inspired science and technology and the humanoid hospital. An inaugural tour on April 25 introduced university senior leadership, the ICTAS stakeholder and faculty advisory boards to the building, providing a glimpse of high impact interdisciplinary research through demonstrations conducted by faculty and students.

I hope you will enjoy this issue of ICTAS Connection and get an appreciation of the multi-faceted research conducted by our faculty in one of the most powerful technologies of our times.
Environmental Biomonitor for Nano Pollutants

by Matthew Hull  |  Interim Associate Director, Virginia Tech Sustainable Nanotechnology (VTSuN)  |  (540) 449-3388  |  mahull@vt.edu

Remember the old saying that finding something particularly elusive that you'd lost—a contact lens in Lane Stadium, perhaps—was “like trying to find a needle in a haystack”? Well, trying to detect engineered nanoparticles in complex environmental media like natural waters, sediments, soils, and biological tissue is a similarly daunting task. However, the minuscule scale at which nanoparticles exist (1 nm = a billionth of a meter) relative to the earth-scale of environmental systems makes searching for a needle in a haystack seem like a leisurely stroll around the Duck Pond. For perspective, if you were looking for a single 50 nm nanoparticle contaminant in your morning cup of coffee, then the task would be equivalent (on a volume scale) to trying to find a single needle in a haystack large enough to fill the Grand Canyon—more than 30 times! To complicate matters further, the composition of many nanoparticles, for example, carbon nanotubes and fullerenes, is similar to that of soils, plant matter, and other organic materials, which makes these particles virtually indistinguishable from materials co-occurring in the natural environment.

Environmental Nanoscience and the Importance of Interdisciplinary Research Teams

Our work in the ICTAS Environmental Nanoscience and Technology Laboratory is focused on overcoming the challenges of the nano-to-earth scale to develop effective tools and strategies for monitoring and understanding the effects of nanoscale materials discharged to natural environments. Many analytical techniques routinely used by environmental and life sciences professionals rely on chemical or mass-based methods developed for conventional chemical pollutants like metal ions or chlorinated organic molecules. While these approaches are still important for monitoring nanomaterials, the added challenges of visualizing the physical structure of nanoparticles (size, shape, morphology) requires the integration of techniques such as x-ray fluorescence microscopy, dynamic light scattering, and electron microscopy, which have traditionally been used in disciplines like Geosciences and Chemical Engineering. For this reason, reliance on interdisciplinary teams has been crucial to the success of our work, and contributions by Drs. Peter Vikesland (Civil & Environmental Engineering), Mike Hochella, Maddy Schreiber and Beth Diesel (Geosciences), Rick Davis (Chemical Engineering) and Mitsu Murayama (Materials Science & Engineering), as well as international collaborators at the CEREGE (Aix en Provence, France) have been especially critical. Virginia Tech undergraduates Jason Jones (Materials Science & Engineering) and Katie Gloe (Civil & Environmental Engineering) have played key roles in sample preparation and executing laboratory experiments. Funding from the National Science Foundation (NSF), Virginia Tech EIGER Program, the Duke Center for Environmental Implications of Nanotechnology (CEINT) and ICTAS has been invaluable for supporting the interdisciplinary collaborations and costly analysis instrumental to accomplishing this work.

Why Worry about Nanoparticles in the Environment?

Why worry about manufactured nanoparticles in the environment? While the societal benefits of nanotechnology are without question, studies have shown that under certain conditions, some engineered nanomaterials are toxic to living systems, and if discharged to the environment in sufficient quantities, may pose public health risks. Consequently, the need for new tools and techniques capable of monitoring nanoscale materials in complex environmental media—where potential environmental and public health threats can be detected and mitigated—has become more pressing.
Coupled with the recent estimate\(^1\) that the number of nanotechnology-enabled consumer products has increased to more than 1,300—with that number expected to rise dramatically in the years to come—it’s easy to see that nanoscale technologies are having a big impact globally on the products we buy and dispose of on a regular basis.

**Our Work—Bio-Assisted Concentration and Detection of Nanoparticles**

Our work focuses on the use of bivalves as biological concentrators and monitors for nanoscale pollutants. Bivalves, particularly Asian clams (*Corbicula fluminea*), are used world-wide as biological sentinels to monitor a broad spectrum of environmental contaminants including metals, pesticides, asbestos fibers, and numerous others. The use of *Corbicula* in biomonitoring and ecotoxicological applications was pioneered by another Virginia Tech researcher, Dr. Donald Cherry, in the late 1970’s for other types of environmental contaminants. Given their functional roles in aquatic ecosystems as water column filters and sediment deposit feeders, clams are susceptible to adverse effects from aquatic pollutants, making them ideal indicator species for measuring pollutant influences on aquatic systems. Post-exposure analysis of clam tissue and depurated fecal matter can help establish a forensic record of exposure-specific geochemical conditions, such as elevated metals levels or limited nutrient availability. The nice thing about the clam model we use is that the clams are remarkably good at taking particulate matter present in environmental samples and concentrating it. Concentration is a key first step to detecting nanoparticles—instead of trying to find that nanoparticle in your coffee cup, the natural filtration and concentration capabilities of the clam now allow you to search for that particle in a tiny pellet of concentrated particulate matter. The integration of this model with advanced characterization techniques available through resources like the Virginia Tech Nanoscale Characterization and Fabrication Laboratory (NCFL) make for a high-powered suite of tools capable of detecting and monitoring nanoparticles in even highly complex environmental media.

Recently, we exposed clams collected from the New River to nanoparticles of varying size, shape, and composition in aquatic microcosm assays. The purpose of these experiments was to determine whether clams could be used as natural biofilters to bioconcentrate nanomaterials from the water column and subsequently facilitate their detection for environmental monitoring applications. Throughout the study, samples of exposure water, clam tissue, and depurated feces were collected and analyzed by a range of nanoscale characterization techniques. Our results showed that clams rapidly filtered nanoparticles from 10 nm to nearly 50 nm in diameter

at rates that were positively related to particle size—the larger the particles, the more rapidly the clams removed them from the water column. Further analysis of the preserved whole clams by x-ray-based imaging revealed that the bulk of gold nanoparticles filtered by clams is retained in the digestive gland and digestive tract, with little evidence of migration to other organ systems.

