Institute for Soldier Nanotechnologies

Now in its third year, the Institute for Soldier Nanotechnologies (ISN) has successfully navigated its start-up phase, including hiring staff and moving into new facilities in Technology Square. As the research begins to yield some early results, prospects are promising for creating the revolutionary advances in soldier survivability that are at the core of the ISN mission.

Through basic research, and collaboration with industry and the Army in technology development, the ISN mission is to provide a dramatic increase in survivability to the individual soldier through nanoengineered materials and devices in a significantly lighter weight uniform. This includes reducing the weight soldiers carry, improving blast and ballistic protection, creating new methods for detecting and detoxifying chemical and biological threats, and improving human performance. The ultimate goal is to create a 21st century battlesuit that combines high-tech capabilities with light weight and comfort.

During its second year, the ISN held two key events: a four-day comprehensive research review meeting in September 2003 and a second Industry Day event in March 2004. The ISN also launched the MIT Soldier Design Competition in September 2003, and the initiative was so successful it will now become an annual event. One new industrial company joined the ISN Industry Consortium in the spring of 2003, and another affiliated as an Interested Industrial Participant.

The ISN's estimated five-year funding now stands at more than $106 million, cash and in-kind contributions, with the Army contributing approximately $50 million in 6.1 funding and an estimated $20 million in 6.2 applied research funding (primarily to industry partners), MIT providing $14.6 million (not including the cost of the dedicated facility, which was estimated at $9.3 million), the founding industrial partners contributing $15.3 million, and new industry partners providing approximately $7 million.

Research

The ISN's interdisciplinary research program made significant strides in its second full year. In contrast to its first year, much of the ISN's second-year research took place in its new facilities at 500 Technology Square. The resulting synergy among the 100+ researchers working in the new laboratories brought the ISN vision of complex problem solving on behalf of soldier survivability into clear focus.

In September 2003, the ISN hosted a four-day research review meeting where each of its 42 research projects was presented and reviewed by a panel of Army and other government subject matter experts (Capability Area Review Teams, or CARTs). About 140 people from the Army, DoD, and ISN industry partner companies attended all or part of the meeting, which featured presentations by nearly 30 faculty members.

In July 2003, the ISN funded four new projects, bringing five new faculty members to the ISN community: Professor George Barbastathis (Mechanical Engineering), Professor Craig Carter (Materials Science and Engineering), Professor Keith Nelson (Chemistry), Professor Raul Radovitzky (Aeronautics and Astronautics), and Professor Henry Smith (Electrical Engineering and Computer Science). In January 2004, the ISN funded two new research projects that brought one new faculty member to the ISN community: Professor Darrell Irvine (Materials Science and Engineering). Two other faculty members joined existing ISN projects: Professor Marc Baldo (Electrical Engineering and Computer Science) and Professor Todd Thorsen (Mechanical Engineering). ISN researchers published 30 technical papers during the year, with another 22 submitted and awaiting publication. Invention disclosures to the MIT Technology Licensing Office numbered 13.

Team-based innovation is a key part of the ISN's approach to complex problems like protecting tomorrow's soldiers from chemical and biological weapons. Seven research teams address various aspects of the overall challenge; the following subsections discuss the second-year research goals and accomplishments of these teams.

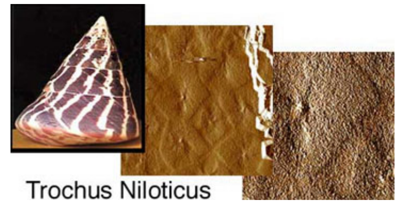
Team 1: Energy-Absorbing Materials

Team 1 focuses on developing energy-absorbing material systems that will protect the future soldier against ballistic impact and blast waves. Using new polymers as well as designs of nanocomposites and mesocomposites, Team 1 is working to create materials beginning at the molecular level that provide the mechanical resistance to withstand blast waves and ballistic fragments and yet are still lightweight and flexible enough to maintain soldier mobility. Such materials must also be capable of integration with and protection of the other components in the future soldier's battlesuit, such as the sensors and biological protection that Team 3 is developing.

Some objectives of Team 1 include, for example, demonstrating novel organizational principles between polymers and other materials; discovering new and more effective energy-dissipating deformation mechanisms, and understanding their relationship to nanoscale structural design principles in composite and natural materials; devising high rate testing capabilities for evaluation of individual materials and material assemblies; and developing numerical simulation capabilities to design and engineer new material systems for ballistic protection.

