Institute for Soldier Nanotechnologies

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Outline

- Institute Introduction
  - Mission, Goals and Objectives
  - ISN Resources and Organization
- Technical Program
  - Project summaries and expected milestones by research team
- Outreach Program
- Summary

Objective Force for Full Spectrum of Missions

Environmental Complexity

High
Urban

Open rolling terrain
Low

Increased strategic responsiveness

- *Brigade in 96 hrs; Division in 120 hrs; Five Divisions in 30 days*
- *Fight immediately upon arrival*
- *Simultaneous air and sea lift*

Stability and Support Operations — *Small Scale Contingencies* — *Major Theater War*

Spectrum of Conflict

Capabilities for an Uncertain Future

OFW Capabilities Create A Formidable Warrior…

Lethality - Direct and indirect engagement; less than lethal engagement; target detection/recognition; synchronization of fires; target handoff; ID friendly/ enemy/non-combatants; target designation

C4I – multifunctional materials for embedded sensors, Signature Management

Power Sources – energetic materials

Analysis & Assessment - Modeling tools to enable optimal system development and assessment; virtual prototyping; individual and force on force modeling

Survivability – Chem/Bio Detection and Protection, Exoskeleton Components, Enviromental Protection, Multilayered polymers in face shields for laser protection

Mobility – Nanofibers for lighter weight materials, multifunctional materials to reduce overall system weight, Compact Power Source Materials such as Fuel Cell Membranes

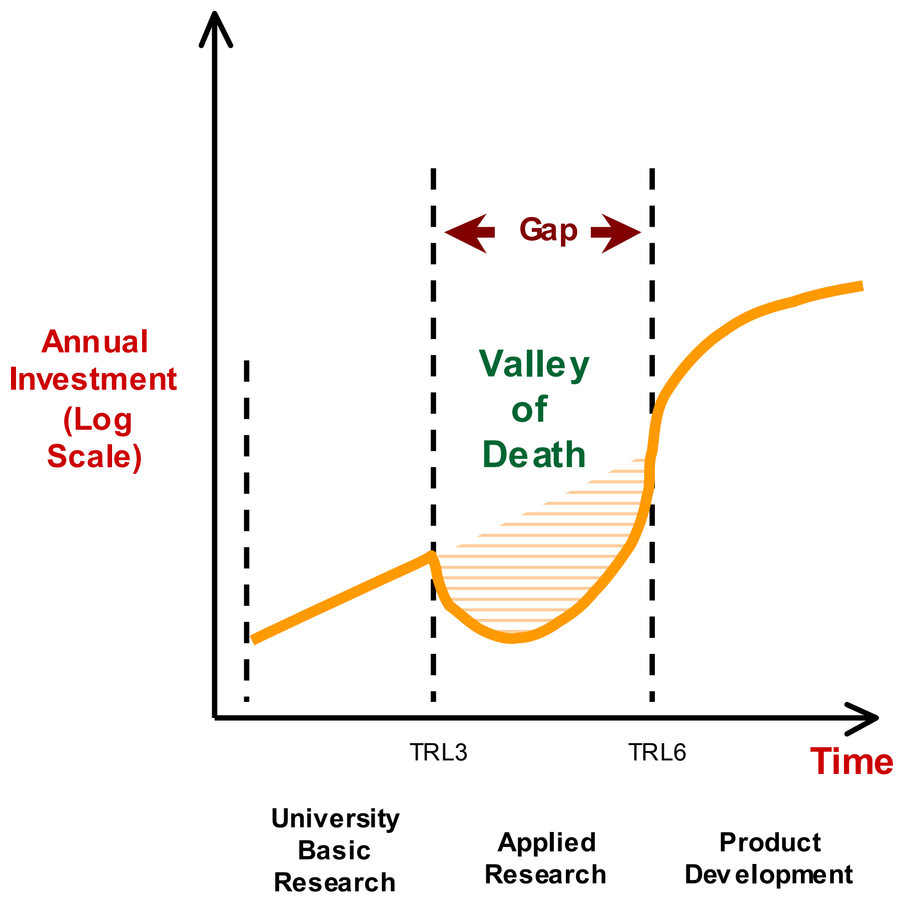
Sustainability –Materials for water quality testing (MIP)

Training - Individual, small unit, leader training concepts; embedded training, novel TTPs to exploit OFW capabilities

Human Performance – Micro-Climate Conditioning, Biomonitoring/Triage

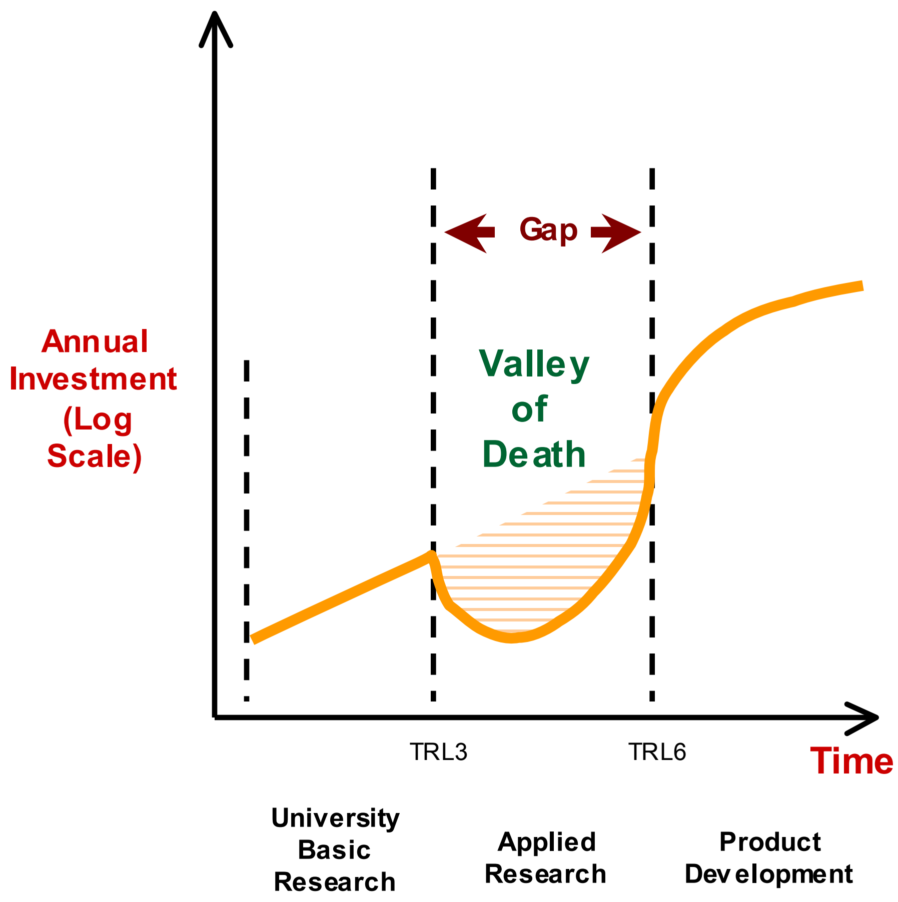
System Engineering and Integration - Integrate all technical areas into comprehensive, integrated system of systems; weight, power, and cost treated as independent variables

Transition Time Concept / Goal



- Basic Research at University
  - Basic concept developed and a lab-scale demonstration or proof of concept made of the basic technology (TRL3)
  - Possible applications and uses of technology are discussed.
- System Development
  - Must have technology at TRL6-7
  - Must fit within current system concepts
    - Operational requirements, doctrine etc.
    - Current fielded capabilities
- Between is the "Valley of Death"

Why the "Valley"?



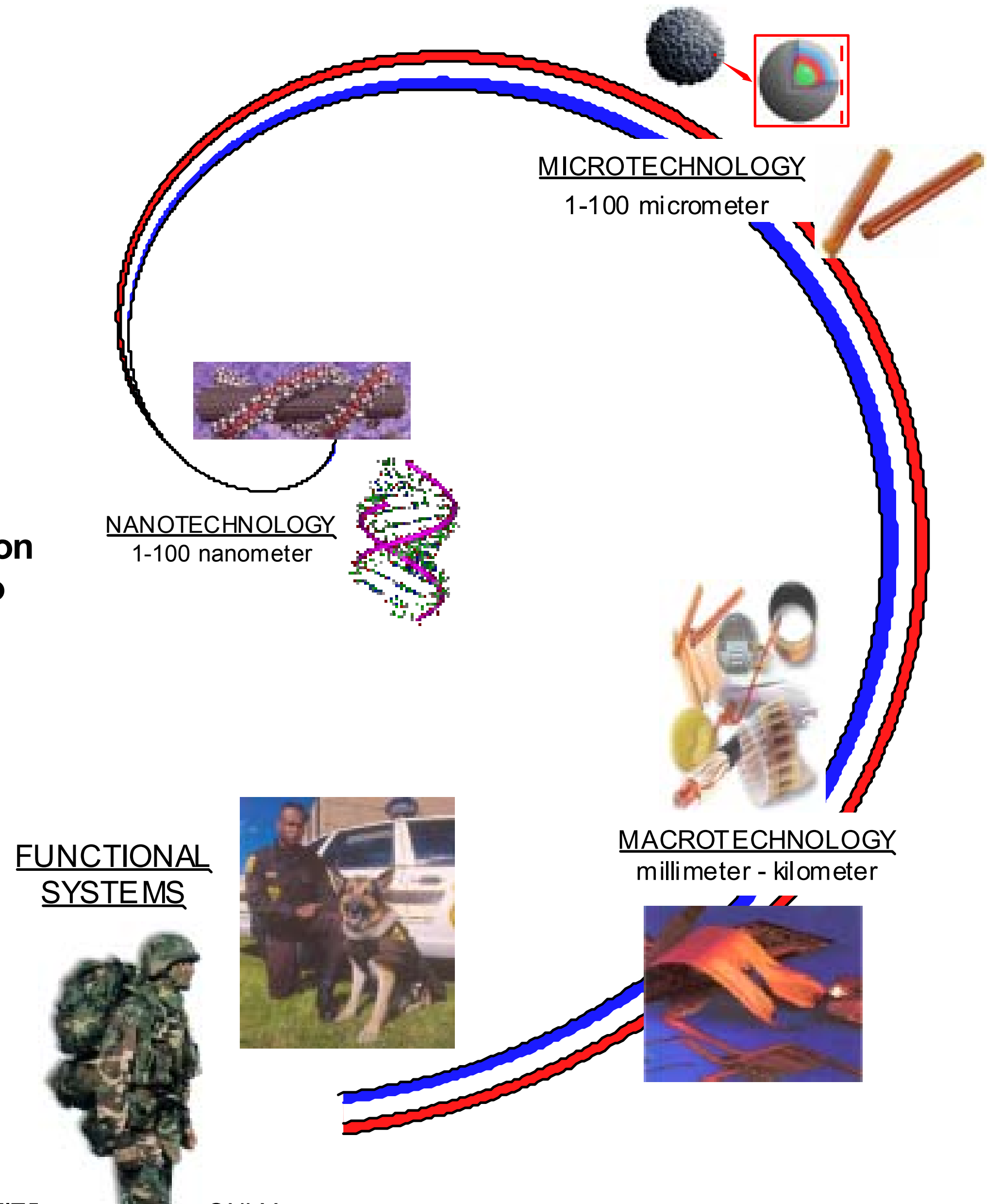
- Time and Capital Intensive
  - 5-10 years and a total of $7-20M at an applied research lab
  - Scale-up work is difficult, even QC et al.
  - Need a Customer and a profitable product … and to get it out fast!
- University Concerns
  - Diluted research efforts & lack of experience in commercialization
  - Researchers can't run companies and transition technologies
  - Venture Capital is very hard to get!
- Development Lab Concerns
  - "Not Invented Here"
    - Need training to get started right away doing relevant work
    - Require access to SOA equipment and expertise in new field
  - Disruptive Technologies
    - "We can't use that!"
    - "We don't work that way!"
  - Venture Capital is very hard to get!

University Affiliated Research Centre

- Basic Research funded at University
  - Maintain science infrastructure
  - Train new graduate students in relevant fields
- Industrial Partners
  - Strong presence at University to learn about technology opportunities
  - Access to all IP created by University work
  - Access to full research facilities for development and scale-up work
  - Access to potential customers (Army) to enhance product acceptance
- Army Partnering and Oversight
  - Presence at University to learn about technology applications
    - Implications on current systems and doctrine
  - Provide Technology projections to allow Venture Capital to see future value of technologies
  - Create a realistic "Tech-Pull" from the customer base

Institute Mission

- Basic research, transitioning, and outreach in nanomaterials and nanotechnology to enable revolutionary advances in soldier protection and survivability
- Nanoscience/Nanoengineering:
  - Some properties become size dependent below some critical length scale.
  - Ability to design and build structures on the nanoscale and assemble them into macroscopic systems.
- Opportunities:
  - New materials, new properties, new phenomena.
  - Hybrid material combinations unattainable in nature.
  - Hierarchical structures; gradients, sandwiches
  - Dynamically tunable materials and properties



Institute Connection to Army

- University Affiliated Research Centre (UARC)
  - University Group identified as a national resource for research
  - Long term, special relationship with Government
  - Intended to provide technical support to the Army for Research, Systems Development and Systems Acquisition
- Connection to Army
  - Large scale investment in a critical technology area
  - Plans to maintain investment for 10 years or more
  - Cannot create this type of talent pool in this area in the government in the time needed for the programme
    - Outsourcing of basic research in this critical area
    - Frees Army R&D infrastructure to accomplish core missions
  - Will maintain this group as a research asset for the DoD until the mission is considered accomplished
- New Paradigm for the Army S&T Community

Institute for Soldier Nanotechnologies

- Management
  - Director : Prof. Ned Thomas
  - Three Founding Industrial Partners
    - Strong involvement in proposal
    - Will add more industrial partners
- 130 -140+ Research Personnel
  - 33 faculty
  - 65 → 80 grad students
  - 28 → 25 post-doc
  - 3 professional staff
  - 4/3 → 8/8 Guest professionals (Army/Industry)
- Facility
  - 28,000 ft^2 on/near MIT campus and 1,400 ft^2 clean room space

Raytheon

DUPONT

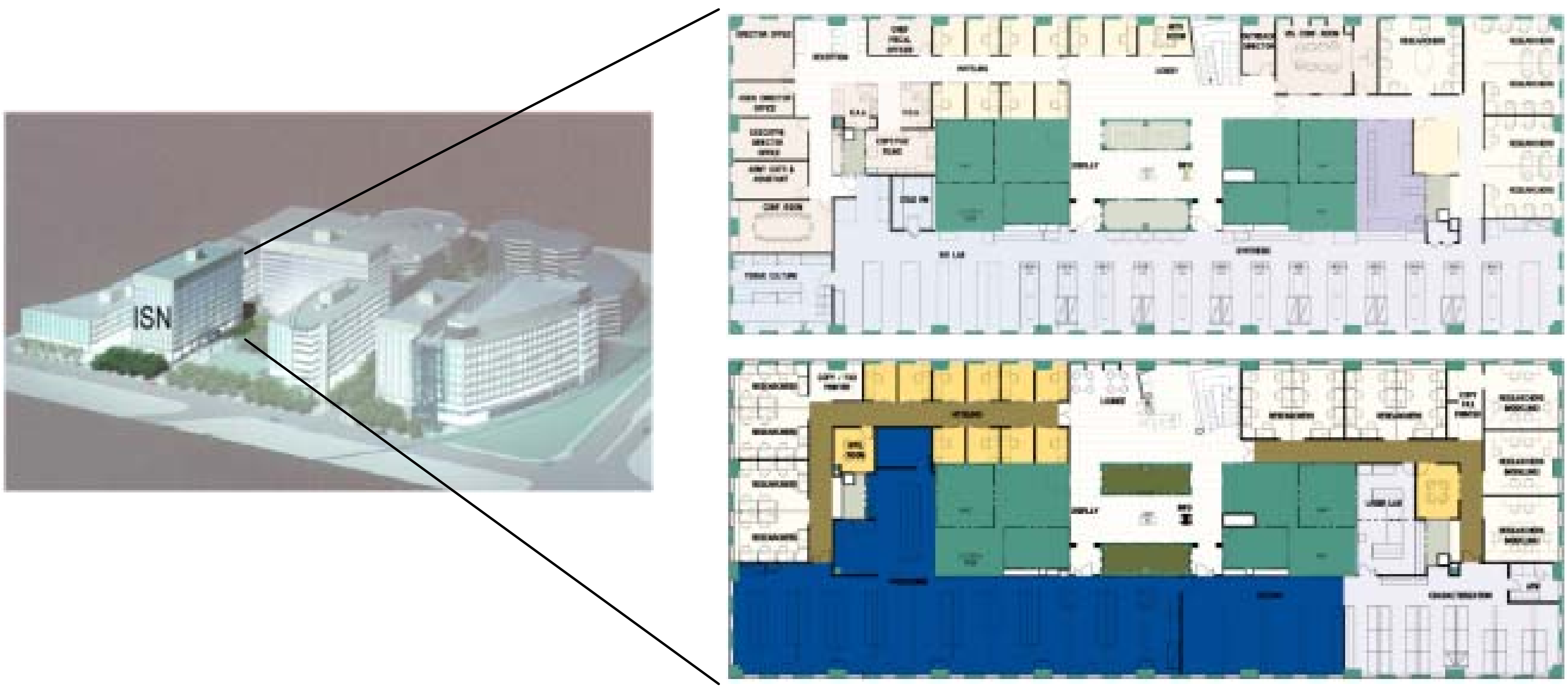
CIMIT Innovative Technology for Medicine

BRIGHAM AND WOMEN'S HOSPITAL Specializing in care for a lifetime

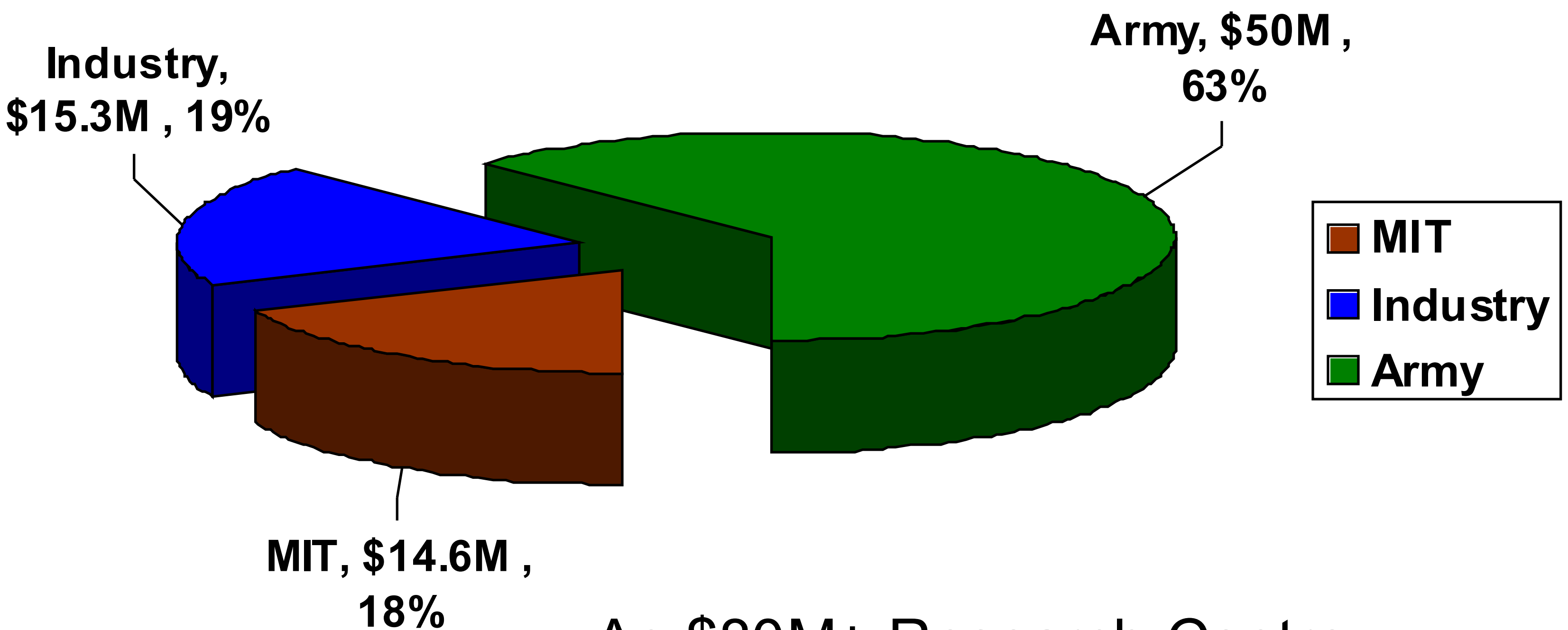
MASSACHUSETTS GENERAL HOSPITAL

Dedicated ISN Facility

- Innovative Collaboration-Centred Design of Laboratory Space
- 4th and 5th floors of 500 Tech Sq
- 28,000 ft^2 on/near MIT campus and 1,400 ft^2 clean room space



