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Military Applications of Nanotechnology

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Student White Paper

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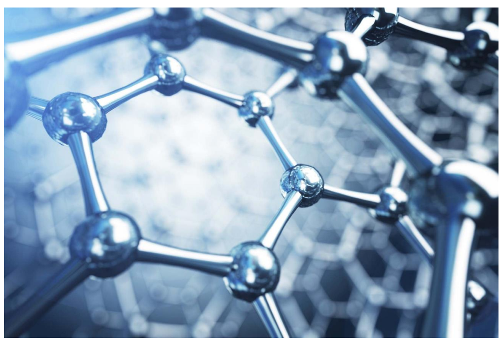

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Table of Contents

Introduction

Over the past few decades technology has advanced significantly to better meet the needs of people who use them. The very first computer required a whole room and a significant amount of electrical power to make it work. The layperson now has access to technology that is more advanced than the onboard computer of the Mars rover and it is only the size of their hand. We have the capabilities to engineer components at the scale of a nanometer and they can contribute to more advances in technology. The applications of nanotechnology are vast, but one of the areas in which its potential is not realized is the armed forces. Some of the weapons used today date back to World War II and the development and implementation of new weapons is slow. This begs the question, what are the policies of the armed forces when it comes to nanotechnology? In this paper we explore the implications of nanotechnology in the military with a focus on the U.S military. We will explore current policy, ethical considerations, risks, and benefits.

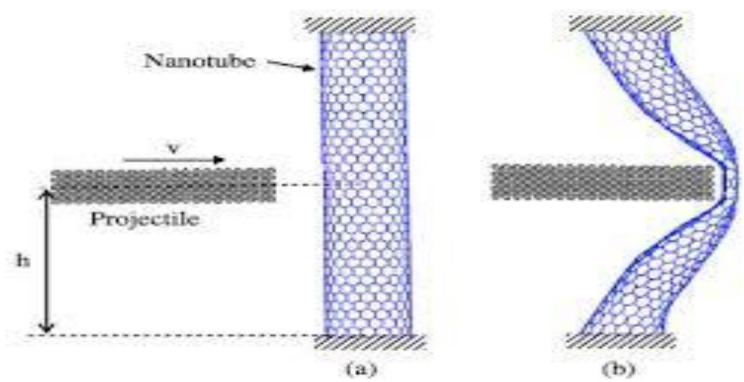
Definition and examples of nanotechnology

What is nanotechnology? The first thing that might come into mind is a tiny bug-like mechanical object that can be controlled from far away through a computer and while that technically counts as nanotechnology, there are more objects that fit under the umbrella of nanotechnology. In fact, nanotechnology isn't as new as most people think and there are artifacts that date back to 400 A.D (Daw, 2012). One example of such an artifact is the Lycurgus cup which contained nanoparticles that changed the color of the glass with exposure to light. With advancements in technology the scope of what is considered nanotechnology has changed quite a bit, but the definition the National Nanotechnology Initiative uses is "The science, engineering, and technology related to the understanding and control of matter at the length scale of approximately 1 to 100 nanometers." (Kennedy J, 2007). To put nanometers into perspective, consider a strand of hair, 1 nanometer is 100,000 times smaller than that.

Nanotechnology can also be divided into types of nanostructures which can form Nanosystems (Kennedy 2007). The earliest nanostructure that scientists worked with are known as passive nanostructures. These take advantage of the physical properties of a material and can include things like polymers, metals, and liquid coating being enhanced. The second generation of nanostructures are known as active nanostructures and are mobile and can seek out targets. An example of this is in medicine where nanotechnology can be implemented in the body to monitor basic functions such as heart rate, oxygen levels, etc. There have also been examples of this being used in medicine where nanotechnology was used to target tumors in mice, and they had remarkable results on recovery. The future involves systems of nanotechnology where nanotechnology can produce molecules almost like living cells.