Team 1 efforts include collaborative research projects that extend across several disciplines and departments, including chemistry, materials science and engineering, mechanical engineering and chemical engineering. A few representative accomplishments over the past year include:

—Professors Christine Ortiz (Materials Science and Engineering) and Mary Boyce (Mechanical Engineering) have pursued a synergistic multiscale experimental and theoretical approach to study natural biocomposite materials in order to discover new and more effective energy-dissipating deformation mechanisms and to understand their relationship to nanostructured design principles. In particular, the composition, nanostructure, properties and deformation mechanisms of the microlaminated nacreous biocomposite of Trochus Niloticus seashells are under study as a model system designed to withstand penetration from predators. Quantitative assessment of local nanomechanical properties (e.g., Young's modulus and yield stress) and deformation mechanisms (e.g., nanoasperity flattening, plastic deformation, and material pile-up) of individual aragonite tablets has been accomplished using the techniques of nanoindentation, in situ atomic force microscopy imaging, and elastic-perfectly plastic numerical simulations. Constitutive models of the protein-based organic matrix have been constructed and used in micromechanics simulations of mechanical loading of the nacre microstructure. Ongoing work focuses on using these simulations to reveal the role of mechanically induced protein unfolding in attenuating load transfer and thus toughness in these nanostructured natural armor materials.



Trochus Niloticus shell with surface magnifications

—Professors Paula Hammond (Chemical Engineering) and Gareth McKinley (Mechanical Engineering) are pursing the development of synthetic polymeric materials which emulate the nanostructure and the superior mechanical properties of natural materials such as silk, a protein-based natural polymeric material. New polyurethanes with triphase morphologies have been synthesized via introduction of rigid oligomers or sequestered nanoparticles in the soft segment or interfacial regions of the hard domains, with the goal of creating enhanced toughness and cut/tear resistance for soldier battlesuit fibers. Certain of these systems exhibit mechanical properties exceeding those of typical polyurethanes, and ongoing work is investigating the role of the ternary phase in deformation and the spinning of these systems into fibers using a novel resin spinning method.

—Professors Tim Swager (Chemistry) and Ned Thomas (Materials Science and Engineering) have developed a new structural class of polymers containing three-dimensional structural units called iptycenes. The iptycene groups create a physically interlocking structure that lacks strong interpolymer bonding interactions yet produces dramatic enhancements in the mechanical properties of the polymers. Extensions of this new design concept to materials with ballistic protective applications is the goal of the ongoing research.

—Professors Mary Boyce and Simona Socrate (Mechanical Engineering) have built a testing facility that focuses on the high strain rate behavior of polymeric-based materials, fabrics, and soft materials including soft tissues, for purposes of characterizing and simulating trauma to the human body due to impact loadings. The split Hopkinson Pressure Bar has quantified special features of the high rate behavior of amorphous homopolymers, where the high strain rates encountered during ballistic impact events activate frequency responses of inherent molecular-level deformation events not encountered in more conventional loading conditions.

Dr. Alex Hsieh (Army Research Laboratory) and graduate student Adam Mulliken at the ISN gas gun

Constitutive models of the high rate stress-strain behavior have been developed to take these materials features into account when simulating blast and ballistic loading events. Projectile impact loading conditions on polymeric-based targets are also now facilitated by the new gas gun capability; projectile impacts into target material systems are visualized using a new high speed camera that enables direct observation of the projectile engagement with the target.

Team 2: Mechanically Active Materials and Devices

Team 2 is developing nanomaterials that are capable of mechanical actuation and dynamic stiffness. Mechanical actuators embedded as part of a soldier's uniform could permit transformation from a flexible and compliant material to a noncompliant, armor-like material that protects the soldier by distributing impact. Soft switchable clothing could also be transformed into a reconfigurable cast that stabilizes an injury such as a broken leg. Contracting materials could be made to apply direct pressure to a wound, function as a tourniquet, or even perform CPR when needed. Mechanical actuators might also be used as exo-muscles to augment a soldier's physical strength or agility.

Some objectives of Team 2 include, for example, achieving control of a material's stiffness with actuator polymers; illuminating new chemistries to enable electrically induced changes in the configuration and size of tiny materials; and developing magnetic nanoparticles that can be switched chemically between strongly and weakly magnetic states. One use of the latter would be a magnetically activated fluid to be incorporated into the battlesuit.

New liquid crystal block copolymers for actuator applications have recently been synthesized through the joint efforts of the research group of Professor Richard Schrock (Chemistry), which has successfully created a well defined series of polymers using ring opening polymerization methods, and the research group of Professor Paula Hammond, which has synthesized mesogens with high polarizability. Nematic and ferroelectric smectic systems exhibiting elastomeric properties are now being examined for mechanical and electromechanical properties.

