RESEARCH PROFILE: NANOTECHNOLOGY LOGISTICS TRANSFORMATION

For Task 9 Logistics Transformation
Nanotechnology * Microelectronics * Standards

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1.0 INTRODUCTION

Nanotechnology has captured the attention and energized the imagination of the scientific community and the public at large. It is often described as the next technological revolution that will change every facet of life. While some of the excitement is hyperbole, there is a fundamental kernel of truth to the importance and spanning reach that nanotechnology will have in the coming decades. The initial impact of nanotechnology on everyday life will be subtle and gradual, like plastic fifty years ago.[1] However, before long we will not be able to imagine a product, device, or material that is not enabled by nanotechnology.[2] Nanotechnology-enabled products are estimated to reach $1 trillion in 10 to 15 years.[3] For these reasons, it is critical that organizations, such as the Department of Defense (DoD), who are involved in technology development and strategic planning are positioned to benefit from nanotechnology. Nanotechnology has tremendous potential for military applications in a wide range of DoD operations and systems, including those involved with DoD Logistics support systems, personnel, and materials. Nanotechnology can provide enhanced or additional properties and functions to components and systems. In addition, these advances can enable new operational capabilities to meet DoD Logistics mission goals.

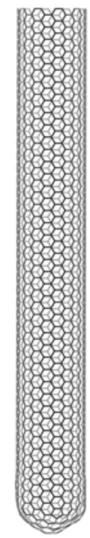

Figure 1.1 Carbon Nanotube Courtesy of Unidym, Inc.

"…The U.S. Armed Forces will continue to rely on a capacity for intellectual and technical innovation. The pace of technological change, especially as it fuels changes in the strategic environment, will place a premium on our ability to foster innovation in our people and organizations across the entire range of joint operations." – Joint Vision 2020[4]

"For 229 years, the strength of the U.S. military has been its ability to adapt and change. As the rate of change of technology continues to accelerate, it will be even more important that the U.S. military keep pace…The greater institutional risk for DoD is over reliance on traditional platforms and delaying the advent of new technologies and systems." – Gordon England, Deputy Defense Secretary[5]

2.0 NANOTECHNOLOGY: A PRIMER

Nanotechnology - The understanding and control of matter at dimensions of roughly 1 to 100 nanometers (i.e., nanoscale), where unique phenomena enable novel applications.[6]

Nanotechnology has emerged over the last decade as a critical and powerful enabling science. It has been made possible through advances in instrumentation, improved computing power, and the intersection of traditional fields of science.[7] Over the past two decades, the instruments and tools available for scientists have advanced significantly. These powerful instruments provided the means for discovering, characterizing, and understanding the nanostructures that populate nanotechnology, such as Carbon Nanotubes (CNTs) and Quantum Dots (QDs). Through a direct understanding of their properties, applications are now possible which utilize their impressive and unique characteristics. In addition, because of affordable and accessible computers, accurate modeling, simulations, and predictions based on first principles at the nanoscale are possible. The interaction between theoretical and experimental nanotechnology research is enabling scientists to tailor materials and devices for exploring and exploiting nanoscale behavior in specific applications. Finally, an even greater synergy that defines nanotechnology is its interdisciplinary nature. Over the last half century, physics, chemistry, and biology have been converging on a single size scale - the nanoscale.[8] The resulting scientific landscape is a convergence of traditionally isolated fields which are recognizing similarities and previously undiscovered compatibilities.

Because of the intersection of these situations, nanotechnology has become the epicenter of tremendous amounts of research. In addition, industry has come to recognize the value of nanotechnology and is funding much of the groundbreaking research that is rapidly enabling products and applications. While nanotechnology is generally considered in its infancy, these technologies have passed through many of the steps and time required of a technology base to emerge as an industrial base.[3] Nanotechnology is a powerful area of Research and Development (R&D) with defining characteristics and qualities - bottom-up manipulation of matter, true interdisciplinary research, and unique and enhanced properties at the nanoscale.

At its core, nanotechnology is about the understanding and manipulation of matter on the nanoscale to assemble devices and materials. Traditional manufacturing is often called a "top-down" approach. An object or device starts from a larger block of material, which is etched, machined, and shaped to create the desired product. This approach is limited by the starting molecular composition of the material and is often crude (relative to the atomic scale). Nanotechnology is about building the desired product from the "bottom-up" through controlled manipulation of molecules and structures on the nanoscale. The result is a greater control and understanding of the fundamental nanoscale structures that compose the larger material or device.

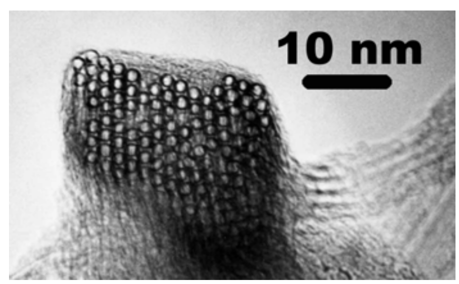

Figure 2.2 Bundle of CNTs From [9].
Reprinted with permission from AAAS.

A second aspect of nanotechnology is its interdisciplinary nature.[10] As the size scale of leading edge research in physics, chemistry, and biology converge, scientists are discovering similarities and synergies between previously separated fields of study. In many ways, nanotechnology is the last unexplored frontier of science.[8] The significant and unexpected breakthroughs in nanotechnology inevitably involve a fusion of multiple areas of science, whether it is through unexpected material interactions, unorthodox applications of nanostructures, or nanoscale characterization methods previously unconsidered.

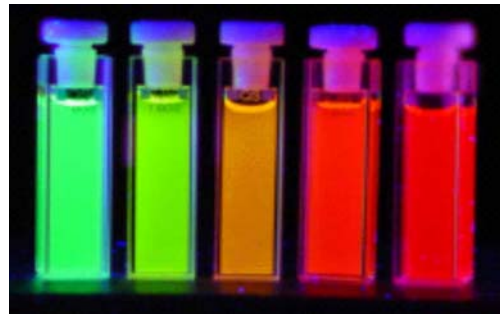

Figure 2.3 Suspensions of QDs Varying size QDs emit different light upon excitation by the same light source. Courtesy of Koninklijke Philips Electronics, N.V.