ISN Funding for 5 Years



An $80M+ Research Centre,

Research Extensions and Dedicated Facility Not Included

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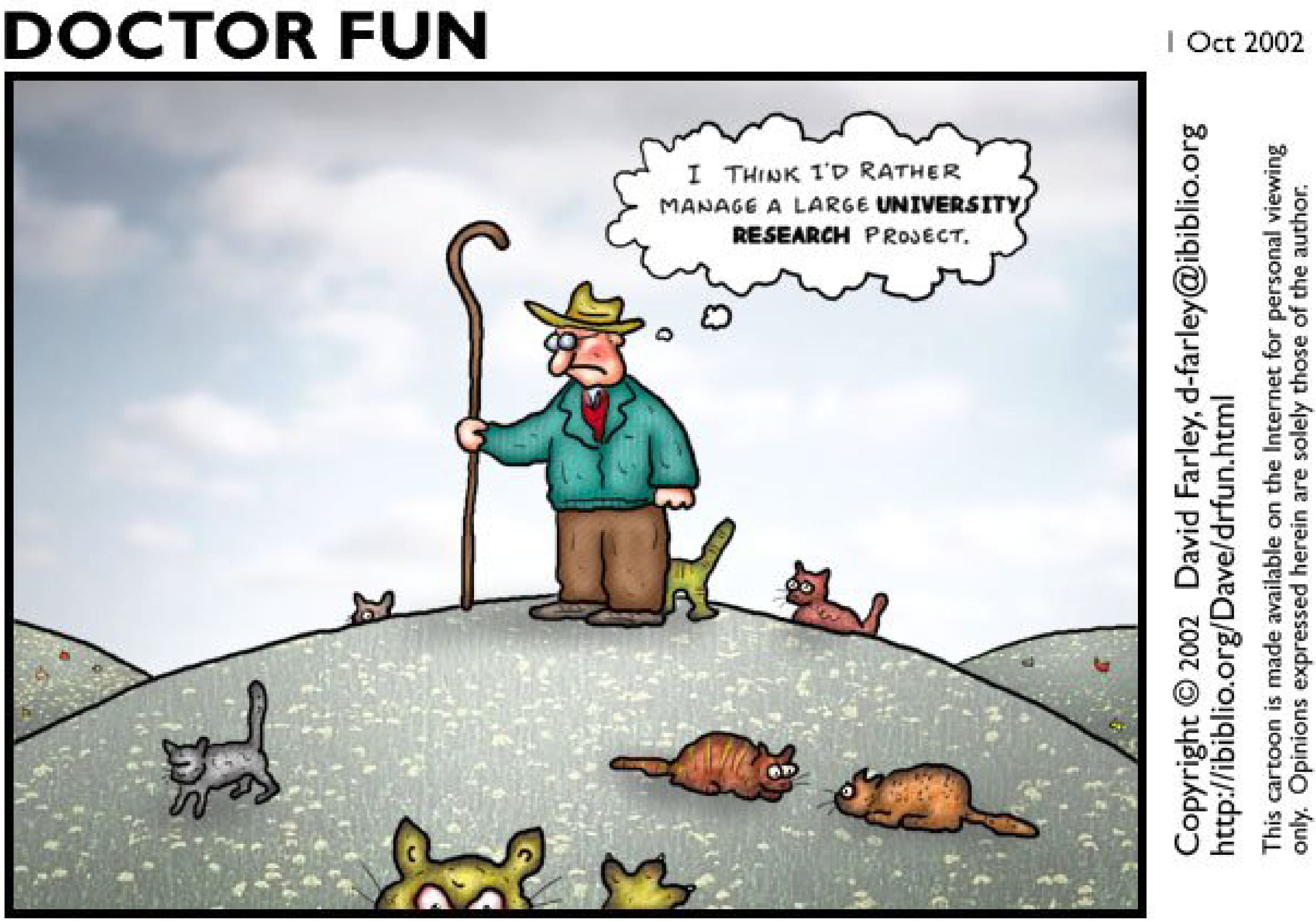
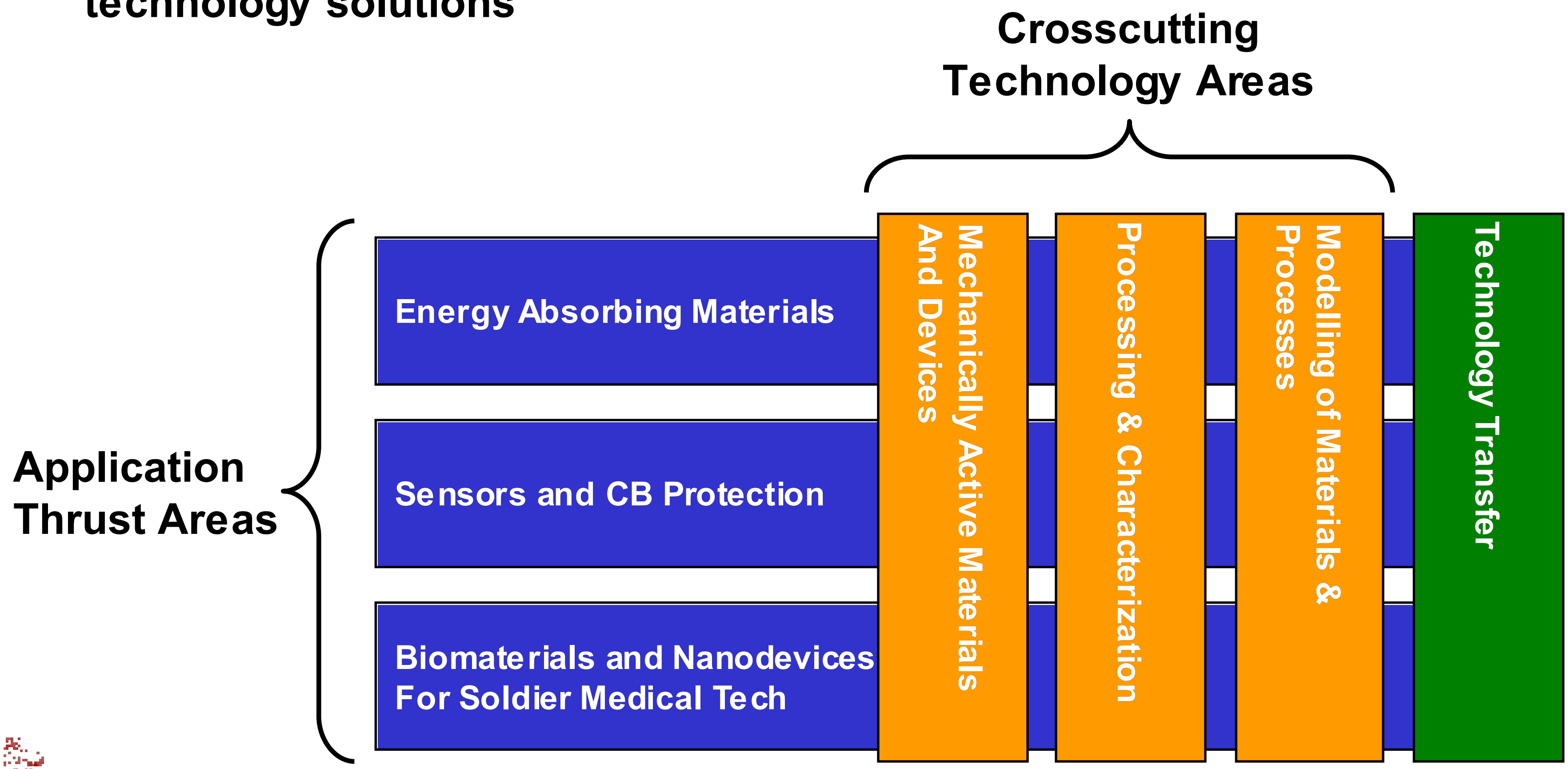
ISN Research Organization



The daydreams of cat herders

Research Staff Organization

- 6 Research Teams organized as 3 interlocking Development Groups
- Prevents "stovepiping" of technology solutions
- Overarching Tech Transfer team to speed integration into Soldier Systems.



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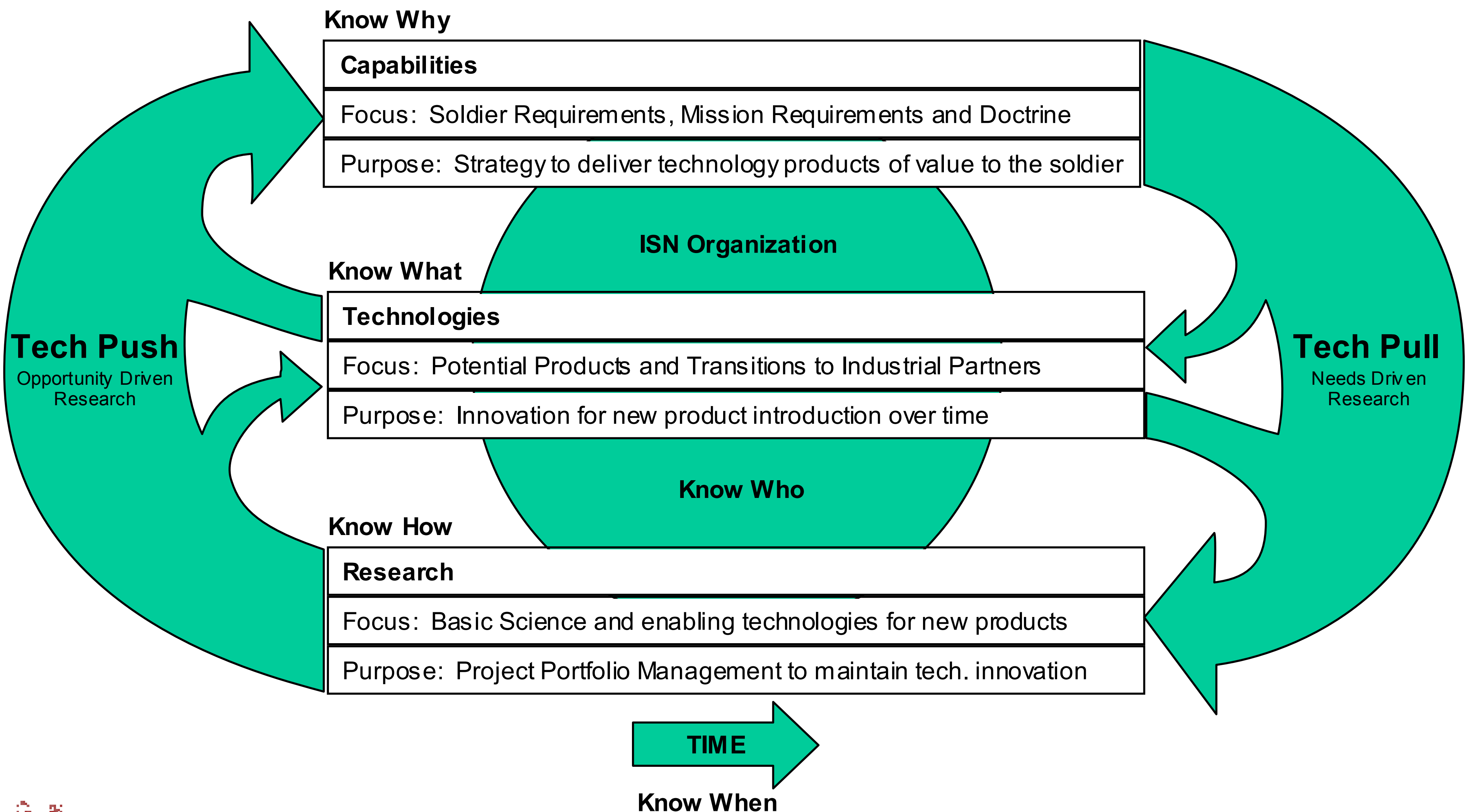
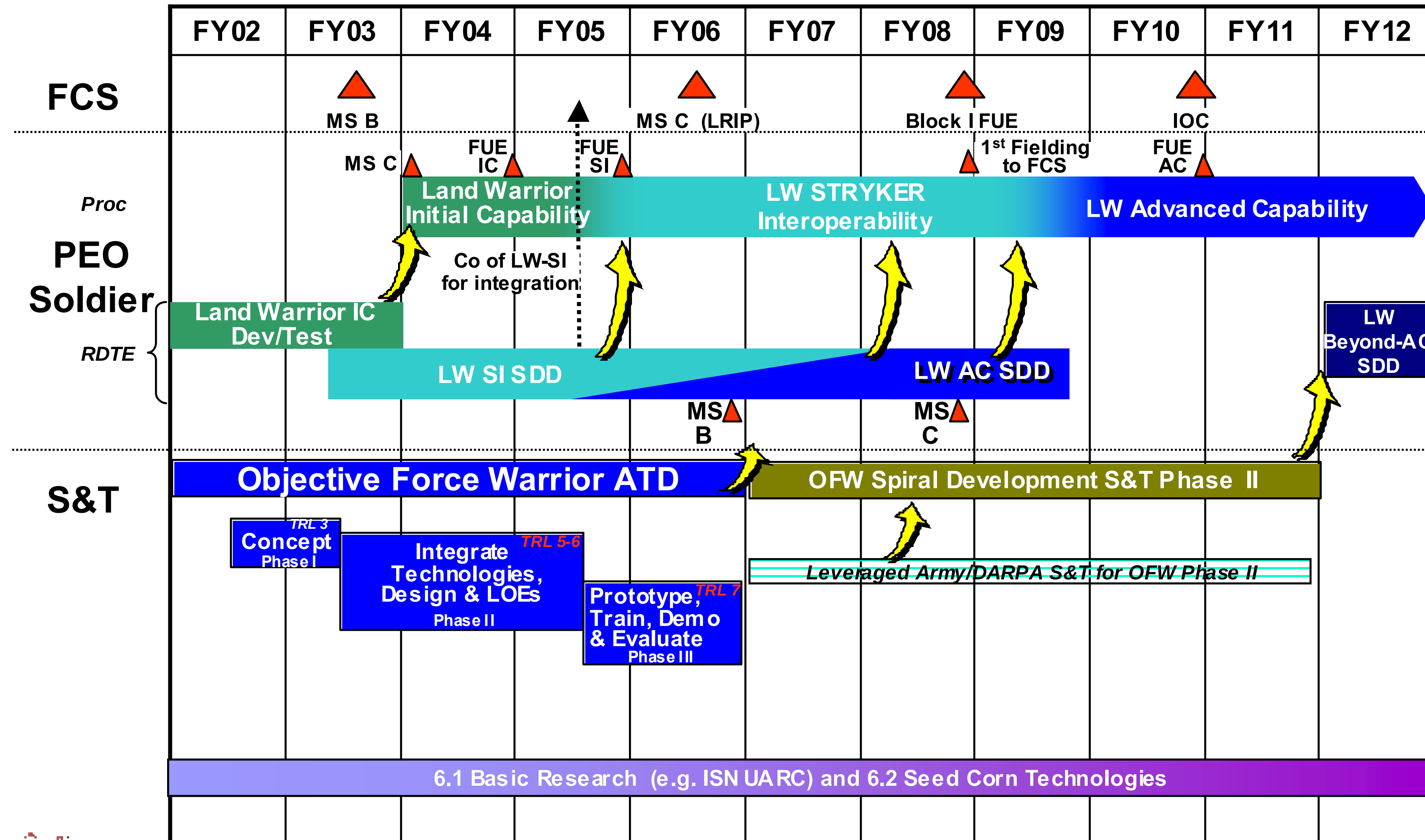
Roadmapping Process



Soldier Systems Acquisition Roadmap



Capability Areas

- Physical Protection
  - Ballistic, Puncture, Shock and Impact protection
  - Traditionally, Body Armour
- Chem/Bio Protection
  - Protection from CB agents
- Environmental Protection
  - Insects (ticks, mosquitoes, leaches, spiders etc)
  - Real-time, local, autonomous detection of CB agents
  - Snakes/lizards & other small animals
  - Local endemic diseases
- Projected Energy Protection
  - Laser eye protection, microwave energy protection
  - Hearing protection (sound, concussion)
- Performance Enhancement
  - Cooling/Heating to optimize physical performance
  - Autonomous load carrying systems (like DARPA EHPA)
- Injury Intervention and Cure
  - Performance monitoring
  - Triage & auto/remote treatment

Capability Area Review Teams

- Protection (Physical Protection; Chem/Bio Protection; Environmental Protection; Projected Energy Protection)
- Performance Enhancement
- Injury Intervention and Cure

ISN Capability Areas

- Protection
  - Develop lightweight ballistic and impact resistant functional materials
  - Adaptable/multifunctional materials and devices for protection from kinetic and chem/bio assaults
- Performance Enhancement
  - Sustain the ability to perform missions when impaired
  - Impart superhuman capabilities
- Injury Intervention and Treatment
  - Autonomous battlefield triage; life sustainment/splints/casts
  - Detect and mitigate chem/bio threats
  - Enhanced wound healing

Physical Protection

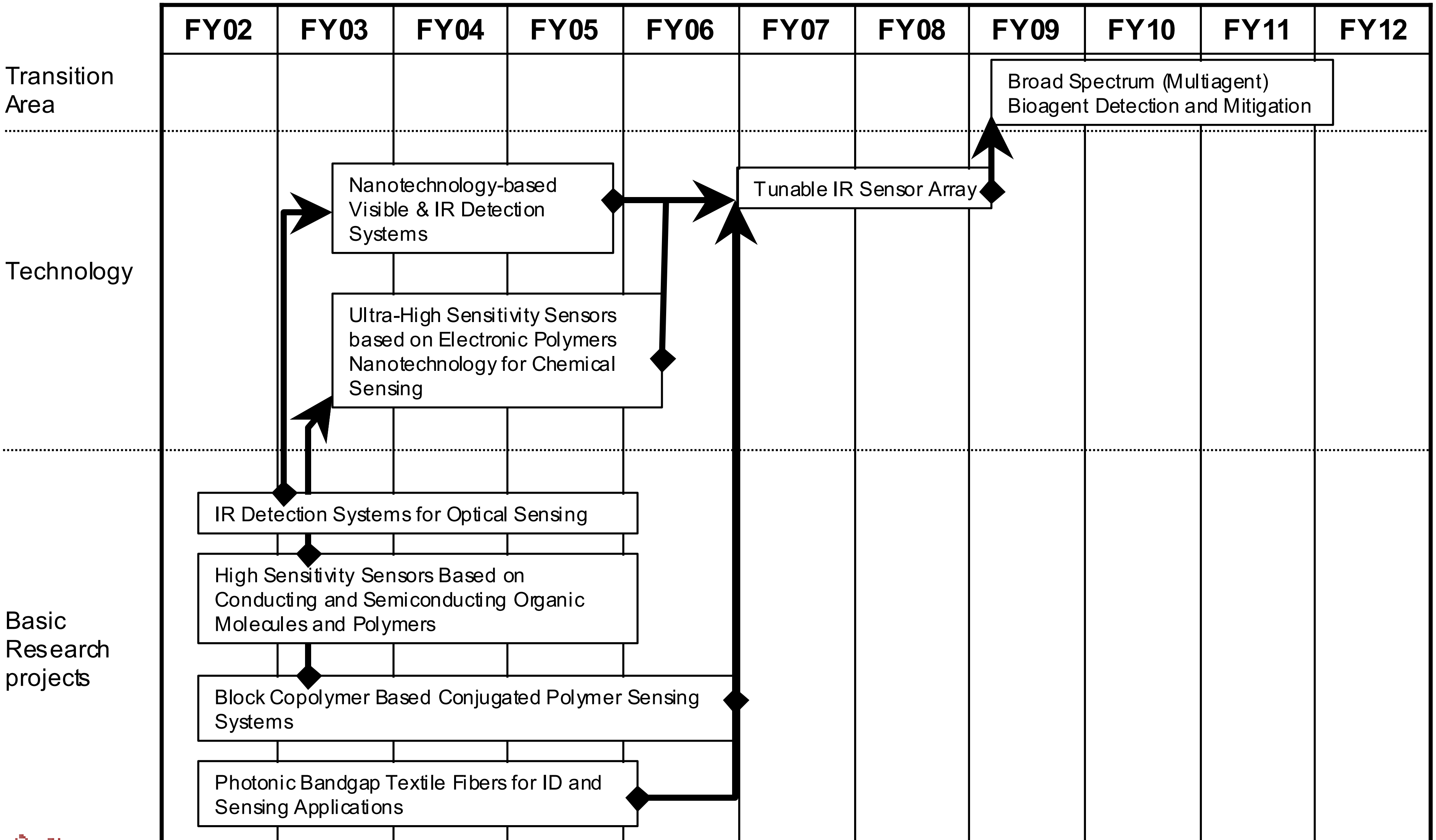
- Technology Areas
  - High strength nanofibres
  - Spinning of synthetic silk-like polymers
  - Design and predictive analysis tools for ballistic performance of armour systems
  - High ballistic performance nanocomposite laminates
  - Molecular "Chain-Mail" for Ballistic/Puncture protection
  - Adaptive Armour

- Research Projects
  - New Molecular Architectures for Ultra-Strong Energy Absorbing Polymers
  - Ultra Lightweight Nanorelief Networks, Self Assembled MicroTrusses and Photopatterned Nanocomposites
  - Mechanics of Active Materials
  - Synthesis & Resin Spinning of Artificial Silk-Like Polymers
  - Spectroscopic Interrogation of Materials Deformation At Variable Strain Rates
  - Multiscale Design and Evaluation of Biological and Synthetic Nanostructured Composite Materials
  - Dynamic FTIR Microstructural Evaluation
  - Nano-scale Multilayer Film Processing – Materials Studies
  - Hierarchical Material Assemblies For Ballistic Protection
  - Investigation of Deformation & Failure Mechanisms in High Performance Fabrics
  - Processing of Fibers and Fibrous Materials
  - Nano-scale Multilayer Film Processing
  - Chemical Vapor Deposition Polymers for Soldier Interconnection
  - Hierarchical Material Assemblies For Ballistic and Blast Protection - Modeling and Simulation Studies
  - Design/ Tuning Nanoparticles for Mechanical, Electronic & Chem. Properties
  - Dissipative Particle Dynamics Studies of Nanocomposite Rheology
  - Multiscale modeling of nanocomposites
  - Modeling and simulation of deformation & failure behavior in woven fabrics