The development of conducting polymer actuators is a major theme of Team 2. Professors Ian Hunter (Mechanical Engineering) and Tim Swager (Chemistry) are engaged in efforts to translate novel molecular mechanical structures into materials capable of undergoing large dimensional changes and large forces when exposed to an electric field. Nanostructured conducting polymers have been produced by the joint efforts of Professors Ned Thomas, Ian Hunter, and Tim Swager using the principles of self-assembly of block copolymers. Professor Neville Hogan (Mechanical Engineering) has been developing models for controlling polypyrrole actuators, and his modeling methodology has now successfully shown that the electromechanical coupling is, in fact, essentially symmetric (as expected) but that strain is related to charge *squared* (not linearly to charge, as previously assumed).

Team 3: Sensing and Counteraction

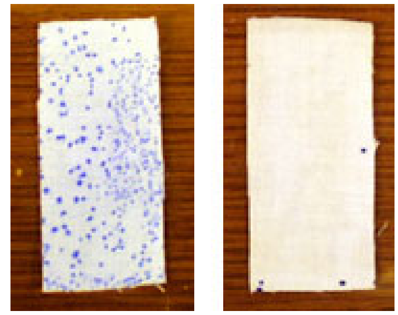
Team 3 is developing new materials systems which can ultimately be integrated into highly sensitive chemical and biological sensors in collaborative efforts with the Army and industrial partners. The goal of the team's basic research and engineering efforts is the enhancement of a soldier's awareness of chem/bio agents, poisons, or other environmental toxins, and protection from them. In collaboration with other ISN teams, members of Team 3 are also developing protective fiber and fabric coatings that will neutralize or significantly decrease bacterial contaminants, as well as chemical attack agents such as nerve gas. In addition, novel organic-inorganic hybrid nanocomposites, consisting of nanoparticles and formed using simple dip processing methods, will combine sensing and reactive components. Team 3 is also developing ways of using IR (infrared) monitoring to detect the presence of chemical agents or other threats, based on hollow photonic band gap fibers or nanoparticle quantum dot systems. Team 3 represents collaborations across several departments, including Physics, Chemistry, Chemical Engineering, Materials Science and Engineering, Mechanical Engineering, and Biotechnology Process Engineering.

This past year, several industrial partners were involved in Team 3 investigations, many of which have led to 6.2-level funding for the companies affiliated with the ISN; these include new projects with DuPont and Raytheon. The year has led to several new developments in the lab, including the examples given below.

The research groups of Professors Vladimir Bulovic (Electrical Engineering and Computer Science) and Tim Swager (Chemistry) have developed a new class of high electron affinity polymers that are resistant to photobleaching and are photochemically responsive to the amino acids tryptophan and tyrosine as well as some neurotransmitters. The fluorescence of the polymers is extraordinarily sensitive to proteins and, when applied with the proper molecular recognition, will be useful for the creation of biosensory systems. Present research is directed at generating novel electrical sensors using these materials as chemically sensitive charge injection layers.

The research groups of Professors Paula Hammond (Chemical Engineering) and Jackie Ying (Chemical Engineering) have been examining the incorporation of semiconductor nanoparticles in ultrathin polymer films that may act as decontaminants or adsorptive protective films on exposure to chemical agents. Several thin films consisting of highly branched organic dendrimers, capable of adsorbing nerve gas and other toxins at high capacities, have been constructed; titania nanoparticles have been incorporated into some of these films to act as catalytic agents to break down the absorbed toxic chemicals. Current work is focused on adsorbing these flexible thin films on fibers and fabrics, and testing will be performed at the US Army Natick Soldier Center.

In addition, Professor Alex Klibanov (Chemistry) has studied the mechanism of bactericidal and fungicidal activity of textiles modified by hydrophobic cations. His group showed that common textiles (cotton, wool, nylon, and polyesters) could be derivatized with a polyethylamine (PEA) and showed excellent antibacterial action due to the ability of the long PEA chain to penetrate the cell membrane. Collaborations with Professor Karen Gleason (Chemical Engineering) from Team 5 led to water-resistant antibacterial fabric coatings. Over the past year, the Klibanov group has found that dendrimers can be grafted to the surface of these thin films to yield surfaces with antiviral properties. At this time, work is ongoing to combine antibacterial and antiviral properties in these films. Klibanov was invited to be a UNAM Distinguished Lecturer at the Autonomous University of Mexico (Mexico City) in March 2004, to present this work.