The third defining aspect of nanotechnology is the unique and enhanced properties that manifest at the nanoscale. The two dominant reasons for these properties are increased surface-to-volume ratios and the emergence of quantum mechanical effects. As an object shrinks in size, the number of atoms in the bulk volume decreases more rapidly than the number of atoms on the surface. Surface atoms are predominantly responsible for chemical reactivity and interfacial interactions. The result is that nanoscale structures have an increased chemical reactivity over their bulk counterparts for a given mass. Improved surface interactions are also critical for devices or materials that rely on surface adsorption or adhesion. The second reason for unique nanoscale properties is the manifestation of quantum mechanical effects. These are electrical, optical, or magnetic properties which cannot be extrapolated from bulk material properties and exist only at sufficiently small size scales. The result is characteristics that can be exploited for unique applications.

2.1 The National Nanotechnology Initiative

To facilitate and advance the development of nanotechnology, the United States (U.S.) federal Government has established the National Nanotechnology Initiative (NNI). The vision of the NNI is a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry.[6] To realize its goals, the NNI's strategy combines a significant allocation of funds with a focused agenda and an organized collaboration between multiple participating agencies. The annual federal investment in nanotechnology R&D has more than doubled to over $1 billion since 2001.[11] In addition, substantial NNI resources have been spent establishing large multidisciplinary research centers, with over 50 centers and networks established to date.

3.0 FOCUSED LOGISTICS

DoD is currently undergoing a force transformation, a change in the way the warfighter prepares, plans, and executes operations. This paradigm change involves a shift from a traditional threat-based to a capabilities-based force in an effort to streamline, optimize, and modernize U.S. military operations. Force transformation is inextricably linked to technology, and therefore to nanotechnology. Focused Logistics (FL) is part of the greater process of force transformation. It guides logistics operations, planning, and organizations. FL describes a comprehensive, integrated approach for transforming DoD logistics capabilities and for dramatically improving the quality of logistics support.[12,13] Fundamentally, FL is the ability to provide the right personnel, equipment, supplies, and support in the right place, at the right time, and in the right quantities, across the full spectrum of military operations.[14]

Figure 3.4 Infantry Squad
U.S. Navy Photo by Journalist First Class Jeremy Woods. (Released)

3.1. Focused Logistics Capability Areas

A set of seven capability areas have been laid out to describe the nature of FL.[12] They detail aspects of DoD logistics operations which are critical to logistics force transformation and the tenets of a capabilities-based military. Nanotechnology has the potential to directly benefit four of the seven capabilities of FL – Agile Sustainment (AS), Operational Engineering (OE), Force Health Protection (FHP), and Information Fusion (IF).

Table 3.1 FL Capabilities vs. Nanotechnology Benefits Matrix

The areas of nanotechnology which are expected to provide Direct (X) or Secondary (S) benefits to the capabilities of FL.

FL Capabilities	Nanotechnology Benefits				
	Nanomaterials	Nanomedicine	Nanosensors	Nanoelectronics	Nanoenergy
Joint Deployment/ Rapid Distribution	S				S
Agile Sustainment	X		X	X	X
Operational Engineering	X				X
Multinational Logistics					
Force Health Protection	X	X	X	X	
Information Fusion			X	X	
Joint Theater Logistics Management			S	S	

AS emphasizes the need for agile, flexible, and precise support to the warfighter. Supplies, maintenance, and materials must be able to adapt and respond to the wide variety of operations that the full spectrum warfighter might face in the next century. Two essential characteristics of AS can directly benefit from the enhanced properties or functionality imparted by nanotechnology – remote monitoring and system support. Nanosensors and nanoelectronics can provide miniaturized, sensitive solutions for remote monitoring and diagnosis/prognosis of failures and supply consumption. The potential for a pervasive, robust supply and maintenance sensor network powered by nanosensors is encouraging for FL. In addition, nanomaterials implemented in systems can dramatically improve life cycle and maintenance results. These applications directly improve system support.

Figure 3.5 Supplies
U.S. Air Force Photo

OE involves improving the capabilities and response of engineering support for military forces. Nanotechnology can improve the materials and components of engineered structures. These materials can reduce the logistic burden to engineer units while maintaining support to military operations. In addition, nanoenergy technologies are evolving robust, portable, high performance energy solutions for incorporation into civil engineering structures. These improved energy capabilities reduce the logistics footprint of structures and enable their use in more demanding environmental conditions.

FHP involves protection from all health threats across the full range of military operations. Nanotechnology will provide enhanced and additional benefits to general medical treatment, health monitoring, and chemical and biological warfare (ChemBio) protection. DoD will benefit from these nanomedicine advances along with the rest of the population, thereby improving the health of the warfighter. Individual health status monitors, physiological sensors, diagnostic/prognostic technologies, and improved patient tracking are all examples of health monitoring. These capabilities provide military forces with information, adaptability, and options for protecting and insuring the safety of the warfighter. In addition, nanotechnology will enable many aspects of ChemBio protection. Nanomaterials can provide durable, nanostructured materials for chemically resistant protective gear. Nanosensors will allow efficient, ever-present sensitive detection of ChemBio agents, deployable on a tactical level.

IF is a complete, distributed network of information across the entire battlespace. DoD has embraced network-centric (netcentric) warfare as the future.[15] Nanotechnology is poised to play a significant role in the implementation of IF and netcentric warfare through advances in electronics and sensors. Nanoelectronics will continue to improve upon the high performance, affordable, miniaturized electronics that we have come to depend on. Nanoelectronics will provide a needed level of complete connection and communication. Nanosensors will enable a pervasive blanket of sensing capability at all levels of operation. Improvements will be seen in conventional electronic sensors deployed on unmanned aerial vehicles and satellites as well as in miniature tactical sensors integrated into field gear and personal vehicles.

3.2. Logistics Benefits of Nanotechnology

There are many attributes shared by the capability areas of FL.[14] These descriptors provide a framework of dynamic principles that summarize the philosophical and operational mindset of FL. In addition, there are common attributes shared by nanotechnology within and across its subfields, which illustrate the types of benefits, nanotechnology can bring to DoD Logistics, or any technology-enabled topic for that matter. By recognizing these application-oriented characteristics, connections can be drawn between nanotechnology and FL (Table 3.2). Nanotechnology attributes commonly include multifunctionality, efficiency, and enhanced performance.