Electron microscopy of deposited fecal material reveals the presence of nanoscale particles as dense clusters of individual particles, which we confirmed as gold. That filter-feeding clams can concentrate nanoparticles from the water column in their feces suggests that these organisms may be especially useful for determining the presence of nanoscale materials in aquatic environments. It is currently unclear whether such approaches can be successfully applied at environmentally relevant concentrations of nanoparticles, and additional studies are required to evaluate this potential. If successful, these efforts may result in a coupled bioconcentration and analytical technique suitable for the detection of nanoparticles in complex aquatic ecosystems. A tool like that, we hope, should help environmental professionals get a better handle on where nanoparticles go when they enter the environment and how they impact living systems.


Matthew Hull is currently a PhD student and NSF IGERT/VT EIGER fellow in the Department of Civil & Environmental Engineering where his doctoral research is focused on understanding the factors influencing partitioning of engineered nanomaterials in the environment. Matthew also serves as Interim Associate Director of the VT Sustainable Nanotechnologies Center (VT SuN).
Assessing Realistic Emissions of Airborne Nanomaterials from Consumer Products

by Marina E. Quadros | PhD Student, Civil & Environmental Engineering | (540) 449-8585 | marinaeq@vt.edu

Introduction

We live in a period of great scientific advances in nanoscale science and technology. Novel chemical and physical properties attributed to the minute size of nanomaterials create immense possibilities for industrial and environmental applications. Because of their antimicrobial and anti-odor properties, silver nanoparticles (AgNPs) can presently be found in hundreds of consumer products. Silver nanotechnology is used in products such as electronics, laundry machines, paints, cooking utensils, medical instruments and drug delivery devices, clothing, personal care products (toothpaste, shampoo, cosmetics), soaps and detergents. Normal use of several types of silver nanotechnology-related consumer products, such as sprays, mists, humidifiers, and hairdryers, may lead to inhalation exposure of engineered nanoparticles.

Historically, silver compounds have been used in close contact to people, in jewelry, cutlery, and currency. Before the discovery of penicillin, silver compounds, such as silver nitrate and silver sulfadizine, were used in topical wound dressings to prevent infection. These were heavily used during World War I, with no obvious toxic effects to humans. Silver salts have been reportedly used for treating mental illness, epilepsy, nicotine addiction, gastroenteritis, and infectious diseases.

For silver nanoparticles, much like many other types of nanoparticles, solubility and reactivity highly increase as size decreases due to an increase in the ratio of surface area per unit volume. This means that more atoms are available at a nanoparticle’s surface to interact with its surroundings. Once released, silver ions are very reactive cations, which quickly bind to available negatively charged ions, such as thiols (-C-SH). Reaction with thiols in intracellular proteins and enzymes are the main mechanism for silver ions to interrupt bacterial growth. Antibacterial effects are enhanced in the presence of silver nanoparticles versus ions due to what is described as the Trojan-horse mechanism: Once a nanoparticle enters a cell, it continuously releases silver ions to cause cytotoxicity. If silver only is present in ionic form, these ions might become inactivated by reacting with extracellular compounds before reaching a cell’s vital components.

It is well established that inhalation of nanoparticles, regardless of composition, is associated with adverse health effects, namely inflammation in the respiratory and cardiovascular systems. Nanoscale particles are capable of penetrating further into the respiratory system than are larger, micrometer-scale particles. They can also translocate through cell membranes of organisms and interact with subcellular structures. In vitro and in vivo studies have demonstrated that the toxicity of AgNPs can be higher than that of other nanomaterials. However, the entirety of in vitro and in vivo studies uses high-purity, monodisperse nanoparticles carried by inert gases, which is expected to minimize experimental variability but may not represent realistic human exposure scenarios. It is likely that aerosols generated from the normal use of consumer products are polydisperse, mixed with impurities (e.g., other ingredients within the product) and may be subject to atmospheric processing (e.g., agglomeration, growth, coating).

In order to determine whether AgNPs pose a real long-term risk to consumers, we must assess the AgNP levels at which consumers will be exposed in real-life situations (Figure 1). It is equally important to thoroughly describe aerosol physical and chemical characteristics to determine whether novel toxicity studies must be performed using more “realistic” aerosols. The objectives of my
work are to characterize the emissions of airborne particles from the normal use of consumer products that claim to contain silver nanoparticles or ions and to assess the long-term exposure of consumers to inhaled silver particles.

**Experimental Methods**

Three spray products were chosen for this work based on their claim of containing elemental silver and potential for generating aerosols during normal use: an anti-odor spray for hunters, a surface disinfecting spray, and a throat spray. Products are sprayed from their own bottles into a 0.5 m³ polyethylene chamber that is initially filled with filtered, particle-free air at low relative humidity (Figure 2). I then use real-time aerosol instrumentation (i.e., a scanning mobility particle sizer and an optical particle counter) to measure the aerosol concentrations and size distributions. The chamber is modeled as a continuously-stirred tank reactor (CSTR) for which particle wall losses are quantified. I also collect samples for bulk chemical analysis by collecting aerosols on filters using a 4-stage cascade impactor, which segregates the aerosol into 5 different size ranges (Figure 3). Then, silver is extracted from these filters and quantified using inductively-coupled plasma mass spectrometry (ICP-MS).

I have also built a thermophoretic precipitator to collect airborne particles onto TEM grids for subsequent electron microscopy analyses. This instrument comprises an aerosol sampler that uses the thermophoresis phenomenon to deposit particles on a surface. The movement of particles that are smaller than the mean free path for air (about 65 nm at 21°C and 1 atm) is mainly governed by Brownian motion. Thus, if we apply a temperature gradient to a stream of small particles, a preferential particle movement is observed from the hot side (more agitation within gas molecules) to the cold side (less agitation). The thermophoretic precipitator used in this study uses a 10 W electric heater and a 15.9 V thermo-electric cooler (Figure 4).