The textile sample treated with a microbicidal coating (right) shows far fewer bacterial colonies, shown as blue dots, than the untreated sample (left).

Professors Angela Belcher (Materials Science and Engineering) and Paula Hammond are working together to create viral arrays on surfaces, for which the viral systems can be designed to act as components in chemical or biological sensors. The researchers have successfully created single component 2D arrays of nanoparticle systems; the use of TiO_2 templating allows the creation of patterned metal oxide surfaces, and nanoparticles used in their current array technology rely on receptor-ligand interactions to attach viral particles. An initial demonstration of controlled viral deposition was accomplished using nonlithographic methods via contact printing approaches on the micron scale. Important recent achievements include the ability to pattern down to the nanometer length scale using nonlithographic printing and molding techniques, while obtaining chemical functionality using polymer transfer and stamping methods.

Several new developments have occurred in the past year with regard to new research efforts in Team 3. These efforts include the addition of a new ISN faculty member, Professor Darrell Irvine (Materials Science and Engineering and Biological Engineering Division), who will lead an effort on the use of immunological T cells to recognize specific antigens when arrayed on surfaces that are nanostructured using block copolymer self-assembly. This new project, a collaboration with Professors Robert Cohen (Chemical Engineering) and Paula Hammond, was initiated in January 2004.

Team 4: Biomaterials and Nanodevices for Soldier Medical Technology

Team 4 focuses on using nanotechnology to improve the detection and treatment of life-threatening injuries such as hemorrhage, fracture, or infection. With new approaches to soldier triage and with automatic first aid, Team 4's goal is to begin recovery while the patient is still on the battlefield.

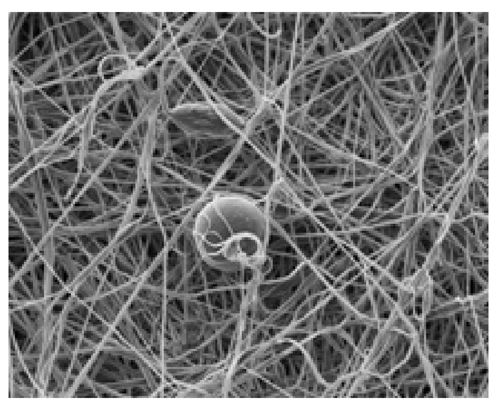
Working in collaboration with other ISN teams, Team 4 is developing ways to monitor patient physiology, as well as novel materials for wound healing. Battlesuit sensors could relay details about a soldier's location and physical condition to headquarters. New nanosurfaces could detect biological and chemical agents and then protect the future soldier from those threats. Biomedical monitoring might use ultrasound to detect a hemorrhage in the injured soldier and then cauterize vessels to staunch the bleeding. Soldiers' uniforms could become exomuscular devices for medical applications, such as tourniquets and splints for broken bones. And new nanomaterials could instantaneously change their properties by electrical switching, thereby controlling the delivery and release of life-saving medications.

Dr. Sonya Shortkroff (Harvard Medical School/ CIMIT) with undergraduate Nalini Gupta in the ISN's tissue culture room

In addition, ISN draws on the interests and work of its industrial partners. Raytheon and DuPont provide electronics and materials platforms to enable the transition from the lab to the future Army application. And ISN's collaboration with the Center for the Integration of Medicine and Innovative Technology (CIMIT) is essential as physicians and other scientists from Massachusetts General and Brigham and Women's hospitals develop medical applications for ISN's new devices and materials. Civilian applications of exomuscular devices, for example, could include smart back-boards, neck braces, splints, and casts as well as active fabric tourniquets. Nanoscopic approaches to medical treatments will benefit civilians as well as enhance survivability of the future soldier.

Team 4 member Professor Robert Langer (Chemical Engineering) and his group have recently designed surfaces that could exhibit dynamic properties, including wettability, due to an applied electric field. Transformation from hydrophobic to hydrophilic behavior was possible by end grafting 16-mercapto hexadecanoic molecules to a gold substrate. By applying a field, the molecule rearranges from its elongated, hydrophilic state to a bent, hydrophobic conformation. Such reversible surfaces have obvious implications for biocompatibility and microfabrication for controlled-released devices. Professor Langer is also developing ultrasound methods to administer medicines through the skin and withdraw fluids for diagnostics.