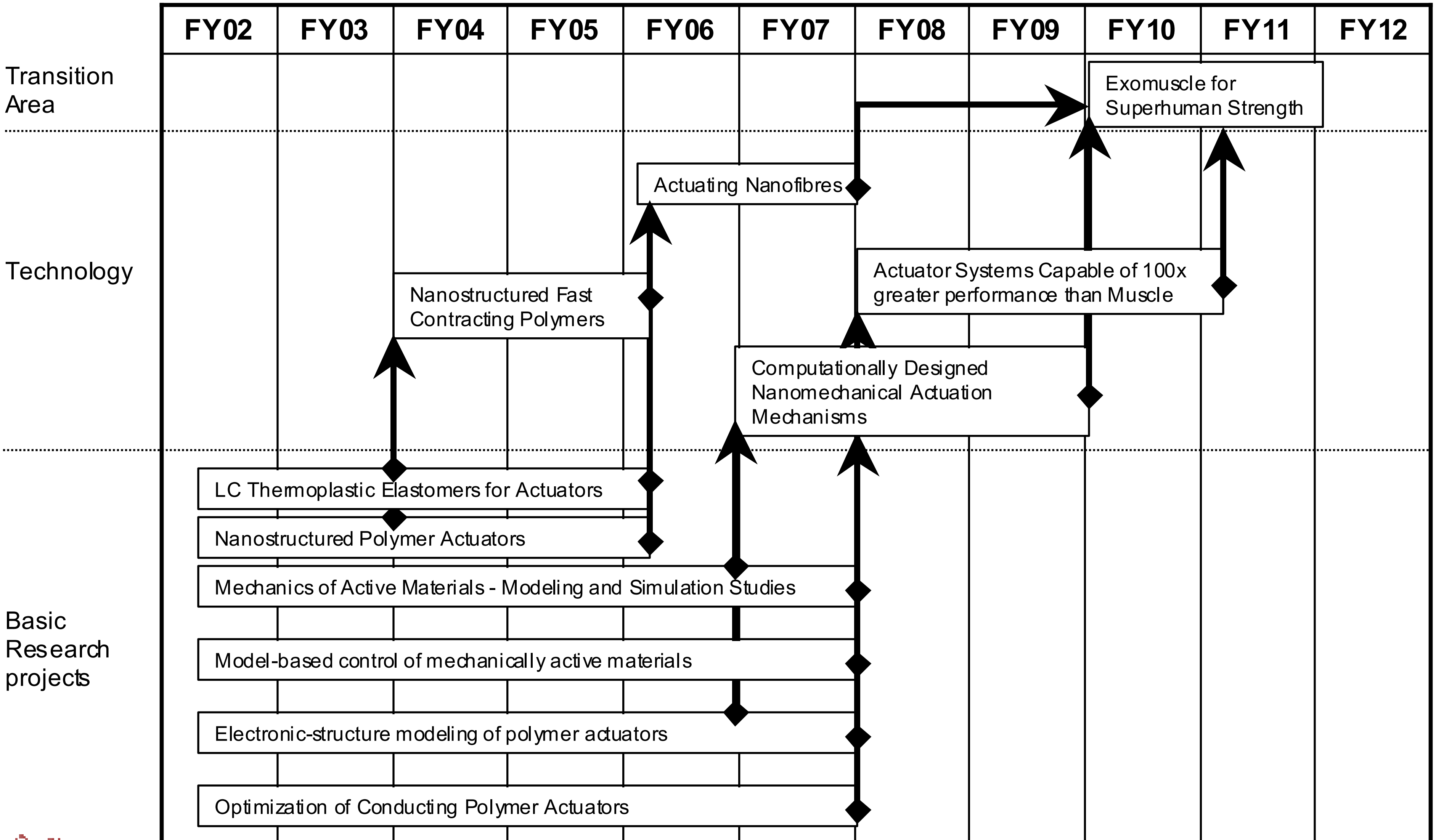
Chem/Bio Protection

- Technology Areas
  - Tunable IR Sensor Array
  - Broad spectrum (multiagent) bioagent detection and mitigation
- Research Projects
  - IR Detection Systems for Optical Sensing
  - Photonic Bandgap Textile Fibers for Sensing Applications
  - Viral/Peptide Bio Array Sensing Systems
  - Dendrimer/Nanoparticle Assemblies as Chemical Toxin
  - High Sensitivity Sensors Based on Conducting and Semiconducting Organic Molecules and Polymers
  - Block Copolymer Based Conjugated Polymer Sensing Systems
  - Low P Material Deposition by Misted Solution Transport

Chem/Bio Protection



Performance Enhancement



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Protection: Success Assessment

Revolutionary (Red)

Yellow

Evolutionary (Green)

CHALLENGES

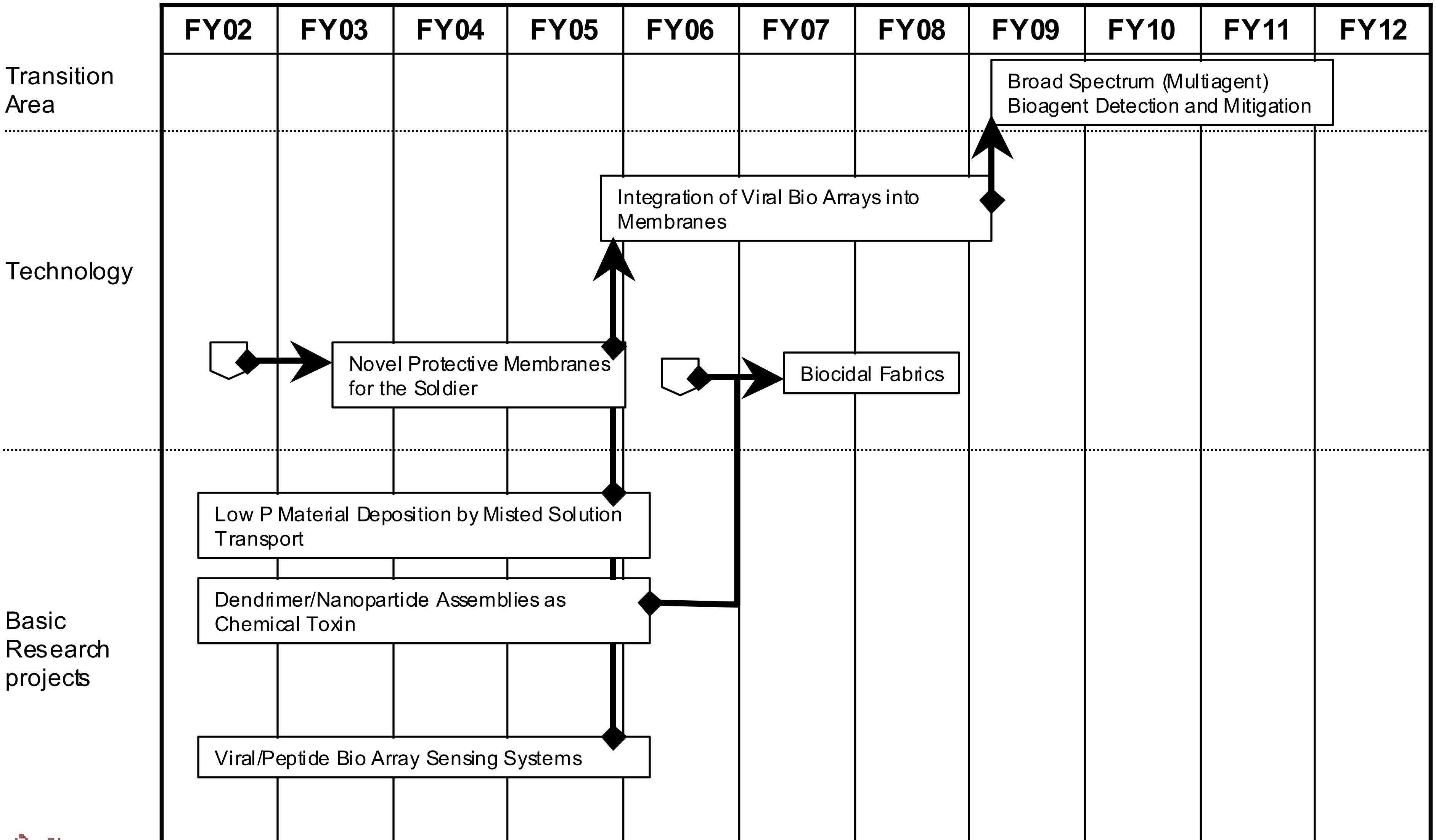
TECHNICAL APPROACHES

TECHNICAL APPROACHES	Enhanced energy dissipation at high rates	High strain rate physics poorly understood	Armor effects on soldier (hard impacts)	Weight vs. protection tradeoffs	High sensitivity/specificity/ robust sensors	Systems Integration
Spatially & orientationally patterned hierarchical nanostructured materials-composites/synthetic silk	Green	Red	Yellow	Yellow	Red	
Materials testing/feedback from modeling of materials at high strain rates	Yellow	Red				
Molecular fabric and interlocking structures	Yellow	Red				
Detection and mitigation of Chem/Bio agents				Green	Red	Red
Dynamic systems for adaptive armor	Red	Red	Red	Red		Red
Tunable Vis/IR sensor array for situational awareness				Green	Red	Red
Electronic/Photonic textiles	Red			Green	Red	Red

Performance Enhancement

- Technology Areas
  - Nanostructured fast-contracting polymers
  - Actuating nanofibres
  - Computationally designed nanomechanical actuation mechanisms
  - Actuator systems capable of 100X greater performance than muscle
  - Exomuscle for superhuman strength
- Research Projects
  - Nanostructured Polymer Actuators
  - Optimization of Conducting Polymer Actuators
  - LC Thermoplastic Elastomers for Actuators
  - Chemically-Switchable Magnetism
  - Model-based control of mechanically active materials
  - Switchable Surfaces
  - Semi-active variable-impedance materials
  - Field-Responsive Fluids in Microchannels and Microfluidic Devices
  - Three Dimensional Integration of Microfluidic Devices and Fiber Networks
  - Novel Electro-osmotic Microfluidic Devices
  - Electronic-structure modeling of polymer actuators
  - Mechanics of Active Materials - Modeling and Simulation Studies

Chem/Bio Protection



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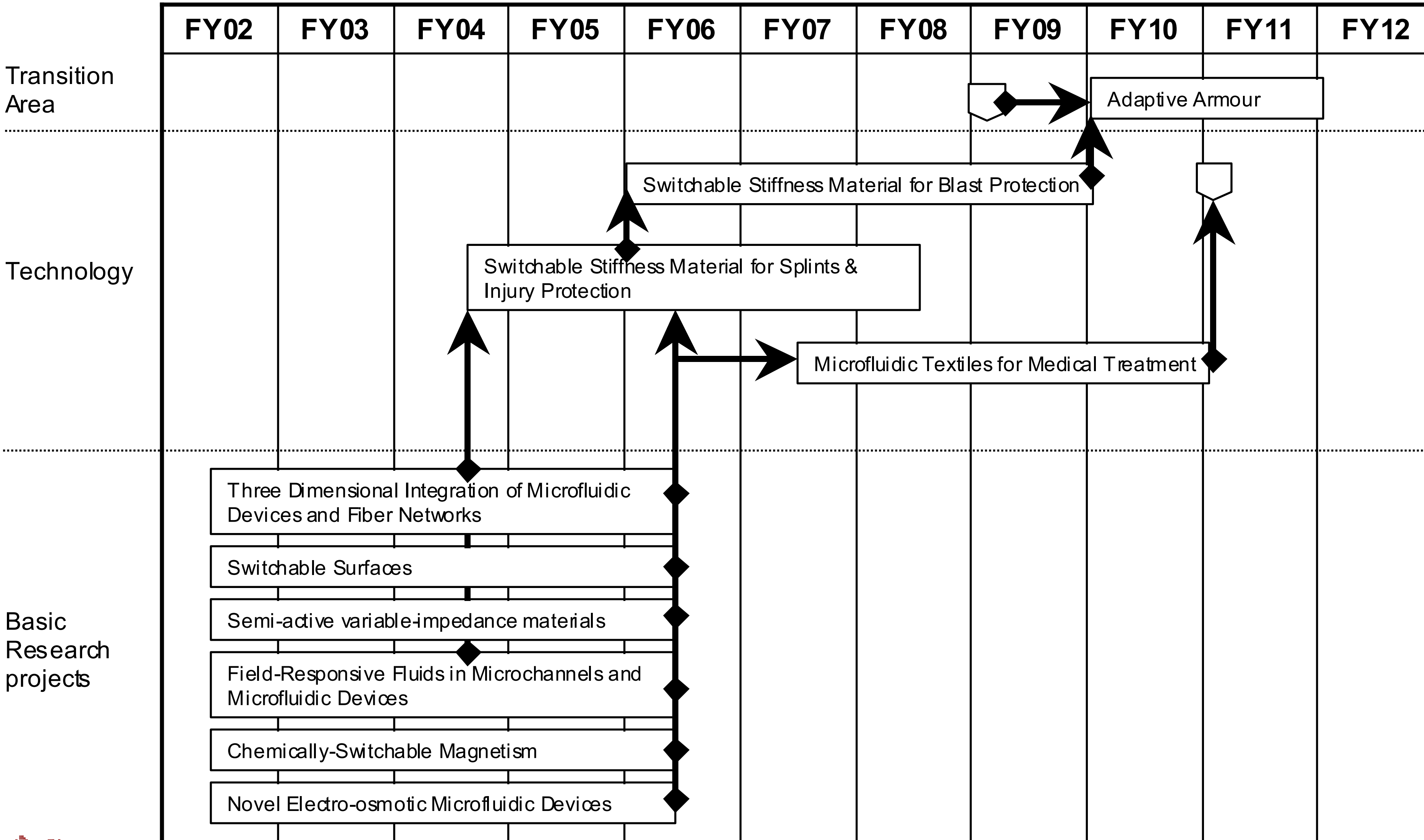
Performance Enhancement



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Performance Enhancement: Success Assessment

Revolutionary (Red)
Yellow
Evolutionary (Green)

CHALLENGES

TECHNICAL APPROACHES

TECHNICAL APPROACHES	Improved Kinetics	Exceed mammalian muscle tension	Creation of giant Contractiale/expansion	Increases to electro-mechanical efficiency	Need high power to mass	Systems Integration
Nanostructured actuator polymers	Green	Red	Red	Yellow	Red	Red
Chem-/magnetic-switchable materials	Yellow	Red			Yellow	Red
High throughput materials design and testing	Red	Red	Red	Yellow	Yellow	
Integrated polymer electronics control systems	Red					Red
Nanomechanisms for achieving unprecedented properties	Red	Red	Yellow	Red	Red	Red
Liquid crystal thermoplastic elastomers	Green	Yellow		Yellow	Red	Red
Model-based controls	Green					Red

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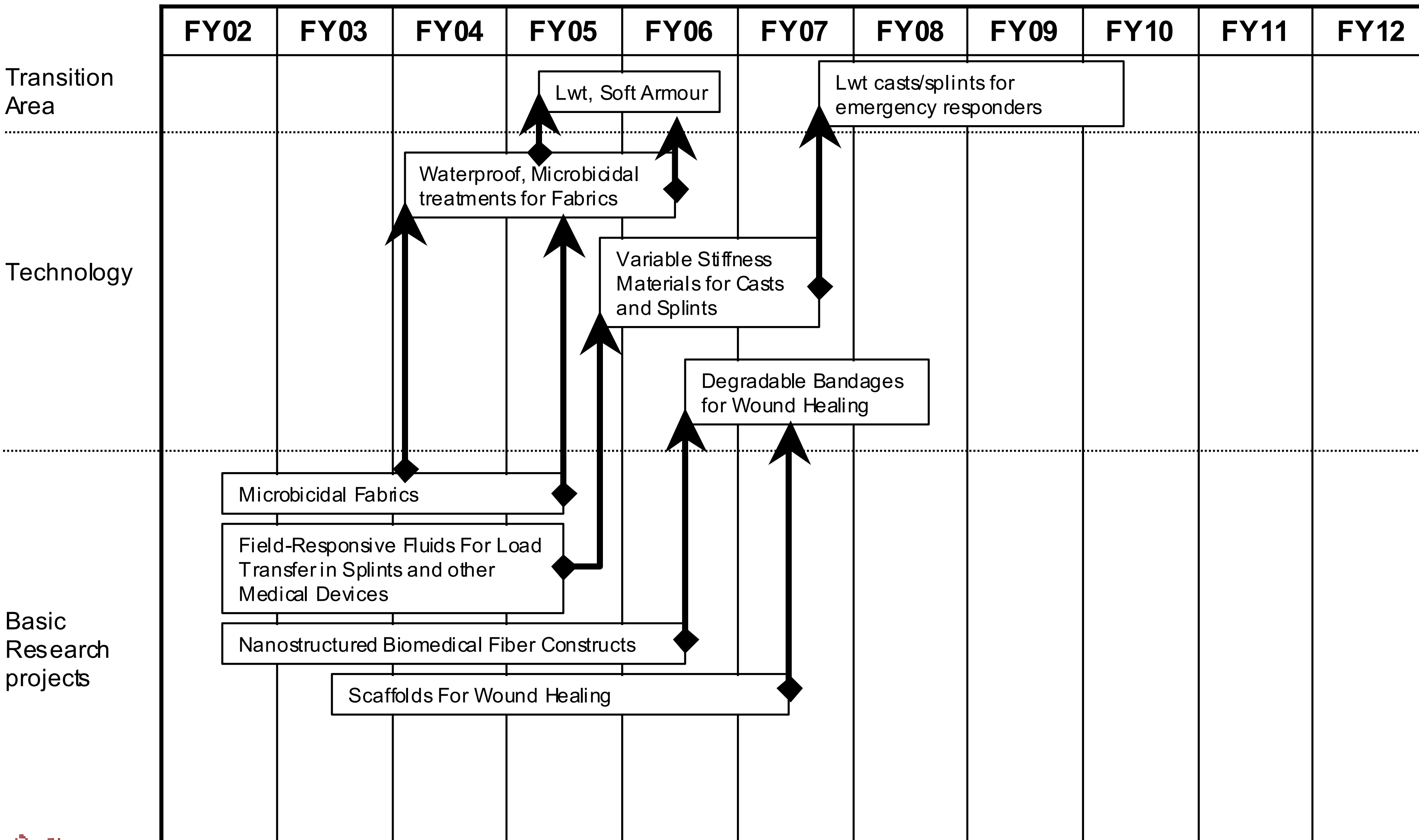
Injury Intervention and Cure

- Technology Areas
  - Biocidal, degradable bandages to speed wound healing
  - Variable stiffness materials for Casts and Splints
  - Microfluidic Textiles for Medical Treatment
  - Engineered injectable stabilization/treatment of penetrating trauma
  - Automated CPR for life sustainment
  - Demonstration of Critical Elements for Automonous Medical Treatment by Battlesuit
- Research Projects
  - Microbicidal Fabrics and Other Materials
  - Engineering Design and Synthesis of Scaffolds For Wound Healing
  - High Performance Sensors for Unknown Infectious Agents
  - Non-invasive Diagnostics and Delivery of Injury Intervention Agents
  - Nanostructured Biomedical Fiber Constructs
  - Field-Responsive Fluids For Load Transfer in Splints and other Medical Devices
  - Simulation of Behind-armor Effects of Ballistic Threats
  - Virtual Human Project - Continuum Model to Determine Physiological Responses

Injury Intervention and Cure



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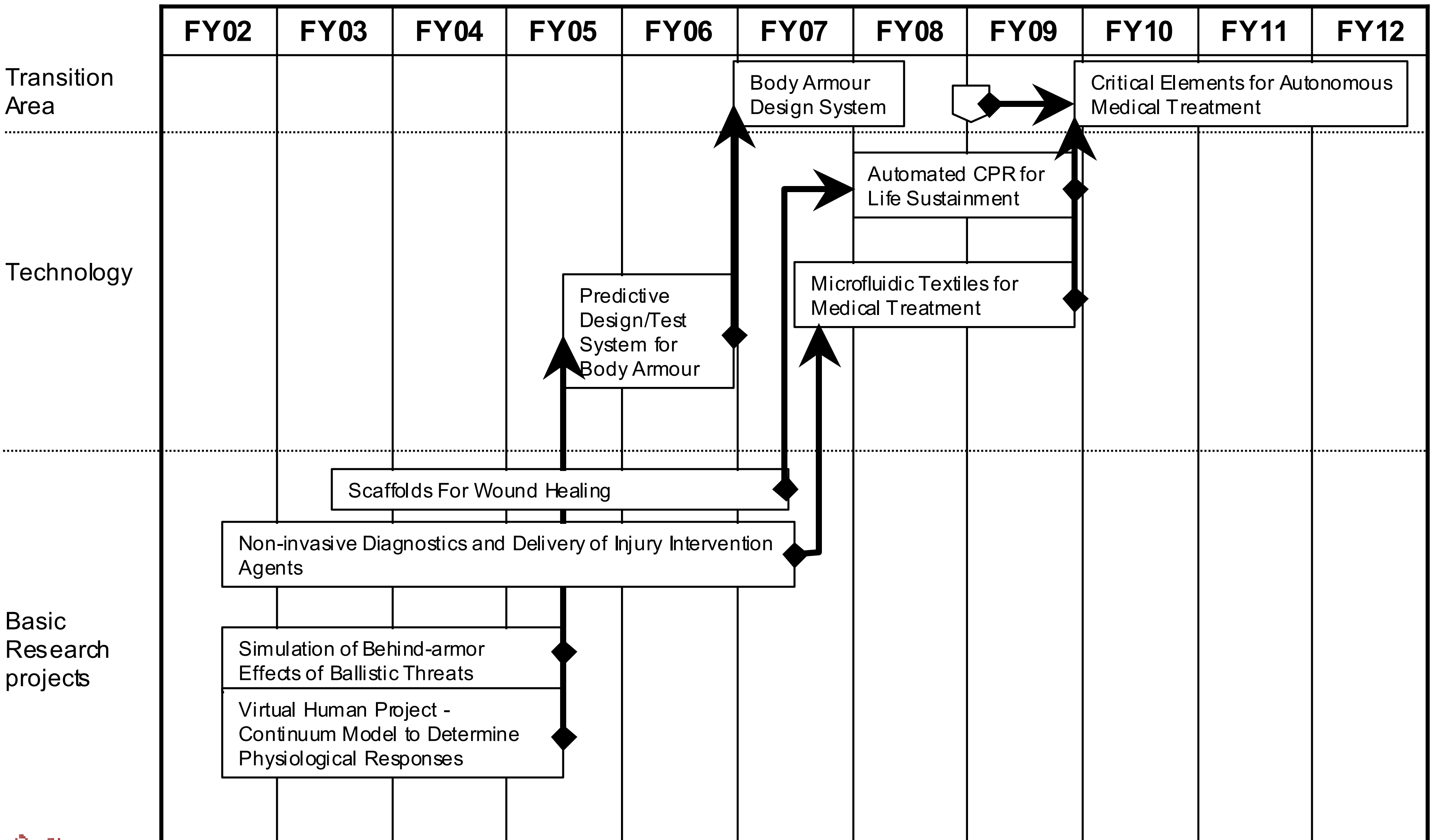
Injury Intervention and Cure



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Injury Intervention and Treatment: Success Assessment

Revolutionary (Red)

↑ (Yellow)

Evolutionary (Green)

