TECHNICAL REPORTS

ROUTING AND ACTION MEMORANDUM

ROUTING

TO: (1) Chemistry Division Division
(Paur, Richard)

Report is available for review on the EDMS

(2) Proposal Files

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PRINCIPAL INVESTIGATOR: Dr. Mark W. Grinstaff

SCIENTIFIC LIAISON:

TYPE REPORT: Final Report
Period Covered (if applicable): 01-Sep-2000 31-Aug-2001

TITLE: workshop: The Biotechnology and Nanotechnology Interface

ACTION TAKEN BY DIVISION

(✓) Report has been reviewed for technical sufficiency and [✓] *IS* [ ] *IS NOT* satisfactory.

(✓) Material has been given an OPSEC review and it has been determined to be nonsensitive and, except for manuscripts and progress reports, suitable for public release.

( ) Further action requested:

Richard J Paur
(Signature)

1 Oct 01
(Date)

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15 Mar 89

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Prescribed by ANSI Std. 239-18
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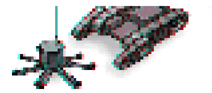
Proceedings from the

Workshop on

Nanoscience for the Soldier



sponsored by the Army Research Office

February 8-9, 2001

held at the

North Carolina Biotechnology Center

Durham, North Carolina

Back to ARO Home Page   Continue

Nanoscience for the Soldier

Workshop (held 8-9 February 2001)

This website contains all the information currently available regarding the recent ARO-sponsored "Workshop on Nanoscience for the Soldier." Dr. A. Michael Andrews, Deputy Assistant Secretary of the Army for Research and Technology, has announced that he would like to create a university research center concentrating on nanoscience for the soldier. This website is being posted to provide all interested parties a common source of information. No other information about the proposed center is available at this time.

Continue

Workshop on Nanoscience for the Soldier

Proceedings

TABLE OF CONTENTS

Workshop on Nanoscience for the Soldier

SECTION I

Workshop Agenda

08-Feb-01

8:30	Introduction	Henry Everitt	ARO, Physics Division
8:50	Army Research	Robert Whalin	Director, ARL
9:00	Nanoscience and the Soldier	A. Michael Andrews	Deputy Assistant Secretary of the Army for Research & Technology
9:40	Soldier Systems	William Brower	PM, Soldier Systems
10:05	Future Soldier System	Cheryl Stewardson	Natick
10:30	Break		
10:50	Mobile Power	Richard Paur	ARO, Chemistry Division
11:10	Soldier Status Monitoring	Richard Satava	Yale University
11:35	Nanoscience for Sensing	Sanford Asher	University of Pittsburgh
12:00	Lunch		
1:00	Break-out into 4 working groups:		
	Materials and Fabrics	Chair: Gary Hagnauer/Michael Sennett	
	Power, Energy Distribution & Cooling	Chair: Richard Paur/Michael Philpott	
	Soldier Status Monitoring & Modeling	Chair: Mark Ratner	
	Displays, Detectors & Antennas	Chair: Eric Van Stryland	

5:00	End of day

<u>09-Feb-01</u>

8:30	Working groups resume
12:00	Lunch
1:00	Presentation of Final Conclusions
2:00	End of meeting

Workshop on Nanoscience for the Soldier

SECTION II

Attendees

MATERIALS & FABRICS

NAME	AFFILIATION
Bernholc, Jerry	NC State U.
Campbell, Robert	ARO
Decker, Shawn	Nanoscale Materials, Inc.
Hagnauer, Gary	ARL
Jarvis, Chris	Clemson U.
Kiserow, Doug	ARO
Liu, Jie	Duke U. Medical Center
McKnight, Steve	ARL
Ren, Zhifeng	Boston College
Sennett, Michael	Natick
Siegel, Richard	Rensselaer Polytechnic Inst.
Stepp, Dave	ARO
Stewardson, Cheryl	Natick
Tassinari, Tom	Natick

POWER & COOLING

Chen, Gang	UCLA
Chu, Deryn	ARL
Fedkiw, Peter	ARO/NC State
Mahan, Gerry	U. Tennessee
Masadi, Roger	Natick Soldier Center
Masel, Rich	UIUC
Paur, Dick	ARO
Pellegrino, John	ARL
Philpott, Mike	UIUC
Rowe, Jack	ARO
Samuelson, Lynne	Natick Soldier Center
Wolfenstine, Jeff	ARL

DISPLAYS, DETECTORS & ANTENNAS

Ahner, Joachim	U. of Pittsburgh
Amirtharaj, Paul	ARL
Boreman, Glen	UCF/CREOL
Ciftan, Mikael	ARO
Guenther, Bob	Duke U.
Kempa, Kris	Boston College & Nanolab
Khoo, I.C.	Penn State U.
O'Brien, Bob	Natick Soldier Center
Strub, Michael	ARL
Van Stryland, Eric	UCF/CREOL/School of Optics
Wood, Gary	ARL/SEDD/Optics Br.
Wu, Shin-Tson	Hughes Research Labs

SOLDIER STATUS MONITORING & MODELING

Allender, Laurel	ARL/HRED
Asher, Sanford	U. of Pittsburgh
Hellinga, Homme	Duke U. Med Center
Jayaraman, Sundaresan	Georgia Tech
Jenkins, Amanda	ARL/WMRD
Lee, Jaime	WRAIR
Lee, Stephen	ARO
Namburu, Raju	ARL
Ratner, Mark	Northwestern U.
Satava, Rick	Yale/USA Med Res & Mgt Command
Strub, Michael	ARL/HRED

Workshop on Nanoscience for the Soldier

SECTION III

Presentations
(8 February)

- 

- Henry Everitt - ARO Physics Division
- Robert Whalin - Director, ARL
- A. Michael Andrews - Deputy Assistant Secretary of the Army for Research & Technology
- William Brower - PM, Soldier Systems
- Cheryl Stewardson - Natick
- Richard Paur - ARO, Chemistry Division
- Richard Satava - Yale University
- Sanford Asher - University of Pittsburgh

Workshop on Nanoscience for the Soldier

Henry Everitt
ARL/ARO Physics Division

Feb. 8-9, 2001

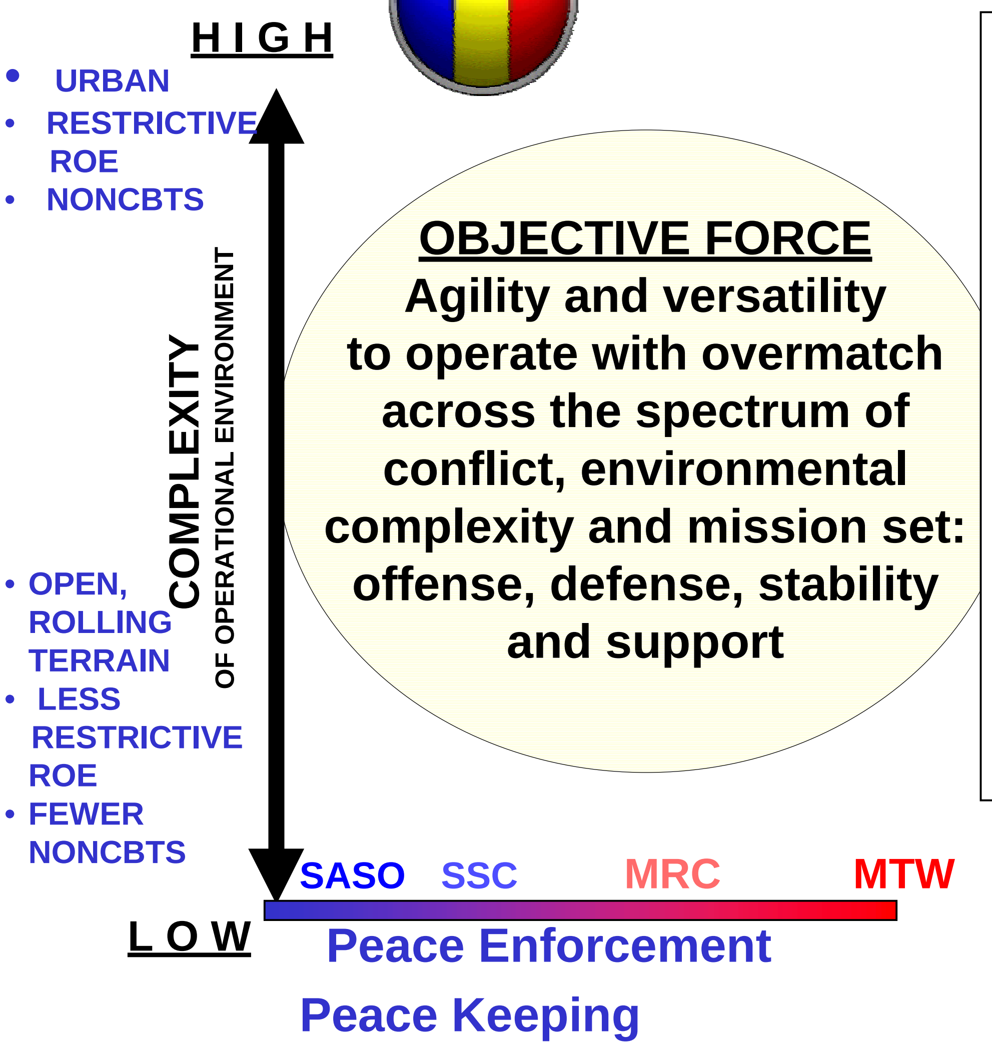
Army Research Office

OBJECTIVE FORCE WARFIGHTER TECHNOLOGY ASSESSMENT

FINDINGS AND RECOMMENDATIONS OF THE IRT

17 NOVEMBER 2000

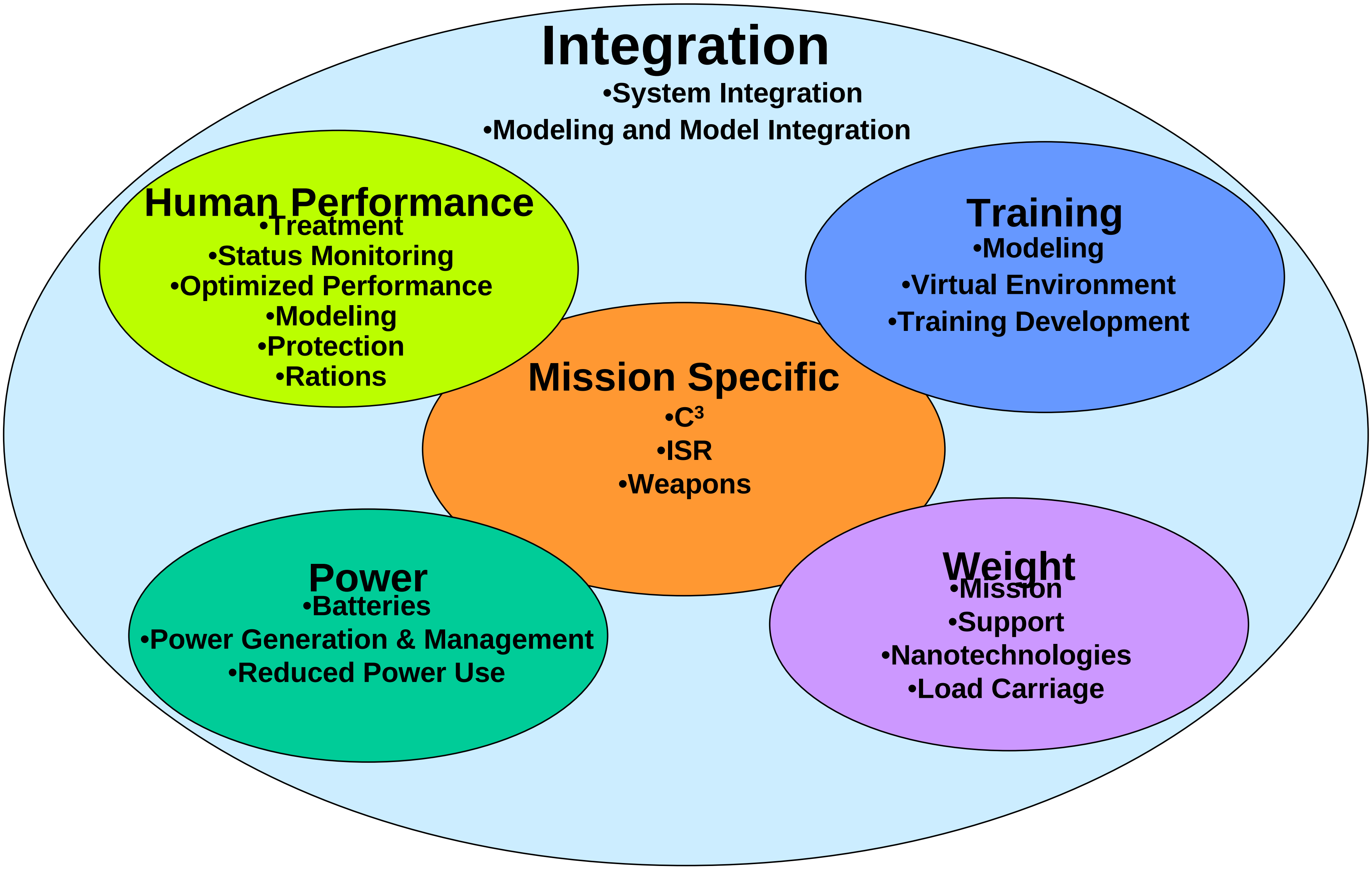
Objective Force Warrior Challenge



Enable Future Objective Force Warriors, within their unit of action, to achieve

- **their full spectrum of tasks**
- **across a full spectrum of missions and environments**
- **against a full spectrum of threats**

How the Warrior Technology Investment is Organized



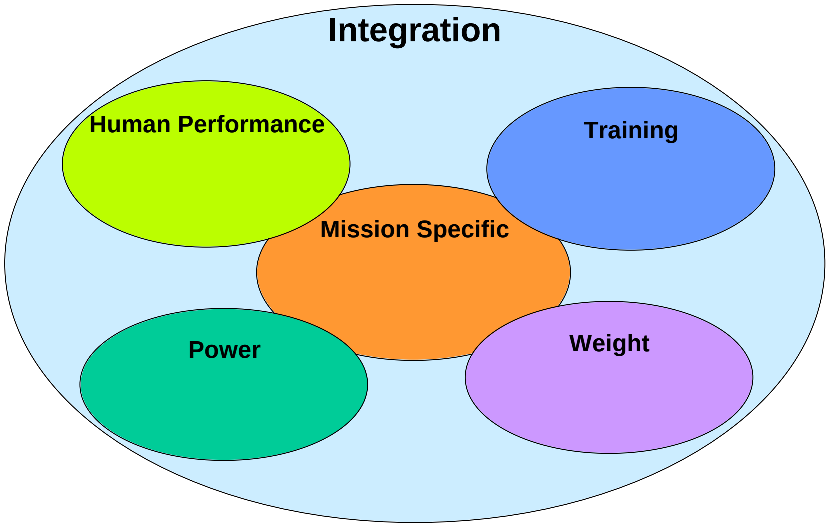
Summary

- **Findings**
  - The Objective Force Warrior vision cannot be realized within this decade on the current course
  - More can be done, and more quickly, to enhance the capabilities of the Objective Force Warrior
  - The S&T program can yield revolutionary soldier performance in this decade *if* the program is redefined/re-resourced

Revolutionary Soldier Performance Requires Aggressive, High Risk Actions

Where can Nanotechnology help?

- **Investment Areas**
  - Power
  - Weight
  - Human Performance
  - Mission Specific
  - Integration



- **Nanoscience Research Opportunities**
  - Power sources and energy distribution
  - Materials and fabrics for protection and scaffolding
  - Cooling
  - Soldier status monitoring and modeling
  - Displays, Detectors, and Antennas

Workshop on Nanoscience for the Soldier

Army Research Office

- **Purpose**
  - **Identify research requirements**
    - What must be done to respond to need/opportunity?
    - What are the fundamental limits?
  - **Identify opportunities provided by nanoscience for the soldier**
    - Specify DoD need
    - List opportunities for revolutionary impact

- **Workshop Rules**
  - **General Rules**
    - Discuss problems, not solutions
      - Concentrate on the “needed”, not the “neat”
    - DoD application must be clear
      - Concentrate on current weaknesses and revolutionary opportunities
    - Nanoscience should be the solution
      - Nanoscience should be the only way or the best way
  - **Final Product: The written report!**

Workshop on Nanoscience for the Soldier

- **Workshop Presentation Format**
  - **Speakers will give overview of field**
    - Discuss the state-of-the-art and rationale/justification
    - Identify need or opportunity for the soldier
    - Summarize seminal research findings
    - Speculate about research roadblocks
    - Stimulate working group discussions
  - **Attendees**
    - Part Army and part University
    - Audience should ask only clarifying questions
    - Dialogue should occur during working groups

Workshop on Nanoscience for the Soldier

- **Working Group Charter**
  - **Four Parallel Working Groups**
    - Materials and fabrics for protection and scaffolding
      - Congressional Room
    - Power, Energy distribution, and Cooling
      - President's Room
    - Soldier status monitoring and Modeling
      - RTF Room
    - Displays, Detectors, and Antennas
      - Catalyst Room
  - **Participation**
    - Each attendee will participate in only one working group
      - University participants are nanoscience experts
      - Army participants are soldier experts
  - **Objective**
    - Identify critical **needs** for research to address
    - Identify critical **opportunities** from research that might benefit soldier
      - *Do not attempt to try to answer questions or solve problems!!*

- **Working Group Discussion Format**
  - **Working Group**
    - E.g. Displays, detectors, and antennas
  - **Identify Area**
    - E.g. "Nanostructures for antennas"
  - **Identify Objective(s)**
    - Specify desired capability
      - E.g. "Conformal, low glint antenna for soldier communication"
  - **Identify Research Requirements**
    - List
      - Requirements for nanoscience to address
        - » E.g. "How do you prevent antenna drain when placed near the soldier?"
      - And/or nanoscience opportunities to exploit
        - » E.g. "Photonic crystals can shepherd electromagnetic radiation."
    - Identify Key Proof-of-Concept Demonstrations
      - E.g. "Demonstrate a lightweight, conformal, broadband antenna ground plane that can be woven into uniform or molded inside helmet."

Workshop on Nanoscience for the Soldier

Army Research Office

- **Workshop Worksheet**
  - **Each working group will address two or three "Areas":**
    - Two
      - Materials / Fabrics for Protection and Scaffolding
      - Soldier Status Monitoring (including CBD) and Modeling
    - Three
      - Power, Energy Distribution, and Cooling
      - Displays, Detectors, and Antennas
  - **Each "Area" will have several "Objectives"**
    - One worksheet for each Objective
  - **Each "Objective" will have many "Research Requirements"**
    - Need-driven research
    - Opportunity-driven research
    - Critical proof-of-concept demonstrations

Area

Objective

Research Requirements

Need-driven research

Opportunity-driven research

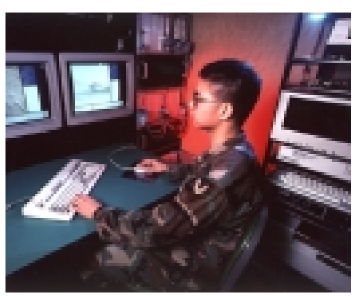
Critical proof-of-concept demonstrations

Workshop on Nanoscience for the Soldier

- **Workshop Agenda**
  - **Presentations**
    - Thursday Morning
  - **Working Groups**
    - Thursday Afternoon
      - Complete list of "Objectives"
      - Begin list of "Research Requirements"
    - Friday Morning
      - Complete list of "Research Requirements"
      - Prepare summary presentation
      - Write final report

Smaller, Smarter & Lighter Systems

Nanotechnology Workshop
8 February 2001



Dr. A. Michael Andrews
Deputy Assistant Secretary of the Army,
Research and Technology /
Chief Scientist


Objective Force Warrior - - -
Decisions Today for Tomorrow

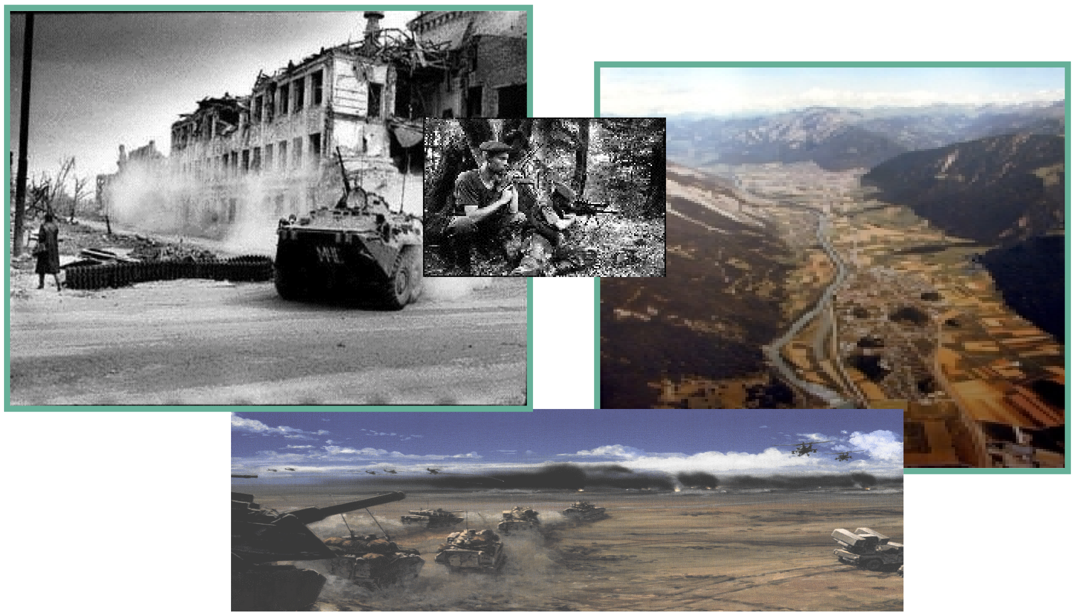
Objective Force for Full Spectrum of Missions

Environmental Complexity

High
- Urban

- Open, rolling terrain

Low



Increased strategic responsiveness

- ✓ BCT in 96 hrs; Div in 120 hrs; 5 Div in 30 days
- ✓ Fight immediately upon arrival
- ✓ Simultaneous air and sea lift

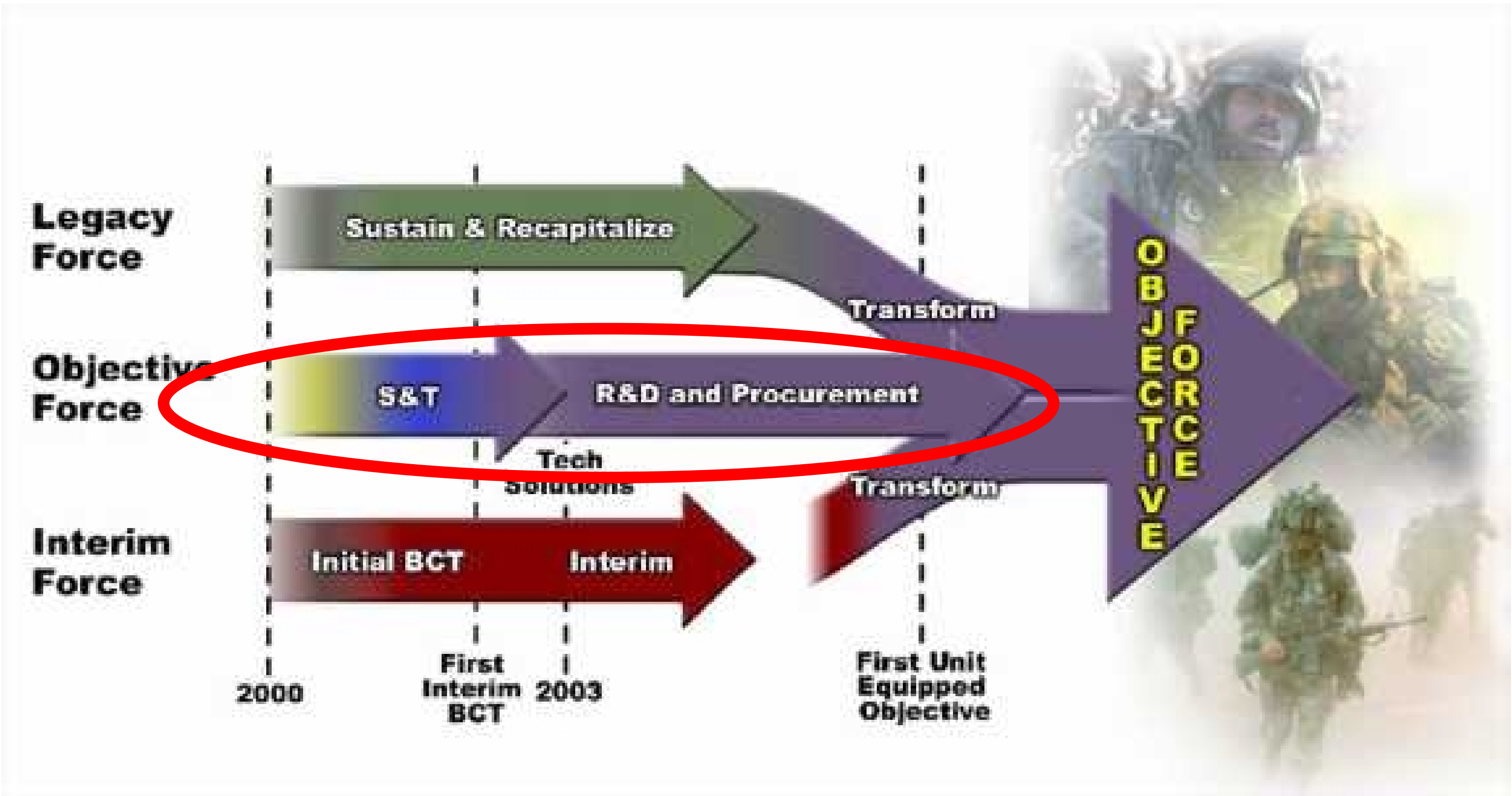
Stability and Support Operations — Small Scale Contingencies — Major Theater War

Spectrum of Conflict

"If we can't get to the fight faster, we're not relevant."

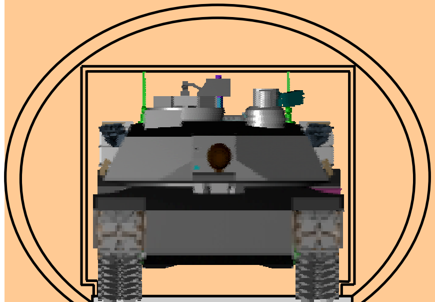
Sec Army Louis Caldera, 6 Nov 00

The Army Transformation



. . . Responsive, Deployable, Agile, Versatile, Lethal, Survivable, Sustainable

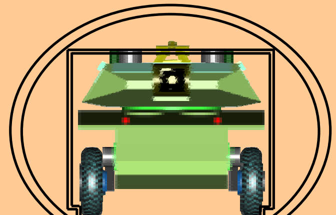
Objective Force Requires Operational and Technology Innovation



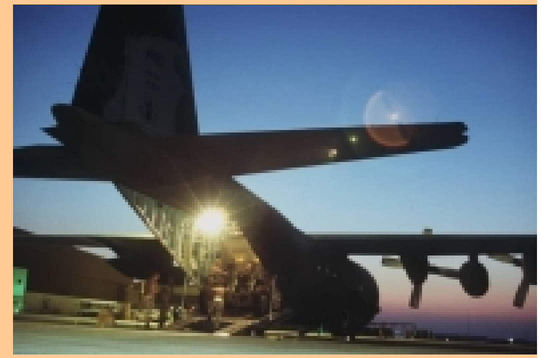
C-17/C-5

Fit the C-130 "Crucible"

Up to:
70% Lighter
50% Smaller



C-130



- ***Dismounted Soldier***
- ***Lethality***
- ***Survivability***
- ***C^3 on the move***

Challenges

Transformation Drives the Army to ...smaller, smarter, and lighter systems

Keeping The Soldier at the Center of The Objective Force

Future Warrior 2025
Weapon Subsystem – Lethality

We Need to Spark Our Imagination - - - "Predator" The Movie

A System of Systems Approach is Needed

Stealth

- Near invisible in visible light

Environmental Protection

- Self contained protection from “alien” environment

Sensors

- Multi-spectral optics
- Acoustic

Power

- Near endless power source

Fightability

- Agile warrior with full gear

Medical

- Self contained Medical kit

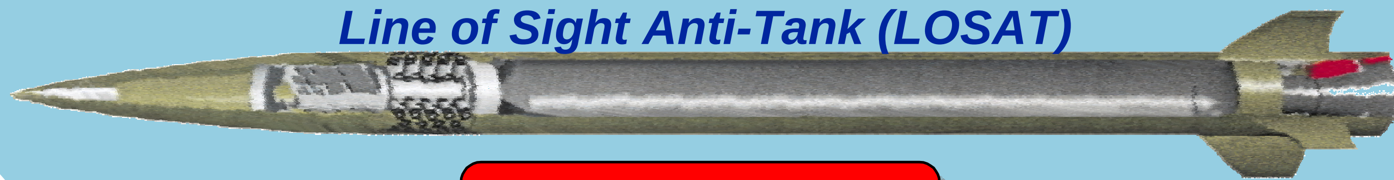
Lethality

- Lightweight laser guide air burst weapon

Ideas for a “nearly invincible” warrior system

Overwhelming lethality in a smaller, lighter, faster kinetic energy missile

Line of Sight Anti-Tank (LOSAT)



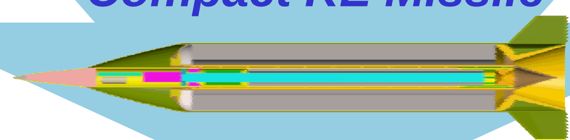
Length	9 ft 9 in
Weight	175 lb.

Increased Speed Required
For Reduced Size

$$KE = \frac{1}{2} MV^2$$

Length	4 ft.
Weight	50 lb.

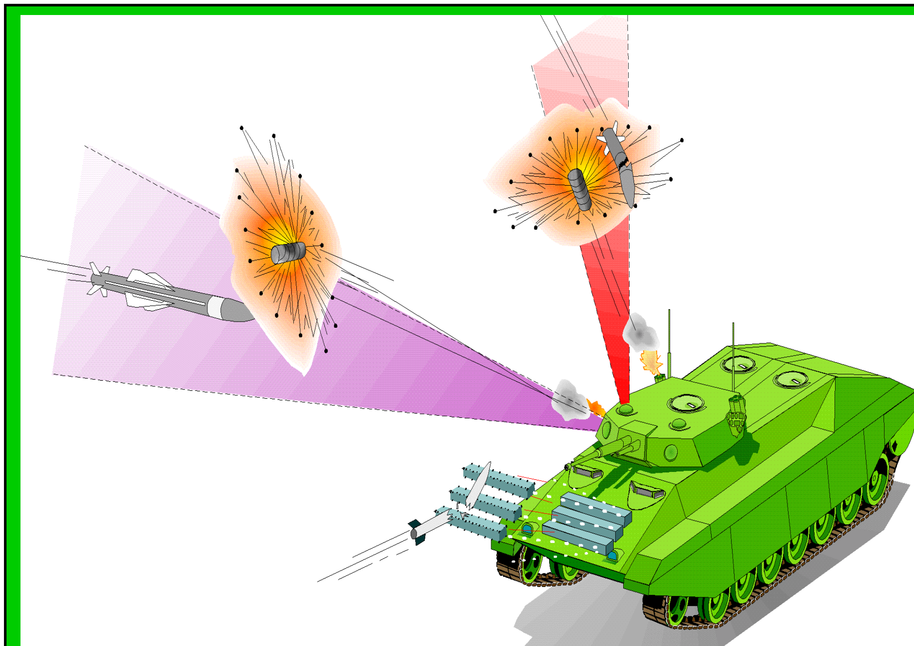
Compact KE Missile



LOSAT-Like Lethality in 4 ft/50 lbs

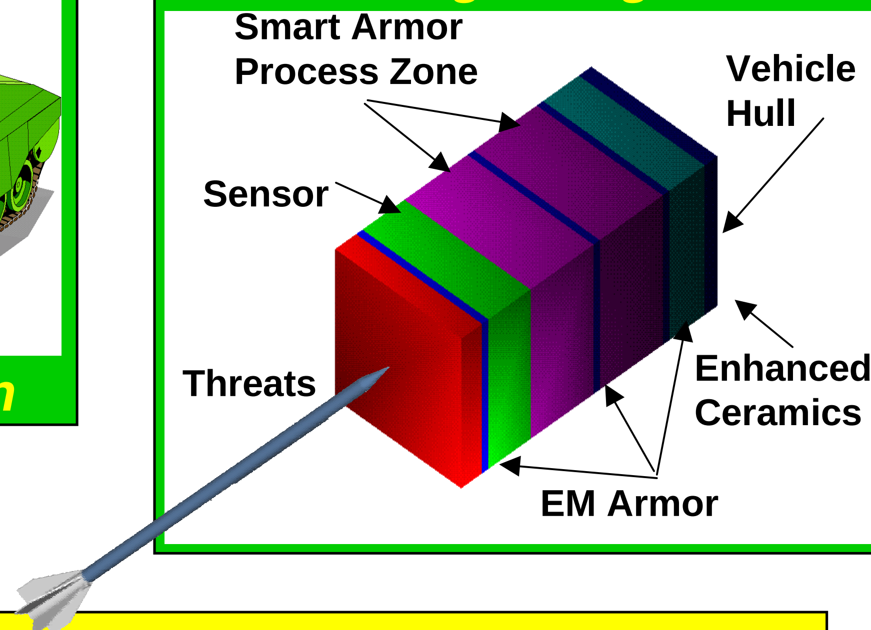
Surviving first round engagements

… 70 ton Survivability in <20 ton Systems



Full Spectrum Active Protection

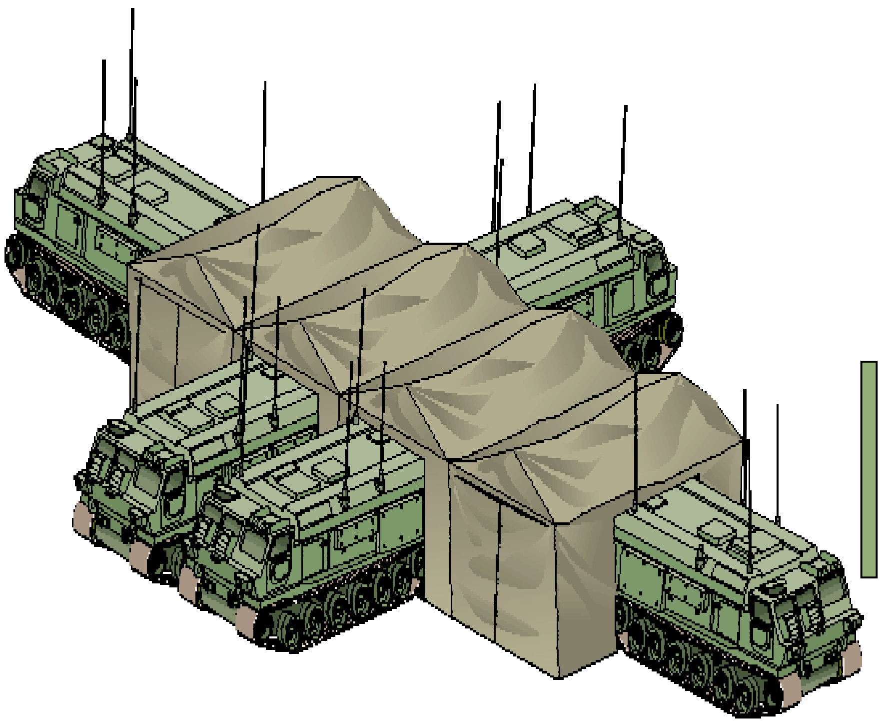
Smart Lightweight Armor

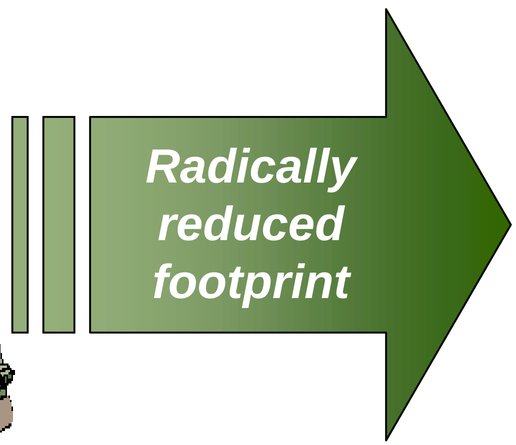


Defeat threats with lighter,smarter systems

Enabling Commander to Control and Direct the Battle from Anywhere in the Battlespace

….Agile Commander ATD





Smaller, smarter systems for mobile C3

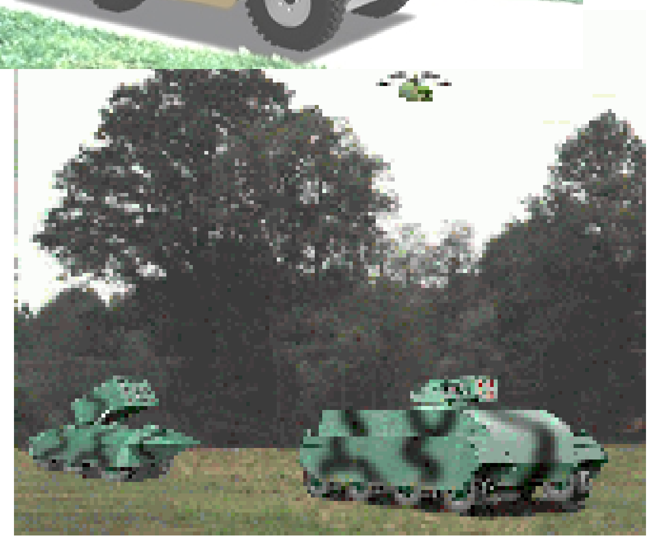
Reducing soldiers' risk ...

Controlled Autonomous Robotic Systems

Ruck Sack Carrier

Convoy

Rear Security



Fires

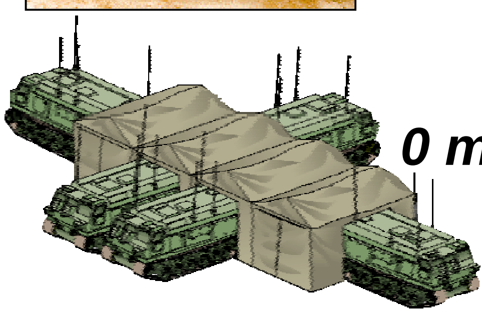
Improved soldier effectiveness with smarter systems

Focusing Technology Innovation . . . Smaller, Smarter & Lighter

Today

~100 lb. load

70+ tons



0 mph

S&T -- Accelerating the pace of Army Transformation

Objective Force

< 30 lb. load

< 20 tons

> 40 mph

Army Nanotechnology . . . Opportunity

- **Pervasive Impact on Future Army Systems**
  - **Low power, intelligent, light weight, multifunctional devices**
- **Revolutionary capabilities, not incremental improvements**
  - **Soldier Systems**
    - **Smaller, Lighter Sensor, Communication, Computing & Power Devices**
    - **Integral Chem/Bio, Laser, and Ballistic Protection**
    - **Integrated Thermal Management**
  - **Combat Systems**
    - **Armors and Structural Components**
    - **Advanced Engines**
    - **Next Generation Pentrators and Warheads**
    - **Next Generation Propellants and Explosives**
    - **Advanced Communications, Electronics and Sensors**
- **Approach - Establish University Affiliated Research Center (UARC) to Harvest Academic/Industry Breakthroughs**

Summary

- ***The path to Army Transformation <u>demands</u> responsive & deployable systems***
- ***Army S&T <u>Focus</u> is on smaller, lighter, and smarter systems***
- ***We are <u>doing</u> things that have never been done before***

"The only thing that matters is Innovation."
Peter Drucker

Soldier Systems

Nanoscience for the Soldier Workshop

8 February 2001

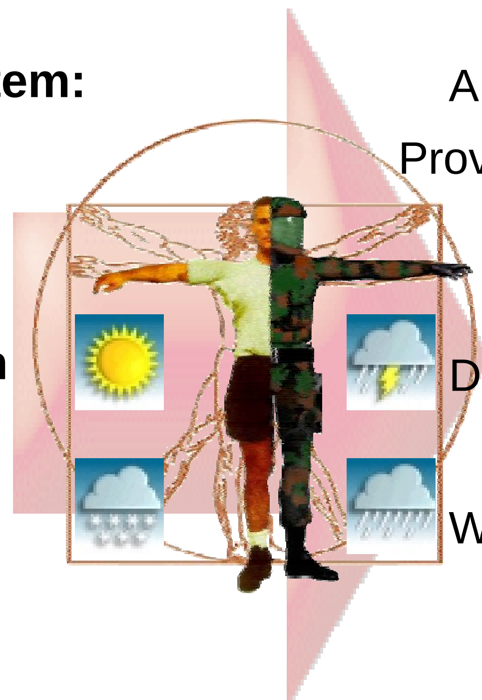
Bill Brower
APM Future Soldier
Office of PM-Soldier Systems
Telephone: (703) 704-2888
wbrower@pmsoldier.belvoir.army.mil

The Soldier System

Definition

A *Fully* Integrated Soldier System:

- Trained and Ready Soldier
- Equipped For Operational Environments
- Enhance Lethality Through Electronic Battlefield
- Seamlessly Integrated With Other Soldiers & Their Weapon Systems



Vision

A Fully | **Integrated Soldier System**
Providing | **Combat Overmatch**
Tailorable for All Soldiers
In | **Full Spectrum Conflict**
During | **Joint**
And | **Coalition Operations**
Within | **A Soldier Support Architecture**

A Focused Effort on The Soldier as a System

Land Warrior

Integration of Infantry Soldier Combat Capabilities into a Warfighting System Optimized for Close Combat

Capabilities:

- **Command & Control**
- **Survivability**
- **Situational Awareness**
- **Lethality**
- **Mobility**
- **Training**

The Land Warrior System
(A Fully Integrated Soldier System)

Integrated Helmet Assembly

Lightweight Helmet with Mounted Display, Laser Detector and Ballistic/Laser Eye Protection

Weapon System

Modular Design allows for Mounting of Video Camera, Thermal Weapons Sight, Close Combat Optics & Laser Rangefinder

Computer/Radio Subsystem

Pentium Computer, Soldier and Squad Radios, Navigation & Handheld Flat Panel Display

Software Subsystem

Modular, Tactical & Mission Software, Designed Avoid Information Overload

Protective Clothing and Individual Equipment Subsystem

Modular Lightweight Load Carrying Equipment, INTERCEPTOR Body Armor, Chem/Bio

“The First System To Provide Overmatch Capability For Ground Soldiers”

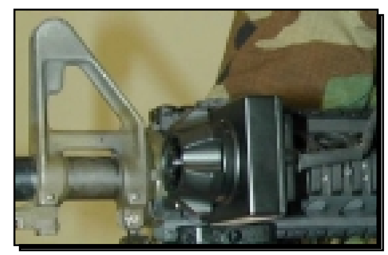
Land Warrior V0.6 Configuration (1 of 2)

Integrated Helmet Assembly

- Light Weight Assault Helmet
- Color Display
- Image Intensification w/Display for Night Operations
- Audio System

Weapon System

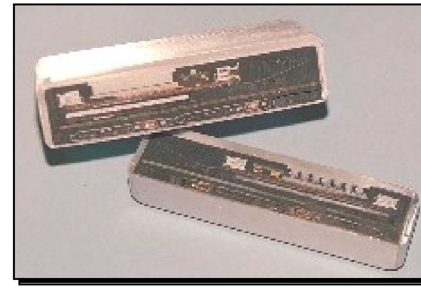
- M4 Modular Weapon System
- Thermal Sight
- Daylight Video Sight
- Close Combat Optic
- Lasers
- Wiring Harnesses/Cabling (Hybrid)
- Other Existing Weapon & Accessories



Land Warrior V0.6 Configuration (2 of 2)

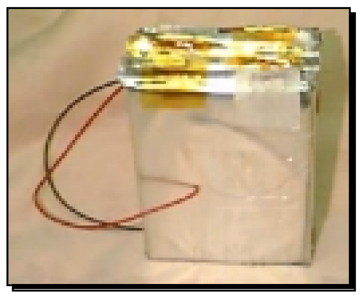
Computer/Radio Subsystem

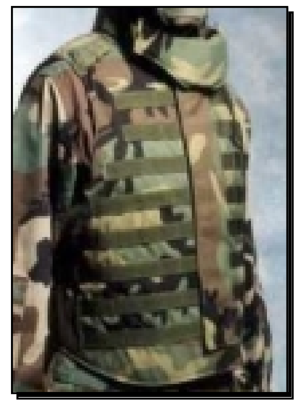
- Computer
- PCMCIA Soldier Radio
- GPS
- Integrated Navigation
- Handheld Flat Panel Display
- Keyboard

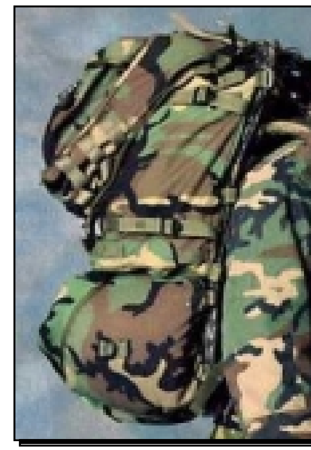


Protective Clothing & Individual Equipment Subsystem

- MOLLE
- Interceptor Body Armor
- Pouch Cell Batteries
- Other Existing CIE

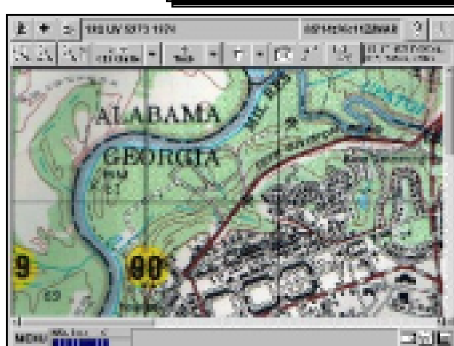




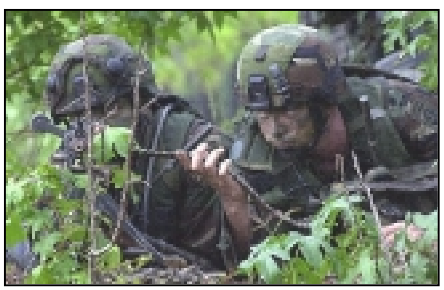


Software Subsystem

- Software



Land Warrior
(JCF-AWE Exercise)



News lines The Army

WE'LL TAKE IT

Land Warrior gives platoon big advantage in field test

ArmyTimes**, 25 September 2000**

Land Warrior V1.0 Functionality

SA/C4I

- Common Tactical Picture
- Map Displays
- Over-the-air Map Data Report
- Graphics, Orders, and Receipts
- Secure Voice & Digital Comms
- Power Management
- Image Capture, Transmission, and Receipt
- ABCS Interoperability
- Checklist Functions
- Mission Data Store
- Mission Planned Enhancement

Survivability

- Interceptor Body Armor
- Engage Targets From Cover
- Fratricide Avoidance SA.
- Integrated Combat ID
- Logistically Supportable

Sustainability

- 12 Mission Hours with 2.0 Pound Battery
- Water Immersion, Parachuting
- Full Temp Range

Lethality

- Target Acquisition & Engagement
- Accurate Target Locations
- Multi-Function Laser

Mobility

- GPS – Integrated Navigation
- Decreased Weight Over Current Soldier Load
- Modular, Tailorable Loading

Denotes KPPs

Full Connectivity, Full Tested, Fully Supported

Land Warrior Now What?

ocus is on Version 1.0 and Testing

evelopmental Testing

nitial Operational Test & Evaluation

Company Level

ccelerating Testing for Milestone III

onsortium of Contractors to Build Version 1.0

- Incorporating a Production Company to Ensure Producibility
- Overall Same Design as Version 0.6 but Upgraded

Land Warrior Requirements for Weight and Power

Dec 00 ORD

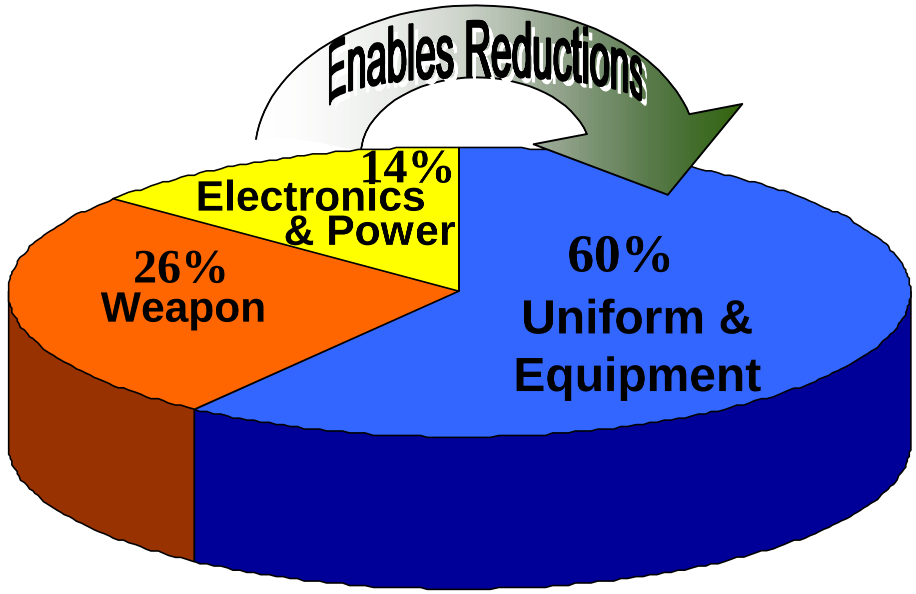
Time Phase	Threshold/KPP		Objective	
	Weight	Power	Weight	Power
Initial Prod (IP)	92.6 lbs	12 Hours 2.0 lbs max	83.3 lbs	24 Hours 2.0 lbs max
IP + 2.5 Years	No Increase	24 Hours	No Increase	48 Hours
IP + 6 Years	83.3 lbs	48 Hours	83.3 lbs	96 Hours
IP + 10 Years	66.7 lbs	96 Hours	66.7 lbs	144 Hours

Note: Hours are Mission Hours

Decreasing Weight – Increasing Mission Duration

Soldier Systems Weight Distribution
Combat Load

92.6 lbs is Current Soldier Combat Load



Electronics – 13 Lbs.
Uniform/ Equip – 55 Lbs.
Weapon – 24 Lbs.