Team 5: Processing and Characterization—The Nanofoundries



Micrograph of electrospun fibers

Team 5 researchers use a multidisciplinary approach to developing the scientific and engineering understanding needed to process nanoscale building blocks into useful macroscale materials and devices. Efficacious nanoprocessing technologies must be capable of effectively processing a wide range of components: nanoscale fibers and films; multilayered materials; membranes and microdevices; microfluidic devices; functional hollow fibers; and field-responsive materials and devices.

One of Team 5's goals is the fabrication and integration of hierarchically structured materials to achieve multiple and synergistic property combinations. Other Team 5 objectives include providing fiber fabrication capabilities for new nanomaterials developed by the ISN; designing a fabrication and processing facility for producing multilayer composites with individual layer thicknesses of 10 nm–1μm; and prototyping multilevel CVD polymeric interconnects for textiles. Four specific examples of achievements within the past year are:

- The production of sub-micron diameter nanofibers incorporating aligned super-paramagnetic nanoparticles through the process of electrospinning.
- Complete exfoliation of synthetic discotic nanoparticles and induced microcrystallinity within a thermoplastic-urethane material commonly used in packaging films. The resulting nanocomposite has both an enhanced modulus and an improved strain-to-failure, resulting in an order-of-magnitude increase in toughness.
- Synthesis of core-shell nanoparticles possessing polarizable ferrite-shells, subsequent microfluidic assembly into micron-scale bead-rod columns, and finally incorporation of these anisotropic rod-like particles as a reinforcing agent for low-density field-responsive magnetorheological fluids with large yield strength.
- Development of a multi-layer film extrusion die and coextrusion facility capable of simultaneously extruding 8,192 layers (each less than 500 nm thick) of two thermoplastics with complementary mechanical properties. Nanoscale reinforcing agents such as polyhedral oligomeric silsesquioxane nanoparticles or carbon nanotubes can be incorporated into each layer for improving the ballistic impact resistance, nanoscratch resistance, or thermal and electrical conductivity.

Team 6: Modeling and Simulation of Materials and Processes

The focus of Team 6 is on providing computational modeling and simulation of nanostructured materials designed to protect the future soldier. Working closely with the other ISN teams, Team 6 will establish basic insight into the structure and properties of nanomaterials and nanostructured materials. As such, it will provide direct guidance for engineering and materials research, with an emphasis on the novel properties of nanosized and nanostructured materials and on the synergistic effects achieved through hierarchical materials design.

Team 6 has as its primary goals the modeling, simulation, and prediction of nanoscale phenomena and macroscopic properties; the prediction and optimization of materials response; and the design of novel nanoassemblies to protect the soldier from a variety of adverse loading conditions. Some objectives of Team 6 include developing a fundamental understanding of the structure, property, and processing relationships in nanosystems; developing numerical simulation capability to design and engineer new nanomaterial systems; and developing three-dimensional constitutive models of soft tissue response in order to design protective materials to protect the human body from trauma. Some particular accomplishments include the following:

—The development and use of large-scale *ab-initio* simulations by Professors Gerbrand Ceder (Materials Science and Engineering) and Nicola Marzari (Materials Science and Engineering) which have demonstrated that semiconductor nanoparticles can absorb a substantial amount of energy in a shock wave—for example, by pressure-induced phase transformations.

Professors Simona Socrate (Mechanical Engineering) and Raul Radovitzky (Aeronaustics and Astronautics) are working on computational models to simulate behind-armor effects of threats on the human body. The long-term objective of this study is to assist in the design of ballistic studies to evaluate body armor and its ability to minimize injury and trauma from nonpenetrating projectiles and blast loading. Directed experimentation and detailed finite element modeling are used to determine constitutive behavior and material properties for different classes of tissues and synthetic simulants to be used as backing in ballistic testing. An important component of this study is the development of novel experimental techniques to measure high rate properties of biological tissue in vivo. This component of the project is conducted in cooperation with Mark Ottensmeyer (CIMIT).

Professor Simona Socrate and students are conducting experimental studies and developing numerical models for the deformation and failure mechanisms in high performance woven and nonwoven fabrics. The constitutive behavior (deformation and failure) of single yarns is incorporated into detailed three-dimensional finite element models of woven fabrics where shape and geometry of the yarns in the weave can be modified to match the actual morphology, or to perform parametric studies of the effectiveness of innovative fabric configurations. Using the information gained from experimental investigations and from detailed simulations, microstructurally based constitutive models have been developed where the material is treated as a continuum. The model can be used to study and optimize the stiffness, flexibility, strength, and toughness of different fabric designs subject to different loading scenarios. The continuum model is naturally suited to be integrated in computational studies of the multilayered assemblies characteristic of body armor.