There are a wide variety of uses for nanotechnology including health monitoring, structural management, weapons enhancement, and much more. From 2010 to 2025 there are a number of potential discoveries a panel of experts suggested might happen (Glenn, 2006). Some examples include an artificial red blood cell that is believed to be able to carry 236 times the amount of oxygen that natural blood cells carry to tissues per unit volume (Freitas, 1996), nanoparticles for bioweapons, and make muscles in the body more efficient. While some of these are still not yet possible, these ideas can give a rough sense of what uses nanotechnology will have and the possible issues these could present. These nanoparticles that are supposed to enhance the body could have negative side effects that we should consider.

A technology that is currently in development is the carbon nanotube (CNT) body armor. Carbon nanotubes are 117 times stronger than steel and can serve as bullet proof vests and helmets (Kristoff, 2017). There are some design limitations that are limiting the progress of this type of body armor and hence they are not on the market. CNT on the macroscale is not as strong and is brittle and can be cut by steel. However, scientists are close to developing a strong CNT body armor by combining it with alloys to enhance its durability.



Another example of nanotechnology that serves the same purpose as the CNT body armor is known as Magneto rheological Fluid or MR Fluid. This technology is a fluid that when disturbed is proportional to the magnetic field strength (Olabi & Grunwald, 2007). Essentially what that means is that the fluid can be intelligently controlled using a magnetic field (Olabi & Grunwald, 2007). When this occurs the state of the fluid can be changed between a solid and liquid. This will allow the military to create a variety of armor technologies that can be adapted based on the battle conditions. This nanotechnology can be combined with other similar wearable technology to revolutionize the militaries uniform which hasn't changed much in the past couple decades.

Adding onto the wearable nanotech, research and development of body armor for the military has progressed significantly with the increased interest in CNT body armor but that isn't the only way nanotechnology can be implemented into wearable tech for the military. One of the most inconvenient issue's soldiers are running into is battling against different climates in different environments. Most of the gear worn by the army was designed over a decade ago and causes overheating due to exertion (Kristoff, 2017). The lack of adaptability of the gear also does a poor job of keeping soldiers' extremities from going numb which can prevent them from performing how they should (Kristoff, 2017). There are different solutions to these issues but some of the most promising have some form on nanotechnology.

One solution for this using nanotechnology has to do with embedding fabrics in the soldiers' uniforms with nanowires. This would allow soldiers to control the amount of heat they receive depending on their environment to prevent their body from going numb or keep their body cooled down (Kristoff, 2017). Researchers also believe they could incorporate a layer of hydrogel particles made of polyethylene glycol which would absorb sweat and prevent the other layers with the nanowires from getting wet and heavier (Kristoff, 2017). Another application for nanotech in uniforms targets the need for self-aid soldiers may require on the battlefield. By combining sensors and Nanofibers the soldier's uniform could constrict into a tourniquet when it senses that the soldier may have been injured (National Defense Homeland Security, n.d, pg.10). Such an application could help prevent massive blood loss until the soldier can be treated giving them a better chance of recovery.

There are also more examples of passive nanostructures like the one above. According to a paper published by the environmental protection agency, nanomaterials increased material functionality has many implications on the energy that could be saved in the equipment soldiers use. Nanotechnology can increase the efficiency of catalytic converters by reducing the mass of catalysts required by 95% (Morris, J., & Willis, J. 2007). This also means the need for toxic materials such as lead decrease. Staying on the subject of catalysts, there is also an application in fuel additives. Catalysts can be added to fuel to decrease emissions and some companies claim that these catalysts make it such that there is a slight decrease in fuel consumption while giving the same distance per unit of consumption.

Another implication of nanotechnology that is farther away than other innovations mentioned is essentially a form of cloaking in the environment. By using electrochromic devices along with micro-nanostructures to produce an electric signal the soldier could change the color of their uniform to better blend into their environment (National Defense Homeland Security, n.d, pg.6). This would be a tremendous asset on the battlefield allowing soldiers to get in and out of situations safer than before.

Nanotechnology has the potential to revolutionize warfare for individual soldiers and their commanding officers. Militaries around the world might choose to implant or inject their soldiers with nanomachines for a number of possible benefits. The potential of every soldier having these nanomachines in their bodies would be the implementation of a system that monitors in real-time every single soldier engaged in combat action. Each individual soldier would be ID-tagged by the nanomachines injected into their bodies for that purpose.