79 Lbs. (Uniform/ Equip + Weapon)

92 Lbs.

Without Electronics The Soldier Still Carries 79 Lbs!

How Can Nanoscience Help This Soldier?
Some Thoughts

Priority is to Reduce the Soldier's Load

- **Light Weight High Durability Fabrics**
  - **-Uniform**
  - **-Packs**
- **Light Weight Materials**
  - **-Ruck Frame**
  - **-Bayonet**
  - **-Rifle/Ammo**
  - **-Tools**

- **Reduced Weight Ballistic Protection**
  - **-Small Arms Plates**
  - **-Fragmentation Vest**
- **Laser Eye Protection**

Sustainment Load Plus Distribution of Company Load Results in Soldier Loads of 120-145 Pounds or More

How Can Nanoscience Help This Soldier?

Some Thoughts

Previous Plus the Following

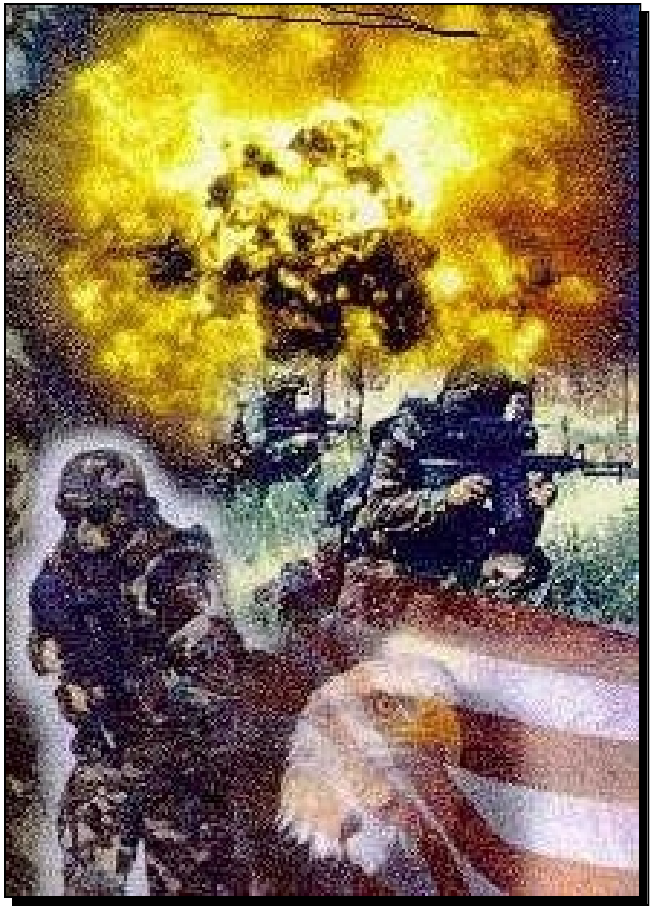
- **Next Generation Displays**
  - **Ultra Thin High Resolution**
- **Information Processing & Storage**
  - **Small Massive Durable Storage Devices**
  - **Distributed Micro Processors**
  - **Conductive Fibers Embedded in Fabric**

- **Artificial Muscles**
  - **Actuators for Increased Human Performance**
- **Power Storage/Energy Generation**
  - **Harvest Energy from Fabric Flexure**
  - **Hydrogen Storage**
  - **Embedded Flexible Batteries**
- **Drug and Nutrient Delivery on Demand**

Technology Must Be Affordable

Summary

- Land Warrior Version 0.6 Proved Successful at JCF AWE
- Focus is now on Version 1.0 Land Warrior
  - Developmental Testing 4QFY01-4QFY02
  - IOT&E FY03
  - Milestone III FY03
- Nanoscience has the potential to provide substantial benefits to the Soldier – Need to Mature Technology
- Soldier Technology must be affordable
  - Large acquisition objective quantities



Future Soldier System – Objective Force Warrior

Ms. Cheryl Stewardson
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Natick Soldier Center
US Army Soldier & Biological Chemical Command
508-233-5427
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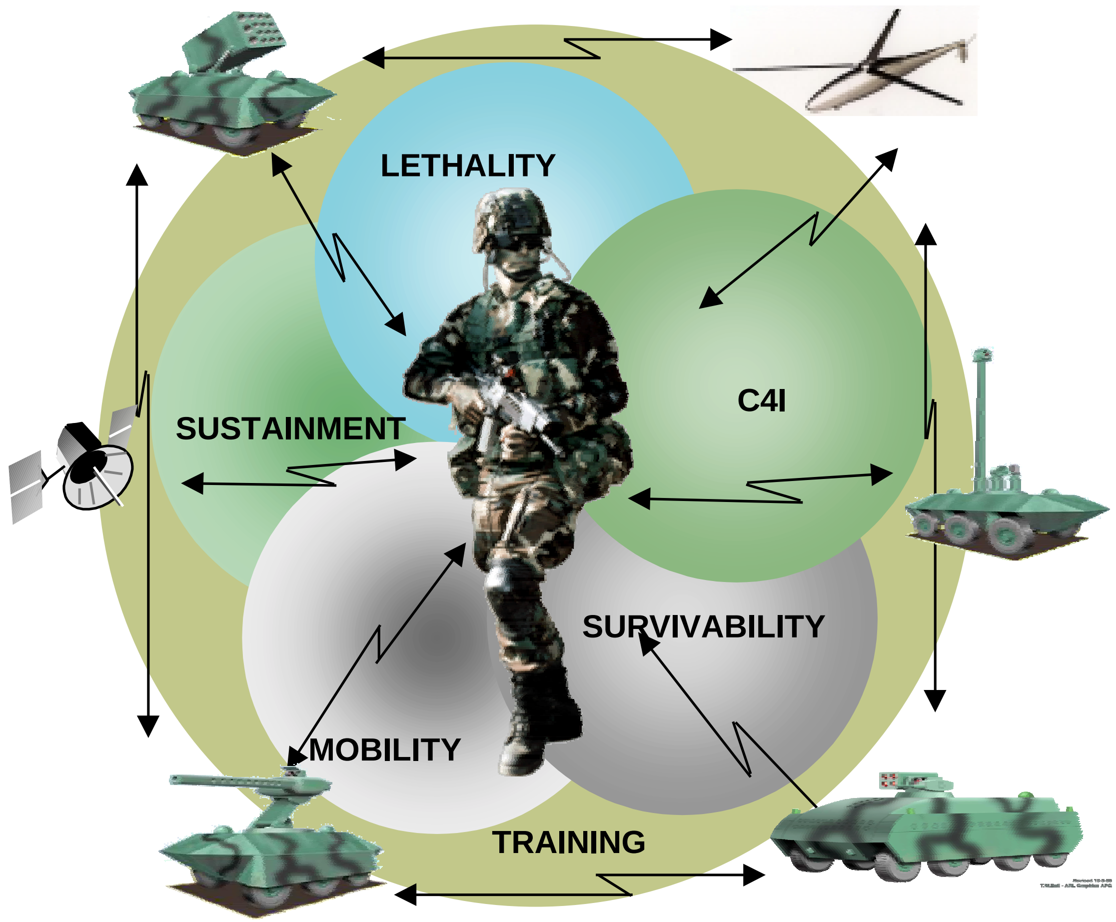
Presented to:
Workshop on Nanoscience for the Soldier

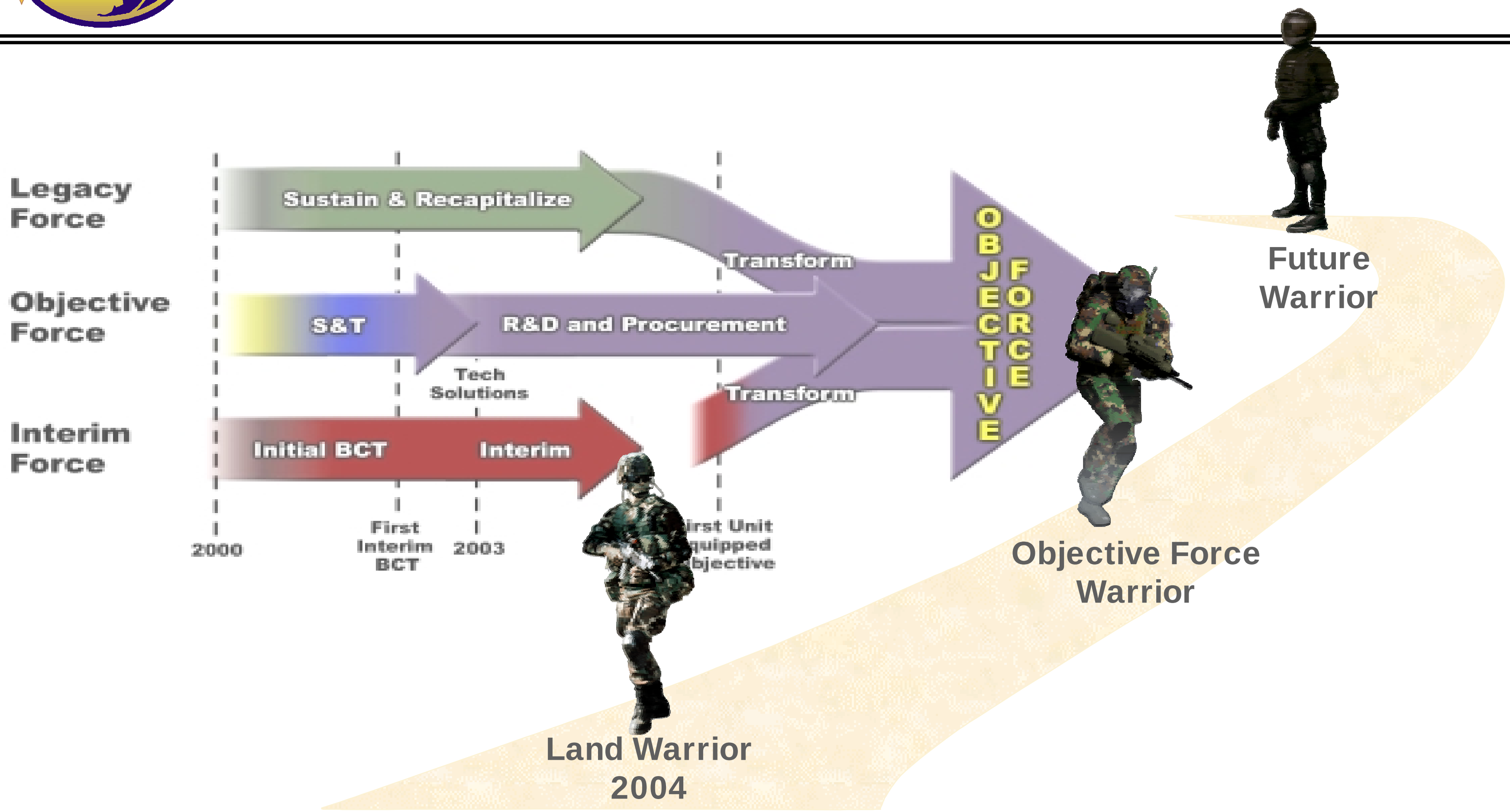
8 February 2001

The Army's Objective Force Is…



…Soldier-Centric

The Warrior System: Supporting Army Transformation



. . . Responsive, Deployable, Agile, Versatile, Lethal, Survivable, Sustainable.

Objective Force Warrior

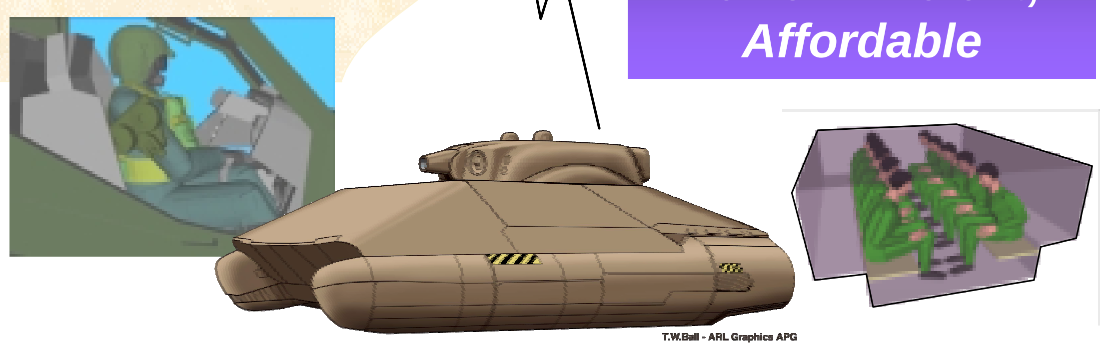
Project Objective: - Demonstrate Revolutionary, Integrated Warrior Systems as the "Centerpiece of the Objective Force Formation", Accelerating Key Technologies & Fostering Innovation through Competition

Objective Force Warrior

Agile, Versatile, Lethal, Survivable, Overmatching Capabilities

Ultra-Light, Low Bulk, Power Efficient, Affordable

Synchronizing Combat Warriors with Future Combat Systems



Objective Force Warrior
Complex "System of Systems" Integration

Power & Energy

– Extend System Operation from 12 hrs to 72 hrs (Goal) without replacing or renewing energy source (not including cooling)

Weight Reduction

– Drive down System Weight from 92 pounds, leading to 35% of body weight

Affordability

– Reduce Total Ownership Costs by 50% (Stretch Goal)

Balance Weight, Power, Cost & Performance

Human Performance & Integration

Competitive System Design Teams

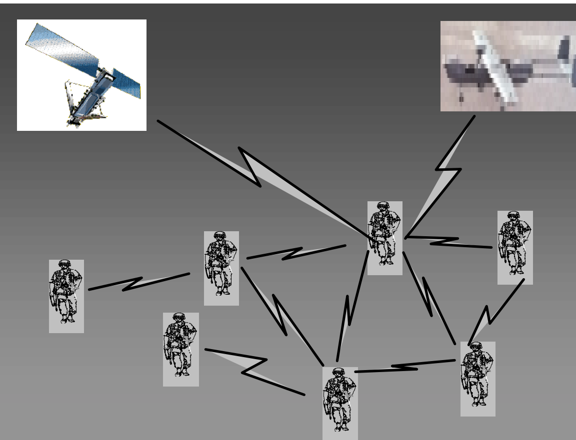
Smart Incorporation of Revolutionary Technologies

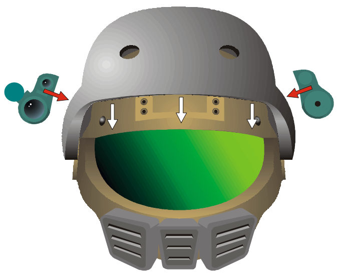
Full Spectrum of Missions, Environments & Threats

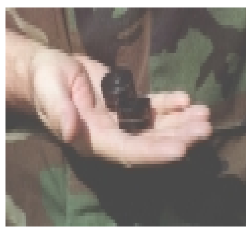
"Network-Centric" Sensors, Communications & Power

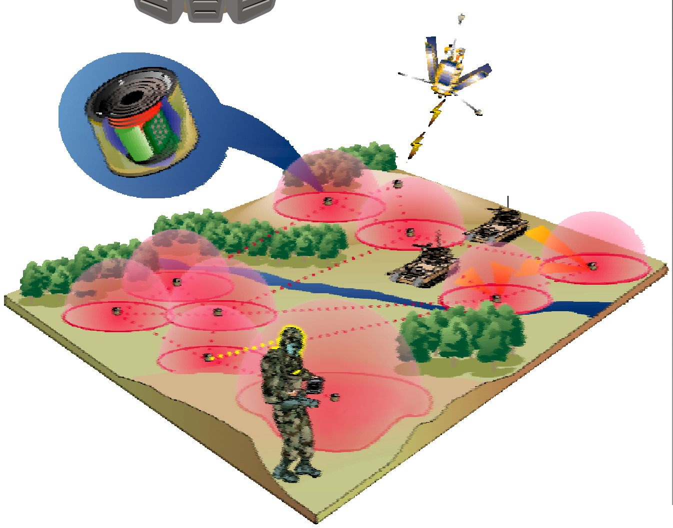
Robust, Secure, Adaptable Communications

- Adapted for Objective Force Operations in Complex Terrain (MOUT)
- Selectable, Robust Bandwidth & Range
- Frequency Agility
- Self-Organizing, Ad-Hoc Networks
- Relays through Warrior, Space, Micro-UAV, UGV and/or Unattended Sensor Assets









Overmatching Sensors – System of Systems

- Multi-Functional, Unattended Micro-Sensors (Multi-Spectral Imaging, Seismic, Acoustic, Magnetic, Fusion & Comms Relay)
- Headborne, Multi-Spectral Image Fusion
- Physiological & Medical
- Chem/Bio & Laser Warning
- Counter-Sniper & Counter-Mine

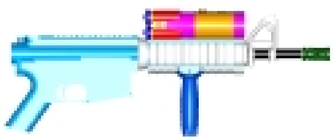
Revolutionary Power Sources

- Advanced, Hybrid Fuel Cells
- Nano-Particle Polymer Photo-Voltaic
- Leverage DARPA Palm Power

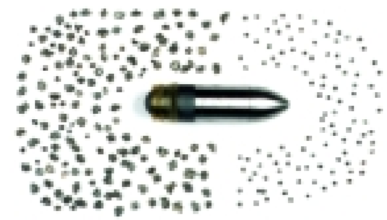
Integrated, Lightweight Weapons & Fire Control Capability

Highly Accurate & Lethal in Complex Terrain / Urban Environments

MEMS Miniature Electro- Mechanical Fuzing



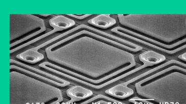
Embedded Simulation



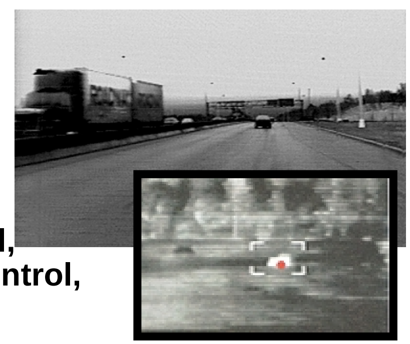
Directed Fragmentation

Low Cost, Lightweight Air-Bursting Munitions

Low Cost Sensors through Dual Use - Commercial Volume



VO_x Microbridge Uncooled FPA



Uncooled Thermal, Integrated Fire Control, Target Tracker & Laser Steering

Modular & Multifunctional

20-70% Reduction in Weapon Weight

0-7X Increase in Lethality

Dominant Close Combat Power

Integrated Protection Ensembles
"Scorpion"

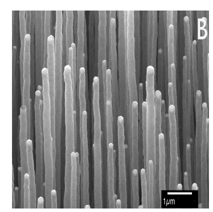
Revolutionary Design Paradigm
Highly Integrated & Multi-Functional
Modular for Mission Flexibility
Combined "Head-to-Toe" Protection
(Ballistic, Laser Eye, Chem/Bio, Environmental)
Bio-Mechanically Engineered Design
Low Observable

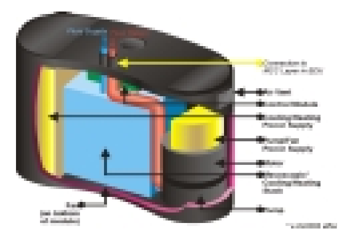
Enabled by Active Devices
Miniature Ventilation, Cooling & Heating
Multi-Functional, Hybrid Power
Embedded Micro-Sensors & Electro-Textiles
Integrated Water Solutions

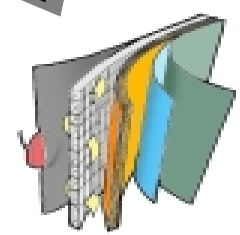
Advanced Materials
Revolutionary Nano-Materials
Ultra-Light, Multi-Functional Innovation
Smart Structures
Affordable, Durable, Flexible

Unmatched, Full Spectrum Survivability

Foundation for Ultra-Light, Low Bulk Systems

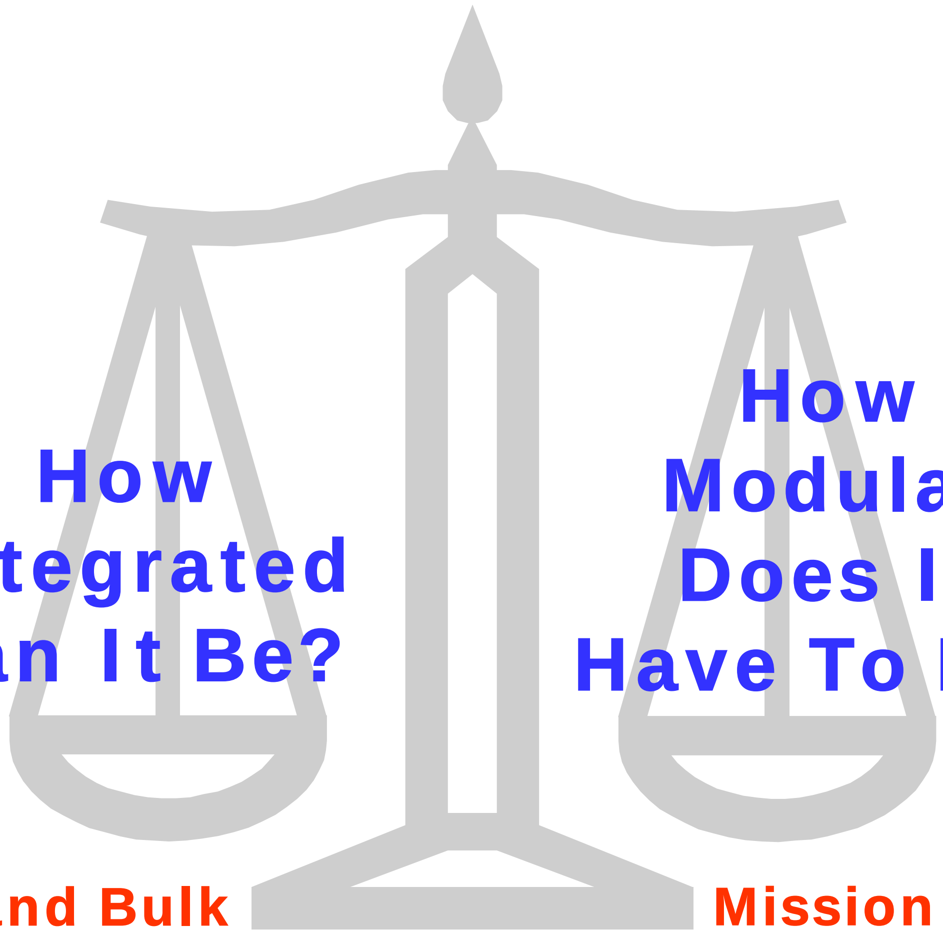






Overmatching Physical/Mental Agility & Endurance

The Real Questions:



How
Integrated
Can It Be?

How
Modular
Does It
Have To Be?

Weight and Bulk

Mission Flexibility
Technology Upgrades

Scorpion
Conceptual Platform Features

- **Consciously designed “Integration Platform”**
- **Apply lightweight materials technologies**
  - e.g., Nano-technology, advanced ballistic protection
- **Combine Chemical/Biological and Environmental (cold, rain, snow, wind) protection into a single ensemble**
  - Durable, abrasion resistant, waterproof
  - Augment C/B protection & decontamination with emerging skin creams
  - Eliminate need for separate chemical and wet weather ensembles
- **Improve Signature Management**
  - Improved Visual & Near IR Camouflage
  - Thermal Signature Management

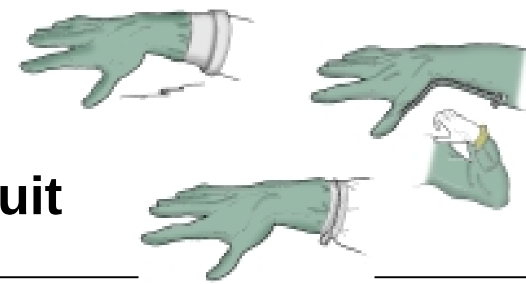
Potential 60% Weight Savings from Integration of Chemical, Biological & Wet Weather Protective Technologies

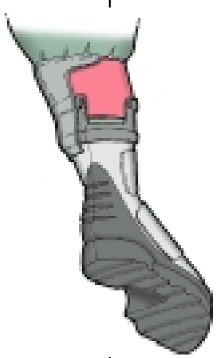
Scorpion
Conceptual Platform Features

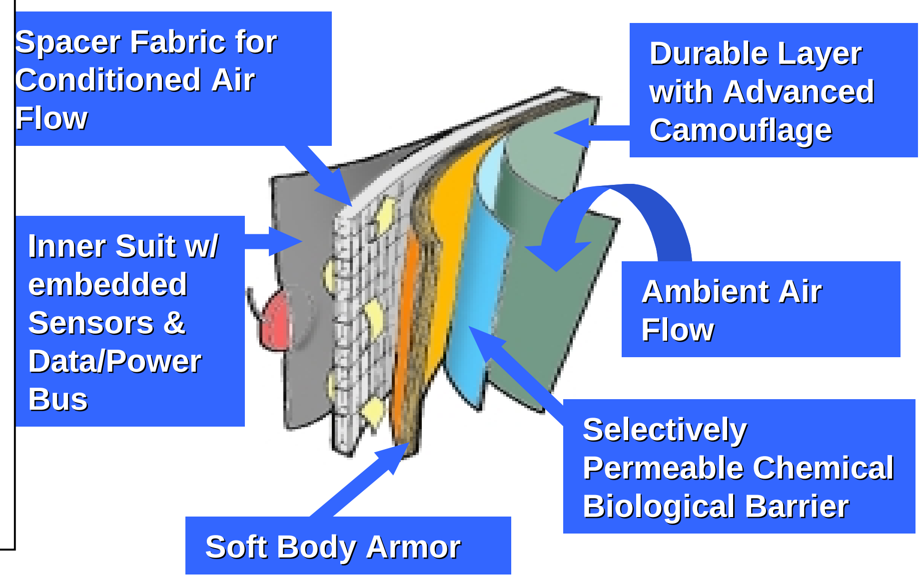
- **Integrate armor and load carriage capabilities into combat ensemble**
  - 25-45% weight reduction against current conventional threats
  - Load carriage design based on biomechanical and human performance data
  - Improved Fightability
- **Razor-Back multi-functional element**
  - Rifle protection, back support & comfort, load bearing stability & interfaces with family of back packs & cooling/heating system
- **Configurable personal load vest system**
  - Soft/hard armor for front abdomen integrated with load vest
  - Baffled water carriage bladders embedded in vest
- **Advanced modular combat footwear**
  - Embedded work rate sensor
  - Heel strike energy generation

Scorpion
Conceptual Platform Features

- **“Quick-seal” chemical interfaces with mask, gloves & boots**
  - *“Soldier Keeps Dry in a Swamp”*
- **Conditioned air flows beneath outer suit**
- **Integrated waste elimination**
- **Close fitting (elastomeric) one piece inner suit**
  - Breathable, moisture-wicking, launderable
  - Integrated physiological & medical sensors
  - Conductive or Fiber Optic fibers for Data & Power Distribution
  - Carbon Fiber Heating at wrists, kidneys and ankles
  - Impact pads integrated at knees and elbows
    - Hard caps Snap-On to outer suit

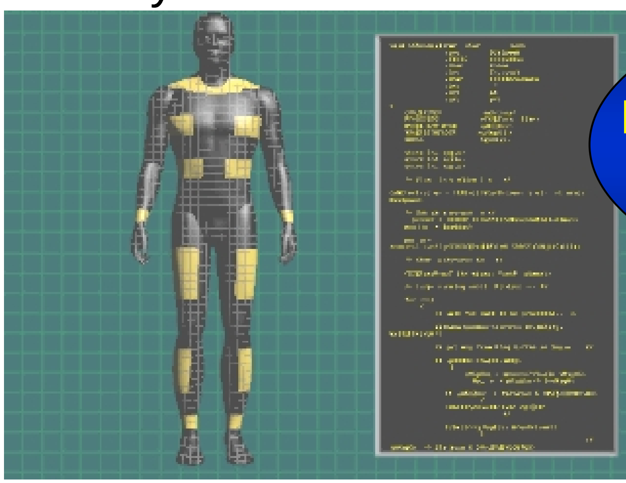




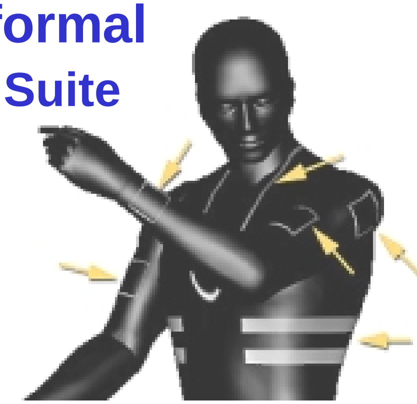


Scorpion
Conceptual Platform Features

- **Integrated Personal Area Network (IPAN) Data and Power Bus**
  - IEEE1394 Firewire
  - Blue Tooth Wireless Body LAN
  - Hybrid Firewire & Wireless LAN



Body Conformal Antennae Suite



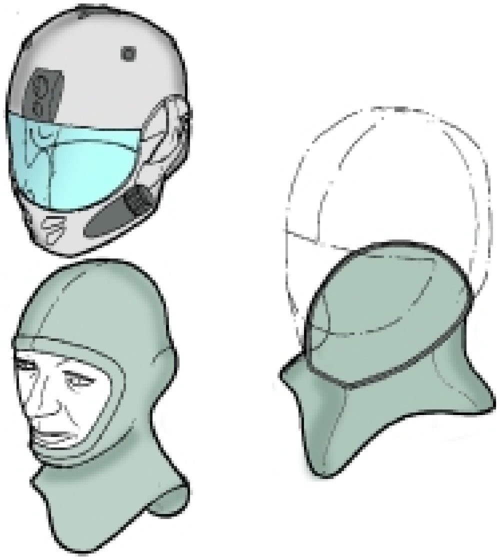
Electromagnetic shielding for human and equipment

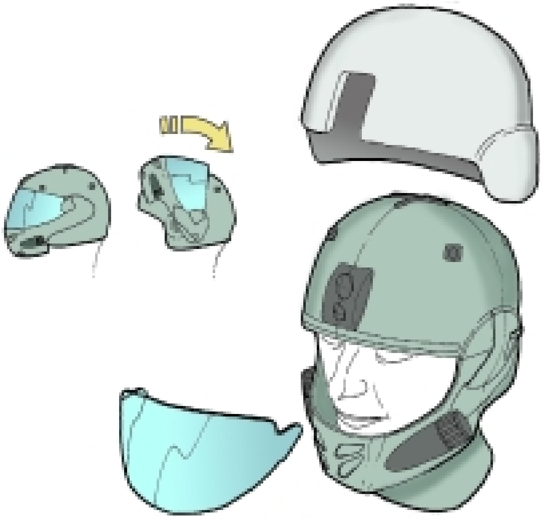
Photovoltaic technology for power generation/storage

Physiological Status Monitoring

- Hydration state
- Thermal stress
- Energy balance
- Sleep status and performance
- Psychological status
- Fatigue (physical and cognitive)

Scorpion
Conceptual Platform Features





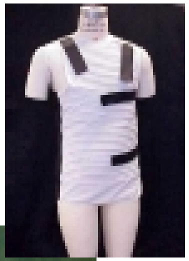
- Air Flow, Water, Video, Power & Data

- Uniform Chemical Seal Interface with Helmet, Neck, & Mask

- Modular Ballistic Protection & Respiratory Mask Integration

Scorpion
Conceptual Platform Features

- **Microclimate Conditioning (MCC) System:**
  - Miniaturized Vapor Compression Cooling
  - Air Ventilation & Resistive Heating
  - Advanced Fuel Cell
  - Ergonomic Design
- **Significant mission benefits**
  - Longer mission time (endurance) in hot, and/or C/B environments
  - Improved soldier performance, both physical and cognitive – Combat Overmatch
  - Reduced heat stress casualties
  - Reduced water intake requirements
    - Weight Savings up to 30%
  - Enhance cold weather protection – potential to reduce weight/bulk

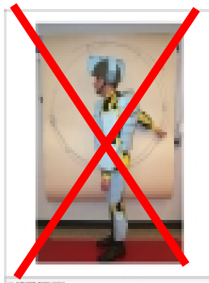


Current Cooling System Prototype

Potential weight reduction from 26 to 12 pounds by 2005

Integrated Designs, Virtual & Physical Prototypes, Field Demonstrations

From…



Hand Cutting And Placement Of Component Mock-ups to…

Through…

Virtual Prototype Form, Fit, Function Prior to Breadboard Prototyping

To…

Robust, Platoon Level Field Demonstration

Reduced Risk Breadboards, Brassboards, Field Tests of Integrated "System of Systems"

Human Performance Data
- **Injury Mechanisms**
- **Component Mass Properties**
- **Mobility As a Function of Load and Load Carriage Equipment**
- **Biomechanics of Fatigue and Individual Movement**

Interaction of Human Body, System Equipment & Combat Performance

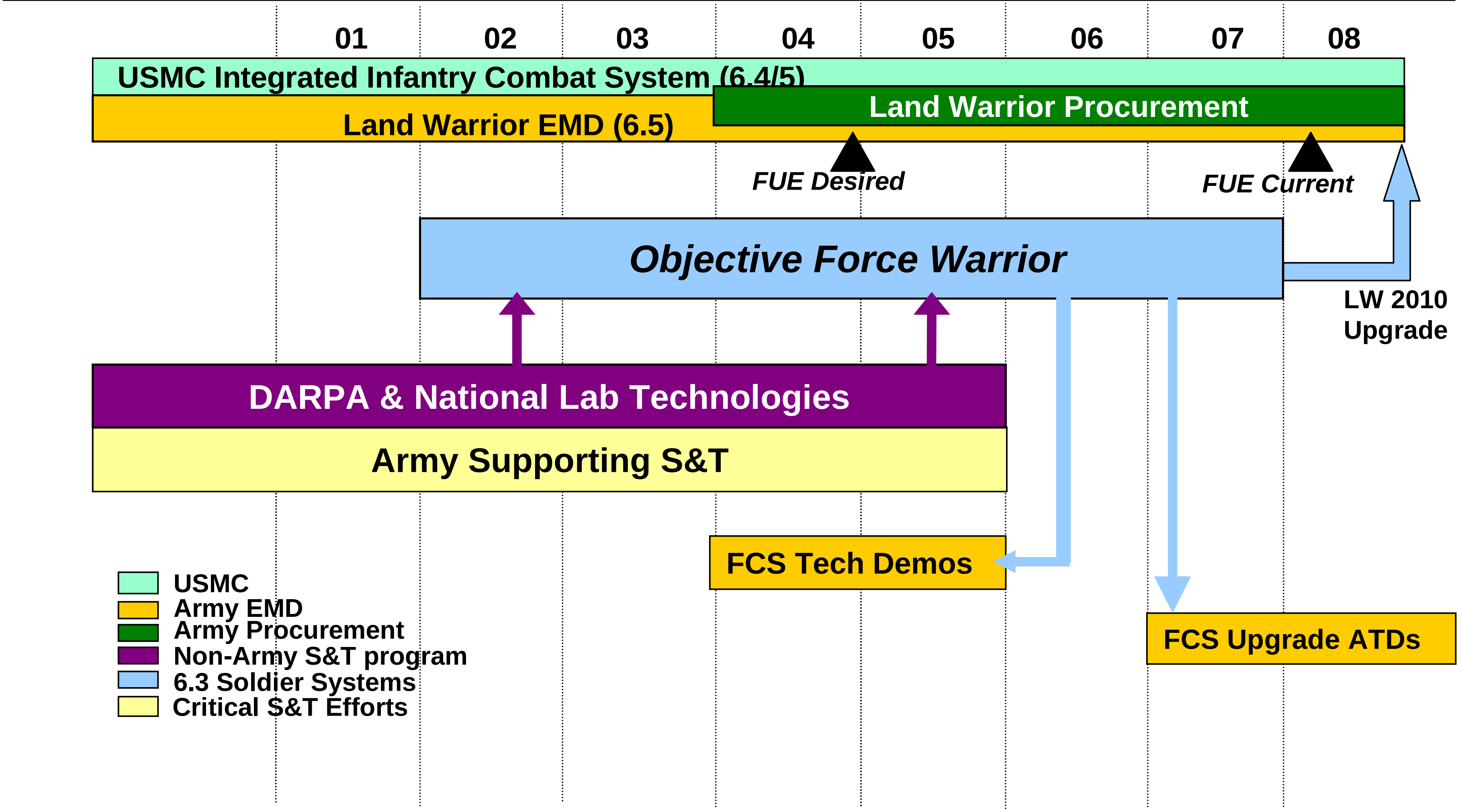
Infantry Warrior Virtual Prototype Simulation
- **Bio-mechanic Simulation Tool**
- **Analysis of Human and Equipment Performance Under Realistic Use Conditions.**

Objective Force Warrior

Technology Transition

- **PM Soldier Systems Acquisition Strategy calls for Land Warrior Upgrades in FY06 (Version 3.0) and FY09 (Version 4.0)**
  - **Objective Force Warrior ATD transition to Land Warrior version 4.0 in FY08**
- **Future Requirements documented in TRADOC PAM 525-66, Land Warrior ORD, Soldier System MNS and Soldier System CRD Justify Transitions**
- **PM Soldier Systems has clearly stated the need for these technologies to meet Future Requirements**
  - **Coordinated Budget & Program Planning will ensure Smooth Transition in FY08**

Objective Force Warrior
Roadmap



How can Nanoscience Enable the Future Warrior?

How can Nanoscience Enable the Future Warrior?