Particles collected using the thermophoretic precipitator are first surveyed using a scanning electron microscope (SEM) at the Nanoscale Characterization and Fabrication Laboratory (NCFL), equipped with detectors for secondary and backscattered electrons, which facilitates visualizing high atomic number elements, such as silver. This SEM is also equipped with energy-dispersive X-ray spectroscopy (EDS), which allows for a preliminary chemical characterization of the aerosol. Particles can be further characterized for size and morphology using a transmission electron microscope (TEM) or a high-resolution TEM, which can perform single-particle chemical and morphological characterizations.

**Expected outcomes**

Using the CSTR model and size-resolved particle concentrations, which range from 7 nanometers to 10 micrometers in diameter, I am developing emission factors describing the total amount of particles emitted per spray action of each product. Using the size-resolved silver mass concentrations, I am also calculating mass emission factors of silver per spray action. Combined with size-dependent deposition efficiencies of particles in the respiratory system, these results will indicate where the airborne silver generated by the products tested will deposit if inhaled. Results can be used to guide the selection of relevant particle doses in nanotoxicity testing, to predict scenarios for realistic exposure to nanoparticle emissions in indoor air quality models, and to develop regulations to ensure consumer safety.

**Acknowledgments:** This work is part of the Nanoscale Science and Engineering research thrust of ICTAS, which I and my advisor, Dr. Linsey Marr (VT Civil and Environmental Engineering) participate. This work is also supported by the National Science Foundation (NSF) and the Environmental Protection Agency (EPA) Center for the Environmental Implications of NanoTechnology (CEINT).
The ICTAS Nanoscale Science and Engineering Thrust

continued from front page

The Origin of Nanoscience and Nanotechnology
Nanoscale science is typically defined to be relevant between one nanometer and a few tens to perhaps one hundred nanometers. Scientific historians do not point to the earliest beginnings of nanoscale science and technology until 1959, the year that Richard Feynman, a quantum physicist and one of the 20th century’s greatest scientists, gave a speech to the American Physical Society entitled “There’s Plenty of Room at the Bottom.” Feynman was fascinated by the notion of scaling; and in this speech, he imagined that a single bit of information could be stored in a nanospace (specifically a 125 atom cluster), an exceptionally bold prediction at that time. At that scale of miniaturization used for the encryption of alphabetic letters, he estimated that all the text ever written in books in the history of the world could be stored within a cube 0.2 millimeters on a side (and thus his lecture title). His genius was not this, but his realization that “all things do not simply scale down in proportion,” and this is now considered the cornerstone of nanoscience. What he was predicting was that as one scaled things down into the nanometer size range, materials would behave differently, and that this could be turned into an advantage.

Near the end of his talk, he posed the ultimate challenge of matter when he said: “I am not afraid to consider the final question. Can (we) arrange atoms the way we want, all the way down?” The general reaction to his comments was amusement, as statements like these were considered scientifically radical, not necessarily visionary. For example, one of the great theoretical physicists of the last century, Erwin Schrödinger, predicted in the 1950’s that we would never experiment with just one atom or molecule. In reality, this feat took three more decades. In the late-1980’s, the direct manipulation of individual atoms by humans became a reality. Unfortunately, Feynman did not live long enough to witness this monumental achievement.

How much interest has nanoscale science and engineering attracted?
In order to accelerate the commercial development of nanotechnology, which has enormous commercial potential and benefits to society, the National Nanotechnology Initiative (NNI) was launched by the Clinton administration in 2000. Over the next decade, the United States government pumped nearly 12 billion dollars into nanoscale research and the development of nanotechnology, and the investment continues today. Impressive programs were also initiated in other countries. The corporate world, in the meantime, was not about to be left behind. In some cases, they have been leading the charge. Giants such as IBM, Motorola, Dow Chemical, and other science-based corporations are cumulatively investing billions of dollars in nanoscale science and technology. Just as importantly, hundreds of new and relatively small nanotechnology-based companies have been established.

What could nanotechnology mean to society in the long run?
According to the National Science and Technology Council, nanotechnology “stands out as a likely launch pad to a new technological era because it focuses on perhaps the final engineering scales people have yet to master.” For example, it is widely anticipated that the future impact of nanotechnology will eventually far exceed the impact of the silicon-based integrated circuit (i.e., computer technology as we know it today). This is because nanoscience has applications in all areas of science, and nanotechnology has applications to most fields of technology, including robotics, chemical and mechanical engineering, medicine, computing, and so on. Like the present molecular biology revolution (genomics, proteomics, etc.) and other health-related sciences, the importance of nanoscale science and technology is so sweeping and so vast that no boundaries can yet be reliably defined, and no limits can yet be clearly foreseen. Scientific historians know all too well that technology predictions are notoriously inaccurate. What seems certain is that nanotechnology will make a dramatic and lasting impact on every scientific field, and also in every major area of modern technology. The nano-revolution is here to stay.

There’s nothing nano about Virginia Tech efforts in nanoscience and engineering!
There are nearly 30 professors and their groups from 12 departments in three colleges (Colleges of Engineering, Science, and Natural Resources) that are central to nanoscience and nanotechnology at Virginia Tech. The departments that are represented are diverse, from mechanical to electrical engineering, and from wood science to physics. Specific articles on nanoscience and technology in this issue of ICTAS Connection will give the reader an idea of the diversity and
importance of nano-research on the Virginia Tech campus.