One of the advantages nanotechnology often provides is multifunctionality. Nanotechnology emphasizes an understanding and manipulation of matter at the nanoscale. One product of this exploration is the ability to engineer materials and devices, which incorporate multiple functions without sacrificing the original performance. At the nanoscale, there is tremendous real estate that was previously untapped. For materials, this often involves the addition of nanostructures that impart enhancements to the bulk phase. Through understanding the interaction between the different material phases and selecting the appropriate nanoengineered additives, multifunctional nanomaterials are possible. Devices benefit from the multifunctionality of nanotechnology in a slightly different manner. Individual nanotechnology-enabled devices often possess a single function (albeit, often with enhanced performance), however because of the size of the device, many different devices can be combined on the component level. What would normal require microns to millimeters for a single device, can now incorporate dozens if not hundreds of nanoscale devices without any additional size or weight. Because of this, nanotechnology can impart multifunctionality at the component and system level.

Table 3.2 FL Attributes vs. Nanotechnology Attributes

	Nanotechnology Attributes		
	Multifunctionality	**Efficiency**	**Enhanced Performance**
Integrated	X	X	
Expeditionary		X	X
Networked		X	X
Decentralized		X	X
Adaptable	X	X	
Decision Superiority		X	X
Effective	X	X	X
Reliable	X		X
Affordable	X	X	X

A second attribute of nanotechnology is efficiency. Nanotechnology-enabled products are often efficient in terms of power usage and size/weight per function. Both are related to their nanoscale size. The active elements in nanoelectronics and nanosensors usually require significantly less energy to operate. In addition, their smaller size generally equates to smaller power requirements for operation. This is because their nanoscale size results in enhanced or unique electrical, thermal, or chemical properties, which are sensitive to their environment. Micro and macroscale devices often rely on bulk ensemble behavior of the active materials and therefore necessitate larger energy inputs to access that behavior. Nanotechnology is also often efficient in terms of size/weight per function. This is a direct result of the continued miniaturization of nanotechnology. In addition, nanotechnology involves an unprecedented control of the properties to achieve a desired application or goal. Nanotechnology enables products tailored for a specific use. A desired performance can be achieved with less material or smaller devices because the efficiency of the electrical, thermal, or chemical processes of the involved nanotechnology is greater than that of larger counterparts.

Finally, nanotechnology is often characterized by its enhanced performance. The fundamental mechanisms and interactions of many physical systems possess critical lengths on the nanoscale.[16] By understanding and engineering materials and devices on the nanoscale, these properties can be exploited to greater effect. Enhanced performance has been witnessed on the individual device and material level as well as on the component and system level. Nanomaterials have been developed with enhanced mechanical properties through the inclusion of nanostructures or manipulation of inherent physical structure. Nanoelectronics and nanosensors have utilized the unique properties of nanostructures as alternative active elements with enhanced sensitivity and electrical properties. Conventional electronics has built upon nanotechnology techniques and instrumentation, further evolving components and systems.

4.0 NANOMATERIALS

Nanotechnology-enabled materials (i.e., nanomaterials) are currently a sustaining technology providing small, but notable improvements to existing material properties and applications.[3] Many newly discovered nanostructures possess unique properties which cannot be extrapolated from their bulk versions.[17] Research is focused on characterizing and studying nanostructures in an effort to impart their unique and enhanced mechanical, thermal, electrical, and optical properties to bulk materials.[18] Nanoparticles have been found to have significantly improved chemical reactivity due to their increased surface-to-volume ratio and have already been exploited in applications such as cosmetics, fuel additives, and environmental remediation. Composite research has focused on incorporating nanostructures in traditional methods to produce materials with improved performance and multifunctional properties. They have found applications in structural materials and anti-static packaging for electronics. However, significant challenges still exist which prevent the full realization of nanoscale properties at the bulk scale. Thin films have seen dramatic improvements through the adoption of nanoscale particles. Thin films of titania, alumina, and other nanoparticles have shown to provide significantly improved anti-corrosion, wear resistance, and friction reduction. In general, nanomaterials have been the first to benefit from nanotechnology, but many experts believe that their evolution and improvement will be slower than expected due to the inherent challenges of relating nanoscale behavior to bulk properties and manufacturing issues related to scalability and process control.

4.1 Nanomaterial Logistics Applications

- Anti-Corrosion Coatings
- Anti-Fouling Coatings
- Anti-Static Plastics
- Bonded Assembly
- Elastomeric Materials
- Electromagnetic Shielding
- Environmental Remediation
- Food Packaging
- Hydrophobic Coatings
- Lightning Strike Protection
- Lightweight Strong Materials
- Lubricating Materials
- Optical Coatings
- Smart Coatings
- Wear Resistant Coatings
- Self-Repairing Composites
- Thermal Composites
- Vehicle Health Monitoring
- Water Filtration

4.2. Nanomaterial Application: Anti-Corrosion Coatings

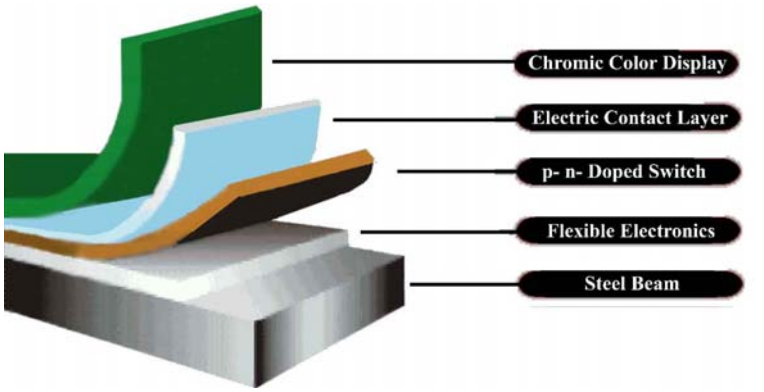

Figure 4.6 Multifunctional Anti-Corrosion Coating
Coatings are under development that combine enhanced corrosion protection with display technology and stress/strain sensing.
Courtesy of the Active Coatings Technologies Program, U.S. Army Research, Development, and Engineering Command

DoD maintains billions of dollars worth of equipment and infrastructure used in corrosive environments around the world. Maintenance costs related to corrosion are estimated at \$10 – 20 billion annually.[19] One research effort is focusing on developing a multi-functional "smart" anti-corrosion coating that incorporates a display layer on top of an improved corrosion protection layer of doped Single-Walled Carbon Nanotubes (SWNTs) and a third sensor layer for detecting stress/strain in the underlying bulk material.[20]