- Multifunctional Protection Capabilities/Technologies
- Reactive / Smart Materials
- Embedded Electronics Network (data/power)
- Signature Management
- Electromagnetic Shielding
- Power Generation/Storage
- Nano and Embedded Sensors
- Self-Mending Functions
- See-through Displays
- Thermal Stability Aids
- Agile Laser Eye Protection
- Durable, Affordable Materials

ARO Advanced Energy Conversion

Some Thoughts about the Possible Impact of Nanotechnology on Soldier Power

8 February 2001

by
Dr. Richard J Paur
Chemical Sciences Division
US Army Research Office
US Army Research Laboratory
919-549-4208, paur@arl.army.mil

Compact Power Rationale

- **Computer/radio subsystem (including GPS) requires 45.1W**
- **Integrated helmet and sight subsystem requires 5.6W**
- **Weapon subsystem (laser rangefinder, laser aiming light, thermal weapon sight, etc.) requires 6W**
- **Micro-climate cooling requires >100W**
- **Weight of non-rechargeable batteries needed for a 72-hour mission is approximately 13 lbs *without micro-climate cooling***

Source: "Energy-Efficient Technologies for the Dismounted Soldier," Committee on Electrical Power for the Dismounted Soldier, Board of Army Science and Technology, NRC Press, 1997

The ‘Real-World’ Customer

Photo by Sarah Underhill

The Objective Warfighter

Regardless of the uniform, the Soldier will need reliable, affordable power

SPECIFIC ENERGY (Wh/kg)

SOURCE	SPECIFIC ENERGY (Theoretical)		SPECIFIC ENERGY (Practical)
Springs (watch)	0.25		0.15
Rechargeable Batteries			35-200
Primary Li/SO_2	1,400		175
Primary $Li/SOCl_2$	1,400		300
Zinc/air			300-400
TNT	1,400		N/A
Methanol	6,200	} Energy of Combustion	1,500-3,100
Ammonia	8,900		1,000-4,000
Diesel (JP-8 similar)	13,200		1,320-5,000
Hydrogen	33,000		1,000-17,000
Nuclear	2,800,000		190,000

Batteries have many desirable properties (self-contained, convenient, familiar, quite safe, ...) and are likely to be key components of hybrid power systems

The User's Constraints

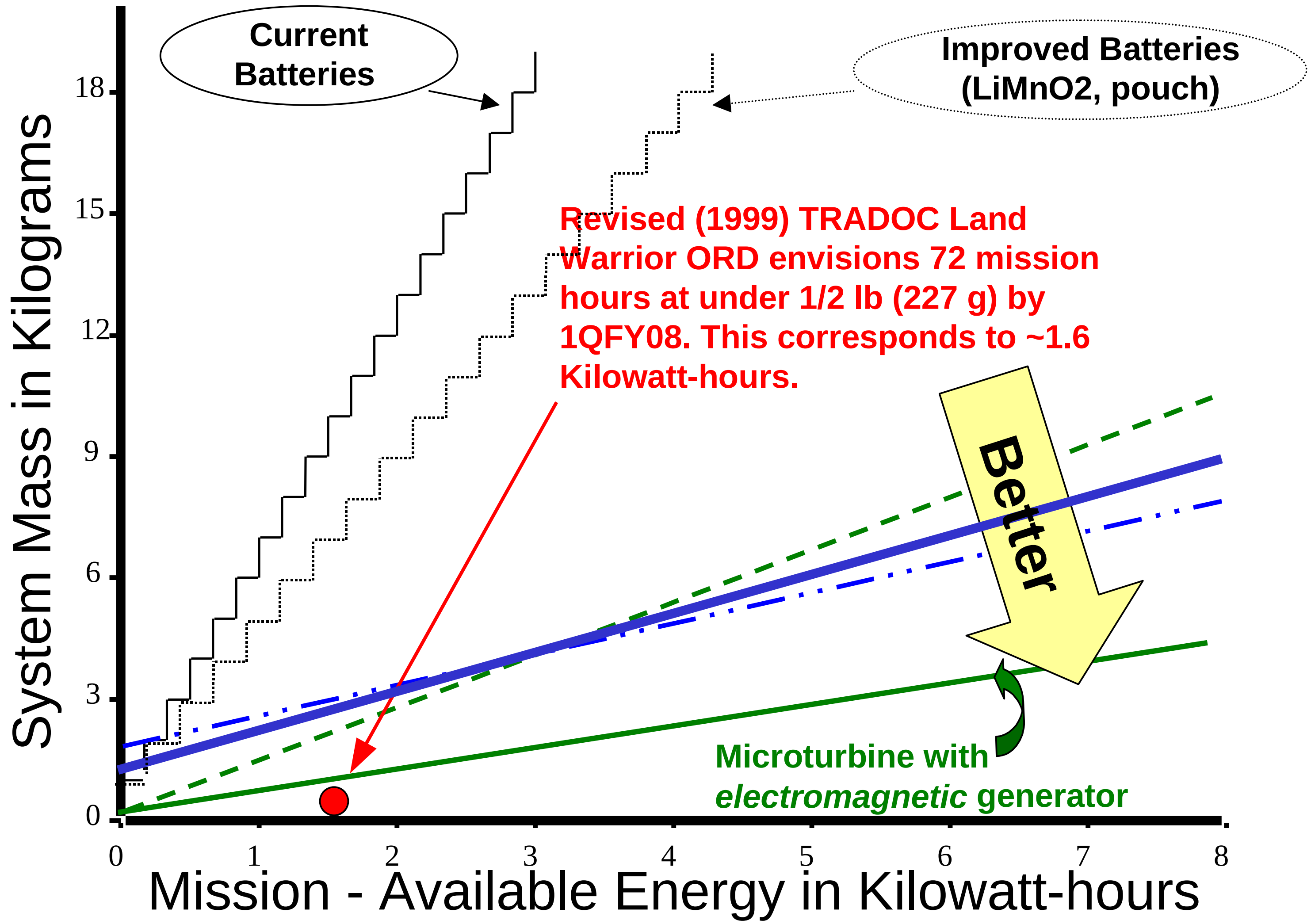
Mass-Energy Plots of Energy Conversion Systems

BA5590 Battery
1 kg device
50 W
170 Wh/kg (total)

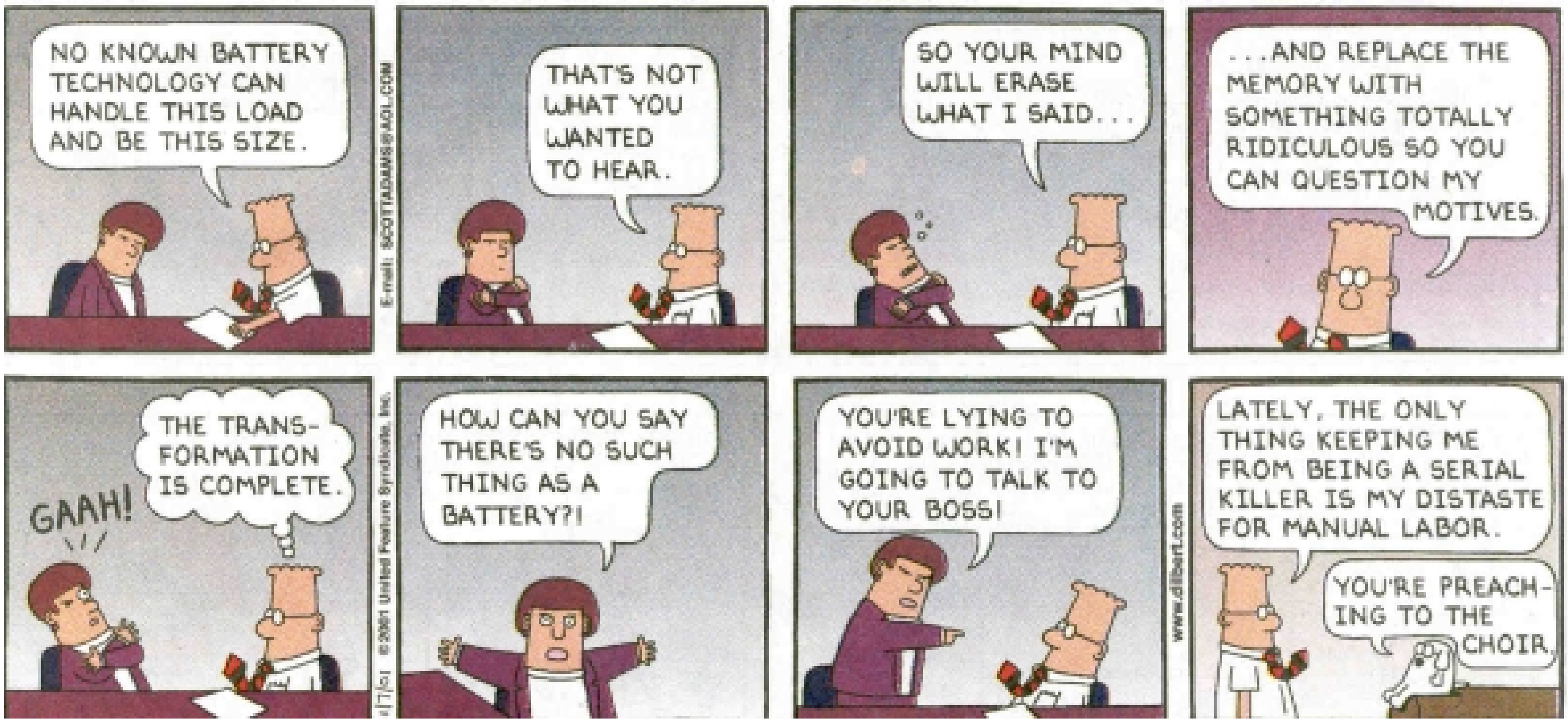
H_2/Air Fuel Cell
0.7 kg device
15- 25 W
1 kWh/kg (fuel)

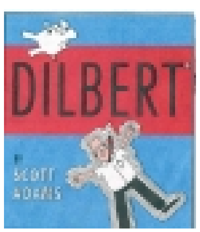
DMFC Fuel Cell
2 kg device
50-100 W
1.3 kWh/kg (fuel)

Micro gas turbine
<100 g device
50-100 W
.78 kWh/kg (fuel)



Everybody knows about batteries





From News & Observer, 8 Jan 2001

Advanced Energy Conversion Focus Areas

Electrocatalysts

Proton Conducting Membranes

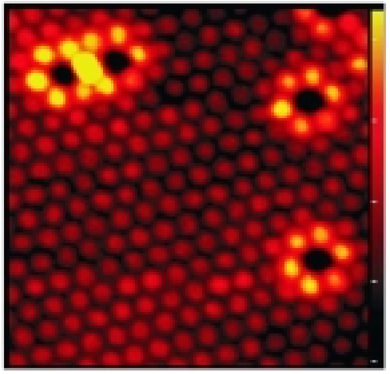
Microchemical Systems

Micro Turbine Power Systems

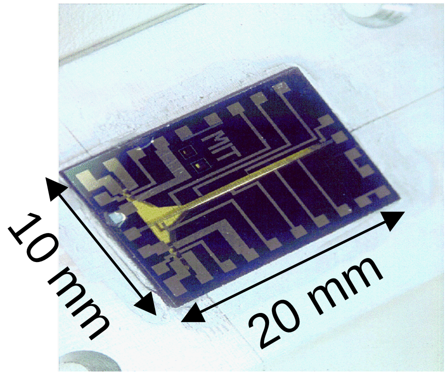
Hydrogen Sources/Storage

Hybrid Power Systems

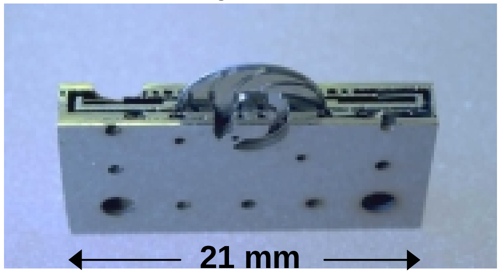
Thermophotovoltaics



Designed Catalyst - Norskov



Microchemical system - Jensen



Microturbine - Epstein

Examples in H_2/Air fuel cell evolution

- **<u>1992 - Analytic Power - SBIR:</u>**
- **15 W (on a good day)**
- **No fuel included**
- **5 pounds**
- **Short life**
- **Analytic Power now produces much better stacks**

- **<u>1996 - H-Power -DARPA/ARO:</u>**
- **40 W sustained**
- **90 Wh of stored hydrogen**
- **3.5 pounds**
- **Starts/runs reliably after 3+ years**
- **Stack is used in commercial products**

- **<u>2000?- Ball Aerospace -CECOM??:</u>**
- **Concept based on available technology**
- **15 W sustained, 25 W peak**
- **400 Wh of generated hydrogen**
- **2.2 pounds**

Relative Energy Density

The big challenge is the fuel supply

Fuel cells in field exercise, Oct 1999

Ball Aerospace PPS units supporting radio retrans link at Marines CAX 1/2-99 at the 29 Palms Marine Base on 19 Oct 1999 - support for development of these fuel cells came from DARPA, ARL-ARO/SEDD, SOCOM, CECOM, and the intelligence community.

Cost of operation - $26.18/day for fuel cells vs $900/day for BA5590 batteries

Jens K Norskov,et al, Danish Technical Univ

FIGURE 1: CATALYST DESIGN FROM FIRST PRINCIPLES

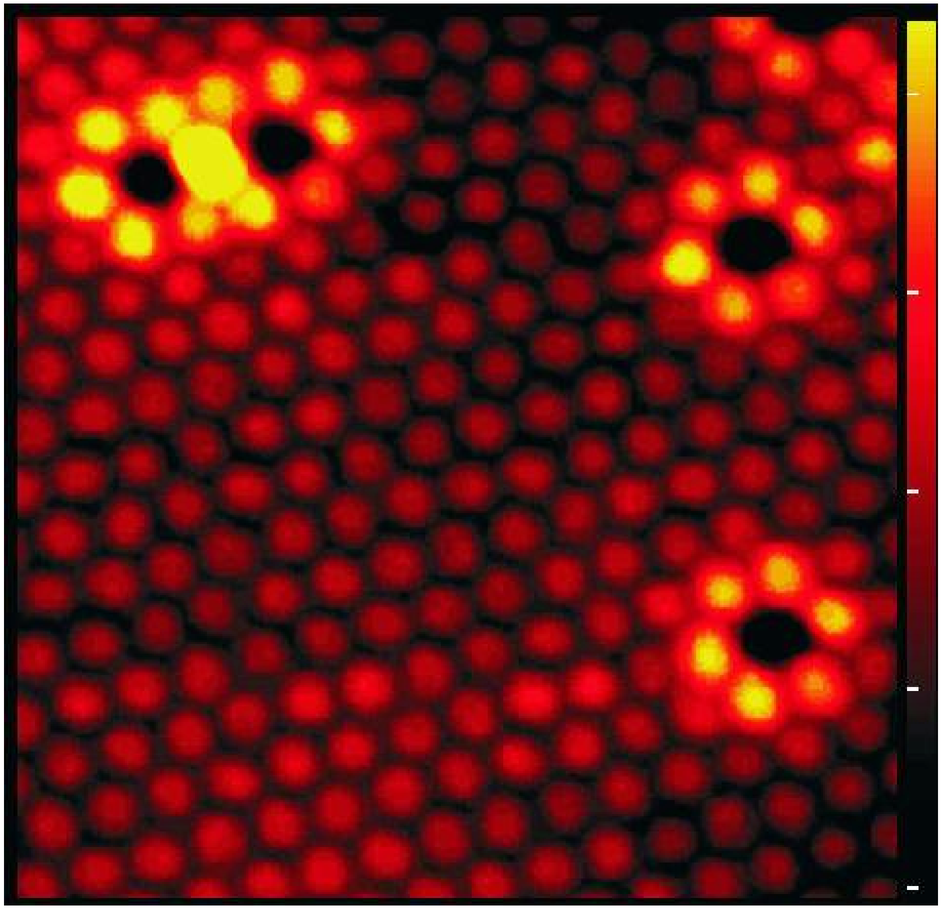


Figure 1: STM image of a Ni(111) surface with 2% of a monolayer of Au. The Au atoms appear black in the images. The Ni atoms next to the Au atoms appear brighter due to a change in geometry and electronic structure, indicating that the chemical activity of the Ni atoms may be modified by nearest neighbor Au atoms.

http://www.fysik.dtu.dk/CAMP/hot0001.html

Jens K Norskov,et al, Danish Technical Univ

FIGURE 3: CATALYST DESIGN FROM FIRST PRINCIPLES

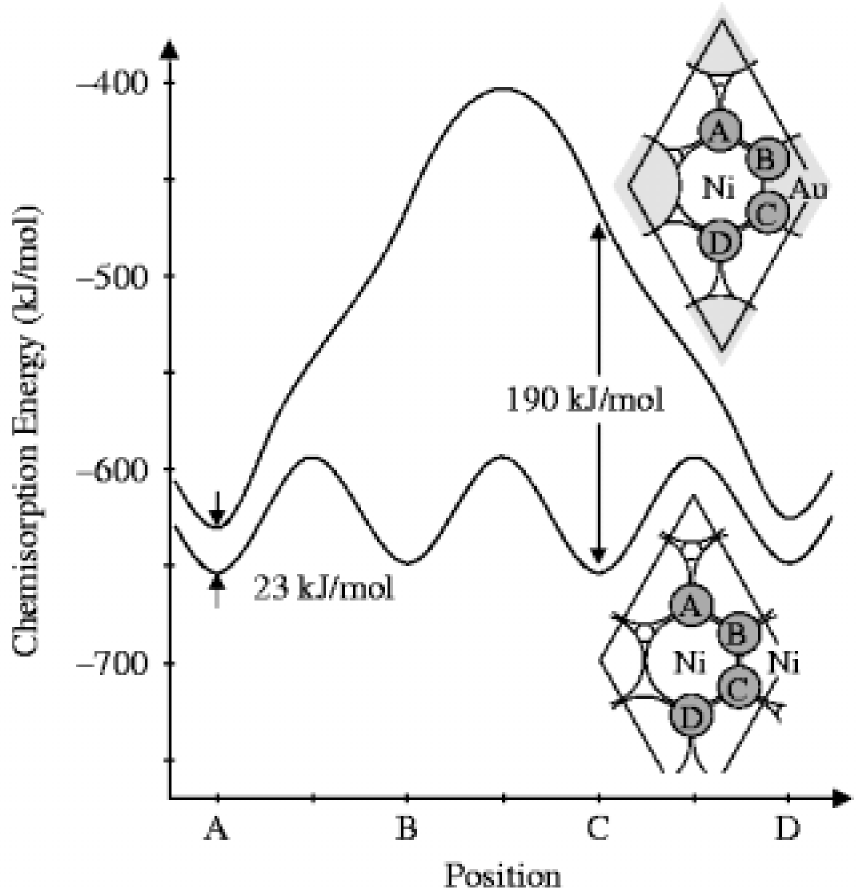


Figure 3: The calculated adsorption energy of a C atom on a Ni(111) surface as a function of position along the surface. The same energy function is shown above when one of the surface Ni atoms has been exchanged for a Au atom. The inserts show the geometry in the two cases

http://www.fysik.dtu.dk/CAMP/hot0001.html

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Figure 4: Catalyst Design From First Principles

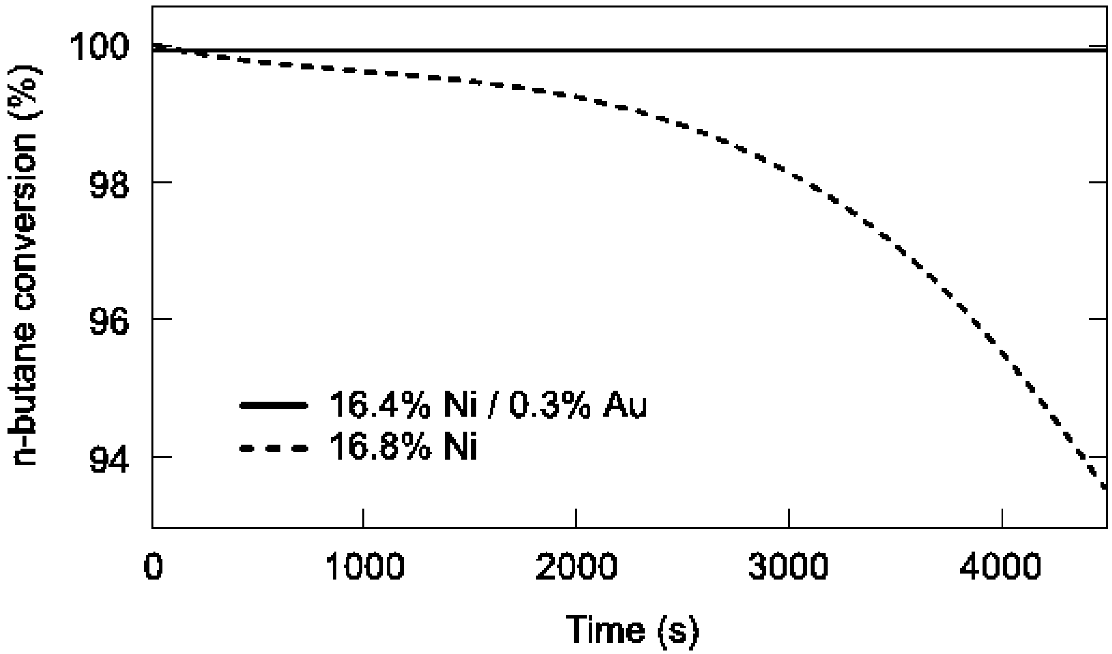

Figure 4: Conversion of n-butane as a function of time during steam reforming in a 3%n-butane-7% hydrogen-3% water in helium mixture at a space velocity of 1.2h-1. The dashed curve shows the n-butane conversion for the Ni and the solid curve is for the Au/Ni supported catalyst.

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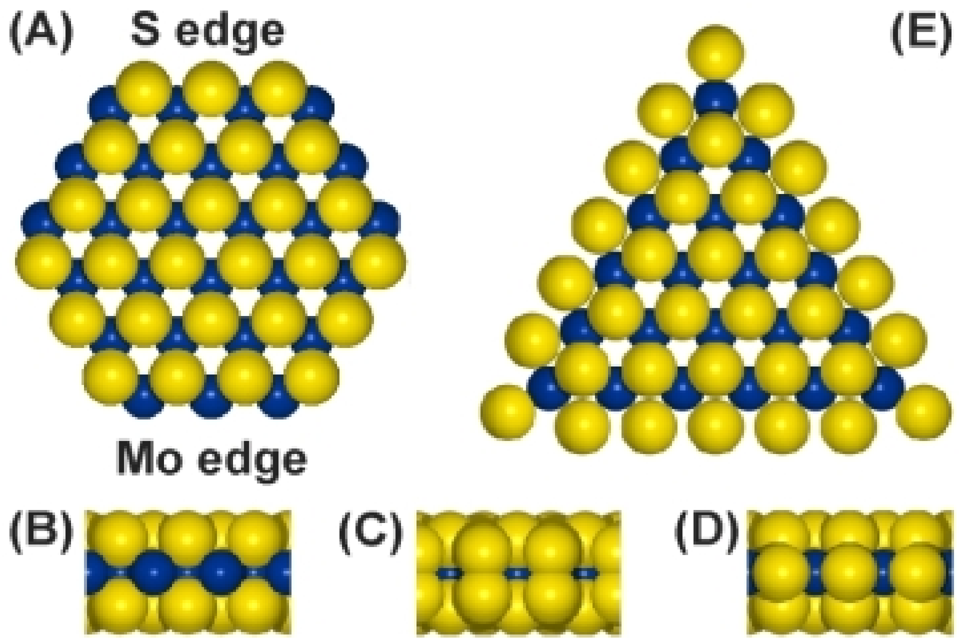
http://www.fysik.dtu.dk/CAMP/hot0001.html

ATOMIC-SCALE STRUCTURE OF SINGLE-LAYER MoS_2 NANOCUSTERS



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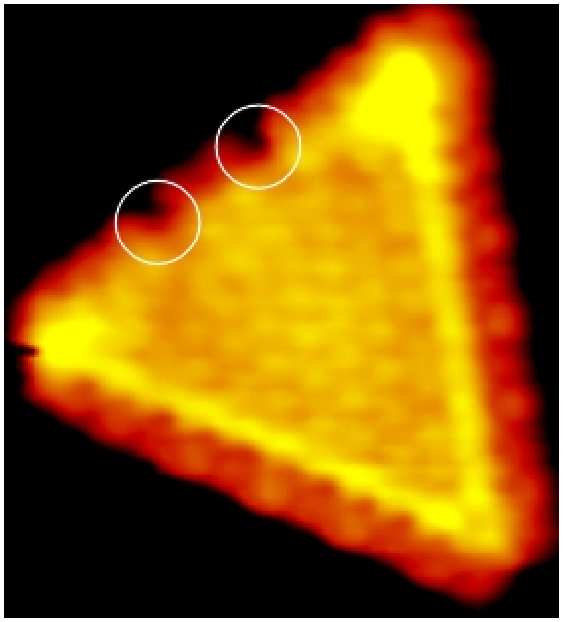
http://www.fysik.dtu.dk/CAMP

ATOMIC-SCALE STRUCTURE OF SINGLE-LAYER MoS_2 NANOCUSTERS



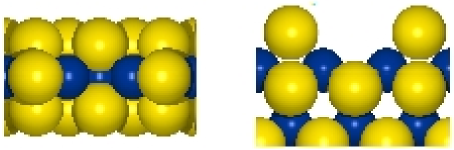


Figure 3: An atom-resolved image of a MoS_2 nanocluster exposed to atomic hydrogen which resulted in the formation o two S vacancies at the edges indicated by the white circles.

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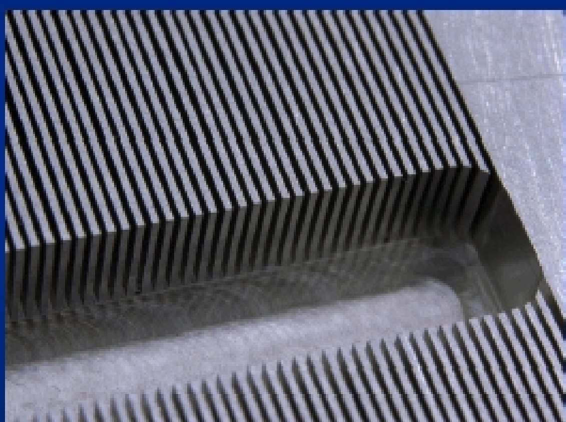
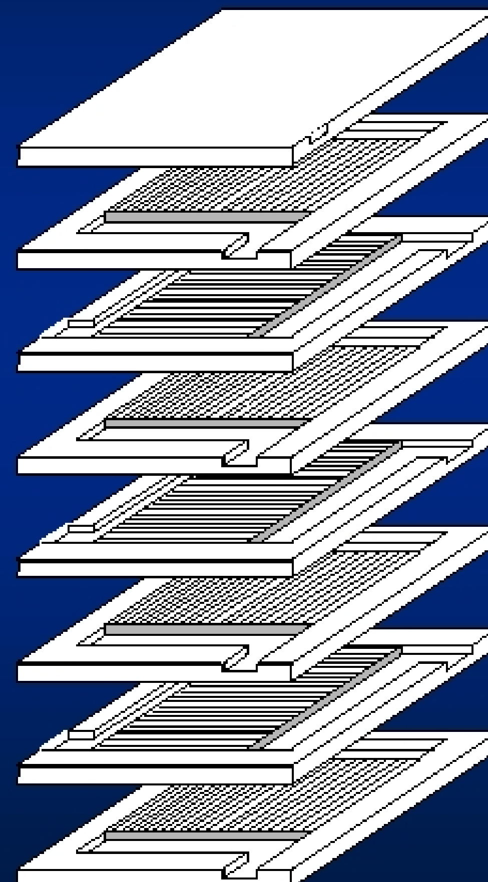
http://www.fysik.dtu.dk/CAMP

Energy Related Microreactor Efforts

- **Pacific Northwest National Laboratory (PNNL)**
  - **Proposed integrated fuel processing unit for hydrogen production from liquid fuel**
  - **Microchannel layered device**

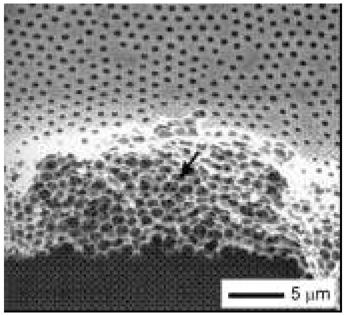




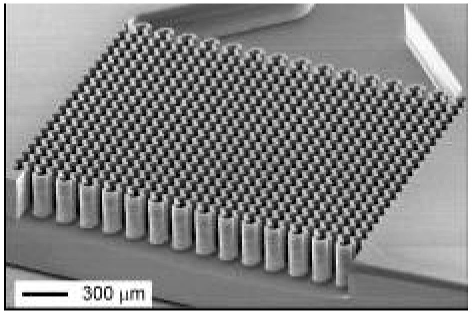
Pre-reformer

Need to get enough surface area/mass transfer to get enough reaction

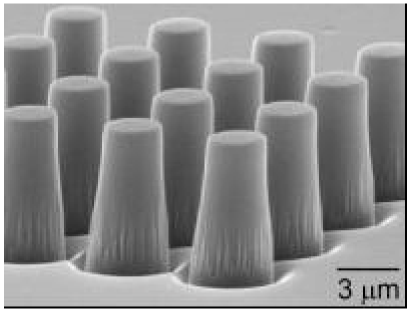
- Need to Build Appropriate Structures



Zia, et al



IMM

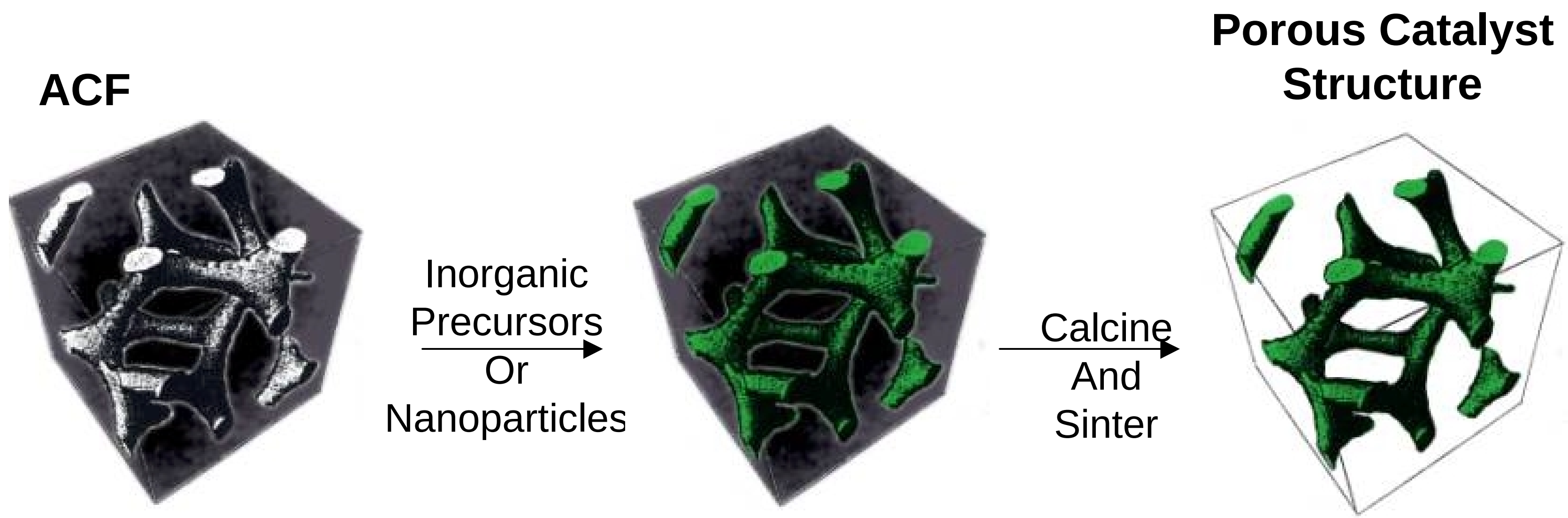


Adesida, UIUC

- Coat With Porous Structures to Hold Catalysts

Courtesy Prof Rich Masel, UIUC

Nanotechnology useful for porous coatings



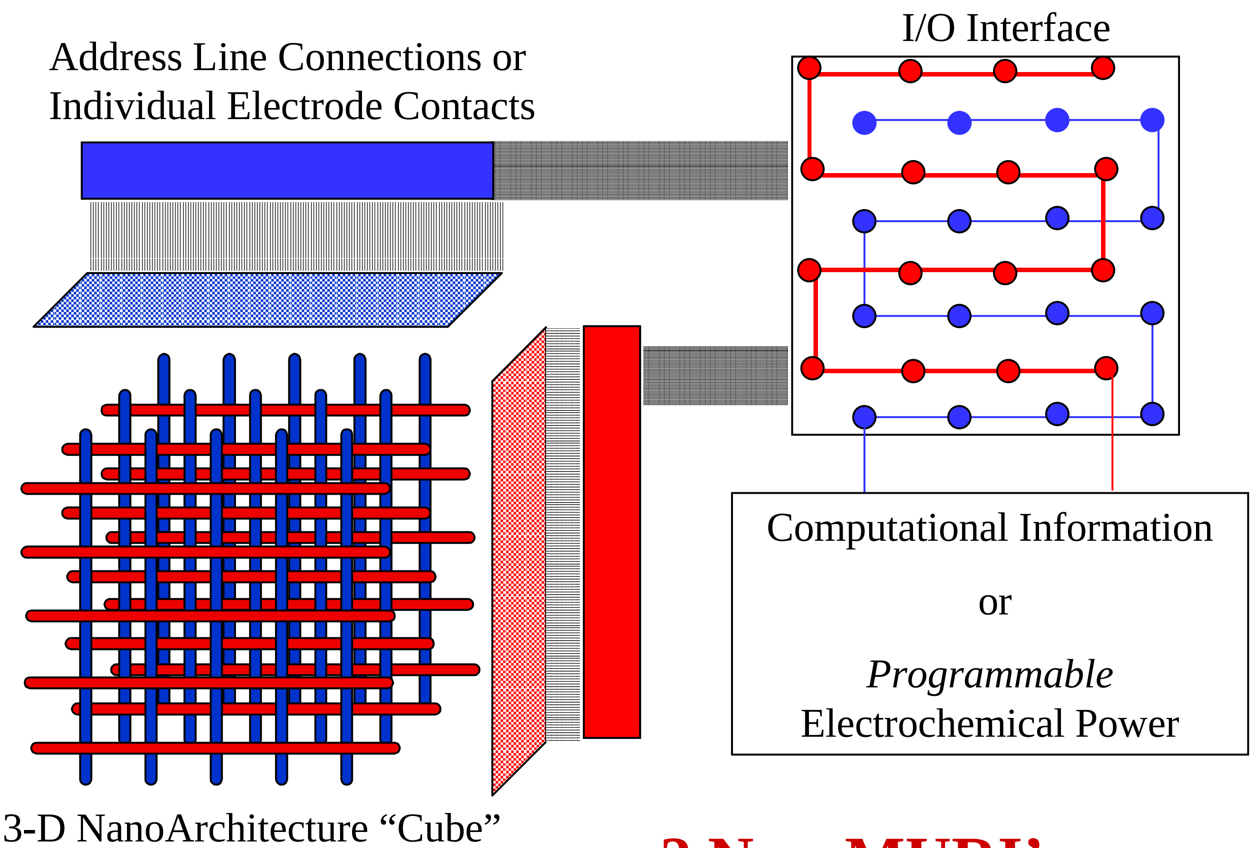
Surface=2000 m²/gm

Courtesy Jim Economy, UIUC

FY01 Multidisciplinary University Research Initiative (MURI)

3-D NanoArchitectures (D^3NA) for Future Electrochemical Power Sources

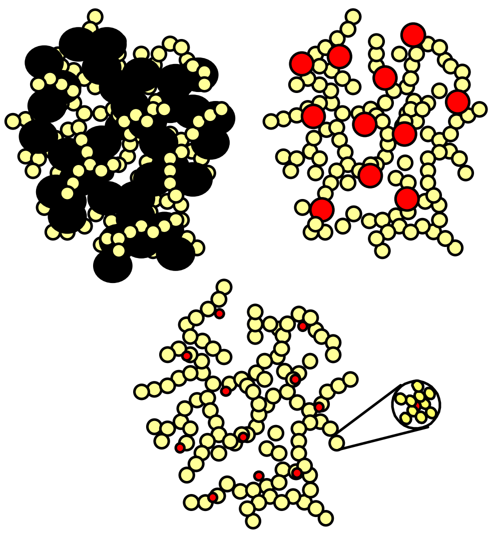
The 3-D Nanoarchitecture (D^3NA) program will develop the scientific underpinnings and the basic nanostructure building blocks for revolutionary approaches to electrochemical power sources. The umbrella concept relies upon the intelligent assembly of electroactive nanometer-scale structures to construct power modules of controllable size (submicron to multi-centimeter) in a manner compatible with microelectronics and microelectromechanical systems.

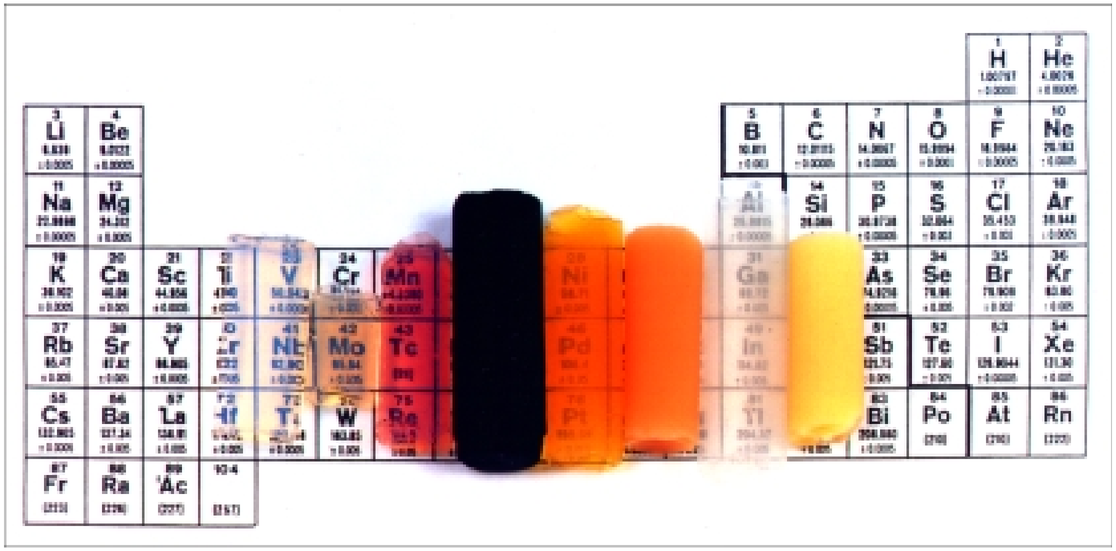


2 New MURI's announced 5 Feb

Electrochemistry ⇔ Nanoscience

Exploit nanoarchitectured electroactive structures & composites to enhance electrochemical performance of macro & microscale power sources while developing a comprehensive understanding of electron and ion transport at nanoscale dimensions.

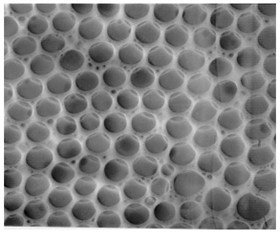




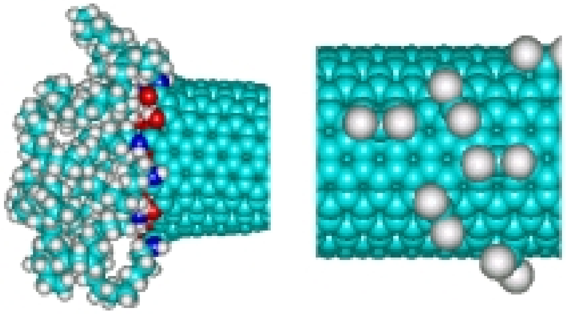
Anderson, Stroud, Morris, Merzbacher, Rolison, *Adv. Engineer. Mater.*

Nanoscience for the Marine 2010

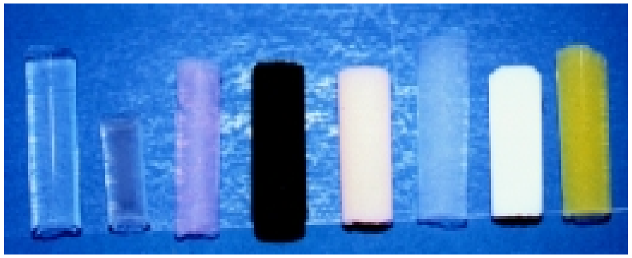
- NanoArchitectured Power Sources for Electronics & Pulsed Weapons
- Aerogel Nanocomposites for CBW Sensors & Filters
- Photonic Bandgap Face Shield Coatings for Laser Protection
- Carbon Nanotube for Lightweight Armor & Nanoelectronics
- Nanoporous Polymers for CBW & Environmental Protective Clothing



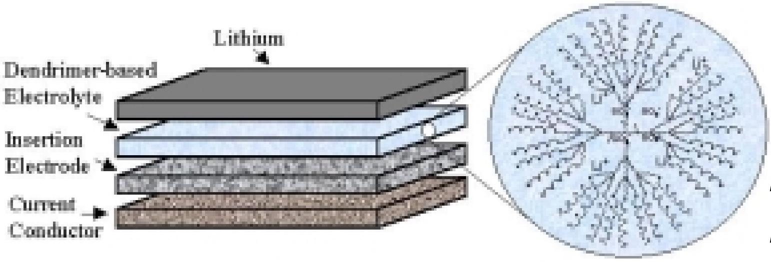
Photonic Bandgap Polymer



Derivatized Carbon Nanotubes

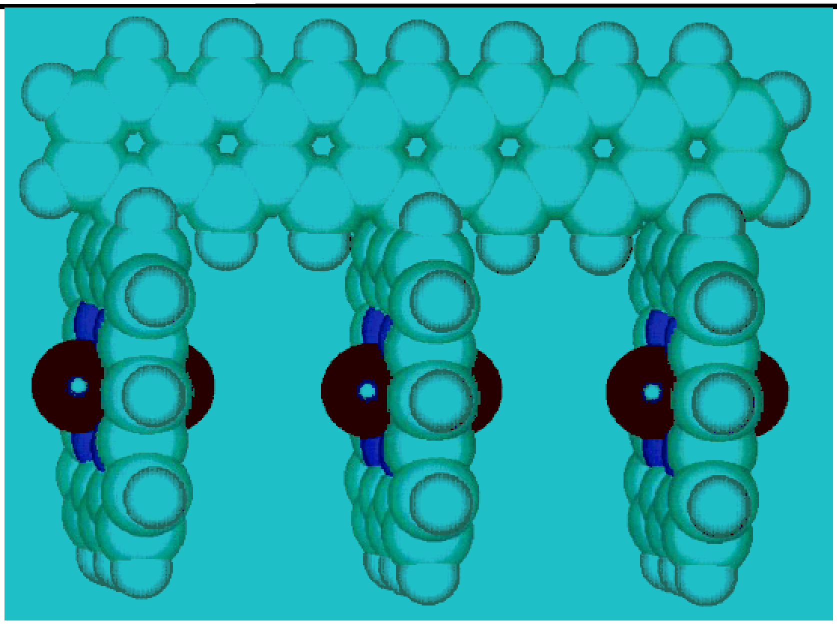


Silica Aerogel Nanocomposites



NanoArchitectured Lithium Battery

Low Dimensional Fast Ion Conductor
Larry Scanlon, AFRL/PO



PURPOSE

- Design and build a single lithium ion conducting polymer electrolyte with a high conductivity (~ 1 mS/cm) over a broad temperature range (+70 to -30°C) that is to be used in the construction of a rechargeable lithium polymer battery
- High electrode electrochemical stability especially at the lithium anode

APPROACH

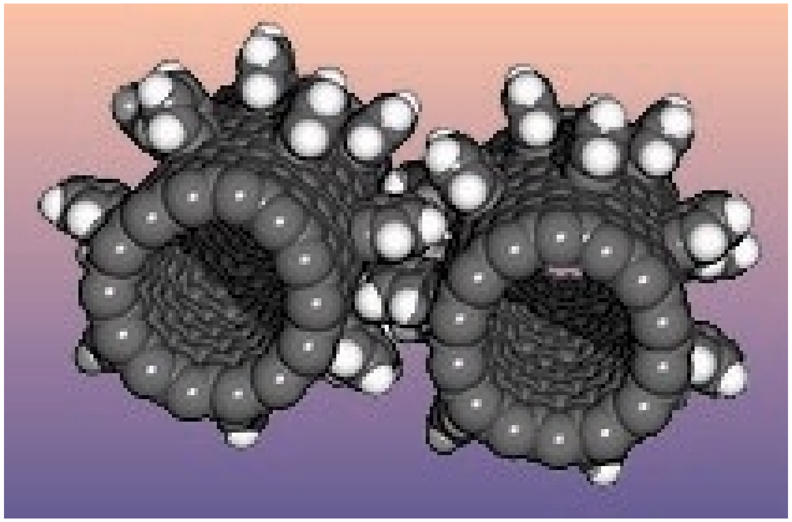
- Molecular orbital calculations were used to design a single Li-ion conducting channel with a constant solvent coordination sphere for lithium ions
- Unsaturated macrocyclic ring is important for achieving high lithium electrode/electrolyte interfacial stability

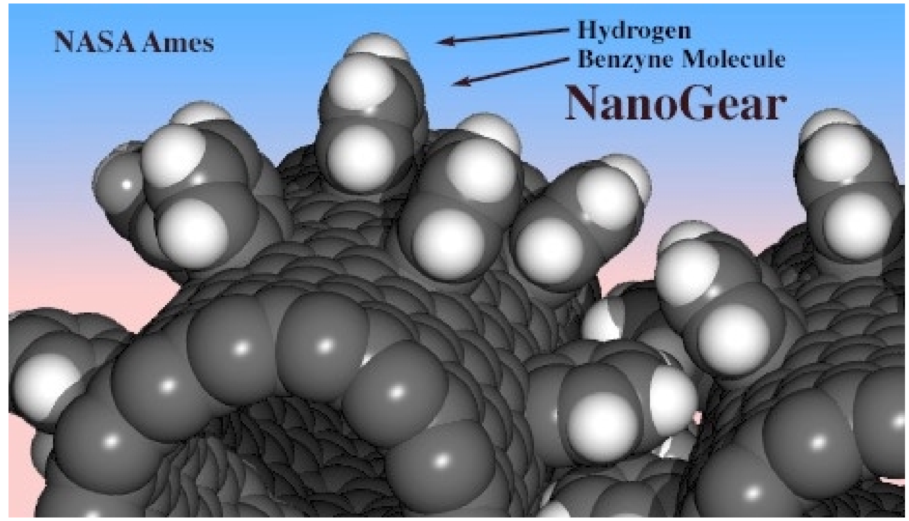
DOD TECH PAYOFF

- Dramatic reduction in percentage of battery weight on satellites and UAV
- Hybrid energy store for burst power applications

Molecular Dynamics Simulations of Carbon Nanotube Based Gears

Jie Han and Al Globus, MRJ, Inc., Richard Jaffe, NASA, and Glenn Deardorff, Sterling Software
NASA Ames Research Center, Moffett Field, CA 94035





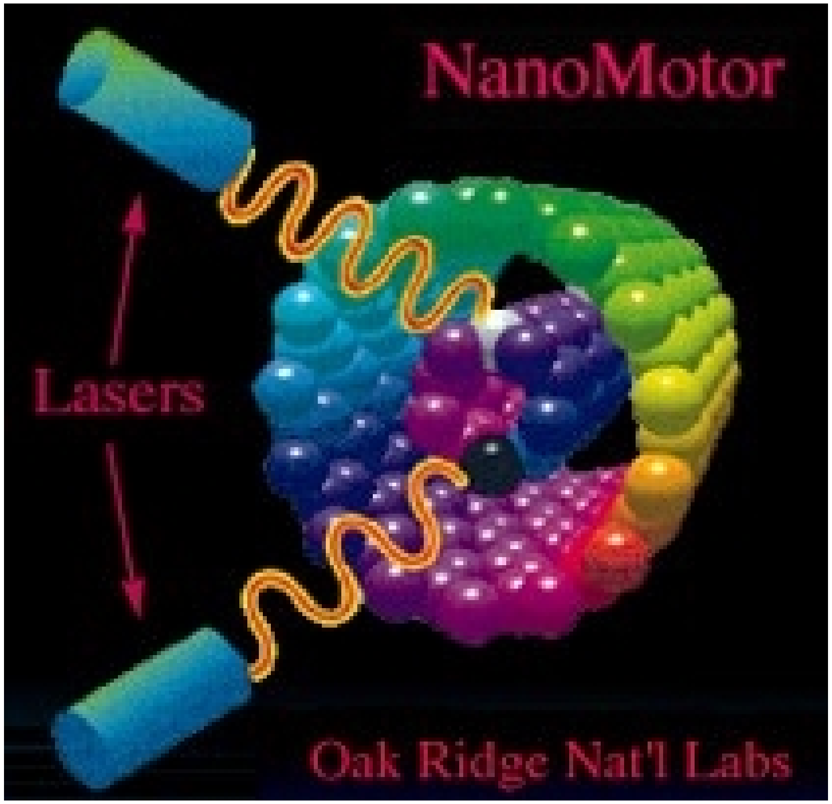
"Results suggest these gears can operate at up to 50-100 gigahertz in a vacuum or inert atmosphere at room temperature. The failure mode involves tooth slip, not bond breaking, so failed gears can be returned to operation by lowering temperature and/or rotation rate."