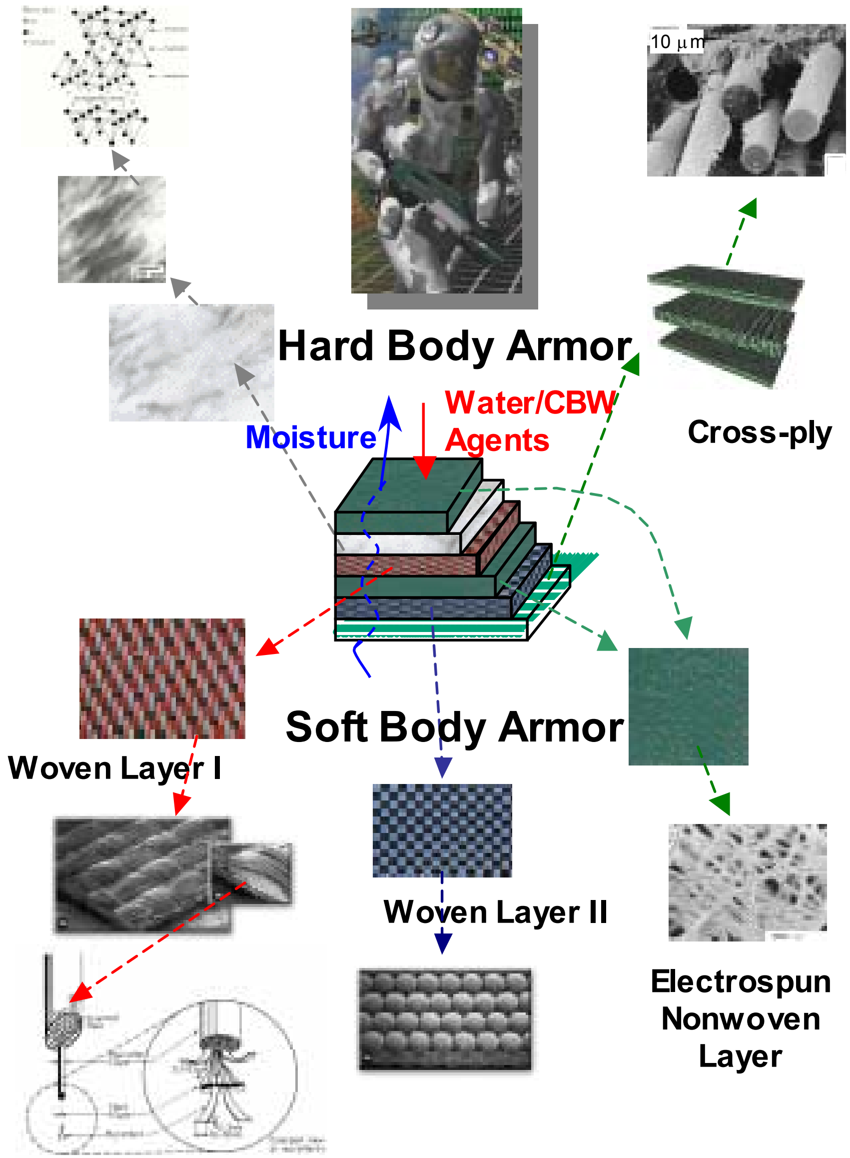
CHALLENGES

TECHNICAL APPROACHES

TECHNICAL APPROACHES	Triage battlesuit (Splints and Tourniquets)	Autonomous Triage and life sustaining systems	Prevention of infection and chem/bio exposure	Minimizing impact injuries by design	State-of-art medicine Insertion into battlespace	Systems Integration
Degradable polymers for enhanced wound healing		Green				Red
Microfluidics in textiles	Red	Red	Green		Red	Red
Polymers actuators and variable stiffness materials	Green	Red		Yellow	Red	Red
Breath sensors for monitoring of vital signs					Red	Red
Chem/bio sensor systems for detection and mitigation		Red	Red		Red	Red
Biocide textiles			Green		Green	Green
Drug administration by battlesuit		Red	Red		Red	Red

Team 1: Energy Absorbing Materials

- **Objective: To develop lightweight ballistic and impact resistant functional materials**
- **Leaders: Prof. Ned Thomas and Prof. Mary Boyce**
- **Critical requirements**
  - **Ballistic and impact resistance**
  - **Tactical mobility**
  - **Freedom for integration of other components (e.g. bio/chem)**
- **Overlying theme**
  - **Fabrication: new polymers and composites**
  - **Characterization: mechanical, morphology**
  - **Modeling: micromechanics, nanomechanics**



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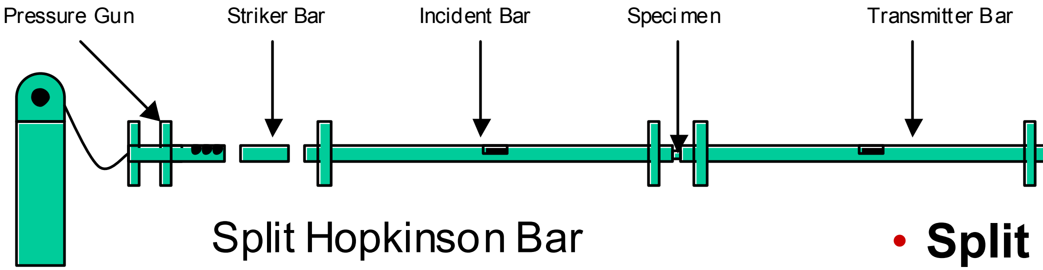
Overlying Theme

- **Fabrication**
  - New Chemistry
    - Design and synthesis of molecularly tough polymers
  - Blending
    - Molecular chainmail
  - Extrusion
    - Multilayer microlaminates
  - Self-Assembly
    - Multilayers and 3D microtrusses
  - Fiber spinning
    - Artificial silk and 3D interlocked arrays
- **Characterization**
  - Mechanical
    - Composites and individual components
    - Quasi-static and high rate loading
  - Morphological
    - Hierarchical length scale understanding of orientation and dispersion of nanoparticles
    - In-situ monitoring of morphology evolution during deformation
- **Modelling**
  - Hierarchically structured nanocomposites
    - Blunt trauma modeling of ballistic impact on body with armor system
    - Structure-property relationship understanding
    - Constitutive equations

High-Rate Testing Capabilities

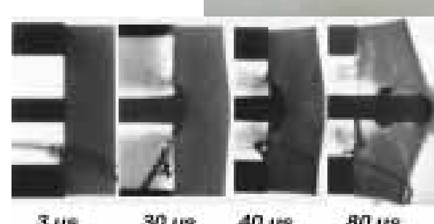


Split Hopkinson Bar

- **Split Hopkinson Bar Testing**
  - **Mechanical characterization at 10^2–10^4 /sec strain rates**
  - **Experiment can be "frozen" at various stages of deformation**

Light Gas Gun

- **Light Gas Gun Testing**
  - **High strain rate characterization**
  - **High speed photography of target**



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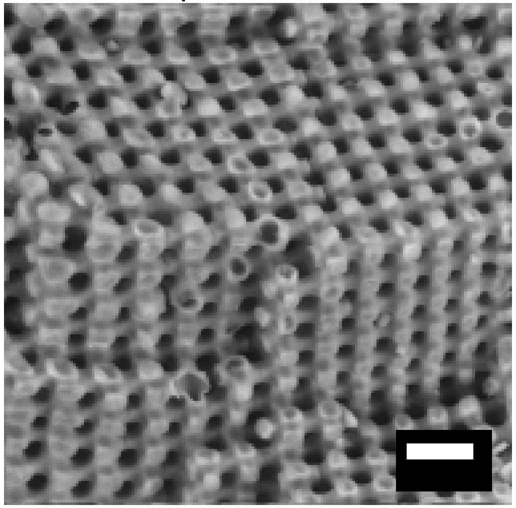
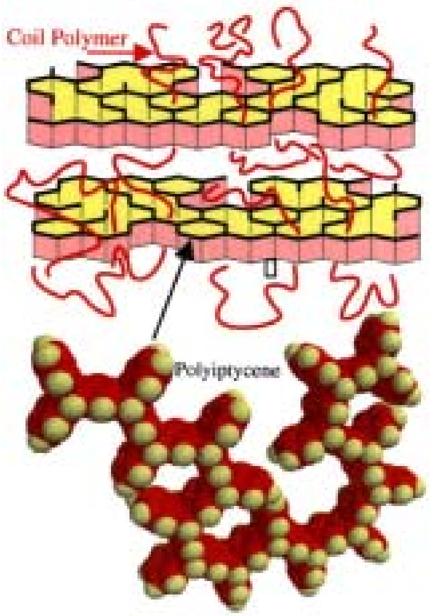
Nanocomposites

- Polymeric/Inorganic Nanocomposites
  - Objectives
    - 3D Truss Structures
    - Designed Ordered Nanocomposites
  - Approaches
    - Holographic Photopolymerization
    - Bio-replication/Templating
    - Self Assembly → Block Copolymers
    - Spatial Sequestration/Orientation of Nanoparticles

PS Replica of Sea Urchin



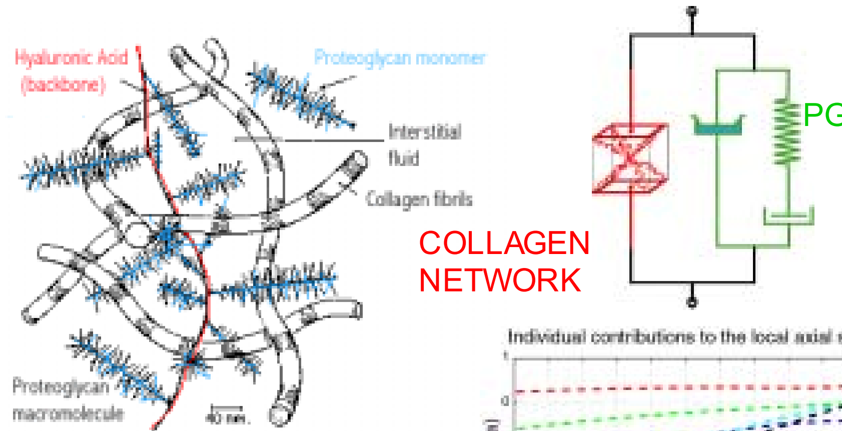


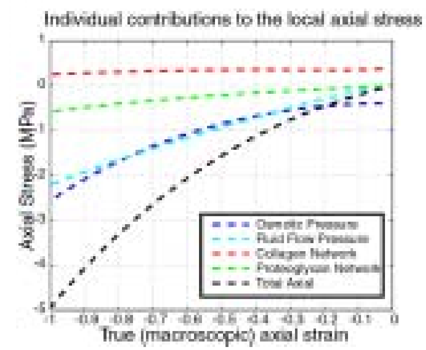
- Polyiptycene-based "Molecular Chain-Mail"
  - Objectives:
    - Produce an inherently puncture and penetration resistant molecular structure
  - Approach
    - Rotaxane type system
    - Large rigid Polyiptycene molecules in a layered, liquid-crystal system
    - Interpenetrating linear polymer to bind the system together

Evaluation of Tissue Trauma

- **Objectives**
  - **Development of Tissue damage models for behind-armour effects prediction**
  - **Design of Synthetic Tissue backing to measure behind armour effects to estimate tissue damage**
- **Approaches**
  - **In-situ measurement of tissue mechanical properties**
  - **Physically-based constitutive modelling of tissue structures**
  - **Development of high fidelity ballistic testing simulations**
  - **Design of synthetic backing materials that simulate human tissue**

Constitutive Modeling of Tissue

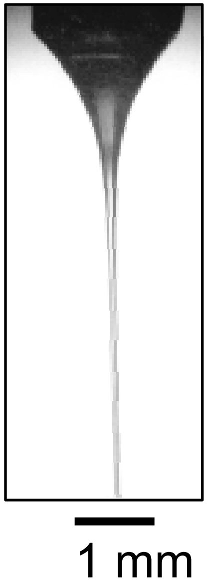


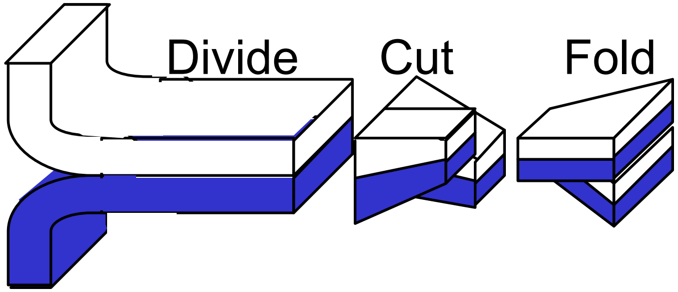


Biaxial Testing of Soft Tissues

Film and Fibre Processing

- Resin-spun synthetic silk
  - Objectives
    - Mimetic of Silkworm and Spider silk
    - Show superior mechanical properties compared to synthesized polymers
  - Approach
    - Develop Synthetic chemistry for system
    - Study crystallization kinetics and rheological properties during processing
    - Optimize for fibre strength

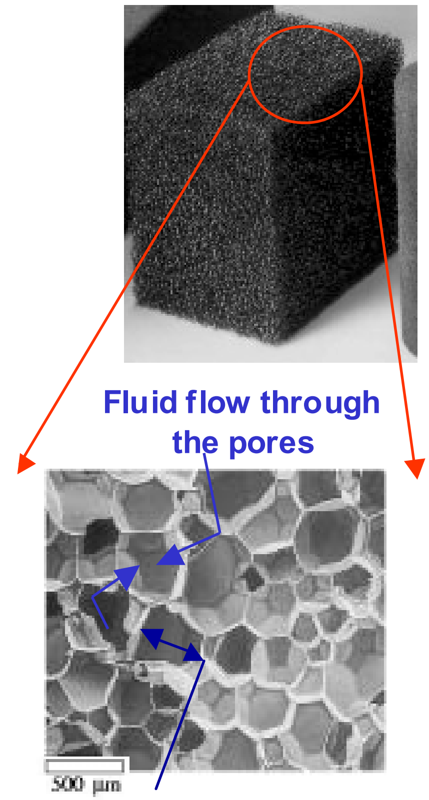


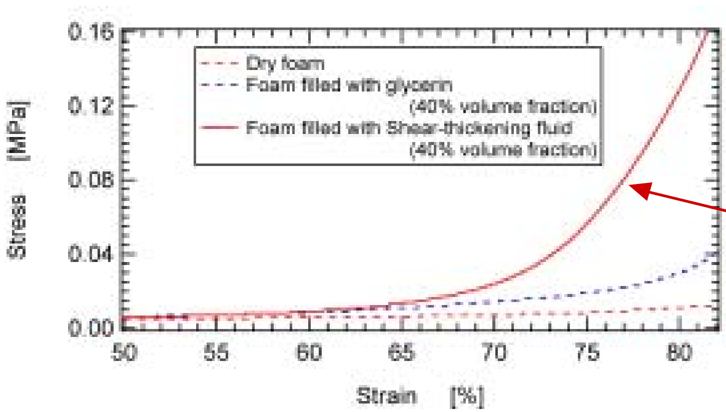


- Multilayer Processing
  - Objectives
    - Nanolayer films for improved ballistic performance
  - Approach
    - Multi-pass extrusion to form multi-layer structure
    - Nano-layers produce novel molecular conformations and resulting properties

Variable Impedance Fluids for Liquid Armor

- Impregnate shear-thickening fluid in open-cell reticulated foam
  - Stress – Strain curves for open-cell polyurethane foams in compression with and without shear-thickening fluid.
- Energy absorption increases dramatically at higher strains & strain-rates
  and can be controlled by pore size, volume fraction, wall thickness:
  - Controllable crush-resistance and energy dissipation on impact
  - No field-switching required





Foam impregnated with Shear-thickening fluid

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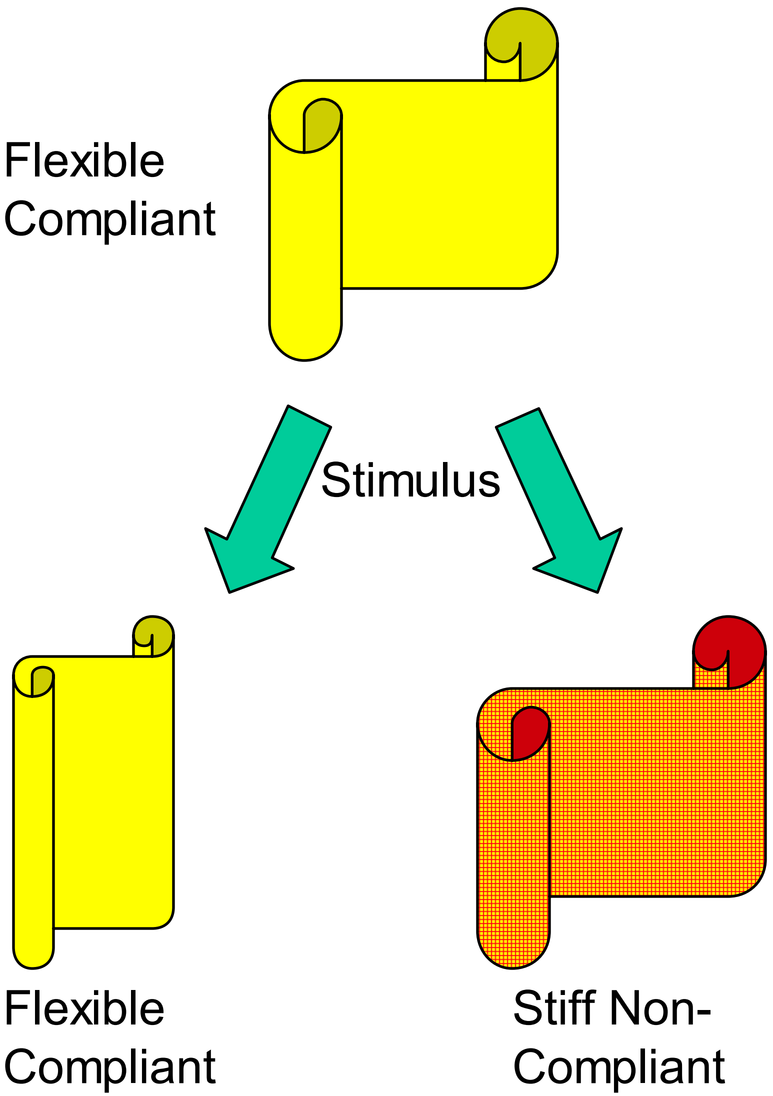
Team 2: Mechanically Active Materials

- **Objective: To develop materials capable of superhuman mechanical actuation and dynamic stiffness**
- **Leader: Prof. Tim Swager**
- **Critical requirements**
  - **Energy efficient actuator (move or jump obstacles)**
  - **Variable impedance materials (armor and medical splint)**
  - **Tactical mobility (lightweight)**
- **Overlying theme**
  - **Switchable Materials**
  - **Actuators exceeding mammalian skeletal muscle**
  - **Feedback and Control**
  - **Low Power**
  - **Nanostructured Actuator Block Copolymers**

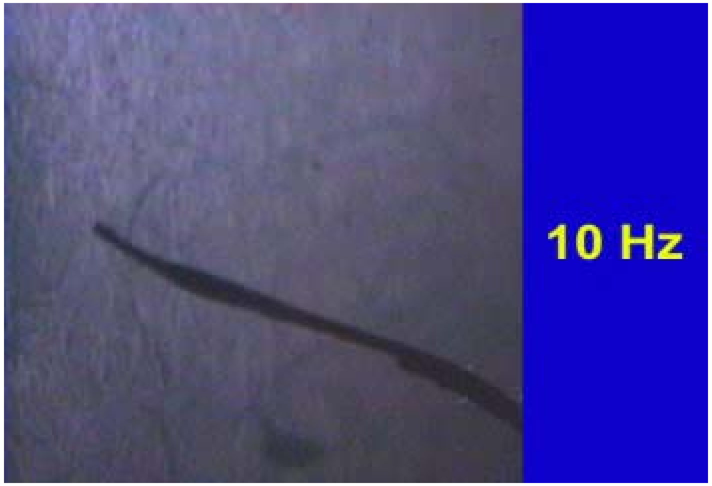


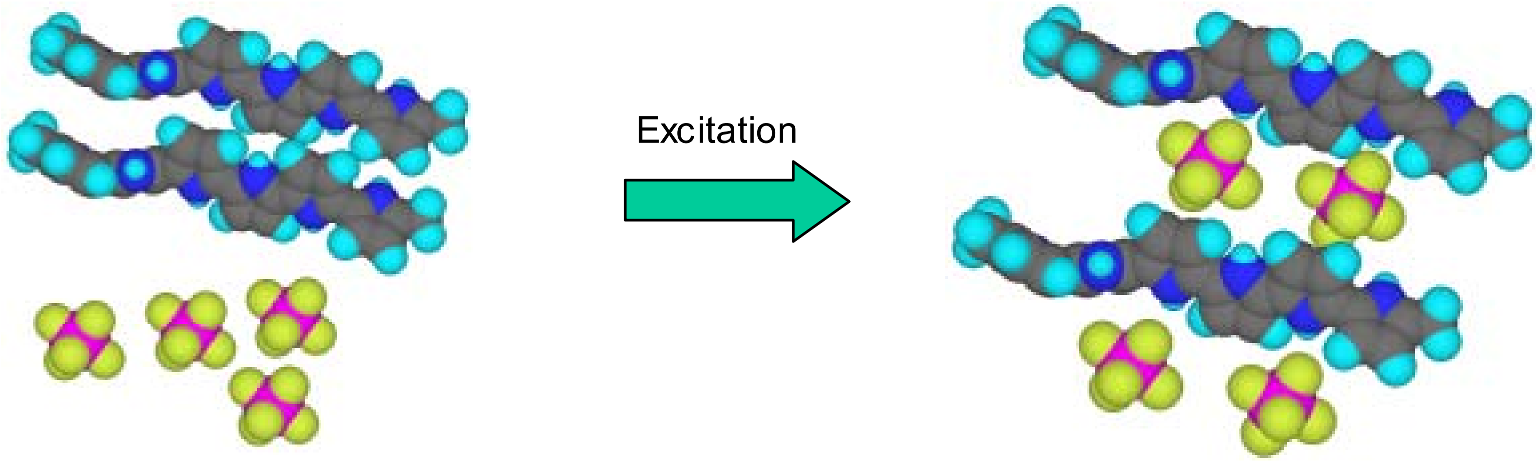
Overlying theme

- Switchable Materials
  - Development of materials and devices
  - Achieve 100-fold change in stiffness
  - Prototype production of a sheet of material
  - Such materials will allow soldiers to stabilize an injury, distribute impact, maintain a pose
- Actuators exceeding mammalian skeletal muscle
  - Create force in excess of 1 MN/m2
  - Display more than 10% strain
- Feedback and Control
  - For transduction of force, displacement, and acceleration
  - Local feedback loops to be devised for dynamic mechanical properties
  - Will allow system control of actuated battlesuits
- Low Power
  - Provide very high force and readily activated in an emergency
  - Future: No external power supply
- Nanostructured Actuator Block Copolymers
  - Conducting block for actuation, elastomeric blocks for matrix
  - High speed due to rapid diffusion over nanometer distances
  - Synthesis, morphology, processing and property evaluation

Polypyrrole Actuators

- **Objective**
  - **High efficiency polymer actuator material**
- **Approach**
  - **Crystallization of polypyrrole**
  - **Intercalation of solvents to cause swelling with applied field**