4.3 Nanomaterial Application: Wear Resistant Coatings

Figure 4.7 USS Ardent Propulsion Shaft Coating
(A) Propulsion shaft used to suffer from significant wear during normal operation. (B) A nanostructured ceramic coating was applied to the shaft to improve wear resistance. (C) After over two years in service, no wear has been observed on the propeller shaft.[21]
Courtesy of Ken Scandell, Naval Sea Systems Command Carderock Division

Mechanical wear is a critical and ubiquitous issue during the operation and maintenance of DoD systems. Nanomaterial coatings can impart significant wear resistance to materials utilizing many of the same processing techniques as conventional coatings. An alumina/titania nanocomposite coating is currently undergoing extended field-testing on several Mine Countermeasure naval ships.[21] Prior to their use, the brass shafts would wear easily within ~1 year. None of the ships using the nanocomposite coating have experienced any visible damage. The projected Return on Investment cost avoidance is greater than $34 million.

5.0 NANOMEDICINE

Nanotechnology-enabled medicine (i.e., nanomedicine) has witnessed an explosive growth in research over the past five years due to high levels of funding and a void of prior fundamental nanoscience. The result is a subfield of nanotechnology that is quickly recognizing new synergies and applications for nanotechnology. These developments are poised to have a tremendous impact on world health. In general, the primary aim of much current research is to obtain a detailed understanding of basic biochemical and biophysical mechanisms at the level of individual molecules.[10] Alternative disease treatments and medical imaging techniques, both utilizing biocompatible nanoparticles, have witnessed the greatest advances in recent years. Neither technology has been introduced commercially, but is considered 1-5 years away. Disease treatments have focused on using nanoparticles modified to be attracted to specific regions of the body. These particles are then used to provide localized treatment through external stimuli or drug molecules bound to their surfaces. Medical imaging has taken advantage of the improved signal of nanoscale particles compared to larger micron-sized counterparts and the improved permeation of nanoparticles throughout the body. Other areas of nanomedicine have had promising developments, but are farther away from commercialization. Applications expected in the long term include personalized medicine for superior diagnostics and treatments; extensive use of miniature biological devices for monitoring, regulating, and treatment of physiological functions; and a dramatic reduction, if not elimination, of cancer.[22]

5.1 Nanomedicine Logistics Applications

- Anti-Bacterial Materials
- Automated/Remote Medicine
- ChemBio Protection
- General Medical Advances

5.2 Nanomedicine Application: Nanoparticle Diagnostic and Therapeutic Agents

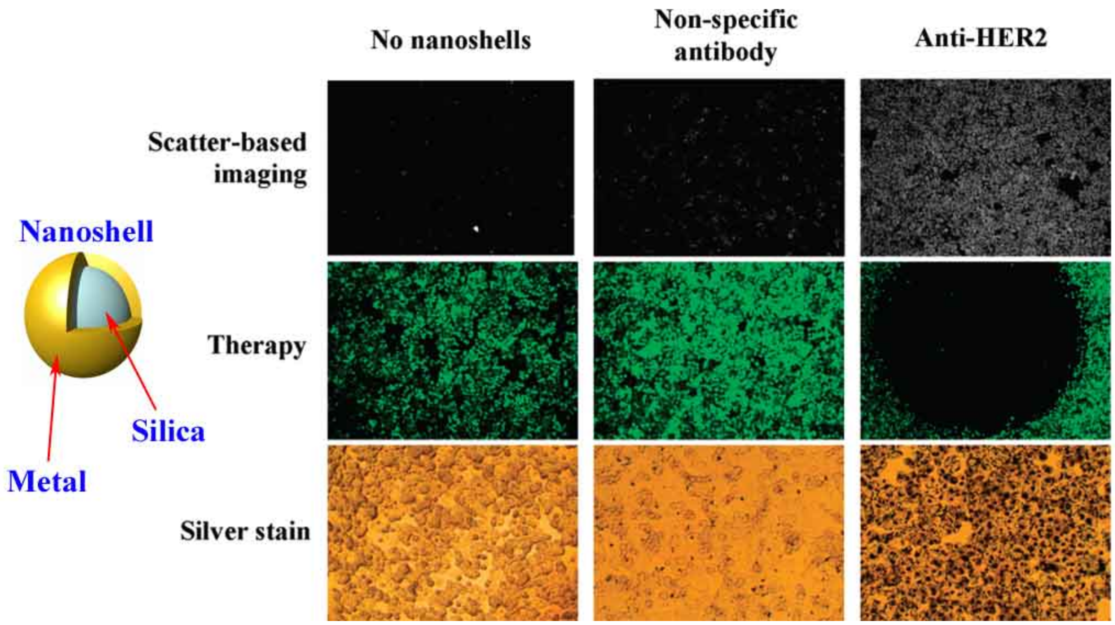

Figure 5.8 Nanoshell Cancer Treatment
Cancer cells are irradiated with an infrared laser after exposure to (left to right) no nanoshells, nanoshells with non-specific antibodies, and nanoshells with cancer-selective antibodies [anti-Human Epidermal Growth Factor Receptor 2 (HER2)]. Only the cancer-selective nanoshells produced any thermal damage during therapy.
(left) Source: Nanospectra Biosciences, Inc. © 2006
(right) Reprinted with permission from [23]
Copyright 2005 American Chemical Society

Research into the delivery and targeting of pharmaceutical, therapeutic, and diagnostic agents via intravenous and interstitial routes of administration of nanostructures is at the forefront of nanomedicine.[24] Nanoshells, nanoparticles with a silica core and thin metal coating, have been shown to be effective in both image contrast and therapeutic applications. Engineered nanoshells can be modified to adsorb onto the surface of cancer cells. Upon irradiation with infrared light, the nanoshells heat up, selectively destroying the cancer cells and leaving the surrounding normal cells undamaged.[23]