Abstract

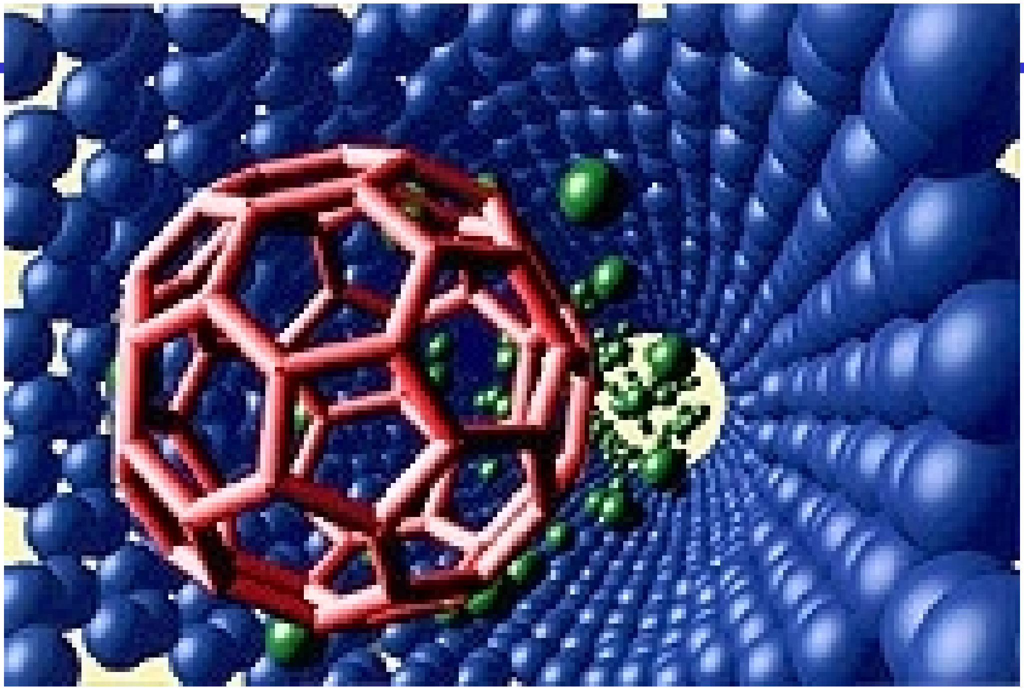
We used molecular dynamics to investigate the properties and design space of molecular gears fashioned from carbon nanotubes with teeth added via a benzyne reaction known to occur with C60 [Hoke 92]. A modified, parallelized version of Brenner's potential [Brenner 90] was used to model interatomic forces within each molecule. A Leonard-Jones 6-12 potential [Allen 87] was used for forces between molecules. One gear was powered by forcing the atoms near the end of the buckytube to rotate, and a second gear was allowed to rotate by keeping the atoms near the end of its buckytube on a cylinder. The meshing aromatic gear teeth transfer angular momentum from the powered gear to the driven gear. A number of gear and gear/shaft configurations were simulated. Cases in vacuum and with an inert atmosphere were examined. In an extension to molecular dynamics technology, some simulations used a thermostat on the atmosphere while the hydrocarbon gear's temperature was allowed to fluctuate. This models cooling the gears with an atmosphere. Results suggest that these gears can operate at up to 50-100 gigahertz in a vacuum or inert atmosphere at room temperature. The failure mode involves tooth slip, not bond breaking, so failed gears can be returned to operation by lowering temperature and/or rotation rate.

See Full paper at…...

http://www.nas.nasa.gov/Groups/Nanotechnology/publications/MGMS_EC1/simulation/paper.html



"The motors consisted of two concentric graphite cylinders (shaft and sleeve) with one positive and one negative electric charge attached to the shaft. Rotational motion of the shaft was induced by applying one or sometimes two oscillating laser fields. The shaft cycled between periods of rotational pendulum-like behavior and unidirectional rotation (motor-like behavior). The motor on and off times strongly depended on the motor size, field strength and frequency, and relative location of the attached positive and negative charges."



NanoPipes... Buckytubes, the multi-use nano component grow to different diameters and conduct electricity like copper, even better when stuffed with metal atoms. Larger tubes are big enough to pipe full sized C60 Buckyball molecules as in the illustration of the soccer ball shape (red) followed by Helium atoms (green), used as a transport "fluid". In addition to piping atoms and molecules, for perhaps a nanomachine construction sites, these tubes could be used as ultra small chemical reaction vessels.

Odds and Ends

- Fuel Cell interfaces
  - Fuel transport to catalyst
  - Ion mobility away from catalyst to electrolyte
  - Electron mobility away from catalyst to current collector
  - ‘Exhaust’ product transport away from catalyst (CO in DMFCs)
- Nanofluidics
  - Ion channels, biomimetics

Soldier Status Monitoring

Richard M. Satava, MD FACS

Professor of Surgery
Yale University School of Medicine

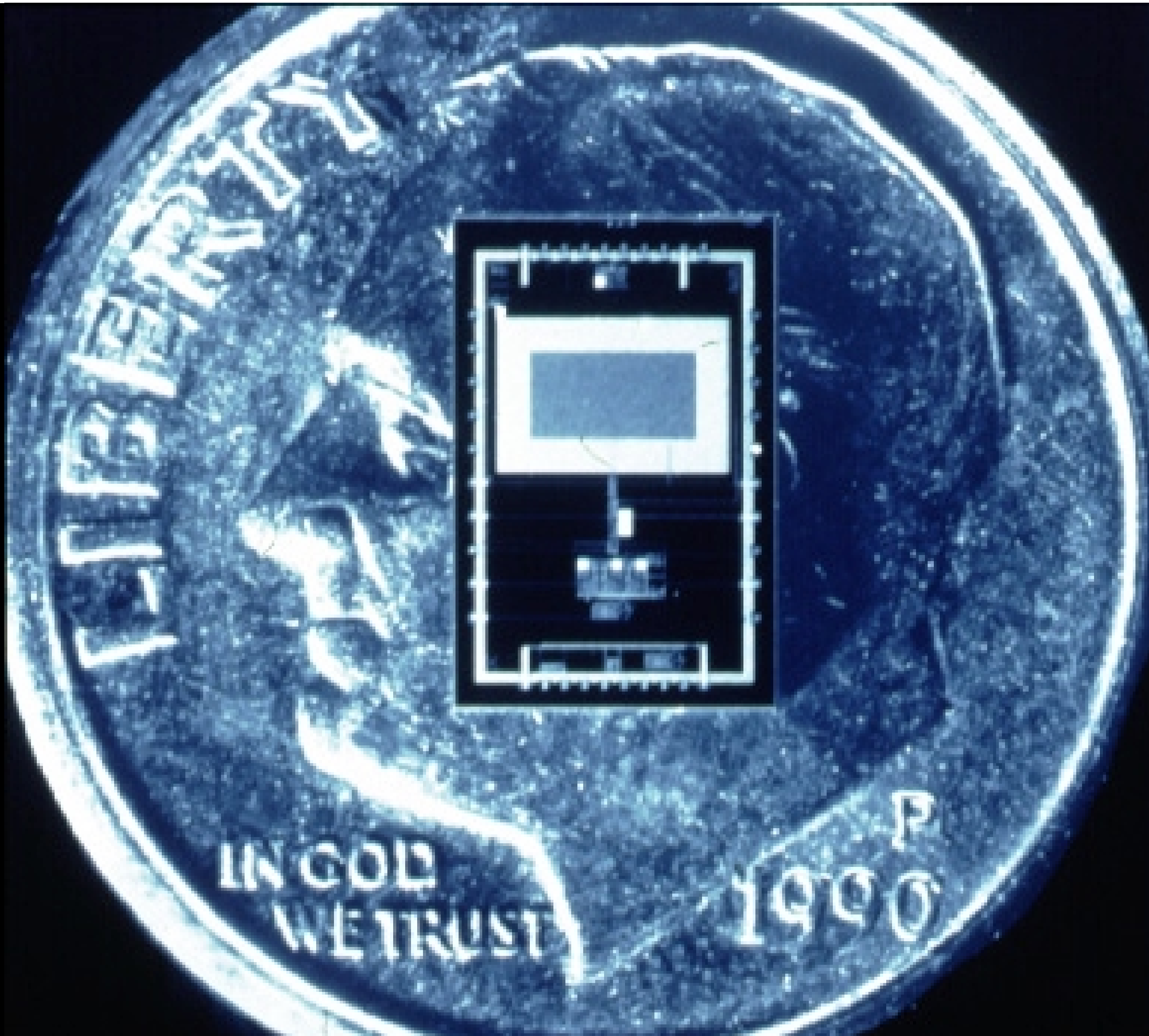
Special Assistant, Advanced Technologies
Telemedicine and Advanced Technology Research Center
US Army Medical Research and Materiel Command
Ft. Detrick, MD

Nanoscience for the Soldier
Research Triangle Institute
Raleigh-Durham, NC
February 8-10, 2001

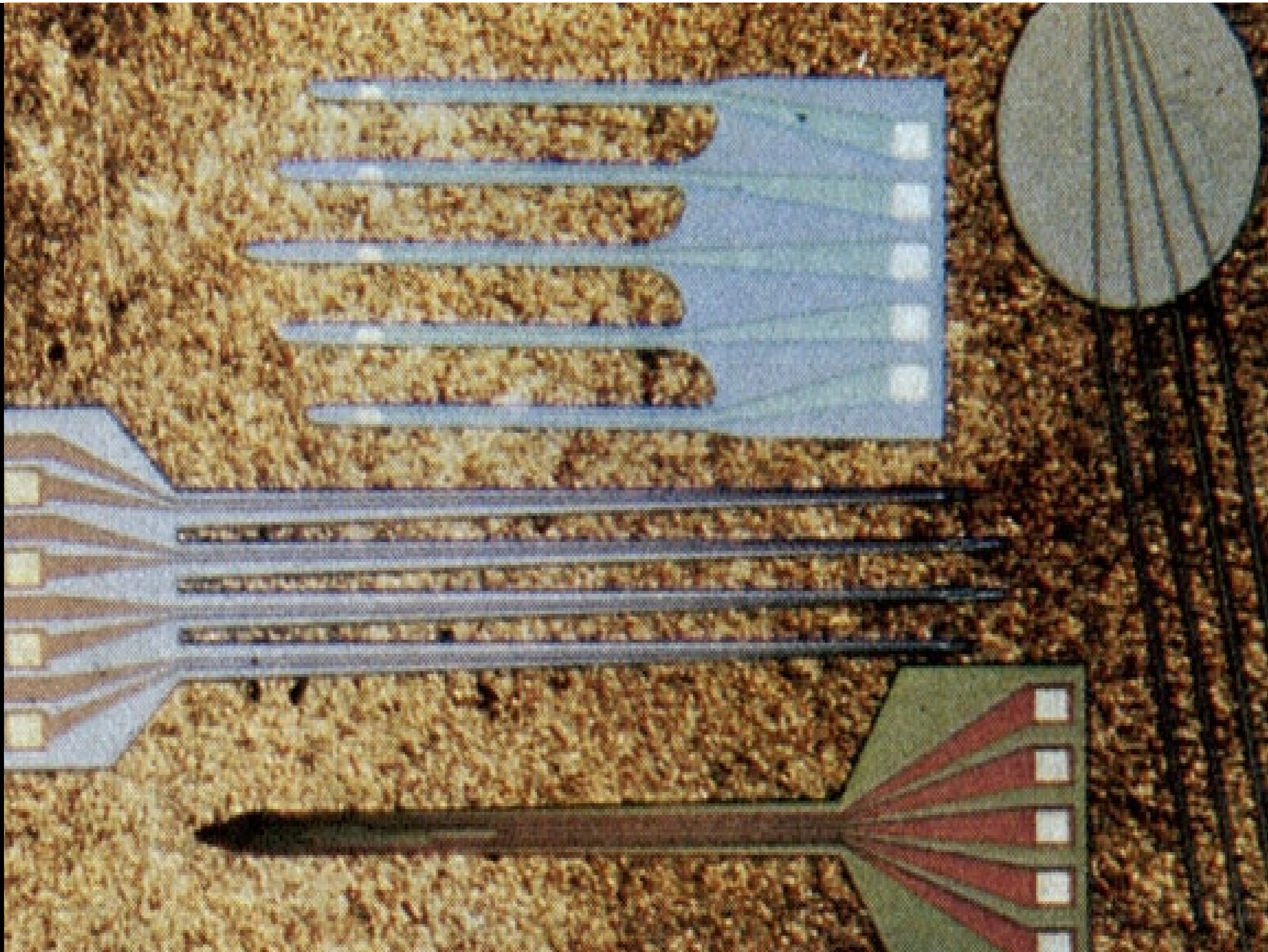
Historical Events in Wearable Monitoring

1960	**Holter**	**Holter Monitor**
1970	**Mann (MIT)**	**Wearable computers**
1986	**Shichiri**	**Glucose monitor**
1991	**Mittal**	**Pill temperature sensor**
1996	**US Army**	**PSM @ Camp Rudder**
1997	**Richey**	**Ambulatory BP (not real time)**
1997	**Montgomery**	**Vital Signs on commercial flight**
1999	**Mt. Everest**	**Everest Extreme Expedition**

Courtesy Ken Gabriel DARPA/Carnegie Mellon 1994

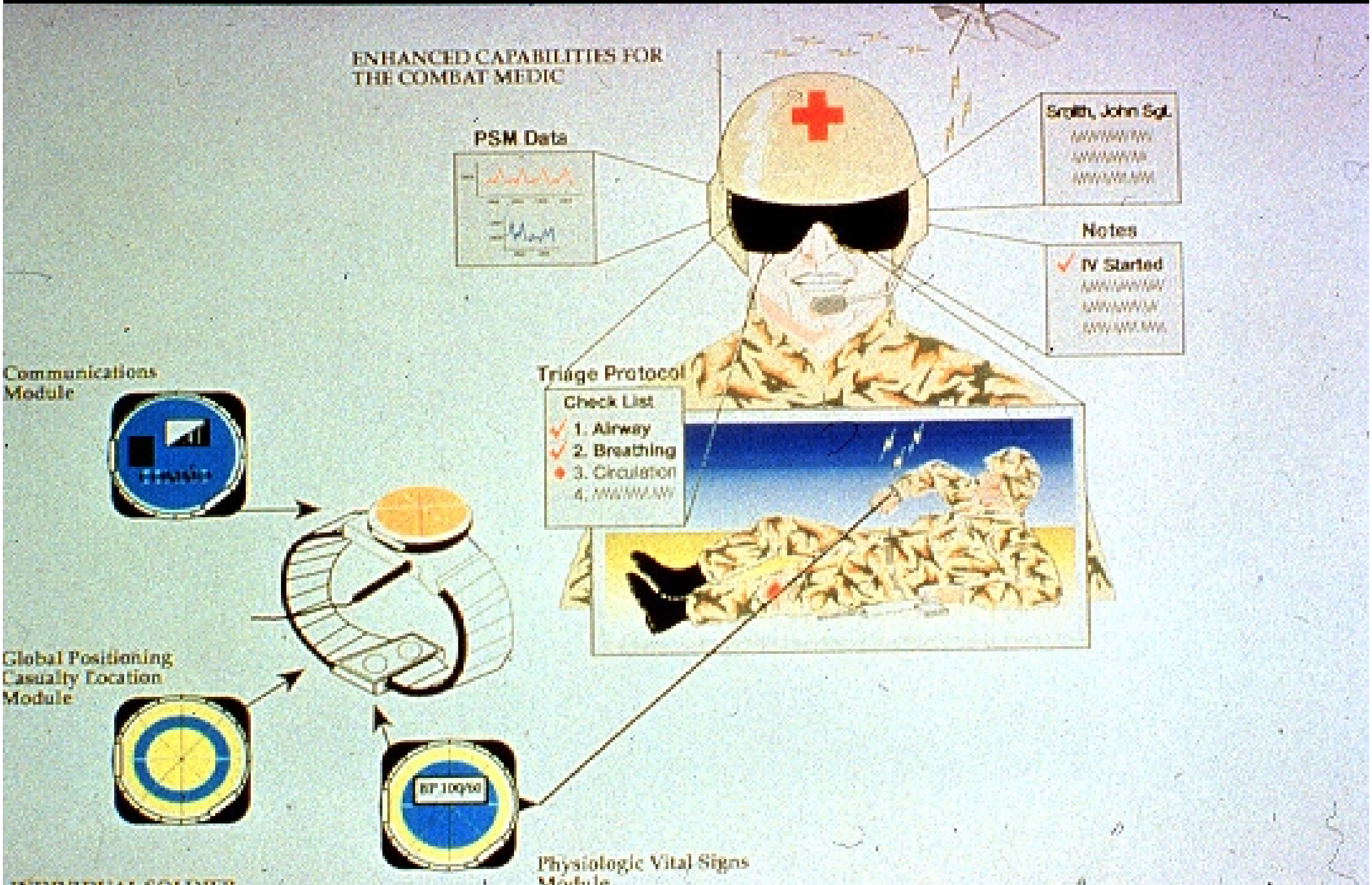


Courtesy Tom Ferrell, Oak Ridge National Labs, 1995

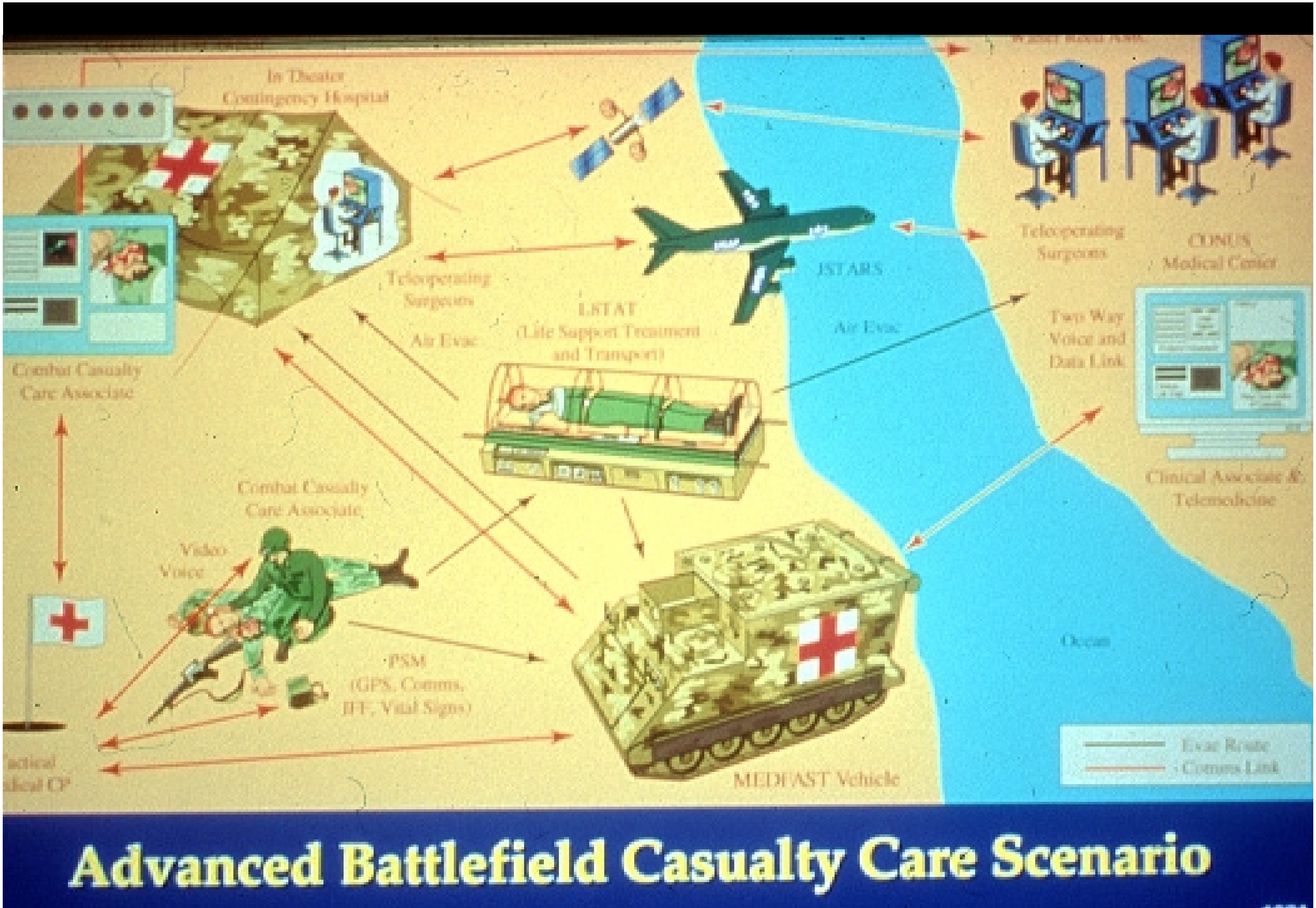


Neural micro-probes 50microns Courtesy of Greg Kovacs, Stanford, 1990

Land Warrior 21 - 1996

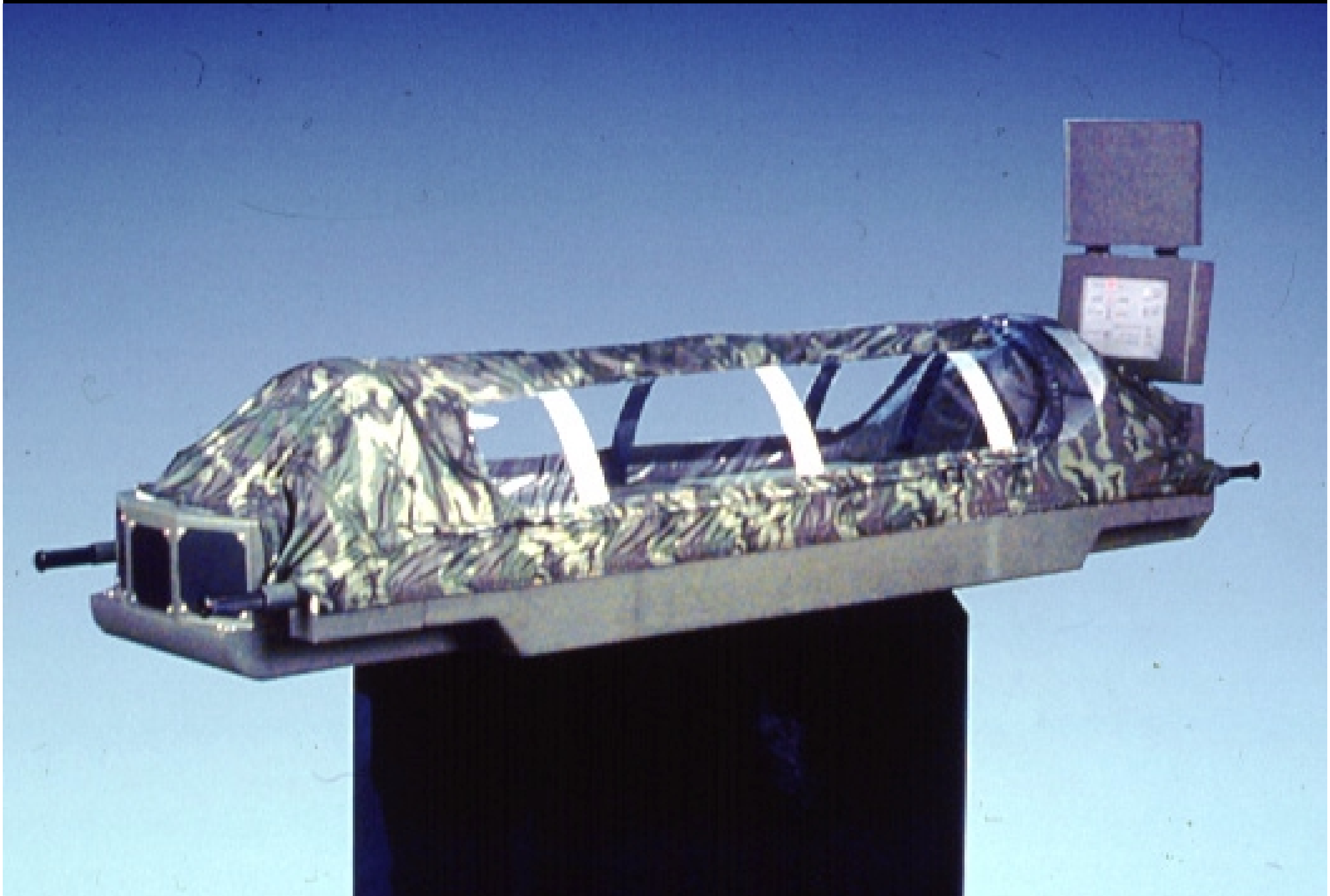


DARPA Advanced Biomedical Technologies Program, 1993-99



DARPA Advanced Biomedical Technologies Program, 1993-99

Personal Status Monitor (PSM) - Courtesy Steve Jacobsen, Sarcos, Inc 1996



Life Support for Trauma and Transport (LSTAT) Courtesy Matt Hanson, IMS, Inc, Pico Rivera, CA

Non-invasive Physiologic Monitoring (6.2)

Pneumothorax on the Battlefield: Improving the Ability of the Warrior Medic to Provide Triage and Care for the Combat Casualty	Bentley (WRAIR)
a. Use of the Impact Ventilator (Model 754) with the Ohmeda Portable Anesthesia Complete (PAC)b. Development of Compact Volatile Anesthetic Agent Monitors	Calkins (WRAIR)
Development of Microimplulse Radar for Non-Invasive, Vital Sign and Cardiac Output Monitoring	Pearce (WRAIR)
Development of Warrior Medic Therapeutic and Non-Invasive Physiologic Monitoring System (DATAPAK)	Lee (WRAIR)
Development of a Wounding Event Detection System for Land Warrior/Warrior Medic	Van Albert (WRAIR)
Electrocardiographic Assessment of Heart Rate Variability During Acute Hemorrhage in Humans	Cancio (ISR)
Evaluation of Lower Body Negative Pressure as a Surrogate Model of Hemorrhagic Schock	Convertino (ISR)

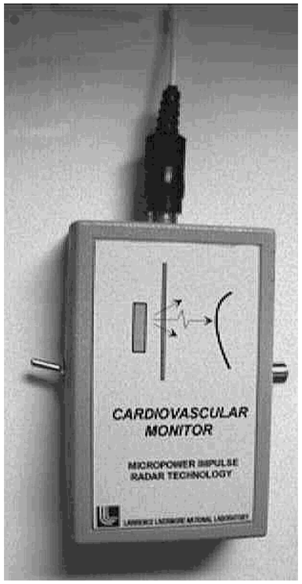
Field Diagnostic Device (6.2)

Micro-impulse Radar Vital Signs Monitor

- **Problem:** Due to the high acoustic noise and high vibration environments of the battlefield , traditional non-invasive vital sign and blood pressure measurement devices do not work well. A highly reliable and non-invasive alternative is required which is capable of continuous measurement which will allow a better assessment of stability and responsiveness to therapy. This information impacts both triage and evacuation decision making.
- **Approach:** Investigate range-gated and range finder versions of microimpulse radar for life signs detection
- **Development:** Collaborative development with Lawrence Livermore National Lab. Targeting hand-held for medic and body worn versions for LW. Coordinated with STO H, WPSM activity.
- **Results to Date:** Have demonstrated "through clothing" vital sign detection and improved HR detection in high vibration helicopter environment..
- **Future Plans:** Demonstrate sensitive life signs detection in all body types and position compared to manual pulse detection.

Other Potential Applications

- Cardiac output
- Intra-abdominal fluid detection
- Subdural hematoma detection
- Pneumothorax detection
- Hemothorax detection
- Limb edema detection

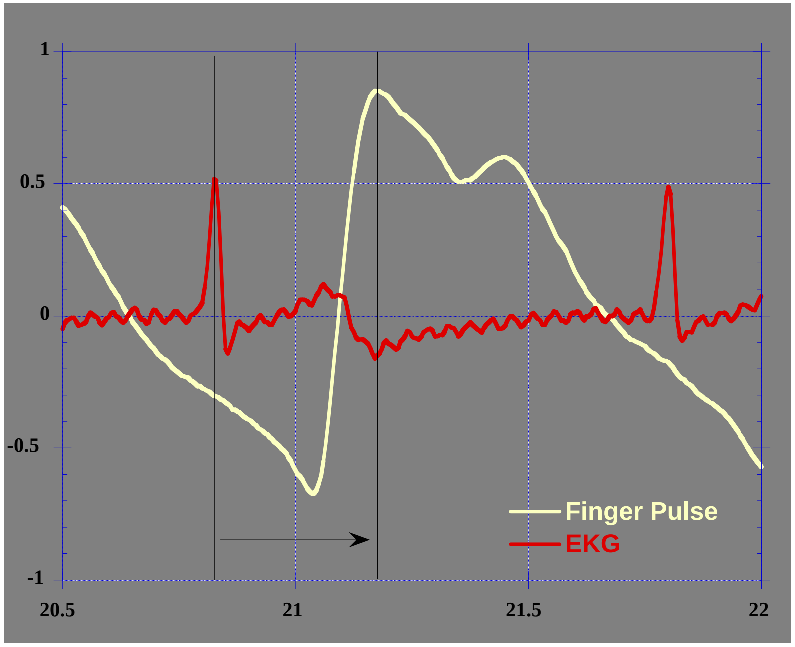


Field Diagnostic Device

Physiologic Monitoring

- **Problem:** Develop cuffless blood pressure monitoring suitable for continuous assessment (5/min) and feedback control of fluid infusion
- **Approach:** Investigate the potential for using the pulse wave transmission technique to measure blood pressure down to 40 mm Hg
- **Development:** Intramural
- **Results to Date:**
- **Milestones:**

Volts



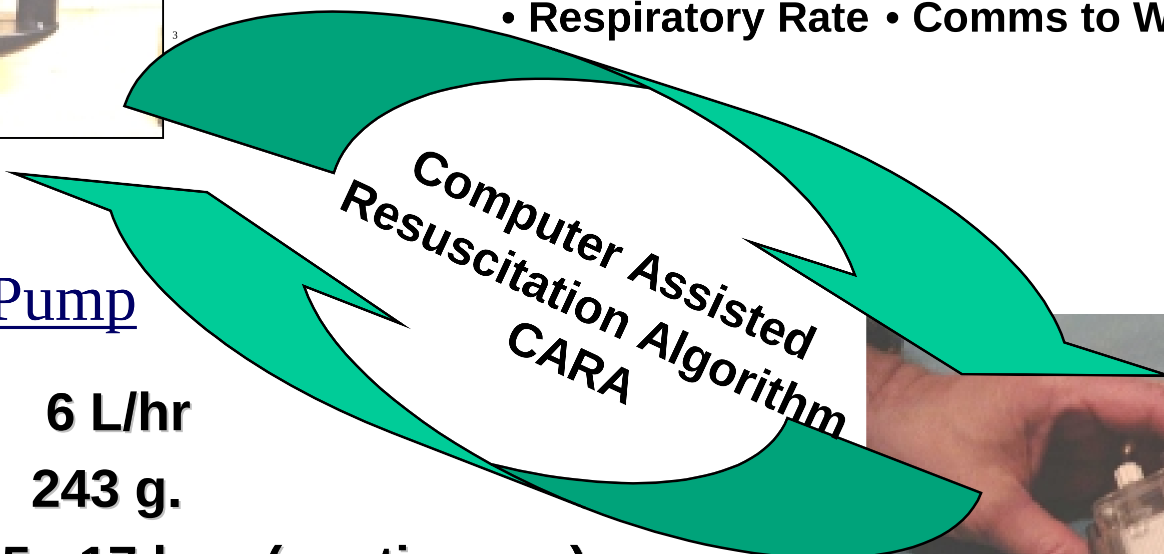
Time (Seconds)

Medic Physiological Monitoring (DataPac)

(Non-DTO)

Physiologic Monitor

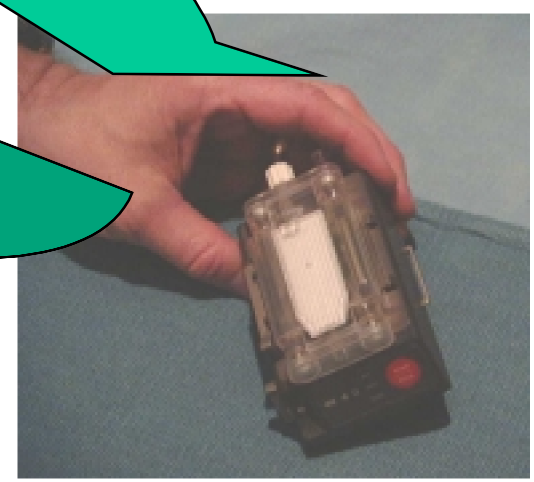
- Blood Pressure
- Pulse Oximetry
- Cardiac Output
- Core/Skin Temp.
- Heart Rate
- Respiratory Rate
- Circulatory Volume
- Pneumothorax detection
- CNS assessment
- Drive voltage to IV pump
- Data Logging
- Comms to WM Computer



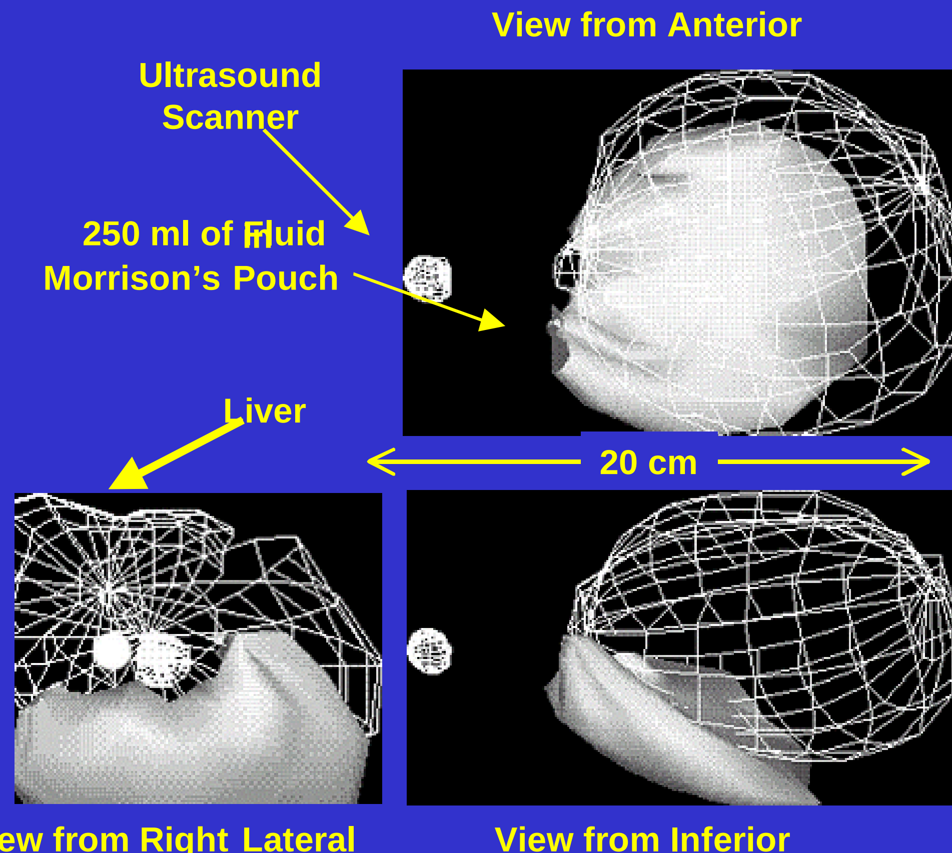
Resuscitation Pump

Max Flow Rate	**6 L/hr**
Weight	**243 g.**
Battery Life	**5 - 17 hrs. (continuous)**
Battery Shelf Life	**5+ years**

Servo-controllable using NIBP



Internal Bleeding Can Be Detected with Portable Diagnostic Ultrasound Scanners



Peritoneal fluid (surface rendered) and liver (wire frame) taken with a prototype palm-size 3-D ultrasound imager

Everest Extreme Expedtion (E³)
Parameters Monitored

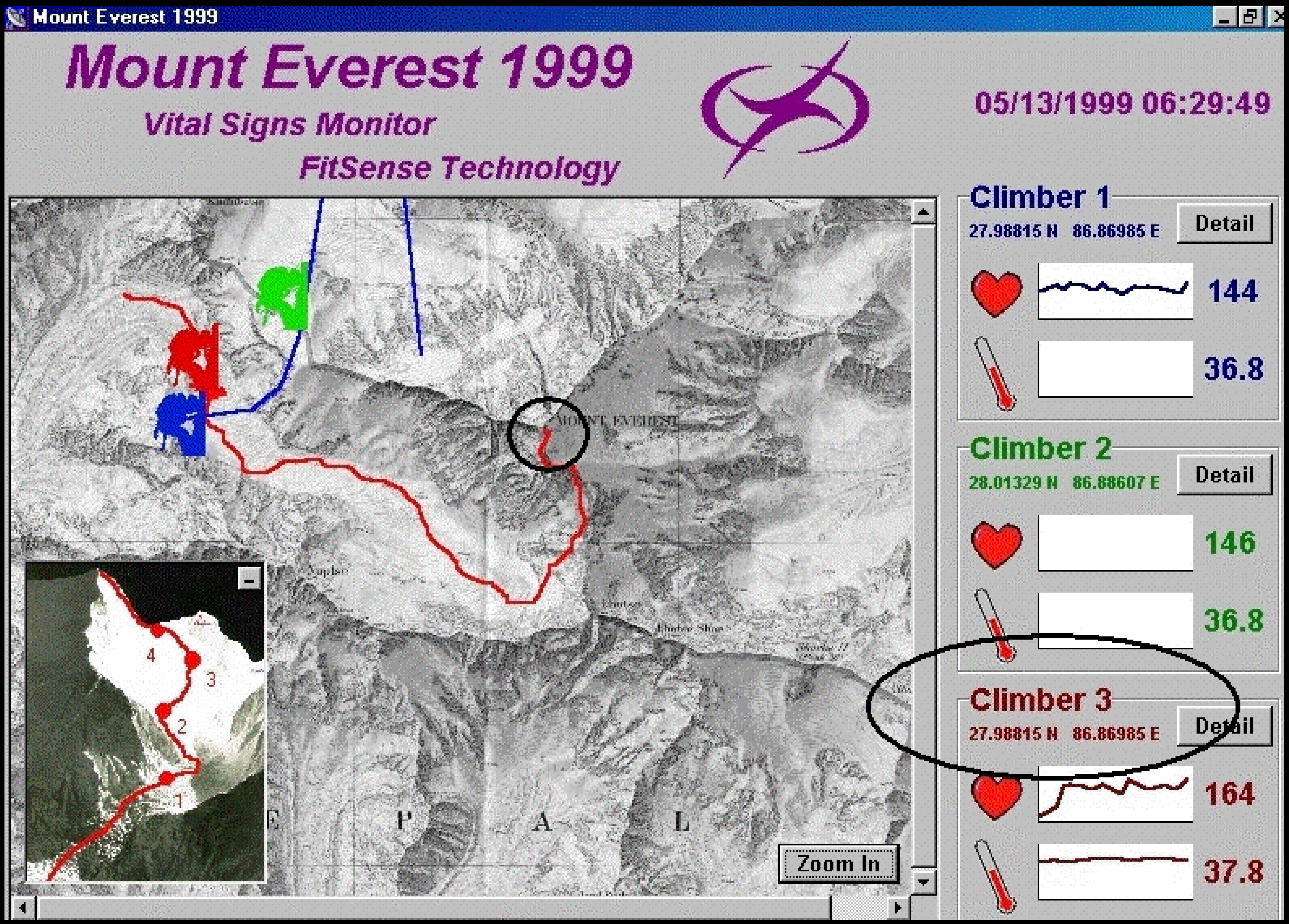
Parameter	Accuracy
Heart Rate	4 bpm
EKG	3 Lead
Activity	accelerometer
Skin Temp	0.01ºC
Core Temp	0.04ºC
GPS	0.75meters

Results - Vital Signs

Heart Rate	86-164 bpm
Skin Temp	22.1 - 34.3^{o}C
Core Temp	36.7 - 39.6^{o}C
Activity	11-64 pm

Skin temp	4-7^{o}C of Core body temp
Core temp	varied with drinking
Activity	not correlated

Terrain Display on Monitor

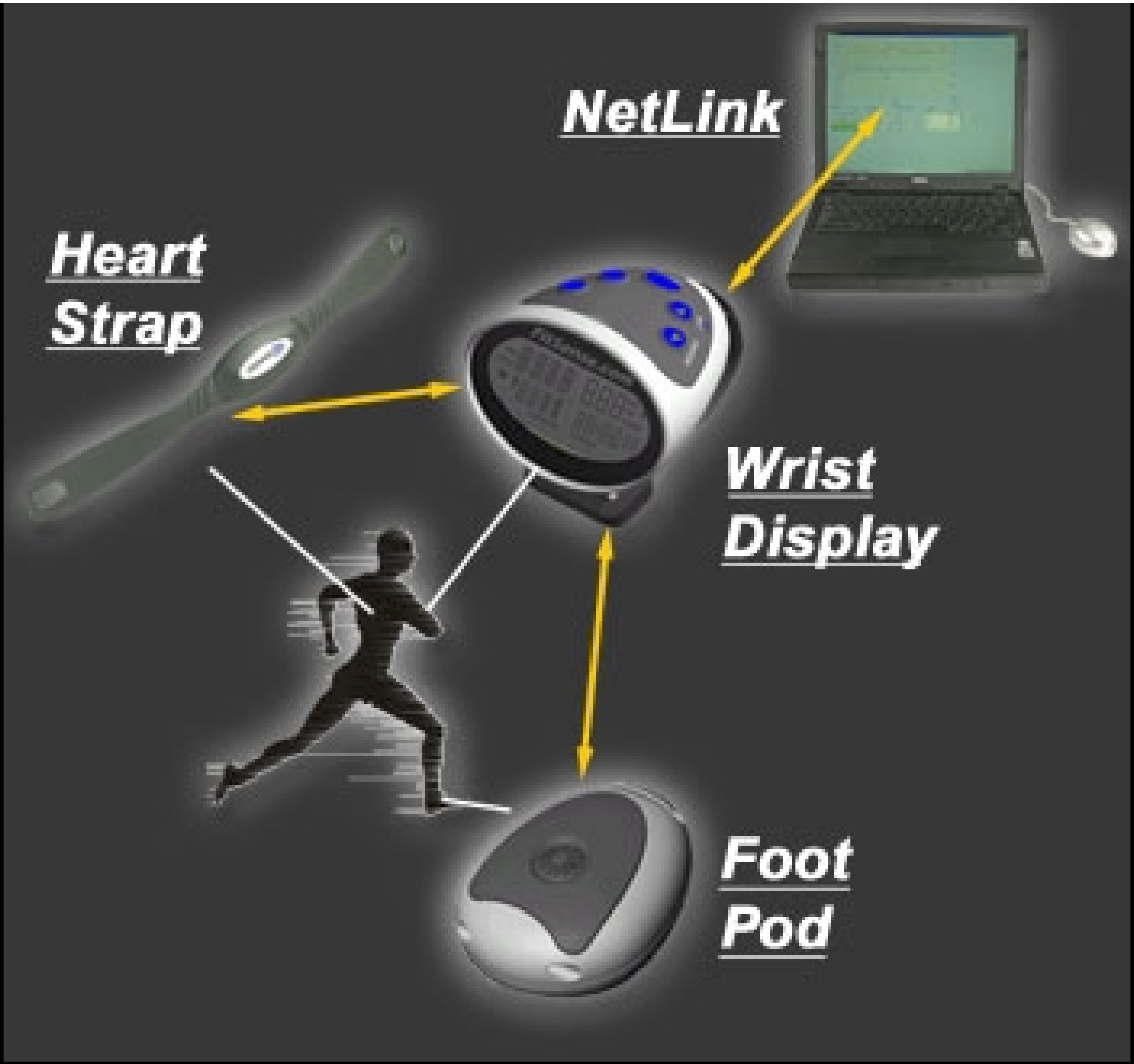


Courtesy Tom Blackadar, Fitsense Technologies, Boston, MA - 1999

Courtesy Tom Blackadar, Fitsense Technologies, Boston, MA - 1999

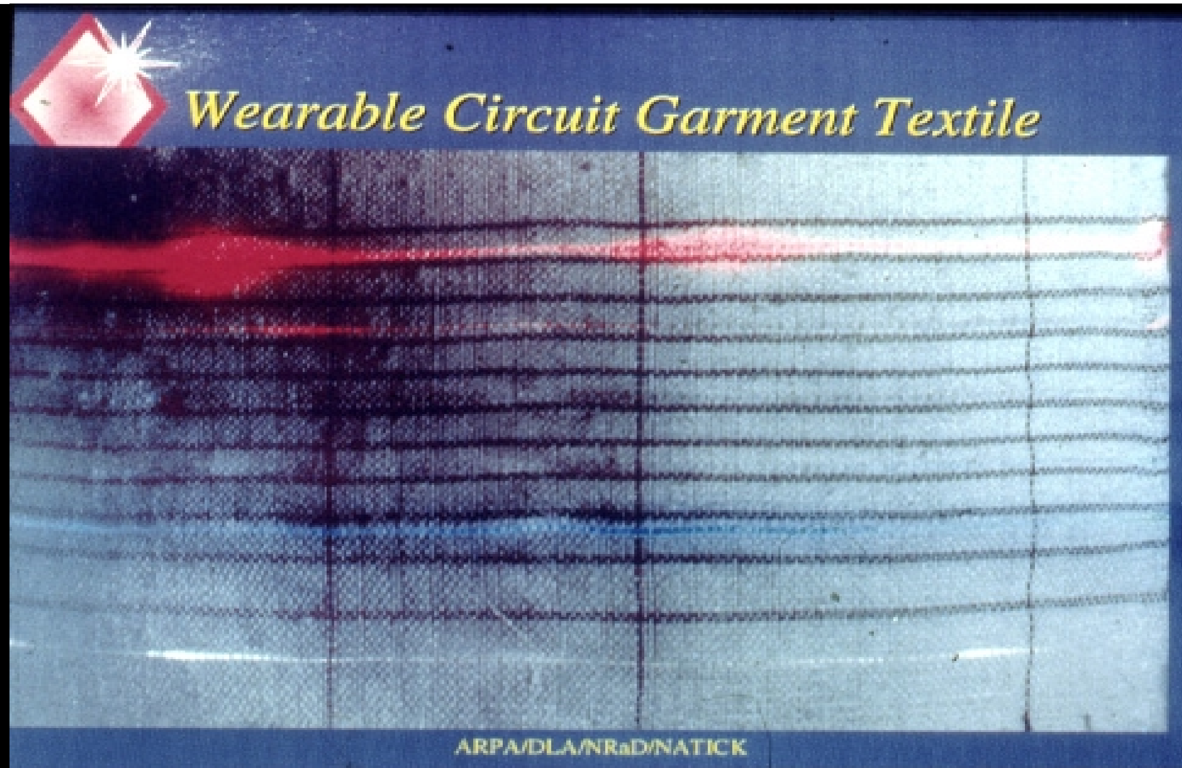
Typical Data From Vital Signs Monitors

Data ID #	Time (GMT)	Latitude	Longtitude	Heart Rate	Activity	Skin Temp	Core Temp
3380	23:22:43	28.00658	86.86138	96	16	22.11	37.36
3381	23:35:47	28.00725	86.86089	84	27	24.11	37.12
3382	23:40:35	28.00704	86.86126	84	48	25.16	37.27
3383	23:45:47	28.00716	86.85998	148	44	25.85	37.95
3384	23:50:47	28.00625	86.86282	128	36	26.55	37.67
3385	0:00:01	-37.3914	122.0376	128	37	27.68	37.61
3386	0:00:01	26.63363	29.78837	124	48	29.7	37.53
3387	0:05:47	28.00522	86.86506	100	18	31.19	37.45
3388	0:10:47	28.0039	86.86366	160	44	31.71	37.36
3389	0:15:47	28.00399	86.86554	168	49	32.36	37.53
3390	0:20:47	28.00293	86.86737	172	38	32.86	37.8
3391	0:25:47	28.00216	86.86763	172	30	33.05	37.95
3392	0:30:47	28.00199	86.86862	176	37	33.18	38.13
3393	0:35:47	28.00154	86.86896	172	35	33.25	38.21
3394	0:40:47	28.00136	86.86934	180	38	33.34	38.23
3395	0:45:47	28.00012	86.87052	176	32	33.16	38.26
3396	0:50:47	27.9993	86.8708	172	26	33.16	38.23
3397	0:55:47	27.99964	86.87203	172	31	33.13	38.26
3398	1:00:41	27.99952	86.87135	172	26	33.01	38.26
3399	1:05:46	27.99786	86.87095	172	31	32.94	38.15
3400	1:10:46	27.99752	86.87148	168	26	32.96	38.08
3401	1:15:47	27.99665	86.87207	156	37	32.74	38.02
3402	1:20:47	27.99625	86.87303	164	29	32.64	38.06
3403	1:25:47	27.99513	86.87352	168	33	32.46	38.26
3404	1:30:45	27.99513	86.87316	168	35	32.28	38.04
3405	1:35:44	27.9941	86.87302	152	32	31.93	38.08