**Virginia Tech is an integral part of a national nanoscience consortium called CEINT**  
The Center for the Environmental Implications of NanoTechnology (CEINT), as stated on the CEINT website (http://www.ceint.duke.edu/), is elucidating the relationship between a vast array of nanomaterials—from natural, to manufactured, to those produced incidentally by human activities—and their potential environmental exposure, biological effects, and ecological consequences. Headquartered at Duke University, CEINT is a collaborative effort between Duke, Carnegie Mellon University, Howard University, Virginia Tech, the University of Kentucky, and Stanford University. CEINT academic collaborations in the US also include on-going activities coordinated with faculty at Clemson, North Carolina State, Rice, UCLA and North Carolina Central universities, with researchers at NIST and EPA government labs, and with key international partners. CEINT was created in 2008 with funding from the National Science Foundation and the US Environmental Protection Agency, and supports many of the professors, research associates, and students who work in the ICTAS Environmental Nanoscience and Technology Laboratory located on the second floor of ICTAS on Stanger Street.

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**The newest ICTAS center, VT SuN (Sustainable Nanotechnology)**  
Given that nanotechnology is becoming more pervasive and widespread in our lives, it is important to consider whether this technology is being developed responsibly to avoid negative consequences to human health and the environment. Indeed, it is imperative that we avoid problems created by past technologies (e.g. asbestos-based materials). Ideally, nanotechnology should be safe for humans and the environment, as well as being environmentally-sustainable throughout its life cycle (from production to disposal). Nevertheless, in the design of many nanomaterials, sustainability and safety have not necessarily been considered. For example, many nanomaterials contain toxic metals of environmental concern, and are manufactured using energy-intensive or high waste-generating processes.

We believe that an alternative approach to the development of nanotechnology is possible, in which nanotechnology is engineered to be not only functional, but safe and sustainable. Developing nanotechnologies in this way entails an iterative process, in which the design of nanomaterials is informed by studies on their safety and sustainability. The Virginia Tech Center for Sustainable Nanotechnology (VT SuN) was created with this in mind. The scientists and engineers of VT SuN span the broad range of disciplines necessary to achieve this task. Our vision is to coordinate world-class research and education efforts contributing to the development of safe, environmentally-sustainable nanotechnologies. The mission of VT SuN is to conduct and publicly disseminate research concerning the development and evaluation of promising green nanomaterials, nanodevices, and nanotechnologies for their environmental sustainability and safety, as well as the application of nanotechnology and nanoscience to environmental sustainability issues.

**Nanoscience highlights one of the first four IGEPs offered at VT**  
The Graduate School, under leadership of Dean Karen DePauw, has recently announced the formation for four Interdisciplinary Graduate Education Programs (IGEPs) from the many applications submitted, and one of them is based on ICTAS’s Center for Sustainable Nanotechnology (VT SuN). The SuN IGEP is being led by Civil and Environmental Engineering professor Peter Vikesland, supported by five additional professors from 4 departments in 3 colleges. SuN IGEP will be awarded four GRA positions by the Graduate School, as well as funding for recruitment and operations. The primary educational goal of the SuN IGEP is to produce doctoral graduates that have the skills and expertise to provide leadership in the interdisciplinary field of sustainable nanotechnologies. The primary research goal of the SuN IGEP is to incorporate sustainability concepts into all aspects of nanotechnology, including raw material choice, manufacturing processes, and disposal. The initial research focus will be on the potential environmental impacts of nanocellulosic materials, such as cellulose nanocrystals and nanofibrillated cellulose. These plant-derived nanomaterials have a wide range of potential applications; however, at present their potential toxicity and environmental implications are virtually unknown. Ph.D. students in the SuN IGEP will examine the life cycle of nanocellulose from cradle to grave, consider its cellular and organismal toxicity, and its environmental fate and transport.

**Virginia Tech nano goes undergrad, and even to high schools nationally!**  
Beate Schmittmann, Chair of the Department of Physics, is leading an effort to create an undergraduate major in nanoscience sponsored by the College of Science. Pending State Council of Higher Education in Virginia (SCHEV) approval, this will be one of the very few nanoscience undergraduate degree programs offered in the United States. Starting in the 2011-2012 academic year, professors Randy Heffin, Mike Hochella, and Tim Long will team-teach a two-semester course entitled Introduction to Nanoscience. Over the next
three years, nanoscience majors will take Introduction to Quantum Physics of Nanostructures, Synthesis and Self-Assembly of Nanomaterials, Fabrication and Characterization of Nanostructures, Nanomedicine, Nanoscience and the Environment, and finally Nanomaterials and Devices. Graduates of the program will be prepared to enter a rapidly growing nanoscience workforce, or continue their education and training in a graduate degree program in the field.

Virginia Tech nanoscience has even created the first environmental nanoscience curriculum for high schools in the country. Entitled “Welcome to Nanoscience: Interdisciplinary Environmental Explorations, Grades 9-12,” or Nano2Earth for short, this major work brings nanoscale science and technology to life in the context of the Earth and environmental sciences. Nanoscale science and technology, working together and with environmental science issues, transcends traditional scientific knowledge and processes presented in high school chemistry, biology, geoscience, and environmental science classes today. Nevertheless, every aspect of the curriculum addresses one or more of the National Science Education Standards. Nano2Earth originated as an outreach project in the Hochella group at Virginia Tech. The project, lead by Virginia Tech’s Andy Madden (now a professor at the University of Oklahoma), is a collaborative effort conceived, written, and classroom-tested by five high school science teachers from southwest Virginia, as well as several VT professors and graduate students. Nano2Earth will be published and distributed by the National Science Teachers Association (NSTA) starting this summer, and it will touch the lives of thousands of high school students. With a membership of 60,000, NSTA is the largest organization of science teachers in the world.

This NASA image of Earth reminds us that the Earth’s atmosphere is perilously thin, only about one quarter of one percent of the radius of the planet. What roles do natural and human-generated nanoparticles play here, as well as in the oceans and on the continents? These are some of the questions that ICTAS-supported VT scientists and engineers take on.
Spring 2011 Seminar Series: Getting Acquainted with Virginia Tech Research Institutes

All seminars are held in ICTAS Room 310, located in the third floor of the ICTAS Building on Stanger Street.