5.3 Nanomedicine Application: Automated/Remote Medicine

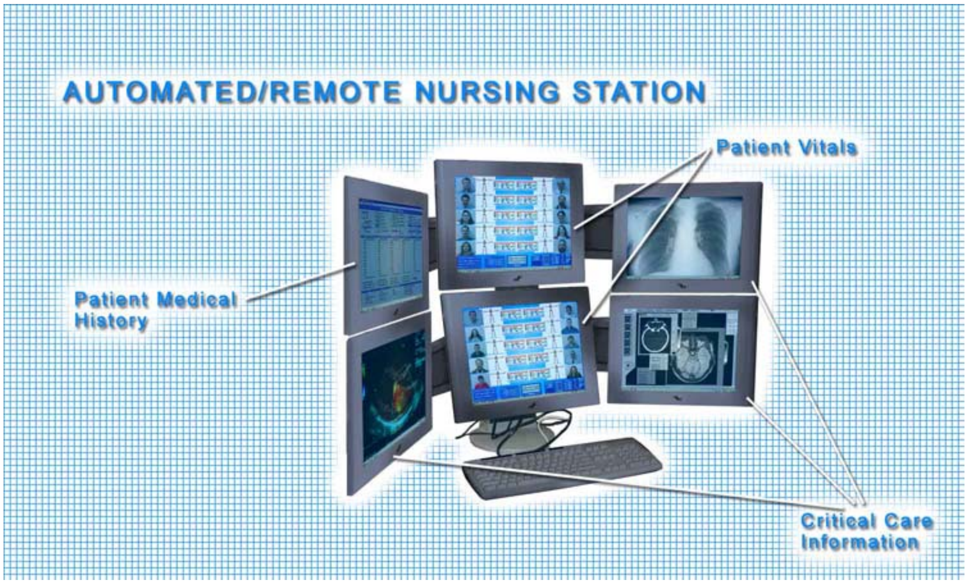

Figure 5.9 Remote Medical Monitoring
Concept graphic depicting a remote nursing station, which can monitor the physiological condition of patients remotely via nanomedicine devices.

Maximizing the decision making abilities of trained medical personnel for important medical events using automated and remote medicine would reduce the logistical overhead and improve FHP. Biological nanosystems are being developed which can monitor a variety of patient physiological statistics. Through coupling these devices to centralized monitoring stations at medical facilities, the number of medical support staff can be reduced without any loss of health services. The same biological nanosystems could be coupled to drug delivery or physical treatments for automated and/or efficient healthcare response.

6.0 NANOSENSORS

Sensor applications benefit from two aspects of nanotechnology - miniaturization and sensitivity. Like electronics, miniaturization of sensors allows for their incorporation into more products and environments, reducing their intrusiveness. Nanostructures have also been shown to be more sensitive to their environment because of their increased surface-to-volume ratio and quantum mechanical properties. Currently, significant research is underway in the area of chemical and biological molecular sensors. This focus is due to concerns about ChemBio agents on the battlefield and in terrorist scenarios as well as an increasing understanding of the interactions between nanostructures and molecules. The foundation of these various systems is currently being explored in the laboratory. Commercial products have been limited to simple molecular sensors; durability and reliability in open real-world environments remains challenging. As chemical and biological interactions between nanostructures are further explored, more complex and robust sensors will be developed. Short-term advances will focus on reliable devices for the detection of complex chemical and biological molecules.[25] Longer-term applications will involve the integration of nanosensors into other materials and products. Other types of sensor research (e.g., gravitational, electrical, and magnetic) exist, but are minor compared to chemical or biological nanosensors. However, conventional microelectronic sensors are witnessing continued aggressive development utilizing nanotechnology fabrication techniques.

6.1 Nanosensor Logistics Applications

- Chemical Sensors
- Climate Sensors
- Electromagnetic Sensors
- Equipment Condition Monitoring
- Smart Dust

6.2 Nanosensor Application: Chemical Sensors

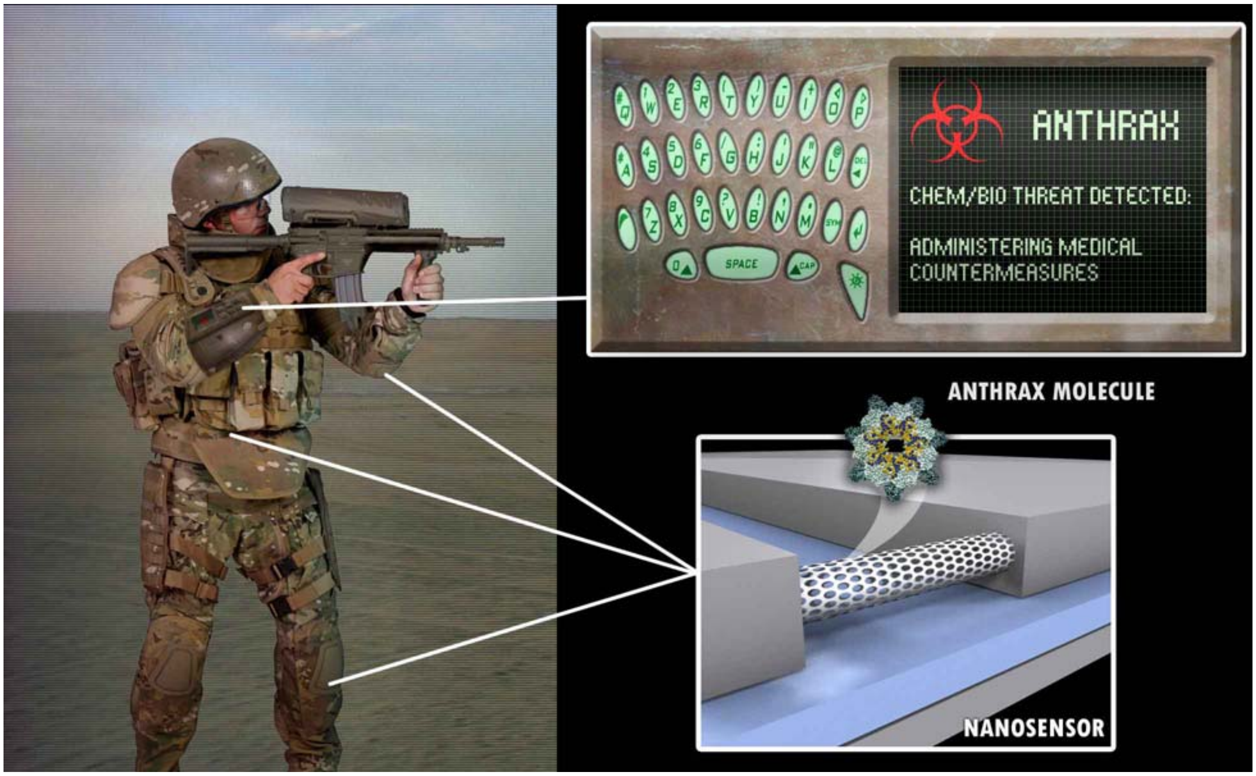

Figure 6.10 Integrated ChemBio Defenses
Concept graphic depicting ChemBio nanosensors integrated throughout infantry battle dress detecting a chemical threat and automatically administering medical countermeasures.