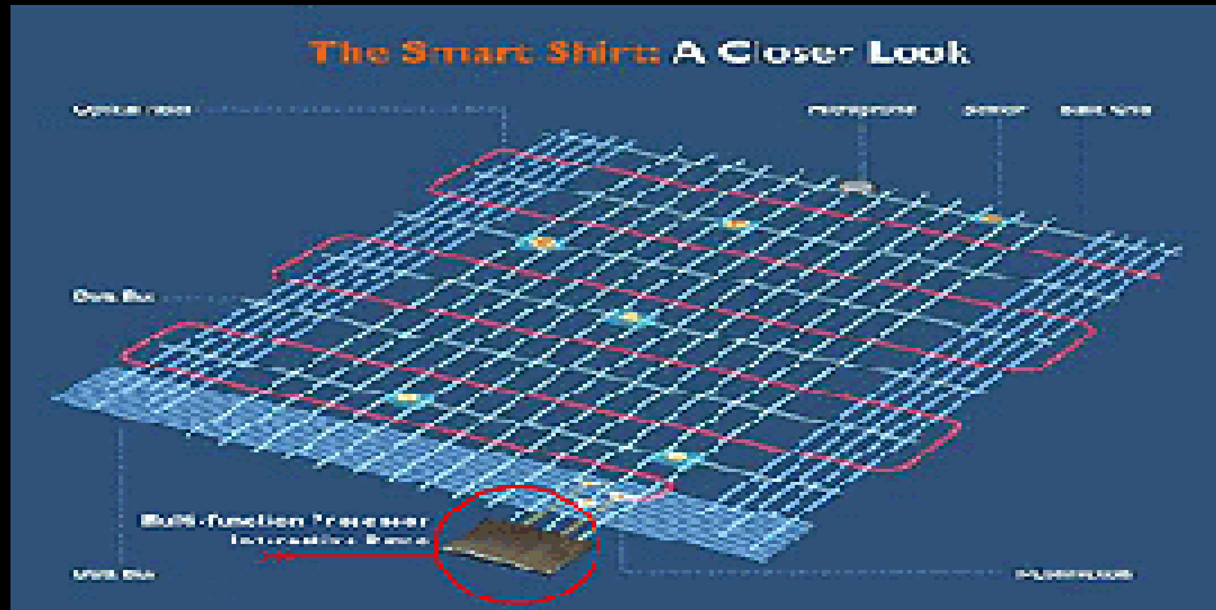
Courtesy Tom Blackadar, Fitsense Technlogies, Boston, MA

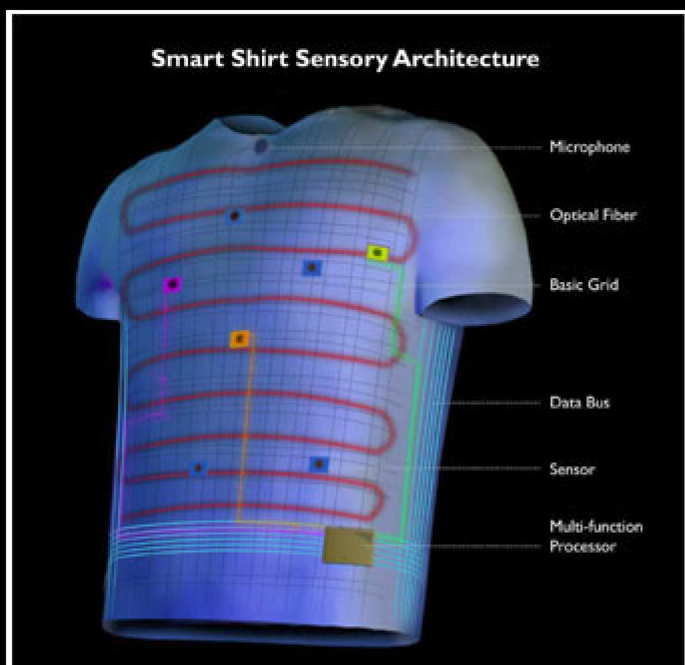
Smart Tee-Shirt

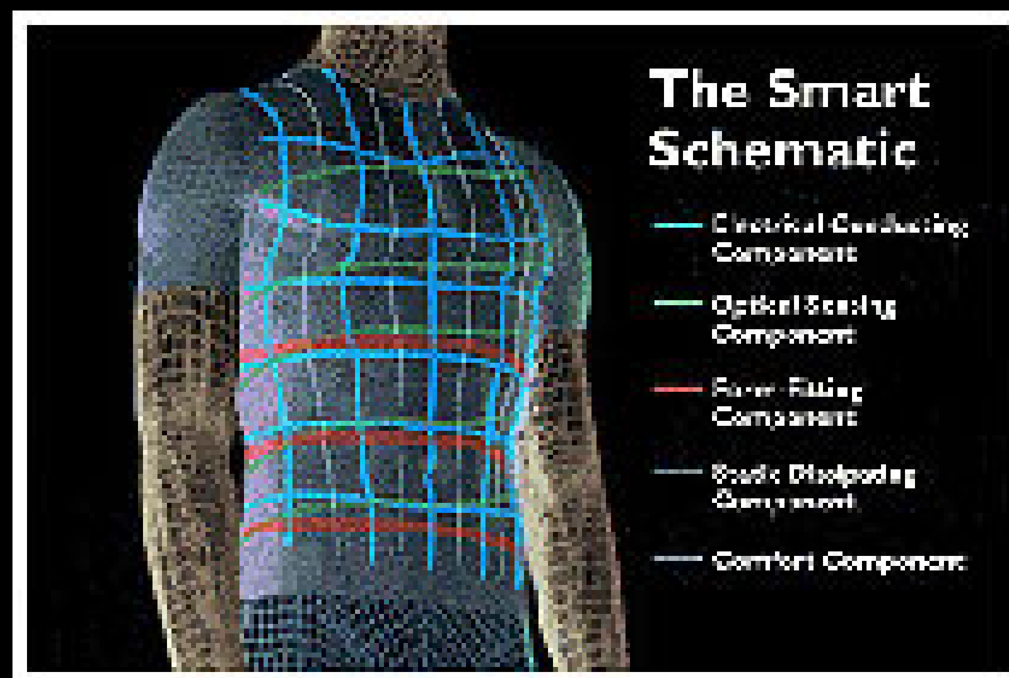


Courtesy Sundaresan Jayaraman, Georgia Tech - 1996

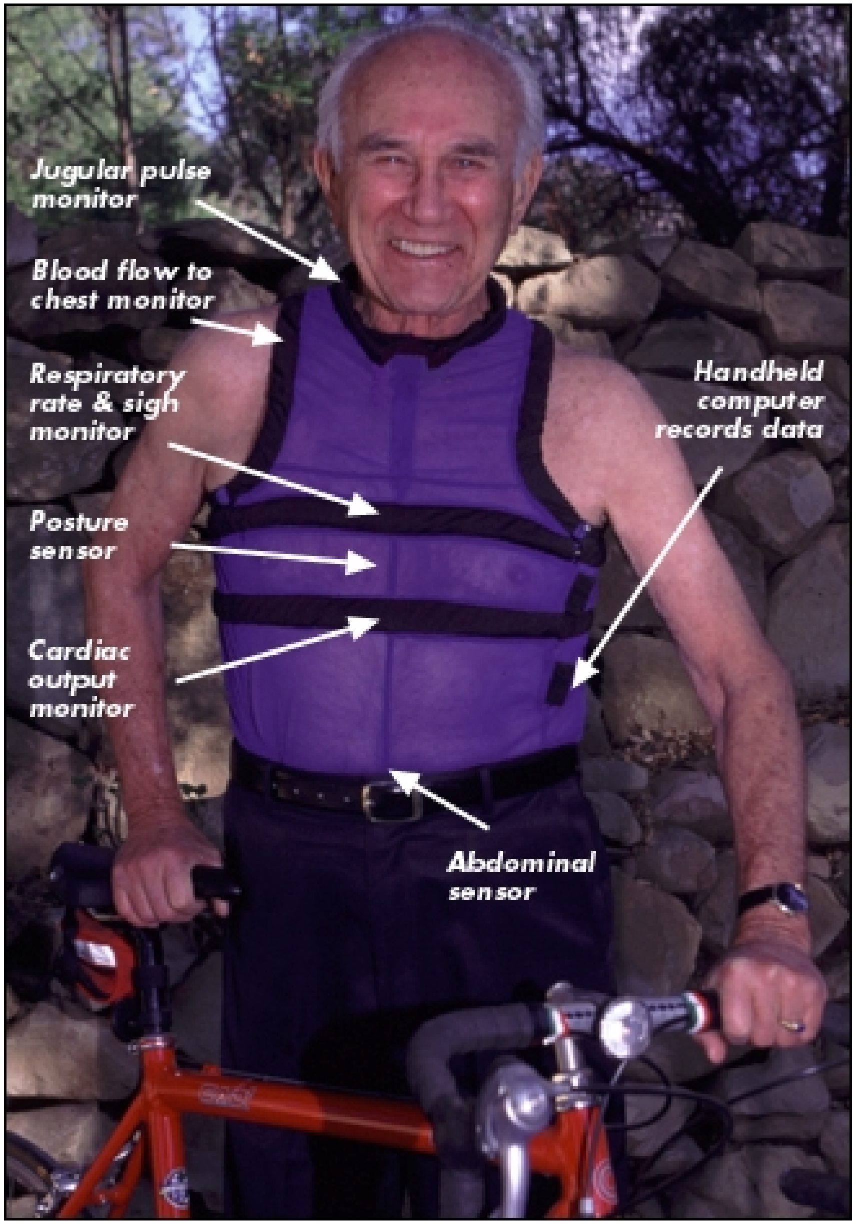
Smart Tee-Shirt







Courtesy Sensatex Technologies, New York, NY



The LifeShirt System

- a comfortable garment that can be worn under normal clothing.
- automatically and continuously monitors over 40 physical signs.
- data are stored on Handspring PDA for daily upload to LifeShirt.com's website.
- patients may enter their symptoms, mood, and activities on PDA and get medication alerts.

Courtesy Paul Kennedy, VivoMetrics, Inc., Ojai, CA

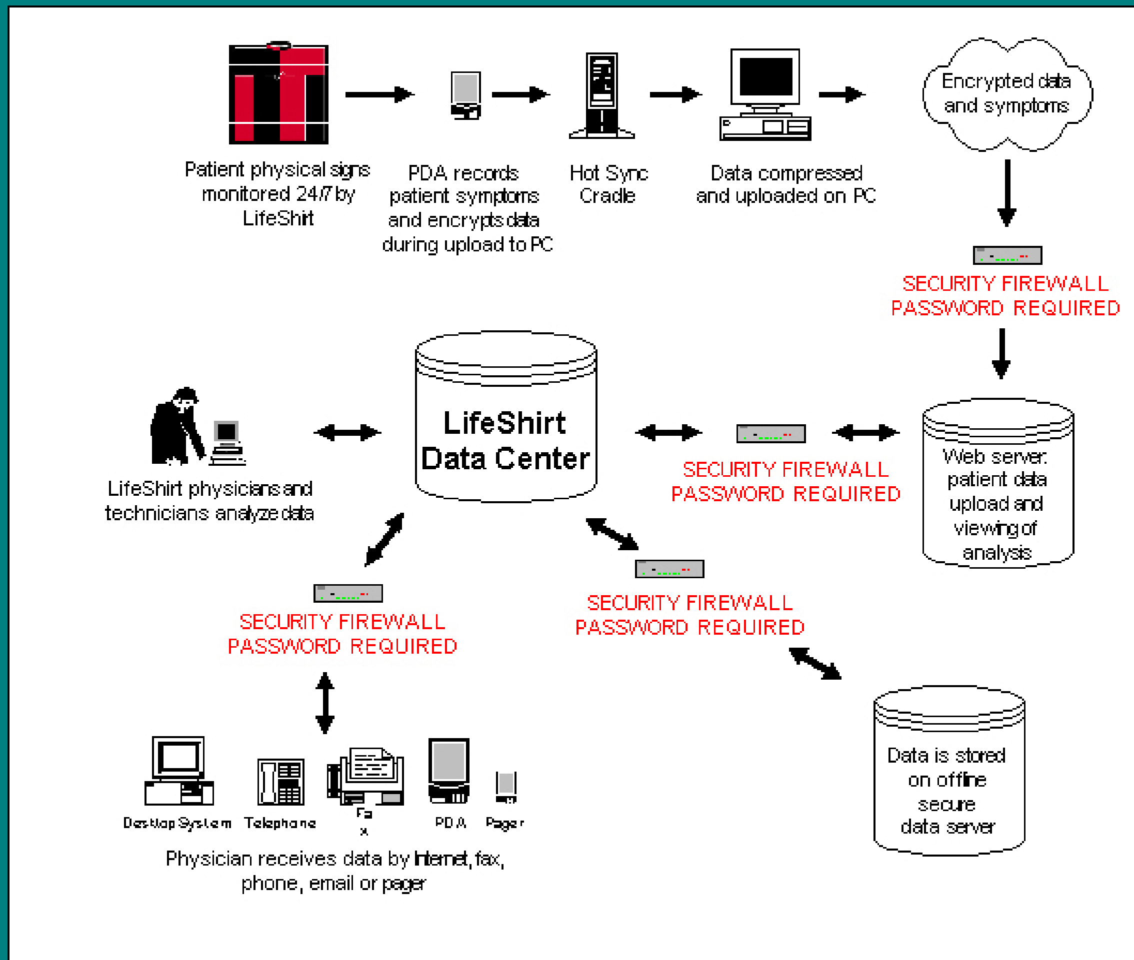
Over 40 Physical Signs

- Respiratory rate
- Tidal volume
- Ventilation
- Sigh count
- Peak inspiratory flow
- Ventilation/peak inspiratory flow
- Peak inspiratory flow/mean inspiratory flow
- Peak expiratory flow/mean expiratory flow
- Phase relation
- %RC/Vt
- Apnea/hypopnea detection
- Apnea/hypopnea classification
- MPer
- Changes of VtFRC
- Peak expiratory flow
- Volume expired in one sec
- Right minus left hemithoracic tidal volume

- Right versus left hemithoracic phase relation
- Respiratory efforts
- Pre-ejection period/Left ventricular ejection time (PEP/LVET)
- Central venous pressure
- Jugular venous pulse trace
- Swallow counts
- Pulse wave transit time
- Amplitude of cardiac pulsation
- Amplitude of cardiac pulsation times heart rate
- PEP/LVET
- Deceleration time from mathematical derivative cardiac pulsation
- Heart rate
- Arrhythmias
- Respiratory sinus arrhythmia
- Counts method (sNN50)
- Arterial oxygen saturation
- Arterial pulse wave

LIFESHIRT•COM
vital signs online

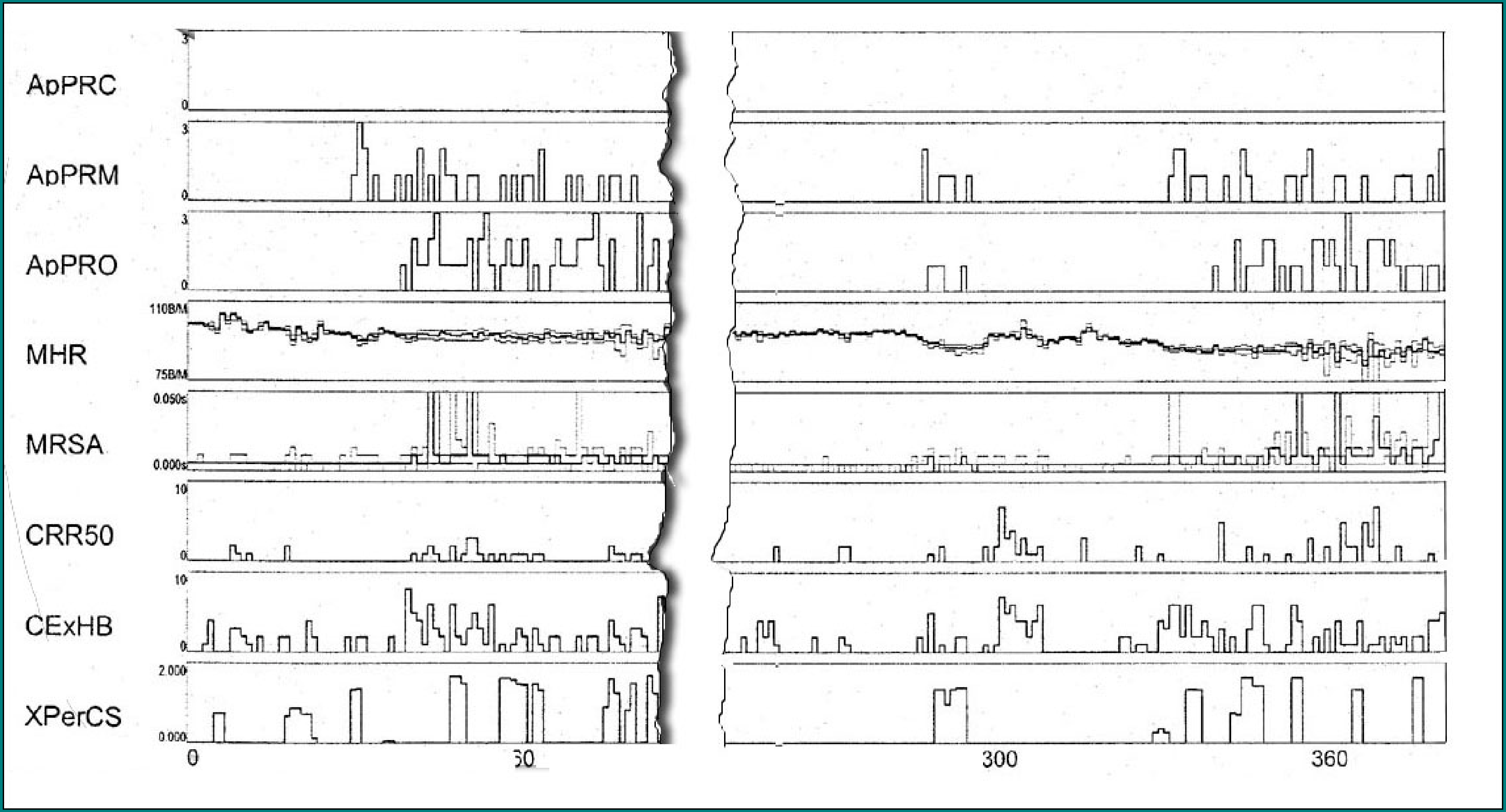
The Data Flow



Courtesy Paul Kennedy, VivoMetrics, Inc., Ojai, CA

Sample LifeShirt Report

Graphical Components--B



Courtesy Paul Kennedy, VivoMetrics, Inc., Ojai, CA

Thoracocardiograph

Systolic Function

29) Amplitude of ventricular volume trace Equivalent to stroke volume (SV) but reflects changes from baseline not absolute values since it cannot be independently calibrated to volume

30) Amplitude of ventricular volume trace times heart rate Equivalent to cardiac output but reflects changes from baseline not absolute values since it cannot be independently calibrated to volume

31) PEP Reflects myocardial contractility, with lower values consistent with good contractility and high values poor contractility

32) 1st 1/3 ejection/SV Measure of systolic function; higher the value, the better the function

Diastolic Function

33) E/A ratio Peak of **E**arly rapid filling of ventricle wave divided by peak of filling of ventricle wave from **A**trial contraction. High values consistent with restrictive myocardopathy as well as elevated pulmonary capillary wedge pressure; low values consistent with low pulmonary capillary wedge pressures; E/A ratio is highly specific but not sensitive

Electrocardiogram

38) Heart rate Sensitive but non-specific sign of cardiac function

39) ECG waveform Needed to interpret cardiac arrhythmias; in some instances, requires addition of jugular venous pulse to distinguish atrial contraction to diagnose type of tachyarrhythmia

40) Respiratory sinus arrhythmia Instantaneous heart rates timed with Respitrace® inspiratory and expiratory tidal volumes; direct correlates with parasympathetic nervous system activity; low values reflect emotional stress

41) Counts method (sNN50) Counts # RR intervals of ECG where successive beats exceed 50 msec; low values consistent with impaired parasympathetic nervous system activity

Posture and Activity

42) Posture Two, dual axes accelerometers, one over sternum and other on lateral aspect of upper thigh give indications of standing, sitting, supine, prone, and lateral decubitus

43) Activity Two, dual axes accelerometers, one over sternum and the other on lateral aspect of upper thigh indicate activity through measurement of accelerations during walking and running.

Pulse Oximeter (option during sleep)

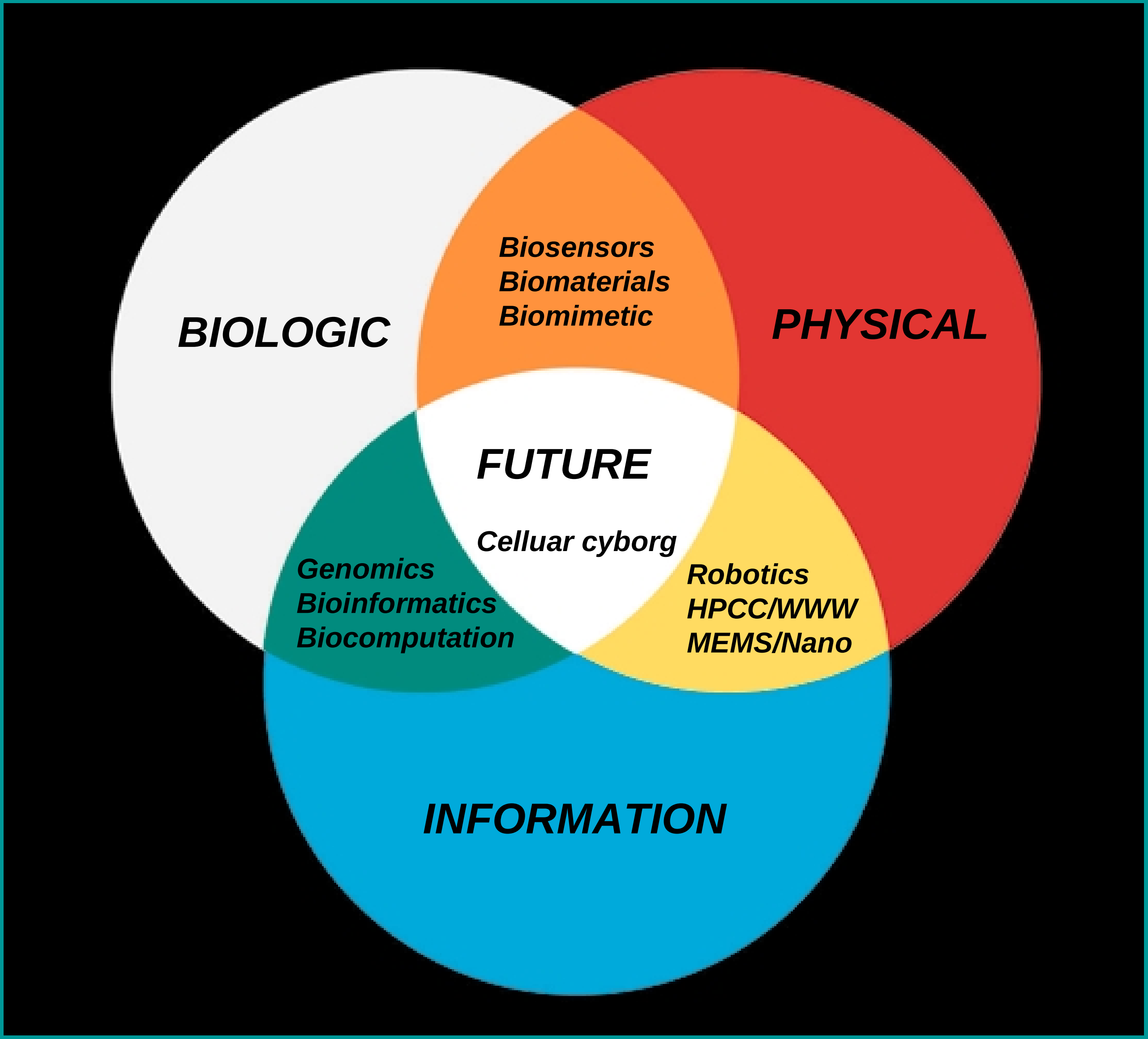
44) Arterial oxygen saturation Assesses amount of oxygen in arterial blood & is component of sleep study

45) Arterial pulse wave Validates accuracy of arterial oxygen saturation reading values by measurement of pulse upstroke time

46) Pulse bad indicator Artifactual pulse as indicated from upstroke times outside of normal range; also serves as a movement indicator for wake state

47) Pulse transit time Time from R wave to pulse oximeter wave upstroke; brief transient decreases signify microarousals from sleep because pulse transit time decreases with elevation of blood pressure

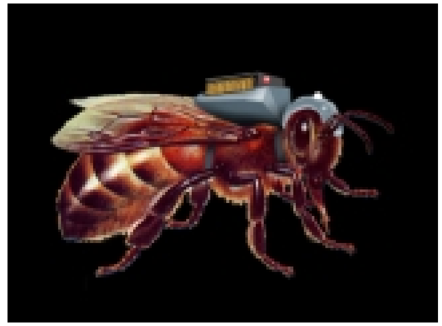
BIO INTELLIGENCE AGE



DARPA: The 7 Focus Areas

1	Modeling of Biologic behavior	(Virtual Human)
2	Biological Computers	(DNA, cells)
3	The Language of Biology	(decoding genes)
4	Interfacing biotic to abiotic world	(cellular cyborg)
5	Mimicking the brain	(molecules to cognition)
6	Biology on the move	(how biology creates work)
7	Biomaterials	(unique properties, self assembly)

DARPA Controlled Biological Systems Program



Animats — Machine — Living — Animals

Biomimetic Systems

- Integration of biological design for sensorimotor function
  - neural control architecture
  - biomechanical self-stabilization
  - sensor/performance
- Autonomous navigation
- Modular design/fabrication of fault tolerant mobile sensor platforms

Biohybrid Organisms

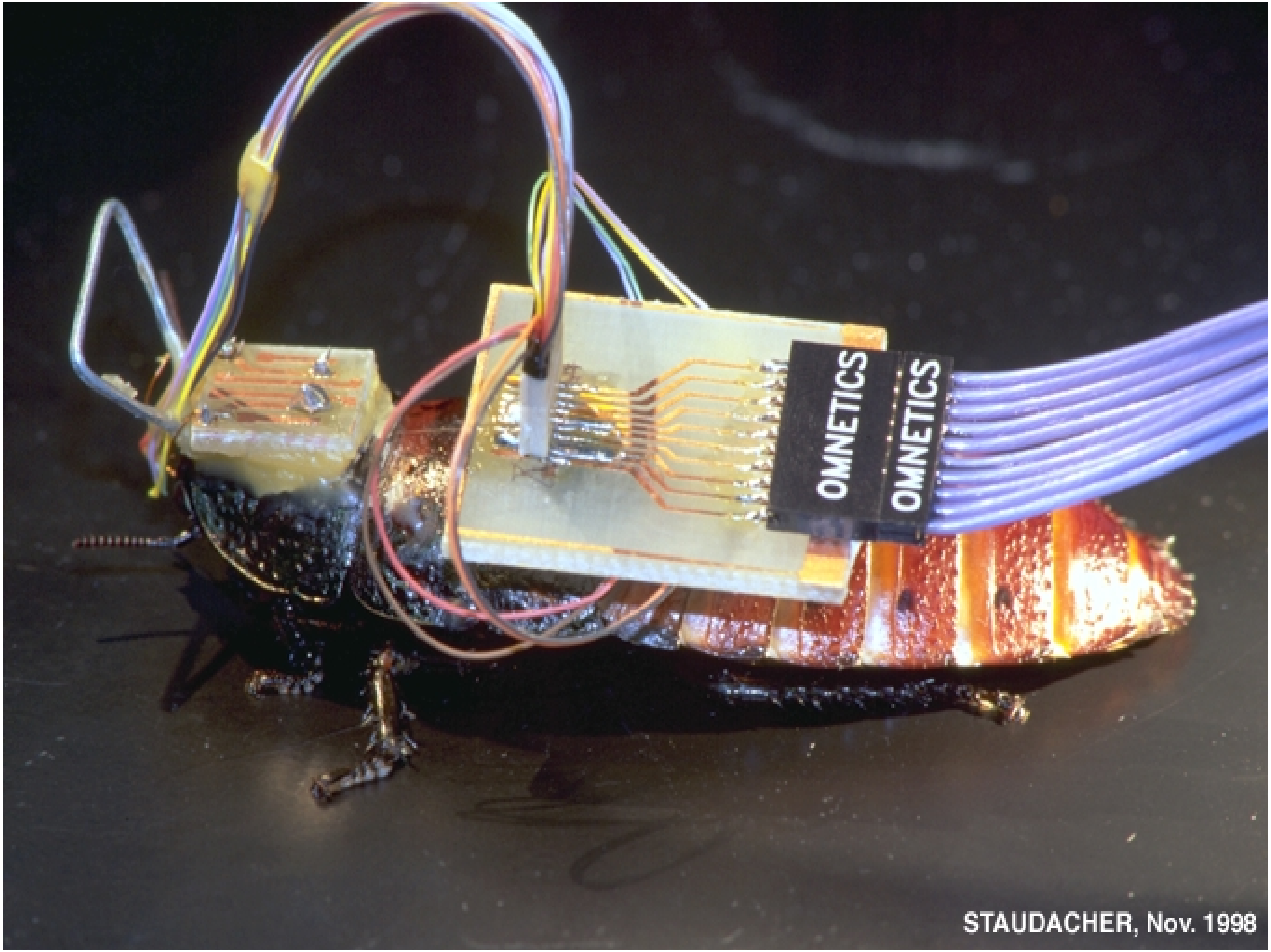
- New interfaces for measuring neural-muscular outputs sensorimotor control in freely moving/sensing behaving biological systems
- Stimulation of neural and muscular systems to influence sensorimotor function
- Inexpensive attachment of sensors (chem/bio)

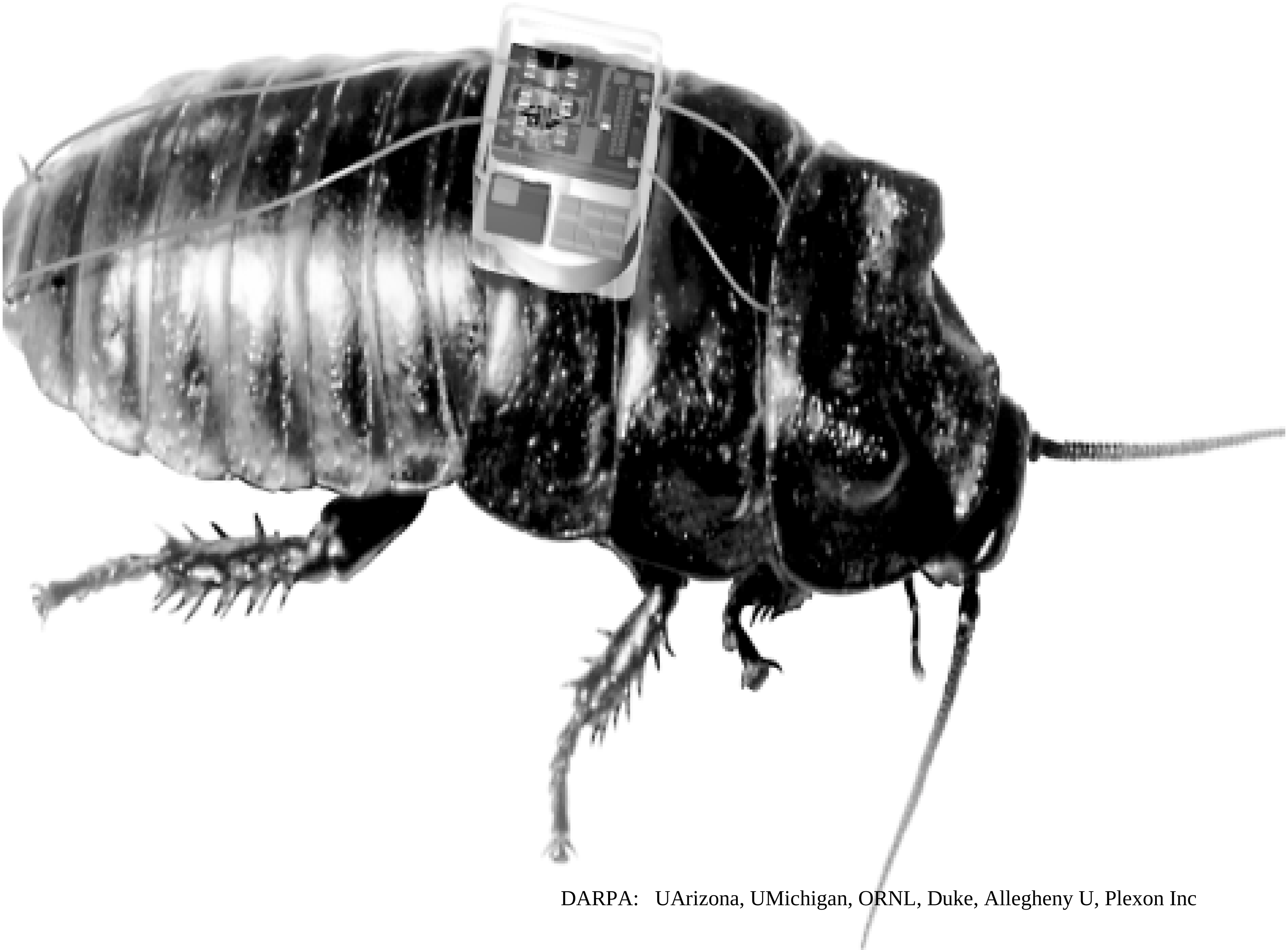
Biological Systems

- Pheremone control of sensorimotor output - plume tracing
- Plasticity of associative learning to threats of interest (conditioned training)
- Investigate behavior with sensor motor architecture

Courtesy Alan Rudolph, Program Manager, 1999

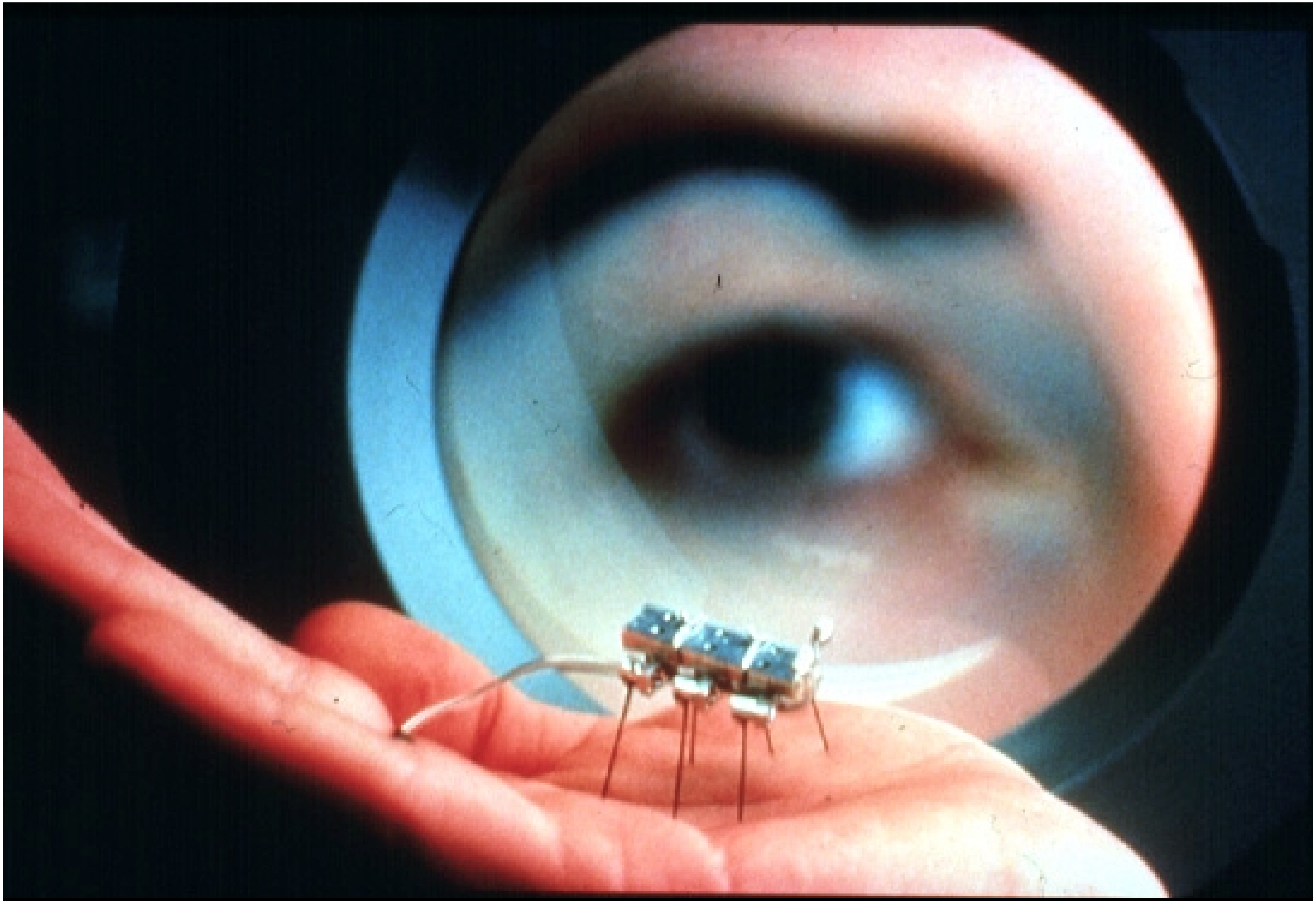
University of Montana, 1999


OMNETICS
OMNETICS
STAUDACHER, Nov. 1998



DARPA: UArizona, UMichigan, ORNL, Duke, Allegheny U, Plexon Inc

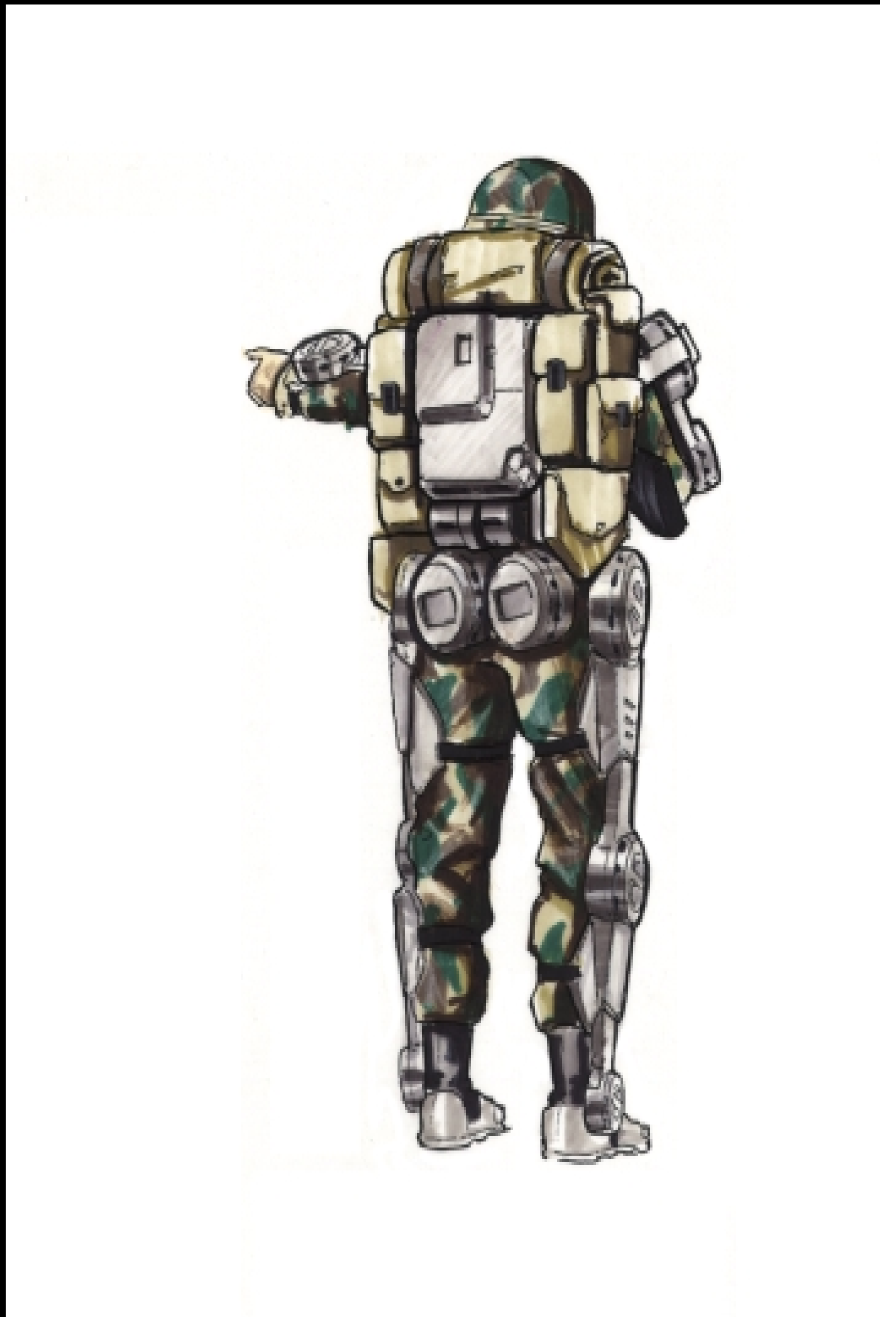
DARPA: UArizona, UMichigan, ORNL, Duke, Allegheny U, Plexon Inc