The nanomachines would keep track of combatants and their real-time personal data 24/7. Each combatants position would be monitored, as well as data like walk and run speed, ammo supply, firing accuracy, wounds and injuries, and food and water intake. Bodily functions would be monitored as well, data like sweat secreted, heart rate, blood pressure, blood sugar levels, and oxygen content. All the data collected on body condition, sensory organ data showing how pain and fear are being managed, all this data showing internal bodily functions; all of it would be gathered and analyzed by an AI. This data is then monitored at HQ to enable militaries to make quicker, more precise, more rational decisions.

Soldiers on the ground would see several combat benefits. Individual soldiers could have access to personalized crisis management. The situation on the battlefield around them would be clearer, and stressful situations for the human body could be mitigated and brought under control. Machines that can interface with the human nervous system could be used to "contact nerves and brain to reduce the reaction time or to communicate sensory impressions".(Altman and Gubrud, 2004) Medicine could be delivered in real-time as injuries happen, reducing the number of preventable casualties because a medic wasn't present or didn't make it in time. Soldiers would think twice about committing human rights violations on the battlefield knowing that their actions are constantly being monitored. Commanding officers would make decisions with a live overview of the battlefield, enabling them to update soldiers on the ground in real-time. Nanotechnology implanted into the bodies of every soldier would create a cleaner, safer, and more predictable battlefield of the 21st century.

Policy Summary

The complexity of nanotechnology coupled with the inherent technological restraints surrounding it have created a relatively uncharted area in the world of governmental policy documents surrounding nanomachines. The slow-moving nature of bureaucratic government means that majority of policy documents in the area of nanotech are outdated with respect to the pace of technological development of nanotechnologies. The United States Military and Department of Defense have released policy outlines in this area, but they do not capture the modern potential offered by nanotech as discussed in academia.

The most notable event in this area was the establishment by Congress of the Defense Nanotechnology Research and Development Program (DNRDP) in 2003. This program was meant to ensure that the United States (US) remained on the cutting edge of nanotechnology. The goals of this program are to assess the militaristic capabilities of nanotechnology, discover and control the phenomena that matter at the nanometer scale, and “to meet national standards to avoid technological surprises” (US Department of Defense, 2009).

Six years following the establishment of the DNRDP, the Department of Defense (DOD) published a report outlining the purpose of the program itself as well as potential applications in three branches of the military: The US Air Force, The US Army, and The US Navy. The technologies mentioned here are of use to The United States Air Force. One of these is the photon-plasmon-electron conversion, which enables imaging by conversion of photon to plasmon waves and decreases the detector size by 50% compared with existing technology. Another area of progress is in nanomaterials for explosives, where munitions are enhanced by nano-aluminum powder to provide increased performance and lethality. This is because nanoparticles have a higher surface area to volume ratio compared to conventional powder which means they are more reactive (Defense Nanotechnology Research and Development Program P.14). But with new progress in the field comes new guidelines and regulations to help enforce the initial goals of the program.

One addition to the DNRDP came from section 240 of the FY 2008 National Defense Authorization Act. New requirements that came about as a result of this act included enhanced strategic planning and coordination of research plans, as well as increased review and assessment associated with possible applications for the technology (US Department of Defense, 2009). These additions help monitor the technology in manufacturing, industrial bases, and global research. One initiative created before Congress established the DNRDP was the U.S. National Nanotechnology Initiative (NNI). This initiative began in 2000 as a U.S Government research and development involving nanotechnology throughout twenty departments and independent agencies (US Department of Defense, 2009). Its creation helped researchers benefit from each other's insights, accelerate technology development, foster commercialization across disciples, and eventually set the pace for nanotechnology innovation worldwide (US Department of Defense, 2009).