Chemical sensors are necessary for early detection and rapid response to potentially harmful and dangerous substances. Nanotechnology enabled chemical sensors can provide dramatic improvements in sensitivity, selectivity, and portability. In addition to performance enhancements, nanosensors can be deployed unobtrusively with soldiers, equipment, and vehicles to facilitate a persistent battlespace awareness of ChemBio and explosive threats. Detection of a Sarin nerve agent simulant has been demonstrated by a SWNT transistor network below one part per billion.[26] A conjugated polymer-based nanosensor for battlefield explosives detection has been fabricated into commercially viable platforms for the U.S. Army and is undergoing field tests in Iraq.[27,28]

6.3 Nanosensor Application: Equipment Condition Monitoring

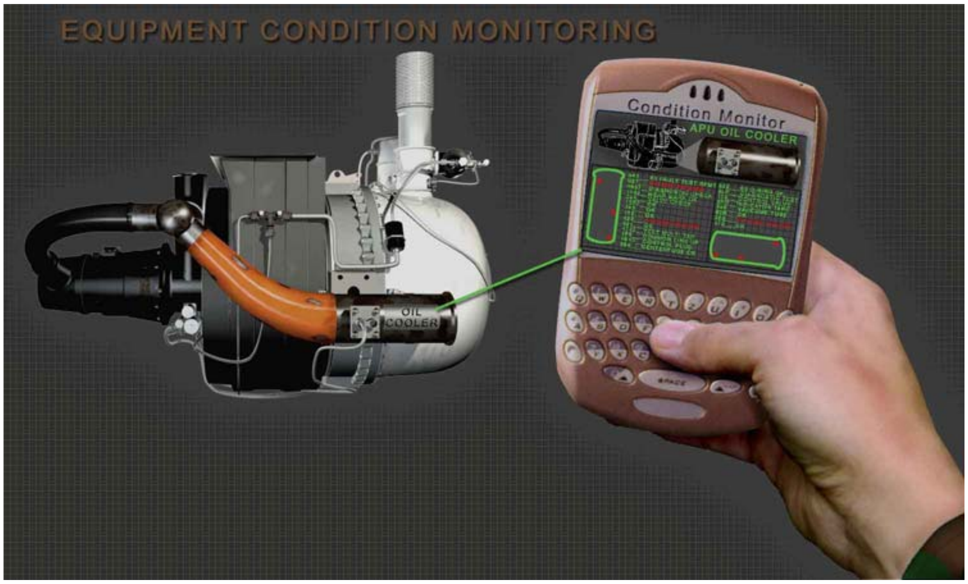

Figure 6.11 Equipment Condition Monitoring
Concept graphic depicting nanosensors integrated into equipment for monitoring and reporting maintenance condition and material performance.

Nanosensors could be integrated into the components of equipment to continuously monitor and report on their condition. Nanocomposite coatings have been developed which can detect stress/strain in underlying bulk materials and provide a representative color change.[20] Sensors can be incorporated into the mechanical, electrical, and hydraulic subcomponents of equipment to monitor their condition. Coupled with low-power communications electronics, equipment could conceivably transmit a notice to maintenance personnel at the first signs of failure or upon other operational conditions. Replacement parts would be sent and be available immediately upon failure. Alternatively, preventative or minor repairs could be conducted to avoid failure events and extend the lifetime of materiel. The ability for nanosensors to be engineered in a miniaturized and integrated fashion, coupled with their enhanced sensitivity make equipment condition monitoring a realistic medium term application.

7.0 NANOELECTRONICS

In the area of electronics, the semiconductor industry has quietly evolved into the realm of nanotechnology over the last ten years through continued miniaturization. Silicon is currently the dominant technology and will continue to be so for the next ten years. Nanotechnology holds significant promise for alternative, next-generation electronics, which have the potential to solve the limitations and/or facilitate the continued evolution of silicon microelectronics. Although the impact of nanotechnology on electronics has not been felt, its potential is widely recognized. Over the next five years, nanotechnology will sneak into cutting edge electronics as components of hybrid devices to provide incremental improvements.[29] Much research is underway exploring alternative nanotechnology-enabled electronics (i.e., nanoelectronics) that have the potential to disrupt the electronics market in the long term. Many research teams have developed computing and memory architectures utilizing nanowires and other nanostructures and are currently focusing on systems integration issues.[30] Over the next five years, nanotechnology will enable radiation tolerant electronics,[31] plastic-based electronics,[10] optoelectronics, NanoElectroMechanical Systems,[10] and improved flat panel displays.[32] As silicon technology reaches its final stages due to rapidly rising fabrication costs and resolution limits of existing fabrication methods, longer term nanoelectronics will be the next generation replacements.[3] Nanostructure-based transistors (e.g., CNT transistors) and molecular electronics are being aggressively researched for that purpose. Quantum mechanical effects will also be exploited for cryptography and computing purposes in the medium and long terms, respectively.

7.1 Nanoelectronic Logistics Applications

- Cryptography
- Flat Panel Displays
- Flexible Electronics
- General Electronic Advances
- Hardened Memory
- Radio Frequency Identification (RFID)
- Lasers
- Virtual Reality Training

7.2 Nanoelectronics Application: Hardened Non-Volatile Computer Memory

Nanotube Random Access Memory (NRAM™) utilizes SWNTs as electrically controlled switches for storing memory.[33] Because of the mechanical durability and electrical properties of nanotubes, the memory is a scalable, nonvolatile RAM capable of replacing all existing forms of memory. NRAM™ can be made in existing semiconductor fabrication facilities with existing processes with no limit to scaling (down to 5 nm). In addition, the memory can be embedded with logic processes and possesses a near unlimited lifetime (> 10^{15} cycles). Finally, the design is resistant to heat, cold, magnetism, vibration, and radiation. NRAM™ will start to be incorporated into existing electronic devices within 1 – 2 years.[33]

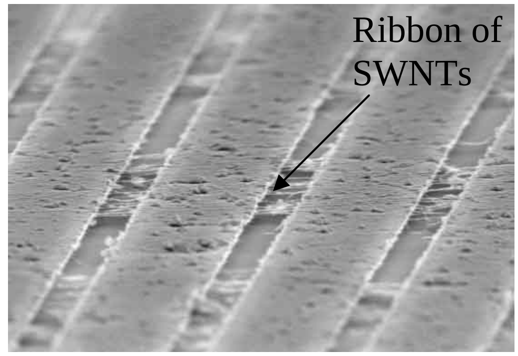

Figure 7.12 NRAM™ - SWNT Non-Volatile Memory
Image of SWNT memory elements
Courtesy of Nantero, Inc.