Professor Mary Boyce (Mechanical Engineering) and colleagues have developed constitutive models for the high rate behavior of polymeric materials which incorporate information on the underlying molecular-level events operating in different frequency regimes that become important during extremely high rate deformation events as seen in ballistic and blast loadings. These models are used together with finite element simulations in the design of a hierarchically designed material structure to withstand projectile impacts. These models are also the starting point for designing polymeric based nanocomposites with tailored rate-dependent mechanical behavior—research that is currently underway.

Professors Mary Boyce and Christine Ortiz (Materials Science and Engineering) have constructed a constitutive model of protein-rich organic molecular networked polymers found in natural armor materials such as the nacre of sea shells; this material model is used in conjunction with finite element–based micromechanical models of the nacre micro/nanostructure of aragonite platelets bonded together by a protein-rich organic matrix. These models provide detailed information on the nature of load transfer and energy absorption in these natural materials and the role of the various constituents in achieving the unique mechanical behavior.

Team 7: Systems Design, Hardening, Integration, and Transitioning

The overall objective of Team 7 is to illuminate and apply systems integration requirements for using nanotechnologies to protect soldiers. To provide the individual soldier with unprecedented survivability capabilities, the ISN envisions a dynamic, multifunctional battlesuit that synergistically integrates diverse nano and other components within a lightweight, comfortable garment. This suit is expected to be a complex system of systems. Therefore, to be effective, the suit components must perform in harmony with one another *and* the suit must interact synchronously with two other complex systems, the soldier's body and the soldier's operating environment. Team 7 provides the understanding needed to assure that these systems work together and not at cross purposes. Its specific objectives are to:

- Develop scientific and engineering understanding so as to integrate different nanomaterials and nanodevices to provide multiple survivability capabilities in macroscale platforms.
- Validate and refine this understanding through the design, construction, and experimental testing of simple prototype systems incorporating at least two nanocomponents.
- Draw inspiration for battlesuit design and operation from other complex systems for human protection.
- Use the understanding from the first and third objectives above to formulate candidate systems architectures for the battlesuit.
- Inform ISN research of systems integration requirements.
- In collaboration with industry partners and the Army, identify ISN basic research showing promise for transitioning toward practical applications for the soldier.

During the past year, studies of spacesuits and the human body identified performance requirements in common with the battlesuit, as well as spacesuit and bio-inspired survivability solutions and nanotechnologies showing the potential to imitate those solutions in the battlesuit. Team 7 began the design and fabrication of a prototype fluid pumping system based on integration of two distinctly different nanocomponents, and an industry partner, Raytheon, launched a systems-integration working group to prepare nanotechnology roadmaps to enable key soldier survivability capabilities.

Team 7 will help define and evaluate battlesuit architectures to exploit the unique capabilities of nanotechnology to provide the individual soldier with multiple survivability capabilities while meeting weight, power, maneuverability, and other performance specifications. These architectures will in turn elucidate design tradeoffs, systems weaknesses and synergisms, basic research needs, and transitioning opportunities.

Soldier Design Competition

In September 2003, the ISN launched the first annual Soldier Design Competition, offering $11,000 in cash prizes. The goal was to get more undergraduates involved in solving the problems of the modern soldier. Focused on practical, non-weapons products like pocket-sized bolt cutters and a personal cooling system, the technology that comes out of the competition is expected to have dual-use potential for firefighters, police, or even athletes. In its first year, competition participants chose from six design challenges drawn from nearly 60 submitted to the ISN by experts at the Army. There was also an open design category where participants could propose their own idea.

In its first year, the competition attracted more than 23 teams made up of nearly 75 MIT undergraduates, graduate students, postdocs, staff, and alumni. In addition to submitting design challenges, the Army also supplied mentors to help the teams design the best possible product. Judges for the semifinal round and final round came from the Army, MIT, and industry.

Competition judges with TacShot team leader at the final judging in February 2004. Left to right: Command Sergeant Major Michael Kelso, Colonel Ernest Forrest, and MIT alumnus Andrew Heafitz.