Table 4. DoD Collaborations With Other Agencies

Areas of Interest	DOE	NASA	NSF	NIST	NIH
Quantum computing	X	X	X	X	
Directed energy (DE)	X	X			
Thermal energy conversion	X	X			
Manufacturing			X	X	
R&D partnerships	X	X	X		
Electrodes and catalysts	X	X	X		
Tumor destruction					X
Materials research centers			X		
CB defense	X				
Fiber photocells/ batteries		X			

The policies that are in place and collaborations seem sound, however, working with up and coming companies that are developing nanotechnology may benefit the government more. This is similar to how many experts recommended that the government should collaborate with google or amazon to move their data to cloud storage. Many government officials might be hesitant in letting a private company help due to the sensitive nature of the information, but this will be better in the long run for innovation and to stay ahead of the rest of the world in this field. Something that was interesting in the report to congress was that there was no mention of environmentally friendly practices of any sort. With the potential side effects on the body due to nanoparticles, they should look into making sure that they do not produce hazardous material in decomposition and come up with alternatives if they do. Pollution is also an issue, and this is something that National Nanotechnology Initiative (NNI) could work on with the Environmental protection agency (EPA) to study lifetime of these particles and their effects on the environment. There is so much focus on developing the latest bioweapon or the next big thing that could aid in war that there is not enough attention being given to the possible side effects.

The US government and the US military are allowing official policy concerning nanotechnology to languish into redundancy. The policy positions that exist in the public sphere today are in desperate need of an update. The establishment of the DNRDP back in 2003 was a good start by the US Congress, however subsequent literature on the topic has either become increasingly dated or does not exist at all. The military – in particular the DOD – must update its current policy guidance in this area to ensure that "the United States remains at the forefront of nanotechnology developments" (US Department of Defense, 2009).

Risk-Benefit Analysis and Ethical Considerations

The exciting potential offered by nanomachines in the realm of military affairs can overshadow some of the difficult choices and considerations that must be made as to how this technology should be used and implemented.

The idea of implanting soldiers with nanomachines carries with it a number of ethical implications that need to be considered. One of the largest and most glaring is the inherent privacy invasion of monitoring a person for an extended period of time via machines inside their bodies. The right to privacy would essentially be eliminated in the face of a monitoring system that would be nearly undetectable. (Chen, 2002). Exporting data on all of a person's bodily functions and live location into an algorithm for the purposes of optimizing the battlefield is a prospect that many would be uncomfortable with. Soldiers implanted with these devices would certainly exhibit altered behavior knowing they are being constantly watched and may develop a mistrust for commanding officers knowing they are always watching.

There is also the ethical issue of altering the human body's natural processes with help of nanomachines. Should we use synthetic machines to enhance the performance of organic human beings? When implanting these machines inside humans the human body may reject them altogether, with the immune system potentially identifying them as a threat. The response of the human body will not truly be known until these machines are tested on humans. Human testing is a controversial subject in and of itself but using members of the military as lab rats for an untested technology is particularly distasteful. Not to mention the "god like" powers that this technology will bestow on us, allowing us to manipulate human capabilities at will. (Chen, 2002).

There are also a number of ethical considerations with regards to the environment and controlling nanoparticles. Nanoparticles might pass through filters due to their size and congregate in the environment and pose a threat to the environment and humans. (S. Florczyk et al., 2007, p.6). This is a very important problem because there have been many times in human history where a revolutionary idea was found to have negative consequences such as radioactivity and cancer. Due to their size, there is a chance that these particles could enter our body and cause harm in ways that we have not seen before.

In addition to ethical concerns, there are also regulatory concerns. This includes the sophistication of current laws or whether it even exists to deal with the materials involved with nanotechnology. According to S. Florczyk et al, "Social science needs to interact with science and help to promote social awareness and acceptance of nanotechnology." (S. Florczyk et al., 2007, p.8). This is important and is not emphasized enough in many of the articles related to nanotechnology in the military. It can take very long to understand regulation and how a given piece of technology works and the interaction of social science and science can expedite this process. The article theorizes that there will also be not one, but several regulatory boards due to the interdisciplinary nature of nanotechnology.

It should be noted that even though we do not know the risks of nanotechnology in our body, there are already examples of nanotechnology reducing our carbon footprint. Nanoparticles are being used at waste sites across the U.S to eliminate and treat a class of compounds known as chloro-organics (Morris, J., & Willis, J. 2007). These specific nanoparticles employ iron and are known in the scientific community as zero valent iron. It essentially gets rid of chlorine which prevents more toxic chemicals from being formed. Studies have showed that more types of waste can be eliminated by this same mechanism. Nanoparticles have also been studied to remove metal contaminants such as toxic mercury. Silica-titania is one such compound and its effects are two-fold: the silica adsorbs the mercury vapors while the titanium turns the mercury into a less hazardous form of mercury. This technique is being studied to eliminate other metals that are harmful to the environment.