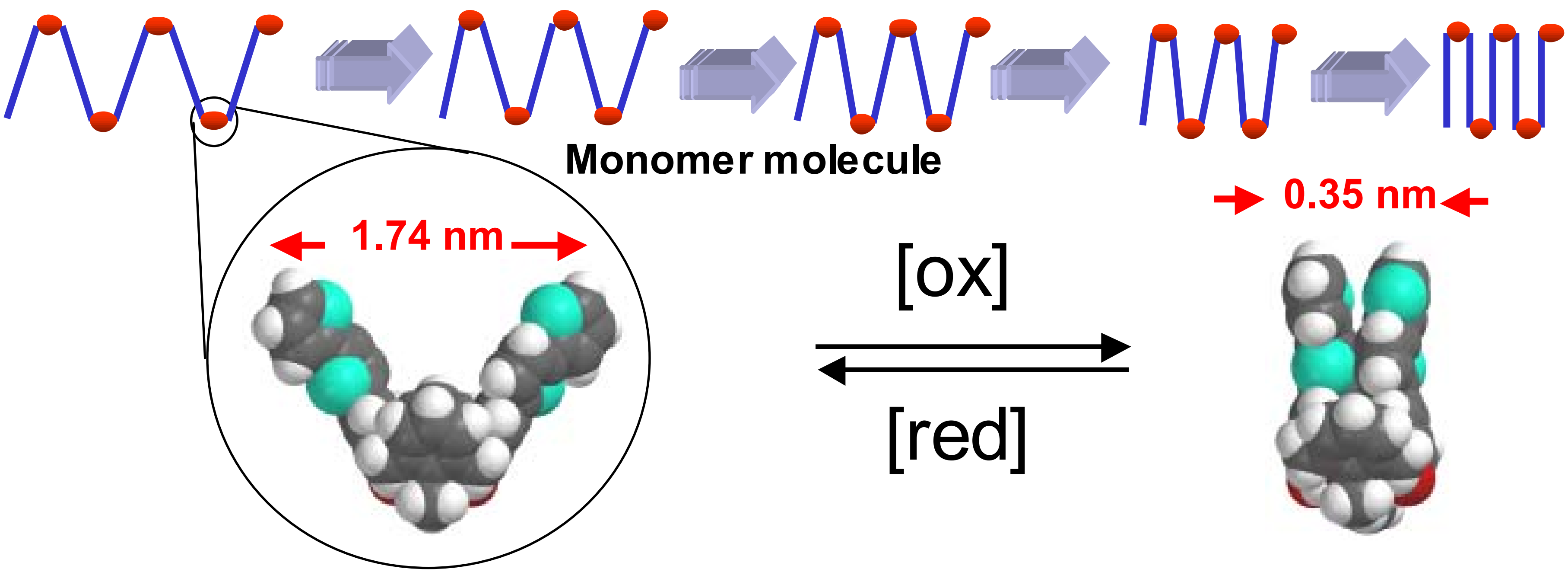




High Strain Polymer Actuators

- **Objective**
  - **High strain, high efficiency polymer actuator**

- **Approach**
  - **Hinged, rigid zig-zag structure**
  - **Corners fold on oxidation to produce reversible strain in system**



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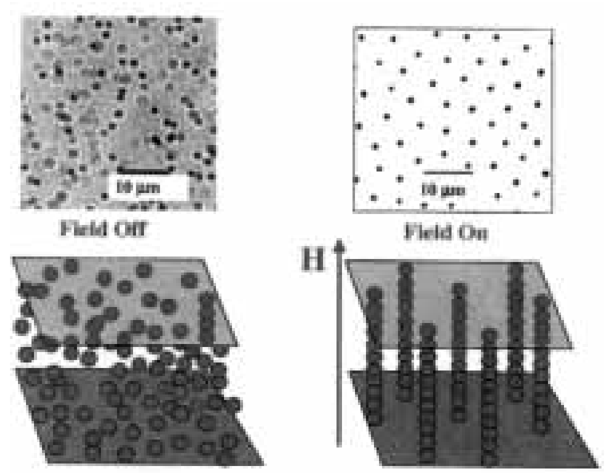
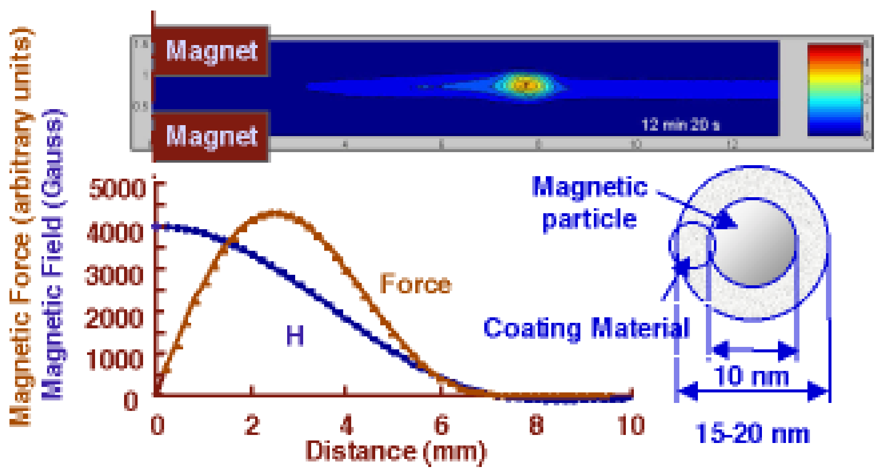
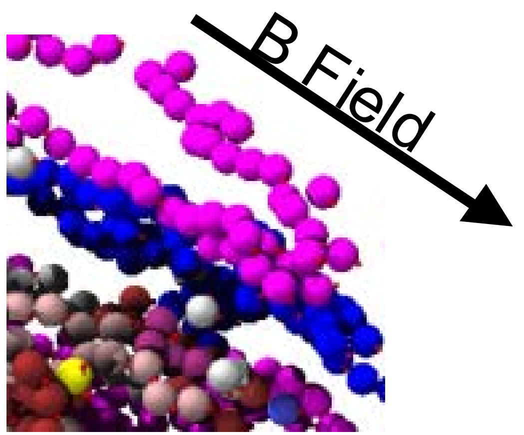
Electro/Magneto-Rheologically Active Systems

- **Objective**
  - **"Smart Fabrics" with variable stiffness and impedance**
- **Approach**
  - **Nanoscale electroactive particles in stable suspension**
  - **Application of fields leads to particle interactions and formation of ordered structures**
  - **Particle structures dramatically effect fluid viscosity and bulk modulus**







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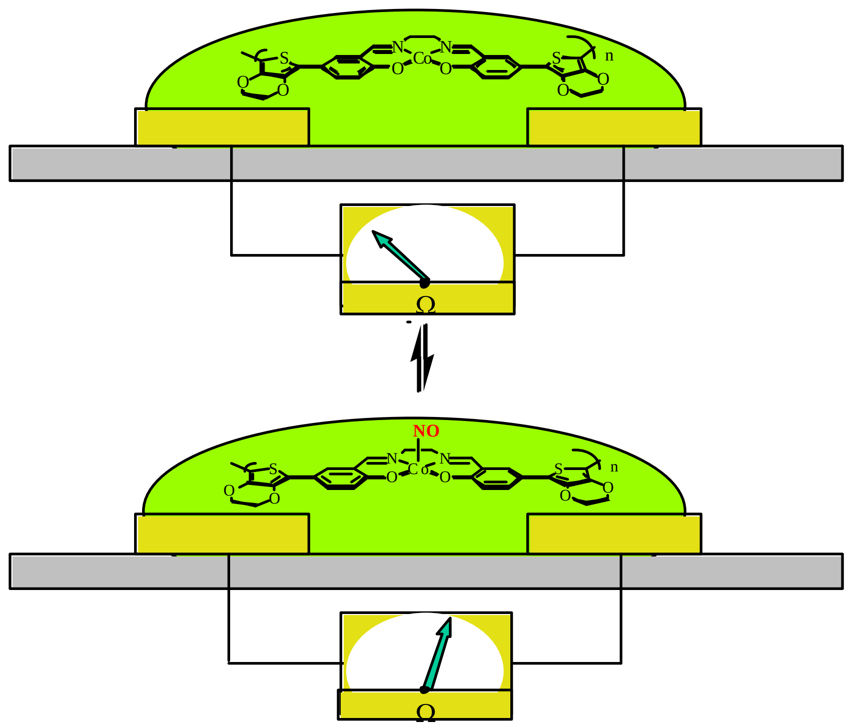
Team 3: Sensors and Chem/Bio Detection

- **Objective**
  - **Enhance soldier awareness of environmental threats**
  - **Develop & incorporate responsive materials for detection of & protection from chemical and biological agents.**
- **Leader: Prof. Paula Hammond**
- **Approach**
  - **Chromic systems for detection and displays**
  - **Systems for detection and soldier protection**
- **Overlying Theme**
  - **Detection**
  - **Protection**
  - **IR Tagging and Marking**

Resistance Based Nitric Oxide Detection



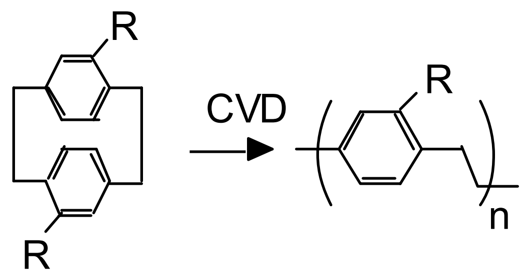
Overlying Theme

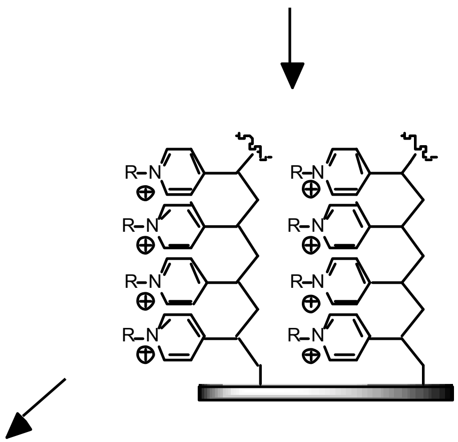
- **Detection:**
  - **Ratiometric conducting polymer sensors for chemical agent detection incorporated into thin film or fiber form.**
  - **Biofunctionalized surfaces, inorganic nanoparticle, and hybrid organic-inorganic systems for bioagent detection. (in cooperation with Team 4)**
- **Protection:**
  - **Functional polymer thin films that react with or counteract chem/bio exposure.**
  - **Responsive nano-pores which “close” upon detection of agent based on polymer brush behavior (in cooperation with Team 2)**
- **IR Tagging and Marking**
  - **Tunable IR reflective fibres for IFF applications**

Anti-Microbial Surface Treatments

- **Objective**
  - **Surface treatments that spontaneously kill microbes on contact**
- **Approach**
  - **Grafting of reactive parylenes onto surfaces using large-scale CVD processes**

Chemical vapor deposition of reactive parylene coatings



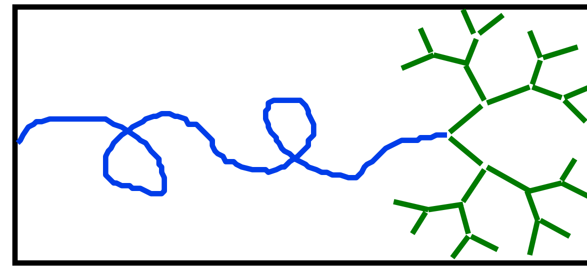


Reel-to-Reel CVD processing system at MIT

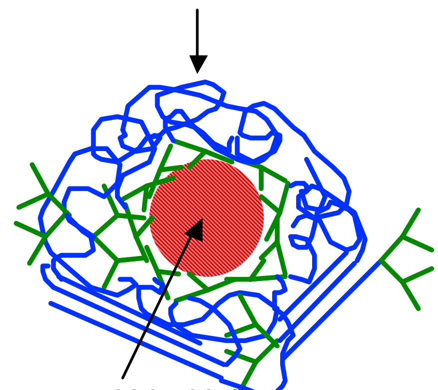
Anti-microbial properties as tested against *S. aureus* cells

Protective Reactive Coatings

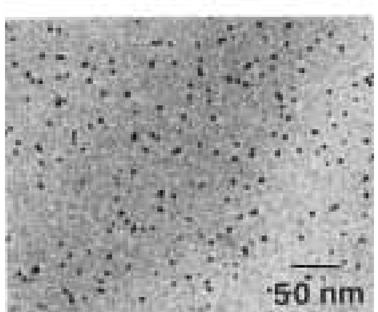
- **Objective**
  - **Surface coatings to protect from both Chemical and Biological threats**
- **Approach**
  - **Dendrimer copolymers used as surfactants on microbicidal nanoparticles**
  - **Could be used as a polymer (or paint) additive**
  - **Could be used as a topical cream (as per previous ARL work)**



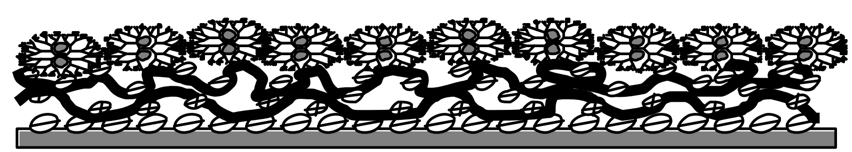
Dendrimer copolymer with Chem-decon functionality in denrimer segment



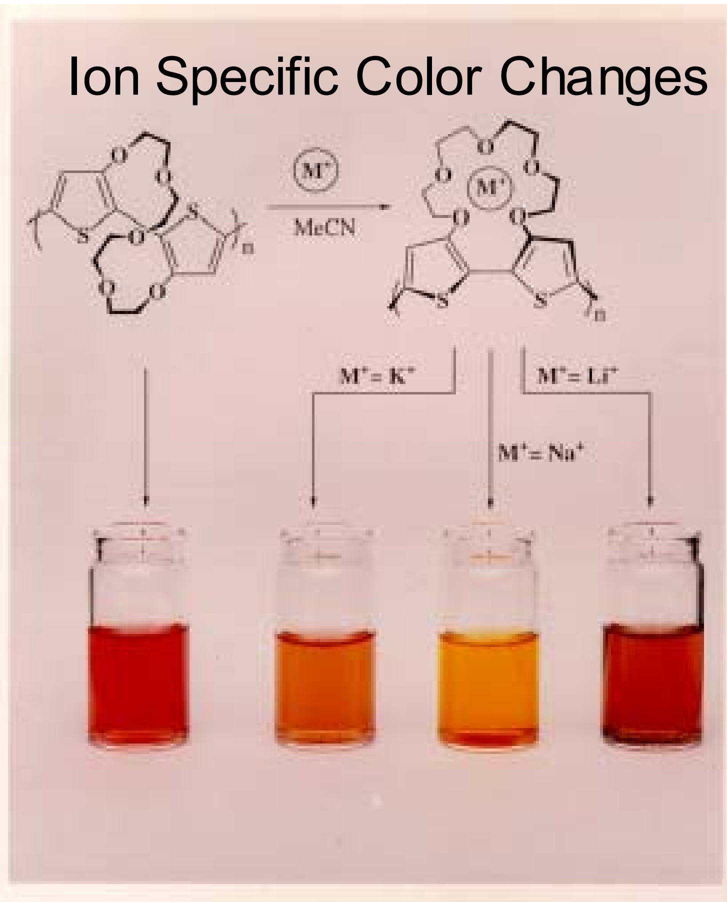
Surfactant coated biocidal nanoparticle (SnO_2, WO_3, Ga_2O_3 and ZnO)

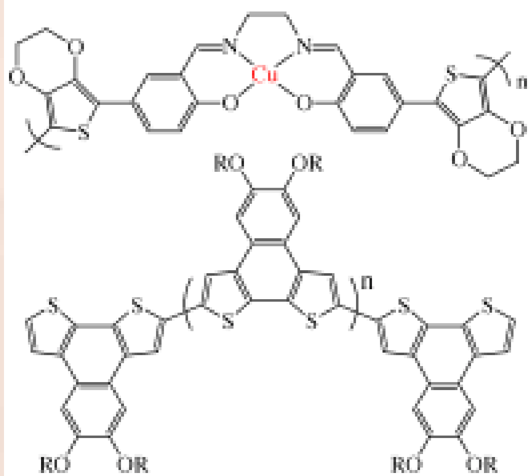


Surfactant coated nanoparticles in a compatable polymer film



Detection Example: Color Change as Response: Sensor Systems





Spectral
Changes
With Oxidation

Robust, Highly Conducting Polymers - Ion, Temp, Strain, Photo, Chemo Responsive

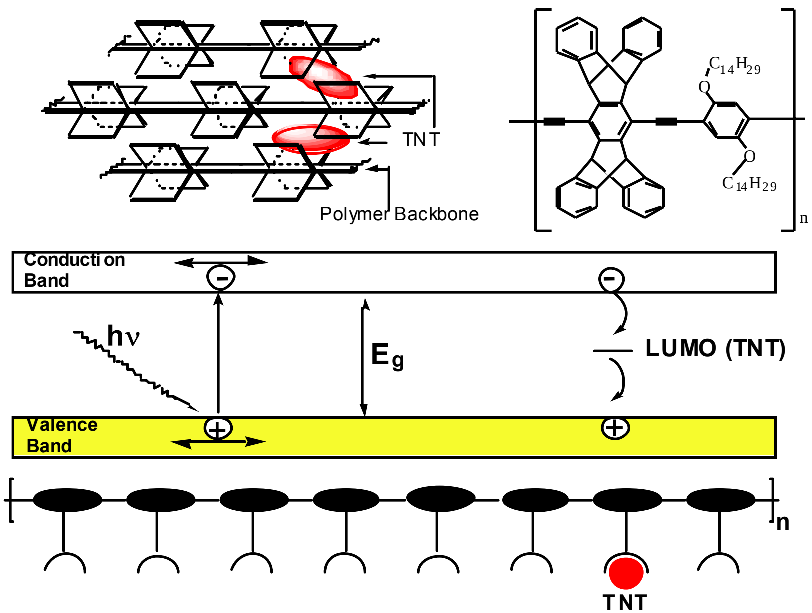
Can detect toxic agents through use of electrical, optical, and chemo-chromic responses convertible to optical

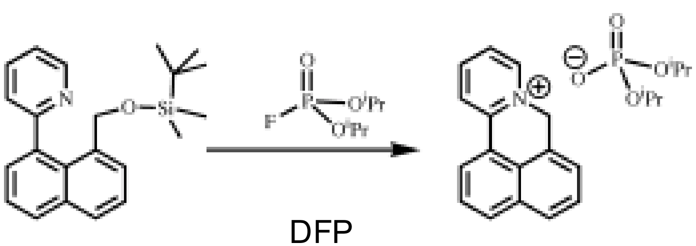
or electronic signals.

Sensors Based On Electronic Polymers

- **Objectives**
  - **Ultra-high sensitive detection of chemicals at low-cost**
- **Approach**
  - **Conductive polymer devices that react with target molecules to change electronic properties**
  - **Demonstrated to produce very small detection thresholds in very inexpensive systems (ie TNT detection)**
  - **New indicator chemistry needed for CW applications**

TNT Sensors ≈10^{-16} g Detection Limits

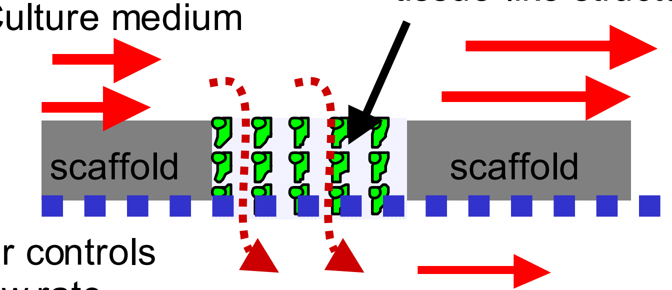


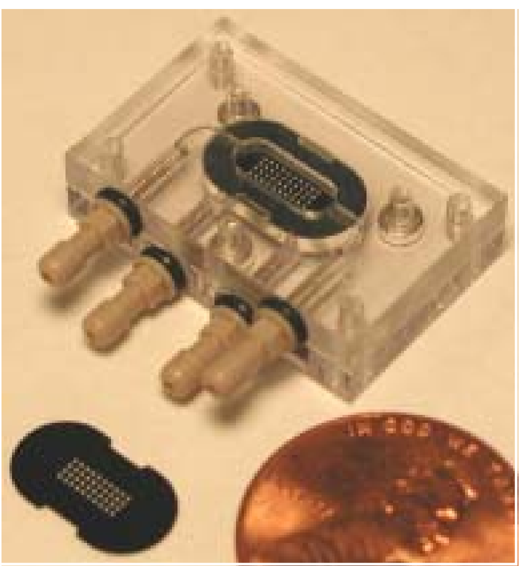


Potential indicator chemistry to detect nerve agents in conductive polymer system

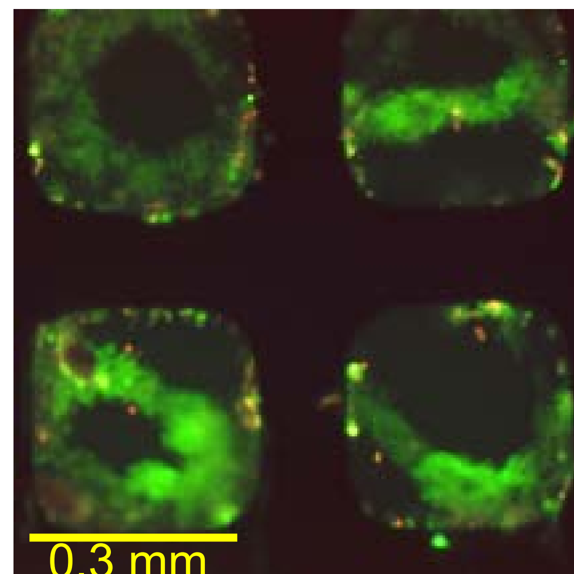
Liver Chip System for the Detection of Pathogens and Toxins

- **Objective**
  - **Rapid detection of toxins**
- **Approach**
  - **Culture liver cells into a detector chip**
  - **Monitor cell function to detect effects of toxins**
  - **Combine with lab-on-chip technology to reduce system size and costs.**





Prototype device w/ life support system attachments



Rat liver cells after 13d in reactor (17 days after isolation). Cells begin forming tissue structures in 24-48 hrs after seeding and remain stable thereafter.