Seven Virginia Tech institutes support research and creative scholarship in strategically important areas, drawing upon the university's established strengths.

The Institute for Critical Technology and Applied Science, Fralin Life Science Institute, and the Institute for Society, Culture, and Environment provide resources to develop opportunities at the intersection of engineering, science, and medicine; target infectious disease; and advance human development and the arts.

The Virginia Tech Carilion School of Medicine and Research Institute, the Virginia Tech Transportation Institute, and the Virginia Bioinformatics Institute focus on national research priorities, including translational health and medical research, national security, and safe infrastructure.

The Institute for Creativity, the Arts and Technology will explore the infinite synergies between the arts and technology, providing an innovative platform for transdisciplinary research and scholarship to enrich PK-12 learning environments and advance student career and scholarship capabilities.

Virginia Bioinformatics Institute
with Skip Garner, Director
Friday, March 11, 3:00 - 4:30 pm

Virginia Tech Transportation Institute
with Thomas Dingus, Director
Friday, March 25, 3:00 - 4:30 pm

Virginia Tech Carilion School of Medicine and Research Institute
with Michael Friedlander, Director
Tuesday, April 5, 3:00 - 4:30 pm

Institute for Society, Culture and Environment
with Karen Roberto, Director
Friday, April 8, 2:30 - 4:00 pm

Fralin Life Science Institute
with Dennis Dean, Director
Monday, April 25, 2:00 - 3:30 pm

Institute for Creativity, Arts and Technology
with Ruth Waalkes, Executive Director, Center for the Arts at Virginia Tech
Friday, April 29, 2:00 - 3:30 pm

Institute for Critical Technology and Applied Science
with Roop Mahajan, Director
Friday, May 6, 2:00 - 3:30 pm

Special Seminar on Nuclear Engineering
Wednesday, April 27, 2011
Hosted by Satish Kulkarni and Alireza Haghighat

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The Dorn Research Group at Virginia Tech is comprised of graduate and undergraduate students whose research focuses on the applications of nanomaterials (specifically carbon nanotubes, carbon nanohorns and “Buckyballs”). Students in the group have published in such prestigious journals as Science, Nature, and the Journal of the American Chemical Society, to name a few.

The 1999 discovery of trimetallic nitride template endohedral metallofullerenes (TNT EMFs), or metal atoms inserted into fullerene cages, is the group’s best known research finding. This novel family of molecules laid the architecture for a new field of chemistry. The encapsulation of metals and metal clusters opens new vistas for polymers that can capture solar energy, molecular semiconductors, quantum computing and medical applications.

The Dorn Group is currently focused on the application of TNT EMFs as MRI contrast agents. Of over 150 million MRI diagnostic procedures performed yearly, 25-50% of them require the use of a contrast agent. Commercial agents, such as Omniscan®, have recently been linked to a disorder called nephrogenic systemic fibrosis (NSF). This is a debilitating and painful disorder that affects the skin and systemic tissues in patients with renal insufficiency and is associated with exposure to Gd$^{3+}$ ions. The carbon cage of fullerenes has an inherent advantage due to its high stability and characteristic resistance to any potential cage-opening process. The encapsulation of trimetallic nitride endohedral metallofullerenes allows for the Gd$^{3+}$ ions to remain inside the fullerene cage and prevents the release of the toxic metal ions into surrounding tissues, serum, and other biological components.

From 2005-2009 our research group, in conjunction with Virginia Commonwealth University, collaborated on the NSF-NIRT project entitled “An Optimized Nanosphere Platform for High Resolution, Multi-Modality Imaging Applications.” This project saw the encapsulation of TNT EMFs lead the way for near-future, next-generation clinical MRI agents. The MRI relaxivities for the new TNT EMFs are 30-40 times higher than those for commercial agents. This...
allows the use of significantly lower concentrations (10-100-fold), minimizing the risk of NSF for clinical studies. The multi-modality of a related agent was also demonstrated in convection enhanced delivery (CED) infusion rat brain glioma by MRI and fluorescence imaging.

The Nanotechnology in Cancer Alliance Project ("Metallofullerene Nanoplatform for Imaging and Treating Glioblastoma"), another joint collaboration with VCU, began in 2005 and continued through 2010. During the course of this project, optimally functionalized and targeted TNT EMFs (f-EMFs) constituted a nanoscale platform that has several advantages for therapeutic and diagnostic (also recently termed “theranostic”) applications. The optimized f-EMFs loaded with radioactive particles distribute throughout infiltrative tumors (glioblastoma) when infused intra-cerebrally and are selectively retained. This method delivers a highly targeted and effective therapy.

In 2009, a partnership with collaborators at VCU resulted in the invention of a remote control process for filling fullerenes with radioactive material. The new device also allows for the production of radiolabeled (177Lu) metallofullerenes that can be functionalized and targeted as new carbonaceous nanoplatforms for diagnostic and therapeutic applications. More information on these targeted and tagged nanomedical agents can be found in the Journal of the American Chemical Society article, "Encapsulation of a Radiolabeled Cluster Inside a Fullerene Cage, 177Lu, 175Lu, 64Cu@C80: An Interleukin-13 Conjugated Radiolabeled Metallofullerene Platform."

A National Science Foundation Nanotechnology Undergraduate Education grant in 2004-06 supported delivery of a series of hands-on short courses entitled “Buckyballs, Nanotubes, and other Nanomaterials.” The courses were held at Virginia Tech and Emory & Henry College, with hands-on lab experiments in nanomaterials as well as other outreach activities of the Carbonaceous Nanomaterials Center (CNC).

In June 2006, our research group participated in “Summer Around the Drillfield,” a 3-day event held in various locations around the Drillfield of the Virginia Tech campus for K-12 students and their parents. The event included a field trip to the duck pond, presentations by many of the chemistry professors and their groups of students, the “Tragedy of Commons” game, and a picnic in conjunction with the Summer Arts Festival.