7.3 Nanoelectronics Application: Flexible Electronic Displays

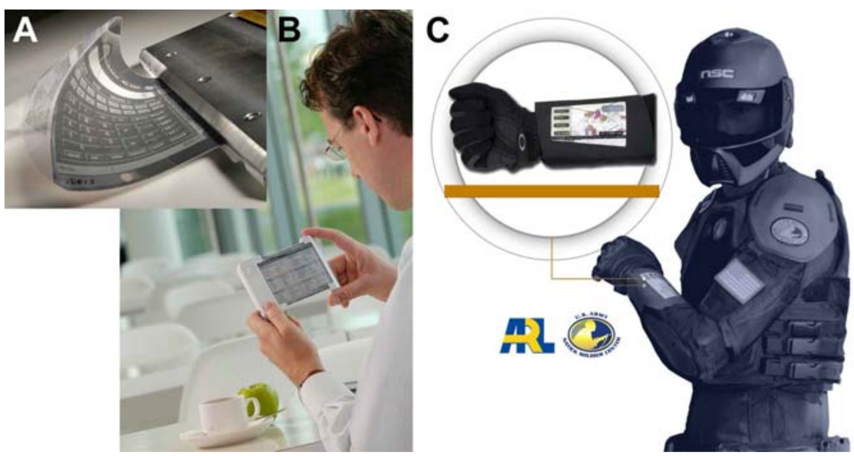

Figure 7.13 Flexible Display Technology
(A,B) Courtesy of Koninklijke Philips Electronics, N.V. (Polymer Vision)
(C) Courtesy of the Flexible Display Center, Arizona State University

The DoD Logistics concepts of IF and netcentricity require an integrated and robust information system on both the strategic and tactical levels. Nanoscale thin films are entering the market that allow flexible, robust electronics and displays on plastic substrates. Devices are being produced which are lightweight, portable, and durable. In some, the displays can retract inside the housing, rolling up without any damage or loss of performance. The U.S. Army envisions use in personal integrated displays for the future warrior.

8.0 NANOENERGY

Nanotechnology-enabled energy (i.e., nanoenergy) may hold the solution to a scenario in which energy consumption is increasing and hydrocarbon reserves are decreasing. Because of their increased surface-to-volume ratio and unique properties, nanostructures are ideally suited for many energy applications. Many battery and fuel cell architectures rely on chemical reactions at the surfaces of materials, so by increasing the surface area for a given mass of material, nanotechnology can improve performance and reduce cost and size. Nanostructured materials have already been incorporated into batteries, and are scheduled for commercialization within the next couple of years. In the future, nanotechnology is expected to provide significant advances in all energy applications. As the understanding of physical and chemical phenomena on the nanoscale progresses, researchers will be able to exploit their knowledge base to produce more efficient energy-related devices and materials. The core nanostructures and properties have been identified and characterized that will enable more advanced energy solutions, future work will focus on optimizing efficiency and implementation. Fuel cells, solar materials, and solid-state lighting will all benefit from nanotechnology.

8.1 Nanoenergy Logistics Applications

- Electrochemical Power Sources
- Fuel Efficiency Additives
- Solar Energy
- Solid-State Lighting
- Universal Fuel Additives

8.2 Nanoenergy Application: Fuel Efficiency Additives

Figure 8.14 Nanoparticle Fuel Efficiency Additives
(left) Nanoparticle diesel fuel efficiency additive, Courtesy of Oxonica Energy
(right) U.S. Army High-Mobility Multipurpose Wheeled Vehicle, Photo courtesy of U.S. Army.

In 2004, DoD spent $8.2 billion on energy.[34] It is estimated that each of the 150,000 soldiers in Operation Iraqi Freedom (OIF) consume ~9 gallons of diesel fuel daily. The logistical burden of procuring, distributing, and protecting these fuel supplies is significant. Nanoparticle fuel additives have been developed for improving vehicle combustion efficiency. A cerium oxide nanoparticle has been developed which modifies the combustion profile so that more useful work is delivered from each combustion cycle for a given quantity of fuel and lowers the temperature at which carbon combusts, allowing the engine to operate with increased efficiency.[35] Extensive tests have been performed, which show a reduction of more than 5% in fuel consumption by civilian buses that used the cerium oxide nanoparticles.[36] Additional companies have developed fuel additives based on similar nanotechnologies to enhance catalysis during combustion.[37] A recent long-term fleet test of heavy duty diesel trucks using a second nanotechnology fuel additive showed a 12.5% fuel savings and substantial emissions reduction.[38] Based on a conservative $2/gallon, a simple 5% improvement in fuel efficiency for diesel vehicles used in OIF would result in an annual cost savings of over $49 million.

8.3 Nanoenergy Application: Solid-State Lighting

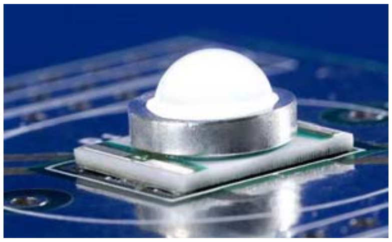

Figure 8.15 XLamp™ 7090 Solid-State LED
Courtesy of Cree, Inc.