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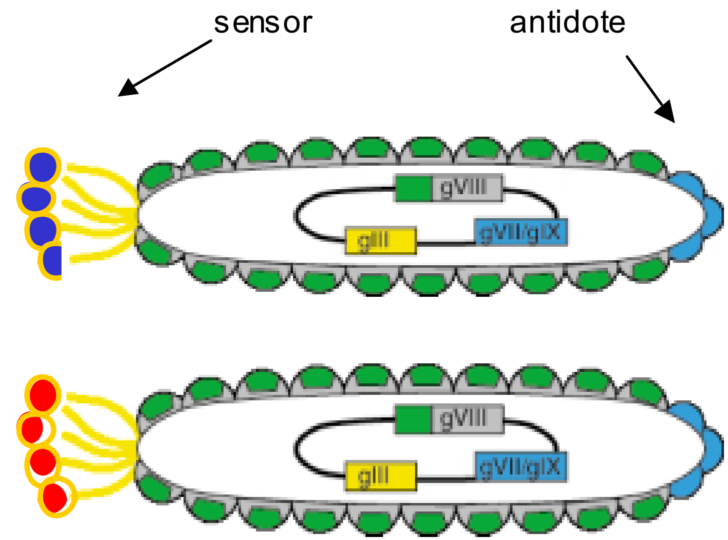
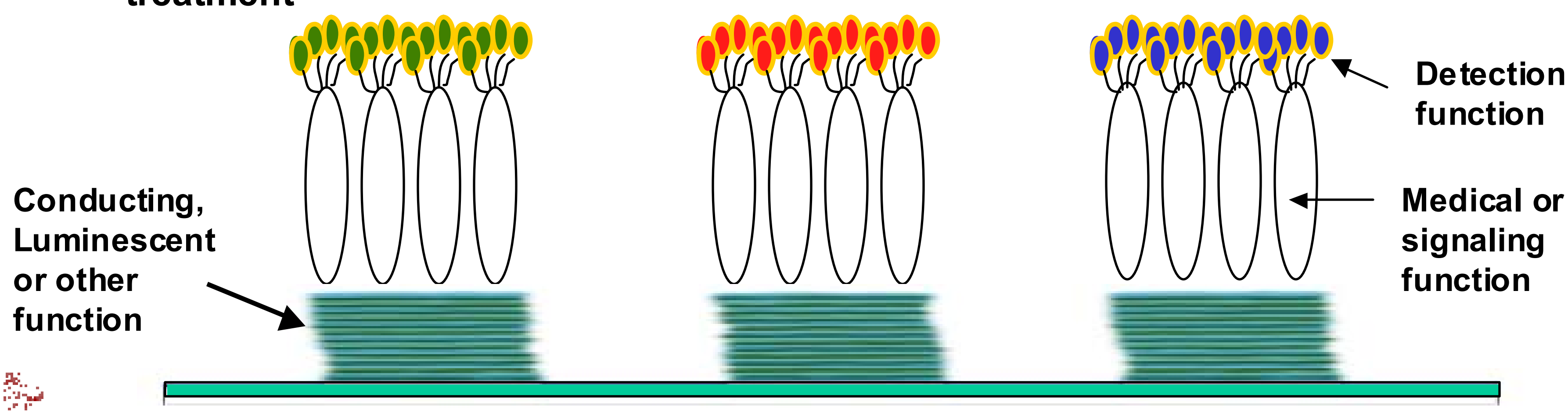
Multifunctional Viral Arrays for Detection and Treatment

- **Objective**
  - **High-speed, low cost detection & treatment from CB agents**
- **Approach**
  - **Genetically engineered bateriophages (viruses) contain both sensor and antidote**
  - **Adsorption of various functional phages on electroptical reporter system to quench activity**
  - **Agent removes phages and produces signal in system – simultaneously provides treatment**





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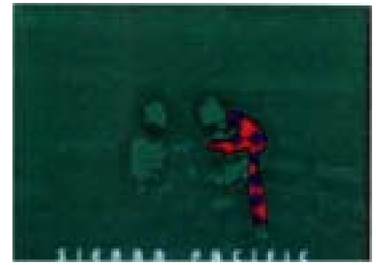
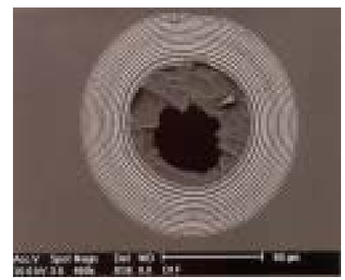
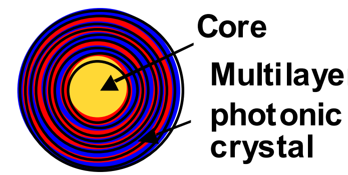
IR Detection and IFF

- **Objective**
  - **IR Friend or Foe Identification and IR Detection integrated into textile system**
- **Approach**
  - **IR reflective and detection technologies based on photonic band gap materials, nanoparticle systems, and emitting organic and inorganic materials.**
  - **Photonic, hollow fibers:**
    - **Reflective Signal can be made tunable**
    - **Integration with other materials systems, ie. mechanically active cores**
    - **PBG systems, quantum dot assemblies will be applied to IR detection**



Simulated goal for IR-IFF image of friendly with an unknown.



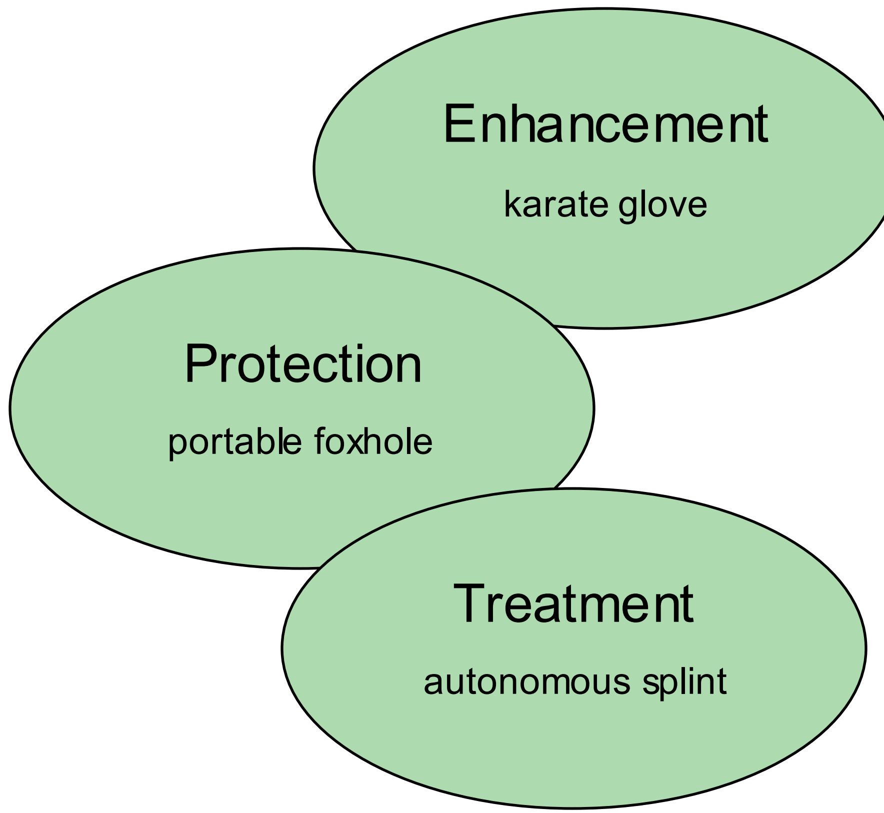


PBG fibres produced at MIT, being readied for evaluation at DuPont

Team 4: Soldier Biomedical Technology

- **Objective**
  - **Developing unique and biologically derived or inspired materials and medical devices incorporated in the soldiers uniform**
- **Leaders: Prof. N. Hogan and Prof. L. Griffith**
- **Approach:**
  - **Polymer and peptide enhanced wound healing**
  - **Peptide nanomaterials and nanotubes materials**
  - **Bio-agent protection**
- **Overlying theme**
  - **Enhanced Wound Healing**
  - **Variable Impedance Exoskeletons**
  - **BioAgent Detection and Protection**

Variable Impedance Exoskeleton Applications

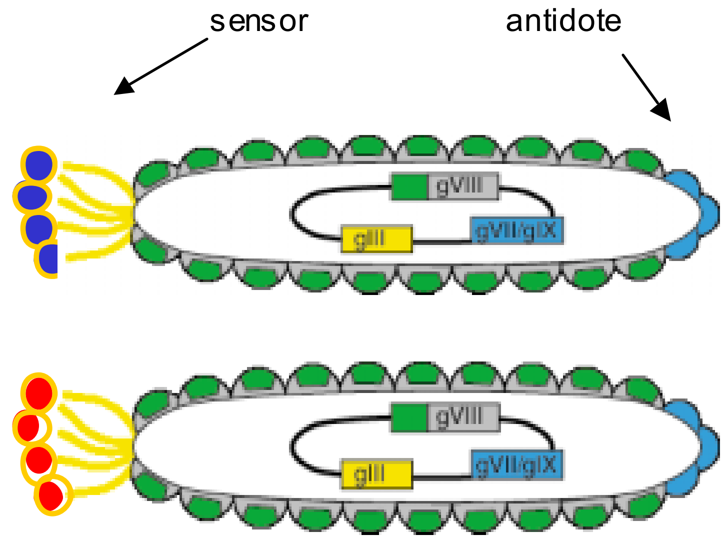


Overlying Theme

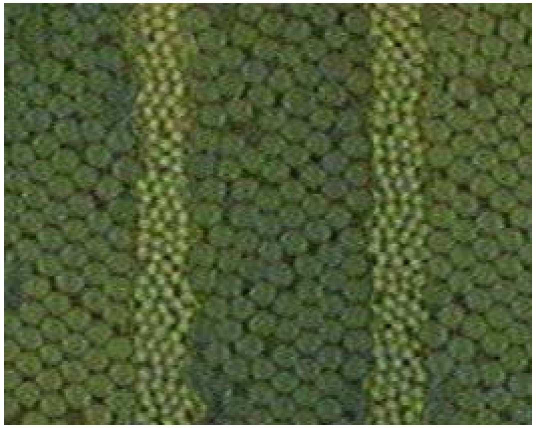
- Enhanced Wound Healing
  - Directed evolution of degradable polymers for scaffolds (Griffith)
  - Engineering design & synthesis of wound scaffolds (Griffith)
- Variable Impedance Exoskeletons
  - Biomechanical design principles (Hogan/Teams 2 &6)
  - Imaging-assisted integration with patients (Mezrich)
  - Sensor integration (Rutledge)
- BioAgent Detection and Protection
  - Bioagent molecular recognition by CVD films (Jensen, Schmidt, Langer)
  - Bioagent epitope identification (Mezrich)

On-Demand Antidotes and Vaccines

- **Objective**
  - **Long-term storage of on-demand vaccines and antidotes**
- **Approach**
  - **Genetically engineered bacteriophage containing both agent sensor and antidote**
  - **Long-term storage as edible liquid-crystal viral films**
  - **Easily replicated in small labs for film replenishment**

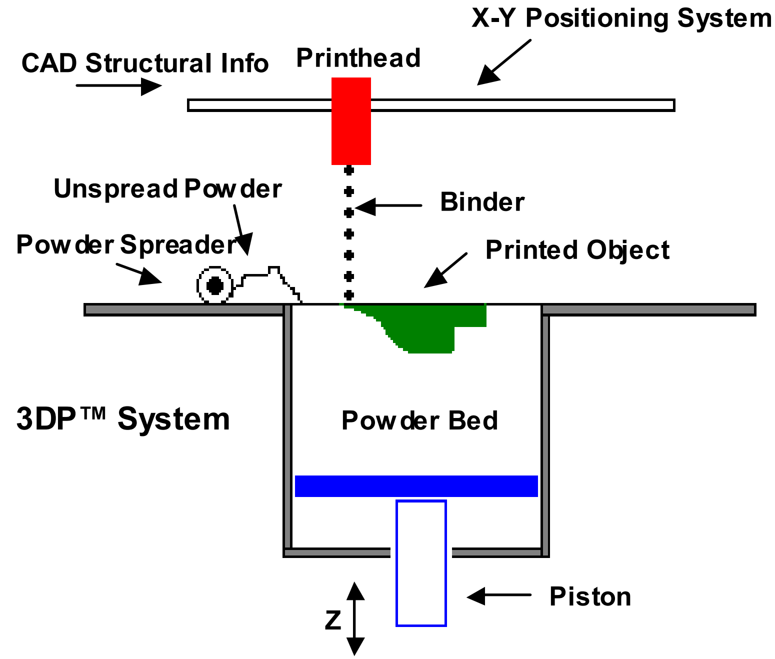


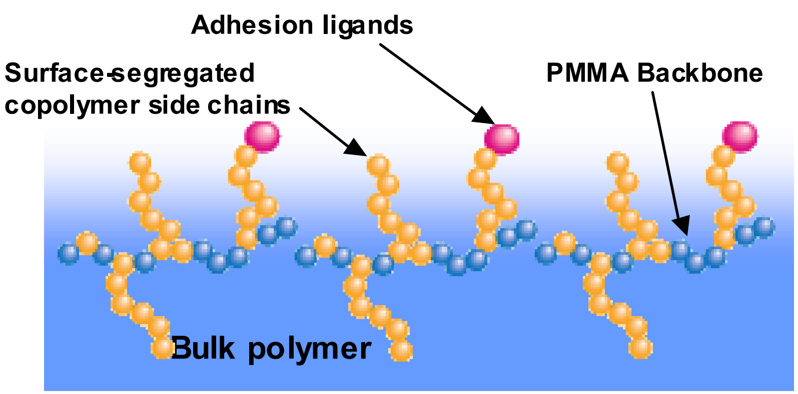
“Shelf-stable” liquid crystal viral flim consisting of genetically engineered bacteriophages

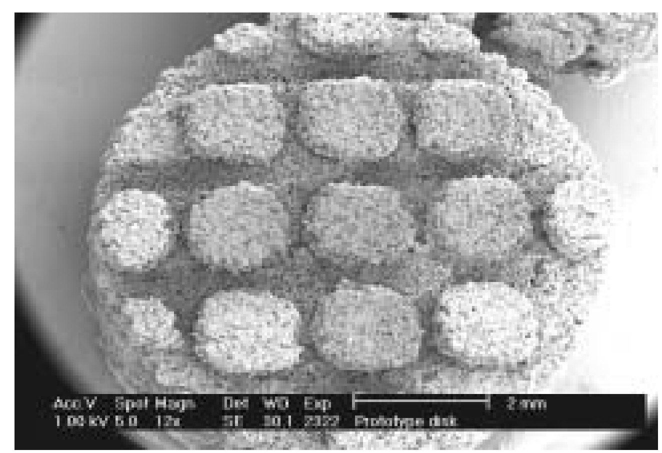


3DP™ of Tissue Scaffolds

- **Objective**
  - **High precision tissue scaffolds for surgical treatment of wounds**
- **Approach**
  - **3DP™ Polymeric Constructs to provide shape and local control of polymer composition**
  - **Addition of modified copolymer to present specific adhesion ligands at cell-scaffold interface to imitate natural ECM**





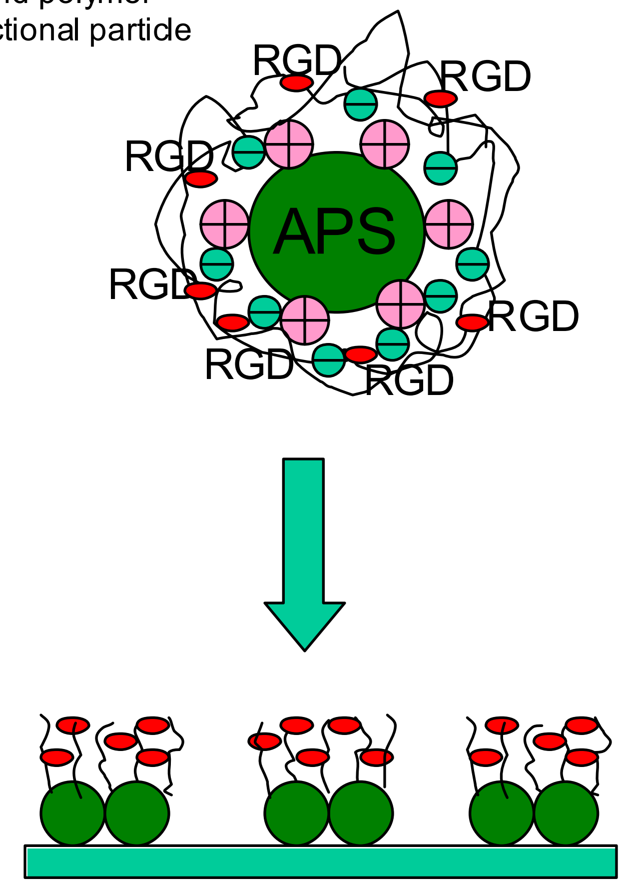


PMMA scaffold printed with chloroform binder containing 0.1% comb polymer

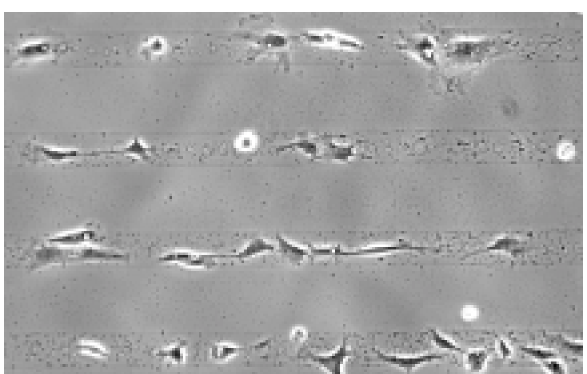
Dendrimer/Particle Cell Scaffolds

- **Objective**
  - **Self-Assembling tissue scaffold systems for rapid wound healing**
- **Approach**
  - **Dendrimer copolymer coated nanoparticles**
  - **Functionalization of dendrimer with RDG ligands to increase cell attachment**
  - **Use self-assembly of particles in gels or polymers to form scaffold systems**

Ligand-polymer
Functional particle



Self-Organization of particles into active scaffold structure



Segregation of particles in gel system to produce tissue scaffold

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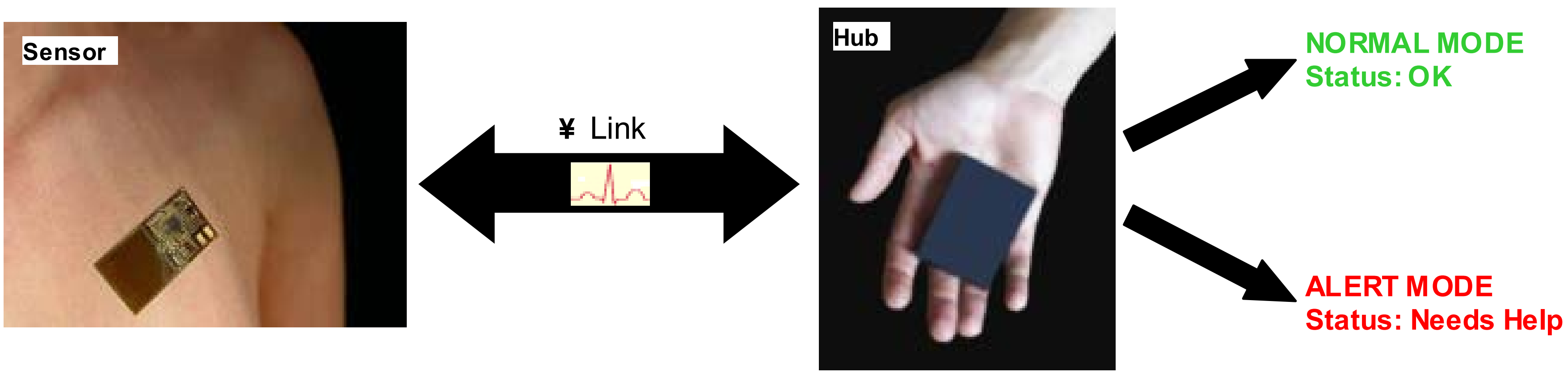
Sensor System Framework

- **Objective**
  - **Remote monitoring of soldier status with low-power, autonomous system**
- **Approach**
  - **Cutaneous sensors linked with wireless network protocol**
  - **Network hub reports status of Soldier**

- **ISN Research Activities**
  - **Miniaturization of sensors**
  - **Novel sensor designs**
  - **Novel on-board power systems for the sensors**
  - **Integration with automatic treatment systems**



Team 5: Processing and Characterization

- **Objective**
  - **To develop the processing and device fabrication technologies required to manufacture and deliver functional nano-materials in the ISN for soldier protection**
- **Leaders: Prof. G. Rutledge and Prof. G. McKinley**
- **Approach:**
  - **Nanotechnology processing platforms**
  - **On-demand processing**
  - **Characterization/microstructural evaluation**
- **Overlying Theme**
  - **CVD textile processing**
  - **3D Microfluidic Integration**
  - **Field-Responsive Fluids**
  - **Characterization**

ISN Dedicated Processing and Characterization Facility

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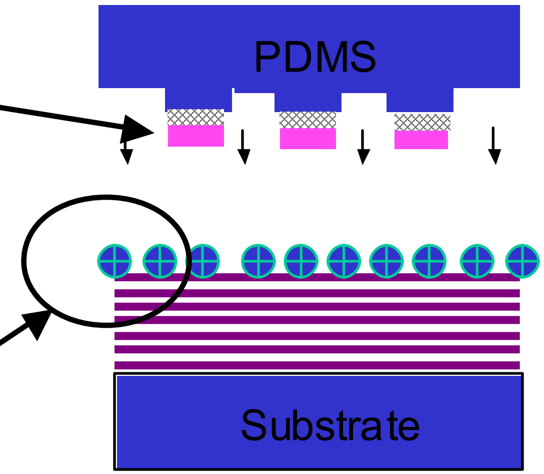
Overlying Theme

- CVD textile processing (Gleason, Jensen, Bulovic)
  - Plasma & Hot filament - passivation layers, dielectric layers, integration (T3,T4)
  - Roll-to-Roll CVD- scale-up (T1-4)
- 3D Microfluidic Integration (Jensen, Schmidt, Smith):
  - Hard and soft lithography- self-assembly, device interconnection, valves, fluid distribution (T1-4)
- Field-Responsive Fluids (Hatton, Doyle, McKinley):
  - Electro/magneto-rheologically active fibers - variable rigidity, energy dissipation (T1), devices (T2)
- Characterization (Thomas, Cohen, Gleason, Boyce, Socrate, Rutledge, McKinley, MTL / Natick, ARL, DuPont, MGH/BWH)
  - Materials Characterization Core Lab:
    - microscopy (optical, fluorescence, atomic force, SEM, TEM@CMSE)
    - spectroscopy (WAXS/SAXS, in situ @ BNL, FTIR, UV-Vis for chemistry)
    - high speed photography
    - barrier properties for textiles
    - laser facility
  - MTL-ISN Nanofabrication Lab - lithographic facilities
  - Partners:
    - DuPont (weaving, structured fibers & testing, scale-up)
    - MGH/BWH (biomedical, in vitro/in vivo testing)
    - Natick SC, ARL (ballistic testing, textile characterization)

