Nanotechnology in the Military

National Defense

Homeland Security

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From the east coast to the west coast, from the north to the south, from the Army to the Navy, from the Air Force to the Marines.

How can small science help us protect such a big country?

A description -

- Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, or nanoscale.

- Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules.

- Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.

Note: This slide and the next 9 slides are the same for all research areas.

Resource: www.nano.gov
How BIG is nano?

**Macrosize**
- **Child**: A child is about 1 meter tall. 1 meter = 1,000,000,000 nm (1 billion nanometers).
- **Hand**: A hand is about 1 decimeter wide. 1 decimeter = 100,000,000 nm (100 million nanometers).
- **Pinky Finger**: A pinky finger is about 1 centimeter wide. 1 centimeter = 10,000,000 nm (10 million nanometers).
- **Freckle**: A freckle is about 1 millimeter wide. 1 millimeter = 1,000,000 nm (1 million nanometers).
- **Strand of Hair**: A hair is about one tenth of a millimeter wide. 0.1 millimeter = 100,000 nm (100 thousand nanometers).

**Microsize**
- **Red Blood Cell**: A red blood cell is about 10 micrometers wide. 10 micrometers = 10,000 nm (10 thousand nanometers).
- **Bacteria**: A bacterium is about 1 micrometer wide. 1 micrometer = 1,000 nm (1 thousand nanometers).

**Nanosize**
- **Virus**: A viron is about one tenth of a micrometer wide. 0.1 micrometer = 100 nm (1 hundred nanometers).
- **Cell Membrane**: A cell membrane is about 10 nanometers wide. 10 nanometers = 10 nm.
- **Sugar Molecule**: A sugar molecule is about 1 nanometer wide. 1 nanometer = 1 nm.
- **Atom**: An atom is about one tenth of a nanometer wide. 0.1 nanometer = 0.1 nm.
1 nanometer = 1 billionth \( (10^{-9}) \) of a meter

D  
10^9 D

a marble
Why do we care?

Things behave differently at this scale

• Quantum mechanics plays a much more important role

• For example,
  – A brick of gold is shiny and “gold”-colored.
  – A vial of gold nanoparticles in solution can be a range of colors depending on the size of the nanoparticles.
  – This is because of a phenomenon know as quantum confinement.

Suspensions of discrete (separated) gold nanoparticles in clear solution vary in color from pink to purple as the nanoparticle size gets bigger.

Why else do we care?

This is the scale of biological processes

- Human cells and bacteria have diameters around 1-10 \textit{micrometers}
  
- But

- Cellular machinery is on the \textit{nanoscale}
  - Diameter of DNA is \textit{\sim}2 nanometers
  - Hemoglobin, the protein that carries oxygen through the body, is 5.5 nanometers in diameter
One more reason: surface area

Another reason nanomaterials behave differently from bulk materials of the same chemical is because of surface area – or the area of an object that is an exposed surface.

Volume (in cubic meters):

For this cube, each edge is 1 meter in length.

\[ 1\text{m} \times 1\text{m} \times 1\text{m} = 1\text{ m}^3 \]

Surface Area (in square meters):

\[ (1\text{m} \times 1\text{m}) \times 6 \text{ sides} = 6\text{ m}^2 \]

For these cubes, each edge is 0.1 meters in length, but there are 1000 cubes.

\[ (0.1\text{m} \times 0.1\text{m} \times 0.1\text{m}) \times 1000 \text{ cubes} = 1\text{ m}^3 \]

\[ (0.1\text{m} \times 0.1\text{m}) \times 6 \text{ sides} \times 1000 \text{ cubes} = 60\text{ m}^2 \]
Surface Area and Reactions

• This increased surface area allows chemical reactions to go much faster.

• Think about it this way:
Which dissolves faster in your coffee or tea, a sugar cube or a teaspoon of granulated sugar?

Answer: Granulated sugar
Nano-enabled Consumer Products

As of the March 10, 2011, there are over 1300 consumer products around the world that are manufacturer-identified as nanotechnology-based.

- Touch screens (iPhone)
- Sunscreens
- Cosmetics
- Tennis rackets
- Bicycles
- Fabric
- Computer memory
- Many more...