In 2009 CNC collaborations expanded to include a successful and highly popular graduate distance learning course, jointly taught with Professor Mool Gupta at the University of Virginia. The course, entitled “Buckyballs, Metallofullerenes, and Nanotubes: New Carbonaceous Nanomaterials” was offered to various institutions across the Commonwealth of Virginia including Virginia Tech, UVA, VCU, and the College of William and Mary. Funded by the National Science Foundation, this course introduced students to the “state-of-the-art” in the area of advanced carbon nanomaterials applications.

In early 2011, the University of Virginia hosted a hands-on lecture to area high school teachers. Our contribution to “Getting Hands-On with Nanotechnology for K-12” was part of a nanotechnology workshop, attended by over 60 people, which showcased methods for teaching nanotechnology within the Virginia Standards of Learning test requirements.

The teaching of multiple courses during more than 35 years spent with the Chemistry Department at Virginia Tech, both undergraduate and graduate and ranging from General to Organic Chemistry, has led me to a recent undertaking of a combination graduate-undergraduate course entitled “Identification of Organic Compounds/Molecular Structure Determination.” The combined contribution to the educational community of the years of knowledge transfer backed by groundbreaking research is inestimable.

The Dorn Research Group holds 8 patents representing the body of work explored over the years. The metal-filled fullerenes developed by the group are currently manufactured by Luna Innovations as improved MRI reagents for disease diagnosis and therapy. These Trimetasphere® carbon nanomaterials are manufactured in Danville, VA at Luna nanoWorks, a facility that has been a large economic contributor in Southwest Virginia.

Our group has put research to work, creating new and exciting imaging agents that provide enhanced contrast and safety, new pathways to treating diseases such as Parkinson’s, diabetes, arthritis and radiation therapy, and energy solutions like providing for more efficient, less expensive organic solar power. Disease-targeting agents, like the MRI contrast materials, offer a higher relaxivity which constitutes a lower dose, thereby reducing the amount of rare-earth metals in usage. Increased safety (provided by the encapsulation of the Gd atoms) makes the new material attractive to the medical community as well as various funding agencies interested in assisting the progress of this groundbreaking research.

The Dorn Research Group is at the forefront of a trend in the field of nanotechnology, paving the way for researchers both nationally and internationally to advance in this novel and exciting discipline.

For more information on the Dorn Research Group and its work, please visit www.dorn.chem.vt.edu.


Significant contribution to this article by Stephanie Hurt, Research Assistant, Chemistry.
The Origin of Nanoscale-Derived Properties in Nanoparticles

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Nanotechnology’s promise arises from novel phenomena traceable to spatial features in the nanometer range. One of the more established kinds of this technology involves nanoparticles – small pieces of matter a few nanometers across. Nanoparticle pigments and catalysts have been used in industrial processes and commercial products for many decades, but developments in the ways nanoparticles are synthesized and studied are enabling engineers to design new types of nanoparticles with specific functional properties. For example, nanoparticles are beginning to appear that deliver drugs to specific sites in the body, act as molecular sensors, simplify electronic packaging, impart antimicrobial properties, and serve many other functions.

The unique characteristics of nanoparticles often are associated with physical interactions taking place on the nanometer length scale. For example, metallic gold has a deep yellow color, but if it is converted to powder particles less than about 100 nm in size (less than the wavelength of visible light), it is no longer yellow. Depending upon how the particles are spaced and arranged relative to each other, they can be made to absorb or scatter specific wavelengths and appear invisible, black, red, or almost any color one might want. Phonons, many kinds of electromagnetic waves, magnetic interactions and even chemical interactions can take place at the nanometer length scale, and consequently can couple with nanoparticles to produce interesting behavior.

In order to effectively design new nanoparticles, it is important to develop an understanding of the stability of these small particles and how it changes with the size of the particles. We hope to shed some light on this issue by using analytical microscopy to assess directly the structure and composition of individual nanoparticles of metallic alloys as a function of their size and shape.

One of the groups of alloys we are investigating is the copper-gold system. Copper-gold alloys can adopt a number of crystal structures in bulk samples (these have dimensions greater than about a micron) depending upon the temperature and relative concentrations of copper and gold. These structures differ in the periodic patterns, or order, of copper and gold atoms arranged on a crystal lattice. The way one structure transforms to another is well known in samples of bulk size. This makes copper-gold a good model system for studying the influence of particle size on the transformation behavior.

Figure 1 shows an example of copper-gold nanoparticles less than about 5 nm in diameter. These particles were made by generating a plasma of copper and gold atoms with a pulsed laser and then condensing the energetic atoms onto a substrate. The larger particles in the figure are about 5 nm in diameter. The as-formed particles adopt a face-centered cubic crystal structure, which is metastable at room temperature. Energetically speaking, an equal mixture of copper and gold atoms would rather rearrange themselves into an ordered structure.

If the particles are warmed slightly, the atoms acquire enough energy to transform into an ordered structure, but the dimensions of the particles can affect this process. For example, the atoms adjacent to a particle’s surface experience a different environment than atoms located deeper in the particle, and this difference can influence the stability of the ordered phase.

Also, in larger bulk crystals, the initial metastable structure converts to the ordered version by the migration of vacant sites on the crystal lattice. However, the concentration of these vacancies is always small, and when the particle size is reduced to the nanometer range, a significant number of the particles may contain no vacancies at all. It is an open question whether the vacancy-free particles are able to convert from a metastable structure to a stable one.

There are other factors that can influence the stability of the particles and
their ability to convert from one structure to another. As the size of the particles decrease into the nanometer range, it is possible for the particle size to drop below the so-called critical nucleus size, a theoretical size below which it becomes statistically unlikely for the stable structure to appear from a metastable one.

Finally, the chemical reactivity of the nanoparticles is sensitive to the precise locations of the different atom types (gold and copper in the case of Figure 1) on the particle surfaces.