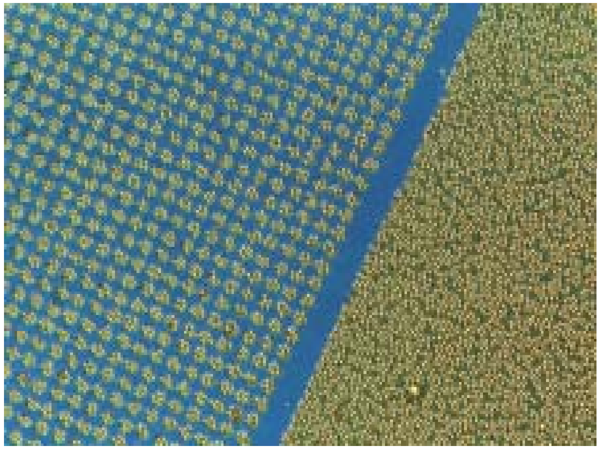
Micro to Nanoscale Polymer-on-Polymer Stamping

- **Objective**
  - **High resolution production of multi-scale structures**
- **Approach**
  - **Polymer stamping moulds of PDMS**
  - **Use of surface electrostatic, H-bonding or covalent bonding to transfer polymers, dyes of polyions**
  - **Can be used as substrate for further processing**

Pattern transfer by stamping of copolymers, dyes, polyions



Surface acid or base groups. Basis of pattern transfer: electrostatic, covalent, or H-bonding



Patterned Colloid by POPS

Example stamping operation

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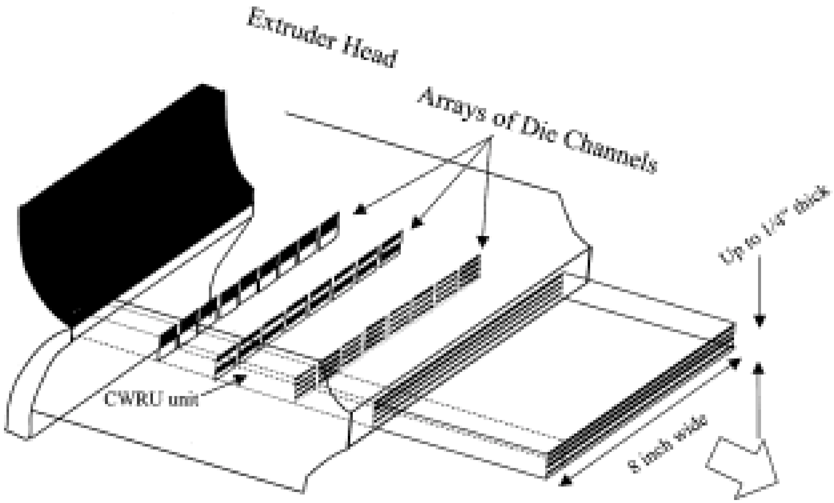
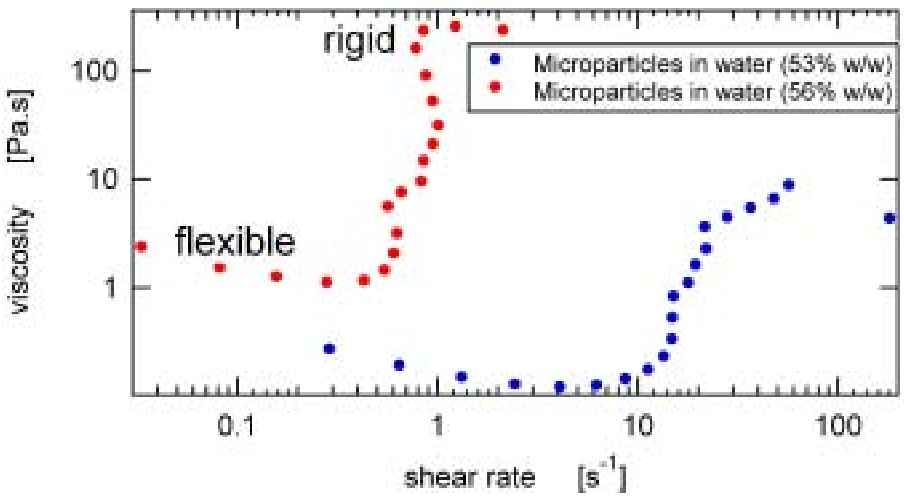
Processing of Armour Materials

- **Complex Multilayer Arrangements**
  - **Objective**
    - **Low cost production of multilayer polymeric structures through extrusion**
  - **Approach**
    - **Multi-stage extrusion die design**





- **Passive Fluids for Variable Impedance Applications**
  - **Objective**
    - **Dilatant fluid for soft armour applications**
  - **Approach**
    - **Nano-size charged colloidal particles at high volume fraction (≥50%)**
    - **Transition in viscosity at large deformation rates**

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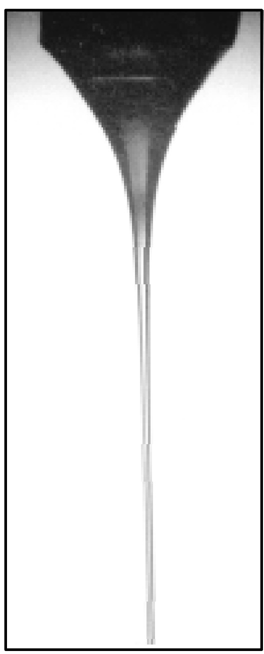
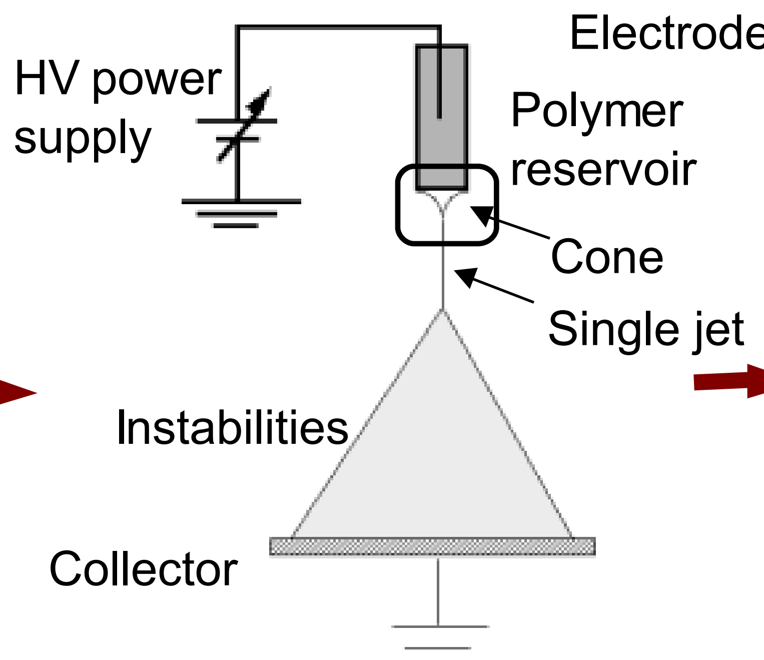
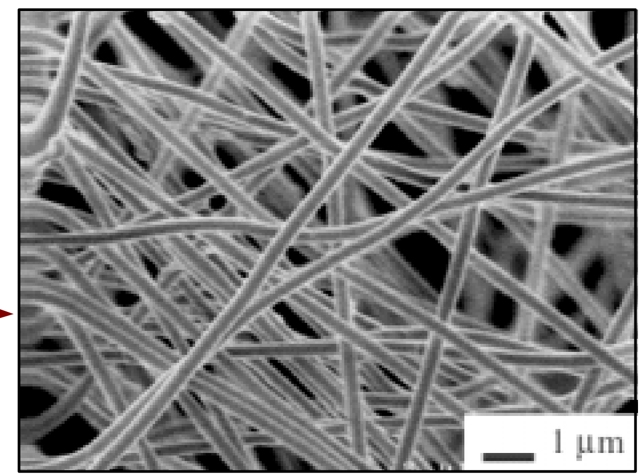
Electrospinning of Fibres and Fabrics

- **Objective**
  - **Production of polymer nanofibers and nonwoven textiles with exceptional surface area, porosity**
- **Approach**
  - **Electrospinning of polymer dopes**



1 mm





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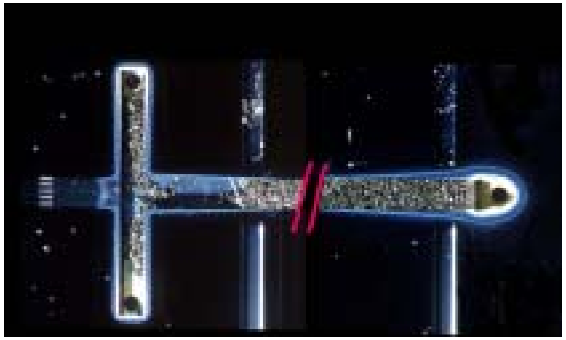
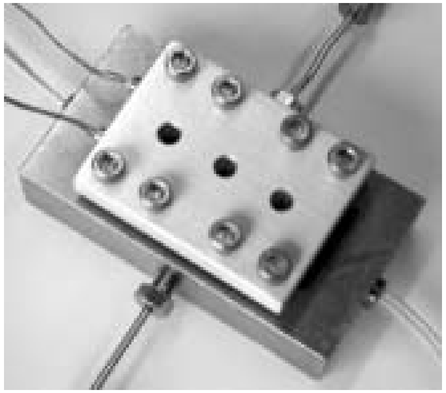
3D Microfluidic Integration

- **Objective**
  - **Integration of microfluidic systems and lab-on-chip technologies with textile systems**
- **Approach**
  - **Hard and soft lithography**
  - **Miniaturization of current technology through direct laser writing and hot embossing fab lines**
  - **Polymer actuators and conducting polymer hollow fibres as microfluidic pumps**

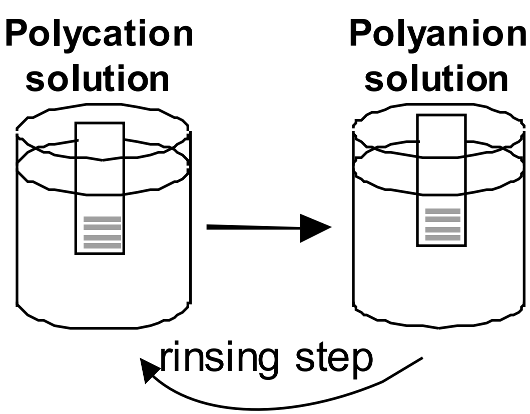


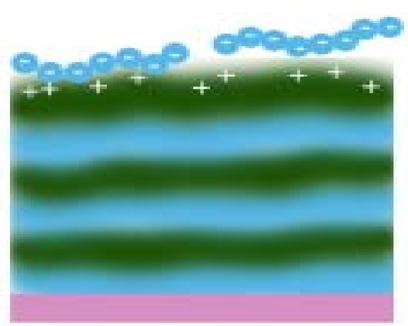
Single channel multiphase microreactor for solid catalyzed gas-liquid reactions

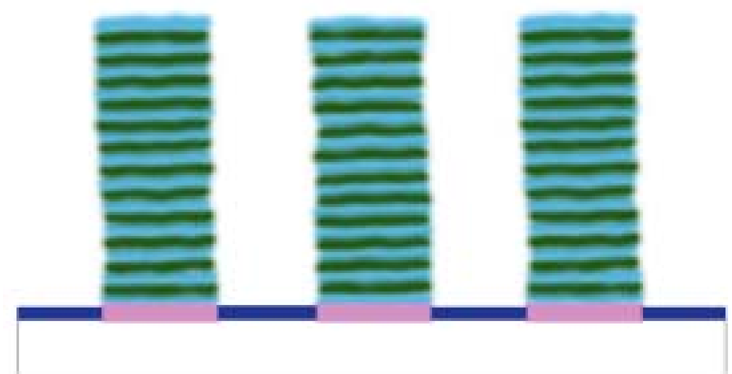


Chemistry Directed Selective Deposition of Multilayers

- **Objective**
  - **Production of patterned multilayer structures for electrooptical applications**
- **Approach**
  - **POPS patterning of polyionomer onto substrate**
  - **Alternating layer deposition to form multilayer stacks**
  - **Suitable as intermediate processing step for many device applications**

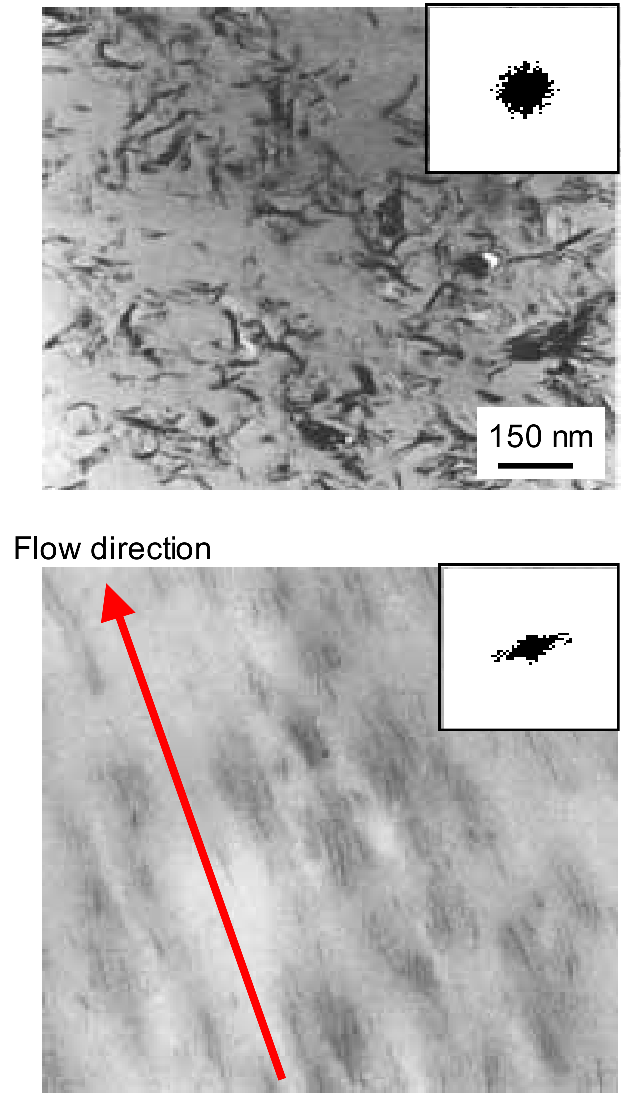






Coupling of Flow and Microstructure

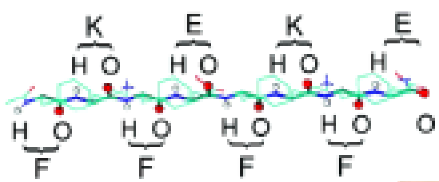
- **Objective**
  - **Maximize dispersion of nanoscale fillers and reinforcements**
  - **Optimize properties of fibre and film nanocomposites**
- **Approach**
  - **Application of optimal flow patterns during composite processing**
  - **Characterization of processing effects on composite structure**
  - **Modelling of processing operations and composite propoerties**



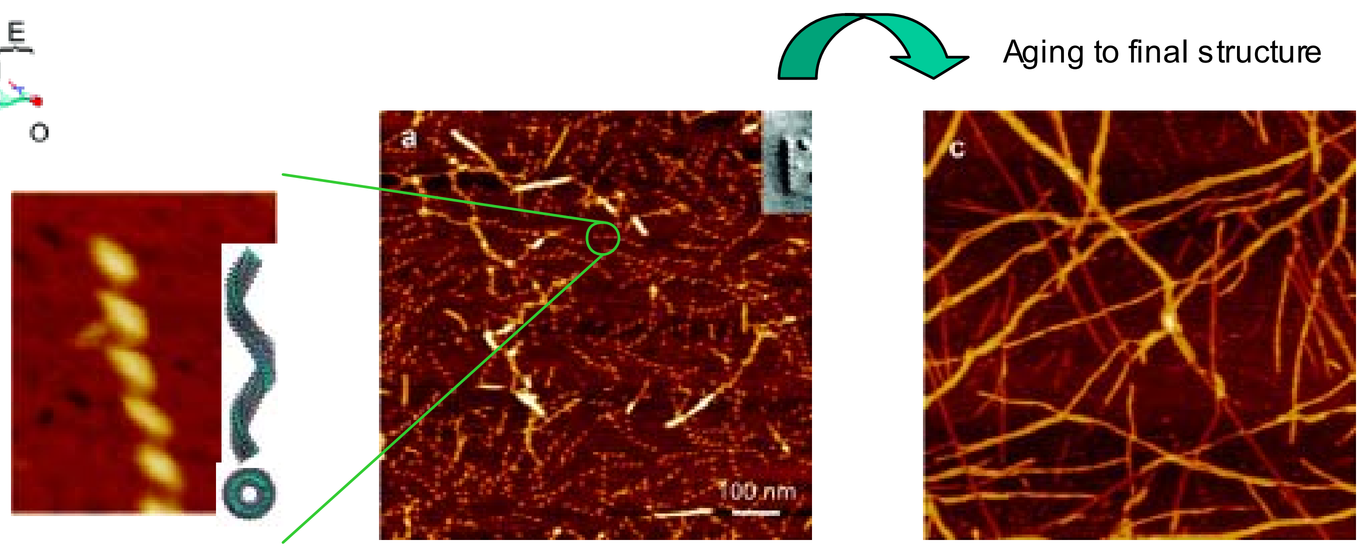
Nylon-6/Montmorillonite Polymer Nanocomposites

Self-Assembly of Fibre Structures

- **Objective**
  - **Biomimetic self-assembly of nanosystems**
  - **Assembly and crystallization of synthetic polypeptide analogues to silk and other high performance fibres**
- **Approach**
  - **Kinetics of self-assembly of small peptide chains**
  - **Development of self-assembling nanotubules and nanofibres**
  - **Directed assembly of nanotubules into mesoscale structures**

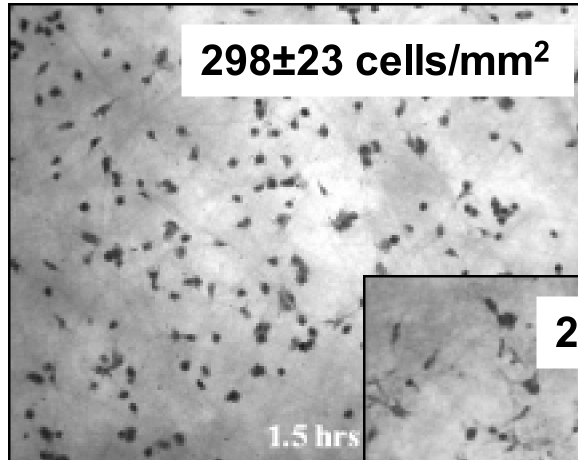


AFM images of intermediate helix structure during self-assembly of polypeptide into fibular tissue scaffolds.