These products are here, ready to buy today!

Resources: The Project on Emerging Nanotechnologies website: http://www.nanotechproject.org/
Activity Description

• You have been assigned an area of nanotechnology research to support.
• Go through this presentation and any other credible sources to identify three benefits of research in nanotechnology toward your area of interest and up to three potential risks you perceive in your area of interest.
• As a group, we will weigh the risks and benefits of each area to decide how much of our federal nanotechnology budget should go to each research area.
Disclaimer: this is a contrived scenario

- There are no federal nanotechnology budget cuts
  - $1.7 billion estimated for FY2012 (fiscal year 2012)
  - Increased investment proposed for FY2013 (nearly $1.8 billion)
- Nanoscale Science, Engineering and Technology (NSET) subcommittee of the National Science and Technology Council's Committee on Technology is an actual government entity
  - Composed of representatives from 25 federal agencies (NIH, DOE, DOD, etc.)
  - Purpose is to coordinate planning, budgeting, and implementation of the National Nanotechnology Initiative (NNI)
  - These representatives work together to create an integrated federal program.
- Actual nano “budget” is different from what is proposed in this activity
  - Actual “budget” is given as a supplement to the President’s 2013 Budget Request submitted to Congress
  - It represents the sum of the investment in nanotechnology and nanoscience planned for 2013 by federal agencies
  - The agencies submit how much they are planning to spend on nanoscience
  - In the activity scenario, we’re doing the opposite of what the actual NNI Budget represents in that we’re distributing a pre-determined amount amongst these research areas.

Resources: NNI Budget website: [http://www.nano.gov/about-nni/what/funding](http://www.nano.gov/about-nni/what/funding)
In this presentation, you will learn about some of the developments in nanotechnology in military and national security research.
Consider the following when learning about these developments:

1. Might these nanotechnology developments infringe on human rights to privacy and freedom?
2. Is it safe for me? Is it safe for others?
3. Could the use of this nanotechnology development have unwanted and negative environmental effects?
4. What economic impact could the use of this nanotechnology development have on producers, consumers, and other industries? Might they be negative or positive?
What About Your Rights?

If so, are these developments more important than

- Your privacy?
- Your rights as a citizen?
- Your rights as a human being?

Are the answers somewhere in between?

Image source: http://www.info4security.com/Pictures/web/w/v/m/iStock_Law.jpg
Links to outside sources

Within this presentation will be many underlined words. If you click on the underlined text, your browser will take you to other websites, videos, or other resources to learn more about what is on the slide.

These links are chosen to give you additional information, but these presentations can stand alone. It is unnecessary to go to the links for the purpose of this activity.

We try to make sure the links are active, but given the ever-changing nature of the internet, you might find a few that take you to a location that is no longer active. Please let the facilitator know if you find an inactive link.
Nanotechnology in National Defense

What can nanotechnology do for the military? Nanotechnology research in the following areas can help the military:

- **Fabrics/Materials**
  - Armor
  - Withstand extreme conditions
- **Robotics**
- **Security**
- **Weapons**
  - Detection
  - Defense
  - Development
- **Vehicles**
  - Fuel economy
  - Soldier protection
  - Stealth movement
- **Military personnel health**
  - Medicine
  - Diagnosis
The Institute for Soldier Nanotechnologies is a research center founded through a U.S. Army Research Office contract with Massachusetts Institute of Technology (MIT).

The goal of this center is to create a lightweight and comfortable, high-tech battlesuit for the modern soldier.

They imagine that nanotechnology will help them create “a bullet-resistant jumpsuit, no thicker than ordinary spandex, that monitors health, eases injuries, communicates automatically, and reacts instantly to chemical and biological agents.”

Waterproof and Bullet-proof Vests

• One of the first advancements that came out of the center was developed by Prof. Karen Gleason.
• She and her researchers were able to create ultrahydrophobic surfaces (waterproof) using a technique called chemical vapor deposition (CVD).
• With CVD they could deposit nanolayers of Teflon (yes, the same stuff that’s on your frying pan) on Kevlar panels, the material used to make bullet-proof vests. [1]

Watch this video to learn more about Prof. Gleason’s research.

An Invisibility Cloak?