Nanotechnology can also support the sustainability of water and some forms of energy. An example of this is in filtration efficiency, nanotechnology flow capacitors can do the same work as a reverse osmosis system with just 10% of the energy. This can make water filtration plants more environmentally friendly and improve water quality around the world. Nanotechnology can also increase efficiency of current energy processes through lighter materials and more efficient energy transfer, however, the engineering of nanotechnology itself is somewhat intensive in resources so there is still some debate on whether this would be energy efficient or not in the long run.

Nanotechnology has the potential to change how humans live their daily lives. From allowing us to monitor our vitals, to potentially enhancing certain aspects of our organic bodies

(Chen, 2002). These changes in how humans live could be very beneficial but at the same time raise many ethical concerns as mentioned before. Being "god like", although attainable due to nanotechnology, may be something that shouldn't be messed with. At one point are we overstepping the boundaries? Nanotechnology will always be pushing against this question, but if this technology has the potential to save lives with different applications why should it be limited? The answer to how far this technology will be able to grow, only time will be able to tell.

Financial and Societal Costs

Nanotechnology in warfare is evolving around the globe and countries spend millions of dollars in developing the latest technology (Defense Nanotechnology Research and Development Program: Report to Congress p.24-37). There are both financial and societal costs posed by nanotechnology in the military.

The department of defense coordinates with many agencies such as National Aeronautics and Space Administration (NASA), Department of Energy (DOE), National Science Foundation (NSF), National Institute of Standards and Technology (NIST), and National Institutes of Health (NIH) in several areas of nanotechnology. This is a mutualistic relationship, however, collaborating with many departments comes at a cost. The incredibly small size that is a trademark of nanotechnologies allows for them to be used in a host of applications. Indeed, the possibilities are nearly limitless for what humankind can accomplish with this new technology. However, the societal costs of harnessing this technology, particularly its potential effect on the human body and privacy must be considered before adoption in any form is taken.

Implanting humans with nanomachines is a potentially risky endeavor given that the effect it will have on the organic processes is not fully understood. "Nanoparticles have been shown to be absorbed in the livers of research animals and even cause brain damage in fish exposed to them after just 48 hours."(The Nanoethics Group, 2003-2008) If particles at the nanometer level can have such an adverse effect on animals – albeit ones smaller than humans – properly ensuring that nanomachines do no disrupt human functions is paramount. There is also a scary scenario where nanoparticles could be in the air and could just be breathed in by humans and be floating in their body without any detection. This would require more medical research to be done in detecting and destroying these types of particles and increases the cost of nanotechnology.

However, monitoring the effects of nanomachines on a wider scale – assuming full implementation – is no small feat. In order to properly ensure no one is adversely affected by this technology we may be forced to turn "a free society into a Big Brother scenario."(The Nanoethics Group, 2003-2008) To properly enjoy the benefits of nanotech implants, society at large may have to give up the right to privacy enjoyed by so many, at least, as it is defined today. This sets up the potential for abuse of any system of monitoring, potentially further straining trust in governing bodies that will be forced to insert themselves into people's lives seemingly for their own safety. Analyzing the financial side of nanotechnology isn't as simple as looking at the societal costs. Like mentioned before, nanotechnology is a newer technology when looking at the implications in industry and within the military. Because of this the financial data of nanotechnology being implemented isn't as old as other technologies being used today, but that doesn't mean that nanotechnology isn't a wealthy industry. According to the Defense Nanotechnology Research report to congress the spending for the fiscal year of 2008 was about $460,418,000. This did however decrease going into 2010 to about $378,601,000 (Defense Nanotechnology Research and Development Program: Report to Congress p.18). When looking at the financial side, the opportunity cost must also be considered. The money that is being put into nanotechnology weapons research could be put into other areas such as helping eliminate poverty or focusing on bettering education.