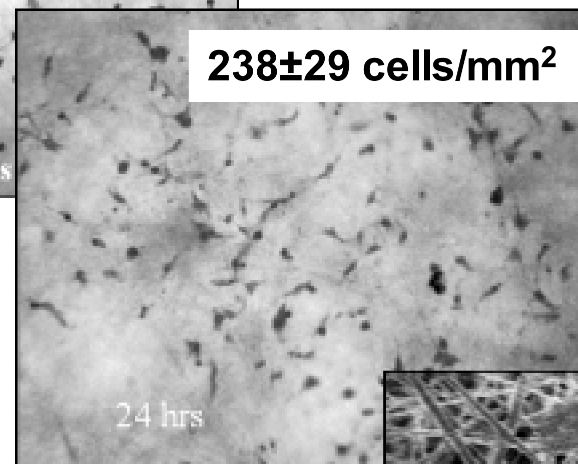


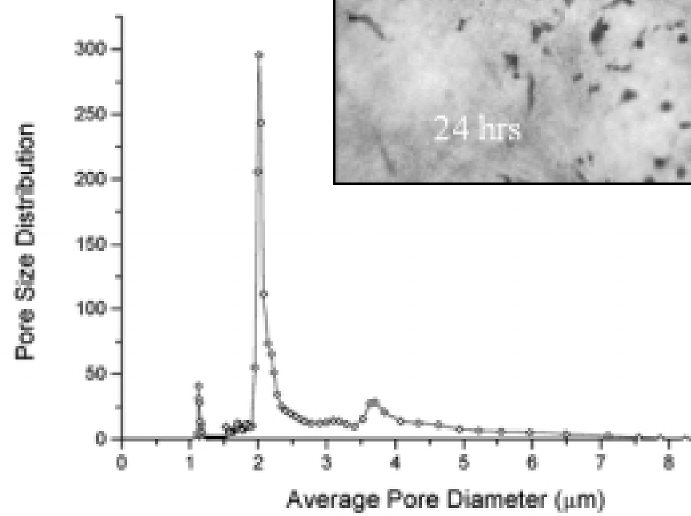
Tissue Scaffolds via Electrospinning

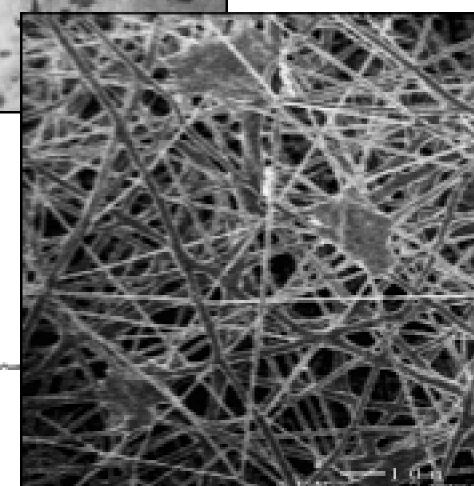
- **Objective**
  - **Optimal tissue scaffolds of degradable polymers**
- **Approach**
  - **Electrospinning of degradable polymers into porous films**
  - **Control of film porosity and size distribution**
  - **Control of polymer structure and surface properties**
  - **Results produce optimal films for tissue regeneration and growth**



Fibroblasts adherent to PCL scaffolds
10wt%, dichloromethane:methanol=3:1,
Point-plate geometry, V=12kV, D=15cm
fiber diameters 0.6-8 μm
porosity ca. 90%



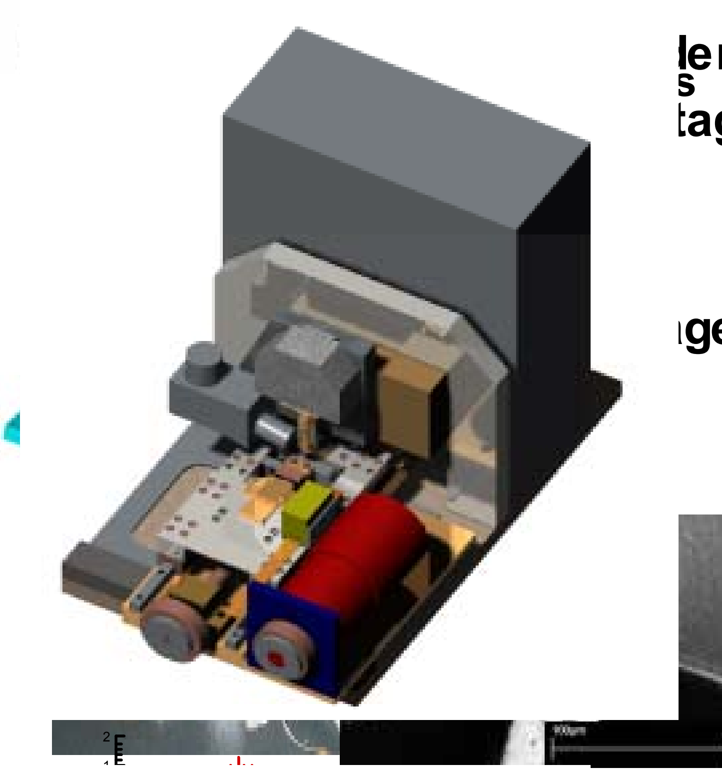


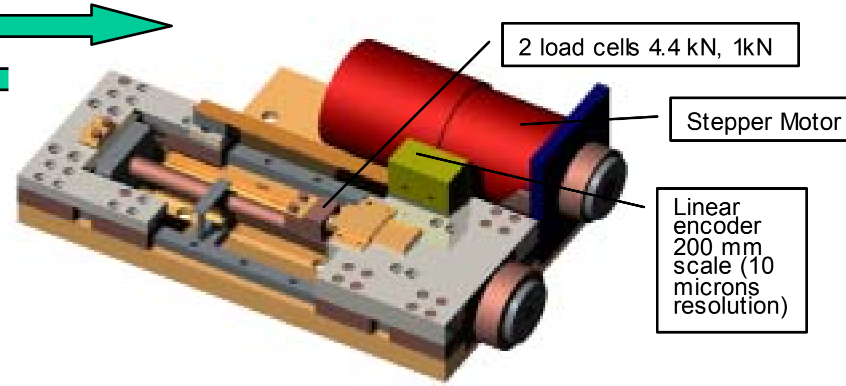


Characterization Facilities

- **ISN Investigator Facilities**
  - Servohydraulic tension/compression (Boyce, Cohen, Thomas)
  - Screw Driven Instron with Video Extensometer and Temperature Chamber (Boyce)
  - Abrasion/Scratch Resistance (Boyce, Cohen)
  - Tensile Impact Test (Boyce)
  - Shear, Extensional Rheology (McKinley)
  - Hardness Testing (McKinley, Boyce)
  - TEM, SEM (Cohen,Thomas)
  - In-situ NMR Probe (Gleason, Cohen)
  - In-situ WAXS (Thomas, Brookhaven NL)
  - In-situ SAXS (Thomas, Brookhaven NL)
  - in-situ AFM (Thomas, Boyce, Bamberg)
  - In-situ SEM Abrasion Test (Boyce)
  - FTIR/Tensile Stretching (Gleason, Cohen)
  - Gas diffusion (Cohen)
  - Electrical Conductivity (Cohen)
  - Single Molecule Testing (Ortiz)

- **ISN**





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Team 6: Materials Modelling & Simulation

- Objectives
  - Control
    - Basic understanding of physical, chemical and mechanical properties of nanostructured materials and interaction of length scales in hierarchically designed material assemblies to achieve required macroscopic response
  - Efficiency
    - Provide direct guidance for engineering and materials research
- Leader: Prof. Gerd Ceder and Prof. Mary Boyce
- Approach:
  - Electronic and chemical properties
  - Mass and energy transport through nanoscaled structures
  - Systems Concept Exploration (what if!)

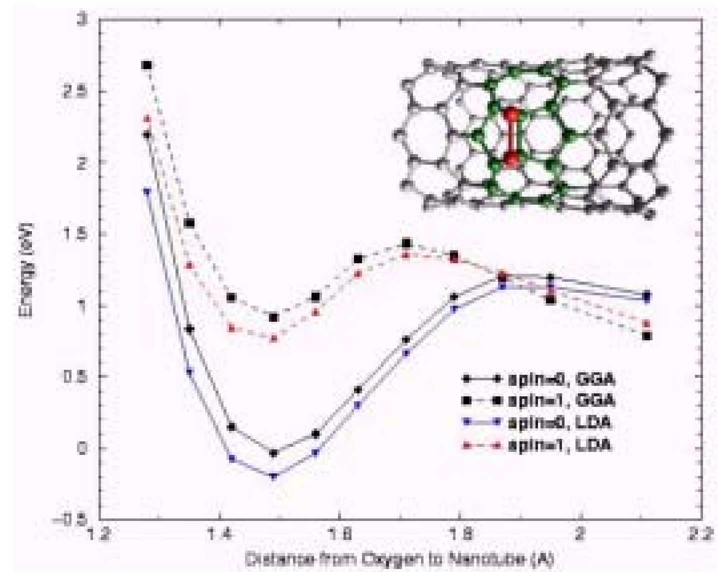
- Role of Modeling in ISN
  - Develop science of materials used for soldier protection
  - Emphasis on
    - Novel properties of nano-sized materials
    - Synergistic effects achieved through hierarchical materials design
  - Give guidance on where to search (composition, structure, size) for novel properties.
  - Work closely with experimental groups.

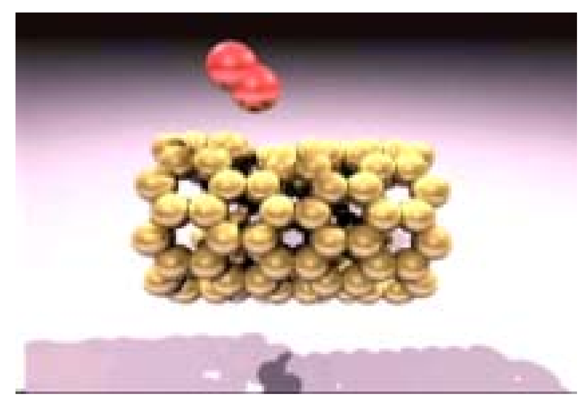
Projects

- Modeling of Material and Material Assembly Response to Ballistic and Blast Loading (Boyce, Socrate, Beers)
- Understanding, designing, and tuning the response of nano-particles to target mechanical, electronic, and chemical properties (Ceder, Marzari, Fink)
- Modeling and Simulation of Novel Electro-Osmotic
- Microfluidic Pumps and Mixers (Bazant, Schmidt, Jensen)
- First-principles description and macrocopic constitutive modeling of the structural, mechanical and electronic properties of conducting polymer actuators (Marzari, Boyce, Hunter, Swager)
- Nanoscale structure formation with dissipative particle dynamics (DPD) (Barton, Beers)

Nanotubes and Nanowires As Chemical Sensors

- **Objective**
  - **Determine mechanism and efficacy of carbon nanotube as an oxygen sensor**
- **Approach**
  - **Electronic Level Structure Simulations of Oxygen adsorption in carbon nanotubes**
  - **Understand geometry and energetics of binding of simple and complex molecules to nanowires**
  - **Predict how interaction alters macroscopic property such as electrical conductivity for use as a chem/bio sensor**
  - **Simulations as a materials design/screening tool**





Calixarenes and Polythiophenes as Building Blocks for Electroactuators

- **Objective**
  - **Prediction of actuator structure and properties**
- **Approach**
  - **Electronic structure calculations of component molecules**
  - **Calculation of coupling interactions of macromolecule**

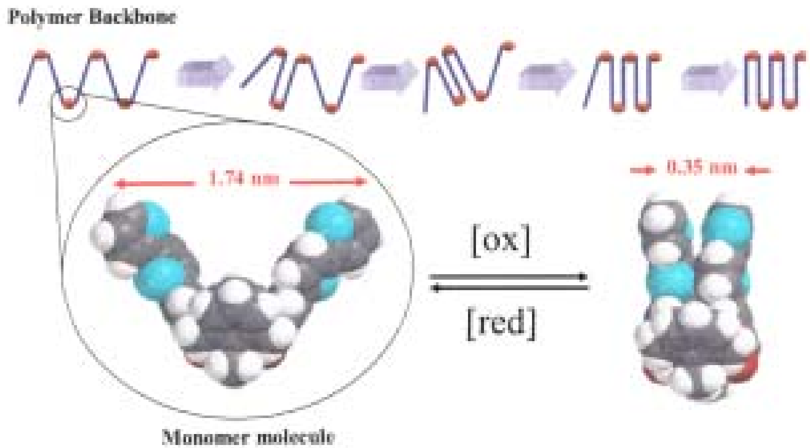
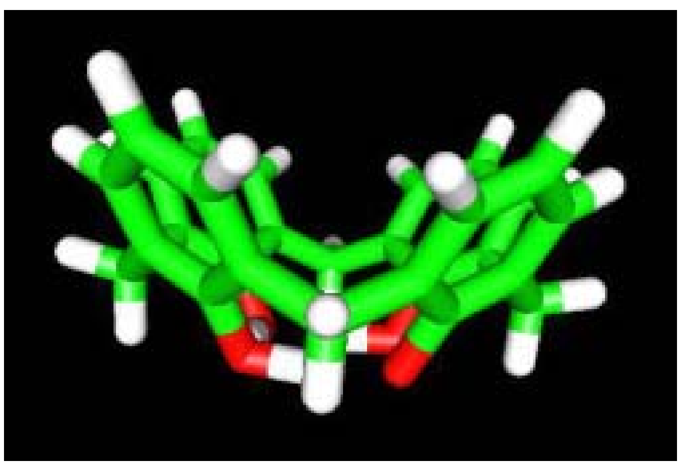
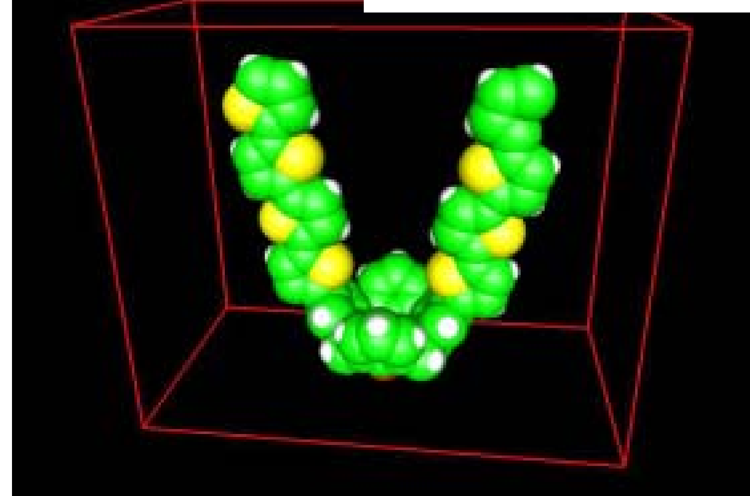


Figure 3: Schematic actuation mechanism of polymer 1.

Neutral Structure of Calixarene

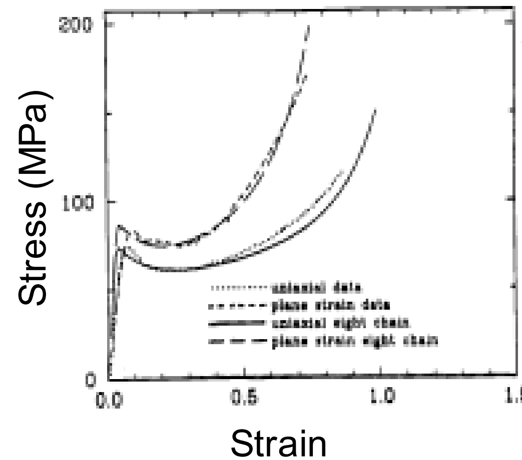


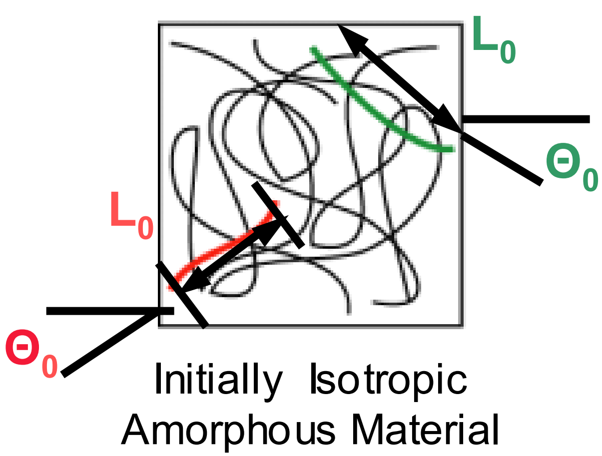
Neutral Configuration: 2 QT + calixarene



Continuum Level Constitutive Modeling of Coupled Behavior

- **Objective**
  - **Determine physically-based constitutive models of molecular orientation-induced strain hardening in polymers**
- **Approach**
  - **Mean-field continuum modelling of polymer configuration**
  - **Analytical expression of constitutive behavior vs. polymer structure parameters**

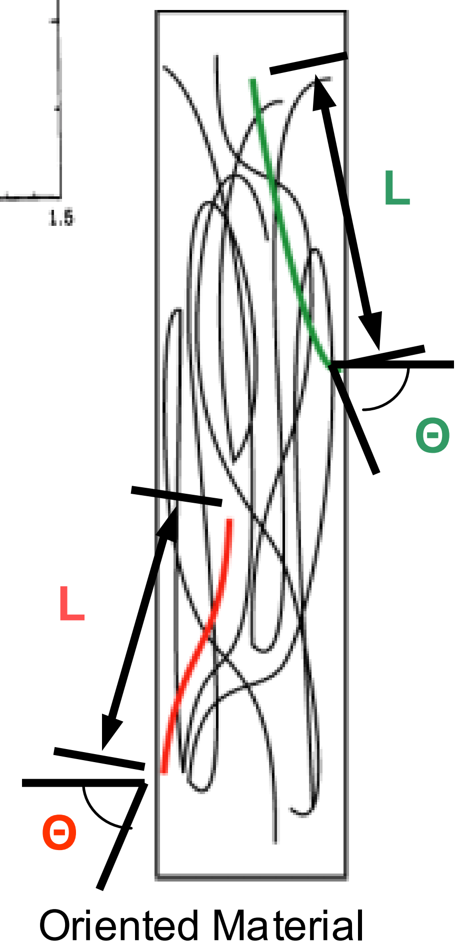




Applied Loading

Chain Stretch:

$\varepsilon = L/L_0$



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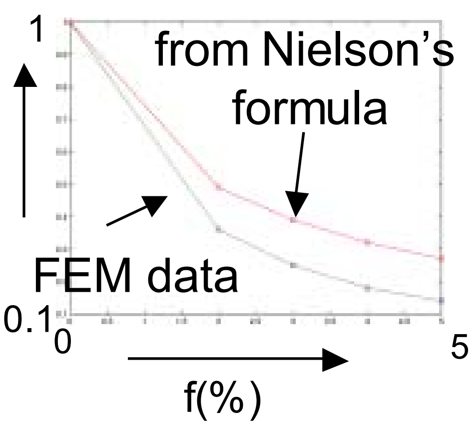
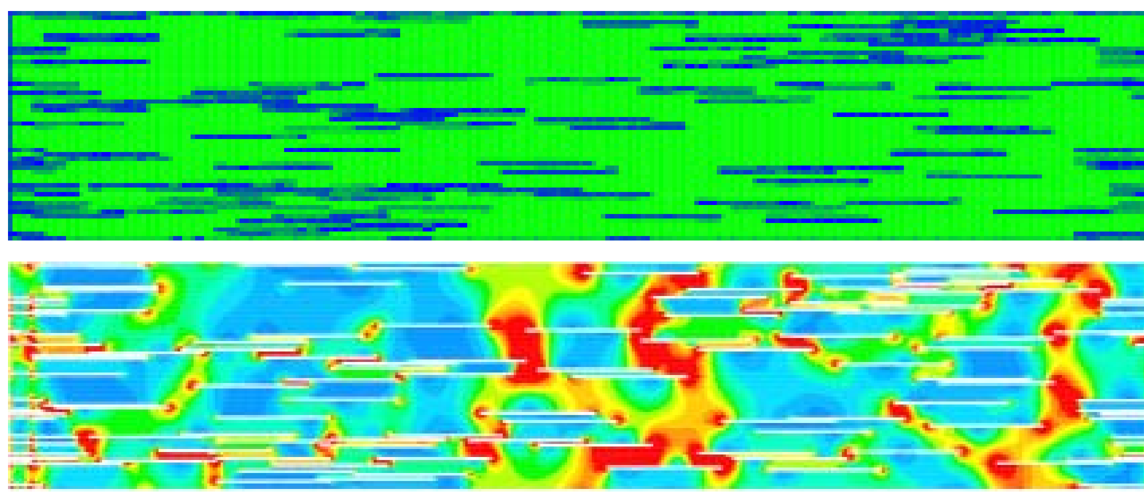
Mechanistic Modeling of Permeability

- **Objective**
  - **Predict structure/property relationships of randon nanoclay/polymer systems**
  - **Develop average relationships to allow design of composite systems**
- **Approach**
  - **Finite element modelling of random exfoliated nanoclay/polymer nanocomposites**
  - **Analysis of “average” permeability based on particle distribution statistics**

RVE: 100 particles
f= 5%, L/t =100

Effect of volume fraction on permeability, L/t=100





Flux Contours

MIT-ISN

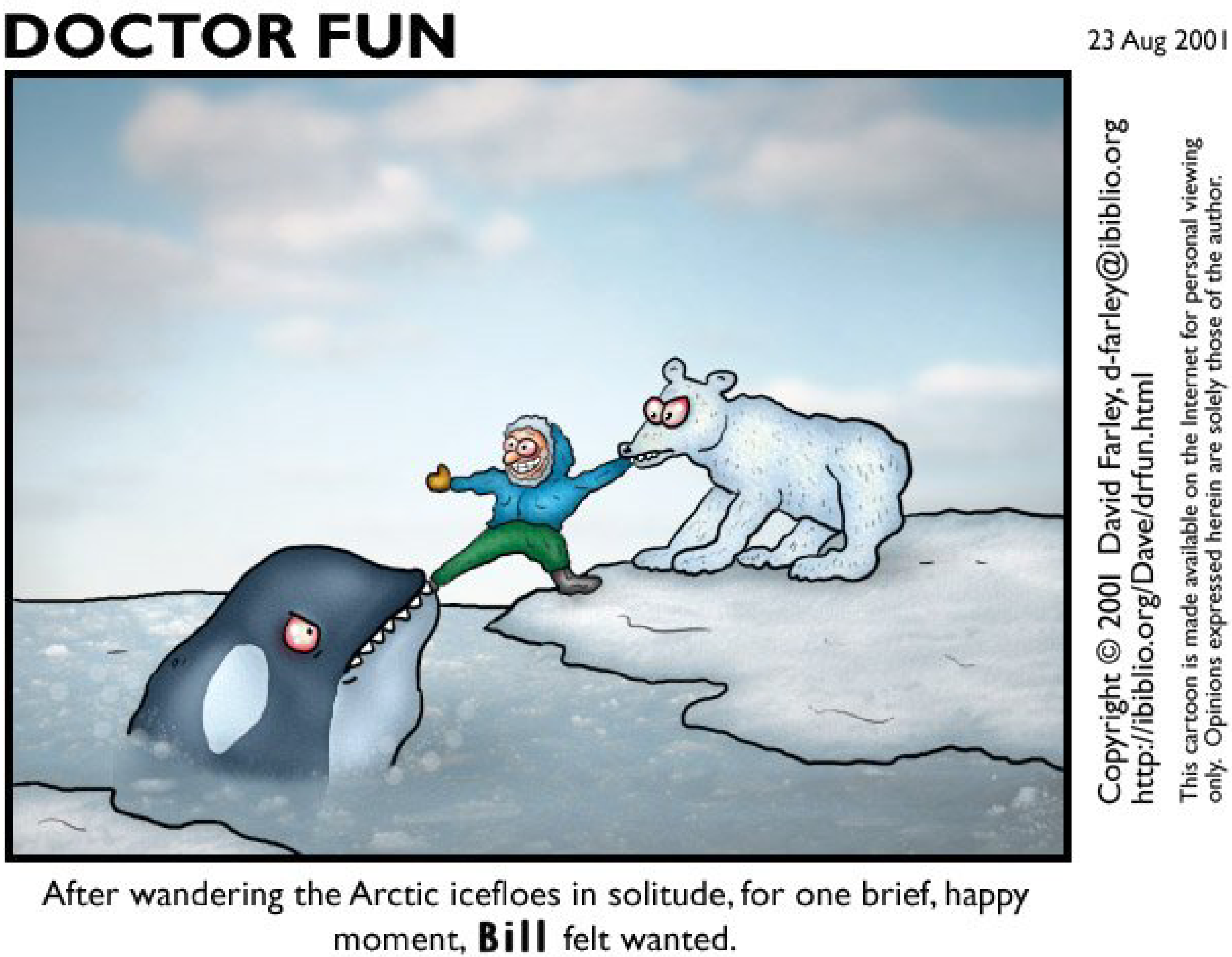
Summary

- **The Army Transformation requires advances in nanotechnology to meet goals**

- **The ISN is focused on creating and commercializing new technologies to enhance soldier protection to meet these goals**

- **We are very interested in forming new partnerships with the ISN to help foster and transition new technologies**

Thank You


DOCTOR FUN
23 Aug 2001
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http://ibiblio.org/Dave/drfun.html
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After wandering the Arctic icefloes in solitude, for one brief, happy moment, Bill felt wanted.