In February 2004, the top prize and $5,000 went to team TacShot—undergraduates Pete Augenbergs '04, Fred Gay '07, Chris Pentacoff '06, and alumnus Andrew Heafitz '91 (MS '01)—for a rocket-launched aerial reconnaissance photography system. Second prize and $3,000 went to Team Surreptiles—undergraduates Byron Hsu '06, Forrest Liau '06, David Lin '06, Han Xu '06, and lecturer Tony Eng—for a system to translate soldiers' silent hand-arm signals into computerized messages for use when individuals are not in visual contact. Third prize and $2,000 went to Team TXI—undergraduates Matthew Carvey '05 and Benjamin Smith '05—for a parachute release mechanism using accelerometers and a cable-release mechanism. Team EVCO—undergraduates Corey Fucetola '04, Jonathan Gibbons '04, Mark Porter '04, Stephen Samouhos '04, and graduate student Jay Fucetola—also received a special $1,000 Director's Award for inventing an electricity generator that runs on waste body heat.

Competition participants own the intellectual property rights to their inventions and are encouraged to pursue patents and commercialization, as well as enter their invention in the MIT $50K Competition for business plans. Several of the first year's teams are also pursuing collaborative relationships with the Army.

The ISN plans to continue the Soldier Design Competition on an annual basis. Next year's competition will involve cadets from the US Military Academy, who will participate as part of their capstone senior-year engineering design course.

Industrial Collaboration

Industry partners are critical to the ISN mission because of the need to turn laboratory innovations into real products and scale them up for affordable manufacture. The ISN Industry Consortium, launched in 2002 with founding partners Raytheon, DuPont, and Partners Healthcare, added two new partners in early 2004, bringing the total number of partner companies to 12. Zyvex Corporation joined as a Small Business Industrial Member, and Mine Safety Appliances joined as an Interested Industrial Participant. Both companies attended the ISN's second Industry Day, held on March 16, 2004, where they learned more about ISN research, the needs of the soldier, and membership in the consortium.

The ISN plans to further develop collaborative research with its partners through workshops at MIT and at company sites. The first of these meetings took place in June 2004 at DuPont in Wilmington, Delaware, and a second workshop will take place in the fall of 2004 at Dow Corning.

From time to time, competition funding will be made available by the Army to assist ISN industry partners in performing applied research and development to transition promising ISN basic research results into practical products for the soldier. In 2004, four transitioning proposals out of seven that were submitted were selected for funding after review by the ISN and by the Army. It is anticipated that additional competitions for these 6.2 applied research funds will occur in fiscal year 2005 and beyond.

Facilities

The ISN's dedicated facilities saw tremendous change in their first full year of operation. Nearly all of the $6 million in capital equipment planned for the ISN has been installed, and a comprehensive user training program is in place. Important new pieces of equipment include a small-angle X-ray scattering system for evaluation of order in crystalline solids and polymeric systems; a state-of-the-art laser facility; two-dimensional mechanical testers for fabrics, soft materials, and tissue; fiber spinning and multilayer extrusion systems for polymer processing of fibers and composite thin films; a focused ion beam system; and a nano-manipulator.

Graduate student LaRuth McAfee at the ISN's small-angle X-ray scattering system

Use of the new facilities has continually increased as new equipment has been introduced and research volume increases. Approximately 110 people are now working part- or full-time in the ISN's facilities, including two scientists from the Army and four scientists from the ISN's industrial partners. Late in the year, the ISN added a new full-time professional manager for the dedicated facility, Dr. Catherine Byrne.

Outreach

During its second year, the ISN's outreach efforts focused on fostering collaboration between MIT and the Army and other parts of DoD, and on hosting visitors to the ISN. With the move into new facilities at 500 Technology Square late in the previous year, the demand for visits increased dramatically. In fiscal year 2004, the ISN hosted nearly 370 visitors, ranging from officers and scientists from the Army, Marine Corps, and Navy to members of industry, international scientists, MIT alumni, schoolchildren, and members of the general public. Prominent visitors included General Paul J. Kern, commanding general of Army Materiel Command; Lieutenant General John Caldwell and Brigadier General Robert Durbin of the Army; General Michael Hagee, commandant of the Marine Corps and a member of the Joint Chiefs of Staff; Mr. Gary Cowger, president of GM North America; the Honorable Michael A. Sullivan, mayor of Cambridge; Ms. Mieke Eoyang, legislative assistant to Senator Edward Kennedy; and Dr. David Bolka, head of the Homeland Security Advanced Research Projects Agency.

Professor Ned Thomas with General Paul J. Kern

General Michael Hagee, commandant of the Marine Corps, sees a lab demonstration during his visit. With him (left to right) are Professor Tim Swager, Professor Ned Thomas, and Dr. Kateri Paul (Nomadics).