In the early years of nanotechnology, there wasn't much profit from sales, but there has been a steady increase. From the years 2005-2014, the increase in profit from sales for nanotechnology has gone from around 250 billion dollars to 3 trillion dollars (Ferris, 2014). These numbers tell us that within the next couple of years the financial side of nanotechnology is only going to increase. With every disruptive innovation comes a cost for the industry, but these costs are only adding to the potential money that can be made in the industry.

Table 3. Funding Summary for Defense-Related Nanotechnology Research

	DoD Funding Crosscut		
NNI PCAs	**FY 2008 ($K)**	**FY 2009 ($K)**	**FY 2010 ($K)**
Fundamental nanoscale phenomena and processes	200,243	192,644	174,814
Nanomaterials	73,933	76,607	61,631
Nanoscale devices and systems	137,861	131,832	100,633
Instrumentation research, metrology, and standards for nanotechnology	8,090	8,931	4,629
Nanomanufacturing	7,799	25,273	14,192
Major research facilities and instrumentation acquisition	28,681	25,198	20,992
Societal dimensions – environment, health, and safety	3,811	3,687	1,710
Societal dimensions – education and ethical, legal, and other societal issues	0	0	0
Totals	460,418	464,172	378,601

Nanotechnology in Foreign Countries

So far, we have considered applications of nanotechnology in the U.S military. It is also vital to consider how other countries are using nanotechnology to get a better idea of where we stand and what we need to do to be technologically on par with the rest of the world. The countries with the most nanoscience research include the European Union, Russia, China, Japan, Singapore, South Korea, and Taiwan (Defense Nanotechnology Research and Development Program: Report to Congress p.24). China seems to be one of the countries that is very ahead of the U.S. China has been doing research on nanomaterials in several fields including nanobiology, nanodevices, and nanofabrication since the 1980s (Innovation with Chinese Characteristics). It is one of their government's highest priorities and should be ours as well.

Japan is one of the countries that is collaborating with the U.S on projects that could potentially be applied in the military, the Yamamoto quantum fluctuation project. This project takes into account existing quantum principles and combines nanotechnology to create strong lasers. It is a collaboration between Stanford University and the NTT laboratory in Japan. Russia is a country that publishes a considerable amount of research in nanomaterials with military applications. Examples include nano energetic propellant fuel, and nanomaterials with increased durability and flexibility similar to the CNT body armor mentioned previously. It is important that as a country we can stay technologically on par with these countries so we can maintain our position as a superpower and to deter future wars if it were to ever become an issue.

Suggestions for New Policy

From looking at current policy in nanotechnology in military in the U.S and research around the world, it is clear that implementation of nanotechnology in the military is essential as it can give us advantages that our outdated weaponry cannot. It is important that all branches of the military be educated about this and more open minded to trying to implement new technology. It is easier to implement it when there is not as much pressure rather than a time where the U.S is at war.

A bill should be passed to make nanotechnology our top priority and to allocate more money towards nanotechnology weapons research. It is almost common knowledge that the U.S spends the most money on military compared to any other country in the world so it should be easier to allocate money to this and cut budgets in other places. The government should also work with other countries and companies to innovate newer technology. Developing nanotechnology with other countries can strengthen our bonds and can lead to more intel on the status of research in these countries. The Environmental Protection Agency (EPA) released a whitepaper detailing the environmental effects of nanotechnology and they should be kept in mind with any innovation (Morris, J., & Willis, J).

Conclusion

Nanotechnology in the military is still somewhat in its infancy and there are still a lot of questions that remain unanswered. It is unclear whether we can meet the environmentally friendly demands of the earth, whether the nanobots that enter our body to enhance us will have any adverse effects on us, there is no guarantee that we can develop nanotechnology that can enhance us within the next decade. What we do know is that nanotechnology is a field with a lot of potential and lots of application in the military. In this stage, countries should be ready to work with each other to assess the risk of these ideas, to collaborate, and to develop nanotechnology to bring the ideas discussed in this paper to fruition. Once the world has a better idea on how to develop active nanostructures for war, more of their work can be done independently. Nanotechnology in military is uncharted territory for most of the world but if the government can expand the range of their research and collaborations, it can revolutionize the world and war as we know it.

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