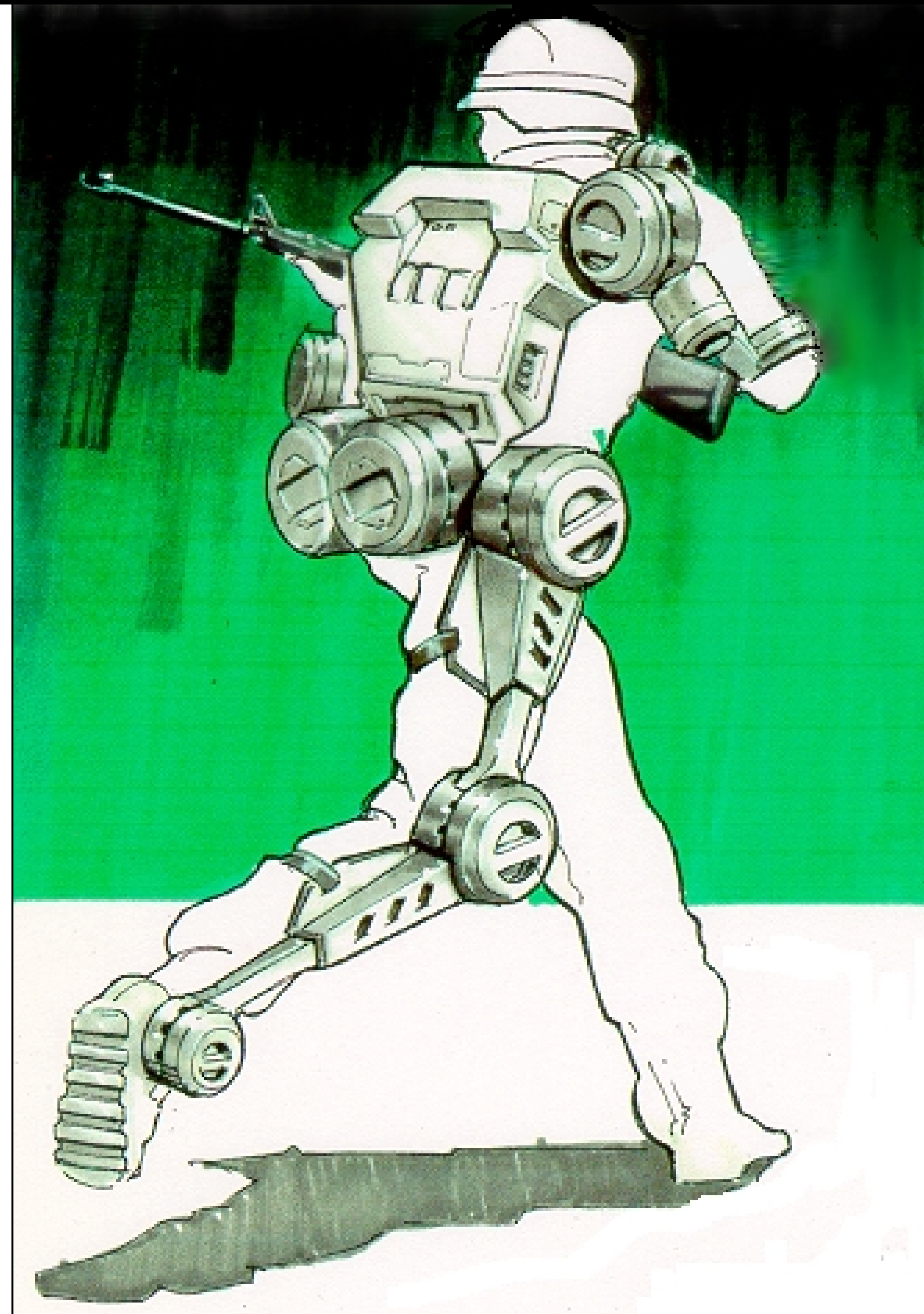


Micro-robot with micro-video Anita Flynn, MIT 1994

Biomimetic Micro-robot

Courtesy Sandia National Labs





E Garcia DARPA Jan, 2000

The 5 P's

of the

Future of Soldier Health Support

Predictive - Genetics, allergies, specific medications

Preventive - Acting proactively with preventive medicine

Point of care - Mobile communications & ubiquitous computing
Local intelligence

Parametric - Multiple parameters, over time, referenced to patient's own baseline, compared to standard model

Personalized - Individual treatment for each patient

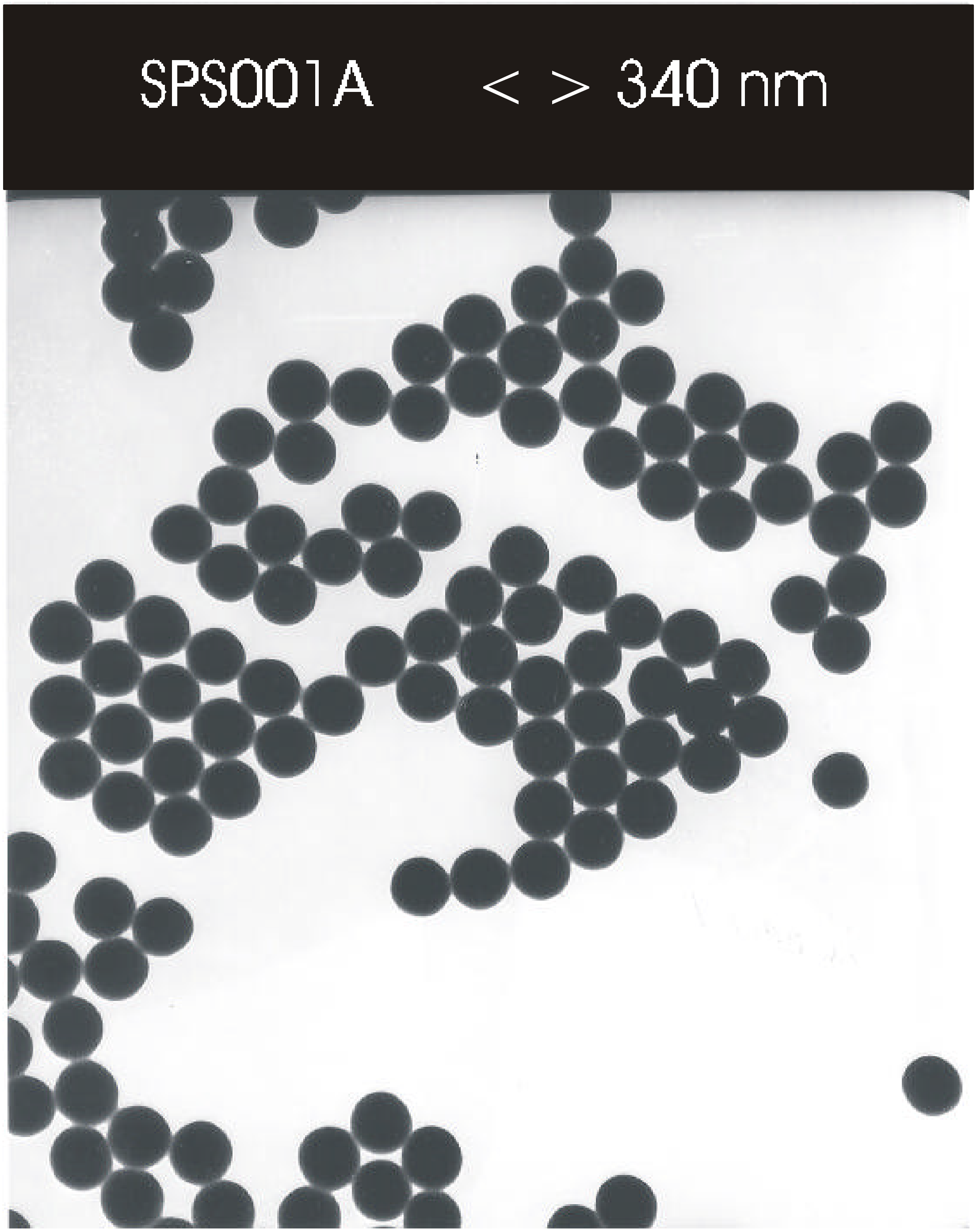
[redacted]

PSM needs for monitoring

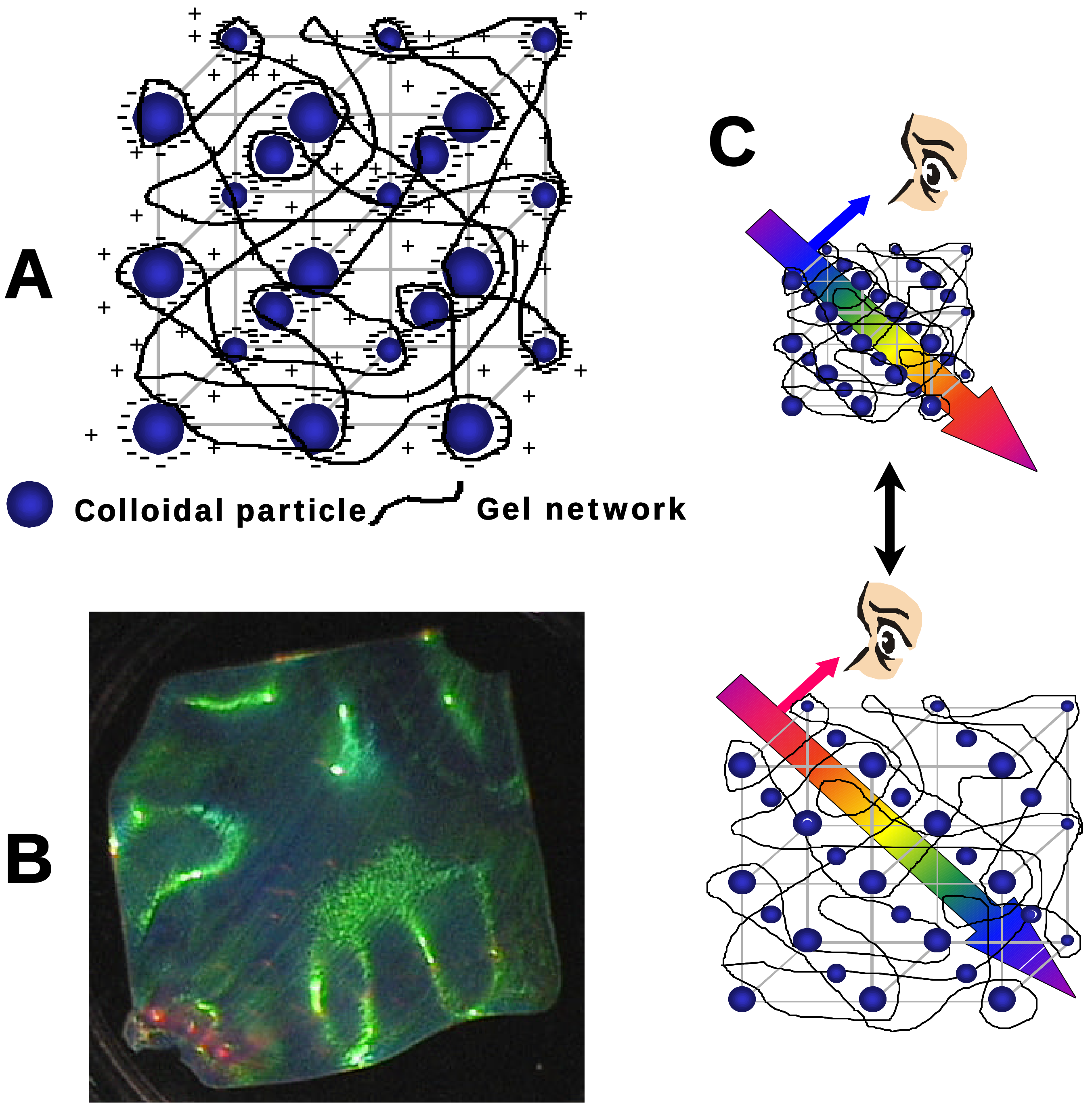
Thermal
Hydration
Fatigue
Physiologic status

S. A. Asher, Department of Chemistry

TEM of Polystyrene Spheres
300 nm (QLS)



S. A. Asher, Department of Chemistry



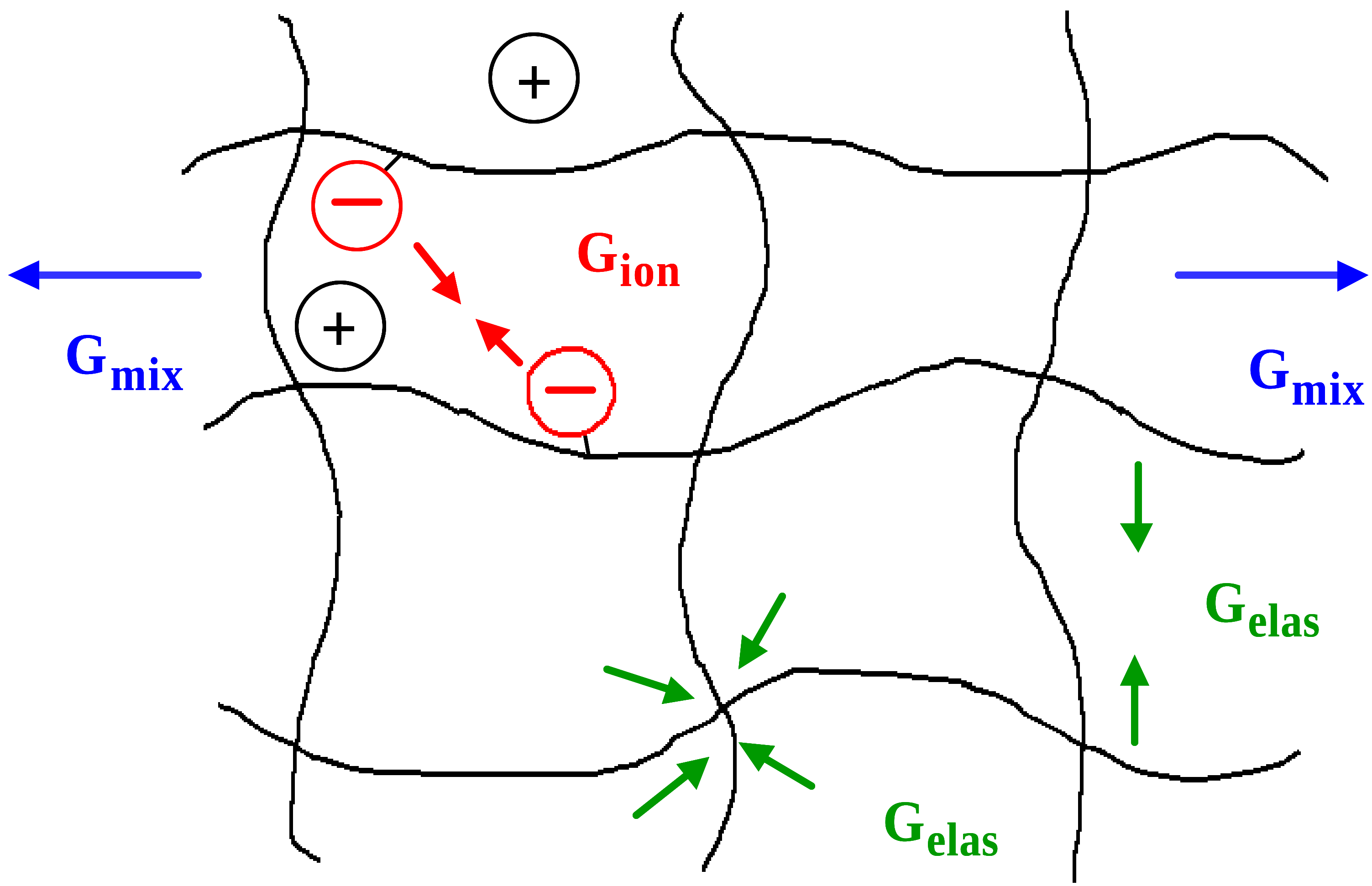
A) Polymerized crystalline colloidal array (PCCA)

B) Photograph of typical PCCA showing bright iridescence.

C) As the hydrogels shrink and swell, the lattice spacing of the CCA locked within changes as well. Thus, the volume changes of the gel can be observed by monitoring the change in diffraction.

FREE ENERGY CONTRIBUTIONS TO GEL VOLUME

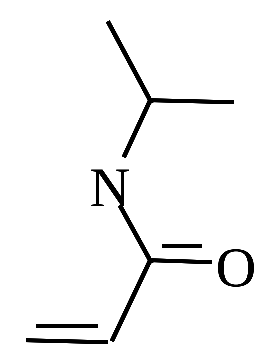
$$G_{tot} = G_{mix} + G_{ion} + G_{elas}$$



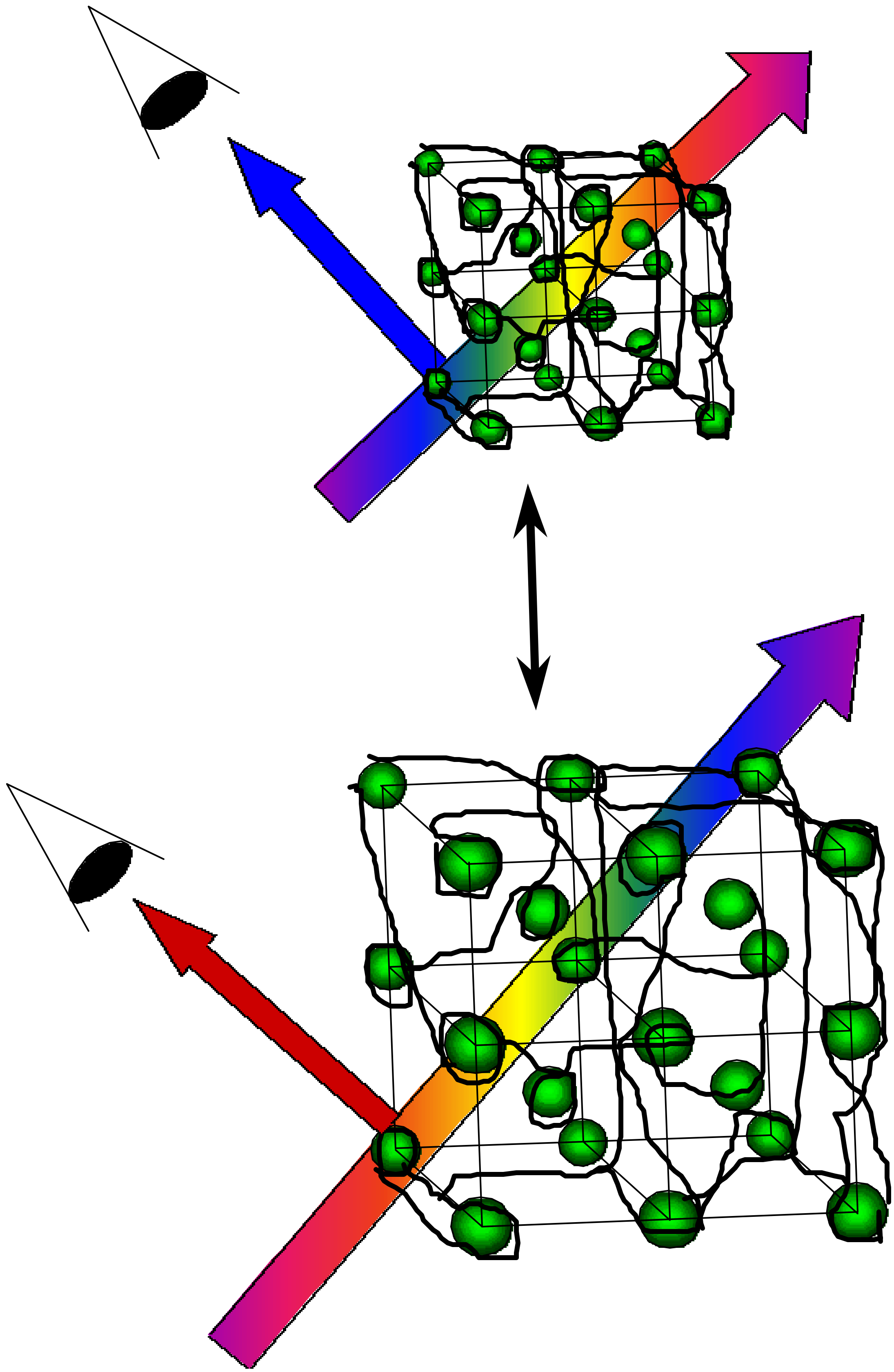
Poly(N-isopropylacrylamide) : The Driving Force

Poly(N-isopropylacrylamide) (PNIPAM) undergoes a reversible phase transition when heated above 32.1 ^{o}C. This coil-globule transition is analogous to a liquid-vapor phase transition. The recipe and synthesis conditions determine the extent of volume changes and whether they are continuous or discontinuous.

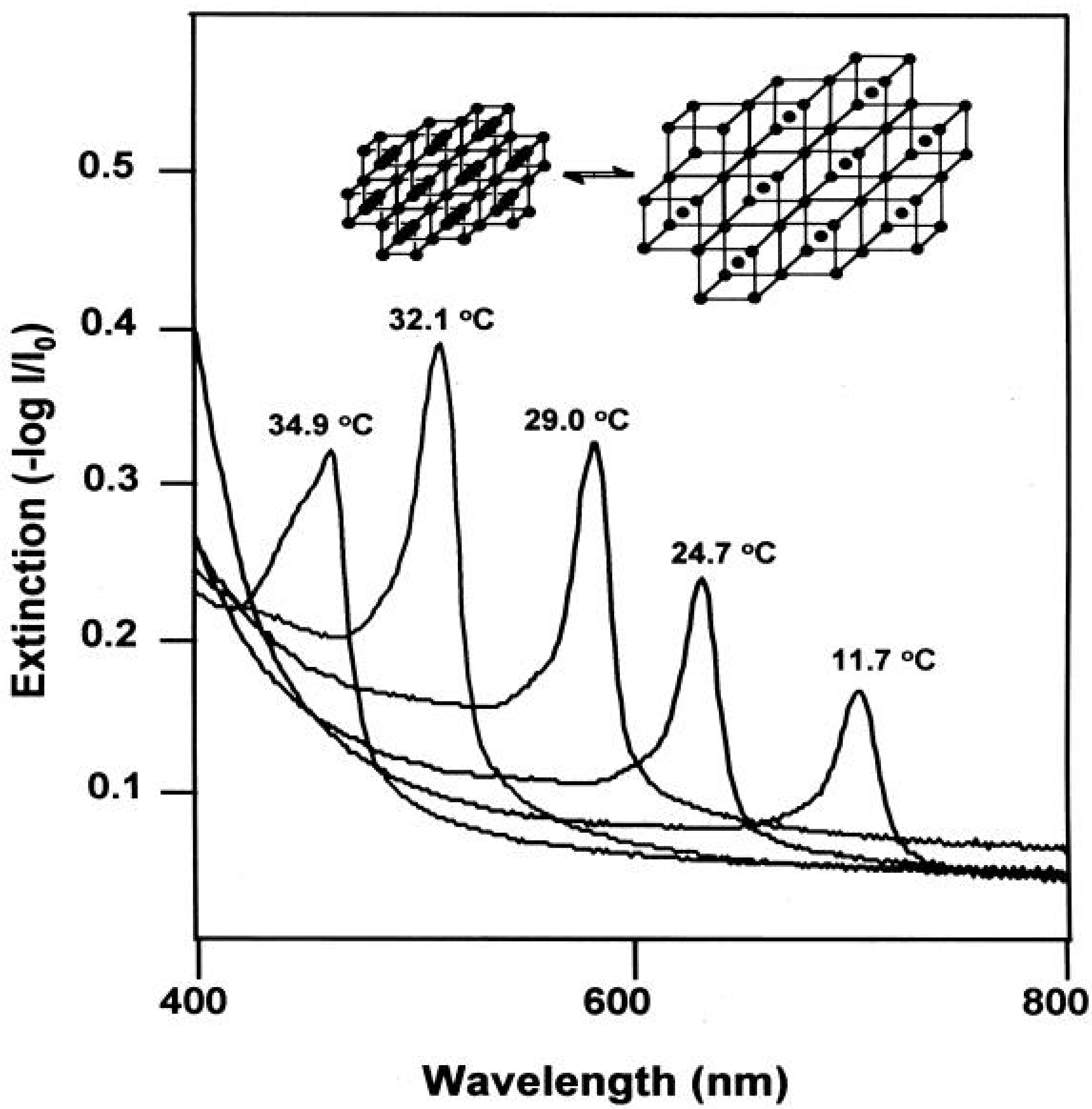
Chemical Structure of NIPAM



S. A. Asher, Department of Chemistry



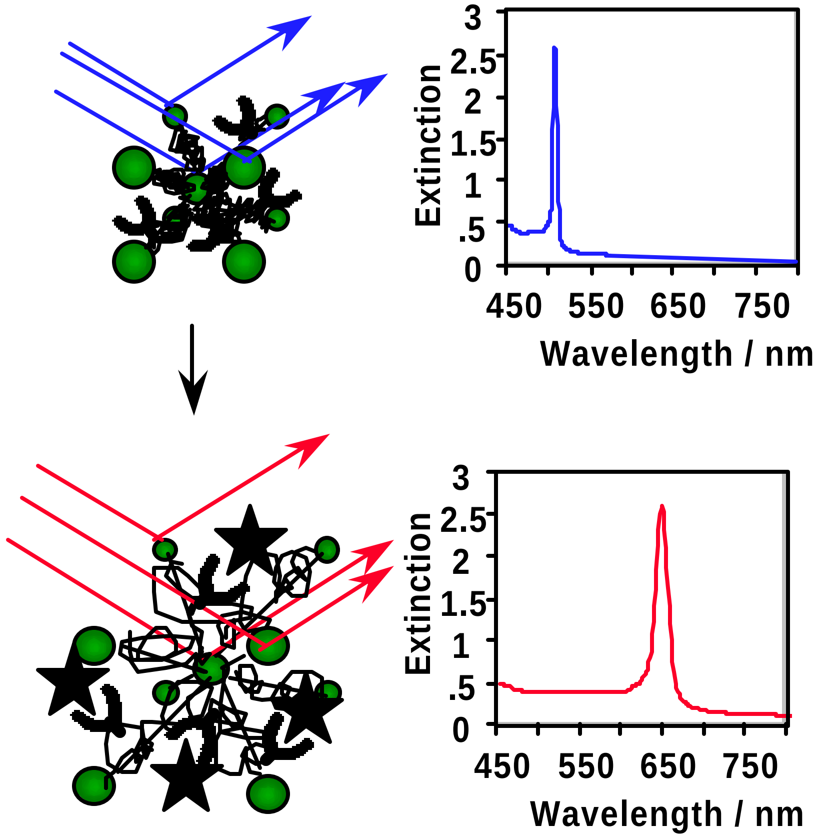
S. A. Asher, Department of Chemistry



Wavelength selective reflector tuned across the visible spectrum

S. A. Asher, Department of Chemistry

Diffracting Materials for Chemical Sensing



Polystyrene colloid.

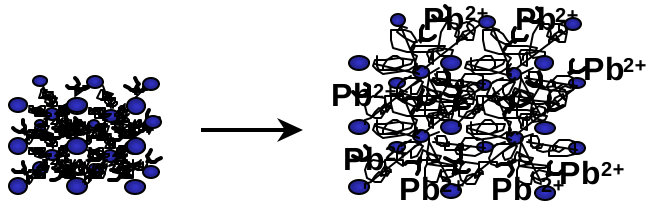
Side group capable of molecular recognition.

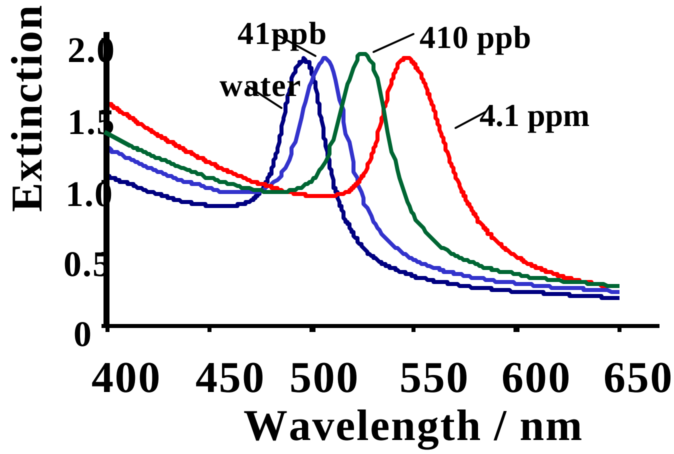
Substrate to be recognized.

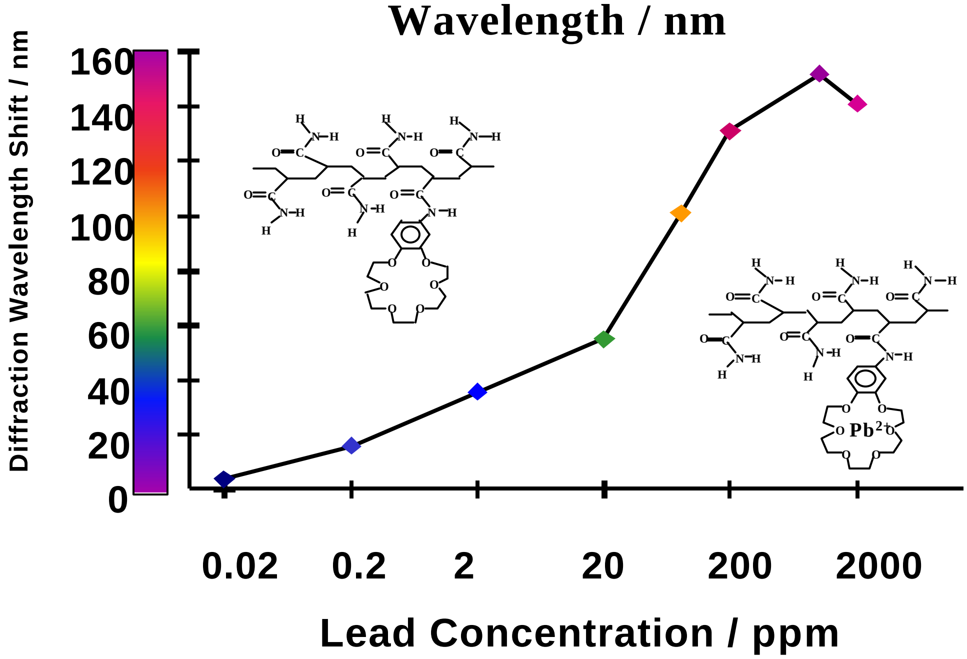
Hydrogel matrix.

S. A. Asher, Department of Chemistry

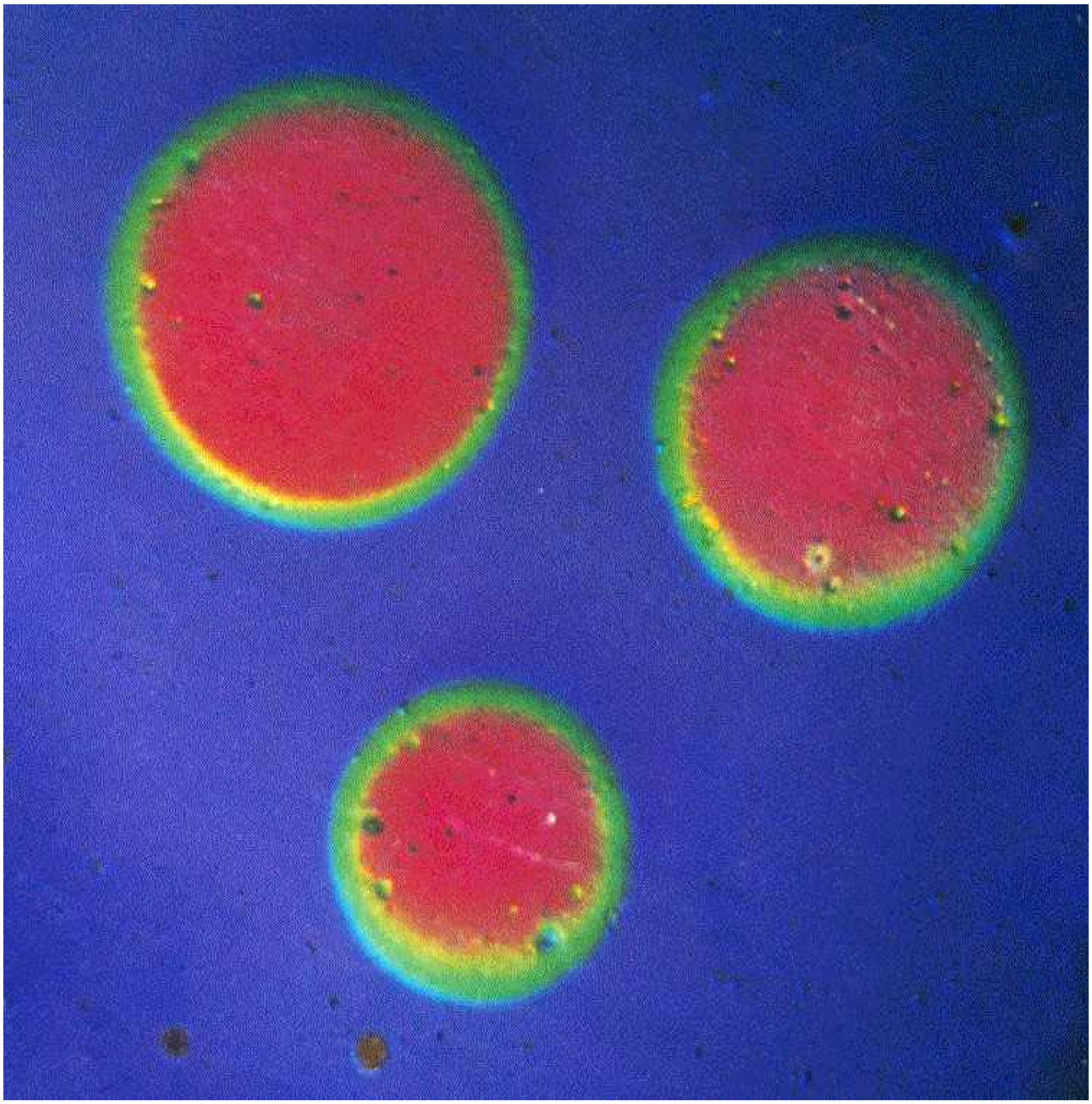
We constructed cation and anion sensors by attaching chelating agents to the PCCA. Chelation of the analyte ion results in immobilization of the counterion which results in an osmotic pressure which swells the gel and red shifts the diffraction in proportion to the analyte concentration.



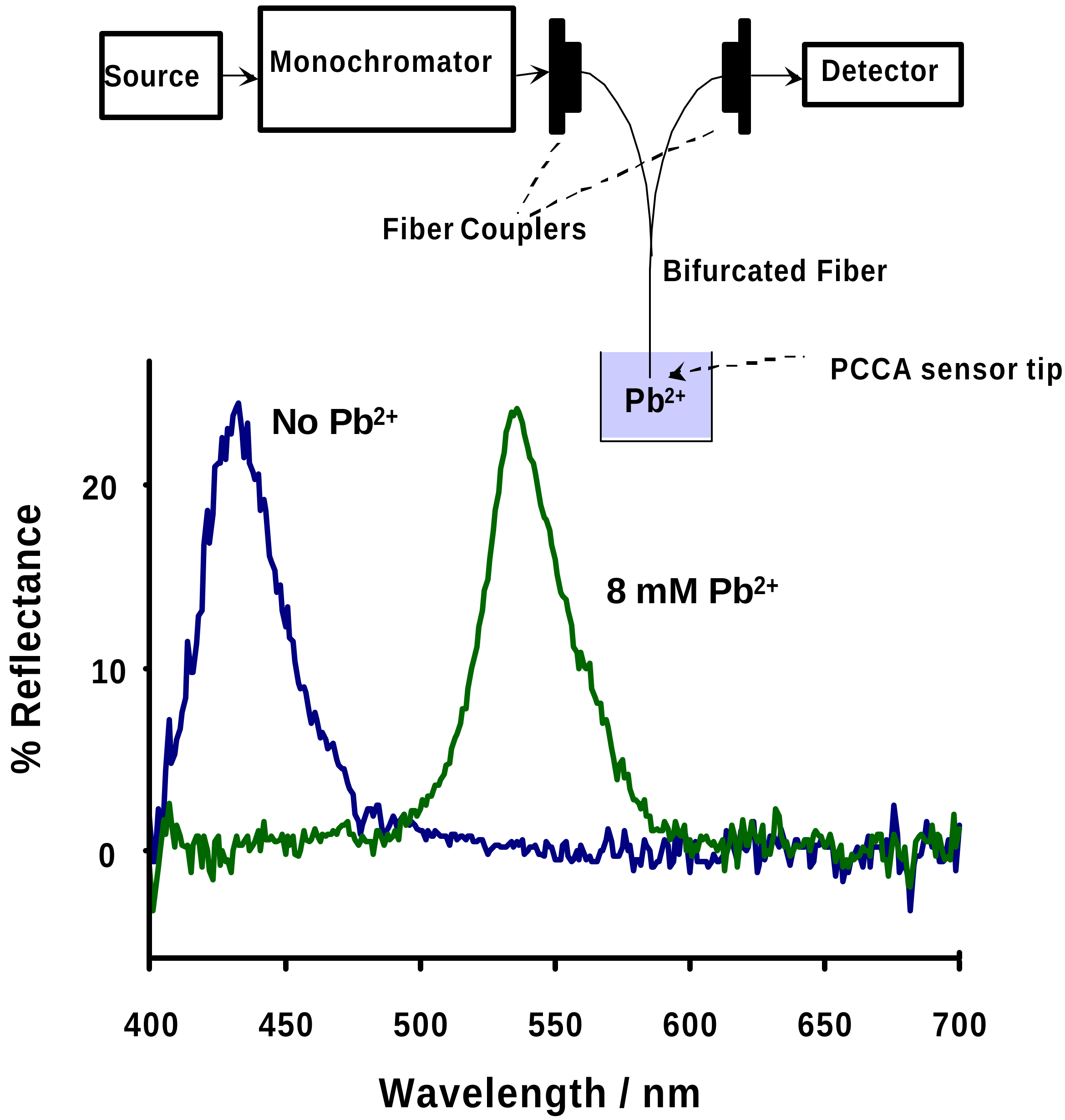




S. A. Asher, Department of Chemistry



S. A. Asher, Department of Chemistry



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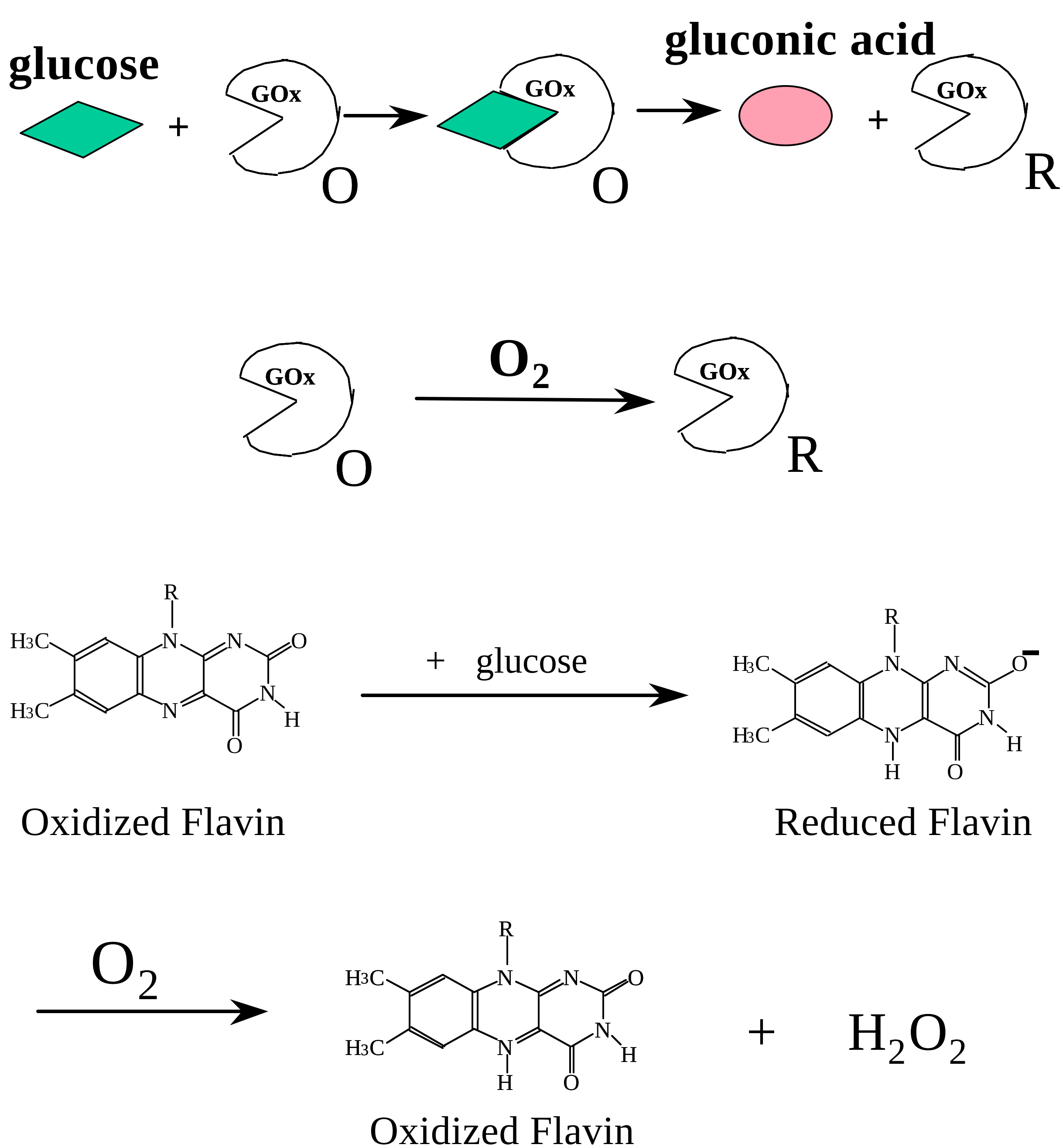
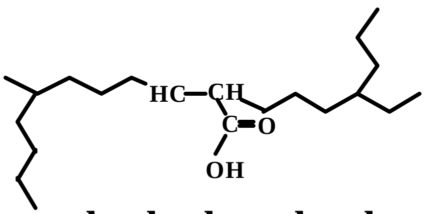
Glucose Oxidase Reaction Mechanism



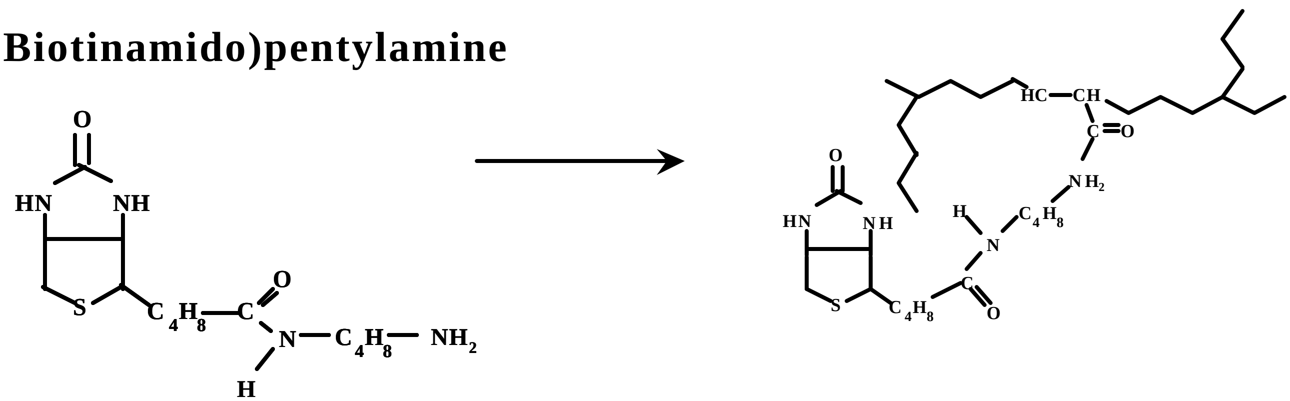
1-(3-Dimethylaminopropyl)-3-ethylcarbodiimide