Taken together, the influence of particle size on a nanoparticle’s stable structure, its ability to transform, and its chemical reactivity are all important issues in the design of nanoparticles, but they remain to be explored. Understanding the influence these size effects on particle stability and transformation kinetics is important for designing functional nanoparticles such as catalysts for the energy industry or memory devices.

Our approach consists of comparing analytical S/TEM observations of the processes in individual particles to data from bulk alloys. Concurrently, first principle and variational computational models are being developed to provide a framework for interpreting the critical thermodynamic and kinetic factors controlling the processes. A central issue to address in the thermodynamic analyses of small particles is to identify the relevant thermodynamic potentials that define equilibrium. Classical nucleation theory assumes the critical nucleus is in equilibrium with its surroundings and typically uses equality of chemical potentials in the nucleus and surroundings to assess this. However, in nanoparticles, it is not possible to form a fluctuation without simultaneously changing the composition of the rest of the particle. Thus, a somewhat different thermodynamic formulation is needed to describe the stability of small particles. To perform realistic modeling of the physical chemistry of individual nanoparticles, we are accumulating experimental results from statistically reasonable amount of individual nanoparticles.

Scanning transmission electron microscopy provides the nanometer-level resolution and high chemical sensitivity needed to explore the aforementioned issues. The FEI-TITAN at the Nanoscale Characterization and Fabrication Laboratory has two comprehensive chemical analysis capabilities that enable these kinds of measurements: an energy dispersive X-ray spectrometer (EDS), and an electron energy loss spectrometer (EELS). Together, these permit analysis of atomic species allow us to probe electronic structure such as oxidation states and bonding orbitals. The Titan has better than 0.2 nm spatial resolution in scanning transmission electron microscopy (STEM) high angle annular dark field (HAADF) mode, providing direct atomic column-by-column imaging.

Figure 2 is an example of a second type of alloy system we are investigating with these techniques. These nanoparticles are a mixture of iron and platinum, and they are the focus of intense study by numerous researchers for next generation magnetic memories. Like copper-gold nanoparticles, iron-platinum nanoparticles can adopt a variety of crystal structures. The magnetic characteristics required for memory components are peculiar to one ordered phase. The ordered state of the particles can be identified by electron diffraction (Figure 3), and we are correlating the crystal structure of the nanoparticles to their size.

One goal of our work is to provide answers to several intriguing fundamental questions. How does an alloy that is metastable at bulk sizes behave in a particle whose size is near the characteristic length scale of the transition processes? Is nucleation even possible in particles below the dimensions of a critical nucleus, and can phase separation take place in particles smaller than the critical wavelength? The answers to these questions are important to establishing the stability of nanoparticles, and we are trying to resolve these questions through a combination of direct observation of kinetic processes in individual nanoparticles.

It is hoped the answers to these questions will provide insights into predicting stable nanoparticle structures. This, in turn, can provide tools for designing nanoparticles with specific atomic configurations for a variety of applications.
Welcome recent additions to the ICTAS team

Olga Ivanova, Postdoctoral Associate | olgasi@vt.edu

Ivanova joined ICTAS on February 4, 2011 as a postdoctoral associate working with Dr. Thomas Campbell in the area of nanomaterials and additive manufacturing (3D Printing). She completed a Ph. D. in chemistry at the University of Louisville in December 2010 where her research interests included the size-controlled synthesis of metal nanostructures, electrochemical and optical properties and morphology of metal nanostructures as a function of size, the effect of nanoparticle size on under potential deposition, the electrochemical oxidation of Au/Ag alloy nanoparticles and the electrochemical behavior of metal nanoparticles-polymer multilayer films.

Vicki Kaylor, Receptionist, ICTAS on Washington Street | vickik@vt.edu

Kaylor, who joined ICTAS on March 9, 2011, is based in Suite 110 at ICTAS on Washington Street. This is her first employment at Virginia Tech. Previous to this position, she worked for a local real estate appraisal company. Kaylor works Monday through Friday, 10:00 am – 4:00 pm, scheduling conference rooms and managing deliveries and tracking of packages for tenants of the ICTAS on Washington Street building.

Satish Kulkarni, Director for Energy Initiatives | svk1212@vt.edu

Kulkarni, a Virginia Tech alumnus residing in Arlington, Va. joined Virginia Tech on March 30, 2011 to promote energy-related research and initiatives across the university. Creation of this position is the result of recognition of the societal need for advanced technological solutions to energy concerns and is jointly sponsored by the by the Institute for Critical Technology and Applied Science and the Office of the Vice President for Research. Until recently Kulkarni was associate vice president for new initiatives and partnerships at Georgetown University. Previously he was the counselor to science, technology, environment and health affairs at the U.S. Embassy in New Delhi, India with the Department of State.

Mitsu Murayama, Associate Professor, Materials Science and Engineering | murayama@vt.edu

Murayama, previously a research associate professor with ICTAS, was promoted to associate professor in the department of materials science and engineering on February 10, 2011. He will continue to be responsible for the electron microscopy activity at the Nanoscale Characterization and Fabrication Laboratory (ICTAS-NCFL), especially high resolution scanning/transmission electron microscopy (FEI TITAN). He also provides operational support and oversees strategic management of resources including long-term strategic planning.
At Georgetown, Kulkarni’s activities included developing joint projects with several national laboratories and Virginia Tech, and engagement with the Chesapeake Crescent Initiative, a Virginia, Maryland, and Washington, D.C., consortium to bring together the capabilities of local universities, private enterprise, and government to create opportunities in life science, energy, and security. He also played a key role in the development of the university’s strategy for engagement with India.

As part of his assignment with the U.S. Embassy in New Delhi, Kulkarni helped facilitate the interaction between U.S. and Indian scientists and engineers in the nuclear energy/science field. He also was responsible for the climate change portfolio and worked closely with the White House Council on Environmental Quality in launching the Asia-Pacific Partnership for Clean Development and Climate in India.