• Though far from becoming a reality, researchers are making strides in optical negative-index metamaterials (NIM) to make objects invisible.

• Metamaterials are typically man-made to have properties that cannot be found in nature.

• Optical NIM have the ability to bend light in ways different from conventional materials.

• Professor Vladimir Shalaev at Purdue University is studying nanostructured composites to create these metamaterials.

• Beyond the invisibility ability, these structures also have applications in microscopes, circuits, and antennae.

Resources
Nature’s Armor

- MIT Professor Christine Ortiz is taking a cue from nature in developing materials to protect the modern soldier.
- Using a **scanning electron microscope** (SEM), Prof. Ortiz and her students were able to examine the nanostructure of the scales of the Senegal bichir or the dinosaur eel, a species that has been able to survive enemy attacks for over 96 million years.
- The four layers of the scales dissipate the energy of a strike, protect the soft tissue beneath the scales, and also prevent the spread of fractures within the scale.

Now this knowledge can be applied toward human body armor.

**Resources:**
Chemical and Biological Warfare

From the Defense Threat Reduction Agency & US STRATCOM Center for Combating WMD (DTRA and SCC-WMD) [Website]:

“Nuclear warheads are not the only weapons of mass destruction threatening the United States and our allies. Because nuclear weapons require sophisticated technologies and elements difficult to obtain, our nation’s adversaries may find chemical and biological weapons more attractive.

DTRA and SCC-WMD are actively engaged in efforts to defend against chemical and biological weapons. Our work in this arena has global reach, impacting everyone from our men and women serving on the frontlines to American citizens in the heartland.”
Chemical and Biological Warfare

Chemical: mustard gas, phosgene, chlorine, sarin…
We’ve all heard of these chemicals, and they have been used on the battlefield as early as World War I and have since also been used in acts of terrorism.

Biological: anthrax, Ebola virus, Brucella…
Examples of their use in history range from poisoned tipped arrows of Antiquity to the letters containing anthrax spores after the September 11, 2001 attacks.

Both: toxins like botulinum neurotoxin and ricin which are produced by living organisms

How do we defend ourselves? The first thing we need to do is to know they are there.
Chemical and Biological Sensors

According to a study commissioned by Defense Advanced Research Projects Agency (DARPA), key sensor metrics are:

- Sensitivity
- Probability of correct detection
- False positive rate
- Response time

The requirements for these metrics vary depending on perceived threat levels and mission objectives.

Other attributes affect the sensor utility for missions: cost, power consumption, reliability, maintenance/logistics, as well as form factors like size, weight and shape.

Resources:
Nanosensors

Nanotechnology can help!

- “With their small size, light weight, and large reactive surface area… engineered nanostructures have been shown to improve – by orders of magnitude – sensitivity, selectivity, and response time of sensor technology (thereby providing an advantage over slower, more costly, laboratory-based analytical methods), and to dramatically reduce size, weight and power requirements of the resulting monitoring devices compared to the conventional, macroscaled alternatives.” [1]

- Detection of multiple chemical species
  - Conventional chemical sensors are optimized to detect a single chemical – some nanosensor designs are capable of detecting a target chemical amongst multiple chemical species because they allow for numerous sensors within a single monitoring device. [1]
  - Each nanosensor is chemically coated or decorated with functional groups that can recognize a specific chemical or biological agent. [1]

Jing Li, a physical scientist at NASA's Ames Research Center working under the Cell-All program in the Department of Homeland Security’s Science and Technology Directorate developed an iPhone chemical sensor [1]

- With 64 nanosensors, it can detect airborne chemicals including ammonia, methane, and chlorine gas. [1]
- “Cell phone owners could use their phone's GPS to provide sensor location information to emergency operation centers.” [2]
- One goal of the Cell-All program is to “crowd-source” human safety – anywhere a threat breaks out, authorities are notified, and if more people have the sensors, it makes it easier for first responders to distinguish false positives from true threats. [3]

Resources:

Photo credit: Dominic Hart/NASA
Bio-inspired Nanosensors

• In August 2010, DARPA awarded a $6.3 million grant to Radislav Potyrailo and his team at GE Global Research’s Chemical and Biological Sensing Laboratory to develop sensors inspired by chemical sensing nanostructures found on the scales of the wings of the Morpho butterfly. [1, 2]