In turn, members of the ISN community visited several Army and other DoD installations during the year, including the War College in Carlisle, Pennsylvania; the Training and Doctrine Command's Army Futures Center at Fort Monroe, Virginia; Special Operations Command in Tampa, Florida; the Army Research Laboratory in Adelphi, Maryland; the Army Research Laboratory in Aberdeen, Maryland; and the US Military Academy at West Point, New York. A group of researchers also visited the NIST Polymer Division and Center for Neutron Research in Gaithersburg, Maryland. In additional, Professor Edwin Thomas attended two meetings of the Board on Army Science and Technology and three meetings of the Army Science Board.

Seven ISN faculty and staff, 10 members of ISN partner companies, and four Army scientists participated in a field excursion to Fort Leonard Wood, Missouri, in May 2004, visiting the Chemical School, Engineers School, and Military Police School. More field excursions are planned for the coming year.

The ISN communications program evolved with the launch of a newsletter ("ISN News") in September 2003, to be published three times a year. In January 2004, the ISN released its first identity DVD, entitled "Soldier of the Future." Running 12 minutes, the video describes the ISN's mission and research and includes three short animated vignettes that illustrate how the ISN's research might help the soldier of the future. The piece, which won a Telly Award for its producers and animators (North Bridge Productions of Concord, MA, and Boston Animation of Boston, MA), has been very popular with the media, and more than 200 of the DVDs have been given to visitors or other requestors.

Media interest in the ISN leveled off somewhat from its first year, but still continued strong. The ISN appeared nearly 50 times in print, electronic, and broadcast media, including *BusinessWeek*, the *Wall Street Journal*, BBC World, *The Economist*, *Jane's Defense Weekly*, the History Channel, the *Boston Globe*, *Technology Review*, MSNBC, *Popular Mechanics*, *Die Zeit* (Germany), and *Chemical and Engineering News*.

The ISN launched a regular seminar series in the fall of 2003. The Army Nanotechnology Seminar series (ANTS) brings distinguished scientists and experts from the Army and other government agencies, as well as academia, to the ISN to speak on a topic of interest. Speakers for the 2003–2004 academic year included Ms. Heidi Shreuder-Gibson, Lieutenant Colonel Charles Dean, Mr. Jean-Louis DeGay, and Staff Sergeant Raul Lopez from the Natick Soldier Center, Professor Satish Kumar from the Georgia Institute of Technology, and Dr. Steven McKnight from the Army Research Laboratory.

Mr. Jean-Louis DeGay (right), from the Army's Natick Soldier Center, explains the soldier's body armor system at an ANTS seminar in April 2004.

Future outreach plans include documenting the ISN's evolution, in both print and video, to enable the production of success stories down the road. Additional video vignettes profiling ISN research projects will also be created, with a new ISN DVD produced some time in 2005. An ISN Day event is also being planned for next year to provide interested communities within the DoD, academia, and industry an opportunity to hear about new research developments from the ISN.

Appointments, Visitors, and Awards

During the past year, the ISN appointed two additional headquarters staff members: Mr. Franklin E. W. Hadley, outreach assistant (December 2003), and Dr. Catherine Byrne, laboratory manager (June 2004).

Dr. Alex Hsieh from the Army Research Laboratory joined the ISN as a visiting researcher in October 2003, and Dr. Tommy Wong, also from the Army Research Laboratory, continued as a full-time visiting scientist at the ISN. Dr. Demetri Psaltis from Caltech also worked at the ISN for several months. In addition, several research scientists from the ISN's industrial partners now work in the ISN's laboratories either part-time or full-time: Dr. Randal Hill (Dow Corning), Dr. Joongho Moon (Nomadics), Professor Sonya Shortkroff (Harvard Medical School/CIMIT), and Dr. Kateri Paul (Nomadics).

Professor Ned Thomas, ISN director, was appointed a member of the Board on Army Science and Technology in January 2004.

In June 2003, seven members of the ISN headquarters staff were honored with an Infinite Mile Award from Professor Alice Gast for outstanding teamwork on the first annual Soldier Design Competition.

Future Plans

In the coming year, the ISN research enterprise will further evolve as new results begin to shape the direction of the research. Areas where early transitioning is likely will also begin to emerge. A Technical Advisory Board (TAB) will replace last year's Capability Area Review Teams (CARTs), and will meet for the first time in late September 2004. The second annual Soldier Design Competition will also kick off in September.

During this extraordinary time when so many American men and women are serving in conflicts overseas, the ISN's mission has never been more relevant. We expect that interest in our research and successes will continue to be very strong.

Edwin L. Thomas
Director
Morris Cohen Professor of Materials Science and Engineering

More information about the Institute for Soldier Nanotechnologies can be found at http://web.mit.edu/isn/.