At the University of California, he helped develop a strategy that incorporated the university’s 10 campuses and three national laboratories (Berkeley, Los Alamos, and Livermore), and identified science and technology intersection areas for joint initiatives. As a division leader at LLNL, he transformed the former nuclear test division to one with a multiprogram role in homeland security, nonproliferation, energy and environment, and biosciences.

He has a Bachelor of Science degree from Calcutta University, a Master of Science degree from the India Institute of Technology in Kanpur, and earned a Ph.D. in engineering mechanics from Virginia Tech in 1973 and was recently inducted into the Academy of Engineering Excellence at Virginia Tech for “meritorious lifetime achievements and contributions to the engineering profession.”

Founded in 1872 as a land-grant college, Virginia Tech is the most comprehensive university in the Commonwealth of Virginia and is among the top research universities in the nation. Today, Virginia Tech’s nine colleges are dedicated to quality, innovation, and results through teaching, research, and outreach activities. At its 2,600-acre main campus located in Blacksburg and other campus centers in Northern Virginia, Southwest Virginia, Hampton Roads, Richmond, Southside, and Roanoke, Virginia Tech enrolls more than 28,000 undergraduate and graduate students from all 50 states and more than 100 countries in 180 academic degree programs.
Update on ICTAS Buildings

The Institute for Critical Technology and Applied Science takes pride in more than 170,000 square feet of modern facility space equipped with state-of-the-art equipment and brimming with cutting-edge interdisciplinary research activity originating at the intersections of engineering, science, and medicine. ICTAS is currently planning expansion into approximately 7,000 square feet of additional space in the Virginia Tech National Capital Region facility during the summer of 2011.

ICTAS on Stanger Street
(March 2009)
The four-storey headquarters building encompasses 99,411 square feet of space and is located on the Blacksburg Campus at the corner of Turner and Stanger Streets. This building is headquarters for institute operations. Diverse research activity including targeted delivery of nanomedicine, tissue engineering, cognitive radio, environmental nanoscience and technology, sustainable energy, bio-based materials, and advanced multifunctional materials is housed in the building as well as related office, meeting and conference space. This building is also home to the School of Biomedical Engineering and Sciences (SBES).

ICTAS at the Virginia Tech Corporate Research Center
(July 2007)
The two-storey ICTAS Corporate Research Center facility encompasses 32,000 square feet of space and is located at 1991 Kraft Drive, Blacksburg, VA. This building is designed to minimize interference to instruments from environmental factors such as building vibration, stray electromagnetic fields and temperature fluctuations and is home to the ICTAS Nanoscale Characterization and Fabrication Laboratory (NCFL). The NCFL occupies the first floor or approximately 16,000 square feet of space in the building offering sophisticated instrumentation valued at more than $10 million for bio- and nano-characterization.

The second floor space in the building is home to an array of research activities including nuclear research, nano CT, X-ray imaging, bio-AFM, nano biomaterials, sensors and structural health monitoring, SuperDARN radar development, Extreme Laboratory research on material response at high temperature, and disaster and risk management, as well as related work and meeting rooms. Recent changes at the Nanoscale Characterization and Fabrication Laboratory (NCFL) include a major upgrade to the facility’s analytical scanning transmission electron microscope, an FEI TitanTM. Made possible by a $400,000 grant from the Department of Energy to Professors M. Hochella and M. Murayama, the upgrade increases the microscopes maximum accelerating voltage to 300 kV, adds a new diffraction camera with TV-speed readout, replaces several optical components, and replaces the electron gun assembly. The changes substantially improve the microscope’s resolution, 3D imaging capabilities, and stability. Modifications to the instrument were completed during April 2011.

In addition, the NCFL recently transferred the 2-Photon Excitation Microscope (a confocal laser scanning microscope) to the optics group located in the ICTAS building on Washington Street.
ICTAS on Washington Street
(January 2011)
The three-storey ICTAS building encompasses 42,190 square feet and is located on the Blacksburg campus at 116 Washington Street.
This building is home to research laboratories, office space and conference meeting rooms. Research activity includes applied environmental biochemistry, fluvial processes, a global laboratory for bio-inspired science and technology, nanobiology, nonlinear imaging and spectroscopy, organic nanostructures, pathogen ecology, pipeline corrosion and the humanoid hospital.

ICTAS in the National Capital Region
(Summer 2011)
ICTAS is a tenant in the five-storey Virginia Tech National Capital Region facility encompassing 144,000 square feet and located in the 800-900 block of North Glebe Road in Ballston, Va.
ICTAS research activity in the Ballston facility is focused in four areas: energy, cyber security, data analytic and biomedical computing and nano-sensing. Initially, ICTAS space in the facility spans approximately 7,000 square feet apportioned among two floors.
ICTAS Announces Doctoral Scholar Selection for 2011

Seven exceptional Ph. D. candidates, representing eight departments among five colleges, will begin fall semester studies with the prestigious designation of ICTAS Doctoral Scholar. This class of scholars brings total participation in the ICTAS Doctoral Scholar Program to forty three awardees since the program began in fall semester of 2007. The first graduate of the program, Marcel Remillieux, was awarded the Ph.D. in Mechanical Engineering in May 2010. Four more scholars plan to graduate in May 2011.

The 2011 ICTAS Doctoral Scholars are:

Kyle Ashley, a geological sciences doctoral candidate in the College of Science.

Sungseok Lee, a biomedical and veterinary sciences program doctoral candidate in the College of Veterinary Medicine.

Kelly McCutcheon, a physics doctoral candidate in the College of Science.

Ashley Peery, an entomology doctoral candidate in the College of Agriculture and Life Sciences.

Rachel Umbel, a materials science and engineering doctoral candidate in the College of Engineering.

Yuan Yuan, an agricultural and applied economics doctoral candidate in the College of Agriculture and Life Sciences.

Ruoran Zhang, a macromolecular science and engineering doctoral candidate in the College of Natural Resources and Environment.