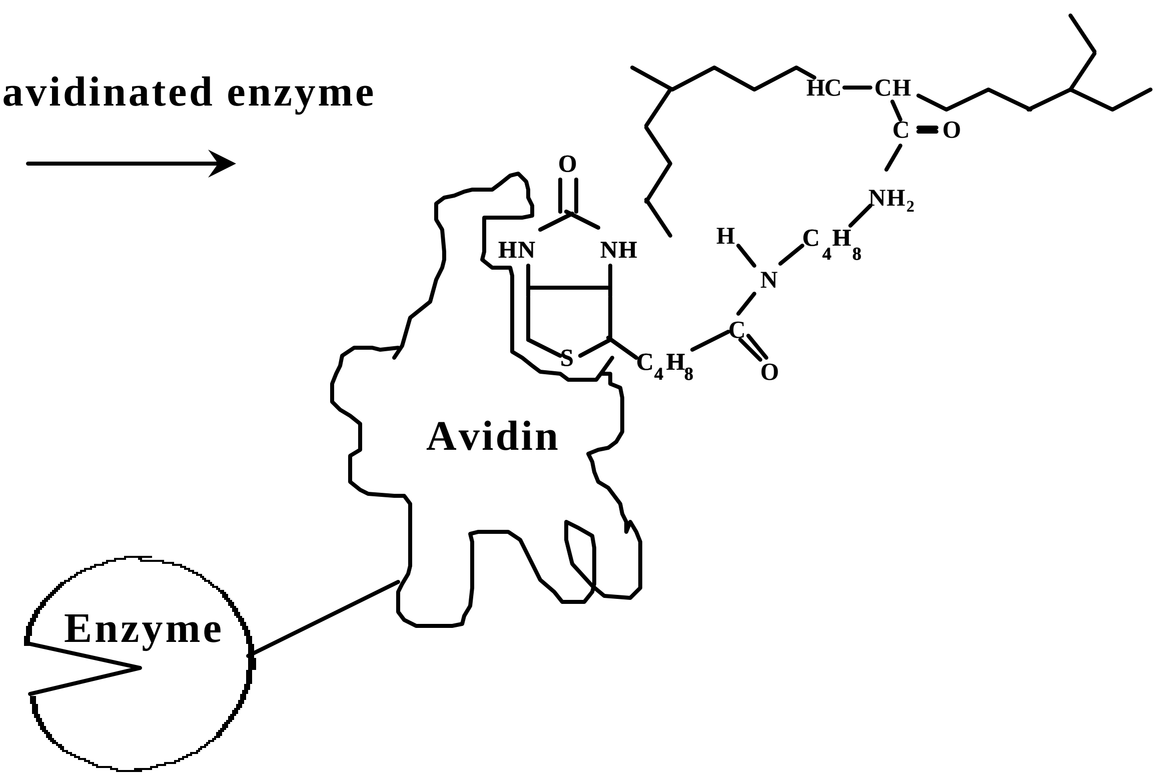
+ $C_2H_5-N=C=N-C_3H_6-N(CH_3)_2$ +

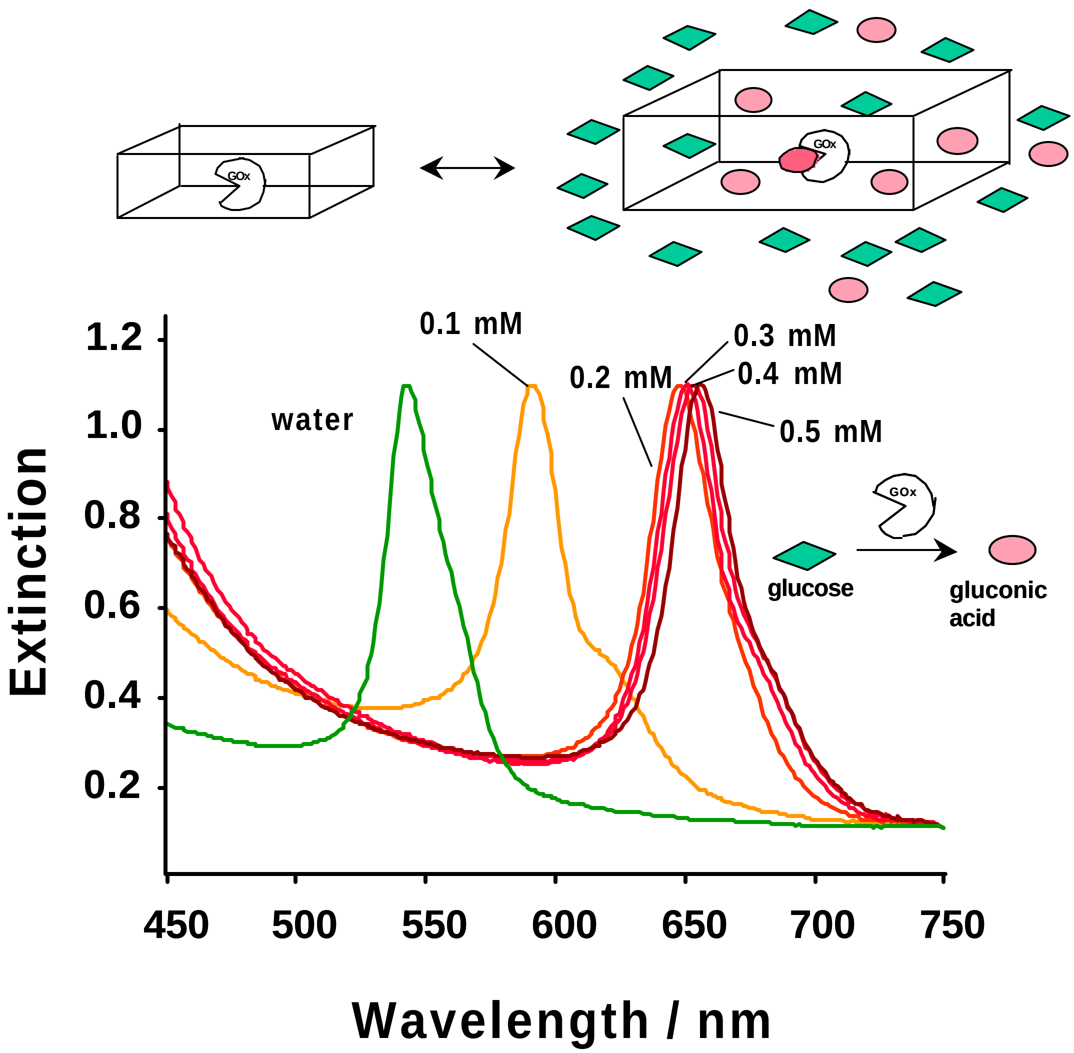
hydrolyzed gel

5-(Biotinamido)pentylamine

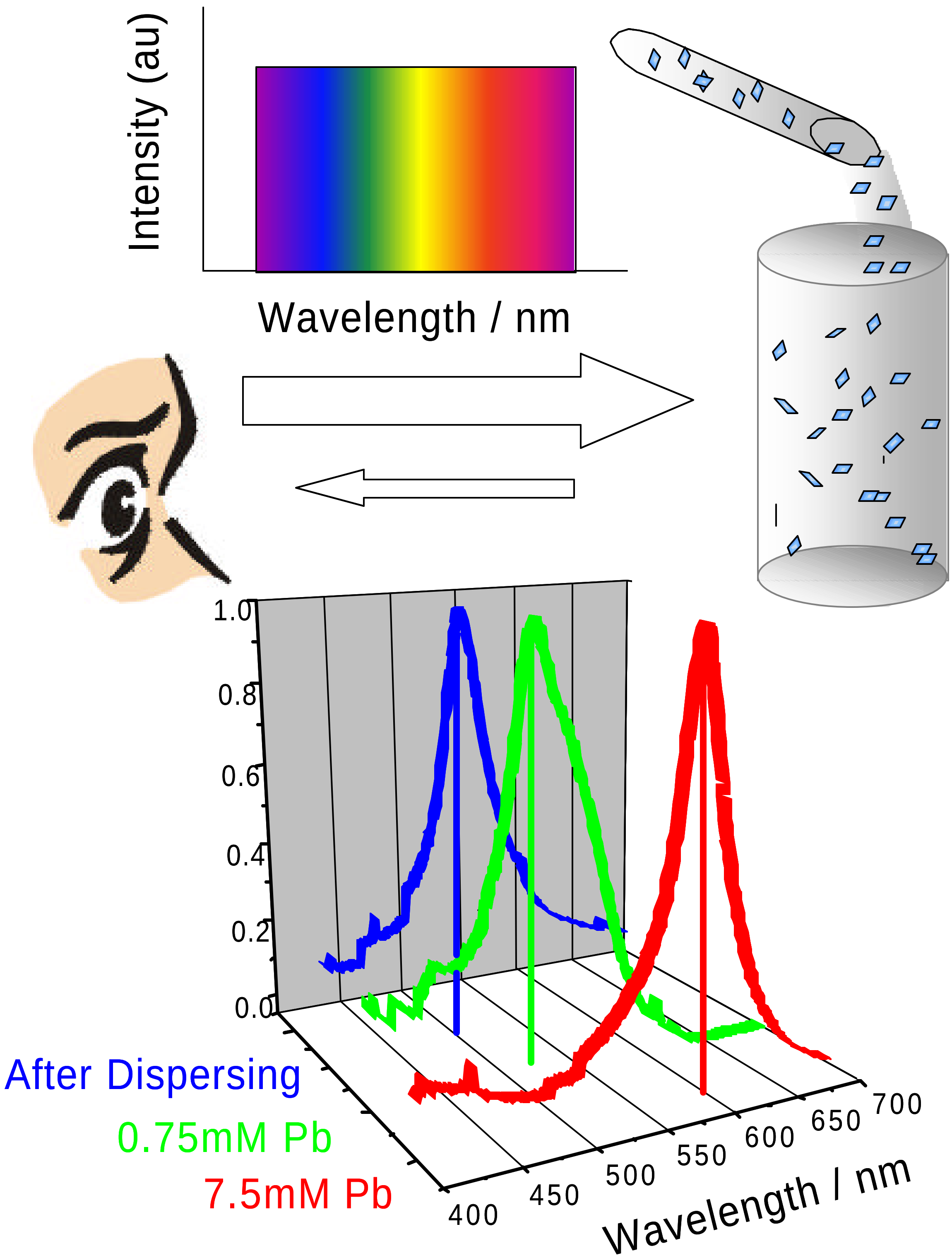


+ avidinated enzyme




GOx
GOx
0.1 mM
0.2 mM
0.3 mM
0.4 mM
0.5 mM
water
GOx
glucose
gluconic acid
Extinction
1.2
1.0
0.8
0.6
0.4
0.2
450
500
550
600
650
700
750
Wavelength / nm

Gel Particulate Colorimetric Reagent



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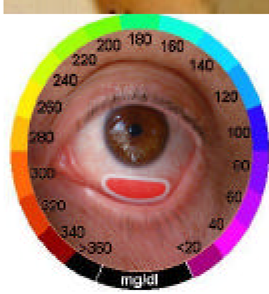
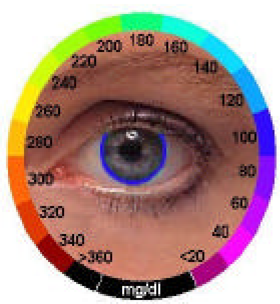
Chemical (glucose) Sensing Fantasies

Fig. 1 Concept for glucose sensing device for tear fluid and for implants. The color diffracted defines the glucose concentration.





Glucoview™
Ocular Insert

Glucoview™
Diagnostic Contact Lens

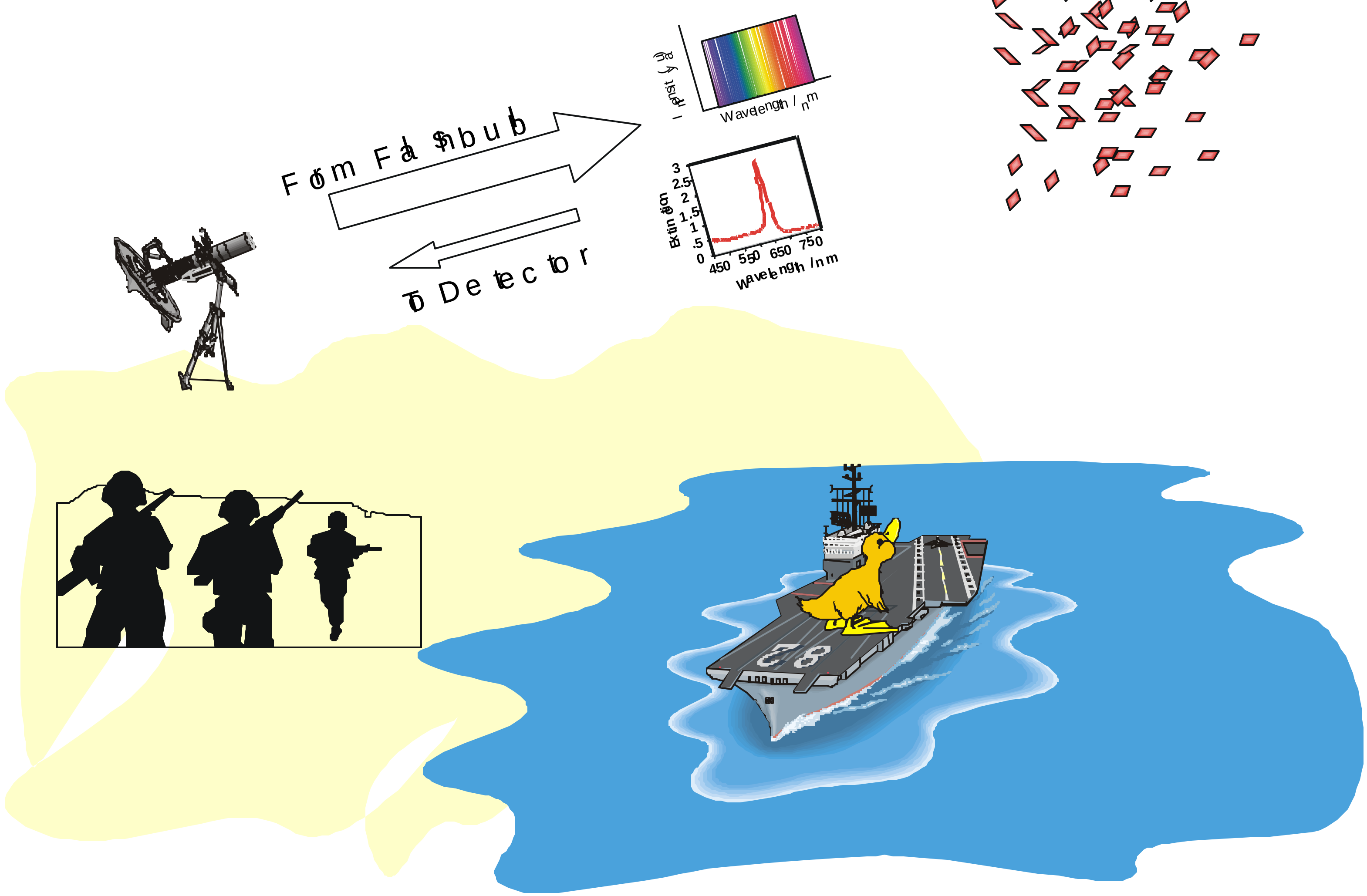
Glucoview™
Subcutaneous Insert

S. A. Asher, Department of Chemistry

PCCA Sensing Array for Glucose, pH, Recreational Pharmaceuticals and Alcohol, Stress Hormones, etc.

Subcutaneous Sensors

Remote Sensing



Collaborators:

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Professor Ajay Sood	Indian Institute of Science
Dr. Rasu Kesavamoorthy	Indira Gandhi Centre for Atomic Research
Professor Craig Wilcox	University of Pittsburgh

Graduate Students:

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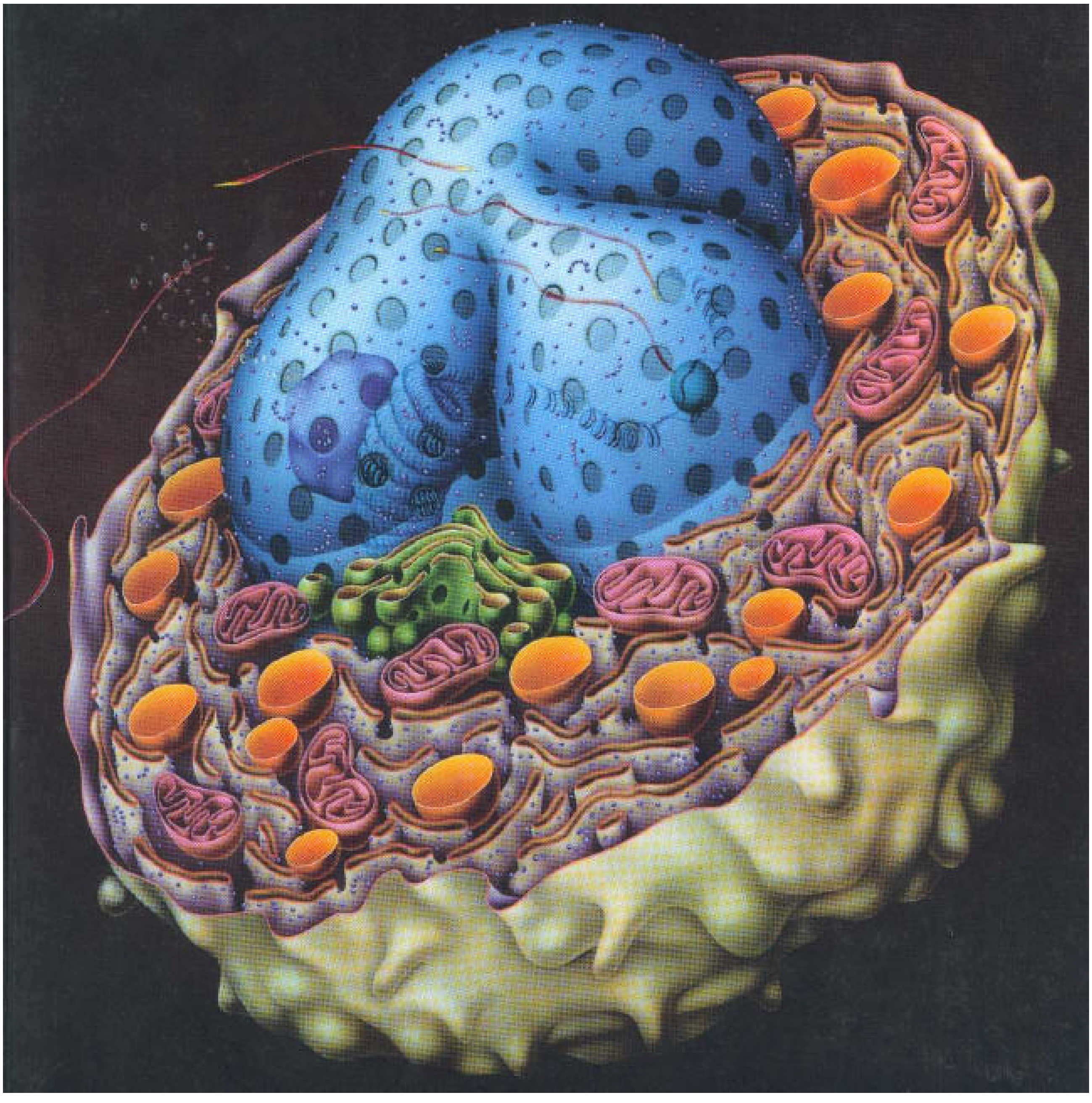
Dr. Perry Flaugh	Sun Oil
Dr. Jim Conners	Institute of Paper Chemistry
Charles Brnardic	Eli Lilly
Zhijun Wu	Monsanto
Dr. John Holtz	Katz School of Business
Guisheng Pan	Colgate Palmolive
Dr. Lei Liu	PraxAir
Jesse Weissman	UniLever
Hua Zhang	
Jonathan Keim	
Marta Kamenjicki	
Michael Baltusavich	
Chad Reese	

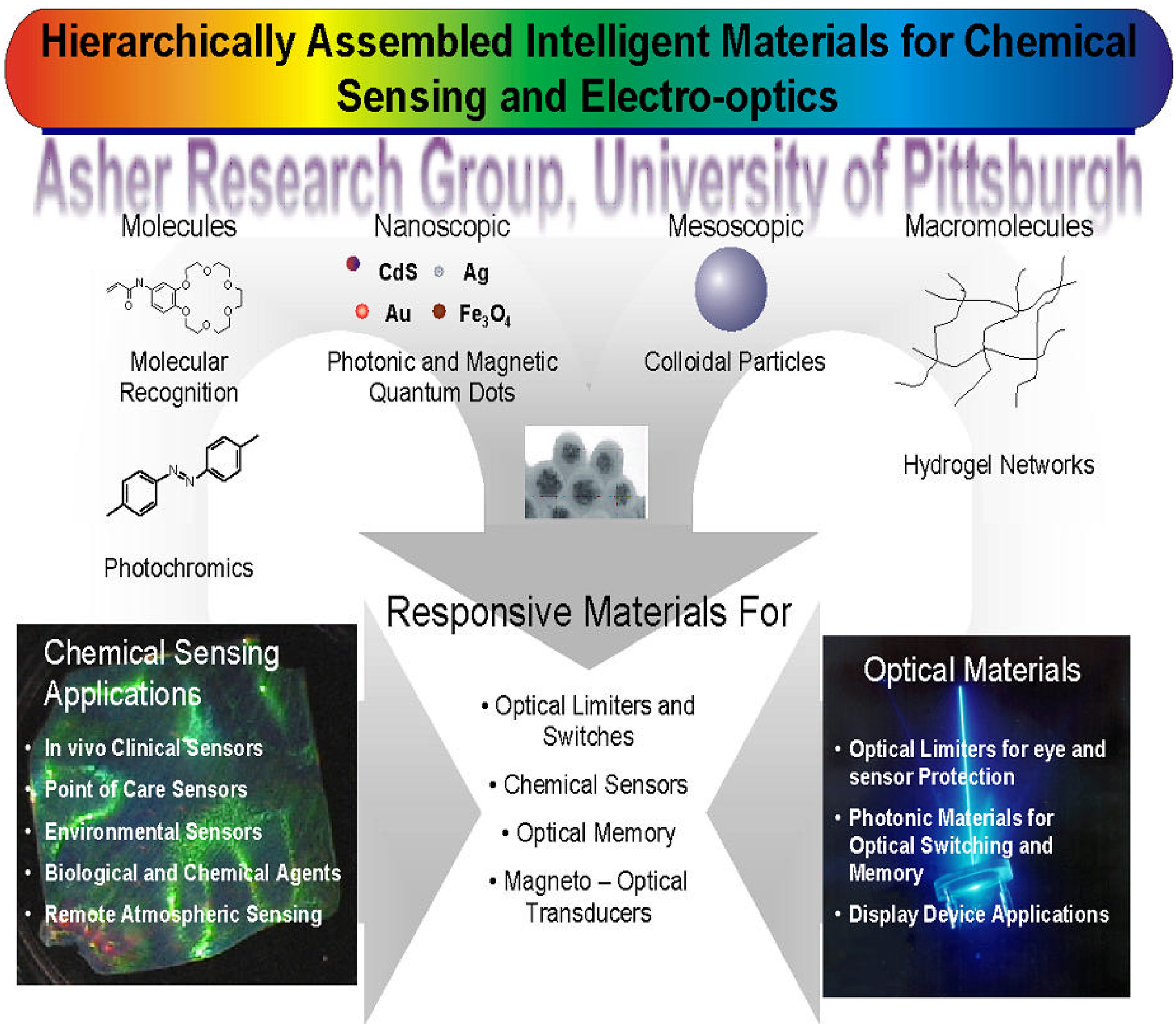
Post Docs:

Dr. Sesh Jagannathan	Eastman Kodak
Dr. Panos Photinos	S. Oregon State University
Dr. Song-Yuan Chang	EM Industries
Dr. Albert Tse	Reichhold Chemical
Dr. Hari Sunkara	DuPont
Dr. Calum Munro	PPG Industries, Inc.
Kangtaek Lee	Inje University, Korea
Wei Wang	
Igor Lednev	
Ying Wang	
Serban Peteu	
Xu Xiangling	

Funding:

ARMY	NSF
ONR	NIH
DARPA	





Hierarchically Assembled Intelligent Materials for Chemical Sensing and Electro-optics
Asher Research Group, University of Pittsburgh
Molecules
Nanoscopic
Mesoscopic
Macromolecules
CdS
Ag
Au
Fe_3O_4
Molecular Recognition
Photonic and Magnetic Quantum Dots
Colloidal Particles
Hydrogel Networks
Photochromics
Responsive Materials For
• Optical Limiters and Switches
• Chemical Sensors
• Optical Memory
• Magneto – Optical Transducers
Chemical Sensing Applications
• In vivo Clinical Sensors
• Point of Care Sensors
• Environmental Sensors
• Biological and Chemical Agents
• Remote Atmospheric Sensing
Optical Materials
• Optical Limiters for eye and sensor Protection
• Photonic Materials for Optical Switching and Memory
• Display Device Applications

Application of Nanoscience for Chemical Sensing

Science (2000) ***289***: 1757
Scanometric DNA Array Detection with Nanoparticle Probes

T.A. Taton, **C.A. Mirkin**, and R.L. Letsinger
Northwestern University, Evanston, IL

Science (2000) ***287***: 622
Nanotube Molecular Wires as Chemical Sensors

J. Kong, N.R. Franklin, C. Zhou, M.G. Chapline, S. Peng, K. Cho, **H. Dai**
Stanford University, Stanford, CA 94305

Science (1997) ***278***: 840
A Porous Silicon-Based Optical Interferometric Biosensor

V.S.-Y. Lin, K. Motesharei, K.-P.S. Dancil, **M.J. Sailor**, M.R. Ghadiri
University of California, San Diego, La Jolla, CA
The Scripps Research Institute, La Jolla, CA

Science (2001) ***291***: 443
NANOMATERIALS: Stretching the Mold

T.E. Mallouk
Pennsylvania State University, University Park, PA

J.Am. Chem. Soc. (1997) ***119***: 11306
Diffusion-Limited Size-Selective Ion Sensing Based on SAM-Supported Peptide Nanotubes (SAM – Self-assembled monolayers)

K. Motesharei and M.R. Ghadiri
The Scripps Research Institute, La Jolla, CA

. c

Nanosynthesis for Materials Development

Nanosynthesis can fill a gap in our capabilities.

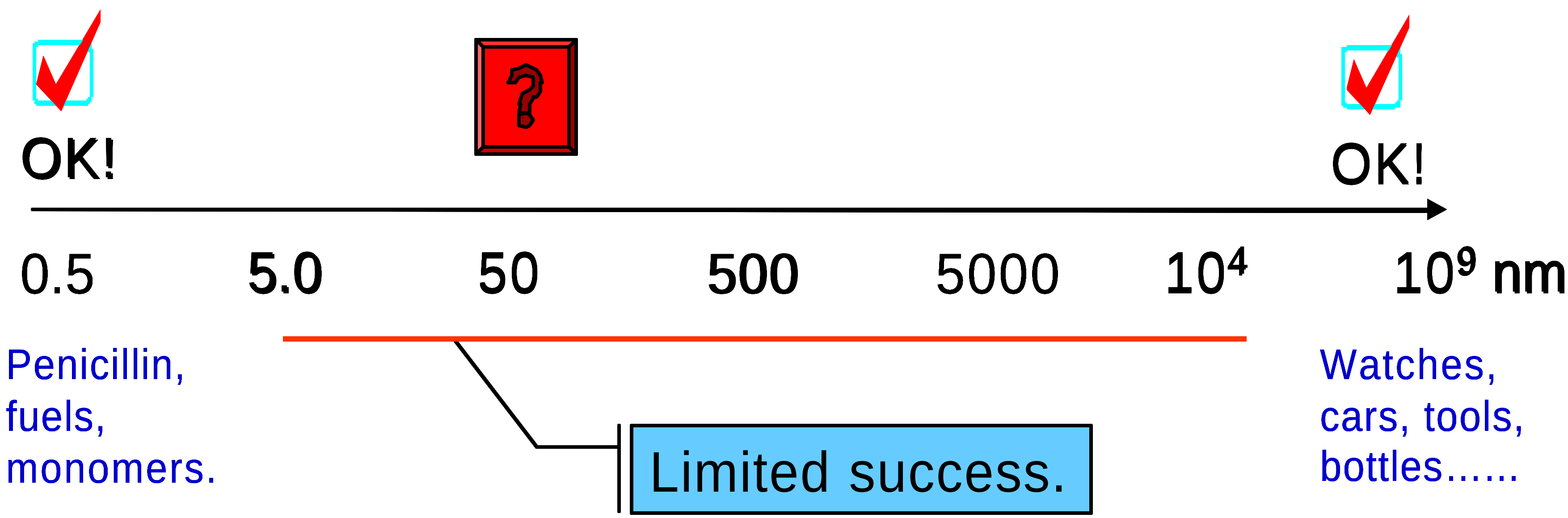
Atoms. —Chemical synthesis→ Functional molecules.

Nanofragments. —"Nano synthesis"→ Functional nanodevices.

Cast shapes and small assemblies. —Manufacturing→ Functional machines.

Nanosynthesis for Materials Development

Current status in production according to scale.



<u>The goal of this subproject is to fill in the middle.</u>

S. A. Asher, Department of Chemistry

Periodic Table of the Elements

New Designation / Original Designation

s-block (groups 1–2) · *d-block* — *Transition Metals* (groups 3–12) · *p-block* (groups 13–18) — **Non-Metals** (groups 13–17) · *s-block* (group 18)

Atomic # / Symbol / Atomic Mass

Period	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H 1.0094																	2 He 4.00260
2	3 Li 6.941	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.179
3	11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.06	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
5	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.91	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	57 to 71	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.21	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra 226.03	89 to 103	104 Unq (261)	105 Unp (262)	106 Unh (263)	107 Uns (262)	108 Uno (265)	109 Une (266)	110 Uun (267)								

Metals

(Mass Numbers in Parentheses are from the most stable of common isotopes.)

Phases
Solid
Liquid
Gas

Rare Earth Elements — *d-block* (La, Ac) · *f-block* (Ce–Lu, Th–Lr)

Lanthanide Series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
Actinide Series	89 Ac 227.03	90 Th 232.04	91 Pa 231 04	92 U 238.03	93 Np 237.05	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

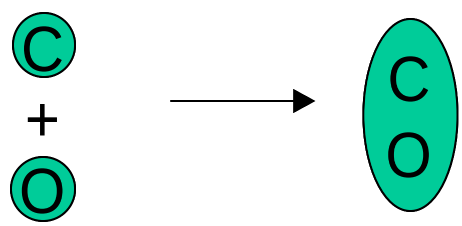
From Hyper Chemistry on the Web! http://library.thinkquest.org/2690/ptable/ptable.html

C. Wilcox, Department of Chemistry

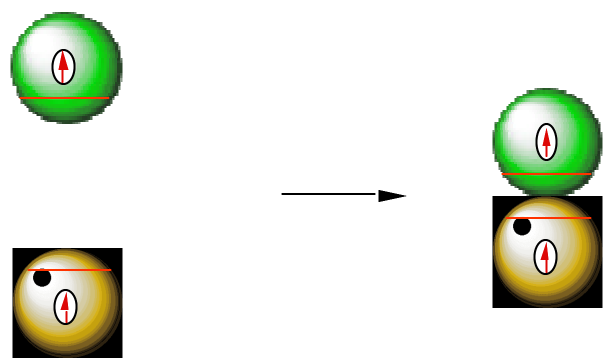
Nanotech: Process and Materials Development

The "Diatomic Molecule" of Nanosynthesis.

Chemical synthesis



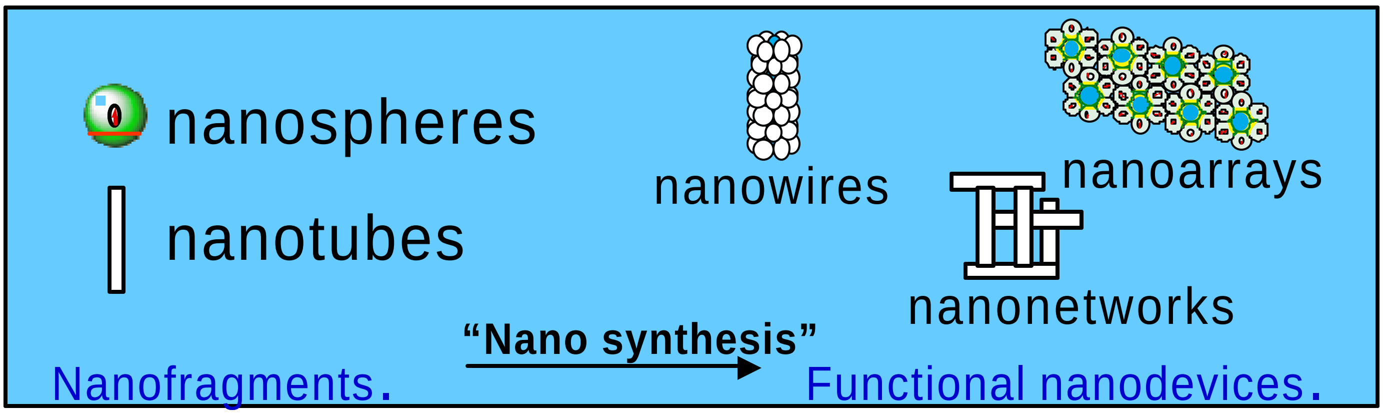
Nano synthesis



Rational control of microsphere assembly.

C. Wilcox, Department of Chemistry

Nanosynthesis for Materials Development



What do we need to succeed?

- Anisotropic building blocks. (atoms, molecules)
- Bonding strategies - nanoadhesives. (bonding)
- Techniques for handling - dispersion. (solvation)
- Separation and purification methods

Payoff: <u>Unlimited capacity to prepare mesoscale structures.</u>

S. A. Asher, Department of Chemistry

Crystalline Colloidal Self-Assembly:

MOTIF

FOR

CREATING SUBMICRON

PERIODIC SMART MATERIALS

S. A. Asher, Department of Chemistry

CRYSTALLINE COLLOIDAL ARRAYS CONTAINING MOLECULAR RECOGNITION AGENTS: CHEMICAL SENSING MATERIALS

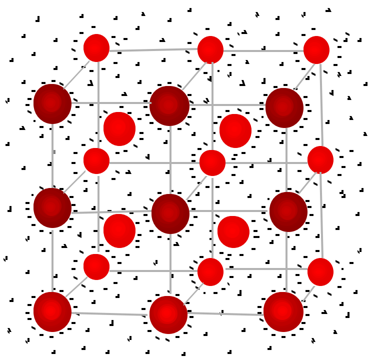
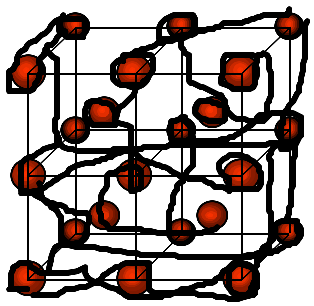
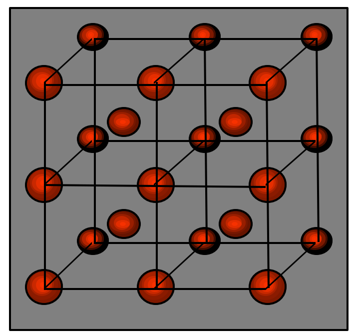
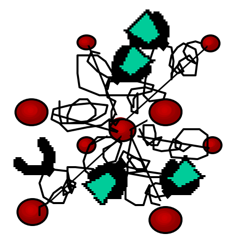
A MOTIF FOR SENSING

<u>ALL</u>, MANY, SOME, A FEW

CHEMICAL SPECIES

S. A. Asher, Department of Chemistry

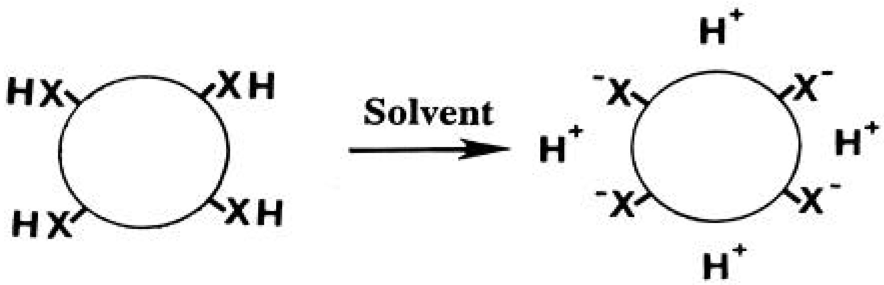
Mesoscopically Periodic Materials

CCA	PCCA	SCCA	IPCCA
			
Self-Assembling Diffracting Structure	Hydrogel Volume Phase Transition	Rigid 3-D Periodic Materials	Electronically Chemically Thermally Responsive Materials
Fragile	Robust	Rugged	Smart Materials
	Tunable Spacings		
Optical Filters	Optical Filters	Optical Filters	Agile Optical Filters
	NLO Switches	NLO Switches	Chemical Sensing
	Optical Limiters	Optical Limiters	Display Devices

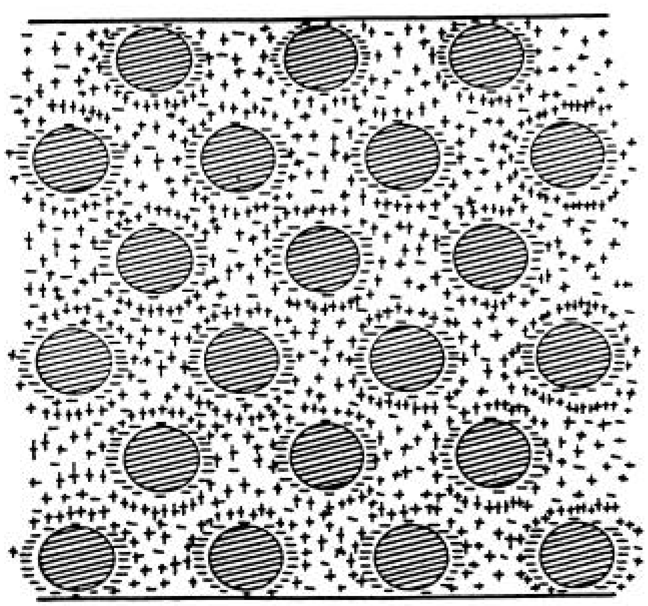
S. A. Asher, Department of Chemistry

Crystalline Colloidal Arrays

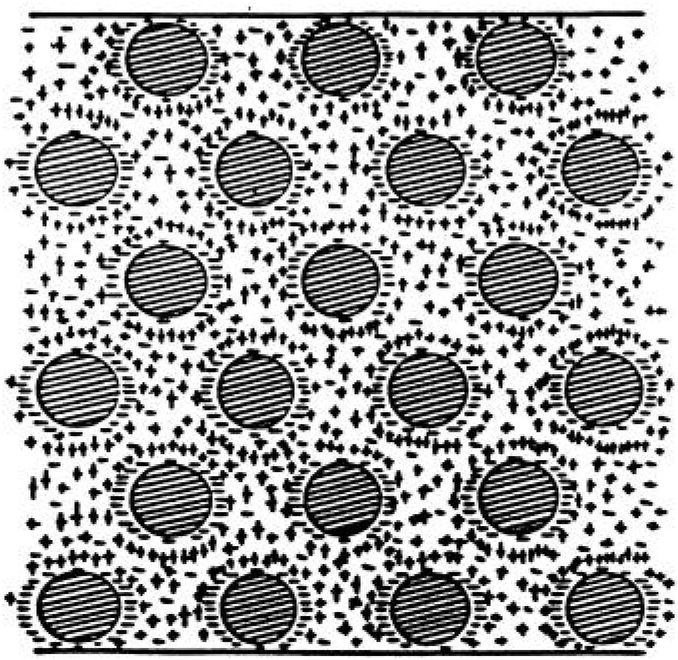
1. **Fabricated From Colloidal Particles**



2. **Particles Self Assemble Into 3-D Ordered Crystal Structure**



For 10^{13} spheres/cc < = = > Crystalline Colloidal Array



Spacings only depend upon the Particle Number Density and Crystal Structure.

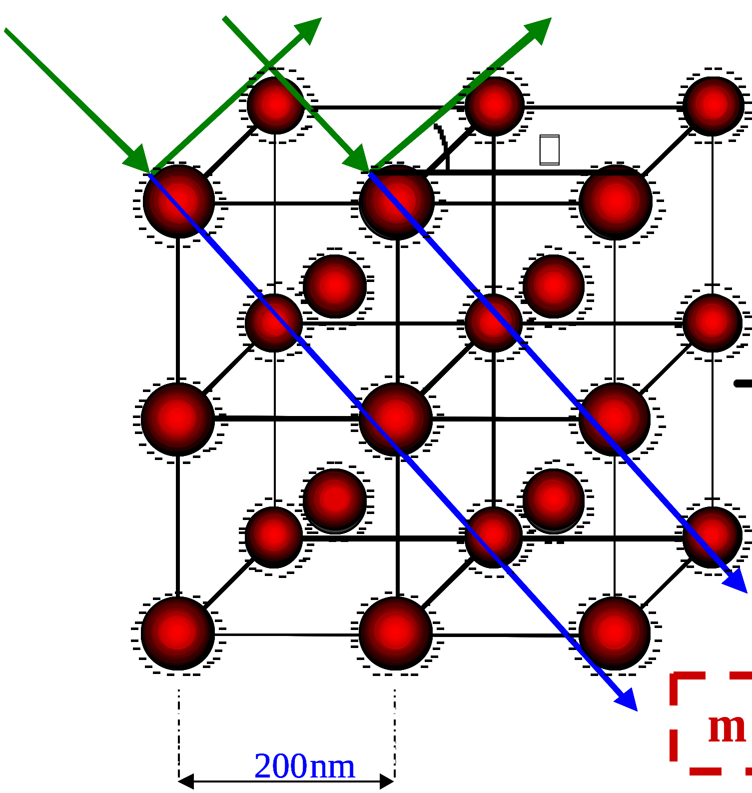
Bragg Diffraction occurs with Phenomenal Efficiency

Transmittance < 10^{-8} for 0.5 mm Thickness

- Dynamical Diffraction Limit

S.A. Asher, Department of Chemistry, University of Pittsburgh

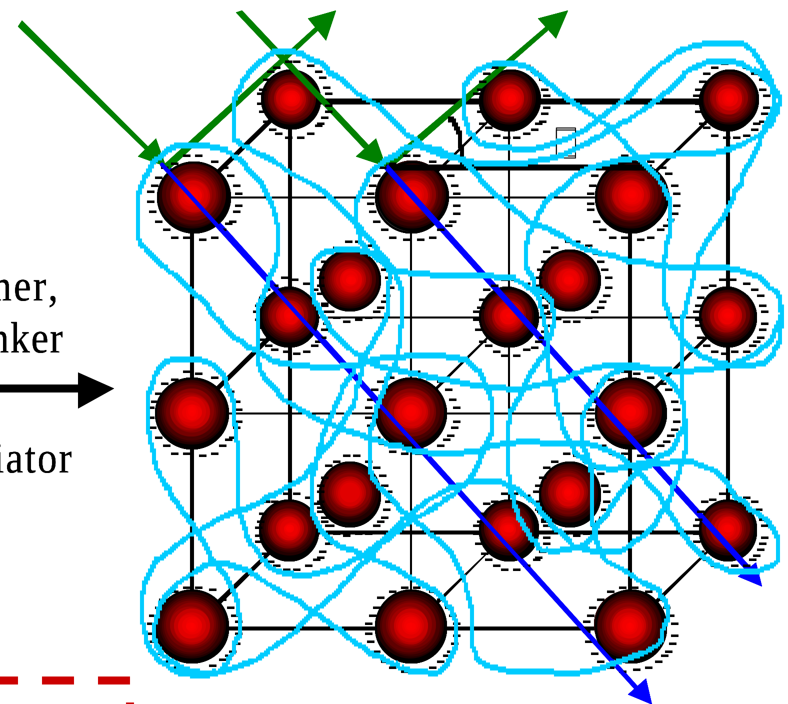
Introduction



Crystalline Colloidal Array

monomer,
crosslinker

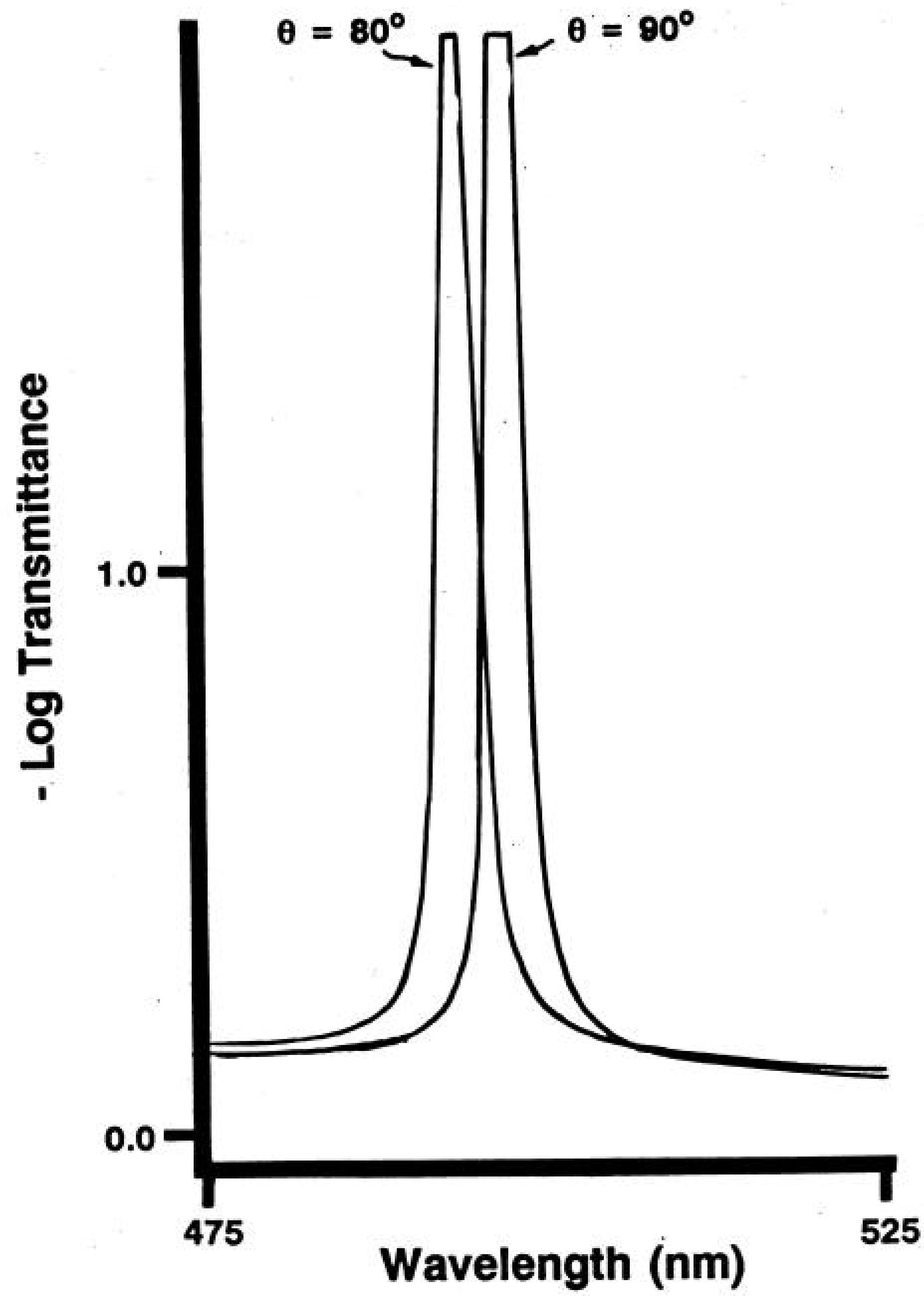
UV initiator



Polymerized
Crystalline Colloidal Array

$m\lambda_o = 2nd\sin\theta$

S. A. Asher, Department of Chemistry



Workshop on Nanoscience for the Soldier

SECTION IV

Working Group Results

(9 February)

- Materials and Fabrics
- Power, Energy Distribution, and Cooling
- Soldier Status Monitoring and Modeling
- Displays, Detectors & Antennas

Materials Group Worksheets

Area 1. High Strength, Ultra-lightweight Materials

Objective: 5-to-10 fold weight (or related size/thickness) reduction with same or better performance (including innovative design paradigms enabled by materials performance).