One of the more mundane, but widespread, DoD expenses is providing basic lighting to buildings, facilities, and naval ships. Conventional lighting technology is tremendously inefficient – incandescent lights have 5% efficiency and fluorescent lights 25%.[17] Nanoenergy solid-state technology has seen significant improvements over the last ten years. Colored Light Emitting Diodes (LEDs) have already been implemented in over 1/3 of existing traffic lights in the U.S., resulting in a savings of $1000 per intersection per year.[17] Solid-state lighting offers several advantages over fluorescent lighting, such as improved safety (no glass or gases), reduced maintenance (longer lifetimes), reduced storage space needs, reduced weight, and increased electrical efficiency.[39]

9.0 NANOTECHNOLOGY STANDARDS

Nanotechnology standardization is in the early stages of development, both domestically and internationally. Organizations have recognized the importance and need for nanotechnology standards, and have initiated many associated projects and activities. For the most part these organizations have only just formed the necessary committees over the last two years that will be addressing nanotechnology. The administrative actions necessary to organize, coordinate, and execute operations within standards bodies are significant and have occupied the majority of work to date. Significant work is underway within both standards development organizations and standard certification bodies. In general, standards organizations have all similarly identified three topics of high priority. Terminology and Nomenclature efforts are working to define terms, materials, techniques, and phenomena associated with nanotechnology. Measurement and Characterization work is focusing on protocols and techniques for characterizing nanoscale properties and phenomenon. Environmental Health and Safety groups are working to establish the exposure and hazards associated with nanotechnology.

9.1 Nanotechnology Standards Organizations

- International Organization for Standardization (ISO) TC 229 Nanotechnologies
- American National Standards Institute (ANSI) Nanotechnology Standards Panel
- ANSI Technical Advisory Group to ISO/TC 229
- Institute of Electrical and Electronics Engineers, Inc. Nanotechnology Standards Initiative
- ASTM International Committee E56 on Nanotechnology

10.0 NANOMANUFACTURING

Nanotechnology has produced promising results in the laboratory environment, but the true impact of technology can only be realized through industrialization. Producing nanotechnology-enabled products at the commercial level will be the true test of nanotechnology's value. Significant efforts are underway to understand and facilitate the transition of nanotechnology from the laboratories of academia to the assembly lines of industry. Up until recently, the majority of federal funding, through the NNI, has been focused on basic nanotechnology research. The NNI is now shifting its emphasis to include nanomanufacturing. The National Science Foundation (NSF) has funded four (4) Nanoscale Science and Engineering Centers dedicated to nanomanufacturing. In addition, a Nanoscale Science, Engineering and Technology subcommittee Industry Liaison Working Group has been established to work with industry representatives to establish channels for communicating NNI R&D activities and industry concerns/suggestions for supporting pre-competitive R&D needs.[40] Liaison activities have been initiated with representatives from the semiconductor, chemical, aerospace, biotechnology, and automotive industries.

10.1 NCMS Survey on Nanomanufacturing

A National Center for Manufacturing Sciences (NCMS) survey indicates that the U.S. has the best-developed and mature research facilities, entrepreneurial culture and governance infrastructure for promoting new nanotechnology driven economic development.[41] Over half of the respondents in the survey indicated their organizations were directly involved in nanomanufacturing and that nanomanufacturing is considered a high priority. The nanotechnology industry is currently defined by exploratory partnerships and co-development between academia, government, and other companies. Of the respondents, 60% expect to have nanotechnology-enabled products on the market by 2009. Table 10.1 lists the top ten application markets for nanotechnology-enabled products.

Table 10.3 Nanotechnology Developments by Industry Sector

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Courtesy of the National Center for Manufacturing Sciences

Response Rate (%)	Industry Sector
52.36	Equipment, Logistics, Distribution
46.46	Electronics & Semiconductor
46.3	Computing, Information Technology, Telecommunications
38.05	Aerospace
34.68	Automotive
33.84	Chemicals & Process Industries
29.29	Sensing/Environment/Security
28.96	Energy & Utilities
27.95	Fabricated Products
25.42	Consumer Items & Textiles

Nanomanufacturing faces many challenges before it can become commercially viable. On the business side, there are technology transition issues and foreign competitiveness concerns. Technical barriers exist in developing a robust supply chain of large quantities of well-defined reliable nanomaterials with established standards for regulation and characterization, and mature modeling and engineering processes. All of these aspects of nanomanufacturing are lacking, but progress is being made. In the private sector, several scaled up production factories have been established or announced for bulk synthesis of key nanostructures, such as CNTs, QDs, and nanowires. The engineering, instrumentation, and modeling of manufacturing have yet to be applied on a significant scale to nanotechnology. To improve this aspect of nanotechnology, NNI is shifting its emphasis away from solely basic science research to include more applied nanomanufacturing research. These efforts, coupled with industry's increasing involvement in nanotechnology, will enable nanomanufacturing to overcome these technical challenges.

11.0 FUTURE ANALYSIS

Nanotechnology can provide significant advantage to a wide range of logistics operations, technologies, and capabilities. To take advantage of technologies and systems enabled by nanotechnology, it is critical that aspects be identified that can provide benefit to the mission goals and operations of DoD Logistics. By drawing concrete connections between emerging nanotechnologies and existing technology-facilitated components of operation, DoD Logistics can provide a specific context in which nanotechnology can aid and assist.

ManTech e-IC is developing a roadmap that will contribute towards nanotechnology-enabled logistics transformation. The report will provide specific recommended actions for pursing the benefits of nanotechnology and applying them to DoD Logistics, recommendations that will help facilitate the role and importance of nanotechnology in DoD Logistics. Future efforts will focus on providing detailed research analyses and technology transfer/implementation support for specific nanotechnologies of high-benefit potential with short to medium term viability.

APPENDIX A: ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
AS	Agile Sustainment
ChemBio	Chemical and Biological Warfare
CNT	Carbon Nanotube
DoD	Department of Defense
DOE	Department of Energy
FHP	Force Health Protection
FL	Focused Logistics
HER2	Human Epidermal Growth Factor Receptor 2
IF	Information Fusion
ISO	International Organization for Standardization
JCS	Joint Chiefs of Staff
LED	Light Emitting Diode
NASA	National Aeronautics and Space Administration
NCMS	National Center for Manufacturing Sciences
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NRAM™	Nanotube Random Access Memory
NRL	Naval Research Laboratory
NSF	National Science Foundation
OE	Operational Engineering
OFT	Office of Force Transformation
OIF	Operation Iraqi Freedom
OSD	Office of the Secretary of Defense
QD	Quantum Dot
R&D	Research and Development
SWNT	Single-Walled Carbon Nanotube
UK	United Kingdom
U.S.	United States

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