• The left set of wings on the Morpho butterfly on the right has been exposed to the liquids ethanol (forewing) and toluene (hindwing). See how it changes color? [3]

• The group uses nanophotonics depicted in the bottom figure to selectively detect numerous gases with a single sensor rather than an array of sensors. [3]

• **Nanophotonics** is “the science and engineering of light-matter interactions that take place on wavelength and subwavelength scales where the physical, chemical or structural nature of natural or artificial nanostructured matter controls the interactions.” [4]

Resources:

Kenneth Suslick, Professor of Chemistry at the University of Illinois at Urbana-Champaign, and his collaborators have developed a handheld sensor that can be used to differentiate 19 different toxic industrial chemicals. [1]

- Similar to the smelling response of mammals, distinguishing one chemical from another comes from a composite response of many sensors rather than the response of a single chemical-specific sensor. [1]
- The array is comprised of a diverse set of nanoporous pigments with colors that are changed by chemical reactions with the “smelled” chemical [1].
- Prof. Suslick has co-founded iSense with this research. [2]

Resources:
Nano Air Vehicle

• AeroVironment, based out of Monrovia, CA, has developed their Nano Hummingbird under a DARPA research contract. [1]

• The goal was to create an air vehicle system that could fly both indoors and outdoors.

• On February 17, 2011, they announced they had reached a major milestone, “controlled precision hovering and fast-forward flight of a two-wing, flapping wing aircraft that carries its own energy source, and uses only the flapping wings for propulsion and control.” [2]

Follow this link to watch it fly.

Resources:
Warships

• The U.S. Navy is getting a next-generation all-electric warship with the help of researchers at the University at Buffalo, and it’s expected to be ready by 2012.

• It’s predicted that this ship can be run by a crew of 100 people, much smaller than the thousands of people that run battleships in service now.

• The biggest problem is distributing power to the entire ship.

• Cemal Besaran, director of the Electronic Packaging Laboratory at UB, is turning to nanotechnology to solve this problem.

Resources:
Smart Fabrics

Imagine uniforms that can diagnose and treat a soldier in the field, no doctor needed. The following development is the first step in achieving that goal.

Professor Joseph Wang at the University of California at San Diego has developed method for screen printing sensors on the waistband of underwear [1, 2].

On the waistband, the sensor is in close contact to the skin where it can monitor biomarkers in the sweat of the person wearing the underwear [1, 2].

Undergraduate student, Jimmy Chou, describes the work in this video found at this link.

Resources:
More links on the Military and Nanotechnology

Nanotechnology and the Military research

• Northwestern University’s Discover Nano website describing applications of nanotechnology and national security
  http://www.discovernano.northwestern.edu/affect/applications_content/security

• MIT’s Institute for Soldier Nanotechnologies website – founded by a contract with the U.S. http://web.mit.edu/isn/

• U.S. Naval Research Lab Institute for Nanoscience
  http://www.nrl.navy.mil/nanoscience/

• Defense Advanced Research Projects Agency
  Search term “nano” to identify projects in nanoscience

Military Research Priorities

• Department of Defense Research & Engineering website
  http://www.acq.osd.mil/ddre/

• Armed with Science – Department of Defense’s webcast on the role of science and technology in the military http://science.dodlive.mil/
Nano-enabled consumer products

To learn more about nano-enabled consumer products in all areas of research visit the Project on Emerging Nanotechnologies

- Established in April 2005 as a partnership between the Woodrow Wilson International Center for Scholars and the Pew Charitable Trusts
- “The Project is dedicated to helping ensure that as nanotechnologies advance, possible risks are minimized, public and consumer engagement remains strong, and the potential benefits of these new technologies are realized.”
- Their website includes news and publications about issues with nanotechnology.
- It also includes inventories of consumer products that are manufacturer-identified as nanotechnology based, and as of the March 10, 2011 update, there are over 1300 products around the world.

Resources: The Project on Emerging Nanotechnologies website: http://www.nanotechproject.org/
If time allows, return to the main website and watch some of the videos that provide “expert testimony” in the area of nanotechnology in military and national security.

[Click here]