Research Requirements:

Need-driven research -

- Ballistic and multi-threat (fragments, flechettes, blast, thermobaric, fire/flame resistance, directed energy/laser, EM shielding, chem./bio, cut, puncture, tear, etc.) protection.
- Load carriage, shelters, packaging, etc. (significantly enhanced mobility, and sustainment).
- Small arms weapons and munitions (significantly enhanced lethality).

Opportunity-driven research -

- Nanoscale building blocks: carbon nanotubes, other nanotube compositions (e.g., SiC), nanoparticles, nanofibers, alternative nano-level geometries, architectures (1D/2D/3D), and networks (2D/3D), nano-surface functionalization, etc.
- Directed assembly of nano-structures: self assembly, patterning (nanoscale and higher), physical and biological templating, multi-scale hierarchical ordering, etc.
- Predictive modeling across multiple length and time scales
  - Develop fundamental theory for modeling and design
  - Relating nanoscale properties/architectures to macroscale performance
- Synthesis and Processing
  - Nanocomposites materials (dispersion, thermodynamics/kinetics, nano-filler/matrix interactions and control)
  - Organic/inorganic hybrid materials
  - Biomimetic materials
  - Protein engineering/functional genomics/bio-derived materials
  - Nanoscale alloying
- Surface and interface science: design, control, functionalization, adhesion, biocompatibilization, etc.
- Characterization: nanoscale composition and structure, heterogeneities, surfaces and interfaces (non-vacuum methods), metrology (measurement of physical properties and phenomena at the nanoscale), high throughput screening techniques, etc.
- Nanoscale dynamics and interactions: mechanics/mechanical response, nanoscale physics, phase equilibria, high strain rate behavior of nanoscale structures, etc.
- Scale-up and manufacturing science: nanofabrication techniques and non-conventional manufacturing techniques (e.g., direct writing of nanostructures, AFM approach, dip-tank processing, etc.)
- Nanoenergetic materials

Critical proof-of-concept demonstrations -

- Ballistic protection
  - Laboratory scale demonstration of tensile/compressive strengths 5-to-10 fold improvement over existing materials.
  - Demonstrate 5-to-10 fold reduction in weight for protection against current and emerging threats in ballistic tests.
  - Demonstrate scale-up capability and feasibility for large-scale fabrication.
- Multi-threat protection (fragments, flechettes, blast, thermobaric, fire/flame, directed energy/laser, EM shielding, chem./bio, puncture, cut, tear, etc.)
  - 5-to-10 fold reduction in weight/volume of protective systems such as uniform, rescue blanket, glove, boot, etc.
  - Multi-functionality of protective system contributing to 5-to-10 fold weight/volume reduction.
- Load Carriage, Shelters, Packaging, etc.
  - Demonstrate 5-to-10 fold enhancement of material properties (strength, stiffness, fracture resistance, durability) using nanoscale structures as opposed to micron-scale or higher structures.
  - Demonstrate 5-to10 fold enhancement of fiber properties (strength, elasticity, processing, durability) over current state-of-the-art fibers.
- Small Arms Weapon Systems and Munitions
  - Greater than 50% reduction in weight for weapon/ammo with no degradation in performance of weapon system.
  - 5-to-10 fold reduction in weapon system volume with no degradation in performance of weapon system.
  - 5-fold enhancement of propellant/explosive energy.
  - Enabling design for revolutionary weapon technology.

Area 2. Adaptive, Multi-Functional Materials

Objective: Revolutionary, new materials and systems-of-materials doing tomorrow what materials/materials systems cannot do today.

Research Requirements:

Need-driven research -

- Signature management
  - Make soldier invisible across the EM spectrum (passive)
  - Adaptive camouflage (chameleon)
- Interactive textile/clothing
  - Power/data distribution/sensing network
  - Active fibers/textiles (shape memory/adaptive/responsive)
  - Insulation/cooling (passive)

- Barrier/selectively permeable materials
- Chem/bio detection/protection/decon
- Self cleaning clothing
- EM/RF shielding

- Directed energy/laser eye protection
- Energy conversion/harvesting/storage materials
- Flexible and robust devices and component packaging/containment
- Individual waste disposal/water recovery and recycling
- Medical and Biocompatible Materials
- ***Opportunity-driven research –***
- Nanoscale building blocks: carbon nanotubes, other nanotube compositions (e.g., SiC), nanoparticles, nanofibers, alternative nano-level geometries, architectures (1D/2D/3D), and networks (2D/3D), nano-surface functionalization, etc.
- Directed assembly of nano-structures: self assembly, patterning (nanoscale and higher), physical and biological templating, multi-scale hierarchical ordering, etc.
- Predictive modeling across multiple length and time scales
    - Develop fundamental theory for modeling and design
    - Relating nanoscale properties/architectures to macroscale performance
- Synthesis and Processing
    - Nanocomposites materials (dispersion, thermodynamics/kinetics, nano-filler/matrix interactions and control)
    - Organic/inorganic hybrid materials
    - Biomimetic materials
    - Protein engineering/functional genomics/bio-derived materials
    - Nanoscale alloying
- Surface and interface science: design, control, functionalization, adhesion, biocompatibilization, etc.
- Characterization: nanoscale composition and structure, heterogeneities, surfaces and interfaces (non-vacuum methods), metrology (measurement of physical properties and phenomena at the nanoscale), high throughput screening techniques, etc.
- Nanoscale dynamics and interactions: mechanics/mechanical response, nanoscale physics, phase equilibria, etc.
- Scale-up and manufacturing science: nanofabrication techniques and non-conventional manufacturing techniques (e.g., direct writing of nanostructures, AFM approach, dip-tank processing, etc.)
- Multifunctional packaging
- Molecular Recognition/Sensor Materials
- Catalysis (activity at ambient conditions, biocatalysis, etc.)
- High surface area electronic applications (electrodes, capacitance, dielectrics, insulators)

- Nanoelectrodes (e.g., physiological probes, supercapacitors)
- Highly anisotropic materials (anisotropic functionality)
- Responsive materials: environmental monitoring, applied stimulus, photo-chromic, electro-chromic, light absorption/emission/reflection, active filtration, shape memory, magneto- and electro-rheological materials.
- Living/self-repairing materials/regenerative materials
- Integration of nanoscale systems to NEMS/MEMS
- Nanoscale switching
- Nanofluidics (e.g., lubricants and sealants)
- Magnetic nanomaterials: storage and sensing
- Nanostructured coatings (superhard, corrosion resistant, biologically inert, bio-degradable, chem./bio barrier, high temperature, self-lubricating, multi-functional, optical, etc.)

Critical proof-of-concept demonstrations -

- Make soldier invisible across the EM spectrum
  - Match thermal/IR/visible/EMI signature to environment sufficiently to avoid detection by current and emerging detection devices
  - Create material with control of absorption reflection and emission across the broad EM spectrum
- Adaptive camouflage
  - Demonstrate ability to control absorption, reflection and emission of EM radiation across a broad spectrum in real time
- Interactive textiles/clothing
  - Demonstrate functionalities including power/data distribution, barrier, selective permeability, variable insulation properties, sensing, CBW protection, EM shielding and/or self-cleaning in a textile that meets all existing functional requirements for textile materials.
  - Demonstrate real-time active control of the properties in (a).
- Directed Energy Protection
  - Self-actuating materials that absorb/redirect energy impinging on warrior.
- Energy conversion/harvesting/storage
  - Demonstrate the ability of any part of the material system to generate and/or store power while performing the other functions required of the specific component into which it has been integrated
- Flexible robust device components
  - Thin, flexible optical and electronic sensing devices
  - Display materials technology that is flexible, durable and lightweight
  - Flexible/durable thermoelectric materials
  - Flexible/durable fuel-cell structures
- Individual waste disposal/handling/recycling

    - Harvest/extract moisture from all potential sources in the warrior micro-environment
- Bio-medical materials
    - Self-contained functionality to induce blood-clotting and administer other therapeutic agents to the body when required.

Power and Cooling

The power and cooling working group organized their plan around three main areas. The areas were:

- Development of revolutionary primary power sources with specific power density greater than 1 kW/kg and stored energy of 1 kWh/kg to enable the soldier the soldier to operate autonomously for >144 hours.
- Development of leap-ahead conformal alternative power sources to provide supplemental (modular), back up (emergency) and self-sustainable (get more when needed) power.
- Development revolutionary warrior body cooling devices that provide > 150 W of cooling for <30 W of input power to significantly reduce the thermal stress of the warrior and enable sustained performance under environmental conditions which would incapacitate unprotected soldiers.

There are a number of present or envisioned technologies which might provide solutions, or partial solutions, in each of the above areas. Therefore, the group generated sub-areas within the major areas and discussed each sub-area in terms of an objective statement, including some form of metric and an indication of the expected enabling result of successful needs-driven nano-science research in the sub-area. The team also identified opportunity driven nano-science research thrusts and example proof-of-concept demonstrations for each sub-area.

Several general themes seemed to apply to all areas:

- Nanostructured materials could lead to flexible conformal systems which would be more comfortable and less likely to cause injury than the current rigid packages with relatively sharp corners.
- Nanostructured materials could be stronger and therefore allow for lower weight systems to lessen the Soldier's burden.

The area and sub-area research is described below.

Power and Cooling

<u>Area 1:</u> Develop revolutionary primary power sources with specific power density greater than 1 kW/kg and stored energy of 1 kWh/kg to enable the soldier the soldier to operate autonomously for >144 hours.

Sub-area 1.1, Fuel Cells (includes hydrogen/air, direct oxidation of methanol, and solid oxide fuel cells)

<u>Objective 1.1</u>

- Develop fuel processors to generate hydrogen from safe easily transported fuels

<u>Research Requirements:</u>

<u>Need-driven research 1.1</u>

- Develop sulfur tolerant fuel processing catalysts to allow logistic fuels to be used
- Develop microchemical concepts to enable soldier transportable fuel processor systems based on safe fuels
- Develop novel fluid handling elements to reduce ancillary weight below 0.5 kg/kW

Opportunity-driven research 1.1

- Quantum mechanical modeling to help design or identify catalysts with desirable properties
- Combinatorial methods to allow discovery of CO and sulfur tolerant nanophase catalysts for fuel cells and fuel converter.
- Novel sonochemical methods to create nanostructured catalysts with improved sulfur tolerance
- Develop nanostructured wicking structures as pumps without motors
- Use nanostructured surfaces to allow flexible heat exchangers and thermo-capillary heat sinks with performance at least equal to current rigid systems
- Develop nano-architectured electrochemical interfaces to increase power

Critical proof of concepts 1.1

- Hydrogen source to support 20 watt fuel cell from butane in a portable device weighing less than 100 gms
- Hydrogen source to support 20 watt fuel cell from JP8 in a portable device weighting less than 200 gms
- High temperature aerogel insulation achiving R-factor greater than 5 at 800 C
- Nanostructured electrodes achieving 10 amp/cm^2
- Pump producing 2 l/min of air consuming less that 0.01 watt weighing less than 5 gms

Sub-area 1.2, Batteries

Objective 1.2

- Use nanostructured electrodes to push available power above 1kW/kg and energy above 1 kWh/kg and while maintaining current degree of safety
- Use nanostructured/solid electrolytes to produce safer batteries for critical applications.
- Develop diagnostics to monitor state of charge, cycle life.

Research Requirements:

Need-driven research: 1.2

- Develop high conductivity nanocomposite electrolyte for solid-state battery
- Nanostructured electrodes to push available power above 1 kW/kg and energy above 1 kWh/kg

Opportunity-driven research: 1.2

- Modelling of ion transport for better design
- Sensors for internal chemistry of battery to monitor charge and lifetime
- Use nanostructured interfaces to enable flexible microdevices to replace macrodevices and push useful power above 1 kW/kg
- Develop nano-architectured electrochemical interfaces to increase power

Critical proof of concepts: 1.2

- Batteries with 1 kWh/kg that operate over military temperature range

Sub-area 1.3.1: Microturbines

Objective 1.3.1:

- Design and Fabricate Meso-scale Electrical Power Conversion circuits that operate from MHz to DC for soldier applications

Research Requirements:

Need-driven research: 1.3.1

- Reduce size of power converter components from 5 cm to 5 mm dimensions using novel nano-scale materials with MEMS-like fabrication

Opportunity-driven research: 1.3.1

- Use of nano-scale self-assembly to achieve nano-composite materials with 10 to 100 times higher magnetic permeability for reduced size inductor components
- Novel circuit design using hybrid analog and digital integrated circuits based on new approaches to sensor electronics

Critical proof of concepts: 1.3.1

- Demonstrate new power conversion circuits with 30-50 times smaller size than present discrete components at power levels of at least 3 watts

Sub-area 1.3.2: Microturbines

Objective 1.3.2:

- Prevent oxidative degradation of materials which can be microfabricated to the mechanical tolerances required for microturbine power sources

Research Requirements:

Need-driven research: 1.3.2

- Develop surface treatments to protect silicon from oxidation at high temperatures

Opportunity-driven research: 1.3.2

- Develop microfabrication techniques for materials like Al2O3

Critical proof of concepts: 1.3.2

- Develop high-aspect ratio etching techniques for high temperature materials such as Al2O3 with surface control to 200 nanometers

Sub-area 1.3.3: Microturbines

Objective 1.3.3:

- Achieve wafer bonding with dissimilar materials for microturbine applications.

Research Requirements:

Need-driven research: 1.3.3

- Control thermal stresses
- Reduce interfacial roughness

Opportunity-driven research: 1.3.3

- Make use of atomic-scale simulations using supercomputer methods
- Develop new approaches to chemical/mechanical polishing using multi-probe atomic microscopes (STM's)

Critical proof of concepts: 1.3.3

- Demonstrate Wafer-bonded Si-SiC interfaces that are stable to temperatures in the range 1000 – 1100 deg C
- Demonstrate smoothness of both Si and SiC surfaces of micro-machined turbine components with rms roughness less than 0.05 nm over 5 μmeter length scales

Power and Cooling

Area 2: Supplemental/Backup Power Systems which rely on nano-science for efficient, unobtrusive electrical power

Objective 2.1:

Develop leap-ahead conformal alternative power sources to provide supplemental (modular), back up (emergency) and self-sustainable (get more when needed) power.

Research Requirements:

Need-driven research: 2.1

- Devices that are lightweight, conformal and multipurpose (serve as load-bearing materials as well as power genrating devices). This will significantly cut down on the total weight the soldier carries.
- Improve efficiencies to provide adequate and reliable power as needed.
- Devices that are 'rugged', survive under all environmental conditions.
- Low signature; minimal visual (camoflauge), noise, and thermal signature.
- Devices that can be "tailored" to suit a specific power requirement (voltage, current) for a particular electronic device in a modular (distributed) architecture.

Opportunity-driven research: 2.1

- Nano-based technolgies offers unsurpassed opportunities to overcome current "hurdles" in development of nano-based photovoltaics and thermophotovoltaics. It is anticipated that nanomaterials will provide a minimum of doubling of the energy conversion efficienciesof current state-of-the-art devices (to >10 % efficiency)

- Nanotechnology approaches to new materials such as greatly improved piezoelectrics which would enable energy harvesting from sources such as heel strike
- Nanotechnolgy to tune band gap for electronic, photonic and phononic absorption and energy transduction.
- Theoretical modeling to predict, design and optimize light harvesting materials energy transduction and nanoengineering.
- Nanofabrication to make conformal and integratable devices. Techniques include nanoinjection molding, nanocomposites, reel to reel processing and molecular assembly.

Critical proof-of-concept demonstrations: 2.1

- Photovoltaics – Current state-of-the-art for all solid-state organic nano-based solar cells have efficiencies of 7% on rigid substrates. Proof-of-concept would include efficiencies of >10% on flexible, conformable substrates such as plastics and textiles.
- Thermoelectric – Current state of the-art devices have a ZT of <1. Proof-of-concept would use nanostructures to engineer electron and phonon transport to reach ZT>3, at room temperature.

Power and Cooling

Area 3: Body Cooling to enhance warrior performance and endurance

Objective 3.1:

- Develop revolutionary cooling devices that provide > 150 W of cooling for <30 W of input power to significantly reduce the thermal stress of the warrior.
- Reduce cooling burden for Soldier to < 2 kg and overall size < 1 liter.

Research Requirements:

Need-driven research 3.1:

Vapor compression based coolers:

- Reduce surface roughness of moving parts to nanometer scale (valves, bore/cavities, etc) to reduce friction and leakage
- High efficiency electrostatic compressor: membrane with dielectric strength >1000 V/micron at deposited thickness < 500 nm and high dielectric constant.

Thermoelectrics:

- Develop ZT>5 for macroscopic cooling using nanoscale arrays.

Evaporative:

- Develop arrays of micro air pumps capable of output flow rates >400 l/min @ 8 cm water guage pressure with a weight of < 100 g and power consumption < 7 W.

Opportunity-driven Research:

- Use nanotechnology to develop thin film lightweight heat exchangers.
- Develop small and robust thermo-accoustic refrigerators
- Develop soft thermoelectric devices and materials for cooling the skin.
- Invent new thermoelectric material with ZT>1 and half the weight of Bi2Te3

Critical proof of concept

- Test membranes with deposited materials for >1000 V/micron, 12 mm diamater < 500 nm thick
- Material with ZT>5 thermoelectric measure

SOLDIER STATUS MONITORING

The Soldier Status Monitoring Operation pursued the concept of the INVINCIBLE SOLDIER. Facilitating technologies would include capabilities to:

- Monitor soldier status
- Enhance soldier performance
- Predict soldier performance
- Minimize soldier casualty

These capabilities in turn suggest five areas for research and development in the general field of soldier status monitoring. These areas are operational capability, casualty monitoring, casualty care, NBC detection and modeling methodologies.

Originally, the group suggested ten different objectives. It might make sense to group these into a large cluster of objectives that deals with biologically oriented projects involving direct interaction inside the soldier's body, and a series of less invasive objectives. The less invasive objectives would include those labeled one to five and eight in the document to follow. Areas six, and seven comprise the invasive procedures.

The different target objectives have different time scales. These are as follows:

Objective Title Timescale

1. Critical Laboratory and Pharmacy on the Soldier Long term to visionary
2. Soldier Status Direct Monitoring Near term to long term
3. Local Area Monitoring Near term to long term
4. Soldier Performance Prediction and Virtual Near term to long term

   Prototyping
5. Active Water Reclamation Long term to visionary
6. Enhanced Biological Interaction with the Soldier Long term to visionary
7. Internal Data, Chemical, Communications and Visionary

   Signal Processing (artificial systems within the soldier)
8. Integrated Bioenergy Devices For Driving Sensors Long term to visionary

Objective 1: Clinical Laboratory and Pharmacy on the Soldier - Real Time Assessment and Intervention

Areas: Operational capability, NBC detection, casualty monitoring

General Idea: Soldier performance and status are related to a number of definable and measurable benchmarks. Additionally, external systems such as clothing and cooling can directly enhance operational capability.

RESEARCH REQUIREMENTS:

Need-Driven Research:

Automatic monitoring and response to predetermined criteria (developing a set of standards for intervention)

Blood pressure stabilization

Advanced, dynamically reconfigurable, sensitive, robust sensors

Controlled release of pharmacological agents

Opportunity-Driven Research:

Develop clothing to stop bleeding, by artificial skin formation, compression/ constriction

Build pharmacy platform for release, with figures of merit

Critical Proof of Concept Demonstrations:

Assessing trauma in real time

Response to trauma in real time - blood pressure stabilization, skin patch formation, pharma dosing

Objective 2: Soldier Status Direct Monitoring: Biochemical, Physiological, Sensory and Psychological; Status Security

Areas: Operational capability, casualty monitoring, modeling

General Idea: Permit quantifying and measurement of markers for health, psychological and physiological well-being, sensory capabilities and operational functionality of the individual soldier. Also communicate with command after mortality.

RESEARCH REQUIREMENTS:

Need-Driven Research:

System must be modular, compatible, open and dynamical architecture

Exact requirements for what must be measured and the accuracy with which the measurements are needed must be established

Components must be biocompatible

Ideally, the general chemical and biochemical framework should be established to permit development of new sensors for any given target within a two month period. Optical or electrical nano response seem obvious ways to do this.

Allow command to know if individual soldier has died

Opportunity-Driven Research:

Dynamic molecular recognition with signal transduction based both on implantable and surface technologies

Tissues to do artificial sensing (amplification of signals, entrained biosensors)

Develop novel molecules/new molecular categories/macromolecular recognition elements

Develop new sensors, on the two-month timescale for physical, biological and chemical markers

Integrate sensing with efficient automated secure communications with command

Critical Proof of Concept Demonstrations:

Demonstration of a wide array of simultaneous sensing capability, without interference

Match performance targets for signal/noise

Demonstrate that a single unified platform can be used for various analytes at the same time - for example, biotoxins and neuro transmitter levels

Demonstration of sensing within living systems

Objective 3: Local Area Monitoring

Areas: NBC detection

General Idea: To permit the soldier to be aware of any NBC factors within his perimeter, in real time and with appropriate sensitivity

RESEARCH REQUIREMENTS:

Need-Driven Research:

Develop extremely sensitive and selective nanoscale sensors for all important N, B, C markers

Determine which factors need to be detected, and what sensitivities are required

Plume mapping for predictive capability and motion guiding in opportunity given research

Develop generic sensors that can be optimized to recognize threats that are not predicted

Single molecule detection

Chemical cascade detection

Sensors for acoustic or other types of weapons - non-molecular threats, including electromagnetics

Integrating sensing/modeling for prediction of threats – real time modeling

Critical Proof of Concept Demonstrations:

Detection at appropriate levels, in realtime atmospheric conditions

Detection in presence of interfering substances and NBC signals

Object 4: Soldier Performance Prediction and Virtual Prototyping

Areas: Operational capability, casualty monitoring and modeling

General Idea: Integrate specific data to evaluate overall capability and predict performance.

RESEARCH REQUIREMENTS:

Need-Driven Research:

Establish minimal and maxima for performance - quantitative criteria

Collect and integrate data based on a wide-array of nanosensor structures

Integrate modeling capabilities to predict performance of individual soldiers

Opportunity-Driven Research:

Multi-parametric prediction algorithms, with realtime capability

Biomimetic data analysis, in computational and predictive algorithms

Critical Proof of Concept Demonstrations:

Performance based on animal modeling comparison with measurement

Implant nanosensors in animal testing

Demonstrate monitoring of critical status in living organisms, by nanosensor measurements and integrated data analysis

Objective 5: Active Water Reclamation - "Dune still suit"

Areas: Operational capability, casualty care

General Idea: Recycle water from biological body wastes, to provide recyclable water source.

RESEARCH REQUIREMENTS:

Need-Driven Research:

- Reduce necessity for soldier to carry water
- Develop purification schemes of high efficiency
- Develop delivery system for collection and storage of water
- Balance electrolytes and hydration for individual soldiers

Opportunity-Driven Research:

- Increase the amount of water reclaimed
- High throughput nano-filtration
- Quantitative estimates of amounts of water that can be reclaimed from various sources (sweat, exhalation, urine)

Critical Proof of Concept Demonstrations:

- Demonstrate lack of dehydration in living organism with highly reduced added water

Objective 6: Total Sensory and Mechanical Enhancement (Biological)

Areas: Operational capability and modeling

General Idea: Utilize electrical, physical and electromagnetic, as well as biological, structures to enhance the native senses of the individual soldier

RESEARCH REQUIREMENTS:

Need-Driven Research:

- Widen observed visible and audible spectra
- Dramatically increase sensitivity of senses within the individual soldier; provide maximum capabilities for information process and utilization
- Dramatically increase physical capability
- Advance spectral filtering methods (visual, auditory)

Opportunity-Driven Research:

Neuro functional implants

Spectral mapping (materials, frequency)

Integrated enhanced tissue, muscle, bones, tendons

Critical Proof of Conduct Demonstration:

Soft contact lense that does realtime spectral mapping

Enhance muscle performance over current human capabilities

Dynamical auditory balancing structure, to permit optimal hearing sensitivity over multi decibel range

Objective 7: Internal Data, Chemical, Communications and Signal Processing (artificial systems within the soldier)

Areas: Operational capability, NBC detection, casualty care, casualty monitoring and modeling

General Idea: This is a high risk, visionary program to develop internal measuring, monitoring, data processing and communications capabilities. It should all be integrated with the command structure, and function without requiring attention from the individual soldier.

RESEARCH REQUIREMENTS:

Need-Driven Research:

Single transduction reception with the soldier and back to command

All components (implanted and native) must communicate, be transduced and link to command center

Develop pin-size, biocompatable nano computers that can transduce data from sensors, process and communicate with command

Onboard integration and control of sensing elements, without external manipulation

Biological input/output structures

Determine where placement of automatic monitoring/response structures within the body should be

Opportunity-Driven Research:

Molecular computing and communication - robust and effective data processing and communication using natural energy sources

Communication within the body and to external command and control

Computer assembly and/or implantation within the body

Institute biopolymer growth

Institute chemical delivery as required

Artificial therapeutic issues

Critical Proof of Concept Demonstrations:

Demonstrate patching of wounds/regeneration of tissues within accelerated timescales or hours or minutes

Demonstrate in-situ chemical delivery without external sources - integrate sensing and dosage

Demonstrate implanted miniature computers that can process signals, receive signals and transmit signals in living organisms

Demonstrate deep implant sensing physiological markers

Demonstrate capability of deep implants to process data and relay to external site

Objective 8: Integrated Bioenergy Devices For Driving Sensors

Areas: Operational capability, casualty monitoring and care

General Idea: Retain the energy generated by the individual soldier that would, otherwise, be lost.

RESEARCH REQUIREMENTS:

Need-Driven Research:

Need molecular energy source to drive sensors

Utilize power generated by human activity

Opportunity-Driven Research:

Use of metabolites and chemicals to drive soldier systems

Use dynamic thermal gradients based on temperature differentials between the soldier body and the external environment to provide power as needed

Critical Proof of Concept Demonstrations:

Use fat, ion gradients, metabolites to power sensors

Demonstrate energy generation from thermal atmospheric/body temperature gradients in continuously functional device. Require "working fluids" that can work in elevated or reduced external temperatures

Nanoscience for the Soldier

The sub-group on Detectors, Antennae, Displays (see Appendix A for names and contact information) addressed each of the topics and identified several issues that were important to these subsytems but were beyond the scope of the technologies that supported these subsystems. Three issues could be addressed by other groups:

- Communications between "suit" and helmet/soldier
- Information management: WEBS
- Security of soldier system

There were other topics we identified but felt inadequate to address in the time available. These were:

- 3D displays for simulation and training
- Nano materials for 3D displays, e.g. embedded two-photon induced fluorescing nanoclusters
- Modeling of nanotubes, how do create nanotubes at an affordable cost?
- Reflective l selective "paints" (nanocomposites) for marking the trail or target, or for signature reduction.

The group then developed a list of science areas that might provide useful capabilities for the soldier.

DISPLAYS

1. Nano-structured surfaces for alignment of LCD (Liquid Crystal Displays) (ferroelectric LC's are fast and would provide useful displays. Could their cost be decreased and their performance increased by placing LC on pattered silicon that also contained signal processing components?)
2. Encapsulated liquid crystals (to provide for example holographic LC grating beam steering as a means of direct write of the display to the soldier's retina
3. Direct retinal scan? using "nems" (nano-electro-mechanical devices) for steering
4. Enhanced emission with structured surfaces (100x) = lower power consumption and should increase lifetime, lower weight of displays
5. Charged nanotubes arrays in vacuum for low voltage CRT's
6. OLED (organic light emitting diode) arrays – high frame rate and high resolution
7. Porous Si? – shown to emit, and nano-surface modification has improved silicon's ability to detect the infrared. Such structures would be integrateable?
8. Light source: electroluminescence, LED, or OLED, multicolor arrays
9. Nano-structure – in pixels? Quantum well/wire/dot emitters, or atomic clusters for limporved
10. LCD nano molecules – nanotubes as active elements
11. Photonic bandgap (PBG) materials for reflective image from visor? Uniform, omnidirectional refelctivity
12. Active camouflage: e.g. PBG's, or electronically controlled nanolayers to alter reflectivity (e.g. MQW's or PBG's), or electrically addressed LC's in suit. All this must be combined with detecting and imaging of the surrounding and mimicking it (chameleon effect)

ANTENNA

1. PBG (Photonic Bandgap Material materials to enhance the beam pattern of antennae
2. PBG could also protect the soldier from electromagnetic fields
3. Embed molecular entities within PBG
4. Increase FOV (field of view) in wavelength filters used to protect the soldier
5. Arrays of aligned nanotubes as steerable antenna
6. e-beam lithographically written antenna arrays for use as electronic, IR, of Visible detection or imaging systems. This could give polarization, direction, or wavelength control
7. Other antenna arrays – THz
8. Lenslet arrays, diffractive elements – could provide a color capability for IR detection
9. Negative e , negative m (low loss) materials with special reflection properties
10. active glasses (LCD on/off switching from transparent to opaque with each eye to give heads up info)

DETECTORS

1. PBG – enhanced fields on detectors: nano-surface modification has improved silicon's ability to detect the infrared.
2. Detector arrays for use as l filters, angular sensitivity, polarization sensitive, tunable wavelength sensitivity (all electronic control) also multi l
3. Optics for imaging across the visible –IR band.Use diffractive optics for color correction and other aberrations. This should reduce the size, weight and cost of the optical system for example; Diffractive optics saves space between focusing element and detector
4. Nano cavities (or surface enhanced Raman) – resonant structures on detectors to give multicolor detection
5. Quantum well/wire/dots (Size effects)
6. Sol gels, ormosils (useful for sensor protection – incorporate nonlinear materials in pores-size effects?)
7. Carbon suspensions and carbon nanotubes for sensor protection, also semiconductor-doped glass (quantum dots) and doped aerogels
8. Integrated diffractive optics on a semiconductor chip for detection and display
9. Also bulk (3D) holographic gratings using photo-thermal-refractive glasses (nanocrystallites) integrated with optical system & electrical chip
10. PBG's/diffrative optics for rapid optical signal processing
11. Nanophase materials wirh electrically tunable "bandgap" so the wavelength sensitivity could be tunable.
12. Active illumination/detection using PBG enhanced (lowered threshold) lasers (lower power)

Final Conclusions

The group came to the conclusion that the differences between detectors and antennae were blurred when discussing nanoscience and research in the science would impact both applications. We were able to identify the most probable areas where an impact on the soldier might be found. In the area of antenna and detectors:

1. The use of nano-sized surface structures to produce field enhancement for improved signal detection or radiation patterns.
2. Nanolayers of detector material spatially located at focal plane of an imaging system to provide sensor fusion by discriminating wavelength.
3. Electronically controlled detection using arrays of nano-detectors/antennae for polarization, l , angle, etc**.**
4. In a different light, the use of fractal-based antennae for wavelength insensitivity (broadband detection).
5. Nanostructures such as quantum dots for enhance sensitivity without cooling.
6. Sensor protection with nanotubes, PBG's, solgel, ormosils etc. (e.g. fill pores with nonlinear materials)

In the area of displays, the group took a liberal interpretation of displays to identify the following research opportunities:

1. Active camouflage: conformal electrically addressable "image" on "uniform" (nano-paints, PBG's, preferably with real-time active control). Also Electronically addressed nanolayers in "uniform" to alter reflectivity.
2. The use of nanostructures in Field effect devices such as nanotubes to serve as non-eroding electrodes in CRT's.
3. Organic light emitting diodes (OLED) – for large area displays. Currently lifetime is an issue but the use of nanotubes would reduce current density which should extend lifetime.
4. Liquid Crystal displays (LCD) require some black magic to the surface to insure the liquid crystals are aligned to the surface. Surface nanostructures could be used to enhanced LC alignment.
5. If the display is to appear on the soldier's face shield then something must be do to reduce the angular fall off in intensity. PBG's would provide angle independent projection display in the soldier's visor heads up display.
6. If the display is to be written on the soldier's retina then encapsulated LC's to generate holographic grating for beam steering could be used for direct retinal writing.

Detailed write-ups on a number of the applications were prepared by the attendees and can be found in Appendix B.

Appendix A

Participants for Detectors, Antennae, Displays

1. Eric Van Stryland, School of Optics/CREOL, U. of Central Florida
2. Paul Amirtraraj, USARL
3. Bob O'Brien, Natick Soldier Center

4. Joachim Ahner, U. of Pittsburgh
5. Glenn Boreman, School of Optics/CREOL, U. of Central Florida
6. I.C. Khoo, Penn State U.
7. Gary Wood, ARL/SEDD/Optics Br.
8. Michael Ciftan, ARO
9. Kris Kempa, Boston College & NanoLab
10. Michael Strub, USARL
11. Shin-Tspon Wu, Hughes Research Labs
12. Bob Guenther, Duke U.

Appendix B

Van Stryland:

Detectors

Objective: protect sensors from laser induced damage. General area called optical limiting.

Nano materials may have significant impact on sensor protection/hardening

Carbon black suspensions (CBS) are currently among the best (certainly the broadest spectral coverage) of any known material for optical limiting. CBS most certainly contains nanoparticles of carbon. Additionally, preliminary experiments with C nanotubes shows at least as good limiting (but research has only just started and the quality of C nanotubes used is poor. Research on other nano particles (e.g. suspensions of metal nanoparticles may also yield useful results. Work on organic nanoparticles is also of interest. Another approach to nanoparticles is to fill the pores of nanoporous materials such as sol gels or ormosils or aerogels with nonlinear materials. A limited amount of research has been done in this area to date.

A different area is the use of PBG's in optical limiting. Initial research has shown promising results (e.g. NRL Shirk) – but again in its infancy. The difficulty is the availability of materials. As PBG materials improve and move toward smaller length scales optical limiting research should utilize these materials. A goal is 90% transmittance with a limited output of 0.1 m J up to 100 mJ input for pulses from 100 ps to 100 m sec.

Joachim Ahner

Carbon nanotubes for displays.

Metallic single wall carbon nanotubes exhibit extraordinary mechanical (and electronic properties. Theoretical calculations (and recent experiments) show that electrons are transmitted in a ballistic way (Dresselhaus 96, and DeHeer 2000), with very stable band structure. If used for conductors, these CNT's minimize power consumption due to low resistivity. These properties, together with the fact that they act as very sharp and chemically stable tips make them ideal building blocks for efficient, stable field emitters for long lasting displays.

By aligned growth of parallel, upstanding CNT's on prepared Ni –pattern & tip densities of up to 10^4/m m^2 are possible. State-of-the-art FED arrays made by lithography methods provide about 1 tip/m m^2.

Kris Kempa

OLED's on arrays of nanotubes

Organic light emitting diodes (OLED's) are formed by "sandwiching" a layer of organic material between tewo conductors (one of them transparent). They are easy to make, deposit (screen printing, inkjet printing) and can be used to obtain flexible (foldable) displays. The problem of present OLED's is the organic semiconductor lifetime is lowered by the need for relatively large current densities. The current density can be reduced by forming OLED on a corrugated surface- e.g. on a carbon nanotube array. For the same light intensity the current density can be lowered by 10x. This increases the lifetime. (G. Jabbor – U. of Arizona, photonic center.

Kris Kempa

Segments of straight carbon nanotubes for the active molecules of LCD

Multiwall nanotubes grown by PECVD (Plasm enhanced chemical vapor deposition) have a "bamboo" structure, i.e. they are made of straight segments. By grinding these, one gets a nanotube powder of these segments. These behave as molecules of an LCD if immersed in a liquid. Placing these between two conductors forms an LCD. They can be faster, give more conduction, are more compact than conventional LCD's.

Carbon nanotubes powders Z. Ren (Boston College)

Kris Kempa

OLED's for large area DISPLAYS

OLED's are easy to make (e.g. screen printing, inkjet printing) and can be made in form of large flexible sheets. These would be useful for low resolution large display, possibly "chameleon" uniforms.

OLED's: G. Jannour (U of Arizona, photonics center)

Kris Kempa

Novel radiation sources based on SWNT arrays capped with nanoparticles (20 nm) exhibiting e.g. plasmon modes

Goal is to achieve elecroluminescence and lazing of small metallic particles attached to metallic nanotubes. Surface has vertical nanotubes with metal nanoparticles on top. This allows for dense packing and efficient emission. These may serve as future displays.

PRL 70, 2036 (1989)

APL 76, 2071 (2000)

S.T. Wu

Nanotechnology for LC orientation

LC's are nano-sized molecules. In order to form uniaxial crystals, these molecules need surface alignment. At the present time, rubbed polymers are used for such alignment. However, detailed alignment is not completely understood. Nanoscience may help uncover such mysteries.

S.T. Wu

Nanotechnology for ultra high resolution display

At he present time the State-of-the-art LCD has resolution of about 2056x2056. For military applications this is still insufficient. Nanotechnology should boost display resolution at least 2 orders of magnitude. Nanotechnology would help holographic polymer- dispersed LC's (H-PDLC) can be used for laser eye protection In an H-PLDC LC droplets are in 100 nm, size. Nanotech would help control the droplet uniformity and enhance light diffraction efficiency while reducing operation voltage.

B.D. Guenther

Displays: provide bright transparent (heads up display) on helmet's face screen

PBG crystals give reflection that is independent of angle. By placing the crystal on a face screen a l selective display surface could be produced.

Proof of principle experiment:

Create the actual face screen with the PBF material

Boreman

Detectors/Antennae

Can use nanostructure to exploit field- enhancements/or quantum confinement effect. But as structure sizes shrink – there will need to be antenna structures to couple radiation in .

Reconfigurable IR-Vis- I^2R-THz detectors for multiband, polarization switching, tunable field of regard can be integrated into focal plane formats – provide enhanced information to soldier for defeat of energy camouflage without having him do the tuning.

Critical POC Demo

Single quantum –dot IR sensor (can be very sensitive, very fast, tunable

Tunable field of regard demo of electronic charge 100K angle

Tunable l sensor/multiband THz, Vis, IR senon

Nano cavities can enhance the absorption in smaller volume

Bormean

Application of antenna techniques across the EM spectrum from RF to visible.

Gets nano as l gets smaller because tuning structures will need to be smaller than the antenna arms.

Tuning & electronic reconfiguration is necessary in order to reuse the same structure for different functionalities – can we use the antenna array for various frequencies of communication, omnidirectional vs. directional (nano secure – low probability of intercept) Antenna arrays (PBG, nanotubes arrays, e-beam lithography metallic structures) can enable new functionalities in vis, IR & THz application – polarization sensing Coherence detection & direction finding were you lased – and if so where from

Can enhance detection of man made structures. Just cycle through various polarization states and different wavelength for imaging systems – don't ry to have soldier tune it – automatic cycle. Also fractal-based antenna structures inherently broadband. They could conceivably detect from RF to Visible.

Boreman

Antennae

Electronically reconfigurable, tuable l tunable directionality, tunable polarization. Low backscattered signature – low probability of intercept

PBG to block field from RF communication links to soldiers head.

Passive antenna backscatter for no-power consumption

IFF

Antenna arrays for signature suppression in IR thermal-imaging wavebands

Tunability of antennae opens up active camouflage

Electronic reconfigurability of antenna structure for l , polarization field of regard

Demonstrate same antenna structure having

Very broad response – e.g. mmw & IR

IR & vis

RF & IR THz & Vis

Ir signature suppression even signature enhancement.

Bob O'Brien

ID Friend or Foe

Depending on implementation method, e.g. laser interrogation and RF reply, nanotechnology research needed to miniaturize detectors to permit unobtrusive placement of detectors on many locations on the human body. This is necessary to allow detection of interrogation signal while in any combat posture (e.g. standing, kneeling, prone). Research also necessary to determine how detectors are integratedgated into the warrior system, e.g. Electro-textile interfaces, connectors. Also, detector on board processing of the signal (you have been queried by a friendly) would be helpful. Finally, if RF reply is the approach, antenna arrays also must send and secure the signal when the soldier is in any posture.

B.D. Guenther

Detectors: l selectivity, enhanced detectivity

Detector systems with resonant structures have shown increased responsivity. This could increase the performance for the soldier without any increase in weight or power consumption.

Surface enhanced Raman scattering from clusters has been demonstrated and may provide an opportunity for l selectivity at the focal plane

Construct a 3-color detector array with l selectivity at the focal plane.

Nanostructures can be used to enhance the performance of individual detectors. For example gratings can be placed on a detector to enhance the electric field at a particular l . The increased electric field produces an effective enhancement in the detector response . Examples of people who have published in this area are Dennis Hall (while at Rochester) who used structures to enhance detector performance. The use of clusters to produce enhanced Raman scattering was first done by Richard Chang at Yale.

Kris Kempa

Arrays of aligned carbon nanotubes for antennae

Periodic arrays of aligned carbon nanotubes are grown by Z Ren at Boston College/ nanolab also Otto Zhou, NCSU

1. *IR & visible frequency*

   Aligned periodic arrays of conductive nanotubes can be grown to form the l matched antenna (l ~L, nanotube length) antenna arrays tuned via nanotube length to a particular frequency in the visible (few 100's of nm) to the IR (few m m's. These arrays would work essentially as photonic crystals allowing for high degree of directionality, directional field enhancement. By implanting defects into nanotubes nonlinear elements can be achieved which would allow for detection, demodulation multiplexing etc. The idea has been patented : Robert Gouley

2. *Radio frequencies*

Arrays of aligned nanotubes can also be used as unmatched (L<<l) antenna arrays. Even though each unmatched (Hertz dipole) antenna is inefficient, the arrays will have a large total efficiency, which scales with the nanotube number. Such antennae will be broadband, isotropic (multidirectional, and could be embedded into cloth fabric. Nanotube arrays are grwon by Z. Ren (Boston College nanolab)

Gary Wood

Diffractive Optical elements as nanostructures:

Focal plane array detectors can have improved performance with focused radiation on to the detector elements. Therefore, an array of focusing elements can improve performance. However, space constraints also dictate that the optical elements take as little space as possible (i.e. be very close to the FPA). DOE's can be made fairly flat and hence could be positioned close to the FPA. In addition a sharply focused light beam often allows better coupling to certain nanostructured detector elements. In order to drastically reduce the DOE from the FPA spacing focal lengths f/# <1 are desired. However, in order to have sufficient (most of diffracted light at focus) DOE's with f/#<1 requires subwavelength etched structures on the DOE. These subwavelength etched structures can be binary in depth and will be limited to thicknesses available from current lithography. These nanostructured DOE's therefore are efficient manufacturable and should improve detector performance and enhance it's capabilities (ie. Polarization selectivity)

Proof of concept: design, fabricate and test binary DOE's with efficiency>90% at f/0.2 and demonstrate polarization selectivity.

Gary Wood

Detectors

High sensitivity nano-sized based elements that detect electromagnetic radiation with high quantum efficiency for reducing weight and size. Investigate detectivity parameters of atomic cluster and quantum dot quantum wire and quantum well based nanostructures for high quantum efficiency and high sensitivity, low operating power operational at 1 W or less

Recently optical nonolinearities of four orders of magnitude higher than any known nonlinearity in materials has been discovered. This was based on the use of nano-sized elements embedded into liquid crystals. Other nano-sized elements as above and molecular entities such as dendritic molecules may similarly increase the responsivity of detectors.

The electronic energy level structures of such nano-0sized elements that can be evoked to respond (absorb) electromagnetic radiation in particular wavelength & then produce a macroscopic effect such as conductivity change will be a proof of concept demonstration for the potentiality of such to become a detector.

Paul Amirtraraj

Photon detectors IR – 8-12 m m, 3-5 m m, near IR I^2*, visible , UV (solar blind)*

Objective: improve sensitivity (70% now to ~100%); operating temperature (100^0 K for IR to ~300^0K), operability, power consumption, resolution (pixel size), size, multicolor (8-12 and 3-5 m m), multi range (IR, NIR, Vis, UV)

<u>Materials driven</u> – new nanophase materials with appropriate bandgap, band-discontinuities and other controllable electronic properties (effective mass, lifetime, etc.) Fractal materials, porous materials

<u>Structure driven</u> – quantum dots, superlattice-type structures for photon detection – realization of artificial-atom and artificial dopants (embedded artificial atoms in a matrix)

<u>Novel properties driven</u> – special properties especially spin , e-e- correlation etc.

MBE/MOCVD capability extension for nano fabrication of materials and structures

Nano-electronics – extension of the m - fab to nano-fab, focused ion beam (IB), e-beam (high resolution)

STM bond fab and analysis

Proof of concept demo:

Response at l and T (temp) of nano-related materials

Capability of making electrical contacts

Capability to fabricate

First step in integration - combine 2 l ’s ranges